Preparatory Seminar for
1983 RARC on
Broadcast Satellite Planning
Principles and Methodology,
May 4-8, 1981, Ottawa, Canada
: final report
vol. I

MATERIAL
Slides
Presentation

1983 RARC Preparatory Seminar
Ottawa, May 1981

Monday - May 4

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKERS	TITLE
I	0900-1030	Introduction	G. Warren	I 1 I 2 I 3	A. Curran ✓ A. Berrada? ✓ (R. Severini?)	Welcoming Address ~~[illegible]~~ OTERA - Moolerrin
	1000-1030	COFFEE		COFFEE		COFFEE
1(a)	1030-1230	Approaches to Planning (a)	R. Zeitoun	1.1 1.2 1.3	J. Chambers P. Balduino Head Brazil Delg. J. Miller	8) DBS Planning in Canada 7, 2, 4 9 channel plan Spectrum/Orbit Planning Alternatives 6 ; 6 ~~7~~ Bilingual Approaches to Planning 6, 8, 8 IWP 4/1, SG10/11 USA papers color & clear even when crowded.
	1230-1400	LUNCH		LUNCH		LUNCH
1(b)	1400-1530	Approaches to Planning (b)	R. Zeitoun	1.4 1.5 1.6	H. Hupe E. Jacobs C. Siocos	Interim Systems and Flexibility Report of U.S. Domestic DBS Activities 3PM TIMMERS IWP 10-11/2 and CCIR 10-11S Activities
	1530-1600	COFFEE		COFFEE		COFFEE 4PM
2	1600-1730	Internetwork Coordination	DiWeese Tillotson	2.1 2.2 2.3	R. Amero? C. Azevedo E. Reinhardt	Inter-Regional Sharing Considerations Overview on Sharing Involving the BSS of Region 2 Inter-Regional Sharing Considerations

1830 Reception

1983 RARC Preparatory Seminar
Ottawa, May 1981

Tuesday - May 5

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
3	0900-1100	System Constraints and Technical Considerations		3.1	R. Bowen	Consideration of Noise and Interference in a BSS
				3.2	K. Brown	Frequency Re-Use Constraints for 12 GHz Broad. Sat. Service in Region 2
				3.3	R. Douville	Satellite Direct Broadcast TV Receivers-Tradeoff Considerations
				3.4	B. Pattan	Overview of BSS Systems - A Technical Study by the FCC
	1100-1130	COFFEE		COFFEE		COFFEE
4 SPARE Time	1130-1230	Propagation Effects		4.1	J. Strickland J. Schlesak	Measurements of Precipitation Attenuation, Depolarization and Site Diversity Improvements in Canada
				4.2	M. Pontes M. Assis	Propagation Conditions in South and Central America
				4.3	J. Miller	Propagation Considerations
	1230-1400	LUNCH		LUNCH		LUNCH
5	1400-1600	Satellite Technology	C.A. Franklin	5.1	G. Lo M. Bouchard	Broadcasting Satellite Technology
				5.2	J. Clark	Satellite Characteristics
				5.3	H. Cohen	Alternative Spacecraft Designs for US Direct Broadcasting Systems
				5.4	E. Martin	Direct Broadcasting Satellite Service for the US - A System Description
	1600-1630	COFFEE		COFFEE		COFFEE
6	1630-1800	Spacecraft and Earth Station Economics		6.1	E. Martin	Direct Broadcasting Satellite Service for the US - Tradeoffs
				6.2	H. Raine R. Trenholm	Broadcast Satellite System Cost Estimation
				6.3	A. Vaisnys	BSS System Cost Considerations

1983 RARC Preparatory Seminar
Ottawa, May 1981

Wednesday - May 6

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
7	0900-1100	Feeder Links	MILLER (NASA)	7.1	H. Ng	Feeder Link Planning Considerations
				7.2	M. Bouchard	Planning of National Feeder Links in Multibeam BSS
				7.3	L. Cheveau	Some Considerations Relating to the Planning of Feeder Links
				7.4	H. Fromm J. McEwen	Possible Implications of the Geneva Plan - 1977 on the Feeder Link for European BSS
	1100-1130	COFFEE		COFFEE		COFFEE
8	1130-1230	Beam Fitting	H Cohen (TRW) *	8.1	G. Chouinard	Satellite Beam Optimization for the Broadcasting Satellite Service
				8.2	P. Sawitz	Description of the SOUP Program (Shaped beams and Synthesis)
				~~8.3~~	~~D. Thorpe?~~	
	1230-1430	LUNCH		LUNCH		LUNCH
* 9(a)	1430-1530	Synthesis of Plans (a)	H. Mertens	9.1	D. Sauvet-Goichon	Computer Planning Methods Used by the EBU for the Pre. of the WARC-BS
				9.2	G. Phillips	Evolving Plans at WARC '77: A Manual Method with the help of Computer Matrice
	1530-1600	COFFEE		COFFEE		COFFEE
9(b) Possible phone	1600-1730	Synthesis of Plans (b)	H. Mertens	9.3	G. Chouinard M. Vachon	Computer Synthesis Process Using a Branch and Bound Algorithm
				9.4	M. Nedzela J. Sidney	(Minimum Impact) A Synthesis Algorithm for Planning the BSS
				9.5	J. Christensen	BSS - Computer Aided Planning System

1983 RARC Preparatory Seminar
Ottawa, May 1981

Thursday - May 7

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
CRC	0900-1300		M Bouchard	C.1 C.2 C.3	B. Blevis G. Davies J. Day	Canadian Space Communications Results of Hermes and ANIK B Broadcast Satellite Experiments ANIK B Broadcast Satellite Demonstration
	1300-1400	LUNCH		LUNCH		LUNCH
* 10	1400-1530	Analysis of Plans	D. Dron Verveer	10.1 10.2 10.3	K. Brown H. Mertens P. Sawitz	Factors to be Considered in the Analysis of a Plan The Analysis of a Satellite Broadcasting Plan Description of SQUP program (Analysis)
	1530-1600	COFFEE		COFFEE		COFFEE
* 11	1600-1730	Alternative Services for the BSS	H. Haupt NTIA	11.1 11.2 11.3	M. Cioni J. Ramarsastry T. Kerr	Telidon/Satellite Delivery: A Alternative for Opportunities in Education High Resolution TV in the 12 GHz bands Service Development in Canada using Communications Satellites

2000 Dinner

1983 RARC Preparatory Seminar
Ottawa, May 1981

Friday - May 8

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
* PI	0900-1030	Panel - Introduction of Draft Report		P.1	R. Bowen	
				P.2	C. Siocos	
				P.3	P. Balduino?	
				P.4	L. Valencia	
				P.5	(US)	
				P.6	(US)	
		COFFEE		COFFEE		COFFEE
PLEN	1600-1730	Plenary Meeting Adoption of Final Report	R. Severini			

Preliminary List of Participants
Liste préliminaire des participants
Lista preliminar de Participantes

Revised edition

PREPARATORY MEETINGS FOR 1983 RARC
REUNIONS PREPARATOIRES A LA CARR DE 1983
REUNION PREPARATORIA PARA LA CARR 1983

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Ing. Savio C. Pinheiro	No. 004	
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Mr. Paulo Richardo Balduino 1.2?	No. 006	Speaker ?
Mr. Lourenco Chehab	No. 007	

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Mr. Ib Lønberg	No. 012	

NETHERLANDS

MR. Hans-Hermann Fromm	No. 013	Speaker ~~7.4~~ 7.4

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Mr. R. C. Kirby	No. 014	Speaker I.?
Mr. A. G. W. Timmers	No. 015	
Mr. A. Berrada	No. 016	Panel Chairman, Speaker I.2
Mr. Pedro Chaher	No. 008	

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Ing. Javier Romero	No. 017

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Mr. Peter J. Kerry	No. 019
Dr. Geoffrey J. Phillips	No. 020 Speaker 9.2✓

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Ing. Juan Manuel Zamudio	No. 022 Panel, Rapporteur
Ing. Raul A. Gonzalez	No. 023
Mr. Alfredo Delgado	No. 024

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M. Daniel Sauvet-Goichon	No. 027 Speaker 9.1

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Ing. Hector Hernandez	No. 028
Mr. Enrique Claude	No. 0.29

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Mr. J. Fung	No. 038
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Mr. P. Sawitz	No. 040	Speaker 8.2, 10.3
Mr. J. Rama~~s~~Rastry	No. 042	Speaker 11.2
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Mrs. Marlene Pontes	No. 044	Speaker 4.2
Mr. Edward R. Jacobs	No. 045	Speaker, Panel 1.5
Mr. Fred Zusman	No. 046	
Mr. Richard Shrum	No. 047	Rapporteur
Mr. Herb Cohen	No. 048	Speaker 5.3
Mrs. M. Case	No. 050	
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Mr. Ron Stowe	No. 053	
Ms. E. Battino	No. 055	
Mr. Ernesto Martin	No. 056	Speaker 5.4/6.1
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Mr. Keith Fagan	No. 059	
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M. Roland Grenier	No. 071	
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Mr. R. G. Amero	No. 079	Speaker 2·1
Dr. R. R. Bowen	No. 080	Speaker, Panel 3·1
Dr. C. Siocos	No. 081	Speaker, Panel 1·6
Mr. K. E. Brown	No. 082	Speaker ~~3~~ 3·2, 10·1
Mr. R. Douville	No. 083	Speaker 3·3
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Mr. H. R. Raine 6·2 Trenholm	No. 089	Speaker ?
Mr. G. Chouinard	No. 090	Speaker 8·1, 9·3

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Mr. T. Kerr	No. 096	Speaker 11.3
Dr. B. C. Blevis	No. 097	Chairman, Speaker C.1
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Mr. G. I. Warren	No. 103	Chairman
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PREPARATORY SEMINAR FOR 1983 RARC ON BROADCAST-SATELLITE PLANNING

COLLOQUE PREPARATOIRE EN VUE DE LA CARR 1983

SEMINARIO PRELIMINAR PARA LA CARR 1983 SOBRE PLANIFICACION DE SATELITES DE RADIODIFUSION

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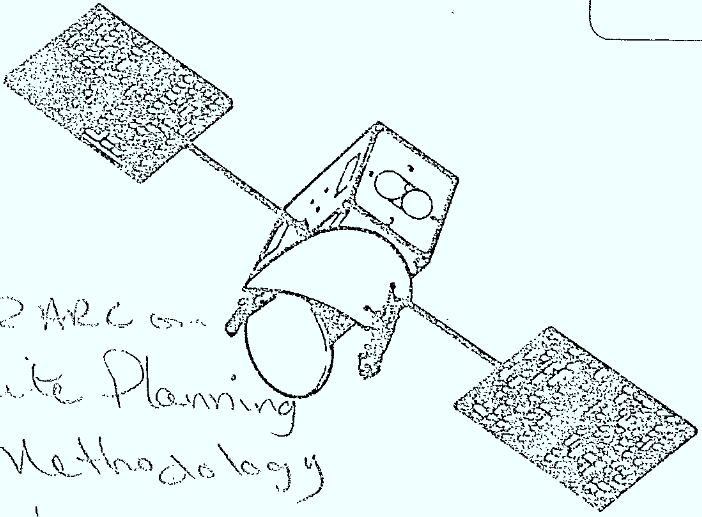

1° Seminar for 1983 RARC on
Broadcast Satellite Planning
Principles and Methodology
(1981 : Ottawa)

2° Preparatory Seminar for 1983 RARC on Broadcast Satellite Planning Principles and Methodology

May 4-8, 1981, Ottawa, Canada.

FINAL REPORT

Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

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Opening Session

The opening session of the Seminar took place on Monday morning, May 4 and was chaired by Mr. G. Warren (Director General of International Relations, Department of Communications of Canada). Mr. Warren expressed the pleasure of the Canadian telecommunications sector that the series of three meetings (CCIR'S IWP 10-11/2, Preparatory Seminar, Joint Meeting of CITEL'S PTC II and III) was being held in Ottawa. He pointed out that the 83 RARC is one of a number of important conferences, including the 1982 Plenipotentiary Conference, which will fully test the Administrations of the ITU and the region of the Americas. He was confident that the exemplary professional and personal relationships, developed by the experts of the Americas during recent conferences and during the current meetings in Ottawa, would facilitate success at the 83 RARC and other conferences.

Mr. A. Curran (Assistant Deputy Minister, Space Program, Department of Communications of Canada) welcomed the experts to Canada. He considered that one of the most important results which could result from the Seminar would be the development of an understanding and consensus on the methodology and the tools to be used in the planning process for the 1983 RARC. He outlined the technological developments in DBS that have taken place since the 1977 WARC. He also said that the planning process will have to take into account the startling rate of growth of new satellite-delivered television programs currently or soon to be offered in such countries as the USA. He also referred to Canadian experiments transmitting teletext signals via the ANIK-B satellite, as well as in tele-education. He concluded that the region must plan carefully for long-term growth, recognizing that DBS may be the only practical means for a large segment of the population to access the growing and increasingly important sources of entertainment and information services. It is therefore doubly important, he said, to make full and efficient use of the frequency band allocated to this service.

Mr. A. Berrada (Member of the ITU's IFRB) outlined the events which had led from the 1971 WARC to the 1977 and 1979 WARCs and set the stage for the 1983 RARC. He said that the Final Acts of the 1979 WARC do not contain a plan for Region 2, but Article 13 clearly stipulates that the Final Acts applies world-wide. This means, he said, that certain provisions apply to Region 2 and must, either wholly or in part, be applied by Region 2. He considered that a useful IFRB contribution would be to draw up, before the 1983 RARC, a list of the provisions of the Radio Regulations (Article 8 and Appendix 30) which apply to Region 2. It will be necessary to know the extent to which the decisions adopted by WARC could be revised by the 1983 RARC. He said that it would be necessary to study with care the resolution that the Administrative Council would approve this year to define the agenda for the Conference.

Mr. R. Kirby (Director of the ITU's CCIR) outlined the way in which the CCIR was working with the Administrations of the region to establish the technical basis of the 1983 RARC. He was encouraged by the excellent progress made the previous week by IWP 10-11/2 under the chairmanship of Dr. C. Siocos. He welcomed the active participation in the CCIR meeting of a wide cross-section of Administrations of the region and hoped that this would spread to other important CCIR meetings.

Mr. M. Otero (the official of the Argentine Administration representing COM/CITEL Chairman R. Severini) thanked Canada for hosting the series of meetings. He explained how the annual session of COM/CITEL (held recently in Cordoba, Argentina), and the Joint meeting next week of CITEL's PTC II and III, were part of a program in which CITEL was cooperating with the ITU to ensure effective regional participation in crucial ITU conferences.

Session 1 - Approaches to Planning

Paper 1.1: DBS Planning in Canada, by J.G. Chambers (Canada)

Canadian DBS activities, including experience with HERMES and ANIK-B satellites, are described. A comprehensive study to determine possible DBS applications and preparations in Canada for the 1983 RARC are reported in detail. While still in progress, the requirements study indicates that 4-6 channels in each of 4-6 service areas will be needed in a first-generation system. As many as 12 channels may be needed in a subsequent DBS system. It is concluded that the planning approach should allow for the economical implementation of each country's first generation system, while still resulting in relatively high efficiency in the use of the frequency/orbit resource in the long term. Example assignment schemes providing 9 and 18 channels to each of 72 services areas in Region 2 are shown to demonstrate the high capacity available to the Americas.

Comment: The author suggested that the 1983 conference should not necessarily limit its consideration to detailed plans, since some degree of flexibility may be needed.

Paper 1.2: Spectrum/Orbit Planning Alternatives, by P. Balduino

Various planning approaches for the 12 GHz broadcasting satellite service are presented. Five methods, ranging from a fully detailed, long-term plan to a coordination procedure which could guarantee access to the spectrum/orbit resource, are described, based on existing work of CCIR IWP 4/1 which is preparing for the 1984 Space WARC. A set of criteria to evaluate the alternative planning methods is also described. It is concluded that Region 2 countries should select the most appropriate method at the 1983 RARC, rather than limit consideration to detailed planning of the type adopted by Regions 1 and 3. This is particularly relevant since most countries in the Region will not be in a position to implement BSS system for many years and therefore may not be in a position to state their requirements or describe the type of system they would eventually need.

Comment: One participant questioned the applicability of IWP 4/1 efforts to the 1983 RARC, since he felt that preparations should proceed in the context of Resolution No. 701 and the work of IWP 10-11/2. The speaker replied that various approaches to planning must be studies to assist Region 2 countries in selecting the most appropriate method.

Paper 1.3: Alternative Spectrum Management Methods for the 12 GHz Broadcasting-Satellite Service in Region 2, by J.E. Miller (USA)

Several spectrum management methods for the 12 GHz band are examined in preparation for the 1983 RARC. The term "spectrum management" is defined and a list of spectrum management objectives is presented. Key elements such as service requirements, technical parameters, interference criteria assignment status and modification procedures are identified and described for each of five methods, based on the work of the CCIR IWP 4/1 in preparation for the 1984 Space WARC. It is concluded that the most suitable spectrum management method will depend upon each country's objectives for the broadcasting-satellite service. It urges members of Region 2 to determine their own objectives through further study and to decide which spectrum management method will most likely permit the realization of those objectives.

Comment: A participant asked how much flexibility existed for the scope of the 1983 RARC, in view of the resolutions adopted by the 1977 and 1979 WARCs. The speaker agreed that this question would have to be considered, but he expressed his opinion that the upcoming conference could consider all options for the Region provided the decisions did not adversely affect the Plan adopted for Regions 1 and 3.

Paper 1.4: Interim Systems and Flexibility by H. Hupé (USA)

A number of factors which will affect the early and economical implementation of DBS systems are examined. The cost-effective advantages of sharing a DBS satellite with other space services and/or other countries are presented, together with the technological improvements available for multi-beam antennas and foreseen for large space platforms. It is noted that the orbit and frequency requirements for a practical first-generation system will normally be much different from requirements in the longer term. The paper concludes that detailed planning of the type adopted by Regions 1 and 3 will present great difficulties and restraints to the early implementation of such shared satellites, and that flexibility in the planning method for Region 2 will resolve some of these problems. In particular, the use of multi-service and multi-beam space stations requires further study with respect to planning.

Paper 1.5: Report of U.S. Domestic DBS Activities by E.R. Jacobs (USA)

Current activities in the U.S. in regard to the Domestic implementation of interim DBS systems is reported. The Federal Communications Commission (FCC) has received a request from Comsat's Satellite Television Corporation (STC) and others to operate a DBS system in the near future. In response the FCC has adopted proposed rules for the new service that will require very little regulation; however, any approved systems will be required to comply with the results of 1983 RARC. FCC preparations for the conference, which includes a public Notice of Inquiry to obtain comments and views, is also described. Initial results indicate that there is considerable uncertainty as to the type and form of services to be provided by DBS satellites in the U.S. and the rest of Region 2. Advances in technology in the past several years and a feeling that the 1977 WARC procedures are too complex and constraining suggests that the 1983 Conference must consider procedures which allow more ease of implementation of DBS systems in Region 2. It is concluded that the RARC should provide the greatest degree of flexibility that is possible in view of the great uncertainty about the future of BSS.

Paper 1.6: CCIR Preparations for RARC 83-BSS and Recent Activities in the Broadcasting-Satellite Field, by C.A. Siocos (CAN)

A brief history of CCIR activities since 1962 relative to the broadcasting-satellite service is presented. Technical preparations for past and future radio conferences is described, with particular emphasis on Interim Working Party (IWP) 10-11/2 established to prepare for the 1983 RARC. The author, who is also the chairman of the IWP, reports on the results of the recent meeting in Ottawa (April 28 - May 1) and lays out the future work program and schedule. The end objective is to provide a final complete technical report in approximately August 1982 to all administrations to assist them in their preparations for the Region 2 conference and to the 1983 RARC itself.

Comment: In reply to a question, the speaker and the Director of the CCIR, Mr. R. Kirby, further described the status of the IWP report and the procedure for introducing new material to be included in the report, such as the study of alternative planning methods outlined in other papers.

Session 2: Internetwork Coordination

Chairman: D. Weese (Canada)

Session 2 on Internetwork Coordination dealt with the various aspects of both intra-regional and inter-regional sharing for the Broadcasting-Satellite Service. Three papers were presented which dealt with various aspects of this topic.

2.1 Overview on sharing involving the BSS in Region 2

Author: C. Azevedo (Brazil)

The first paper covered in a very thorough manner, all issues which needed to be considered at RARC 83 concerning sharing within Region 2 and between Region 2 and Regions 1 and 3. The sharing interfaces discussed encompassed:

(a) The intra-regional sharing between services within Region 2:

- with terrestrial services, and
- between systems in the Broadcasting-Satellite Service;

(b) The inter-regional sharing, with services of Regions 1 and 3:

- with terrestrial services
- with Broadcasting-Satellite Services
- with the uplink of the Fixed-Satellite Service (Region 1) and
- with the downlink of the Fixed-Satellite Service.

When the paper was opened for discussion, a question was raised on how the interests of other Regions are protected in a Regional Conference. The author indicated that the question should be referred to a representative of the ITU, and Mr. Berrada, of the IFRB, replied with two examples: the Broadcasting Conference for Medium Waves for Region 2, which stations have to protect the stations of other Regions recorded in the Reference List of the IFRB. The second example referred to the 1983 RARC-BS, for which two footnotes of the Radio Regulations state that such Conference and its resulting planning should protect all stations contained in the Plan of Regions 1 and 3.

2.2. Inter-regional sharing considerations, I

Author: R. Amero (Canada)

The paper reviewed the series of inter-regional agreements adopted by WARC-77-BS and WARC-79 in the context of planning the Broadcasting Satellite Service at the RARC-83. The complex resolutions adopted by WARC-79 to secure the new frequency allocation at 12.1 - 12.7GHz include many inter-regional restrictions. Five specific BSS downlink beams were examined to determine the magnitude of the problem in meeting three different limits. In most cases the limits could be met by the proper choice of satellite orbital position and size of the downlink service area. In two cases, Eastern Greenland and Alaska, particular difficulties were identified and other techniques may be necessary. In closing, the paper stresses the need for Region 2 to observe the inter-regional interference limits when developing the BSS plan in 1983.

2.3 Inter-regional sharing considerations, II

Author: E. Reinhart (United States)

The third paper discussed inter-regional sharing issues as they applied to one proposed USA DBS system (the DBS system proposed by STC). Using technical information from the STC filing to the FCC, Mr. Reinhart showed that the proposed STC system could meet the various inter-regional sharing criteria. In this case the beam covering Alaska was directed primarily towards Fairbanks and Anchorage and thus minimizes sharing problems with Region 3 (USSR).

Session 3: System constraints and technical considerations

Chairman: B. Blevis (Canada)

3.1 Consideration of noise and interference in a BSS

Author: R. Bowen (Canada)

Consideration of system noise and inter-network interference are major constraints in the design of a broadcasting-satellite system and in the planning of the spectrum and geostationary orbit which such systems use. In planning such systems, and in planning the frequencies and orbit positions that such systems will use, one must take into account the noise budget, cost budget, and weight budget of individual systems, and the interference budget between systems. Balancing these budgets involves choice of many system parameters, including satellite EIRP, earth station G/T, antenna diameters, signal bandwidths, spacings between satellites, and several other parameters. The ways in which each of these parameters effect the different system budgets is discussed in the paper. It is shown that although most parameters affect only one or two budgets, choice of Earth terminal antenna diameter affects all of the budgets considered.

When the paper was opened for debate, the perception that may have been given that the possible use of alternate set of values was a direct result of technological advances since 1977 was questioned. Except for G/T, it was stated that the difference was primarily in the level of service provided and, even the case of G/T, European Administrations were aware of the possibility of G/T values of 10 dB/^{O}K. Nevertheless it was agreed that it was a very legitimate subject. It has also been questioned the basis for minimizing overall cost when considering direct-to-home service where it may not be as relevant, noting that the costs and tradeoffs of terrestrial broadcasting systems are constantly changing. It was commented that the use of reduced bandwidth might create difficulties in the use of additional sound channels. This point was also pursued by another intervener who noted that an earlier study of truncation noise as a function of C/N indicated a rapid increase in truncation noise for lower values of C/N. Dr. Bowen responded by stating that some work had been done at the Communications Research Centre and that ANIK-B uses over deviation. Dr. Bowen commented further that e.i.r.p. and link budgets could possibly vary throughout a region, not only because of differences in rain margins and other technical parameters but also in terms of the service quality requirements of Administrations.

3.2 Frequency re-use constraints for 12 GHz Broadcasting-Satellite Service in Region 2

Author: K. Brown (Canada)

This paper examines the constraints on frequency re-use for the 12 GHz broadcast satellite service based on the specifications set by the 1977 WARC-BS. Upper and lower bounds on the minimum orbital separation of two satellites for a given separation of the two service areas are derived. Two methods for reducing the constraints are examined - reduced protection ratio requirements and use of advanced technology satellite antenna. These methods could be used singly or in combination. Although it is not possible with this limited study to predict the exact impact of these techniques it is estimated that the spectrum-orbit resource can be increased up to five or six times by use of these two approaches. Other methods of further increasing the net resource are indicated but not examined. It may be necessary to embark on regional planning exercises to obtain quantitative results on the capacity of the spectrum-orbit resource as it applies to Region 2 planning, plan flexibility and adaptability, etc., for various combinations of these resource enhancement techniques. The results given in this report are, however, useful for broad prediction and as an aid in initiating planning exercises, and could also be used in conjunction with geographic data readily obtained from satellicentric maps or by computer to generate detailed Regional plans if required.

The discussion that took place afterwards suggested the need to study more carefully the matter of pointing and station-keeping accuracy for which small motions would result in considerable shift of coverage areas. Amongst the list of techniques for reducing interference, beam shaping of receiving earth stations was proposed as requiring more attention.

3.3 Satellite direct broadcast TV receivers trade-off considerations

Author: R. Douville (Canada)

Earth terminals for reception of TV directly from broadcast satellites must meet exacting performance requirements while maintaining low cost. This paper addresses recent technology developments which affect the tradeoff. In particular, it is shown that a G/T improvement of up to 6 dB over that suggested in previous CCIR Reports is practical and realistic using modern technology. Some of the consequences of low-cost fabrication and errors in assembly and orientations are also addressed.

It prompted a discussion of several aspects of FM threshold and threshold extension. During this discussion it was noted that about 1 1/2 dB of threshold extension had been included in the calculations but the question was raised as to whether the same improvement was achieved in subjective performance. Results were for a single audio sub-carrier although the speaker noted that a current study was looking at the use of additional sub-carriers for sound broadcasting.

3.4 Overview of BSS Systems - A Technical Study by the FCC

Author: B. Pattan (United States)

This paper provides a system and technology overview of Broadcasting Satellite Service satellite systems. Several areas are considered, including system parameters and resulting uplink, satellite and receiver requirements. This study incorporated the guidelines setforth at the WARC-BS 77. This mode of communication is indeed viable based on studies and experimental systems and will continue to improve as the technology matures.

Session 4

Chairman Mr. E. Reinhart

4 Propagation Effects

Three papers were presented to discuss the various propagation problems in the frequency bands of the BSS.

4.1 Measurements of precipitation attenuation, depolarization and site diversity improvements in Canada.

Author: J. Schlesak and J. Strickland.

Results of various experiments performed by the research centre of the canadian Department of Communications, to study the propagation effects in the 12/14 GHz frequency band were discussed.

The presentation covered the results of measurements carried out in Canada during several years, to determine the rain attenuation, diversity improvements and depolarization effects of signals in the 12/14 GHz bands. Measurement procedures as well as evaluation methods were discussed in detail.

4.2 Propagation conditions in South and Central America

M. Pontes and M. Assis

This report discusses the propagation conditions in South and Central America and their dependence on meteorological parameters. The work was based on data from Brazil, although to a limited extent it also used information from Argentina, Venezuela and Panama.

The first topic is a climatic classification for South and Central America. Next section describes the behaviour of refractive index in these climates, including problems with spatial and temporal variations of rain and the question of rain attenuation. The following discussion deals with tropospheric and ionospheric scintillation ending with an analysis of interfering propagation mechanisms, suggestions were made for future studies.

4.3 Radio Propagation Factors

Author: J.E. Miller

This presentation was primarily a revision of Section 3 of the CCIR Report to the 1977 WARC-BS prepared by the Joint Working Party of the CCIR in 1976. The discussion dealt with propagation factors affecting link reliability and interference. New material from the Interim Meetings (1980) of Study Groups 5 and 10-11 was presented, in particular, worst-month statistics, precipitation attenuation prediction methods, frequency scaling, and the effects of precipitation on the choice of elevation angle and depolarization were discussed. Since these factors will probably be among the more significant technical issues to be dealt with during the 1983 RARC, these issues should be reviewed for adequacy and completeness for the whole of Region 2.

Session 5

Chairman: Mr. J. Almond

5 Satellite Technology

Many importants and new aspects in satellite technology including alternative spacecraft designs and a description of one DBS, were presented in three papers.

5.1 Broadcasting Satellite Technology

Author: G.J.P. Lo and M. Bouchard

An overview of the state-of-the-art payload technologies for broadcasting satellites is summarized with particular reference to those that affect systems planning. Two key areas of the satellite payload are the antenna and the transponder. Design considerations and implications of certain design approaches are illustrated. Wherever possible, hardware parameters are provided to assist the optimization of system configurations for the planning of the Broadcasting Satellite Service.

5.2 Alternative Spacecraft for U.S. Direct Broadcast Systems

Author: H. Cohen

The purpose of this discussion is to present a number of alternative spacecraft designs suitable for U.S. direct to home broadcast systems at 12/18 GHz. A number of system design assumptions are invoked, some of which are peculiar to Region 2. These are in contrast with the groundrules adopted by the Region 1-3 system designers following WARC 1977 and 1979. The essential result is a lower powered satellite because of use of shaped beams and higher G/T at the home.

Communications system considerations including coverage areas, shaped beam antenna design and RF downlink power budgets were shown.

Launch vehicle capability both forthe space transportation system and various expendable boosters was reviewed. A wide range of capability will be available in the 1984-5 time frame. Key spacecraft technology is surveyed and found to be available.

Typical 3-axis spacecraft designs including comparative power and weight summaries for 3 classes of spacecraft were also included.

Session 6 - Spacecraft and Earth Station Economics

Paper 5.4/6.1: A Direct Broadcast Satellite Service for the United States - System Description and Trade- by E.R. Martin (USA)

In late 1980, Satellite Television Corporation (STC), a subsidiary of COMSAT, applied for authorization to build the first DBS system for the United States. The proposed system will provide three channels of television to the contiguous U.S. and to the major populated areas of Alaska and Hawaii. Signals from the satellite will be received by means of home equipment with both indoor and outdoor units. Because the proposed system will be supported by audience subscriptions, satellite transmissions will be scrambled to prevent unauthorized reception.

Part I provides a detailed description of the system and its principal elements. The proposed four satellites will be spaced 20° apart along the geostationary arc at 115°W, 135°W, 155°W and 175°W longitude. Each satellite will serve an area approximately the size of the four time zones with a typical EIRP of 57 dBW. The typical receiving antenna will be 0.75 meter diameter. Television quality objectives and system parameters are generally consistent with those adopted for Region 2 in the 1977 WARC.

Part II of the paper defines the reasons behind the system parameters for both the space and earth terminal segments. It identifies the performance versus cost trade-offs, the considerations of orbit/spectrum efficiency and other major factors which influenced system design.

Comment: The paper generated considerable interest. When asked how the proposed DBS system would accommodate decisions of the 1983 RARC which might be incompatible with the current design, the speaker noted that the first satellite would not be launched until two years after the Conference, providing sufficient time to make any necessary adjustments to the system. The speaker also pointed out that the choice of operating frequencies will not be made until 1983 and that some flexibility in final design would be maintained regarding the exact orbit locations. In reply to a question about the possibility of detrimental effects if the RARC adopted a higher value for EIRP, the author indicated that the system design had sufficient C/I margin to be able to accept any reasonable increase in interference level.

One participant questioned the appropriateness of the technical parameters of the proposed initial system for use in later generation systems, given the inevitable gains in technology over the next several years. The speaker felt that increases in expectations and standards for TV quality in the second-generation system could use up many such improvements in technology. Another participant commented that the proposed orbit positions did not seem to make the best use of the available orbital space, if both U.S. and Canadian requirements were considered. The speaker replied that studies show that stated requirements for North America could be fully satisfied, and that the situation for countries south of the U.S. was actually improved by the 4-satellite configuration (versus the use of two orbit positions) due to their westward location.

Paper 6.2: Broadcast Satellite System Cost Estimation, by H. Raine and R. Trenholm (Canada)

An approach to provide cost estimates for a BSS system as a part of the planning process is illustrated. A method to estimate the acquisition cost of the space segment and parametric curves relating user earth terminal costs to performance and production quantities are presented. Some insight is provided into the impact of various system options on the costs of the overall system as well as the main segments thereof. The cost estimation process will assist the system planner in early planning stages to identify the most feasible and cost-effective approaches. It is concluded that, for the specific service requirements assumed in the analysis, a space segment utilizing colocated active satellites with a spare appears to offer advantages over alternative configurations.

Comment: One participant noted that studies for the NORDSAT program indicated it is normally less costly to use a minimum number of satellites for a given reliability, simply because a larger number of launches has a higher probability of malfunction than a single system, since the degree of complexity in a larger bus vehicle is not significantly greater than a smaller one. He also pointed out that the apparent discontinuities in cost due to a move to a different upper stage were not valid in the longer term, because upper stage designs are in development which are expected to remove these discontinuities.

Paper 6.3: System Costs and Optimization, by A. Vaisnys (USA) - presented by J. Miller (USA)

This paper is the U.S. contribution to the October 1980 meeting of CCIR IWP Plen/3, for use as Chapter 6, System Costs and Optimization, in its report. It describes a method for synthesizing television broadcasting satellite systems, and a set of techniques for estimating the various elements of the system cost. The cost-estimating techniques and the cost data are useful in trade-off studies in preliminary system design. However, final system cost estimates should be made using the most recent data available because of rapidly changing technology and prices. Specific quotations from system and equipment manufacturers are preferred.

Comment: It was observed that the empirical curves presented are not entirely appropriate for DBS systems. In particular, the weight-to-power relationship is substantially different for DBS-type satellites from that of fixed satellites. It was noted that cost estimates prepared for the NORDSAT program showed substantially lower impact of satellite EIRP on cost than the model described; for example, an increase of about 6 dB in EIRP resulted in an increase of only 50% in cost. It was concluded that this matter needs further investigation.

Session 7 - Feeder Links

Paper 7.1: Feeder Link Planning Considerations, by H.J. Ng (USA)

The author presents some general aspects of inter-service sharing between feeder links (in the fixed satellite service) for the broadcasting satellite service and the other radio services allocated in the band 17.3-18.1 GHz. Operational constraints on the location of feeder link earth stations and possible trade-offs are discussed with respect to the overall performance of the combined feeder link and BSS down-path. System planning will involve a choice of feeder link and down-path parameters which provide a proper balance of several factors, including carrier-to-noise ratios, protection ratios, outage times and attenuation due to rain. Some effects on each of these parameters are illustrated by examples.

Comment: A question was raised as to the coordination required between a planned service, such as the Broadcasting-Satellite Service, and an unplanned service, such as the Fixed and Mobile Services: What criteria and coordination procedures would be used by the 1983 RARC? In response it was noted that the Final Acts of the 1977 WARC-BS provides a precedent in that criteria and procedures are given for the possible sharing situations.

Paper 7.2: Planning of National Feeder Links in Multi-Beam Broadcasting Satellite Systems, by M. Bouchard

The paper presents an analysis of the feeder link requirements to a DBS satellite with multiple down-path beams, i.e., providing signals to two or more service areas. Two types of service requirement are considered: a national service which implies simultaneous broadcast of the same program to each service area and a regional service which provides a different program to each area. The need to provide inherent flexibility for feeder links is described. Inter-network and intra-network interference is examined, and the necessary technical sharing criteria are discussed with respect to minimum earth station transmit antenna diameter and orbital separation between interfering satellites. It is concluded that the desired national channels can be planned with no additional requirements for feeder links or channels provided appropriate sharing criteria are established.

Comment: One participant expressed a view that feeder link earth station cost was not a consideration in determining the range of feeder link earth station antenna diameters used in the study.

Paper 7.3: Some Considerations Relating to the Planning of Feeder Links, by L. Cheveau (BEL)

Certain problems are examined from a technical standpoint in the planning of feeder links for broadcasting satellites in the 12 GHz band. The contribution of the links to the noise over the entire signal path are studied in detail, on a statistical basis for atmospheric attentuation. The possible use of a power-control system at the earth station and its effect on the mutual interference between feeder links is examined. A comparison is made of the respective advantages between linear and circular polarization. The Plan adopted by the 1977 WARC for Regions 1 and 3 is used as the basis for studying the feeder link considerations. An example of a practical application for orbital position 19° West is presented.

Comment: It was pointed out that the broadcasting-satellite transponder assumed for the study was a hard limiting type; that is, the received envelope fluctuations on the uplink are completely removed so that the broadcasting-satellite transmits a constant-envelope, constant-power signal. One participant asked the speaker to comment on how the results and conclusions might be affected in the case where a probability density function other than the log-normal was assumed for the rain attenuation. Discussion revealed that other density functions had been studied, and for the particular case of the Rayleigh density function, the results were identical at the two points given in Figure 1 of the paper.

Paper 7.4: Direct Broadcast Satellite Feeder Links - Examples of Possible Implications of the Region 1 and 3 Plan for Feeder Links to European Broadcast Satellites, by H.H. Fromm and N.J. McEwan

The planning of feeder links for Regions 1 and 3 is studied with respect to compatibility with the existing downlink plan. Using the satellite orbit position of 19°West as an example, the significance of adjacent channel interference between circularly polarized feeder links in adjacent countries is illustrated. Up-to-date statistics on propagation conditions for the European climate are presented. Practical concepts and performance predictions are presented. It is concluded that the currently unsatisfactory situation in regard to feeder links can be avoided by the use of certain system improvements, such as uplink power control and forward cross-polarization cancellation techniques.

Comment A participant asked if the simultaneous planning of feeder links and downlinks, as foreseen at the 1983 RARC, might not have avoided the problems being encountered by European systems to be operated at 19°W. The author replied that simultaneous planning was the preferred approach, however, the fundamental problem is adjacent channels in adjacent service areas being served from the same orbital position. In response to another question, the speaker explained that the use of a downlink TV/FM carrier to make amplitude and polarization measurements, instead of the 12 GHz beacon signal, had not been evaluated. The reason was that the beacon is already required for other functions and provides a ready means for the amplitude and polarization measurements.

The speaker agreed with an observation that some sort of agreement must be made as to the limits on change of EIRP, if feeder link power control is to be used. It was also noted from the floor that Comsat experience with frequency scaling, that is, making amplitude and polarization measurements at more than one frequency and predicting them at a second frequency, had not been very encouraging. The speaker indicated that, based on similar experiments in Europe using the 12/14 GHz band, he was confident that frequency scaling to the 18 GHz band would not be a problem.

Session 8: Beam Fitting
Chairman: H. Cohen (United States)

8.1 Satellite Beam Optimization for the Broadcasting-Satellite Service, by G. Chouinard (Canada)

The paper describes the process used in a computer program to optimize the satellite beam necessary to cover any given service area so that the necessary transmit power is minimized. This process will define the satellite beam parameters and the necessary on-axis EIRP so that the required quality of service will be met anywhere within the service area defined by a limited number of geographical points forming a convex polygon encompassing the area to be covered.

During the process, the geometry aspect is kept to two dimensions by using spherical trigonometry. The optimization is brought down to a simple 2-dimensional convergence process by the use of multiple coordinate transformations. This completely automated optimization process is limited to the fitting of circular and elliptical beams.

Two phenomena of stochastic nature are also considered in the beam fitting process. These are the rain attenuation and the satellite attitude control errors. These factors will contribute to the additional amount of satellite power necessary to provide the required quality of service for the specified percentage of time.

8.2 Description of the SOUP Program (Shaped Beams and Synthesis) by P. Sawitz (United States)

The lecture consisted of three papers submitted by the United States to the Final Meetings of the CCIR in Geneva in September of 1981.

The first paper describes that part of the Spectrum-Orbit Utilization Program (SOUP) that allows the use of arbitrary antenna patterns in the computation of antenna gains. The program allows each of the four antennas in each link (earth-station transmit, satellite receive, satellite transmit, and earth-station receive) to have its own pattern, different from every other pattern if so desired. Each pattern is specified by a type number and by the number of a table in which the co-efficient values or locations with associated gains, as applicable, are listed. Seven different types are available. They include all reference patterns, both for the broadcasting-satellites (BSS) and for the fixed-satellite service (FSS), described in CCIR reports, but with co-efficients that can be selected as inputs. They also include irregular patterns described by matrices of gains associated with points on the ground or in the antenna plane (the plane perpendicular to the beam axis).

The second paper describes a program that finds the parameters of the ellipse of minimum area to cover a given set of points, e.g., the corners of a polygon used to describe a service area. The program uses a non-linear programming technique. The program includes the effects of antenna pointing and rotation tolerances. The output of the program is in a form that can be used directly as input to the SOUP.

The last paper describes the application of a non-linear programming technique to the optimization of the orbital positions of a set of non-homogeneous broadcasting satellites. Various optimization criteria can be used, such as minimization of the total arc occupied subject to meeting all margin requirements, or maximizing the lowest margin obtained in the worst link.

Session 9 - Synthesis of Plans

Chairman: Mr. H. Mertens

During this session, two papers were presented which explain the planning considerations used in the 1977 WARC by the countries of Regions 1 and 3, in order to develop a detailed plan in the 12 GHz band for the BSS. The presentations cover the problems found during the plan elaboration, the analysis of the various alternatives and the solutions reached.

9.1: Computer Planning Methods Used by the EBU for the Preparation of the WARC-BS

Author: D. Sauvet-Goichon

The programs were run a great deal during the two years prior to the Conference and quite early on, it became apparent that they had a number of limitations. The first problem concerned the calculation time required. The second limitation arose from a poor estimation of the degree of freedom planners had to work with certain parameters. The third limitation concerned the optimization algorithms themselves. This overview of program use, viewed several years later, might make it possible - should the process need to be repeated - to approach the problem differently, placing less emphasis on the computer and more on human abilities.

On the other hand - and this is the very positive aspect of the overview - the main merit of these programs was that they made it possible to set up an international team of trained planners. In France, for example, TDF hosted engineers from a number of European countries for several months. They were able to obtain thorough knowledge of how best to use the synthesis programs and to form a team which was well acquainted with the advantages and disadvantages of the tool which would be used at the time of the Conference.

9.2: Envolving Plans at WARC 77: A Manual Method with the Help of Computer Matrice

Author: G. Phillips

A concise account is given how plans for orbit positions and channels were evolved, starting from the stage at which the beams to cover required service areas have been fixed. The use of regular spaced orbit positions and, in most cases, of standard channel groups permitted a trial-and-error approach for assignments.

A computed matrix gave, for each pair of beams, the contribution of the directivity of the satellite antenna to the prevention of mutual interference between the two service areas. Simple rules for the additional isolation available from receiver directivity could be formulated, as a function of the orbital spacing for the two beams. The total isolation from transmitter and receiver directivities could then be compared with the interference protection requirements. If it exceeded the protection ratio by a suitable margin, that pair of assignments could be retained in the trial plan.

Finally some features and special cases of the WARC-77 plan are discussed, and an orbit position/channel table for the 1977 Plan positions from - 37° to + 17° is given as an example of a convenient type of summary chart for planning purposes.

Comment: Questions at the end of the session were related to the computer plan synthesis and the selection of parameters to elaborate the plan. Some of the parameters were selected in advance of the synthesis, since several countries from Regions 1 and 3 went to the Conference looking for a particular orbit position. There were also some political and economic considerations which had to be taken into account.

The experience obtained during the last few years shows that the parameters used in the elaboration of the 1977 plan were the more likely at that time, and still could be considered as appropriate values for the BSS plan in Regions 1 and 3.

During the evaluation of the computer methods used during the 1977 WARC, EBU experts obtained valuable experience which shows that the plan synthesis could be performed by simpler methods, instead of very complicated computer synthesis, taking into account that the best computer available is the human brain.

Session 9 (Part 2)

The second part of this session gives an additional overview of methods of synthesizing a BSS plan which were used at the 1977 WARC-BS. The merits and disadvantages of each were discussed. Different approaches were also presented for the analysis and synthesis of a plan to be elaborated in 1983 for Region 2.

9.3: A Synthesis Procedure of a Plan by Computer Using an Assignment Method and Inductive Selection

Authors: G. Chouinard and M. Vachon

One of the goals of the 1983 RARC for the planning of a broadcasting-satellite service will be to utilize the orbit/ spectrum resource in the most efficient manner and in such a way that all criteria concerning quality and the number of programs are met for each administration. The planning consists of the assignment of three variables to each service area; namely: an orbital position, a channel and a polarization. Based on the experience of planning the Regions 1 and 3 in 1977 the best approach seems to be the interaction between an expert planner and a computer.

Given that the three variables cannot be treated in a straightforward and simple manner, it has been resolved to here leave the assignment of orbital positions manual and to automate as far as possible the assignment of the two other variables using a computer. The computer program which was developed is relatively complex and use operations research principles such as the concept of induction or more precisely implicit enumeration. The procedure described here thus permits the complexity of the planning problem to be minimized by reducing it to a manual assignment of the variable most easily grasped by the planning expert and to an inter-active control of the computer program assignments in order to avoid excessive calculation time.

9.4: A Synthesis Algorithm for Broadcasting Satellite Service

Authors: M. Nedzela and J. Sidney

For several years, researches have been developing tools to assist spectrum planners charged with the task of spectrum allocation for broadcasting in Region 2. To assist in this effort, this research team has attempted to develop a new synthesis approach, which builds upon and complements existing methods. This effort has so far resulted in two algorithms, ADELES-1 and ADELES-2, for different versions of the synthesis problem. These algorithms provide the basis for the development of more sophisticated algorithms which hopefully will be useful for the spectrum allocation exercise to take place in 1983.

ADELES-2 is a modification of ADELES-1, which permits service area linkage requirements. A group of service areas are "linked" if they must share the same orbital position (linkage facilitates sharing of signals). Still under development, ADELES-2 has successfully obtained a feasible solution to the linked problem in 188 seconds using service area groups as submitted to WARC' 77. Eclipse protection was not utilized.

9.5: BSS CAPS - A System Description

Author: J. Christensen

Because it is difficult to predict the exact planning methodology and constraints which will be favoured at the 1983 RARC a flexible planning system had to be designed. BSS CAPS was designed in response to this requirement. BSS CAPS is both a planning system and an optimizing system which produces a "plan" even if negative single-entry C/I margins are present. Furthermore, the system readily accepts manual planner input or inputs derived from other planning systems. This is possible because of the following system features:

(i) The rapid evaluation of a single-valued objective function which is a measure of the severity of the total interference of the BSS plan being synthesized.

(ii) A menu of computer programs which enables the planner to successively make changes both manually and automatically in the assignments of the satellite longitudes, channels or polarizations.

In all cases it must be remembered that the resulting solution is a local optimum and not necessarily a global optimum.

Comment: A desirable feature of the program was the technique of identifying coverage areas with a large number of interference problems, and then continuing the solution with groups of countries having the most incompatibilities among them. The flexibility of these programs to accept new parameter inputs was also discussed in detail. An interesting discussion occurred regarding the constraints that may be introduced as a result of the requirements from Region 2 administrations, such as preferred orbit position and/or orbital arc, numbers of channels, bandwidth and others. Resuming the discussion, it was found that there is not a formula to determine the optimum solution. The intention is to reach an acceptable solution, and the possibilities to find it will be reduced in the same proportions as the requirements grow. The development of these programs will give a powerful and rapid tool for the planning of the BSS at the time of 1983.

Session 10: Analysis of Plans

Chairman: D. Doran-Veevers (Canada)

10.1 Factors to be considered in the analysis of a plan

Author: K. Brown (Canada)

Detailed analysis of any plan is intended to estimate the potential levels of service for the various service areas considered and to determine the potential level of interference into other services in the same or related frequency bands as a result of the frequency, polarization, power level and orbit allotments of that plan. To accomplish this intent it is necessary to model the many factors that contribute to the estimate of the signal levels and to postulate parameter values which are representative of the range of values which inevitably will apply to each parameter. Some models are of necessity fairly crude due either to the complexity of the procedure the accumulation of tolerances is difficult to predict due to insufficient experience and data. As a result there is a tendency to assume a worst case combination of tolerance effects whereas it may be more realistic to consider a statistical combination. Finally, for the broadcast satellite service, it may be necessary to assume that all the planned satellites are put into operation in the same time frame and all utilizing the upper bound characteristics specified in the initial plan. In practice some services will probably never be implemented during the period of validity of the plan and other services will be implemented to below the specified levels and thus produce less interference.

Factors to be considered in the development of an analysis package are presented. The dimensions of the analysis problem dictate a computerized approach. Various interactions in the feeder link and in the downlink separately and in combination, are discussed. Irrespective of how sophisticated and complex the various models required are made the analysis of a broadcast satellite plan can, at best, only be a pessimistic estimate of the worst that could happen and even then with a low probability of occurance. Thus the results must be viewed with a certain amount of circumspection.

Comments:

Considerable discussion ensued concerning the tolerance on beam rotation, its impact on satellite yaw control, beam size and tube power. This is an area that requires further study.

One intervenor questioned the magnitude of the figures for rain fade assumed for discussion purposes.

It was pointed out that, in some conditions, the small signal suppression effect of a non linear t.w.t. may in fact be a small signal enhancement thus potentially degrading the carrier to interference ratio.

10.2 The analysis of a Satellite Broadcasting Plan

Author: H. Mertens (Belgium)

Whatever criteria may be selected with a view to the establishment of a satellite broadcasting plan, and whatever might be the method used in formulating that plan, it is indispensible to be able to analyse the service quality which it will allow to be offered in respect of noise and, above all, since this is the more complex aspect, in respect of the interference situation. This analysis is brought into play, either in a summary fashion or in detail, in the various stages of the planning process, either for consideration of examples of plans produced as exercises before the Planning Conference, or of draft plans established during the Conference, or of the final Plan produced by the Conference the merits and, where appropriate, the failings of which must be fully appreciated. Furthermore a rapide - and hence simplified and approximate - analysis is an essential aid to the process of synthesising a plan because in order to minimise the interference it is necessary to have a set of rules enabling it to be evaluated.

After a reminder of the methods for calculating interference set out in CCIR Report 633-1 (MOD I), it is indicated in this paper the general structure of the computer program developed at the EBU Technical Centre in preparation for the WARC-BS 1977 and some conclusions are drawn from the experience we have had with this program in the planning of the 12-GHz satellite broadcasting service for Regions 1 and 3. Except where we specifically state otherwise, the 12-GHz satellite broadcasting service itself is considered: that is the down-links only.

Comments:

It was asked if the EBU negative margin analysis assumed the worst case for pointing tolerances of both wanted and interfering beams, and whether a more meaningful analysis of margins on a statistical probability basis had been considered. The author replied that the EBU analysis referred to in the paper assumed worst pointing in each case, (WARC 77 values). An analysis had however been made of the plan with zero tolerances, to give more typical values of margins. A statistical result could also be derived, given the probability of various values of pointing error.

10.3 Description of SOUP Program (Analysis)

Author: P. Sawitz

The Spectrum-Orbit Utilization Program (SOUP) was originally developed by General Electric, Space Systems Organization, Valley Forge Space Center, in 1969. The work was first monitored by the then Office of Telecommunications Policy, Executive Office of the President. Later, the responsibility for this effort was transferred to the National Aeronautics and Space Administration (NASA), and ORI, Inc., under contract with the NASA, adapted the program for use on the IBM 360/95 computer and made extensive modifications to enhance its utility as a tool in the study of domestic communication satellite systems. More recently, extensive additional modifications have been made to make the SOUP more useful as a planning tool for broadcasting satellite systems. While the SOUP basically is an analysis tool, several building blocks of a synthesis program, such as will eventually be required to generate complete plans for the broadcasting-satellite service (BSS), exist already, and the most recent modifications were specifically designed to facilitate incorporation of the SOUP into an eventual complete synthesis program.

The principal purpose of the program is to compute the mutual interference between a large number of communication links operating at the same or overlapping frequencies between earth stations at specified locations through satellites in specified orbital positions. Since mutual interference is the main limiting factor in the use of the geostationary arc by systems operating in the same frequency bands, the SOUP is a most valuable tool in the optimization of spectrum-orbit utilization.

An additional purpose of the program is to compute certain quantities, such as thermal noise and power flux densities, which, while not related directly to mutual interference, nevertheless are useful in the study and evaluation of satellite communication systems.

Comments:

Some discussion followed on the fact that in the computer printout, it appeared that there was only one frequency used in the analysis. It was felt by the speaker that this was of minor importance. It was also indicated by the speaker that the rotation error around the beam axis was not included at this time.

Session 11 - Alternative Services for BSS

Chairman: H. Hupe (USA)

Paper 11.1: Telidon/Satellite Delivery: An Alternative for for Opportunities in Education

Author: Dr. M.L. Cioni (CAN)

Telidon, the Canadian Videotex System may be provided by broadcast, two-way cable, FM, and telephone. This paper points out that it can also be delivered by satellite, and has been experimentally using ANIK B's 12/14 GHz transponders. This delivery mode may be of special importance in rural areas. "Self programmed" education via Teledon is one example of a socially important innovative service.

Paper 11.2: High Resolution TV in the 12 GHz Bands

Author: Dr. J. Ramasastry (USA)

This paper describes the conceptual and detailed development of a high-resolution TV system and in particular describes a digital modulation, bit rate reduction scheme which could result in a signal with a bandwidth capable of being delivered by a 12 GHz BSS system. The paper points out that planning in 1983 should take into consideration the possibility of high-definition TV and other advanced technologies for education and entertainment, particularly insofar as they may utilize technical parameters different from conventional systems.

Paper 11.3: Service Development in Canada using Communications Satellites

Author: W.T. Kerr (CAN)

The paper focuses on Canada's experimental and developmental activities using communications satellites to improve the delivery of services to the people throughout the country. Brief background information is provided to establish the Canadian context and to identify the specific needs which required Canada to enter into space communications. The history of Canada's space program is described briefly, before detailed discussions of experimental and developmental work undertaken with the Hermes and ANIK-B communications satellites. Examples are given of activities in the fields of education, health care, community communications and broadcasting, including direct-to-home broadcasting. The paper concludes with a preview of future space communications endeavours in Canada, and some perspectives on potential applications for the developing countries.

Paper 11.4: New Services in an Existing Plan

Author: H. Mertens

This paper addresses the problem of implementing advanced technology and new service concepts within an existing a-priori plan. Both constraints and freedoms exist. A variety of services are possible, e.g. multiple sound channels, data services (such as teletext), still pictures, and high definition TV. One means of providing such services within the WARC 77 plan is with "sound" sub-carriers with the TV picture; another is substitution of services for the TV signal (e.g. 16 sound stereo programs).

Session C - Communications Research Center - Shirley Bay

Paper C.1: Canadian Space Communications

Author: B.C. Blevis

The session started with a welcome address by the Director General of the Space Technology and Applications, Dr. B.C. Blevis. Dr. Blevis also gave a description of the Organization of the Department of Communications (see Annex 1) and a general description of a few of the current major projects of the Space Sector at the CRC (ANIK-B, SARSAT and others).

Paper C.2: Result of HERMES and ANIK-B Broadcasting Satellite Experiments

Author: N.G. Davies

This paper describes a number of trials and experiments to explore the technology and implementation of satellite TV broadcasting that have been carried out in Canada in the time period 1976 to the present using the experimental Hermes and ANIK-B satellites in the frequency band 11.7-12.2 GHz. The scope of the trials and some of the results, particularly with respect to long duration trials using low values of EIRP are discussed.

Comment: Comments on the system characteristics particularly those at low elevation angles and those outside Canada were generated. It was said that below 1^{o} elevation angle, typical in the very far north, the transmission may suffer troposcatter fading. In the range of 2^{o} to 5^{o}, the rain climate in the north of Canada allows better service availability than for many southern regions with heavier rainfall. In the North, ice crystals have not produced noticeable decrease in service availability.

Next, the level of e.i.r.p. of ANIK-B versus that of HERMES was addressed. It was noted that although the ANIK-B maximum e.i.r.p. of 49.5 dBW is somewhat lower than that of HERMES, 59 dBW, the service is intended for remote parts of the country where TV service is either poor or non-existent and that this level gives customers a much desirable service. In addition, by using either the 1.2 m. or 1.8 m. antennas the grade of service can be selected by the customers. It was noted that many customers in remote localities preferred to have two or three TV channels served by one transponder rather than only one channel of a higher grade quality. Finally, reception below threshold, which may sometimes be experienced briefly during rain events does not correspond to complete service outages but simply degraded picture quality, considered still viewable, down to several dB below threshold.

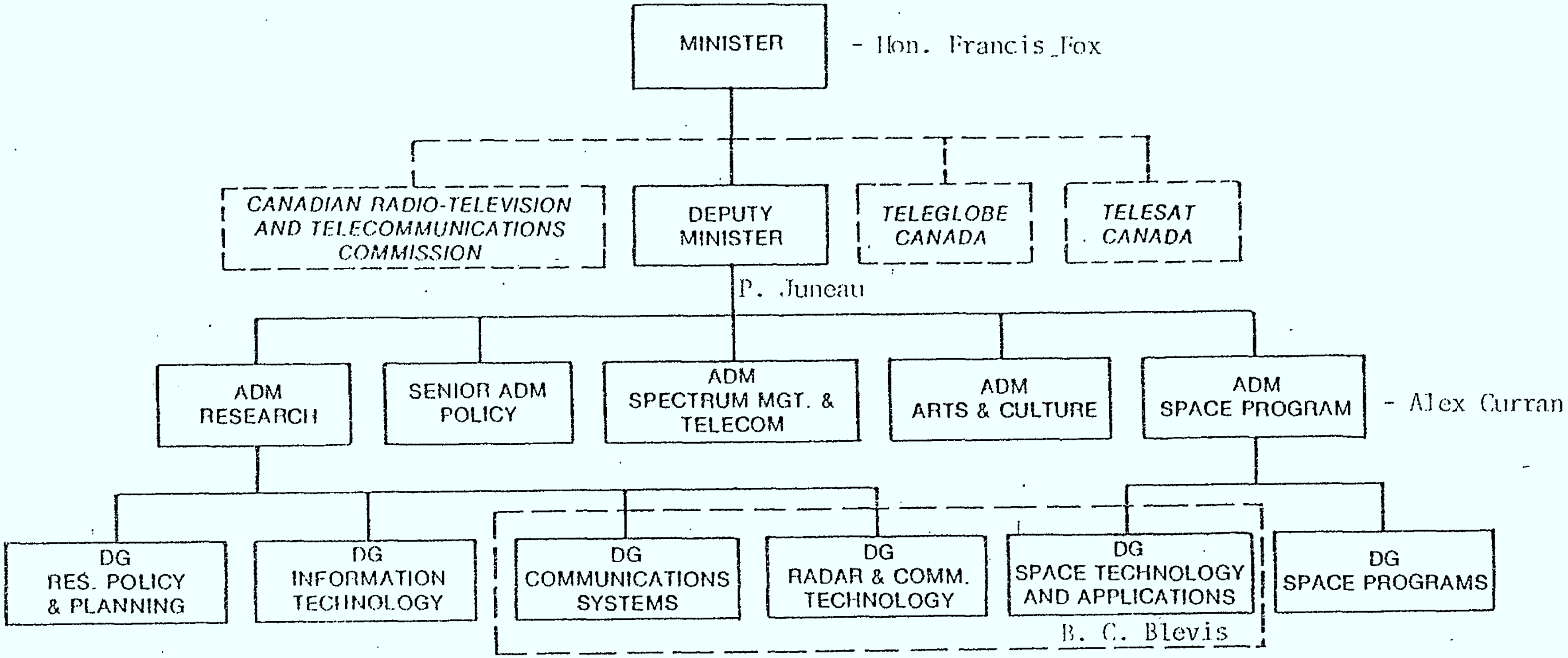
A question related to the long range planning in Canada for both the fixed-satellite service for TV distribution and the broadcasting-satellite service for TV broadcasting raised some interest. It was stated that the orderly development of these services both domestically and internationally requires considerable effort. This topic is currently being studied by several Canadian organizations.

Paper C.3: Demonstration of 12 GHz TV Reception from ANIK-B

Author: J.W.B. Day (CRC)

A video demonstration of ANIK-B, including rain fade effects, was very well received. Many comments on technical characteristics and on service quality were made. These comments were of the same nature as those following the previous paper. Annex 2 shows the effect of artificially introducing simulated rain attenuation on picture quality.

A visit of the integration and testing facilities, the David Florida Laboratory was also found to be very interesting. The attendees were given brief descriptions of the engineering model of the HERMES spacecraft launched in 1976 and of the integration of spacecrafts of the ANIK-C (14/12 GHz) and ANIK-D (6/14 GHz) programs.


MINISTER
- Hon. Francis Fox
CANADIAN RADIO-TELEVISION AND TELECOMMUNICATIONS COMMISSION
DEPUTY MINISTER
TELEGLOBE CANADA
TELESAT CANADA
P. Juneau
ADM RESEARCH
SENIOR ADM POLICY
ADM SPECTRUM MGT. & TELECOM
ADM ARTS & CULTURE
ADM SPACE PROGRAM
- Alex Curran
DG RES. POLICY & PLANNING
DG INFORMATION TECHNOLOGY
DG COMMUNICATIONS SYSTEMS
DG RADAR & COMM. TECHNOLOGY
DG SPACE TECHNOLOGY AND APPLICATIONS
DG SPACE PROGRAMS
B. C. Blevis

ANNEX 1

CARRIER POWER (dB RELATIVE TO STATIC THRESHOLD)	PICTURE QUALITY
+4	No threshold noise
+2	Threshold noise just starts to appear on color bars; not generally noticeable on pictures except those having wide deviation components.
+1.5	Dynamic threshold; threshold noise just starts to appear on pictures.
0	Significant threshold noise on color bars; noticeable on pictures.
-2	Large amount of threshold noise on color bars; significant on pictures.
-4	Large amount of noise on all pictures; at some point below this the picture will be lost.

ANNEX 2

Preparatory Seminar for the 1983 RARC

Panel Session - Friday May 8, 1981

Chairman	Mr. A. Berrada	IFRB
Panel Members	Mr. P. Balduino	Brazil
	Mr. J. Zamudio	Mexico
	Mr. E. Reinhart	U.S.A.
	Mr. E. Jacobs	U.S.A.
	Dr. C. Siocos	Canada
	Dr. R. Bowen	Canada

A lively discussion on the approaches and needs for planning was summarized by the chairman as follows:

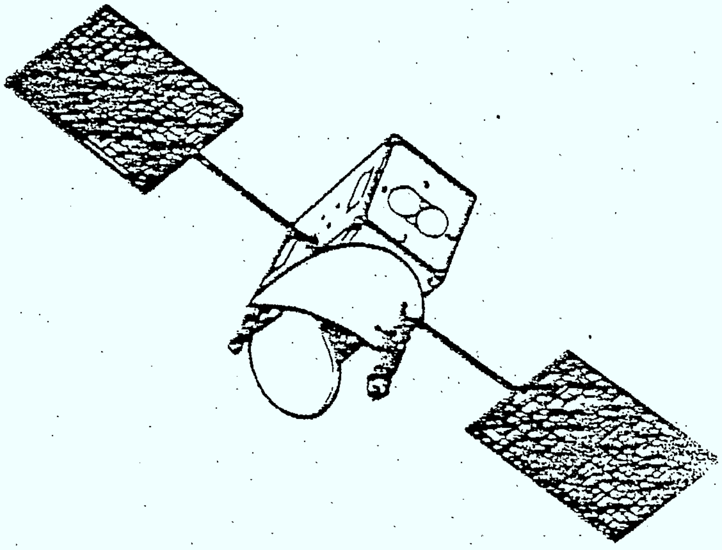
1) The channel spacing to be adopted should permit other uses than frequency modulation television.

2) The criteria to be adopted for planning such as e.i.r.p., protection ratio, receiving system characteristics, should be considered as reference criteria permitting at the implementation stage of a system the use of an assigned channel for other purposes than FM TV signals.

3) The planning of orbital positions and beams may consider differently:

   - countries to be covered by a single beam which have one degree of flexibility
   - countries to be covered by more than one beam for which there exists two degrees of flexibility i.e. the orbital position and the number of beams.

   For these latter, one may foresee a procedure as simple as possible which permit them to modify the beams with the view to cope with the actual requirements as they may derive from the implementation process.



Preparatory Seminar for 1983 RARC on Broadcast Satellite Planning Principles and Methodology

May 4-8, 1981, Ottawa, Canada.

PROGRAM

Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

1983 RARC Preparatory Seminar
Auditorium, Lester B. Pearson Building,
Ottawa, May 1981

FRIDAY - MAY 8

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
P1	0900-1030	Panel - Introduction of Draft Report	A. Berrada (IFRB)	P.1 P.2 P.3 P.4 P.5	R. Bowen C. Siocos P. Balduino? E. Reinhart E. Jacobs	
		COFFEE		COFFEE		COFFEE
PLEN	1600-1730	Plenary Meeting Adoption of Final Report	R. Severini (CITEL)			

1983 RARC Preparatory Seminar
Auditorium, Lester B. Pearson Building,
Ottawa, May 1981

THURSDAY - MAY 7

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
CRC	0900-1300		M. Bouchard (Session Coordinator)	C.1	B. Blevis	Canadian Space Communications
				C.2	G. Davies	Results of Hermes and ANIK B Broadcast Satellite Experiments
				C.3	J. Day	ANIK B Broadcast Satellite Demonstration
	1300-1400	LUNCH		LUNCH		LUNCH
10	1400-1530	Analysis of Plans	D. Doran-Veevers (DOC Canada)	10.1	K. Brown	Factors to be Considered in the Analysis of a Plan
				10.2	H. Mertens	The Analysis of a Satellite Broadcasting Plan
				10.3	P. Sawitz	Description of SOUP program (Analysis)
	1530-1600	COFFEE		COFFEE		COFFEE
11	1600-1730	Alternative Services for the BSS	H. Hupe (NTIA)	11.1	M. Cioni	Telidon/Satellite Delivery: A Alternative for Opportunities in Education
				11.2	J. Ramarsastry	High Resolution TV in the 12 GHz bands
				11.3	T. Kerr	Service Development in Canada using Communications Satellites

2000 DINNER

1983 RARC Preparatory Seminar
Auditorium, Lester B. Pearson Building,
Ottawa, May 1981

WEDNESDAY - MAY 6

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
7	0900-1100	Feeder Links	J. Miller (NASA)	7.1	H. Ng	Feeder Link Planning Considerations
				7.2	M. Bouchard	Planning of National Feeder Links in Multibeam BSS
				7.3	L. Cheveau	Some Considerations Relating to the Planning of Feeder Links
				7.4	H. Fromm J. McEwen	Possible Implications of the Geneva Plan - 1977 on the Feeder Link for European BSS
	1100-1130	COFFEE		COFFEE		COFFEE
8	1130-1230	Beam Fitting	H. Cohen (TRW)	8.1	G. Chouinard	Satellite Beam Optimization for the Broadcasting Satellite Service
				8.2	P. Sawitz	Description of the SOUP Program (Shaped beams and Synthesis)
				8.3	D. Thorpe	
	1230-1430	LUNCH		LUNCH		LUNCH
9(a)	1430-1530	Synthesis of Plans (a)	H. Mertens (EBU)	9.1	D. Sauvet-Goichon	Computer Planning Methods Used by the EBU for the Pre. of the WARC-BS
				9.2	G. Phillips	Evolving Plans at WARC '77: A Manual Method with the help of Computer Matrice
	1530-1600	COFFEE		COFFEE		COFFEE
9(b)	1600-1730	Synthesis of Plans (b)	H. Mertens (EBU)	9.3	G. Chouinard M. Vachon	Computer Synthesis Process Using a Branch and Bound Algorithm
				9.4	M. Nedzela J. Sidney	(Minimum Impact) A Synthesis Algorithm for Planning the BSS
				9.5	J. Christensen	BSS - Computer Aided Planning System

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Ottawa, May 1981

TUESDAY - MAY 5

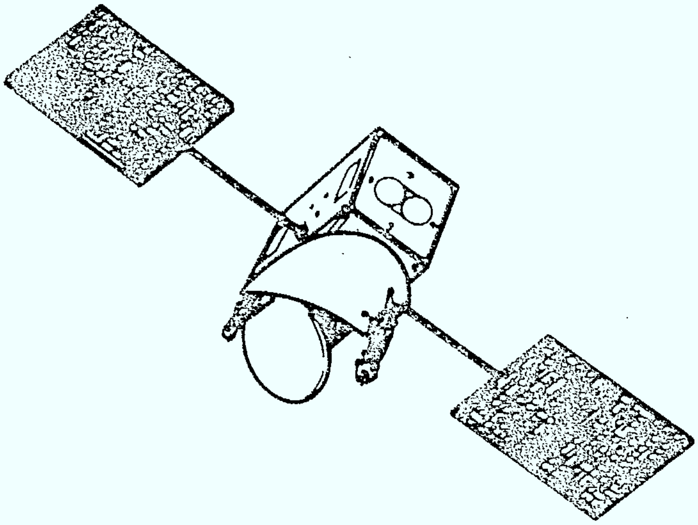
SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKER	TITLE
3	0900-1100	System Constraints and Technical Considerations	B. Blevis (DOC Canada)	3.1	R. Bowen	Consideration of Noise and Interference in a BSS
				3.2	K. Brown	Frequency Re-Use Constraints for 12 GHz Broad. Sat. Service in Region 2
				3.3	R. Douville	Satellite Direct Broadcast TV Receivers-Tradeoff Considerations
				3.4	B. Pattan	Overview of BSS Systems - A Technical Study by the FCC
	1100-1130	COFFEE		COFFEE		COFFEE
4	1130-1230	Propagation Effects	E. Reinhart (COMSAT)	4.1	J. Strickland } J. Schlesak }	Measurements of Precipitation Attenuation, Depolarization and Site Diversity Improvements in Canada
				4.2	M. Pontes } M. Assis }	Propagation Conditions in South and Central America
				4.3	J. Miller	Propagation Considerations
	1230-1400	LUNCH		LUNCH		LUNCH
5	1400-1530	Satellite Technology	J. Almond (Telesat Canada)	5.1	C. Lo } M. Bouchard }	Broadcasting Satellite Technology
				~~5.2~~	~~J. Clark~~	~~Satellite Characteristics~~ (paper withdrawn)
				5.3	H. Cohen	Alternative Spacecraft Designs for US Direct Broadcasting Systems
				5.4	E. Martin	Direct Broadcasting Satellite Service for the US - A System Description
	1530-1600	COFFEE		COFFEE		COFFEE
6	1600-1730	Spacecraft and Earth Station Economics	J.C. Chambers (DOC Canada)	6.1	E. Martin	Direct Broadcasting Satellite Service for the US - Tradeoffs
				6.2	H. Raine } R. Trenholm }	Broadcast Satellite System Cost Estimation
				6.3	A. Vaisnys	BSS System Cost Considerations

1983 RARC Preparatory Seminar
Auditorium, Lester B. Pearson Building,
Ottawa, May 1981

MONDAY - MAY 4

SESSION	TIME	TOPIC	CHAIRMAN	PAPER	SPEAKERS	TITLE
I	0900-1030	Introduction	C. Warren (DOC Canada)	I 1 I 2 I 3	A. Curran A. Berrada R. Severini	Welcoming Address
	1000-1030	COFFEE		COFFEE		COFFEE
1(a)	1030-1230	Approaches to Planning (a)	R. Zeitoun (CRTC Canada)	1.1 1.2 1.3	J. Chambers P. Balduino J. Miller	DBS Planning in Canada Spectrum/Orbit Planning Alternatives Approaches to Planning
	1230-1400	LUNCH		LUNCH		LUNCH
1(b)	1400-1530	Approaches to Planning (b)	R. Zeitoun (CRTC Canada)	1.4 1.5 1.6	H. Hupe E. Jacobs C. Siocos	Interim Systems and Flexibility Report of U.S. Domestic DBS Activities IWP 10-11/2 and CCIR 10-11S Activities
	1530-1600	COFFEE		COFFEE		COFFEE
2	1600-1730	Internetwork Coordination	D. Weese (Telesat Canada)	2.1 2.2	R. Amero E. Reinhart C. Azevedo	Inter-Regional Sharing Considerations Overview on Sharing Involving the BSS of Region 2

1830 RECEPTION



TITLE : PREPARATION OF THE 1983 REGIONAL ADMINISTRATIVE RADIO CONFERENCE

AUTHOR : A. BERRADA

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

Government of Canada Department of Communications	Gouvernement du Canada Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

ORIGINAL: FRENCH

Preparation of the 1983 Regional Administrative Radio Conference

A Berrada
Member of

The period preceding the second Space Conference held in 1971 was a very productive one in the area of satellite broadcasting both with the CCIR and other international organizations such as UNESCO and the United Nations. Interest among these latter organizations was primarily directed at the programs and their political repercussions. It should be noted, however, that at this time, ideas concerning the possible uses of satellite broadcasting were not yet clear and it was easy to confuse such systems as Mondovision and the direct reception or transmission already provided by Intelsat. However, many people felt that, for once, the international community should determine the regulations for this new service before its implementation and preferably, plan its development.

At the 1971 Conference, the assignment of frequency bands to satellite broadcasting seemed to take second place to the desire for certain preliminary guarantees as to the use of this service. Two principles on use kept resurfacing in discussions, namely, equal access to this service by all countries and protection against unacceptable transmissions. It was these concerns which delayed the assignment of bands to this service until the latter part of the Conference, when an agreement had been reached on:

- the provisions of No 428A (RR2674) which solved the problem of overlapping, as well as the problem of the coverage of one country by a satellite belonging to another country;

- Resolution No SPA2-2 which solved the problem of equal rights and led to the 1977 planning conference and to the conference which will soon be held for Region 2.

Once the principle of planning had been accepted, it remained to be decided whether this principle should be applied on a world or regional basis. The resolution adopted covering this point left it up to the Administrative Council to decide, with the agreement of all countries, on the solution to be adopted. The 1977 World Conference that was held to plan the satellite broadcasting service was confronted with two opposing opinions: one school of thought was for the preparation and adoption of a classical world plan, while the other called for evolutive planning. A compromise was achieved whereby:

- a plan was adopted for Regions 1 and 3; and

- the planning for Region 2 would be carried out at a later date.

During this Conference, some of the countries in Region 2 wished to know to what extent the planning criteria adopted could be applied to Region 2 and they asked the IFRB to draft a tentative plan. The result of this work was presented in a Conference document as well as an IFRB circular which was distributed to all countries in Region 2 (Circular No 379 of April 27, 1977).

No sooner had the problem of planning been resolved but another legal problem arose concerning the form which the decisions of the Conference should take - an amendment of the Regulations or an agreement which would only be binding upon those countries which signed it.

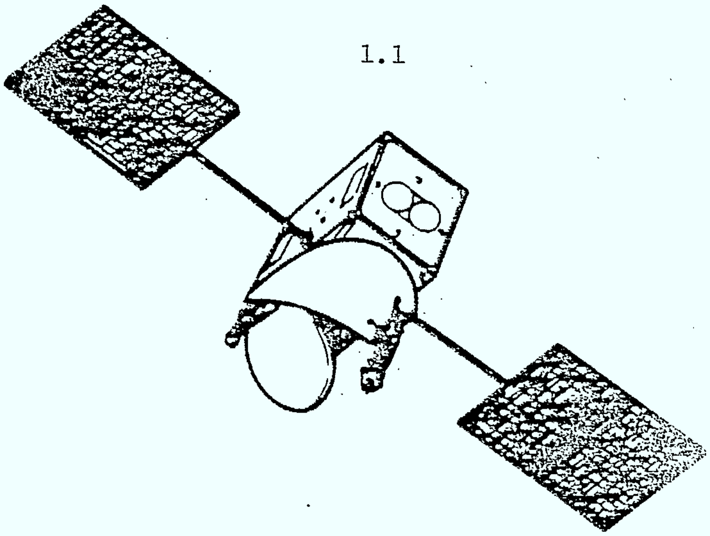
The compromise reached was to sign the Final Acts and to request a later World Administrative Radio Conference to include them <u>per se</u> in the Regulations. This was done at the WARC in 1979.

Although the Final Acts of the 1977 WARC do not contain a plan for Region 2, Article 13 clearly states that the Acts apply on a world basis. This means that some of the provisions apply to Region 2 and that these provisions, either in whole or in part, must be applied by Region 2. It might be useful for the IFRB to establish a list of the provisions of the Regulations (Article 8 and Appendix 30) which apply to the Region and to provide the appropriate interpretation before the Conference. Some of these provisions do, in fact, require an interpretation. One example is the 12.1 - 12.3 GHz band which is assigned to satellite broadcasting in the Table but the note on Table No 839 stipulates that this service is subject to Article 14, the provisions of which make compliance with the Regulations dependent upon the agreement of the countries concerned. A country could, therefore, find its use of this service blocked, for just cause or not, by some other country and there would not even be recourse to Resolution No 33 or notification of the IFRB under RR 342, since Resolution 33 does not allow this. If I am confusing you with all of these references, I must apologize. I merely wished to give a general idea of the complexity of the situation which is made even more difficult by another legal problem which arises from the special situation in which Region 2 finds itself. This problem is to determine whether the provisions adopted by a World Conference can be amended by a Regional Conference since we must remember that the 1983 Conference is a Regional one. In the past, when the Administrative Council has called this type of conference it has always been to reach an agreement which would only be binding on the signatories (see the Resolution on the

Convocation of the Regional Planning Conference for middle-frequency broadcasting in Region 2). In the case of the 1983 Conference, Resolution 701 of the 1979 WARC provided for a regional conference whose sole activity would be the drafting of a plan and related procedures which would be included in the Regulations at a later date. In view of these facts, I can only emphasize the need to examine with great care the resolution which the Administrative Council is to prepare this year to set the agenda for the Conference to ensure that the Conference is not faced with these problems.

I have assessed the human resources which the IFRB would require to prepare the Conference in accordance with the provisions of the Regulations. We would be working on developing the computer programs needed for the planning process. The conclusion that I reached was that we would required a considerable financial commitment from the ITU. In actual fact, our work will be to reinvent the processes which the administrations developed earlier for their national planning processes. It might be worthwhile to investigate the possibility of co-ordinating the efforts of the various administrations and those of the IFRB.

In this time of numerous conferences, experience has shown us the importance of distributing information on problems with which these conferences will have to deal. On behalf of the IFBR and the ITU, I would like to thank Canada for organizing this seminar which will undoubtedly be one of the key elements in the success of the 1983 Conference.



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TITLE : DBS PLANNING IN CANADA

AUTHOR : J.G. CHAMBERS

CAN

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
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DBS PLANNING IN CANADA

By J.G. Chambers

ABSTRACT

Canada has been engaged in DBS-related studies for over a decade. The HERMES and ANIK-B programs have provided a wealth of data and experience in the use of DBS systems. In parallel with the preparation of positions for the 1983 Regional Administrative Radio Conference on the Broadcasting Satellite Service, a report is in preparation on the requirement for a DBS system for Canada. While consultation with interested parties in Canada is still in progress, indications are that a first-generation DBS system will require 4-6 programs in each of 4-6 beams and a second-generation system as many as 12 or more programs in each beam, if this were to be possible. It is concluded that the pressures generating these requirements are not unique to Canada, and an approach to orbit frequency planning is suggested that would allow for the economical implementation of first generation and possible second-generation systems without a requirement for eclipse protection, followed by a later expansion to systems requiring such protection.

DBS PLANNING IN CANADA

1. Introduction

The concept of broadcasting television and radio programs from a satellite directly to individual home receivers has been under study in Canada in one way or another for over a decade. It was on 20 April 1971, that the Canadian Department of Communications and the United States National Aeronautics and Space Administration signed an agreement for the joint Communications Technology Satellite (CTS) program. This satellite, launched in 1976 and named HERMES, carried a 200 watt TWTA operating in the 11.7-12.2 GHz band. HERMES was used, until the end of its life in November 1979, to carry out a series of tests and trials of small low-cost earth stations suitable for home receivers.

However, under the terms of the agreement with NASA, HERMES was available to each country on alternate days, and its two transponders (200 watt and 20 watt) were shared among a large number of experimenters. The launch of Telesat's ANIK-B satellite in 1978 provided the possibility of DBS field trials under operational conditions. Even though ANIK-B generates a boresight EIRP of only 51 dBW, compared to 59 dBW for HERMES, good quality reception is still possible with home receiver antenna diameters as small as 1.2 metres. DBS pilot projects using ANIK-B have been in operation for about one and one-half years in two regions of Canada, Ontario in the east and British Columbia and parts of the Yukon and the Northwest Territories in the west. The reaction of users to the grade of service that it is possible to provide at these lower satellite powers has been surprisingly positive. Also, in the ANIK-B trials, experience is being gained in the operation of low-cost DBS terminals in a wide variety of environments, in regions with rainfall rates of up to 800 cm per year, under various snowfall conditions, and at temperatures as low as -50°C.

The HERMES and ANIK-B trials provide a sound base of information and experience on which to plan for an operational DBS system in Canada. A program of studies is presently under way, examining the technical, economic, social and regulatory implications of implementing such a system, in order that a decision can be taken as soon as the results of the 1983 RARC are known.

In parallel with these domestic studies, preparations have been under way for some time in Canada for the 1983 RARC itself. These preparations are being carried out under the general guidance of the Canadian Interdepartmental Committee for the Preparation for the 1983 RARC. A special government industry working group of the Committee is coordinating input from non-government sources.

2. <u>The Canadian DBS Study Program</u>

Canada is the most heavily cabled country in the world. Over 75% of all Canadians have access to cable television and about 55% actually subscribe to the service. In the larger centres, these subscribers have up to 20 television programs available to them with an average of 11 channels being available on a national basis. In the U.S., there has been an explosive growth in satellite-carried TV programs, with some 30 channels available or about to become available from this source alone. It can be expected that a rapid growth in available programming will also take place in Canada over the next 5-10 years.

However, many Canadians live outside population centres large enough to support cable television systems. Even now these Canadians are expressing dissatisfaction at the much lower level of radio and television services available to them compared to their urban counterparts, and this disparity will increase markedly as satellite-carried cable programs proliferate. While there is still considerable potential to extend cable services to include a greater percentage of the population, there will always be a substantial number, about 10%, for which cable systems are not practical. Thus, other means to provide the service are being examined, of which DBS is the most promising.

A study program is underway which is intended to result in a comprehensive report on the requirements for a DBS system in Canada and on the possible nature of such a system. A list of the studies and study areas is attached as Appendix A. Also attached as Appendix B is a program schedule.

A study of the statistics of television coverage in rural and remote areas has just been completed by Professor P.S. Anderson of the Telecommunications Research Group of Simon Fraser University, Burnaby, B.C. The rural and remote category includes about one-quarter of the total population of Canada. This study shows, for example, that while about 1 million in this group receive 7 channels or more of television, 2.6 million receive two channels or less, and 0.26 million receive no television.

Another question that is currently receiving considerable attention in Canada is that of Pay-TV. While such programs are proving to be profitable on cable systems in the U.S., it is not clear that they can be economically viable in the much more limited context of a Canadian DBS system. However, preliminary results from another contracted study, being carried out by TAMEC Inc. Montreal, lead to cautious optimism in this regard. Pay-TV and other types of programming that might be carried on a DBS system are discussed at greater length below.

Work is also underway on system engineering modelling. In one study, being carried out by Spar Aerospace in Montreal, the technical feasibility and cost of models ranging from 4 channels in each of 4 beams to 8 channels in each of 6 beams are being analyzed. Also the sensitivity of the spacecraft weight, power and cost over a boresight EIRP range from 53 dBW to 58 dBW is being examined for system models having active satellites at 1, 2 or 3 orbital positions. A more general cost modelling computer program has also been developed, as will be discussed in a later paper.

Another study, being undertaken by Telesat Canada for DOC, is on the possible use of the ANIK-C system to provide a DBS service. Results from the ANIK-B program demonstrate that the ANIK-C system, which has satellite EIRPs close to those of ANIK-B, will be capable of delivering an acceptable grade of service to home and community receivers with antennas in the 1.2-1.8 metre diameter range. However, ANIK-C operates in the 11.7-12.2 GHz band and uses linear polarization, and one of the questions being examined is the cost and inconvenience of converting receivers at some future date to operate in accordance with plans to be developed at the 1983 RARC.

3. Projected Canadian Requirements

As noted above, the most immediate pressure to establish a DBS service in Canada is to provide universal access to a basic package of radio and television programs in both official languages. Beyond this, another immediate pressure is to reduce the gap between the present average of 11 programs available to cable subscribers and the much smaller number generally available to inhabitants of rural and remote areas.

It is becoming increasingly clear, however, that the requirement for DBS services is going to quickly expand far beyond this basic service. The first pressure in this direction will come from the general increase in conventional entertainment and public affairs programming made available to cable systems through satellite delivery networks, as discussed above. In addition to this, however, is a predicted development of specialized programs and services, partly as a result of increased energy costs, and partly as a result of the increasingly important role that information and information industries are playing in our lives and in our nations economies.

Thus, in addition to a basic package of 6 or so channels presently being provided in Canada, a significant number of new programs will have to be included in this "basic" package over the next 5-10 years. Pay-TV movie channels are obvious early candidates. There are already so-called Super-Station aspirants in Canada, Specialized programming directed towards children, women, religious groups, native groups, etc., are other candidates. Teletext services to provide, on a selective basis, information on shopping, the weather, news, airline schedules, etc., are already being tested for public acceptance many are suitable for DBS delivery. DBS systems also offer the possibility of improved radio service to many rural and remote areas. Finally, public service satellite applications have been under study for many years in Canada and other countries. DBS systems are suitable for many of these services, for example, in the areas of health education, adult or even university education, and to provide general information, on federal or provincial government programs and services, etc.

It is difficult to be precise about future public demand for services at the best of times, but the rapid growth now underway in satellite-delivered services makes such prediction doubly difficult. As a minimum, one can point to a practical near-term requirement for about 6 channels for a Canadian DBS system. However, before the end of this decade, this will assuredly grow to 12 channels or more.

4. Planning for System Growth

In Canada, then, and presumably in other countries, it is possible to project a longer term growth in the requirements for broadcasting satellite services that will stretch the capacity of the portion of the 12 GHz band allocated for this purpose. To achieve this ultimate capacity of the band will require careful overall planning, with full use being made of techniques for making the most efficient use of the orbit, such as frequency reuse, angular discrimination through the use of cross beaming, careful filtering in the satellite and in the earth stations to allow the closest possible packing of channels, and so on. The use of such techniques, however, generally involves additional costs either in technology development or in system operation.

For first generation systems, however, the requirements will generally be for about 4-6 channels per beam. In general, it will be possible to accommodate this number of channels per beam without resorting to these orbit/frequency efficient techniques. Since there will be strong pressures to construct these early systems as economically as possible, there will be a correspondingly strong resistance to incurring additional costs against future benefits to the general population of users of the orbit. The challenge then, is to develop a planning approach that will result in an efficient use of the total orbit/frequency resource without requiring substantial additional costs in the early phases.

Administrations in Region 2 have identified a requirement for a total of approximately 72 separate service areas. For reference, these service areas are shown in Figure 1. A later paper by K. Brown notes that a complete analysis of one of a plan for the Region could potentially require up to 2 x 10^7 link calculations to be performed and stored. In practice, ways can be found to reduce this number significantly, but it is still necessary to make extensive use of computers in synthesizing and analyzing Region-wide plans.

In Canada, we have been concentrating on the development of the required computer programs. The synthesis programs are nearly complete. Several terminals have been set up in this Conference Centre to demonstrate the synthesis software and allow you to experiment with it. Also, a beginning has been made on the development of the analysis programs, and it is expected that this software package will be completed by the fall of this year. This work is being carried out in a cooperative effort by staff from the

Canadian Broadcasting Corporation, the Canadian Radio-Television and Telecommunications Commission and of the Department of Communications, under the general guidance of the Canadian Interdepartmental Committee, mentioned above.

Returning to the question of how to plan for system growth, I would like to use some preliminary planning exercises that have been developed with the synthesis program to illustrate one possible approach to this problem. It should be emphasized that these are preliminary plans. They do not adhere completely to 77 WARC system parameters; for example, a single-entry co-channel protection ratio of 33 dB has been used, rather than 35 dB. They are used here for illustrative purposes only.

Table I shows the points of origination in the orbit of Region 2 beams for an 18 channel per beam plan. It can be seen that many beams originate from orbit positions east of the area being served, that is, batteries are required for eclipse protection. There are a total of 37 satellite positions used in this plan. The degree of cross-beaming required is indicated, for example, by the span of 83° in orbit position for beams serving Brazil or of 70° for those serving Canada. Again, it should be emphasized that this plan, in particular, is not considered practical for implementation in the near future, but it does meet criteria that are reasonable to assume for systems going into operation in the mid-1990's.

Table II gives beam orbit positions for a 9 channel per beam plan which does not require eclipse protection up to local midnight for any service area. Only 23 orbit positions are required in this case. It should be noted that this particular plan incorporates the orbit positions proposed for the COMSAT system. A similar plan, without this constraint, resulted in a total of 20 orbit positions. Using the same procedure as for the 9 and 18 channel plans, a 6 channel per beam plan was also derived, resulting in a total of 17 orbit positions.

These results suggest an approach to orbit/frequency planning that would provide a guarantee to all Administrations of economical first-generation and in most cases second-generation systems, while still resulting in relatively high efficiency in the use of the orbit/frequency resource in the longer term. It would involve first establishing a relatively detailed plan based on the maximum capacity that can be achieved at reasonable cost, for example, similar to the 9 channel plan discussed above. As indicated above, it would appear to be a relatively minor constraint to require first-generation 4-6 channel systems to be compatible with this higher capacity system. The development of systems with satellites lying east of the service areas being served might be then left as the subject of a future planning conference.

Table 1

Orbital Positions - 18 Channel Plan

Orbital Position (°W)	Beams
16.0	St-Pierre & Miquelon, French Antilles
22.0	Brazil 3, 5
34.0	Colombia 1, 2
44.7	Brazil 6, 7
47.0	Greenland 1, 2, Cuba
53.0	Surinam, French Guyana
56.0	British Antilles 3, Grenada
58.2	Argentina 1, 2
59.5	Bahamas Islands
61.0	Brazil A, B
63.0	British Antilles 1, Jamaica
68.0	Guatemala, Belize
70.5	Bolivia, Peru
74.0	Canada 3, 4
77.7	Brazil 4
80.0	Dominican Republic, Haiti
84.0	Dutch Antilles 1, 2
85.7	El Salvador
86.0	Juan Fernandez, S. Felix, S. Ambrosio, Chile
89.0	Brazil D, C
95.0	Easter Island & Sala-T-Gomez Island, Chile (Central &North)
97.0	Canada 5, 6
99.0	Venezuela, Guyana
101.0	USA 1, 2
103.0	Bermudas, British Antilles 2
105.2	Brazil 8, 9
107.1	Nicaragua, Honduras
109.0	Ecuador, Galapagos Islands
112.8	Uruguay, Paraguay
114.0	Peurto Rico (incl. Virgin Islands)
118.0	Brazil 1, 2
123.0	USA 3, 4
127.0	Trinidad & Tobago, Barbados
130.0	Panama, Costa Rica
144.0	Canada 1, 2
147.0	Mexico North 1, South 2
180.0	Hawaiian I., Alaska

Table 2

Orbital Positions - 9 Channel Plan

Orbital Position (^{o}W)	Beams
58.7	Greenland 1, 2, Brazil 8, A, B
66.0	Brazil 5, C, 9
72.5	Paraguay, Brazil 4, D, 7
74.0	Trinidad & Tobago, Grenada, Bermudas
79.0	Dutch Antilles 1, 2, Surinam
83.8	Argentina 1, 2, Bolivia
84.0	French Guyana, St.-Pierre & Miquelon, Haiti, Fr. Antilles
90.6	Chile (Cen. N&S) Juan Fer. S. Felix&Amb. Eas. I & SalYGom I
91.7	Guyana, British Antilles 1, 2, 3
96.4	Cuba, Dominican Republic, Panama, Costa Rica
101.6	Barbados, Jamaica, Bahamas Islands, Belize
103.6	Brazil 1, 2, 3, 6
105.0	Canada 4, 5, 6
107.0	Galapagos Islands, Uruguay, Ecuador
109.8	Colombia 1, 2, Venezuela
115.0	USA 4, Puerto Rico (incl. Virgin Islands)
118.4	Honduras, Peru, Nicaragua, Guatemala, El Salvador
135.0	USA 3
136.0	Mexico 1, 2
143.0	Canada 1, 2, 3
155.0	USA 2
170.0	Hawaiian I., Alaska
175.0	USA 1

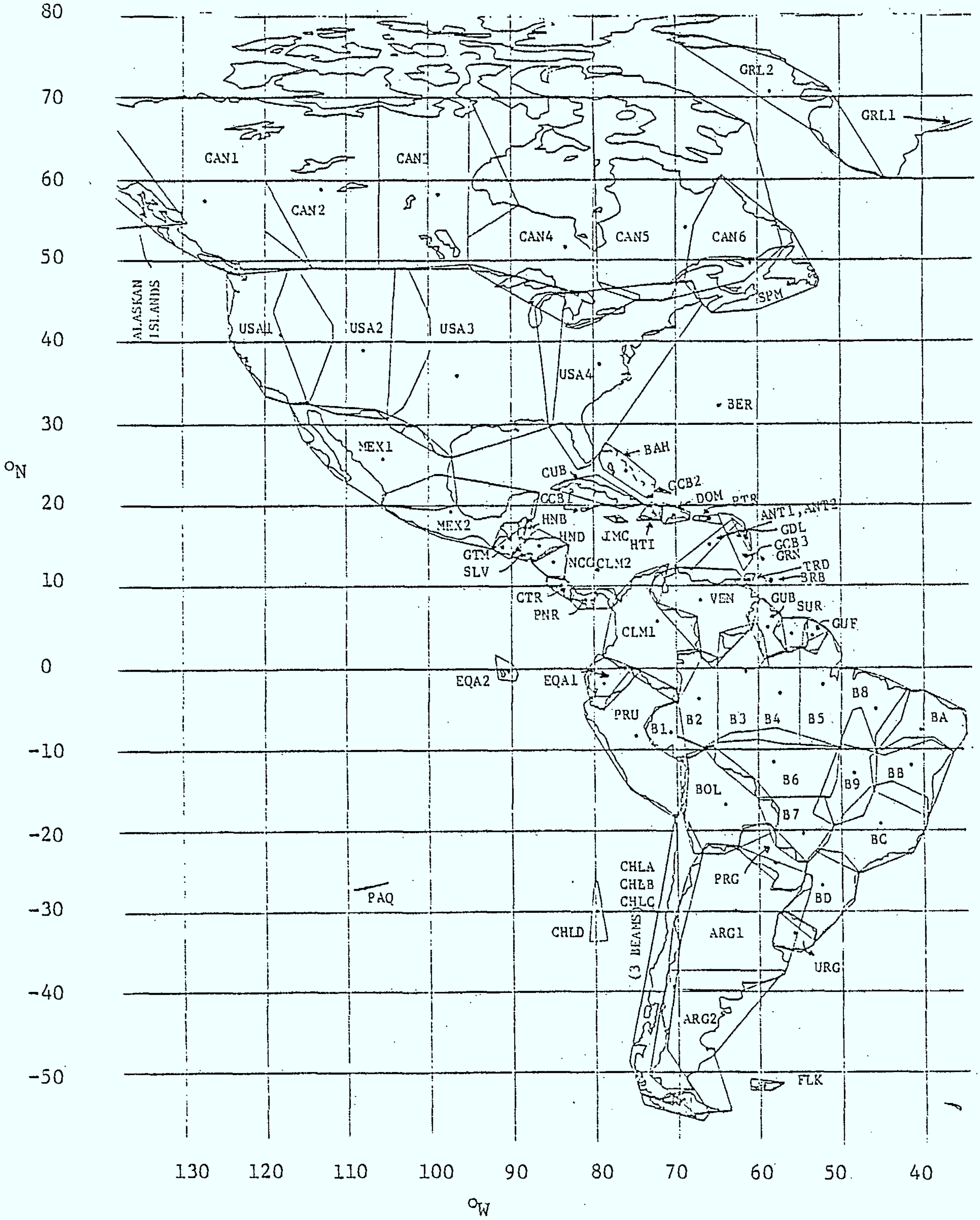


Figure 1 Assumed DBS Services Areas for Region 2

DIRECT BROADCASTING SATELLITE STUDIES PROGRAM

1. Television Service Availability in Rural and Remote Areas

   - obtaining statistics on television availability vs. demographic distribution and partitioning on a population density basis. Data to be used for market forecasting, alternative system modelling, economic analysis.

2. Rural Demand Survey

   - being carried out by the Research sector. A major portion of the survey deals with the rural market demand for more television, and price elasticity.

3. Requirements for Non-TV Service for Delivery via a DBS

   - market forecasting, technical implications of narrow-band services which could be delivered along with television on a DBS, e.g., broadcast Telidon, radio programming, electronic newspaper, etc.

4. Use of ANIK-C for Interim DBS Service

   - examination of feasibility and implications of using ANIK-C to deliver television to individual home receivers or community antenna systems. Contracted to Telesat, with Telesat supporting 50% of cost.

5. Impact of a DBS on the Broadcasting Industry

   - assessment of the socio-economic input of the introduction of DBS service in Canada on the broadcasters, CATV and MATV operators, producers, advertisers, and carriers, through economic modelling of a number of likely future scenarios. Financial/economic issues are to be emphasized, and potential opportunities as well as any negative effects will be considered.

6. Potential Impact of U.S. DBS Services on Canada

   - determination of the extent of availability in Canada of signals from U.S. direct broadcasting satellites which could compete for the Canadian television market, and the assessment of the potential impact of their availability.

7. Economic Feasibility of DBS Programming

   - analysis for economic feasibility of the range of television program and other services which could be candidates for carriage on a Canadian DBS, taking into account factors such as number of home receivers, regional beam coverage, etc.; develop scenarios of viable service offerings, including required tariff ranges.

8. Regulatory Implications of a DBS System

   - identification and analysis of regulatory issues relevant to the introduction of DBS services in Canada arising from existing legislative instruments and regulatory practices; discussion of policy and regulatory options which could facilitate the introduction of DBS services.

9. Legal Questions

   - in-depth study of specific legal issues identified in the course of other studies.

10. Economic Analysis of System Alternatives for Television Delivery

   - comparison of individual home receiver models vs. community antenna models or a combination of the two, considering DBS, ANIK C, and ANIK D space systems, as applicable, and UHF/VHF or cable terrestrial delivery systems, where secondary distribution is required.

11. System Engineering Modelling

   - development of several alternative technical models of a DBS system meeting Canadian requirements; selection of one for optimization and detailed development, including estimation of implementation costs.

12. Engineering Economic Analysis of Optimized System Model

   - conversion of development, implementation, and operating costs into economic data needed for decision making purposes.

13. Options for Institutional Arrangements

   - study of institutional arrangements for the introduction of a DBS system; roles of Telesat, carriers, broadcasters, cable operators, regulatory bodies, etc.; financial arrangements options, program supplier options, mechanisms for access, etc.

14. DBS Penetration into Urban Markets

   - study of urban demand for programming carried on DBS. Forecast of number of urban subscribers to DBS programming via owned terminals and via existing cable TV.

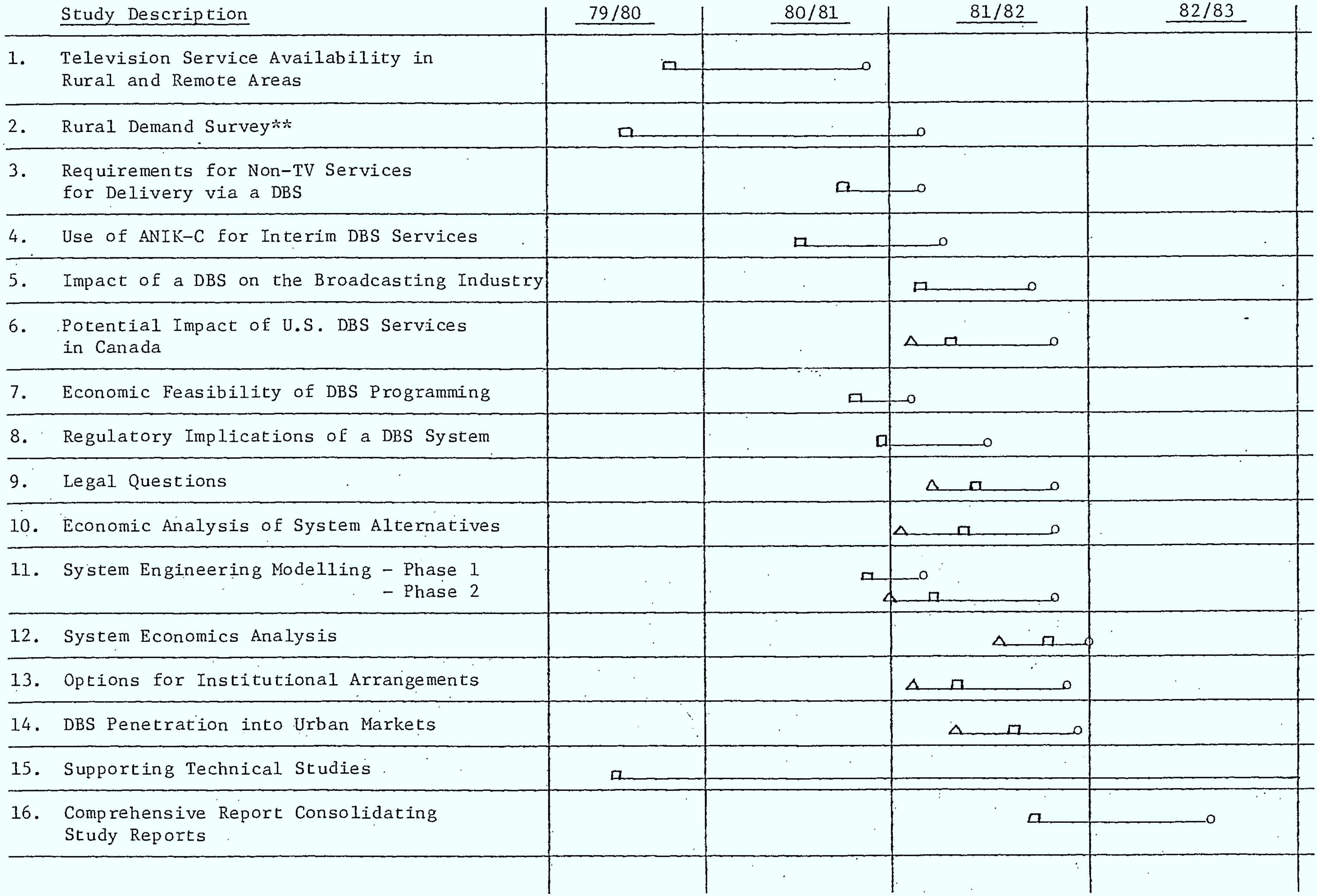
15. Supporting Technical Studies

   - research and development and technical studies at the CRC in support of the DBS studies program, including evaluation of the ANIK B demonstration project; technical studies in support of Canada's position at the 1983 RARC.

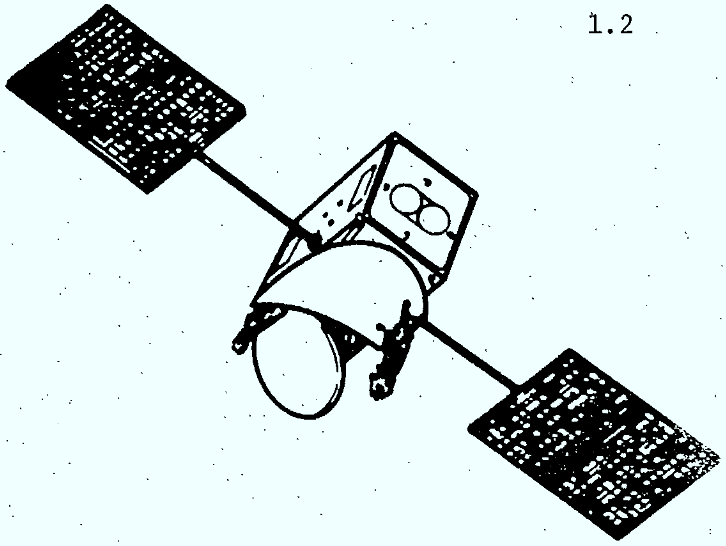
16. Comprehensive Report Consolidating Study Results

   - preparation of a report for public comment using the results of all studies carried out, describing a possible DBS system for Canada and the factors and issues involved in its implementation.

DBS STUDIES PROGRAM SCHEDULE



Appendix B



TITLE : VARIOUS PLANNING OPTIONS FOR THE BROADCASTING-SATELLITE SERVICE IN REGION 2

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Brazil

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VARIOUS PLANNING OPTIONS
FOR THE BROADCASTING-SATELLITE SERVICE
IN REGION 2

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Summary

This document underscores the need for a detailed examination of the various planning options available in regard to the 12 GHz Broadcasting-Satellite Service in Region 2. It looks at the development of new technology in the area of satellite telecommunications, and summarises recent CCIR studies on a variety of planning alternatives for satellite services.

1. Introduction

Both in the preparations for the 1977 World Administrative Radio Conference (WARC) for the planning of the Broadcasting-Satellite Service (BSS), and while the Conference was under way, two very different alternatives were considered for planning the BSS:

a) Advance planning: Under this alternative, frequencies and orbital positions would be assigned to individual countries and an effort would be made to accommodate each country's requirements, which would have to be submitted in detail and be valid for at least 15 to 20 years (thus, the 1977 Plan would have to be revised 20 years later).

b) "Evolving" planning: Although this planning alternative would still make use of a practical model, it would at the same time permit an orderly utilisation of the frequency bands and would guarantee access to geostationary orbit without requiring the sort of technical and operational detail that would be necessary under the first alternative.

For various reasons, the countries in Regions 1 and 3 opted for the advance planning alternative. Many of those countries had already been able to determine their requirements for the Broadcasting-Satellite Service, or they intended to use the 11.7-12.5 GHz or 11.7-12 GHz bands for ground services and for practical or regulatory reasons could only do so without detriment to the Broadcasting-Satellite Service if a firm plan were laid down in advance, or perhaps they regarded that method of planning as a way to guarantee their access to geostationary satellite orbit.*

Faced with a choice between advance planning, which would entail the complex task of defining requirements for a service that will not be implemented in the short or medium term, and the notion of an evolving plan only loosely defined in terms of rules and procedures,

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* Translator's Note: In the original text, the foregoing paragraph is garbled, and its exact meaning is uncertain.

Region 2 decided to put off its decision regarding the use of the 11.7-12.2 GHz band.

In view of the fact that the 1979 WARC decided that BSS planning in Region 2 in the 12.1-12.7 GHz band should be the subject of a Regional Administrative Radio Conference (RARC) in 1983, we believe that certain fundamental questions should be reexamined:

(1) Has planning become necessary because the countries in Region 2 wish to introduce their BSS systems, and does the introduction of such systems therefore hinge on the outcome of the 1983 RARC?

(2) Does the 12.1-12.7 GHz band have to be used for the other ground services to which it is also allotted, and is BSS planning necessary for this reason? (Note 3787D 844.)

(3) Is BSS planning justified on account of a need to guarantee equitable access and use with regard both to the number of channels and to suitable orbital positions?

The answer to any of these three questions leads us to a fourth question, one which is also fundamental:

(4) What sort of planning method best meets the needs of Region 2 and should therefore be adopted: advance planning, evolving planning, or some new method that has come to light since 1977?

The aim of this document, then, is to set forth certain considerations with regard to these basic questions, and to bring forward for the benefit of the 1983 RARC-BSS some information on studies and analyses being carried out within the CCIR through Interim Working Party (IWP) 4/1 concerning new and different options for planning satellite services - options that may not have been so clearly available when the 1977 WARC was held. It is crucial that Region 2 gain the greatest possible benefit from the advances made in the area of satellite communications since 1977, not only so far as the available technology is concerned but also with regard to the alternatives for planning satellite services.

2. What sort of planning is needed, and why?

On the basis of detailed analyses of Brazil's needs, bearing in mind the first three fundamental questions set forth above, and as the result of an exchange of information with various countries in Region 2, and considering moreover the opinions expressed on this subject at the 1979 WARC, we believe that we are in a position to infer that most of the countries in Region 2 have no plans to set up or operate broadcasting-satellite systems for at least the next 10 years. Consequently, a detailed definition of requirements at this time would amount to a theoretical planning exercise, the results of which would not in all likelihood reflect the Region's real needs at that point some years in the future when the countries in question actually come to establish their broadcasting-satellite systems.

It is therefore our view that, of the first three questions set forth above, only the last two have real meaning, and it is the following order of priorities that should concern us:

1) Equitable access to geostationary satellite orbit and equitable use of the 12 GHz band for the Broadcasting-Satellite Service.
2) The need for the same band to be used for those ground services to which it is also allotted.

Assuming that these are indeed the priorities of most of the countries in Region 2, it becomes plain that we must look for the answer to the fourth fundamental question: what planning method is best suited to the Region's needs?

Since the 1979 WARC decided that another World Conference in 1984 should plan satellite services, seeking to ensure equality of access to geostationary satellite orbit and to the radio frequency spectrum, the CCIR initiated preparatory studies for the 1984 Conference, which are being coordinated by Interim Working Party (IWP) 4/1.

At its last meeting, IWP 4/1 identified five planning methods for satellite services, which might be applicable to the Broadcasting-Satellite Service.

The Interim Working Party also identified a total of eleven criteria whereby the various planning methods might be evaluated and compared.

Neither the methods nor the criteria whereby they might be analysed have yet been subjected to detailed study by IWP 4/1. This work is to be done at the Working Party's next meeting, scheduled to be held in Geneva during the last two weeks of May. The list of methods and evaluation criteria is not exhaustive, and may be amended or expanded as more detailed studies are completed.

Owing to the importance of the various planning methods and evaluation criteria identified in the preparatory work for the 1983 RARC, we believe that they should be presented at the seminar.

3. Planning methods

The five alternative planning methods being analysed by IWP 4/1 are outlined below. Full definitions are contained in document IWP 4/1/901.

3.1 Advance planning:

According to this method, orbital positions and frequencies would be allocated in advance for a long period (10 to 20 years). The Plan would contain a procedure similar to Article 4 of the Final Acts of the 1977 WARC-BSS, for revising the requirements of the Plan. New requirements could be accommodated only if they do not cause unacceptable interference to those systems established in the Plan.

3.2 Periodic revisions:

By this method, conferences would be convened periodically (every 3 to 5 years) at which technical parameters and regulatory procedures would be revised, to accommodate new requirements. At each conference, all existing networks and all new requirements would be accommodated. During the interval between conferences, new requirements would be accommodated provided that they did not cause unacceptable interference to networks in the Plan.

3.3 Revisions, with guaranteed access:

By this method, conferences would be convened as necessary (at intervals of 10 years or less) to revise technical parameters and regulatory procedures. At these conferences, all existing systems and new requirements would be accommodated. During the intervals between conferences, new requirements would be guaranteed access to the orbit/spectrum by special mechanisms, such as:

- by reserving capacity in the orbit or spectrum for systems not provided for at the time of the conference; or
- by some method similar to method 3.4 described below.

3.4 Guaranteed access through multilateral coordination:

By this method, the conference would not establish a formal plan but rather would establish procedures for guaranteed orbit/spectrum access. In general, orbit/spectrum access would be coordinated according to procedures such as those described in method 3.5 below. If a new requirement could not be accommodated by means of these procedures, a special meeting would be held of the administrations that would be affected to find a way to accommodate the new requirement.

3.5 Periodic revision of coordination procedures and technical factors:

According to this method, regulatory procedures and CCIR Recommendations would be revised periodically, and new procedures, regulations, and Recommendations aimed at making more efficient use of the orbit and spectrum would be developed.

Some of these methods also offer the flexibility of being used for a specific orbital arc or for a specific geographic area in a Region. This increased flexibility results from the possibility of considering a Region to be made up of sub-regions that are, to a degree, independent of one another: thus, it might well be possible to plan for one sub-region without significantly affecting plans for other sub-regions. For instance, one sub-region could decide to put off the elaboration of a more detailed plan, while maintaining its right of access to geostationary satellite orbit and to the radio spectrum, while other sub-regions might consider it necessary to go ahead and draw up such a plan for their own areas.

Methods 3.1, 3.2, and 3.3 offer this flexibility.

Region 2 could be divided into three sub-regions which would be sufficiently independent of each other: South America, Central America and the Caribbean, and North America.

4. Criteria for evaluating the planning methods

The eleven criteria identified by Interim Working Party 4/1 are listed below. The five methods described above in Section 3 should be evaluated and compared on the basis of these criteria, by answering the following questions:

4.1 Equitable access: In practice, does the planning method guarantee equitable acess for all countries to the orbit and frequency bands allocated to satellite services?

4.2 Identification of requirements: Can realistic forecasts of requirements be made that can be used as basic information in elaborating the plan?

4.3 Technical parameters and interference criteria: Can technical parameters and interference criteria be used that are compatible with both the evolving technology and the changes in requirements that are likely to occur during the life of the plan?

4.4 Accommodation of unforeseen new networks or changes in requirements: Is it possible to accommodate new networks not considered in the plan or incorporate changes in the original requirements considered when the plan was drawn up?

4.5 Modification of technical parameters: Can the technical parameters (ie, the characteristics of the system) considered in the plan be modified so as to take advantage of technological advances that might result in more efficient and less costly systems?

4.6 Impact on system costs: Are there any features of the plan that could oblige administrations to use more expensive systems?

4.7 Restrictions due to sharing with ground systems: Does the plan impose restrictions on ground systems that share the same frequency band?

4.8 Administrative costs: Would the implementation of the plan result in higher administrative costs for the countries, and would it entail excessive work for technical and administrative staff?

4.9 Accommodation of existing networks: Does the method guarantee equitable treatment, and does it minimise the possibility of existing operating networks being displaced as the method is implemented?

4.10 Efficient use of the orbit and spectrum: Does the method represent the most efficient use of orbit/spectrum resources? Does it offer incentives for the use of optimal technical parameters?

4.11 Multinational networks: Does the method allow for regional or sub-regional networks to be introduced?

5. General analysis of methods

In order to conduct a detailed analysis of the five methods (and any other methods that may be proposed), priorities must be established for the evaluation criteria on the basis of Region 2's interests, and the questions set out against each criterion must be answered for each planning method. By comparing the advantages and disadvantages of each method, a decision can be reached as to which method should be adopted; clearly, the preferable method will be the one that satisfies the greatest number of major criteria while entailing the fewest drawbacks.

It is not our intent to undertake a detailed analysis here. Such a task would require a great deal of time and study, and may be left to the preparatory meetings for the 1983 RARC. The following is but a very general analysis intended as an example to illustrate how a suitable planning method might be chosen.

Looking at certain general features of the five planning methods, we could identify which features are desirable and which are undesirable as illustrated below:

FEATURES	ASSESSMENT
1) Possibility for regional or sub-regional planning	Desirable
2) Advance definition of unknown requirements	Undesirable
3) Long-term planning (10 to 15 years)	Undesirable
4) Possibility of revising the plan from time to time	Desirable
5) Guaranteed access to the orbit/spectrum	Desirable
6) Minimum restrictions on ground services	Desirable

An analysis of this kind would therefore reveal that the planning method chosen should embody features 1, 4, 5, and 6, as well as features that are the opposite of features 2 and 3. By this method, then, the following features would be identified as the optimal features that the planning method chosen should contain:

- the possibility of regional or sub-regional planning.
- planning based on actual known requirements, or on more precise forecasts (ie, short-term planning).
- the possibility of periodic revision.
- guaranteed access for any new requirement at any time.
- the imposition of minimum restrictions on ground services.

Obviously, a detailed element-by-element analysis along the lines of this example must be aimed at finding a method which yields the rating "desirable" for all eleven evaluation criteria, or as many of them as possible. Since two different methods rated in this way could show equal numbers of desirable features, albeit not the same features, it would be necessary to assign some order of priority to the eleven criteria before making a final decision as to the best planning method.

6. Conclusions

Bearing in mind all the new developments in the field of satellite telecommunications, which have been briefly commented upon in this document, it seems clear that the great advances made since 1977 and the more recent studies of the CCIR will provide the 1983 RARC with a major advantage over the 1977 WARC, namely the possibility of choosing from among a greater number of real planning options for the Broadcasting-Satellite Service so that a method suited to the needs and realities of the countries in Region 2 may be adopted.

Whatever solution is adopted by the 1983 RARC, it must be the result of a study of the various planning methods and criteria available. Consequently, in preparing for the 1983 RARC-BSS, one of the most important tasks will be to identify the evaluation criteria for Region 2, assign priorities to those criteria, and conduct a detailed analysis of the preferable planning methods so that, after assessing and comparing their respective advantages and disadvantages, the best method might be selected.

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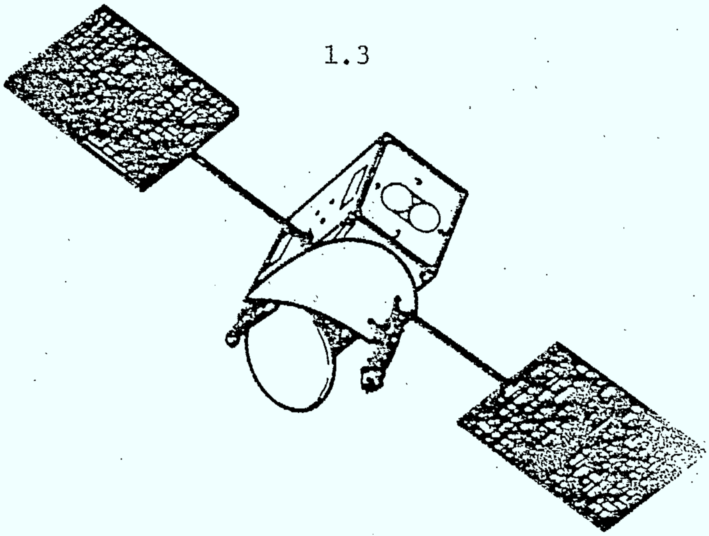

TITLE : ALTERNATIVE SPECTRUM MANAGEMENT METHODS FOR THE 12 GHz BROADCASTING-SATELLITE SERVICE IN REGION 2

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NASA

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
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Government of Canada
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ALTERNATIVE SPECTRUM MANAGEMENT METHODS FOR THE 12 GHZ BROADCASTING-SATELLITE SERVICE IN REGION 2

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April 1981

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for '83 RARC on Broadcast
Satellite Planning, May 4-8, 1981
Ottawa, Canada

1.0 Introduction

At the 1977 WARC-BS, Region 2 countries agreed that it was premature to plan the 12 GHz Broadcasting-Satellite Service (BSS) and agreed instead to convene a Regional Administrative Radio Conference (RARC) in 1982 (which was subsequently rescheduled for 1983) for that purpose. Section 12.9, et sequence, of Article 12 of the Final Acts of the 1977 WARC-BS provides guidance on the type of planning to be carried out at the RARC-83: a type of planning that was perhaps responsive to a set of objectives set forth in 1977. In light of the passage of time and the evolution of requirements and technology, it would seem desirable to re-evaluate the planning objectives and the effectiveness of alternative planning methods to fulfill those objectives.

The purpose of this paper is to describe five alternative methods for planning the 12 GHz BSS so that they may be further studied and evaluated in the context of each Administration's objectives for the service. It should be noted that in the broad sense a "planning method" is a management plan which describes a course of action to be followed in achieving a set of objectives. When the use of the radio frequency spectrum is required to meet the objectives, the management plan is embodied in the concept and in the structure of "spectrum management".

2.0 Spectrum Management Objectives

Spectrum management objectives and the associated procedures, analytical methods, and technical parameters and criteria for the terrestrial services have evolved to a relatively mature and sophisticated state as a result of the maturity of the services. To date, the only spectrum management method, i.e., the priori method of the 1977 WARC-BS, to be applied to the BSS, is an extension of that which has been used for the terrestrial Broadcasting Service -- a service which has not changed significantly during the past 40 years.

A number of possible objectives that the chosen spectrum management method must meet may be derived from the evaluation criteria developed by IWP 4/1 at its November 1980 meeting [Doc. 4/1/901]. These criteria were developed to guide the evaluation of alternative spectrum management methods, primarily as they related to the Fixed-Satellite Service. However, with slight modification they are applicable to the Region 2 12 GHz Broadcasting-Satellite Service. When stated as objectives, these criteria become:

1. Equitable Access - The spectrum management method must guarantee in practice, for all Region 2 countries, equitable access to the geostationary satellite orbit to satisfy their 12 GHz broadcasting satellite requirements;

2. Service Requirements - The spectrum management method must accommodate a variety of broadcasting service requirements as they evolve over time;

3. Technical Parameters and Interference Criteria - The spectrum management method must accommodate changing technology and interference criteria over time;

4. Unforeseen Service Requirements - The spectrum management method must accommodate unforeseen changes in the service requirements;

5. Modification of Technical Parameters- The spectrum management method must provide for the modification of the technical parameters so that advantage may be taken of technical developments that are more spectrum efficient and/or less costly;

6. Impact on System Cost - The spectrum management method should not impose on Administrations the requirement to utilize more costly satellite systems;

7. Sharing with Terrestrial Systems - The spectrum management method should not be constrained by terrestrial systems;

8. Administrative Costs - The spectrum management method should not burden Administrations with costs associated with excessive administrative and technical staffs;

9. Accommodation of Existing Systems - The spectrum management method must ensure equitable treatment and minimize the dislocation of existing operational systems during the implementation and operation of the method;

10. Efficient Use of the Orbit/Spectrum - The spectrum management method must ensure efficient use of the orbit/spectrum resource and provide the incentive to use optimum technical standards; and

11. Access for Multi-Administration Broadcasting Satellite Systems - The spectrum management method must accommodate the introduction or expansion of multi-Administration broadcasting satellite systems.

These objectives have been presented in an arbitrary order, recognizing that the relative importance of each will differ between individual Administrations. However, the important step is to first determine the objectives, and their relative importance, and then to evaluate the ability of each spectrum management method to meet those objectives.

3.0 Key Elements of Spectrum Management

The key elements of a spectrum management plan for the BSS are descriptions or specifications of: 1) the broadcasting service requirements to be satisfied, 2) the range of technical parameters and interference criteria, 3) the structure of the plan and the resulting allotments, and 4) the methods for subsequent modifications to accommodate changing service requirements and technology. Each of the key elements will be discussed in turn.

3.1 Service Requirements

Service requirements are prepared and/or coordinated by individual administrations or groups of Administrations to reflect domestic or regional broadcasting satellite requirements. The specification of these requirements could range from a single statement of the total bandwidth, preferred orbital position and associated service area to a complete delineation of the types and number of broadcasting channels and their service area.

Service requirements are closely coupled to the time element dictated by the particular approach to spectrum management. For one particular approach, it may only be necessary to forecast the requirements for a period of the first two to three years; the intention of the system operator/owner being to expand the system based on actual requirements derived from operating experience.

Using a different spectrum management approach, it would be necessary to fully specify all service requirements over a much longer period of time; 15 years for example.

It should be appreciated that the most speculative forecasts are those made over the longest term, whereas the most accurate are those for the short-term.

Service requirements may be difficult to forecast for reasons other than the time element. For example, in the United States there is one view that bringing the 12 GHz BSS allocation into service may provide the first opportunity in 40 years to open up a totally new concept in television broadcasting: one that would be virtually impossible to implement by means of terrestrial broadcasting systems. High resolution, 3x5 aspect ratio television is an emerging technology which is under development in a number of countries. With this technology a number of new program options would be available to the viewer. The programs would not simply be a replication of the type available using the present CCIR television standards.

The option to develop a totally new service should not be foreclosed by the spectrum management method to be adopted by the 1983 RARC.

3.2 Technical Parameters and Criteria

Depending on the type of service and its state of development, the technical parameters and intersystem interference criteria may vary from system to system and with time. Using one spectrum management approach each Administration would have the flexibility to construct and expand its broadcasting satellite system in accordance with their service requirements and by their own criteria, minimum cost for example. The management approach would facilitate the orderly development of the system from perhaps a pre-operational system providing only one or two T.V. channels to evaluate the system effectiveness for social and economic development to a more sophisticated, multi-channel operational system. For this management approach, the technical parameters and intersystem interference criteria would change with time in response to changing service requirements, technology and cost.

Using a different management approach the parameters and criteria would need to be fully specified for all systems for, perhaps, a 15 year period.

3.3 Structure and Allotments

Allotments might be made in various forms and for various periods of time. Allotments or allocations of the frequency spectrum and orbital arc might be made separately or in combination; to the particular type of television service (videotex/teletext, limited motion educational T.V., conventional T.V., and high-resolution T.V.): to specific types of transmission parameters (analog, digital, narrowband, wideband, etc.): or to Administrations separately or in combination for a finite or indefinite period of time.

Using one particular management approach, assignments are recorded in the Master Register after successful coordination with other systems. These frequency and orbit position assignments in the Master Register constitute one possible structure of a plan.

Using a different management approach, band segments and orbit positions would be allotted to each Administration or groups of Administrations for perhaps a 15 year period.

3.4 Modification

The final major element of alternative spectrum management approaches is the accommodation of changes in service requirements, technical parameters, criteria, and technology, and, consequential changes in the allotment. Over a period of 3 to 5 years, service requirements are likely to change for a number of reasons. The demand for different types of services (videotex/teletext, limited motion educational TV, conventional TV, and high-resolution TV) will respond in different ways to economic and technological change, market forces, and national social and economic development policy. New categories of services may develop and experience a service demand which was not foreseen. The ability and the degree to which changing requirements may be accommodated within a plan depends on the spectrum management approach adopted and that portion of the total capacity of the geostationary orbit/spectrum resource not already allotted in the plan. The capacity is a function of the technical parameters of the systems in the plan and the satellites' position on the geostationary orbit. Under the present Radio Regulations and practices currently employed in the international coordination process, modifications could be relatively easy. During the coordination process, every effort would be made to preserve as much flexibility as possible to accommodate future requirements.

Using the a priori planning approach to spectrum management, it could be much more difficult to accommodate new requirements as a consequence of the technical parameters adopted, which could be obsolete, and the allotted capacity (that which has been brought into service plus that which has not been brought into service) relative to the capacity of the geostationary orbit/spectrum.

4.0 Spectrum Management Methods

Five spectrum management methods have been identified for further study as possible methods for managing the development and implementation of the 12 GHz Broadcasting-Satellite Service in Region 2. These are:

1. Regional Detailed Long-Term (10-20 years) A Priori Allotment Plan

   A long-term Regional a priori frequency/orbit allotment plan with a procedure for the revision of requirements that is similar to Article 4 of Appendix 30A (the 1977 Broadcasting Satellite Plan). Under this procedure new requirements may be accommodated only if they do not cause unacceptable interference to those networks within the Plan.

2. Periodically Revised (3-5 years) Regional Detailed Allotment Plan

   Conferences would be convened periodically (3-5 years) to revise the technical parameters and regulatory procedures for the plan and to accommodate new requirements. At each conference it is understood that all of the existing networks and all of the new requirements would be accommodated. During the interval between conferences, new requirements would be accommodated to the extent that they did not cause unacceptable interference to networks in the plan.

3. Regional or Sub-Regional Allotment Plan with Guaranteed Access

   Conferences would be convened from time to time as required (at intervals of 10 years or less) to revise the overall technical parameters and regulatory procedures. At these conferences, all existing networks and new requirements would be accommodated in the plan. Between conferences, there would be guaranteed access for new requirements. Access would be guaranteed by such mechanisms as reserving spectrum/orbit capacity for future requirements unforeseen at the time of the conference or by a procedure similar to that contained in Method 4.

4. Guaranteed Access by Means of Multilateral Co-ordination

The conference would not establish a formal plan but would establish procedures for guaranteed frequency/orbit access for new requirements. Normally, frequency/orbit access would be co-ordinated in accordance with the procedures contained Method 5. When a new requirement could not be accommodated by using these procedures, a special meeting would be called of those Administrations which might be affected and a means would be found to accommodate the new requirement.

5. Co-ordination Procedures and Technical Factors which are Revised Periodically

This approach to planning is a phased revision of the existing regulatory procedures, regulations and CCIR Recommendations (simplified to the extent possible) leading to more efficient use of the geostationary satellite orbit/spectrum resource.

A brief description of the major elements for each spectrum management method is given in the following sections.

4.1 Method 1: Regional Detailed Long-Term (10-20 years) A Priori Allotment Plan

The implementation of this method would follow the same kinds of steps and procedures as those which lead to the 1977 WARC-BS Plan, and which are set forth in Section 12.9, et sequence, in Article 12 of the Final Acts (Appendix 30 to the Radio Regulations).

4.1.1 Service Requirements

The service requirements would be submitted to the IFRB at least one year prior to the Regional Conference. They would be stated in terms of the number of channels and the associated service areas. Conventional television service (as currently practiced using terrestrial broadcasting techniques) is likely to be assumed. These requirements would necessarily have to be forecast over a period of from 10 to 20 years, and the maximum requirements submitted to the conference. Not all of these requirements would need to be met when the allotment plan goes into force, but by the nature of the spectrum management method, the maximum requirements must be known since they form the basis of the plan.

4.1.2 Technical Parameters and Criteria

Technical parameters and criteria characterizing all Region 2 broadcasting satellite networks for 10 to 20 years will be adopted by the Conference. These parameters and criteria will likely apply only to individual reception networks rather than a combination of individual and community reception networks.

4.1.3 Structure and Allotments

An orbit and frequency allotment plan would be drawn up satisfying, to the extent possible, each Administration's maximum service requirements.

It might not be possible in all cases to satisfy all of the requirements using the technical parameters adopted for planning. In these instances it will be necessary to reduce the number of channels available to some Administrations. One means to accomplish this is on the basis of "equal burden." That is, whenever the requirements of one Administration can not be met because of the requirements of other Administrations, the burden created by the changes needed to arrive at a workable plan would be shared equally.

Following the pattern of the 1977 WARC-BS, the Conference would prepare Final Acts containing the orbit and channel allotments, the technical characteristics, and regulatory procedures. These Final Acts, after approval by the members of the ITU, would govern the technical and operating characteristics of Region 2 broadcasting satellite systems for between 10 and 20 years.

4.1.4 Modifications

An important facet of a plan is the way in which it can be modified in response to developments which may make changes either desirable or necessary, such as changes in service requirements or technical characteristics.

Changes in service requirements may be necessary or desirable for a number of reasons. However, because of the highly structured nature of the allotment plan, and thus the interdependence of allotments within the plan, modifications could not generally be made unilaterally. The only unilateral changes that could be made are those which would not cause more interference to existing allotments within the plan and not require more protection than afforded by the plan.

Where it is desired to make a modification which could not be undertaken unilaterally, an Administration could request another Administration to effect a modification to accommodate the change sought. However, it is likely that more than one Administration would be affected, thereby greatly complicating the coordination required to permit the change to be made. Therefore, this spectrum management method will not likely permit changes to be made easily in response to changing service requirements.

Modifications to the technical characteristics incorporated in the plan may be necessary or desirable in order to accommodate new service requirements, to increase the capacity of the geostationary orbit/spectrum resource, or to permit the use of lower cost technology.

Technology may progress to the point where, had the allotment plan been drawn up several years later, the spacing between satellites could have been closer thus accommodating additional service requirements or creating "reserve" capacity. However, to incorporate new technology at a later date would require a complete re-structuring of the allotment plan. While some Administrations might voluntarily do this, there would be no incentives to do so, and as a result the capacity of the orbit would remain at a level below that which would be possible and necessary to satisfy emerging requirements.

Although regulatory procedures to modify the allotment plan would be included in the Final Acts of the Conference, it is likely in practice that it will require a re-structuring of the allotment plan, at least in the part of the orbit affected, in order to accommodate new requirements and technology. This would require the concurrence and cooperation of all affected Administrations. It would very difficult, therefore, to change allotments or assignments which have been brought into service using this spectrum management method.

4.2 Method 2: Periodically Revised (3-5 years) Regional Detailed Allotment Plan

The approach of periodic planning conferences could be used as a means to develop and to update any plan or regulatory procedure established at the 1983 RARC so as to consider future technological innovations or the future service requirements of Administrations. This approach would permit a certain degree of flexibility in the development, implementation or utilization of a plan or regulatory procedure.

4.2.1 Service Requirements:

At each conference (especially the initial conference), an administration would identify and submit its requirements. These requirements, initial and future, would be categorized as either operational or planned. Those that are planned would be further categorized into those that are intended for operation in the near future and those that are planned for the more distant future. As a possible means of identification, one could ascertain those requirements that are nearly operational as those requirements that have been submitted to the IFRB under the advance publication procedures of Appendix 1B. Those requirements that are planned for the more distant future, say more than five years could be identified but may not be effected within the plan until the succeeding planning conference. Requirements that are planned but do not have sufficient economic or other resources for implementation could be included within this latter category. The key is to recognize and to provide planning procedures for all of the planned and operational requirements of the Administrations. However, at the same time, the detailed orbit/frequency plan should accommodate, as they are needed, all the requirements that are operational or nearly operational. Each future conference would review, add and update the requirements for each administration. Those requirements that have not been implemented or have not changed status in the interim period would be reconsidered on an equal basis with any new requirements at the succeeding conference.

4.2.2 Structure and Allotments

The initial plan established by the 1983 RARC, according to the method description, would be a Regional Detailed

Allotment Plan. It is assumed that the detailed allotment plan is a plan which has the orbit locations, frequency channels, EIRP's, antenna parameters, service areas, etc. identified, described and alloted to user countries. This plan could be a "tight" plan or a somewhat "looser" plan. A "tight" plan in this context would mean all available orbit/frequency capacity is alloted. A "loose" plan would mean that some reserve orbital/frequency capacity is remaining for future requirements, say beyond the five year time interval, to be considered at a succeeding conference. As long term planned or new requirements become firm, the plan could accomodate these requirements through the use of this reserve capacity. Each succeeding conference could revise the plan structure, and make modification to orbital locations, satellite spacings, frequency channel allotments, size of the service areas, etc. to satisfy new user requirements. Each succeeding conference could also develop, revise and modify the regulatory procedures for implementation of any detailed plan. These regulatory procedures could define implementation dates and transition periods. In any event, each periodic conference would be competent to review the plan and the associated regulatory procedures in light of the requirements submitted by the administrations and advances in satellite technology during the interim period. The agenda for each future conference would be dependent upon the regulatory procedures and detailed plan adopted at the preceding conference.

It is possible that a sub-regional plan, instead of a Regional plan, would be more appropriate. In these instances, interregional and intersub-regional interactions must be considered and sharing criteria must be developed to keep the plans separate and independent from each other. In this way, conferences could be convened periodically at different intervals from each other depending only upon the needs and requirements of the Region or sub-regions.

4.2.3 Technical Parameters and Criteria

Each conference would be required to review the associated technical parameters of the detailed frequency/orbit plan for adequacy, accuracy, completeness and efficiency. These technical parameters would also be reviewed so as to promote the efficient use of the orbit/spectrum resource based upon recent technological advances.

It may be possible at the initial conference to develop plans completely independent from each other. In order to have this independence, interregional and intersub-regional sharing criteria will be required. It will be possible then to convene independently periodic conferences to consider the new requirements of adminstrations within the Region and it will also permit the introduction of future technology at different rates of implementation for each sub-region.

4.2.4 Modifications

The Regional or sub-regional detailed allotment plan could be modified in two ways. First, the detailed plan with the associated technical parameters, interference criteria and regulatory procedures would be reconsidered and modified at a future conference to be convened 3-5 years after the previous conference. Secondly, modifications to the plan during the interim period between conferences would be limited to the accommodation of new requirements to the extent that these new requirements do not cause unacceptable interference to networks in the plan. Hence, at a conference everything within the plan could be revised. Accommodation of new requirements in the plan at a conference would tend to equalize the burden for guaranteed access between the existing user and the new requirement. This may necessitate changes in interference criteria, technical parameters, orbital/frequency allotments, and regulatory procedures of this plan in order to accommodate new requirements. On the other hand, when the new requirement is being implemented in the interval between conferences, the burden for orbital access falls entirely upon the new user. The new requirement cannot cause unacceptable interference to the networks in the plan. However, this is a temporary situation. At the following conference these new requirements would be considered and accommodated as appropriate with other new requirements that are submitted by administrations.

Periodic planning conferences would be convened at regularly scheduled intervals, say three to five years. A five year interval appears appropriate for the BSS. The need for a regular schedule is to insure that all administrations know when changes in the plan, and new requirements, would be considered. However, it may be decided to convene only when necessary as determined by some "trigger mechanism" previously agreed to at the preceding conference.

4.3 Method 3: Regional or Sub-Regional Allotment Plan with Guaranteed Access

This spectrum management method is based on the division of the Region into smaller sub-regions. There could perhaps be three to five sub-regions, although this requires further study. Each sub-region would be contiguous and contain a number of Administrations having similar service requirements, and to the extent possible, similar economic development. Associated with each sub-region would be a service arc or service arcs. Between sub-regions there would be a degree of independence such that orbital positions, frequency assignments and system technical parameters could be adopted or changed without significant effect on the plan or plans of other sub-regions.

The sub-regional approach to planning has two important features. First, it takes into account the fact that the efficiency with which the geostationary orbit/spectrum resource is used is a function of the ground-segment and space-segment technology which, in turn, has cost implications. By aggregating Administrations with contiguous borders and service requirements (and perhaps similar economic development), it should be possible to adopt planning parameters representing an "appropriate technology" for each particular sub-region.

A second feature is that the burden to accommodate new requirements of an Administration within a sub-region falls primarily on the member Administrations of that subregion.

4.3.1 Service Requirements

At the initial conference, actual and imminent service requirements would be submitted by Administrations. These estimates would have to be accurate only for the period of the plan. Speculative requirements would not need to be included by any Administration to guarantee that any requirements which could conceivably eventuate would be accommodated. There would be, in fact, an incentive to submit only those requirements which might reasonably be implemented, since the submission of highly-speculative requirements would needlessly complicate the technology required for the sub-region and thereby needlessly increase system costs for the members of the sub-region.

At succeeding conferences, service requirements based on operating experience and reasonable extrapolations thereof would be submitted.

4.3.2 Technical Parameters and Criteria

At the initial planning conference, sub-regions would be defined along the lines previously discussed. For each sub-region, technical parameters and criteria would be adopted which are appropriate to each sub-region. These parameters would be derived so as to insure the relative independence between sub-regions: and so that the geostationary orbit-spectrum resource capacity would be sufficient to accomodate all service requirements submitted to the conference by the Administrations of that sub-region. In addition, there would be a significant percentage, (say 25%) which would be held in "reserve" to accommodate new and unforeseen service requirements. It is possible that different earth station and space station antenna gain envelopes might be adopted in different sub-regions, depending on the geostationary orbit-spectrum capacity requirements of the sub-region.

At succeeding conferences, these technical parameters and criteria would be revised based on the service requirements of the sub-region.

4.3.3 Structure and Allotments

The structure and allotments in the plan could take several forms and be different in different sub-regions. On the one hand, it could be those of a rigid plan. That is, the plan would specify orbital locations, channels within the band of frequencies covered by the plan, polarization, service areas and perhaps transmission parameters for each particular channel (say, teletext in certain channels, high resolution T.V. in others, etc.).

On the other hand, the allotments could be made to provide flexibility in system implementation. As an example, block frequency allotments could be made to each Administration with an associated service area and service arc (or segment of a service arc). Transmission parameters and interference criteria would be adopted such that any type of signal could be transmitted so long as it neither created more interference into, nor required more protection from other networks within the plan.

4.3.4 Modification

The method to be used to modify the plan would depend upon the time at which the need arises during the planning cycle. Should the need arise between the planning conferences, it might be possible for the Administration to implement the new service requirements from the "reserve" capacity established at the prior conference. Notification would be made through the IFRB of the Administration's intent to utilize part or all of the reserve. The procedure would be similar to the present notification and coordination procedure. Upon successful completion of the procedure, the new network or addition thereto would be recorded in the plan.

Should the attempt to coordinate the use of the reserve not be successful, then the multilateral coordination procedure discussed under method 4 would be invoked.

Modifications to the plan would also be made at the periodic planning conferences that are held every 10 years or less. At each of these conferences the technical parameters and criteria are modified so that new requirements may be accommodated and to reestablish the "reserve" geostationary orbit/spectrum capacity.

4.4 Method 4: Guaranteed Access by Means of Multilateral Co-ordination

Since the special meeting envisioned in this method would entail simultaneous coordination among at least the Administrations that would be affected under the existing bilateral coordination procedures, the method will be referred to as the "multilateral coordination" approach.

The description of the multilateral coordination method is arranged as follows. Section 4.4.1 discusses the guiding premises which permit this method to assure orbital access to a new network when conventional bilateral coordination is unsuccessful. Section 4.4.2 then describes the four key elements of multilateral coordination as a spectrum management approach, highlighting its similarities to and differences from the other management approaches. Finally, Section 4.4.3 provides an example of how a multilateral coordination procedure might be incorporated in the Radio Regulations.

4.4.1 Guiding Premises

The possibility of developing a multilateral coordination approach that effectively guarantees orbit-frequency access to new broadcasting satellite system applicants is based on the following three guiding premises:

A. At any given stage in the utilization of the orbit-spectrum resource, there will be a limited number of pending, new system applicants, each of whom will affect only a limited number of existing networks;

B. The technical means to accommodate a particular new application (or applications, if they affect the same existing or planned systems) are in the hands of the new applicant himself and the owners of the limited number of existing networks that would be affected;

C. The traffic capacity of the geostationary orbit-spectrum, though finite, is progressively expandable.

Premise A lies at the heart of the multilateral approach. Under this premise, it is unnecessary to reserve orbit and spectrum for all possible future users as long as all current applicants can be assured of access. This assurance is tantamount to an invocable "floating" guarantee as against the fixed guarantee seen in a regional *a priori* orbit and frequency allotment plan.

Premise B sets forth a fact of life under the current bilateral coordination procedures. However, the fact that existing system owners wield the major part of the power for accepting a new entrant would, under a guaranteed access approach, be turned into a tool for the new entrant. Access would be guaranteed by making it obligatory on the existing system owners to accommodate the new entrant; if he failed to achieve access through the conventional coordination and notification procedures, they would collectively be the guarantor.

The collective nature of the guarantor may pose certain practical problems. However, one should be able to identify direct and effective means by which pressure could be brought to bear on the guarantor to reach an equitable solution to an access request.

Premise C is one of the major agruments against preassignment of orbital positions and constitutes the material basis on which the guarantor should be able to continue accommodating new entrants. The premise implies that progress in technology and in the implementation and operation of systems would allow for a gradual increase in orbit utilization efficiency which, in turn, would allow more and more entrants to be accommodated as they wish to do so, and that the eventually achievable orbit utilization efficiency would outpace that which a preassignment plan would be capable of providing.

4.4.2 Key Elements

4.4.2.1 Service Requirements

As with the other spectrum management methods, the service requirements to be met by the new broadcasting satellite networks involved in multilateral coordination would be presented by the individual Administrations, or regional groups of Administrations, that are responsible for planning future satellite networks. In the multilateral coordination method, however, the service requirements differ from those needed for an *a priori* planning conference in significant ways. At any given time they need be specified only for the limited number of new applicants at that time, rather than covering all of the estimated potential service requirements of all countries and groups of countries. Since the service requirements would be those for which the applicant has designed a system which he is prepared to launch in five years or less, they will tend to be firm, realistic requirements, rather than long-range estimates that must, of necessity, involve considerable uncertainty and allowance for contingencies.

4.4.2.2 Technical Parameters and Interference Criteria

As with any spectrum managment method, certain conditions would have to be established for both the applicants and the guarantor, but unlike the case of an *a priori* plan, the conditions could be flexible and subject to negotiation. For example, considering that advancing technology and increasingly sophisticated implementation and operating modes are main sources of new orbit-spectrum "capacity", new networks should comply with the most recent design, operating and coordination guidelines. This condition should be reciprocal: the guarantor's networks, if so required, should also meet the "latest guidelines" provisions. In general, it should not be expected from a completely new entrant that he advance the state-of-the-art in implementing his network; however, this may, from time to time, be required of a guarantor administration's system or network when it is due for expansion or renewal. Periodic revision of the guidelines would be one of the obligations of the special multilateral coordination meetings.

The means which application of the guaranteed access planning method could draw upon fall into two general categories:

a) Short-Term Means. These would be adjustments to the manner in which existing or firmly-planned networks would be utilized and thus could be introduced with a minimum of delay on an in-orbit basis. Among the operational means to facilitate the accommodation of a new access are the following:

  - relocation of a satellite
  - adjustment of transmission parameters
  - adjustment of frequency plans
  - acceptance of increased interference
  - acceptance of lesser performance
  - repointing of satellite antenna beams
  - adoption of advanced modulation, and coding methods
  - lease arrangements

b) Long-Term Means. These encompass the short-term means listed above, but as part of the initial planning of a broadcasting satellite network rather than invoked by short-term requirements. In addition, though, they include the following which cannot be instantly realized:

  - minimum-coverage satellite beam design
  - high rate of decay satellite antenna sidelobe design
  - high rate of decay earth station antenna sidelobe design
  - high-gain earth station antenna design
  - introduction of advanced modulation and coding techniques
  - implementation of special design features such as linear amplifiers, high-decay filtering, interference suppression techniques
  - high frequency reuse design (dual polarization; multibeam satellite antenna systems)
  - use of joint venture or lease arrangements.

All of these means are, of course, the same ones currently available to system planners, but within the context of a dynamic spectrum management approach as outlined, they would be invoked systematically and equitably.

4.4.2.3 Allotments

The special meetings at which multilateral coordination would take place may be viewed as small ad hoc planning conferences confined to the segment of the geostationary orbit containing the systems potentially affected by the new applicant. Similarly, the decisions reached in multilateral coordination may be viewed as a reallotment of the orbit-spectrum resource among the new applicant and the existing and already-planned systems.

4.4.2.4 Procedure for Subsequent Modifications

In a very real sense, multilateral coordination is, in itself, a modification procedure, since its objective is to modify in an equitable manner the "plan" represented by existing and already-planned systems in order to guarantee access to the new applicant. Thus, the "modification procedure" for the plan developed at one multilateral coordination meeting is the next multilateral coordination meeting that affects the same part of the geostationary orbit.

4.4.3 Example of a Possible Multilateral Coordination Method

An example of how the multilateral coordination method for assuring orbital access might be incorporated into the existing bilateral coordination procedures of the Radio Regulations was provided by the following proposal submitted to the 1979 WARC by the Canadian Administration (Addendum No. 3 (Rev. 1) to Document No. 60A, 2 November 1979):

ADD 4131A Where the Board has received a request under 4108/639AG or 4127/639AB and has been unable to resolve the difficulties or to effect coordination, the Board, at the request of the Administration seeking coordination, shall convene a meeting of representatives, including technical experts, of the requesting Administration, Administrations with existing or proposed space stations on the geostationary satellite orbit which calculations using Appendix 29 procedures indicate might be affected, and those Administrations which have submitted comments under 4108/639AD. The meeting shall identify the most appropriate means of satisfying the requirements of the requesting Administration, while ensuring that disruption to existing or proposed systems is minimized.

ADD 4131B The Chairman of the meeting shall be agreed upon by the participating Administrations and may be a member of the IFRB, a representative of one of the participating Administrations, or any person who would be acceptable to all parties concerned.

ADD 4131C In arranging for such a meeting, the Board shall publish in a special section of its weekly circular the names of Administrations concerned or affected. The date for the beginning of the meeting shall be indicated and shall not be later the 90 days from the date of the weekly circular.

ADD 4131D Unless all parties concerned agree otherwise, the Board shall make appropriate arrangements for the meetings, mentioned in No. 4131A, at the ITU facilities in Geneva, and shall provide frequency assignment records and other technical data to assist the meeting, as well as secretarial and translation services.

ADD 4131E The Board, together with the Directors of the CCIR and CCITT, shall provide technical assistance and advice as required.

ADD 4131F Any Administration mentioned in No. 4131C, which declines to participate in the meeting, shall not cause harmful interference to any assignments which may be made in accordance with the conclusions of the meeting, and shall not be entitled to have assignments for its satellite network(s), planned or existing, taken into account with respect to protection from harmful interference resulting from agreements reached at the meeting. The Board shall enter suitable symbols, against such assignments, in the Master Register.

ADD 4131G The Board shall publish, in a special section of its weekly circular, a statement of the agreement reached. This statement shall be agreed upon by the

Administrations represented at the meeting and shall constitute the completion of coordination. When publishing such statements, the Board shall include the information required in Appendix 1A for new assignments and assignments affected by the agreement.

4.5 Method 5: Co-ordination Procedures and Technical Factors which are Revised Periodically

This approach takes into account the needs, the administrative, regulatory and operating experience of member administrations to revise and develop the regulatory procedures and regulations so that they do not become outdated, but are responsive to current and future needs of administrations. In essence, feedback would be formally introduced into the regulatory process to ensure that the process remains viable.

Examples of the techniques under this approach are: 1) multilateral coordination of a new entry rather than multiple bilateral coordinations, 2) the incorporation of the concept of equal burden into the coordination process, and 3) the incorporation of specific technical adjustments to be mutually made during the coordination process such as orbital location, frequency plans or emission parameters,

Similarly, CCIR Recommendations and regulations pertaining to technical parameters would be developed and/or revised to promote more efficient use of the geostationary satellite orbit/spectrum resource. These technical parameters would be revised to reflect the current or projected state-of-the-art. Examples include: 1) increased interference noise allowance to be balanced in an operating system by decreased thermal noise allowance while maintaining the overall channel noise objective, 2) improvement in earth station off-axis antenna gain envelope, 3) the introduction of satellite shaped beam antenna technology with improved off-axis antenna gain envelope, and 4) the introduction of digitial modulation techniques with forward error correction capability.

4.5.1 Service Requirements

Under this approach to planning, there would be no need for a formal submission by adminstrations or groups of adminstrations of their service requirements. However, their near term and therefore most reliable requirements would be implicit in the filings submitted to the IFRB in accordance with Article N11 of the Radio Regulations.

4.5.2 Technical Parameters and Criteria

The technical characteristics of earth stations and space stations would conform to the Regulations and Recommendations effective at the time of Advance Publication.

Coordination would be triggered by the criteria set forth in Appendix 29. Bilateral or multilateral coordination would be conducted using the appropriate criteria set forth in CCIR Recommendations.

4.5.3 Structure and Allotments

Assignments in the Master Register would continue to be the basic instrument of the plan in this approach to planning. Allotments would not be made to individual administrations or groups of administrations

4.5.4 Modifications

Planned modifications and the development of new regulatory procedures, regulations and CCIR Recommendations `re the key features of this approach to planning. The objectives are to simplify access to the geostationary satellite orbit by new networks and to increase the available capacity of the geostationary satellite orbit by the introduction of new technology and/or the relaxation of the interference criteria.

One approach to achieving these objectives would be to convene periodic administrative radio conferences to review the short-term (5 years for example) service requirements, the adequacy of the regulatory procedures, and to identify those technical parameters and interference criteria which if changed would provide a significant increase in the available capacity of the geostationary satellite orbit.

Administrations would submit to the conference their short term service requirements. These would include those already implemented in existing networks, those for networks in the Advanced Publication and Coordination stage, and those which may be confidently predicted. Each new requirement is examined to determine if it can be accommodated within its service-arc and if changes to existing and planned networks may be desirable (or necessary) to accommodate the new requirements. These changes could include: an adjustment of the orbital location of an existing network, the channel assignment plan, the emission parameters, increased intersystem interference allowance, reduced earth station and/or space station antenna gain envelope, the use of satellite shaped beam technology, and the use of more interference-tolerant modulation techniques. When the examination of all new requirements has been completed, the relative occurence of each is used to rank or establish priorities for the kinds of technical changes needed to facilitate the introduction of future networks. The CCIR would then be requested to study the feasibility of modifying an existing Recommendation or developing a new Recommendation to effect the change. The CCIR would be informed of the relative priority of each study effort; and where appropriate, would be given a completion date for the study.

The conference would also be competent to revise the relevant regulatory provisions. Proposals would be submitted to the conference by administrations with the view towards simplifying the access to the geostationary satellite orbit. Examples of the modifications which might be proposed include: multilateral coordination rather than multiple bilateral coordination procedures as described under method 4, the introduction of the concept of "equal burden" into the coordination process, and specifying the maximum number of times and number of degrees the space station in an existing network would be required to move in order to accomodate a new network.

5. Summary and Conclusions

The 1983 RARC will provide Region 2 Administrations the opportunity to reassess the method by which the geostationary orbit/spectrum resource will be managed as it relates to the 12 GHz Broadcasting-Satellite Service. Five alternative spectrum management methods appropriate to the 12 GHz BSS have been described with the intention that they be further refined and studied by each Administration to determine which of the methods most fully satisfies the Administration's objectives for the 12 GHz Broadcasting-Satellite Service. As an aid in the evaluation, a number of objectives have been presented in an arbitrary order, recognizing that the relative importance of each will differ from Administration to Administration, and that the list is probably not exhaustive.

6. Acknowledgements

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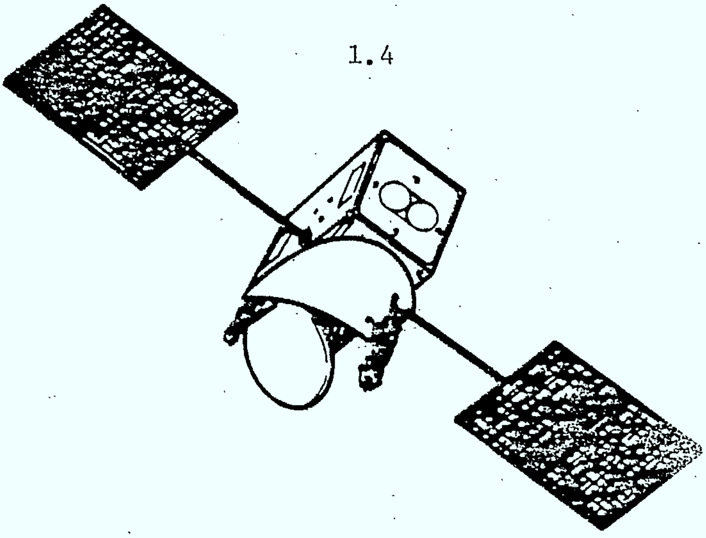

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INTERIM SYSTEMS AND FLEXIBILITY

A Paper for the CITEL Seminar (May 4-8) Ottawa, Canada

Howard Hupe

U.S.A.

This paper is an elaboration of Report 633-1(MOD I)--Orbit and Frequency Planning in the Broadcasting-Satellite Service, and in particular Sec. 2.4--Impact on Planning of Multi-Service (Hybrid) and Multi-Beam Satellites.

633-1(MOD

In planning for the Broadcasting-Satellite Service, a variety of actual scenarios must be considered. One of the most important is a *change over time* in the type of system which would best serve the practical and affordable requirements of Administrations. In the near or interim future, while broadcasting-satellite systems are just developing, a limited capacity service, e.g. 1-3 channels, may best suit the practical needs of an Administration. The most cost-effective means of obtaining access to such capacity may be to share a satellite with one or more other services and/or with one or more other Administrations, just as in some cases (presumably) interim domestic service is today provided by Intelsat while the using Administrations may be planning on *dedicated* domestic satellites in the future. For example, an interim system might serve five service areas--which could be service areas within an Administration or could be entirely separate Administrations-from a single satellite location with one channel per service area. While this would meet interim requirements at an affordable cost, long term requirements might call for five channels per service area and require five satellite orbital locations.

The problem is that the orbital positions and frequencies that best serve the needs of Administrations for long-range dedicated, multi-channel services may not be at all compatable with the orbital positions and frequencies that will economically serve the short term shared-satellite approach where some as-yet undetermined group of Administrations may share one or more satellites providing some as-yet undetermined set of space services.

Hybrid satellites are already coming into service, for example, Intelsat V, Molniya 1, Anik B, TDRS/Advanced Westar, Insat, France Telecom 1, Japan CS, Sirio, and Fleetsatcom are all dual-band satellites.

If these are reasonable and probable scenarios, it would be best to consider how such changing-over-time requirements can be met by a flexible planning process. Report 633-1 addresses this problem, but as yet we have no clear solution:

Impact on planning of multi-service (hybrid) and multibeam satellites

It is technically feasible, and in some cases may be economically desirable, to use a single space station (a hybrid satellite) to provide two or more services such as BSS, FSS and MSS. This multi-service concept might be developed by including several specialized transponders on a given spacecraft, perhaps in different frequency bands. Alternatively, it might be done by using one or more transponders in a multi-function role. It is also feasible to provide one or more of these services to more than one Administration using multiple beams (as discussed in Section 3.1.4 of Report 810), or by time-sharing steerable beams, and it may be economically desirable to do so, particularly in the case of those Administrations which have modest communications requirements for a limited time period. For example, this may be the case where services are just developing and have not yet reached their full potential requirement which might ultimately require a fully dedicated space station for each service or Administration.

Certain studies /Edelson and Morgan, 1977; Fordyce and Stamminger, 1979/ have suggested that such multiple service/ multiple beam systems may be particularly attractive economically given the growing capability to launch large space platforms, although more conventional space stations can also be efficiently used to provide such services where total power requirements are modest.

Total power requirements would depend on whether the concerned Administrations desired to implement, at any given time, the full number of channels available to them and/or the full transponder power allowed by a plan or other regulatory limitation. For example, an interim service scheme is conceivable in which less full capacity and/or power would be used, at the choice of the concerned Administrations, for a period of time (e.g., the life of the satellite) until the full service was implemented at a later date. Several Administrations, allotted different orbital positions on the basis of their ultimate requirements may, for interim or developmental service, wish to share the same space station with one or more channels assigned to each Administration.

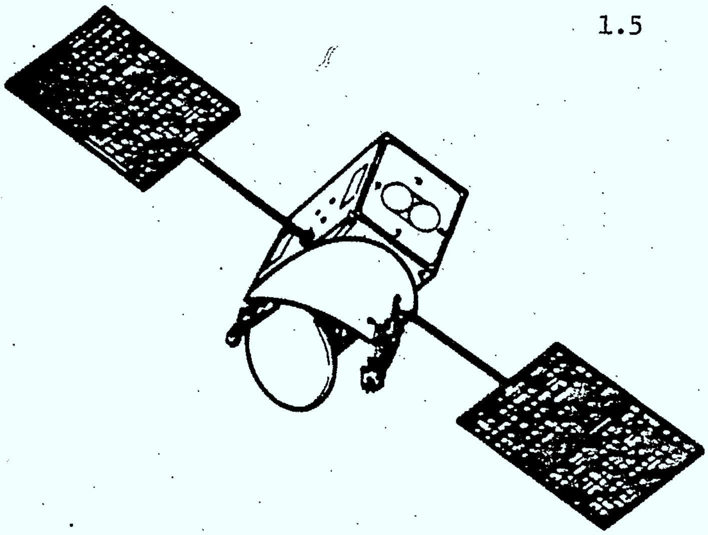
Report 665 notes that space station antennae can be steered or directed using arrays. Mechanically steered antennas operating over wide areas have been demonstrated on ATS-6 and CTS spacecraft. Thus, it is possible to time share a given satllite capacity, including individual transponders, among two or more Administrations.

Where two or more Administrations time share the same channel, they would be using the same frequencies, which may not be the frequencies allotted to each of them in a plan. For a single space station, separate up-link frequency bands, or portions of bands would be required for each down-link service. Where multiple Administrations are served, different specific frequencies may be necessary for each Administration or service area, depending upon such factors as antenna discrimination, beamwidth, separation of service areas, interference objectives, etc. Thus, up-link considerations in multibeam or multi-service satellites present important limitations.

Plans which allot specific orbital positions and frequencies for one service will not, in general, be compatible with such plans for another service. Because of differing requirements and technical characteristics in different services, orbital allotments will not, in general, be the same for the different services in the same Administration or service area. Thus, unless substantial flexibility were built into those plans, or plans were carefully coordinated with each other, multi-service satellites would not be possible to implement, and the economic advantages of such satellites could not be achieved. /CCIR, 1978-82a/

The difficulties imposed by specific plans on the potentially technically and economically attractive shared use of space stations by different services or different Administrations should be taken into consideration in planning the BSS in Region 2. Flexibility in the implementation of a plan or bringing into service systems affected by a plan (such as stated as a principal for planning in Region 2 by Annex VI to the Final Acts of the 1977 WARC (BS) could help to resolve some of the difficulties.

Precise methods of taking multiple service/multiple beam space stations into consideration in planning have not been developed and require further study.



TITLE : REPORT OF U.S. DOMESTIC DBS ACTIVITIES

AUTHOR : EDWARD R. JACOBS

USA

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

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ORGANIZACION DE LOS ESTADOS AMERICANOS
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INTERNATIONAL TELECOMMUNICATION UNION

May 4, 1981
Session 1.5
Edward R. Jacobs, USA

Report of U.S. Domestic DBS Activities

Current U.S. domestic DBS activities can be placed into several general categories. The first of these concerns the treatment of interim DBS systems, in other words, those DBS systems that might be authorized prior to the 1983 Region 2 Conference, and the development of long-term domestic regulatory policy for DBS. A second concerns our activities directly related to preparation for the 1983 Conference. I will address principally this first aspect, and to a lesser extent, the second. Recognizing that DBS could become a reality within the U.S. in the not too distant future, the U.S. Federal Communications Commission (FCC) completed two studies in the summer of 1980 on two aspects of DBS. One of these, Technical Aspects Related to Direct Broadcast Satellite Systems, addressed DBS technical aspects and the other, Policies for Regulation of Direct Broadcast Satellites, addressed various policy issues. The first of these reports will be discussed later during our seminar. What these reports showed was that DBS is a technically viable concept, that it poses no threat to the viability of the current system of domestic terrestrial broadcasting, and that a minimum of regulation, both technical or otherwise, should be imposed upon the development of the service.

In October of 1980, the FCC issued a Notice of Inquiry seeking comment on recommended interim licensing provisions and on long term domestic policy. The two earlier mentioned staff reports were released with this Notice for comment. Shortly after the release of the Notice, an application was filed by the Satellite Television Corporation (STC) for authority to construct, launch, and operate an interim DBS system. The specifics of this system will be described in detail later, but the application calls for providing a DBS service direct to the home on a subscription basis. Also, just within the past several weeks a letter was sent to the FCC which notified of the intent to file for a DBS authorization. This second application is expected from a company called DBS, Incorporated, and would also provide a service direct to the home; however, this service would be free of charge to the home recipient.

On April 21 of this year, the FCC adopted a Notice of Proposed Rule Making proposing rules for interim U.S. DBS systems. The FCC also formally accepted the STC application for filing, placed it on public notice (meaning that the public can comment on the merits of the system), and informed the public of a cut-off date for filing DBS applications to be considered in conjunction with that of STC. In the Notice of Proposed Rule Making a few significant policy determinations were made. One, which I am certain is of interest to most of those present here, is that any interim system must comply with the outcome of the 1983 Conference. Part of the review of any application for an interim DBS system will be to analyze its ability to exist within the constraints of any reasonable plan to be adopted at the 1983 Conference. Such an analysis, albeit only preliminary, was performed on the STC application. To ensure compatibility with the outcome of the 1983 Conference, the specific operating frequencies for interim system s will not be specified until after the 1983 Conference. Perhaps I should further clarify here what is meant by interim systems. An interim system is one for which authority to construct the satellite has been given prior to the adoption of final rules governing the service. Because of construction lead times and the scheduling of launch facilities, even the STC system, if authority were granted today, could not be put into service until 1985 - well after the 1983 Conference. It is because of these long lead times that we feel that authorization of interim systems prior to the 1983 Conference will not prejudice the outcome of that Conference. Any adjustments required because of the Conference can be made during the construction phase of the satellite system development.

Another policy determination made with respect to interim systems reflects a general consensus, both within the FCC and I believe within the U.S. as a whole, on the uncertainty of the ultimate services to be provided via DBS. Just reflecting back for a moment upon the two applications mentioned above, we see one DBS system (STC) that would operate in the mode of a traditional broadcaster where they would control all of the programming, and another system (DBS, Inc.) that would operate as a common carrier and lease programming time to whomever cared to use its facilities. This certainly raises questions about how DBS systems are to be operated that we are not prepared to answer at this time. DBS interim systems and experiments may help to answer this question. The question of licensing requirements, however, is not directly related to our considerations for the 1983 Conference. The types of services provided via DBS, however, is relevant. As you will hear later, in the description of the STC system, experimentation with high definition television is proposed. This type of service would use bandwidths that are significantly greater than the bandwidths required for traditional television systems. We in the U.S. are examining the effect of wideband services on the utilization of the 12 GHz band. This effect will have consequences upon how the band is developed in the U.S. and even before that, upon the various approaches to planning at the 1983 Conference. Certainly the advent or promise of these types of services requires us to provide the greatest degree of flexibility in the details of the planning in 1983. For this reason, and others, our proposed rules for interim DBS systems places no constraints upon the specific technical characteristics of the interim DBS systems. As mentioned earlier, however, the particulars of any proposed interim system will have to be examined and a determination made as to whether it was flexible enough to adopt to any reasonable outcome of the 1983 Conference.

The question of DBS sharing with terrestrial fixed services was also addressed in our examination of interim systems. The U.S. fully recognizes the intent and impact of international footnote 3787D adopted at WARC-79 that says that existing and future terrestrial radiocommunication services shall not cause harmful interference to the space services operating in accordance with the 1983 plan, nor impose any restrictions on the elaboration of such a plan. Under the proposed interim rules, terrestrial fixed services would be allowed to continue operation, but would be required to provide protection to any DBS system that is authorized and operating in accordance with the 1983 Conference results.

The proposed interim rules also look towards the accommodation of the feeder links for DBS to be provided for in the 17.3-18.1 GHz band made available by WARC-79 for this purpose. Specifically, the lower portion of the band is being targeted for use by interim systems. The final determination on what part of the band is to be designated as available for planning purposes is to be made at the 1983 Conference. However, we feel that the background of the discussions that occurred at WARC-79 indicated sufficient preference for the lower part of the band so as to allow us to designate this part for interim systems. As you can see, the interim procedures for U.S. DBS systems that we are proposing reflect an uncertainty about how this service may eventually develop and the types of services that might be provided. We are attempting to maintain the maximum degree of flexibility that is possible.

As mentioned earlier, current U.S. DBS activities fall into several general categories. A second of these concerns activities in direct support of the 1983 Conference. These activities include the issuance by the FCC of a public Notice of Inquiry, the formation of a public advisory committee, the development of computer aids to planning, increased CCIR activity (particularly in IWP 10/11-2), and the formation of an inter-agency preparatory committee. Some of these activities will be addressed by later speakers, in particular the CCIR activities and the computer aids to planning. I would like to very briefly address the Notice of Inquiry that was released and the public comment that was received in response. The Notice was issued in July of 1980 and comments were received in October and November. The Notice requested comment in the areas of requirements, technical planning parameters, and planning principles and procedures. The comments on requirements covered a broad spectrum of possible uses that could be put into three general categories: 1) video entertainment programming; 2) public service; and 3) public data distribution. The wide variety of possible uses mentioned in the comments highlights the uncertainty present concerning the eventual development of the 12 GHz band and the difficulties this poses in defining requirements in the conference planning process.

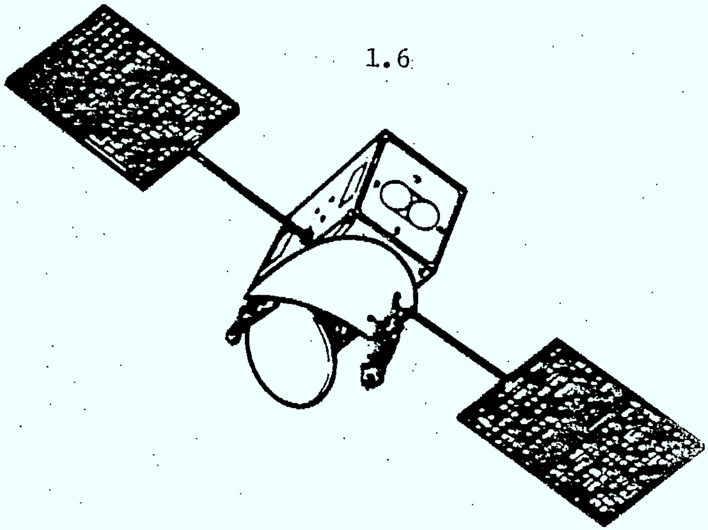
With respect to the second subject treated in the Notice, technical planning parameters, the comments were generally more consistent. Nearly everyone concedes that the parameters used at WARC-BS for planning can be exceeded by today's technology. However, there was some considerable comment that technical parameters assumed for planning should be conservative to allow flexibility needed by system designers.

Comments on planning principles and procedures reflected a general opinion that as much flexibility as possible should be provided for in the planning process. There was some feeling that the procedures of the WARC-BS were too detailed and cumbersome and that the 1983 conference should adopt procedures that are more responsive to the easy implementation of the broadcasting-satellite service.

As can be noted form the comments mentioned, there appears to be a great desire to maintain as much flexibility as possible in the establishment of the international regulatory framework for DBS. We can see that there is also a desire to begin the initial development and implementation of this service. Accommodation of these initial systems without pre-empting the numerous service possibilities that DBS holds will be one of the challenges of the 1983 conference. It may involve unusual concepts in planning and could possibly involve accepting short term inefficiencies to obtain long term benefits.

The U.S. will be developing its official views on these subjects in the upcoming months based upon the evaluation of these comments, and upon other information available to us, such as that which we will receive from this seminar. I look forward to discussing many of these topics with all of you in the upcoming week and know that the information, views and opinions exchanged here will prove invaluable in our preparations for the 1983 conference. Thank you.

1.6



TITLE : CCIR PREPARATIONS FOR RARC 83-BSS AND RECENT ACTIVITIES IN THE BROADCASTING-SATELLITE FIELD

AUTHOR : C.A. SIOCOS

CAN

Preparatory Seminar for 1983 RARC on Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

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CCIR PREPARATIONS FOR RARC 83-BSS

AND

RECENT ACTIVITIES IN THE BROADCASTING-SATELLITE FIELD

C.A. Siocos
Canadian Broadcasting Corporation, Montreal, Quebec
Vice-Chairman, CCIR Study Group 11(Television)

INTRODUCTION

In the context of its communications satellite studies, the CCIR began looking into the feasibility of direct broadcasting from space as early as its 1960-1963 Study Period the last year of which coincided with the ITU Extraordinary Administrative Radio Conference to Allocate Frequency Bands for Space Radiocommunication Purposes convened in Geneva in 1963. Indeed, that Conference recognized the Broadcasting-Satellite Service (BSS) as a distinct radiocommunication service and adopted a formal definition for it. The Xth Plenary Assembly of the CCIR, convening also in Geneva in 1963, adopted the first CCIR Report, No.215, on the subject of that Service. Its title was "Feasibility of Direct Sound and Television Broadcasting from Satellites."

Since the 1962 Interim Meetings of CCIR Study Groups in Washington, D.C., when the first documents on broadcasting from satellites were submitted to the CCIR by participating countries, a lot has transpired, both in the development of the BSS foreseen by the aforementioned ITU Space Conference of 1963 and in the efforts of the CCIR to use the latest and most advanced studies for the purpose of establishing the technical base for the necessary international regulations governing that Service.

It is, in the author's view, an impressive measure of the foresight of the ITU members and their technical representatives in the CCIR that recognition of the Broadcasting-Satellite Service and development of internationally accepted rules to ensure its orderly function happened so many years before the first fully operational system in that Service was introduced ("Ekran", in the USSR in 1976, for community reception).

ORGANIZATION OF BROADCASTING-SATELLITE STUDIES

During their earlier stages, broadcasting satellite studies in the CCIR were conducted under the auspices of the then Study Group IV (Space Systems and Radio Astronomy) with the cooperation, as required, of the CCIR Television and Sound Broadcasting Study Groups.

.../2

These early studies, from 1962 to 1966, concentrated on feasibility aspects. In 1966, the XIth Plenary Assembly, at Oslo, decided that broadcasting satellite studies should be conducted on the main by the Broadcasting Study Groups and this arrangement proved productive.

Accordingly, the bulk of the studies of CCIR in the field of space broadcasting has been conducted, since then, within the broadcasting Study Groups 10 (Radio) and 11 (Television) but uplinks serving broadcasting satellites are studied also by Study Group 4 (Fixed-Satellite Service).

Study Groups 10 and 11 conduct together their technical and allied studies concerning the Broadcasting-Satellite Service by instituting for this purpose a Joint Working Group whose recent number is 10-11S.

The CCIR, however, is not concerned solely with system studies for the Broadcasting-Satellite Service. Additionally, it often has to produce preparatory technical documentation for an ITU Administrative Radio Conference regarding that Service. This requirement is transmitted to the CCIR by an appropriate ITU Conference or the Administrative Council. Past examples were parts of the SJM Report submitted to the Second Space Conference of 1971, the JWP Report submitted to WARC-77 BSS and parts of the SPM Report submitted to WARC-79. The present requirements for preparatory technical documentation originate from requests by WARC-79 and concern:

1) the Region 2 broadcasting-satellite service planning Conference of June/July 1983 (Resolution No. 701/WARC-79);

2) the Conference on the use of the geostationary-satellite orbit and the planning of space service utilizing it, whose first (technical) session is scheduled for 1984 (Resolution No. 3/WARC-79);

3) the Regions 1 and 3 broadcasting-satellite feeder links Conference (Resolution No. 101/WARC-79), whose date has not been set as yet.

As may well be appreciated, the time available for readying technical reports for use of the aforementioned Conferences is very short, particularly with respect to the 1983 conference for Region 2. To cope with this situation, two new Interim Working Parties, labelled 10-11/1 and 10-11/2, were constituted jointly by CCIR Study Groups 10 and 11 to work in the time between Interim and Final Meetings of the present study period of the CCIR so as to further the action required for preparation of the technical information to be submitted to these Conferences.

.../3

IWP 10-11/2, with which this talk is concerned, is charged with such work regarding RARC-83 BSS while IWP 10-11/1 will deal to a large extent with requirements of WARC-84 Spa. CCIR rules stipulate that an Interim Working Party is instituted for the current study period only and must submit its report to the Final Meeting of the parent Study Group. The Study Group decides at that time whether the work assigned to the IWP has been completed and, if not, may recommend to the Plenary Assembly that the IWP continue functioning during the next study period.

INTERIM WORKING PARTY 10-11/2

IWP 10-11/2 was set up during the Interim Meetings of Study Groups 10 and 11 in October 1980 and the date of January 1, 1981, was given as the target for interested Administrations to appoint their representatives so that work might begin without delay.

The Vice-Chairman of Study Group 11 was appointed as Chairman of the IWP and Mr. Celso Azevedo from Brazil as its Vice-Chairman. By the end of March 1981, ten administrations and the EBU had appointed representatives on IWP 10-11/2.

It was thought that if IWP 10-11/2 needed to have meetings it would be appropriate that they take place in Region 2, the ITU Region encompassing the Americas, as the 1983 RARC will be concerned with its Broadcasting-Satellite Service. It was, therefore with great pleasure that the Chairman of IWP 10-11/2 and the Director of the CCIR received an invitation by the Canadian Administration to hold such a meeting between the dates of 28 April and 1 May, 1981 in Ottawa.

This meeting took place as scheduled and I am pleased to note that ... experts from ... Administrations and from the EBU participated in it. As well, Mr. R. Kirby, the Director of the CCIR, and Mr. B. Berrada, member of the International Frequency Registration Board, were present.

A conference preparatory report by the CCIR must reach Administrations in plenty of time to assist them in their preparations for that conference. Taking into account the time required for editorial refinement and publishing, it is believed that such a report must reach the CCIR Secretariat no later than ten months before the start of the conference. As RARC 83-BSS is scheduled to start in mid-June 1983, the deadline for finalization by the CCIR Study Groups of the conference preparatory report is mid-August 1982. This is the date that dominates the organization of the work. Scheduling is further constrained by the dates of the XVth Plenary Assembly of the CCIR,

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i.e. 15 February - 3 March 1982, and by the dates of the Final Meetings of the CCIR Study Groups concerned which extend from the last week of August to the end of October in 1981.

It may be seen that it is only after the output of IWP 10-11/2 has received approval of the Study Groups 10 and 11, in September/October 1981, that Study Groups 4 and 9 (which also have important input to contribute due to considerations for frequency sharing, up-link provision etc.) will meet. The early days of the XVth Plenary may provide the chance of amalgamating their late information in the CCIR report but special arrangements would have to be made then since Plenary Assemblies do not usually undertake work requiring detailed expertise. At any rate, other than such reconciliation of texts, if it is required, not much else can be done between the Final Meetings and the Plenary Assembly. Additionally plans for further work during the five months following the XVth Plenary until the deadline of Mid-August 1982 have not been made known.

The above considerations made it clear to the Chairman of IWP 10-11/2 that, during the short period from 1 January 1981 to the beginning of the Interim Meetings of Study Groups 10 and 11 in September 1981, the IWP should produce a complete report analogous to that produced prior to WARC 77-BSS by the JWP chaired by the late Dr. John Saxton, then Chairman of Study Group 5. Accordingly the plan of action that was devised consisted of first preparing in consultation with the Director of CCIR a table showing the desired contents of this Report and, then, assigning in consultation with participants the authoring of a first, basic, draft of one or two chapters of the report to a given Administration adhering to IWP 10-11/2 and to the CCIR specialized Secretariat. This first draft, consisted of just selected excerpts from existing CCIR Recommendations and Reports so as to form a solid base for the final report but also a point of departure for it since any administration can send additional information to the IWP to be taken into account and, to the extent agreed upon, be included in the final report. In addition to the specialized Secretariat which produced drafts for the radio propagation and the terminology chapters, Brazil produced the draft for the technology chapter, Canada for the service planning chapters and the USA for the frequency sharing chapter.

The examination of this first draft, its adjustment to later information and its adoption as the IWP Report was carried out last week during the meeting of IWP 10-11/2 here, in Ottawa. This Report will be submitted to the parent Study Group 10 and 11 for approval during their Final Meetings this Fall. As the CCIR texts concerned with broadcasting from satellites will, no doubt, be updated during said Final

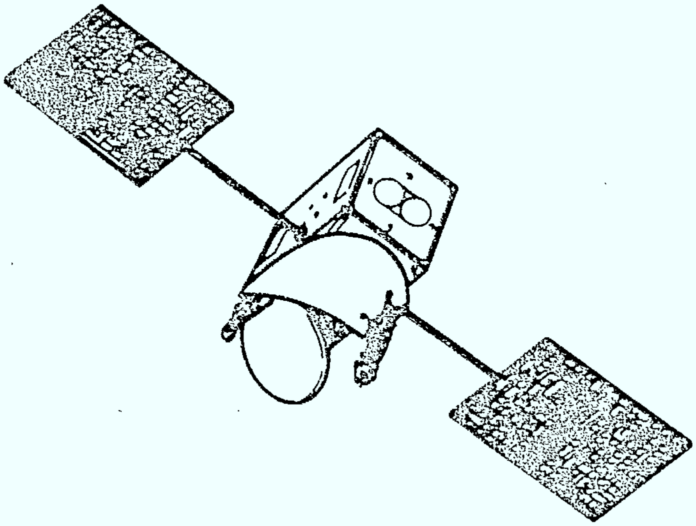
.../5

Meetings and new ones may be adopted, and as not only Study Groups 10 and 11 but also Study Groups 4, 5 and 9 are involved, a mechanism must be put in place by the CCIR to make possible the incorporation into the IWP 10-11/2 report of the results of the Final Meetings and perhaps additional information and for the approval of the final text as a CCIR submission to RARC 83-BSS. As stated earlier this subsequent process must not go beyond mid-August 1982.

CONCLUSION

This has been an exercise in accelerating the pace of a CCIR IWP to conform with a tight schedule set not by the total time available but by the need to conform to the dates set for general CCIR work. Through the excellent efforts of Administrations and the specialized Secretariat of the CCIR, the task set for IWP 10-11/2, i.e. the preparation of a report for submission to Study Groups 10 and 11 for their Final Meetings was accomplished on time.

2.1
(Corrigendum)



TITLE : INTER-REGIONAL SHARING RESTRICTIONS ON PLANNING AT THE RARC-83

AUTHOR : R.G. AMERO

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Paper 2.1

CORRIGENDUM

INTER-REGIONAL SHARING RESTRICTIONS ON PLANNING AT THE RARC-83

In reviewing the tables in paper 2.1, an error was discovered which affects the calculation of the satellite antenna discrimination. While the results and conclusions of the paper are still valid, revised tables have been included for the sake of accuracy.

R. G. Amero

Beam name:		P1	P2	P3	P4
Brazil	location	(15^{o}N; 17^{o}W)	(10N; 14W)	(4N: 7.5W)	(1S; 9E)
	elev. ∢^{o}	55	58	52	34
	range (km)	36,308	36,334	36,650	37,960
Beam size:					
1.565					
2.025					
@ 8.93^{o} orientation ∢					
Boresight:	O.A ∢^{o}	5.49	5.37	5.77	7.42
7.36^{o}S	3 dB ∢^{o}	1.69	1.76	1.88	1.96
40.71^{o} W	Ratio	3.26	3.04	3.07	3.78
	D (dB)	30.3	30.0	30.0	31.9
Sat. Long	L_{fs}(dB)	162.2	162.2	162.3	162.6
40^{o}W					
E = 64 dBW	pfd (dBW/m^{2}/4kHz)	-153.5	-153.2	-153.3	-155.5
P = 3 dB	limit 1	-125	-125	-125	-125
		ok	ok	ok	ok
	limit 2	-148	-148	-148	-148
		ok	ok	ok	ok
	pfd (dBW/m^{2}/5MHz)	-131.5	-131.2	-131.3	-133.5
	limit 3	-111	-111	-111	-111
		ok	ok	ok	ok

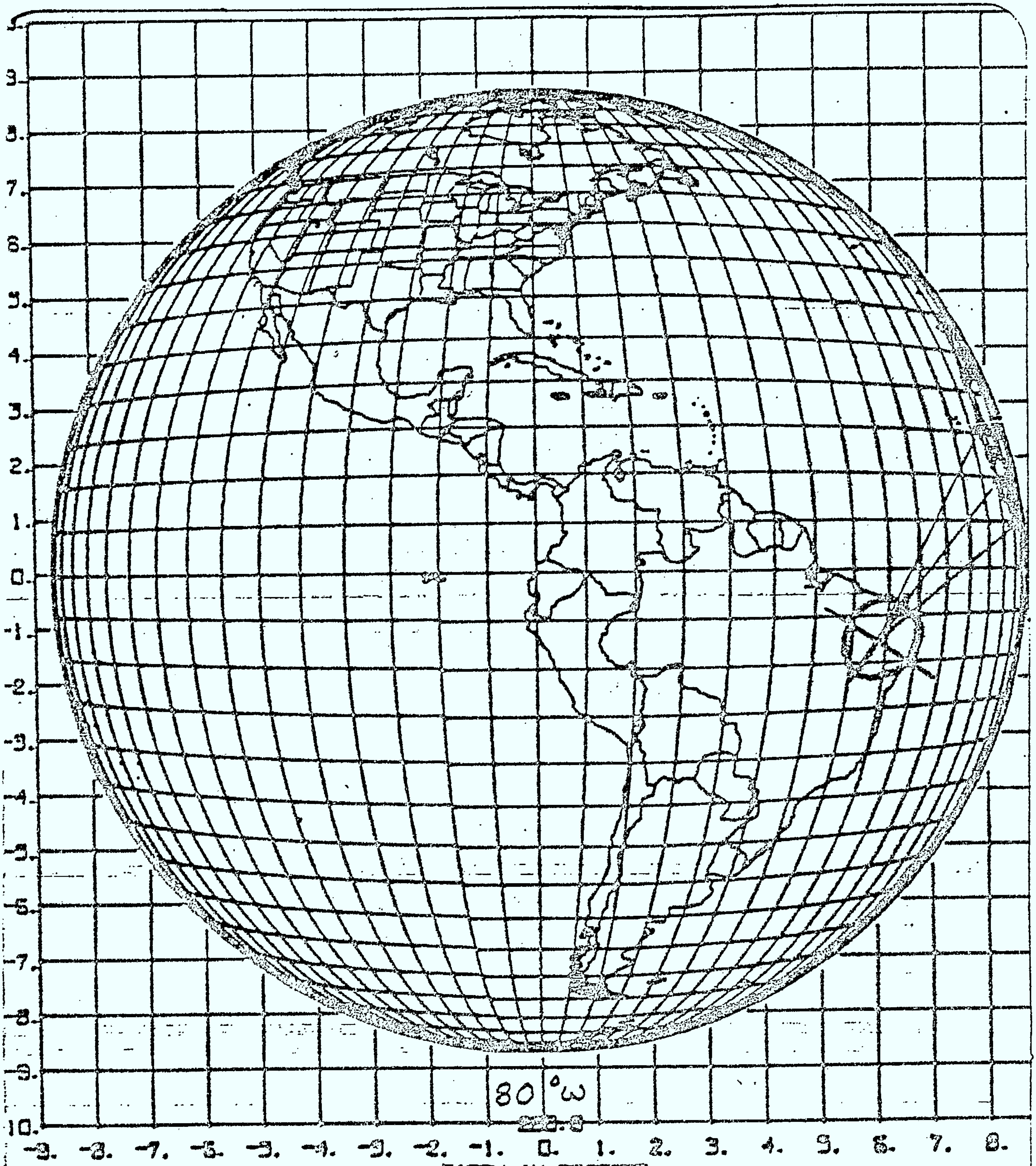
Notes: Limit 1 - Resolution 31, Resolves 4, part (a)
Limit 2 - FSS limits RR6071
Limit 3 - Resolution 31, Resolves 4, part (b)

- even for 0^{o} elevation angles, all limits would be met

Table 3.3.A.1 Interference from Brazilian Beam

Figure 3.3.A.3

A B



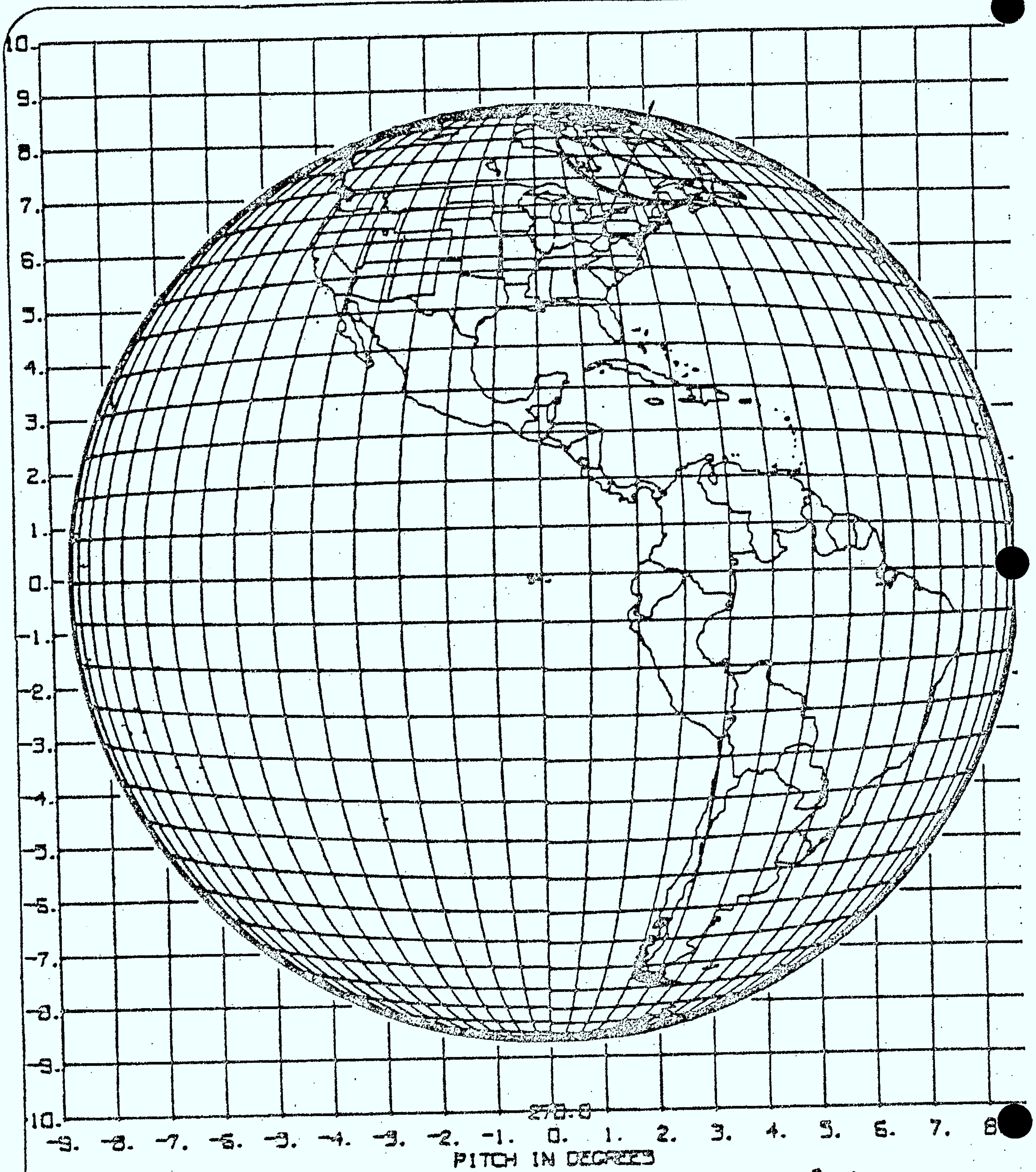
INTERFERENCE ANGLES FROM EAST BRASIL SAT at 80°W

Beam name:		P1	P2	P3	P4
Brazil	location	(15N; 17W)	(10N; 14W)	(4N; 7.5W)	(1S; 9E)
	Elev.∢°	15	15	9	over horizon
Beam size	range (km)	39861	39861	40483	
1.319°					
1.615°	O.A∢°	4.07	3.56	3.11	
@ 55.33°	3 dB∢°	1.37	1.34	1.32	
	Ratio	2.97	2.66	2.36	
Boresight	D (dB)	30.0	30.0	30.0	
7.39°S	L_{fs} (dB)	163.0	163.0	163.1	
41.12°W					
Sat. Long	pfd (dBw/m^2/4kHz)	-154.0	-154.0	-153.9	-
80°W	limit 1	-125	-125	-125	
E = 64 dBw		ok	ok	ok	ok
P = 3 dB	limit 2	-143	-143	-146	
		ok	ok	ok	ok
	pfd (dBW/m^2/5mHz)	-132.0	-132.2	-131.9	-
	limit 3	-111.0	-111.0	-132.0	
		ok	ok	ok	ok

Note: see Table 3.3.A.1 for definition of limits

Table 3.3.A.2 Interference from Brazilian Beam

Figure 3.3.B.1



EASTERN CANADIAN SAT. at 90° W

Beam name:		P1	P2	P3
CAN 5	location	(66; 25)	(38; 28)	(29; 19)
	elev. $\measuredangle^{0}$	1	13^{0}	5^{0}
	range (km)	41350	40064	40913
Beam size				
1.440^{0}				
2.926^{0}	0.A $\measuredangle^{0}$	1.64	5.05	6.58
@ 157.10^{0}	3 dB $\measuredangle^{0}$	2.87	1.81	1.70
	Ratio	0.57	2.80	3.87
Boresight	D (dB)	3.9	30.0	32.2
54.00N	L_{fs} (dB)	163.3	163.1	163.2
72.40W				
Sat. Long	pfd (dBW/m^2/4kHz)	-128.2	-154.1	-156.4
90^{0} W				
	limit 1	-125	-125	-125
		ok	ok	ok
E = 64 dBW P = 3 dB	limit 2	-148	-144	-148
		19.8	ok	ok
	pfd (dBW/m^2/5mHz)	-106.2	-132.1	-134.4
	limit 3	-132	-119.4	-132
		25.8	ok	ok

Note: see Table 3.3.A.1 for definition of limits

* objective will be to reduce this negative value

Table 3.3.B.1 Interference from Eastern Canadian Beam

Figure 3.3.8.2

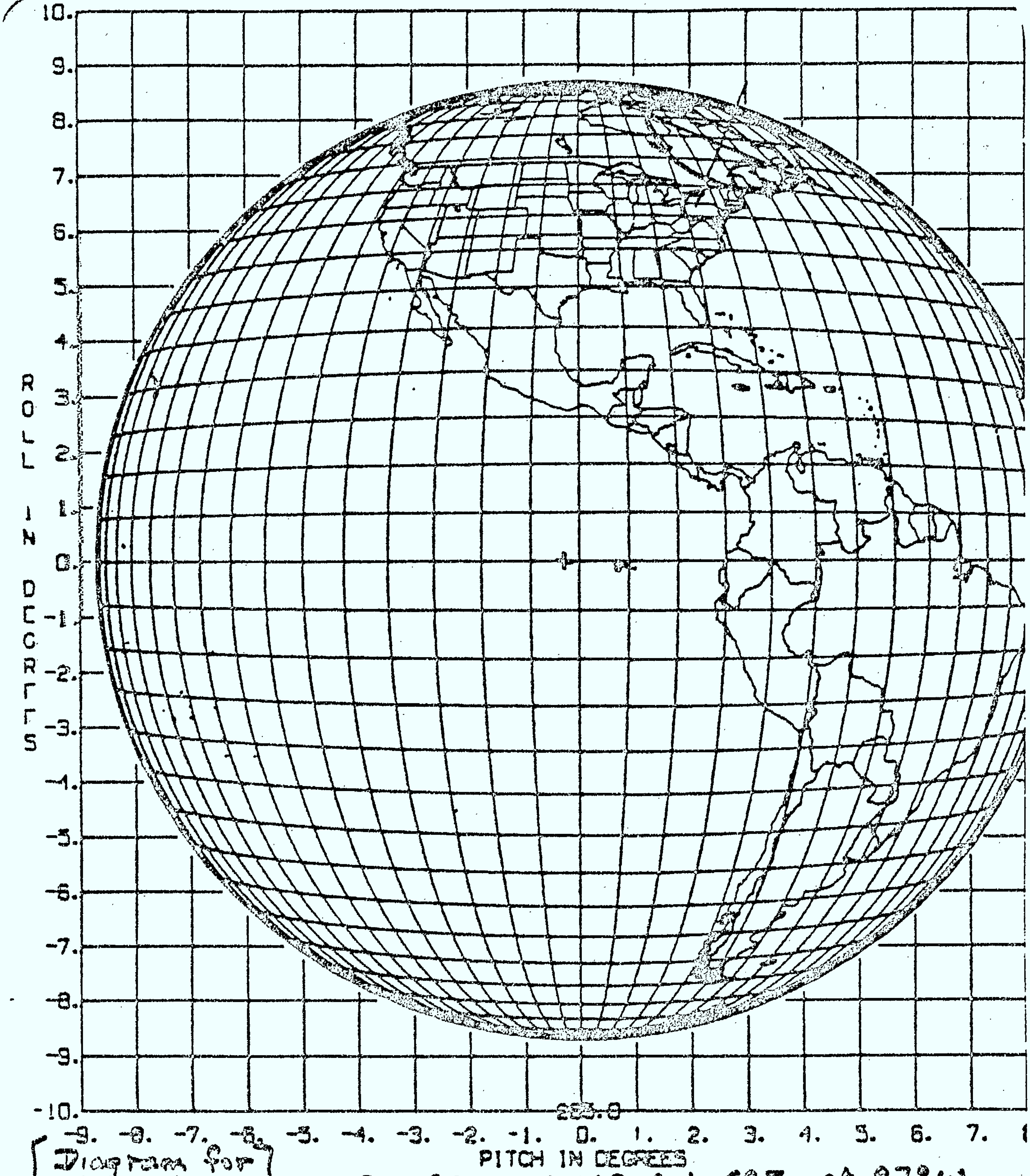


Diagram for illustration only

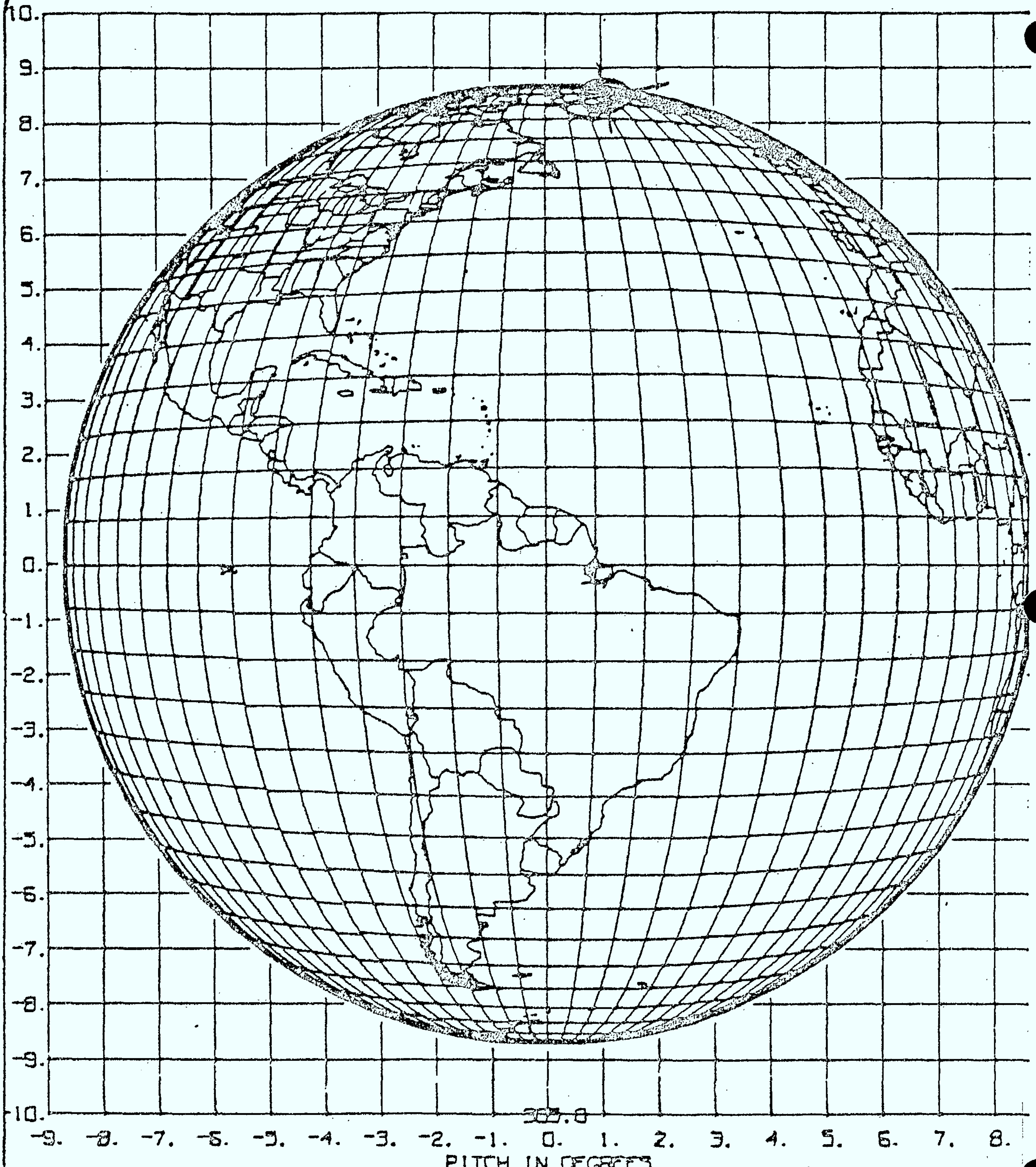
EASTERN CANADIAN SAT at 97°W

Beam name:		P1	P2	P3	P4
CAN 5	location	(66; 25)	(38; 28)	29; 19)	15; 17)
	elev. $\measuredangle^{o}$	over horizon	8	over horizon	0.5^{o}
Beam size	range (km)		40590		41516
1.280^{o}					
3.114^{o}	O.A. $\measuredangle^{o}$		4.80		8.08
@ 154.09^{o}	3 dB $\measuredangle^{o}$		1.57		1.37
	Ratio		3.07		5.88
Boresight	D (dB)		30.0		6.7
53.89^{o}N	L_{fs}(dB)		163.2		163.4
73.09^{o}W					
Sat. Long.	pfd (dBW/m^2/4kHz)	-	-154.2	-	-161.1
97^{o}W					
	limit 1	-	-125	-	-125
		ok	ok	ok	ok
E = 64 dBW					
P = 3 dB	limit 2	-	-146.5	-	-148
		ok	ok	ok	ok
	pfd (dBW/m^2/5mHz)	-	-132.2	-	-139.1
	limit 3	-	-132.0	-	-132.0
		ok	ok	ok	ok

Note: see Table 3.3.A.1 for definition of limits

Table 3.3.B.2 Interference from Eastern Canadian Beam

Figure 3.3.C.1



GREENLAND SAT at 55°W

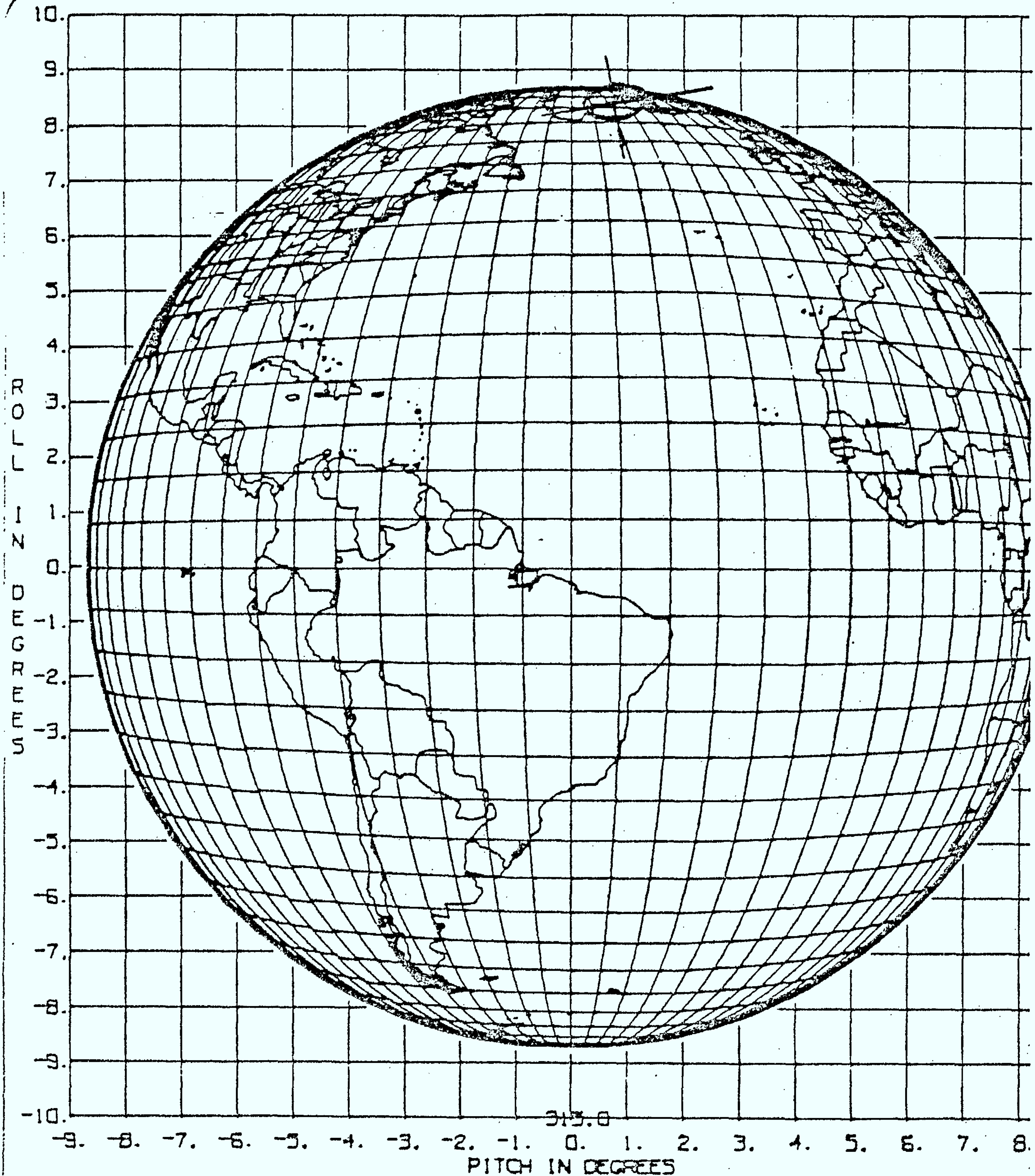
Beam Name		P1	P2	P3
E. Greenland	location	(66; 25)	(58.5; 6.5)	(54; 10)
	elev. $\measuredangle^{o}$	14.5	11.5	16°
	range (km)	40168	40232	39963
Beam size				
0.60°				
0.953°				
@ 12.24°	O.A $\measuredangle^{o}$	0.52	2.30	2.66
	3 dB $\measuredangle^{o}$	0.95	0.95	0.93
Boresight	Ratio	0.55	2.43	2.84
67.83°N	D (dB)	3.6	30.0	30.0
32.11°W	L_{fs} (dB)	163.1	163.1	163.0
Sat. Long	pfd ($dBW/m^2/4kHz$)	-127.7	-154.1	-154.0
55°W				
	limit 1	-125	-125	-125
E = 64 dBW		ok	ok	ok
P = 3 dB				
	limit 2	-143.3	-144.8	-142.8
		15.6	ok	ok
	pfd ($dBW/m^2/5MHz$)	-105.7	-132.1	-132.0
	limit 3	-113.1	-125.7	-132
		7.4	6.4	ok

Notes: - see Table 3.3.A.1 for definition of limits

- try to resolve excess pfd by shifting satellite position eastward to have larger off-axis discrimination angles

Table 3.3.C.1 Interference from Eastern Greenland Beam

Figure 3.3.C.2



EAST GREENLAND SAT. at 45° W

Beam name		P1	P2	P3
E. Greenland	location	(66; 25)	(58.5; 6.5)	(54; 10)
	elev. $\measuredangle^{0}$	14	16	21
	range (km)	40168	39760	39265
Beam size				
0.60^{0}				
1.178^{0}	O.A $\measuredangle^{0}$	0.49	2.27	2.50
@ 10.51^{0}	3 dB $\measuredangle^{0}$	1.18	1.17	1.12
	Ratio	0.41	1.94	2.23
Boresight	D (dB)	2.0	30.0	30.0
67.41^{0}N	L_{fs}(dB)	163.1	163.0	162.9
32.04^{0}W				
Sat. Long	pfd (dBW/m^2/4kHz)	-126.1	-154.0	-153.9
45^{0}W				
	limit 1	-125	-125	-125
E = 64 dBW		ok	ok	ok
P = 3 dB				
	limit 2	-143.5	-142.5	-140.0
		17.4	ok	ok
	pfd (dBW/m^2/5MHz)	-104.1**	-132.0	-131.9
	limit 3	-115.2	-111	-111
		11.1	ok	ok

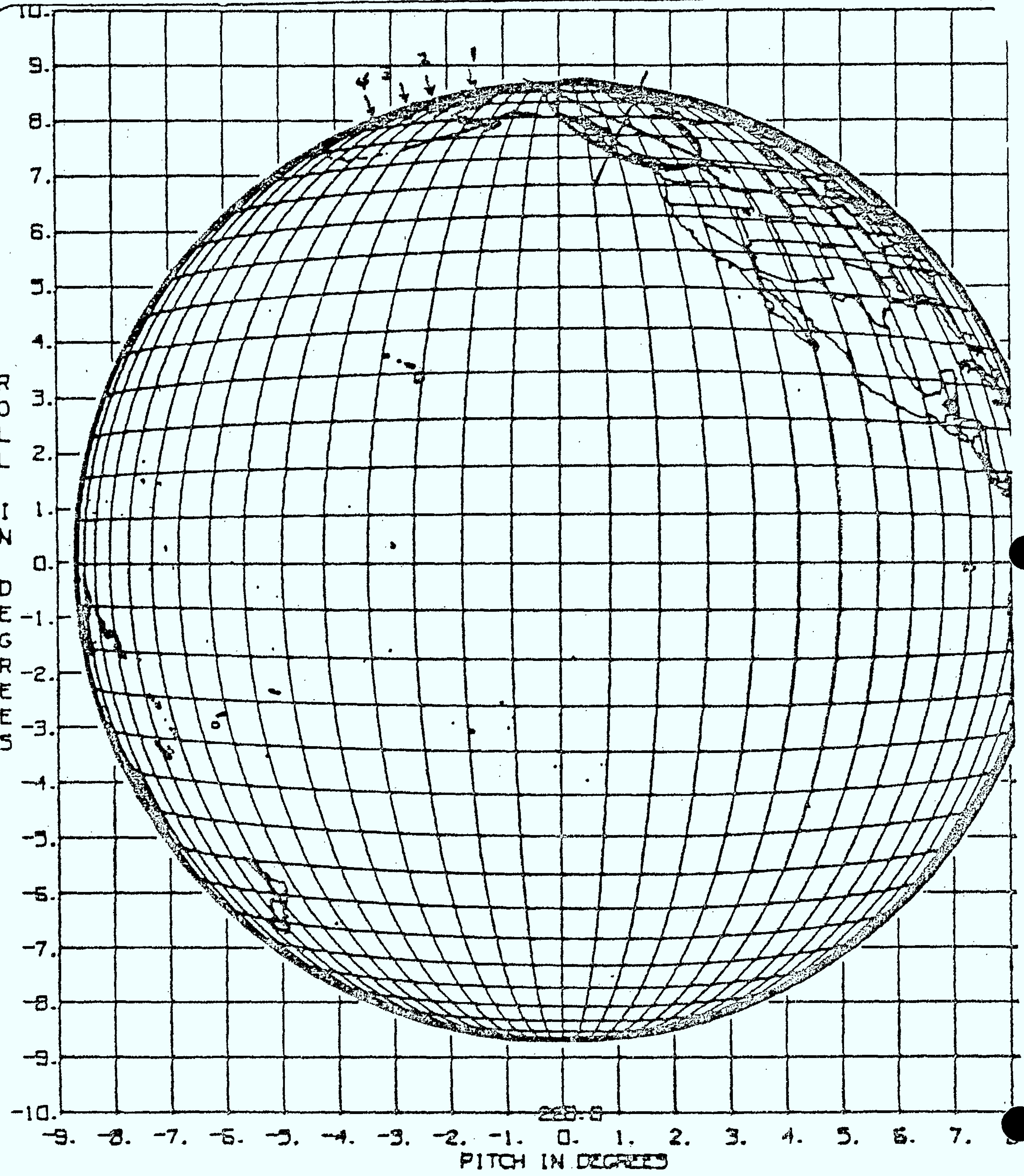
Notes: see Table 3.3.A.1 for definition of limits

* problem at P2 has been overcome by satellite move but P1 has become worse

** this value of pfd would have to be co-ordinated with P1 of the Region 1 & 3 plan under resolves 3 of Resolution 31 (P1 is in Iceland)

Table 3.3.C.2 Interference from Eastern Greenland Beam

Figure 3.3.D.1



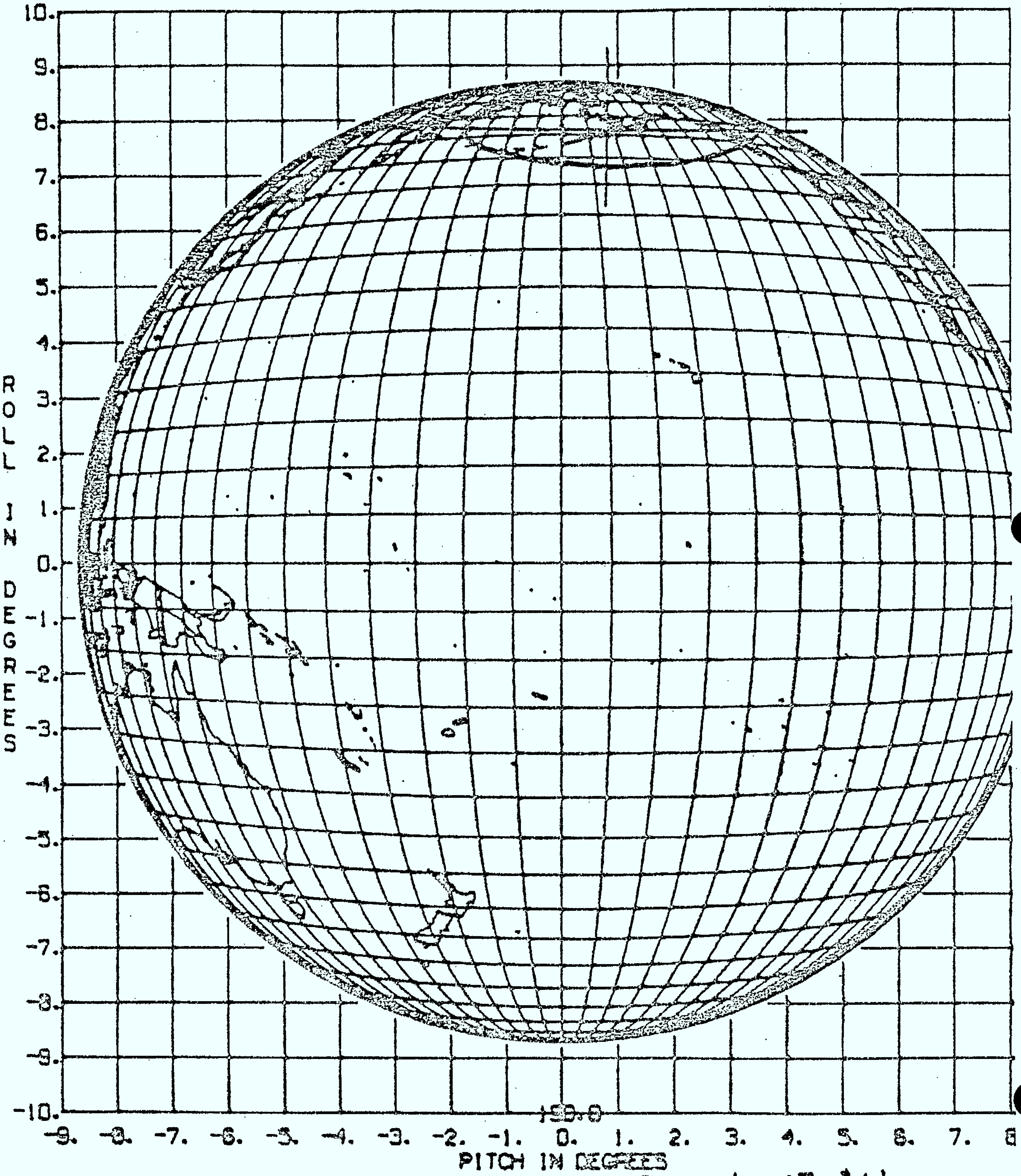
WESTERN CANADIAN SAT. at 140°W

Beam name:		P1	P2	P3	P4
CAN 1	location	(66; 170)	(64; 173)	(62; 179E)	(60; 170^{o}E)
	elev. $\measuredangle^{o}$	12	13	12	10
Beam size	range (km)	40220	40064	40220	40375
1.025					
2.978	O.A. $\measuredangle^{o}$	3.06	3.37	3.98	4.64
@ 155.46	3 dB $\measuredangle^{o}$	1.68	1.76	1.88	1.99
	Ratio	1.83	1.91	2.12	2.33
Boresight	D (dB)	30.0	30.0	30.0	30.0
57.40^{o}N	L_{fs}(dB)	163.1	163.0	163.1	163.1
126.21^{o}W					
Sat. Long.	pfd (dBW/m^{2}/4kHz)	-154.1	-154.0	-154.1	-154.1
140^{o}W					
	limit 1	-125	-125	-125	-125
		ok	ok	ok	ok
E = 64 dBw					
P = 3 dB					
	limit 2	-144.5	-144.0	-144.5	-145.5
		ok	ok	ok	ok
	pfd (dBW/m^{2}/5MHz)	-132.1	-132.0	-132.1	-132.1
	limit 3	-123.6	-119.4	-123.6	-132.0
		ok	ok	ok	ok

Notes: see Table 3.3.A.1 for definition of limits

Table 3.3.D Interference from Western Canadian Beam

Figure 3.3.E



ALASKAN SAT. at 170° W

Beam name		P1	P2	P3	P4
Alaska	location	(66; 170)	(62; 179E)	(60; 170E)	(55; 162E)
	elev ∢^{0}	15	19	20	22
Beam size	range (km)	39,861	39,475	39,370	39,170
1.379^0					
5.168^0					
@ 178.7^0	O.A ∢^{0}	0.93	1.61	2.33	3.25
	3 dB ∢^{0}	2.41	3.95	4.82	5.13
Boresight	Ratio	0.433	0.408	0.484	0.635
56.54^{0}N	D (dB)	2.2	2.0	2.8	4.8
161.63^{0}W	L sp (dB)	163.0	162.9	162.9	162.8
Sat. Long	pfd (4kHz)	-126.2	-125.9	-126.7	-128.6
170^{0}W					
	limit 1	-125	-125	-125	-125
		ok	ok	ok	ok
E = 64 dBW					
P = 3 dB					
	limit 2	-143.0	-141.0	-140.5	-139.5
		16.8	15.1	11.3	10.9
	pfd (5 MHz)	-104.2	-103.9	-104.7	-106.6
	limit 3	-111	-111	-111	-111
		6.8	7.1	6.3	4.4

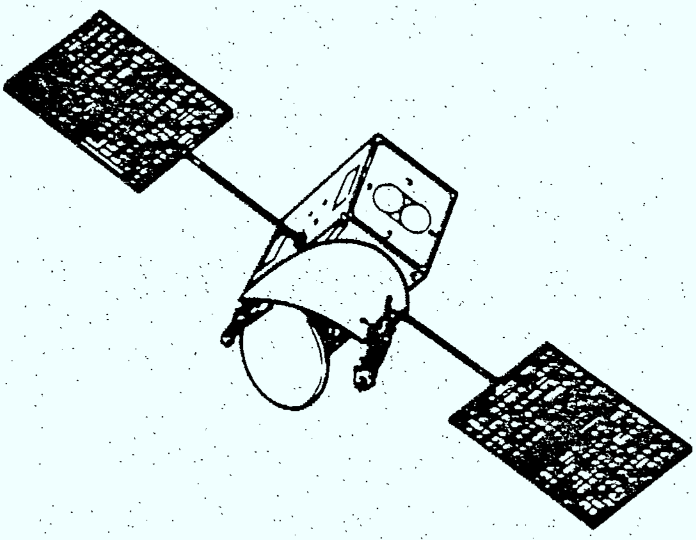
Notes: see Table 3.3.A.1 for definition of

* these pfd values would have to be co-ordinated with the Region 1 & 3 plan

Table 3.3.E Interference from Alaskan Beam (continued)

	P5	P6
location	(51; 157E)	(43; 145E)
elev ∢°	24	23
range (km)	38,980	39,076
0.A ∢°	3.98	5.74
3 db ∢°	4.76	3.97
Ratio	0.836	1.45
D (dB)	8.4	29.4
L_{fs}	162.8	162.8
pfd (4kHz)	132.2	-153.2
limit 1	-125	-125
	ok	ok
limit 2	-138.5	-139.0
	6.3	ok
pfd (5MHz)	-110.2	-131.2
limit 3	-111	-111
	0.8	ok

Table 3.3.E (continued)



TITLE : INTER-REGIONAL SHARING RESTRICTIONS ON PLANNING AT THE PARC-83

AUTHOR : R.G. AMERO

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Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

INTER-REGIONAL SHARING RESTRICTIONS ON PLANNING AT THE RARC-83

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1. Introduction

The Administrations of Region 2, the Americas, made a fundamental decision at the 1977 World Administrative Radio Conference (WARC) on Broadcasting Satellites (12 GHz) that it was premature to do detailed planning as was undertaken by the rest of the world. Instead, certain interim provisions were adopted, including a request for a subsequent regional conference (RARC) to undertake such planning. Region 2 was also unique in that it had two space services allocated on an equal primary basis in the 11.7 - 12.2 GHz band, i.e. the Fixed Satellite Service (FSS) in addition to the Broadcasting Satellite Service (BSS).

Meanwhile, as part of the discussions at the 1979 WARC, the Administrations of Region 2 recognized the importance of making the utmost use of both these space services and so decided to separate them in the frequency domains so that the development of the plan for broadcasting satellite systems would not be constrained to using only part of the geostationary satellite orbit, for example. On the other hand, the fixed satellite systems could develop independent of the BSS plan. The end result was the upward shift, frequency-wise, of the BSS allocation from 11.7 - 12.2 GHz to 12.1 or 12.3 - 12.7 GHz (the lower limit to be decided by the RARC).

To achieve this ideal solution required considerable negotiation with Regions 1 and 3 since the future Region 2 BSS plan would use frequencies higher than those planned at WARC-77. Thus, there is the potential for interference into their space (FSS) and terrestrial services, where before, there was none. To have the allocation accepted at WARC-79, several very complex documents were drafted to reduce the potential for harmful interference by extending the inter-regional sharing restrictions of WARC-77. Some nine footnotes and six resolutions were required before agreement could be reached.

This paper briefly addresses these restrictions on BSS planning concentrating on the down-link. The paper will also examine the restrictions relating to maximum power flux density by using example spacecraft antenna beams for several service areas throughout Region 2. The treatment is not purported to be exhaustive, but simply to estimate the magnitude of the problem.

.../2

2. Regulatory Restrictions Agreed at WARC-79

2.1 Resolution 31/CI

Perhaps the most important resolution of WARC-79 with respect to inter-regional sharing would be Resolution 31/CI which delineates how the WARC-77 provisions are to be extended to cover the revised frequency allocation. The resolution is summarized in Annex I for convenience.

Resolves 1 and 2 specify the degree to which Region 1 and 3 will protect Region 2 BSS. Herein, as elsewhere, the principle used was that of equal reciprocal protection, that is, protection of Region 2 to the same extent that Regions 1 and 3 were protected by WARC-77. Resolves 3 gives power flux density (pfd) levels above which co-ordination with Region 1 and 3 is necessary. Specific pfd limits to protect Region 1 and 3 terrestrial systems are specified in Resolves 4. Finally, Resolves 5 treats interim provisions pending the RARC.

These provisions must be reviewed with the provisions of WARC-77 (adopted as Appendix 30/29A) to appreciate their significance. It is these provisions against which the Region 2 BSS plan must be evaluated before it is adopted. Such restrictions may necessitate revisions to the initial plans to satisfy inter-regional agreements.

2.2 Resolution 700/CJ

In Regions 1 and 3, there are allocations to the FSS which will have to share with BSS systems operating under a plan in Region 2. For these reasons, Resolution 700/CJ was adopted. CCIR studies on sharing were requested and pending the RARC, Region 2 BSS systems would co-ordinate with Regions 1 and 3 FSS using established procedures. More significantly, however, the resolution states that the Region 2 BSS plan should not restrict Regions 1 and 3 FSS more than was imposed on Region 2 in the lower frequency band at WARC-79.

2.3 Consideration of Restrictions on the Basis of Frequency Band

Annex 2 lists the articles, footnotes, and resolutions pertinent to each of the following frequency bands:

12.1 - 12.3 GHz
12.3 - 12.7 GHz
17.3 - 17.7 GHz
17.7 - 18.1 GHz

It is hoped that such a breakdown will assist the reader in reviewing the regulations pertinent to each frequency band.

.../3

3. Preliminary Assessment

3.1 Test Criteria

In undertaking this assessment, the criteria given in Resolution 31/CI was used, namely:

a) Annex 5 to Appendix 30/29A (i.e. WARC-77)

- to protect terrestrial fixed systems, a maximum pfd of
  - 125 $\mathrm{dBW/m^2/4kHz}$ when circular polarization is used
  - 128 $\mathrm{dBW/m^2/4kHz}$ when linear polarization is used
- to protect terrestrial broadcasting in Region 3 and Region 1 west of 30° E longitude

$$\left.\begin{array}{ll} -132 & \delta \leq 10^{\circ} \\ -132 + 4.2\,(\delta - 10) & 10^{\circ} < \gamma \leq 15^{\circ} \\ -111 & \delta > 15^{\circ} \end{array}\right)\ \mathrm{dBW/m^2/5MHz}$$

where δ is angle of arrival of the signal above the horizontal plane.

b) for comparison, Radio Regulation 6071-6074 of Article 27/N25 was included which specifies maximum pfd from FSS in Region 1 and 3 terrestrial services

$$\left.\begin{array}{ll} -148 & \delta \leqslant 5^{\circ} \\ -148 + 0.5\,(\delta - 5) & 5^{\circ} < \delta \leqslant 25^{\circ} \\ -138 & \delta > 25^{\circ} \end{array}\right)\ \text{in } \mathrm{dBW/m^2/4kHz}$$

where δ is the arrival angle above the horizontal plane.

c) resolves 3 indicates that a Region 2 BSS will have to be co-ordinated with the Region 1 and 3 BSS plan if the former exceeds a pfd of

$$\left.\begin{array}{ll} -147 & \theta \leqslant 0.44^{\circ} \\ -138 + 25\log\theta & 0.44 < \theta \leqslant 19.1^{\circ} \\ -106 & \theta > 19^{\circ} \end{array}\right)\ \mathrm{dBW/m^2/27MHz}$$

where θ is the orbital separation angle.

.../4

3.2 Mathematical Models

The following formula can be used to calculate the pfd of a broadcasting satellite system:

$$\text{pfd} = E - G_d - L_{fs} - D - P \quad (\text{dBW/m}^2/4\text{kHz}) \quad (1)$$

where E = spacecraft on-axis eirp
G_d = antenna discrimination
L_{fs} = free-space, spreading loss
D = energy dispersal factor
P = polarization factor

Drawing upon both the WARC-77 values, as well as, those in various CCIR reports, the above parameters were determined for use herein:

$$G_d = 12\,(\phi/\phi_o)^2 \text{ dB} \qquad 0 < \phi/\phi_o \leqslant 1.58$$

$$= 30 \text{ dB} \qquad 1.58 < \phi/\phi_o \leqslant 3.16$$

$$= 17.5 + 25 \log (\phi/\phi_o) \text{ dB} \qquad \phi/\phi_o > 3.16$$

where ϕ_o is the 3dB beamwidth of the spacecraft in the direction of interest
(This is the co-polar reference antenna pattern adopted by WARC-77).

D is the energy dispersal effect. At WARC-77, 600 kHz was adopted, which would give a factor relative to 4kHz of 22 dB. However, in a 5MHz reference bandwidth, the effect of 600 kHz of energy dispersal is negligible; hence D = 0 dB.

P is 3 dB for circular polarization.

3.3 Test Cases

The following test cases were made to assess the difficulties in meeting the test criteria given in section 3.1. The BSS beams included:

a) western Brazil interfering into Africa
b) eastern Canada interfering into north-western Region 1
c) western Greenland interfering into north-western Region 1
d) western Canada interfering into eastern Region 1 & 3
e) Alaska interfering into eastern Region 1 & 3.

3.3(A) Figure 3.3.A.1 is an illustration of a service area in eastern Brazil as specified by that Administration to WARC-77. The beam was calculated for a satellite position of 40° W longitude for illustrative purposes only. The results of a beam-fitting computer programme were used for this study. Figure 3.3.A.2 show the relationship of the beam to the test points in western Africa.

The results of this analysis, given in Table 3.3.A.1, indicate no problem sharing with Region 1, based upon the three limits specified in section 3.1, even for a relatively high e.i.r.p. of 64 dBW. (This value of e.i.r.p. was chosen for this analysis because it is a rather high value sometimes used for calculation in various CCIR texts. The actual e.i.r.p. of each beam of the plan will be unique to it based on many technical factors).

Figure 3.3.A.3 and Table 3.3.A.2 examine the sensitivity of the results to a shift in satellite orbital position to the west. Still there are no difficulties meeting the test criteria.

3.3(B) The situation of a rather large beam into eastern Canada was examined in Figure 3.3.B.1. The anlaysis of Table 3.3.B.1 shows a problem with limit 3 in one particular location (Iceland to be specific) due to the low angle of arrival. To overcome this problem the satellite was shifted slightly westward as shown in Figure 3.3.B.2. The result of this shift was to put the serious interference case over the horizon. Otherwise, the interference would be well under control.

3.3(C) At WARC-77, Greenland requested permission to use a portion of the orbit in the range 55° - 60° W longitude. Based upon this and the service area provided to the WARC, a calculation was made as presented in Figure 3.3.C.1 and analysed in Table 3.3.C.1. Two test points indicate interference over the criteria, one in Iceland, the other in the Hebrides. A change in orbital position to the east would increase the off-axis angles relative to the down-link beam and perhaps improve the interference situation. This test is illustrated in Figure 3.3.C.2 and table 3.3.C.2 which shows a resolution of the interference into test point 2, but an increase in interference into Iceland. Other means may have to be found to resolve this problem as discussed later.

3.3(D) On the western portion of Region 2, two cases were examined, i.e., a western Canadian beam and a beam into Alaska. Figure 3.3.D.1 illustrates the first case. Table 3.3.D finds a minor problem with limit 3 into test point 1 which could easily be overcome. Otherwise, no particular problem areas arise.

3.3(E) The Alaskan beam poses a very interesting problem especially if that beam must cover the whole land mass including the Aleutian Islands (see Figure 3.3.E). Such a requirement would involve a rather large beam which in fact would probably encompass portions of Region 1. Table 3.3.E shows the serious nature of the problem. There are excessive pfd values for most test points under criteria 2 and 3. A simple change in orbital position will not overcome this particular problem.

Possible solutions to the high level of interference would be applicable to any BSS allotment. These would include a reduction in e.i.r.p., in this case a reduction of 2.4 dB would obviate the need for co-ordination with the Region 1 and 3 plan in the band 12.2 - 12.5 GHz. A reduction in the down-link beam size or a reconfiguration of the service area would also help find a solution. Better satellite antenna patterns with sharper discrimination or even beam shaping should be examined. The choice of which technique to use could be a significant decision.

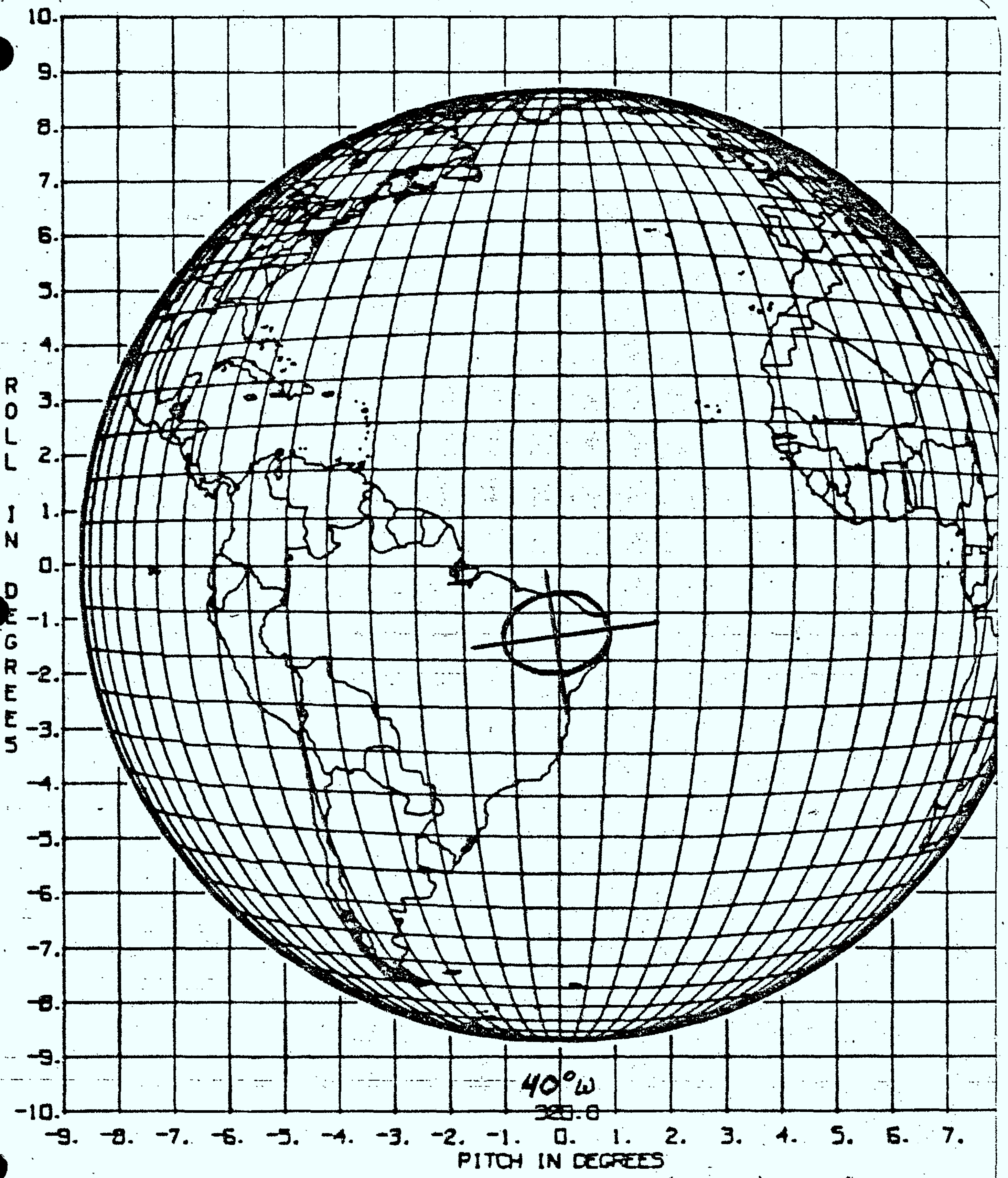
4. Summary and Preliminary Assessment

This paper has attempted to describe the nature of the inter-regional sharing problem and to illustrate the magnitude of the problem by using actual interference geometry from possible service areas identified at WARC-77.

It can be seen that the re-allocation of the BSS band at WARC-79 complicated sharing, especially from an inter-regional viewpoint. In developing the Region 2 BSS plan, it will be necessary to observe the specified limits on interference into Region 1 and 3 systems operating (1) under the BSS, (2) terrestrial systems, and (3) fixed satellite systems.

The paper has illustrated that some areas of Region 2 more than others, have the potential for causing excessive interference into Region 1 and 3 radiocommunication services. However, it is estimated that such restrictions are not insurmountable in developing the plan by the proper choice of satellite orbital position, size of the service area, satellite e.i.r.p. or antenna characteristics, etc.

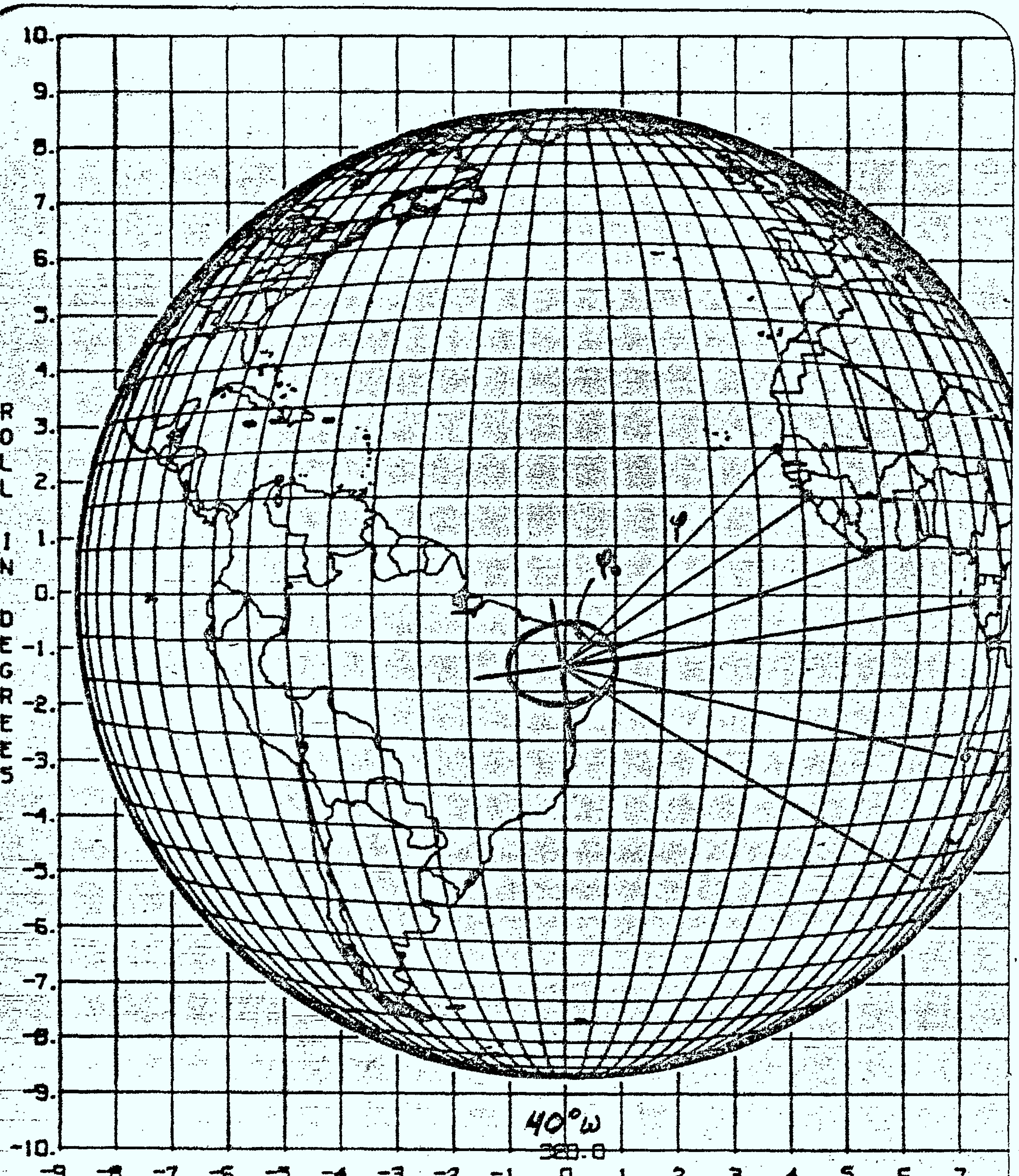
Finally, it should be noted that Region 2 must and will make a concerted effort to meet the criteria for the protection of the Region 1 and 3 services when developing their BSS plan.



EAST. BRAZIL SAT at 40°W

Figure 3.3.A.2

A B



INTERFERENCE ANGLES FROM EAST. BRAZIL SAT at 40° W

Beam name:		P1	P2	P3	P4
Brazil	location	(15°N; 17°W)	(10N; 14W)	(4N: 7.5W)	(1S; 9E)
	elev. ∡$^{\circ}$	55	58	52	34
	range (km)	36,308	36,334	36,650	37,960
Beam size:					
1.565					
2.025					
@ 8.93° orientation ∡					
Boresight:	O.A ∡$^{\circ}$	5.49	5.37	5.77	7.42
7.36°S	3 dB ∡$^{\circ}$	1.82	1.91	1.91	2.03
40.71° W	Ratio	3.01	2.81	2.81	3.66
	D (dB)	30.0	30.0	30.0	31.6
Sat. Long	L_{fs}(dB)	162.2	162.2	162.3	162.6
40°W					
E = 64 dBW	pfd (dBW/m^2/4kHz)	-153.2	-153.2	-153.3	-155.2
P = 3 dB	limit 1	-125	-125	-125	-125
		ok	ok	ok	ok
	limit 2	-148	-148	-148	-148
		ok	ok	ok	ok
	pfd (dBW/m^2/5MHz)	-131.2	-131.2	-131.3	-133.2
	limit 3	-111	-111	-111	-111
		ok	ok	ok	ok

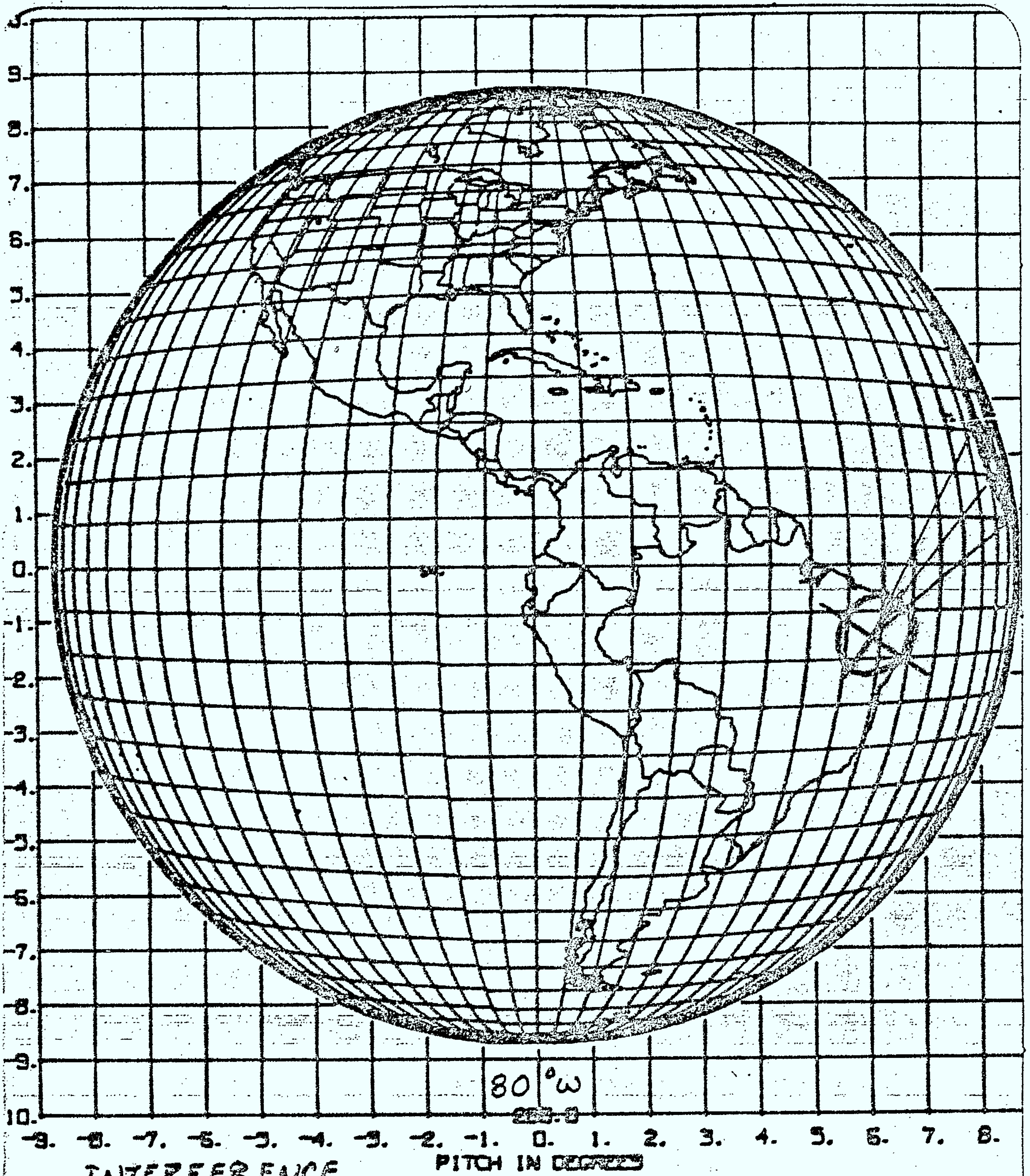
Notes: Limit 1 - Resolution 31, Resolves 4, part (a)
Limit 2 - FSS limits RR6071
Limit 3 - Resolution 31, Resolves 4, part (b)

- even for 0° elevation angles, all limits would be met

Table 3.3.A.1 Interference from Brazilian Beam

Figure 3.3.A.3

A B



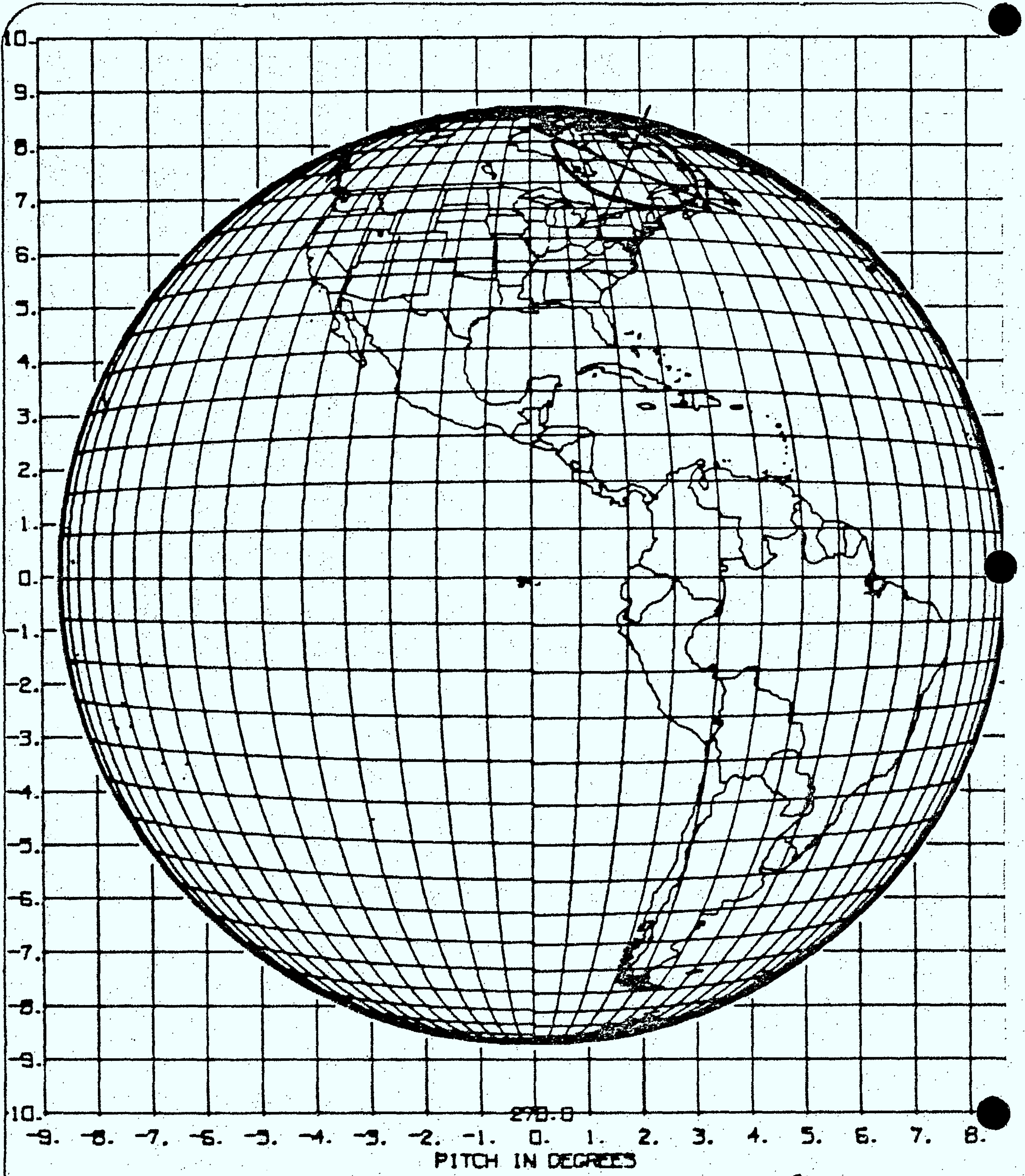
INTERFERENCE
ANGLES FROM EAST BRAZIL SAT at 80°W

Beam name:		P1	P2	P3	P4
Brazil	location	(15N; 17W)	(10N; 14W)	(4N; 7.5W)	(1S; 9E)
	Elev.∢°	15	15	9	over horizon
Beam size	range (km)	39861	39861	40483	
1.319°					
1.615°	O.A∢°	4.07	3.56	3.11	
@ 55.33°	3 dB∢°	1.61	1.61	1.58	
	Ratio	2.53	2.21	1.98	
Boresight	D (dB)	30.0	30.0	30.0	
7.39°S	L_{fs}(dB)	163.0	163.0	163.1	
41.12°W					
Sat. Long	pfd (dBW/m^2/4kHz)	-154.0	-154.0	-153.9	-
80°W					
	limit 1	-125	-125	-125	
E = 64 dBw		ok	ok	ok	ok
P = 3 dB	limit 2	-143	-143	-146	
		ok	ok	ok	ok
	pfd (dBW/m^2/5mHz)	-132.0	-132.2	-131.9	-
	limit 3	-111.0	-111.0	-132.0	
		ok	ok	ok	ok

Note: see Table 3.3.A.1 for definition of limits

Table 3.3.A.2 Interference from Brazilian Beam

Figure 3.3.B.1



EASTERN CANADIAN SAT. at 90°W

Beam name:		P1	P2	P3
CAN 5	location	(66; 25)	(38; 28)	(29; 19)
	elev. ∡°	1	13°	5°
	range (km)	41350	40064	40913
Beam size				
1.440°				
2.926°	O.A ∡°	1.64	5.06	6.58
@ 157.10°	3 dB ∡°	1.95	2.93	2.87
	Ratio	0.841	1.73	2.30
Boresight	D (dB)	8.5	30.0	30.0
54.00N	L_{fs} (dB)	163.3	163.1	163.2
72.40W				
Sat. Long	pfd (dBW/m^2/4kHz)	-132.8	-154.1	-154.2
90° W				
	limit 1	-125	-125	-125
		ok	ok	ok
E = 64 dBW P = 3 dB	limit 2	-148	-144	-148
		ok	ok	ok
	pfd (dBW/m^2/5mHz)	-110.8	-132.1	-132.2
	limit 3	-132	-119.4	-132
		21.2*	ok	ok

Note: see Table 3.3.A.1 for definition of limits

* objective will be to reduce this negative value

Table 3.3.B.1 Interference from Eastern Canadian Beam

Figure 3.3.B.2

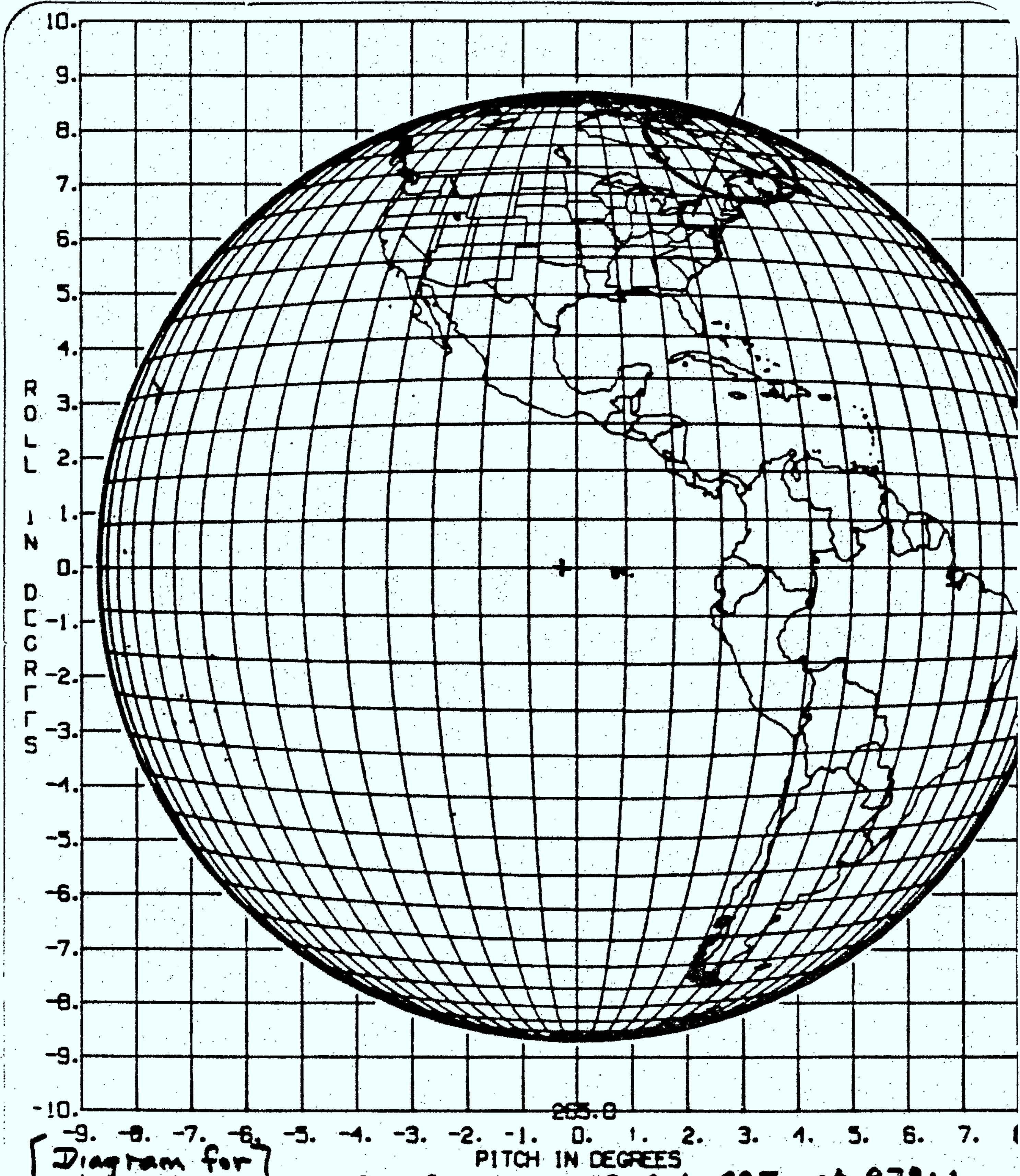


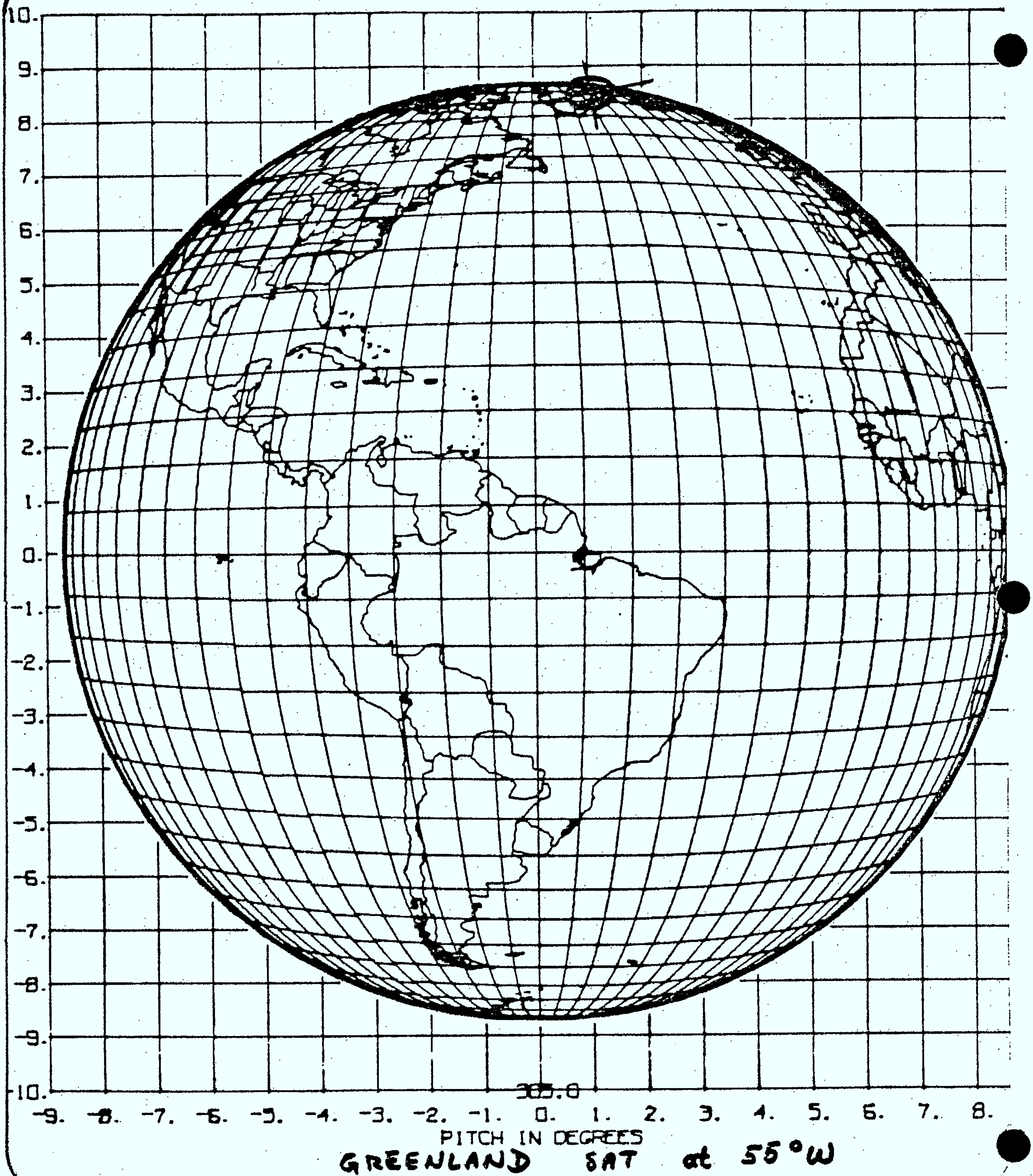
Diagram for illustration only

EASTERN CANADIAN SAT at 97°W

Beam name:		P1	P2	P3	P4
CAN 5	location	(66; 25)	(38; 28)	29; 19)	15; 17)
	elev. ∢°	over horizon	8	over horizon	0.5°
Beam size	range (km)		40590		41516
1.280°					
3.114°	O.A. ∢°		4.80		8.08
@ 154.09°	3 dB ∢°		3.11		2.72
	Ratio		1.54		2.98
Boresight	D (dB)		28.6		30.0
53.89°N	L_{fs}(dB)		163.2		163.4
73.09°W					
Sat. Long.	pfd (dBW/m^2/4kHz)	-	-152.8	-	-154.4
97°W					
	limit 1	-	-125	-	-125
		ok	ok	ok	ok
E = 64 dBW					
P = 3 dB	limit 2	-	-146.5	-	-148
		ok	ok	ok	ok
	pfd (dBW/m^2/5mHz)	-	-130.8	-	-132.4
	limit 3	-	-132.0	-	-132.0
		ok	1.2	ok	ok

Note: see Table 3.3.A.1 for definition of limits

Table 3.3.B.2 Interference from Eastern Canadian Beam



GREENLAND SAT at 55°W

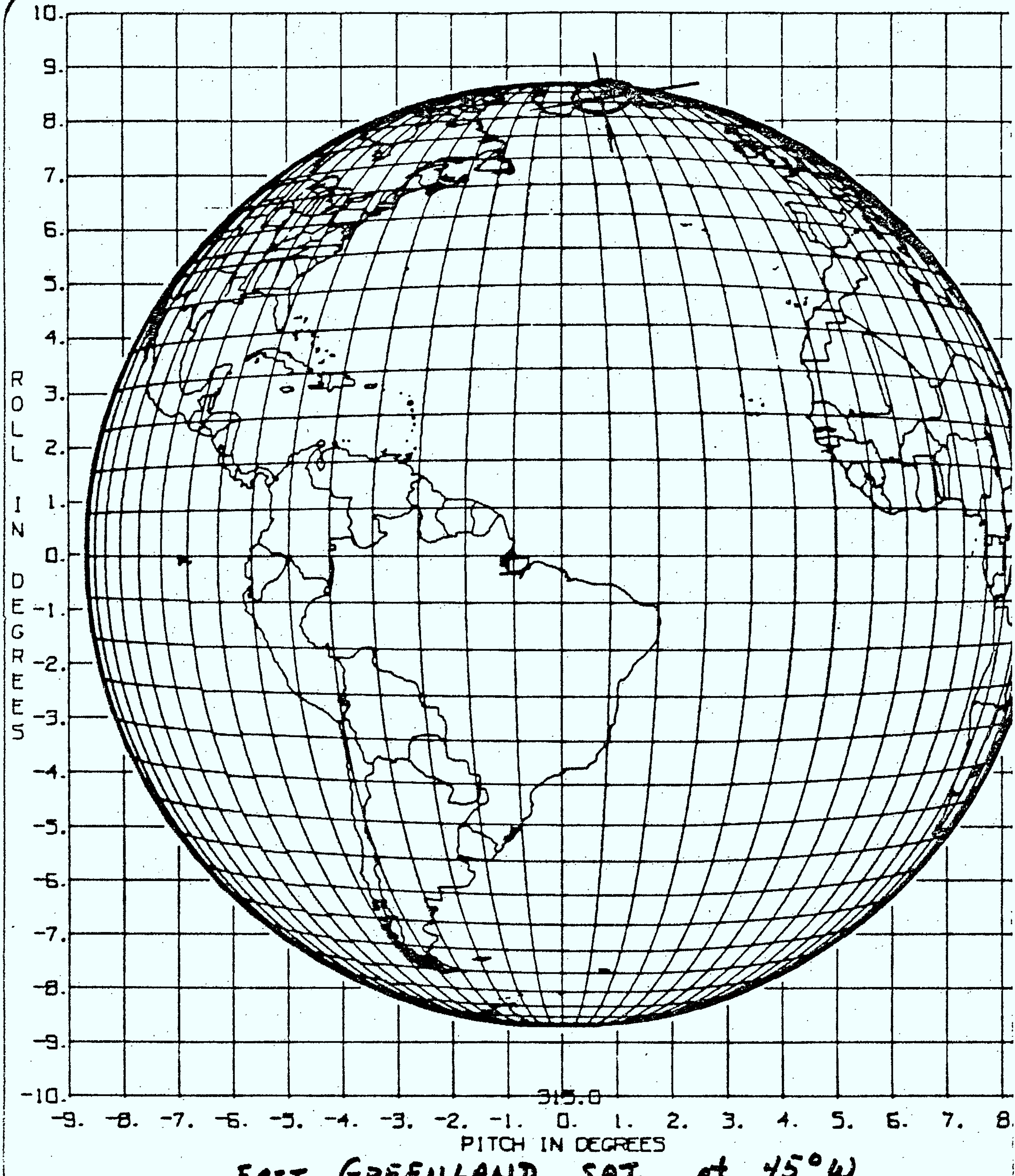
Beam Name		P1	P2	P3
E. Greenland	location	(66; 25)	(58.5; 6.5)	(54; 10)
	elev. ∡°	14.5	11.5	16°
	range (km)	40168	40232	39963
Beam size				
0.60°				
0.953°				
@ 12.24°	O.A ∡°	0.52	2.30	2.66
	3 dB ∡°	0.85	0.82	0.79
Boresight	Ratio	0.62	2.82	3.38
67.83°N	D (dB)	4.5	30.0	30.7
32.11°W	L_{fs} (dB)	163.1	163.1	163.0
Sat. Long	pfd (dBW/m^2/4kHz)	-128.6	-154.1	-154.7
55°W				
	limit 1	-125	-125	-125
E = 64 dBW		ok	ok	ok
P = 3 dB				
	limit 2	-143.3	-144.8	-142.8
		14.7	ok	ok
	pfd (dBW/m^2/5MHz)	106.6	-132.1	-132.7
	limit 3	-113.1	-125.7	-132
		6.3	6.4	ok

Notes: - see Table 3.3.A.1 for definition of limits

- try to resolve excess pfd by shifting satellite position eastward to have larger off-axis discrimination angles

Table 3.3.C.1 Interference from Eastern Greenland Beam

Figure 3.3.C.2



EAST GREENLAND SAT. at 45° W

Beam name		P1	P2	P3
E. Greenland	location	(66; 25)	(58.5; 6.5)	(54; 10)
	elev. ∡°	14	16	21
	range (km)	40168	39760	39265
Beam size				
0.60°				
1.178°	O.A ∡°	0.49	2.27	2.50
@ 10.51°	3 dB ∡°	1.02	0.95	0.88
	Ratio	0.48	2.39	2.84
Boresight	D (dB)	2.7	30.0	30.0
67.41°N	L_{fs}(dB)	163.1	163.0	162.9
32.04°W				
Sat. Long	pfd ($dBW/m^2/4kHz$)	-126.8	-154.0	-153.9
45°W				
	limit 1	-125	-125	-125
E = 64 dBW		ok	ok	ok
P = 3 dB	limit 2	-143.5	-142.5	-140.0
		16.7	ok	ok
	pfd ($dBW/m^2/5MHz$)	-104.8**	-132.0	-131.9
	limit 3	-115.2	-111	-111
		10.4	ok	ok

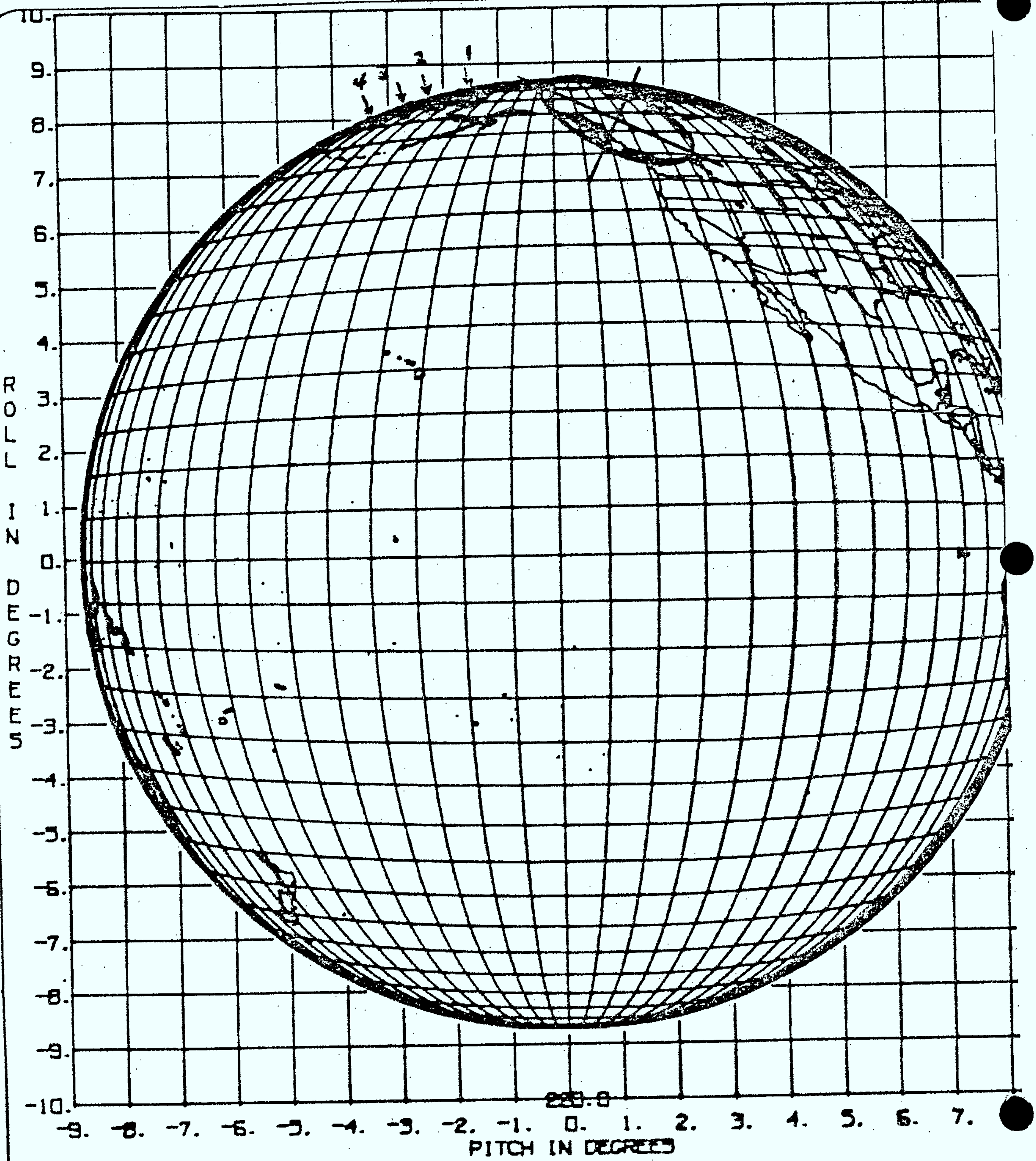
Notes: see Table 3.3.A.1 for definition of limits

* problem at P2 has been overcome by satellite move but P1 has become worse

** this value of pfd would have to be co-ordinated with P1 of the Region 1 & 3 plan under resolves 3 of Resolution 31 (P1 is in Iceland)

Table 3.3.C.2 Interference from Eastern Greenland Beam

Figure 3.3.D.1



WESTERN CANADIAN SAT. at 140°W

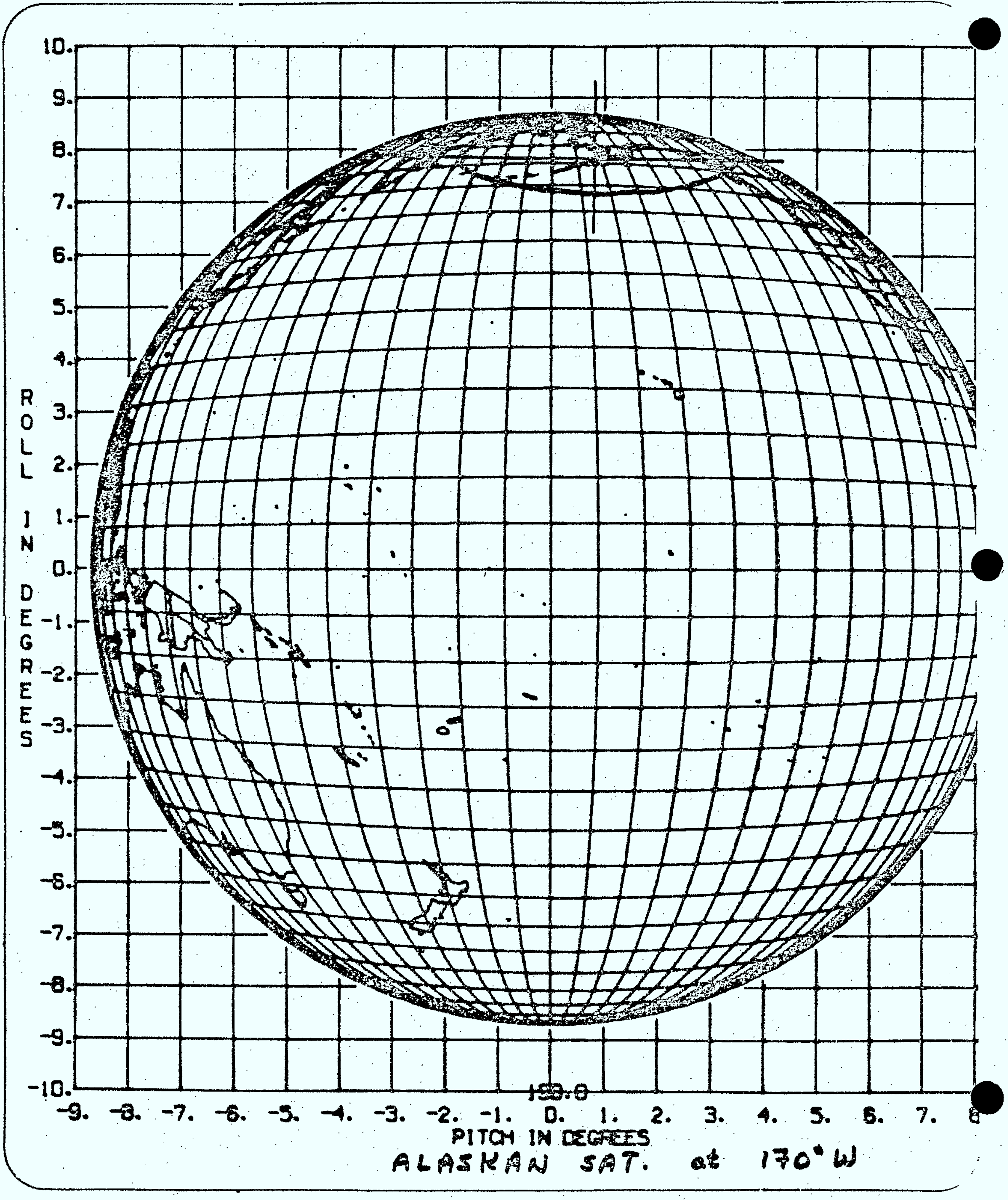
Beam name:		P1	P2	P3	P4
CAN 1	location	(66; 170)	(64; 173)	(62; 179E)	(60; 170°E)
	elev. ∡°	12	13	12	10
Beam size	range (km)	40220	40064	40220	40375
1.025					
2.978	O.A.∡°	3.06	3.37	3.98	3.64
@ 155.46	3 dB ∡°	2.36	2.22	2.07	1.95
	Ratio	1.30	1.52	1.93	2.38
Boresight	D (dB)	20.3	27.7	30.0	30.0
57.40°N	L_{fs}(dB)	163.1	163.0	163.1	163.1
126.21°W					
Sat. Long.	pfd (dBW/m^2/4kHz)	-144.4	-151.7	-154.1	-154.1
140°W					
	limit 1	-125	-125	-125	-125
		ok	ok	ok	ok
E = 64 dBw					
P = 3 dB					
	limit 2	-144.5	-144.0	-144.5	-145.5
		0.1	ok	ok	ok
	pfd (dBW/m^2/5MHz)	-122.4	-129.4	-132.1	-132.1
	limit 3	-123.6	-119.4	-123.6	-132.0
		1.2*	ok	ok	ok

Notes: see Table 3.3.A.1 for definition of limits

* value could be offset by increasing elevation angle by 0.25 degrees, limit would change to give acceptable pfd. Satellite could move position slightly e.g. 0.5°

Table 3.3.D Interference from Western Canadian Beam

Figure 3.3.E



ALASKAN SAT. at 170° W

Beam name		P1	P2	P3	P4
Alaska	location	(66; 170)	(62; 179E)	(60; 170E)	(55; 162E)
	elev ∡°	15	19	20	22
Beam size	range (km)	39,861	39,475	39,370	39,170
1.379°					
5.168°					
@ 178.7°	0.A ∡°	0.93	1.61	2.33	3.25
	3 dB ∡°	2.25	4.26	5.04	4.96
Boresight	Ratio	0.412	0.378	0.463	0.656
56.54°N	D (dB)	2.0	1.7	2.6	5.2
161.63°W	L sp (dB)	163.0	162.9	162.9	162.8
Sat. Long	pfd (4kHz)	-126.0	-125.6	-126.5	-129.0
170°W					
	limit 1	-125	-125	-125	-125
		ok	ok	ok	ok
E = 64 dBW					
P = 3 dB					
	limit 2	-143.0	-141.0	-140.5	-139.5
		17.0	15.4	11.5	10.5
	pfd (5 MHz)	-104.0*	-103.6*	-104.5*	-107.0
	limit 3	-111	-111	-111	-111
		7.0	7.4	6.5	4.0

Notes: see Table 3.3.A.1 for definition of

* these pfd values would have to be co-ordinated with the Region 1 & 3 plan

Table 3.3.E Interference from Alaskan Beam (continued)

	P5	P6
location	(51; 157E)	(43; 145E)
elev ∢°	24	23
range (km)	38,980	39,076
O.A ∢°	3.98	5.74
3 db ∢°	4.46	3.67
Ratio	0.892	1.57
D (dB)	9.5	29.4
L_{fs}	162.8	162.8
pfd (4kHz)	-133.3	-153.2
limit 1	-125	-125
	ok	ok
limit 2	-138.5	-139.0
	5.2	ok
pfd (5MHz)	-111.3	-131.2
limit 3	-111	-111
	ok	ok

Table 3.3.E (continued)

Annex I

RESOLUTION 31/CI : APPLICATION OF WARC-77 PROVISIONS TO REGION 2 USE OF BAND 11.7 - 12.7 GHz

Resolves 1: Apply Article 4 and Annex 1 of App. 30/29A (mod. to
Region 1 & 3 BSS Plan) to protect Region 2
FSS in 12.2 - 12.3 GHz
BSS 12.2 - 12.5 GHz

a) FSS considered affected if change in p.f.d. is 0.25 dB except where p.f.d. is less than -138 dBW/m^2/27 MHz

b) BSS considered affected if p.f.d. exceeds

-147 dB(W/m^2/27 MHz)	$0^o \leqslant \theta \leqslant 0.48^o$
$-139 - 25 \log \Theta$ dB(W/m^2/27 MHz)	$0.48^o < \Theta \leqslant 27.25^o$
-103 dB(W/m^2/27 MHz)	$\Theta > 27.25^o$

where Θ is the orbital separation angle

Resolves 2: Apply Article 6 and Annex 3 of App. 30/29A (co-ordination of terrestrial stations) to protect Region 2 BSS in 12.2 - 12.7 GHz

Resolves 3: Apply Article 7 and Annex 4 of App. 30/29A and
Res. 503/BC to Region 2
FSS in 12.2 - 12.3 GHz
BSS 12.2 - 12.5 GHz

and must co-ordinate with Region 1 & 3 Plan if p.f.d. exceeds

-147 dBW/m^2/27 MHz for $0 \leqslant \Theta \leqslant 0.44^o$
$-138 - 25 \log \Theta$ dBW/m^2/27 MHz for $0.44^o < \Theta \leqslant 19.1^o$
-106 dBW/m^2/27 MHz for $19.1^o < \Theta$

where Θ is the orbital separation angle

RESOLUTION 31/CI (Continued)

Resolves 4: Apply Article 9 and Annex 5 of App. 30/29A (p.f.d. limits to protect Region 1 & 3 terrestrial systems from Region 2 BSS)

i.e. upward extension into 12.2 - 12.5 GHz band to protect:

a) Region 1 & 3

- 125 dBW/m^2/4kHz	circular polarization
- 128 "	linear polarization

b) Region 3 and Region 1 west of 30° E long.

- 132 dBW/m^2/5 MHz	for angles of arrival between 0^0 and 10^0 above the horizontal plane;
- 132 + 4.2 (δ - 10) dBW/m^2/5 MHz	for angles of arrival δ (in degrees) between 10^0 and 15^0 above the horizontal plane;
- 111 dBW/m^2/5 MHz	for angles of arrival between 15^0 and 90^0 above the horizontal plane.

Resolves 5: In interim until RARC-83, use of 12.5 - 12.7 GHz band:

- Region 2 BSS - apply Article 9 and Annex 5 (section 1) of App. 30/29A (i.e. see Resolves 4 (a) above)
- Region 2 FSS - normal FSS p.f.d. limits apply to protect Region 1 & 3 terrestrial services

- 148	$0 < \delta \leq 5^0$
- 148 + 0.5 (δ - 5)	$5^0 < \delta \leq 25^0$
- 138	$\delta > 25^0$

in dBW/m^2/4kHz, where δ is the angle of arrival above the horizontal plane

SUMMARY OF REGULATIONS
ON A FREQUENCY BAND BASIS

<u>12.1 - 12.3 GHz</u> (inter-Regional restrictions only)

A) General restrictions

- FN 840/3787H
- Article 15/N13B

B) Fixed service

- Res. 31/CI : resolves 2

C) FSS

- Res. 31/CI : resolves 1
  : resolves 3
- Res. 700/CJ: resolves 2
- Res. 701/CH: resolves 2
- Appendix 30/29A

D) BSS

- Res. 31/CI : resolves 1
  : resolves 2
  : resolves 3
  : resolves 4
- Res. 700/CJ: resolves 1
- Res. 701/CH: resolves 2

E) Other services - no such restrictions

12.3 - 12.7 GHz (inter-Regional restrictions only)

A) General restrictions

- FN 840/3787H

B) Fixed service

- Res. 31/CI : resolves 2

C) BSS

- Res. 31/CI : resolves 1
  : resolves 2
  : resolves 3
  : resolves 4

- Res. 700/CJ: resolves 1
  : resolves 2

- Res. 701/CH: resolves 2

D) Other services - no such restrictions

17.3 - 17.7 GHz (inter-Regional restrictions only)

A) FSS (feeder links to BSS)

- Res. 701/CH : plan feeder links for Region 2 BSS

B) Other services - all secondary services

17.7 - 18.1 GHz (inter-Regional restrictions only)

A) Fixed & Mobile services

- Article 27/N25 : e.i.r.p. limits provisionally

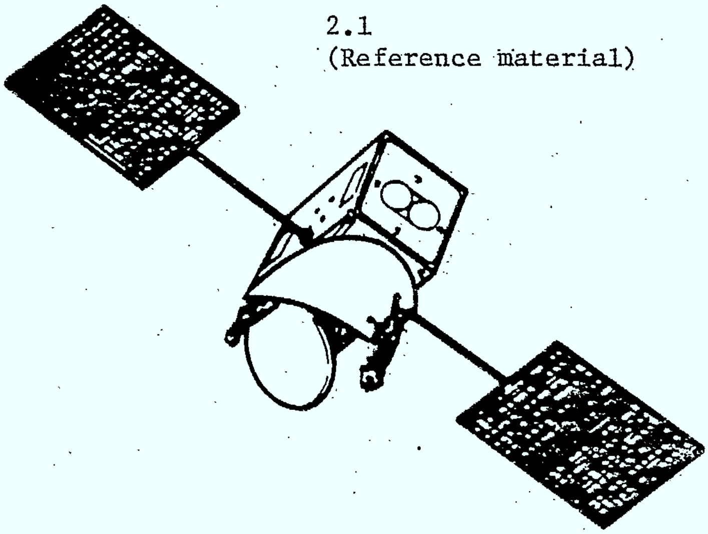
B) FSS (feeder links)

- Res. 701/CH : plan feeder links for Region 2 BSS

C) FSS (down-links)

- Article 28/N26 : down-links p.f.d. limits

2.1
(Reference material)



CCIR REPORT 809* (MOD I)

TITLE : INTER-REGIONAL SHARING OF THE 11.7 TO 12.75 GHz FREQUENCY BAND BETWEEN THE BROADCASTING-SATELLITE SERVICE AND THE FIXED-SATELLITE SERVICE

AUTHOR :

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

DRAFT

REPORT 809 * (MOD I)

INTER-REGIONAL SHARING OF THE 11.7 TO 12.~~2~~75 GHz FREQUENCY BAND BETWEEN THE BROADCASTING-SATELLITE SERVICE AND THE FIXED-SATELLITE SERVICE

(Study Programmes 20C-2/10 and ~~2~~5G-2/11)

(1978)

REPLACE the existing text by the following.

1. Introduction

As a result of different regional allocations to the fixed-satellite service and the broadcasting-satellite service in the 12 GHz band, several inter-regional sharing situations arise between these space services.

The World Administrative Radio Conference for planning the Broadcasting-Satellite Service in the frequency band 11.7 to 12.2 GHz (11.7 to 12.5 GHz in Region 1) met in Geneva, Switzerland, in January 1977 and took the following action [WARC-BS, 1977]:

- it adopted a detailed orbital position and frequency assignment Plan for the Broadcasting-Satellite Service in Regions 1 and 3.
- it adopted a set of provisions governing the Broadcasting-Satellite Service in Region 2 pending the establishment of a detailed plan. These provisions include division of the available orbital arc into separate segments for the Broadcasting-Satellite Service and the Fixed-Satellite Service, and a Regional Administrative Conference to be held not later than 1982 for the purpose of carrying out detailed planning for the Broadcasting-Satellite and Fixed-Satellite Services in Region 2 (see Recommendation No. Sat-8 of the WARC-BS, 1977 ; (see also Resolution No. 701(CH) of the WARC-79).

Subsequently, the WARC-79 allocated separate frequency bands for the two space services in Region 2, thus obviating the need for orbital arc segmentation (see Resolution No. 504(CK) of the WARC-79). The band allocated to the broadcasting-satellite service has a lower limit between 12.1 and 12.3 GHz - this limit will be determined at the Regional Administrative Radio Conference (RARC) (scheduled for 1983)- and an upper limit of 12.7 GHz. The various space service sharing situations are summarized in Table I which makes reference to the applicable footnotes in the Radio Regulations. Table I does not include the terrestrial services allocated in the 11.7 to 12.75 GHz band.

Characteristics of typical fixed-satellite systems are contained in Report 207-4. However, in Region 1, the band 12.5 - 12.75 GHz is allocated exclusively to the fixed-satellite service which may make its parameters different from fixed-satellite systems in which sharing is required.

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* This Report should be brought to the attention of Study Group 4.

ADD new TABLE I.

TABLE I

FSS and BSS sharing situations in the 12 GHz band

Frequency Band (GHz)	Region 1	Region 2	Region 3
11.7 - 12.1	BSS (S-E)	FSS (S-E) BSS(FN3787A) (S-E)	BSS (S-E)
12.1 - 12.2	BSS (S-E)	FSS or BSS (S-E) (FN3787B)	BSS (S-E)
12.2 - 12.3	BSS (S-E)	FSS or BSS (S-E) (FN3787B)	FSS(FN3785B) (S-E)
12.3 - 12.5	BSS (S-E)	BSS (S-E) FSS(FN3787F) (S-E)	FSS(FN3785B) (S-E)
12.5 - 12.7	FSS (S-E) (E-S)	BSS (S-E) FSS(FN3787F) (S-E)	FSS (S-E) BSS(FN3785A) (S-E)
12.7 - 12.75	FSS (S-E) (E-S)	FSS (E-S)	FSS (S-E) BSS(FN3785A) (S-E)

~~*Note.* — Regions 1, 2 and 3 are defined in Article 5, Section 1 of the Radio Regulations (1976).~~

~~1.~~ 2 Sharing between the Broadcasting-Satellite and Fixed-Satellite Services ~~in Region 2 and the Broadcasting-Satellite Service in Regions 1 and 3~~

The problem of sharing between the Broadcasting-Satellite Service and the Fixed-Satellite Service, particularly on the space-to-Earth paths, is a problem of sharing between dissimilar (inhomogeneous) networks. ~~In general, situations of this kind tend to decrease the total number of available channels (though not necessarily the total number of downlinks) unless steps are taken to circumvent it.~~ The factors that tend to enhance orbit-spectrum utilization are reasonably well understood. The extent to which these factors can actually be exploited depends on many operational, economic and design constraints.

Sharing between the Broadcasting-Satellite Service serving Regions 1 and 3 and the Fixed-Satellite Service serving Region 2 is a case of sharing between dissimilar networks with two special features:

- The areas served by the two services are separated generally by large bodies of water with the boundaries running North-South, which facilitates sharing as the side lobe discrimination of the space station antenna will tend to reduce the interference; and
- Regions 1 and 3 have established a detailed Plan for the Broadcasting-Satellite Service while no such plan exists ~~for the Fixed-Satellite Service~~ in Region 2.

This means that the burden of sharing rests with the ~~Fixed-Satellite Service~~ Region 2 space services provided that the Broadcasting-Satellite Service operates within the characteristics specified by the Region 1/3 Plan.

Sharing criteria between these services can be established, in principle, in terms of a power flux-density limit over the area to be protected, or in terms of a minimum separation of space stations in the two services, or in terms of a combination of both. Appendix 29A of ~~T~~ the Final Acts of the WARC ~~BS, 1977,~~ -79 deal s with the problem according to the last of these choices.

Considering, in addition, that the nominal spacing between space stations in the western portion of the arc serving Region 1 is 6° according to the Plan, this means that a space station in the Fixed-Satellite Service with characteristics specified in the Final Acts (on-axis gain of the earth-station receiving antenna of 53 dB and side-lobe gain following the law:

$$\text{Gain (dBi)} = 32 - 25 \log \cancel{\theta}, \varphi$$

where $\overset{\varphi}{\cancel{\theta}}$ is the off-axis angle in degrees) could be placed midway between two broadcasting satellites serving Region 1 providing its characteristics are such that it can tolerate an interfering flux-density of about − 161 dB(W/m^2) at the specified test point. This imposes restrictions on the kind of service that can be provided by the fixed-satellite system, and may prevent certain sensitive systems, such as single-channel-per-carrier (SCPC) or 24-channels-per-carrier systems from using these orbital positions at certain frequencies. However, not all orbital locations in the Plan use all possible frequencies, and it may be possible to accommodate such carriers at these frequencies.

Similar considerations will apply to Region 1 and 3 fixed-satellite services sharing with Region 2 broadcasting-satellite service after the 1983 RARC.

Under Resolution No. 503 (BC) of the Final Acts of the WARC-79, the Region 2 broadcasting-satellite plan to be adopted in 1983 will have to take into account the planned Region 1 and 3 broadcasting-satellite services in the overlapping frequency band.

3. Required orbital separation between Region 1 or 3 fixed-satellites and Region 2 broadcasting satellites / CCIR, 1978-82 /

In the band 12.5 - 12.7 GHz, it is possible that broadcasting satellites in Region 2 could cause interference to fixed-satellite earth stations in Regions 1 and 3. However, the possibility of this interference is greatly reduced in most cases due to the separation of service areas and satellites.

The discrimination of the broadcasting-satellite transmitting antenna (Curve A of Fig. 1 in Report 810) is ≥ 30 dB for $\varphi/\varphi_0 \geq 1.6$, that is, a separation of greater than 1.6 beamwidths as seen from the satellite.

A further reduction of interference potential derives from the discrimination of the FSS earth station's receiving antenna, and thus from the angular separation of fixed satellites in Regions 1 and 3 from broadcasting satellites in Region 2. For typical FSS systems such as those described in Report 207-4, and assuming a BSS e.i.r.p. of 60 dBW and a separation of service areas of 1.6 beamwidths, an angular separation between the broadcasting satellite and fixed satellite of 1.7 degrees for this case is sufficient to reduce the interfering pfd from the BSS to a level below the limit requiring coordination set forth in Annex 4 of Appendix 29A of the Final Acts of the WARC-79.

For FSS systems using small earth station antennae, greater angular separations may be required depending on the difference in e.i.r.p. between the two satellites and the required protection to the FSS receivers. The discrimination, and thus the required angular separation, above the 30 dB usually present due to the separation of service areas, may be determined from an examination of Fig. 2, Curve A', Report 810.

Coordination is not required when :

$$D_{B\ SAT} + D_{F\ Rx} > EIRP_{B\ SAT} - EIRP_{F\ SAT} + PR$$

where

$D_{B\ SAT}$: Discrimination of BSS satellite transmit antenna.

$D_{F\ Rx}$: Discrimination of FSS earth station receive antenna.

$EIRP_{B\ SAT}$: e.i.r.p. of BSS satellite.

$EIRP_{F\ SAT}$: e.i.r.p. of FSS satellite.

PR : Protection ratio required by the FSS down-link.

Further study of specific interference situations is required.

4. Conclusions

Sharing between services in the different regions is governed by the sharing criteria adopted by the WARC-BS, 1977 and by WARC-79 (including, in particular, Appendix 29A and Resolutions Nos, 31(CI), 34(CL), 700(CJ),701(CH), 703(CW) and Recommendation No. 708(ZQ)). The system characteristics adopted in the Plan for the broadcasting-satellite service in Regions 1 and 3 impose restrictions on the use of certain orbital positions near and between the space stations of the Plan for certain sensitive fixed-satellite services.

REFERENCES

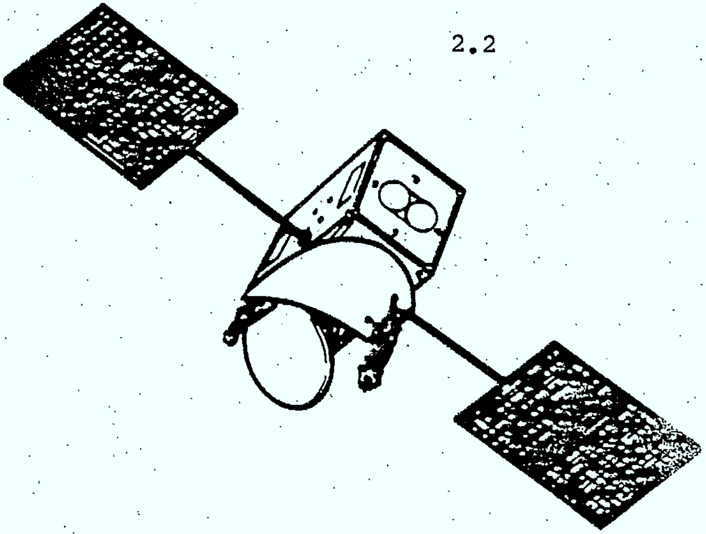
MODIFY as indicated.

REFERENCE

CCIR Document

/¯1978-82_7 : 10-11S/27 (USA).

2.2



TITLE : OVERVIEW ON SHARING INVOLVING THE BROADCASTING-SATELLITE SERVICE OF REGION 2

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Preparatory Seminar for 1983 RARC on
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ORGANIZACION DE LOS ESTADOS AMERICANOS
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OVERVIEW ON SHARING INVOLVING THE BROADCASTING-SATELLITE SERVICE OF REGION 2

1. INTRODUCTION

This paper is not intended to analyze interference criteria, but rather to discuss existing regulatory provisions and procedures on the several sharing interfaces involving the Broadcasting-Satellite Service of Region 2.

Several sharing interfaces can be identified involving the Broadcasting Satellite Service of Region 2, in the 12GHz band. In the Table of Frequency Allocations adopted at the 1979 WARC, the band 11.7-12.3 GHz was allocated to the Fixed-Satellite Service and the band 12.1-12.7 GHz was allocated to the Broadcasting-Satellite Service. However, according to Nº 841 (3787B), the intermediate band 12.1-12.3 GHz shall be divided into two sub-bands by the 1983 RARC, thus avoiding the formal sharing between the two satellite services in Region 2.

Although Nº 816 (3787A) allows for the additional use of transponders on space stations in the Fixed-Satellite Service for transmissions in the Broadcasting-Satellite Service, in the band 11.7-12.1 GHz, in Region 2, it also states that such transmissions shall not cause greater interference or require more protection from interference than the coordinated Fixed-Satellite Service frequency assignments. Therefore, in the analysis of sharing interfaces involving the Broadcasting-Satellite Service of Region 2, it will suffice to study the band 12.1-12.7 GHz, without being necessary to analyze the sharing with the Fixed-Satellite Service within Region 2.

The frequency allocations of the band 12.1-12.7 GHz are presented in Table 1, and the resulting sharing interfaces with the Broadcasting-Satellite Service of Region 2 are shown in Figure 1.

Almost all of these sharing interfaces have already been analyzed and to some extent regulated by the previous 1971 Space Telecommunications WARC and mostly by the 1977 Broadcasting-Satellite WARC, as shown in Table 2. They have also been the subject of 1979 WARC provisions, as summarized in Table 3. Useful material for their technical analysis can also be found in the latest versions of CCIR texts such as those from the XIVth Plenary Assembly, the 1978 Special Preparatory Meeting and the 1980 Interim Meetings of CCIR Joint Working group 10-11S (S for Space), as shown in Table 4.

The different sharing interfaces are here discussed in the light of these existing provisions and texts. They encompass:

a) the intra-regional sharing, between services within Region 2:

- with terrestrial services, and
- between systems in the Broadcasting-Satellite Service;

b) the inter-regional sharing, with services of Regions 1 and 3:

- with terrestrial services,
- with the Broadcasting-Satellite Service,
- with the up-link of the Fixed-Satellite Service (Region 1 only), and
- with the down-link of the Fixed-Satellite Service.

BAND	REGION 1	REGION 2	REGION 3
12.1 -12.2 GHz	FIXED BROADCASTING BROADCASTING SATELLITE	FIXED BROADCASTING MOBILE FIXED-SATELLITE (space-to-Earth) or BROADCASTING-SATELLITE (841/3787B)	FIXED BROADCASTING MOBILE BROADCASTING-SATELLITE
12.2-12.3 GHz	FIXED BROADCASTING BROADCASTING SATELLITE	FIXED BROADCASTING MOBILE FIXED-SATELLITE (Space-to-Earth)or BROADCASTING-SATELLITE (841/3787B)	FIXED BROADCASTING MOBILE FIXED-SATELLITE (Space-to-Earth) (845/3785B)
12.3-12.5 GHz	FIXED BROADCASTING BROADCASTING-SATELLITE	FIXED BROADCASTING MOBILE BROADCASTING-SATELLITE	FIXED BROADCASTING MOBILE FIXED-SATELLITE (Space-to-Earth) (845/3785B)
12.5-12.7 GHz	FIXED (848/3788) (850/3788A) MOBILE (848/3788) (850/3788A)	FIXED BROADCASTING MOBILE BROADCASTING-SATELLITE	FIXED MOBILE FIXED-SATELLITE (Space-to-Earth) BROADCASTING-SATELLITE (847/3785A)

TABLE 1: Allocation of the band 12.1-12.7 GHz, according to the 1979 WARC (not all footnotes are shown).

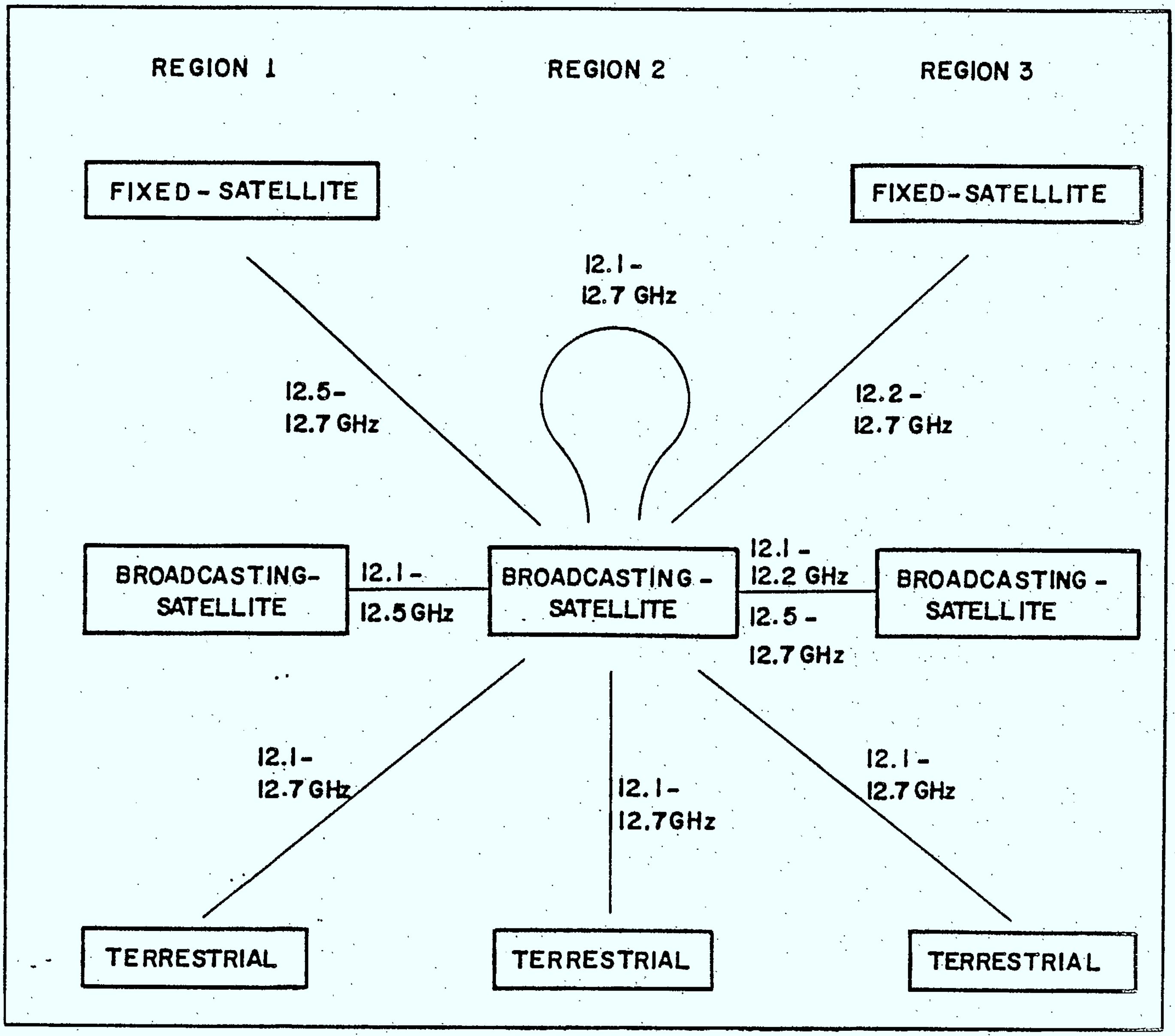


FIGURE 1: Sharing interfaces with the Broadcasting-Satellite Service of Region 2 (the lower limit of 12.1 GHz will be revised at the 1983 RARC).

SHARING INTERFACES OF THE BROADCASTING-SATELLITE SERVICE OF REGION 2			WARC-ST/ 1971	WARC-BS/ 1977												
			Res. 33 (Spa 2-3)	Art.4	Art.6	Art.7	Art.9	Art.10	Ann.1	Ann.3	Ann.4	Ann.5	Ann.9	Ann.11	Res 503 (Sat 5)	Res 100 (Sat-6)
INTRA-REGIONAL SHARING	REGION 2	BSS	X	X					X				X		X	
		TS			X					X			X			
INTER REGIONAL SHARING	REGION 1	BSS	X	X		X		X	X		X		X	X	X	
		FSS	X	S		S		S	S		S		X	S	X	X
		TS			X		X			X		X	X			
	REGION 3	BSS	X	X		X		X	X		X		X	X	X	
		FSS	X			S		S	S		S		X	S	X	X
		TS			X		X			X		X	X			

TABLE 2 : Regulatory provisions relating to sharing of the Region 2 Broadcasting- Satellite Service, according to WARC-ST/1971 and WARC-BS/1977 (BSS: Broadcasting-Satellite Service; FSS: Fixed-Satellite Service; TS: Terrestrial Services, Fixed, Mobile or Broadcasting).
S: deals with a similar sharing situation.

SHARING INTERFACES OF THE BROADCASTING - SATELLITE SERVICE OF REGION 2			WARC/1979							
			844 3787 D	843 3787 E	Res. 503 (BC)	Res. 701 (CH)	Res. 31 (CI)	Res. 700 (CJ)	Res. 34 (CL)	Art. 11 (N11)
INTRA-REGIONAL SHARING	REGION 2	BSS		X	X	X	X			X
		TS	X				X			X
INTER REGIONAL SHARING	REGION 1	BSS			X	X	X			X
		FSS					S	X		X
		TS				X	X			X
	REGION 3	BSS			X	X	X		X	X
		FSS					S	X		X
		TS				X	X			X

TABLE 3 : Regulatory provisions relating to sharing of the Region 2 Broadcasting-Satellite Service, according to WARC/1979
(BSS: Broadcasting-Satellite Service;FSS:Fixed-Satellite Service;
TS: Terrestrial Services, Fixed, Mobile or Broadcasting)
S: deals with a similar sharing situation.

SHARING INTERFACES OF THE BROADCASTING - SATELLITE SERVICE OF REGION 2			C C I R					
			Rep. 631-1 (MOD I)	Rep. 634-1 (MOD I)	Rep. 809 (MOD I)	Rep. 810 (MOD I)	Interim-Meetings of 1980	SPM REPORT
INTRA-REGIONAL SHARING	REGION 2	BSS		X		X		
		TS	X	X		X	10-11S/25 10-11S/102	5.3.3.2
INTER REGIONAL SHARING	REGION 1	BSS		X		X		
		FSS		X	X	X	10-11S/27 4/15	5.3.3.1
		TS	X	X		X	10-11S/25 10-11S/102	5.3.3.2
	REGION 3	BSS		X		X		
		FSS		X	X	X	10-11S/27 4/15	5.3.3.1
		TS	X	X		X	10-11S/25 10-11S/102	5.3.3.2

TABLE 4: CCIR texts relating to sharing of the Region 2 Broadcasting-Satellite Service (BSS: Broadcasting-Satellite Service; FSS:Fixed-Satellite Service;TS:Terrestrial Services, Fixed, Mobile or Broadcasting).

2. SHARING BETWEEN NETWORKS IN THE BROADCASTING-SATELLITE SERVICE.

The mutual interference paths between networks in the Broadcasting-Satellite Service are illustrated in Figure 2, where the space-to-Earth direction only is shown. However, in the case on Region 2, since both the feeder-link and the down-link of networks in the Broadcasting-Satellite Service are to be simultaneously planned, it should be recognized the importance of the "total" link interference criteria, rather than the separate feedr-link and down-link interference criteria. Sharing interfaces in the 17.3-18.1 GHz feeder-link band are further discussed in this paper.

Although the Broadcasting-Satellite Service of Region 2 has not been planned in the 1977 WARC, some of the provisions of its Final Acts should be carefully examined in the regional preparation for the 1983 RARC, specially with regard to sharing. These are briefly commented below:

- Article 4: contains the procedure for modifications to the Plan of Regions 1 and 3, including those which can affect a frequency assignment to a space station in the Broadcasting-Satellite Service of Region 2, which is recorded in the Master Register or
  - which has been coordinated or is being coordinated under the provisions of Resolution Nº 33 (BO or Spa 2-3), or
  - which appears in a Region 2 plan to be adopted at a future regional administrative radio conference.

A similar procedure will certainly also have to be adopted for modifications to the future Plan of Region 2, with regard to assignments both to Region 2 and to Regions 1 and 3.

- Article 10: contains the power flux density limits to protect space services in Region 2 from interference from Broadcasting-Satellite space stations of Regions 1 and 3. A similar procedure

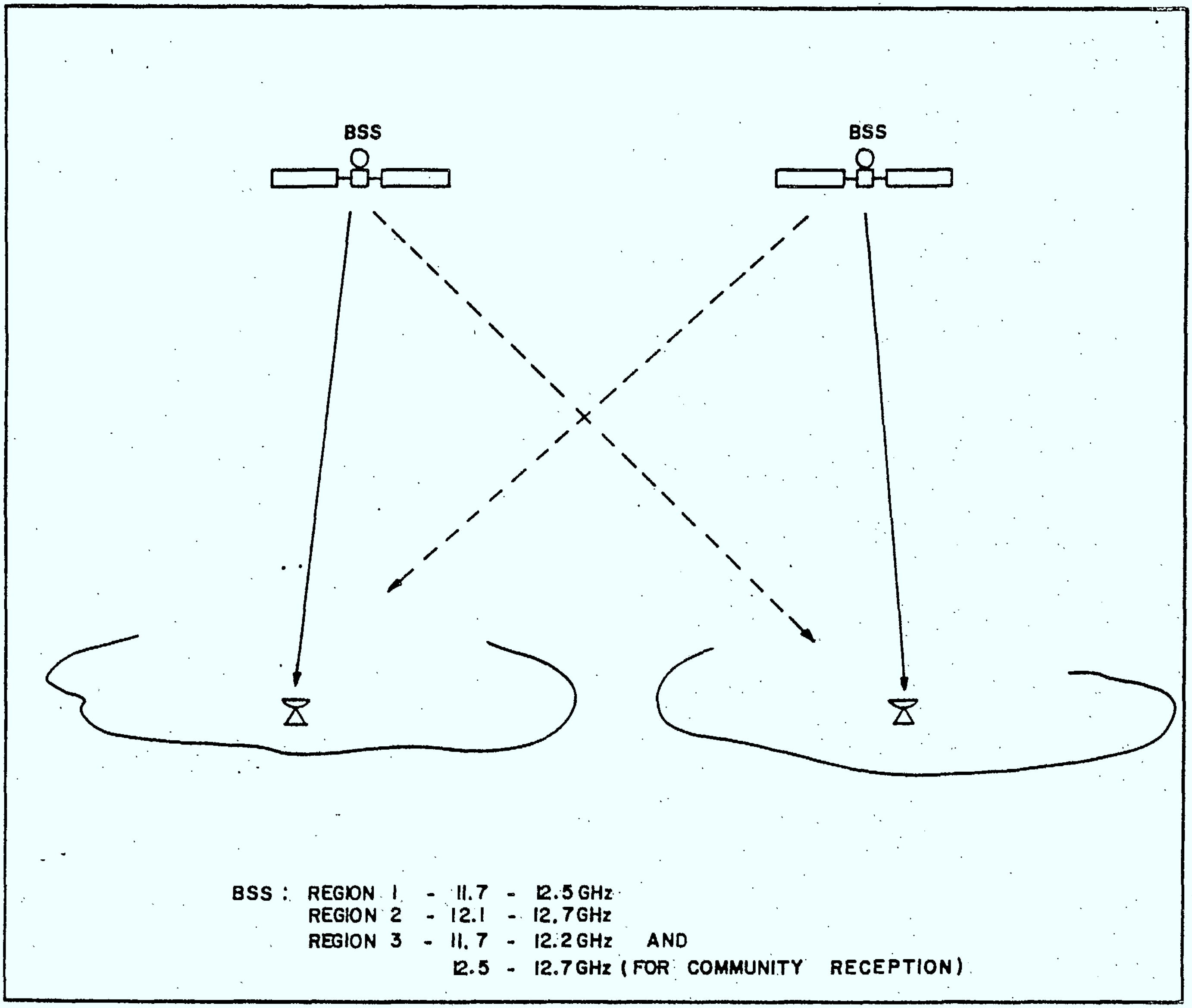


FIGURE 2 : Interference between systems in the Broadcasting-Satellite Service.

will have to be examined for the "inverse situation", that is, for the protection of space services of Regions 1 and 3 from interference produced by emissions from space stations in the Broadcasting-Satellite Service of Region 2.

-Annex 1: presents the limits for determining whether a service of an administration may be considered to be affected by a proposed modification to the Plan of Regions 1 and 3, as in Article 4, including those for the protection of the Broadcasting-Satellite Service of Region 2. Again, it may be assumed that similar limits will have to be discussed at the 1983 RARC, for the protection of the Broadcasting-Satellite Service, the Fixed-Satellite Service and terrestrial services of Regions 1 and 3, from interference to be produced by emissions of space stations in the Broadcasting-Satellite Service of Region 2.

-Annex 4: presents the limits to determine the need for coordination of a space station of Region 2, either in the Broadcasting-Satellite or in the Fixed-Satellite Service, with respect to the Plan of Regions 1 and 3. This procedure is related to the "inverse situation" above mentioned, of Article 10.

-Annex 9: contains several interference criteria for sharing between the different services using the 12 GHz band. Criteria for the interference between networks in the Broadcasting-Satellite Service are also presented. These are represented by a total acceptable carrier-to-interference ratio (C/I) of 30 dB and a single entry C/I of 35 dB. For broadcasting-satellites located at the interfaces of Regions 1 or 3 and Region 2, these values of C/I should be 1 dB higher. Interference criteria like these are some of the most important constraints to be met by the planning algorithms to be built for Region 2. However, it is again worthwhile to note that such criteria have been derived for the down-link interference only, while the total satellite link interference will be the most import criterion for Region 2.

- Annex 11: presents the method of calculating the power flux density produced in the territories of Region 2 by broadcasting-satellites of Regions 1 and 3. This method is to be used in connection with Article 10.

Another important provision adopted at the 1977 WARC is Resolution Nº 503 (BC/SAT-5), which relates to coordination, notification and recording of assignments to stations in the Broadcasting-Satellite Service of Region 2. This Resolution initially states that the relevant provisions of Article 11 (N11) apply for the purpose of coordination of a space station in the Broadcasting- Satellite Service of Region 2 with space systems of other administrations. With regard to the intra-regional sharing, it also states that the relevant provisions of Resolution Nº 33 (Spa 2-3) shall apply to the coordination, notification and recording of stations in the Broadcasting-Satellite Service in Region 2, wherever a station in the Broadcasting-Satellite Service or in the Fixed-Satellite Service of Region 2 is involved. For the inter-regional sharing, it states that the procedures for stations in the Fixed-Satellite Service specified in Article 7 shall also apply to stations in the Broadcasting-Satellite Service of Region 2 with respect to stations in the Broadcasting-Satellite Service with assignments in accordance with the Plan for Regions 1 and 3.

Amongst the provisions adopted at the 1979 WARC, two Resolutions are of importance with regard to sharing within the Broadcasting-Satellite Service:

- Resolution Nº 31 (CI), which states that the provisions of Article 4 and Annex 1, relating to modifications in the Plan of Regions 1 and 3, shall also be applied with respect to the protection of the Broadcasting-Satellite Service of Region 2, in the newly extended-band of 12.2-12.5 GHz. Besides, it also extends the application of the coordination procedures of Resolution Nº 503 (BC/SAT-5), between space stations in the Broadcasting-Satellite Service, to that same new band.

- Resolution Nº 504 (CK), specifying that the provisions of Article 12, relating to arc segmentation in Region 2 are no longer applicable, and that the remaining interim provisions of the 1977 WARC, relating solely to Region 2, shall continue to apply pending the decisions of the 1983 RARC, after which time its Final Acts shall be regarded as superseding such interim provisions for Region 2.

In summary, several provisions of two precedent Conferences, namely the 1977 and the 1979 WARCs, worth to be carefully examined in the preparation for the 1983 RARC. Some of these provisions may simply have to be directly adopted at that future Conference. On the other hand, similar procedures and criteria will have to be built to specifically suit some of the Region 2 needs and planning requirements. For example, a procedure similar to that of Article 4/Annex 1 will have to be examined to apply for modifications in the Region 2 Plan. Moreover, new satellite-link interference criteria will have to be adopted for the joint feeder-link and down-link planning of the Region 2 Broadcasting-Satellite Service.

3. SHARING WITH THE FIXED-SATELLITE SERVICE

At the time of the 1977 RARC, this type of sharing existed in the band 11.7-12.2 GHz, between the Fixed-Satellite Service of Region 2 and the Broadcasting-Satellite Services in Regions 1,2 and 3. With the new allocations made at the 1979 WARC, a new sharing interface was created, similar to that, between the Broadcasting-Satellite Service of Region 2 and the Fixed-Satellite Service of Regions 1 and 3. The mutual interference paths in the down-link, are illustrated in Figure 3 for this new sharing interface.

Since this new situation did not exist at the 1977 WARC, provisions have not been adopted to directly deal with it at that Conference. However, an analysis should be made of the similar situation which exists in the lower band of 11.7-12.2 GHz. Comments on the 1977 WARC provisions dealing with that similar situation are presented below, since an analogy may become valid in the study of the new interface:

- Article 4: contains the procedure for modifications to the Plan of Regions 1 and 3, including those which can affect a frequency assignment to a space station in the Fixed-Satellite Service of Region 2.

- Article 7: contains the preliminary procedures for coordination, notification and recording of assignments to stations in the Fixed-Satellite Service in Region 2, when assignments to broadcasting-satellite stations in accordance with the Plan of Regions 1 and 3 can be affected.

- Article 10: deals with the power flux density limits to protect the space services of Region 2 from interference produced by Broadcasting-Satellite space stations of Regions 1 and 3.

- Annex 1: presents the limits related to the procedure of Article 4, for determining whether the Fixed -Satellite Service of

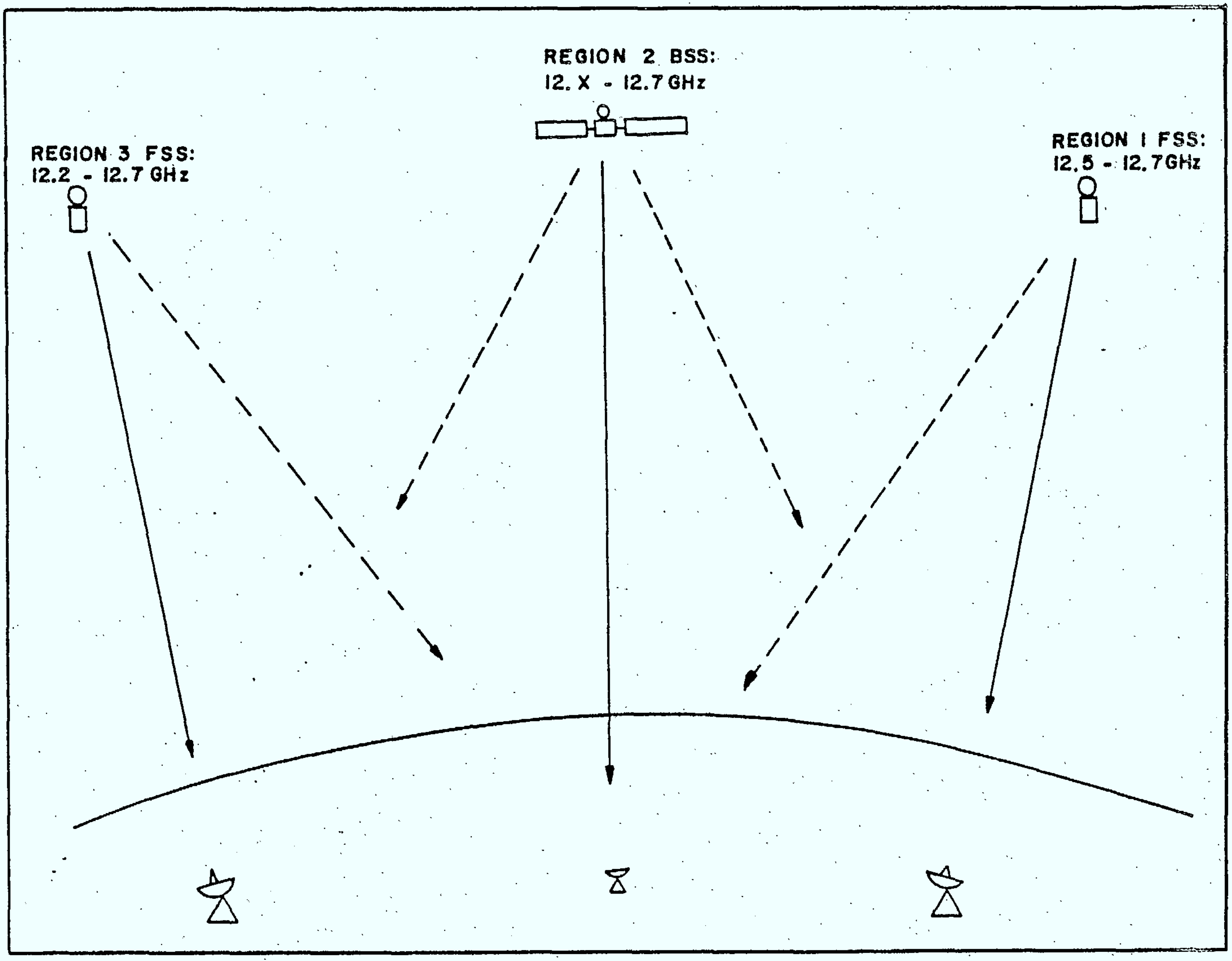


FIGURE 3: Interference paths between Region 2 BSS and Regions 1,3 FSS

Region 2 may be considered as affected by a proposed modification to the Plan of Regions 1 and 3.

- Annex 4: contains the limits of power flux density to be used in connection with Article 7, to determine the need for coordination of a Fixed-Satellite space station of Region 2 with respect to the Plan of Regions 1 and 3.

- Annex 11: contains the method to be used in connection with Article 10, to calculate the power flux density produced in the territories of Region 2, to protect its space services from interference produced by broadcasting-satellites of Regions 1 and 3.

- Annex 9: presents several interference criteria to be used for sharing between services. The proposed criteria for the protection of TV/FM transmissions in the Broadcasting-Satellite Service from interference produced by another TV/FM signal in the Fixed-Satellite Service are the same for interference between two systems in the Broadcasting-Satellite Service. Interference criteria are also proposed for the protection of FDM/FM, TV/FM and 40 -PSK signals in the Fixed-Satellite Service from interference produced by TV/FM signals in the Broadcasting - Satellite Service. Another criterion should be studied for the protection of narrow-band transmissions, like SCPC, in the Fixed-Satellite Service.

We may therefore conclude that the above pairs of articles and annexes (Art. 4/Annex 1, Art.7/Annex 4 and Art.10/ Annex 11) of the 1977 WARC Final Acts deal with the similar sharing between the Fixed-Satellite Service of Region 2 and the Broadcasting-Satellite Service of Regions 1 and 3. An analogy might then be made in the preparation for the 1983 RARC, in order to establish the necessary procedures for the new sharing between the Broadcasting-Satellite Service of Region 2 and the Fixed-Satellite Service of Regions 1 and 3. These procedures would, by analogy, deal with:

- modifications to the Plan to be adopted for Region 2, including those which can affect the Fixed-Satellite Service of Regions 1 and 3;
- coordination, notification and recording of assignments to stations in the Fixed-Satellite Service of Regions 1 and 3, when assignments to stations in accordance with the Plan to be adopted for Region 2 are involved; and
- protection of space services in Regions 1 and 3 from interference produced by Broadcasting-Satellite space stations of Region 2.

Two Resolutions adopted by the 1977 WARC are also related to sharing between the Fixed-Satellite and the Broadcasting-Satellite Services in the 12 GHz band. They are:

- Resolution Nº 503 (BC/Sat-5): which states that for the purpose of coordination between space stations in the Broadcasting-Satellite Service in Region 2 with space systems of other administrations, the relevant provisions of Article 11 (N11) should apply;
- Resolution Nº 100 (Sat-6): which, considering the absence of provisions geverning the coordination, notification and recording of assignments to stations in the Fixed-Satellite Service with respect to stations in the Broadcasting-Satellite Service in Region 2, decided that the provisions of Article 11 (N11)should be applied until this matter be considered by a competent conference.

Amongst the provisions adopted at the 1979 WARC, two Resolutions deal with this new sharing interface, created by the modifications made to the allocation of the 12 GHz band. These are:

- Resolution Nº 31 (CI): according to which the provisions of Article 4/Annex 1, relating to modifications to the Plan for the Broadcasting-Satellite Service of Regions 1 and 3, shall also be applied with respect to the protection of the Fixed-Satellite Service of Region 2 in the band 12.2-12.3 GHz. This Resolution also decided that the provisions of Article 7/Annex 4, relating to preliminary procedures of coordination, notification and recording of assignments to stations in the Fixed- Satellite Service, should apply to the band 12.2-12.3 GHz. It may here be observed that this extended applications may not be necessary after the 1983 RARC, if the allocation to the Fixed-Satellite Service of Region 2 is decided to be limited at 12.2 GHz.

- Resolution Nº 700 (CJ): was adopted to deal exclusively with the new sharing interface, stating that:

  a) until the coming into force of the 1983 RARC provisions, Resolution Nº 33 (Spa 2-3) and Article 11 (N11) shall continue to apply with respect to the coordination between space station in the Broadcasting-Satellite Service of Region 2 and space stations in the Fixed-Satellite Service of Regions 1 and 3;

  b) in the elaboration of a Plan for Region 2, if constraints on the Fixed-Satellite Service of Regions 1 and 3 are considered necessary, they should not in any case be greater than those imposed on the Fixed-Satellite Service of Region 2 by the 1977 WARC.

Another sharing interface involving the two satellite services exists in the band 12.5-12.7 GHz, between the Broadcasting-Satellite Service of Region 2 and the up-link of the Fixed-Satellite Service of Region 1. The interference paths for this sharing interface are shown in Figure 4. This type of sharing did not exist at the 12 GHz band, by the time of the 1977 WARC.

From the reverse use of frequency bands in the up-link of the Fixed-Satellite Service and the down-link of the Broadcasting-Satellite Service, two types of interference may occur:

a) interference from the Region 2 broadcasting-satellite transmitter into the Region 1 fixed-satellite receiver and

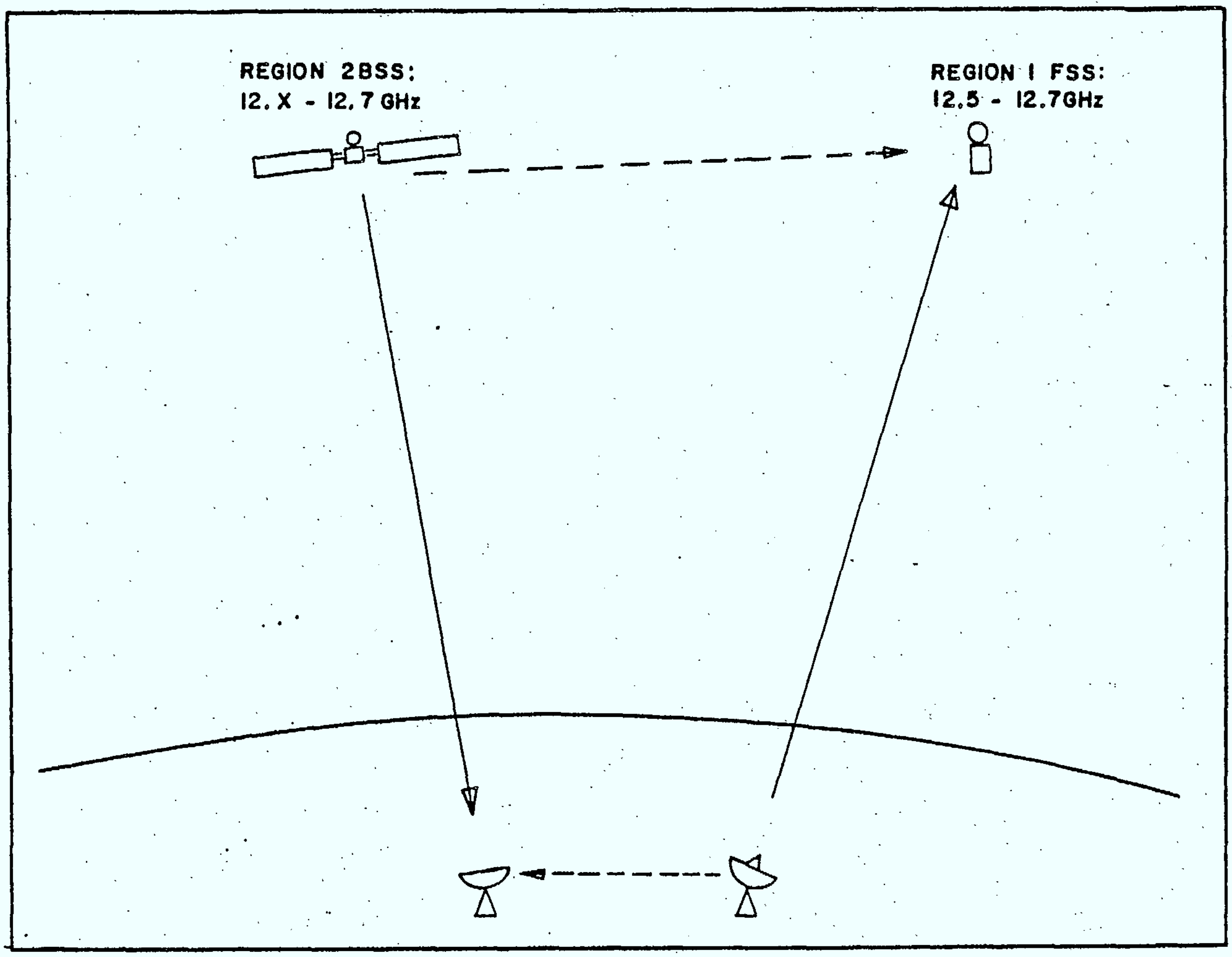


FIGURE 4: Interference paths between Region 2 BSS and the FSS up-link of Region 1

b) interference from the transmitting earth-station in the Region 1 Fixed- Satellite Service into the receiving earth-stations in the Broadcasting-Satellite Service of Region 2.

Due to geographical considerations, this latter interference path may only occur at high north-latitudes and does not affect most of Region 2 administrations. Its analysis mechanism would be similar to that of interference from a terrestrial station into an earth station. It is analyzed in CCIR Report 557 (Volume IV, XIVth Plenary Assembly, Kyoto, 1978) and in the Special Preparatory Meeting Repot, Geneva, 1978. Appendix 29 (N29) of the Radio Regulations also deal with the determination of the need of coordination between two space systems opetating with the reverse use of frequency bands.

The analysis of the first type of interference above mentioned will be of great importance for the cases of broadcasting-satellites of Region 2 and fixed-satellites of Region 1 operating at close orbital locations, as it may happen above the Atlantic Ocean.

4. SHARING WITH TERRESTRIAL SERVICES

The interference paths between the Broadcasting-Satellite Service and the terrestrial Fixed (and Mobile) and Broadcasting-Services are shown in Figure 5. The interference from terrestrial systems into the satellite receiver at the geostationary satellite orbit is not shown in Figure 5, being dealt with in CCIR Report 209-3 (Volume IX, XIVth Plenary Assembly, Kyoto, 1978). This interference is limited by the provisions of Article 27 (N25), applying to the 12 GHz band concerned.

Existing procedures and texts dealing with this typpe of sharing are commented below.

- Article 6: contains the procedures for coordination, notification and recording of assignments to terrestrial stations which may affect a frequency assignment to a broadcasting-satellite station which is in conformity with the Plan of Regions 1 and 3. Although a Plan still does not exist for Region 2 , a similar procedure may have to be adopted at the 1983 RARC for Region 2.

- Article 9: on the power flux density limits to protect terrestrial services in Regions 1 and 3 from interference produced by Region 2 broadcasting-satellite space stations. It is therefore a specific procedure for an inter-regional sharing interface.

- Annex 3: presents the method to be used for determining the power flux density produced by a terrestrial station at the edge of the service area of a broadcasting-satellite system. It is to be used in connection with Article 6.

- Annex 5: contains the power flux density limits to protect terrestrial services in Regions 1 and 3 from interference produced by Region 2 broadcasting-satellite space stations, according to the procedures of Article 9.

- Annex 9: contains criteria for sharing between systems in the Broadcasting-Satellite and terrestrial Services. These criteria are:

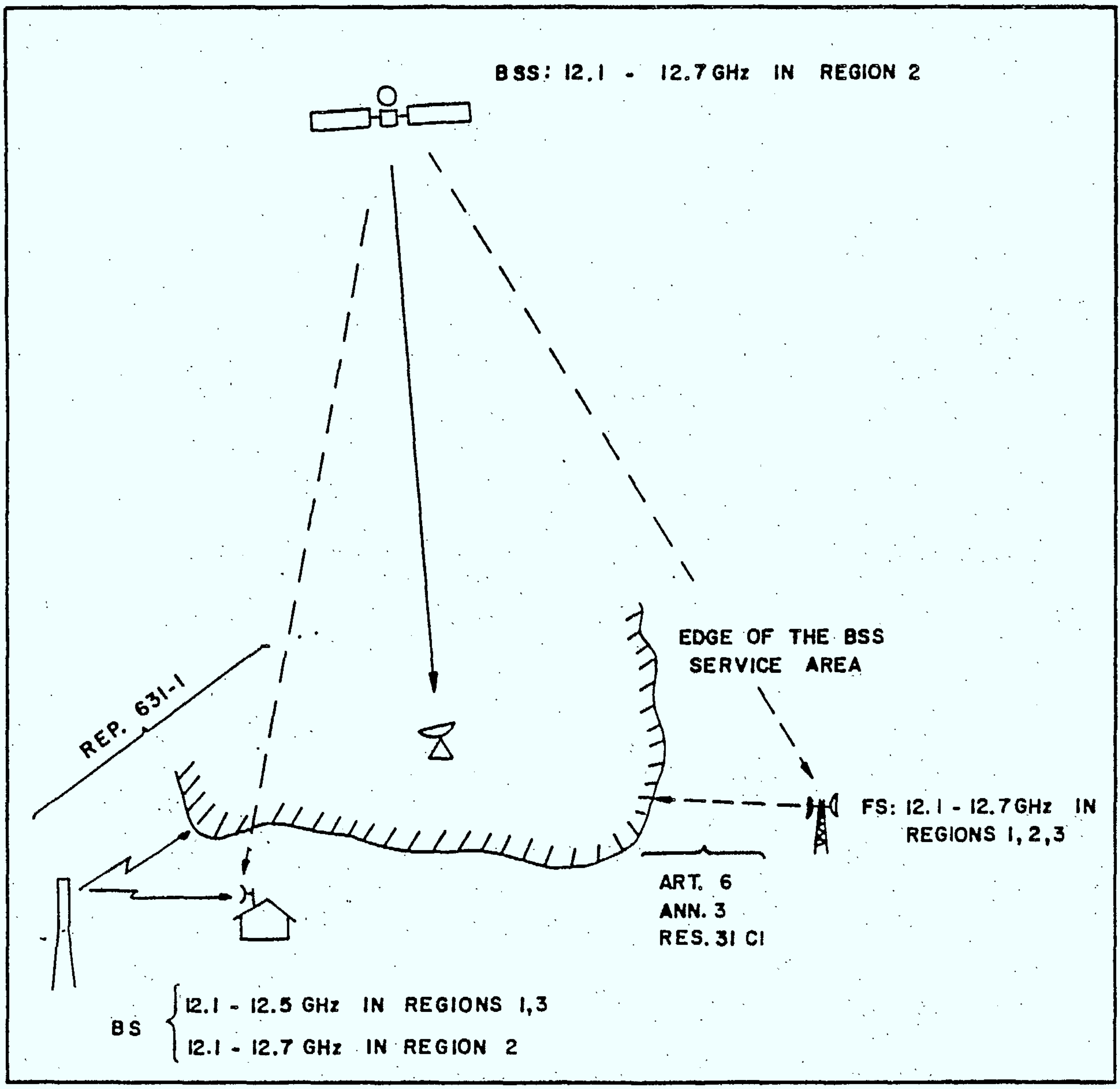


FIGURE 5: Interference between the Broadcasting-Satellite Service of Region 2 and Terrestrial Services at 12 GHz.

a) for the protection of TV/FM signals in the Broadcasting-Satellite Service: a total acceptable C/I of 30 dB and a single entry C/I of 35 dB (for inter-regional sharing these values are 1 dB higher);

b) for the protection of FDM/FM signals in the terrestrial Fixed Service: a total acceptable noise power of 1000 pWOp and a single entry power flux density of- 125 dBW/m2/4kHz;

c) for the protection of TV/VSB signals in the terrestrial Broadcasting Service: a total acceptable C/I ratio of 50 dB.

At the 1979 WARC, Resolution Nº 31 (CI) extended the application of Article 6 and Annex 3 to assignments of terrestrial stations affecting broadcasting-satellite frequency assignments in Region 2, in the band 12.2-12.7 GHz. That Resolution has also extended the provisions of Article 9 and Annex 5, to protect terrestrial services of Regions 1 and 3 from Region 2 broadcasting satellites, to the band 12.2-12.5 GHz. These same provisions have been provisionally extended to the band 12.5-12.7 GHz, until the final decisions are made by the 1983 RARC for this band.

This type of sharing is also analyzed in CCIR Report 631-1 (Vol.XI, XIVth Plenary Assembly, Kyoto, 1978) and in the Special Preparatory Meeting Report, Geneva, 1978.

As far as the intra-regional sharing between the Broadcasting-Satellite Service and terrestrial services in Region 2 is concerned, Nº 844 (3787D) of the 1979 WARC Final Acts specify that in Region 2, in the band 12.1-12.7 GHz, existing and future terrestrial services shall not cause harmful interference to the Broadcasting-Satellite Service operating in accordance with the Plan to be prepared at the 1983 RARC, and shall not impose restrictions on the elaboration of such a Plan. Therefore, in the preparation for this Conference, it will be sufficient to revise the conditions under which an assignment to the Broadcasting-Satellite Service might be affected by a terrestrial system in Region 2. The present procedure for this verification is set forth in Article 6 and Annex 3.

With regard to the inter-regional sharing, two types of interference have to be considered:

a) the interference from terrestrial stations in Regions 1 and 3 into receiving earth stations in the Broadcasting-Satellite Service of Region 2: this sharing interface is regulated by Article 6 and Annex 3, and will exist only at high north-latitudes, thus not affecting most of Region 2 administrations;

b) the interference from broadcasting-satellites of Region 2 into terrestrial services of Regions 1 and 3, regulated by Article 9 and Annex 5. The limits specified by this Annex should be observed as a sharing constraint to the planning algorithms of Region 2.

5. SHARING INVOLVING FEEDER-LINKS TO THE BROADCASTING-SATELLITE SERVICE OF REGION 2, IN THE 17.3-18.1 GHz BAND.

According to Resolution Nº 701 (CH), the 1983 RARC shall also plan feeder-links to the Broadcasting-Satellite Service of Region 2, in a part of the band 17.3-18.1 GHz, of a bandwidth equal to the total bandwidth allocated to the down-link in the 12 GHz band. The allocation of that band is shown in Table 5, and according to Nº 869 (3794H), the use of the band 17.3-18.1 GHz by the Fixed-Satellite Service in the Earth-to-space direction is limited to feeder-links to the Broadcasting-Satellite Service.

The sharing interfaces resulting from this frequency allocation are illustrated in Figure 6. These are:

- with the terrestrial Fixed and Mobile Services,
- between feeder-links to the Broadcasting-Satellite Service, and
- with the down-link of the Fixed-Satellite Service.

5.1. Sharing with terrestrial services

This is the usual sharing between the up-link of a Fixed-Satellite Service and terrestrial systems, where a transmitting earth station may produce interference into a terrestrial station. The coordination procedures and interference criteria are well established in Article 11 (N11) and Appendix 28 (N28) of the ITU Radio Regulations and CCIR Reports and Recommendations, the inter-regional sharing interfaces may occur only at high north-latitudes.

5.2. Sharing between feeder-links

This type of sharing interface at this band is briefly analyzed in Report 561-1, as amended at the 1980 CCIR Interim

BAND	REGION 1	REGION 2	REGION 3
17.3-17.7 GHz	FIXED 868(3794G)* MOBILE 868(3794G)* FIXED-SATELLITE (Earth-to-space)	FIXED-SATELLITE (Earth-to-space)	FIXED 868(3794G)* MOBILE 868(3794G)* FIXED-SATELLITE (Earth-to-space)
17.7-18.1 GHz	FIXED MOBILE FIXED-SATELLITE (Earth-to-space) 869(3794H) (Space-to-Earth)	FIXED MOBILE FIXED-SATELLITE (Earth-to-space) 869(3794H) (Space-to-Earth)	FIXED MOBILE FIXED-SATELLITE (Earth-to-space) 869(3794H) (Space-to-Earth)

TABLE 5: Allocation of the band 17.3-18.1 GHz, according to the 1979 WARC (not all footnotes are shown)

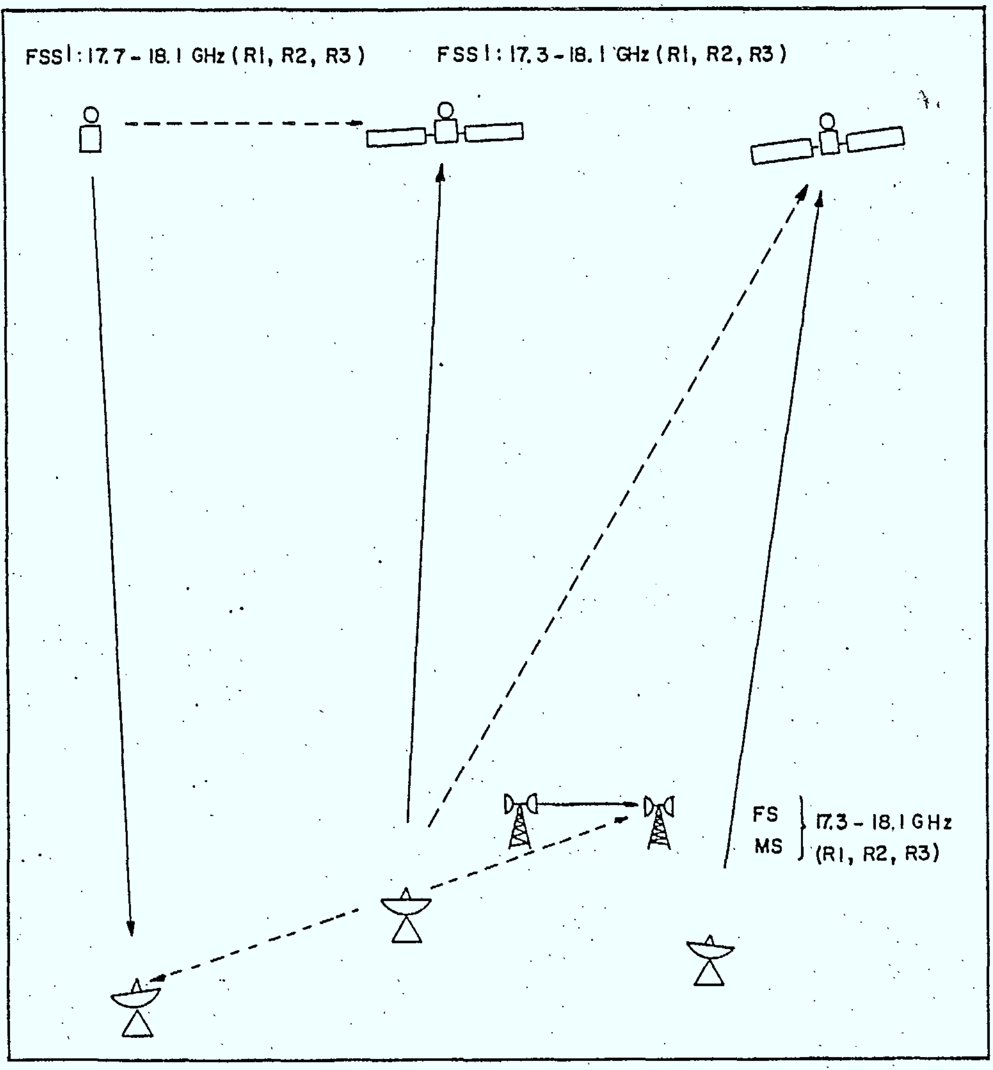


FIGURE 6: Sharing interfaces at the 17.3-18.1 GHz feeder-link band

Meetings. Additional studies must be done in this area, since this sharing interface will directly determine the required angular separation between broadcasting-satellites in a Plan,due to the feeder-link interference. It is however important to bear in mind that, in the case of Region 2, the orbital separation between satellites will be finally determined by the total satellite link interference rather than by the feeder-link and the down-link separate interference levels.

5.3. Sharing with the down-link of the Fixed-Satellite Service

The interference paths for this type of sharing are those corresponding to the reverse use of frequency bands, as shown in Figure 6. Two interference paths may exist:

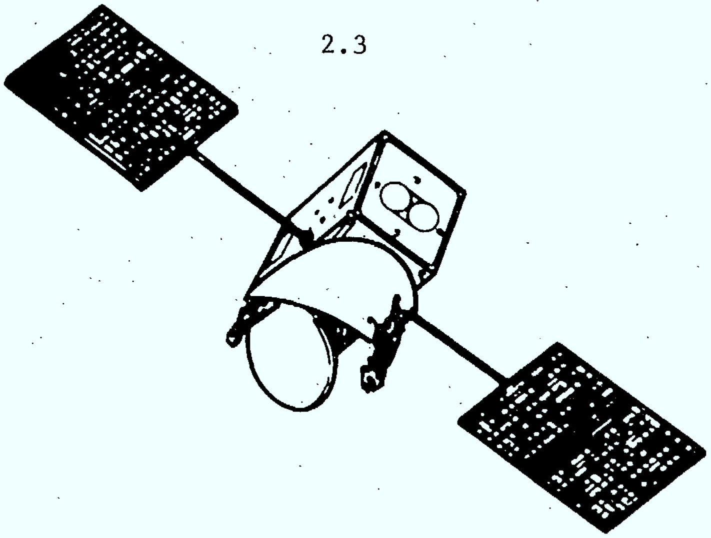
- from the fixed-satellite transmitter into the broadcasting-satellite receiver, and
- from the transmitting earth station in the Broadcasting-Satellite Service into the receiving earth station in the Fixed Satellite Service.

The interference between satellites may involve systems within Region 2 and also those from Regions 1 and 3. However, the interference between earth stations, as far as the inter-regional sharing is concerned, may occur only at hight north-latitudes, and will not affect most of Region 2 administrations.

Another important matter to be studied is that of sharing between feeder-links to the Broadcasting-Satellite Service and up-links to the Fixed-Satellite Service, in Region 2, in the band 14.0-14.5 GHz. Although this frequency band is not to be planned at the 1983 RARC, it can be used for feeder-links to broadcasting-satellites, under a coordinated basis. However, due to the high inhomogeneity which may occur between systems in these two satellite services, this coordination may result difficult, this hight orbital separation arcs being required in certain cases.

If however the propagation conditions in the higher band of 17.3-18.1 GHz so allow, it would be advantageous to use these frequencies for the feeder-links of broadcasting-satellites and the 14 GHz frequencies to fixed-satellites, thus an spectrum segmentation prevailing both at the up and down-links.

2.3



TITLE : APPLICATION OF THE INTER-REGIONAL SHARING CRITERIA TO A PARTICULAR BROADCASTING-SATELLITE SYSTEM

AUTHOR : E.E. REINHART

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Broadcast Satellite Planning Principles and Methodology
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Department of Communications

Gouvernement du Canada
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Application of the Inter-Regional Sharing Criteria to a Particular Broadcasting-Satellite System

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Abstract

The inter-Regional sharing criteria adopted by WARC-77, and extended at WARC-79 to cover allocation changes in the 12 GHz band, are identified for each of the inter-service interfaces involving the Region 2 broadcasting satellite allocation, 12.1-12.7 GHz. These conditions are then applied, for each interface in turn, to the broadcasting-satellite system proposed by the Satellite Television Corporation (STC) for individual reception in the United States. Calculations are presented in each case to determine whether or not the corresponding sharing criterion is met for the STC system and the Region 1 or 3 system for which the interference level is highest. The results of the calculations show that all sharing criteria are well satisfied so that no intersystem coordination or adjustments of system parameters are necessary. It is concluded that this fact owes more to the geographic isolation of most Region 2 systems from the systems of Regions 1 and 3 than it does to the particular characteristics of the STC system.

INTRODUCTION

The sharing criteria and coordination procedures established by WARC-77 and WARC-79 to control inter-Regional interference in the band 11.7-12.75 GHz have been described in detail and applied to some general cases in papers by C. Azevedo (1) and R. Amero (2). In the present paper, the inter-Regional sharing criteria will be illustrated by applying them to a particular broadcasting-satellite system. The system chosen is the one proposed by the Satellite Television Corporation (STC) to provide individual reception in the United States and Canada. The detailed characteristics of this system are given in the paper by E. Martin (3).

For application of the inter-Regional sharing criteria however, it is sufficient to know only the following characteristics of the STC System.

- Satellite locations and service areas

115° W	Eastern area of US
135° W	Central area of US
155° W	Mountain area of US
175° W	Pacific area of US, Hawaiian Is, Alaska

- Satellite antennas and e.i.r.p.
  - Beams shaped to fit large service areas
  - 0.6° circular spot beams for Hawaii and Alaska
  - Sidelobe levels meet WARC-77 reference patters
  - Boresight e.i.r.p.: approx. 58 dBW

- Home receiving antennas and G/T
  - 0.6 - 0.9m diameter parabolas
  - Sidelobe levels meet WARC-77 reference patterns
  - G/T: approx. 9 dB/K

- Signal r.f. characteristics
  - FM/TV
  - Necessary bandwidth: approx. 16 MHz
  - Circular polarized

The applicable sharing criteria can be categorized by service, Region, and band as shown in the following table:

			Applicable Article/Annex of WARC-79 Appendix 30	
Service[o]	Region	Band(s) (GHz)	Interference from Region 2 BSS	Interference to Region 2 BSS
BSS	1	11.7-12.5	7/4	4/1 (para 2)
	3	11.7-12.2, 12.2-12.75		
FSS up	1	12.5-12.75	**	**
FSS down	1	12.5-12.75	12/9	**
	3	12.2-12.75		
FS	1,3	11.7-12.75	9/5*	6/3*
M(xAM)S	3	11.7-12.75		
BS	1,3	11.7-12.75		

* Extended to 12.7 GHz by WARC-79 Resolution 31 (CJ)

** See WARC-79 Resolution 700

[o] Abbreviations: BSS-Broadcasting-satellite Service; FSS-Fixed-satellite Service; FS-Fixed Service; M(xAM)S-Mobile (except Aeronautical Mobile) Service; BS-Broadcasting Service

It should be noted that the Table includes only services in Regions 1 and 3 that have interfaces with the broadcasting-satellite service (BSS) of Region 2. The criteria cited in the Table will now be considered for each of these services in turn. In each case, interference both from and to the STC system will be calculated.

INTERFERENCE INVOLVING THE BSS IN REGIONS 1 AND 3

Interference from the STC System into BSS in Region 1 and 3 Plan

Region 1 and 3 BSS systems conforming to the WARC-77 Plan are protected against interference from Region 2 broadcasting-satellite systems by a requirement to coordinate the Region 2 space station if the power flux density ("pfd"), in dBW/m^2/27 MHz, over the territory of an administration in Region 1 or 3 exceeds the value given in Annex 4 of Appendix 30 (29A)* of the WARC-79 Final Acts, namely:

-147	for $0 \leqq \theta < 0.44^{\circ}$
-138 + 25 log	for $0.44 \leqq \theta < 19.1^{\circ}$
-106	for $\theta \geqq 19.1^{\circ}$

where θ is the difference in degrees between the longitude of the interfering Region 2 broadcasting-satellite and the longitude of the affected broadcasting-satellite in Region 1 or 3.

Given STC's planned orbital locations, EIRPs and coverages, the resultant pfd on the territories of Regions 1 and 3 administrations will be far below these values.

This is clear since the smallest value of the relative longitude θ between an STC satellite and a broadcasting-satellite in the Region 1 or 3 Plan having a frequency allotment in the range 12.1-12.7 GHz, is 27°. This is based on an STC satellite at 175°W longitude and the Tokelau Island allotment of channels 20 and 24 and the Niue Island allotments of channels 19 and 23 at 158°E longitude in the WARC-77 Plan. Since the sidelobe performance of the STC satellite transmitting antenna will be at least as good as that used in preparing the Region 1 and 3 Plan (see Figure 6 of Annex 8 to WARC-79 Appendix 30 (29A)), the EIRP of the STC signal will be less than 28 dBW in the direction of these islands. Hence, the pfd of the STC signal will be less than -135 dBW/m^2/16 MHz which, with $\theta > 19.1^{\circ}$, is 29 dB below the threshold for coordination with the BSS in Regions 1 and 3.

Interference to the STC System from BSS in Region 1 and 3 Plan

There is no Plan requirement that Region 1 and 3 broadcasting satellites protect Region 2 broadcasting-satellite systems, but, in any event, none of the allotments in that Plan can cause interference to STC's home receivers. The Region 1 and 3 coverage areas nearest to those proposed by STC are in Siberia and are served from orbit locations at least 45° further west than STC's westernmost orbit position (175°W longitude). The combination of the discrimination of the Soviet satellite transmitting antenna in the direction of the nearest proposed STC service area in Alaska (30 dB) and the discrimination of the STC ground receiving antennae in the direction of the Soviet satellite (38 dB) is sufficient,

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* Appendix 30 (29A) of the WARC-79 Final Acts embraces the Articles and Annexes of WARC-77.

despite the higher EIRP allowed for the Soviet satellite, to keep the carrier-to-interference ratio well below the single-entry requirement of 35 dB.

Although Region 2 broadcasting satellites are not explicitly protected from Region 1 and 3 broadcasting satellites conforming with the WARC-77 Plan, they are protected against modifications to the Plan. Any such modifications will have to be coordinated with broadcasting satellites in the RARC-83 Plan for Region 2 and with Region 2 systems have have started the IRFB coordination and registration process before RARC-83. In particular, if STC were to begin the coordination process prior to the adoption of a Region 2 Plan, modifications to the Region 1 and 3 Plan would have to be compatible with the STC system in accordance with the procedures of Article 4 in Appendix 30 (29A) of the WARC-79 Final Acts. These procedures would be triggered if the proposed modification resulted in a pfd in the STC service areas exceeding the values in $dBW/m^2/27$ MHz given by Section 2 of Annex 1 of Appendix 30 (29A):

$$\begin{array}{ll} -147 & \varphi \leq 0.48^{\circ} \\ -139 + 25 \log \varphi & 0.48^{\circ} < \varphi \leq 27.25^{\circ} \\ -103 & \varphi > 27.25^{\circ} \end{array}$$

where φ is the difference in degrees between the longitudes of the broadcasting-satellite space station in Region 1 or 3, and the broacasting-satellite space station affected in Region 2.

When the angular discrimination of the STC receiving antenna is taken into account with the above, it is clear the interfering signal at STC's receiver input will always be from 35 to 41 dB less than the wanted signal produced by the - 106 dBW/m /16 MHz edge-of-coverage pfd of the STC satellite. Thus, the 35 dB co-channel single entry protection ratio recommended in Annex 9 of WARC-79 Appendix 30 (29A) will always be achieved.

Interference between the STC System and Region 3 Broadcasting Satellites in the 12.5-12.75 GHz band

WARC-79 allocated the band 12.5-12.75 GHz to the BSS in Region 3 for community reception systems. Until this service is planned, resolve 1 of WARC-79 Resolution 34 (CL) requires that interference compatibility with space stations in the BSS of Region 2 must be established by coordination under the procedures given in Article 11(N11) and Resolution 33 (BO) of WARC-79. However, since the separation of service areas and satellite positions between the STC systems and potential Region 3 community reception systems (e.g. that being planned by Australia) is even greater than that between STC and the worst case of the 8 dB* higher-powered Region 1 and 3 systems in the WARC-77 Plan, the possibility of unacceptable mutual interference is negligible.

INTERFERENCE INVOLVING THE FSS IN REGIONS 1 AND 3

With the WARC-79 change in the Region 2 BSS allocation, new inter-regional interfaces were created with three FSS allocations: the existing bidirectional allocation at 12.5-12.7 GHz in Region 1, the existing downlink allocation of this same band in Region 3, and a new Region 3 downlink band at 12.2-12.5 GHz established by Footnote 3785B. These interfaces are not simple extensions in frequency of those dealt with at WARC-77. WARC-79 Resolution 700 (CJ) specifies that they should be coordinated using the provisions of Resolution 33(BO) and Article 11(N11). However, the large geographic separations between service areas, and the large orbital separations between satellites in STC's proposed system and any anticipated Region 1 or 3 FSS system (e.g., the Australian Domsat and the French Telecom 1), ensure compatibility without the need for coordination.

INTERFERENCE INVOLVING THE TERRESTRIAL SERVICES OF REGIONS 1 AND 3

As noted in the table in the Introduction section to this paper, there are terrestrial allocations in each Region that collectively embrace the entire band allocated to the BSS in Region 2. The inter-regional sharing criteria specified in Appendix 30 (29A) and elsewhere in the Final Acts of WARC-79 do not distinguish among the different terrestrial services, so they are treated collectively.

Interference from the STC System into Regions 1 and 3 Terrestrial Services

The conditions for protection of Regions 1 and 3 terrestrial services against interference from Region 2 broadcasting satellites prior to RARC-83, are given in Article 9 and Annex 5 of Appendix 30 (29A) of WARC-79. These conditions were extended to the new Region 2 BSS frequency band by resolves 4 and 5a of Resolution 31(CI). To protect terrestrial FDM/FM transmissions, it is required that, for all territories of administrations in Regions 1 and 3, the pfd in $dBW/m^2/4$ kHz from Region 2 broadcasting-satellite space stations should not exceed -125 when using circular polarization and -128 when using linear polarization.

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* WARC-79 footnote 3785A limits the Region 3 BSS in the 12.5-12.75 GHz band to community reception with a pfd not to exceed - 111 dBW/m.

To protect future AM/VSB terrestrial television transmissions, it is required that, for all territories of administrations in Region 3 and those in the part of Region 1 west of longitude 30°E, the pfd in dBM/m^2/5 MHz for Region 2 broadcasting satellites should not exceed:

-132 for $0^\circ < \gamma < 10^\circ$

$-132 + 4.2\ (\gamma - 10)$ for $10^\circ < \gamma < 15^\circ$

-111 for $15^\circ < \gamma < 90^\circ$

where γ is the angle of arrival above the horizontal plane.

The worst case of interference from STC's proposed system into a territory of Region 1 occurs with spillover into eastern Siberia from the Alaskan 0.6° spot beam coverage. Figure 1 shows this coverage and its relation to the easternmost part of Siberia as seen from STC's westernmost satellite at 175°W longitude. The boresight EIRP of STC's satellite is 58 dBW and, allowing for a possible 0.1° pointing error, the nearest point in Siberia is 1.4° off boresight. At this off-axis angle, the gain of STC's satellite transmitting antenna is -30 dB relative to boresight. Taking into account the 162.4 dB spreading loss, the pfd into Region 1 will be less than -134.4 dBW/m^2, which is 9 dB or more below the -125 dBW/m^2/4 kHz limit specified for circular-polarized BSS signals into Regions 1 and 3 territories.

No calculations are necessary to show that STC meets the conditions for protecting terrestrial television in that part of Region 1 west of 30°E longitude. The western part of Region 1 (Europe, Iceland and Africa) is entirely below the horizon from all of the proposed STC orbit locations, including 115°W longitude. As for Region 3, the nearest point to an STC coverage area is Palmyra, about 1000 miles south of Hawaii, or about 2.5° from the boresight of the Hawaiian spot beam. At Palmyra, interference from the STC satellite would arrive at elevation angle $\gamma = 72^\circ$. With an EIRP towards Palmyra that is 32 dB below the 58 dBW boresight EIRP, the pfd is less than -136 dBW/m^2/16 MHz, or more than 25 dB below the pfd limit.

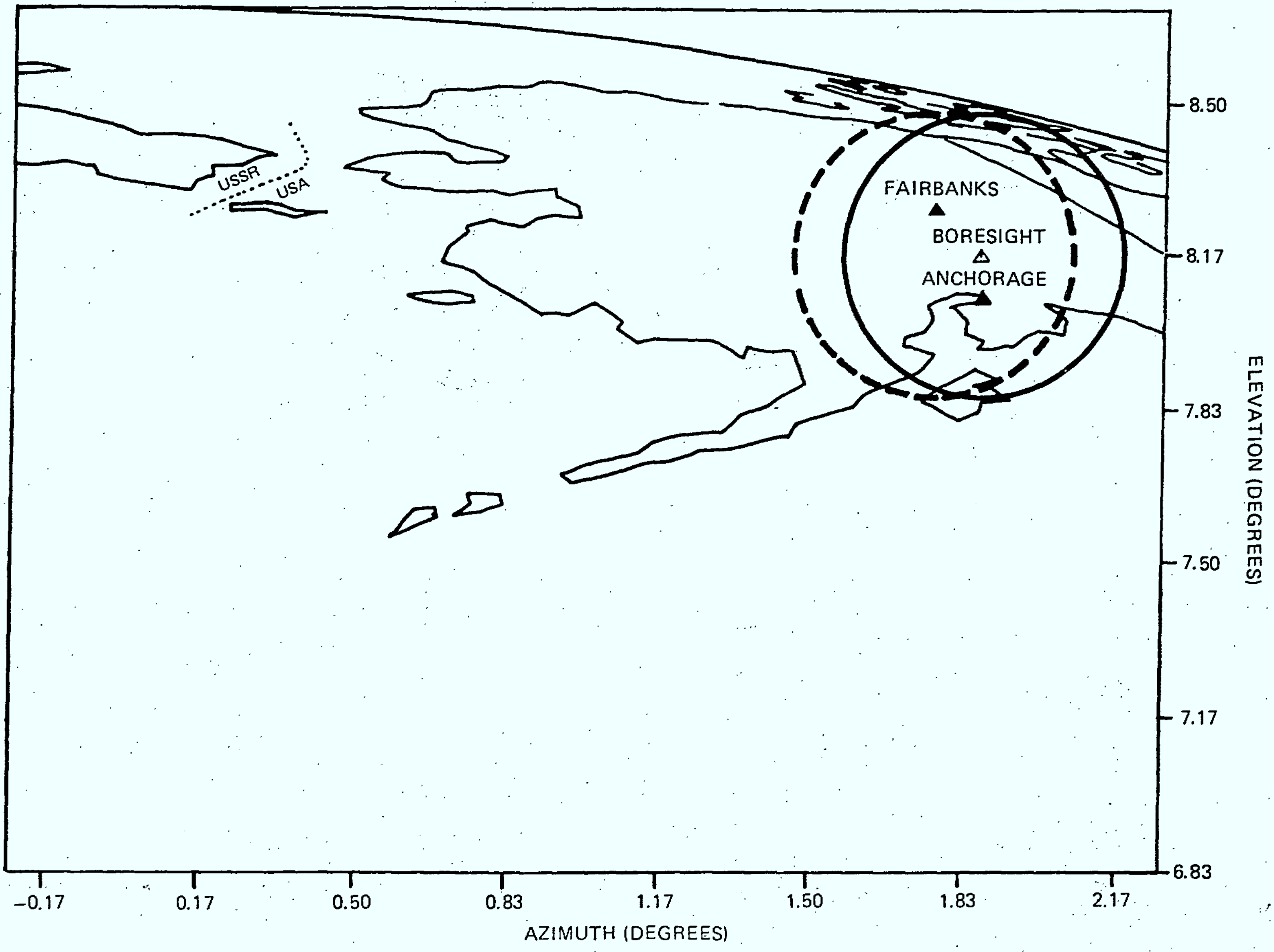

FIGURE 1 ALASKAN SPOT BEAM COVERAGE FROM 175°W LONGITUDE (DASHED LINES INDICATE COVERAGE UNDER WORST CASE POINTING ERROR OF 1°)

Interference to the STC System from Regions 1 and 3 Terrestrial Services

Protection of Region 2 BSS receivers from interference by Regions 1 and 3 terrestrial services is not expected to be a problem because Region 2 BSS service areas are well below the horizon of existing and planned Region 1 and 3 terrestrial transmitters. If an exception should arise (across the Bering Strait, for example), Region 2 BSS service areas are, in any case, protected by the procedures of Article 6 of Appendix 30 (29A) and Article 12 (N12) of the Final Acts of WARC-79. Such coordination is triggered if the pfd of the interference at the edge of the BSS service area produced by the terrestrial station exceeds the value calculated using the method given in Annex 3 of Appendix 30 (29A) of the WARC-79 Final Acts. The applicability of these procedures was extended to cover the new Region 2 BSS band by resolve 2 of WARC-79 Resolution 31(CI).

INTER-REGIONAL SHARING IN THE 17.3-18.1 GHz BSS FEEDER-LINK BAND

After WARC-79, the only other services with a primary allocation in the 17.3-18.1 GHz band are the FSS (space-to-Earth) and the terrestrial fixed and mobile services in the band 17.7-18.1 GHz. The band from 17.3-17.7 GHz contains only a secondary allocation to the radiolocation service.

According to resolve 1.3 of WARC-79 Resolution 701 (CH), RARC-83 will "plan feeder links in a part of the band 17.3-18.1 GHz of a bandwidth equal to the total bandwidth allocated to the BSS for the downlink in the 12 GHz band. However, administrations may use broadcasting-satellite feeder links in frequency bands other than those planned provided that such use does not necessitate any changes in the Plan". It is anticipated that BSS systems in Region 2 will, in fact, use only the 18 GHz band for feeder links. Under this assumption, the inter-Regional interfaces with Region 2 feeder links are as follows:

Service	Regions	Band(s) (GHz)
FSS up	1, 3	17.3 - 18.1
FSS down	1, 3	17.7 - 18.1
FS	1, 3	17.7 - 18.1
MS	1, 3	17.7 - 18.1

It should be noted that, if RARC-83 sets the lower edge of the feeder link band at 17.3 GHz, the upper limit of the bands listed in this table will lie in the range 17.7-17.9 GHz depending on where RARC-83 sets the lower edge of the Region 2 BSS band. Also note that the FSS uplink band shown in the table is limited to feeder links for broadcasting-satellites in the WARC-77 Plan for Regions 1 and 3. It is expected that these feeder links will be planned during the second session of WARC-84/85.

Prior to RARC-83, frequency sharing involving feeder links to Region 2 broadcasting-satellites is governed by the procedures of Articles 11 and 13 of the Final Acts of WARC-79, just as with links in any other band allocated to the FSS. However, this observation is academic so far as the STC system is concerned since it will not be launched prior to RARC-83.

Once RARC-83 has adopted a Plan for Region 2, the question of the interference compatibility of the BSS feeder links for the STC system and other Region 2 broadcasting-satellites will not be an issue. The Region 2 Plan will keep interservice, intra-regional interference acceptably low and will, presumably, take into account the interference compatibility requirements of the BSS feeder links in other Regions, as well as those of the FSS and the terrestrial fixed and mobile services above 17.7 GHz. Thus, the system compatibility of STC feeder links with all other users of the 17.3-18.1 GHz band will be assured by their conformity with the RARC-83 Plan.

SUMMARY AND CONCLUSIONS

It has been shown that the inter-Regional sharing criteria applicable to broadcasting-satellites in Region 2 are easily met by systems of the type proposed by STC for the United States. Inter-Regional interference compatibility exists without intersystem coordination or the modification of system characteristics in any Region. Where another space service was involved, this compatibility was the result of large separations between service areas and/or satellites characteristic of the geographic isolation of Region 2 land masses from most of those in Regions 1 and 3. This same isolation was also largely responsible for meeting the criteria for inter-Regional sharing with the terrestrial services.

It is concluded that the inter-Regional compatibility demonstrated for the STC system will also be readily achieved by the majority of other Region 2 systems.

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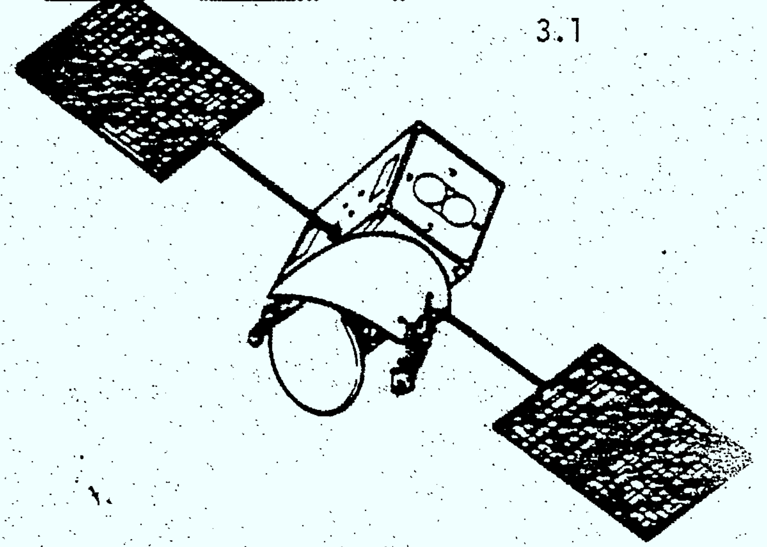

TITLE : CONSIDERATION OF NOISE AND INTERFERENCE
IN A BROADCASTING-SATELLITE SYSTEM

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Consideration of Noise and Interference in a Broadcasting-Satellite System

by Robert R. Bowen

Abstract

Consideration of system noise and inter-network interference are major constraints in the design of a broadcasting-satellite system and in the planning of the spectrum and geostationary orbit which such systems use. In planning such systems, and in planning the frequencies and orbit positions that such systems will use, one must take into account the noise budget, cost budget, and weight budget of individual systems, and the interference budget between systems. Balancing these budgets involves choice of many system parameters, including satellite EIRP, earth station G/T, antenna diameters, signal bandwidths, spacings between satellites, and several other parameters. The ways in which each of these parameters effect the different system budgets is discussed in the paper. It is shown that although most parameters affect only one or two budgets, choice of Earth terminal antenna diameter affects all of the budgets considered.

Consideration of Noise and Interference in a Broadcasting-Satellite System

by Robert R. Bowen

1. Introduction

In designing a broadcasting-satellite system, one must be concerned with a number of "budgets". The final system design is not the result of considering a single "budget", but rather is the result of balancing at least four separate budgets. These include:

(i) the system noise budget, commonly expressed in terms of the overall carrier-to-noise ratio or signal-to-noise ratio;

(ii) the system interference budget, commonly expressed in terms of the overall carrier-to-interference ratio;

(iii) the satellite weight budget, limited by the weight, and possibly the volume, of satellite that can be placed in geostationary orbit with a given launch vehicle, and

(iv) the system cost budget, limited by the total cost that can be spent in a given system, and used most effectively by choosing system parameters that minimize the total system cost for a given noise budget, interference budget, and satellite weight limitation.

In balancing each of these budgets a large number of factors have to be taken into account. The interference budget is perhaps the most complex, because the system designer must consider not only his own system when meeting the demands of this budget, but all the other systems, both satellite and terrestrial, which use the same frequency band as his proposed system. It is not surprising, then, that the design of broadcasting satellite systems, and the formulation of the regulations governing the inter-relationships between such systems, are complex processes.

It is very important to realize that each of these very different complex processes, system-design and formulation of the regulations governing the inter-relationships between these systems, can be divided into four separable simpler processes or problems by dealing with each of the budgets in turn.

This particular paper will consider the system noise budgets and system interference budgets as they affect the formulation of regulations governing system inter-relationships. In passing, brief mention will be made of the other two budgets as they affect the first two. More detailed consideration of the system weight and cost budgets will be given in other papers to follow. And, in fact, all the plan synthesis and analysis papers in later sessions of this seminar are the detailed simultaneous consideration of the carrier to interference budgets of a large number of similar systems.

2. System Noise Budget

Let us first consider the noise budget of a specific single system. It is in at least one sense simpler than the interference budget because there is only one system involved. It is also simpler because the random processes involved are all Gaussian or derivitives of Gaussian, which makes their addition a simple matter (more will be said of this in dealing with the interference budget).

There are two commonly used measures of the noise in a system: there is the carrier-to-noise ratio C/N at a high-signal level before the detector, and there is the post-detection video signal-to-noise ratio S/N. The first of these, C/N, is commonly expressed in terms of the system link parameters by the expression

$$\frac{C}{N} = \mathrm{EIRP} + G/T - 10 \log_{10} k - 10 \log_{10} B - L_{FS} - L_{CA} - L_R - L_U \qquad \ldots(1)$$

where EIRP is the actual effective isotropic radiated power from the satellite at the reception point on the earth;

G/T is the ratio of the gain to noise temperature of the receiving system, the figure of merit of the receiver;

k is Boltzman's constant, 1.38×10^{-23};

B is the system bandwidth in Hz,

L_{FS} is the free-space loss in the downlink;

L_{CA} is the clear air atmospheric loss;

L_R is the loss due to rain propagation; and

L_U is the equivalent loss due to noise in the uplink sub-system.

An interesting variation of equation (1) is

$$\mathrm{EIRP} + G/T = C/N + 10 \log_{10} k + 10 \log_{10} B + L_{FS} + L_{CA} + L_R + L_U \qquad \ldots(2)$$

In this form the parameters at the system designer's disposal, EIRP and G/T, are on the left; he must choose the sum of these parameters large enough to meet the quality specifications of the system, and choose the balance between EIRP and G/T to minimize the cost of his system. But that is another question, getting into the cost budget and the whole question of whether one is dealing with a "community" or an "individual reception" broadcasting satellite system.

Rather, let us consider the likely parameter values of the terms in equations (1) or (2).

Pre-Detection Carrier to Noise Ratio:

This is the value below which it is not desirable to fall below except for very short periods of time. (The sum total of these periods in a month or a year is a function of the rain margin choser, and is likely to be in the range 0.1% to 1% of the total time). The minimum value of C/N that was used at the 1977 WARC was 14 dB. A series of subjective tests carried out in Canada recently (1) indicates that 11 dB can be used as a "base value", the minimum value to be experienced when all of the long-duration or steady-state degredations such as edge of service area antenna gain, spacecraft antenna mispointing, receiver aging and mispointing, and "normal" rain attenuation all occur simultaneously.

Receiver Figure of Merit G/T:

The value of G/T used at the 1977 Conference was 6 dB/K. Improvements in receiver noise figure, in the location of the receiver preamplifier (at the antenna focal point rather than behind the receiver), and in the design of the focal point antenna, have resulted in G/T being in the order of 10 dB/K when 1 meter antennas are used.

Receiver Bandwidth B:

Various system bandwidths can be used. A smaller bandwidth reduces the value of EIRP + G/T necessary to keep the signal above "threshold" under adverse conditions, but reduces the FM "gain" and so the value of S/N for a given C/N. Another factor is that a smaller value of B results in a larger total orbit capacity in terms of the number of television channels available. Values that have been suggested for Region 2 are 18MHz and 23MHz. The smaller value is being given serious consideration in Canada.

Free-Space Loss L_{FS}:

This loss is dependent on the elevation angle at the receiver site, i.e. on the actual distance from the receiving point to the satellite, and on the carrier frequency. It is given by the equation

$$L_{FS} = 92.45 + 20 \log_{10} S + 20 \log_{10} f \qquad \ldots(3)$$

where S is the path length in km from satellite to the earth station, and

f is the carrier frequency in GHz, taken to be 12.5GHz.

At this "midband" frequency L_{FS} varies between 205.5 dB at the subsatellite point to 206.5 dB where the elevation angle is 10°. (At the lower nominal frequency of 12 GHz, used in Regions 1 and 3, L_{FS} would be 206.1 dB rather than 206.5 dB.)

Clear-Air Loss L_{CA}:

This parameter will vary slightly with geographical location and with elevation angle, but is not usually greater than 0.5 dB at 12.5 GHz.

Rain Loss L_R :

This value will vary considerably, depending on the geographical area, elevation angle, and the outage time acceptable, i.e. the time below which the C/N can be allowed to drop below the 11 dB "base value". L_R may vary from less than 1 dB to over 5 dB, depending on rainfall conditions and satellite elevation angle. Planning at the 1977 WARC was done on the basis that L_R would not exceed 2 dB, and satellite orbit positions were chosen with this in mind.

Uplink Equivalent Loss Lu:

This is not a true "loss", but rather a reduction in C/N ratio due to uplink noise. The total system C/N ratio can be expressed in terms of uplink and downlink ratios by the expression

$$(C/N)^{-1} = (C/N)_U^{-1} + (C/N)_D^{-1} \qquad ...(4)$$

When $(C/N)_U$ is in the order of 20 times $(C/N)_D$, a situation in many actual systems, then C/N is in the order of 0.25 dB below $(C/N)_D$, and so Lu would be 0.25 dB in that case.

Required Satellite EIRP at the Edge of the Service Area:

Based on the above parameter values, it is possible to estimate the required satellite EIRP at the edge of the service area, i.e. the minimum EIRP over the service area. Two estimates are of interest: that based on parameter values used in the derivation of the 1977 Region 1/3 Plan, and that based on the alternate parameter values suggested above. The system noise budgets in the two cases are shown in Table 1.

TABLE 1

System Parameter	77 WARC Values	Alternate Values
C/N	14	11
G/T	6	10
B	74.3	72.5
k	-228.6	-228.6
L_{FS}	206.1	206.5
L_{CA}	0.5	0.5
L_U	0.4	0.25
L_R	2.0	L_R
EIRP	62.7	52. + L_R

As indicated the edge-of-beam EIRP is 62.7 dBW in one case, and 52.1 $+ L_R$ in the alternate. If L_R were 3 dB, say, then the edge-of-beam EIRP in the alternate example would be 55.1 dBW.

Required Satellite Transmitted Power Per Television Program:

The required satellite transmitter tube power is of course directly related to the required edge-of-beam EIRP by the expression

$$P_o = EIRP - G_s + L_o + 3 \qquad \ldots(5)$$

where Lo is the power loss in the output multiplexers and filters in the satellite, in the order of 1 dB, Gs is the boresight gain of the satellite antenna, and the factor 3 is included to convert from the edge-of-beam to the centre-of-beam. For an elliptical beam Gs can be described by the expression

$$G_s = 44.3 - 10 \log_{10} \left\{ \theta_1 \; \theta_2 \right\} \qquad \ldots(6)$$

where θ_1 and θ_2 are the major and minor diameters of the elliptical beam, as seen from the satellite, in degrees.

It is possible to reduce P_o by 0.26 dB below that indicated by equations (5) and (6) by using a smaller beam and higher edge-of-beam to boresight EIRP ratio (4.3 dB rather than 3 dB). This can be taken account of either by using 4.3 rather than 3.0 in equation (5) and different values for θ_1 and θ_2 in equation (6), or simply substracting 0.26 dB from the value of P_o. The latter is easier unless one is actually designing the spacecraft antenna.

The above might be clarified by an example. Suppose that the product $\theta_1\theta_2$ were 3 square degrees, a typical value for larger Region 2 beams. Then the required output power would be 27.4 dBW (550 watts) using 77 WARC values, or 19.4 dBW (87 watts) using the alternate values described above.

A final item to consider in examining the system noise budget is the post-detection signal to noise ratio. When the carrier to noise ratio is above threshold, i.e. greater than about 9.5 dB (or lower values if threshold extension techniques are used), the S/N ratio can be expressed in terms of the C/N ratio and the system bandwidths by the expression

$$S/N = 1.76 + C/N + 10 \log_{10} (B/fm) + 20 \log_{10} (\Delta fm/fm) + 6 + P_W \qquad \ldots(7)$$

where B is the total channel bandwidth,

fm is the maximum baseband frequency of the video and an audio channel, approximately 4.2 MHz for a 525 line system,

Δf_m is the peak frequency deviation,

P_W is the pre-emphasis and noise weighting factor, 12.8 dB,

1.76 is the dB equivalent of the factor 3/2 in the f.m. demodulation equation, and

6 is the factor to take into account the fact that black-to-white voltage squared values rather than r.m.s. values are used in specifying S/N.

A strict application of Carson's bandwidth rule

$$B = 2(\Delta f_m + fm) \qquad \text{....(8)}$$

would indicate that the peak frequency deviation should be 4.8 MHz. However, there are indications based on experimental work carried out as part of the ANIK-B broadcasting-satellite program that slight overmodulation (Δf_m = 6.6 MHz) and shaped post-demodulation filter design results in an improved reception. In such a system the "base value" C/N of 11 dB is equivalent to a video S/N of about 42 dB.

In summary, the system noise budget involves making the sum EIRP + G/T large enough to meet the system C/N and S/N requirements. For a given set of service area requirements, this is done by choosing some appropriate combination of spacecraft output tube power, receiving system noise figure, and receiving antenna diameter. Choice of system bandwidth B and shape of the spacecraft antenna characteristic to minimize the required output power for a given EIRP should also be considered in meeting the system noise budget.

3. System Interference Budget

The previous section dealt with the system's incoherent self-noise, largely caused by the noise contributions of the preamplifiers in the satellite receiver and in the user's Earth terminal receiver. This noise usually has a white spectrum and Gaussian characteristics. In contrast, the "interference" considered in this section is caused by a small countable number of discrete interfering sources, many of which are exactly the same as the "signal" except that they are radiated from systems serving other service areas. Further, this interference can be further divided in two ways. It can be thought of as having coherent and incoherent components, i.e. components which are similar to the desired signal and appear on the television picture tube as some sort of picture or pattern, and incoherent components which do not, and so have the characteristics of noise. The incoherent component of the interference is considered here as being a minor addition to the systems thermal noise, and not considered further.

The coherent interference can be further subdivided as being made up of contributions from other networks and contributions from within the system itself, caused by inadequate filtering in the spacecraft, Earth terminal, etc. The intra-network coherent interference might be considered in the '83 RARC planning process when choosing inter-channel frequency separation values, but is not usually considered in the inter-network interference budget since it is under the control of the system designer. When one speaks of the system's interference budget, then, one is usually referring to the interference from coherent transmissions from other networks. The magnitude of the interference is specified in terms of the system's carrier to interference budget C/I. It is also specified in terms of the system "protection ratio", identical to the C/I or carrier-to-interference ratio specification.

When one refers to the C/I ratio one may mean either the single-entry C/I ratio where the interference is that from a single other network, or the aggregate or total interference from all interferers. The total or aggregate interference is usually taken as simply the power summation of all the significant single interferers, although there is room for some doubt as to whether say 5 or 6 coherent interferers of similar magnitude would have the same subjective effect as a single coherent interferer of power level equal to the power sum of that 5 or 6. Until more information on this subject is known however, power addition continues to be used.

As indicated in Annex 9 of the Final Acts of the 1977 WARC, the Region 1/3 12 GHz plan was developed on the basis that the minimum acceptable aggregate carrier-to-interference ratio was 30 dB, taking into account both uplink and downlink. The single-entry C/I level stated was 35 dB, but it would seem that this figure was simply used as a guide in development of the plan, so that the aggregate interference would not fall below 30 dB. The '77 WARC planned only the downlinks of course. Because of this a 1 dB margin was left to take into account the aggregate of the uplink interferers.

At the 1983 Region 2 RARC both the uplinks and the downlinks will be planned. This will allow a tradeoff to be made between the uplink and the downlink contributions to the total interference. One way that this can be done is by making very minor (in the order of one or two degree) variations in the downlink plan to change the amount of uplink interference caused by a given system. This can be an effective plan-synthesis technique because the uplink antenna diameters are expected to be much larger than the downlink Earth terminal antenna diameters, making the uplink antennas much more selective.

Specifically, the carrier-to-single-entry-interference between two downlink satellite networks is given by the following equation:

$$
\begin{aligned}
C/I &= P_S + G_{S,1}(0) - M - L_{FS,1} + G_{E,1}(0) \\
&\quad - P_2 - G_{S,2}(\phi) + L_{FS,2} - G_{E,1}(\theta) \\
&= (P_1 - P_2) - M - (L_{FS,1} - L_{FS,2}) \\
&\quad + \left\{G_{S,1}(0) - G_{S,2}(\phi)\right\} + \left\{G_{E,1}(0) - G_{E,1}(\theta)\right\} \qquad \ldots(9)
\end{aligned}
$$

where

P_1 ; P_2	are the output powers of the desired and interfering satellites;
$L_{FS,1}$; $L_{FS,2}$	are the free-space losses of the desired and interfering signal paths, respectively;
M	is the boresight to edge-of-beam ratio of the desired satellite system;
$G_{S,1}(0)$	is the boresight gain of the desired system's spacecraft antenna;
$G_{S,2}(\phi)$	is the gain of the interfering system's spacecraft antenna ϕ° off boresight;
$G_{E,1}(0)$, $G_{E,1}(\theta)$	are the gains of the receiving Earth terminal at boresight and θ° off boresight.

A number of observations can be made from Equation (9). These include:

1. The single-entry carrier-to-interference ratio between two systems is independent of the actual power levels of the two systems, but is dependent on the difference in their power levels, $P_1 - P_2$. Thus if the EIRP or output powers of all systems in a plan were increased by XdB, the C/I ratios associated with that plan would not change.

2. Since $G_E(\theta)$ decreases with increasing θ, except for special low-angle cases involving cross-polarization gain, the C/I can be increased by increasing θ, up to the point where $G(\theta)$ does not decrease further with increasing θ, i.e. until one is in the backlobe of the antenna pattern. Plan-synthesis is essentially the task of choosing a set of seperation angles θ_{ij}; between networks i and j so that the C/I ratios between these networks is large enough.

3. Since $G_S(\emptyset)$ decreases with increasing $\emptyset$, again except for special cases involving cross-polarization gain at small values of $\emptyset$, small values of θ can be chosen between two satellites when $\emptyset$ is large, i.e. when the satellites serve widely-separated service areas.

Worst-case estimates of C/I include factors to take into account the translation of the spacecraft antenna beams and to take into account the situation where the desired signal is attenuated to rain and the interfering signal is not.

Equation (9) may also be used as an indication of the effects that variations in C/I and in Earth terminal antenna diameter have on orbit utilization. To do this it is convenient to write equation (3) in the form

$$C/I = K - D_{E,1}(\theta) \qquad \ldots(10)$$

where θ is the separation angle between the desired and the interfering satellite,

$D_{E,1}(\theta)$ is the discrimination of the Earth terminal antenna, $G_{E,1}(0)-G_{E,1}(\theta)$ in terms of Equation (9) parameters, and

K is the sum of the other variables of equation 9, all independent of θ .

The relation between single-entry interference and angle separation θ can best be seen through examples. Suppose, for example, that the Earth terminal antenna has a half-power beamwidth θ_o of 1.8°, and that its co-polarization discrimination function is that used in Region 1/3 12GHz planning, i.e.

$$\begin{aligned} D_{E,1}(\theta) &= 9.0 + 20 \log_{10}(\theta/\theta_o) \ ; \ 0.707\ \theta_o < \theta \le 1.26\ \theta_o \\ &= 8.5 + 25 \log_{10}(\theta/\theta_o) \ ; \ 1.26\ \theta_o < \theta \le 15.14\ \theta_o \end{aligned} \qquad \ldots(11)$$

Then the required separations between the two satellites, as a function of the required carrier-to-interference ratio between them, and of the parameter K, are as follows:

	Separation Angle θ, degrees	
C/I, dB	K = 0 dB	K = 10 dB
39.0	29.9	11.9
37.0	24.8	9.9
35.0	20.7	8.3
33.0	17.2	6.8
31.0	14.3	5.7
29.0	11.9	4.7

Thus, as seen from this short table, there is a very strong dependence between required C/I ratio and resulting required separation angle between satellites. These required separation angles translate directly into the capacity available from a plan that utilizes a given amount of spectrum-orbit resource.

The relationship between orbit separation requirements and antenna diameter is also important. The beamwidth θ_o can be specified in terms of the carrier frequency f, in GHz, and the antenna diameter D, in meters, by the expression

$$\theta_o = \frac{22}{fD} \qquad \ldots(12)$$

For a given specified C/I ratio of say 33 dB between two systems, the required separation between the two systems at 12.5 GHz when K = 0 and when K =10 dB is as follows:

Antenna Diameter	θ_o, degrees	Required Separation Angle	
		K = 0 dB	K = 10 dB
1.2	1.46	13.9	5.6
1.0	1.76	16.8	6.7
0.8	2.20	21.0	8.4
0.6	2.93	28.0	11.1

Thus for a given satellite separation angle the C/I ratio between two systems is a strong function of the receiving terminal's antenna diameters, or to put the same relationship another way, for a given specified C/I ratio between two networks, the required separation angle between the two satellites is a strong function of the antenna diameters used.

In summary, the system's carrier-to-interference budget or protection ratio budget is controlled mainly by the positioning of other satellites in the orbit, with respect to the position of the desired satellite. The characteristics of a given system that control the amount of isolation it requires from other satellites are of course its required C/I ratio, the spacecraft antenna patterns Gs $(\emptyset)$, the relative satellite EIRP values, not their absolute values, and the diameters of the receiving antenna diameters. Fortunately, the system's C/N budget and its C/I budget are almost separable, the closest linkage being through choice of the Earth terminal antenna diameter.

4. Inter-relationship between System Budgets

As indicated in the introduction, the design of a broadcasting satellite system involves the balancing of four budgets: the system noise budget, the interference budget, the weight budget of the satellite portion (which may also include spacecraft volume constraints), and the system cost budget. System parameters such as satellite and earth terminal antenna characteristics, satellite transmitter power, receiver noise figure, channel bandwidth and centre frequencies, and satellite orbital positions are chosen to "balance" these various budgets. Fortunately, some of these parameters are specified by only one budget, but others are influenced by several. It is this inter-relationship that is discussed in this section.

The Satellite Weight and Volume Budget:

This budget is of course of most concern to those designing the spacecraft in detail. However, system planners and designers should understand how the choice of system parameters is reflected in such detailed design. The "volume" constraint is fairly simple: it constrains the amount of prime power available if the satellite is to be a spin-stabilized one, and limits the antenna design unless unfurled antennas such as those on ATS-6 are to be used. The weight constraint is more critical. For a given launch vehicle the mass in geostationary orbit is of course limited. For a broadcasting satellite, this limit can be translated approximately into a limit on the output power of each r.f. channel transponder, times the number of active transponders. A significant margin for batteries will be required if the satellite is to operate during solar and moon eclipse. In summary, the primary weight constraint is the total r.f. transmitted power from the spacecraft, with the limit being that which can be placed in orbit with a dedicated Shuttle Launch.

The System Cost Budget:

The system cost budget includes the cost of both the space portion and the Earth terminals, although the costs of the two portions may be weighted in some way because the resources to pay the costs of the two portions may come from different places. In any case, the cost of the system, to be minimized, can be written in the form

$$C_T = C_S\,(EIRP, m) + n\,C_E\,(G/T) \qquad \ldots(13)$$

where C_T is the total system cost,

C_S is the space portion cost, a function of the satellite EIRP and m , the number of spacecraft transponders;

n is the number of receiving Earth terminals in the system, and

C_E is the cost of an Earth terminal, a function of receiver figure-of-merit G/T.

Costs C_S and C_E are addressed in other papers of the seminar. It is sufficient to say here that for a given system performance, specified by EIRP + G/T in equation (2) above, C_T is minimized by choosing the correct balance between EIRP and G/T. When the number of Earth terminals n is a few thousand, a different balance between EIRP and G/T should be used than that when n is in the tens of millions. In the former case C_T is minimized by minimizing C_S , and in the latter case by minimizing C_E . In the Canadian situation, where n is expected to be in the order of a million, the tradeoff between C_S and C_E has to be done carefully to minimize C_T .

Relationship Between the Weight and Cost Budgets and the Noise Budget

The cost budget specifies the cost-effective balance between EIRP and G/T, subject to the sum EIRP + G/T being large enough to meet the noise budget requirements. The weight budget specifies an upper bound on the total spacecraft r.f. power transmitted, and so specifies a maximum EIRP unless the total number of channels to be provided is satisfied through a larger number of operational spacecraft being used.

Relationship between Noise Budget and Interference Budget

Fortunately, these budgets are almost independent. The noise budget, combined with the constraints imposed by the weight and cost budgets, specifies the actual system EIRP and so satellite power P of Equation (5). The interference budget puts no constraints on P, only on the difference in the transmitted powers Pi and Pj of systems i and j (see Equation (9)). The parameter of significant importance to both the noise budget and the interference budget, and to the system cost minimization as well, is the earth terminal antenna diameter. The diameter determines the parameter G in Equation (2), since G is proportional to the square of the antenna diameter, and has a significant effect on the systems C/I as well, as indicated by Equation (12) and the accompanying table.

5. Summary

It is seen that the planning and design of broadcasting satellite systems, and the accompanying planning of the use of the spectrum and orbit by these systems, involves the balancing of several factors or "budgets" by the correct choice of a number of system parameters. It is hoped that the inter-relationships between these factors and parameters, described in this paper, will enable wise choices of the parameter values to be made in the forthcoming planning process, and will enable a balance to be kept when a particular budget and choice of a particular parameter are analysed in detail.

6. References

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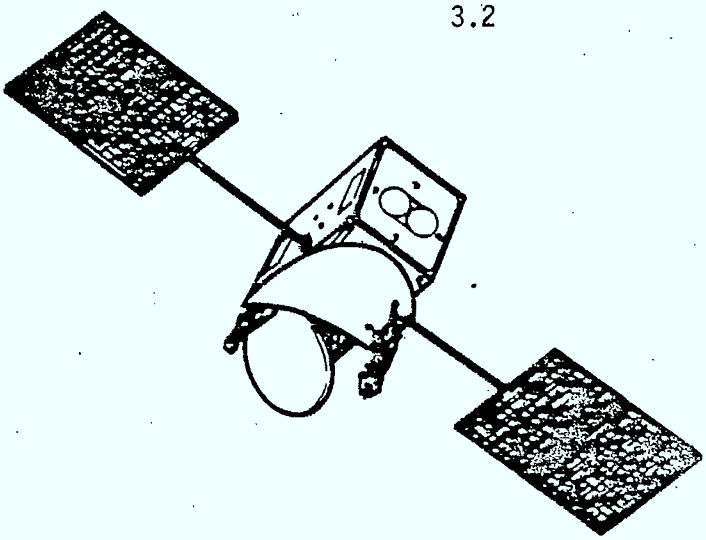

TITLE : FREQUENCY RE-USE CONSTRAINTS FOR
12 GHz BROADCAST SATELLITE SERVICE
IN REGION 2

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FREQUENCY RE-USE CONSTRAINTS
FOR 12 GHz BROADCAST SATELLITE SERVICE
IN REGION 2

K. Brown

ABSTRACT

This paper examines the constraints on frequency re-use for the 12 GHz broadcast satellite service based on the specifications set by the 1977 WARC-BS. Upper and lower bounds on the minimum orbital separation of two satellites for a given separation of the two service areas are derived. Two methods for reducing the constraints are examined - reduced protection ratio requirements and use of advanced technology satellite antenna. These methods could be used singly or in combination. Although it is not possible with this limited study to predict the exact impact of these techniques it is estimated that the spectrum-orbit resource can be increased up to five or six times by use of these two approaches. Other methods of further increasing the net resource are indicated but not examined. It may be necessary to embark on regional planning excercises to obtain quantitative results on the capacity of the spectrum-orbit resource as it applies to Region 2 planning, plan flexibility and adaptability, etc., for various combinations of these resource enhancement techniques. The results given in this report are, however, useful for broad prediction and as an aid in initiating planning excercises, and could also be used in conjunction with geographic data readily obtained from satellicentric maps or by computer to generate detailed Regional plans if required.

FREQUENCY RE-USE CONSTRAINTS
FOR 12 GHz BROADCAST SATELLITE SERVICE
IN REGION 2

K. Brown

Summary

The inter-relationship between the geographic separation of service areas, the orbital separation of broadcast satellites serving those areas, and the possibility of frequency re-use either co-channel or adjacent channel and either co-polar or cross-polar to meet various single-entry carrier to interference ratios is presented for satellite antennas conforming to the WARC '77 specifications and for a hypothetical advanced technology antenna. These curves, in conjunction with geographic data obtained from satellite-view maps or by computer, may be used for manual planning excercises.

Introduction

This paper examines the constraints on frequency re-use for the 12 GHz broadcast satellite service based on the specifications set by the 1977 WARC-BS. Upper and lower bounds on the minimum orbital separation of two satellites for a given separation of the two service areas are derived. Two methods for reducing the constraints are examined - reduced protection ratio requirements and use of advanced technology satellite antenna. These methods could be used singly or in combination. Although it is not possible with this limited study to predict the exact impact of these techniques it is estimated that the spectrum-orbit resource can be increased up to five or six times by use of these two approaches. Other methods of further increasing the net resource are indicated but not examined. It may be necessary to embark on regional planning excercises to obtain quantitative results on the capacity of the spectrum-orbit resource as it applies to Region 2 planning, plan flexibility and adaptability, etc., for various combinations of these resource enhancement techniques. The results given in this report are, however, useful for broad prediction and as an aid in initiating planning excercises, and could also be used in conjunction with geographic data readily obtained from satellicentric maps or by computer to generate detailed Regional plans if required.

Section 1 of this report looks at possible service areas for Region 2. The factors influencing frequency re-use are given in Section 2 and the available orbital service arcs are addressed in Section 3. Possible methods of relaxing the frequency re-use constraints are given in Section 4 and two of these methods are examined in detail. A specific example of the use of the constraint curves to determine the allotment possibilities for a pair of service areas is given in Section 5. Conclusions are drawn in Section 6. Finally, Appendix 1 gives the derivation of the constraint curves.

1. Service Areas

There may be up to 50 separate administrations and up to 80 possible service areas in Region 2.

These areas have not been finalized as far as boundaries or number and the final disposition may not be known until the actual planning conference in 1983.

Figure 1 depicts the service areas assumed for initial planning investigations.

2. Frequency Re-Use

Each service area is to be assigned at least 4 TV channels per Radio Regulation Resolution CH and many areas may require considerably more. Since it is only possible to pack about 30 to 40 channels into the assigned frequency band, the channels will have to be re-used. There are fundamental constraints on frequency re-use due to many technical factors, several of which are unique to broadcast satellites.

These constraints include:

a) very low levels of interference to yield a signal of required broadcast quality.

b) relatively unsophisticated filtering in the receivers to minimize the cost and to facilitate mass production techniques.

c) in many cases multiple service areas, usually close neighbours, must be served from the same satellite location.

d) the existence of some finite power outside the main beam for even narrow beam radiation from the satellite.

e) the existence of some finite gain outside the wanted direction for a directional receiving antenna.

f) the fact that perfect isolation using cross-polarization is not possible to achieve due to imperfect antennas and depolarization by rain.

g) for maximum utilization of the available spectrum, it is not possible to ignore or eliminate the effect of the adjacent channels, (these channels may even overlap the wanted channel).

Figure 2 shows the basic inter-relationship between the orbital separation of two satellites (θ) and the geographic separation of the corresponding service areas represented by the ratio $\varnothing/\varnothing_o$.

The assumed envelope pattern of the satellite transmitting antenna is shown in Figure 3a, and the corresponding envelope pattern of the earth station receiving antenna is shown in Figure 4.

These are the antenna patterns that were used for the planning in 1977 and may no longer be valid due to advances in antenna technology.

To ensure that the interference from one satellite system into another is below a specified level, it is possible to combine these antenna discrimination characteristics to determine the minimum orbital separation (θ) for a given geographic separation (ϕ/ϕ_o) for co-channel, adjacent-channel, co-polar and cross-polar operation.

Figure 5a shows the relationship between orbital separation (θ) and the geographic separation of the service areas (ϕ/ϕ_o) for the four combinations of co-channel and adjacent-channel, and co-polar and cross-polar transmissions. In general there is insignificant interference from the next but one adjacent-channel.

This figure is based on achieving a minimum single-entry C/I of 35 dB at beam edge (3 dB down on beam centre) and assuming a difference in satellite e.i.r.p. of 2 dB for an overall total discrimination of 40 dB. This could be construed as representing a typical worst case. Since in some cases the e.i.r.p. of the wanted satellite may be higher than that of the interfering satellite there could be a net cancellation of the beam edge effect, accordingly. Figure 5b shows the relationships for a total discrimination of 35 dB representative of a typical best case or lower bound. Note, however, that the necessary orbital spacing between two services is dictated by the larger of the interference from service A into service B or from B into A, note also that the quantity ϕ/ϕ_o is,in general,different in the two directions. The derivation of the curves in Figures 5a and 5b are given in Appendix 1.

3. Available Orbital Arc

The available arc for placement of a satellite is a function of the size and latitude of the service area and the minimum required elevation angle to the satellite.

The available orbital arcs for Region 2 countries are given in Figures 7a and 7b.

The arc may be further limited if, due to the high power required, it is not possible to supply enough battery power to maintain the service during periods of eclipse of the sun by the earth. This phenomenon occurs for several days at the two annual equinoxes when the earth eclipses the sun thus shadowing the solar panels, the time of occurence and duration of these eclipses being regular and predictable. Then, to maintain service to, say, local midnight, it is necessary to place the satellite about 10^o west of the service area. Note that satellite solar power will also be lost when the sun, the moon and the satellite are co-linear. Unfortunately these occurences, whilst being predictable are far from regular and no protection can be achieved by orbit placement.

Thus, each service area has a limited available orbital arc and there will, in general, be conflicts between placing satellites in the available arc and separating them sufficiently to enable frequency re-use per Figures 5a or 5b.

As a result of these conflicts, full frequency re-use may not be possible. More than one group of channels may be required in order to assign channels to all service areas without creating unacceptable interference. For example, if 6 groups of channels are required, only 1/6 of the full frequency bandwidth will be available to each service area, if regular channel distribution is assumed. In this case each service area would have access only to every sixth channel.

4. Possible Relaxation of the Re-Use Constraints

There are several avenues for further investigation which could lead to a possible relaxation of these frequency re-use constraints. This,in turn,would facilitate broadcast satellite service assignments and permit more flexibility in the planning process. Some possibilities are:

1) Reduce the single-entry and composite interference specification by say 5 dB. There is some justification for this based on experience with 4 GHz satellite broadcasting.

2) Use of advanced technology shaped beams for the satellite transmit antenna with much higher rate of roll-off of the main lobe and lower side lobe levels than the simple characteristic adopted in 1977. Such antenna have already been modelled and will be implemented in the near future.

3) Review the channel packing criteria. It is feasible that by a combination of overmodulation and increased carrier spacing (i.e., a slight reduction in the total number of channels) the effects of adjacent channel interference could be reduced.

4) Use of advanced auxiliary power technology to permit continuous operation during eclipses thus removing possible orbital constraints.

5) Use of dedicated satellites, i.e., satellites serving at most one or two service areas. This will permit more extensive use of crossed beam geometry.

The above possibilities all imply some penalty which would have to be carefully assessed against the potential benefits.

To illustrate the potential easement of constraints options 1 and 2 above are examined in more detail.

4.1 Reduced Interference Specifications

For a worst case combination of 30 dB single-entry protection ratio (instead of the 35 dB specified in 1977), a 3 dB edge of beam allowance and 2 dB difference in e.i.r.p. a net discrimination of 35 dB is required between two systems. Thus Figure 5b could also be used as a worst case or upper bound for the reduced interference specification case. The best case or lower bound total discrimination would typically be 30 dB and the corresponding constraints are illustrated in Figure 5c. As before the worst case between any two services will dictate the orbital spacing.

4.2 Improved Satellite Antenna Performance

An assumed satellite antenna characteristic with fast roll-off and low side lobes is illustrated in Figure 3b. In this characteristic a fourth order main lobe roll-off down to 40 dB and side-lobes of 40 dB for the main polarization and a cross-polar characteristic of 30 dB until the co-polar curve are assumed. Figures 6a, 6b, and 6c show the relationship between service area separation and satellite separation required to meet a total discrimination of 40 dB, 35 dB and 30 dB respectively. As above Figures 6a and 6b represent upper and lower bounds respectively to meet a single-entry carrier-to-interference ratio of 35 dB and Figures 6b and 6c represent upper and lower bounds respectively to meet a single-entry carrier-to-interference ratio of 30 dB.

5. Example of Use of Constraint Curves

Figure 9 gives a satellite view projection of South America showing in particular possible elliptical beams for Peru and Guyana as an example. By direct measurement on such a map the quantities ϕ/ϕ_0 may be approximated. This is possible since, for the small angles considered, the linear dimension on a satellicentric map is a very good approximation of the angle subtended at the satellite to within a constant scaling factor. Thus for Peru interfering into Guyana ϕ/ϕ_0 is approximately 1.17 and an orbital separation of about 10° for co-channel co-polar operation or 3° for adjacent-channel co-polar operation is required (Figure 5a). In the opposite direction ϕ/ϕ_0 is approximately 2.67 requiring an orbital separation of 3° for co-channel co-polar operation whilst no separation is necessary for adjacent-channel operation. However, since the worst case dictates, the interference of Peru into Guyana will determine the appropriate orbit, channel and polarization possibilities. It should be noted that the quantity ϕ/ϕ_0 is reasonably independent of the actual satellite longitudes for small departures from the nominal longitude selected for the map measurements. The accuracy can be improved if necessary by considering appropriate pairs of maps for each pair of service areas.

The curves given in Figures 5 and 6 can thus be used to determine acceptable combinations of orbit, channel and polarization for each pair of service areas and from this information possible allotment plans can be postulated.

6. Conclusions

Frequency re-use constraints to meet a given single-entry value of carrier-to-interference are expressed as upper and lower bounds on the required orbital separation for a given service area separation. Worst case assumptions regarding pointing error and station-keeping were assumed. The small advantage accrued by use of the topocentric angular separation rather than the geocentric angular separation was ignored. Antenna characteristics specified in 1977 at the WARC-BS are employed in curves 5 and in addition a postulated advanced technology satellite antenna is used to derive curves 6. It is not possible from this simple study to draw definitive conclusions of the net benefit to the planning process as a result of the use of lower interference protection ratios and/or high technology antenna but an indication of the reduction of taboos can be obtained by considering the areas under the curves presented for the various cases considered.

The effect of reducing the protection ratio requirements can be assessed by comparing for example Figures 5a and 5b. Under similar worst case conditions it can be seen that adjacent service areas ($\emptyset/\emptyset_o$ approximately 0.5) cannot be served co-channel for any satellite separation if a 35 dB protection ratio is specified but that for a 30 dB protection ratio a satellite separation of approximately 20° is adequate for full frequency re-use.

Comparing Figures 5b and 6b it can be seen that the advantage due to the use of the postulated satellite antenna is quite dramatic in that the minimum service area separation, assuming co-located satellites, for full frequency re-use - i.e., co-channel, co-polar - is reduced from five beamwidths for the '77 pattern to just over one beamwidth for the postulated antenna. In the former case there are very few pairs of service-areas that are sufficiently far apart to permit this re-use whereas in the latter case there is the potential for complete co-polar frequency re-use three or four times over from the same satellite location.

Finally, to observe the combined effect of reduced protection ratio requirements and the advanced technology antenna, Figures 5a and 6b should be compared since these both correspond to the assumed worst case combination of edge of service area contribution and adverse satellite e.i.r.p. difference. In the first case (Figure 5a) the same frequency can only be used twice-once in each polarization - from a single orbital position and, secondly, adjacent service areas cannot be co-channel. In the second case (Figure 6b) however, it is feasible that the frequency could be re-used three or four times per polarization from the same orbital slot and that adjacent service areas can be co-channel either polarization simply by having the corresponding satellites some 20° apart.

A possible use of these constraint curves is in generating possible plan allotments without necessarily recourse to a large computer. In the process of generating such plans a good understanding of the interplay between the various parameters will also be generated.

APPENDIX 1

FREQUENCY RE-USE CONSTRAINTS

Introduction and Summary

The constraints governing frequency re-use are derived from single-entry interference criteria and the envelope radiation patterns of the transmit and receive antennas. Some assumptions must be made with regard to rain depolarization, in general such assumptions will be optimistic at low elevation angles. The constraints are expressed as curves of required geographic separation of the service-areas against the relative satellite longitude for four cases of interest; co-channel co-polar, co-channel cross-polar, adjacent-channel co-polar, and adjacent-channel cross-polar.

Modes of Interference

Definitions: T = satellite transmit antenna co-polar discrimination

TX = satellite transmit antenna cross-polar discrimination

R = earth station receive antenna co-polar discrimination

RX = earth station receive antenna cross-polar discrimination

AX = rain depolarization factor

The total downlink* discrimination from the transmit and receive antennas if both satellite systems are the <u>same</u> polarization then consists of four components viz:

$$\begin{aligned}
D_1 &= T + R && \approx T + R \\
D_2 &= TX + RX && \approx -53 \\
D_3 &= T + AX + RX && \approx T - 45 \\
D_4 &= TX + AX + R && \approx R - 48
\end{aligned}$$

Where it is assumed that rain depolarization is about -25 dB and, over the region of interest, $TX \leqslant - 33$ dB (ignoring the hard to achieve main-lobe value of -38 dB specified in Annex 8 of the '77 Final Acts) and $RX \leqslant - 20$ dB). It can thus be seen that terms D_2, D_3 and D_4 are all small compared to term D_1 and may thus be ignored.

On the other hand if the two satellite systems are of <u>opposite</u> polarity the relative levels of the four terms are:

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*For this study the uplink contributions have been ignored since in general they will be small in comparison to the downlink contributions. In addition circular polarization has been assumed, linear polarization would require additional terms in the discrimination expressions.

$$X_1 = T + RX \approx T - 20$$

$$X_2 = TX + R \approx R - 33$$

$$X_3 = T + AX + R \approx T + R + 25$$

$$X_4 = TX + AX + RX \approx -78$$

In this case only the term X_4 can safely be disregarded, the other three terms could be of comparable magnitude and must be power summed to obtain the net interference.

Carrier-to-Interference Requirements

The required minimum single-entry carrier-to-interference power is 35 dB. The worst case carrier-to-interference will occur when the victim test point is on the edge of the service-area closest to the interfering beam. Thus, in general, the wanted carrier power will be about 3 dB down on the beam centre carrier power. Assume that the mean difference in satellite e.i.r.p. is 2 dB. Thus, to meet the C/I requirement in the worst case the total discrimination of the interfering satellite antenna and the victim receive antenna is $35 + 3 + 2 = 40$ dB.

Hence the following conditions must be met:

a) Co-channel, co-polar operation

$$D \approx D_1 = T + R \leqslant - 40 \text{ dB}$$

b) Co-channel, cross-polar operation

$$X \approx 10 \log (10^{X_1/10} + 10^{X_2/10} + 10^{X_3/10}) \leqslant - 40 \text{ dB}$$

For adjacent-channel operation a relative protection ratio some 15 dB less than the co-channel requirement is adequate, thus for:

c) Adjacent-channel, co-polar operation

$$D \leqslant - 25 \text{ dB}$$

d) Adjacent-channel, cross-polar operation

$$X \leqslant - 25 \text{ dB}$$

Satellite Antenna Patterns (Figure 3a)

From the '77 Final Acts:

$$
\begin{array}{ll}
T = -12\ (\emptyset/\emptyset_o)^2 & \emptyset \leqslant \emptyset \leqslant 1.58\ \emptyset_o \\
\quad = -30 & 1.58\ \emptyset_o < \emptyset \leqslant 3.16\ \emptyset_o \\
\quad = -(17.5 + 25 \log_{10}(\emptyset/\emptyset_o) & 3.16\ \emptyset_o < \emptyset \leqslant \emptyset_C \\
\quad = -G_o & \emptyset_C < \emptyset \\
TX = -33 & 1.65\ \emptyset \leqslant \emptyset \leqslant 1.67\ \emptyset_o\ * \\
\quad = -(40 + 40 \log_{10} \left| \emptyset/\emptyset_o - 1 \right|) & 1.67\ \emptyset_o < \emptyset \leqslant \emptyset_X \\
\quad = -G_o & \emptyset_X < \emptyset
\end{array}
$$

where $\emptyset$	is the nominal off-axis angle to the victim test point
$\emptyset_o$	is the half power beamwidth in the direction of the test point
$\emptyset_C$, $\emptyset_X$	are the values of off-axis angle at which the envelope patterns equal $-G_o$
G_o	is the on-axis gain of the aggressor satellite.

(* the -38 dB main-lobe specification has been ignored since:

a) it is difficult to meet and

b) has been shown in Europe to offer insignificant advantage).

Since up to 0.1° of beam mispointing may occur the satellite antenna discrimination should be computed for an angle $\emptyset^1 = \emptyset - 0.1$. However, since the expressions are all functions of the parameter $\emptyset/\emptyset_o$ and $\emptyset_o$ is not known at this stage, it is not possible to make this correction. Instead, it is assumed that the average value of $\emptyset_o$ is about 1°, a reasonable approximation of the beam mispointing effect is:

$$(\emptyset/\emptyset_o)^1 = \emptyset/\emptyset_o - 0.1$$

Receiver Antenna Patterns (Figure 4)

From the 1977 Final Acts:

		θ^1
$R = -12\ (\theta/\theta_o)^2$	$0 \leqslant \theta \leqslant 0.707\ \theta_o$	(2.27^o)
$= -(9.0 + 20\ \log_{10}\ \theta/\theta_o)$	$0.707\ \theta_o < \theta \leqslant 1.26\ \theta_o$	(3.27^o)
$= -(8.5 + 25\ \log_{10}\ \theta/\theta_o)$	$1.26\ \theta_o < \theta \leqslant 15.14\ \theta_o$	(28.25^o)
$= -38$	$15.14\ \theta_o < \theta$	
$RX = -25$	$0 \leqslant \theta \leqslant 0.25\ \theta_o$	(1.45^o)
$= -(30 + 40\ \log_{10}\lvert\theta/\theta_o - 1\rvert)$	$0.25\ \theta_o < \theta \leqslant 0.44\ \theta_o$	(1.79^o)
$= -20$	$0.44\ \theta_o < \theta \leqslant 1.4\ \theta_o$	(3.52^o)
$= -(30 + 25\ \log_{10}\lvert\theta/\theta_o - 1\rvert)$	$1.4\ \theta_o < \theta \leqslant 2\ \theta_o$	(4.60^o)
$= -30$	$2\ \theta_o < \theta \leqslant 7.24\ \theta_o$	(14.03^o)
$= -(8.5 + 25\ \log_{10}\ \theta/\theta_o - 1)$	$7.24\ \theta_o < \theta \leqslant 15.14\ \theta_o$	(28.25^o)
$= -38$	$15.14\ \theta_o < \theta \leqslant \theta$	

where θ is the nominal satellite separation

θ_o is the half-power beamwidth $= 1.8^o$
for a 1 metre dish at 12 GHz

To accommodate the interference introduced into the uplink it is assumed that individual satellites within a cluster may have to be moved ± 0.5°. Thus two adjacent satellites may be 1^o closer than the nominal separation determined in the downlink plan. Hence the receiver discrimination must be computed for a reduced separation $\theta^1 = \theta - 1$. Strictly speaking this would correspond to the topocentric displacement which is, on average, 10% higher than the geocentric separation.

Figure 5a gives the tradeoff between nominal geographic spacing ($\varnothing/\varnothing_o$) and nominal satellite spacing (θ) for cases (a) through (d) above, and for a total discrimination of 40 dB. These curves will be generally conservative. Figure 5b gives the same curves for a total discrimination of 35 dB, in this case the curves would be closer to a lower bound. Because of the many break points in the antenna envelope patterns these curves also exhibit breakpoints.

Example

For two neighbouring service areas located such that the worst case $\varnothing/\varnothing_o$ (found from a beam fitting exercise) is 0.6 the following options are available:

1) Conservative Limits:

- Satellites at least 4° apart, adjacent-channel, cross-polar
- Satellites at least 8° apart, adjacent-channel, co-polar
- Satellites at least 26° apart, co-channel, either polarization
- Satellites coincident, adjacent plus one or more channel, either polarization.

2) Absolute Minimum Requirements:

- Satellites coincident, adjacent-channel, cross-polar
- Satellites at least 6° apart, adjacent-channel, co-polar
- Satellites at least 19° apart, co-channel, either polarization.

Conclusion

A set of curves giving bounds on service area and satellite separations to permit frequency re-use are derived. These curves are based on pessimistic simplifying assumptions. Specific situations may arise when satisfactory service can be obtained for a combination of service area and satellite separations below that given. A more rigorous computer analysis will be required in these cases. In general, however, these curves should provide useful insight for manual planning or for checking a computer generated plan.

LIST OF FIGURES

...2

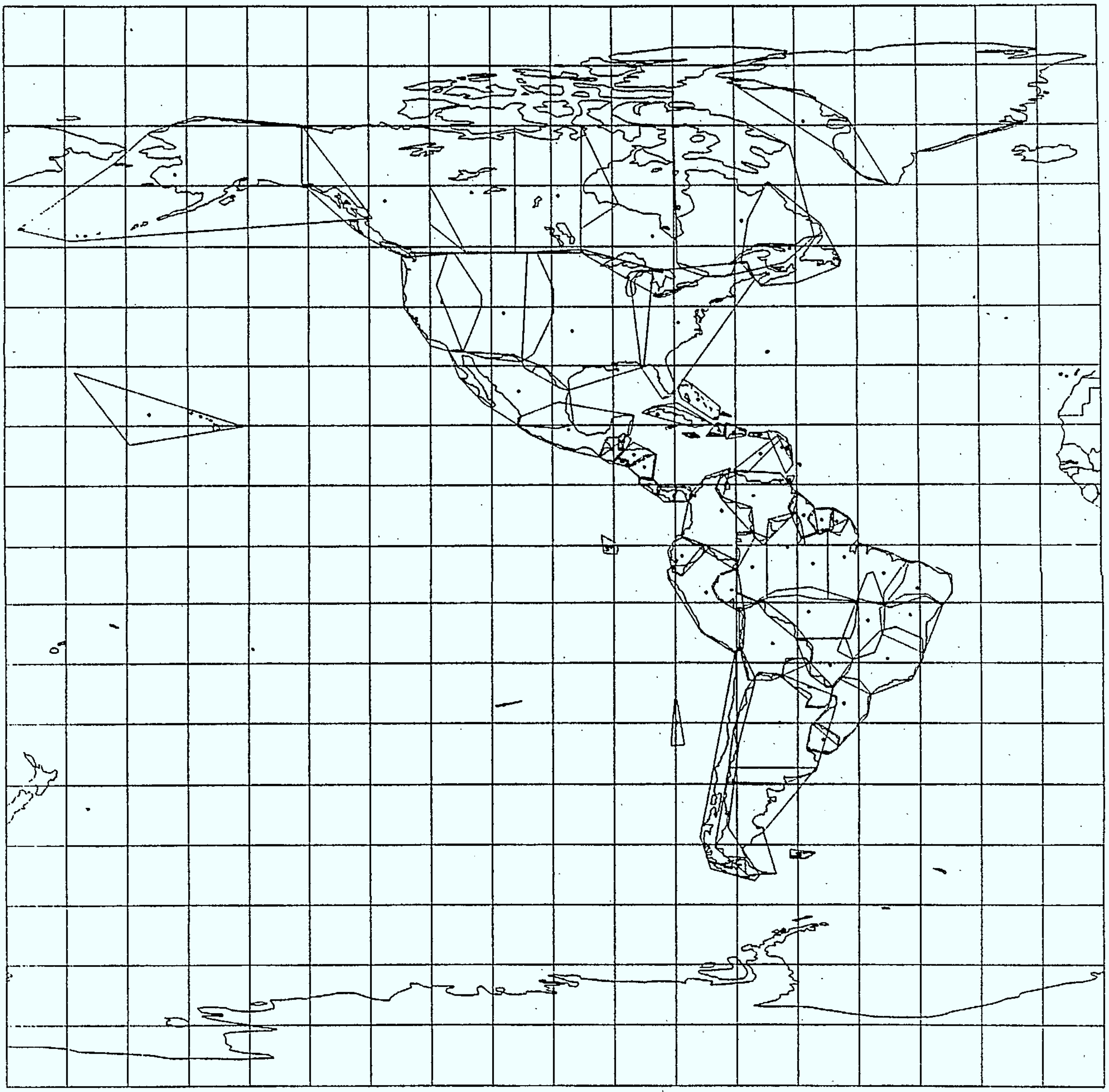


FIGURE 1. POSSIBLE REGION 2 SERVICE AREAS

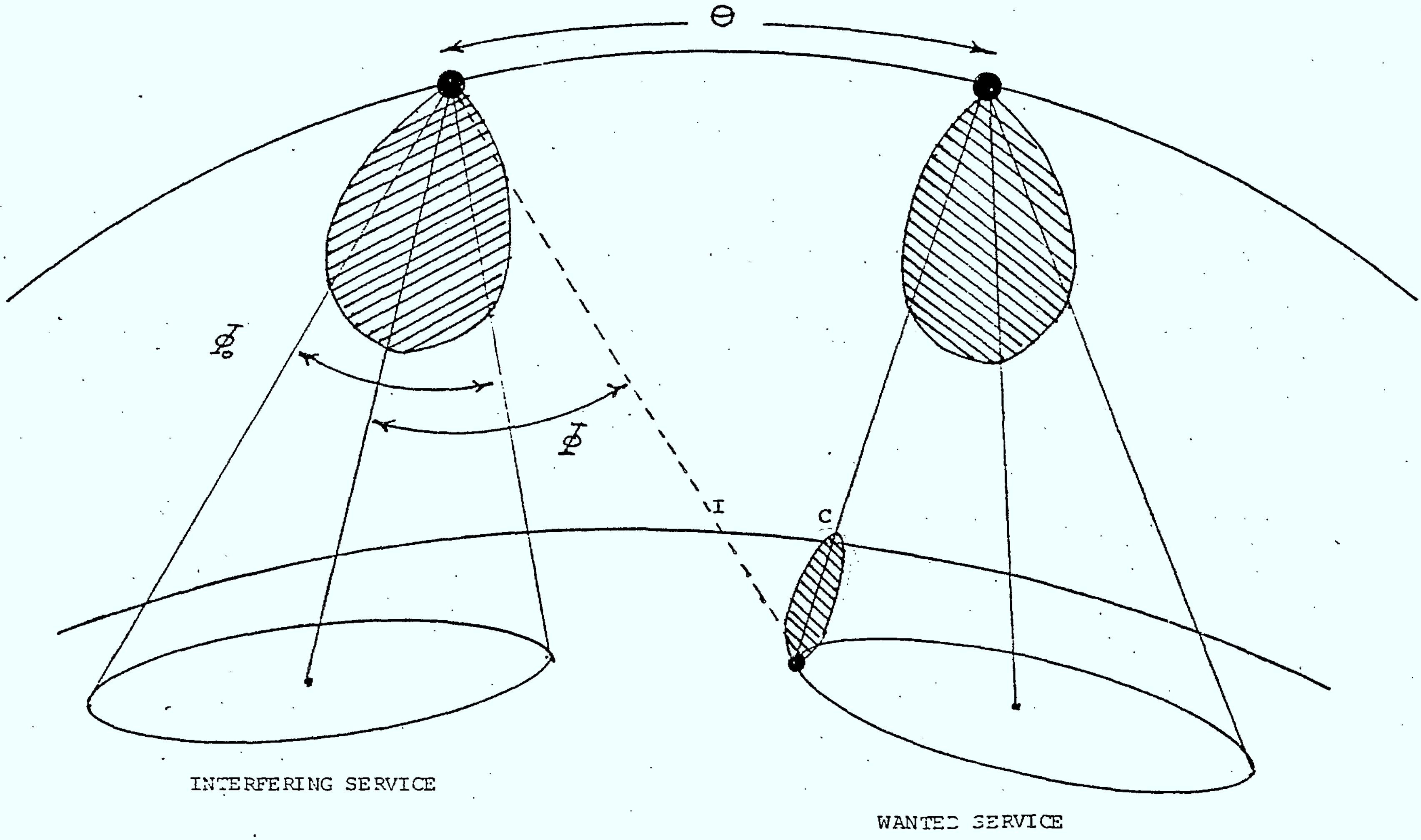


Figure 2 Relationship Between Geographic Separation $(\frac{\emptyset}{\emptyset_o})$ and Orbital Separation (θ) to Meet a Given Carrier to Interference Ratio $(\frac{C}{I})$

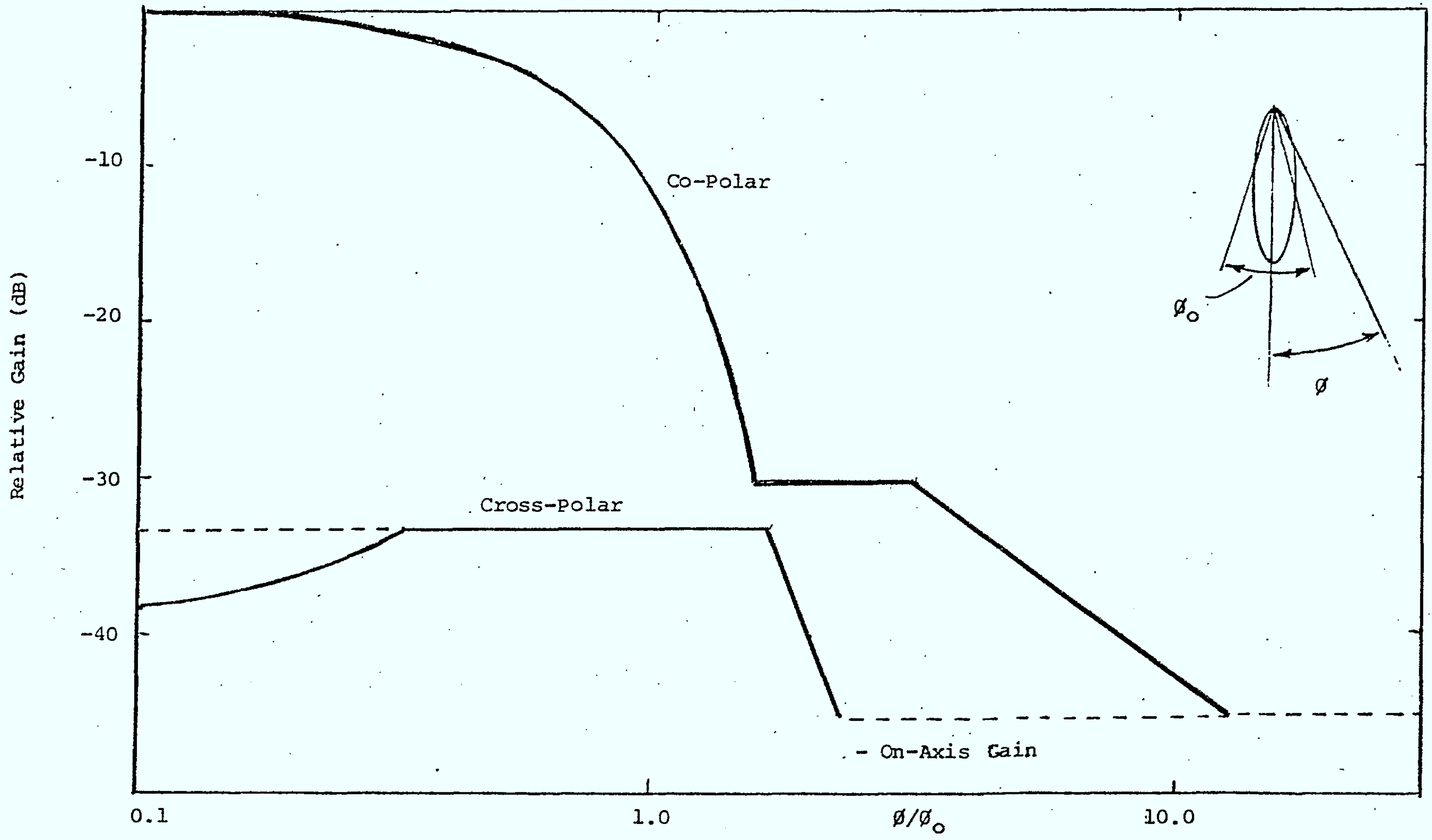


Figure 3a Broadcast Satellite Antenna Pattern (1977 Specification)

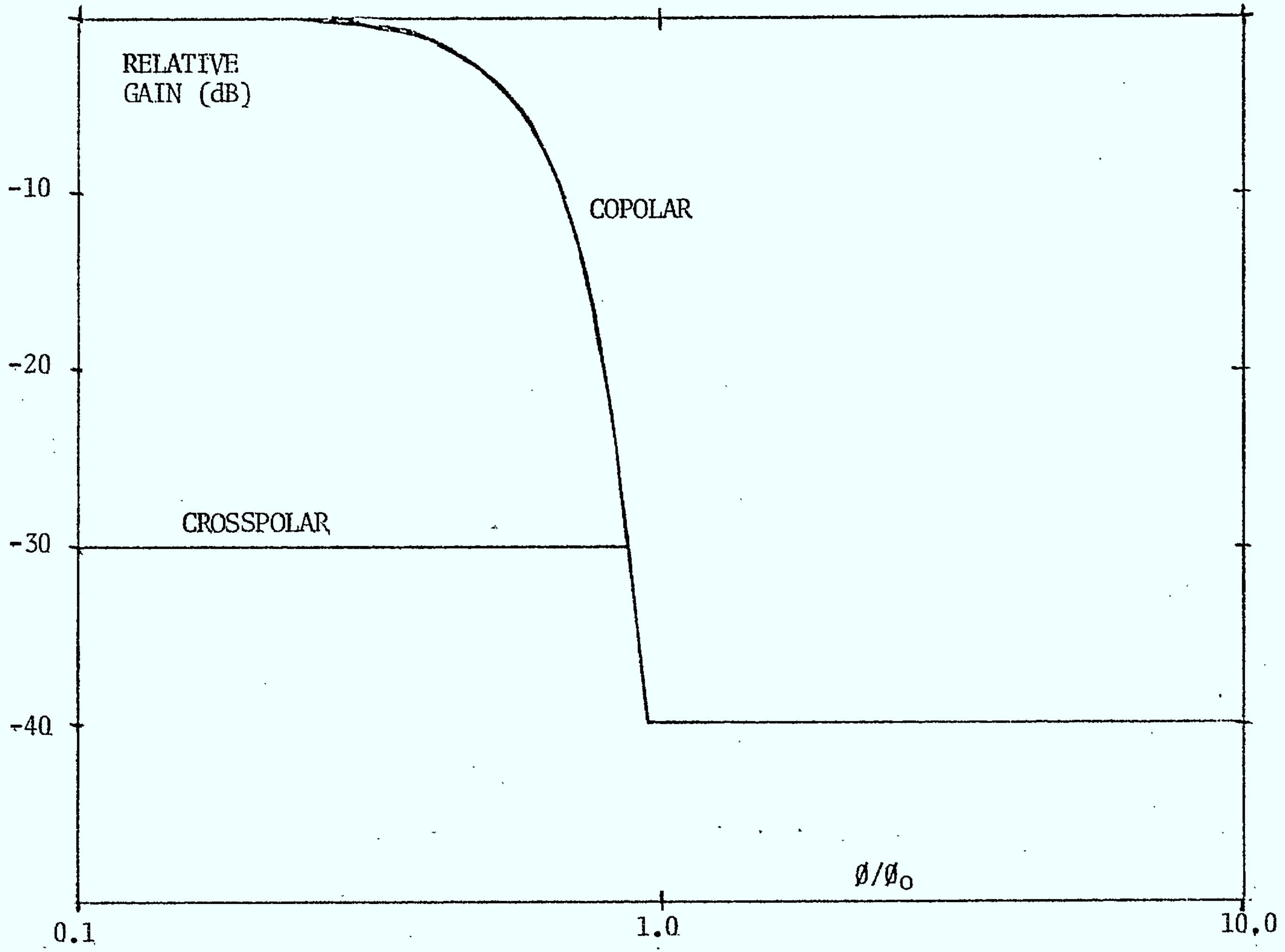


FIGURE 3b BROADCAST SATELLITE ANTENNA PATTERN
(ASSUMED ADVANCED DESIGN)

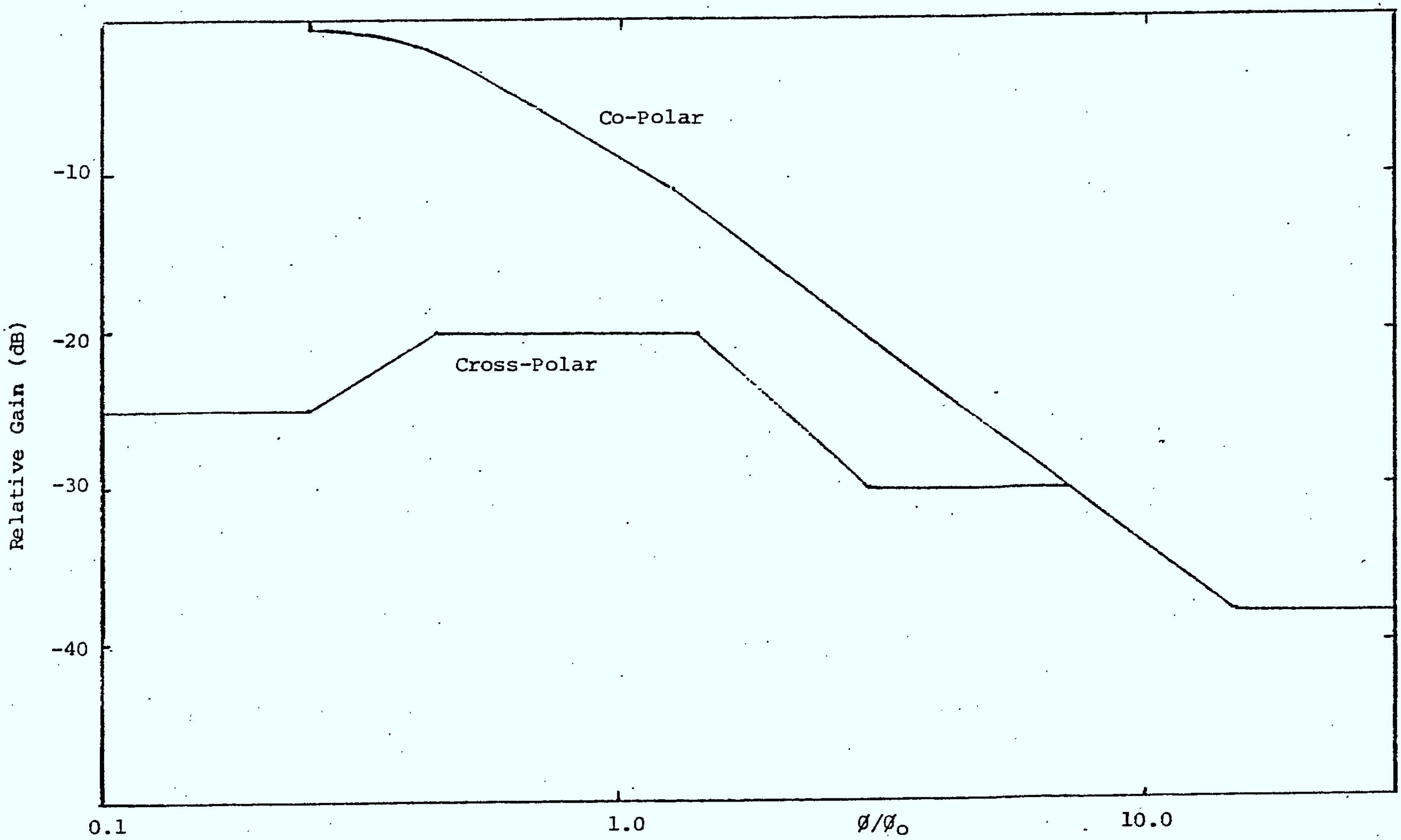
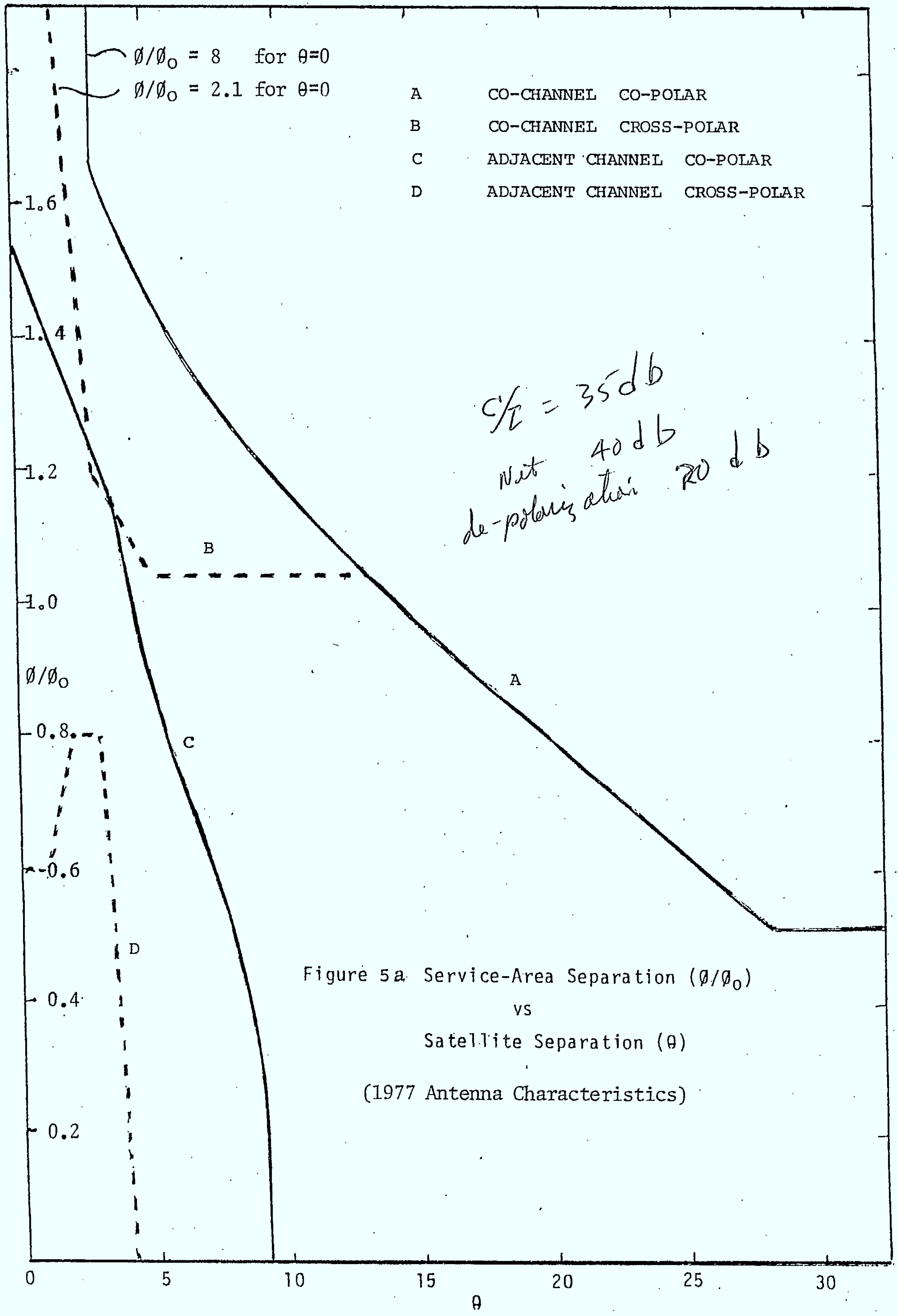


Figure 4 Earth-Terminal Antenna Pattern (1977 Specification)



C/I = 35db

Net 40db

de-polarization 20 db

Figure 5a Service-Area Separation (Ø/Ø$_0$)

vs

Satellite Separation (θ)

(1977 Antenna Characteristics)

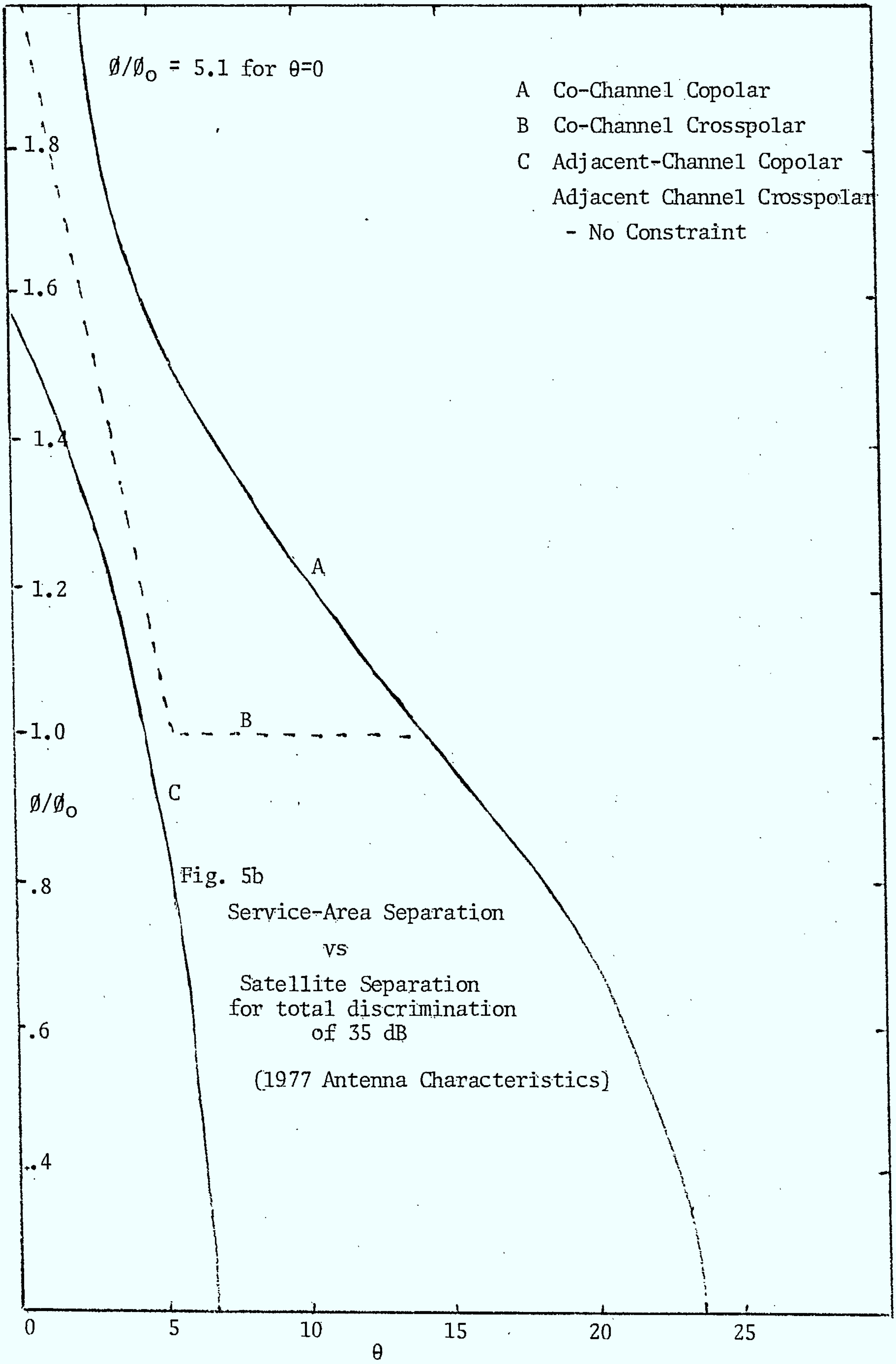


Fig. 5b

Service-Area Separation vs Satellite Separation for total discrimination of 35 dB

(1977 Antenna Characteristics)

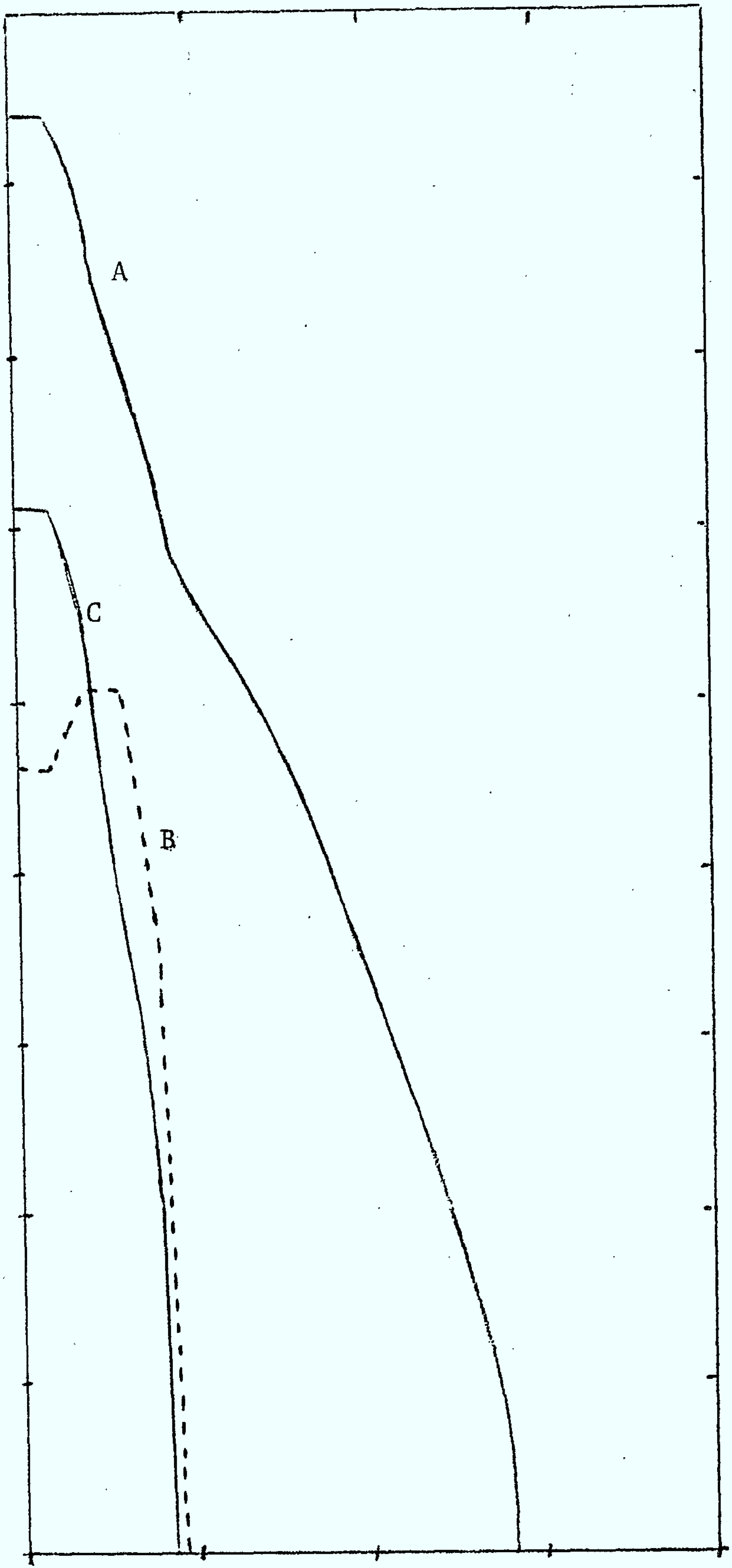


Figure 5c Service-Area Separation ($\emptyset/\emptyset_o$)
vs
Satellite Separation (θ) for a Total
Discrimination of 30 dB

(1977 Specification)

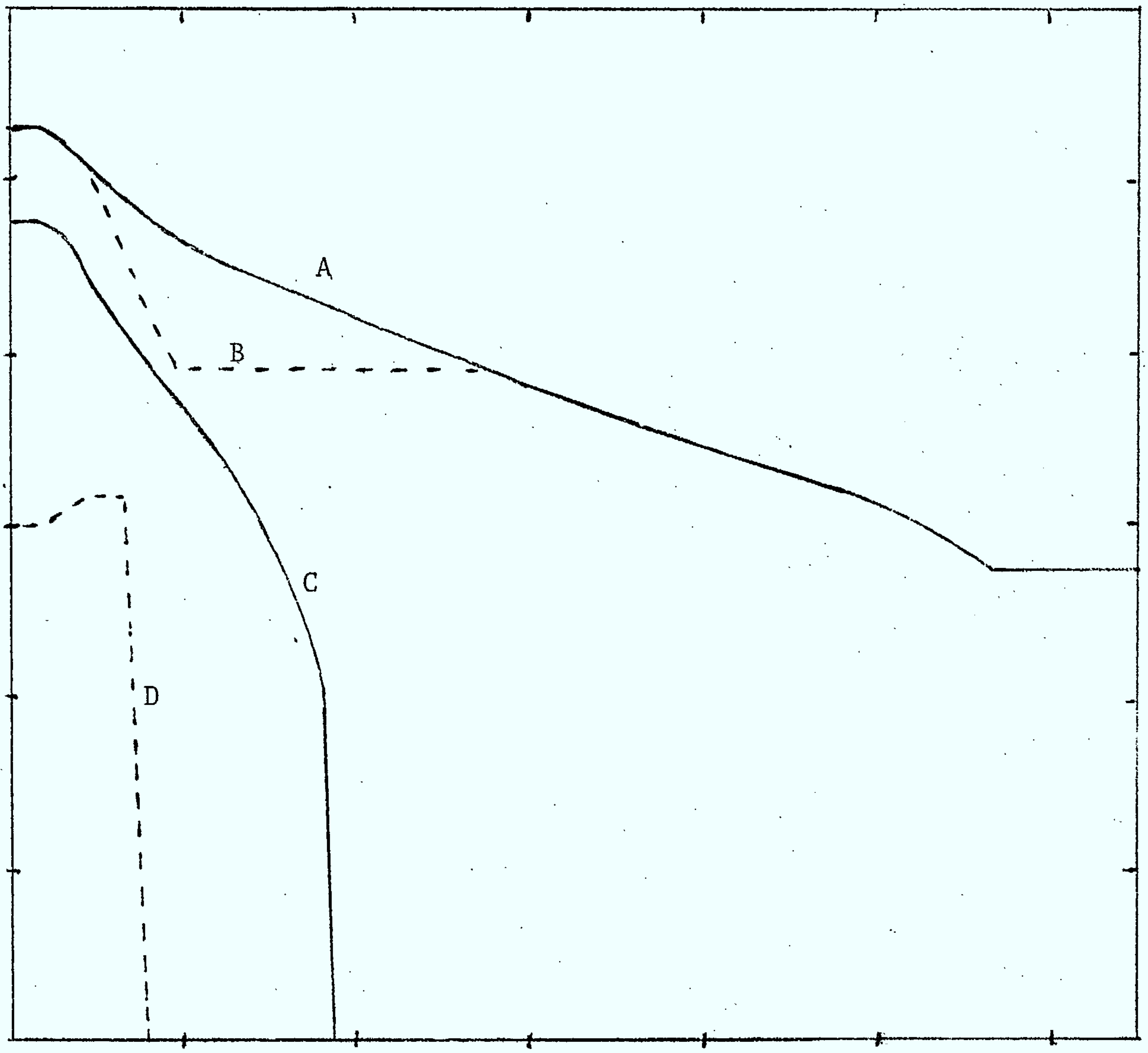


Figure 6a Service-Area Separation ($\emptyset/\emptyset_o$)
vs
Satellite Separation (θ) for a Total
Discrimination of 40 dB

(Advanced Satellite Antenna Design)

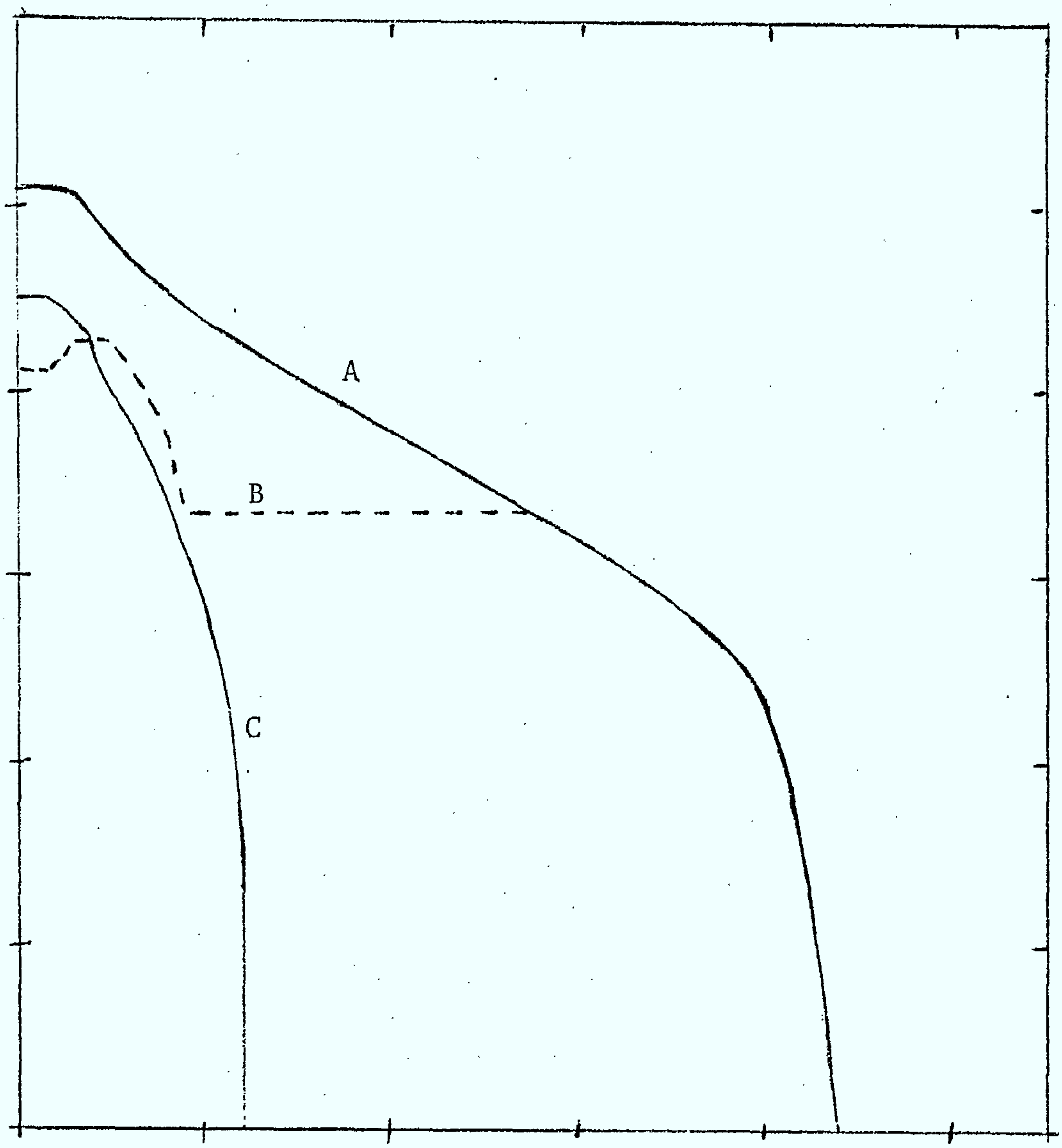


Figure 6b Service-Area Separation ($\emptyset/\emptyset_o$)
vs
Satellite Separation (θ) for a Total
Discrimination of 35 dB

(Advanced Satellite Antenna Design)

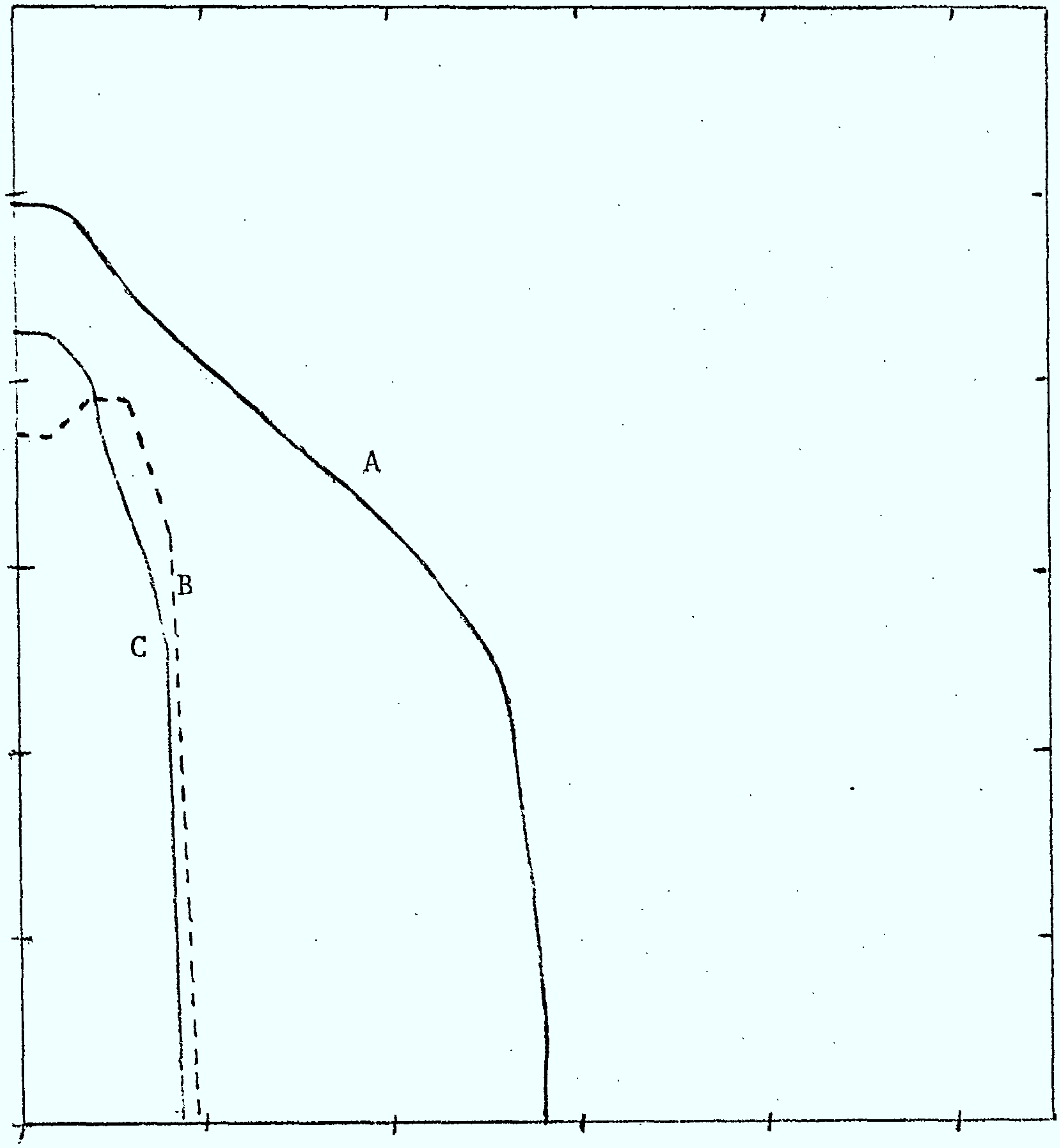


Figure 6c Service-Area Separation ($\emptyset/\emptyset_o$)
vs
Satellite Separation (θ) for a Total Discrimination of 30 dB

(Advanced Satellite Antenna Design)

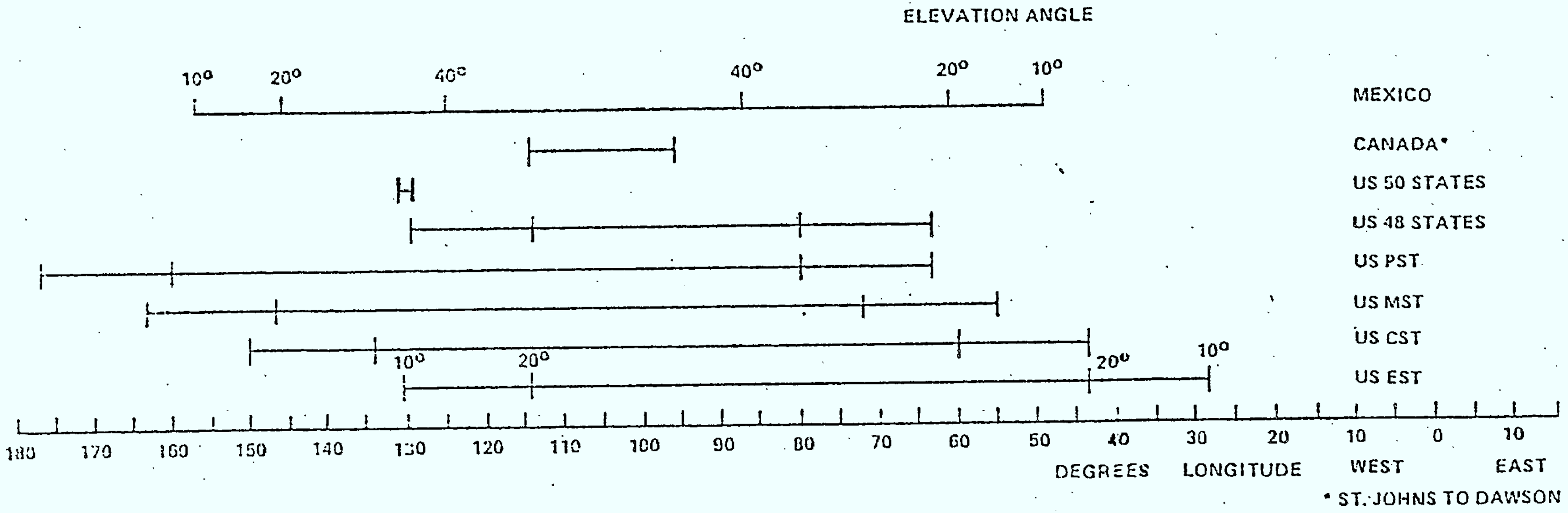


FIGURE 7a AVAILABLE SERVICE ARCS FOR NORTH AMERICA

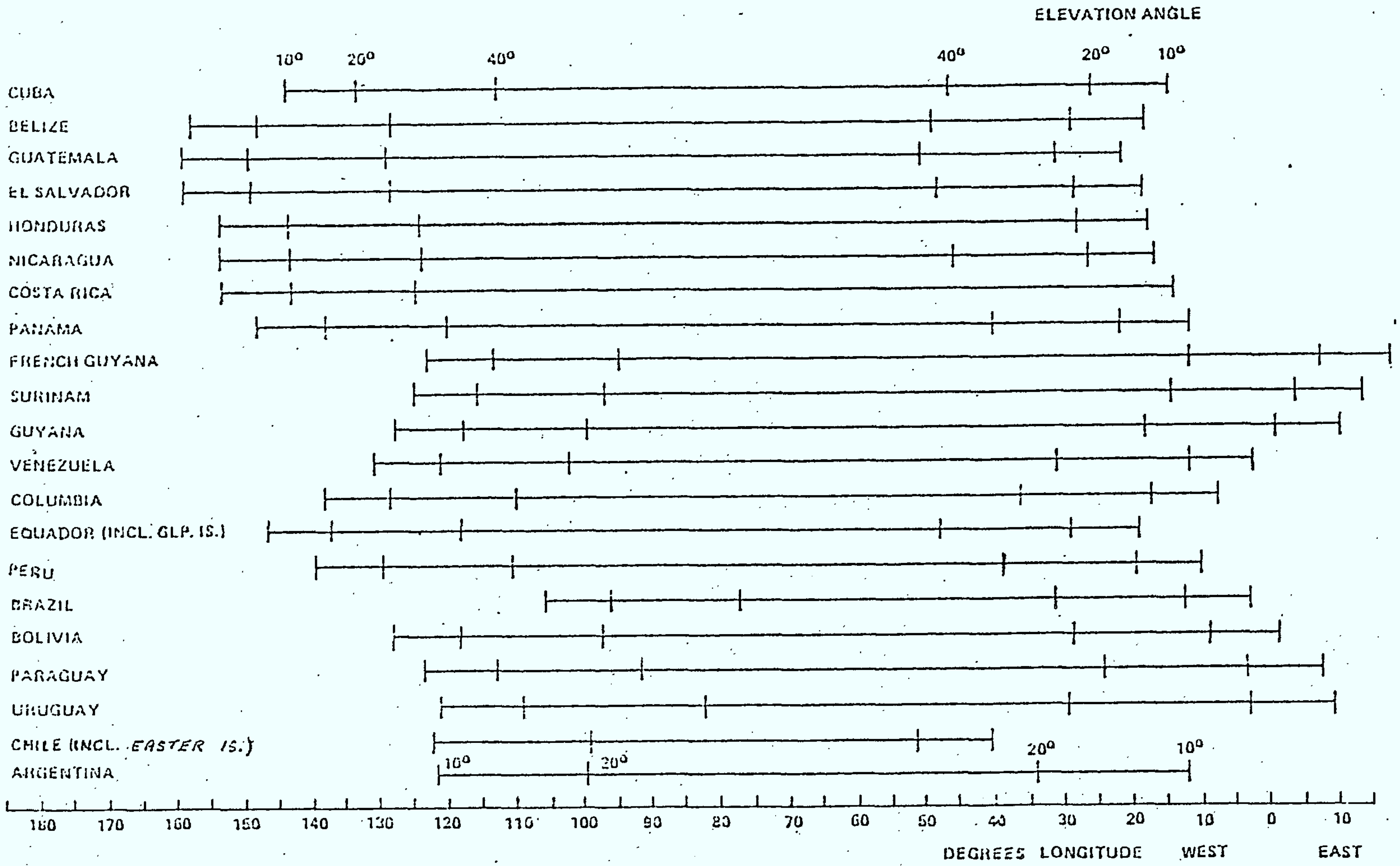


FIGURE 7b AVAILABLE SERVICE ARCS FOR SOUTH AND CENTRAL AMERICA

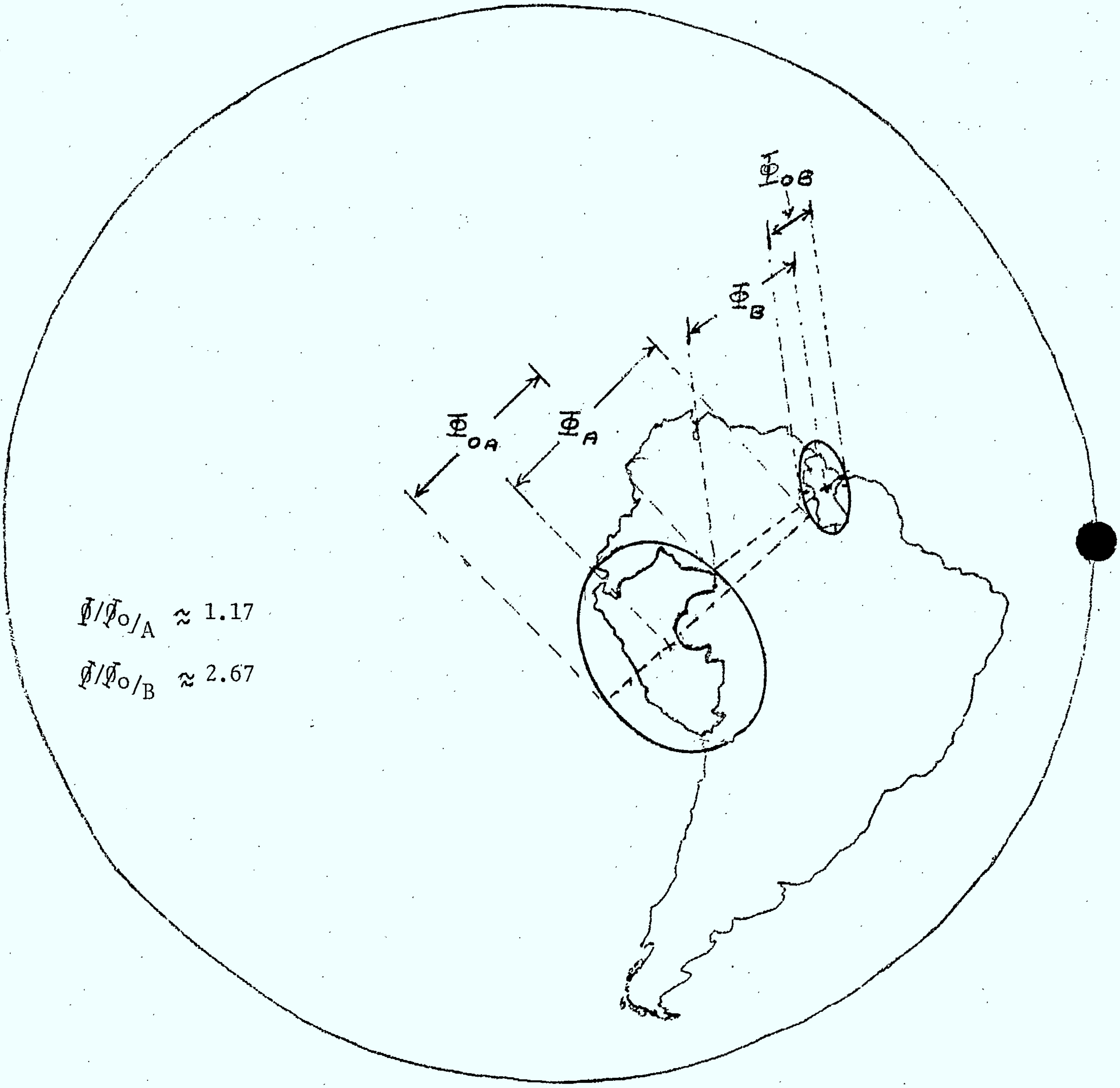
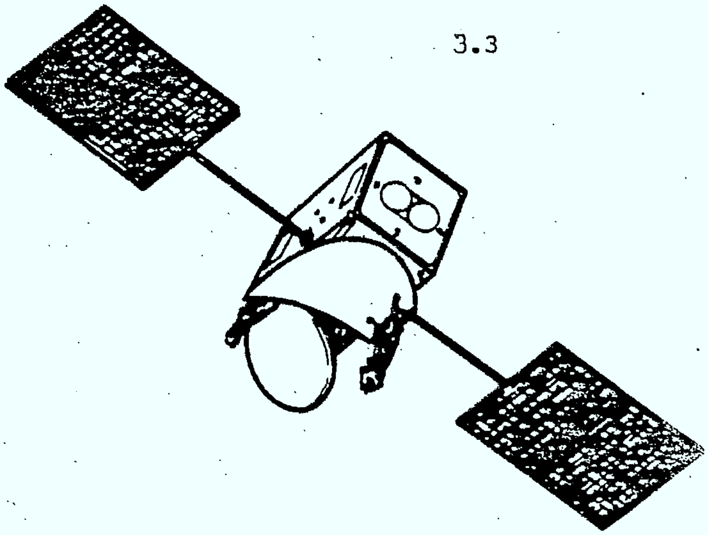


Figure 8 GEOGRAPHIC SEPARATION BETWEEN PERU AND GUYANA FROM 85°W ORBIT LONGITUDE

SAWITZ.

- shaped beams of receiving antenna should also be considered as a means of increasing discrimination



TITLE : SATELLITE DIRECT BROADCAST TV RECEIVERS-TRADEOFF CONSIDERATIONS

AUTHOR : R.J. DOUVILLE

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Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

List of Abbreviations

VHF VSB-AM = Very High Frequency
Vestigial Side Band
Amplitude Modulation

ODU = Outdoor Unit

IDU = Indoor Unit

IFL = Inter Facility Link

LO = Local Oscillator

AFC = Automatic Frequency Control

IF = Intermediate Frequency

EBU = European Broadcast Union

WARC = World Administrative Radio Conference

FET = Field-Effect Transister

LNA = Low Noise Amplifier

MIC = Microwave Integrated Circuit

CRC = Department of Communications Research Centre

PLL = Phase Locked Loop

SCPC = Single Channel Per Carrier

Satellite Direct Broadcast TV Receivers-Tradeoff Considerations

by

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I. Introduction

Earth terminals for reception of TV directly from 12 GHz broadcast satellites must meet very exacting performance requirements. To meet these requirements while maintaining low-cost requires the application of current, and the anticipation of future, technology and techniques. This paper addresses the performance capabilities of current applicable technologies, tradeoff considerations and possible future trends. Emphasis is placed on those parameters which impact on international planning activities.

II. General Considerations

Table I summarizes some of the more general characteristics which the receiver must have and which impose constraints on the ultimate performance which may be achieved. Firstly, the receiver must be tunable to any channel over the available frequency band. This frequency band is generally 400-500 MHz although a tuning range of up to 1000 MHz may be considered. Either continuous tuning or "push-button" tuning may be used. This latter approach is obviously dependent on the channel separations and frequency assignments which remain to be finalized for Region 2 and which are themselves dependent on the achievable terminal performance.

The terminals should be capable of being erected and assembled by the inexperienced consumer although installation by qualified distributors might be conceivable. The size of the antenna impacts on the cost of both transportation and anchoring or "site preparation". These costs can be very high in some countries.

In order to avoid requiring major modifications to TV sets already deployed, the receiver should provide a remodulated VHF VSB-AM output. The growing popularity and availability of TV sets with existing baseband Video Tape Recorder inputs makes it also desirable to provide such an output from the receiver. Increasingly, consideration is being given to incorporating the UHF portion of receivers directly into TV sets. Elimination of the remodulator is highly desirable since cost effective remodulators tend to significantly degrade the ultimate picture quality.

The antenna and outdoor unit for the terminal may be subjected to severe environmental conditions. In Canada, designs have been aimed at an operating temperature range of -45°C to +50°C. In addition to placing severe demands on the performance and reliability of the electronics, this temperature range, as well as harsh wind, precipitation, humidity and solar exposure conditions imposes serious constraints on the choice of materials for both the antennas and outdoor electronics packaging.

The last characteristic listed in Fig. 1 - low cost - is probably the single most important feature since it alone impacts all others. Retail prices ranging from $500 to $1000 have been suggested as realistic indicating material costs must be less than $200 to $500.

III. System Configuration

There are four basic parts of any receiver for TV reception from satellites. These are the antenna, the outdoor unit (ODU), the indoor unit (IDU) and the interfacility link (IFL). The IFL is included here as a separate item although frequently it is ignored in costing the terminals. Typically the IFL is a simple coaxial cable although some schemes require separate lines for frequency tuning in the ODU or for powering the ODU. Since the approach adopted may result in cabling costs in excess of $20-$25 for 30m, the cabling should not be ignored. The remaining components will be addressed in more detail later.

The terminal designer has the choice of single or double conversion configurations. Examples of each are given in Fig. 1.

The single conversion system has the appearance of greater simplicity and lower parts count. Also, should no frontend amplifier be used, the slightly lower noise figure possible for VHF rather than UHF amplifiers would result in a better overall system performance. However, the single conversion system suffers from four major disadvantages. Firstly, the SHF local oscillator (LO) is required to be tunable for automatic frequency control (AFC) for channel selection. The oscillator design is thus very difficult to realize economically particularly over the large operating temperature range. In addition, this approach requires a separate line between IDU and ODU for tuning voltage. In the double conversion approach, the SHF LO may be free running with up to ±5 MHz tolerance on frequency accuracy. AFC and tuning is now applied to the second LO and thus is not subject to extreme temperature variations.

The second disadvantage of the single conversion is that the image frequency typically falls within the receive band at SHF and thus is very difficult to reject. This affects the noise performance as well as the adjacent channel interference problem. In the double conversion approach, the SHF image frequency is now twice the UHF IF frequency away from the signal and can now be rejected using fairly simple microwave filtering.

The third disadvantage is the difficulty in suppressing SHF LO re-radiation in band. Such re-radiation when summed over millions of receivers could seriously impact the performance of the satellite link. In the double conversion approach, the SHF LO is separated from the SHF band by the UHF IF frequency and, like the image, may be suppressed using simple filtering techniques.

A last disadvantage of single conversion is the inability to use several IDUs simultaneously with one ODU. By splitting the

UHF signal, more than one indoor unit can be operated independently and simultaneously. In addition to adding flexibility to the user's terminal, this approach affords a greater degree of commonality with equipment for somewhat larger community systems.

Once a double conversion concept has been adopted, it becomes necessary to define suitable first and second intermediate frequencies (IF). The choice of IF's has been examined in some detail by various bodies most notably, the European Broadcast Union (EBU) [1], [2].

By choosing a sufficiently high 1st IF, both the SHF image and LO are located outside the receive band and are thus more easily suppressed. In addition, the translated spectrum bandwidth becomes a smaller percentage of the 1st IF thus easing design problems at that frequency. A 1st IF of 900-1400 MHz meets these requirement and in addition eases the problem of interference to and from existing terrestrial systems.

It is desirable to choose the 2nd IF to avoid interference particularly by the 2nd LO, both with other received satellite channels as well as into and from conventional broadcast signals in the VHF and UHF band. In particular, a choice of 2nd IF equal to $(2n+1)\ f_s/2$ where f_s is the satellite channel separation (27 MHz WARC '79), would result in the 2nd LO being located exactly in the guard band between received channels. Gaps exist in the VHF and UHF broadcast bands at 68-88 MHz and 100-174 MHz which meet the above criteria. A 2nd IF of 121.5 MHz has been recommended by the EBU. With the general availability of equipment and components at 70 MHz, many systems to date have adopted 70 MHz as the 2nd IF.

IV. The Antennas

The gain, sidelobe properties and cross-polar performances of the antenna must all be considered.

The performance of the receiver is largely defined by the ratio, G/T, of the antenna gain, G, to the terminal noise temperature, T[1]. The importance of the antenna gain is illustrated in Fig. 2 for the case where a G/T of 12.5 dB/K is required. The graph also illustrates the importance of maximizing the antenna efficiency. For the example shown, for a 1 meter reflector, a variation form 50% to 70% in the antenna efficiency makes the difference between the use of a receiver with a very relaxed 4.8 dB noise figure to one with a quite practical 3.8 dB. Should it be desired to use an even smaller reflector, the problem becomes even more acute.

---

[1] Unless otherwise specified, G,T, and G/T as used in this paper do not include the effects of misalignment, rain fade or propagation, polarization or aging losses.

The realized efficiency of an antenna is dependent on many factors including shape accuracy, surface roughnesses, surface reflectivity, feed alignment and positioning accuracy, polarization alignment, reflector alignment accuracy, as well as overall antenna design. Typical effects due to errors in setting the focal length, lateral position and pointing alignment of the feed are illustrated in Fig. 3 for a 1.2m prime focus fed antenna. It should be noted that the errors shown here assume the overall antenna is repointed to compensate for the gross effects of the errors. If this is not done, the loss is much more dramatic. The loss due to surface roughness is a function of the curvature of the antenna used as defined by the ratio F/D of the focal length to diameter. For example, for an F/D of 0.375, a 0.5 mm RMS surface roughness results in a gain loss of 0.2 dB. Lastly, the effects of errors in pointing the reflector are dependent on the beamwidth and therefore the size of the antenna. These effects are shown in Fig. 4. For a 1.0m terminal, a ±0.5° misalignment error results in a 1.0 dB loss in gain.

Several approaches to the antenna and feed design exist which may be used to improve the efficiency. One such, a dual-reflector Cassegrain, is shown in Fig. 5 [3]. This design uses a corrugated scalar feed and shaped subreflector to obtain a net efficiency of 65%. For small antennas, the blockage presented by the subreflector becomes large thus preventing the full performance capability of the Cassegrain to be realized. Fig. 6 shows a prime focus antenna designed and built at the Communications Research Centre which uses a 90° scalar feed to obtain an efficiency of over 70%. The design was selected primarily for its ease of fabrication using volume fabrication techniques.

In addition to the efficiency, the antenna sidelobe properties and cross-polarization behaviour must be considered. Examples of co-polar and cross-polar patterns of a 0.9m antenna employing the high efficiency prime focus feed previously described are given in Fig. 7. Similar curves for conventionally fed 1.0m and 1.6 meter prime focus antennas [4] are shown in Fig. 8. Also shown in these figures is the curve defined in the final acts of the 1977 WARC for Broadcast Satellite receiver-antennas, which specifies a desirable sidelobe behaviour for antennas of this nominal size. Obviously, from the point-of-view of adjacent satellite interference and frequency re-use, these parameters as well as the antenna size are particularly significant. Methods exist for improving them although, in general, a compromise between sidelobe performance and efficiency must be reached. In considering sidelobe performance, the effects of the various feed positioning and alignment factors referred to earlier must also be considered. Fig. 9 illustrates these effects for a 1.2 m antenna. In the case of the lateral displacement, the patterns have been shifted such that maximum gain occurs at 0° thus simulating repointing of the reflector.

In choosing an antenna, other factors such as ease of fabrication, assembly, handling, shipping, and alignment must be considered. The design ideally should have sufficient flexibility to permit its being mounted in locations other than on flat, horizontal surfaces and preferably should be esthetically pleasing. Environmental problems as well as problems of mounting the outdoor unit electronics must be anticipated. An antenna designed and built under contract to DOC and addressing some of the above is shown in Fig. 10. It uses a conductive surface applied to a fibreglass reflector. The entire unit is molded in fibreglass and is capable of 0 to 90° elevation and 360° azimuth adjustment. It is sufficiently rugged to tolerate the weight of a 100 kg weight on its surface without permanent damage and was designed to operate in winds to 100 km/hr.

Other than the Cassegrain and prime focus approaches described above, offset-fed and planar antennas are also being investigated. The offset feed does not lend itself readily to volume production techniques. Planar antenna designs for this application are still in the embryonic stage. The Cassegrain approach has the advantage that the ODU electronics, located behind the reflector is afforded a degree of environmental protection and no feeder loss exists between the feed and ODU. In addition, in the case of linear polarization, polarization alignment is somewhat simplified. However, since the Cassegrain antenna consists of three separate pieces, it is more expensive to fabricate, is more difficult to assemble and increased care is required in aligning the elements of the antenna. The conventional "J-hook" prime focus antenna adds feeder loss prior to the ODU, typically requires a specially fabricated waveguide ODU-to-feed interconnect and is difficult to design to provide both high efficiency and good cross-polar performance. By mounting the ODU behind the feed as shown in Fig. 11, these problems of the prime focus are overcome.

In view of the above considerations, the "best" approach appears to be the prime focus with the ODU mounted at the focal point.

V. The Outdoor Unit

Fig. 12 illustrates in block form the components used in the ODU. The first element shown is an input filter. The function of this filter is to suppress the image frequency and to prevent any LO reradiation. In the case of the double conversion receiver, it may be a simple piece of waveguide beyond cutoff. Image suppression of >60 dB and LO suppression of >40 dB may be readily achieved if a first IF of 900-1400 MHz is used. In the case of the single conversion receiver, this filter would be required to be tunable with the LO. In addition, since it would be narrowband, it would be lossier thus degrading the receiver noise temperature.

The next element is the FET low-noise amplifier (LNA). It is shown in broken lines since in some designs, no LNA is used.

Typically, this amplifier uses two FETs and provides about 15 dB of gain. At present, an overall noise figure of 4.5 dB is achieved reproducibly. Fig. 13 illustrates the current and projected status of FET device state-of-the-art noise performance. Using devices such as those projected a noise figure of 1.5 to 2.0 dB is theoretically possible for a multistage amplifier. However, allowing for volume fabrication methods and recognizing that more than two stages of FET gain will probably be uneconomical, a receive noise figure of 3.0-3.5 dB might be expected to be achieved using these devices. The current cost of suitable FETs is still high ($50-$100 each). However, it is expected this cost will drop dramatically once the volumes increase.

The next element in the ODU is the SHF mixer. In approaches in which no FET LNA is used, the mixers are designed such that signal energy normally translated to the image frequency and dissipated is reactively terminated and thereby recovered at the IF. The resultant low conversion loss coupled with a low noise IF amplifier permits the realization of receiver noise figures as low as 2.5-4.0 dB. Fig. 14 illustrates a microwave integrated circuit (MIC) approach developed at CRC for demonstration with Hermes. This unit, followed by a 2.0 dB noise figure amplifier gave a 6.0 dB receiver noise figure. Other MIC approaches have resulted in noise figures as low as 3.5 dB [5]. A unique approach developed by NHK labs in Japan has yielded noise figures as low as 3.0 dB [6]. One of the primary difficulties with such reactive-image designs is that of reproducibility particularly where bandwidths in excess of 40 MHz are required. This results from the frequency sensitive nature of those parameters which provide the image recovery feature. Where an FET LNA is used, a simple MIC balanced mixer with typically a noise figure of 8-10 dB is employed.

The next element in the ODU is the local oscillator. Both Gunn diode and FET oscillators are used here. Fig. 15 shows an inexpensive temperature compensated 10.8 GHz Gunn oscillator developed at CRC which gave a temperature stability of ±3 MHz over the -45°C to +50°C temperature range. One disadvantage of the Gunn oscillator is the excessive heat dissipation required (e.g up to 4.0W). Fig. 16 shows an MIC FET oscillator. Such a unit used with either a dielectric resonator or temperature compensated cavity is capable of meeting the temperature stability requirements. In those cases where it is desired to tune the LO, difficult turn-on and turn-off problems may be encountered. In addition, active elements used for AFC (e.g. diodes) normally suffer from temperature drifts. One possible approach is to either injection-lock or phase-lock the LO to a reference generated in the IDU.

The FM noise properties of the SHF LO while not stringent for TV reception becomes the limiting factor for those cases where FM radio reception is also required. The noise properties of free-running FET and Gunn oscillators is similar although some question still remains as to both the requirements and the ultimate performance achievable in production.

Following the mixer is a UHF amplifier which typically uses bipolar transistors. Noise figures as low as 1.3 dB may be realized here with 30-40 dB of gain possible from a three-stage amplifier.

Fig. 17 shows a complete ODU which was assembled at CRC and uses the image recovery method. The housing shown in the figure is fabricated of plastic and plated. Fig. 18 shows a unit developed by SED Systems, Saskatoon, Canada which uses an FET LNA. The same antenna feed and LO as in Fig. 27 were used.

Currently, much interest exists in development of a monolithic approach to the ODU electronics. In such a system, the LNA, mixer, LO and UHF amplifier may all be fabricated on one semiconductor substrate. The result would be an extremely compact and mass-producible approach to the ODU. At present, this approach is in its very early stages of development. Some of the problems and consequences which may be worth noting however are:

a) Noise figures as low as those achievable using discrete devices will be difficult to maintain while simultaneously optimizing the fabrication process for the various other functions
b) temperature stabilization of the LO will be very difficult to accomplish except possibly by phase locking to a stable reference in the indoor unit.
c) problems may be anticipated due to the inevitable interactions at microwave frequencies between the various closely packed components leading to possible problems of spurious generation.
d) with the very high active component count and resultant complexity of the overall ODU circuit, fabrication yields may prove too low to permit the savings which the use of monolithic circuits promises.
e) the design, once developed, is very inflexible and thus difficult to modify to meet a variety of requirements or changing conditions.

In summary, the full benefits of the monolithic approach to ODU design may prove difficult to realize and might in any case, be expected to compromise the acceptable G/T requirement for direct broadcast receivers.

VI. The Indoor Unit

Fig. 19 shows the block diagram of a typical indoor unit. One of the most difficult circuits to realize in this unit is the UHF tuner. The primary reason for this is the very large percentage bandwidth which must be accommodated. The unit must convert any channel within frequency bands as wide as 400 to 800 MHz, depending on system requirement and design adopted, to the second IF.

A noise figure of less than 12 dB is required to avoid the need for more UHF gain in the ODU. The UHF oscillator must be tunable over the full bandwidth while remaining sufficiently stable to permit consistent channel capture and lock-up. In addition, it must not degrade the receiver FM noise properties. Lastly, the tuner must be designed to avoid LO leakage out of the connector resulting either in radiated interference or in interference into other receiver IDU's.

One of the most difficult requirements for the tuner is that it must selectively reject the UHF image at twice the 2nd IF from the signal. In order to avoid degradation of the output C/N by noise in the image, an image rejection of 15 dB is sufficient. However, for that portion of the image band which falls within the signal band, a rejection of greater than 25 dB is desirable. This figure is substantially more difficult to achieve using economical design approaches. The problem is alleviated somewhat by choice of a higher 2nd IF since the consequent inband image bandwidth is decreased. By choosing the 2nd IF such that the image falls between channels, this problem may be further reduced although the problem of LO interference mentionned in section III is aggravated. A compromise solution might be possible. For the case of a 70 MHz 2nd IF, the image is located only 5 MHz away from the center of a channel assuming 27 MHz channel spacing. Obviously it would be desirable to avoid the simultaneous allocation of both channels to the same broadcast region.

One approach to the tuner design is shown in Fig. 20. This design uses an image cancellation approach to image rejection and therefore does not require voltage tunable filters. The design illustrated provided > 25 dB image rejection over a 400 MHz image band.

Present designs use fairly conventional VHF and baseband circuit design approaches for the remainder of the IDU electronics. Some care is needed particularly in the design of the 70 MHz noise limiting filter to ensure that both the receiver differential gain and phase margins are not exceeded. A recent development is the use of phase-locked-loop (PLL) integrated circuits for the demodulator. Not only is the design more reproducible and less costly than the discrete components approach, it also is capable of providing up to 1.5 dB of improvement in the threshold performance. Designs in the near future may be expected to incorporate essentially all of the IDU circuitry from the tuner to the final baseband circuits onto one integrated circuit.

Improvements possible by using modified pre- and de-emphasis networks have been investigated at CRC. Results to date suggest improvements of up to 2.5 dB may be realized in the "clear weather" performance of direct broadcast receivers.

Methods for the provision of radio programming through satellite broadcast systems are being investigated in the Canadian Department of Comunications. Two such schemes are the audio subcarrier approach and the single-channel-per-carrier (SCPC) approach. In the first case, the simple addition of a second audio subcarrier filtering and demodulation network similar to that already used is required. This approch obviously suffers from a number of limitations including; restricted number of additional channels, limited to "associated TV" channel and therefore user inflexible, and lastly, the additional deviation requirement compromises the available video C/N. The SCPC system most probably will require a splitter at the UHF IF. Assuming FM radio, the radio program receiver would then appear similar to that for a video IDU. Alternative modulation systems, particularly digital, must also be considered. The SCPC approach places stringent requirements on the temperature stability and the FM noise performance of the LO's, both SHF and UHF.

VII. Terminal Performance

Table II summarizes the projected performance of satellite TV receivers using some of the improvements discussed earlier. For comparison, the parameters presented in CCIR Rep. 473-2 [7] are also presented. The following summarizes the assumptions made in arriving at a value for each parameter.

Gain of Antenna - An efficiency of 70% has been shown to be reproducible in the Canadian trials. Rep. 473-2 assumes 50% thus resulting in a difference of $10\log_{10}(70/50) = 1.5$ dB. This value has been reduced by 0.2 dB to allow for surface tolerances on the reflector resulting in a net difference of 1.3 dB.

Coupling Loss - A value of 0 dB is used here. With the antenna feed designed as an integrated part of the ODU, any coupling losses which may occur are incorporated into the ODU noise figure. It is worth noting that the antenna efficiency of 70% used above already incorporates a coupling loss which, if allowed for, would result in a net antenna efficiency of 73% (0.2 dB > 70%).

Pointing and Polarization Losses - From Fig. 4, for a 1 meter antenna, a ±0.5° error in pointing results in 1.0 dB loss of antenna gain. The antenna may initially be pointed more precisely by observation of the received signal strength. However, observations during the Canadian DBS experiments have shown that a value of ±0.5° is realistic to allow for ground-heaving or other such antenna mounting surface movement. For a linearly polarized signal, polarization losses have been found to be negligible. From Fig. 3 and assuming the feed position is accurate to ±0.5 cm and aligned to ±2 degrees, a total of 0.2 dB gain loss may be arrived at for a 1.0 meter antenna.

Aging Degradation - The reproducibility and aging characteristics of terminals are currently being studied by the Canadian DOC. However results are not yet available and therefore the value of 1.0 dB used in Rep. 473-2 has been used.

Antenna Temperature Referred to Input - The value of 150K used here is that adopted at the 1977 WARC. It is worth noting that, for elevation angles greater than 10°, an antenna temperature less than 50K is typically encountered under "clear weather" conditions. The value of 150K was adopted to allow for the higher sky temperatures encountered during rainfall. It might therefore be most appropriate to incorporate the G/T degradation due to rainfall into the rain margin since effectively the "best" system performance would be somewhat higher than that suggested in Table I. In particular, an increase from 6.2 dB/K to 6.5 dB/K and 10.7 dB/K to 11.65 dB/K would result for the two terminals in Table I with corresponding improvements in "clear weather" C/N and S/N.

Noise Temperature of Coupling - It is worth noting the full impact of the coupling loss on the system G/T particularly in the case of low noise temperature systems. In the case of Rep. 473-2, a 0.5 dB coupling loss and 50K antenna temperature would result in a total of 0.62 dB decrease in G/T. For the "Projected" performance case, a total decrease of 0.77 dB would result. The resultant "clear weather" performance obviously would also drop by the same amount.

Receiver Noise Temperature - From section V, a receiver noise figure of 3.5 dB may be expected to be practical and realistic in the near future for both the FET or image-enhanced mixer approaches. It would also appear the 6 dB figure in 473-2 is overly pessimistic.

Terminal Effective G/T - A total of 4.6 dB improvement in receiver G/T from that recommended in Rep. 473-2 may be considered to be realistic for future terminals. As explained earlier, this corresponds to a difference of 5.15 dB in "clear weather" performance.

Table II compares the operational performance and margins for a hypothetical system using two terminals with the above performance and incorporating selected changes into the electronics. The values specified for propagation loss are those which experiments in Canada have suggested may be exceeded only during very occasional and brief extremes of cloudburst activity. A terminal noise bandwidth of 18 MHz with a signal deviation of 6 MHz has been shown to be a good compromise between the need for system margin and the need for good "clear weather" reception.

Subjectives tests in Canada have shown that a system C/N of 11 dB can provide a video quality which is rated good to excellent. In the examples described here, the terminal specified in Rep. 473-2 would not provide this "clear weather" performance and in addition would have insufficient margin. On the other hand, by anticipating even moderate improvements in the terminal performance capabilities, both requirements can be met and exceeded by several dB using a satellite with a minimum edge-of-beam EIRP of less than only 58.0 dBW and only a 1 meter

Acknowledgment

The author wishes to express his great appreciation to M. Bouchard for his contributions to the paper and for helpful discussion. Thanks also are extended to B. Clarke for contributions to the design of the electronics and A. Kong for the antenna designs. Particular thanks are extended to J.-G. Dumoulin for his much appreciated support in obtaining antenna patterns.

Table I

General Receiver Characteristics

- Multichannel Tunability
- Small, Portable and Easily Installed
- Compatible with Existing TV Sets
- Withstand Severe Environmental Stresses and Operating Conditions
- Low Cost

Table II

Terminal Figure of Merit

		Rep. 473-2	Projected
Gain of Receiving Antenna (1 m)	(dB)	38.7	40.0
Coupling Loss	(dB)	-0.5	0.0
Pointing and Polarization Loss	(dB)	-1.0	-1.2
Aging and Degradation	(dB)	-1.0	-1.0
Net Antenna Gain	(dB)	36.2	37.8
Antenna Temperature Referred to Input-			
Clear Air	(K)	44.6	50.0
Rain		133.7	150.0
Noise Temperature of Coupling	(K)	31.6	0.0
Receiver Noise Temperature	(K)	864.5 (6.0 dB)	359.2(3.5 dB)
Total Effective Noise Temperature -			
Clear Air	(K)	940.7	409.2
Rain	(K)	1029.8	509.2
Terminal G/T - Clear Air	(dB/K)	6.5	11.7
- Rain	(dB/K)	6.1	10.7

Table III

Terminal Performance

		Typical (473-2)	Projected
Satellite EIRP (assumed)	(dBW)	58.0	58.0
Path Loss (40,000 km)	(dB)	-206.1	-206.1
Propagation Loss - Clear Air	(dB)	- 0.5	- 0.5
- Rain	(dB)	- 3.0	- 3.0
Terminal Effective G/T			
- Clear Air	(dB)	6.5	11.7
- Rain	(dB)	6.1	10.7
Boltzmann's Constant	(dB)	-228.6	-228.6
Noise Bandwidth	(dBHz)	74.0 (25 MHz)	72.6 (18MHz)
System C/N - Clear Air	(dB)	12.5	19.1
- Rain	(dB)	9.6	15.6
Threshold C/N	(dB)	10.0	8.5
Margin to Threshold	(dB)	2.5	10.6
System S/N (6 MHz Pk Deviation CCIR Weighted) - Clear Air	(dB)	41.5	48.1
- optimum weighting	(dB)	44.0	50.6

References

1. European Broadcast Union, "Characteristics of the Receiving Installations for 12 GHz Satellite Broadcasting", CCIR Doc. P/79-E, 5 June 1978.

   - "Replies from Industry to EBU Questionnaire on Receivers for 12 GHz", K3-110-E, Jan. 1975.

2. Philips Telecommunicatia Industrie, B.V. "Broadcasting-Satellite Service-Sound and Television", CCIR DOC 10/118-E, 27 April 1976.

3. R.J. Douville, "A 12 GHz Low-Cost Earth Terminal for Direct TV Reception from Broadcast Satellites" IEEE Trans. MTT-25, No. 12, Dec. 1977.

4. Japan, "Characteristics of Ground Receiving Equipment for Broadcasting Satellite Systems in the 12 GHz Band", CCIR DOC. 10/31-E, 7 January 1976.

5. L.E. Dickens, D.W. Maki, "An Integrated Circuit Balanced Mixer, Image and Sum Enhanced", IEEE Trans. MTT-23, No. 3, March, 1975, p. 276.

6. Y. Konishi, "State of the Art in BC Satellite Earth Receivers", 10th International Television Symposium, Montreux, Switzerland, 3-10 June 1977.

7. "Characteristics of Ground Receiving Equipment for Broadcasting-Satellite Systems", CCIR Rep. 473-2.

Tables

Figures

15. A temperature compensated Gunn oscillator for direct-broadcast receivers.

16. An MIC FET oscillator suitable for earth terminals.

17. The CRC outdoor unit with image-enhanced mixer frontend, Gunn diode LO and low-noise UHF bipolar transistor amplifier.

18. The SED outdoor unit with a low-noise FET amplifier and a conventional mixer. The same LO and feed as in the CRC design is used.

19. Block diagram of indoor unit electronics using conventional demodulator.

20. A UHF tuner using the image-rejection concept.

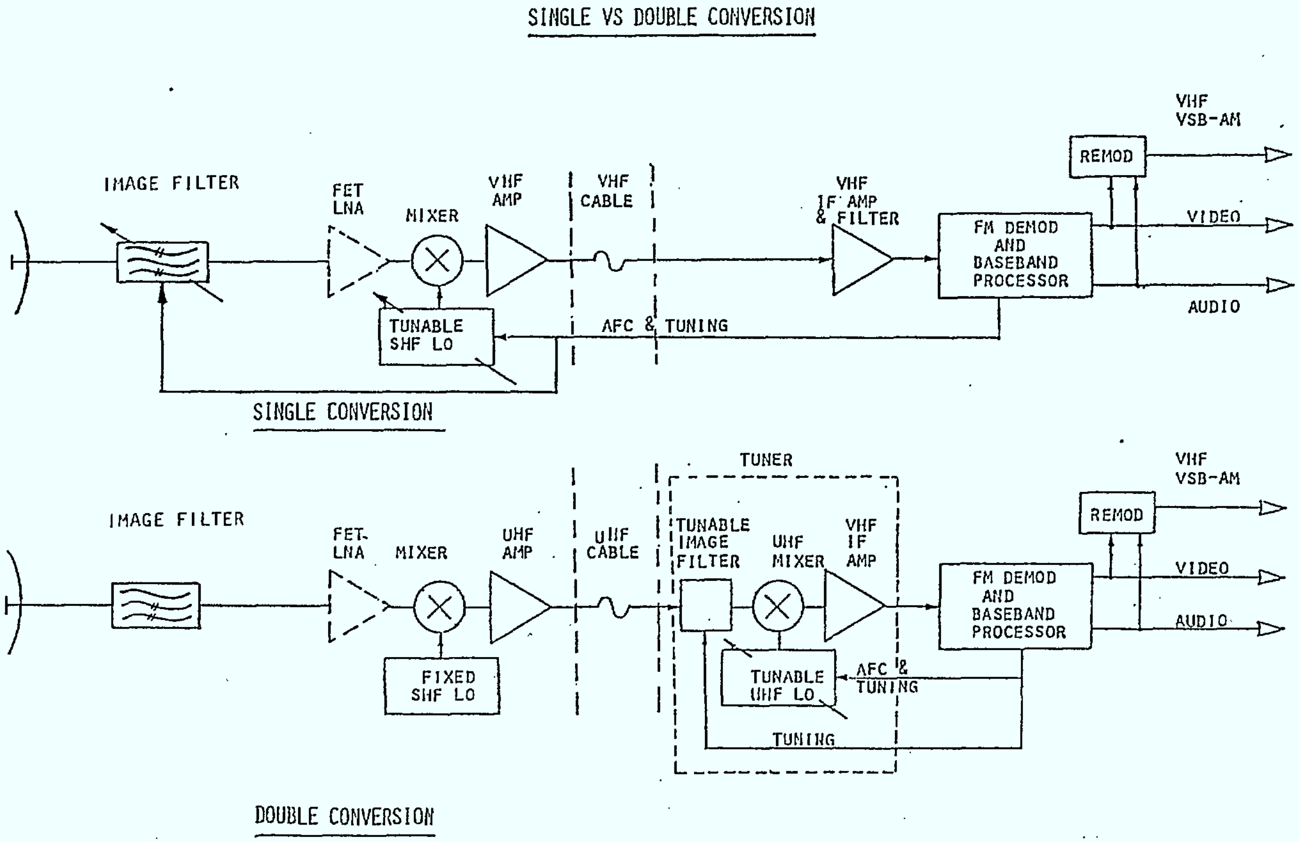


Fig. 1. Typical single and double conversion receiver configuration

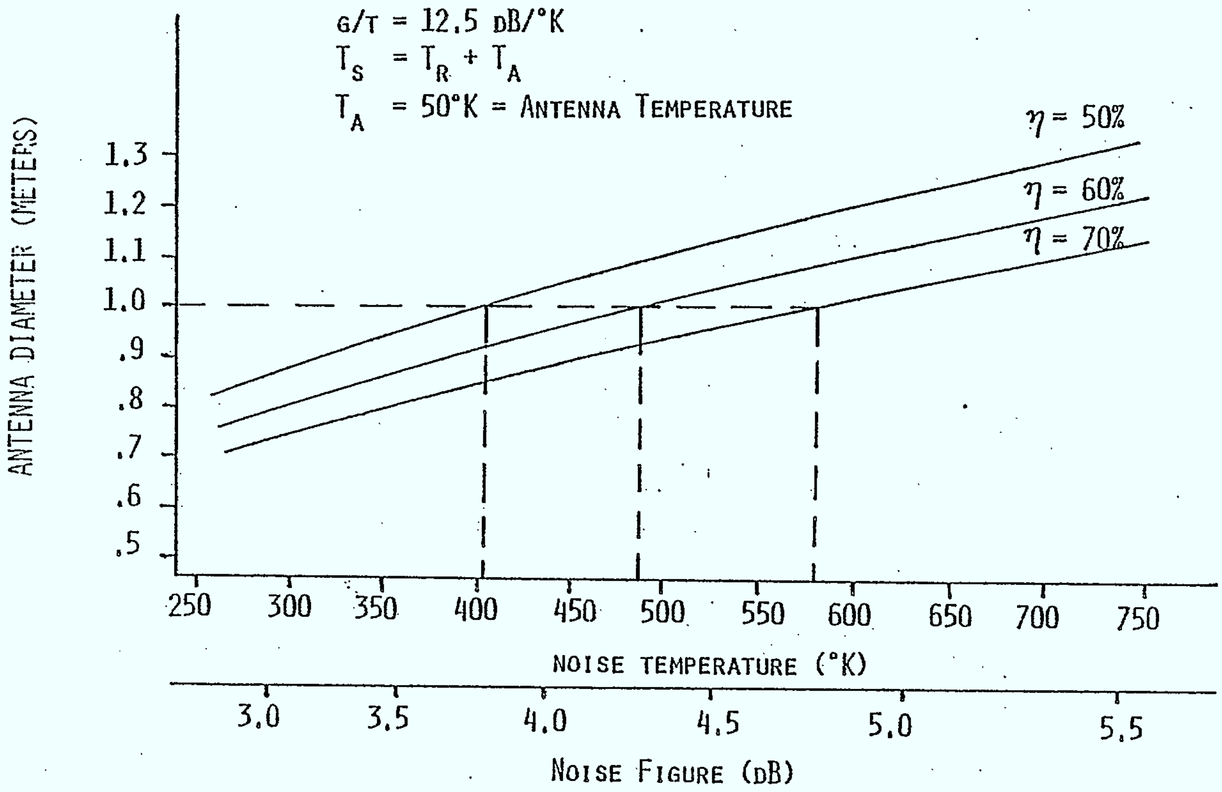


Fig. 2. Antenna diameter to receiver noise figure tradeoffs for G/T = 12.5 dB/K

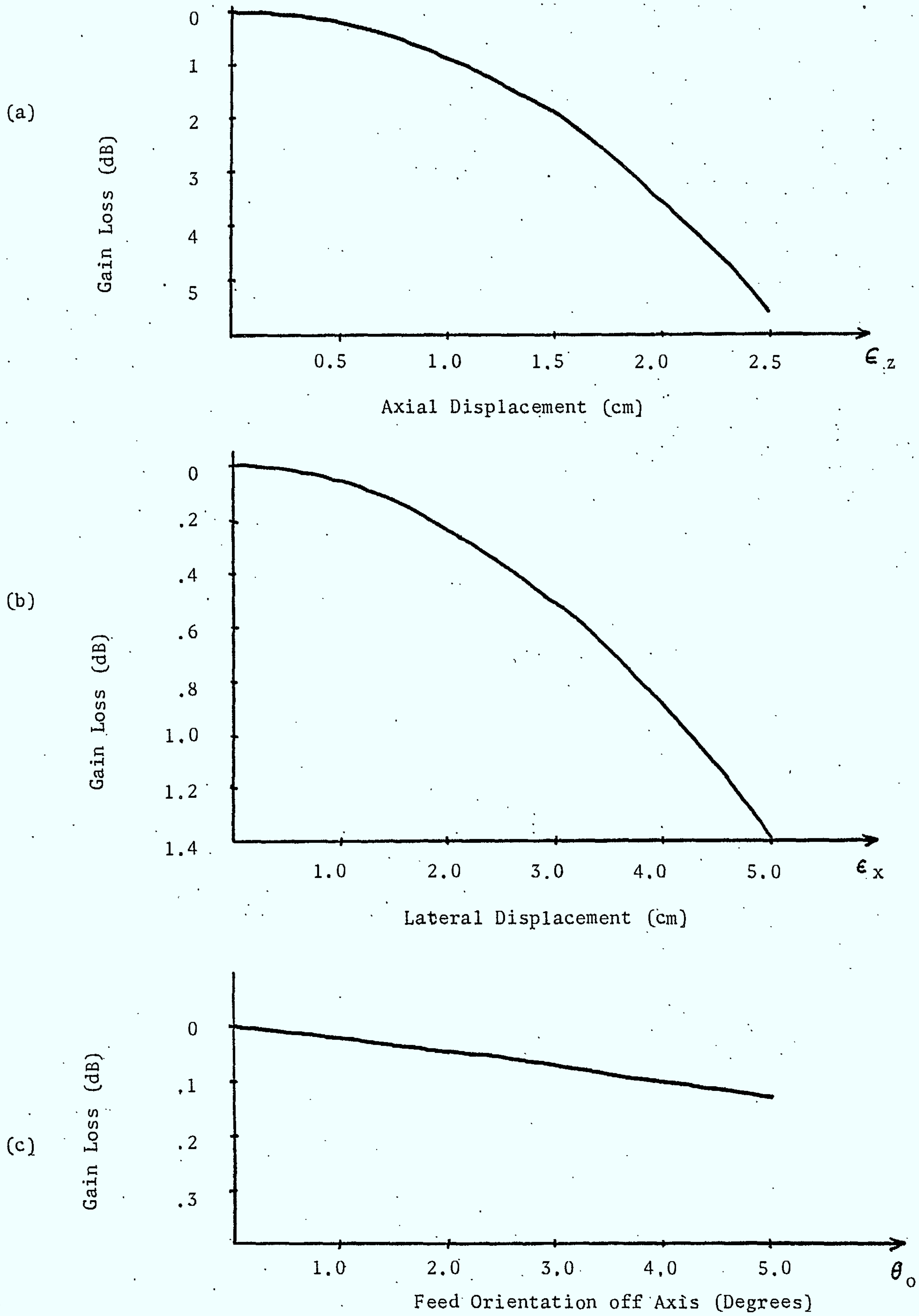


Fig. 3. Effects of feed misalignment on realized antenna gain (a) axial displacement (b) lateral displacement (c) angular orientation error(feed mis-pointing)

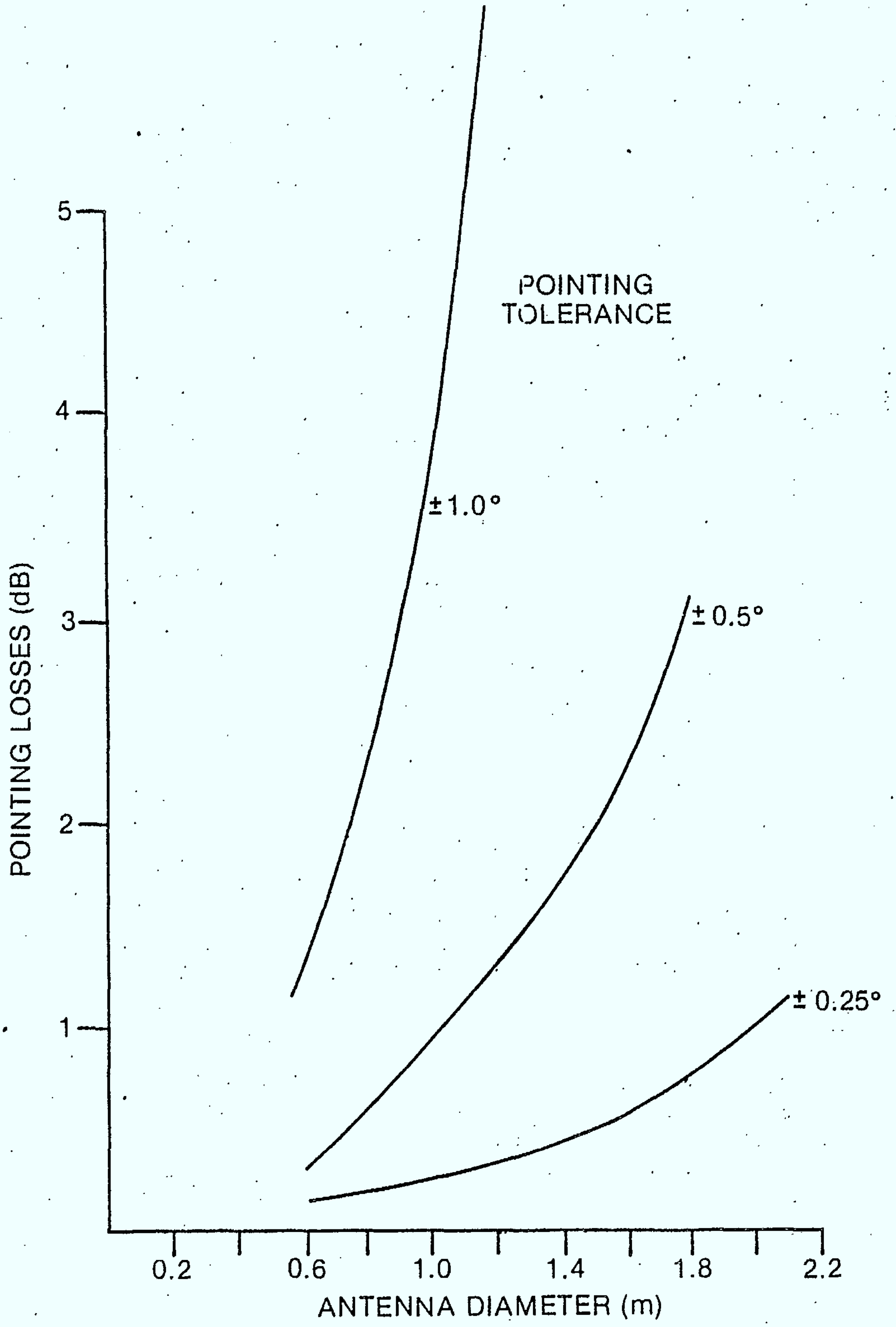


Fig. 4. Gain loss due to reflector pointing error.

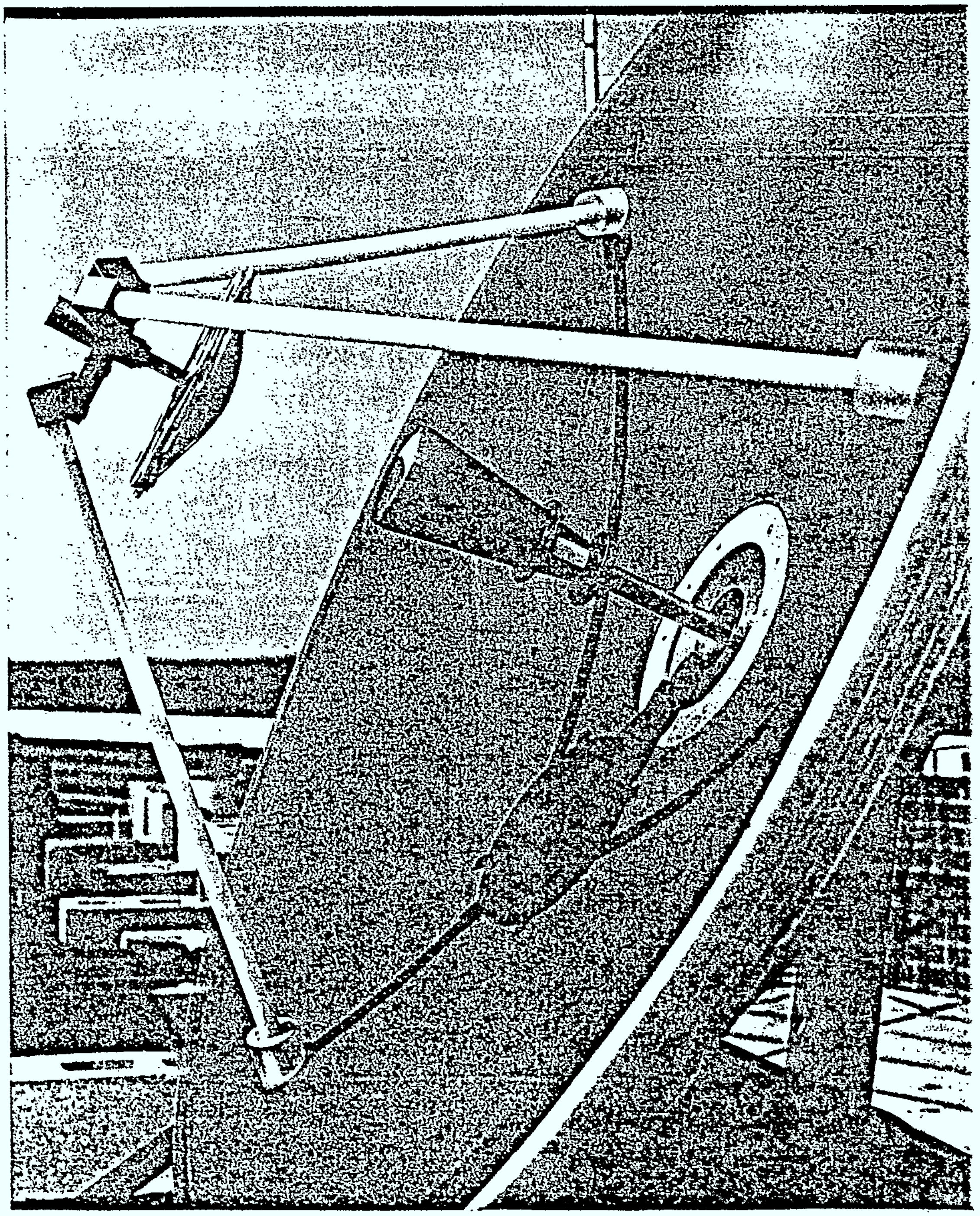


Fig. 5. A Cassegrain Antenna with Shaped Subreflector and Scalar Conical Feed (1.2m)

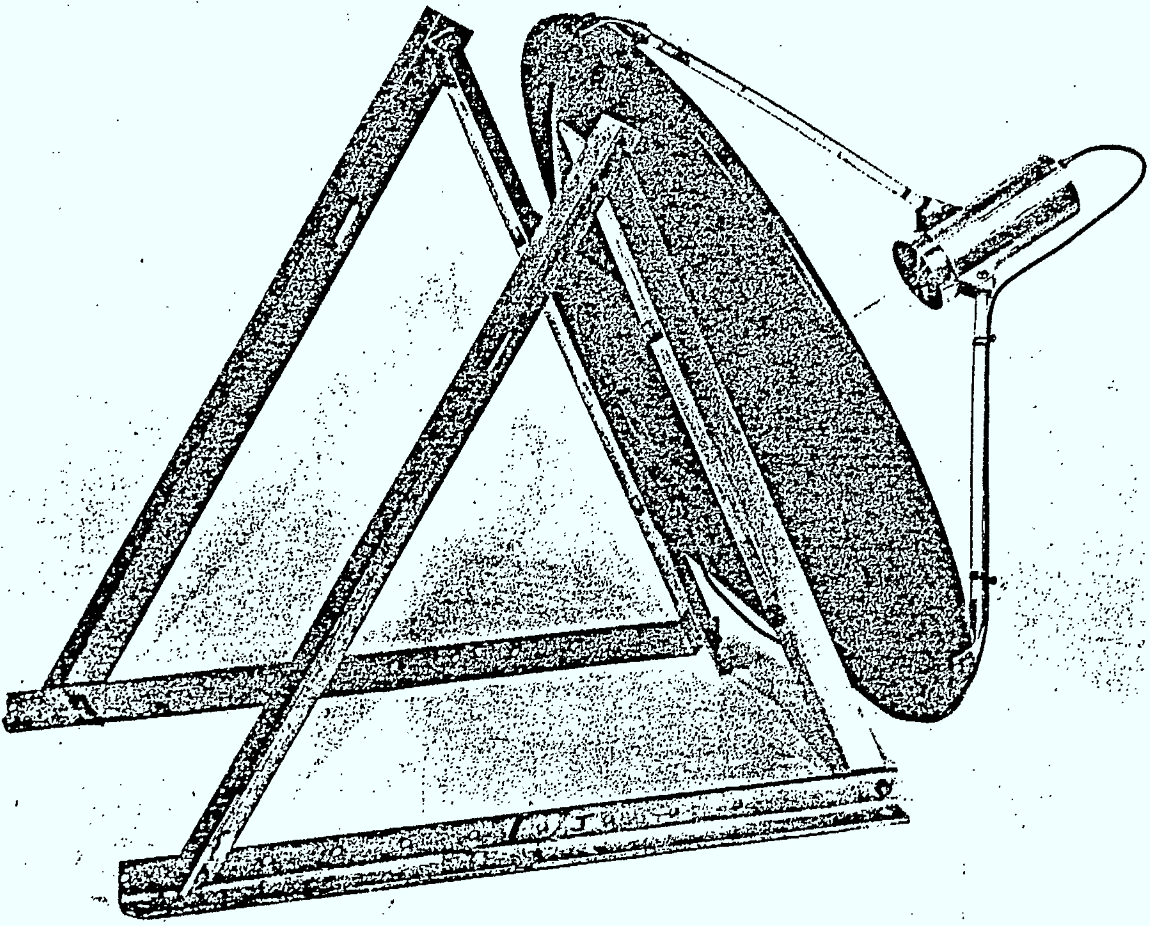


Fig. 6. A prime focus antenna with a 90° scalar high efficiency feed (0.6m)

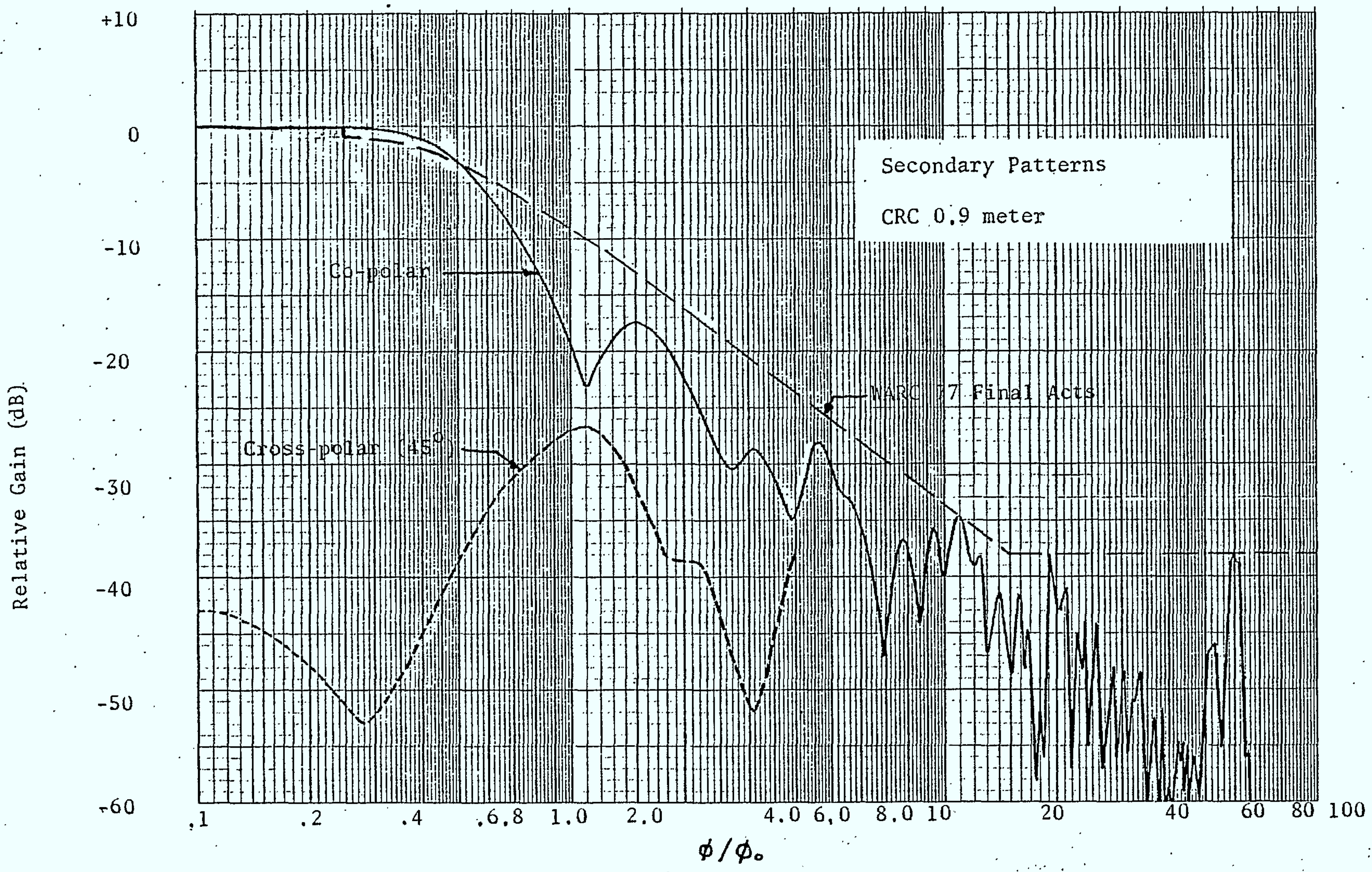


Fig. 7 Co-polar and Cross-polar patterns of a 0.9m antenna using the CRC 90° scalar feed.

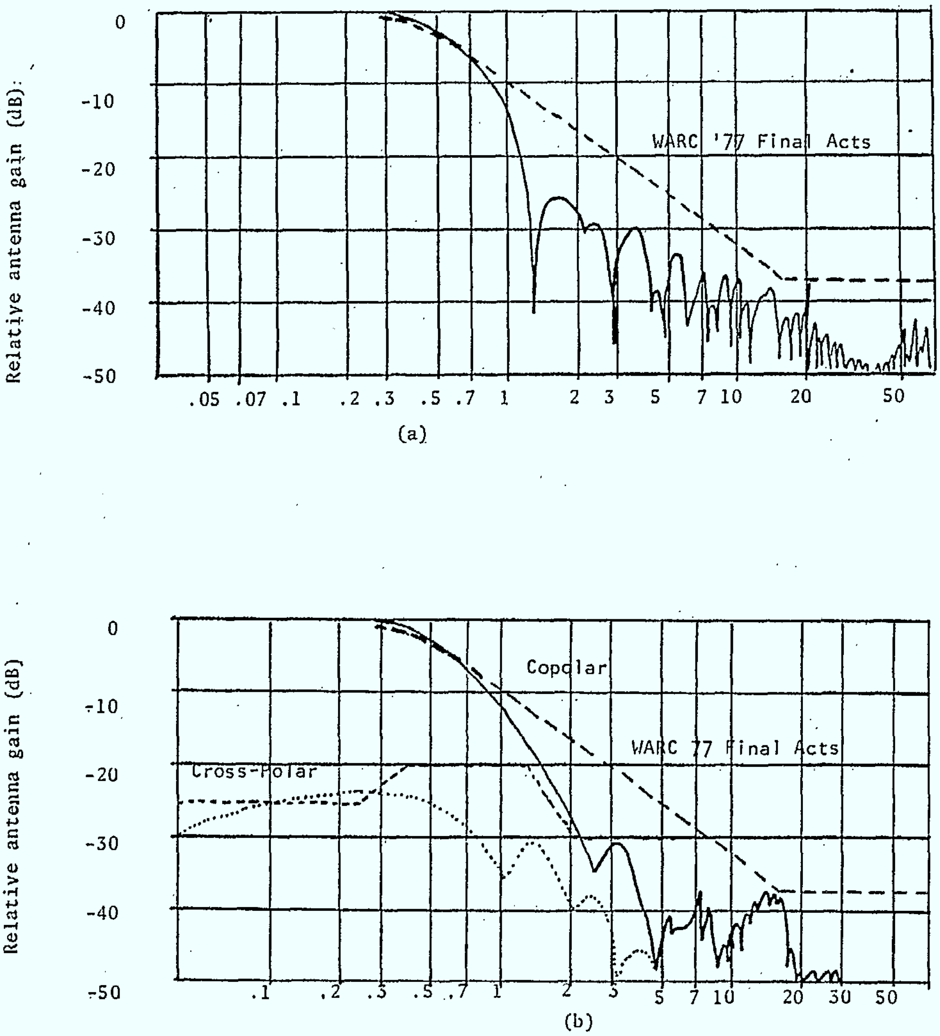


Fig. 8. Co-polar and cross-polar patterns of conventionally fed 1.0 m and 1.6m prime focus antennas [4] (a) 1.meter (b) 1.6 meter

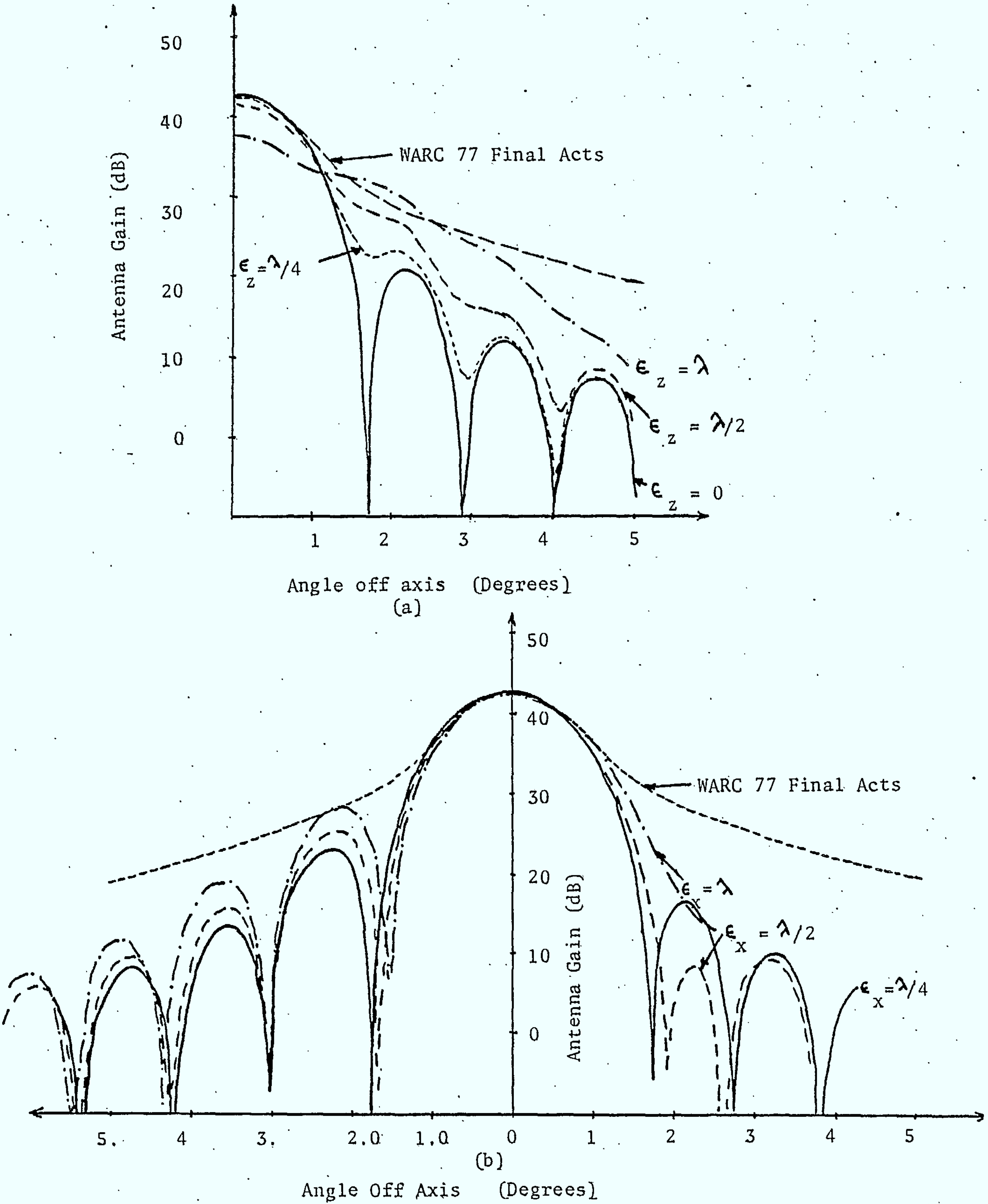


Fig. 9. Effects of feed displacements on antenna sidelobes properties
(a) axial (b) lateral

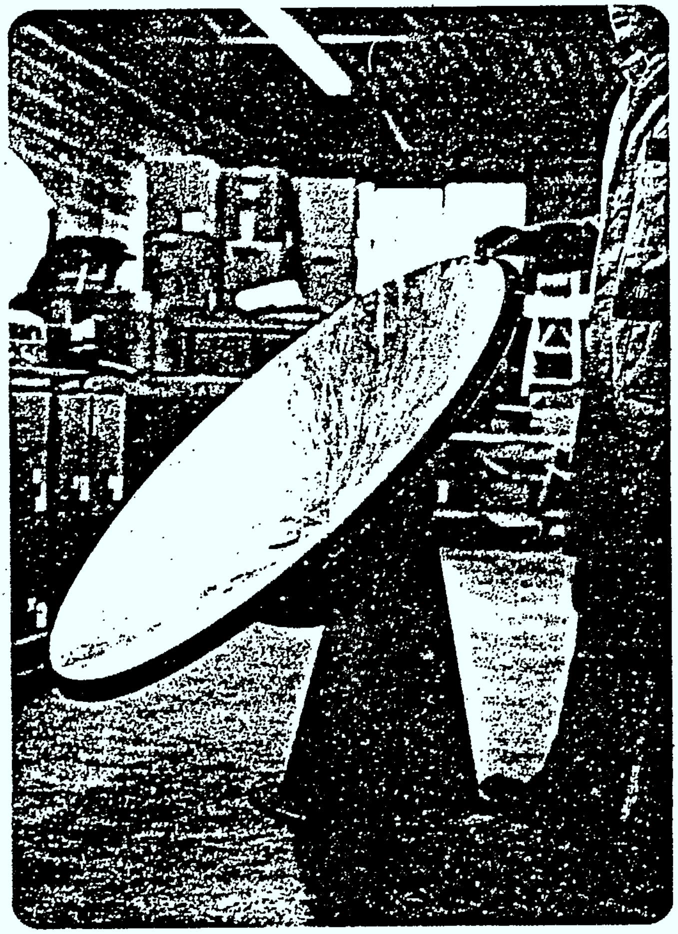


Fig. 10. A fibreglass reflector and mount designed for direct broadcast receivers.

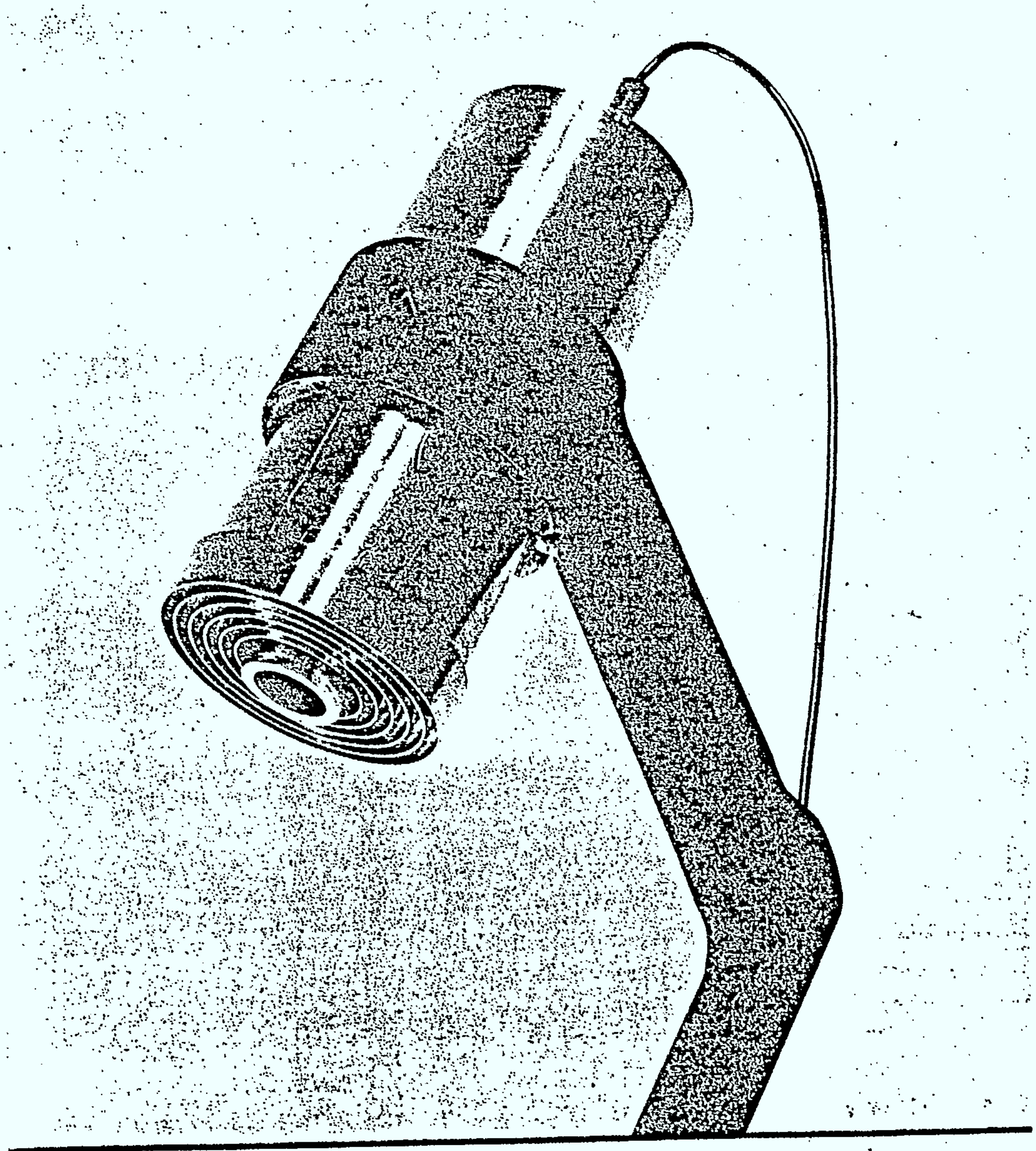


Fig. 11. The high-efficiency prime focus feed with the ODU mounted behind the feed.

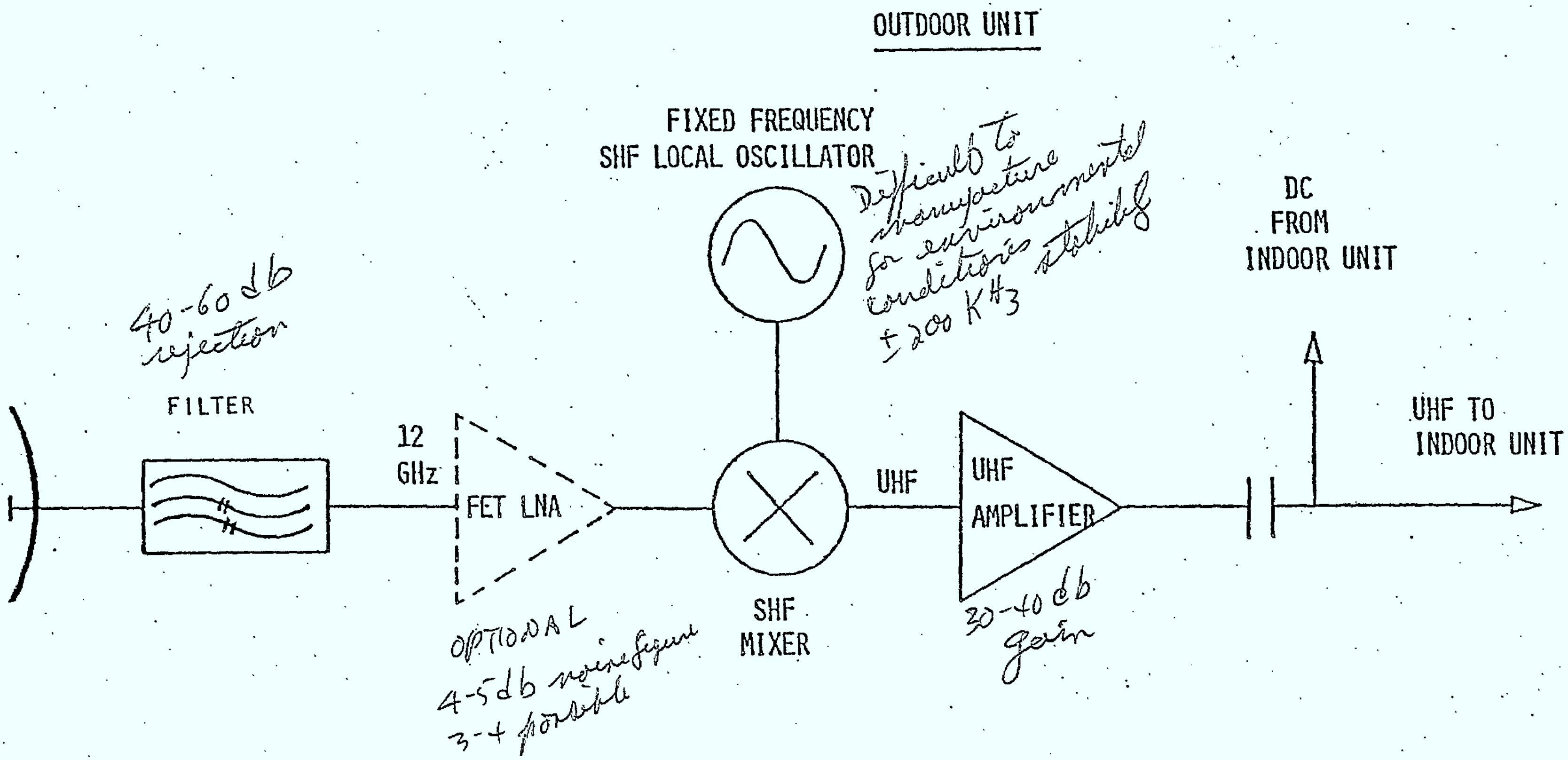


Fig. 12. Block Diagram of Outdoor Unit Electronics.

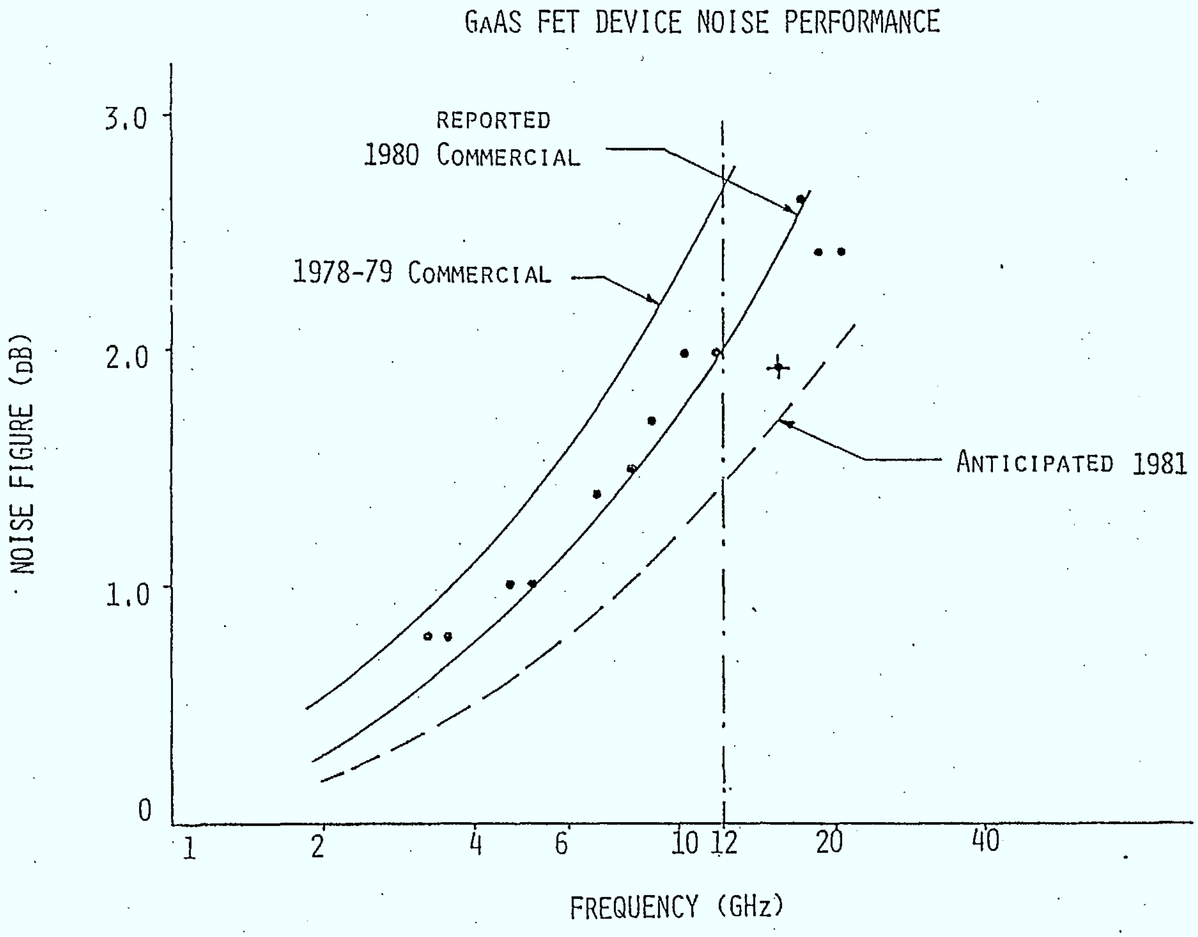


Fig. 13. Present and Anticipated Device Noise Figures for Commercial FETs.

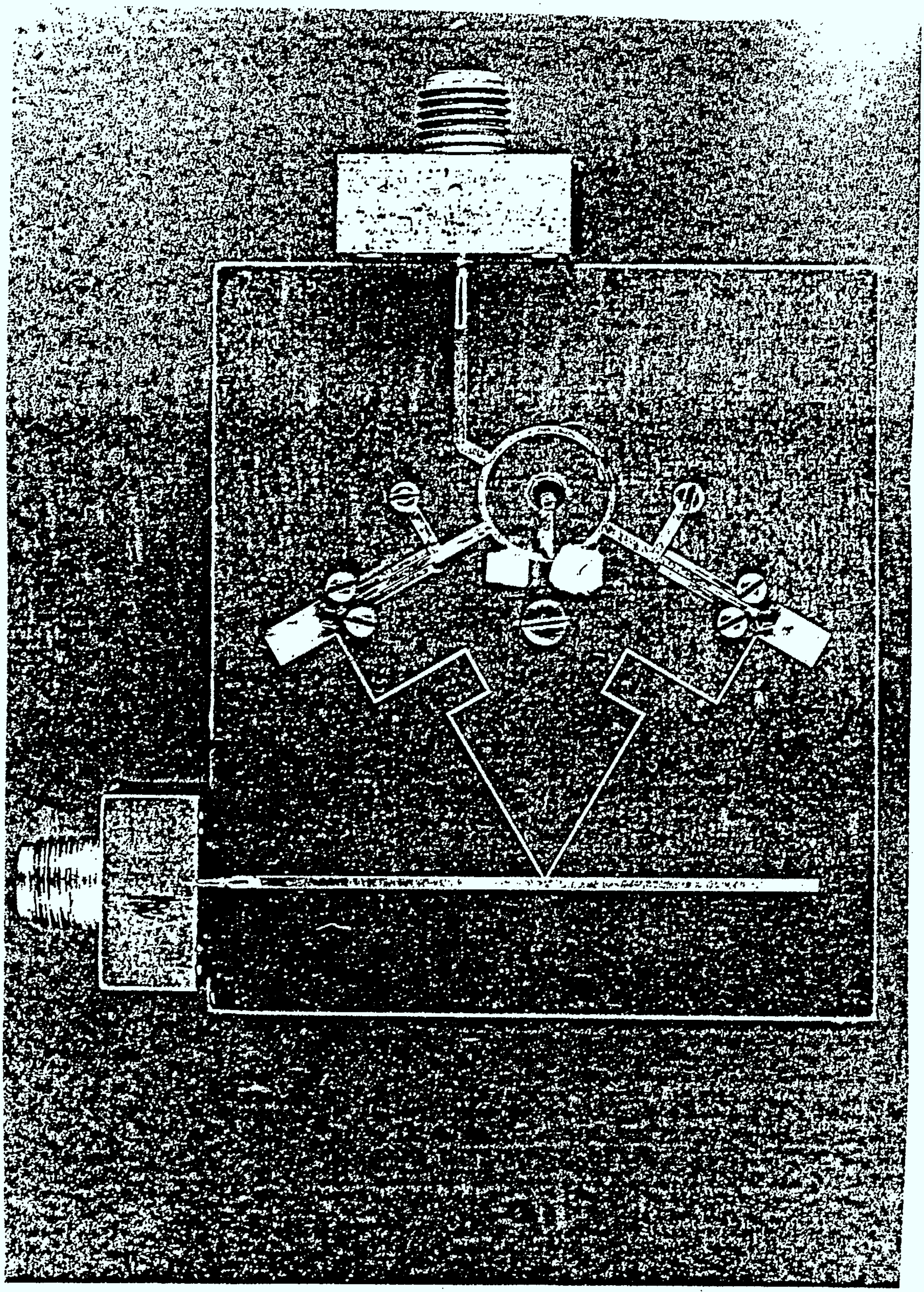


Fig. 14. A MIC Image-Enhanced Mixer at 12 GHz.

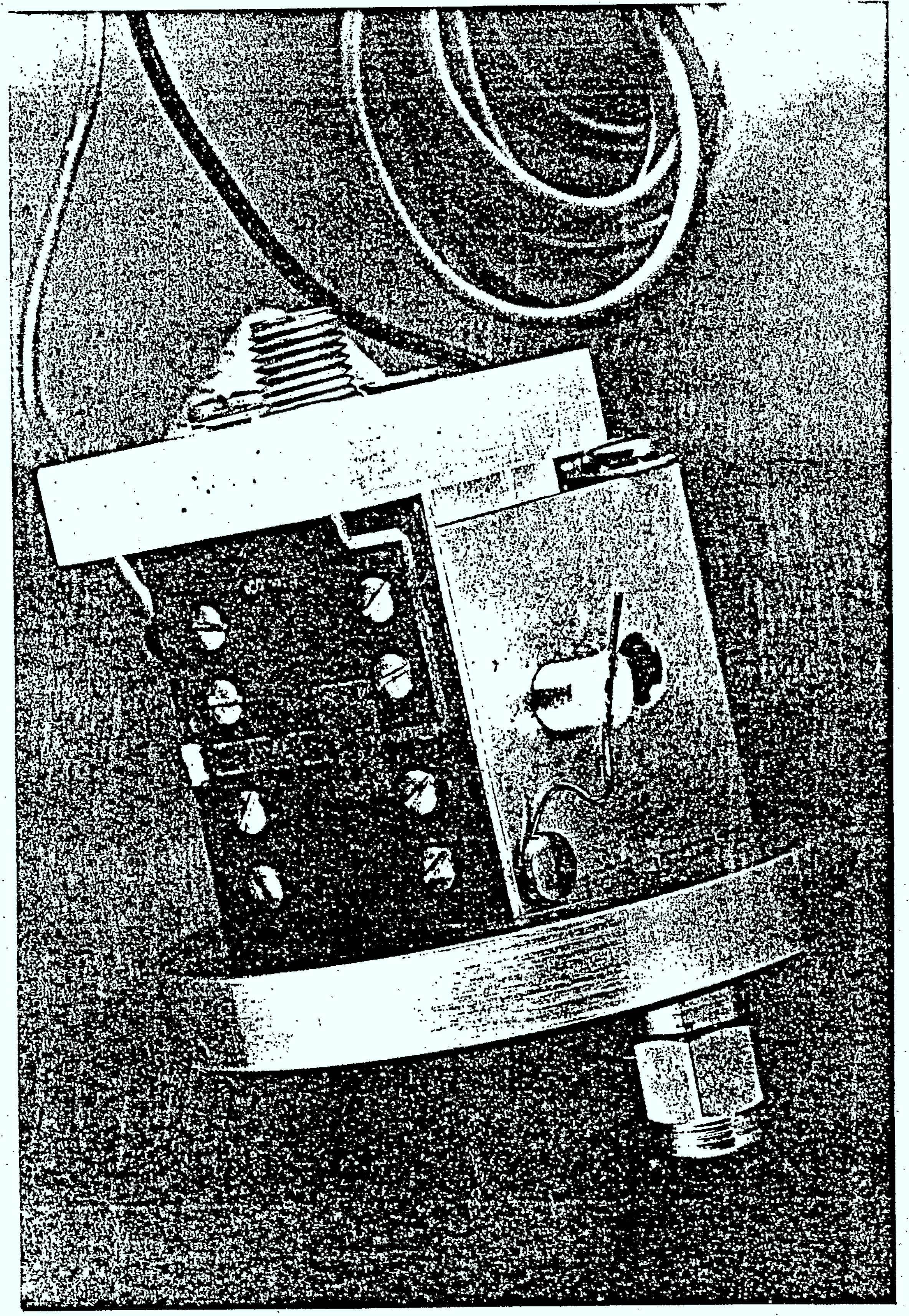


Fig. 15. A temperature compensated Gunn oscillator for direct-broadcast receivers.

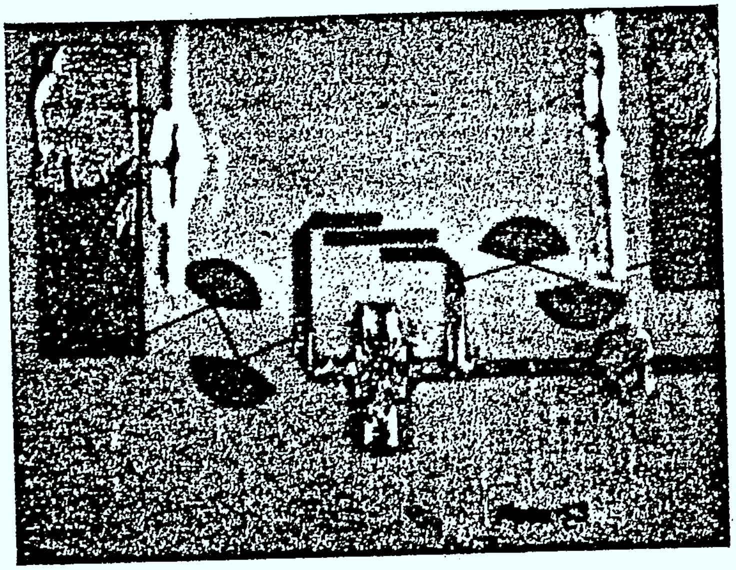


Fig. 16. An MIC FET Oscillator Suitable for Low Cost TV Earth Terminals

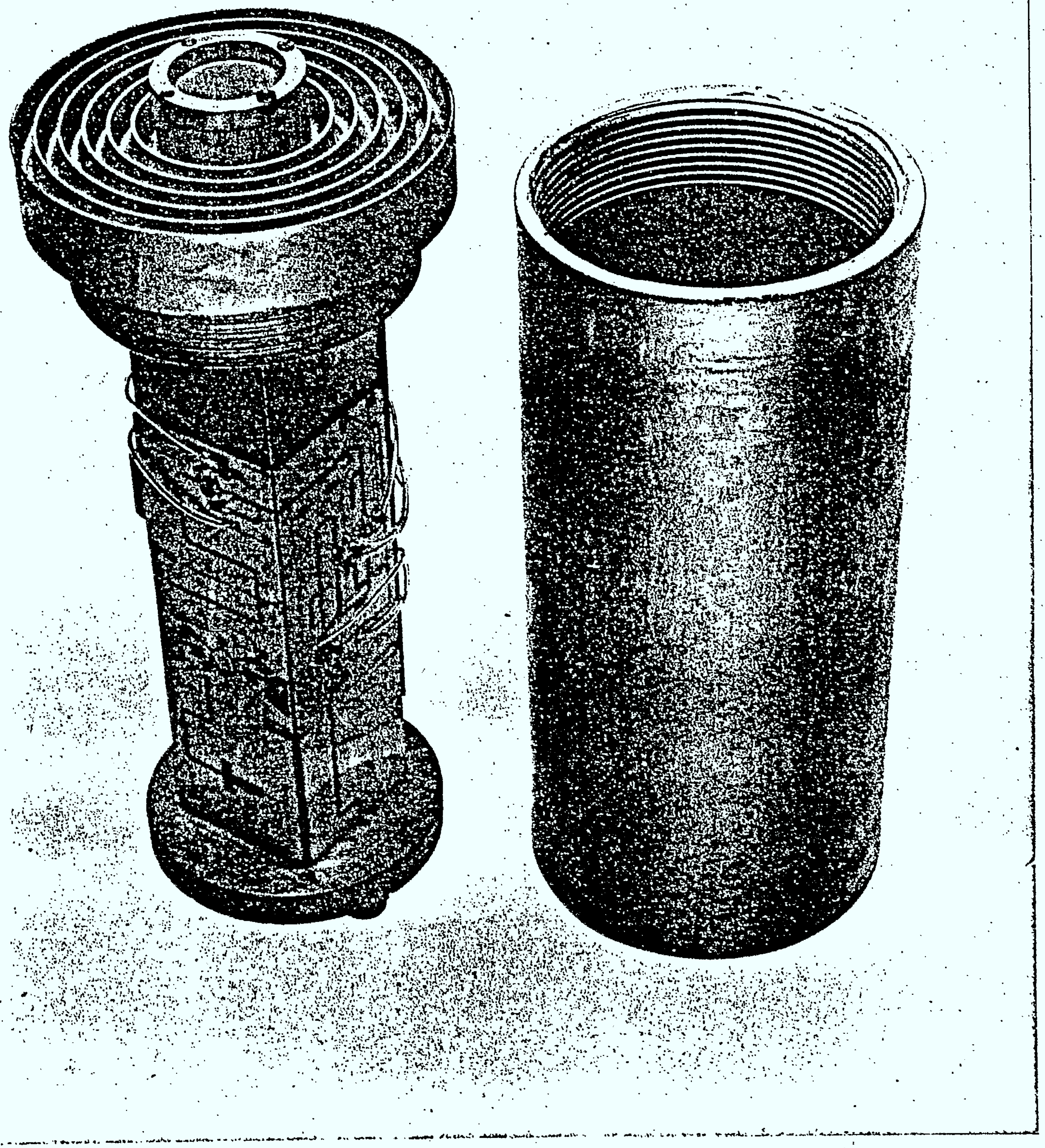


Fig. 17. The CRC outdoor unit with image-enhanced mixer front-end, Gunn-diode LO and low-noise UHF bipolar transistor amplifier.

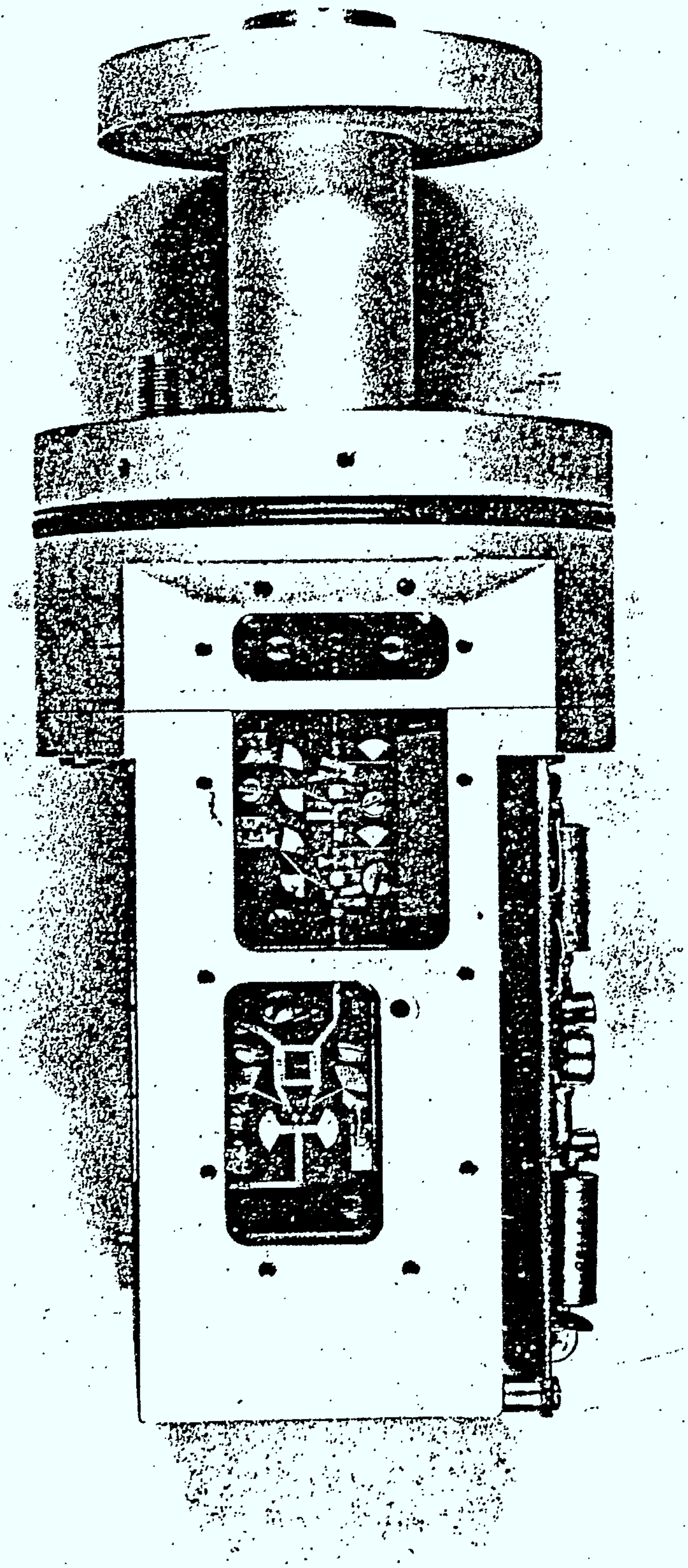


Fig. 18. The SED outdoor unit with a low-noise FET amplifier and a conventional mixer. The same LO and feed as in the CRC design is used.

most difficult to get sufficient rejection over 500 MHz range.

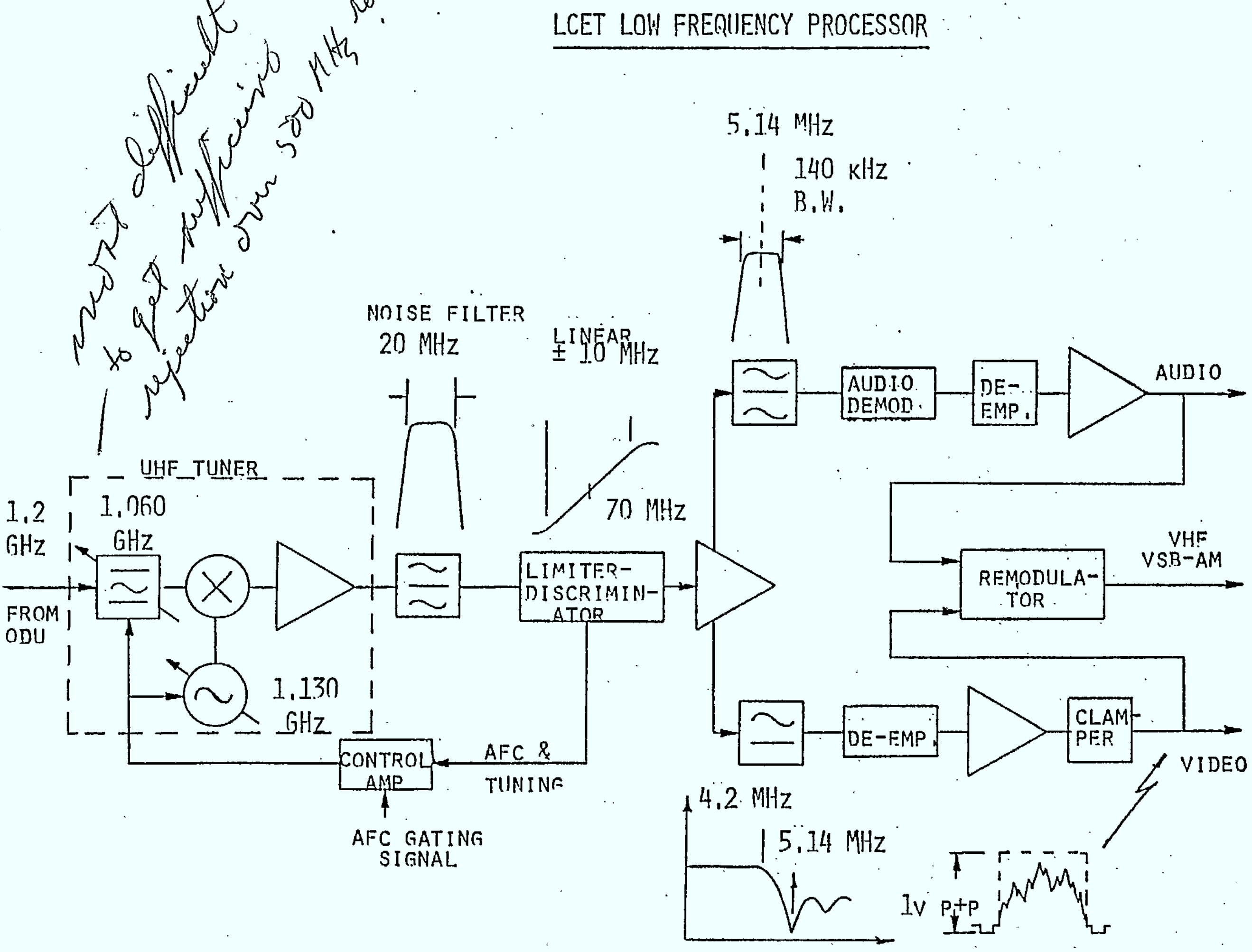


Fig. 19. Block diagram of indoor unit electronics using a conventional demodulator.

expect to integrate into one LSI chip.

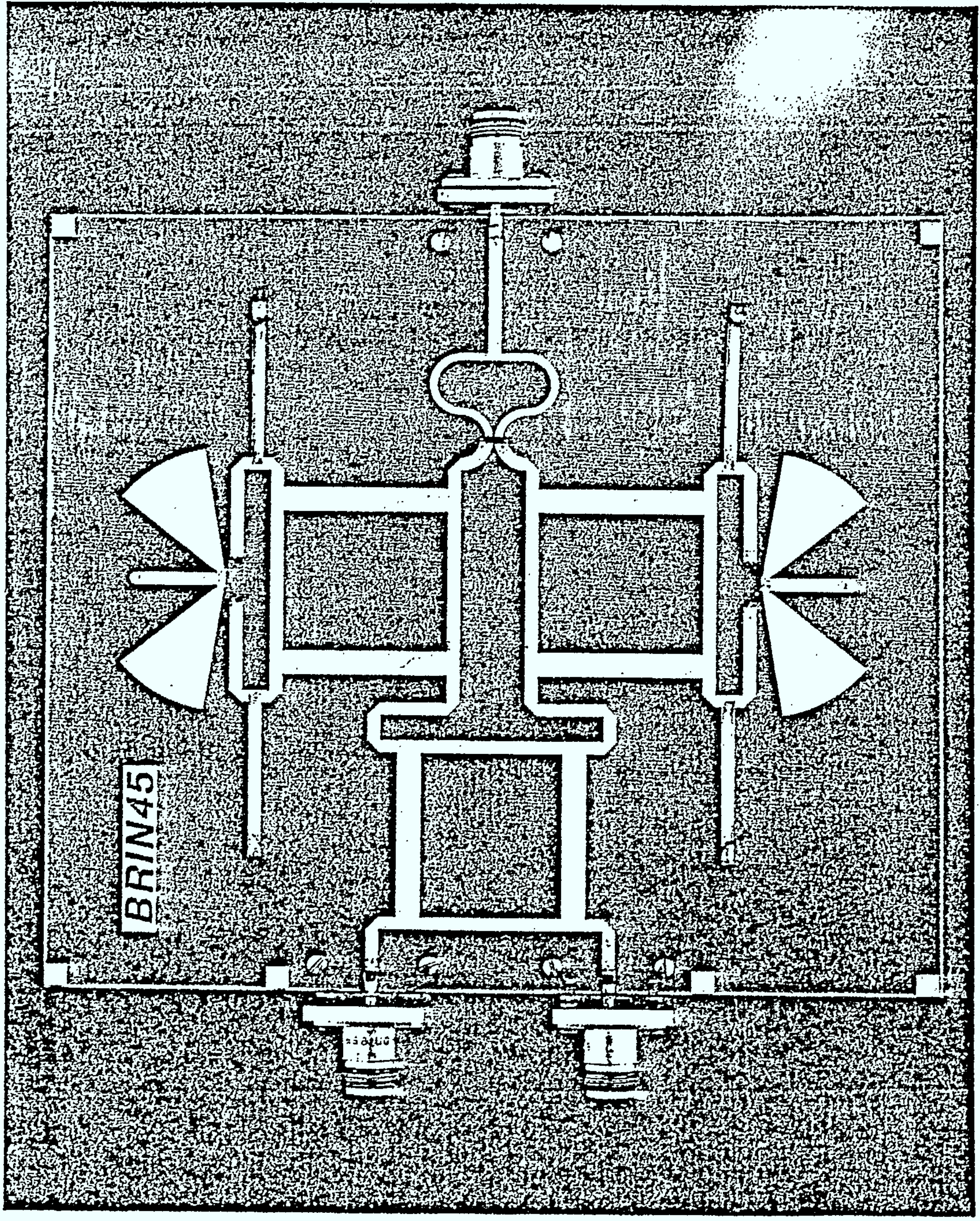
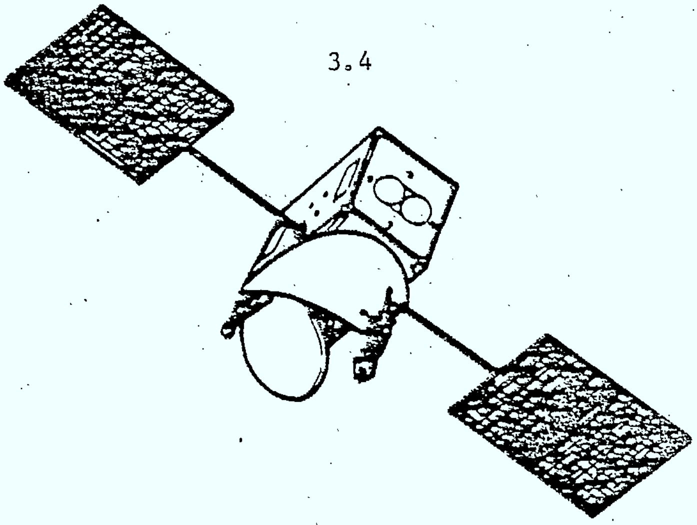


Fig. 20   A UHF tuner using the image-rejection concept

3.4



TITLE : SOME SYSTEM AND TECHNOLOGY CONSIDERATIONS FOR BROADCASTING SATELLITE SERVICE (BSS)

AUTHOR : B. PATTAN

USA

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

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Paper given at Preparatory Seminar
for RARC-83 on Broadcast Satellite
Planning; Ottawa, Canada; May 4-8
1981.

SOME SYSTEM AND TECHNOLOGY CONSIDERATIONS FOR BROADCASTING SATELLITE SERVICE

Bruno Pattan, FCC/OST

The purpose of this paper is to provide a system and technology overview of BSS/DBS systems. The requirements for direct satellites has been studied by various organizations and was also addressed by CCIR Study Groups and reported on as early as 1960 in CCIR Report 215. During these incipient studies, the implementation of direct broadcasting satellite service was not considered practicable because of the limitations in the technology. As the technology progressed, over a gestation period of about ten years, actual hardware came to a fruition and practical systems became feasible and a reality.

The first demonstration of this service was manifested by the NASA satellite ATS-6 in 1974. The system used a large unfurlable antenna operating in the 2 GHz band.* The system, however, did not include operation at the 12 GHz band. By present standards, the capability of the ATS-6 system was modest when one considers the primary power generated (500 W), the number of channels (2) which were used and the size (3.5 m) and cost ($3K) of the ground receiver. As technology in the higher frequencies burgeoned ,systems operating at the 12 GHz band became possible and resulted in a joint U.S. Canada CTS/Hermes (1976) and the Japanese Broadcasting Experimental (BSE) (1978) satellites. In part, these were made possible by the development of high power satellite tubes, high performance receivers and generally overall improvement in satellite technology. Good receivers included antennas of reasonable size, which impacted cost and aesthetics where deployed. The frequency band used was one established (one of six) by the ITU WARC-71. Fortuitously

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* UHF also downlinked, but used by India in their "SITE" experiments.

or otherwise, this band has been universally selected as the broadcast band by the ITU WARC BS-77 Conference.

In a more recent display of maturing technology, Canada has been experimentating with the 12 GHz payload on their hybrid Anik B satellite. The data gleaned and publication of this experience has benefited administrations which are contemplating a venture into this area. One fact which certainly stands out from the Canadian experience* is the conservative nature of the guidelines set down in the Final Acts WARC-77 on planning for ITU Region 2 BSS service. This may also imply a cautionary note in referential adherence to a a-priori plan.

The success of the above cited programs has spurred planning for this kind of service in other countries including India, Germany, France and Nordic countries. The Soviet Union has also been active in this area and have demonstrated this service with their Ekran (Statsionar T) system.

In subsequent sections, more exacting information on system requirements for BSS/DBS systems is presented. This will be followed by technology attributes of the various constituent subsystems: unlink feeders, satellite and ground receiver requirements necessary to satisfy a viable system. This is followed by a brief pictorial history of BSS/DBS systems.

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* B.C. Blevis, "Direct Broadcasting By Satellite In Canada", Symposium given at the National Academy of Sciences; Washington, D.C.; April 8, 1980. J.G. Chambers, "An Evolutionary Approach to the Introduction of Direct Broadcasting Satellite Service", Nat. Telecomm. Conf., 1980.

SOME SYSTEM AND TECHNOLOGY CONSIDERATIONS FOR BROADCASTING SATELLITE SERVICE (BSS)

FCC/OST

> I HAVE HERE ONLY MADE A NOSEGAY OF CULLED FLOWERS AND HAVE BROUGHT NOTHING OF MY OWN BUT THE THREAD THAT TIES THEN TOGETHER.
>
> Michel de Montaigne

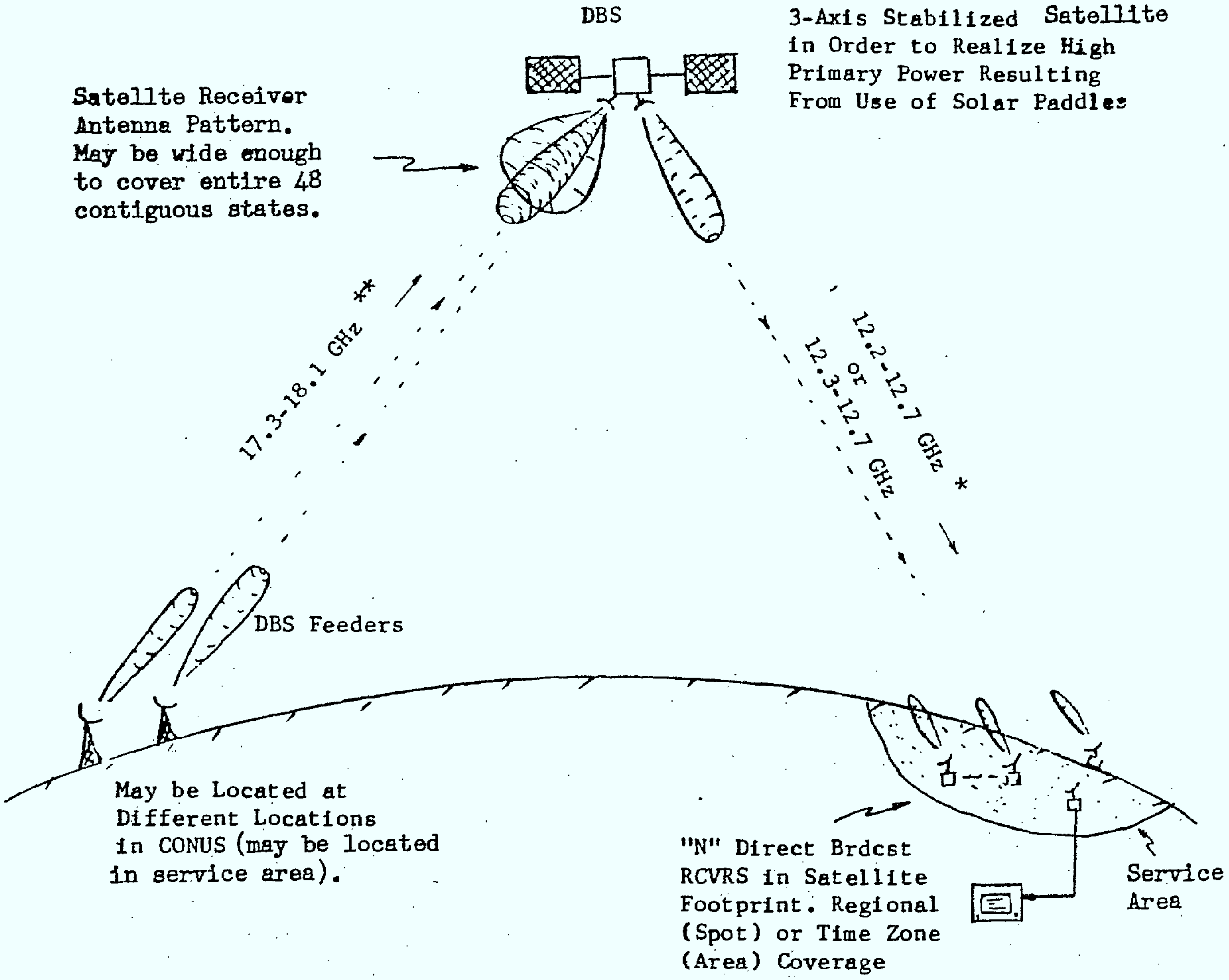
GLOSSARY OF ACRONYMS

ATS : Applications Technology Satellite
CMD : Commands (to the satellite)
C/N : Pre-Demodulator Carrier to Noise Ratio
CNES : Centre National d'Etudes Spatiales (France)
CONUS : Contiguous 48 States
CTS : Communications Technology Satellite
D : Deemphasis (used in FM receiver)
DOC : Department of Communications (Canada)
Δf : Peak Deviation
EIRP : Equivalent Isotropically Radiated Power
EOC : Edge of Coverage (service area)
f_m : Modulating Video Frequency Bandwidth
FN : Footnote
G/T : Figure of Merit, $G(\theta,\emptyset)_{dB} - T_s(\theta,\emptyset)_{dB}$
JAP : Journal of Applied Physics
LNA : Low Noise Amplifier
MI : Modulation Index
NF : Noise Figure
N_w : Weighted Video Noise
PFD : Power Flux Density, (dBW/m^2)
PR : Protection Ratio, (C/I)
RCVR : Receiver
SITE : Satellite Instructional Television Experiment (India)
S_{p-p} : TV Video Peak-to-Peak Signal
STC : Satellite Television Corporation (Comsat)
TASO : Television Allocations Study Organization
TLM : Telemetering (from satellite)
TT&C : Tracking, Telemetering and Command
TVRO : TV Receive Only
W : Weighting (post detection weighting in FM RCVR)
XMTR : Transmitter
XPDR : Transponder

CONTENTS

SYSTEM PARAMETERS

BROADCASTING SATELLITE SERVICE SYSTEM SCENARIO



3-Axis Stabilized Satellite in Order to Realize High Primary Power Resulting From Use of Solar Paddles

Satellite Receiver Antenna Pattern. May be wide enough to cover entire 48 contiguous states.

May be Located at Different Locations in CONUS (may be located in service area).

"N" Direct Brdcst RCVRS in Satellite Footprint. Regional (Spot) or Time Zone (Area) Coverage

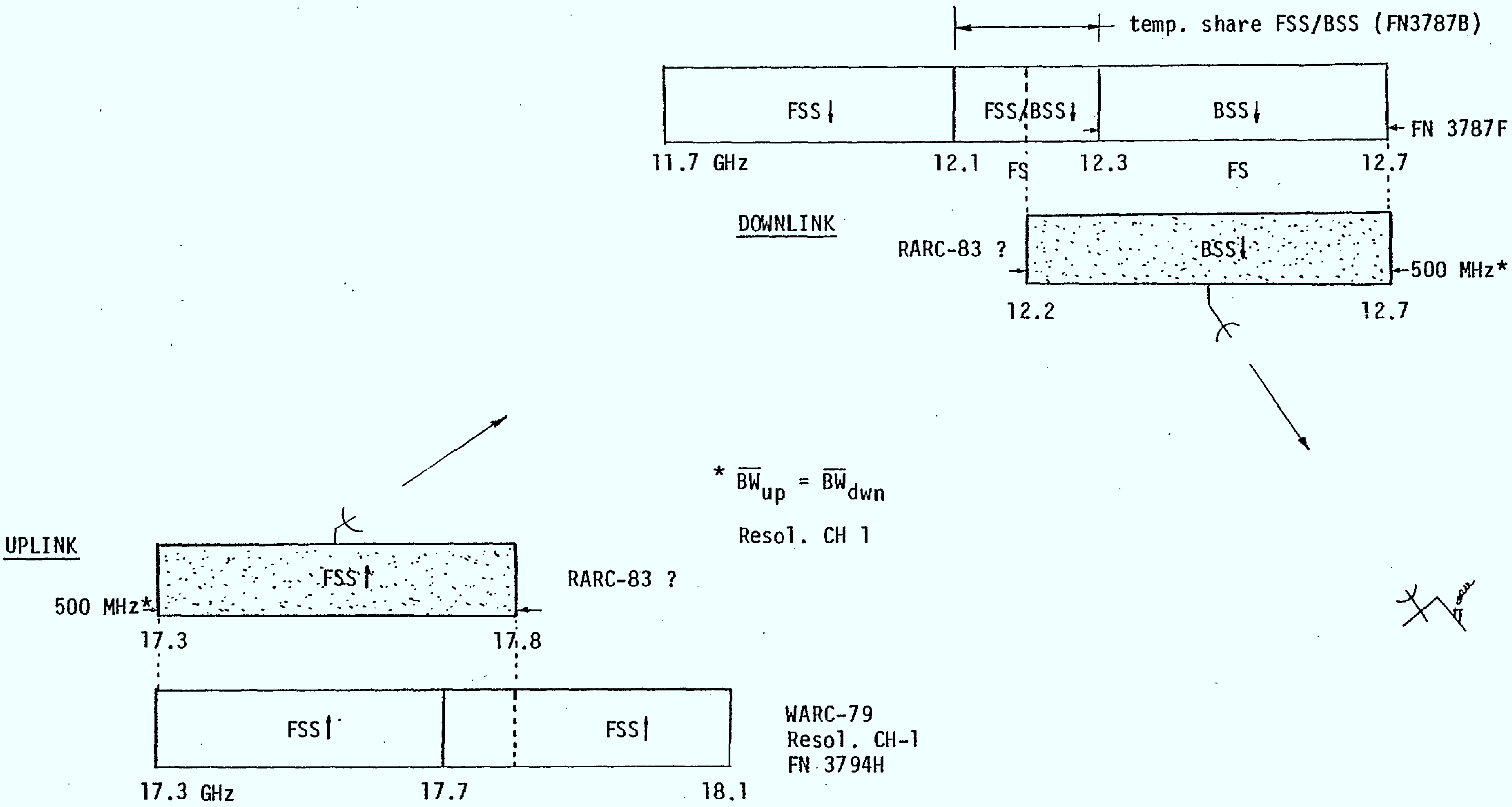
* Final Rendering Will be Made at RARC-83

** U.S. Had Originally Proposed 17.1-17.6 GHz. Uplink will probably match dwnlink, i.e., 500 MHz (17.3-17.8 GHz)

INCREASED VIABILITY OF BSS SYSTEMS RESULTING FROM

- IMPROVEMENT IN SATELLITE ATITUDE AND ORBIT CONTROL
- HIGHER POWER AND MORE EFFICIENT SATELLITE TWTAs
- INCREASE IN SATELLITE PRIMARY POWER GENERATION
- IMPROVEMENT IN GROUND & SATELLITE RECEIVER PERFORMANCE
- USE OF HIGHER FREQUENCIES PERMITS GREATER FLEXIBILITY IN DESIGN SUCH AS BEAM CONTROL, LESS SPILLOVER.
- ADVANCES IN SOLID-STATE AND MATERIAL PROCESSING

ITU REGION 2 PECULIAR SPECTRUM ALLOCATIONS BEING CONSIDERED FOR BSS

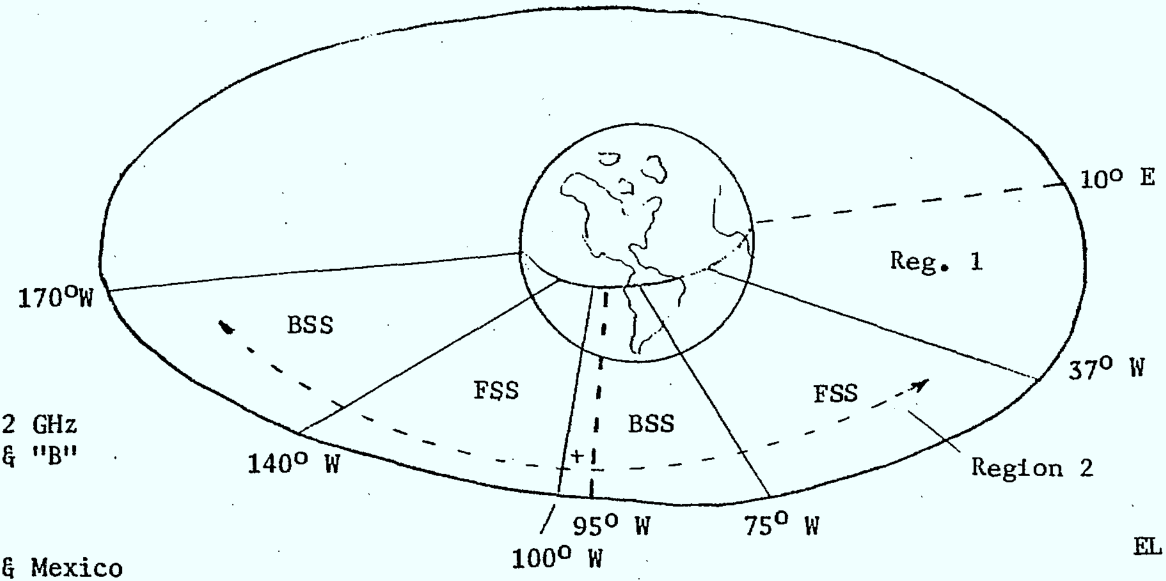


* $\overline{BW}_{up} = \overline{BW}_{dwn}$

Resol. CH 1

N.B.: Other services in band not shown.

ORBITAL ARC ASSIGNMENT FOR FIXED & BRDCST SATELLITES - REGION 2



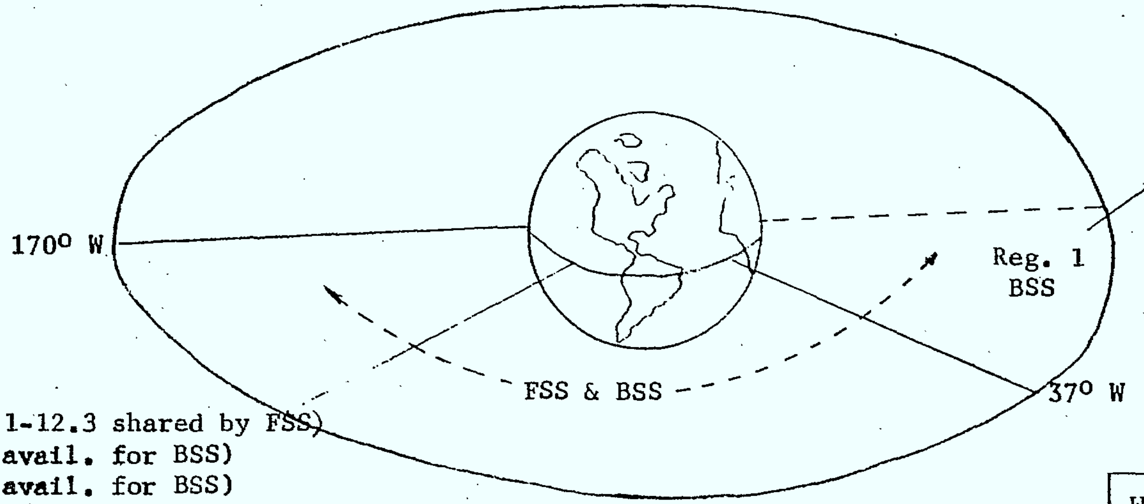
SEGMENTED ARC

WARC-77 ORBITAL ARC ASSIGNMENT

ELIMINATED AT WARC-79

FREQ.: 11.7-12.2 GHz
for "F" & "B"
downlink

+ No U.S., Canada & Mexico broadcast satellites in this arc.



(Europe, Africa will use 11.7 - 12.5 GHz for BSS)

FULL ARC

FREQS.:

- 12.1-12.7 GHz(12.1-12.3 shared by FSS)
- 12.75-13.25 (FSS avail. for BSS)
- 14-14.5 GHz (FSS avail. for BSS)
- 14.5-14.8 (FSS for BSS Exclusive)
- 17.3-18.1 (FSS for BSS but not exclusive)

*

WARC-79 ORBITAL ASSIGNMENTS AND FREQUENCIES

* This will allow greater number of fixed & broadcast satellites than that offered by segmentation allocation above.

WARC BS-77 GUIDELINES

SYSTEM

- FREQUENCY : 11.7-12.2 GHz (WARC-79 : 12.3-12.7 or 12.2-12.7 GHz RARC-83?)
- MODULATION : FM With Pre-emphasis (CCIR Rec. 405-1)
- CHANNEL BANDWIDTH : 18 MHz (525 line)
- CHANNEL SPACING : 12.7 MHz (Region 1 & 3 : BW=27 MHz, Sep.=19.18)
- Polarization : RHCP or LHCP (one polarization to service area)
- ENERGY DISPERSAL : 600 kHz, pk-pk (actually function of EIRP)
- GUARD BANDS : 10 MHz (function of satellite EIRP)
- C/N OBJECTIVE : 14 dB (for 99% of month)
- SINGLE CHANNEL CO-CHANNEL C/I : 35 dB ($C/I|_t$ = 31 dB)
- TOTAL ADJACENT CHANNEL C/I : 15 dB
- POWER FLUX DENSITY (PFD) : -105 dBW/m^2 EOC (function of RCVR G/T)
- ECLIPSE PROTECTION : Prefer Post-Midnight Eclipse Period

SATELLITE

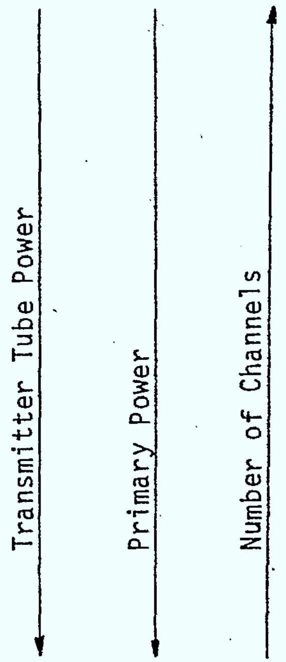
- EIRP : 61 dBW (for PFD = -105 dBW/m^2 EOC)
- BEAMWIDTH (minimum) : 0.6^0 (circular or elliptical)
- POINTING ACCURACY : ± 0.1^0 All Directions
- STATION KEEPING : ±0.1^0 N-S, ±0.1^0 W-E
- ANGULAR ROTATION OF THE BEAM : $\leq + 2^0$
- CH SEPARATION MULTIPLEXED TO COMMON ANTENNA : 40 MHz

RECEIVER

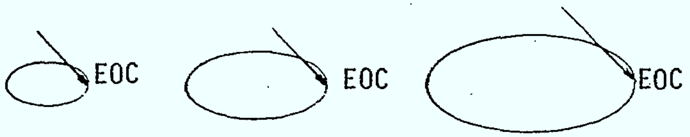
- RECEIVER FIGURE OF MERIT : G/T = 6 dB/K (system noise temp.= 2250^0 for Dia. = 1 meter)
- ANTENNA BEAMWIDTH : 1.8 ^{0}
- ANTENNA BEAM DIAMETER (follows) : 1 meter
- ELEVATION ANGLE : 20^0 (where possible)

POSSIBLE SERVICE AREAS

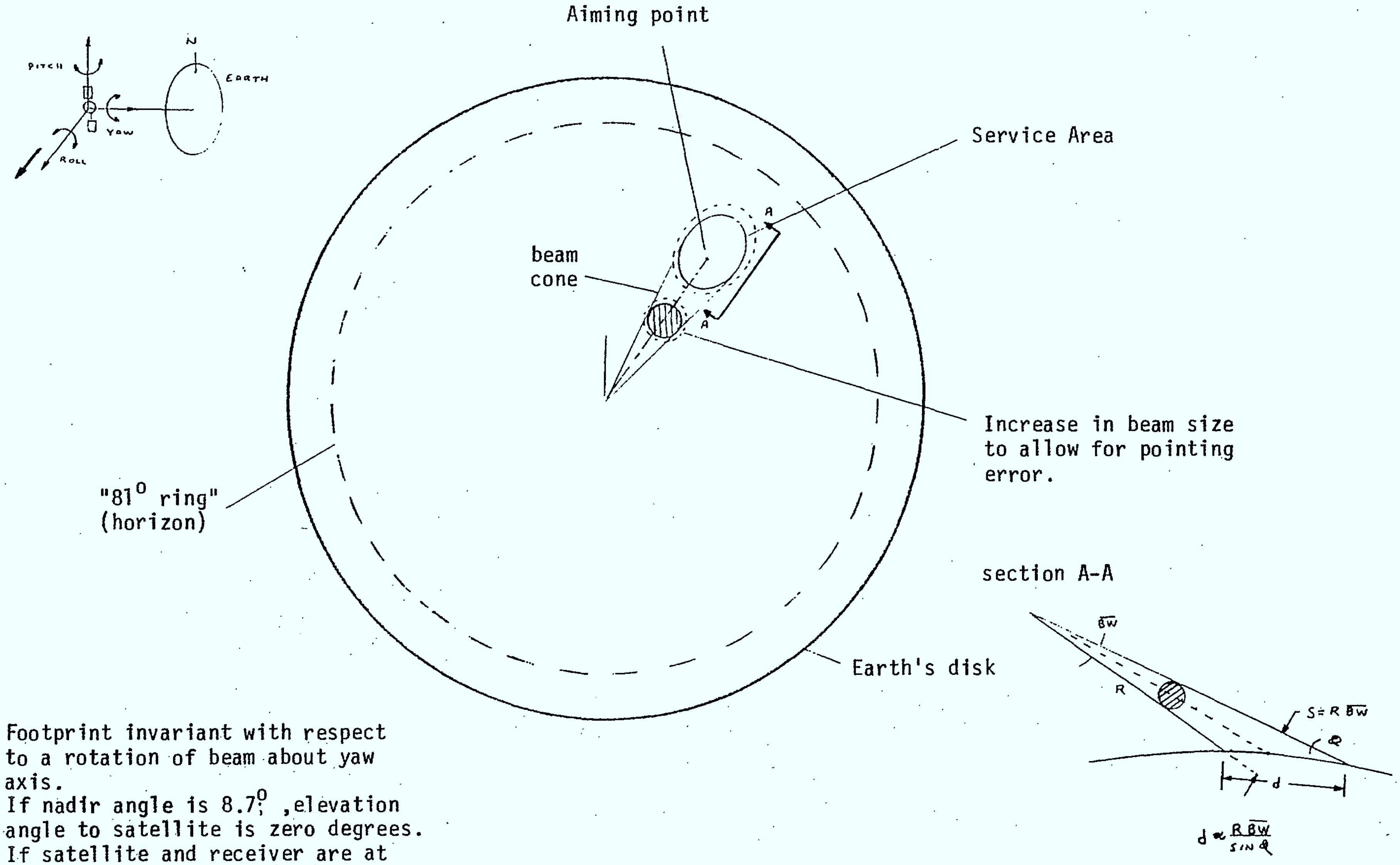
- SPOT BEAMS COVERING URBAN AREAS
- AREA BEAMS COVERING REGIONS OF COUNTRY
- TIME ZONE BEAMS
- COUNTRY-WIDE BEAMS (E.G., CONUS COVERAGE)



No matter what size service area is, PFD_{EOC} = EIRP - 163 = constant (function of G/T)

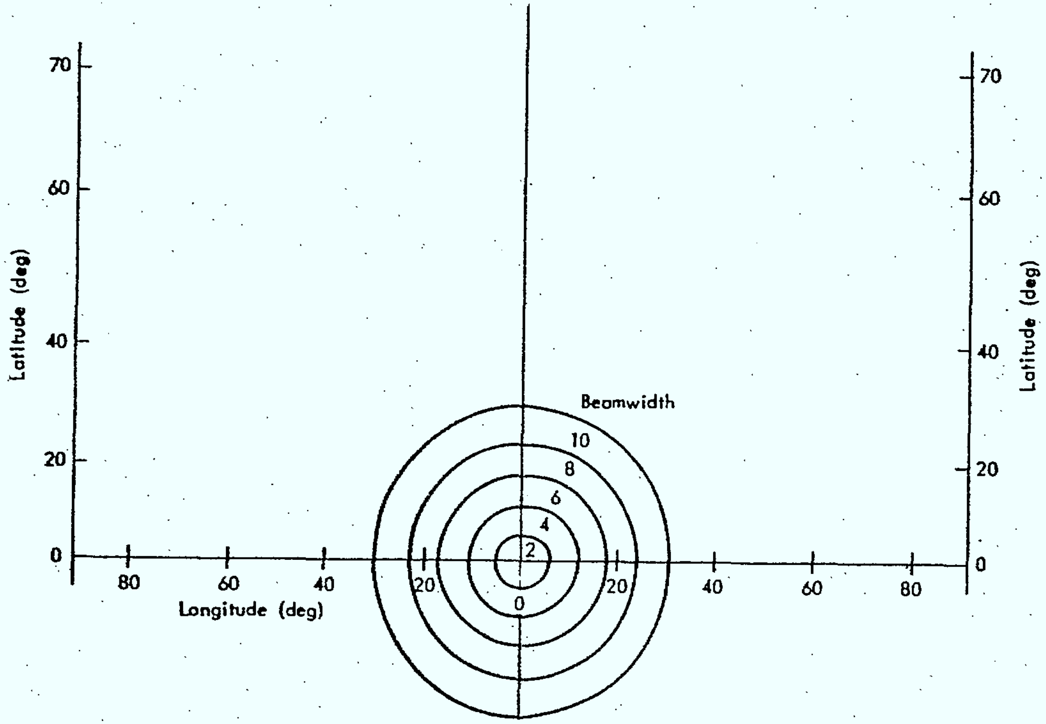


INTERSECTION OF A CONICAL BEAM AND EARTH'S SURFACE



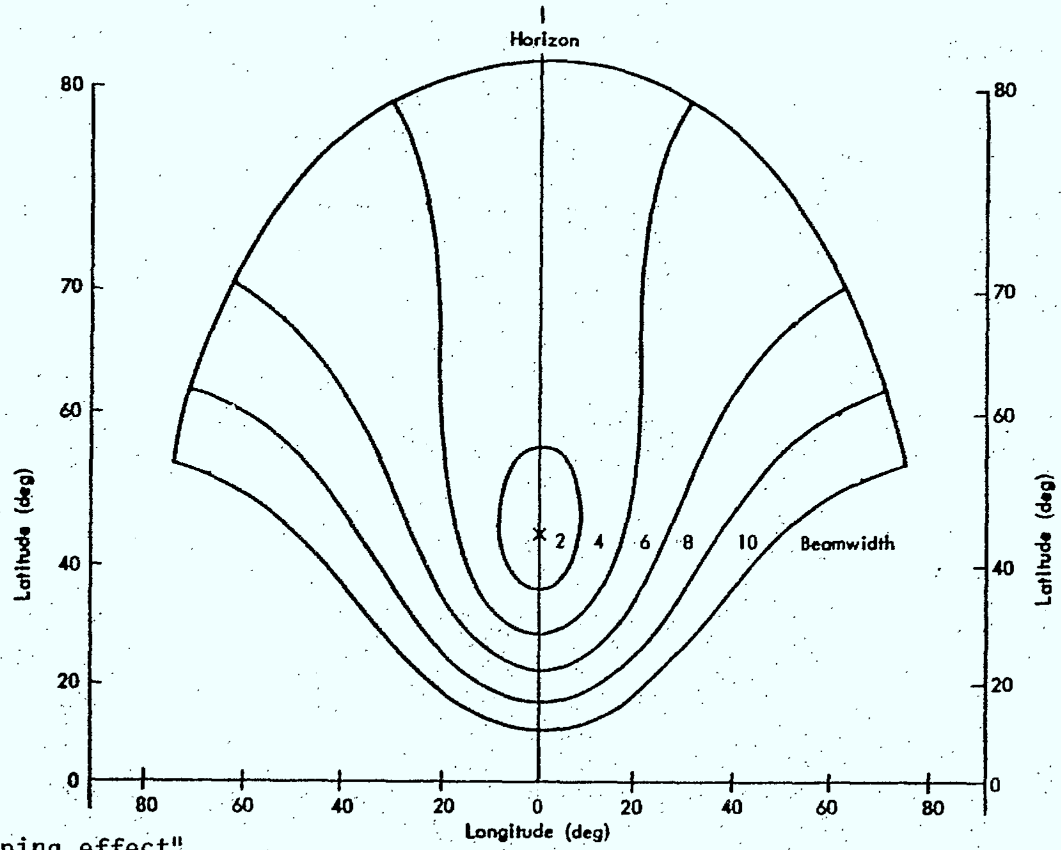
- Footprint invariant with respect to a rotation of beam about yaw axis.
- If nadir angle is 8.7°, elevation angle to satellite is zero degrees. If satellite and receiver are at longitude, latitude of receiver is at 81.3°.

CIRCULAR BEAMS 3 dB FOOTPRINTS DIRECTED AT SATELLITE SUB-POINT



- Nadir angle : 0^0
- RCVR at satellite sub point

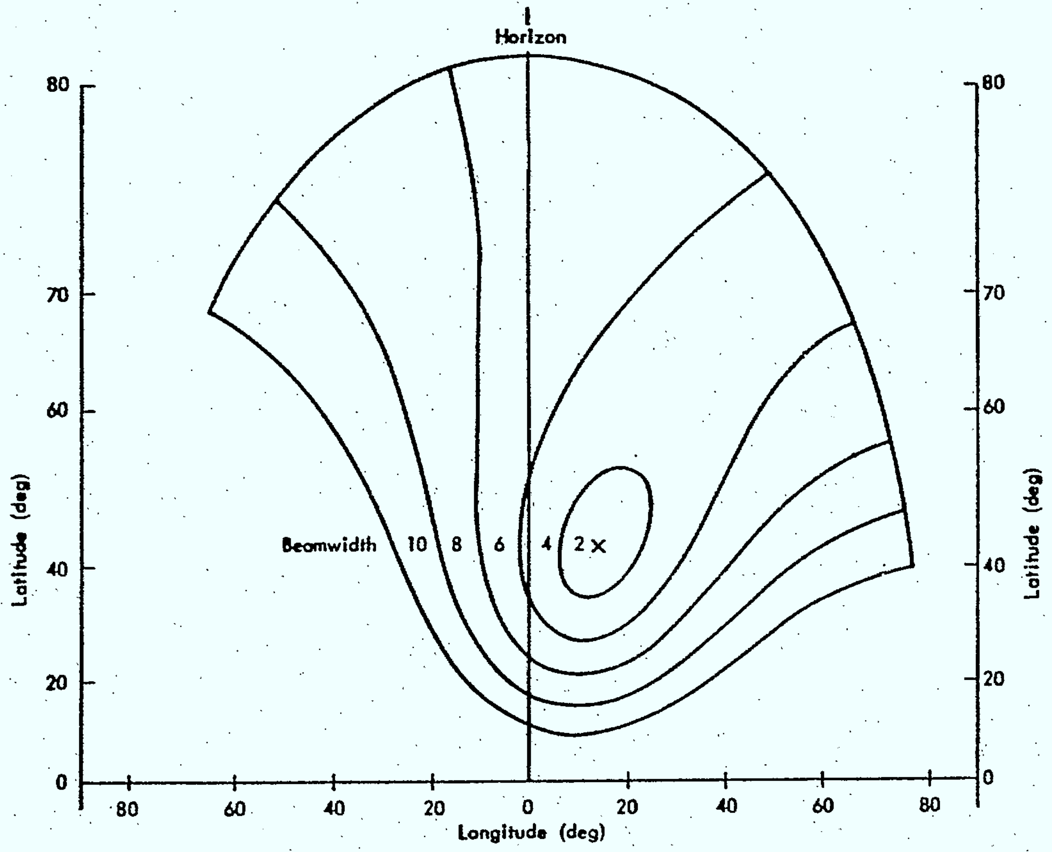
CIRCULAR BEAMS DIRECTED TO NORTHERN LATITUDE



Note so-call"tuliping effect"

- Angle between nadir point & boresight axis : 45^0 (central angle)
- RCVR same longitude as satellite

CIRCULAR BEAMS DIRECTED TO NORTHERN LATITUDE - RCVR TO EAST OF SATELLITE LONGITUDE



- Angle between nadir & boresight axis : 45^0
- RCVR at longitude east of sat. longitude

REQUIREMENTS FOR SERVICES ASSIGNED TO ONE SERVICE AREA

- All Transmissions Must Emanate From A Single Satellite For Home Reception .

- If Possible, Footprint Should Be Confined to Service Area (Beam Shaping Will Help in This Realization).

- There Must be Adequate Separation Between Channels Supporting That Region in Order to Maintain a High C/I Ratio. Use of every other channel or every fourth channel are possible (too close may pose mux problems).

- Must Radiate All Channel Signals With the Same Polarization Making It Compatible With Ground Receiver Antenna.

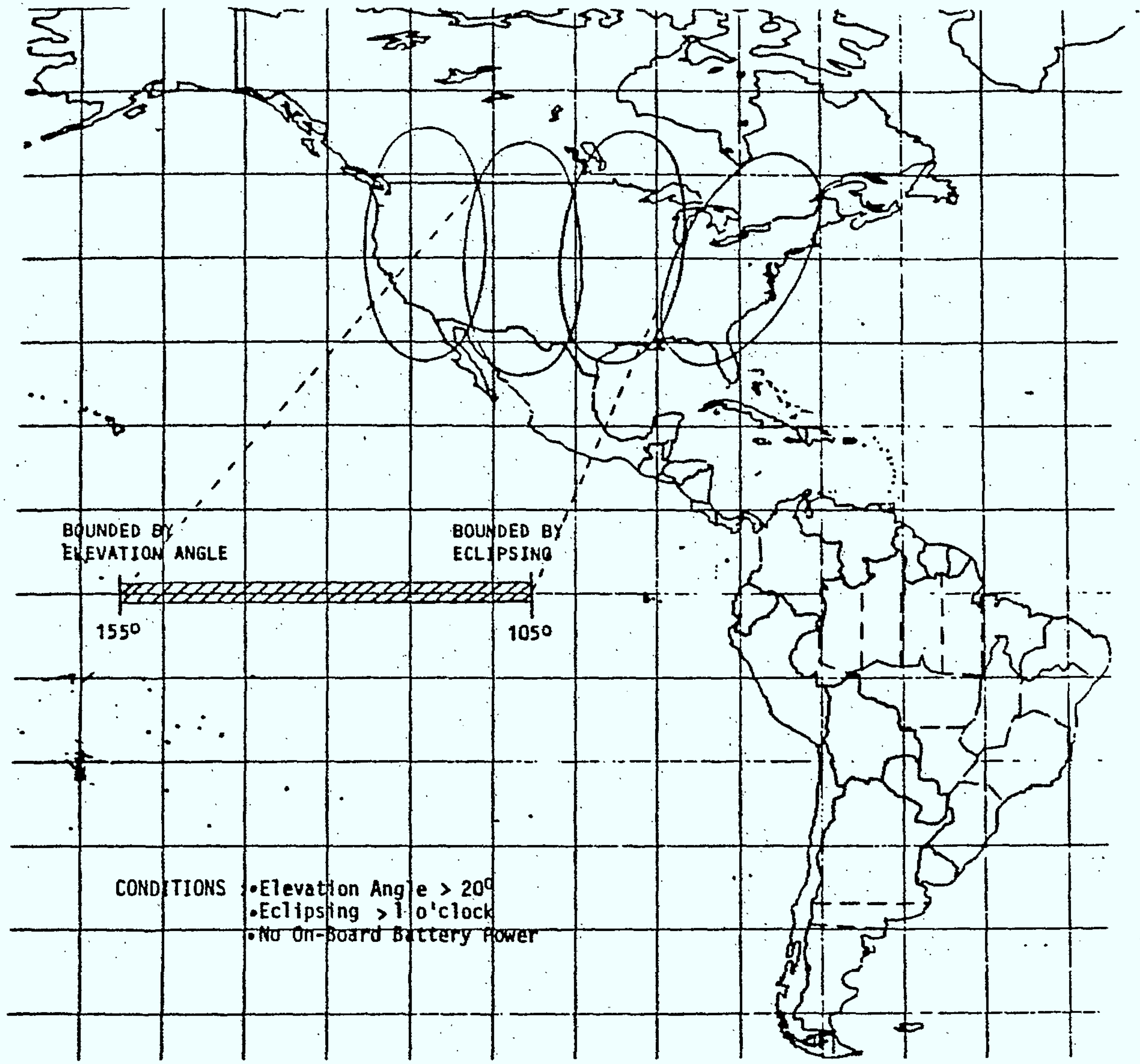
- Polarization Should be Circular in Order Not to Require Orientation of Receiver Antenna Other Than Pointing.

- If Possible, Channels Should Not be Spread Over the Entire Band (500 MHz) in order to Reduce Cost of Receiver Tuner. That is, Channels Should be Grouped on One Side of Band.

- Where Feasible, Elevation Angles of Receiver Beams Should be Greater Than 20°. Determined by Orbital Slot Assigned to Its Parent Satellite. Terrain profile and Weather in Certain Regions Will Require Greater Angles.

- Satellite Should be West of Service Area in Order to Have Eclipsing Occur at Non-Prime Time (assuming no battery power on satellite)

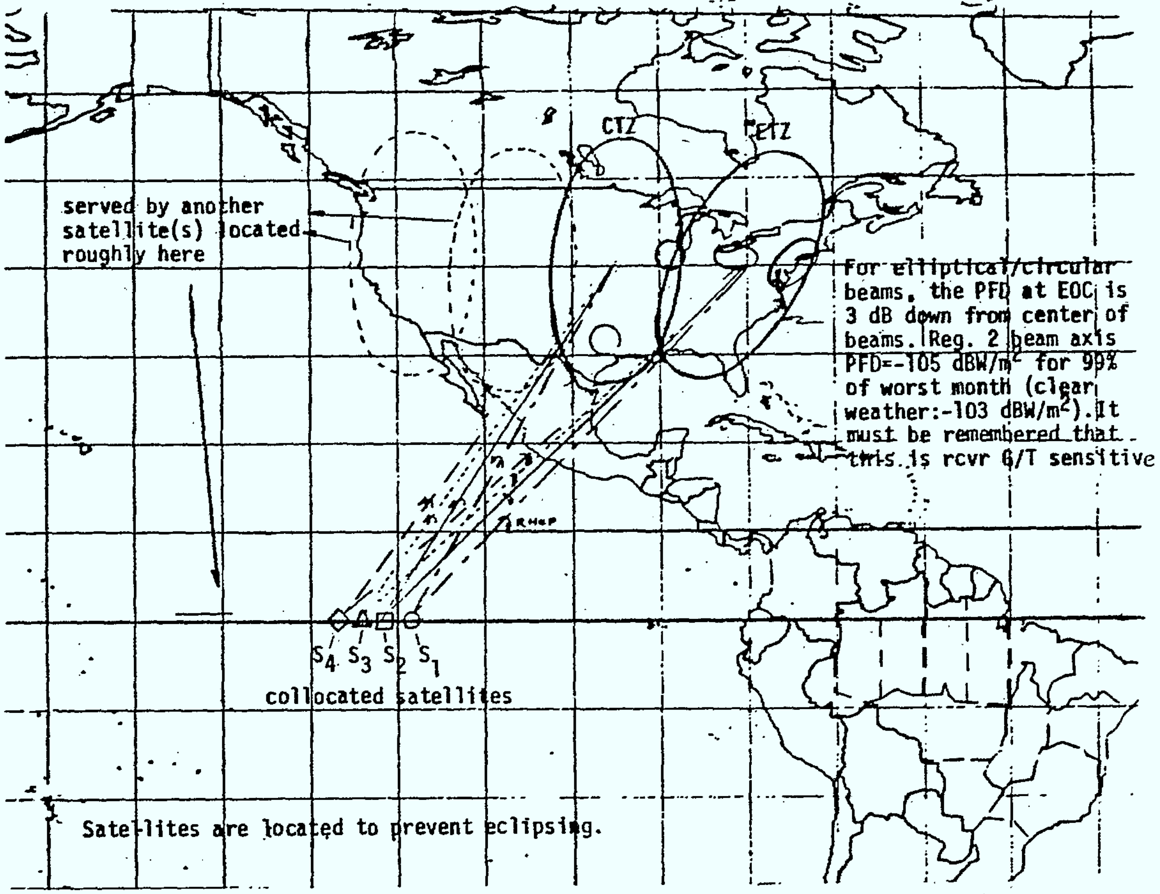
ORBITAL SLOT BOUNDS FOR ONE HOUR ECLIPSE PROTECTION & 20° ELEVATION ANGLE



CONUS FACTS

- Mid-CONUS at 98° W Long. and 39° N Latitude .
- For sat. at mid-CONUS, CONUS spans about 7° in E-W direction & 3° in N-S direction.
- One time zone about 600 x 1000 nmi.
- One time zone is abou 2° x 3°.
- A 2° conical beam can cover a time zone because of flare out in satellite antenna up-dwn direction.
- EOC gain for CONUS is about 27 dB.
- On-axis gain for time zone is about 35 dB.

FIRST-CUT PLANNING SCENARIO (TWO TIME ZONES PER SATELLITE) - I



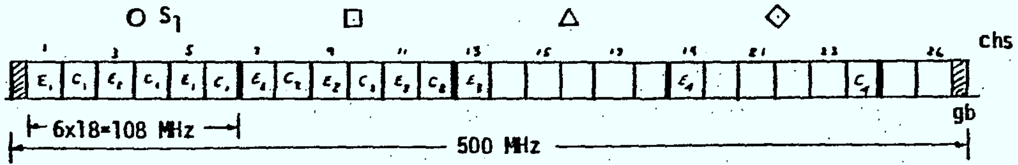
served by another satellite(s) located roughly here

For elliptical/circular beams, the PFD at EOC is 3 dB down from center of beams. Reg. 2 beam axis PFD=-105 dBW/m^2 for 99% of worst month (clear weather:-103 dBW/m^2). It must be remembered that this is rcvr G/T sensitive

collocated satellites

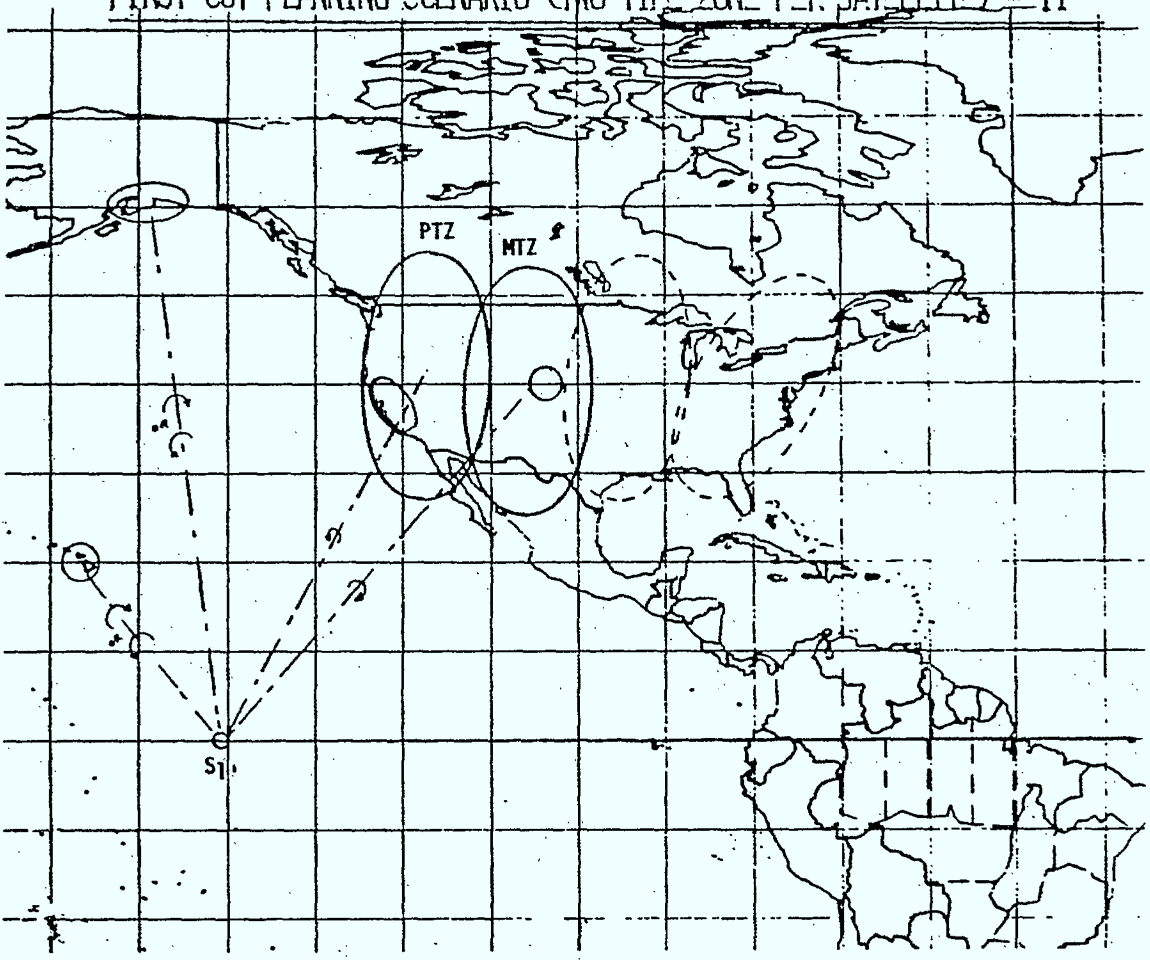
Satellites are located to prevent eclipsing.

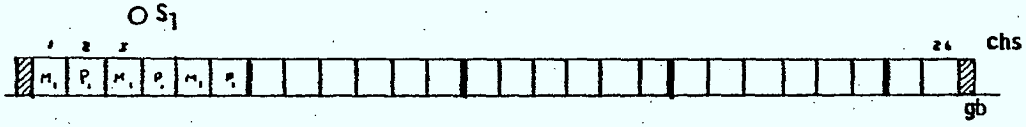
E_1: channel to ETZ



- Each satellite servies two time zones + area & spot zones within time zone.
- Each satellite is assigned 6 channels serving two time zones + internal beams.
- Satellite power constraints & size of service areas puts a bound on the number of channels each satellite can support.
- The beams serving the ETZ and CTZ have opposite sense circular polarization.
- Beams are shown elliptical/circular, but shaped beams are more efficient, less spillover
- The western satellite will serve Alaska & Hawaii (no eclipse protection).
- Since all satellites are collocated, all rcvr beams will point to cluster.
- There is no reason why CTZ cannot be serviced by channels which are not contiguous to channels serving ETZ. This would therefore allow CTZ and ETZ to have same

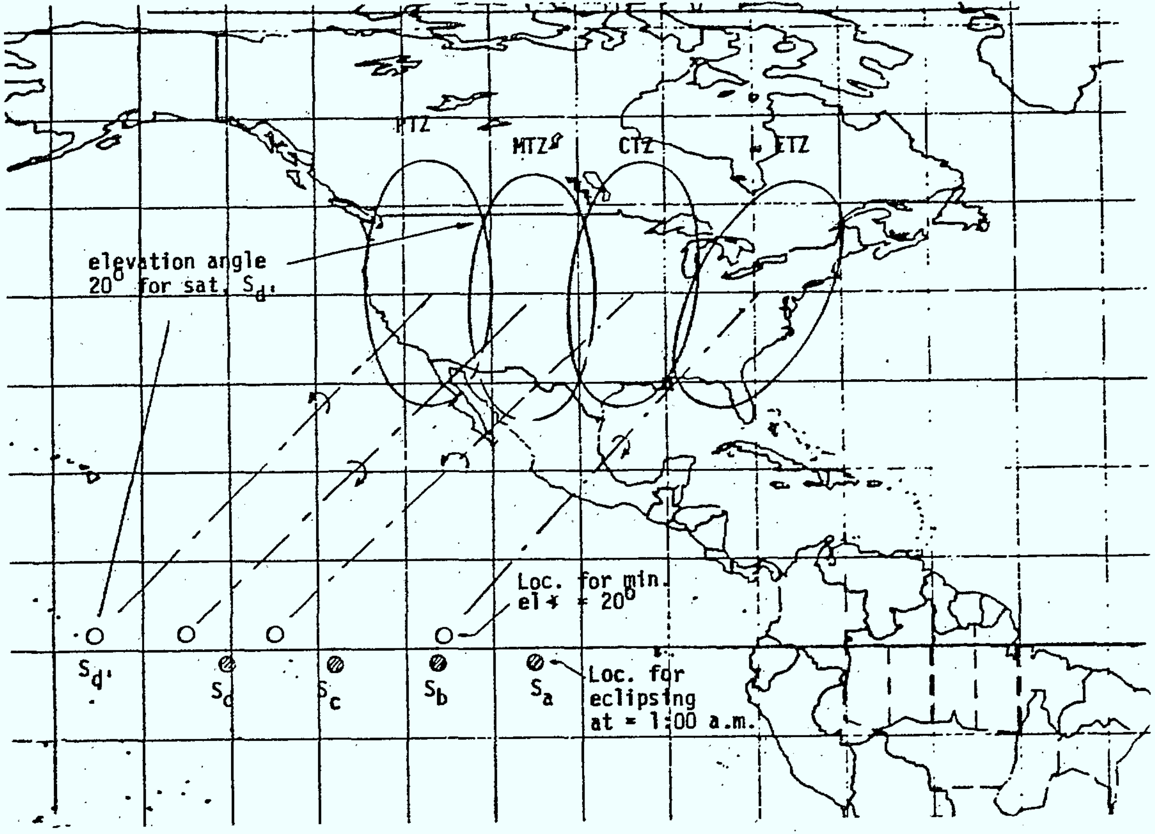
FIRST-CUT PLANNING SCENARIO (TWO TIME ZONE PER SATELLITE) - II

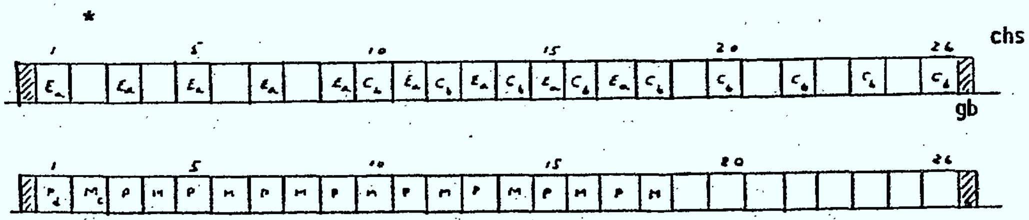




- This satellite provides service to MTZ, PTZ, Alaska, Hawaii, the latter two receive no eclipse protection.
- Number of channels dictated by satellite power and size of service areas.
- Beams have opposite sense circular polarization.
- Each time zone served by three channels
- Beams will be shaped to contour service areas.

FIRST-CUT PLANNING SCENARIO (ONE TIME ZONE PER SATELLITE)

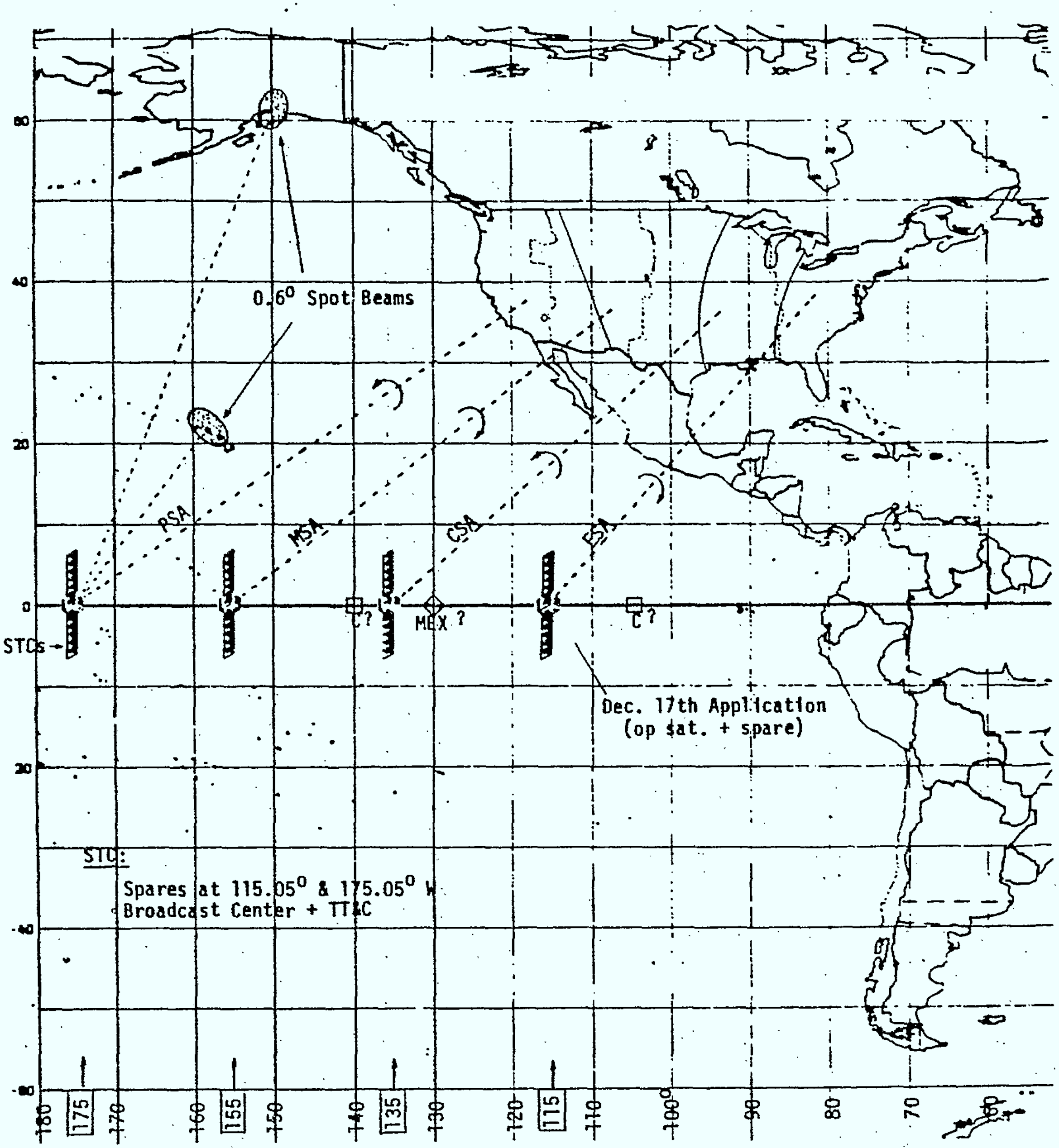




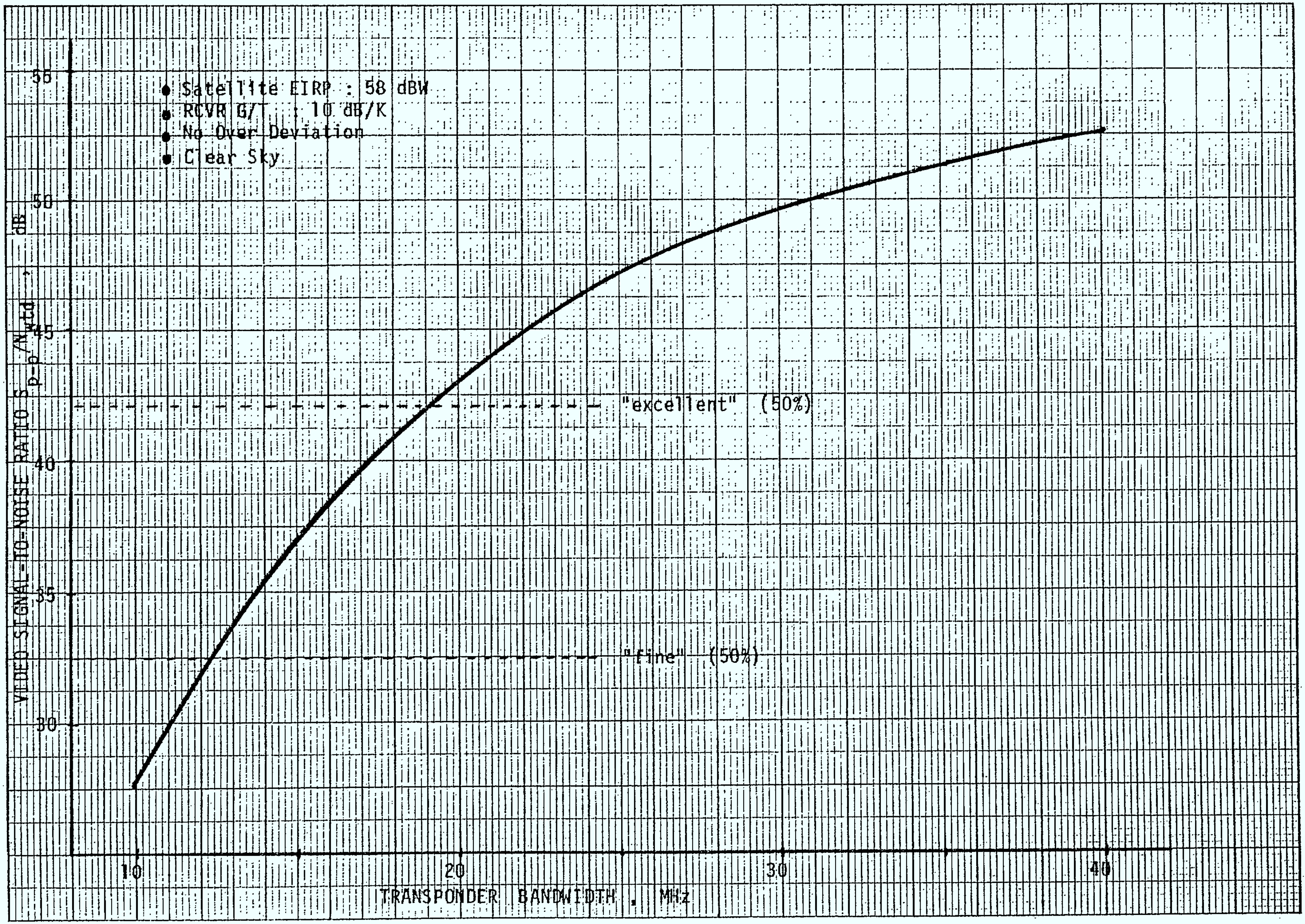
* See last bullet for co-channel operation.

- Since each satellite is now driving only one time zone, the "extra" 200 W can be used to supply additional area or spot beams, e.g., 200/30≈6 spot or 200/70≈3 area beams. Therefore each satellite can serve one time zone and 5 → 8 spot/area beams.
- In the above channelization, 9 chs are assumed (1 time zone, 8 area/spot).
- If a more modest satellite is used, fewer chs would serve a time zone.
- For satellite separation of 15°, the antenna discrimination at the rcvr antenna (BW:1.8°) is about 3o dB. Additional separation can permit co-channel operation, possibly with same polarity (using rcvr reference pattern).

STC'S DBS APPLICATION SUBMISSION TO THE FCC



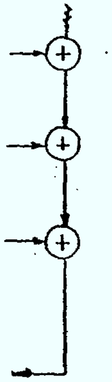
Note: Their footprints
do not straddle
time zones, but
equal areas.



● Satellite EIRP : 58 dBW
● RCVR G/T : 10 dB/K
● No Over Deviation
● Clear Sky
VIDEO SIGNAL-TO-NOISE RATIO S_p-p/N_wtd , dB
55
50
45
40
35
30
"excellent" (50%)
"fine" (50%)
10
20
30
40
TRANSPONDER BANDWIDTH , MHz

ILLUSTRATIVE LINK BUDGET FOR U.S. TIME-ZONE COVERAGE

EIRP_{MAX} $[P_T - L_{T-A} + G_{SAT}(\mathrm{NOSE})]$ $P_T = 200$ W and $G_S = 35$ dB	58	dBW
Free Space Loss	-206	
Edge of Coverage Loss	-3	
Misc. Loss (pol. mismatch, atmos., pointing)	-1	
$(G/T_S)_{REC}$ (clear sky)	+10	
$-(K)$	+228.6	
Bandwidth (20 MHz, say)	-73	
Pre-Demodulator C/N	13.6	dB
Weighting + Deemphasis Improvement + Conversion Factor	+19.1	
FM Improvement Factor (B=20 MHz, F_M=4.2 MHz, ΔF=5.8 MHz)	9.6	
S_{P-P}/N_W	42.3	dB



Would be considered "excellent" by 50% of viewers (TASO)

FUNDAMENTAL SYSTEM RELATIONSHIPS USED IN BSS/DBS

- LINK TRADE-OFF EQUATION :

$$(C/N) = EIRP_{max} - L_{fsl} - L_{EOC} - L_{misc.} + (G/T_s)_R - (k) - B \qquad dB$$

or

$$(C/kT_s) = (C/N_o) = EIRP_{max} - L_{fsl} - L_{EOC} - L_{misc.} + (G/T_s)_R - (k)$$

- (C/N) AT THE RECEIVER :

$$(C/N)_R = \frac{1}{1/(C/N)_u + 1/(C/N)_d} \quad \text{(linear channel)}$$

$(C/N)_{up} >> (C/N)_{dwn}$

usually:

$(C/N)_{up} = 10\text{-}20 \text{ dB} + (C/N)_{dwn}$

- FM DEMODULATOR OUTPUT TV VIDEO (S/N), (above threshold, $(C/N)_t \approx 10$ dB) :

$$(S_{p-p}/N_w) = (C/N) + 10 \log (\Delta f/f_m)^2 + 10 \log (B/f_m) + W\ D + 6.1 \qquad dB \qquad WD = 13 \text{ dB}$$

Since Carson's bandwidth = $2\ (\Delta f + f_m)$

$$= \underbrace{10 \log 3\ \overline{MI}^2\ (B/2f_m)} \quad + (C/N) + 19.1$$

$$= \text{FM Improvement Factor} \quad + (C/N) + 19.1 \qquad dB$$

CIRCULAR VERSUS LINEAR POLARIZATION

ATTRIBUTES	CIRCULAR POLARIZATION	LINEAR POLARIZATION
NO POLARIZATION TRACKING (AT SAT. OR GRD RECEIVER)	✓	
LESS DEPOLARIZATION IN RAIN		✓
ORTHOGONAL OPERATION FOR MULTIPLE SATS. *	✓	
SIDELOBE POLARIZATION PURITY		✓
SIMPLER SPACE CRAFT SHAPED BEAM ANTENNA DESIGN		✓
INCREASED RCVR COST		✓ (no depolarizer)

✓ : BETTER

* It is difficult to maintain orthogonality between 2 adjacent service areas served by two satellites, if linear polarization is used.

USE OF FM TRANSMISSIONS (IN LIEU OF VSB-AM)

- SMALLER SATELLITE POWER
- SMALLER CO-CHANNEL PROTECTION RATIO
- PSEUDO GREATER CHANNEL BANDWIDTH
- CONSTANT AMPLITUDE SIGNAL, THEREFORE NOT SENSITIVE TO CHANNEL AMPLITUDE NON-LINEARTIES

FACTS ABOUT ECLIPSING (SATELLITE IN THE SHADOW OF THE EARTH) *

- Eclipses occur during the spring equinox and autumn equinox.

- Varys in duration from approximately 10 minutes at the beginning and end of eclipse to maximum of 72 minutes at the equinoxes (21st March and 23rd September).

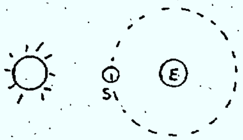
- Eclipse begin 22 days prior to equinox and ends 22 days after equinox. Therefore, in Spring: 27 Feb. to 12 April, Autumn: 1st Sept to 15th of October.

- Eclipse will be greater than one hour for 52 days of year, (8th March - 3rd April, 9th Sept - 6th October).

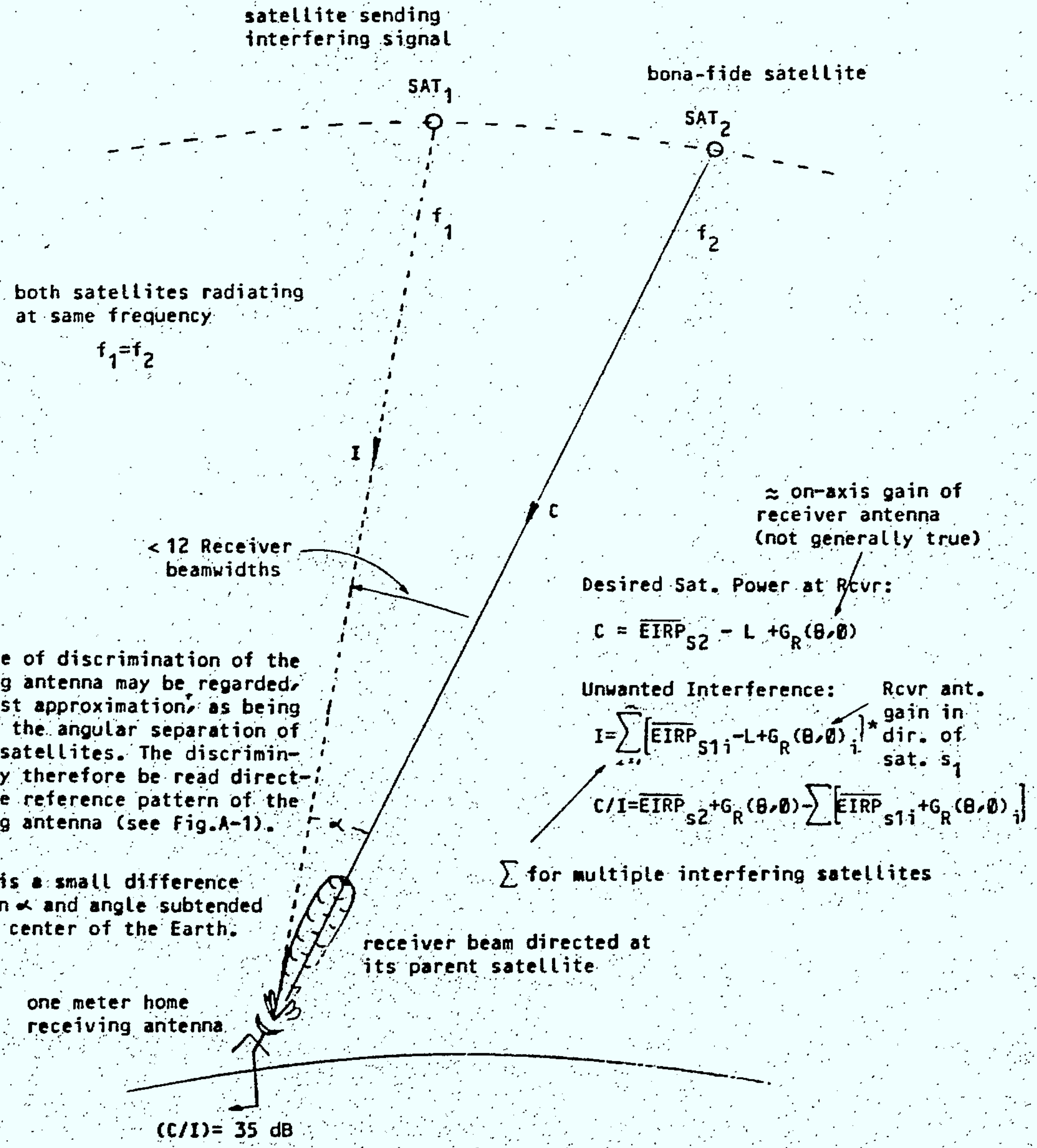
- Moving satellite 4 minutes west of earth receiver longitude, delays eclipse at local time by 1°.

---

* Sun Transit Outage : Another form of outage occurs when the satellite passes directly in front of the sun. This occurs for about 10 minutes five consecutive days twice a year. It is noted that this causes a very large increase in receiver antenna temperature, therefore producing an extremely poor G/T_S. The receiver may become completely inoperative during this period.



SCENARIO FOR INTERFERENCE ANALYSIS



≈ on-axis gain of receiver antenna (not generally true)

Desired Sat. Power at Rcvr:

$$C = \overline{EIRP}_{S2} - L + G_R(\theta,0)$$

Unwanted Interference:

$$I = \sum \left[\overline{EIRP}_{S1i} - L + G_R(\theta,0)_i\right]^*$$

Rcvr ant. gain in dir. of sat. s_1

$$C/I = \overline{EIRP}_{s2} + G_R(\theta,0) - \sum \left[\overline{EIRP}_{s1i} + G_R(\theta,0)_i\right]$$

$\sum$ for multiple interfering satellites

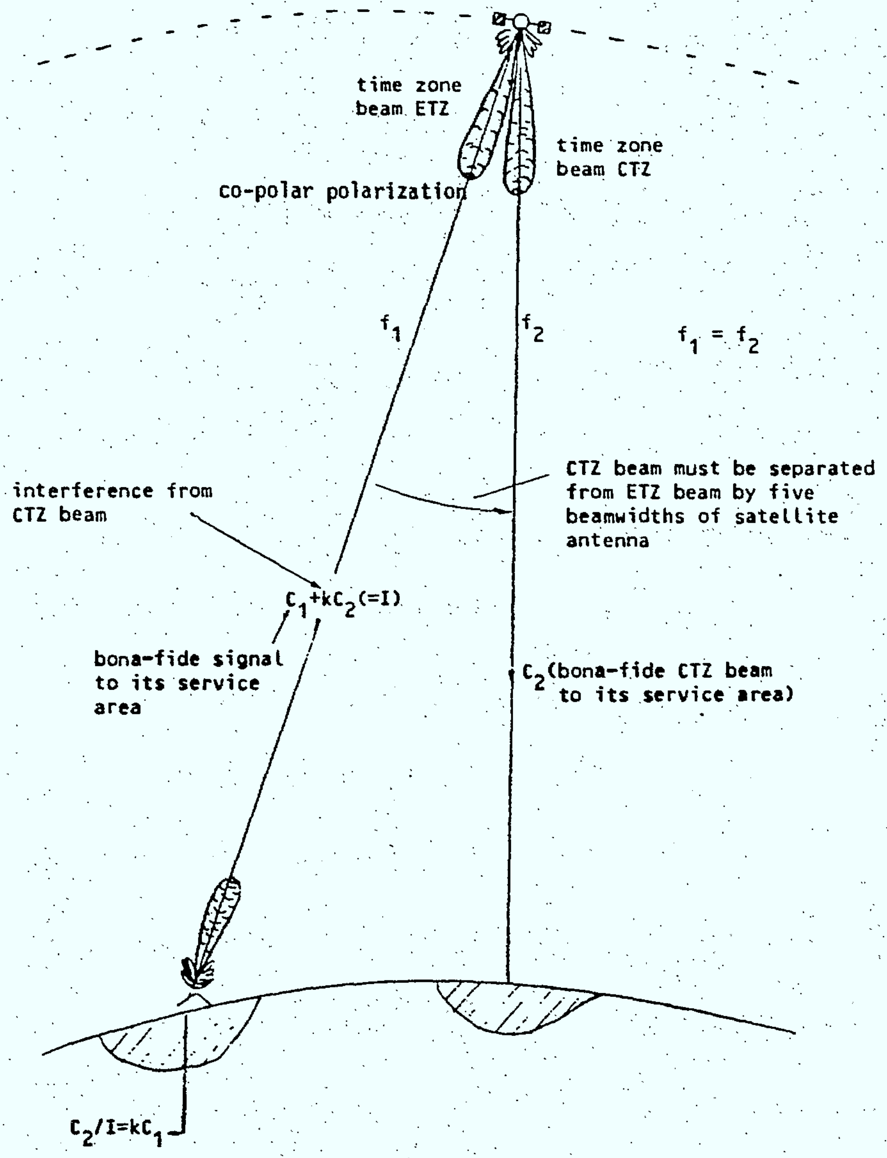
The angle of discrimination of the receiving antenna may be regarded, in a first approximation,* as being equal to the angular separation of the two satellites. The discrimination may therefore be read directly on the reference pattern of the receiving antenna (see Fig.A-1).

* There is a small difference between ∝ and angle subtended at the center of the Earth.

* This expression will contain a polarization discrimination factor if the S_1 sat. has opposite circular polarization. The C/I will improve by this factor.

It is also noted that the full on-axis sat. S_1 EIRP is driving the Rcvr antenna. If S_1 beam axis does not "pierce" the Rcvr, the off-axis gain must be accounted for in the S_1 sat. output EIRP.

SCENARIO FOR INTERFERENCE ANALYSIS



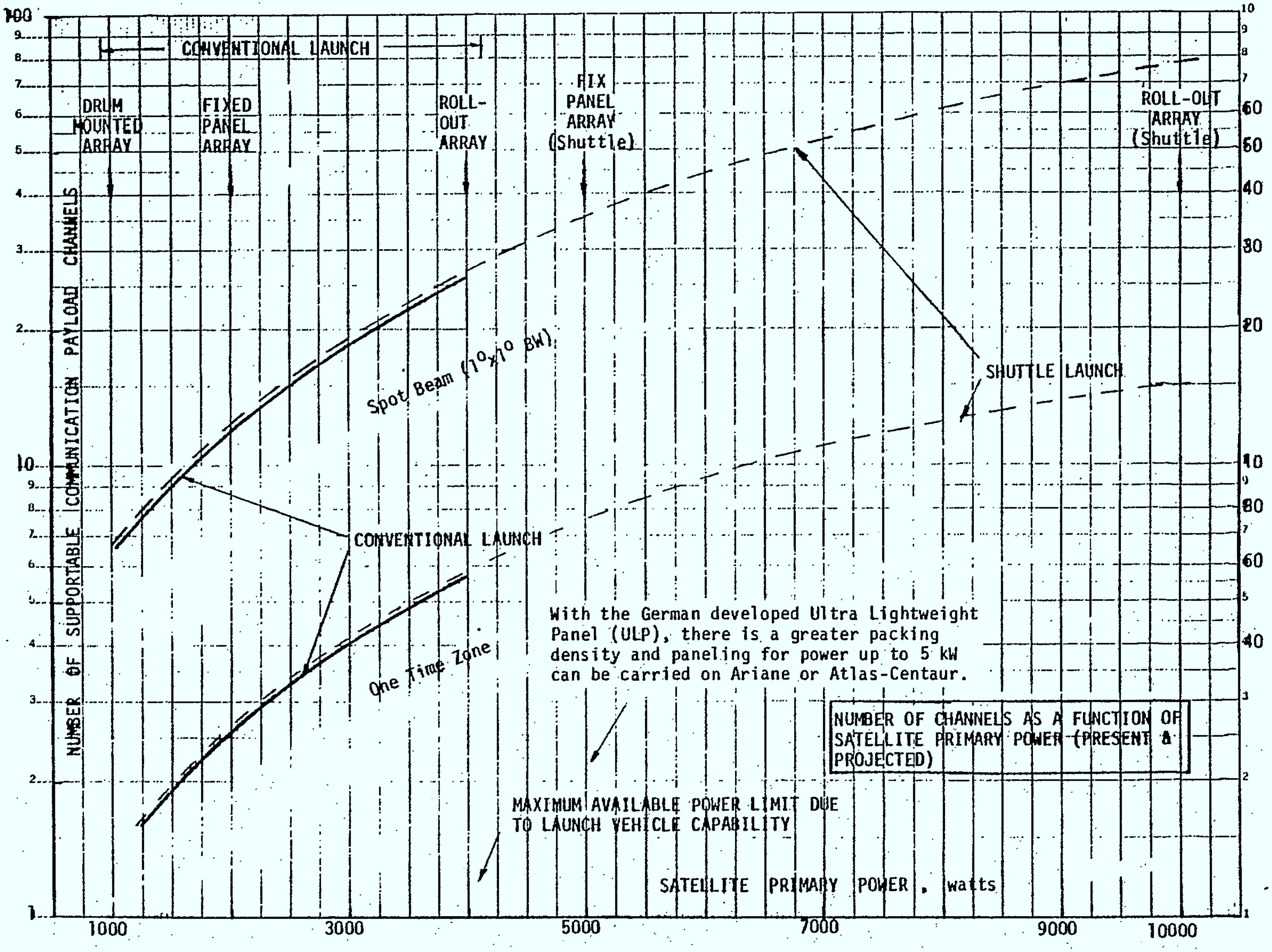
UPLINK FEEDER REQUIREMENTS

SOME GENERAL UPLINK (FEEDER) REQUIREMENTS

- PREFER UPLINK FREQUENCY BANDWIDTH TO MATCH DOWNLINK BANDWIDTH
- PROVIDE ADEQUATE C/N AT SATELLITE TO ENSURE SMALL DEGRADATION OF C/N AT BSS/DBS RECEIVER (TYPICALLY 10-20 dB MORE C/N)
- ORTHOGONAL OR OPPPOSITE SENSE CIRCULAR POLARIZATION TO THAT OF SATELLITE OUTPUT
- CAPABLE OF ALSO PERFORMING TT&C (COMMANDS TO AND TELEMETRY FROM SATELLITE)
- STEERABLE ANTENNA TO PROVIDE SERVICE TO POSSIBLY OTHER SATELLITES BESIDES ITS PARENT SATELLITE (THEREFORE, PROBABLY SELECTABLE RF POLARIZATION)
- CAUSE LITTLE INTERFERENCE TO OTHER SERVICES (OTHER SATS TOO) OCCUPYING THE SAME BAND (PROBABLY IN THE RANGE 17.3-17.8 GHz)

SATELLITE REQUIREMENTS

INTERRELATIONSHIP BETWEEN PRIME POWER, NUMBER OF CHANNELS AND COVERAGE AREA



With the German developed Ultra Lightweight Panel (ULP), there is a greater packing density and paneling for power up to 5 kW can be carried on Ariane or Atlas-Centaur.

NUMBER OF CHANNELS AS A FUNCTION OF SATELLITE PRIMARY POWER (PRESENT & PROJECTED)

Conventional : 30 W/#
GE Rollout : 90 W/#
German ULP : 50 W/#

PRIMARY POWER OF SOME PRESENT DESIGN COMMSATS

• WESTAR (HS 333 BUS)	250 W	(DRUM)	
• ANIK C, SBS (HS 376 BUS)	900 W	(DRUM)	
• LEASAT	1200 W	(DRUM)	SHUTTLE
• INTELSAT V	1300 W	(PADDLES)	
• FLTSATCOM	1200 W	(PADDLES)	
• TDRSS	1700 W	(PADDLES)	SHUTTLE

NOTE : ABOUT 70% OF PRIMARY POWER IS DEVOTED TO PAYLOAD. THE BALANCE DRIVES TT&C, BATTERY CHARGE, THERMAL CONTROL, ATTITUDE CONTROL.

PRIMARY POWER OF BSS/DBS-TYPE SATELLITES

CTS (HERMES)	1100 W	(ROLL OUT SOLAR ARRAY)
BSE	780	(PADDLES)
INSAT	1250	(PADDLES)
EKRAN (STATSIONAR T)	2000	(PADDLES)
TV-SAT-A3 (GERMANY)	4500	(PADDLES)
TDF-1A (FRANCE)	6200	(PADDLES)
NORDSAT	5000	(PADDLES)

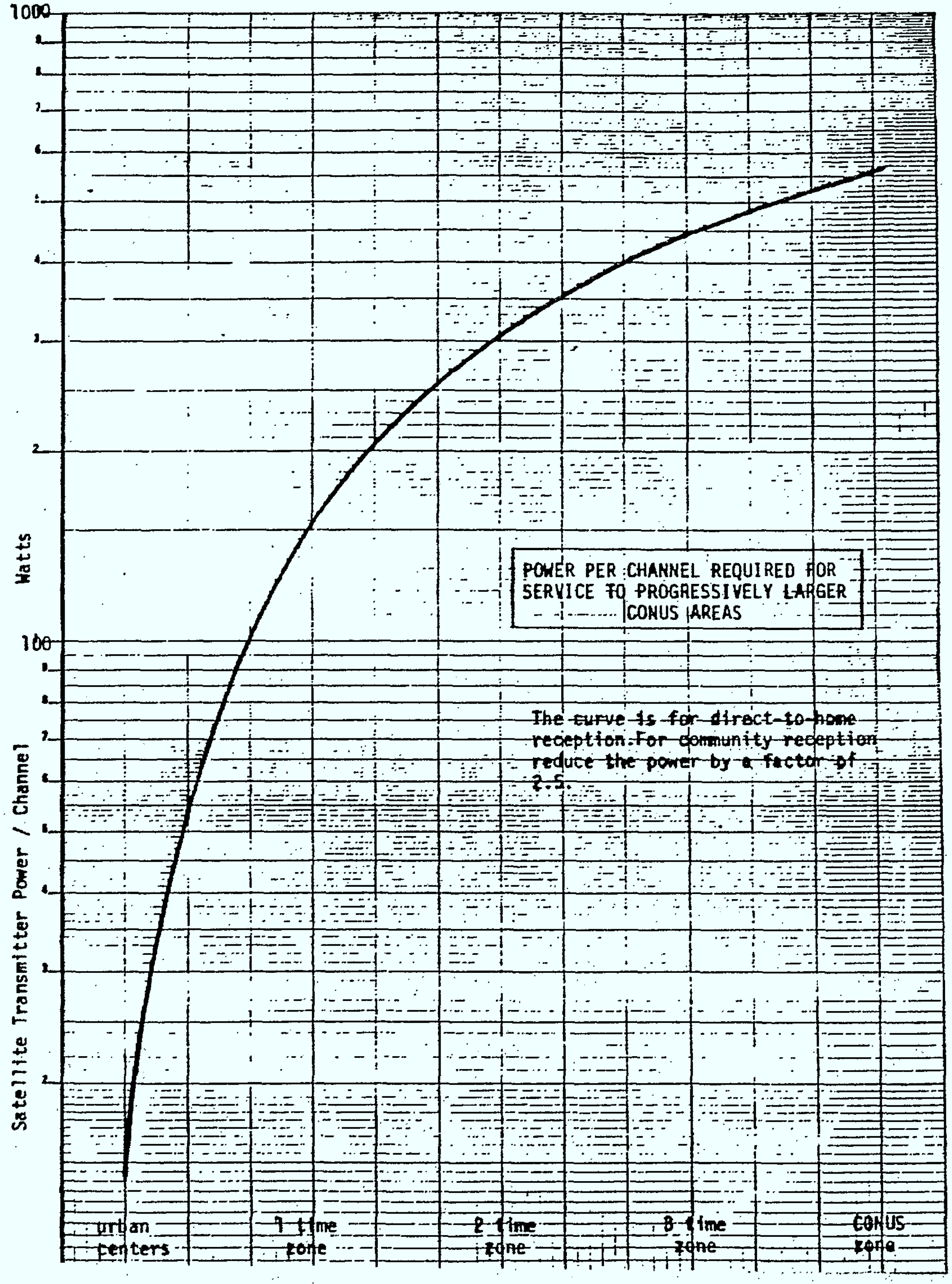
Note : Silicon solar cells are presently being used in spacecraft. Their theor. efficienci is about 25% but only 15% is possible at this time. COMSAT has reported progress with their Violet and Non-Reflective Solar cells. Advances are being made in this area by use of light weight support structures in paddle design.

TECHNOLOGY LIMIT TO THE NUMBER OF CHANNELS TO A SERVICE AREA

- THE NUMBER OF CHANNELS WHICH TECHNOLOGY PERMITS TO A SERVICE AREA IS DETERMINED BY THE SIZE OF THE BEAM (OR SERVICE AREA SIZE) AND THE SATELLITE PRIMARY POWER.

- THE BIGGER THE BEAM (SMALLER ANTENNA GAIN) THE HIGHER THE TRANSMITTER POWER REQUIRED PER CHANNEL, AND THUS FASTER "USURPATION" OF PRIMARY POWER BY A FEWER NUMBER OF CHANNELS.

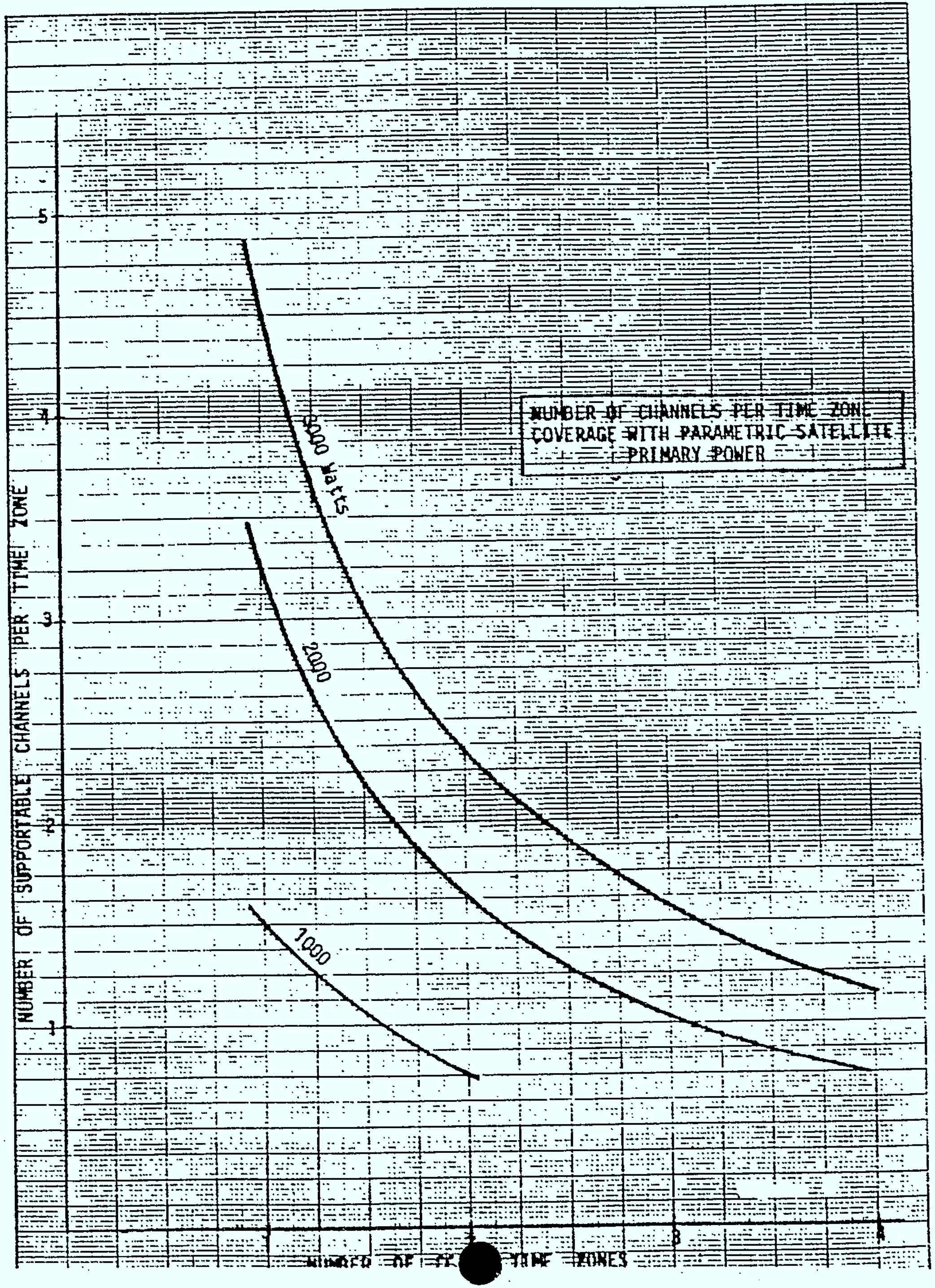
RF POWER REQUIREMENTS PER CHANNE[illegible]S A FUNCTION OF COVERAGE AREAS



POWER PER CHANNEL REQUIRED FOR SERVICE TO PROGRESSIVELY LARGER CONUS AREAS

The curve is for direct-to-home reception. For community reception reduce the power by a factor of 2.5.

NUMBER OF CHANNELS POSSIBLE PER TIME ZONE



HIGH POWER TUBES FOR SAT-BORNE APPLICATIONS

MANUFACTURER	POWER	EFFICIENCY	SLOW-WAVE STRUCTURE	REMARKS
TELEF., THOMSON CSF	20 W *	40 %	HELIX	TH-CSF FLOWN IN CTS
HUGHES	100 W	50	COUPLED CAVITY	FLOWN IN BSE-1
THOMSON-CSF	150	45	HELIX	
TELEFUNKEN	150	45	HELIX	
LITTON	200	45	COUPLED CAVITY	FLOWN IN CTS
THOMSON-CSF	220	50	HELIX	FRENCH TDF-1
TELEFUNKEN	250	45	HELIX	GERMAN TV-SAT-3
TELEFUNKEN	450	50	COUPLED CAVITY	FOR L-SAT ?

POWER ENHANCEMENT MAY ALSO BE REALIZED BY COHERENT COMBINATION OF POWER (PARALLELING).

* THIS IS SATURATED POWER OUTPUT. TUBES ARE MOST EFFICENT WHEN OPERATED IN THIS MODE. THIS IS ALSO THE FULL SATELLITE OUTPUT POWER (LESS OUTPUT LOSSES), AND NO "BACK-OFF" POWER OF THE TUBE IS REQUIRED BECAUSE OF USUALLY SINGLE CHANNEL OPERATION OF TV SIGNALS. "BACK-OFF" IS UTILIZED TO PREVENT GENERATION OF INTERMODULATION PRODUCTS WHICH WOULD FALL IN SATELLITE RECEIVER BAND AND "RING-AROUND" TO SATELLITE INPUT AND BECOMES A SPURIOUS SIGNAL. POWER OUTPUT BACKOFF USUALLY FALLS IN THE RANGE OF -3 TO -10 DB.

Coupled cavity tubes are generally used for higher power, but the helix type have greater bandwidth and better fine grain characteristics (less distortion IMs, AM/PM etc.)

FCC/OST

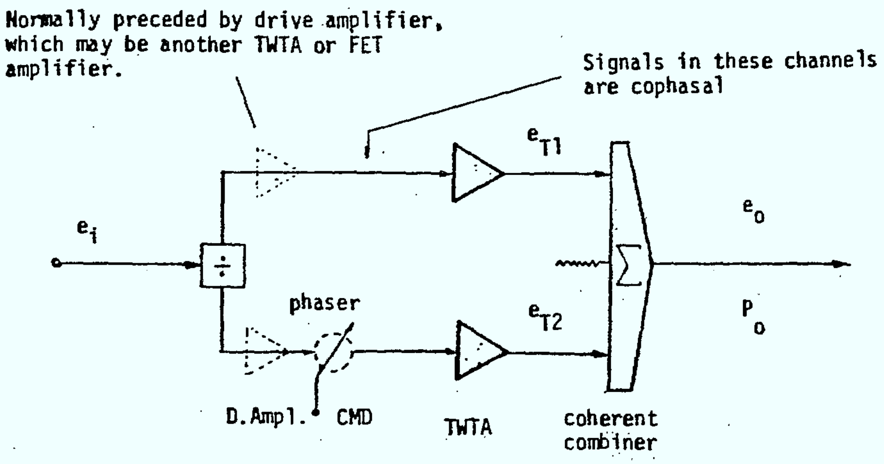
TENTATIVE THOMSON-CSF HELIX TWTA DATA (ALL TUBES 11.7-12.5 GHz)

- THOMSON-CSF HELIX TWTA : 150 W , EFF. = 50 % TH - 3579
  (3 stage depressed collector)
- THOMSON-CSF HELIX TWTA : 120 W , EFF. = 50 % TH - 3579 (FOR BSE-II)
  (3 stage depressed collector)
- THOMSON-CSF HELIX TWTA : 230 W EFF = 50 % TH - 3619 (FOR CNES)
  (4 stage depressed collector)

* Candidate for German/French Broadcast Satellite & STC (COMSAT) DBS.

Tubes may also be paralleled for increased power (TH-CSF has realized 400 W from two TH 3619s).

SATELLITE RF POWER ENHANCEMENT BY PARALLEL COMBINATION OF OUTPUT TUBES



The signal, e_i, in the transponder channel drives the paralleling network. The signal is bifurcated and drives the input of the two output TWTAs. Their output are coherently added in a coherent combiner. The output is e_o.

From the theory, coherent signals are additive (for random signals their powers are additive). Therefore the output of the combiner is: It is assumed that all signals are in phase. Any phase disparity, results in power dumping into the termination on the coherent combiner.

$$e_o = (e_{T1} + e_{T2}) /\sqrt{2}$$

The power output is

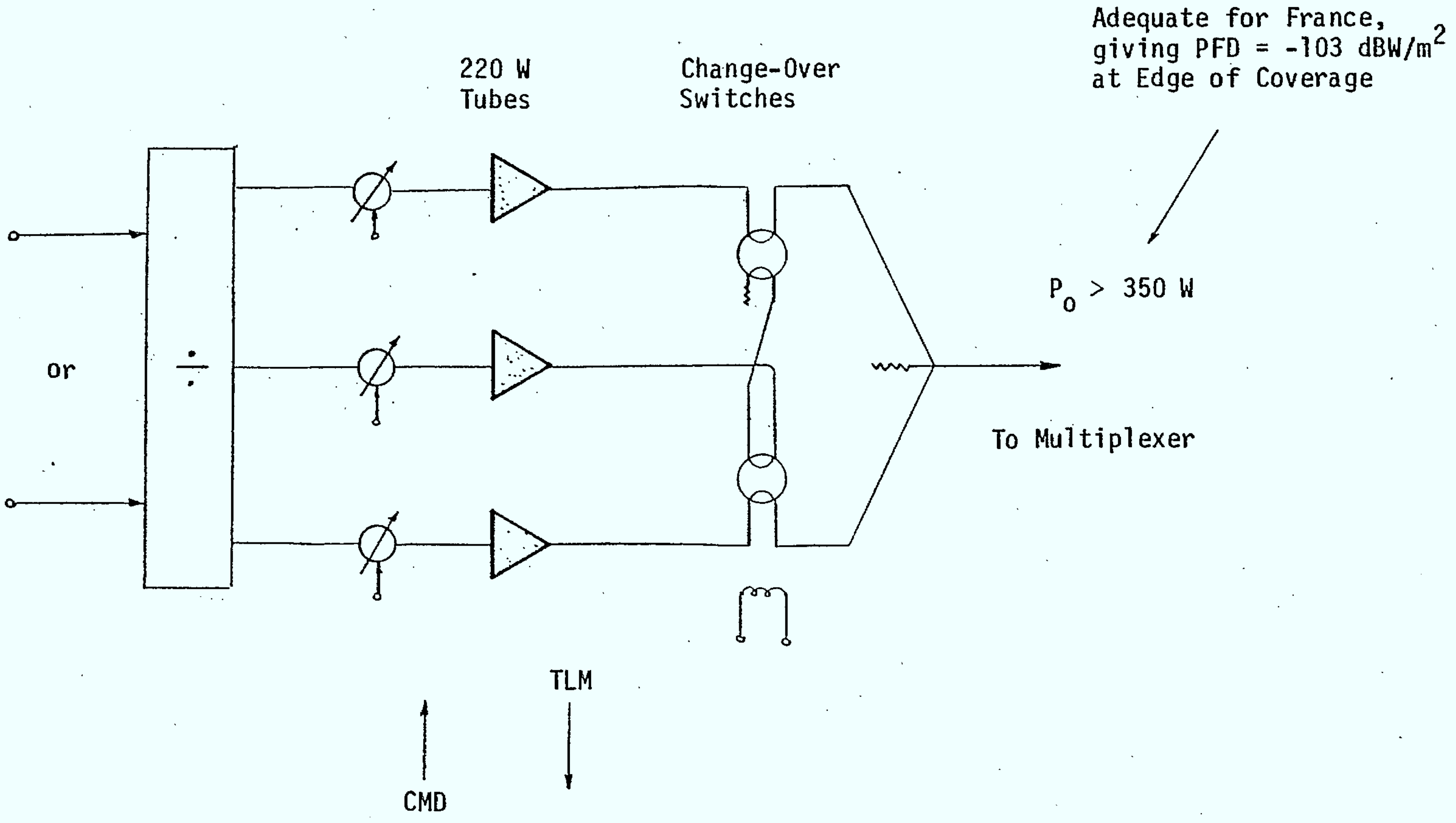
$$P_o = (1/2) (\sum e_T)^2 = (1/2) (e_{T1} + e_{T2}) ^2$$

$$= 2 e_T^{\,2} = 2 P_T$$

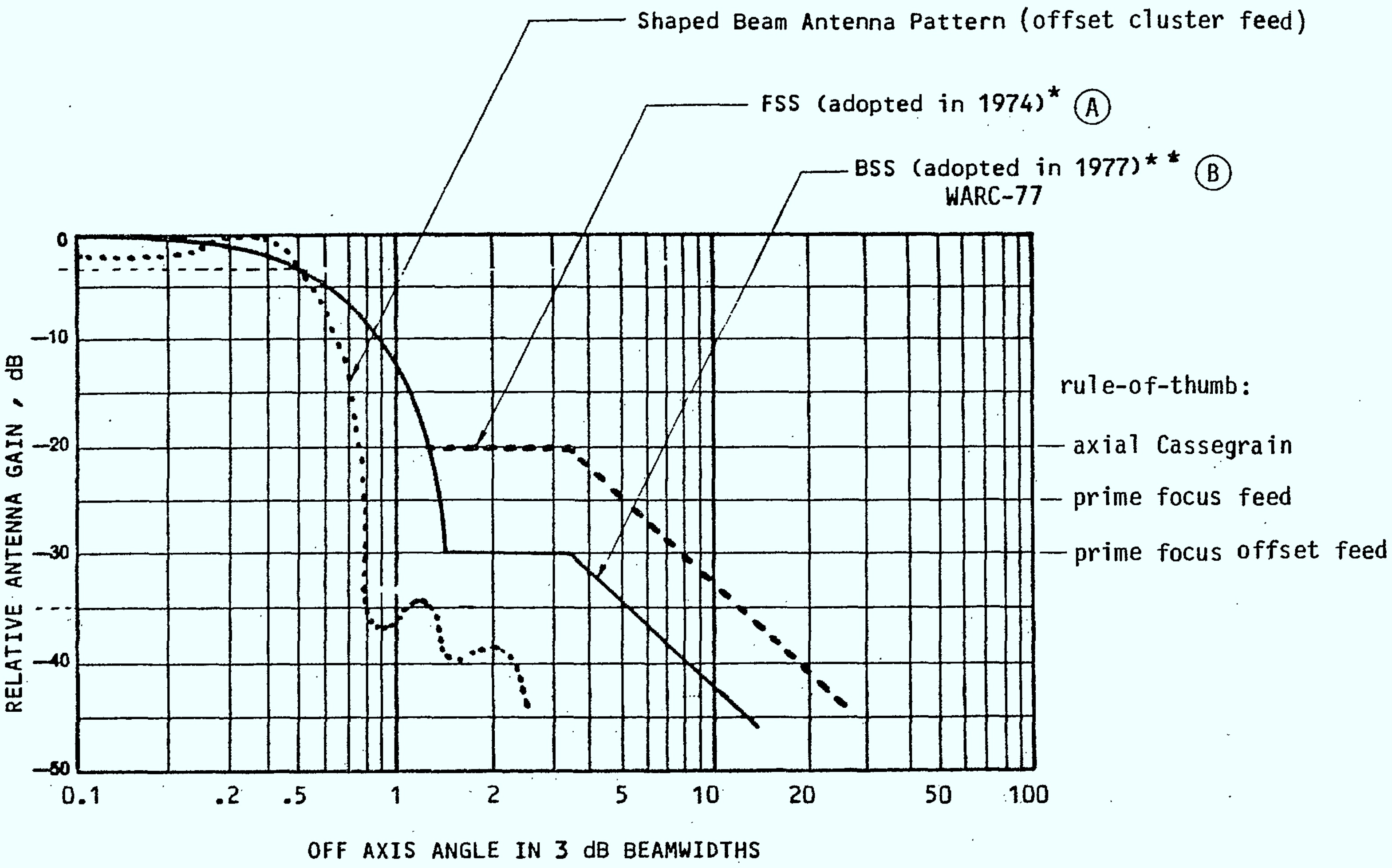
Where P_T is the power output of each tube.

It may be of additional interest to note that if a commandable phaser (via TT&C) is inserted in one of the channels (shown), output power control is possible. Further notice that if one tube fails, the power loss is not catastropic, but there is a 6 dB loss in power.

FRENCH CIRCUIT FOR PARALLING TWO TUBES (WITH 1 FOR 2 REDUNDACY)



REFERENCE PATTERNS Ⓐ , Ⓑ FOR SATELLITE TRANSMITTING ANTENNA

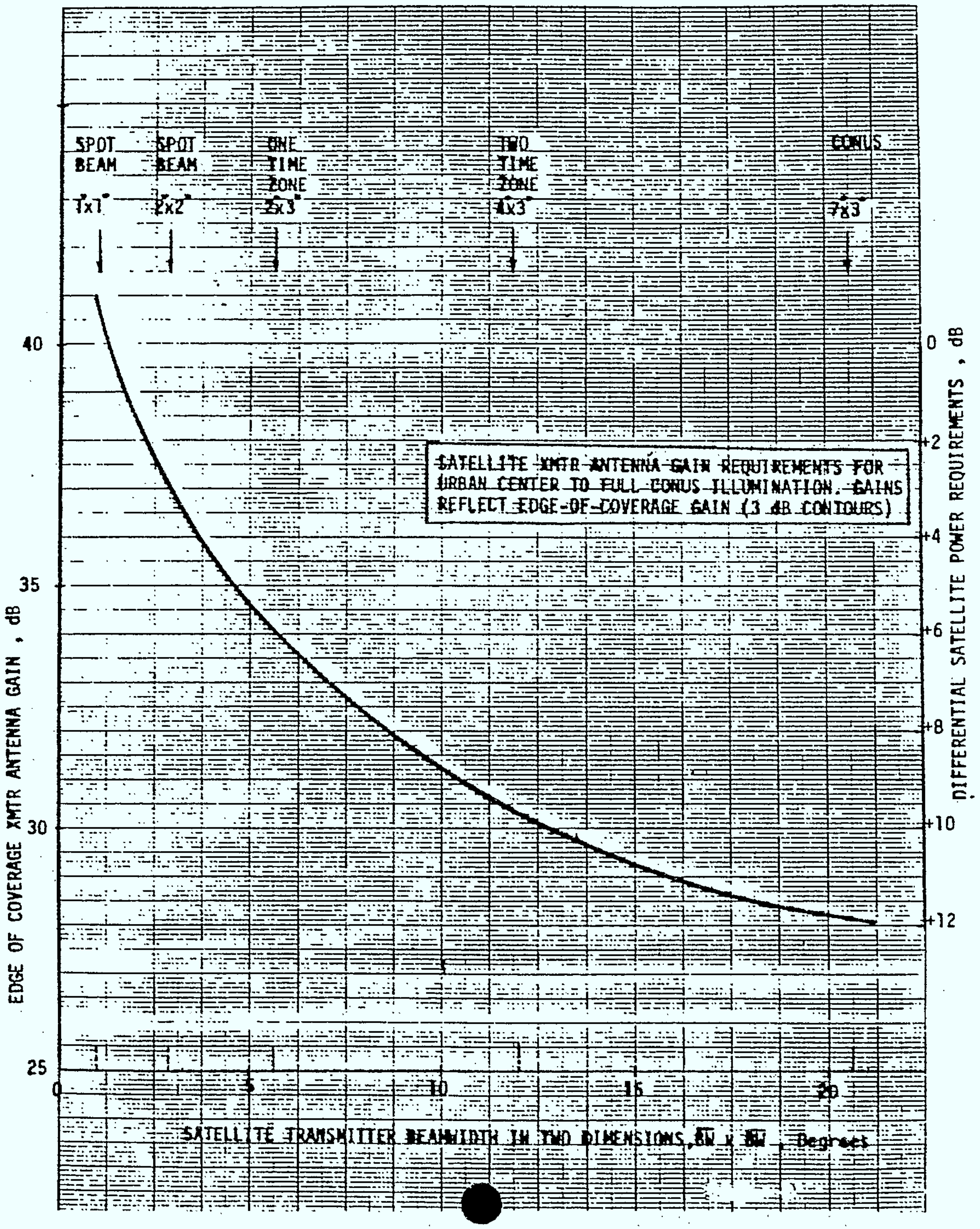


THE TREND IN SATELLITE ANTENNA DESIGN IS TOWARDS OFF-SET FEEDS.

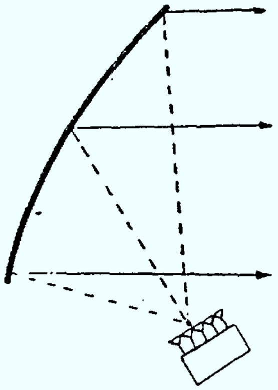
Note : The value of 35 dB is frequenctly used for
the necessary protection ratio between two
satellite networks (31 dB totalfor co-ch, 15 dB for adj.-ch interference)

* Single Feed Antennas (on-axis) conservative for on-axis fed antenna
** Offset Cassegrain feed antenna (also applies to offset single reflector)

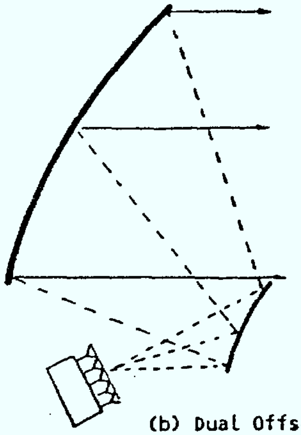
SATELLITE XMIT ANTENNA BEAM GAIN AS A FUNCTION OF BEAM SIZE



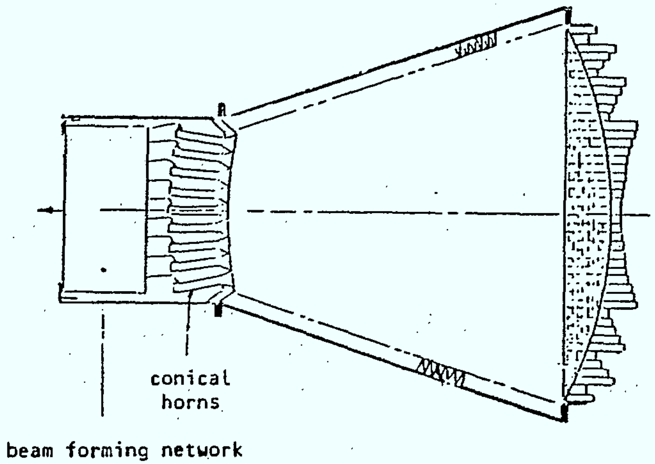
ANTENNA STRUCTURES POSSIBLE FOR SATELLITE-BORNE APPLICATIONS



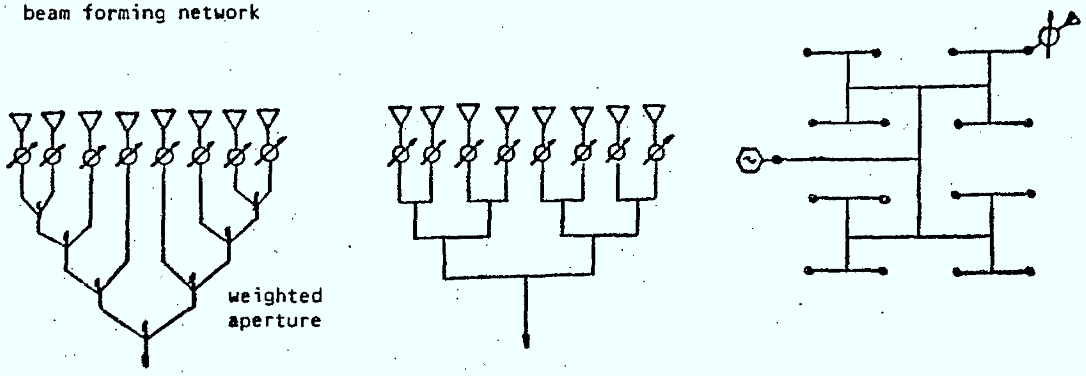
(a) Prime-Focus Fed Offset Reflector



(b) Dual Offset Reflector

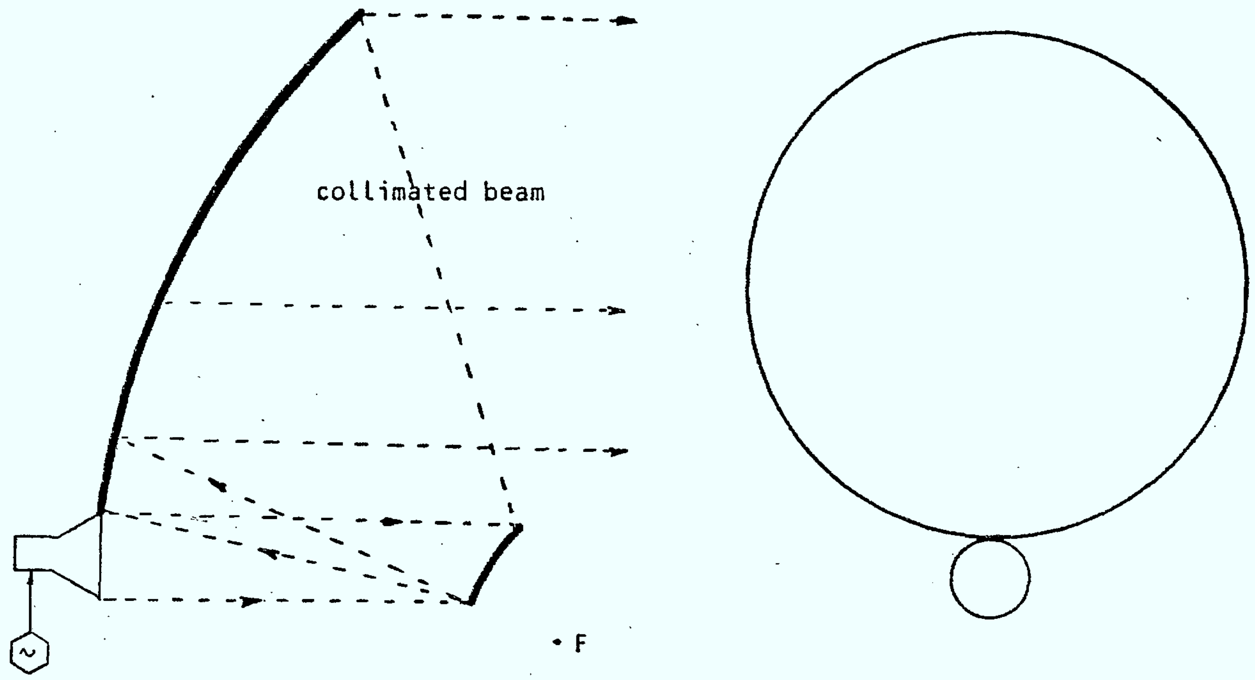


(c) Waveguide Feedthru Lens



(d) Corporate Fed Phased Arrays

OFFSET CASSEGRAIN FEED REFLECTOR



PROPERTIES OF OFFSET REFLECTORS

- IMPROVES SIDELOBE LEVEL OF BEAM SINCE NO FEED BLOCKAGE OCCURS FOR COLLIMATED BEAM
- ALLOWS MULTI-FEED STRUCTURES FOR MULTIPLE BEAM OPERATION & BEAM SHAPING
- PRODUCES NO REACTION IN THE FEED (VSWR) SINCE NO RADIATION BACK INTO FEED
- IF ILLUMINATED BY A LINEARLY POLARIZED WAVE, ASYMMETRY OF DISH WILL CAUSE SOME ENERGY TO BE COUPLED INTO CROSS-POLARIZATION COMPONENT
- IF ILLUMINATED BY A CIRCULARLY POLARIZED WAVE, NO DEPOLARIZATION WILL TAKE PLACE, BUT WILL CAUSE BEAM TO SQUINT OFF BORESIGHT (WILL SQUINT IN OPPOSITE DIRECTIONS FOR RIGHT & LEFT CIRCULAR POLARIZATION)

SHAPED BEAMS PRESENTLY ON

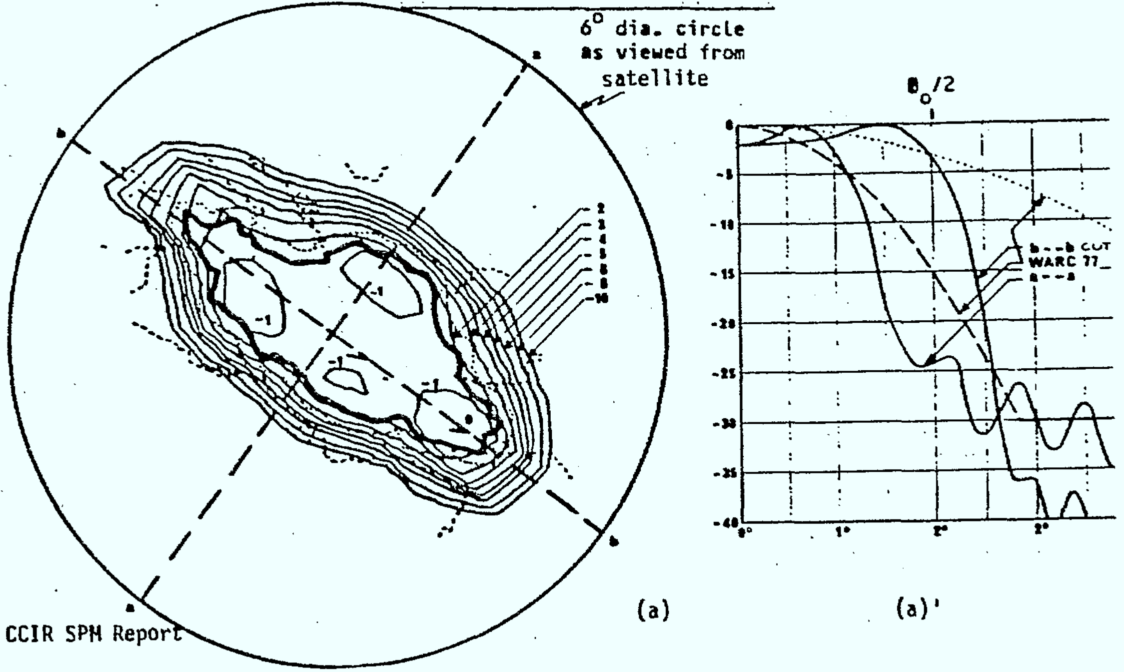
- INTELSAT IV - A
- ECS (EXPERIMENTAL COMMUNICATION SATELLITE) (JAPAN)
- BSE (BROADCASTING SATELLITE EXPERIMENTAL)
- INTELSAT V

Note : Shaped beams have usually been referred to as beam synthesis by shaping the reflector with a modestly complex feed. The Japanese BSE may be considered in this category. More recently, shaped beams has also come to mean beams which contour a country or complex service area. Here, there may be little reflector "distortion", but accompanied by a multiple complex feed with each feed output controlled in amptitude and phase. Because this labyrinth is massive, this would be an off-set feed configuration.

SHAPED BEAMS (AS RECENTLY REDEFINED)

- BEAM IS CONTOURED TO COVER THE SERVICE AREA
- SPILLOVER TO ADJACENT SERVICE AREAS IS MINIMIZED SINCE ANTENNA BEAM HAS A SHARP DROP OFF AT EDGE OF COVERAGE AREA
- PEAK EIRP DOES NOT OCCUR AT CENTER OF BEAM OR SERVICE AREA, POWER FLUX DENSITY IS NEAR-UNIFORM ACROSS SERVICE AREA
- SATELLITE STATION KEEPING MORE CRITICAL IN ORDER TO MAINTAIN COVERAGE TO DESIGNATED SERVICE. RECEIVERS AT EDGE OF SERVICE AREA SUBJECT TO SIGNAL VACILLATION DUE TO POINTING & STATION KEEPING INACCURACIES
- PRESENT MOST POPULAR SCHEME TO PRODUCE SHAPED BEAMS IS TO DRIVE AN OFFSET PARABOLIC SURFACE WITH A CLUSTER OF FEED HORNS
- SHAPED BEAMS GENERALLY REQUIRE A LARGER ANTENNA THAN THAT WHICH WOULD PRODUCE A CIRCULAR OR ELLIPTICAL BEAM. FOR EXAMPLE, THE SHAPED BEAM SHOWN IN FIGURE 5 REQUIRES A 2.5 METER REFLECTOR, THE "WARC-77 REFLECTOR" WOULD BE 1 METER IN DIAMETER

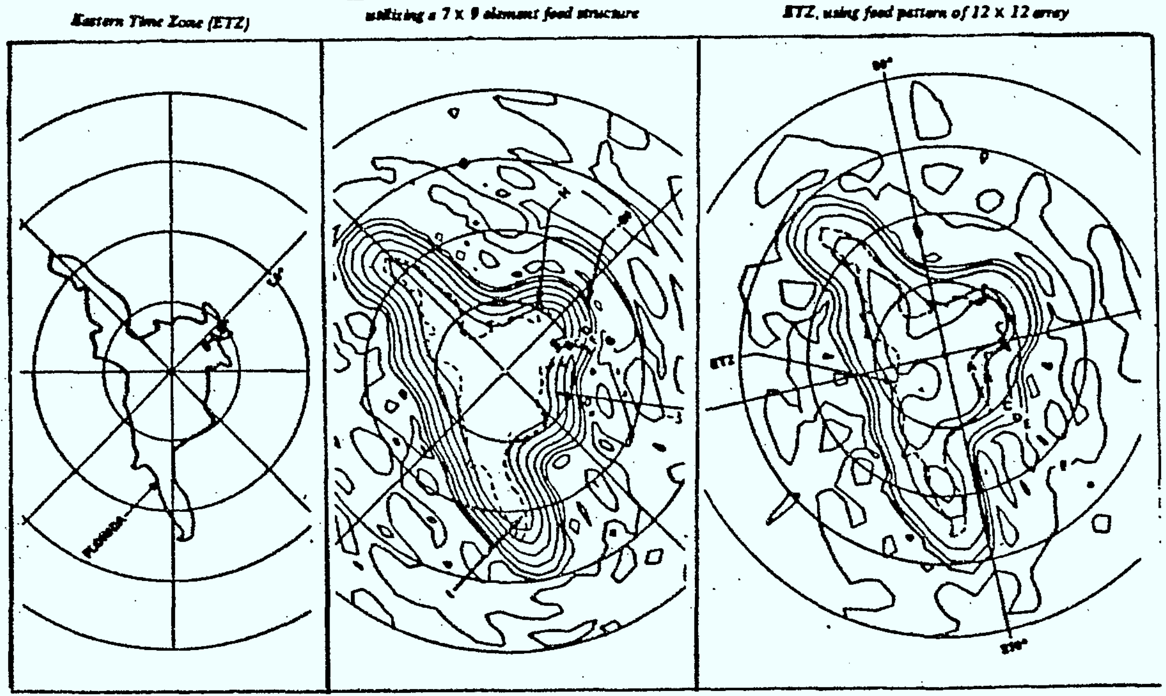
SHAPED BEAM PATTERNS



(a)

(a)'

CCIR SPM Report



CCIR Rep. 676

(b)

A : – 1 dB
B : – 3 dB
C : – 6 dB
D : –10 dB
F : –20 dB
G : –30 dB
H : State [illegible]aine
I : Stat[illegible]orida

A : – 1 dB
B : – 3 dB
C : –10 dB
D : –15 dB
E : –20 dB
F : –30 dB

PRESENT ATITUDE AND ORBIT CONTROL ACCURACY CAPABILITIES

- ROLL : < ± 0.1 °
- PITCH : < ± 0.1 °

IMPROVED INFRARED DETECTOR EARTH SENSOR

< 0.05° RF ON-BOARD SENSOR (COOPERATIVE GRD BEACON ON SATELLITE XMTR BEAM BORESIGHT AXIS

- YAW : ± 0.3 ° (RCA "STABILITE" - NO YAW SENSOR ON-BOARD)

  ± 0.1 ° (ATS-6 POLARIS STAR SENSOR)

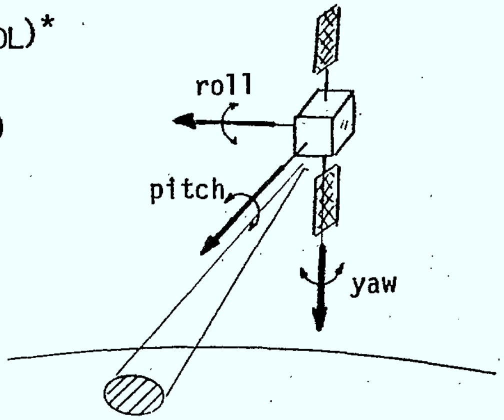
  ± 0.01 POSSIBLE

- STATION KEEPING : N-S : ± 0.1 ° (INCLINATION CONTROL)*

  E-W : ± 0.1 ° (LONGITUDE CONTROL)

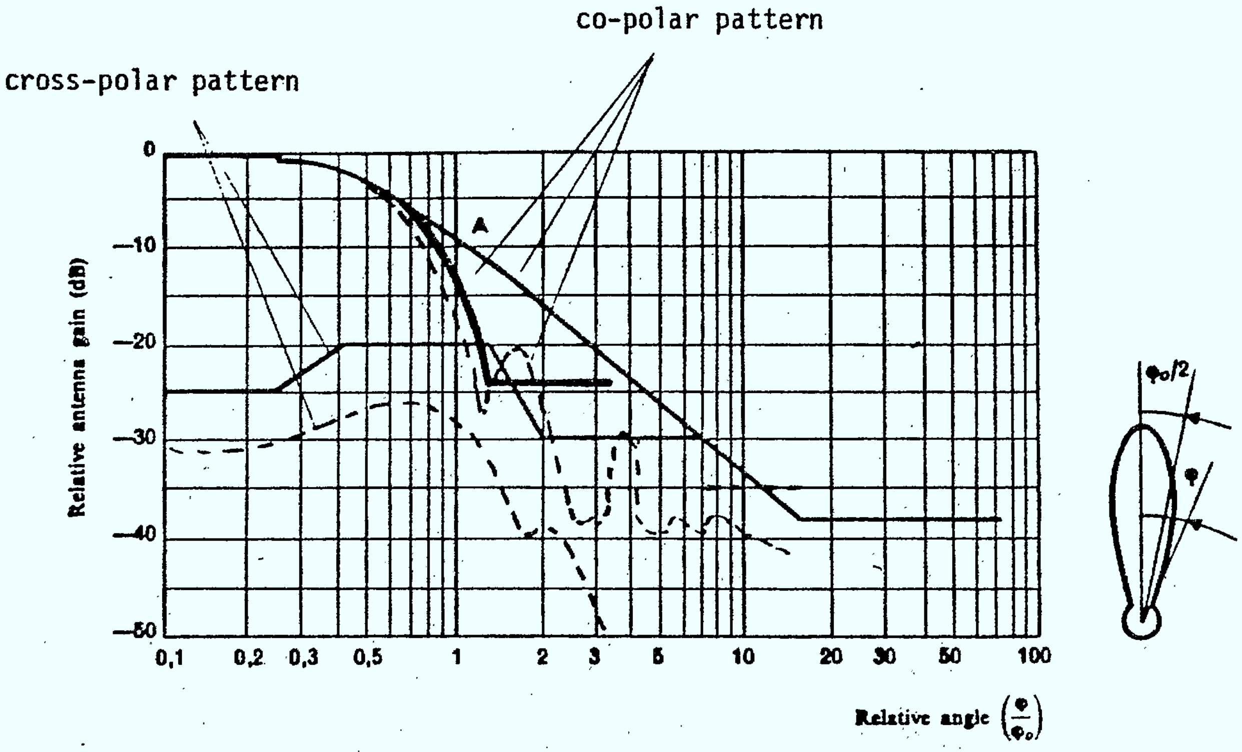
* Obviates the need for grd receiver tracking.

A Reference : CCIR Rpt 546-1, Vol. II, Koyoto



RECEIVER REQUIREMENTS

BSS/DBS RECEIVER REFERENCE PATTERN



---- : Test results on typical antenna

Reference patterns for co-polar and cross-polar components for receiving antennae for individual reception in Region 2*

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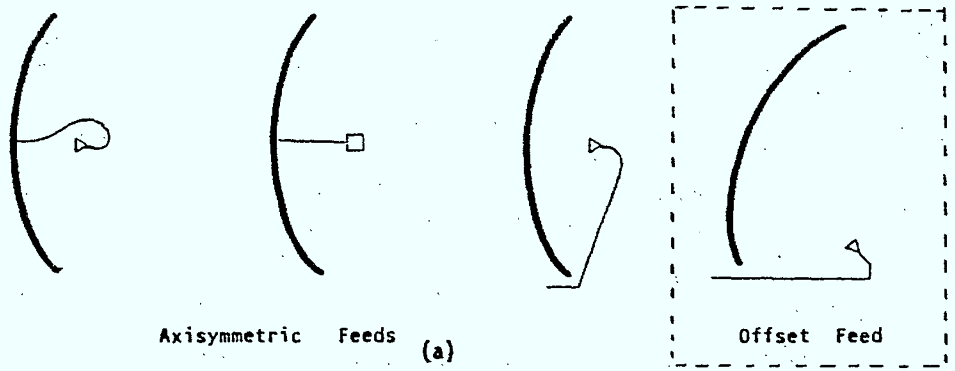
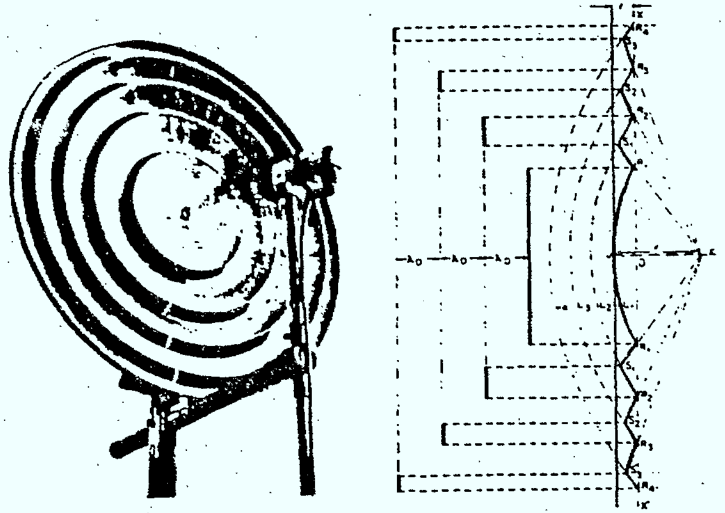
* Light bold curves.

CCIR Final Acts, WARC-77

CANDIDATE ANTENNAS FOR BSS/DBS APPLICATIONS

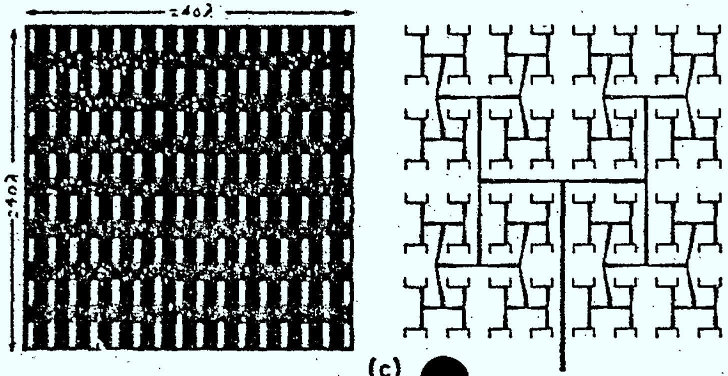


(a)



Zoned Plate
Parabolic
Antenna

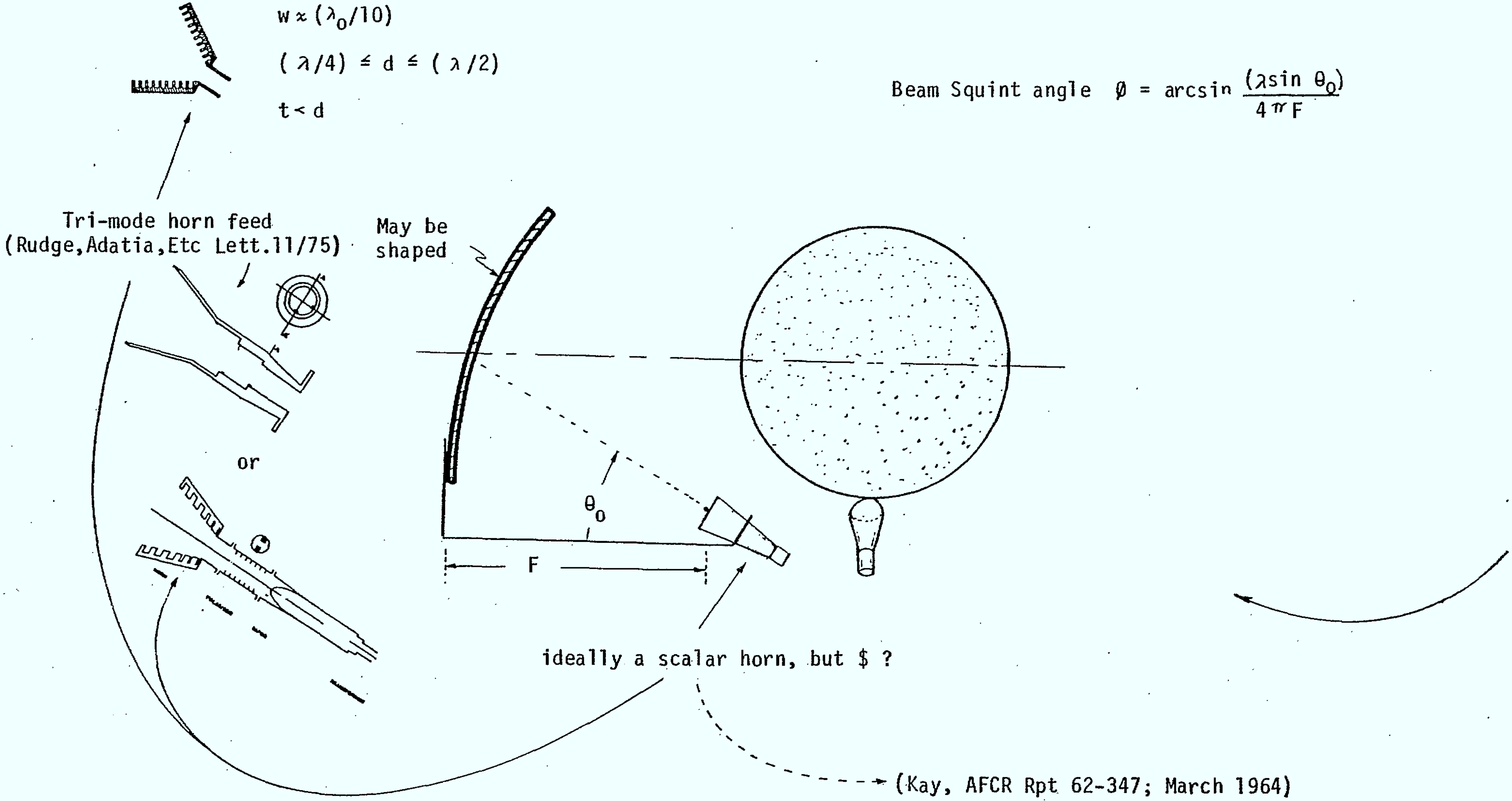
(b)



Planar Array
Antenna

(c)

OFF-SET FEED REFLECTOR



$w \approx (\lambda_0/10)$

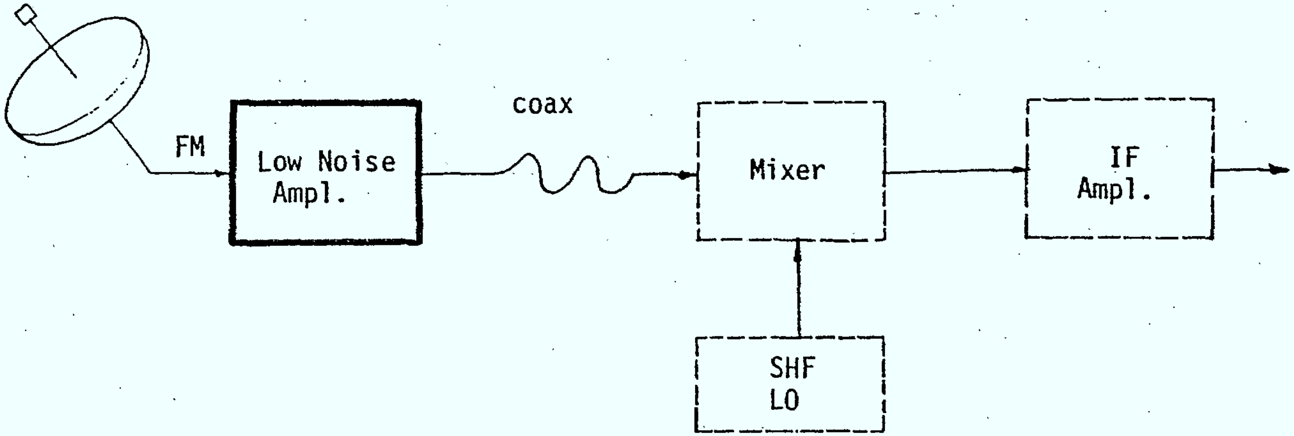
$(\lambda/4) \leq d \leq (\lambda/2)$

$t < d$

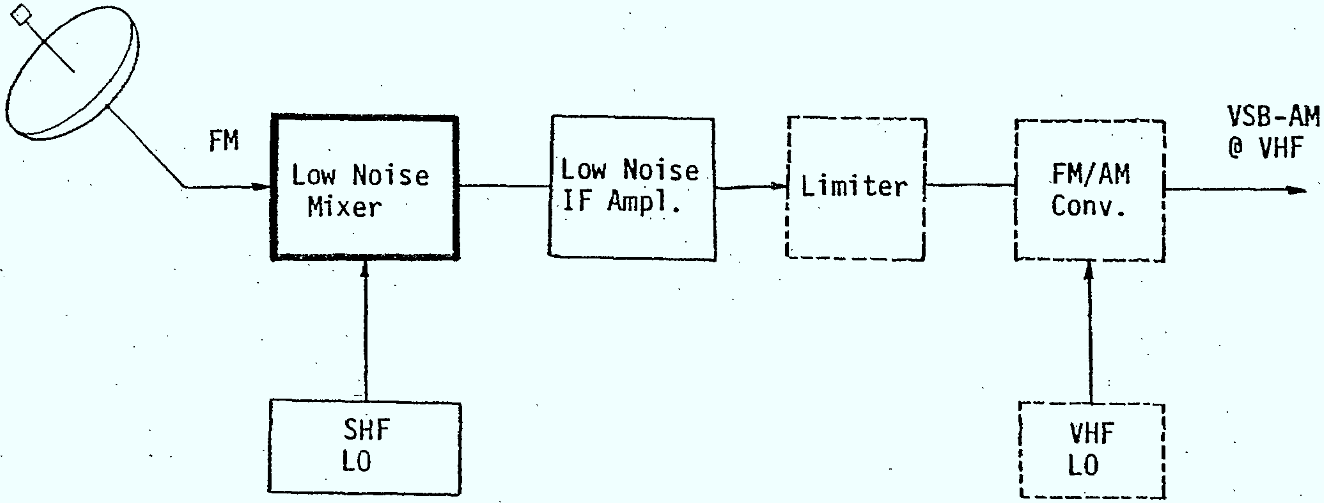
Beam Squint angle $\emptyset = \arcsin \frac{(\lambda \sin \theta_0)}{4\pi F}$

(Kay, AFCR Rpt 62-347; March 1964)

TWO CONTENDING FRONT ENDS FOR BSS/DBS RECEIVER APPLICATIONS

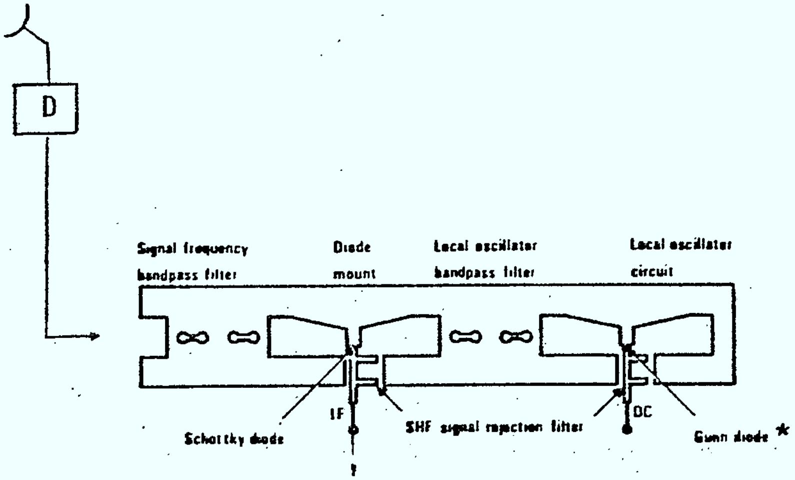


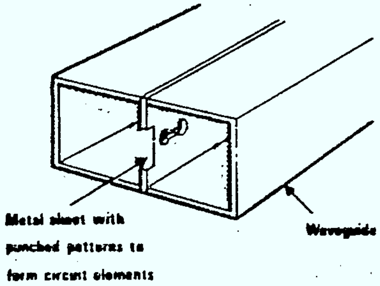
LOW NOISE GaAs FET PREAMPLIFIER FRONT END



KONISHI LOW NOISE MIXER FRONT END

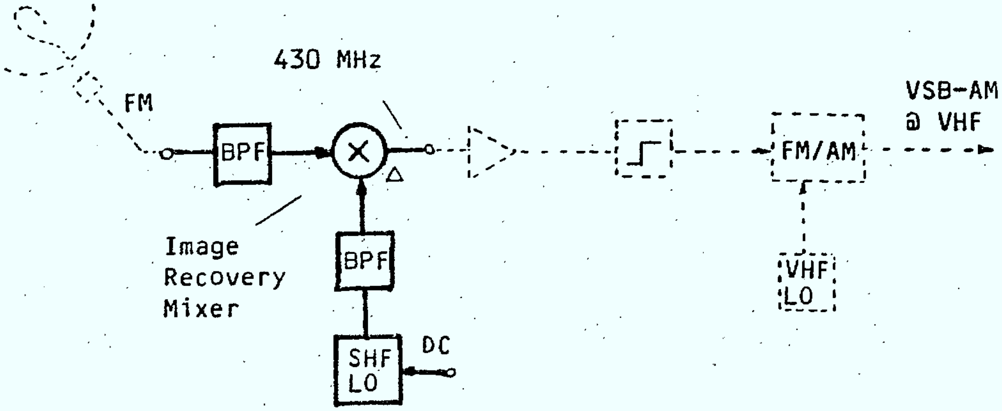
"GUTS" Of The Konishi DBS Receiver Front End



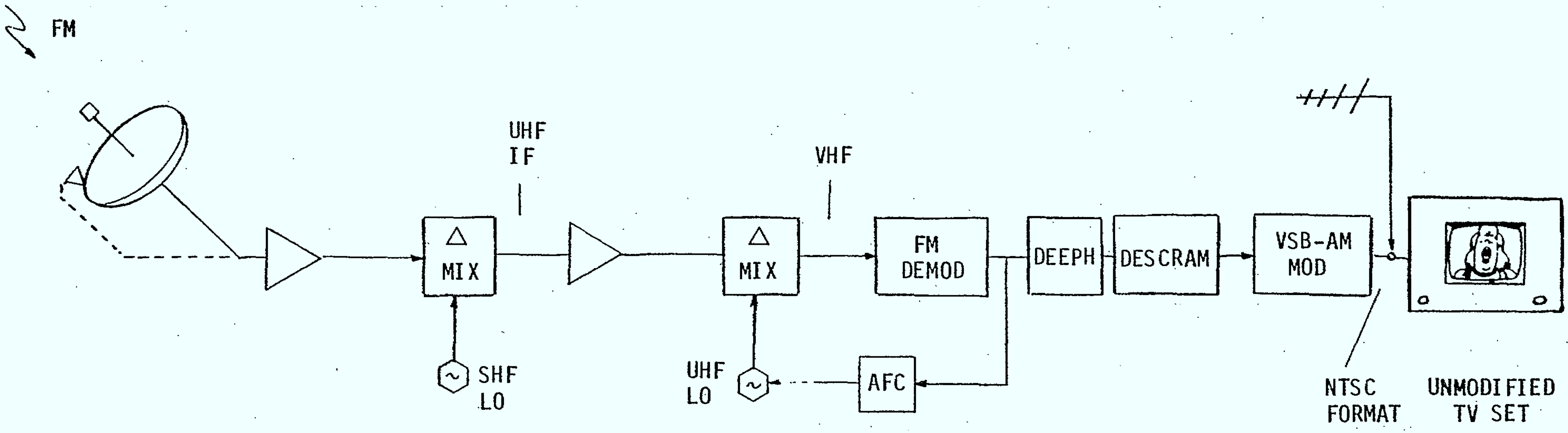


* May also be step recovery diode(SRD).

It is noted that the receiver must be preceded by a depolarizer which changes the circular polarization incident on the antenna to rectangular waveguide TE_{10} dominant mode.

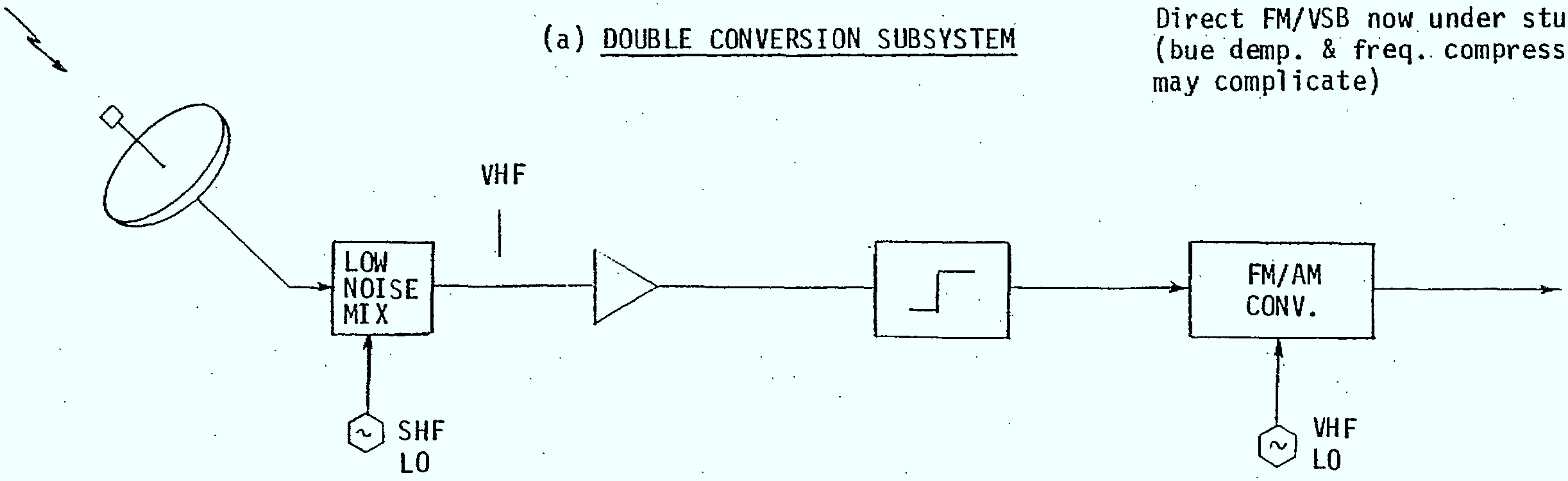


TYPICAL BSS/DBS RECEIVER CHAINS



(a) DOUBLE CONVERSION SUBSYSTEM

Direct FM/VSB now under study (bue demp. & freq. compression may complicate)



(b) NHK RECEIVER SUBSYSTEM

ATTRIBUTES OF DOUBLE CONVERSION SYSTEMS

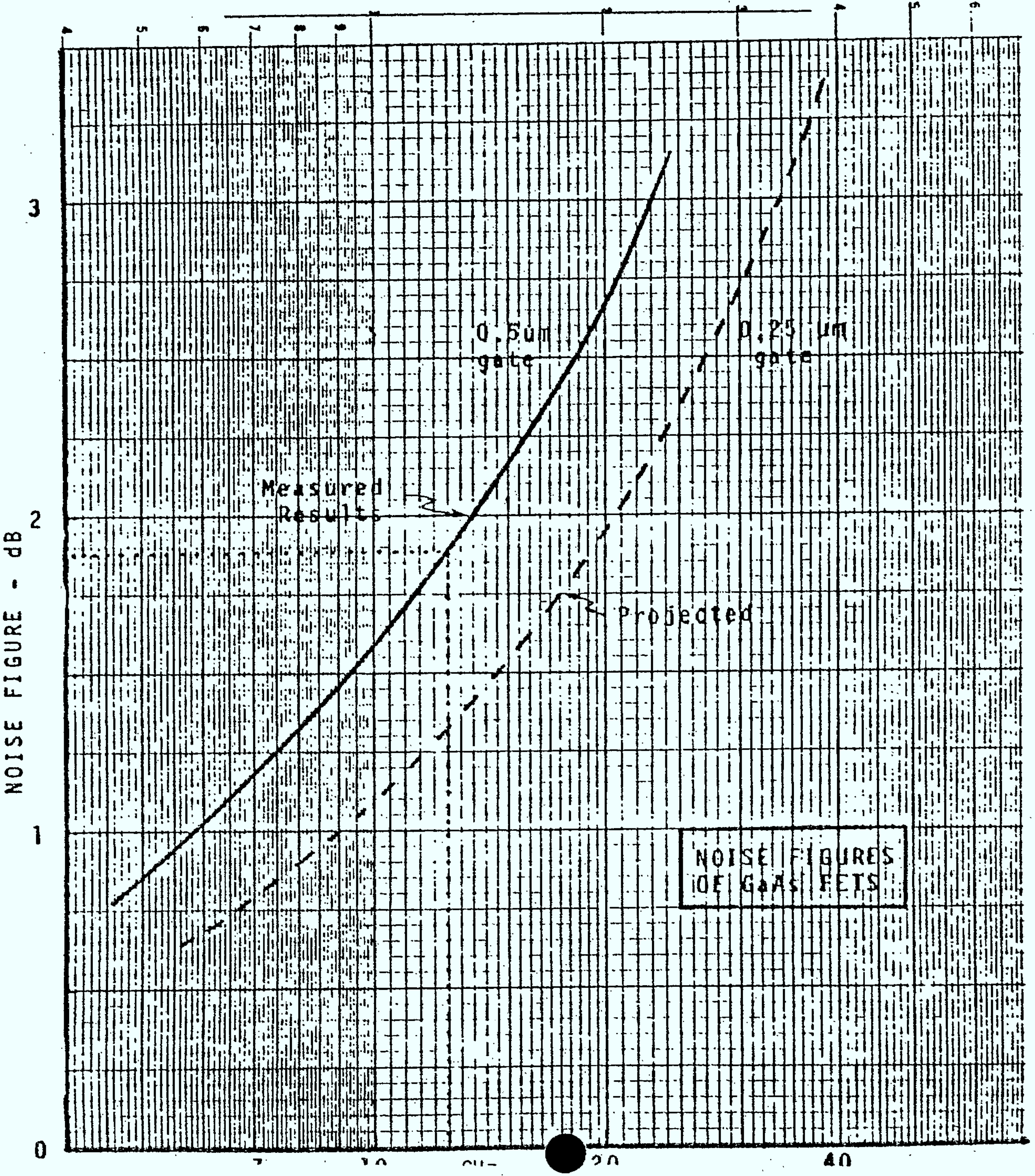
- GREATER EASE IN REJECTING SPURII SUCH AS IMAGE AND LOCAL OSCILLATOR

- AFC ON SECOND LOCAL OSCILLATOR PERMITS THE USE OF SHF LOCAL OSCILLATOR WITH RELAXED STABILITY REQUIREMENTS

- FOR MULTI-CHANNEL OPERATIONS, SECOND LOCAL OSCILLATOR CAN BE SWITCHED FOR CHANNEL SELECTION

- GENERALLY REQUIRE MORE COMPONENTS THAN A SINGLE CONVERSION SYSTEM WITH A SLIGHT INCREASE IN COST

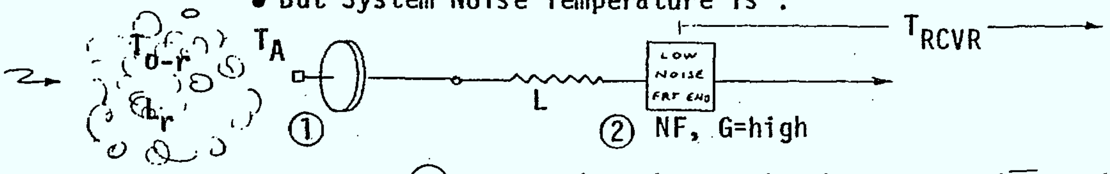
NOISE FIGURES OF GaAs FET AMPLIFIERS



SOME GYMNASTICS CONCERNING BSS/DBS RECEIVER G/T_S

◆ $G/T_s = 10 \log G(\text{nose gain}) - L_{\text{pting loss}} - 10 \log T_s$

- But System Noise Temperature is :



At ② , $T_s = (T_A/L) + T_o\,(1-1)/L + T_o\,(\overline{NF} - 1)$

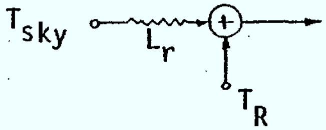
At ① , $T_s = T_A + T_o\,(L - 1) + T_o\,(\overline{NF} - 1)L$

- But if it's Raining :

$$T_s{}' = [T_A{}' + (T_{sky}/L_{rain}) + (\underbrace{[L_r - 1]/L_r)\,T_{o-rain}}_{T_R}] + \text{rest}$$

$T_{o-rain} \approx 290^0$

Rain model :



- The Antenna Gain is :

$$G = G_o \exp - [4\pi\sigma/\lambda]^2 - L_{pting}$$

$$= (\pi D/\lambda)^2 \eta \text{ (smooth surface)} - L_{pt}$$

where : G_o : On-axis gain

D : Dish diameter (A dish is hard to "beat")

η : Antenna efficiency (≈ 55 %)

σ : Surface roughness

L_{pt}: Pointing loss , $12\,(\Delta\theta / BW)^2$ dB

$\Delta\theta$: Pointing error, 0.5^0 (say)

BW : 3 dB beamwidth , $\approx 70\,\lambda/D$

For $\sigma < \lambda/25$, surface loss < 1 dB

(Ruze, Proc. IEEE 1966)

◆ Therefore G/T_s Becomes (Referred to antenna input and clear sky) :

$$(G/T_s) = 10 \log\ (\pi D/\lambda)^2 \eta - L_{pt} - 10 \log [T_A + T_o(L - 1) + T_o(\overline{NF} - 1)L]$$

Antenna temperature is a function of elevation angle, but a good average figure for elevation angle 10-20° , is 50 K. (based on studies by D.C. Hogg of Bell Labs).

SOME PUBLISHED RECEIVER NOISE FIGURES AND G/T_S RATIOS

- NHK(Konishi)

RECEIVER NOISE FIGURE	BANDWIDTH	G/T_S	
		DIA.= 0.6 m G = 34.9 dB	DIA.= 1 m G = 39.5 dB
3.4 dB	300 MHz	9.0 dB/K	13.6 dB/K
3.6	500	8.7	13.3
4.2	800	7.8	12.4

- SONY

3.2	400	9.2	13.8

- Phillips

3.2	400	9.2	13.8

- STC (COMSAT)

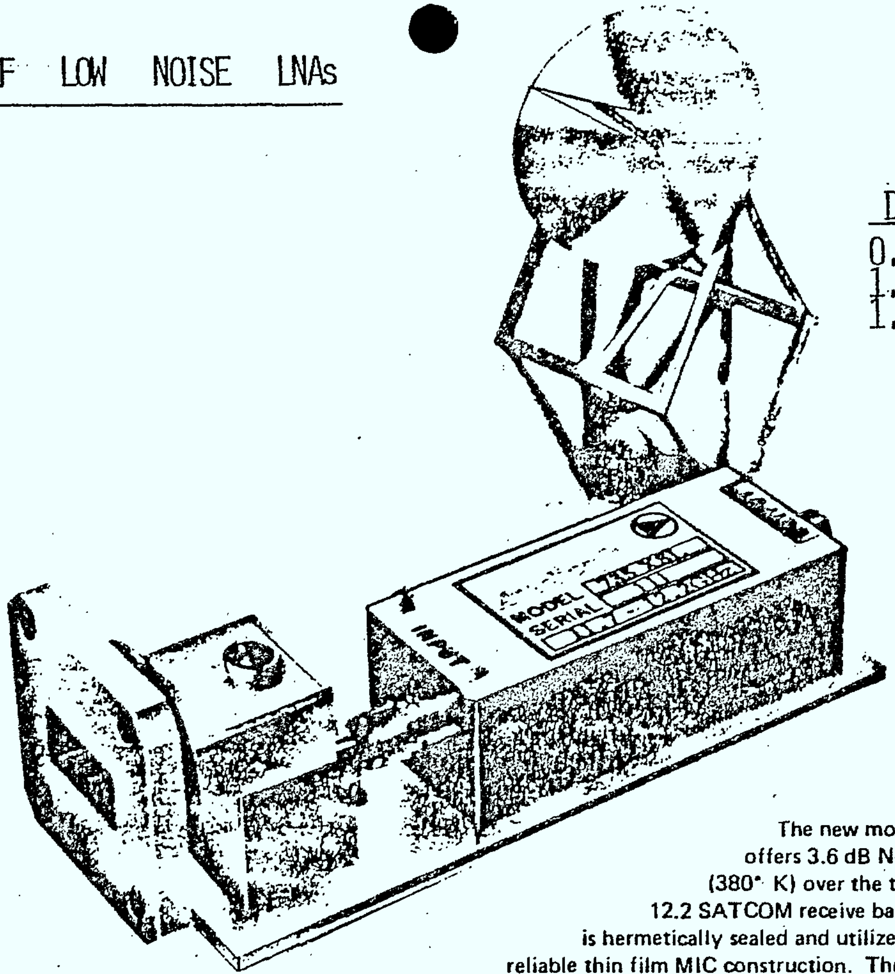
4.7	500	7.4	11.9

$T_S = T_A + T_{RCVR}$

Note : To the above NFs, an antenna noise temperature of 50 K has been added.

N.B. : It is unkown how many dBs should be added to the above Figures to compensate for salesmanship.

OFF - THE - SHELF LOW NOISE LNAs



D	G(0)
0.6M	35 dB
1.0	39.5
1.6	44

Amplica Inc.
Newbury Pk, CA

11.7 to 12.2 GHz Low Noise Amplifiers

$T_E=(\overline{NF}-1)T_0 =$ **380° K Noise Temperature** $= 3.6$ dB $\overline{NF}$

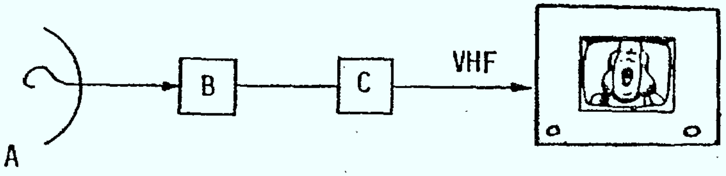
PRE WARC-79 , FSS/BSS

The new model 735 XSL offers 3.6 dB Noise Figure (380° K) over the total 11.7 to 12.2 SATCOM receive band. This unit is hermetically sealed and utilizes rugged, reliable thin film MIC construction. The GaAs FET low noise input stage optimumly combines with a low loss isolator to insure good VSWR and lowest noise temperature. The output stages are balanced stages to insure wide dynamic range and minimum interaction problems due to cascading. This amplifier design approach has been utilized over 500 MHz bands extending from 8.5 GHz to 13 GHz with equally outstanding noise figure performance. Noise figures as low as 2.5 dB are available over narrow frequency bands with center frequencies as high as 10 GHz. Check the following specs and contact us at our new facility. Model 735 XSL is capable of meeting all environments of MIL-STD-5400 or MIL-E-16400.

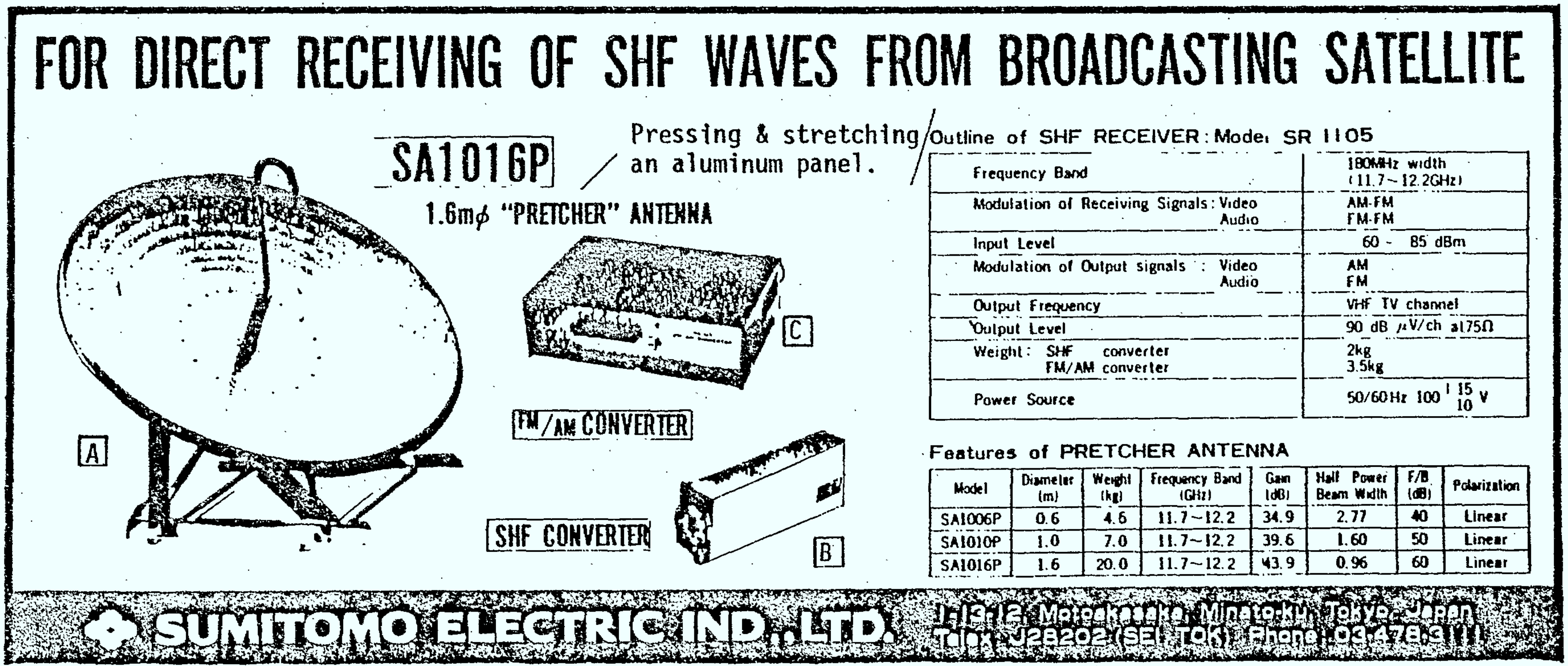
MODEL NO.	FREQUENCY RANGE (GHz)	GAIN MIN. (dB)	NOISE FIGURE MAX. (dB)	GAIN FLATNESS MAX. (± dB)	OUTPUT POWER @ 1 dB COMPRESSION (dBm)	INTERCEPT POINT TYPICAL (dBm)	VSWR IN / OUT MAXIMUM	DC CURRENT @ 13.5 ± 1.5 VDC NOMINAL (mA)
735XSL	11.7 - 12.2	30	3.6	0.5	+10 dBm	+20	1.2/1.3	150
†* 734XSL	11.7 - 12.2	30	4.5	0.5	+10	+20	1.5/1.5	150
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5/1.5	150

OFF - THE - SHELF BSS/DBS RECEIVER SUBSYSTEM

This advertisement is from a Japanese electronic newspaper, "The Telecommunications in Japan", September 15, 1979.



REPRESENTATIVE DBS
GROUND RECEIVER



FOR DIRECT RECEIVING OF SHF WAVES FROM BROADCASTING SATELLITE

SA1016P

1.6mφ "PRETCHER" ANTENNA

Pressing & stretching an aluminum panel.

Outline of SHF RECEIVER : Model SR 1105

Frequency Band	180MHz width (11.7~12.2GHz)
Modulation of Receiving Signals : Video Audio	AM-FM FM-FM
Input Level	60 - 85 dBm
Modulation of Output signals : Video Audio	AM FM
Output Frequency	VHF TV channel
Output Level	90 dB μV/ch at75Ω
Weight : SHF converter FM/AM converter	2kg 3.5kg
Power Source	50/60Hz 100^{15}_{10} V

Features of PRETCHER ANTENNA

Model	Diameter (m)	Weight (kg)	Frequency Band (GHz)	Gain (dB)	Half Power Beam Width	F/B (dB)	Polarization
SA1006P	0.6	4.6	11.7~12.2	34.9	2.77	40	Linear
SA1010P	1.0	7.0	11.7~12.2	39.6	1.60	50	Linear
SA1016P	1.6	20.0	11.7~12.2	43.9	0.96	60	Linear

SUMITOMO ELECTRIC IND., LTD.
1-13-12, Motoakasaka, Minato-ku, Tokyo, Japan
Telex J28202 (SEI TOK) Phone 03-478-3111

PROJECTED IMPROVEMENTS IN RECEIVER DESIGN

- LOWER SIDELOBE ANTENNAS BY THE USE OF OFFSET OFFSET
- LOWER NOISE FIGURE RECEIVERS
- USE OF THRESHOLD EXTENSION TECHNIQUES
- DIRECT FM TO AM CONVERSION DEVICES
- LOWER COSTS THROUGH THE USE OF MONOLITHIC MICROWAVE INTEGRATED CIRCUITS AND OTHER REDUCED LABOR-INTENSIVE MANUFACTURING TECHNIQUES

PROJECTED IMPROVEMENTS IN RECEIVER DESIGN

- LOWER SIDELOBE ANTENNAS BY THE USE OF OFFSET FEED
- LOWER NOISE FIGURE RECEIVERS
- USE OF THRESHOLD EXTENSION TECHNIQUES
- DIRECT FM TO AM CONVERSION DEVICES
- LOWER COSTS THROUGH THE USE OF MONOLITHIC MICROWAVE INTEGRATED CIRCUITS AND OTHER REDUCED LABOR-INTENSIVE MANUFACTURING TECHNIQUES

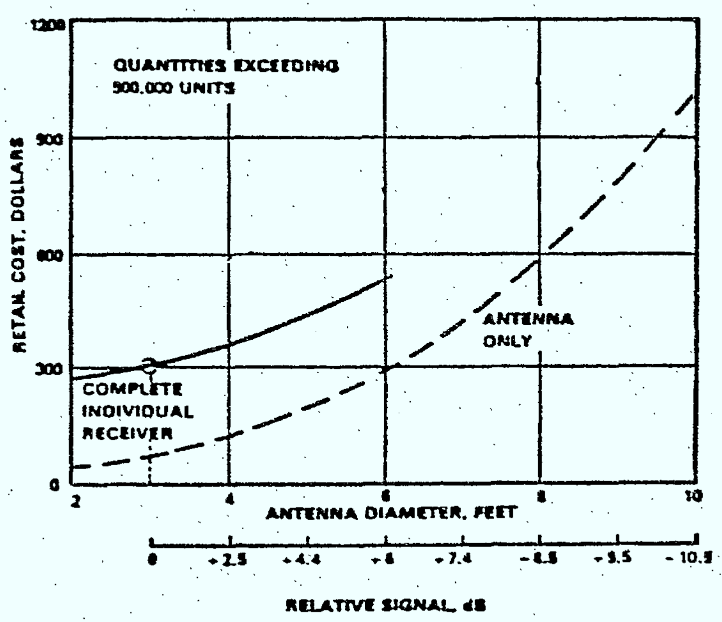
QUOTED COST FIGURES

- NHK (USING KONISHI FRONT END) . . : $ 160 (100K A MONTH)
- SONY (USING LNA FRONT END) . . . : $500 (1 M A YEAR)
- AEG - TELEFUNKEN (LNA FRONT) . . : $ 1000*(LARGE NUMBERS)
- SATELLITE TV CORPORATION . . . . : $ 300 (1-2 M)
- CNES (FRANCE) . . . . : $ 660
- DOC (CANADA) . . . .: $ 500 (>100K)

THE ABOVE PRICES DO NOT REFLECT COST OF TV SET.

* HAS ADDITIONAL COMPLEXITY (WHICH MAY ACCOUNT FOR HIGHER PRICE).

RECEIVER AND ANTENNA COSTS



(Ludwig, EASCON '80)

CCIR Study Grp
Doc.USSG-BC/852

The Technology and Cost Applicable to Antennas for use in Individual Reception at 12 GHz.

COMPONENT	CANDIDATE TECHNOLOGY	DESCRIPTION	ESTIMATED COSTS FOR INDICATED QUANTITIES (IN U.S. 1980 DOLLARS)			
			1-100	100,000	1M	10M
Antenna providing 32-37 dB gain	Prime Focus Feed Parabolic Antenna	1-meter assembly with first side lobes in 12-17 dB range	250	50	40	30
	Off-set Fed Parabolic Antenna	1-meter assembly with first side lobes in 25-35 dB range	300	50	40	30 -
	Slotted waveguide array	36x36 inch flat plate with sidelobes in 40-50 dB	5000	75	50	40
	Printed Circuit Array	36x36 inch flat plate with corporate feed-sidelobes 40-50 dB	10,000	100	60	50

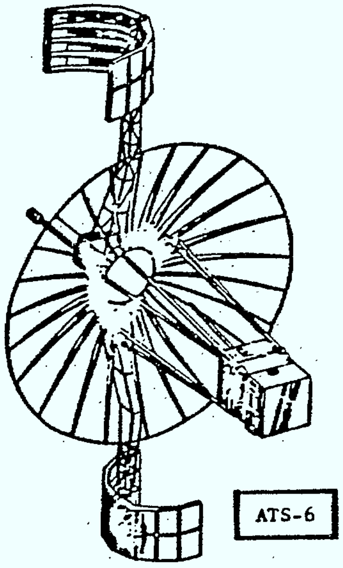
See also CCIR Rpt 473-2
Vol. XI Green Books, Kyoto

The Technology and the Associated Cost Applicable to the LNA and the Receiver Section of a TVRO Earth Terminal at 12 GHz.

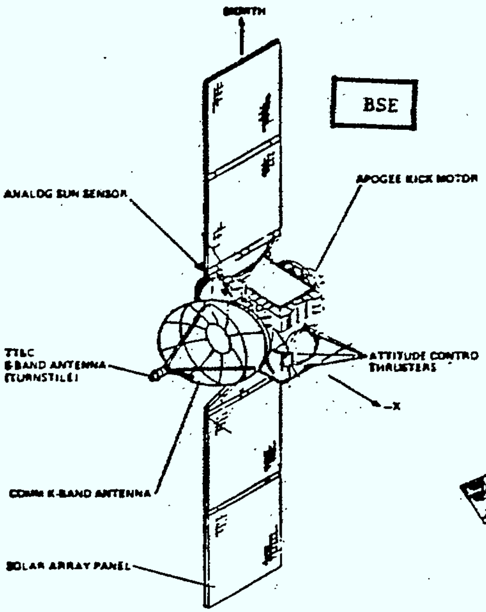
COMPONENT	CANDIDATE TECHNOLOGY	DESCRIPTION	ESTIMATED COST FOR INDICATED QUANTITIES (in U.S. 1980 DOLLARS)			
			1-100	100,000	1M	10M
LOW NOISE AMPLIFIER	FET Amplifier	100-200^{0}NT-presently high cost	1500	1 or 2 IC's		
	Konishi Mixer	400^{0}NT - Wafer assembly in WG	1000	50	30	25
DOWN CONVERTER	Single Conversion	Requires imageless mixer to 70 MHz	350			
	Double Conversion	Preferred app. with intermediate freq. 700 MHz	500			
OSCILLATOR	VCO For Tuning	Varactor Tuned Microwave FET Oscillator-Use Monolithic techniques	150	25	10	7
	Synthesizer Mult for Tuning	Synthesizer IC at UHF/VHF in use	1000	25	10	7
DETECTOR AND VIDEO/AUDIO PROCESSOR	Integrated Circuit	In use for modern color TV receivers	25	15	10	7
REMODULATOR TO UHF/VHF	Integrated Circuit	In use for modern CATV systems	25	15	10	7

BSS/DBS SATELLITES (SOME DEDICATED)

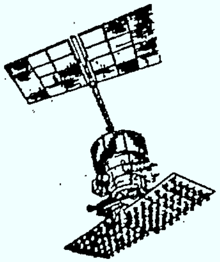
SATELLITES FOR BSS/DBS APPLICATIONS - I



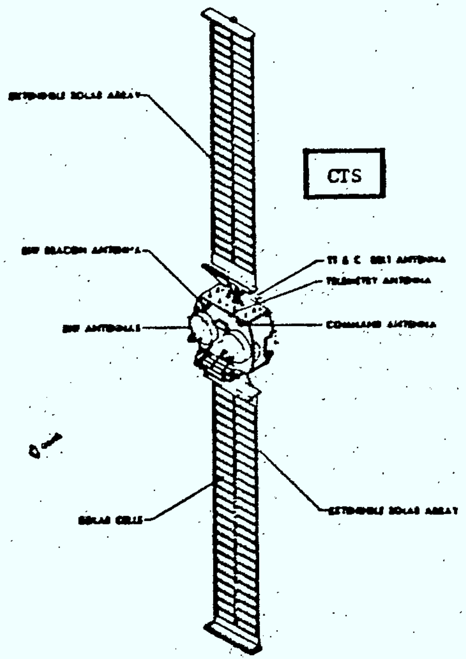
ATS-6



BSE



EKRAN



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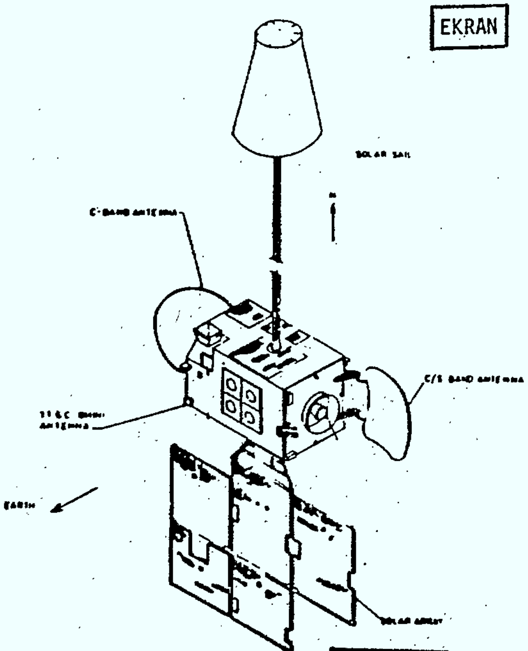
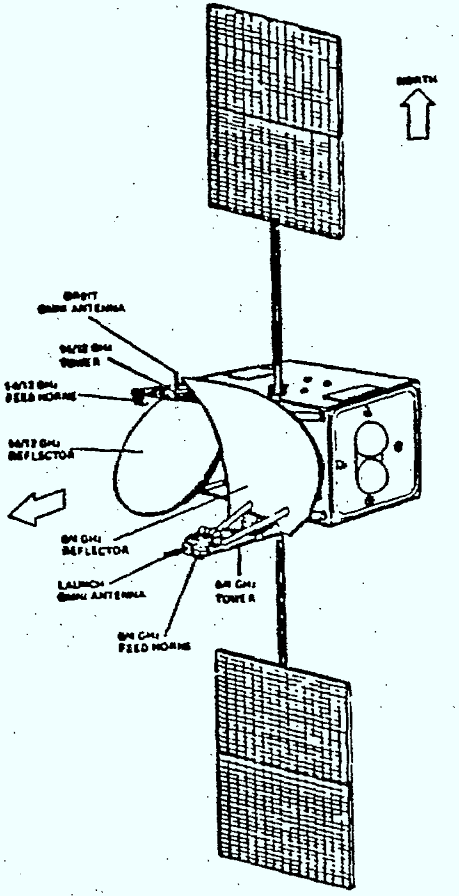


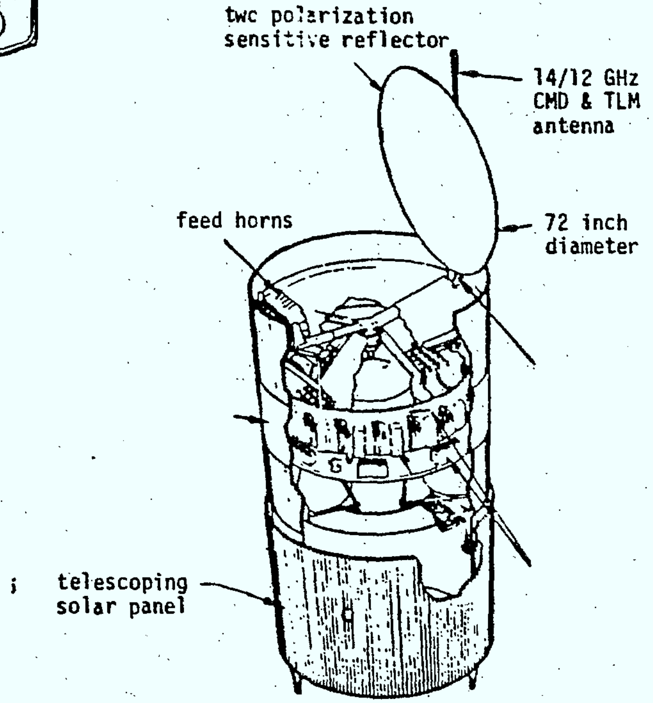
INSAT-1

SATELLITES FOR BSS/DBS APPLICATIONS - II



ANIK B

ANIK C

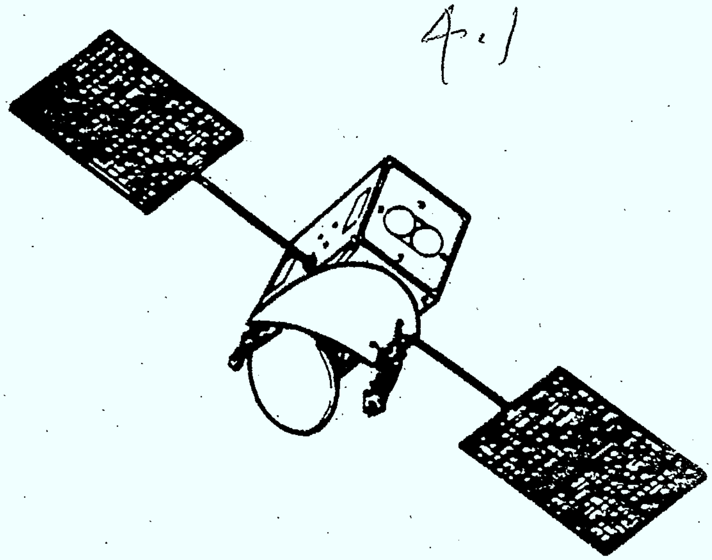


EUROPEAN BSS/DBS SATELLITES

ADMINISTRATION	GERMANY	FRANCE	NORDIC	SEVERAL(1)
NAME	TV-SAT - A3	TDF-1A	NORDSAT	L-SAT (2)
LAUNCH	1983 →	1983 →	1985 - 89	1984 →
UPLINK FREQ.	17 GHz	17 GHz	17 GHz	
DWNLINK FREQ.	12 GHz	12 GHz	12 GHz	12 GHz
EIRP	66 dBW	64 dBW	60/68	
No. XPDRS	3	3	3-4	2
BANDWIDTH	27 MHz	27 MHz	27 MHz	
No. BEAMS	1	1	2 (3)	
PRIM. POWER	4.5 KW	6.2 KW	5 KW	
LOCATION	19° W ?	19° W ?	5° E	19° W

(1) UK, Italy, Netherlands, ..., Canada; no French or German paticipation.
(2) Four payloads, one is DBS.
(3) East Nordic and West Nordic Beam.

4.1



TITLE : MEASUREMENTS OF PRECIPITATION ATTENUATION, DEPOLARIZATION AND SITE DIVERSITY IMPROVEMENTS IN CANADA

AUTHOR : J. SCHLESAK AND J. STRICKLAND 4.1

CAN

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

Government of Canada Gouvernement du Canada
Department of Communications Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

Measurements of Precipitation Attenuation, Depolarization and Site Diversity Improvement in Canada

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1. Introduction

The 12/14 GHz frequency band is being increasingly used in the fixed satellite service and is the designated band for the broadcasting satellite service. This band has the advantage of large bandwidth and is not shared with the fixed terrestrial service, thus eliminating the requirement for site shielding. However, signals at these frequencies suffer from rain attenuation, which increases rapidly with increasing frequency above 10 GHz. Rain also provides a mechanism whereby signals from terrestrial sources or adjacent satellites can interfere with the desired signal.

The capacity of a system may be increased by the use of orthogonal polarizations. Such frequency re-use systems depend on good cross-polar discrimination to prevent interference between the signals on orthogonal channels. Unfortunately, rain and high-altitude ice-crystals when illuminated by a microwave signal, emit radiation not only in the plane of the incident signal but also in the orthogonal plane. Thus, these hydrometeors may produce significant degradation of cross-polarization discrimination.

In this paper, some results of various experiments to study the propagation effects in this band are discussed.

1.1 Variation with climate

Rain attenuation statistics are highly dependent on climatic region. Two locations may have the same total annual rainfall accumulation but quite different distributions of rainfall-rate, giving rise to different attanuation statistics. Eleven distinct climatic regions, classified according to precipitation behaviour, are shown in Figure 1. The Pacific maritime climate (J) is characterized by very high winter precipitation and few storms. The prairie (E) and southern shield (D) areas experience continental climates. The lower great lakes area (C) and St. Lawrence region (B) are characterized by moderate rainfall accumulation, but with many thunderstorm days, typically from 10 to 20. Despite the climatic similarity, measured rain rate statistics show distinct differences, for example, between Montreal (B) and Toronto (C). The Atlantic maritime region (A) experiences nearly uniform rainfall through the year, with several thunderstorm days in the summer.

2. Rain Attenuation Measurements

2.1 Radiometric determination of rain attenuation

Radiometers are useful tools in obtaining rain attenuation statistics if no satellite beacon is available, as is usually the case if propagation measurements are to be made in advance of operational systems. A radiometer is simply a highly sensitive wideband receiver capable of measuring the sky noise temperature with a resolution of 1 Kelvin. Since for the 12/14 GHz band, the sky noise temperature is approximately that which would result if the entire path loss were due to absorption, the path attenuation is simply given by

$$A(dB) = 10 \log (T_m/(T_m - T_a))$$

where T_a is the measured sky noise temperature and T_m is the effective medium temperature of the rain. From the form of this relation it is evident that the calculated attenuation becomes more sensitive to errors in T_m and T_a as the attenuation increases (i.e. as T_m approaches T_a). This restricts the highest values of attenuation which can be calculated from radiometric measurements to approximately 10 dB.

In an experiment conducted at Ottawa during 1970 (Strickland, 1974a), precipitation attennuation was measured directly using the 15.3 GHz beacon signal from the ATS-5 satellite. The receiving antenna was also connected to a radiometer providing simultaneous measurements of sky noise temperature at

15.3 GHz. A comparison of calculated and directly measured attenuations showed excellent agreement. Using an effective medium temperature of 272 K, the standard deviation of the difference between attenuations was found to be less than 1 dB for attenuations up to 8 dB.

Since it is unlikely that satellite communications systems will be provided with margins exceeding 10 dB, radiometers provide a sufficiently accurate means of determining rain attenuation statistics at any location and elevation angle.

2.2 Rain attenuation statistics

Since the characteristics of precipitation attenuation depend on geographic location, an experiment was conducted from 1973 to 1976 in which radiometers were employed to obtain attenuation statistics at seven locations across Canada. At each location, the antennas were pointed at the location of an imaginary geostationary satellite at 114^0 W longitude. The seven locations were chosen to provide rain attenuation data representative of the various areas in Canada.

In Figure 2 are shown the cumulative distributions of the radiometrically determined attenuations at three of the sites - Mill Village, Nova Scotia; Melville, Saskatchewan; and Lake Cowichan, British Columbia. The curves clearly demonstrate the variance of attenuation statistics with climatic region. The attenuation levels exceeded for 0.03% of time are approximately 2, 4 and 9 dB for Mill Village, Melville and Lake Cowichan respectively. At Mill Village, where Atlantic seaboard storms often pass, rainfall is nearly uniform through the year with an average accumulation of 130 cm. By contrast, Melville is typical of the continental climate of the southern central prairies, where much of the rain occurs in short moderately intense storms. The average annual accumulation is 40 cm. The Lake Cowichan location is representative of the Pacific maritime climate in the lee of high mountains, where the average annual rainfall totals 190 cm and thunderstorms are rare. Here, for propagation reliabilities of 99.999% a margin of only 4.2 dB is required.

This variability in attenuation statistics from region to region demonstrates the importance of accurately classifying regions according to rain-rate statistics so that, for locations where attenuation or rain-rate statistics are not available, attenuation prediction procedures may provide reliable results.

Since system performance is specified in terms of percentage of worst month, the relationship between worst month probabilities P_{WM} and annual probabilities P_{YR} was examined. Such a relationship is useful since predicted attenuation statistics are often only available as average annual values. Morita (1974) determined that a power-law relationship holds. In terms of absolute probability

$$P_{WM} = A.P_{YR}^{B}$$

Using rain rate statistics for six locations in Canada, Segal (1979) determined this relation to hold, with regression coefficients A = 0.73 and B = 0.84. These constants varied with climatic regions, with A being more strongly linked to differences in climate than B. Analysis of the measured attenuation statistics yields the following values:

Melville	A = 0.11	B = 0.54
Mill Village	A = 0.32	B = 0.67

Generally, the ratio of the worst month probability to the annual probability lies between 2 and 6 depending on location and probability.

3. Site-Diversity Improvement

3.1 Radar determination of site diversity improvement

During 1970, an S-band (2.86 GHz) weather radar was used to measure the backscatter from precipitation within 100 km radius of Ottawa. The radar was calibrated such that the radar calculated path attenuations at 15.3 GHz agreed with attenuations measured directly using the beacon transmissions from the ATS-5 satellite. The elevation and azimuth scanning of the radar then allowed for the determination of the size distribution of rain cells. It was found that these sizes are log-normally distributed with a median and geometric standard deviation that depend on the attenuation level (Figure 3). For example, at a radar scan elevation of 5^0, for attenuations exceeding 3 dB the median cell size was 6 km, whereas for attenuations exceeding 6 dB the cell size was 5 km.

Given a log normal cell size distribution and assuming that the cross-section of the rain cells is circular, that the cells are randomly oriented and that their translational velocity is independent of size, a universal expression was developed for the relative joint probability that a given attenuation is exceeded in a site-diversity system. This probability is given as a function of path separation and the standard deviation of the cell size distribution (Strickland 1974b). Using values of the median and geometric standard deviation obtained from the radar scans at 5^0 elevation, the path separation required to obtain any desired value of relative joint probability was calculated and is shown in Figure 4. As can be seen, susbstantial reductions in relative joint probability are obtained for separations as small as 10 km.

These calculations do not include the possibility of simultaneous attenuation along two paths separated by a distance comparable with the separation between attenuation cells. The radar observations have shown that cell separations are approximately Rayleigh distributed with a median separation of 29 km.

Another factor affecting site-diversity performance is the orientation of pairs of rain cells. The radar measurements showed that for attenuations exceeding 5 dB, the distribution of orientations of pairs of cells is anisotropic with a pronounced minimum at 50^0 west of north. Therefore for a site diversity system, the probability of simultaneous attenuation along both propagation paths by two attenuation cells can be reduced if the relative orientation of the two stations is along the direction of least probable cell pair orientation. In addition, orientation of the stations perpendicular to the propagation path will reduce the relative joint probability due to a single cell. Depending on the satellite orbital position, it will not always be possible to satisfy both orientation conditions simultaneously.

3.2 Site-diversity improvement measurements

Since 1975 an experiment has been conducted, in conjunction with Teleglobe Canada, to obtain statistics of precipitation attenuation and site-diversity improvement for the 12/14 GHz band in order to aid the planning of an operational system with site-diversity terminals in the Montreal, Quebec and Toronto, Ontario regions.

Measurements were made using 13 GHz radiometers pointed in the direction of a planned satellite at 25^0 W longitude. The elevation angles were approximately 18^0 and 15^0 at the Quebec and Ontario sites respectively. In the initial measurements of 1975/76, the site-diversity pairs for both regions were oriented approximately in a north-south direction. Substantial diversity improvement was obtained for the Quebec pair but not for the Ontario configuration. After examination of these results, new sites were established in 1980 in Quebec to examine alternative site-diversity configurations, and in Ontario to improve on the poor site-diversity performance obtained earlier. The site orientations for Quebec and Ontario are shown in Figures 5 and 6. The horizontal and vertical path separations of 17 km and 6 km respectively, and the north-west orientation of the Ontario pair was expected to provide good site-diversity performance.

The single-site cumulative distributions for the three Quebec sites Weir (W), La Conception (L), and Vernet (V) and the distributions for the diversity pairs (W-L, W-V, L-V) are given in Figure 7. It is seen that the diversity improvement is very good for all pair combinations, and an attenuation of 6 dB was not jointly exceeded. Reliabilities of 99.99% (52 minutes outage per year) are achieved with a joint margin for attenuation of 2.6 dB, and for 99.999% reliability a joint margin of less than 5 dB is required.

In Figure 8 are shown the results for the Ontario diversity pair, Beaver Valley - Meaford (B-M). The diversity performance is much poorer than that in Quebec. For 99.99% reliability a joint margin of more than 6 dB would be required. Terrain features were suspected as the cause of the poor performance for this and the 1975/76 diversity configuration. West-to-east terrain profiles through Beaver Valley and Flesherton (the diversity site in 1975/76) are shown in Figure 9. The origin of each profile is 82^0W longitude, and the location of each site is indicated by a vertical arrow approximately 117 km east of the reference longitude. The land rises from Lake Huron at 177 metres above mean sea level to nearly 518 metres. The orientation of this rise of land is approximately north-south, and hence nearly parallel to the line joining the diversity pair. In it's west-to-east motion, moisture-laden air is uplifted by the land and the consequent adiabatic cooling of the rising air results in an increased likelihood of precipitation in a region parallel to and on the western side of this escarpment. The resultant increased probability of simultaneous attenuation on both paths would account for the relatively poor diversity performance of the Ontario configuration, and shows the importance of topographic features in the planning of site-diversity systems.

3.3 Comparison of measurements with cell size model

Using the cell size distribution model discussed in 3.1, and using values of median cell size and geometric standard deviation obtained from the 1970 radar data, joint probabilities have been calculated for attenuation levels from 3 to 6 dB. These are compared with the joint probabilities calculated from the measured cumulative distributions from both the Quebec and Ontario diversity sites. The joint probability is defined as the probability that a given attenuation is exceeded at both sites of the diversity pair relative to the probability that the same attenuation is exceeded at either site. This comparison is shown in Figure 10 and indicates remarkable agreement of the model-determined joint probabilities with the radiometrically-determined values for Quebec. As expected, agreement is not obtained for Ontario because of the orographic effect. Topographic effects excluded, this result supports the assumptions made in the development of the cell size model for diversity performance.

4. Depolarization

4.1 Depolarization measurements and predictions

For orthogonal-polarization frequency-reuse systems, availability is reduced by cross-polarization interference resulting from signal depolarization that occurs during propagation through non-spherical canted raindrops and high-altitude ice crystals along earth-space paths. To determine the nature and extent of cross-polarization effects, measurements of depolarization and attenuation were obtained at St. John's, Halifax, Toronto and Vancouver using the 11.7 GHz circularly polarized transmissions from the Communications Technology Satellite (CTS) at 116^0 W longitude. The experiment, an extension of a similar study conducted earlier at Ottawa (Nowland et al., (1977b)), was a cooperative project between the Trans Canada Telephone System, Bell Northern Research, and the Communications Research Centre.

The four locations represent both maritime and continental regions. Although the experiment duration at all locations yields a limited base for absolute statistics, sufficient data were obtained to determined adequately the statistical dependence of cross-polarization discrimination (XPD) on co-polar attenuation (CPA).

To compare the experimental data with statistical predictions of XPD from CPA and to determine the empirical relations between the measured parameters, the values of XPD not exceeded and CPA exceeded corresponding to equal percentages of time (p%) were analyzed. The results for each location are plotted in Figure 11. The curves, representing all measured data, illustrate that XPD(p%) is linearly related to the logarithm of CPA(p%) and that this relation can be expressed as

$$\mathrm{XPD}(p\%) = U - V \log (\mathrm{CPA}(p\%)) \qquad (1)$$

The experimentally-derived slope V is approximately the same for all locations (Figure 11) and equal to about 20, indicating that the change in XPD for given change in CPA is independent of location and path elevation angle. The values of U, derived from straight-line fits to the curves in Figure 3, are 30.5, 31.2, 34.3 and 35.3 for St. John's, Halifax, Toronto and Vancouver respectively. These indicate that for given CPA and assuming similar rain characteristics, XPD improves with increasing path elevation angle. These results demonstrate that it should be possible to predict XPD statistics from known CPA statistics at other locations using simple prediction relations similar to the experimentally-derived equation (1), but with constants appropriate for the given system parameters (e.g., frequency, elevation angle, polarization).

Based on the general theory for rain depolarization and on the widely observed dependence of XPD on log (CPA), Nowland et al. (1977a) and Olsen and Nowland (1978) have developed a semi-empirical prediction relation having the form of equation (1) with U and V given by

$$U = 0.0053\sigma^{2} + 30 \log(f) - 40 \log(\cos\varepsilon) - 20 \log \sin 2 (\phi - \tau) \qquad (2)$$

$$V = 20, \quad 8 \leq f \leq 15 \text{ GHz}; \quad V = 23, \quad 15 \leq f \leq 35 \text{ GHz}$$

where f is the frequency, ε is the path elevation angle, τ the polarization tilt angle, ϕ the effective raindrop canting angle, and σ the effective standard deviation of the canting angle distribution. This relation separates the functional dependencies of XPD on the various system parameters, and shows that XPD improves at higher frequencies and greater elevation angles.

The predictions based on equation (2), with $\phi - \tau = 45^{0}$ for circular polarization and with $\sigma = 0$, are compared with the measured relations for Toronto in Figure 12. The lower dashed curve in each figure represents the prediction at 11.7 GHz for the appropriate elevation angle. Excellent agreement is indicated, with two effects being responsible for most of the discrepancies. The first of these, as can be seen from equation (2), is that an improvement of XPD over the values predicted for equi-oriented rainfall ($\sigma = 0$) will occur for real random-oriented rainfall ($\sigma > 0$). The second effect in the next section. The semi-empirical prediction equations provide reasonable estimates of XPD statistics from rain attenuation statistics.

4.2 Effects of ice-crystal depolarization

on several occasions periods of reduced XPD (Figure 13), with values as low as 17 dB, were observed in the absence of significant rain attenuation in the signal path. The XPD degradation is due primarily to a differential phase-shifting medium and has been attributed to high altitude ice crystals. Over the measurement period ice-cloud depolarization effects were recorded at all experimental locations, occurring most frequently at the two eastern maritime locations.

An analysis separating identifiable ice crystals from the data sets demonstrated that ice-crystal depolarization degrades XPD statistics by less than 1 dB at the low percentages of time important to systems design and does not alter the form of the XPD/CPA relation.

5. Conclusions

The principal conclusions that can be drawn from these propagation studies, as they relate to satellite systems planning, are:

- Depending on the level of service, excessive rain margins are not required.

- For more reliable service, site-diversity is not required in the west, particularly British Columbia, but is in the Atlantic provinces and likely as well in parts of Ontario and Quebec.

- The advantage gained by site-diversity is appreciable with path separations as short as 10 km.

- Topographic features, as they affect precipitation behaviour, must be considered in the selection of diversity sites.

- Site-diversity would ensure that interference levels remained low, whereas up-link power control would not.

- For frequency-reuse systems, rain depolarization produces interference which, if co-channel and same service area, may be excessive at some eastern locations. Some advantage is gained to cross-polarize adjacent channels in the same service area or same channels in adjacent service areas.

- Cross-polarization statistics at 12 GHz may be predicted reliably from attenuation statistics using simple semi-empirical relations.

- At 12 GHz, ice crystal depolarization only marginally degrades the statistics at the low percentages of time important to systems design.

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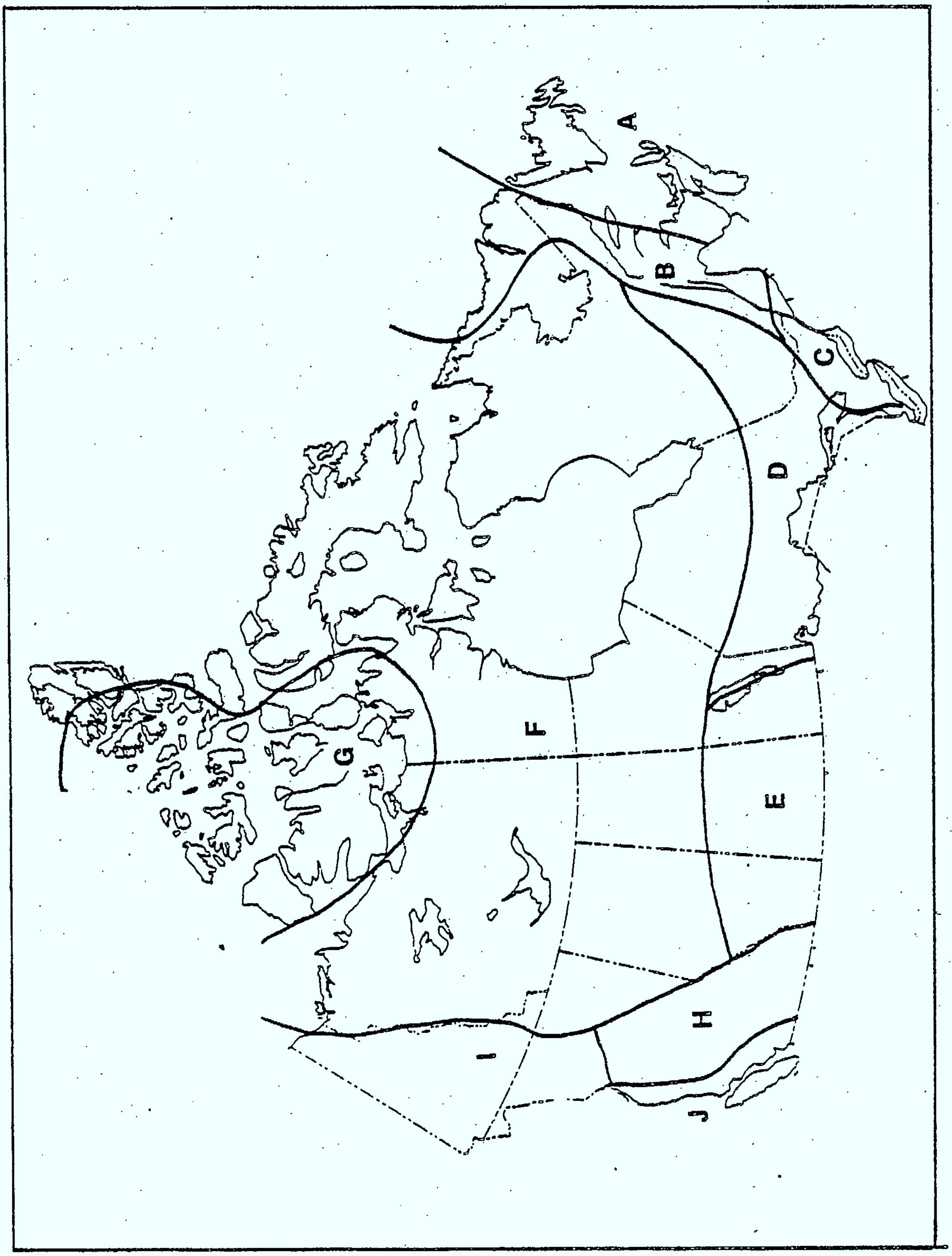


Figure 1 - Precipitation Regions in Canada

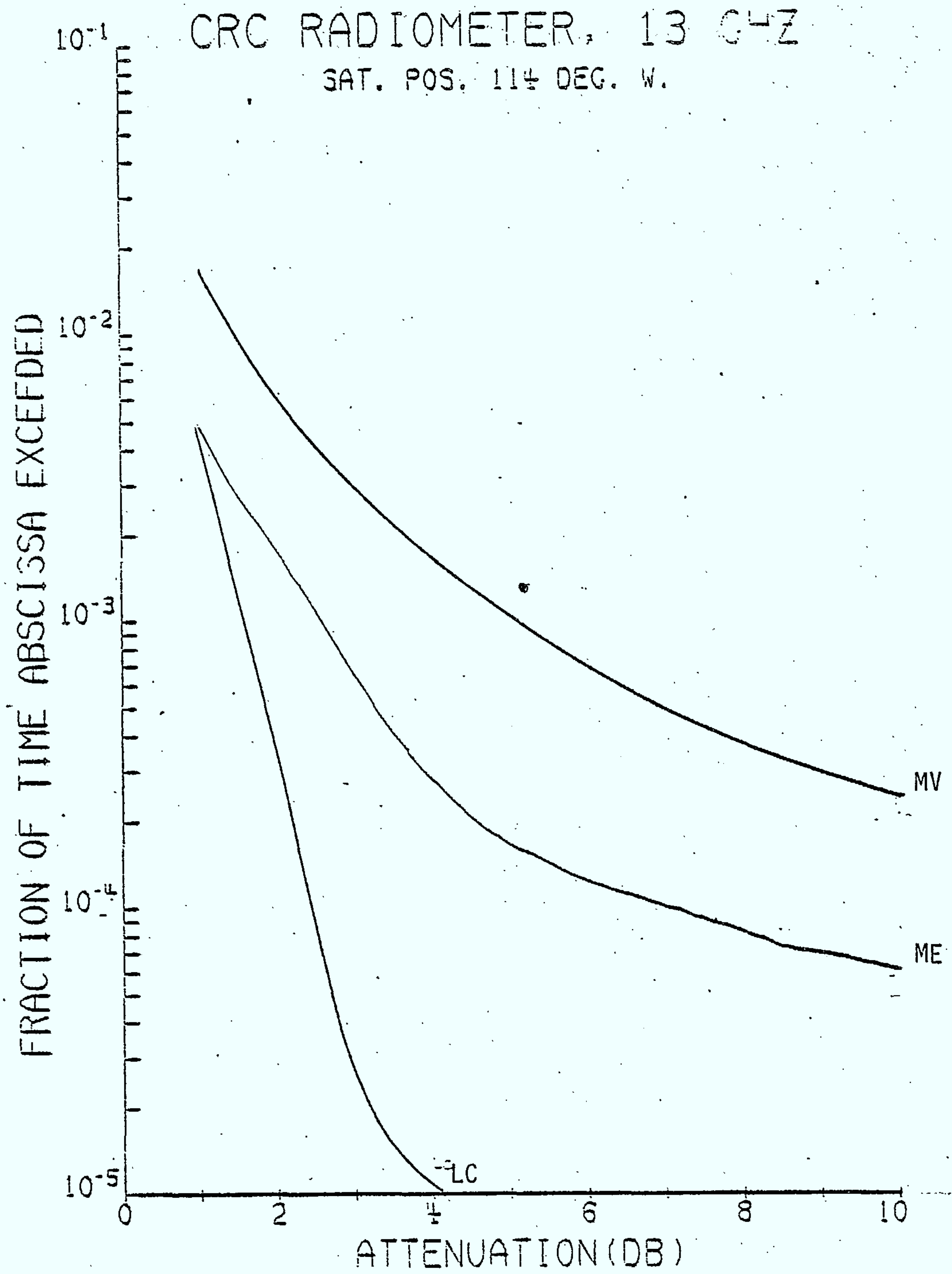


Figure 2 - Cumulative distributions of attenuation at Mill Village (MV), Melville (ME) and Lake Cowichan (LC).

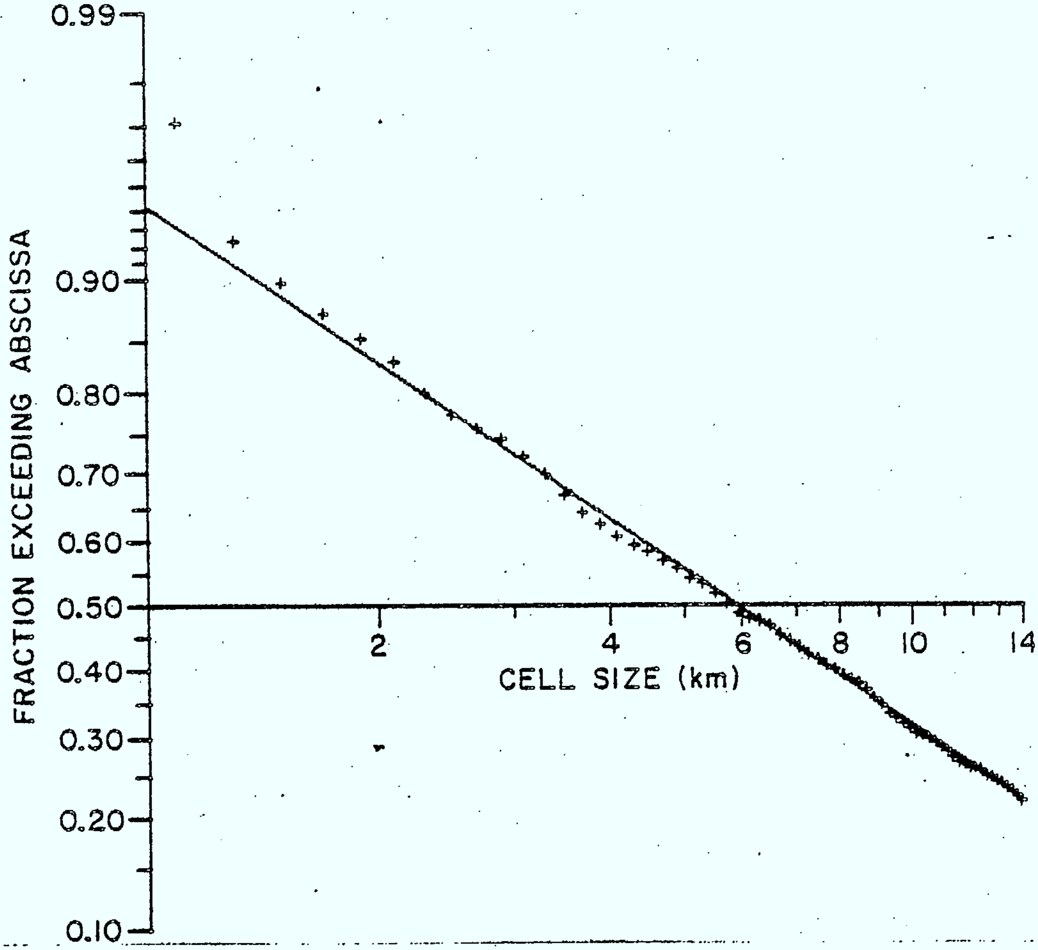


Figure 3 - Attenuation cell size distribution for an elevation angle of 5^o and attenuation level of 3 dB.

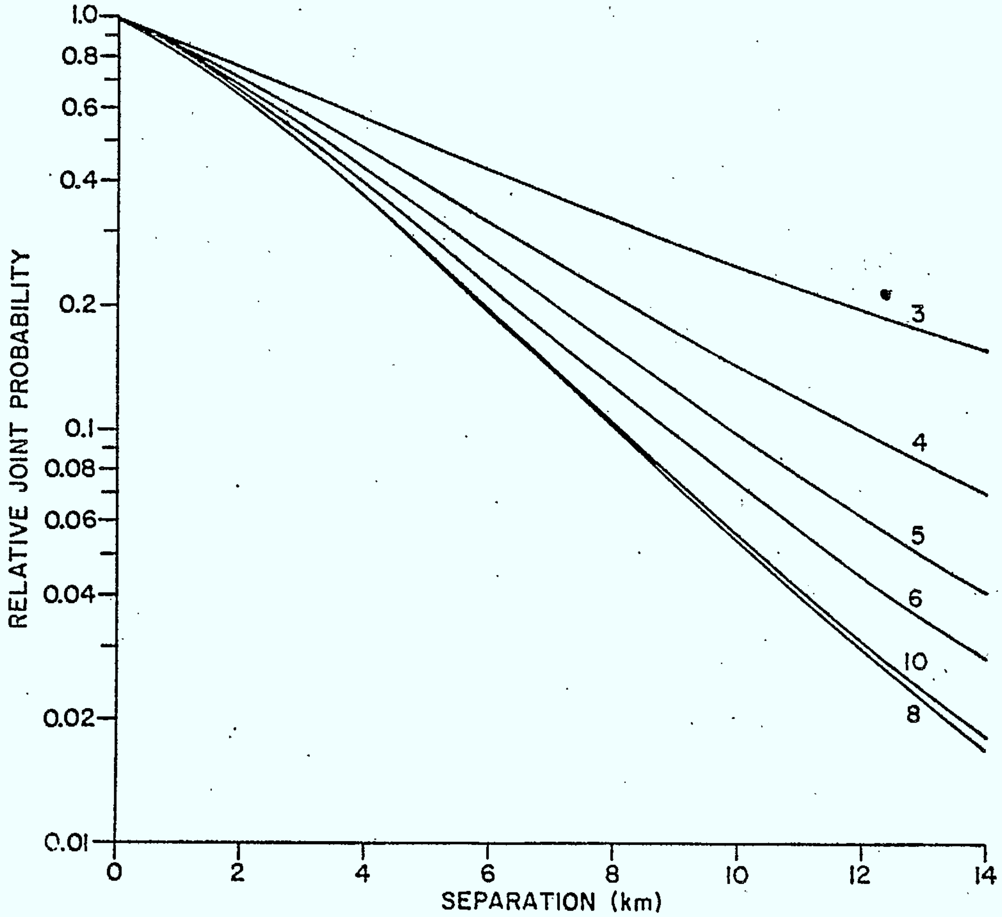


Figure 4 - Variation of relative joint probability at Ottawa with separation for attenuation levels of 3 to 10 dB.

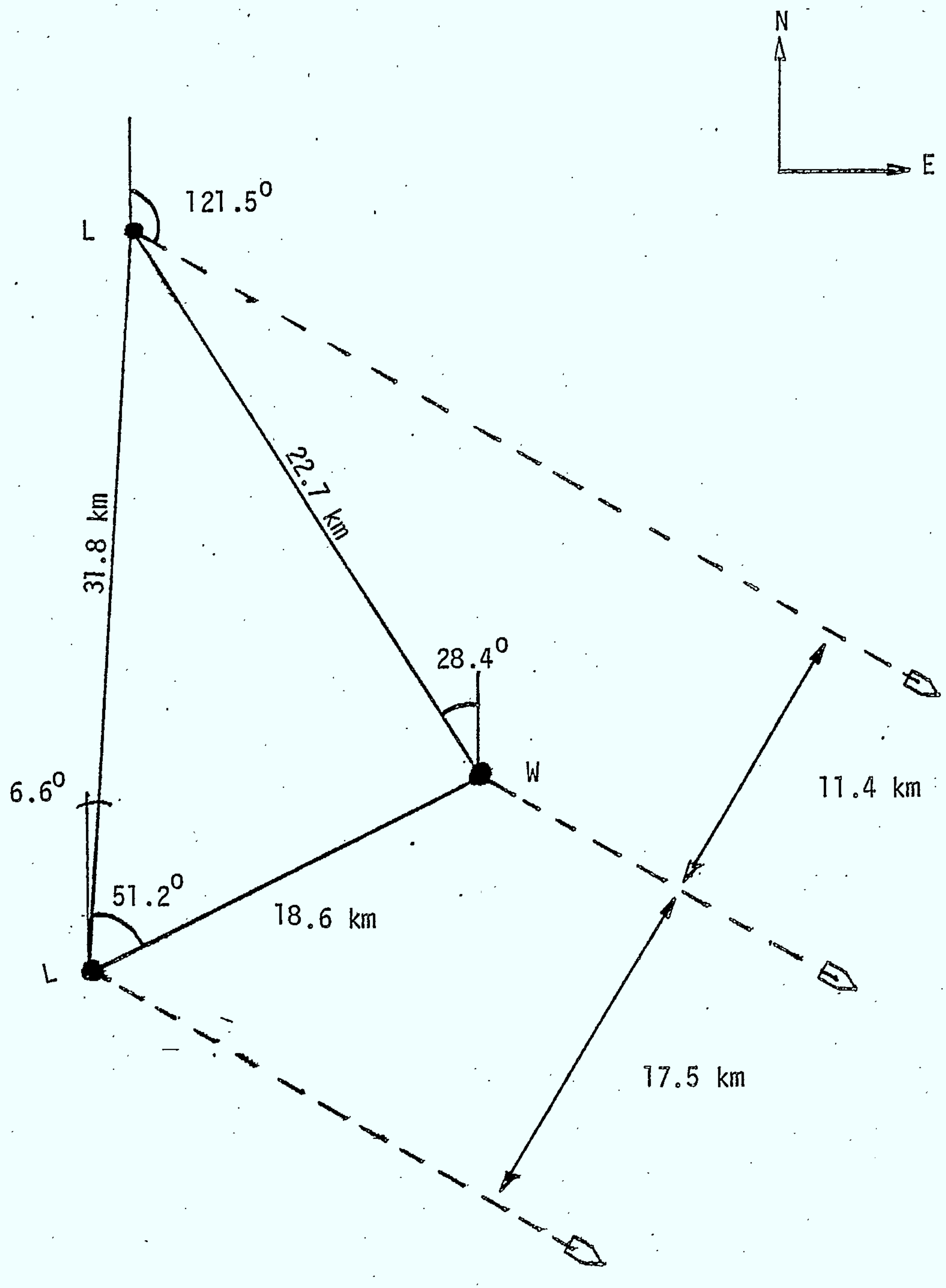


Figure 5 - Québec 3-station site-diversity configuration (1980).

Beaver Valley - Meaford

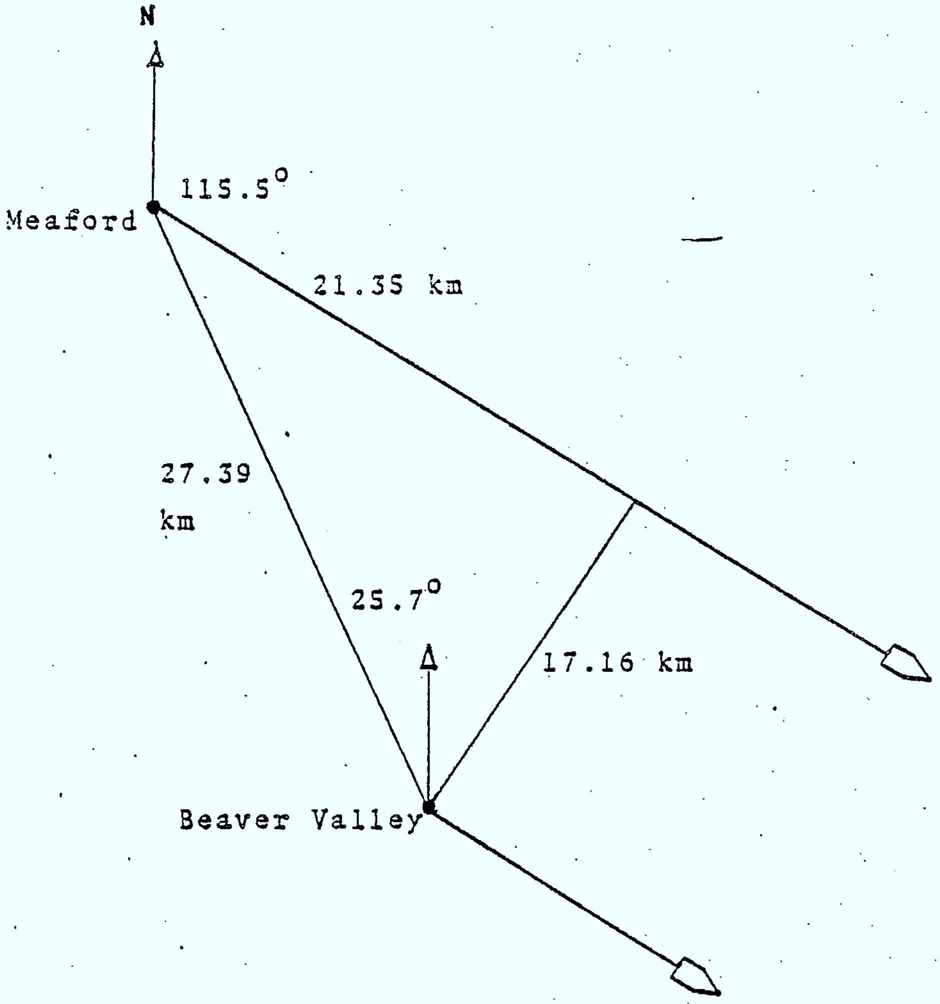


Figure 6 - Ontario site-diversity configuration (1980).

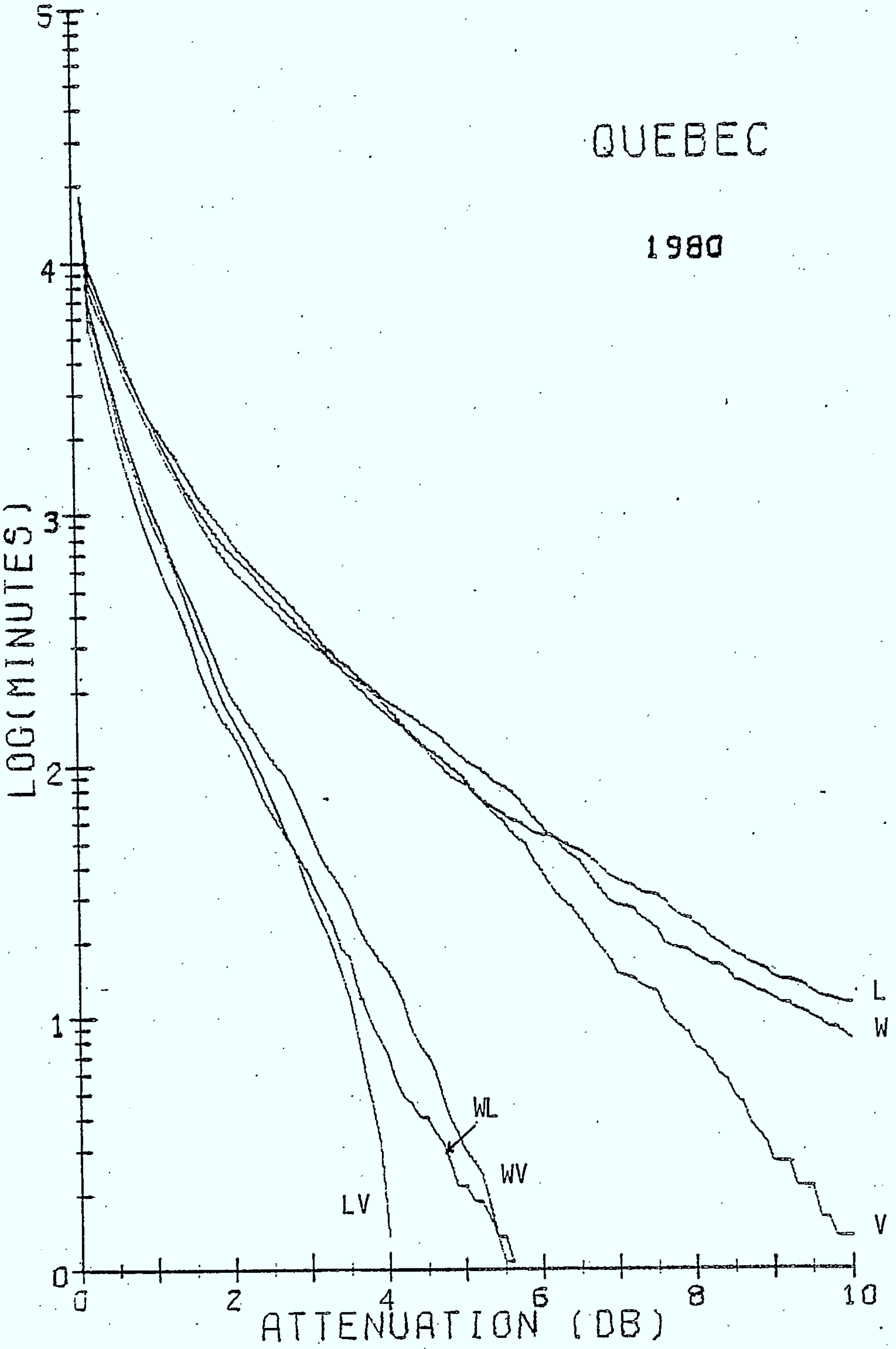


Figure 7 - Cumulative distributions of attenuation for each site (L, W and V) and for the diversity pairs (W-L, W-V and L-V) for Québec 1980.

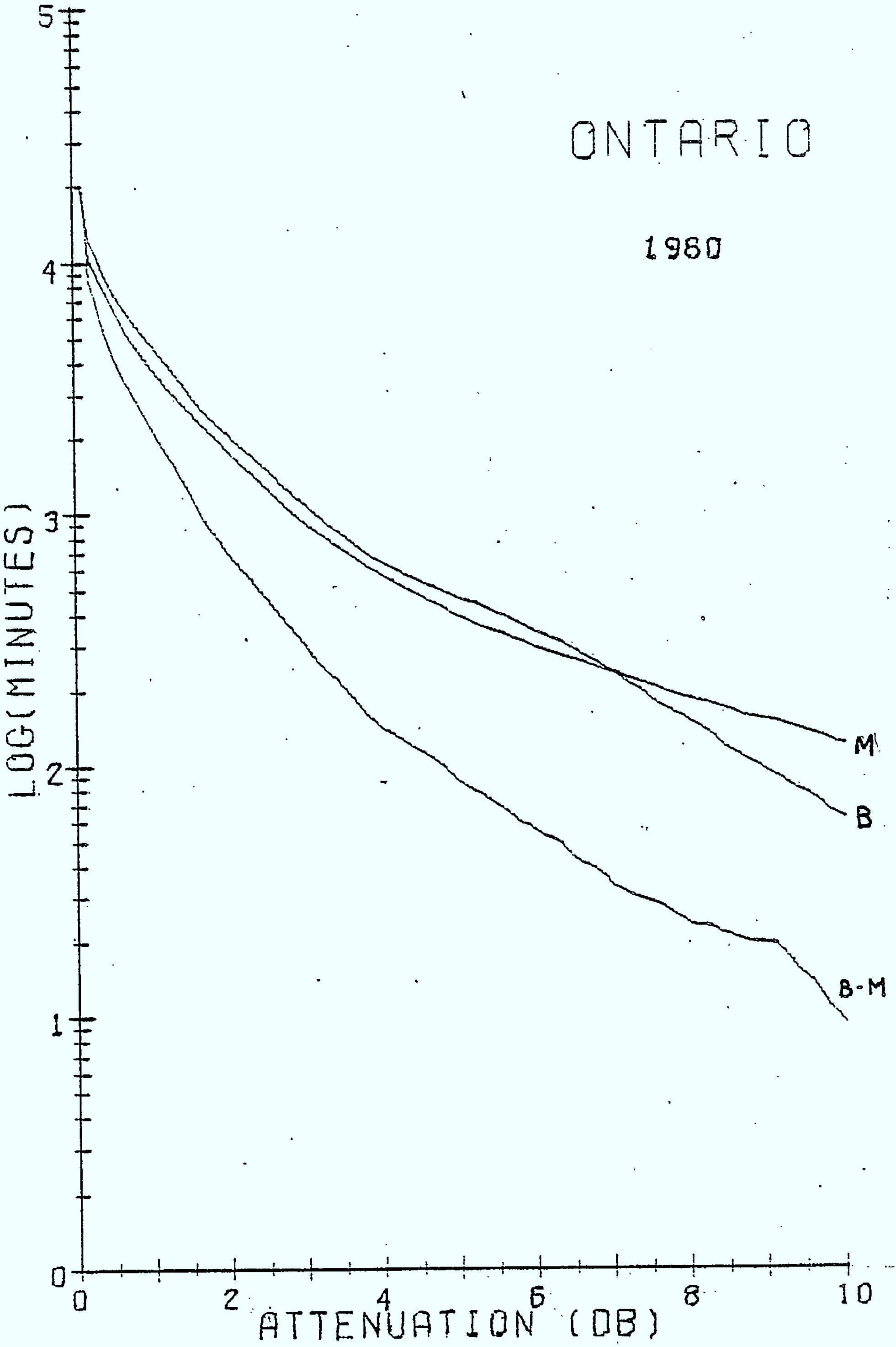


Figure 8 - Cumulative distributions of attenuation for each site (B and M) and for the diversity pair (B-M) for Ontario 1980.

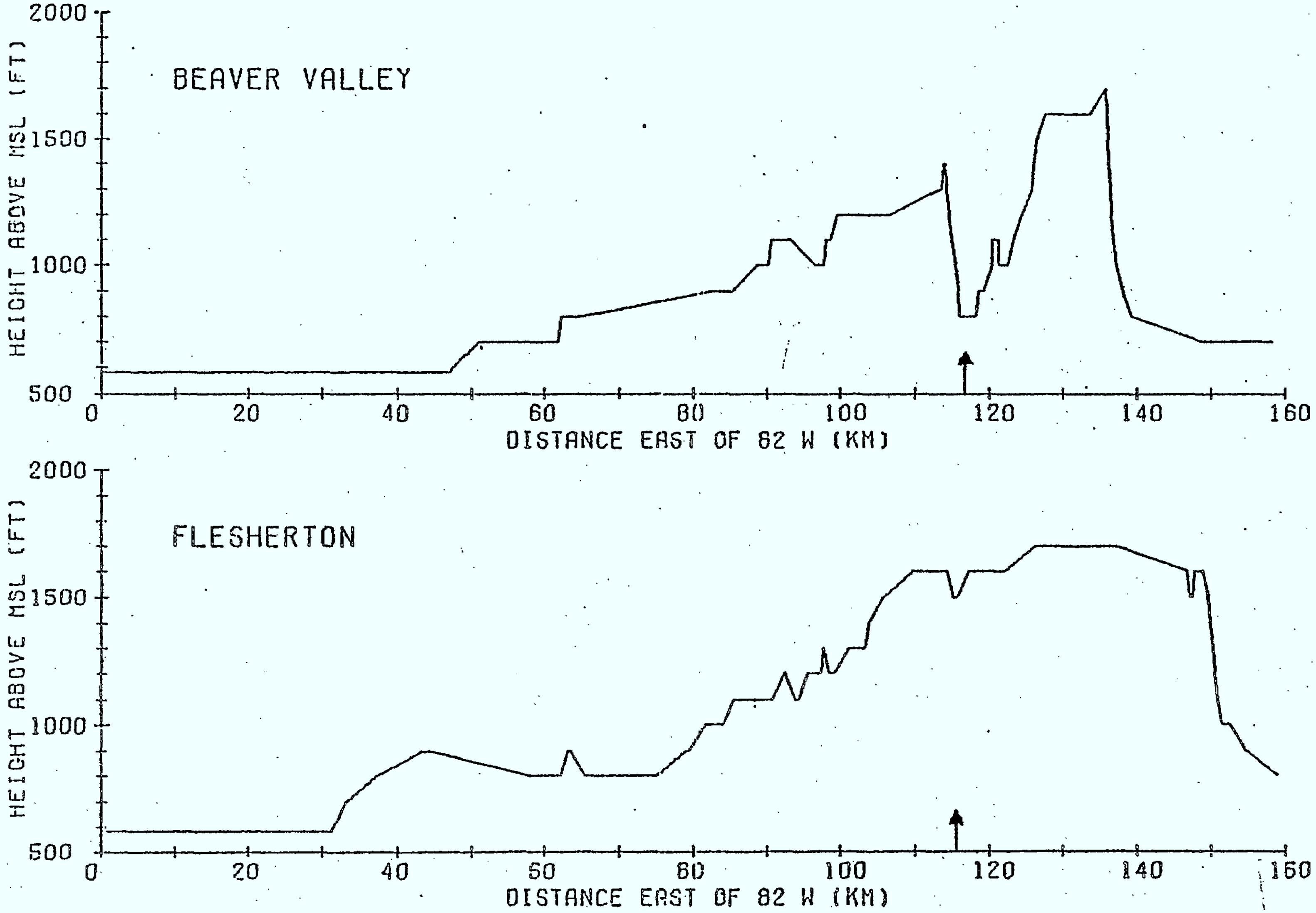


Figure 9 - West to east elevation profile through Ontario diversity sites.

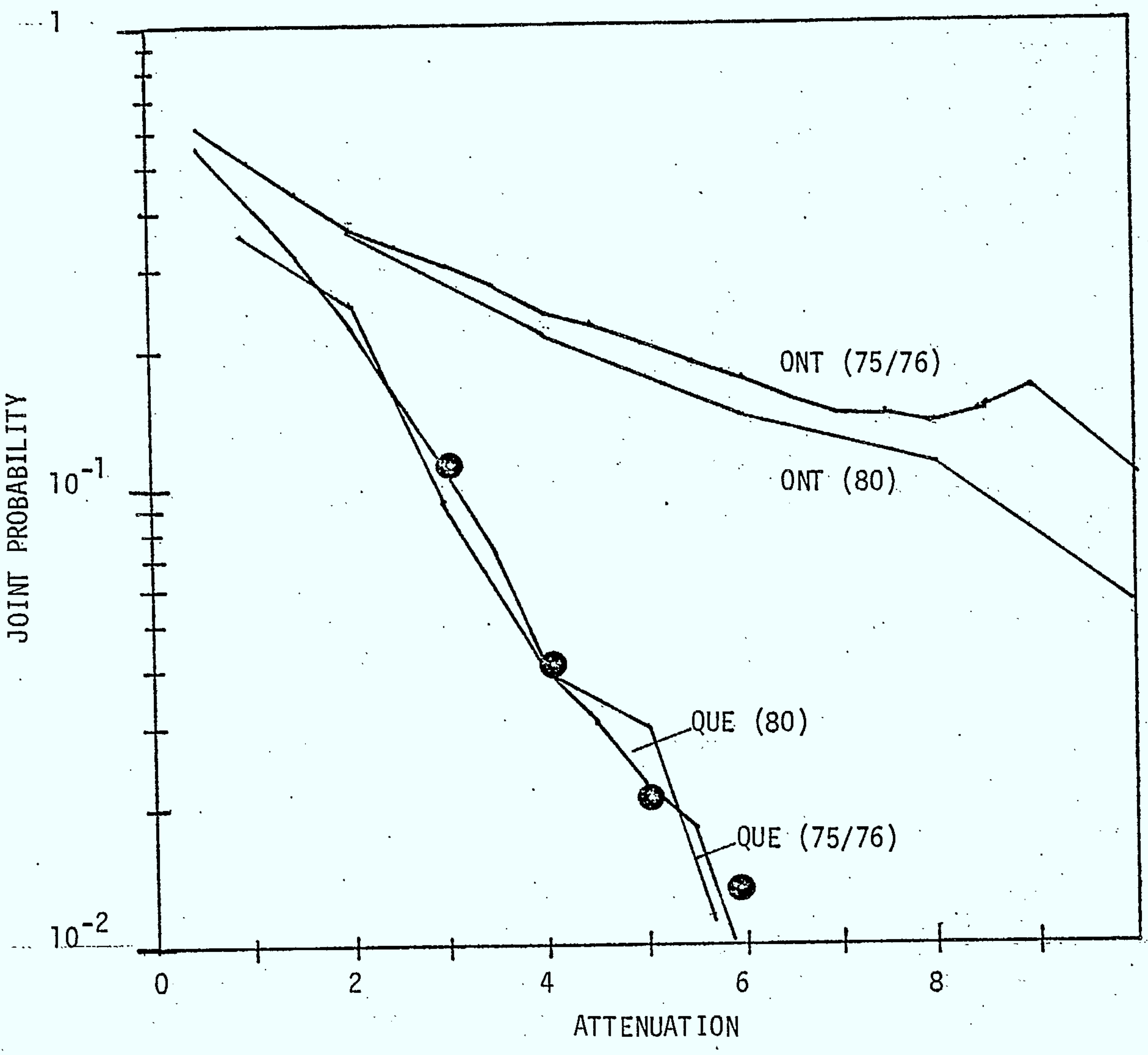


Figure 10 - Joint probabilities for Ontario and Québec diversity sites. Cell size model (●).

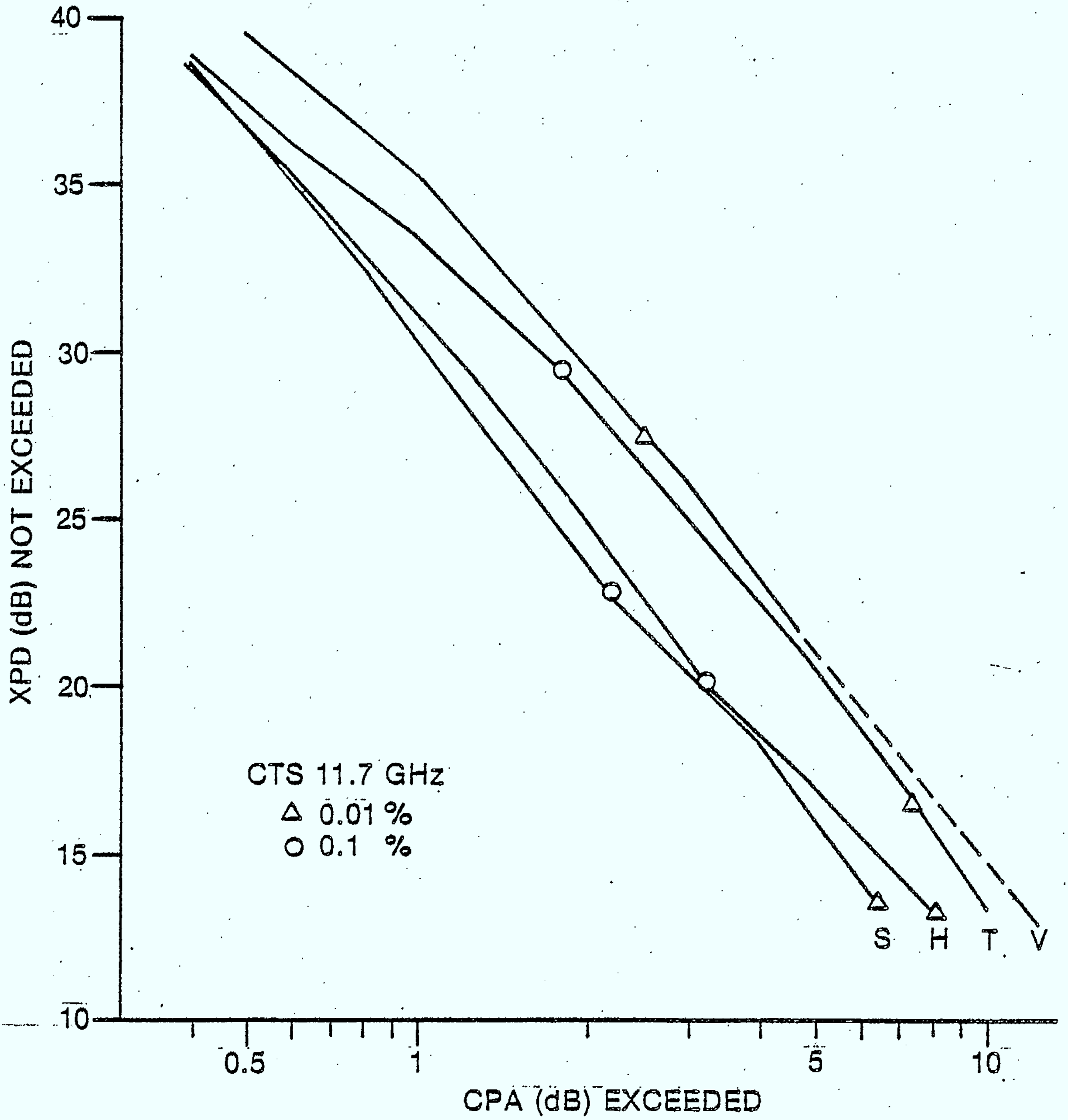


Figure 11 - Equiprobability curves of XPD (p%) vs CPA (p%) for St. John's (S), Halifax (H), Toronto (T) and Vancouver (V).

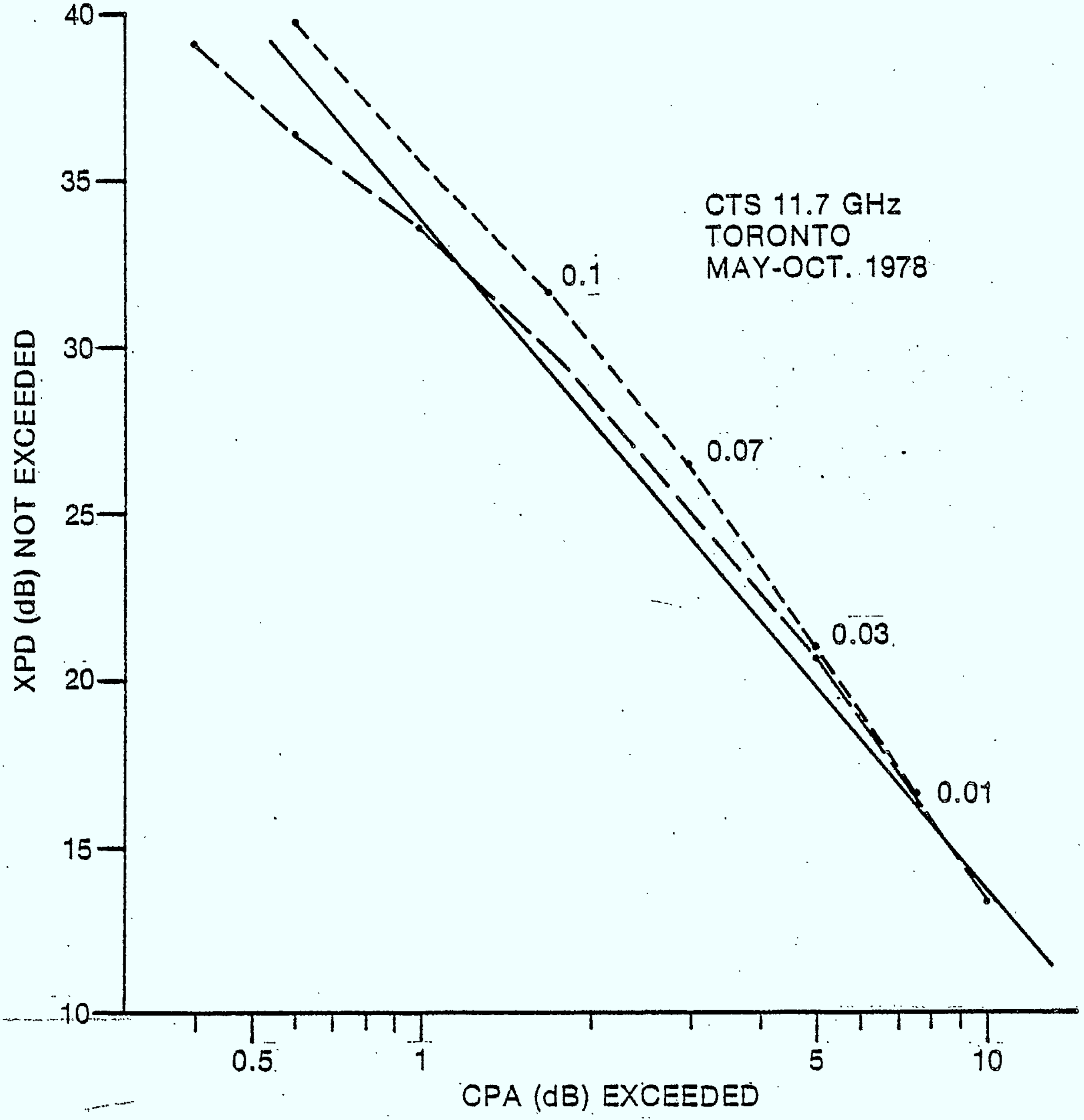


Figure 12 - Equiprobability curve of XPD (p%) vs CPA (p%) for Toronto.
All events (lower--). Rain-only events (upper--). Prediction (____).

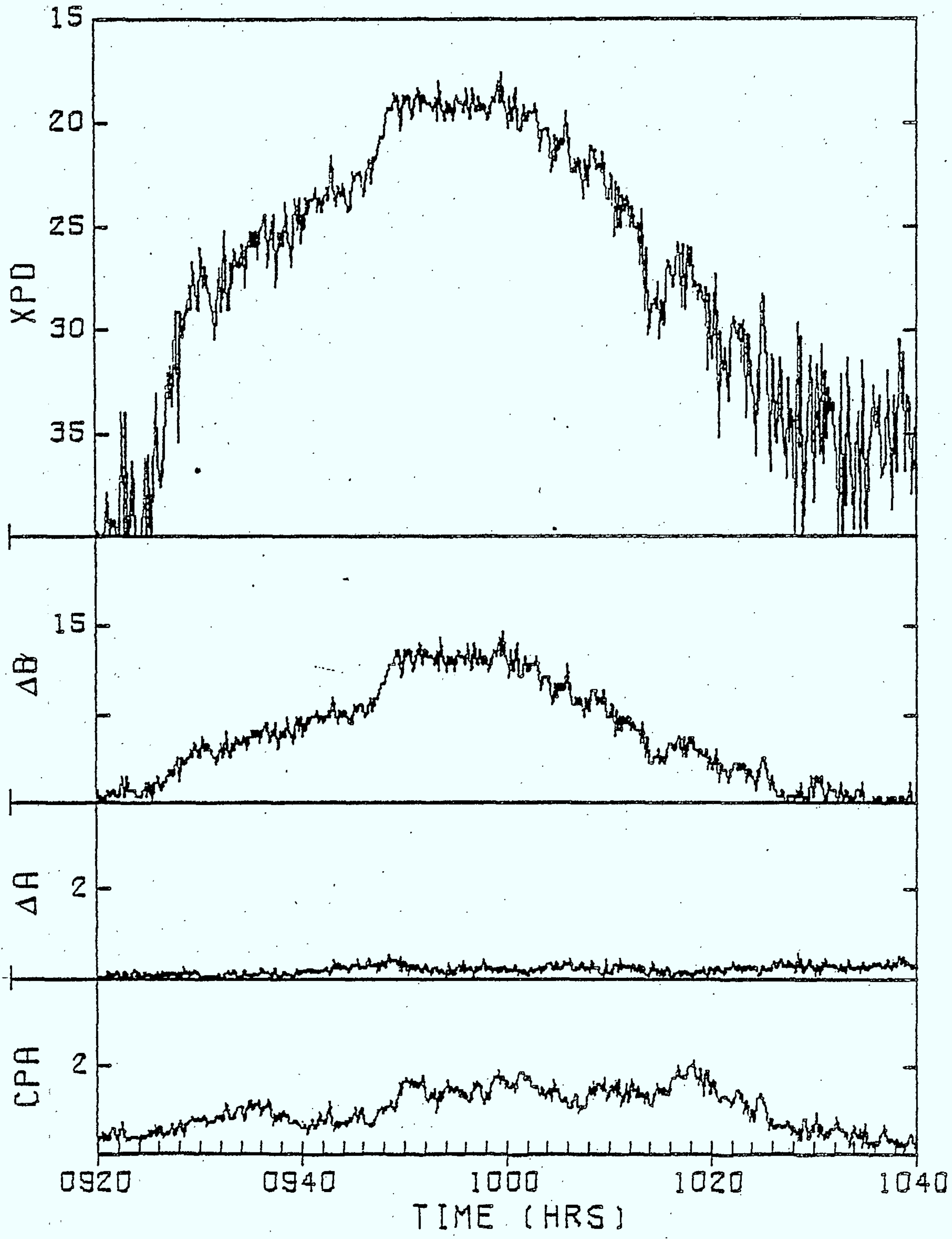
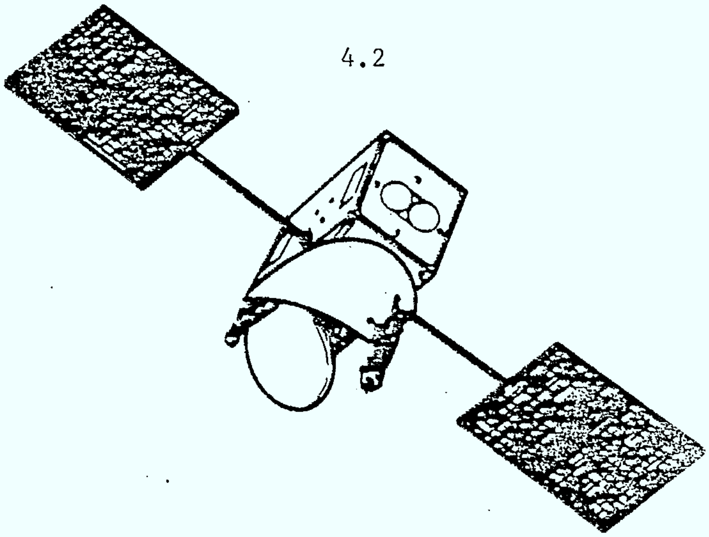


Figure 13 - Ice-crystal depolarization event at St. John's.



TITLE : PROPAGATION CONDITIONS IN SOUTH AND CENTRAL AMERICA

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PROPAGATION CONDITIONS IN SOUTH AND CENTRAL AMERICA

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1. INTRODUCTION

This report discusses the propagation conditions in South and Central America and their dependence on meteorological parameters. Most of the work was based on data from Brazil, although to a limited extent it also used information from Argentina, Venezuela and Panama. The first topic (Section 2) is a climatic classification for South and Central America, where the main characteristics of each type are defined. Section 3 describes the behaviour of refractive index in these climates. Section 4 deals with the problem of spatial and temporal variations of rain. The question of rain attenuation is treated in Section 5. Tropospheric and ionospheric scintillations are studied in Sections 6 and 7, respectively. An analysis of interfering propagation mechanisms is given in Section 8. Section 9 summarizes the most important results and suggests some topics for future work. Finally, the list of references used in the text is presented.

2. CLIMATIC REGIONS IN SOUTH AND CENTRAL AMERICA

Tropical and equatorial climates predominate in South and Central America. Exceptions are made for the highlands in the Andean region and parts of Argentina and Chile. Figures 1 and 2 show the climatic types in South and Central America.

Table 1 complements the information given in these figures. The classification presented here follows Critchfield [1] and Nimer [2] with a few modifications from other publications. The annual variation of monthly mean values of temperature, humidity, and precipitation for the meteorological stations cited in Table 1 are given in Figures 3 to 13.

3. RADIO REFRACTIVITY OF TROPOSPHERE

The refractive index of the troposphere (n) is near unity. So one normally uses the parameter called refractivity (N), which is defined by,

$$N = (n - 1) \times 10^6 = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2} \qquad (1)$$

where,

p = pressure in mbar

T = temperature in degrees Kelvin

e = partial pressure of water vapor in mbar.

The refractivity varies primarily with height. The exponential model provides a good fit for the height dependence. To minimize the effect of surface elevation, the refractivity values can be referred to sea level through the equation

$$N = N_o \, e^{-bh} \qquad (2)$$

where

N_o = refractivity value reduced to sea level

b = constant

h = height in km above the sea level.

If N_s is the mean value of refractivity at the surface of the earth, it is obvious that

$$N_o = N_s e^{bh_s} \tag{3}$$

h_s being the surface height above sea level.

In some climates, it is possible to establish a correlation between N_s and the refractive gradient over the first kilometer. The correlation formula satisfies the equation,

$$\Delta N = A e^{B.N_s} \tag{4}$$

Another important parameter is the effective earth radius (a_e), which is given by

$$a_e = k.a \tag{5}$$

where a is the true earth radius and the k factor is defined by

$$k = \frac{1}{1 + a \frac{dN}{dh} \times 10^{-6}} \tag{6}$$

The data shown in Table 2 for the months of February, May, August, and November [3] were obtained from radiosonde measurements carried out in Brazil during 6 years. A serious limitation of these data comes from the fact that the measurements were made at 12:00 GMT. Because of this constraint it is impossible to analyze the nocturnal phenomena. As it will be seen later, this is quite important in regions where wet-and-dry and semiarid tropical climates prevail.

From radiosonde measurements made at 12:00 GMT in Trindade Island (16° 24'S; 49° 16'W), a small island located far from the continent, it was possible to investigate the refractive index behaviour over the sea. Table 3 shows the exponential variation of refractivity reduced to sea level for February, May, August, and October.

The statistical distribution of refractivity gradient and duct occurrences for ten meteorological stations in Brazil (including Trindade Island) was studied [3] using the values of refractivity from radiosonde data. Figures 14 to 18 show the statistical distributions of refractivity gradient for Belém, Campo Grande, Rio de Janeiro, Curitiba and Trindade Island. The occurrence of ducts for these stations is given in Table 4.

As can be seen in Table 4, there is no indication of ducts in Campo Grande. However, propagation studies conducted in the hinterlands of Brazil, particularly those corresponding to wet-and-dry and semiarid tropical climates, have shown a different behaviour. In fact, during daytime, wind and high temperatures are sufficient for sustaining the turbulence of the troposphere. At night, usually during the rainy season, the situation is quite different. For instance, Figure 19 shows the statistical distribution of the received power [4] in the path from Gurupi (11° 43'S; 49° 04'W) to Alianca do Norte (11° 02'S; 49° 08'W). The difference between daytime and nocturnal signal variation is clear. In day hours, propagation is very well behaved, with a free-space median value and a maximum observed fading of 5 dB. In night hours, the median value is a few dB below free-space and fading depths reach values of 30 dB or more.

The existence of ducts in this area was verified through refractometer measurements and can be explained as follows [5]: as the sun ceases to heat the earth, the natural soil humidity prevails, and the surface temperature tends to decrease while humidity near the earth grows rapidly. The variations of these parameters in high tropospheric layers is much slower than at surface level. So, a positive gradient of temperature combined with a large negative gradient of humidity may occur. Additionally, it must be noted that the absence of wind during night hours in this period (rainy season) is also a favorable condition for stratification in tropospheric layers.

Refractivity measurements were also carried out in Venezuela [6] and Argentina [7]. A summary of data from Maracay meteorological station (Venezuela) is given below:

$$N_s = 358$$

$$N_o = 381$$

$$b = 0.1625$$

$$A = 17.85$$

$$B = 0.00308$$

Statistical distribution of k factor (effective earth radius):

Percent of Time	k factor
99	1.28
80	1.40
50	1.52
20	1.58
1	1.89

The study or refractivity in Argentina has taken into account eight meteorological stations [7]. Here will be presented data from Ezeiza (subtropical) and Comodoro Rivadavia (midlatitude semiarid). Values of N_o, N_s and b for these situations are given in Table 5. The mean values of A and B in equation (4) are given by:

$$A = -2.065$$

$$B = 0.009368$$

Figures 20, 21, and 22 show the statistical distribution of refractivity gradient for Ezeiza (00:00 GMT and 12:00 GMT) and Comodoro Rivadavia (12:00 GMT).

Finally, it must be pointed out that the data from Brazilian meteorological stations have shown a poor correlation between ΔN and N_s [3].

4. RAIN RATE DISTRIBUTIONS

Table 6 [8] shows recent rainfall measurements carried out in Rio de Janeiro (from 07/15/77 to 07/14/80). A rain gauge with 5 min. integration time was used. Following Misme [9], a constant correction of 20 mm/hr was applied to the measured 5-min. rain rates to obtain the 1-min. rain rates shown in Table 6. For other climates defined in Figures 1 and 2 there are no accurate data. A possible solution for this problem is to apply the distributions proposed by CCIR for South and Central America [10].

An important problem in tropical regions (wet-and-dry and semiarid) is the year-to-year rainfall variability. As an example, for 10^{-3} percent of time, the measurements in Rio de Janeiro have shown variations of ±50 mm/hr relative to average year. A similar comment applies to local variations inside the same climatic region.

5. RAIN ATTENUATION

This section presents some results concerning the Brazilian experience on rain attenuation at frequencies above 10 GHz. Up to now there are 3 years of data for an 8.6 km path, operating at 10.915 GHz in the urban area of Rio de Janeiro (maritime tropical climate). Two more paths have begun to be studied recently, one in mid-1980 and the other early this year. The propagation measurements for these paths will be published soon. As a complement to the experimental work, two mathematical models for terrestrial and earth-space paths were developed [11],[12].

5.1 RAIN CELL MODEL

The interpretation of rain attenuation measurements was based in the cylindrical rain cell model (Figure 23) proposed by Misme and Fimbel [13],[14], which dimensions are given by,

$$D(km) = 2.2 \left[\frac{100}{R}\right]^{0.4} \tag{7}$$

and

$$R_o = 10 \text{ mm/hr (residual precipitation)} \quad .$$

According to the authors, these values seem to be independent of climate. In its definition, data from Japan, Malaysia, Switzerland and France [15] have been used. As will be seen later, the results presented here also tend to confirm this assumption.

5.2 TERRESTRIAL PATHS

As cited previously, the first experience in Brazil on rainfall attenuation measurements at frequencies above 10 GHz was carried out in the urban area of Rio de Janeiro. A commercial link owned by EMBRATEL (Brazilian Enterprise of Telecommunications) was used. The link parameters are given below:

Capacity:	2700 Telephonic Channels
Frequency:	10.915 GHz
Distance:	8.6 km
Transmitting Power:	38.5 dBm
Antenna Gain:	49.8 dB
Free Space Attenuation:	132.1 dB
Additional losses:	16.7 dB
Nominal Receiving power:	-10.7 dBm
Receiver Threshold:	-78.5 dBm
Fading Margin:	67.8 dB

Precipitation rate was measured simultaneously with rainfall attenuation. The rain gauge was a Hellmann-Fue type (5 min. integration time) located 3.2 km from one terminal as depicted in Figure 24. The statistical distribution of precipitation rate is shown in Figure 25. A constant correction of 20 mm/hr was introduced in order to adjust the difference between 5 and 1 min. integration time.

Figure 26 shows the theoretical and experimental distributions of rain attenuation, corresponding to the period from 07/15/77 to 07/14/78 [16]. The theoretical calculation has used the precipitation rate data given in Figure 25 and was based in a mathematical model developed by Assis and Einloft [11]. As can be seen from Figure 26, there is a close agreement between theoretical and experimental results. The three years of data, not shown here, covering the period from 07/15/77 to 07/14/80, are also in accordance with predictions by the mathematical model [11].

The theoretical analysis has used a model which is based on the rain cell behaviour along the path, assuming a statistical independence among rain cells and also that, for a long observation period, a given precipitation rate will be exceeded during the same percentage of time at all points in the propagation path. Since the most important contribution for attenuation is given by the area of most intense precipitation (cylinder with diameter D in Figure 23), for a distance d it is possible to have in different periods of time a total of d/D rain cells. According to these ideas, if a rain cell has a diameter D which corresponds to a precipitation rate R exceeded for a time percentage P', the attenuation produced by this cell in a distance d will be exceeded for a percentage P given by [11],

$$P = \frac{d}{D} P' \qquad (8)$$

Using the geometry in Figurre 23 theoretical attenuation can be easily computed by:

$$A(dB) = k\ [R(mm/hr)]^{\alpha}\ D(km) + k[10]^{\alpha}[d(km) - D(km)] \quad , \qquad (9a)$$

for $d < 33$ km, and

$$A(dB) = k[R(mm/hr)]^{\alpha}\ D(km) + k[10]^{\alpha}\ [33 - D(km)] \quad , \qquad (9b)$$

for $d \geqslant 33$ km, where the parameters k and α can be calculated, for instance, from Misme and Benoit-Guyot [17] or Olsen et al. [18].

5.3 EARTH-SPACE PATHS

The Brazilian experience in this case is very small. A few measurements using radiometers were made by EMBRATEL and COMSAT in the Amazonic region (equatorial climate) at 11.7 and 20 GHz [19]. Unfortunately, the experimental results were reliable only for small precipitation rates, up to 10 mm/hr. Other measurements in the equatorial region were carried out by COMSAT in Panama [20]. However, the precipitation rate was also a limitation in the interpretation of rainfall attenuation data.

The correlation between precipitation rate and attenuation was analyzed using a mathematical model [12] which is an extension of the one described in the previous paragraph for terrestrial paths. The only difference is the inclusion of a new parameter to consider the vertical distribution of precipitation (ceiling height). In spite of the constraint represented by the precipitation rate data, the results from the theoretical analysis for both cases cited above were quite good. Tables 7 and 8 show the comparison between theoretical and experimental measurements for Brazil (Manaus) and Panama (Utibe), respectively. The same model was applied to other measurements carried out abroad and the agreement between theory and experimental data was also satisfactory.

Finally, as additional information for earth-space propagation studies, Table 9 gives the height of 0°C isotherm [21] for Brazilian meteorological stations considered in this text.

6. TROPOSPHERIC SCINTILLATION

Measurements were limited to the terrestrial path described in Section 5. The experiment was carried out from October through December 1977, a period in which the climatic conditions were warm and humid, with average temperature between 22 and 25°C and relative humidity ranging from 75 to 80 percent. The refractive index fluctuations were also measured by a two-cavity microwave refractometer (Crain type) located at the same place as the rain gauge shown in Figure 24. The periods of measurements were selected according to the following conditions:

a. around midday when the atmosphere along the path is homogeneous and isotropic due to solar induced turbulence; and

b. during periods where only scintillation effects could be observed (a constant mean signal level for several minutes).

Both the refractive index temporal spectrum and amplitude scintillation spectrum evaluated from experimental results agree with the mathematical model developed by Tatarskii [22]. Details about this comparison were published by Medeiros Filho and Assis [23]. The maximum observed peak-to-peak scintillation was around 1 dB. This parameter is defined as twice the value of the signal excursion that exceeds the mean value during 0.1 percent of time.

7. IONOSPHERIC SCINTILLATION

Since 1970, COMSAT Laboratories has performed work to investigate ionospheric scintillation at many earth stations of the INTELSAT network. The scintillation activity is found between 30°N and 30°S geomagnetic latitudes with a higher occurrence rate near the geomagnetic equator. A diurnal peak of the scintillation was generally observed at about 1 hr after the local sunset, and seasonal peaks near the vernal and autumnal equinoxes. Also, a correlation with sunspot activity was observed [24].

This section presents results of scintillation measurements performed at Tangua, Brazil during approximately 15 months by COMSAT Laboratories under the sponsorship of INTELSAT. Figure 27 shows the cumulative amplitude distribution of the peak-to-peak fluctuation. Figure 28 shows the seasonal variation of scintillations greater than 0.5 dB.

8. LONG RANGE PROPAGATION MECHANISMS

Transhorizon propagation of strong signals for small percentages of time is an important problem in interference studies. In general, three propagation mechanisms must be considered: rain scatter, ducting or super-refraction, and tropospheric (clear air) scatter. In SHF band, for percentages of time of 1 percent or less, usually rain scatter dominates. Ducting or super-refraction may be important for sea paths or over plains. For higher percentages of time tropospheric scatter should also be taken into account.

In South and Central America the experience in interference problems is quite limited, although Brazil has one of the largest troposcatter systems in the world. There is no information about rain scatter. However, for the other two mechanisms, based on a few propagation measurements and meteorological data it is possible to infer some conclusions for equatorial and wet-and-dry tropical regions.

The equatorial climate seems to be appropriate for tropospheric scatter propagation. Measurements carried out in the UHF band have demonstrated this assertion [25]. On the other hand, this study has also shown the tendency of tropospheric stratification during nocturnal periods, leading to duct formation. As was pointed out before (Section 3), the same condition appears in tropical continental regions during the rainy season.

9. CONCLUDING REMARKS

The results presented here are quite stimulating for future research work. South and Central America constitute an almost unexplored area for propagation studies and permit the investigation of problems different from those found in temperate countries. Some topics to be considered in a research program in tropical and equatorial regions are:

a. occurrence of ducts;
b. radar measurements of rain spatial distribution;
c. statistical distributions of rain (temporal);
d. year-to-year variability of rain distribution;

e. rain attenuation measurements with radiometers (and also satellites in the future);

f. site diversity;

g. depolarization studies; and

h. long distance propagation of strong signals using the earth stations existing in South and Central America (rain scatter, ducting, and troposcatter).

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TABLE I

CLIMATIC TYPES IN SOUTH AND CENTRAL AMERICA

Type	Location	Typical data from
Equatorial	Amazonic region, coastal area of Colombia and Ecuador and Atlantic Coast of C.America	Belém, Brazil (01°28'S; 48°29'W)
Wet-and-dry tropical (maritime)	Coastal areas of Venezuela, SE and NE of Brazil and Pacific Coast of Central America	Maracay,Venezuela (10°15'N;67°39') Rio Janeiro,Brazil (22°54'S;43°10'S)
Wet-and-dry tropical (continental)	Most of central Brazil, low-lands of Bolivia, Paraguay, Central Venezuela and Hinterland of C.America	Campo Grande, Brazil (20°28'S;54°40'W)
Tropical semiarid	Northeast of Brazil	Quixeramobim, Brazil (05° 12'S;39°18'W)
Tropical arid	Coastal areas of Peru and Northern Chile	Lima, Peru (12°06'S; 77°02'W)
Sub-tropical	South of Brazil, Uruguay and north-eastern Argentina	Curitiba,Brazil (25°31';49°10'W) Ezeiza,Argentina (34°49'S; 58°32'W)
Mid-latitude semiarid	Western and Southern Argentina	Comodoro Rivadavia Argentina (38°44'S;67°30'W)
Temperate maritime	Coastal areas of Central and Southern Chile	Valdivia, Chile (39°27'S;73°09'W)
Highland	Andean region of Colombia, Ecuador, Peru, Bolivia, Argentina and Chile	Quito, Ecuador (00°08'S;78°29'W)

TABLE II

EXPONENTIALS REDUCED TO SEA LEVEL -

$$N = N_o e^{-b\ h(km)}$$

Meteorological station	Parameter	February	May	August	November
Belẽm	N_o	371.5	373.9	360.4	362.4
	b	0.1584	0.1571	0.1586	0.1585
Rio de Janeiro	N_o	367.4	361.7	343.6	359.8
	b	0.1507	0.1504	0.1471	0.1509
Campo Grande	N_o	368.5	343.3	330.4	348.7
	b	0.1493	0.1440	0.1346	0.1417
Curitiba	N_o	368.1	350.1	336.0	351.6
	b	0.1511	0.1486	0.1414	0.1485

TABLE III

VALUES OF N_o AND b FOR TRINDADE ISLAND

Month	N_o	b
January	362.4	0·1567
February	358.4	0·1555
March	360.6	0·1544
April	354.5	0·1548
May	355.8	0·1505
June	360.4	0·1549
July	347.6	0·1519
August	342.5	0·1468
September	347.6	0·1501
October	351.9	0·1475

TABLE IV

OCCURRENCE OF DUCTS

Meteorological station	Percentage of time												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
Belém	13.0	14.0	21.0	12.5	11.1	11.9	16.1	9.2	24.0	22.2	30.3	259	16.3
Rio de Janeiro	15.4	18.0	19.2	19.7	8.5	7.3	12.3	11.7	10.3	16.1	14.9	14.8	14.1
Campo Grande	-	-	-	-	-	-	-	-	-	-	-	-	-
Curitiba	2.1	-	4.6	-	-	-	-	-	-	-	2.7	1.2	1.2
Trindade Island	52.5	45.5	56.0	38.0	36.0	12.5	9.0	11.5	13.5	20.0	No data	No data	-

TABLE V

RADIOMETEOROLOGICAL DATA FOR EZEIZA AND COMODORO RIVADAVIA

Station	Hour GMT	February			May			August			November		
		N_o	N_s	-b	N_o	N_s	-b	N_o	N_s	-b	N_o	N_s	-b
Ezeiza	00:00	333.2	337.3	0.13830	334.5	333.5	0.15362	326.5	325.5	0.15218	339.1	338.2	0.14648
	12:00	347.2	345.9	0.17812	333.6	332.5	0.16581	327.3	326.3	0.15505	344.2	343.0	0.17859
Comodoro Rivadavia	00:00	302.7	300.6	0.10507	303.6	301.6	0.11264	303.0	301.1	0.10410	298.6	297.0	0.10114
	12:00	306.2	304.1	0.11484	311.5	309.1	0.12739	307.6	305.4	0.12159	307.8	305.6	0.11898

TABLE VI

RAIN STATISTICAL DISTRIBUTION IN RIO DE JANEIRO

Percentage of time	Precipitation rate (mm/h)
3×10^{-4}	260
10^{-3}	200
3×10^{-3}	143
10^{-2}	95
3×10^{-2}	65
10^{-1}	35

TABLE VII

COMPARISON BETWEEN THEORY AND EXPERIMENTAL DATA IN MANAUS - BRAZIL

Precipitation Rate mm/h	Attenuation (dB)			
	11.7 GHz		20 GHz	
	Theory	Experimental	Theory	Experimental
5.6	0.9	1.0	3.0	2.0
7.2	1.3	1.5	3.9	3.5
8.5	1.5	2.0	4.8	5.2
9.6	1.7	2.5	5.5	7.6
10.1	1.9	2.8	5.7	9.5

TABLE VIII

COMPARISON BETWEEN THEORY AND EXPERIMENTAL DATA IN UTIBE - PANAMA

Percentage of time	Attenuation (dB)	
	Theory	Experimental
10^{-1}	11.4	10.0
2×10^{-1}	6.1	7.0
4×10^{-1}	3.2	4.0

Frequency: 15.3 GHz

TABLE IX

HEIGHT OF °C ISOTHERM

Meteorological station	Height (m)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
Belem	4844	4950	4935	5017	5027	4917	4816	4710	4752	4758	4844	4843	4868
Rio de Janeiro	4603	4615	4589	4259	4267	4172	4093	4126	4416	4312	4499	4508	4372
Curitiba	4781	4797	4638	4207	4307	4017	4074	3914	4316	4194	4388	4384	4335
Campo Grande	4800	4808	4827	4813	4620	4599	4463	4414	4503	4588	4836	4826	4675
Trinidade Island	4741	4608	4697	4412	4436	4635	4406	4226	4158	4173	-	-	4449

Fig. 1 - Climatic Regions in South America

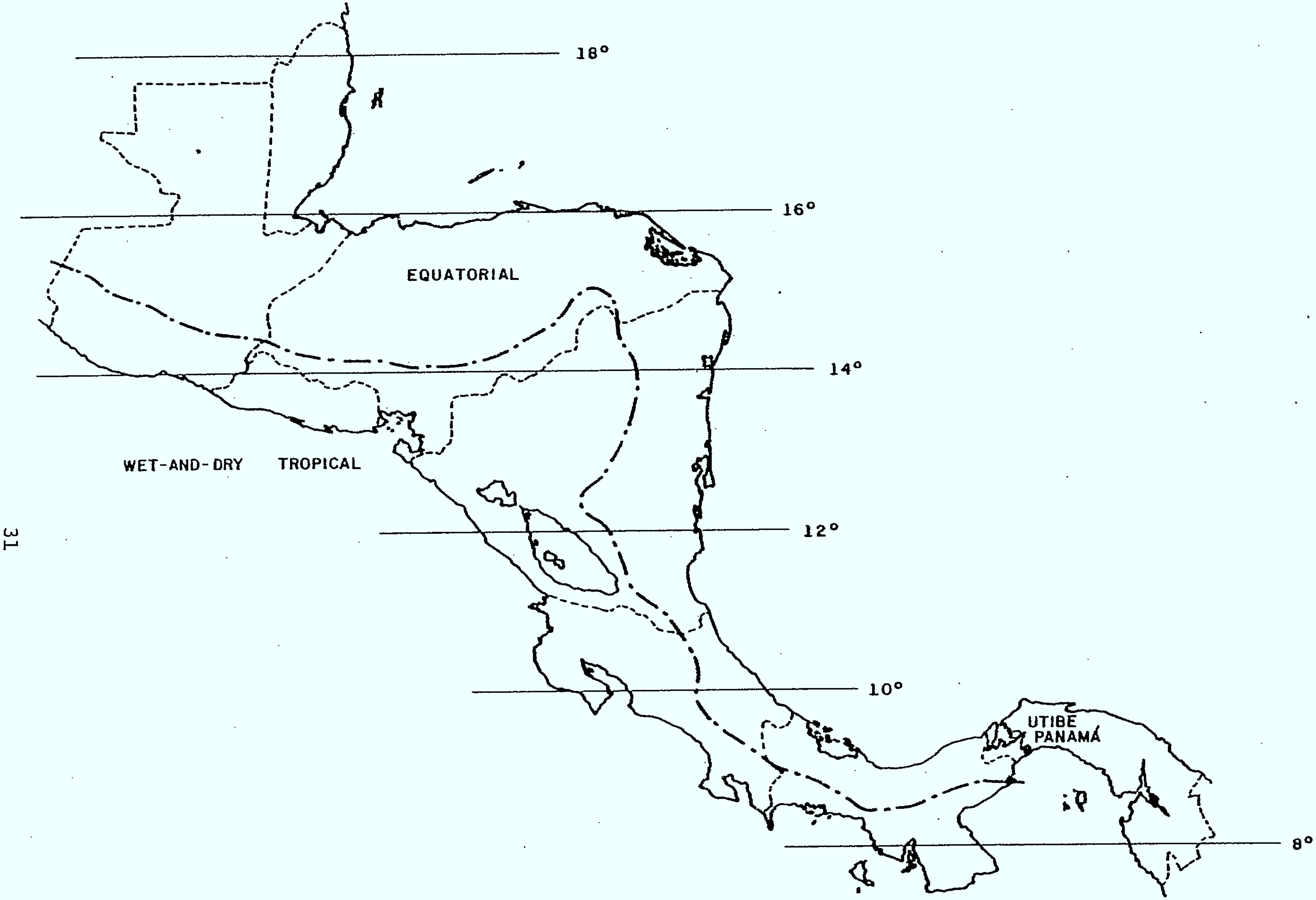
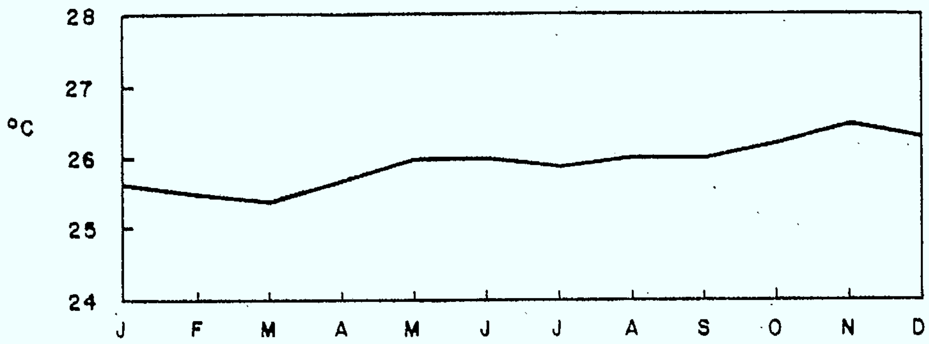


Fig. 2 - Climatic Regions in Central America



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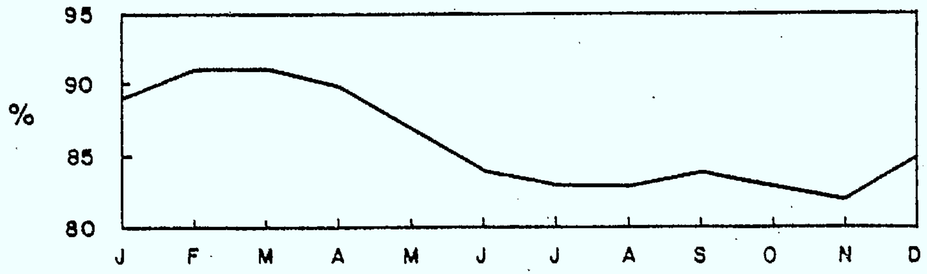

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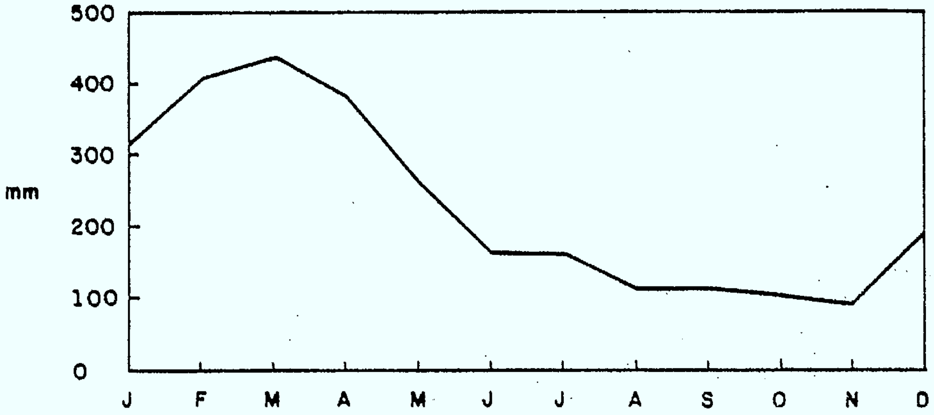
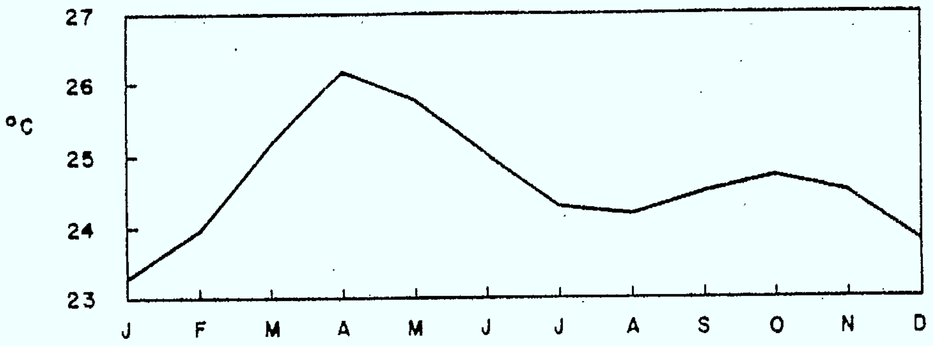


(c) PRECIPITATION

Fig. 3 - Equatorial - Belém



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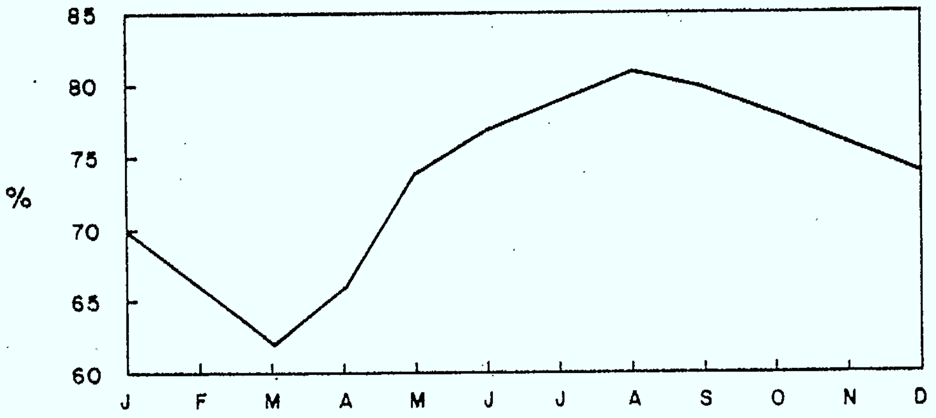

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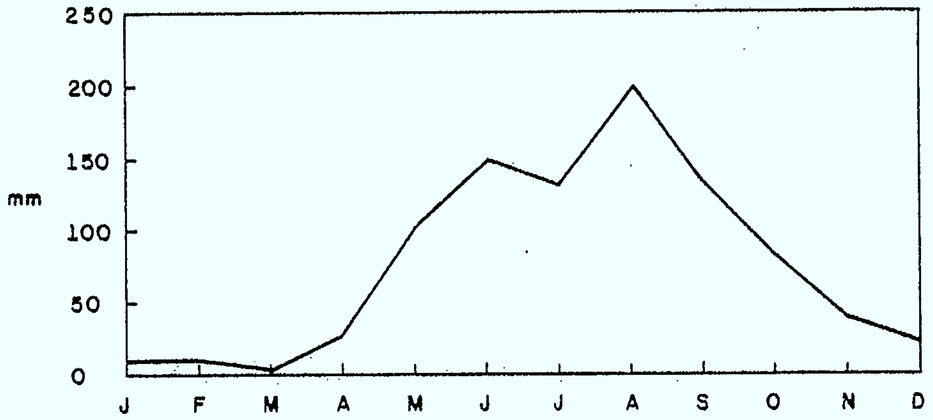
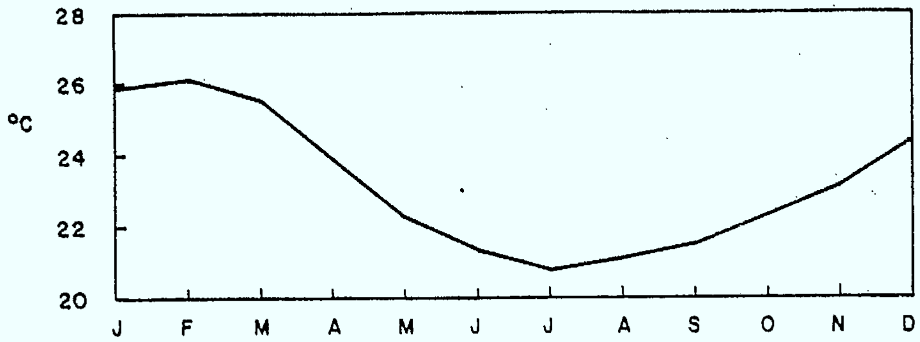


(c) PRECIPITATION

Fig. 4 - Wet-and-dry tropical maritime-Maracay



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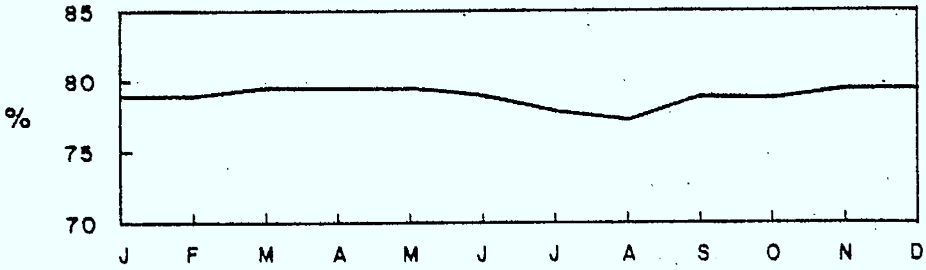

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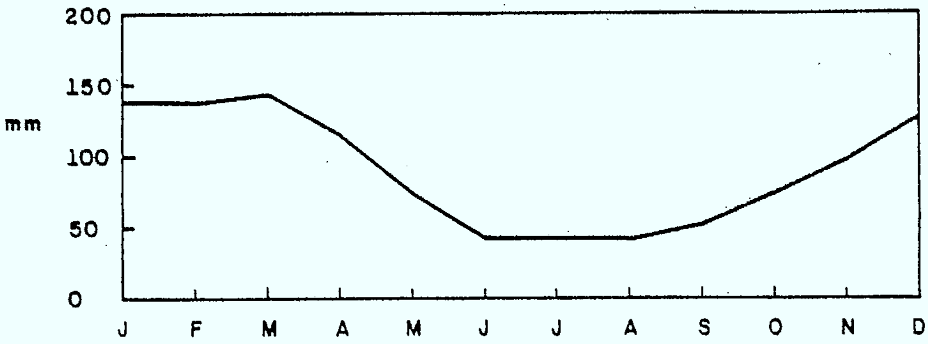

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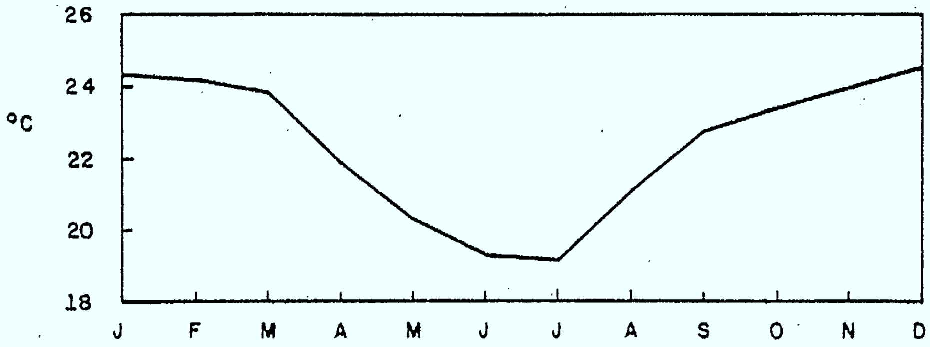
Fig. 5 - Wet-and-dry tropical maritime-Rio de Janeiro



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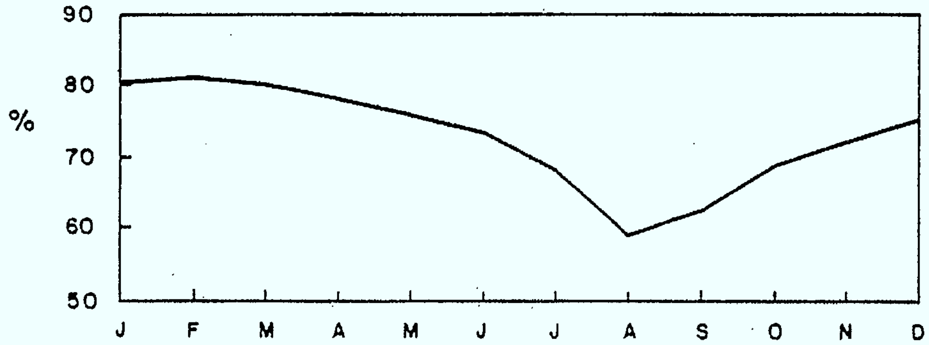

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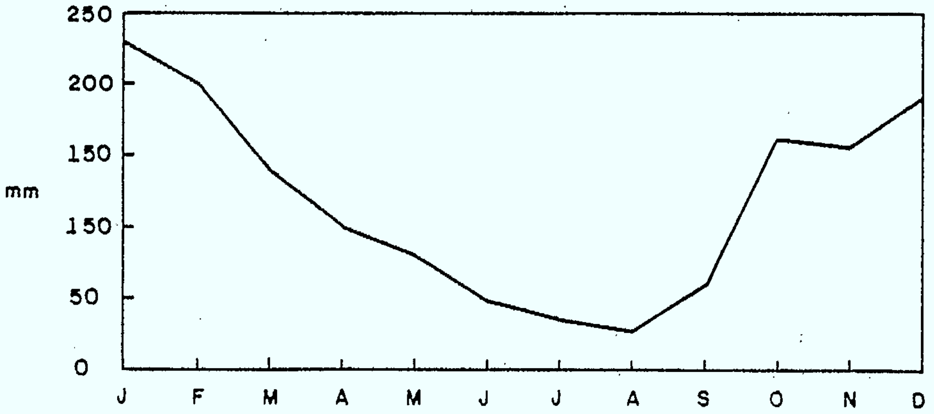

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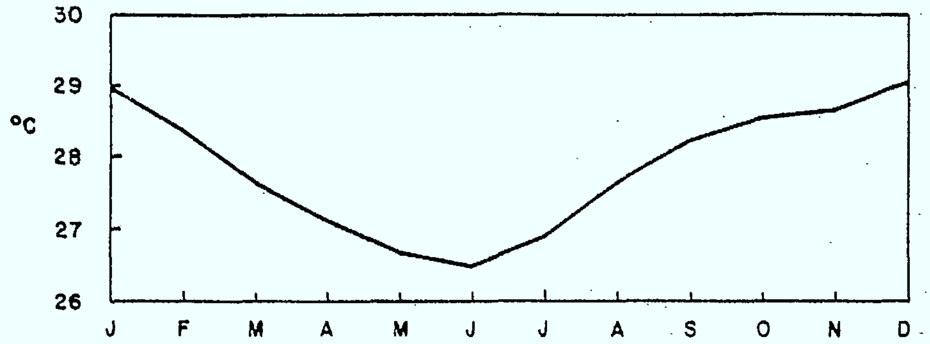
Fig. 6 - Wet-and-dry tropical continental - Campo Grande



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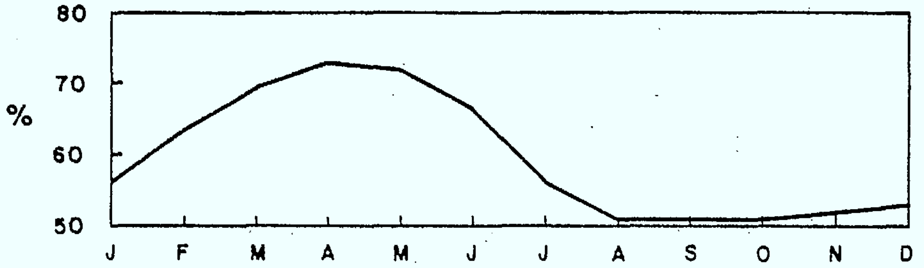

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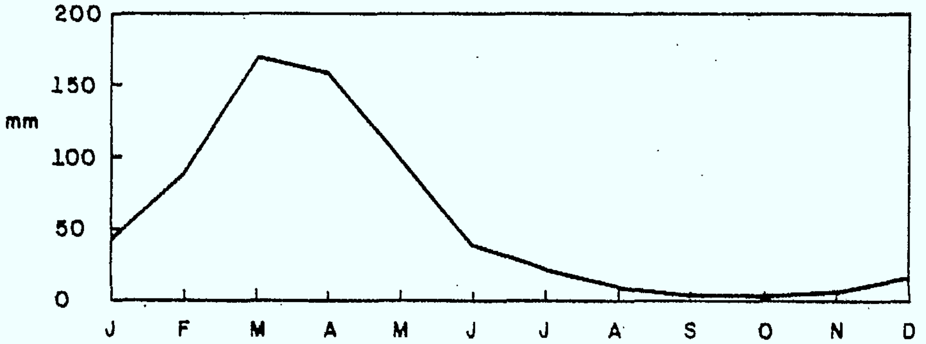

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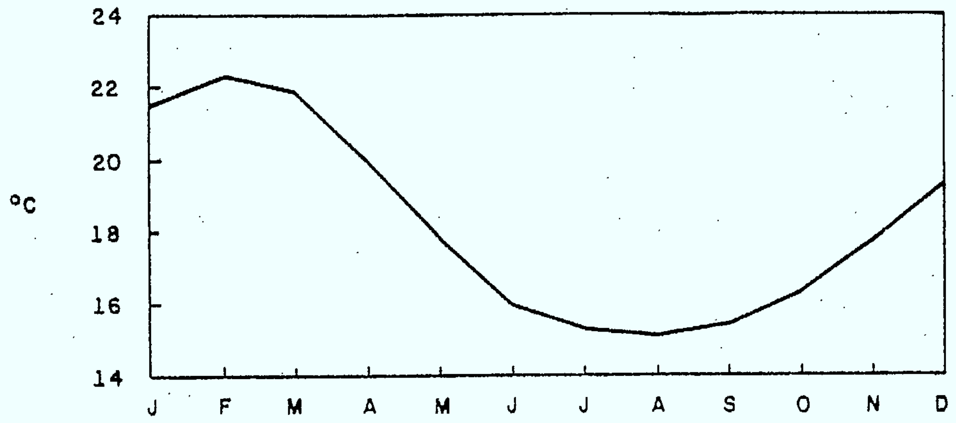
Fig. 7 - Tropical semiarid - Quixeramobim



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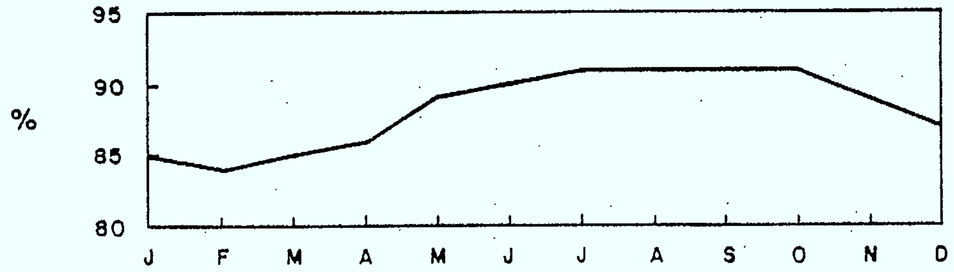

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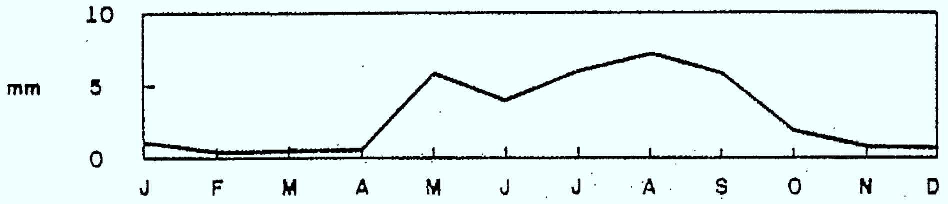

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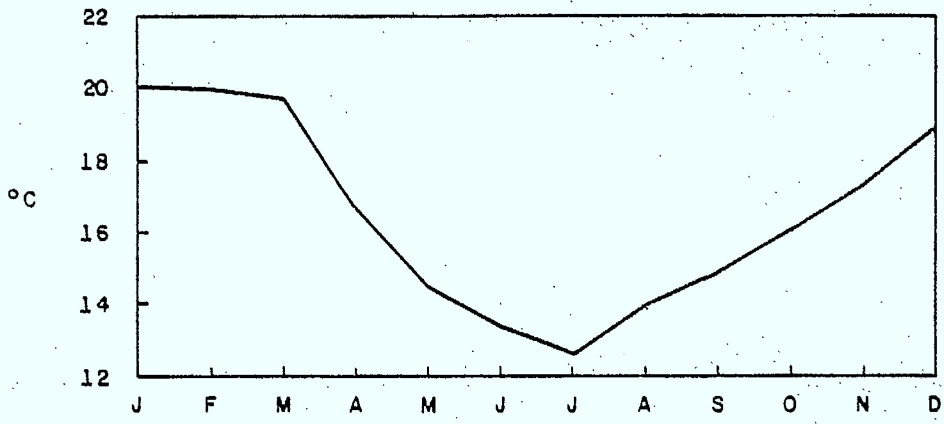
Fig. 8 - Tropical arid - Lima



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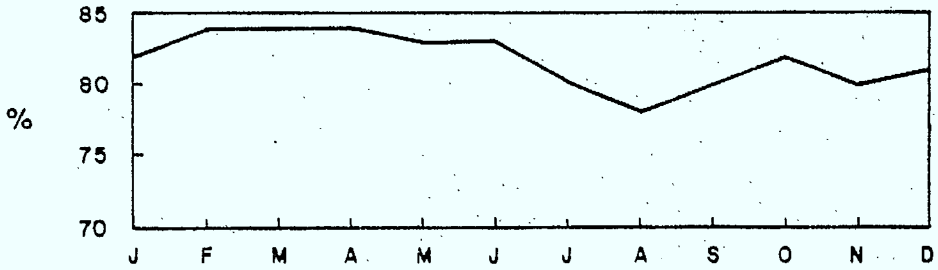

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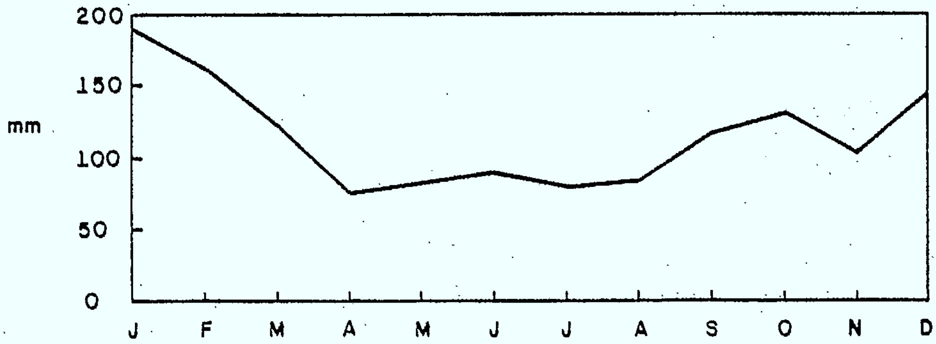
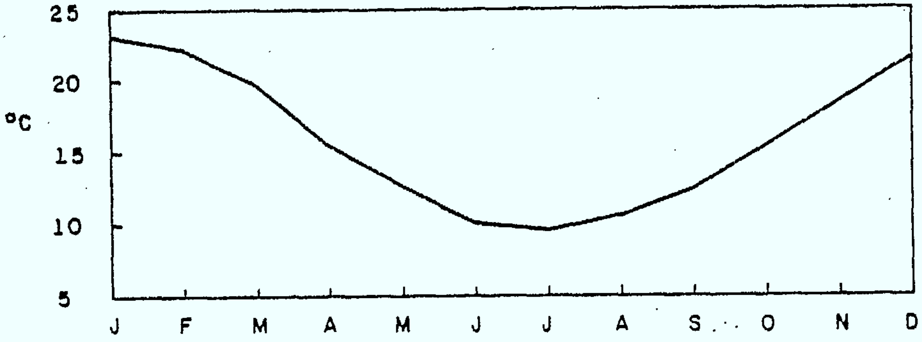


(c) PRECIPITATION

Fig. 9 - Sub-tropical - Curitiba



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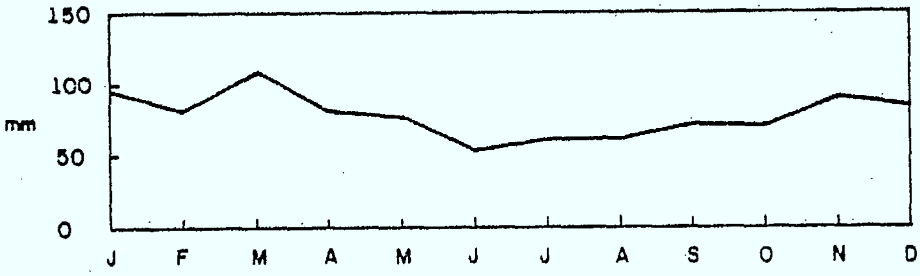

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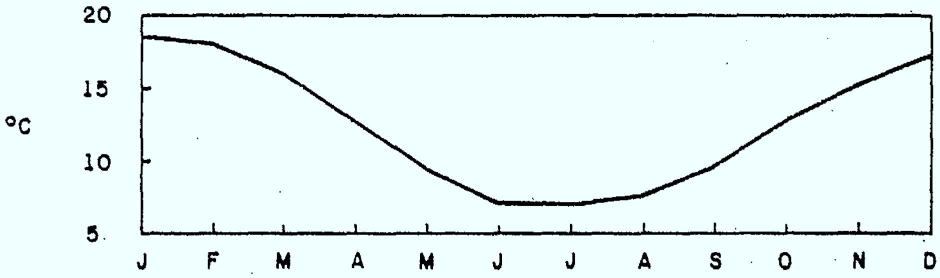
Fig. 10 - Sub-tropical - Ezeiza



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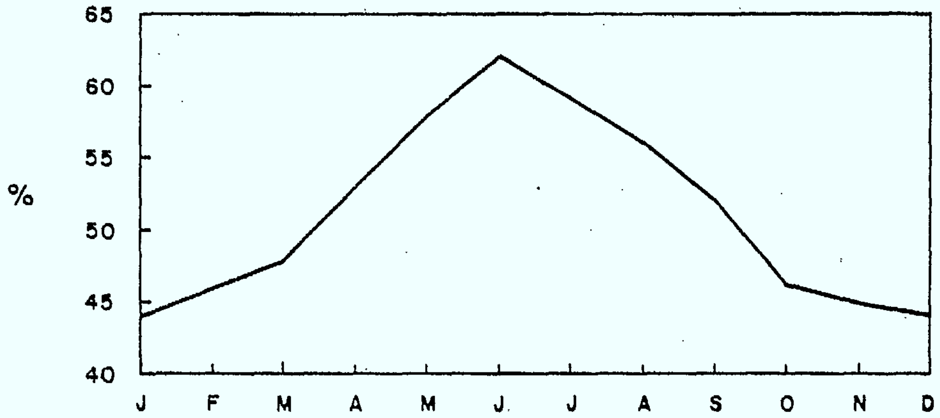

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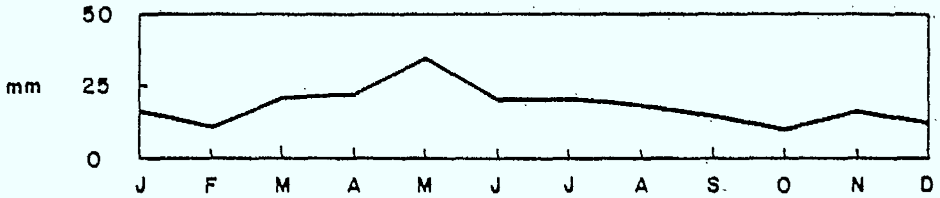

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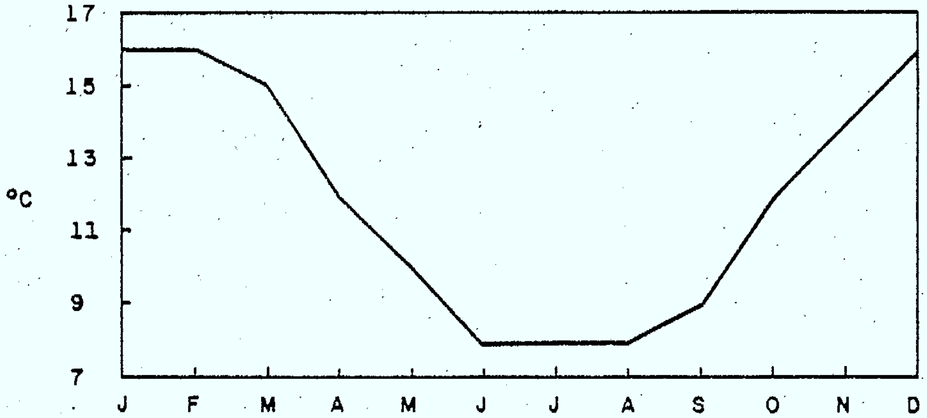
Fig. 11 - Mid-latitude semiarid - Comodoro Rivadavia



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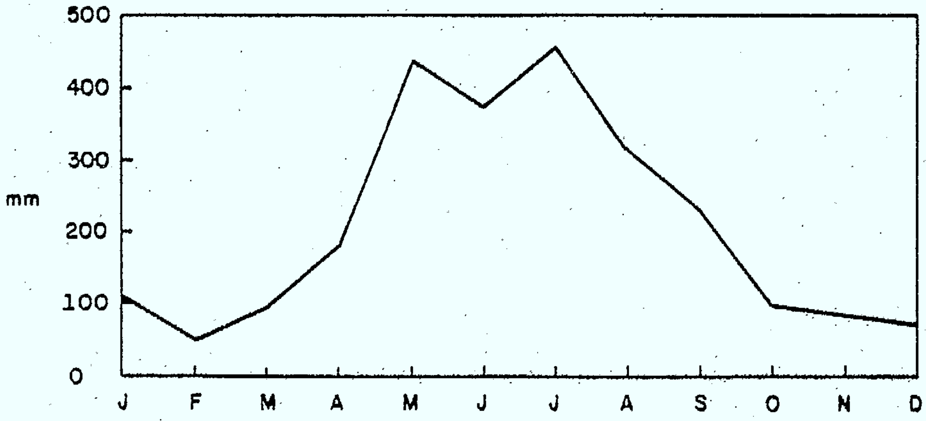
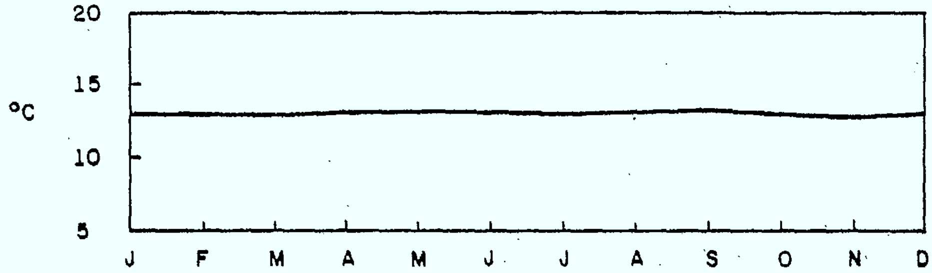


(b) PRECIPITATION

Fig. 12 - Temperate Maritime - Valdivia



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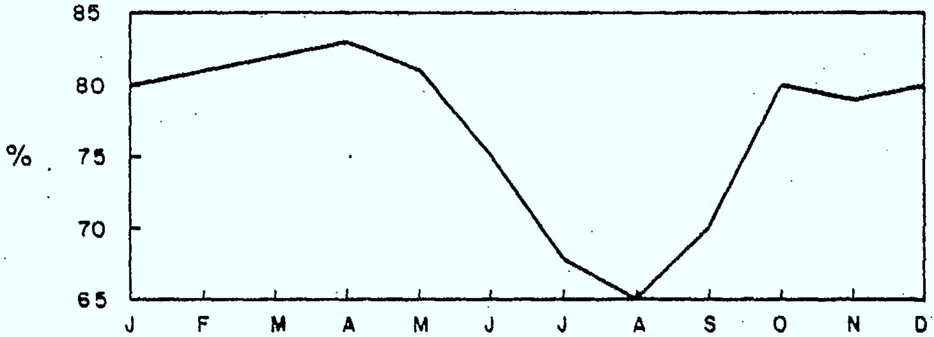

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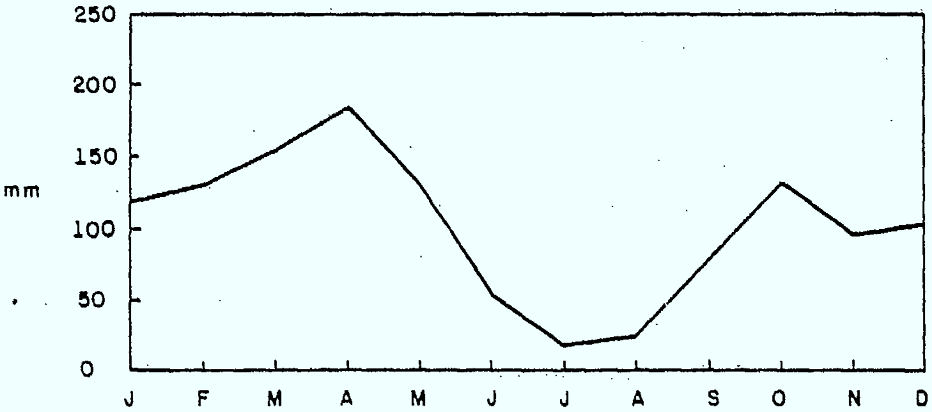

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Fig. 13 - Highland - Quito

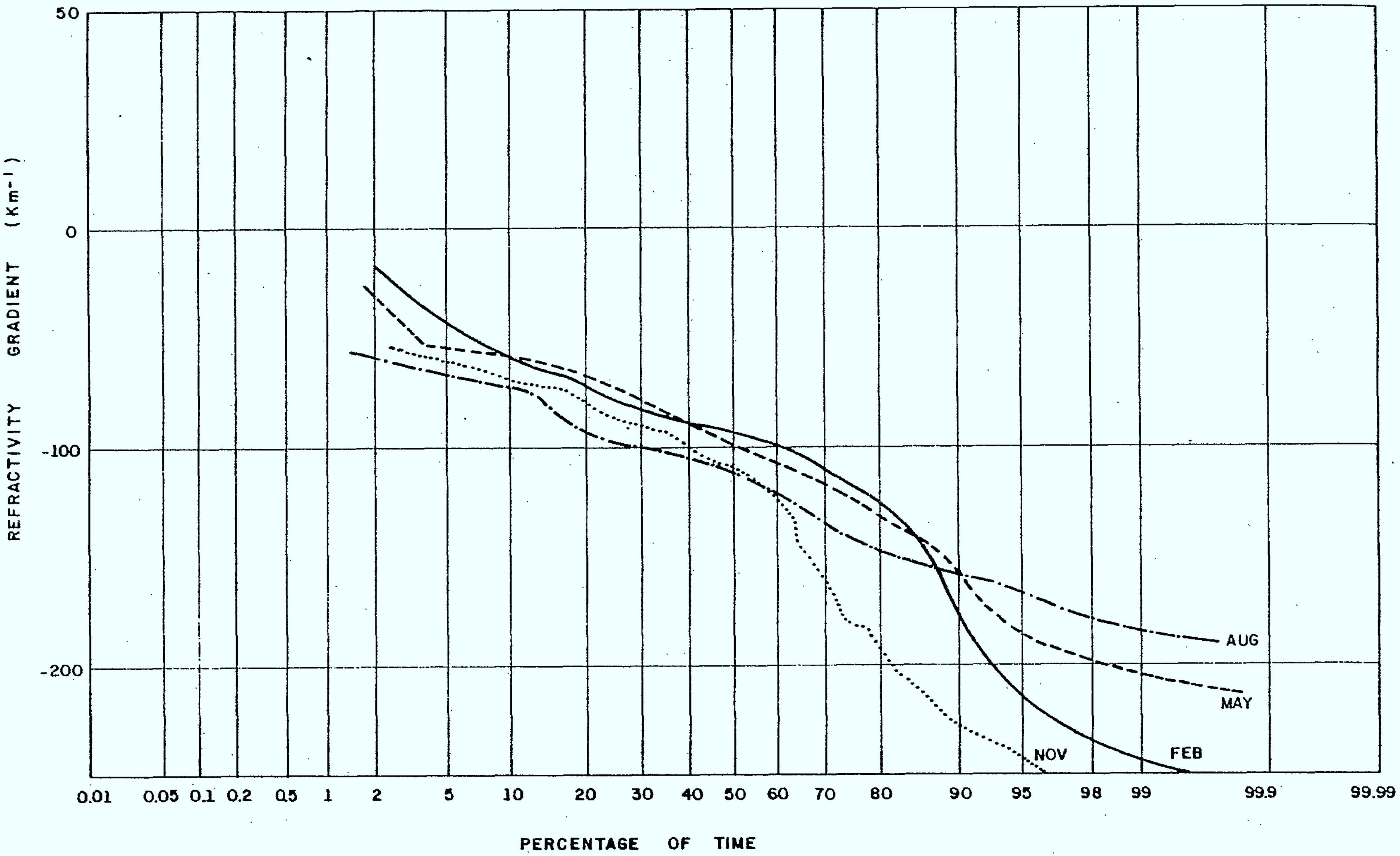


Fig. 14 - Statistical distribution of refractivity Gradient - Belém

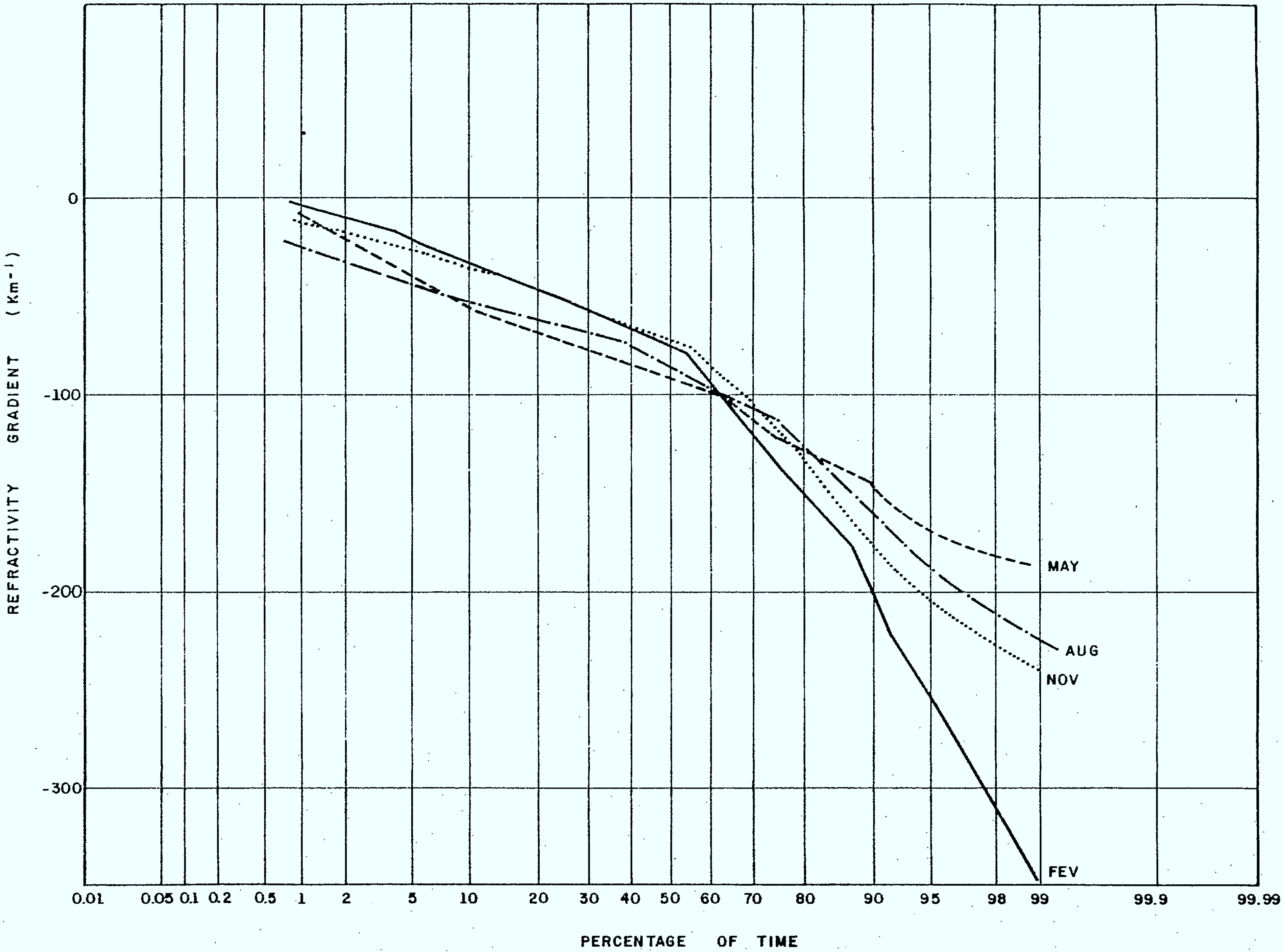


Fig. 15 - Statistical distribution of refractivity gradient-Rio de Janeiro

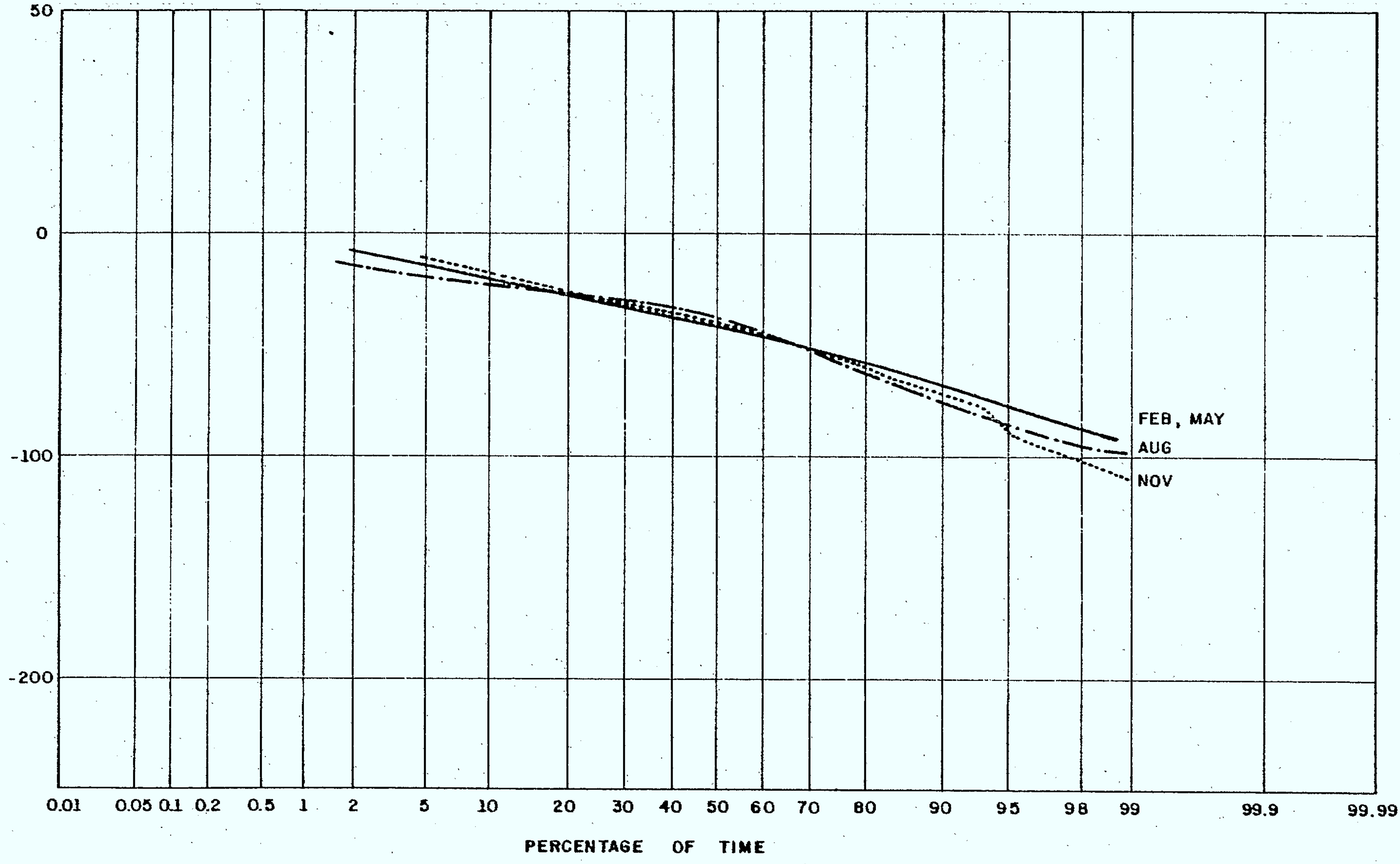


Fig. 16 - Statistical distribution of refractivity gradient-Campo Grande

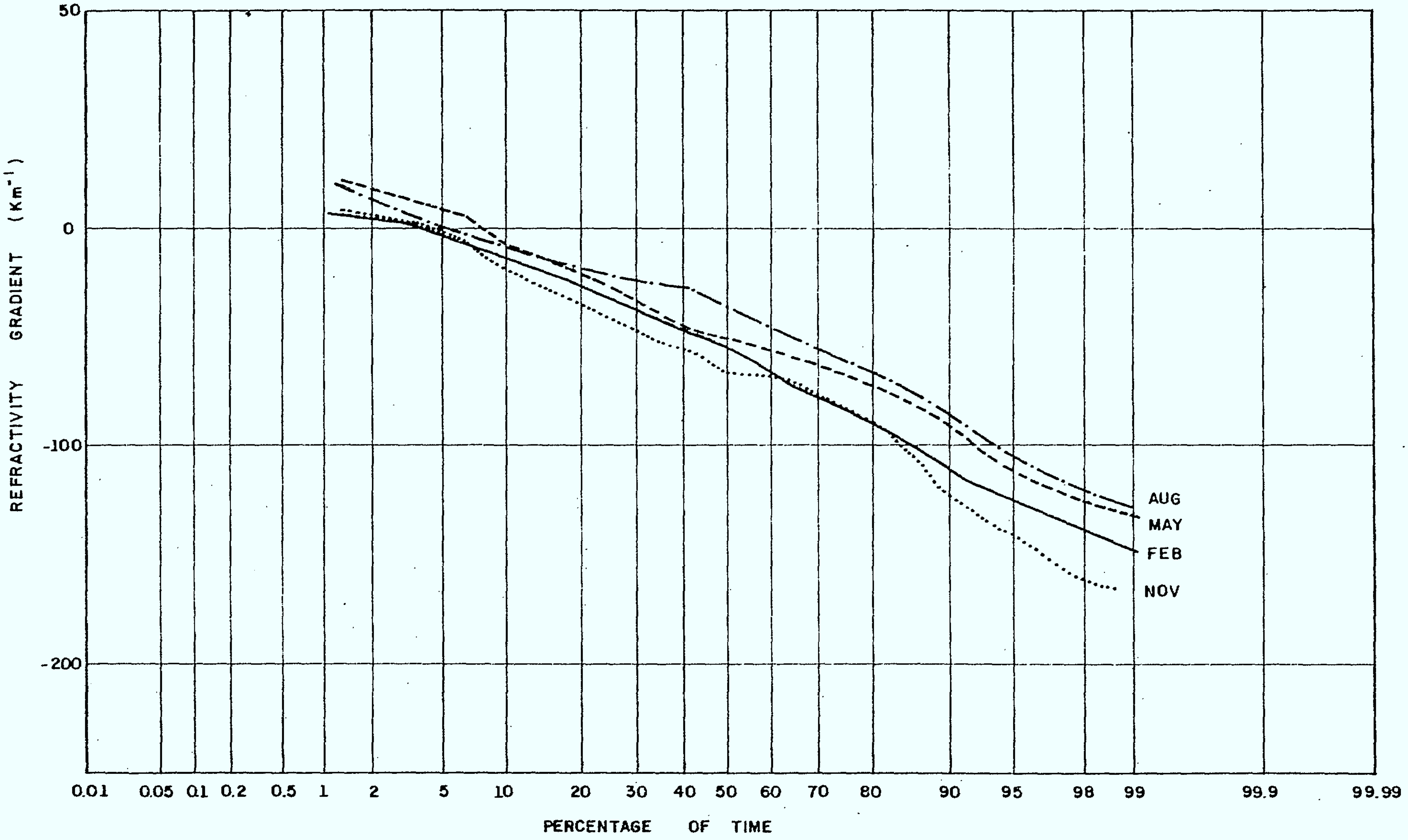


Fig. 17 - Statistical distribution of Refractivity Gradient-Curitiba

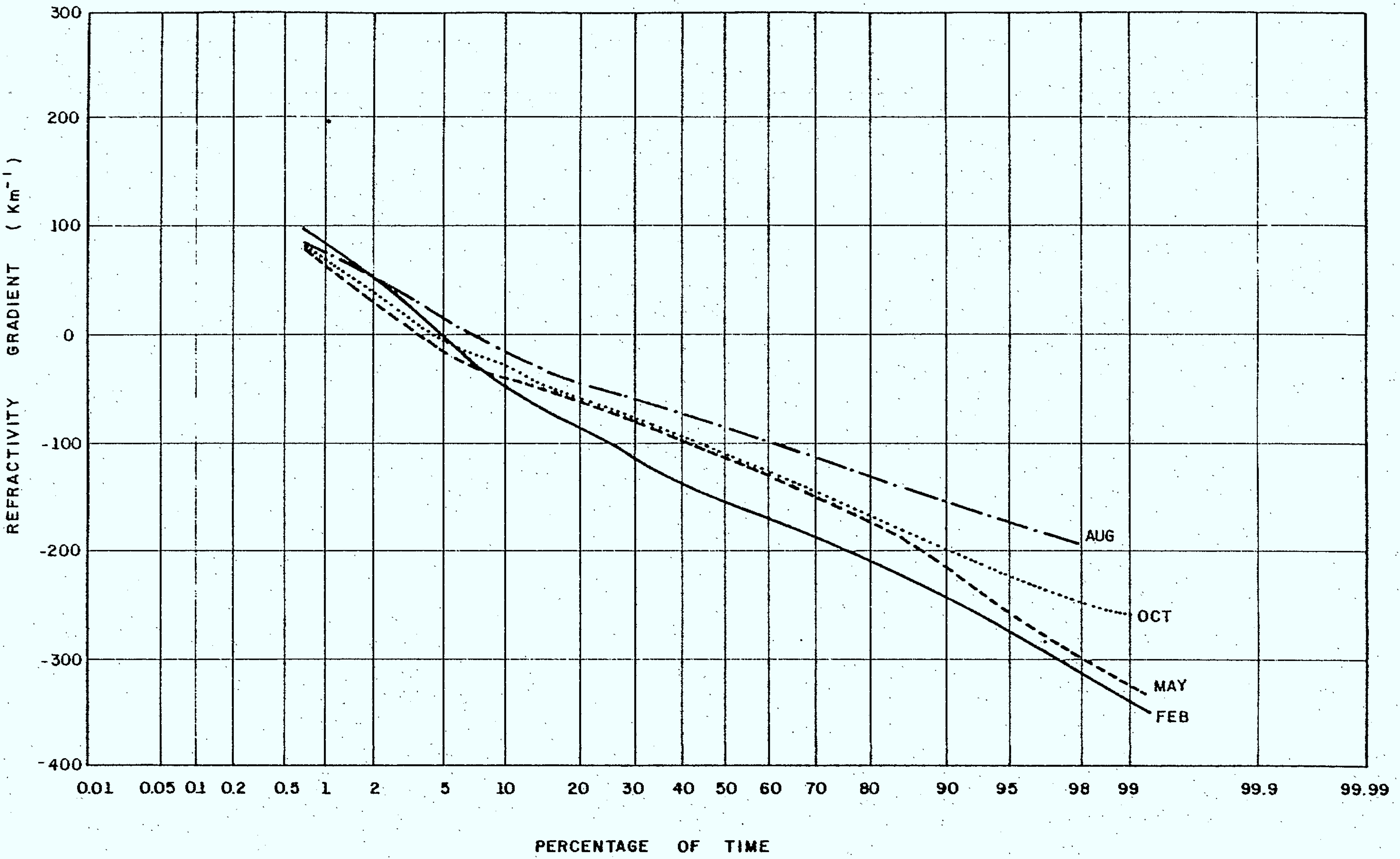


Fig. 18 - Statistical distribution of refractivity gradient - Trindade Island

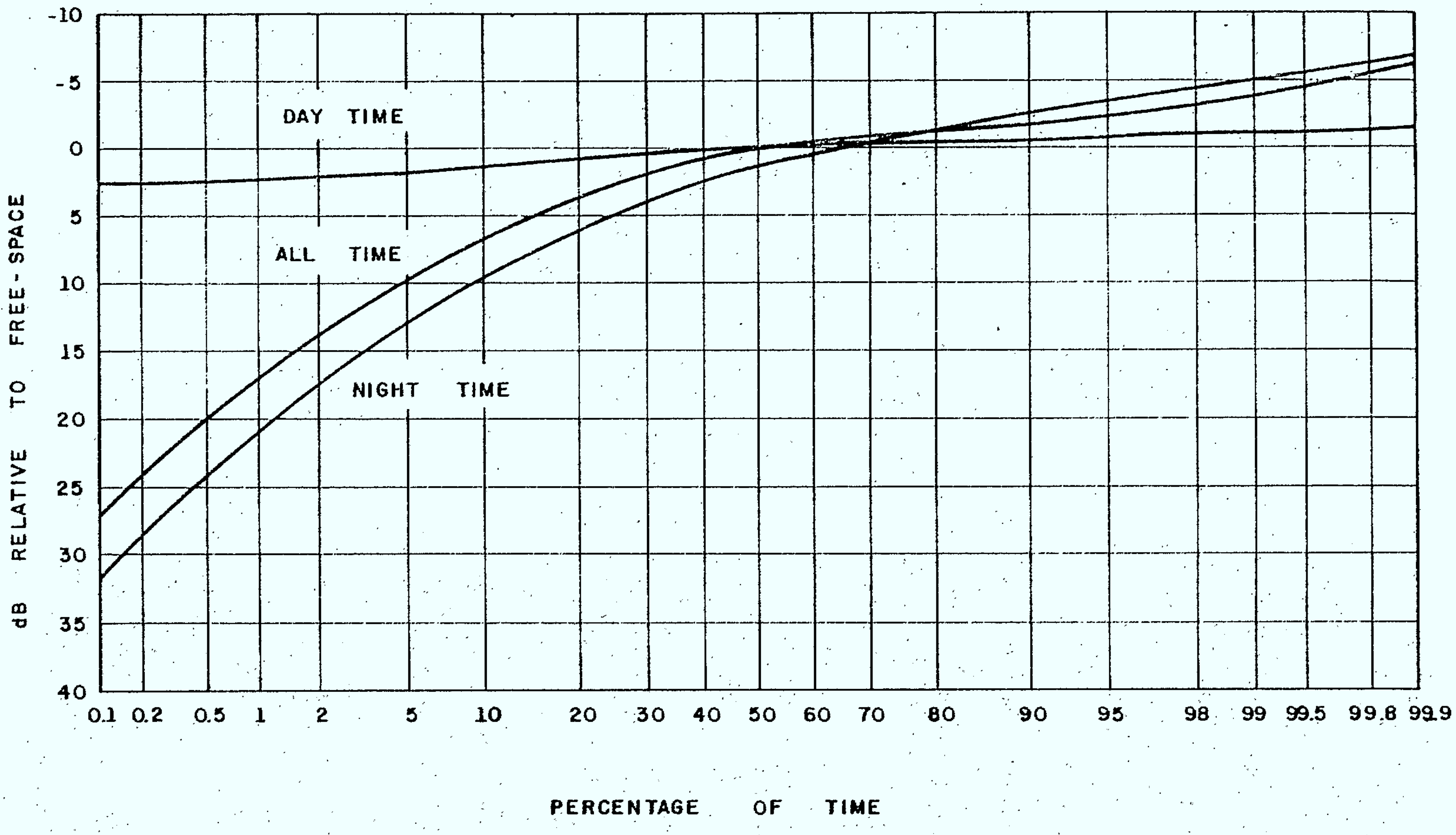


Fig. 19 - Daytime and nocturnal fading distributions

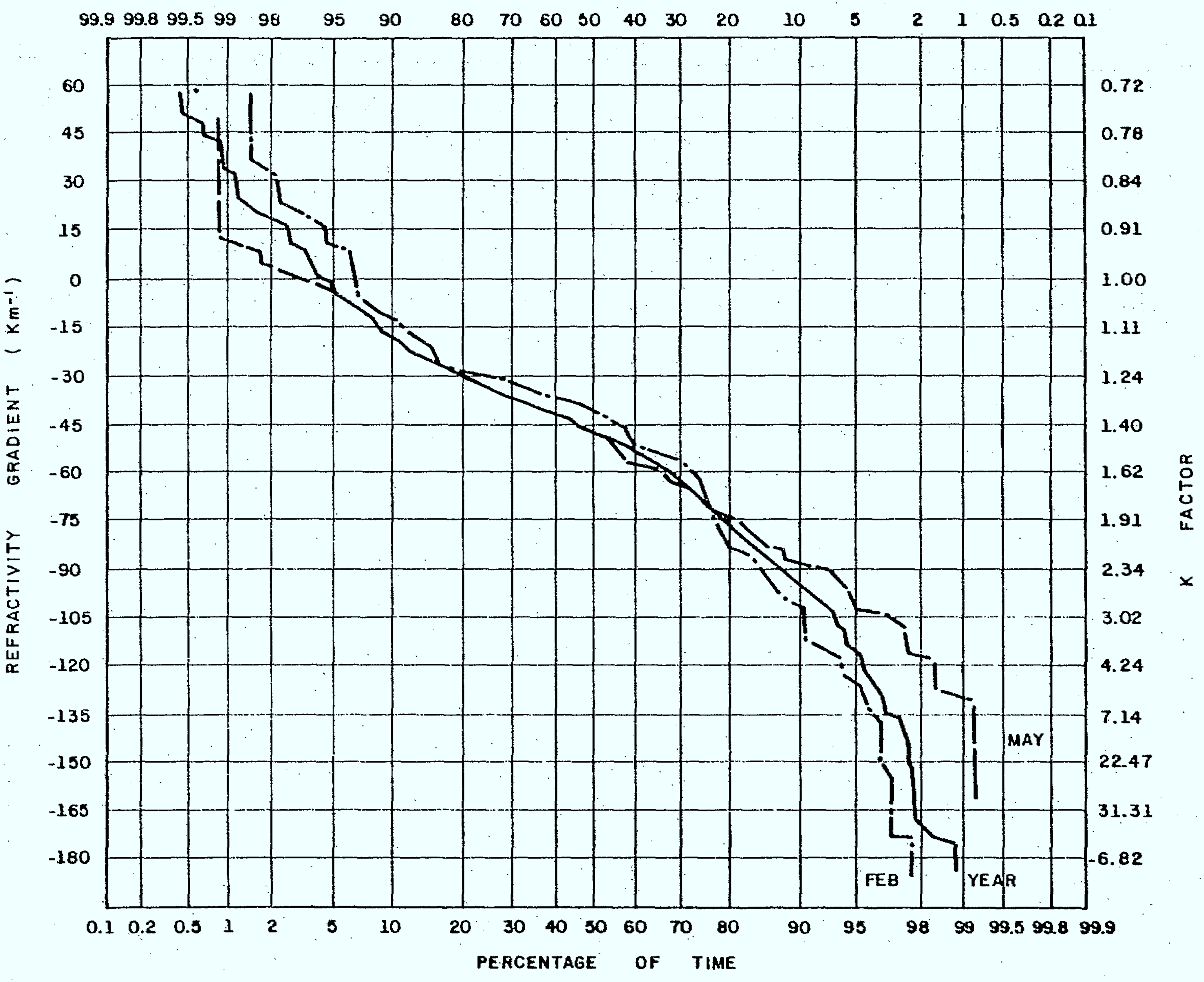


Fig. 20 - Statistical distribution of refractivity gradient-Ezeiza-00:00 GMT

Fig. 21 - Statistical distribution of refractivity gradient-Ezeiza 12:00 GMT

Fig. 22 - Statistical distribution of refractivity gradient-Comodoro Rivadavia 0[illegible]0 GMT

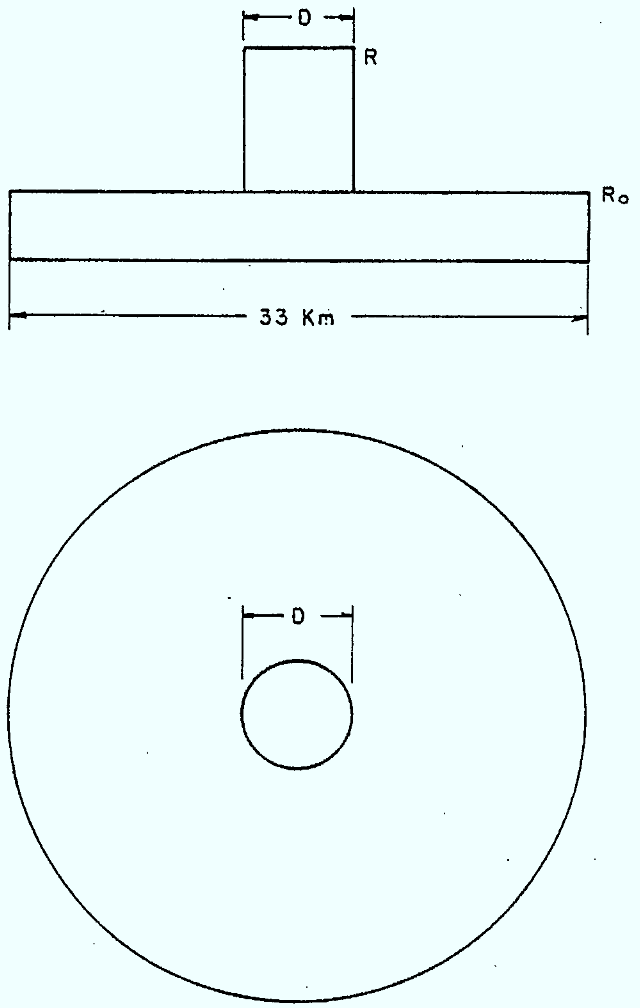


Fig. 23 - Cylindrical rain cell

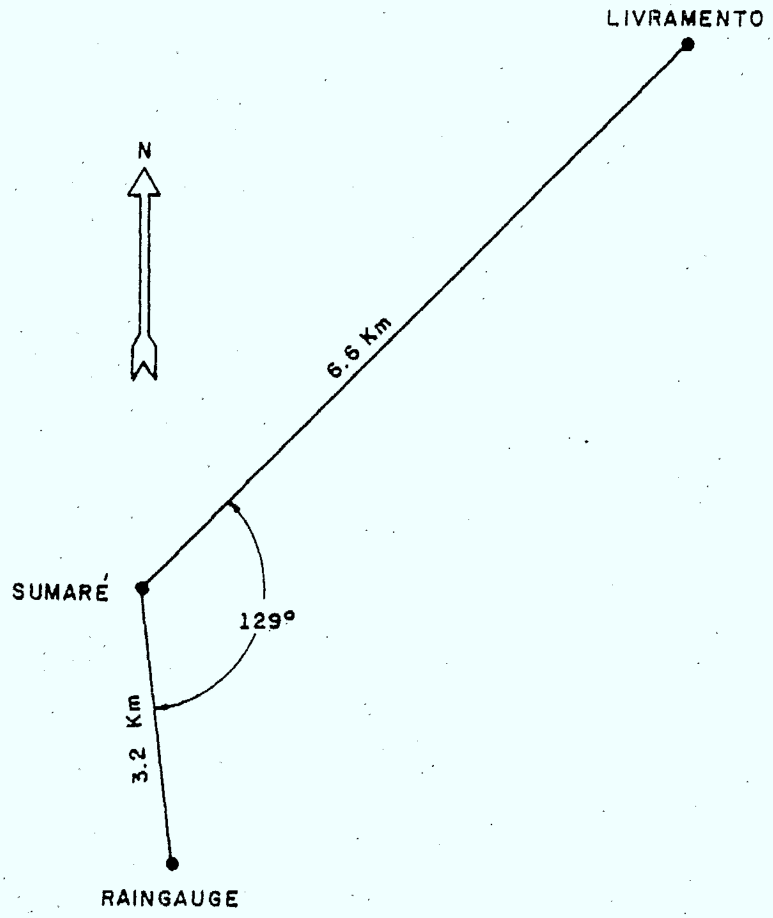


Fig. 24 - Raingauge location relative to radio link

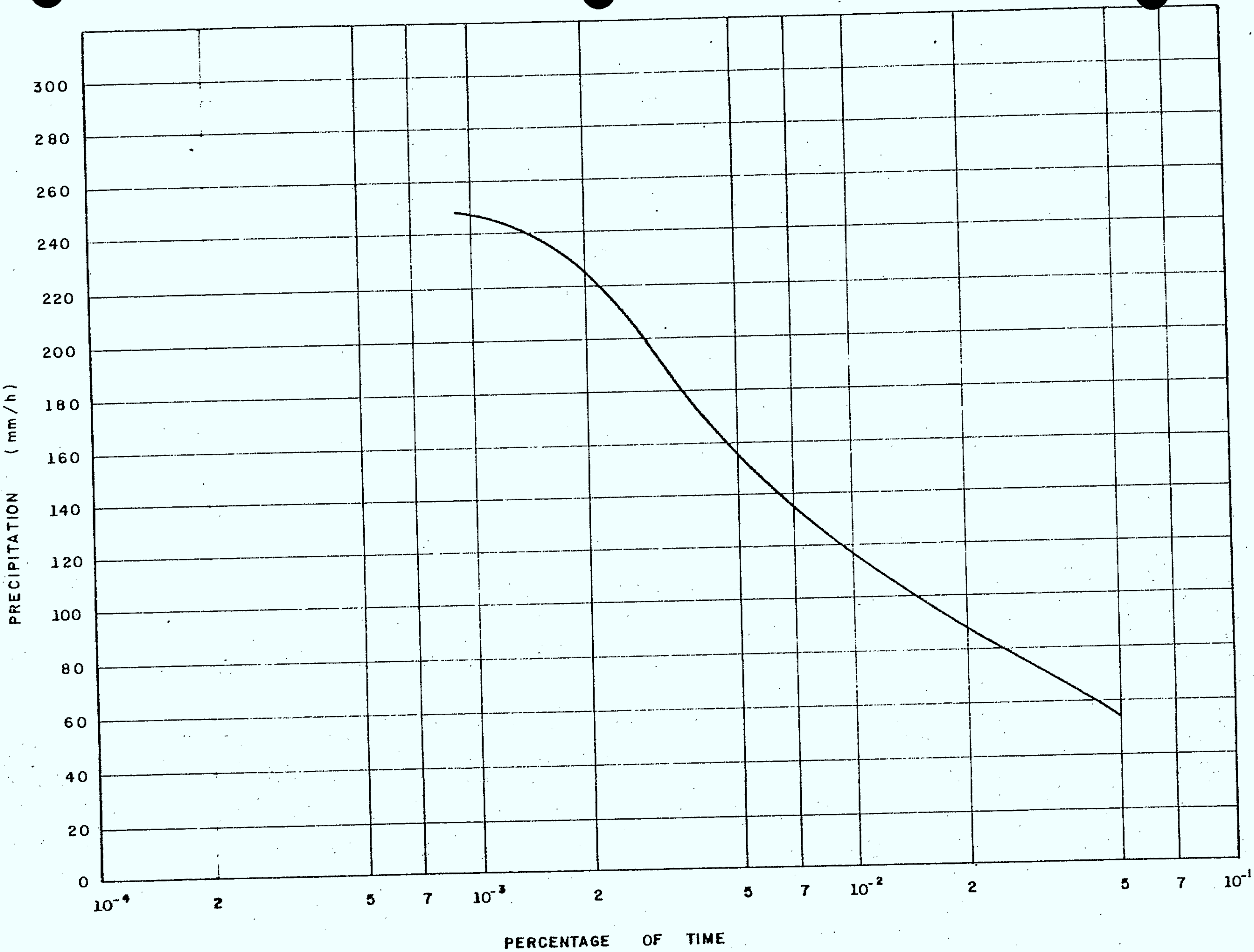


Fig. 25 - Statistical distribution of precipitation rate

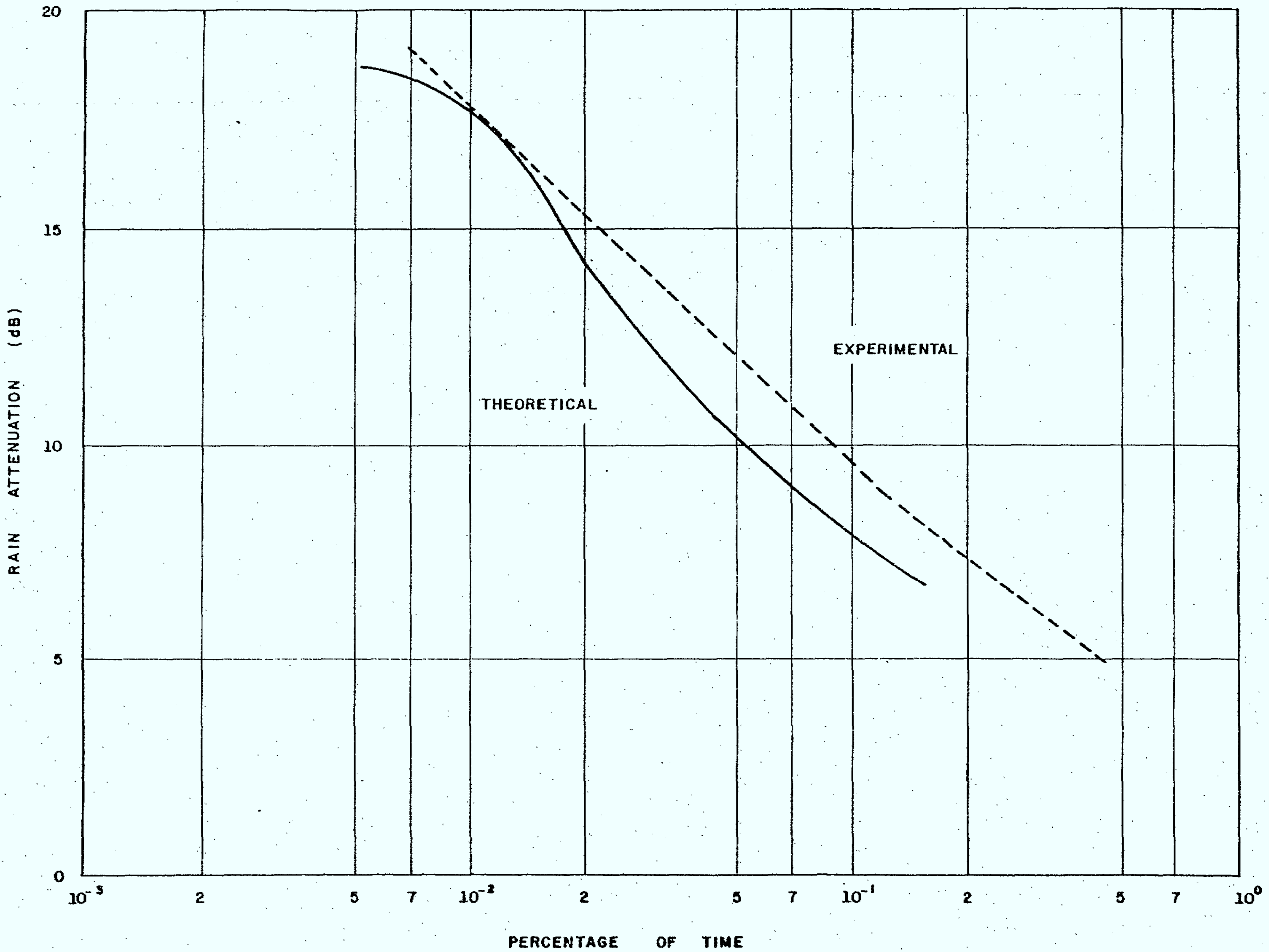


Fig. 26 - Statistical distribution of rain attenuation

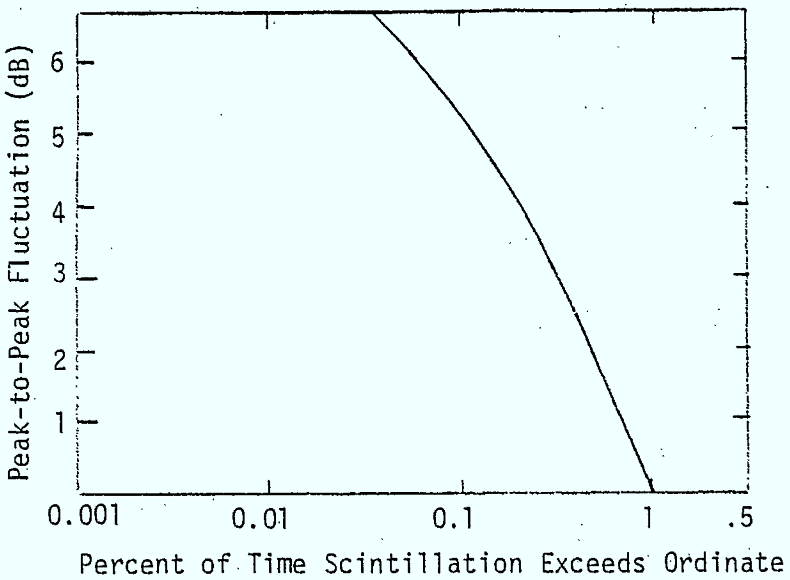


Fig. 27. Cumulative Amplitude Distributions at Tangua (6 GHz)

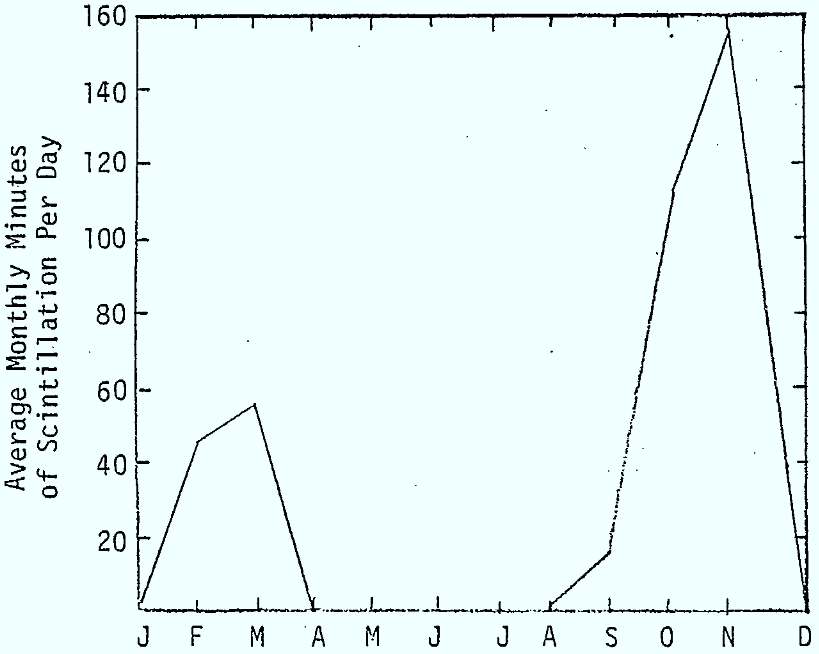
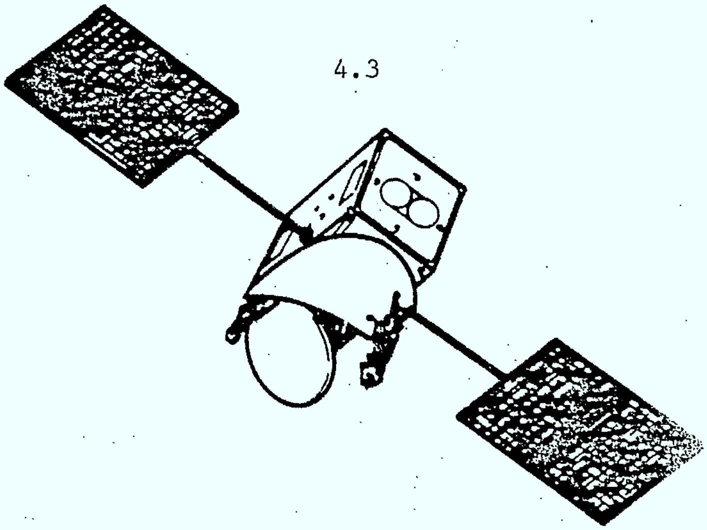


Fig. 28. Seasonal Variation of Ionospheric Scintillation Greater Than 0.5 dB



TITLE : RADIO PROPAGATION FACTORS

AUTHOR : J.E. MILLER

Preparatory Seminar for 1983 RARC on
Broadcast Satellite Planning Principles and Methodology
May 4-8, 1981, Ottawa, Canada.

Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

RADIO PROPAGATION FACTORS

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April 1981

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for '83 RARC on Broadcast
Satellite Planning, May 4-8, 1981
Ottawa, Canada

Preface

This paper is primarily a revision of Section 3, "Radio Propagation Factors," of the report " Technical Information Relevant to Planning for the Use of the 12 GHz Band by the Broadcasting-Satellite Service, and Technical Criteria for Sharing Among Various Services in this Band," prepared by the Joint Working Party (JWP) of the CCIR in 1976 and submitted to the 1977 WARC-BS. Although the paper deals with propagation factors affecting link reliability and interference, it is the factors associated with the former that will probably be among the more significant technical issues to be dealt with by the 1983 RARC. Link reliability directly affects the technical quality of the service as perceived by the viewer, and impacts directly on the broadcasting satellite system cost - the greater the link reliability, the greater the system cost.

For these reasons, I would like to direct your attention to section 4 of the paper. New material has been included on worst-month statistics, precipitation attenuation prediction methods, frequency scaling, the effects of precipitation on the choice of elevation angle, and depolarization. This material should be reviewed for adequacy and completeness as it would be applied to the design and construction of a broadcasting satellite system to serve your country.

John E. Miller
April 1981

Table of Contents

1.0 Introduction

The basic propagation data required for satellite broadcasting systems operating at 12 GHz and their feeder links operating around 17.7 GHz falls into two groups. The first contains information on the large attenuation of the wanted signal which occurs for a small percentage of time on the uplinks and downlinks, i.e., information relevant to reliability. In this case, the effect of heavy rain is dominent. The second category includes data required for evaluating the probability of interference. In this application it is necessary to determine the minimum values of attenuation or transmission loss which may occur on terrestrial or Earth-space paths carrying an unwanted signal.

This paper summarizes propagation data for each of these two applications. The information is based essentially on the conclusions of the Interim Meetings held in 1980. While the following sections provide a self-contained, general guide to the important aspects of propagation data, it does not appear to be desirable to reproduce here extensive extracts from the conclusions of the Interim Meetings. This paper identifies those texts of the XIV Plenary Assembly, Kyoto, 1978 as amended at the 1980 Interim Meetings which should be consulted for more comprehensive information on factors affecting both reliability and interference.

2.0 Reliability Requirements

Because frequency modulation will likely be used for the transmission of television signals in the 12 GHz and 17.7 GHz bands, it is necessary to keep the carrier-to-noise ratio above the threshold for as high as possible a percentage of time (usually 99.9%) and also to achieve a given signal-to-noise ratio objective for a specific percentage of time (usually 99%). Thus it is necessary to choose a margin above threshold such that both requirements are met simultaneously. This margin should include the atmosphere loss and other terms not specifically included in the power budget [Report 215-4 (MOD I)].

Report 811 (MOD I) provides further guidance on the reliability requirements. There it is stated that the carrier-to-noise ratio objective to be achieved at the edge of the service area should be:

- o 14 dB for 99% of the worst month; and,
- o 10 dB for 99.9% of the worst month.

3.0 General Characteristics of Propagation at Frequencies Near 12 GHz and 17.7 GHz

The characteristics of two types of propagation modes are important. In both reliability and interference problems it is necessary to evaluate the additional attenuation, in excess of the free-space value, which results from the presence of various atmospheric constituents on a line-of-sight path (terrestrial or Earth-space). In addition, for interference calculations, propagation over terrestrial paths must be considered in which, by a process of abnormal refraction or ducting, relatively strong signals are occasionally received from sources which are well beyond the normal horizon. This mode of "anomalous" propagation is of first-order importance in all shared systems with ground-based terminals. Some discussion of its role, in the context of satellite broadcasting, is given in section 5.2.1.

It is also possible, in certain restricted conditions, for an interfering signal to arrive at a receiver via a "precipitation scatter" mode. In this situation, heavy rain can be located in such a position that it scatters unwanted signals into the antenna beam of the receiver. This interference mode is also discussed in section 5.2.2.

3.1 Absorption in Gases

A general summary relevant to terrestrial and Earth-space paths is given in Report 719 (Mod I). At frequencies of about 12 GHz and 17.7 GHz, the attenuation in an average clear atmosphere is largely due to oxygen and water vapour. For paths in or near the vertical direction, the total attenuation in clear air through the whole atmosphere (including the ionosphere) is negligible, but the gaseous contribution from the troposphere becomes significant at low angles of elevation because the effective distance through the troposphere is much greater. Moreover, this contribution to the attenuation is accompanied by a related increase in "sky-noise temperature" which may be significant for receiving systems of very low noise factor.

3.2 Effect of rain

The heavy rain, which influences the reliability of the wanted transmission is localized in extent, at least in temperate climates. Unfortunately, lack of detailed information on the spatial characteristics of heavy rain renders the development of a general, reliable prediction method difficult. Moreover, there is usually a large year-to-year variability in the rainfall rate and this further complicates the problem. This factor must be borne in mind in all applications of rainfall data. If, in any particular location, measured data (of adequate statistical reliability) are available on attenuation characteristics, then these should be used in preference to results derived indirectly.

The basic characteristics of rainfall, as they affect microwave propagation, are discussed in Report 563-1 (MOD I). The classification of rainfall distributions, on a world-wide basis as given in Report 563-1 (MOD I) is used in Report 564-1 (MOD I) to provide a procedure for predicting the attenuation caused by rain on Earth-space paths. Report 721 (MOD I) provides a general discussion on rain attenuation prediction methods. Worst-month statistics are covered in Report 723 (MOD I), while Report 811 (MOD I) provides a discussion on the choice of elevation angles to minimize space station mass and cost taking rain attenuation into account. The use of orthogonal polarization to facilitate frequency reuse is also effected by rain as described in Report 814 (MOD I). Finally, the effects of sand and dust on propagation are presented in Report 721 (MOD I).

4.0 Attenuation Data Relevant to Reliability on Earth-Space Paths Operating Around 12 GHz and 17.7 GHZ

4.1 Worst-Month Statistics [Report 723 (MOD I)

Report 723 (MOD I) recommends a definition of the worst-month and presents a procedure for estimating the ratio of time of the worst-month that a preselected threshold is exceeded to the average annual probability (percentage) for exceeding the same threshold level.

4.1.1 Definition of Worst-Month

For a preselected attenuation threshold, the worst-month is defined as that month with the highest probability of exceeding that attenuation threshold. A worst-month can therefore be established for each threshold level. The statistic of interest is the highest monthly probability of exceeding the preselected threshold in one or more years. This worst-month statistic requires that both the threshold and the number of years be specified.

4.1.2 Application

In many cases it is desirable to relate the worst-month statistic to the annual probability of exceeding the same attenuation threshold in an average year simply because the annual attenuation data is either available or because the annual rainfall data is available. In the latter situation, the attenuation threshold levels for various exceedence probabilities may be estimated using the methods described in Reports 563-1 (MOD I), 564-1 (MOD I) and 721 (MOD I).

The ratio of the percentage of time the attenuation threshold is exceeded in the worst-month (X), to the percentage of time it is exceeded in an average year (Y) is defined to be Q, i.e.,

$$Q = \frac{X}{Y} \qquad (1)$$

Figure 1 presents some observations of the ratio Q as a function of the average annual exceedence probability Y. Climatic effects can be seen to be influencing the results [Report 723 (MOD I)]. It has been observed that for a given location the Q-Y relationship for rain attenuation appears to be similar to that for rainfall intensity.

The use of the ratio Q is illustrated by the following example. It is required to determine the average annual worst-month attenuation not exceeded for more than 99% of the time given either predicted values or measured values for the average annual probability that specific values of attenuation will not be exceeded. Note that the probability that the threshold attenuation value will be exceeded during the average annual worst-month is 1- .99

or 0.01. The rain climate for which this probability is required is assumed to be that corresponding to curve 2 of Figure 1. In the region $Y=10^{-3}$, curve 2 is approximated by the equation,

$$Q = -1.125 \log Y + .575 \qquad (2)$$

Equating equations (1) and (2) and solving for X in terms of the required parameter Y yields,

$$X = Y[-1.125 \log Y + .575] \qquad (3)$$

This is a non-linear equation which may be solved by the method of successive approximations such as Newton's Method. Substituting the value of .01 for X and solving, yields a value of about 3×10^{-3} for Y. Therefore, the average annual worst-month attenuation not exceeded for a more than 99% of the time is the same value as the average annual attenuation not exceeded with probability $1\text{-}3\text{x}10^{-3}$, or when expressed as a percentage, 99.7% of the time. Using the same equations it is found that the average annual worst-month attenuation not exceeded for more than 99.9% of the time is the same value as the average annual attenuation not exceeded for more than about 99.98% of the time.

4.2 Prediction Method [Reports 563-1 (MOD I) and 564-1 (MOD I)]

4.2.1 General Remarks

To predict attenuation due to precipitation along an Earth-space path, it is necessary to obtain information on its distribution in space and time, and, on its attenuation coefficient. In Report 563-1 (MOD I), tables are presented for the cumulative distribution of surface rainfall rate associated with a number of different rain climates depicted by the figures in the Report. The tables and figures should only be used in the absence of relevant data for any given location. Using the data of Report 721 (MOD I) to convert from rainfall rate (mm/h) to attenuation coeffecient (dB/Km), these data can be used to estimate the attenuation expected to be exceeded for various percentages of the time under the various climatic conditions, provided also that the length of the path through the rain is known. This process should be followed in the absence of more definitive rain data on Earth-space paths in Report 721 (MOD I).

For the determination of path lengths through rain, one has to consider the different types of rainfall that can be distinguished, and which show very different rain rates and horizontal and vertical extents. These are described in Report 563-1 (MOD I). The variability of rain characteristics clearly indicates the complexity of the problem in predicting Earth-space attenuation on the basis of surface rainfall statistics.

4.2.2 General Method of Prediction

The attenuation along the slant-path from a given location at a particular elevation angle, expected to be exceeded for a specific percentage of time, averaged over a number of years, can be predicted in the following manner. If information is not otherwise available or cannot be otherwise calculated, the surface rainfall rate may be obtained for the specified percentage of the time from Figs. 11 to 17 of Report 563-1 (MOD I) according to the rain climate. The attenuation coefficient (dB/km) corresponding to this rainfall rate may then be determined from Report 721. To determine the expected attenuation, the attenuation coefficient is then multiplied by the effective propagation path length through the rainstorm. Figures 1 and 2 of Report 564-1 (MOD I) show curves of effective path length vs elevation angle, with rain rate as parameter (see Report 721). These curves summarize the available long-term statistics on point-rain rate and slant-path attenuation, measured at the same location for the same period of time. Figure 1 of Report 564-1 (MOD I) summarizes data collected in the northeastern part of North America, in Europe and elsewhere.

The information on effective path length is still inadequate. Therefore the curves of Figs. 1 and 2 of Report 564-1 (MOD I) are tentative and are to be used with great caution in the absence of any other data. It is clear that data on all climates is urgently needed.

4.3 Frequency Scaling [Report 564-1 (MOD I)]

Since data are not always available at the frequency of concern, it is often necessary to scale available information from one frequency to another.

Empirically it has been found that rain attenuation varies with frequency approximately according to:

$$\frac{A_1}{A_2} \approx \left(\frac{f_1}{f_2}\right)^{1.72}$$

over a frequency range of about 10 to 20 GHz, and for attenuations greater than 1 dB. A_1 and A_2 are the values of attenuation in dB at frequencies f_1 and f_2 respectively and are exceeded with equal probability.

Another empirical frequency scaling relationship which has been shown to hold approximately over the frequency range 10 to 25 GHz for rain attenuation is given by:

$$\frac{A_1}{A_2} = \frac{f_1 - 6}{f_2 - 6}$$

where, in this equation, f_1 and f_2 are in GHz.

Frequency scaling is also examined in Report 721, which summarizes the methods currently available. Some of the methods, which use the power-law relationship between specific attenuation and rain rate given in section 2.5 of Report 721, have been tested against attenuation data measured on the slant path. Three of the "single frequency" scaling methods have been found to give relatively good agreement for a limited amount of data.

4.4 Effects on Choice of Elevation Angle [Report 811 (MOD I)]

The satellite position, and so the satellite elevation angle in the service area, should be chosen such that the mass and cost of the satellite which provides an acceptable level of signal strength during rain conditions is minimized, subject to the constraints that the elevation angle throughout the service area is large enough so that shadowing due to buildings, trees and surrounding terrain is not severe, and so that tropospheric fading and multipath effects do not become a dominant factor.

For coverage zones located in latitudes above 60°, the elevation angle is bound to be less than 20°. In favourable terrain conditions almost normal service might be provided with elevation angles as low as 10°. Special measures are needed, however, if service is planned to be extended under this angle or to areas with a less favourable terrain. For mountainous areas even an elevation angle of at least 20° may be insufficient.

An analysis is given in Report 811 (MOD I) which shows that there is an optimum elevation angle which minimizes the space station transmitter power. Figure 1 of that Report shows that depending on the rain attenuation characteristics-characteristics specified in Annex 7 of Appendix 30 of the Radio Regulations (1977 WARC-BS) - this elevation angle is in the range between about 5 degrees and 20 degrees. For rain climate D and an elevation angle of 5 degrees, the transmitter power is about 35% of that which would be required to cover the same size service area at the sub-satellite point. Similarly, for rain climate A and an elevation angle of about 20 degrees, the transmitter power is reduced to about 75% of that required for the same size service area at the sub-satellite point.

Although the analysis did not take into account the possibility of shadowing, as described above, the results should be considered in choosing the orbital position of the broadcasting satellite.

4.5 Depolarization [Report 814 (MOD I)]

4.5.1 Introduction

In addition to their effects on attenuation, clouds and rain can cause depolarization of the radio wave. This is due to the non-spherical nature of the water drops in clouds and rain, which results in differential attenuation and differential phase shift for orthogonal polarizations, thus depolarizing the received radio wave. The magnitude of the effect can be expressed in terms of the cross-polar discrimination D, defined as the ratio in dB of the component of the received signal having the original polarization to the component having the opposite polarization.

4.5.2 Empirical Equations for Dependence on Attenuation

Statistical analysis of measured results suggests that the cross-polar discrimination can be expressed approximately in terms of the attenuation caused by the atmosphere. This is quite reasonable because both the differential attenuation and phase shift which depolarizes the radio waves increase monotonically with the atmospheric attenuation; thus the depolarization should also increase monotonically with the attenuation. The cross-polar discrimination may be expressed by,

$$D = B - 20 \log A \text{ , dB}$$

where A is the co-polar attenuation in dB and B is a constant whose value is dependent on the operating frequency and the polarization of the radio wave.

Preliminary results of measurements made in Canada using circularly polarized waves at an elevation angle of about 25 degrees indicate that at an operating frequency of 11.7 GHz, the value for B is 34 dB.

Measurements made in Region 1 indicate that for circularly polarized waves, the value for B is 30, 33 and 38 dB for operating frequencies of 11 GHz, 18 GHz and 30 Ghz, respectively.

For the case of linear polarization there is only limited statistical analysis of measured data. However, it is suggested as a preliminary guide that 41, 44 and 49 dB be used for B at operating frequencies of 11 GHz, 18 GHz and 30 Ghz, respectively.

4.6 Attenuation By Sand and Dust-Storms [Report 721 (MOD I)]

Sand and dust particles may attenuate radio waves and their effects may be evaluated on the basis of the Mie scattering theory.

Measurements carried out in the laboratory at 10 GHz on simulated dust and sand conditions have shown that, for concentrations of less than 10^{-5}g/cm^3, the attenuation coeffecient would be less than 0.1 dB/km for sand and 0.4 dB/km for clay. For severe storms, and for links operating under grazing conditions, attenuation of microwave signals might be expected to be higher than these values. In the case of satellite broadcasting where the path length through dust storms is expected to vary between 0.5 and 3 km, attenuation of microwave signals is expected to be less than 1 dB under severe conditions.

Further investigation is needed of the meteorological structure of sand and dust-storms, and measurements of actual attenuation are also needed.

5.0 Propagation Data Relevant to Interference Problems in Satellite Broadcasting at 12 GHz and 17.7 GHz

There are several cases to consider in this application, the relevant propagation factors being determined by the characteristics (especially geometry and antenna directivity) in the sharing systems. The following discussion includes information on both the Earth-space and ground-to-ground aspects.

5.1 Interference on Earth-Space Paths (e.g. from Broadcasting Satellites to Receivers in Terrestrial Services)

In this category, the important propagation data are the values of attenuation due to atmospheric gases which are not exceeded for small percentages of time. In addition, there is a small effect, due to defocusing or beam spreading at low angles of elevation. Also at such angles of elevation, scintillation effects may occur due to turbulent fluctuations in the structure of the troposphere.

For all practical purposes, the attenuation due to oxygen can be assumed to be independent of time and climate. The water vapor concentration is, however, variable. It appears for most climates that, during the least humid month of the year, the water vapor concentration on the surface of the Earth is less than about 2 g/m^3 for 20% of the time, and is negligible for 0.01% of the time [Report 564-1 (MOD I)]. Figure 7 of Report 564-1 (MOD I) shows, for example, that at 11 GHz the attenuation not exceeded for both 20% and 0.01% (attenuation is due primarily to oxygen) of the time during the least humid month is about 5 dB at 0 degree elevation angle, decreasing to less than 0.7 dB at 5 degrees. At an operating frequency of 18 GHz, the figure shows that for 0.01% of the time during the least humid month, the attenuation is 6 dB at an elevation angle of 0 degrees, decreasing to about 0.8 dB at 5 degree elevation angle. The attenuation decreases rapidly with increasing elevation angle and becomes negligible for angles above about 20 degrees. It should be noted that marked scintillation effects are possible at elevation angles below 2 to 3 degrees in humid conditions for percentages of time less than about 0.1%. This effect may mask the effect of absorption and produce signals close to the free space value. Consequently, attenuation values for low elevation angles should be used with caution [see Report 564-1 (MOD I)].

It is also possible that refraction and ducting may extend the range of the interfering signal from the satellite beyond the normal horizon point on the Earth's surface. This is a complicated problem, but if the path geometry is known, then the data in Report 569-1 (MOD I) can be used to make an estimate of the additional attenuation. Conversely, if the receiver of the terrestrial system is screened, by obstacles or hills in the direction of an interfering satellite at a low angle of elevation, some protection from interference results. An estimate of this protection can be made by using the data in Report 715 (MOD I)

5.2 Terrestrial-Path Propagation in Relation to Interference

Several propagation modes need to be considered as they relate to interference to broadcasting satellite earth station receivers from transmitters of terrestrial services operating in the 12 GHz band; and to terrestrial receivers and fixed satellite earth station receivers from broadcasting satellite feeder link earth station transmitters operating in the 17.7 GHz band. Report 724 (MOD I) provides a simplified treatment of the terrestrial path propagation factors while Report 569-1 (MOD I) provides a more detailed treatment.

As a general procedure, the method described in Report 724 (MOD I) should be used to determine the distance at which a specified value of transmission loss might be exceeded for all but say 0.01% of the time. This is a "coordination contour" derived on the assumption that the locations of potentially interfering stations are not known and that information is available only on the station around which the contour is to be drawn. For interference calculations within the coordination area, all propagation modes and the path profile must be taken into account as described in Report 569-1 (MOD I). Because of the risk of error in predicting transmission loss over short distances when the exact path geometry is unknown, the minimum coordination distance in all cases is considered to be 100 km.

5.2.1 Great Circle Paths

Propagation phenomena associated with clear air and affected by the presence of the Earth's surface include diffraction, refraction and ducting. These phenomena, classified as Mode A phenomena in Report 724 (MOD I), are confined to propagation along the great circle path. From the curves given in Figures 2, 3 and 4 of Report 724 (MOD I), one can determine the total path loss which is likely to be exceeded for all but 0.01% of the time, at both 12 GHz and 17.7 GHz, as a function of distance. The figures of the Report apply, respectively, to three zones, defined as,

Zone A: land (with a ground irregularity parameter, h, taken as 25 m)

Zone B: seas, oceans and very large lakes, at latitudes greater than 23° N or S, but excepting the Black Sea and the Mediterranean.

Zone C: seas, oceans and very large lakes, at latitudes less than 23° N or S, and including the Black Sea and the Mediterrean.

An additional attenuation due to an elevated horizon is given in Report 724 (MOD I). Limiting distances of 600 km for Zone A, and 1500 km for Zones B and C should be used for the 0.01% calculations since in practice, meteorological factors set a limit to the extent of the duct.

Report 724 (MOD I) also gives a simple method for use with a mixed path extending through more than one Zone.

5.2.2 Rain Scatter

In this mode, defined as Mode B in Report 724 (MOD I), interference may result for quite large scattering angles and for beam intersections outside the great-circle path. The situation of major importance is one in which beams from a terrestrial station or a fixed satellite earth station and broadcast satellite receiving or feeder link earth stations intersect in a region of localized, heavy rain. Since the scattering from the rain is, to a first order, isotropic, the effect can be important even when the beams intersect outside the great-circle plane. Mode B thus contrasts, in this respect, with other beyond-the-horizon modes.

For cases of main beam intersection, the procedures in Report 724 (MOD I) give data on the transmission loss exceeded for all but 0.01% of the time in various rain climates. However it is important to note that since there is a maximum height above which (for a given time percentage) rain scatter is negligible, there will be a maximum distance beyond which this mode can be ignored. For rain climate 1 and 2 these distances are 470 km and 390 km respectively, for 0.01% of the time. For the same time percentage, the distance for rain climates 3, 4 and 5 is 330 km [For information on rain climates see Report 563-1].

If main beam intersection is eliminated by careful site selection, for example, then the possibility of interference via the antenna sidelobes has to be assessed. Report AC/5 (1980) points out that in comparison to main beam-to-main beam coupling, main beam-to-sidelobe or sidelobe-to-sidelobe coupling is only important when the rain is over one of the stations. If the two antennas are within line-of-sight, the line-of-sight sidelobe-to-sidelobe coupling will generally produce higher level signals than can be produced by precipitation scatter within the common volume produced by main lobe intersection.

Report 569-1 (MOD I) provides a summary of the transmission loss models representative of practical precipitation scatter conditions; and emphasizes that a rigorous evaluation of the effect of precipitation scatter covering all possible conditions would be extremely difficult and detailed. Such treatment would require, for example, a knowledge of antenna polar diagrams, especially of the sidelobes, and of the intensity and spatial distribution of heavy rain.

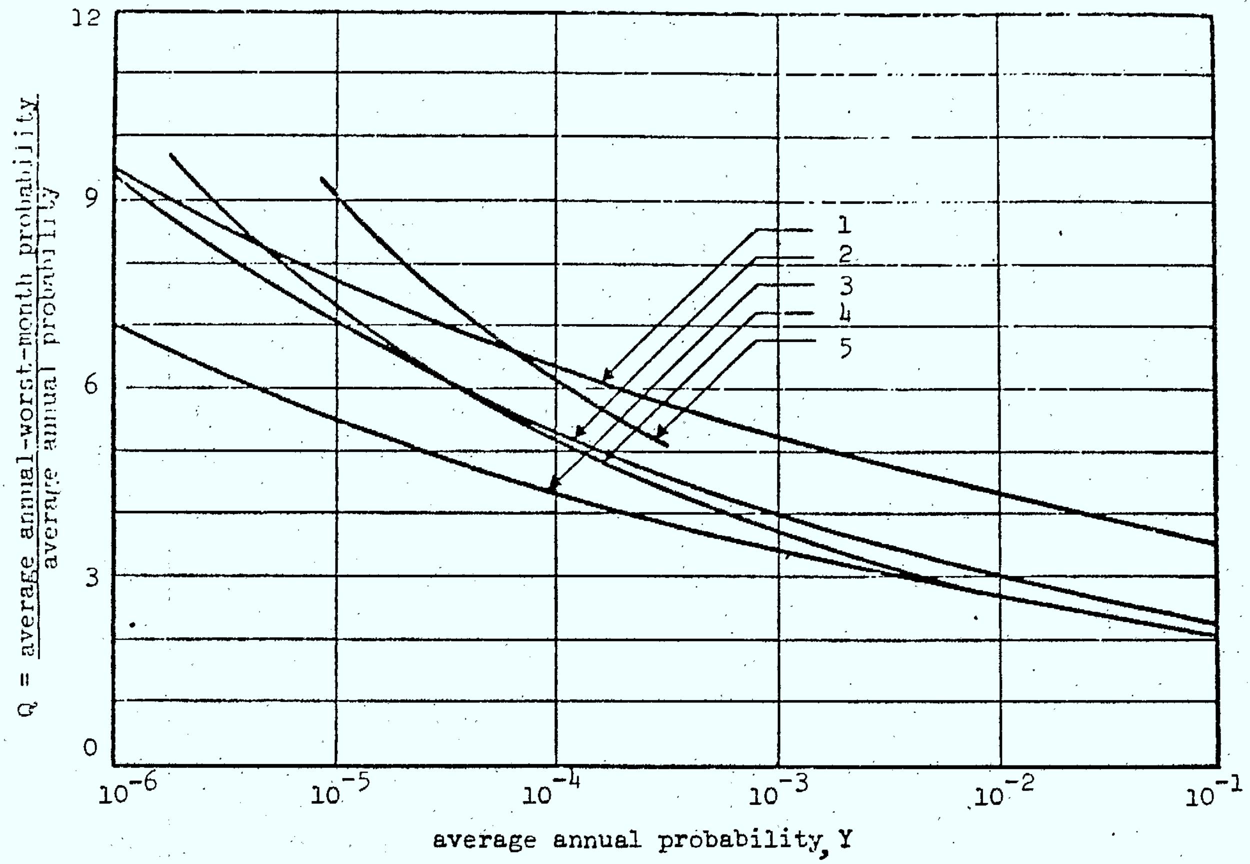
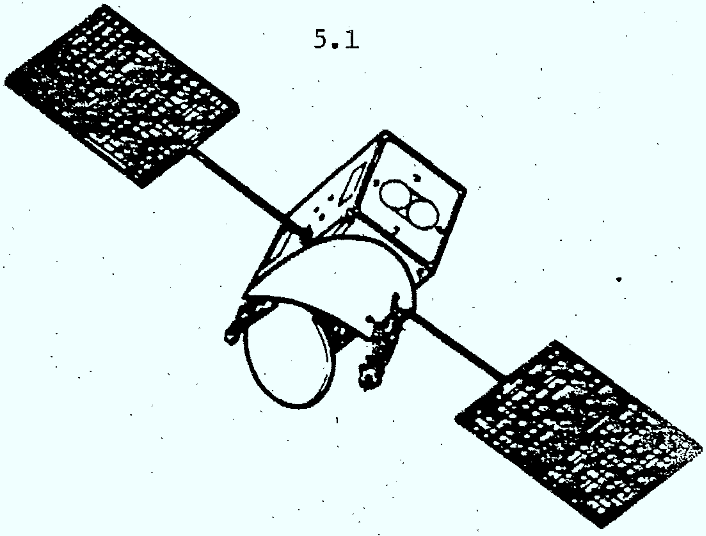


Figure 1 Ratio of annual-worst-month to average annual probability, Q, as a function of average annual probability, Y

1.	Prairie + Northern	rain rate, Canada
2.	Central + Mountain	rain rate, Canada
3.	Coastal + Great Lakes	rain rate, Canada
4.	Rain rate and rain attenuation, Europe, Rain rate and rain attenuation, Netherlands	
5.	Rain rate, Sweden	

5.1



TITLE : BROADCASTING SATELLITE TECHNOLOGY

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BROADCASTING SATELLITE TECHNOLOGY

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ABSTRACT

An overview of the state-of-the-art payload technologies for broadcasting satellites is summarized with particular reference to those that affect systems planning. Two key areas of the satellite payload are the antenna and the transponder. Design considerations and implications of certain design approaches are illustrated. Wherever possible, hardware parameters are provided to assist the optimization of system configurations for the planning of the Broadcasting Satellite Service.

1.0 PLANNING CONSIDERATIONS

Annex 8 of the Final Acts of the 1977 WARC for the planning of the Broadcasting Satellite Service (BSS) in Region 1 and 3 contains a number of technical specifications related to satellite design. The 1983 planning conference for Region 2 will for the first time attempt the planning of the two inter-related services; the BSS in the [12.2][1]-12.7 GHz band and the Fixed Satellite Service (FSS) in the 17.3-[17.8][1]GHz band for the corresponding feeder links.

1.1 Factors Affecting Satellite Antenna Design

In Regions 1 and 3, the satellite transmit antenna is characterized by reference patterns for both co-polar and crosspolar components (see Figure 6 of Annex 8 of 1977 WARC Final Acts), by a pointing accuracy of 0.1 degrees in pitch and roll and by an angular rotation around the beam axis of less than 2.0 degrees. No equivalent characteristics have been retained for the reference patterns of the satellite receive antenna but its pointing accuracy and angular rotation are expected to be similar to those of the satellite transmit antenna. Another factor affecting the satellite antenna design is the type of polarization and polarization purity (circular polarization already adopted for Regions 1 and 3). The shape and size of the downlink beam vary widely with beam size ranging

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[1] For the sake of simplicity, it is assumed in this paper,that the band 12.1 to 12.3 GHz is equally divided between the Broadcasting Satellite and the Fixed Satellite Services and consequently, that the upper limit of the 17.3 to 18.1 GHz used for planning is 17.8 GHz.

from the smallest 0.6° to the largest 5.36° and most beams in the 1 to 3 degree range. At 12 GHz, a 0.6° unshaped beam requires a 3m satellite antenna and a 5.36° beam requires a 35 cm satellite antenna.

1.2 Factors Affecting Satellite Transponder Design

The frequency separation between adjacent 27 MHz wide channels in the 1977 Plan was set at 19.18 MHz. These values give rise to an overlap between adjacent channels but these channels do not feed the same antenna since a minimum separation of 40 MHz is recommended between the assigned frequencies of two channels feeding a common antenna. To the maximum extent possible the Plan grouped all channels of a service area within a 400 MHz frequency band to allow simplicity in the receiver design. In Regions 1 and 3, there are three uplink frequency bands subject to planning at the 1984 WARC. However, in Region 2, only the band 17.3-[17.8] GHz is subject to planning at the 1983 RARC. Assuming a simple translation between the uplink and the downlink frequency plans, the constant translation frequency for Region 2 is 5.1 GHz. Most of the planning characteristics for Region 2 which affect transponder design (e.g., bandwidth, channel separation and frequency plans for both up and down links) have yet to be determined.

Other important planning factors affecting satellite design are the required EIRP, the areas to be served and the orbital position with respect to the service area. In Regions 1 and 3, the planned values of satellite EIRP are in the range of 60 to 70 dBw which, depending on the gain of the satellite transmit antenna requires travelling wave tube output power of between 30 and 600 watts per channel. Each satellite is positioned west of the most westerly longitudes of the service areas so as to minimize satellite battery requirements during eclipse seasons near the vernal and autumnal equinox. The spacecraft life and reliability also have an important impact on its design.

2.0 OVERALL SYSTEM REQUIREMENTS

A broadcasting satellite system provides an intended high quality service to a country or a service area using pre-planned resources such as orbital positions and spectrum. The plans are expected to favor a high potential utilization of the resources. The design engineer must provide appropriate engineering data to the planners and later design the intended system to operate in accordance with the plan.

The downlink service areas are selected on the basis of a number of inter-related social, economic and technical considerations. The most dominent social considerations are the number of time zones within the country, the cultural diversity of its population, and the type of access envisioned (national and/or regional). The overall cost of an operational system depends on the number of earth station receivers, the number of spacecraft and the size and lifetime of each spacecraft. Economic considerations are dealt with in more detail elsewhere in this Seminar.

If all the satellites are located west of the service areas, the available capacity of such a plan may be somewhat constrained. However, when battery and antenna technologies further develop, extra planned capacity for later allotments could be provided. The elevation angle to each satellite from everywhere within its service areas should be kept above a desired minimum angle. This desired minimum elevation angle increases in mountanous areas and in urban areas so as to guard against possible blockage of the incoming signal. In high latitude countries, it may be found difficult to locate the satellite west of the service area and yet provide an adequate service to the northern-most (or southern-most) areas.

In the case of multiple satellite networks, it might in addition be desirable to select orbital positions so that each satellite is seen above the local horizon for every point within the country if direct national access to some channels is desired.

In the case of a single beam system, the uplink service area corresponds to the downlink service area. In the case of a multiple beam system, access to the downlink resources from outside the corresponding downlink service area requires different uplink and downlink service areas. This may have further implications in the satellite antenna design and spectrum re-use via spatial beam isolation on the downlink. Another paper in this Seminar addresses this problem.

The technical requirements of each system are therefore based on careful studies of trade-offs between the number of channels, the access flexibility, the service quality and the interference for the provision of the desired service at minimum cost to the operator and to operators of other planned systems.

3.0 SATELLITE ANTENNA SUBSYSTEM DESIGN CONSIDERATIONS

Satellite antennas play an important part in the overall system design of broadcasting satellites. The satellite antenna affects the system in two major areas, viz (i) the antenna gain or the e.i.r.p. within the desired service area and (ii) the antenna sidelobe levels or sidelobe e.i.r.p.'s in the regions outside the service area. In addition, the choice of polarization, polarization purity and pointing errors of the antenna subsystem will also have significant impact on the overall system. The following sections briefly describe the various state-of-the-art techniques in satellite antenna design.

3.1 Shaped beam versus unshaped beam

Regardless of the shape of the service area, the satellite antenna can always be designed to have either an unshaped elliptical (or circular) pencil beam or a highly shaped beam such that equi-e.i.r.p. contours follow the outline of the service area. To produce an unshaped beam, a single horn illuminating a single elliptical (or circular) reflector is required. The shaped beam antenna is necessarily more complex. For example, the reflector must be somewhat larger than that producing an unshaped beam and the antenna feed is probably an array of feed horns (at SHF frequencies). Fig. 3.1 shows the comparison of the two design approaches. Fig. 3.1(a) shows the simple antenna that produces a simple elliptical pencil beam shown in Fig. 3.2(a). Fig. 3.1(b) shows the more complex antenna design which produces the highly shaped beam shown in Fig. 3.2(b). Note the larger reflector, the feed array and the Beam Forming Network (BFN) used in the shaped beam antenna. In general, the shaped beam offers a higher gain within a given service area than an unshaped beam. However, the shaped beam has a higher gain slope at the beam edge which becomes a significant consideration in the evaluation of beam pointing errors.

3.2 Sidelobe Control

Controlled sidelobe levels of satellite antennas permit spectrum re-use as a result of spatial beam isolation. For sidelobe levels less than about 33 dB below the edge gain of the main beam, an offset-fed paraboloid is normally used. This offset-fed arrangement avoids the blockage of the main beam by the feed and thus does not cause sidelobe degradation. More sophisticated offset arrangements involve the use of folded optics such as the offset Cassegrain and the offset Gregorian antennas as shown in Fig. 3.3. Both arrangements require an additional curved subreflector. Spillover past the subreflector can sometimes become a sidelobe problem. This explains the greater popularity of the simple direct offset-fed designs in the present generation of spacecraft e.g. Intelsat V, ANIK's, SBS etc.

In addition to the offset-fed arrangement, control and reduction in sidelobe levels can be achieved by tapering the feed illumination of the main reflector. This technique is illustrated in Fig. 3.4. Here, a comparison of different types of illumination tapers is made. It can be seen that a highly tapered illumination distribution on the main reflector results in well suppressed sidelobes in the far field antenna pattern. For a given 3 dB beamwidth, a larger antenna is necessary to supress the sidelobes. In a direct offset fed antenna, the tapered illumination is provided mostly by the feed pattern alone whereas in Cassegrain or Gregorian offset-fed antennas, both the main reflector and the subreflector curvatures (or profiles) can be shaped or altered to provide the highly tapered illumination if the feed pattern alone is not adequate to provide it. Shaping the main reflector and the subreflector together will ensure a flat phase front at the aperture. If, however, only one of the reflectors is shaped in the folded optics arrangement, the feed will have to be a complex feed array to maintain the required flat phase front at the aperture.

Beam shaping and sidelobe suppression can be simultaneously achieved using a direct offset-fed unshaped main reflector. This concept is easily visualized as a component beam sidelobe cancellation technique. In Fig. 3.5, three component beams are added together in the far field to produce a shaped beam with highly suppressed sidelobes that result from sidelobe cancellation. A good example of this technique was demonstrated in the Intelsat

IV A spacecraft. Sidelobes of less than 30 dB are usually realizable with this technique.

3.3 Pointing Errors and RF Tracking

In early satellite systems, satellite antenna beamwidths were usually several degrees across and earth sensors on board the spacecraft were effectively used to maintain a beam pointing accuracy of about ±0.2° in both pitch and roll under normal operating environmental conditions. That was adequate because the gain slopes of the main beam at beam edge were usually small e.g. a few dB's per degree. However, for small pencil beam or shaped beam antennas having sharp gain slopes, the effects of small pointing errors can become quite significant. Earth sensors attached to a non-rigid or unstable spacecraft body may become unsuitable for the control of the antenna beam pointing. Microwave sensors may then become a more attractive alternative. For pointing accuracy of less than or equal to ±0.05°, it is necessary to incorporate the microwave sensor into the antenna feed itself. The microwave sensor locks on to an earth beacon to maintain accurate pointing of the antenna beam. Servo control loops can be used to nod the reflector up and down or to gimball the feed to counteract the residual attitude control errors of the spacecraft attitude control subsystem or the thermal distortions of the spacecraft body. An example of a four-horn cluster used as a microwave sensor (known as the difference mode sensor) in a typical horn array of a shaped beam antenna is shown in Fig. 3.6. The four horn cluster provides tracking in the N-S as well as the E-W directions.

3.4 Polarization Discrimination

The use of orthogonal circular or orthogonal linear polarization effectively doubles the available bandwidth if polarization purity is maintained. In linearly polarized systems, the feed of the earth terminal antenna need be rotated to match the orientation of the incoming electric field vector from the satellite. This has to be done in the initial alignment of the earth terminal antenna. No such alignment procedure is necessary in circularly polarized systems, but the antenna feed design (both earth terminal and spacecraft) is a little more complex than those used in a linearly polarized system. Fig. 3.7 illustrates the additional phase shifter section required in each circularly polarized feed element or feed horn. Antenna reflectors used in conjunction with circularly polarized (CP) feeds are necessarily electrically continuous i.e. the reflecting surface is either a continuous sheet of metal or of such fine mesh that it can be considered electrically continuous. For linearly polarized (LP) systems, the antenna reflector can be made out of a wire grid supported by RF transparent lightweight material. The wire grid, if properly designed, can enhance the polarization purity of the linearly polarized signal. These two types of reflectors are illustrated in Fig. 3.8. In general, an LP antenna offers higher polarization purity than a CP antenna e.g. 29 dB polarization isolation is typical of a good CP antenna, whereas LP antennas offers 32 dB or better.

Under clear sky conditions, polarization discrimination between orthogonal LP signals or between orthogonal CP signals is governed by the characteristics of the transmit and receive antennas. However, during periods of precipitation, especially heavy rain storms, discrimination between the orthogonally polarized signals degrades. Fig. 3.9 shows the degradation of cross-polar discrimination (XPD) plotted against co-polar attenuation (CPA) for a typical rain storm in eastern Canada. Note that the XPD of a CP system degrades more than the XPD of an LP system if the satellite antenna of the LP system is arranged such that the received field vectors are close to the local vertical or the local horizontal of the earth terminal. This is normally true because the canting angles of rain drops during a heavy rain storm are close to zero with respect to the local horizontal of the earth terminal. However, the orientation of the field vector of the incoming signal at the earth station is not fixed throughout the service area, but continuously varies on the surface of the earth. The stated improvement of rain induced XPD in an LP system over a CP system is somewhat reduced in a large service area.

If a number of satellites placed along a segment of the orbital arc are all using orthogonal LP systems, and if all the field vectors of these satellites are either perpendicular or parallel to the orbital plane, an observer on the earth will detect a twist in the field vector from one satellite to another. It is also important to note that the cross-polar component of an earth station antenna is measured using the antenna pattern recorder coordinate system. These effects should be considered in the calculation of inter-sytem interference.

3.5 Multiple beam antennas and beam reconfiguration

There are two sparing philosphies for multiple satellite networks:-

(i) a dedicated spare satellite for each prime satellite

(ii) a common spare satellite for all the prime satellites.

Case (i) provides effective but possibly expensive protection. The spare satellite can be co-located with the prime satellite and service restoration in case of failure is in a matter of minutes. Case (ii) requires the use of a reconfigurable antenna on-board the spare satellite. A variation to this is the use of reconfigurable antennas for the prime and the spare satellites.This sparing philosophy is perhaps less expensive but service outage can sometimes be days while the spare satellite drifts towards the orbital position of the failed satellite. In addition to a reconfigurable antenna, the transponder may need to carry all the filters of all the channels assigned to all the service areas if channel assignments are different for different services areas. Satellite design is much simplified if channel assignments are identical for all satellites. Fig. 3.10 is an example of a simplified antenna block diagram for a reconfigurable antenna beam forming network. The reconfiguration of the antenna beam is performed by the switching of the variable power dividers and the in-line phase shifters of the beam forming network behind the feed array.

3.6 Other considerations

In the case of a 14/12 GHz satellite system, the antenna bandwidth required seldom exceeds about 25% and with the antenna feed bandwidth available, there is little or no problem with practical designs. However, for an 18/12 GHz system (or occasionally, a 14/12 GHz system) it is sometimes expedient to separate the receive and the transmit functions into two separate antenna subsystems. This approach allows a simpler design of the feed subsystem, different uplink and downlink coverages and if necessary a steerable spot beam for uplink. The gimballed spot beam technology was demonstrated in the Hermes spacecraft a few years ago. In the case of a single reflector for both transmit and receive, an RF transparent reflector can be designed to have a portion of its surface covered with a solid metallic sheet, and the rest with a frequency selective surface or a polarization selective surface depending on the application. This technique is illustrated in Fig. 3.11 and it will help to achieve nearly identical up and down link coverages at different frequency bands such as the 18 GHz and 12 GHz bands.

4.0 TRANSPONDER DESIGN CONSIDERATIONS

The transponder of the satellite is essentially a microwave frequency translator and repeater with relatively high output power. The major design parameters of a transponder are its front end noise figure, linearity, DC/RF efficiency, redundancy and switching capabilities. External factors influencing its design include frequency plans (channelization), predistorted or undistorted uplink signals, uplink requirements (e.g. multiple uplink locations versus single uplink location and e.i.r.p. of uplink transmitters), low cost earth terminal G/T performance (this affects the TWTA power level) and perhaps modulation schemes. The general design philosphy of a transponder for broadcasting satellites

will be discussed in the following section. State-of-the-art achievements in some of the microwave hardware will be highlighted to illustrate what one can expect from today's technology.

4.1 Block Diagram

A typical transponder can be represented in a block diagram as in Fig. 4.1. The function of each block is now briefly explained.

The input bandpass filter prevents spurious signal and out-of-band thermal noise from entering the transponder. Being ahead of the receiver, the insertion loss of this filter has a direct bearing on the noise figure of the transponder and therefore should be minimized. Next, a redundancy switch can be activated on command from ground to select one of the two or more receiver chains. The receiver chain consists of the front-end low noise amplifer (LNA), the down converter (D/C) or frequency translator and the post converter amplifier (AM). The receiver chains shown in Fig. 4.1 are then joined together using either a

3 dB hybrid or couplers. At this point all of the signals have gone through only linear amplification and translation. The input demultiplexer (I/P Mux) separates individual channels for their further amplification at high levels of power and efficiency. The channel driver and the Travelling Wave Tube Amplifier (TWTA) are active elements in the transponder which need be adequately protected by redundancy. If fairly wideband drivers and TWTA's are used, ring redundancy switching hardware can be used to "sandwich" the active elements. Such a redundancy scheme will allow the use of any driver and TWTA for any channel. Fig. 4.2 illustrates two common types of redundancy schemes in use. Fig. 4.2(a) shows a three-for-two redundancy scheme which can be repeated for every two channels. Fig. 4.2(b) shows the ring redundancy scheme. Fig. 4.3 shows the special three position transfer switch required for the ring redundancy scheme. The redundancy scheme in Fig. 4.2(a) is perhaps more suitable for narrower band TWTA's, e.g. coupled cavity TWTA's as opposed to helix type TWTA's. This allows the spare TWTA to back up two adjacent channels. The output multiplexer (O/P MUX) has the opposite function of the I/P MUX i.e. it recombines all the signals at high power level for delivery to the antenna. Thus insertion loss in the O/P MUX is of vital importance in the design of the transponder since it is directly reflected in the loss of e.i.r.p.

4.2 State-of-the-art Transponder Hardware

Since about 1975, Gallium Arsenide Field Effect Transistors (GaAs FET's) have become very popular in space applications. Numerous satellites have benefited from the advance in FET technology. To-day, an entire microwave receiver can be built and integrated using only FET's. Low noise FET's are used in the front end, either a single gate FET or a dual gate FET can be used for the frequency translator and multi-cell FET's can be used in the drivers or the post down-conversion amplifiers. State-of-the-art FET technology is listed in the following table.

Freq.	Low noise FET's Best Noise Figure (in an amplifier)	Power FET's Output Power (per device)
4 GHz	1.0 dB	5.0W
12 GHz	2.5 dB	1.0W
18 GHz	4.5*dB	-

In the filter area, major advances have also taken place. With the advent of dual mode canonical filters, exact Elliptic function filters can be designed in circular or square waveguides. In addition, group delay equalizers can be provided either as a separate unit in the I/P MUX or as an inherent feature of the filter itself i.e. a self-equalized multiplexing filter. Up-link signal predistortion is not necessary if on-board equalization is used.

A feedback loop can be included in the design of the channel driver amplifier to provide for Automatic Gain Control (AGC) at RF to minimize the effects of uplink fades and non-uniformities in power levels of the various uplink stations.

It is normally assumed that the output TWTA's are maintained at or very close to saturation. For this operating condition, a d.c. to RF efficiency of $\geq$40% is presently achievable with multi-collector tubes and high efficiency power supplies for the tubes.

Depending on the frequency and channelization plan, the O/P MUX can have either the odd/even mode configuration or the single combining mode configuration. Odd/even mode MUX's are required if contiguous channel

---

* Subject to verification

multiplexing is mandatory because the odd and even channels are combined in two separate O/P MUX's (see Fig. 3.1). In this case, the antenna feed and feed input will have to be configured to interface with the two output ports of the transponder. By suitable choice of channel spacing and center frequencies of the channels, this odd/even mode O/P MUX can be avoided by using a single multiplexer. This will reduce the complexity of the antenna feed network as there is only one transponder output port to interface. The technology employed in the I/P MUX can be used in the O/P MUX design. Low insertion loss dictates the use of higher ordered resonant mode cavities in a waveguide structure. Unloaded Q's of $\geq$ 11,000 for these cavities are generally achievable. Such high unloaded Q's result in filter insertion loss of a few tenths of a dB.

5.0 OVERALL PAYLOAD SYSTEM CONSIDERATION

The simplest broadcasting satellite system is one serving one service area with a single antenna beam. The transmit and receive antenna beams can be made coincident and access to the satellite can be made from anywhere within the service area.

For a geographically large multi-beam country, there are a variety of pay load system designs depending on the overall systems requirements. Conceptually, the simplest approach is to use a single satellite with multiple transmit beams. A single country-wide uplink beam allows access from all parts of the country. Due to constraints of spacecraft power subsystem or constraints in weight and size, it is perhaps not cost effective to use one single satellite to serve all the service areas simultaneously. Also, the single satellite with a full coverage receive beam does not permit spectrum re-use via beam isolation.

A more likely approach is to use a network of two or more satellites to serve a large country with multiple service areas. The satellite transmit beams are basically defined by the service areas, but there are a number of options in the choice of satellite receive beam coverage. As an example a few of them are now discussed.

Option (i), there is only one feeder link (uplink) location and programs originated from anywhere else within the country have to be relayed via terrestrial links or fixed satellites to feed the feeder link earth station. This option is depicted in Fig. 5.1 for a two satellite network. The design of the satellite payload is fairly conventional. A high gain antenna for the satellite receive beam is envisaged.

Option (ii), the receive beam for each satellite covers all of its corresponding downlink service areas. The advantage of this system is that programs originated within the service areas covered by the satellite can be delivered to the satellite without additional back-haul facilities. However programs originated from outside the downlink service areas must first be distributed to the downlink service areas for their eventual broadcasting. The satellite receive antenna now has less gain than that in option (i) and a larger earth station antenna is envisaged. If spectrum re-use is contemplated, as shown in Fig. 5.2, only the sidelobes of the transmit earth station antenna are providing isolation when the earth stations transmitters are located between the two uplink service areas. Additional protection is available from the satellite antenna if the earth station transmitters are located inside their corresponding uplink service area.

Option (iii) is depicted in Fig. 5.3. The two satellites shown have identical country-wide uplink service areas. The size of the earth terminal and the frequency re-use capability within the system are inter-related and are influenced by the orbital separation between satellites. Orbital separation greater than 8 to 10 degrees are desirable. The satellite design is still conventional. Separate satellite antennas for transmit and receive may be needed in order to provide very different beamwidths. Option (iii) may not be possible if the satellites are not visible from all parts of the country.

6.0 CONCLUSION

This paper has given an overview of the technologies for broadcasting satellites as presently available to the system designers and planners. The constraints of current technology will no doubt influence the decisions made at the 1983 RARC for tomorrow's satellite systems. The paper has therefore summarized the state-of-the-art technologies that are critical to the planning of broadcasting satellite systems. Various systems related problems that affect the satellite payload design are also discussed.

OFF SET FED REFLECTOR ANTENNA

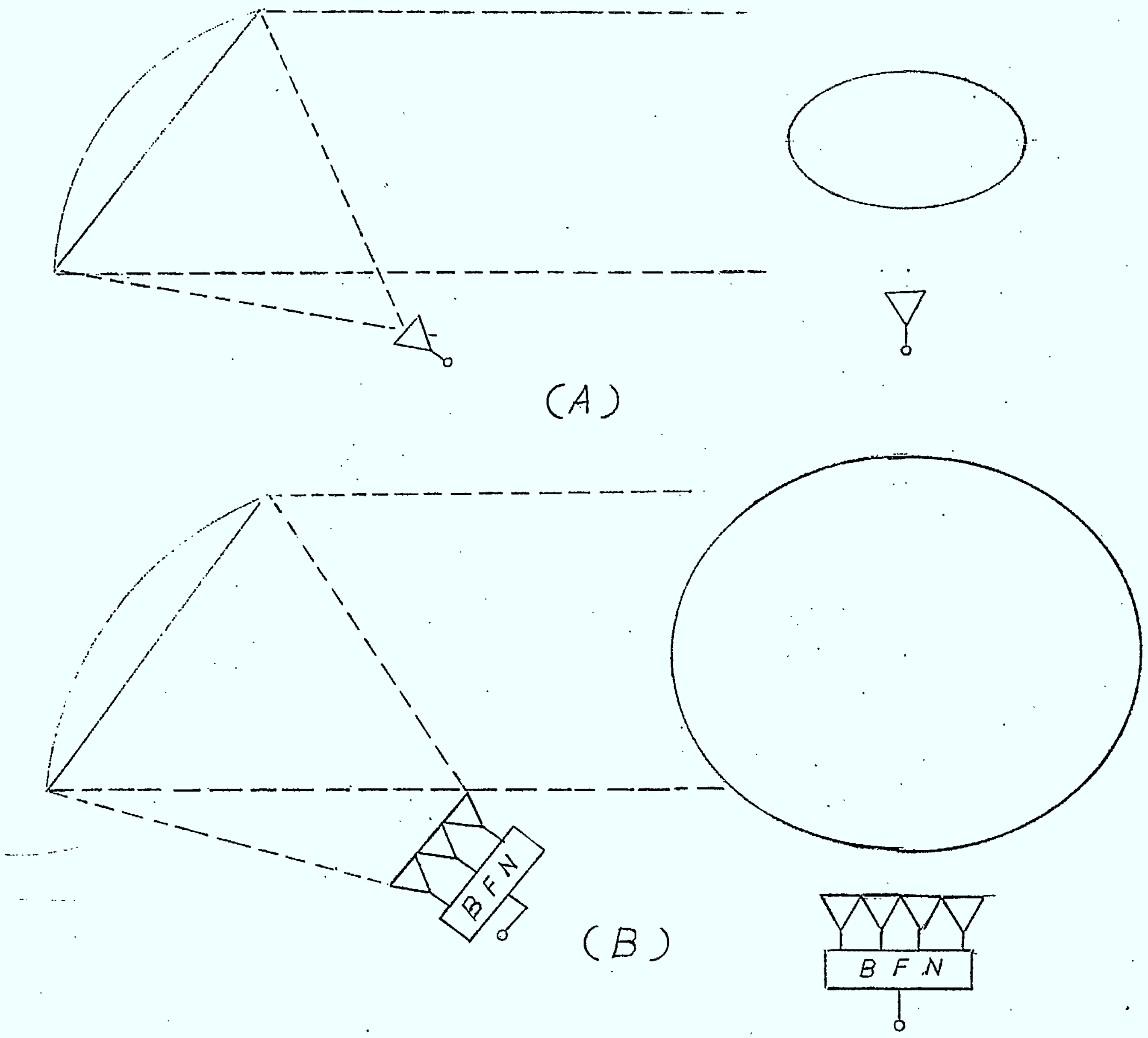
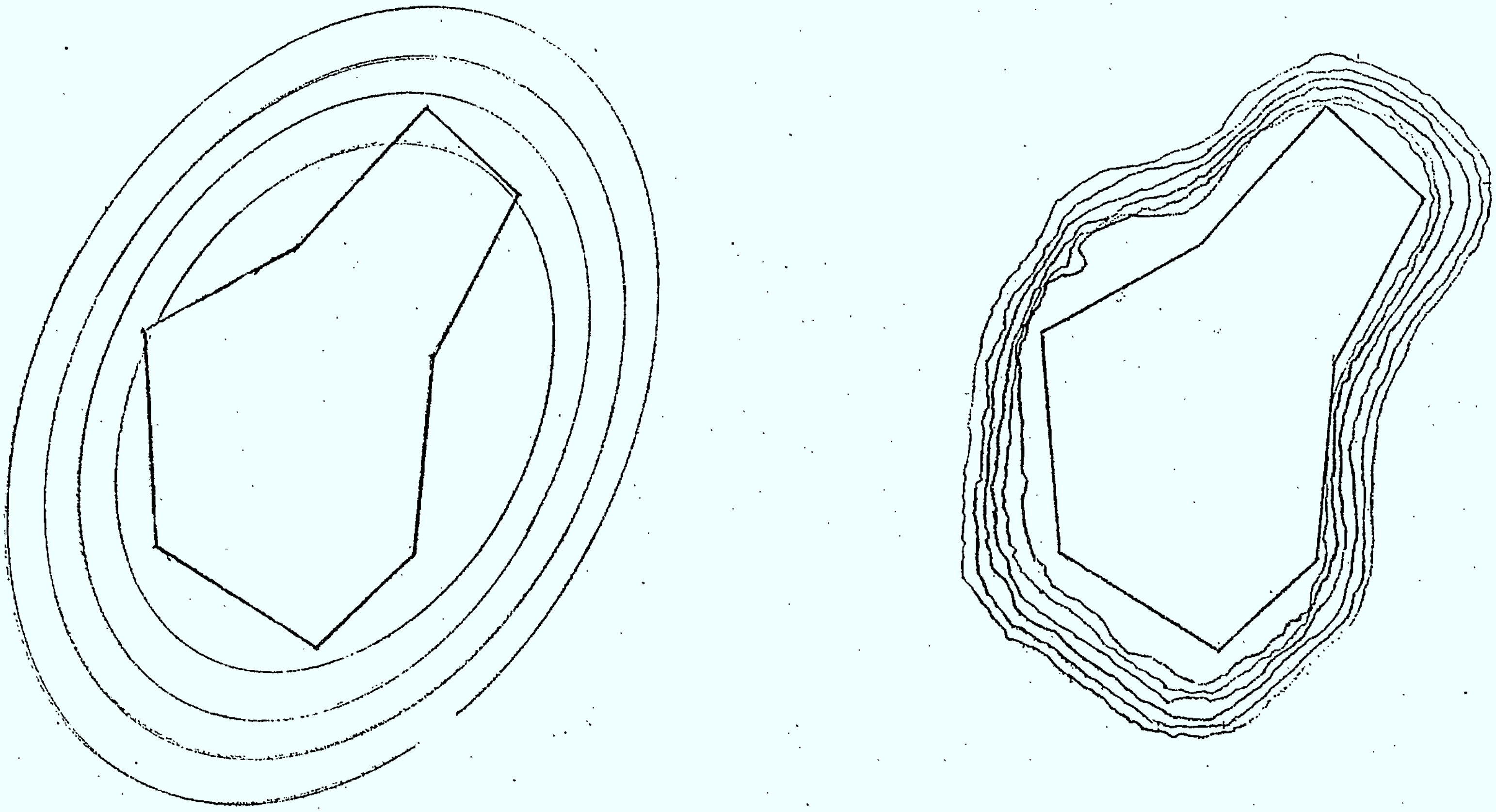


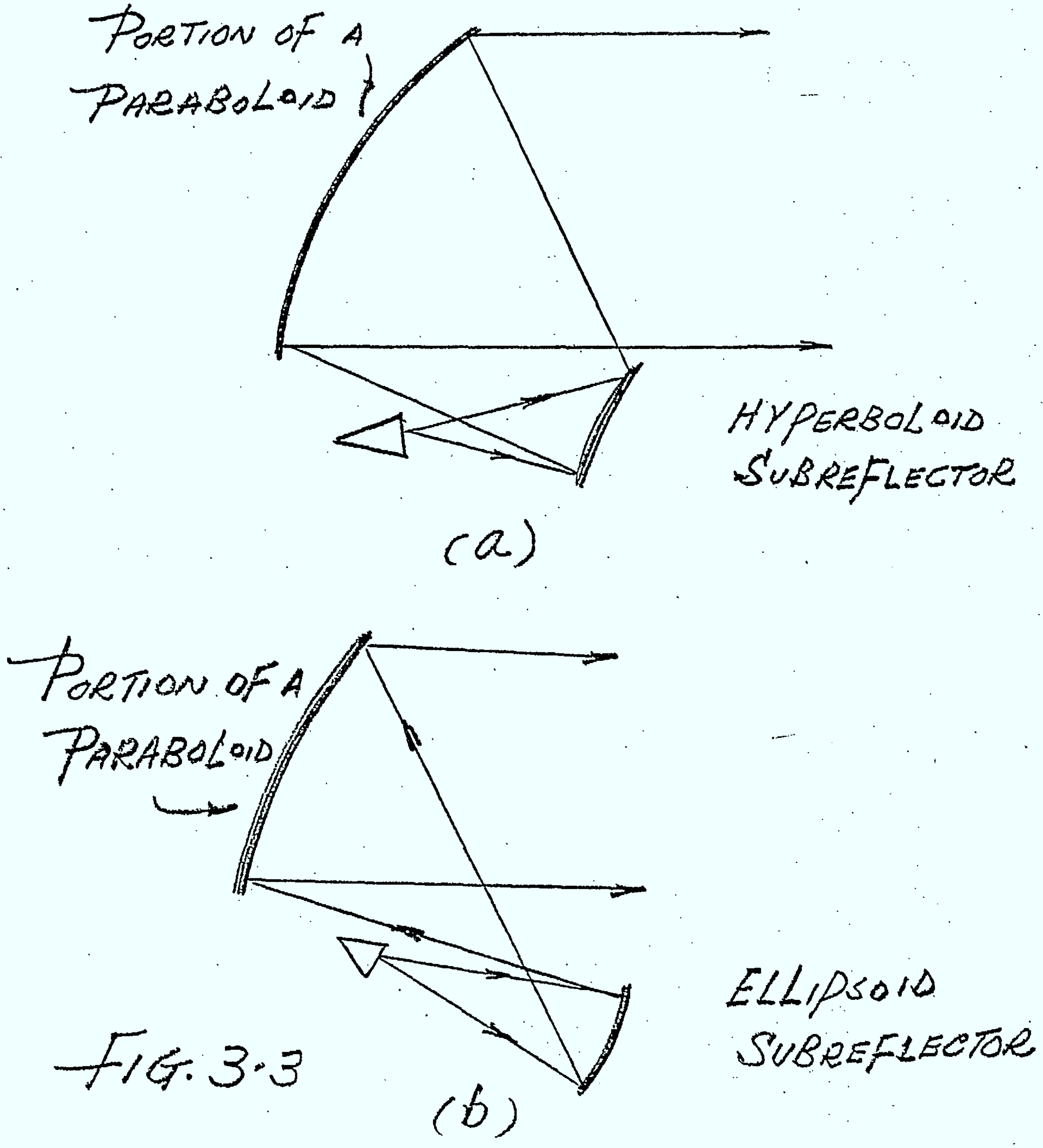
FIG. 3.1



UNSHAPED BEAM.

SHAPED BEAM

FIG 3-2



(a)

(b)

FIG. 3-3

ALL REFLECTORS UNSHAPED

CIRCULAR APERTURE

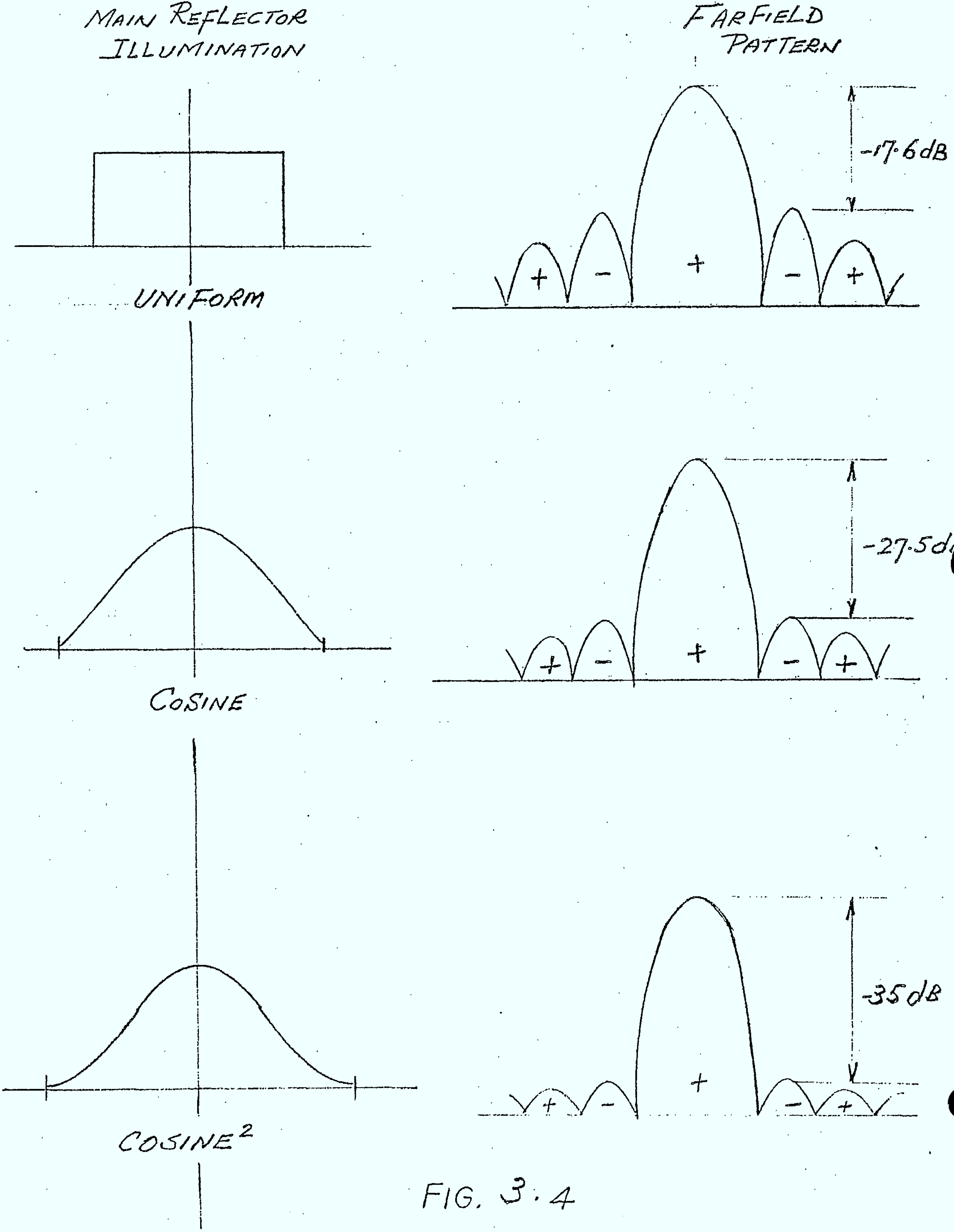


FIG. 3.4

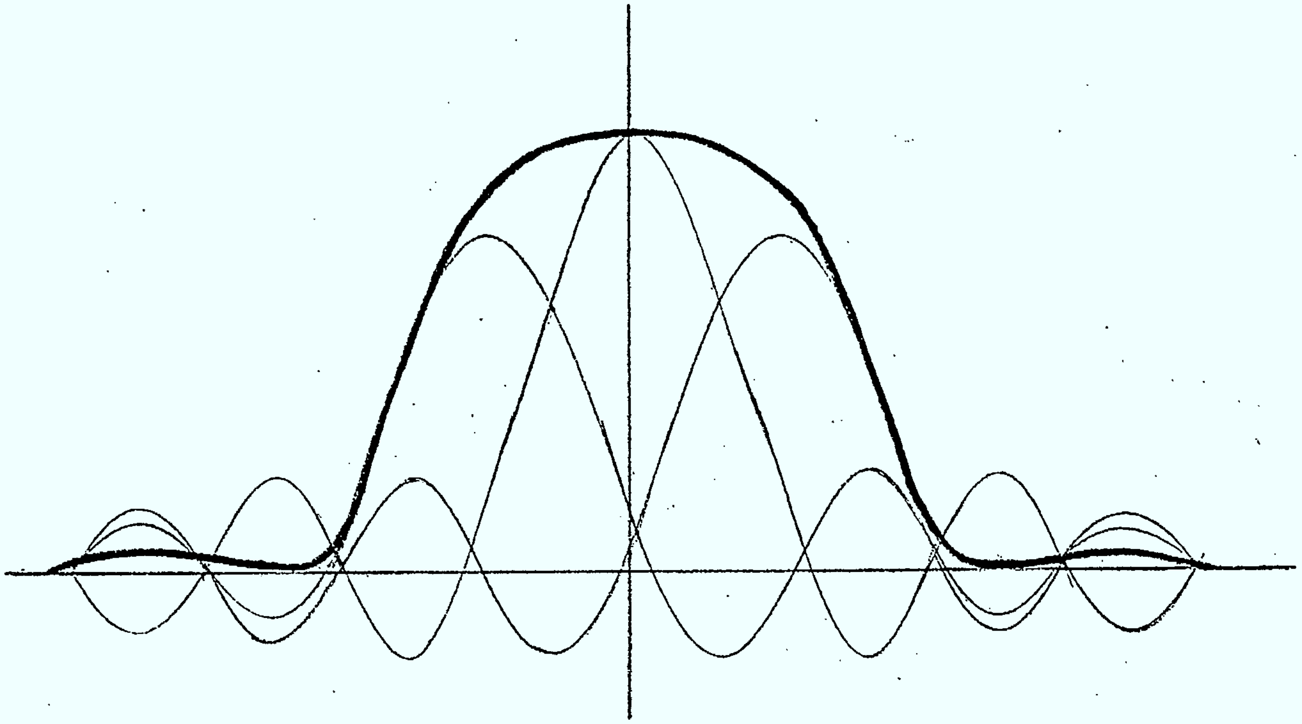


FIG 3-5

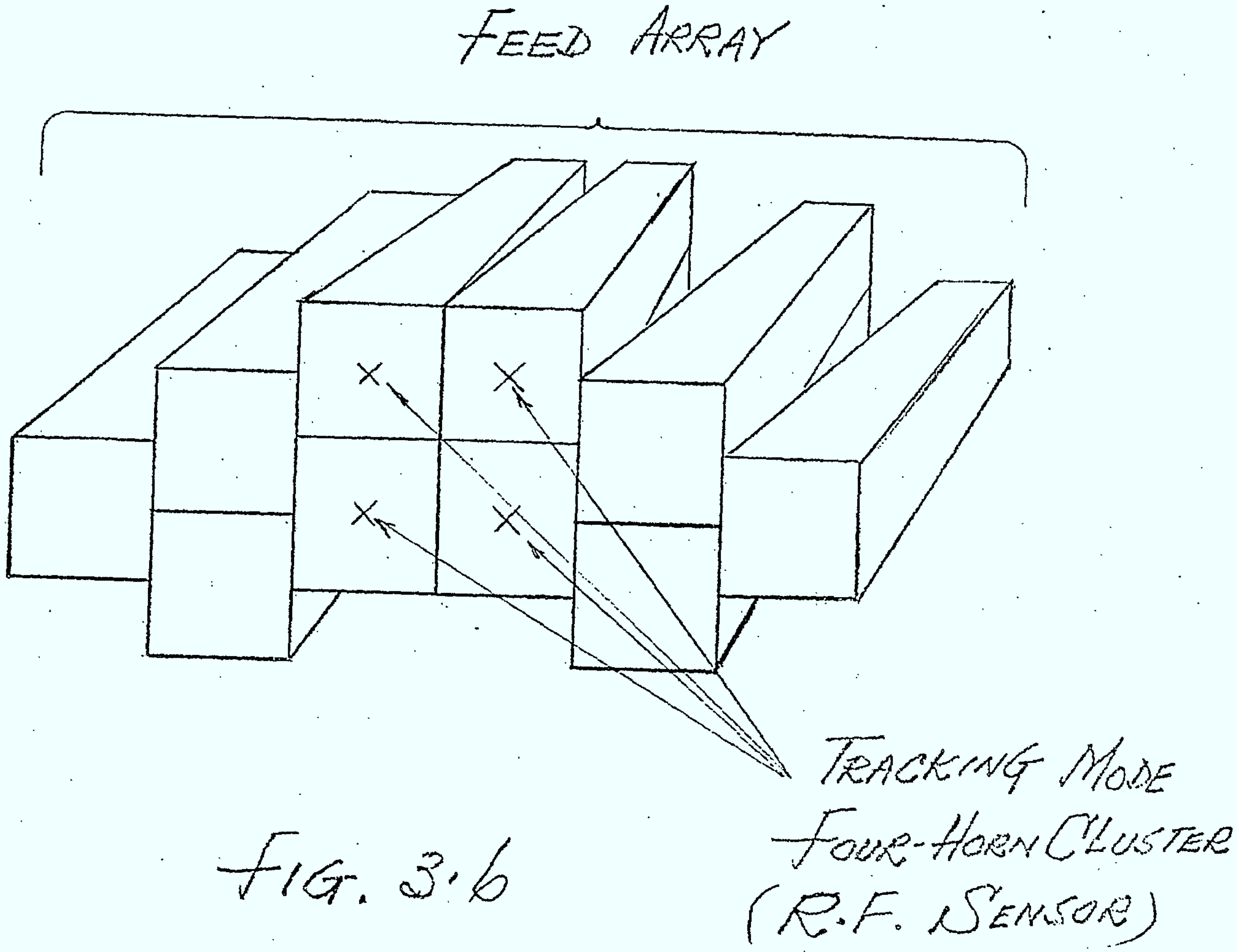


FIG. 3.6

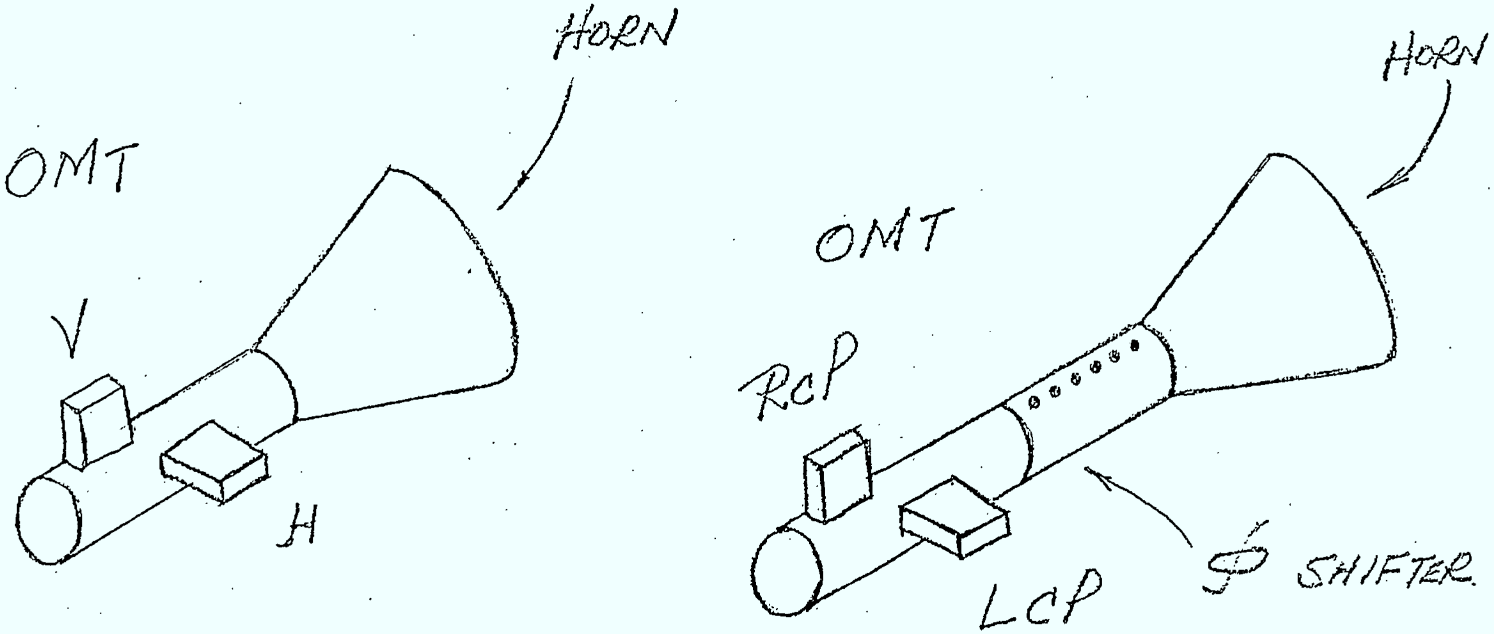
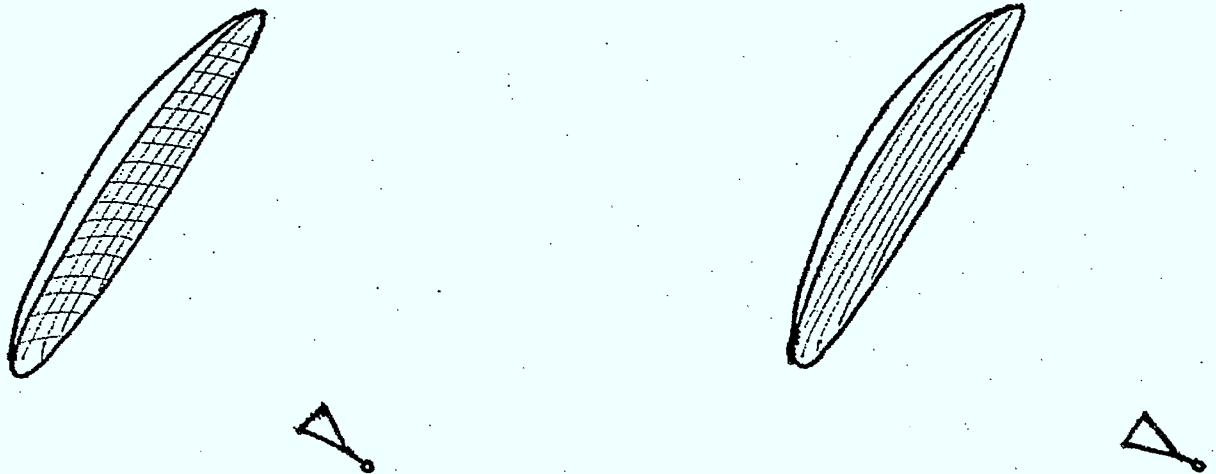


fiG 3·7



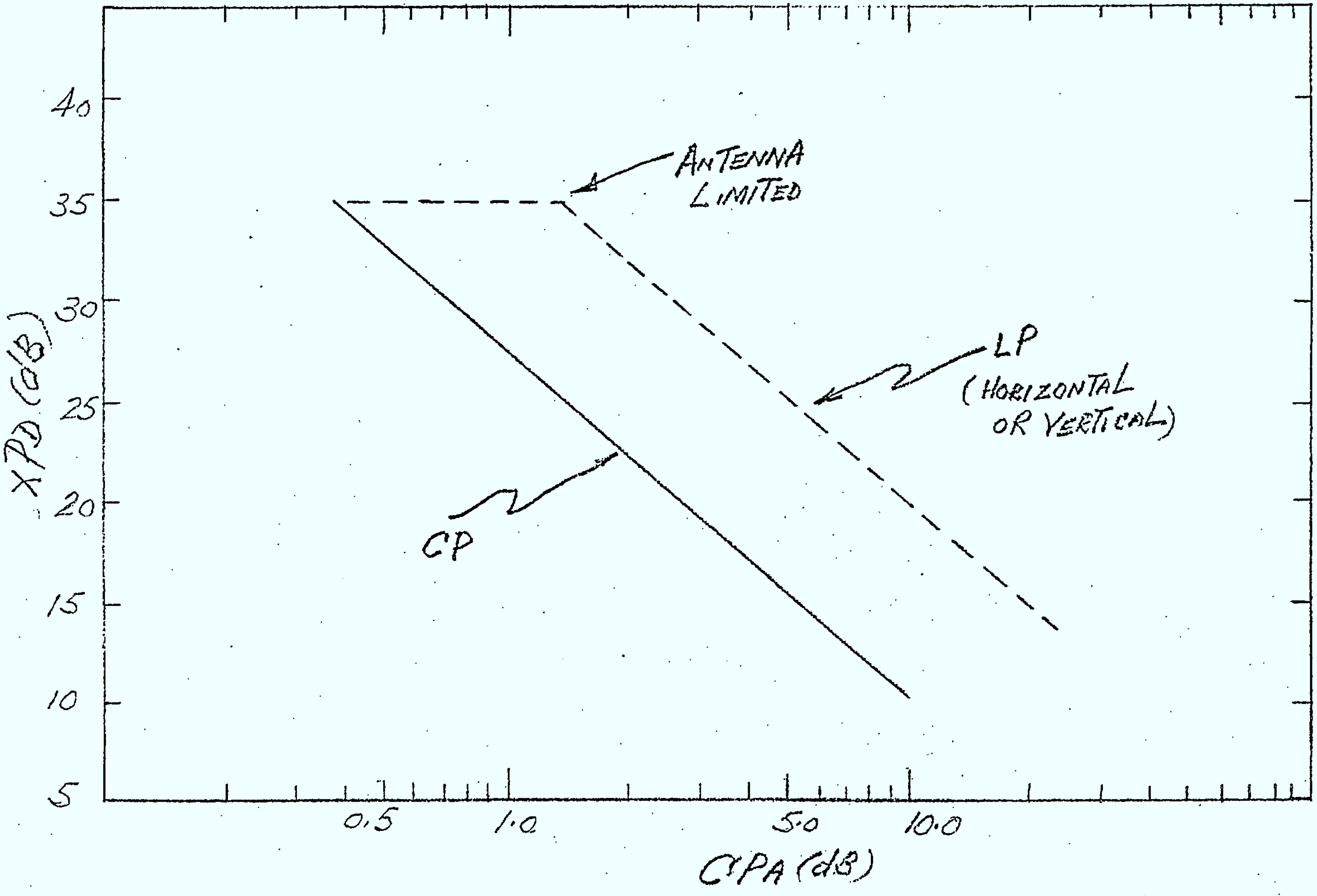
CP

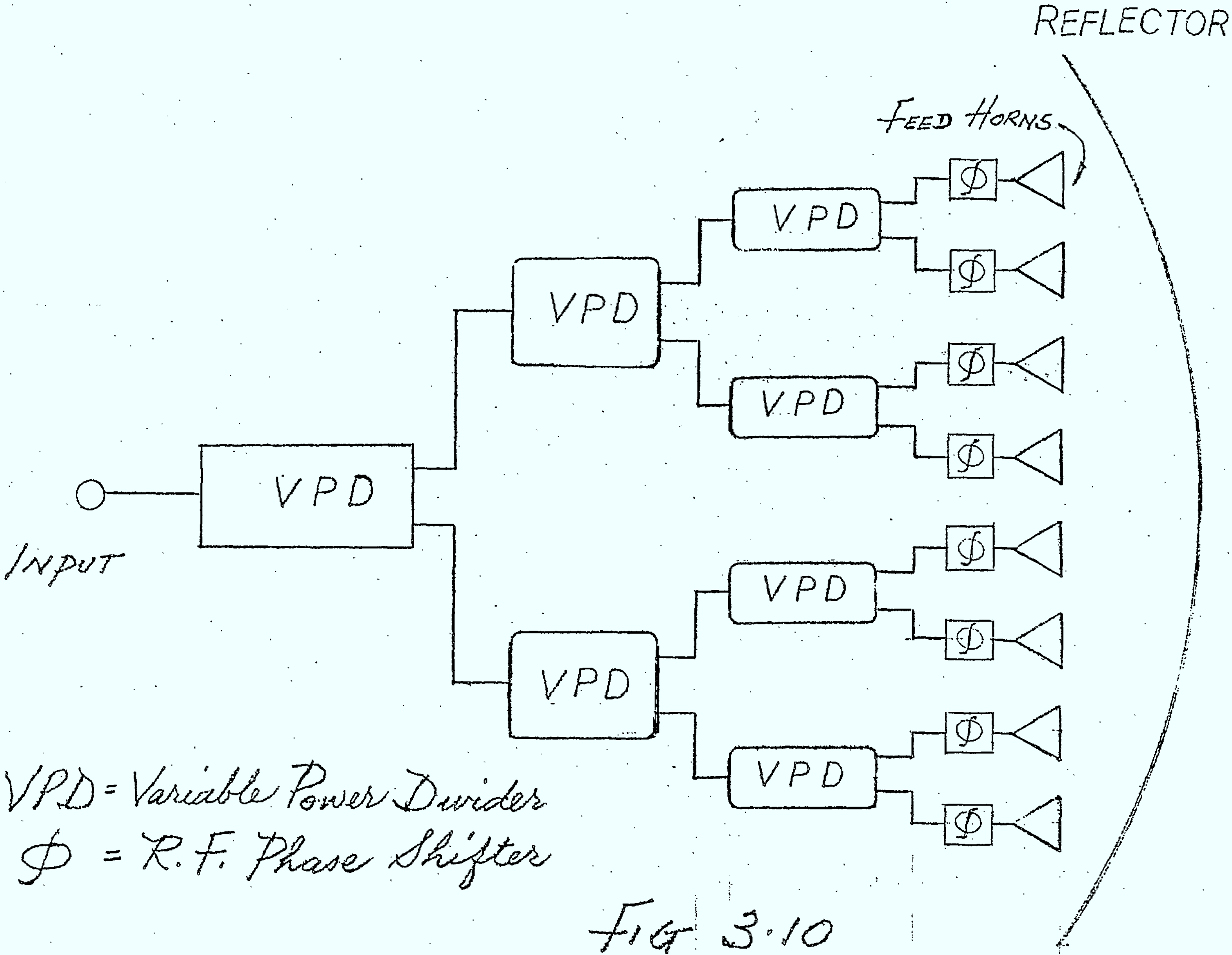
LP
(Vertically Polarized)

FIG. 3.8.

FIG 3.9

RAIN DEPOLARIZATION

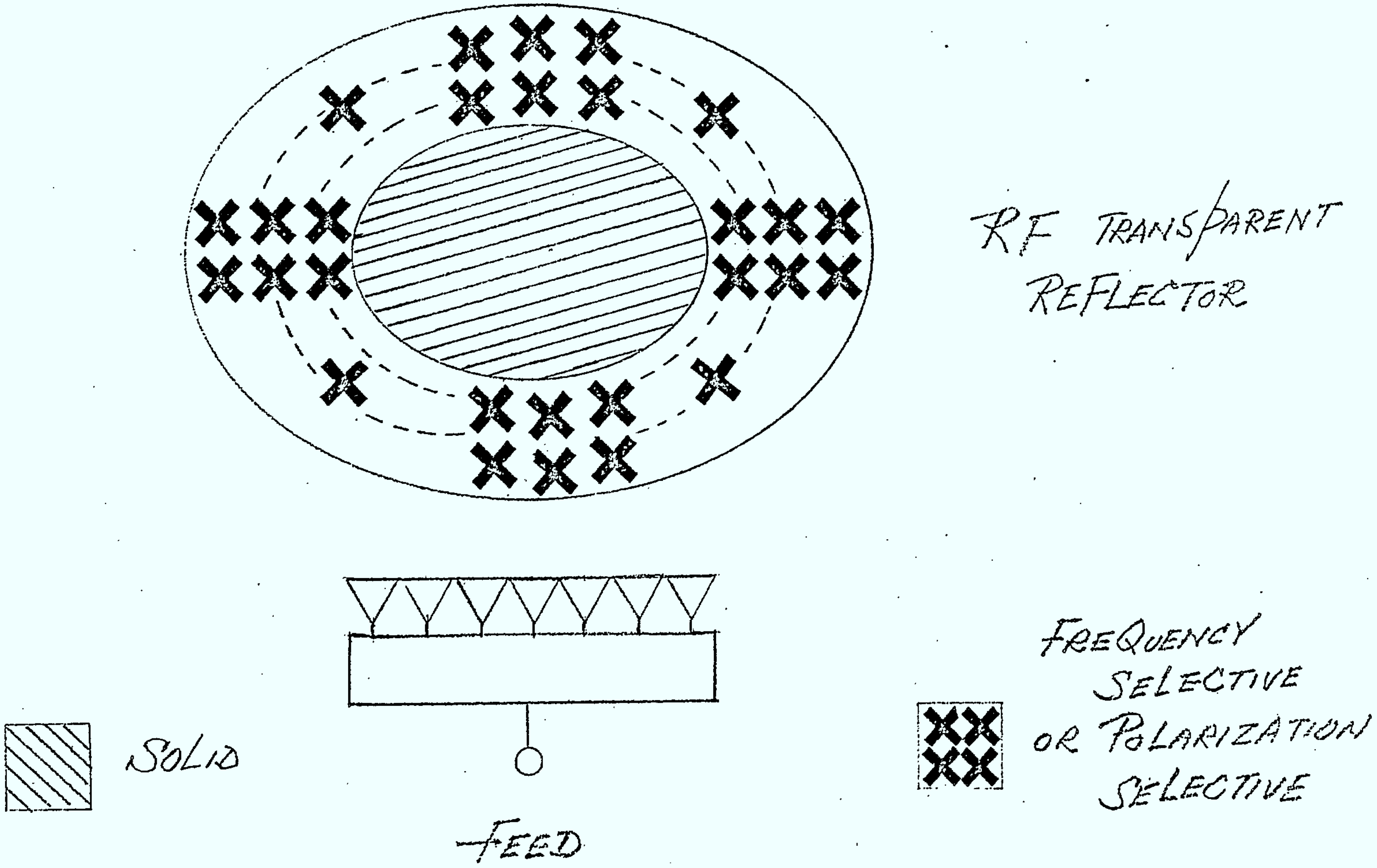


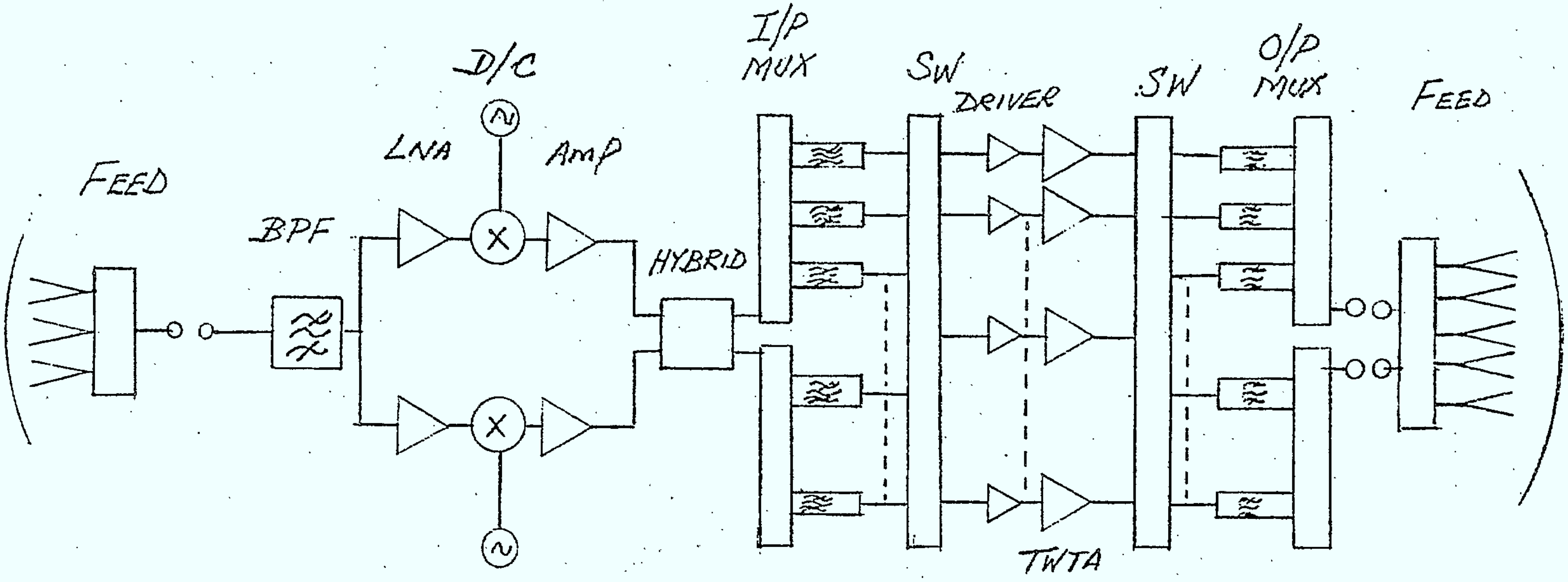


VPD = Variable Power Divider
ɸ = R.F. Phase Shifter

FIG 3.10

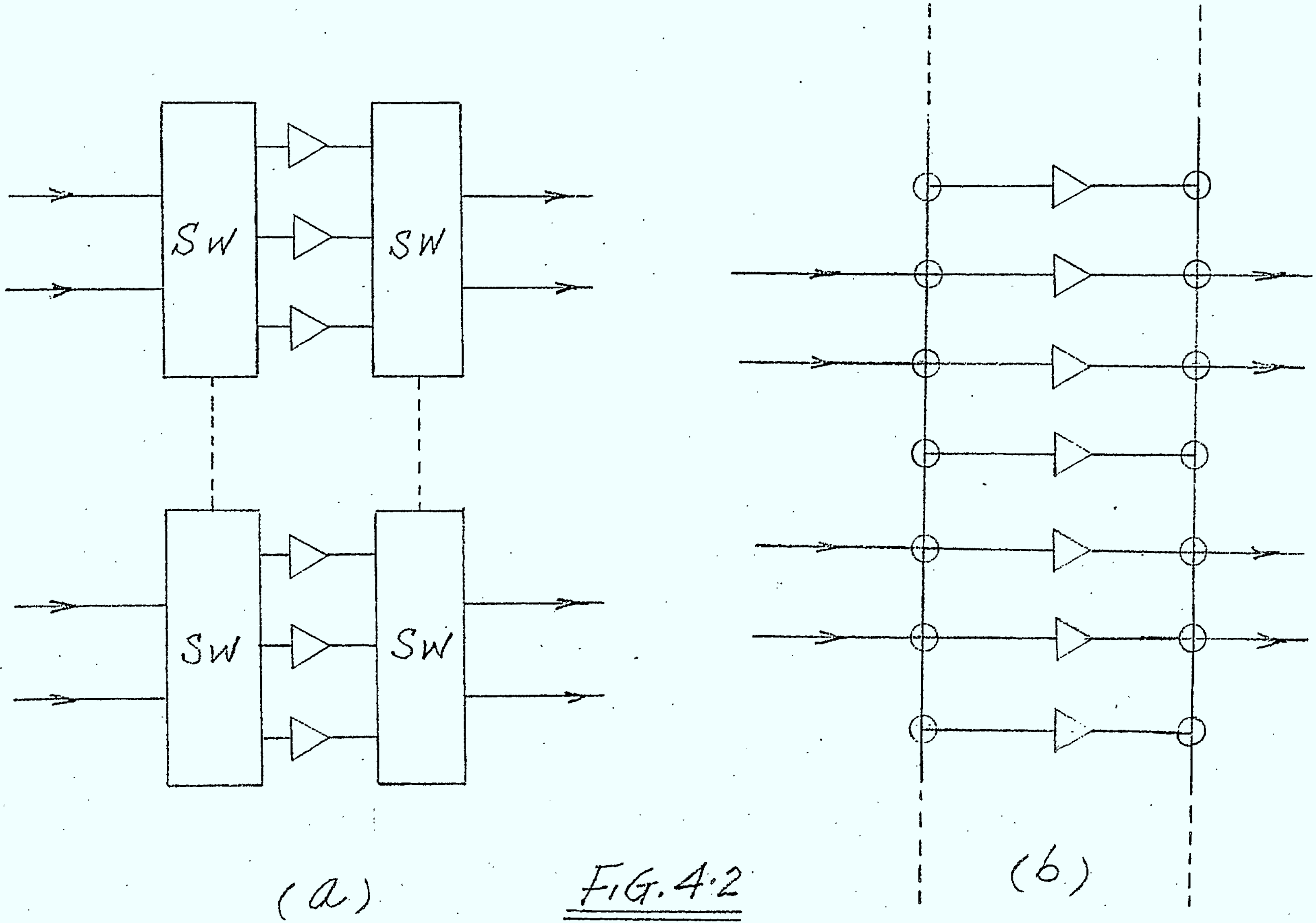
FIG. 3·11


RF TRANSPARENT REFLECTOR
FEED
SOLID
FREQUENCY SELECTIVE OR POLARIZATION SELECTIVE



N-CHANNELS M-AMPLIFIERS M≥N

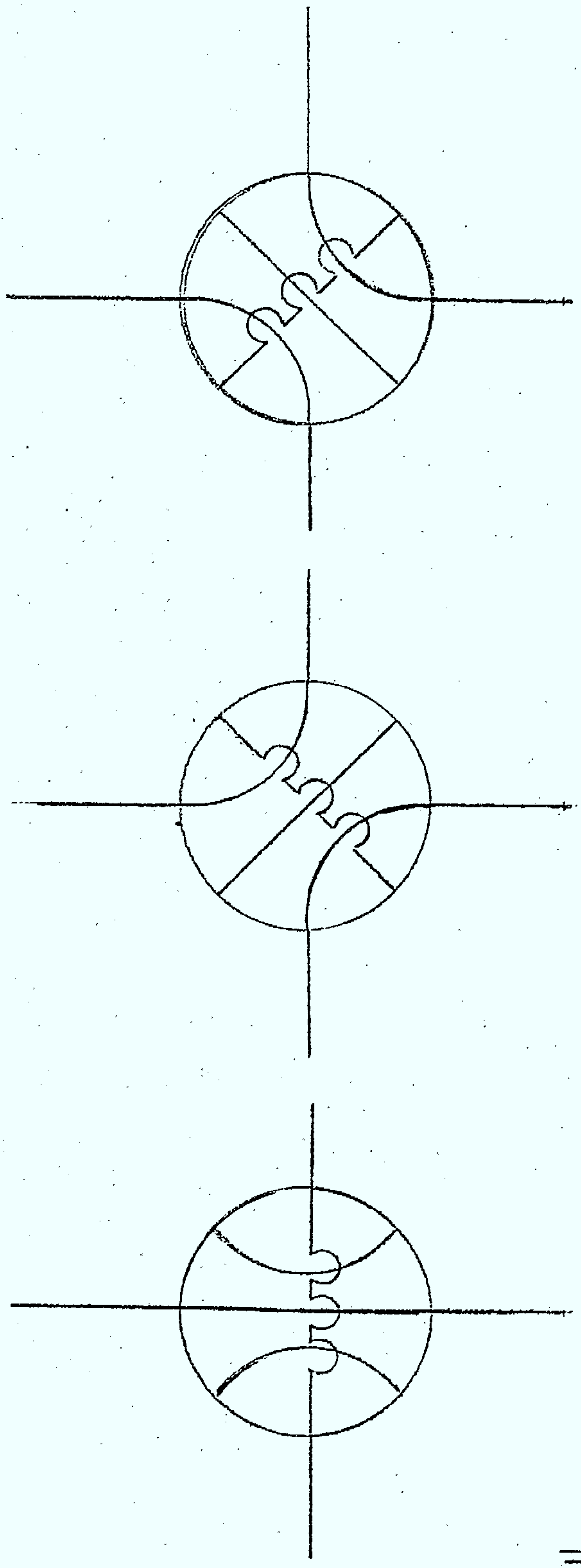
FIG. 4.1



(a)

(b)

FIG. 4·2



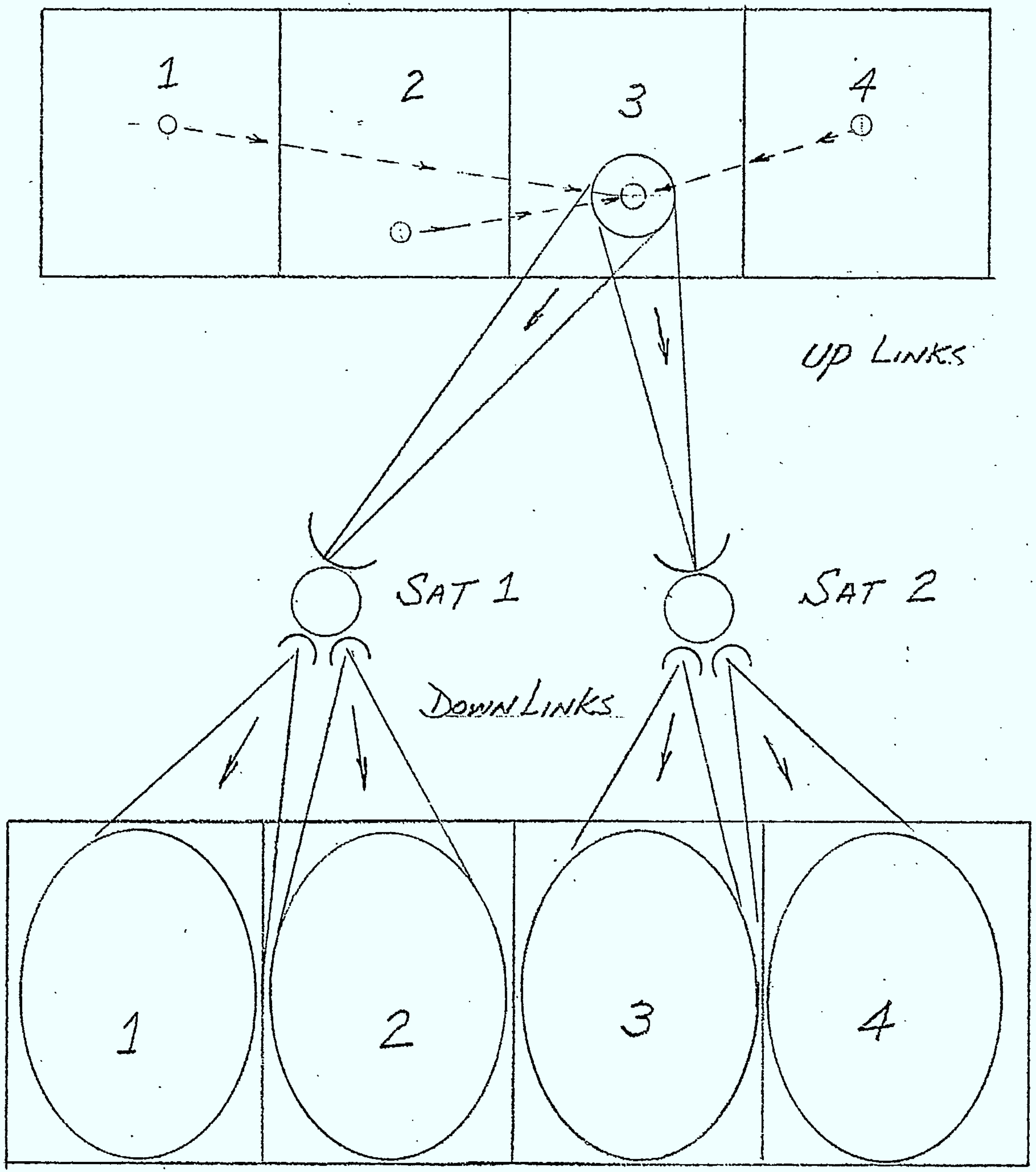
Position 1

Position 2

Position 3

FIG. 4·3

SERVICE AREAS.



SAT 1 Serves -
Areas 1 & 2

FIG. 5.1

SAT 2 Serves -
Areas 3 & 4

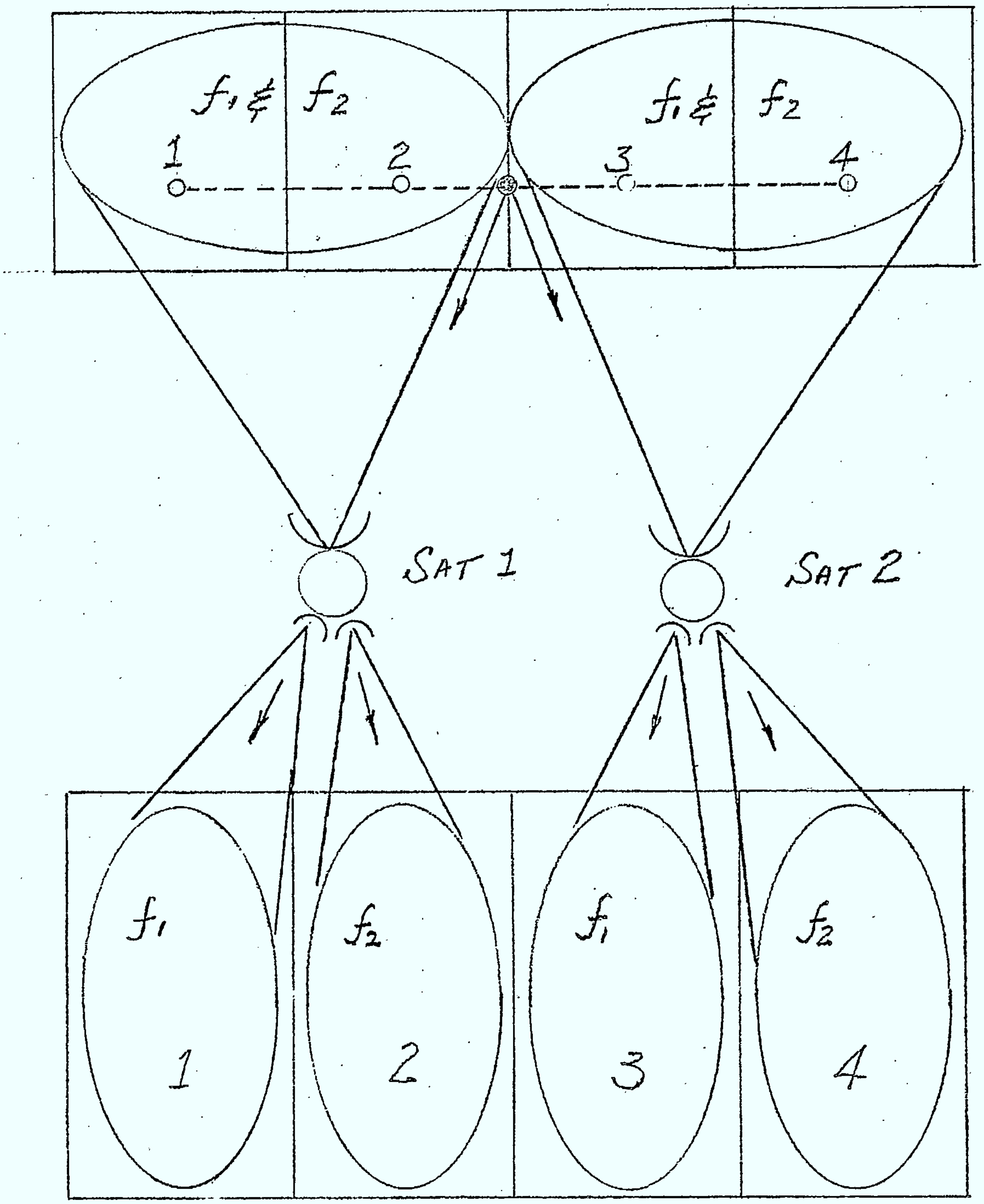


FIG 5·2

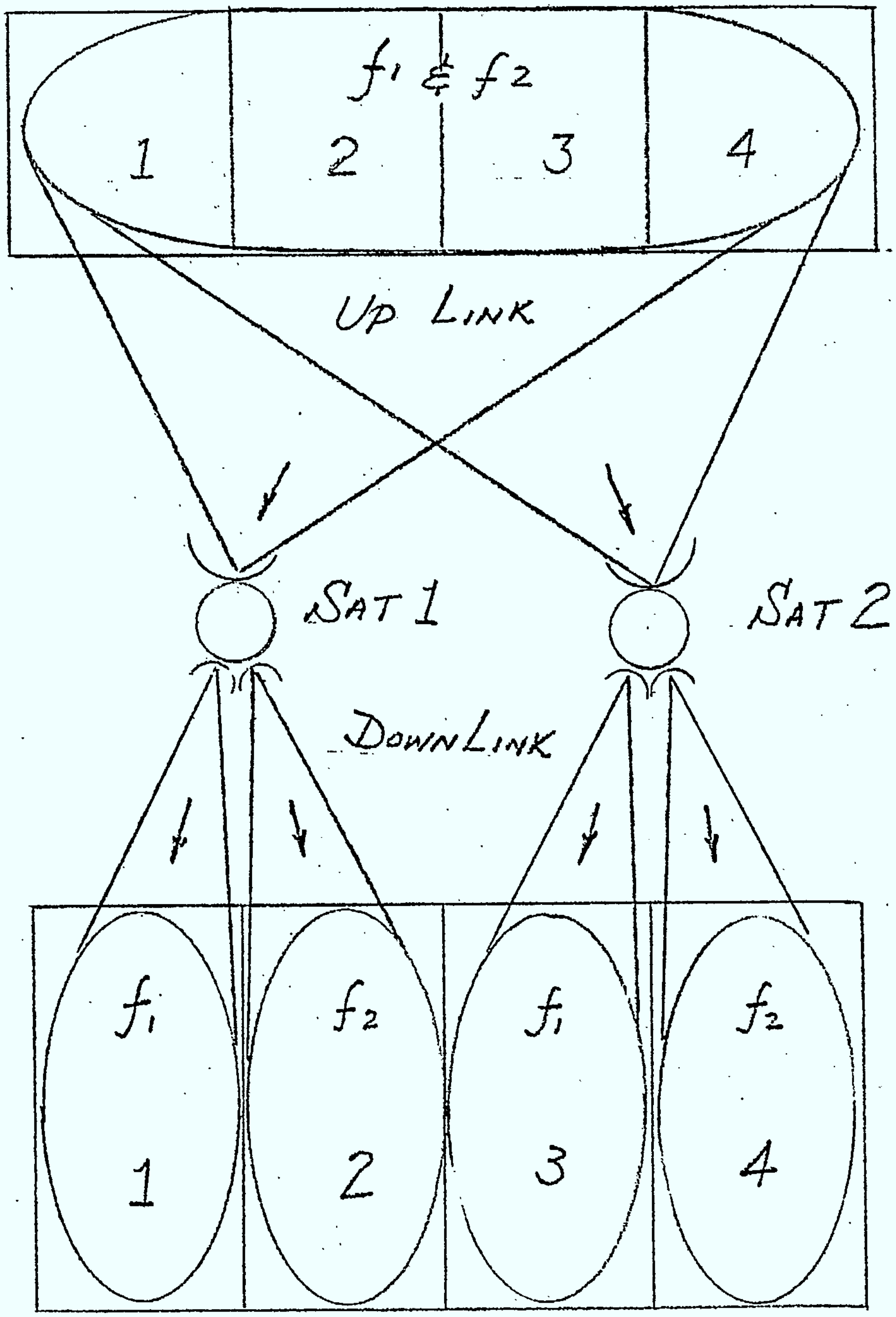
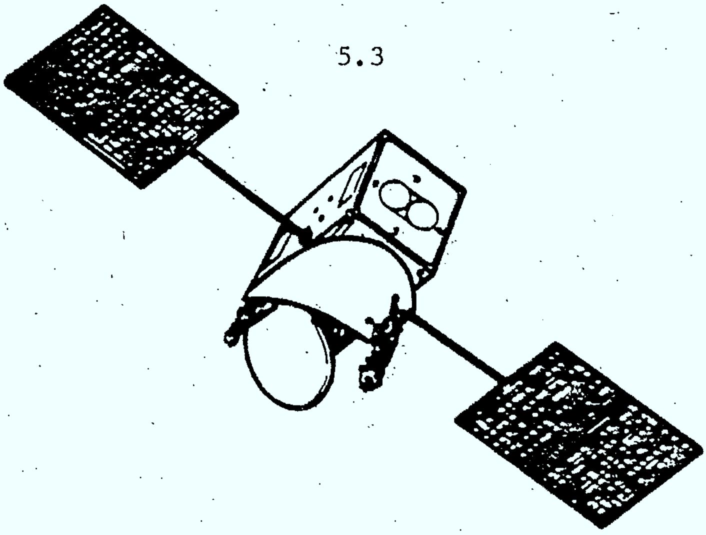


FIG 5.3

5.3



TITLE : ALTERNATIVE SPACECRAFT DESIGNS FOR U.S.
DIRECT BROADCAST SYSTEMS

AUTHOR : H. COHEN

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Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

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ALTERNATIVE SPACECRAFT DESIGNS FOR U. S. DIRECT BROADCAST SYSTEMS

INTRODUCTION

- SYSTEM DESIGN ASSUMPTIONS
- SPACECRAFT SYSTEM MODELLING
- COMMUNICATIONS CONSIDERATIONS
- LAUNCH VEHICLE CAPABILITY
- TECHNOLOGY
- EXAMPLE SPACECRAFT DESIGNS
- CONCLUSIONS

INTRODUCTION

THE PURPOSE OF THIS PAPER IS TO PRESENT A NUMBER OF ALTERNATIVE SPACECRAFT DESIGNS SUITABLE FOR U. S. DIRECT TO HOME BROADCAST SYSTEMS AT 12/18 GHz. A NUMBER OF SYSTEM DESIGN ASSUMPTIONS ARE INVOKED, SOME OF WHICH ARE PECULIAR TO REGION 2. THESE ARE IN CONTRAST WITH THE GROUNDRULES ADOPTED BY THE REGION 1-3 SYSTEM DESIGNERS FOLLOWING WARC 1977 AND 1979. THE ESSENTIAL RESULT IS A LOWER POWERED SATELLITE BECAUSE OF USE OF SHAPED BEAMS AND HIGHER G/T AT THE HOME.

LIMITED SYSTEM MODELLING, SUFFICIENT TO DERIVE SPACECRAFT SYSTEMS OF DIFFERENT SIZE, HAS BEEN PERFORMED. THIS SHOULD IN NO WAY BE CONFUSED WITH REGION 2 PLANNING OF ORBITAL CAPACITY FOR RARC 1983 NOW IN PROGRESS WHICH DOES MODELLING FAR BROADER IN SCOPE IN ORDER TO OPTIMIZE ORBIT CAPACITY. SPACECRAFT PROVIDING 1/4 SERVICE, 1/2 SERVICE AND FULL SERVICE ARE DEFINED. FULL SERVICE IS DEFINED AS 2-3 CHANNELS PER U. S. TIME ZONE PLUS SPOT BEAMS OVER A FEW DENSELY POPULATED AREAS.

COMMUNICATIONS SYSTEM CONSIDERATIONS INCLUDING COVERAGE AREAS, SHAPED BEAM ANTENNA DESIGN AND RF DOWNLINK POWER BUDGETS ARE SHOWN.

LAUNCH VEHICLE CAPABILITY BOTH FOR THE SPACE TRANSPORTATION SYSTEM AND VARIOUS EXPENDABLE BOOSTERS IS REVIEWED. A WIDE RANGE OF CAPABILITY WILL BE AVAILABLE IN THE 1984-5 TIME FRAME. KEY SPACECRAFT TECHNOLOGY IS SURVEYED AND FOUND TO BE AVAILABLE.

TYPICAL 3-AXIS SPACECRAFT DESIGNS INCLUDING COMPARATIVE POWER AND WEIGHT SUMMARIES FOR 3 CLASSES OF SPACECRAFT ARE INCLUDED.

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SYSTEM DESIGN ASSUMPTIONS

- DIRECT TV BROADCAST TO HOME AT 12.2 - 12.7 GHz
- (MODIFIED) TIME ZONE AND SPOT BEAM COVERAGE
  - 2 - 3 CHANNELS EACH
- UPLINK (17.3 - 18.1 GHz) FROM 1 - 2 SPOT BEAMS
- LINEAR OR CIRCULAR POLARIZATION
- SATELLITES WEST OF COVERAGE AREA FOR ECLIPSE PROTECTION
- HOME RECEIVER G/T ≈ 10 dB/°K
  - 0.6 - 1 METER DISH, 3 - 5 dB NOISE FIGURE
- C/N $\geq$ 14 dB (99% OF LEAST FAVORABLE MONTH)
- LAUNCH WITH SHUTTLE OR EXPENDABLES

SYSTEM DESIGN ASSUMPTIONS

THE ASSUMPTIONS LISTED ARE ONLY THOSE NECESSARY FOR SPACECRAFT DESIGN AND SIZING PURPOSES RATHER THAN FOR A TOTAL SYSTEM DESIGN OR REGION 2 PLANNING EXERCISE. TIME ZONE COVERAGE HAS GENERALLY BEEN ACCEPTED AS REASONABLE FOR U. S. SYSTEMS WITH THE OPTION OF ADDITIONAL SPOT BEAM COVERAGE FOR DENSELY POPULATED AREAS. TIME ZONE BOUNDARIES HAVE BEEN MODIFIED BY SOME USERS IN ORDER TO EQUALIZE COVERAGE AREAS THUS ENABLING THE USE OF IDENTICAL TRAVELLING WAVE TUBES (TWTs). UPLINK FROM ONLY A FEW SPOTS IS TAKEN AS A SIMPLIFYING ASSUMPTION CONSISTENT WITH THE REQUIREMENT OF AT LEAST ONE USER. THIS ENABLES DIPLEXING OF A FEW FEEDS - OPTIMIZED FOR THE DOWNLINK - AND MAKING UP FOR THE LOSS IN PERFORMANCE AT 17-18 GHz BY INCREASED UPLINK POWER AND APERTURE SIZE.

REGION 2 MUST DECIDE BETWEEN LINEAR AND CIRCULAR POLARIZATION. IN SOME CASES, LINEAR IS PREFERRED FOR THE SATELLITE ANTENNA IMPLEMENTATION SINCE IT ENABLES MULTIPLE REUSE OF THE APERTURE.

ECLIPSE PROTECTION - PREFERABLY TO 1:00 A.M. LOCAL TIME - IS PROVIDED TO THE MAXIMUM EXTENT POSSIBLE.

A HOME RECEIVER G/T OF THE ORDER 10 dB/°K IS A GENERALLY ACCEPTED FIGURE OF MERIT FOR U.S. SYSTEMS. THIS ENABLES COMPARATIVELY LOWER TRANSMITTER FOR THE SAME C/N USED IN WARC 77-79.

LAUNCH WITH SHUTTLE OR EXPENDABLES IS A NECESSARY REQUIREMENT IN THIS TRANSITION ERA.

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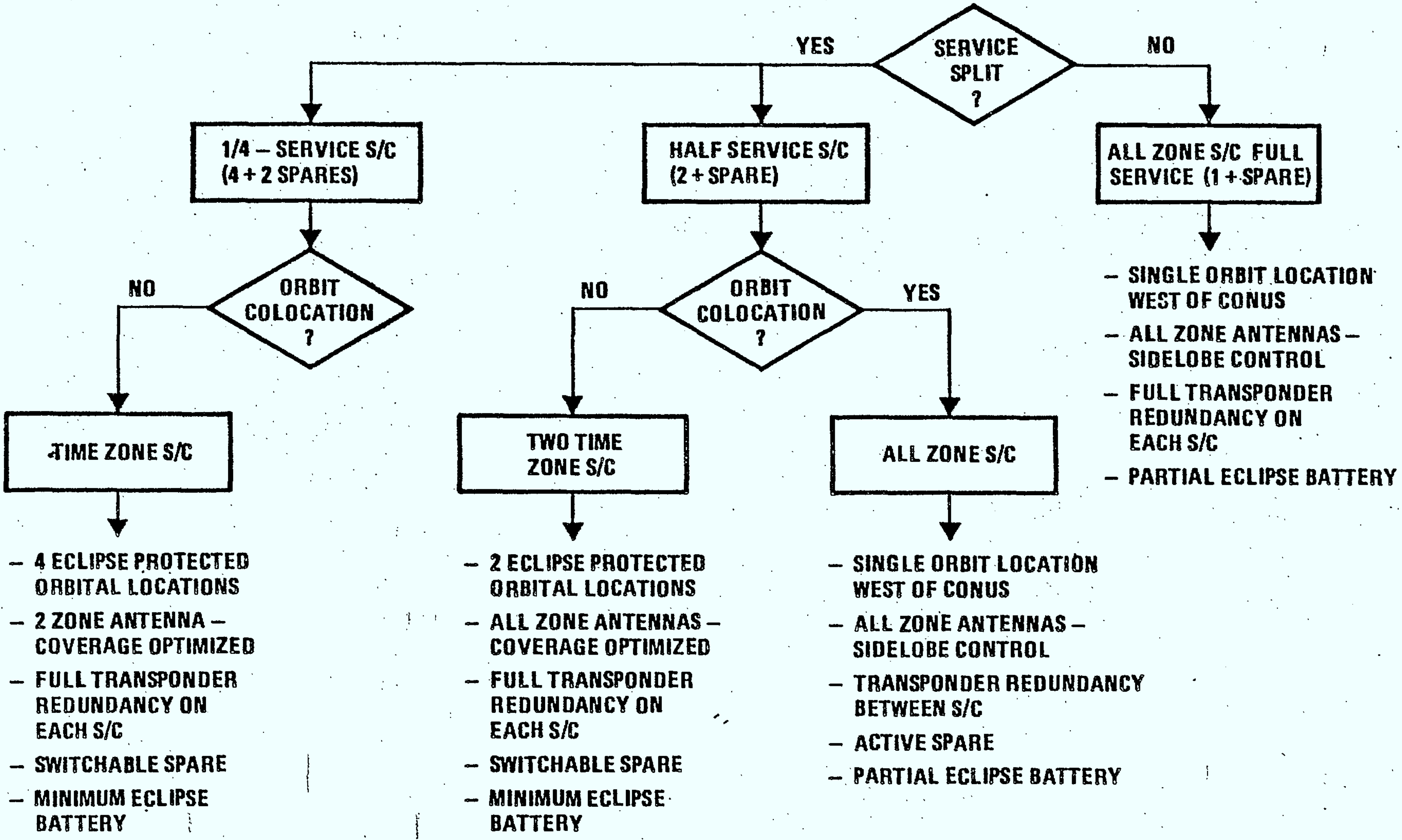
SPACECRAFT SYSTEM MODELLING



SERVICE SPLIT ?

YES

1/4 – SERVICE S/C (4 + 2 SPARES)

ORBIT COLOCATION ?

NO

TIME ZONE S/C

- 4 ECLIPSE PROTECTED ORBITAL LOCATIONS
- 2 ZONE ANTENNA – COVERAGE OPTIMIZED
- FULL TRANSPONDER REDUNDANCY ON EACH S/C
- SWITCHABLE SPARE
- MINIMUM ECLIPSE BATTERY

HALF SERVICE S/C (2 + SPARE)

ORBIT COLOCATION ?

NO

TWO TIME ZONE S/C

- 2 ECLIPSE PROTECTED ORBITAL LOCATIONS
- ALL ZONE ANTENNAS – COVERAGE OPTIMIZED
- FULL TRANSPONDER REDUNDANCY ON EACH S/C
- SWITCHABLE SPARE
- MINIMUM ECLIPSE BATTERY

YES

ALL ZONE S/C

- SINGLE ORBIT LOCATION WEST OF CONUS
- ALL ZONE ANTENNAS – SIDELOBE CONTROL
- TRANSPONDER REDUNDANCY BETWEEN S/C
- ACTIVE SPARE
- PARTIAL ECLIPSE BATTERY

NO

ALL ZONE S/C FULL SERVICE (1 + SPARE)

- SINGLE ORBIT LOCATION WEST OF CONUS
- ALL ZONE ANTENNAS – SIDELOBE CONTROL
- FULL TRANSPONDER REDUNDANCY ON EACH S/C
- PARTIAL ECLIPSE BATTERY

SPACECRAFT SYSTEM MODELLING

THIS GRAPHICAL PRESENTATION IS AN ATTEMPT TO SHOW A HIERARCHY OF SOME OF THE POSSIBLE SPACECRAFT SYSTEM SCENARIOS WHICH CAN BE USED TO PROVIDE U. S. TIME ZONE COVERAGE. THE MOTIVATION IS TO GENERATE A SET OF CRITERIA FOR THE DESIGN OF VARIOUS SIZES OF SPACECRAFT. SERVICE MAY BE PROVIDED BY EITHER A SINGLE LARGE SPACECRAFT, BY TWO HALF SERVICE SPACECRAFT EITHER COLOCATED OR LOCATED TO PROVIDE FULL ECLIPSE PROTECTION OR BY FOUR SPACECRAFT LOCATED TO PROVIDE FULL ECLIPSE PROTECTION.

THE LATTER SYSTEM IS ESSENTIALLY SYNONOMOUS WITH THE ONE IN THE FCC FILING (REF. 1) BY SATELLITE TELEVISION CORPORATION (COMSAT) AND IS REFERRED TO BELOW AS THE COMSAT SYSTEM. THE TWO COLOCATED SYSTEMS ARE BASED ON A RECENT NORDSAT STUDY (REF. 2, 3) PERFORMED BY TRW FOR THE NORDIC TELECOMMUNICATIONS ADMINISTRATION AND USE THE SAME NOMENCLATURE, MODEL A (1/2 SERVICE) AND MODEL D (FULL SERVICE). THE NON-COLOCATED 1/2 SERVICE SYSTEM WAS CONSIDERED BY COMSAT PRIOR TO ITS PRESENT FILING.

THE 1/2 SERVICE COLOCATED (NORDSAT) SPACECRAFT ARE DESIGNED TO SERVICE ALL TIME ZONES BUT WITH ONLY SUFFICIENT POWER FOR 1/2 THE SERVICE. THE SPARE IS ACTIVE. A COMPLETE SET OF NON-REDUNDANT COMMUNICATIONS EQUIPMENT IS PROVIDED AND REDUNDANCY IS PROVIDED BY INTERCHANGING CHANNELS BETWEEN SATELLITES. WITH COLOCATION, IT IS NOT POSSIBLE TO PROVIDE COMPLETE ECLIPSE PROTECTION FOR THE U. S. SINCE THE WESTERLY POSITION IS LIMITED BY THE ANGLE OF ELEVATION OF THE FAR EASTERN RECEIVERS.

THE NON-COLOCATED SYSTEMS SERVICE ONLY A DESIGNATED TIME ZONE OR 2 TIME ZONES. THE ANTENNA MUST BE RECONFIGURABLE OR SWITCHABLE TO COVER THE OTHER TIME ZONE OR 2 TIME ZONES BECAUSE OF THE INTERCHANGEABLE SPARE(S). THE SPARE CAN BE ACTIVE IN ONE OF TWO LOCATIONS ONLY. HENCE, FULL TRANSPONDER REDUNDANCY IS REQUIRED ON EACH SATELLITE. FULL ECLIPSE PROTECTION IS POSSIBLE.

COLOCATED SPACECRAFT ANTENNAS REQUIRE EXCELLENT SIDELOBE CONTROL SINCE COCHANNEL ISOLATION IS PROVIDED BY THE TRANSMIT ANTENNA. NON-COLOCATED SPACECRAFT CAN RELY ON HOME RECEIVE ANTENNA DISCRIMINATION THUS EASING THE SIDELOBE CONTROL REQUIREMENT.

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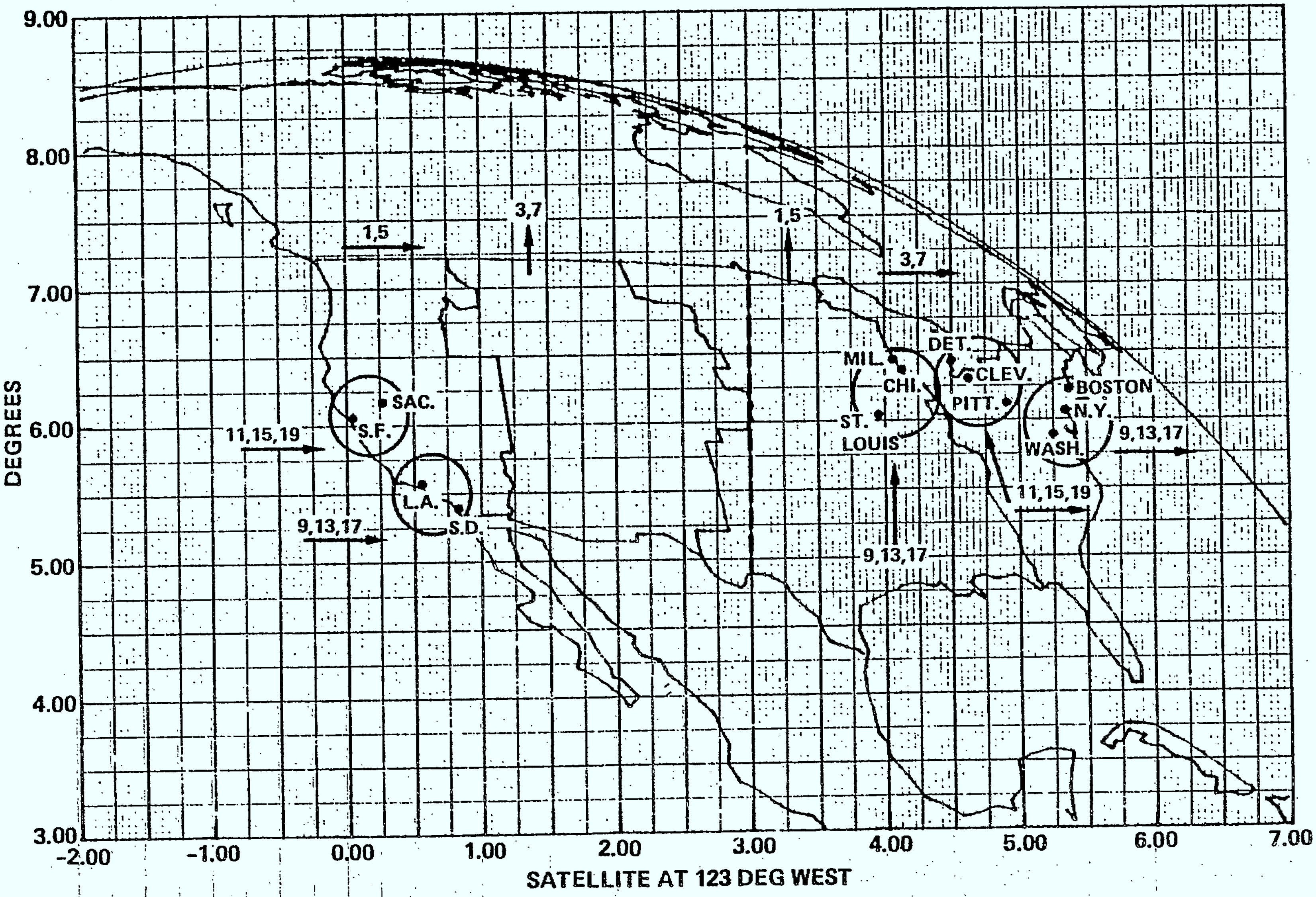
COVERAGE ZONES FOR COLOCATED SPACECRAFT



COVERAGE ZONES FOR COLOCATED SPACECRAFT

SINCE STC IS DESCRIBING ITS SYSTEM IN A SEPARATE PAPER THE COMMUNICATION SYSTEM CONSIDERATIONS WILL COVER THE ALTERNATIVE OF COLOCATED SATELLITES.

THE SERVICE AREAS INCLUDE THE FOUR U. S. TIME ZONES AND 5 SPOT BEAMS AS SEEN FROM A SATELLITE STATIONED AT 123° WEST LONGITUDE. FOR THIS LOCATION (ROUGHLY AT THE LONGITUDE OF SAN FRANCISCO), THE PACIFIC TIME ZONE (PTZ) IS ECLIPSED ROUGHLY AT MIDNIGHT LOCAL TIME. (HAWAII AND ALASKA WOULD BE ECLIPSED 2-3 HOURS EARLIER, LOCAL TIME.) THE ANGLE OF ELEVATION AT BOSTON IS APPROXIMATELY 20° FOR THIS SATELLITE LOCATION. FOR A SATELLITE LONGITUDE STATION OF 138°, SAN FRANCISCO ECLIPSE STARTS AT ROUGHLY 12:30 P.M. WHICH MIGHT BE ACCEPTABLE. THIS MUST BE TRADED WITH AN 8° ELEVATION ANGLE AT BOSTON WHICH COULD PROVIDE UNACCEPTABLE ATTENUATION.

THE DASHED LINE REPRESENTS A MODIFIED BOUNDARY BETWEEN CENTRAL AND MOUNTAIN TIME ZONES IN THE DIRECTION OF EQUALIZING AREAS. IN FACT, MODIFICATIONS OF ALL THE BOUNDARIES ARE NECESSARY IN ORDER TO TRULY EQUALIZE SERVICE ZONE AREAS. THIS PROCESS IS FACILITATED BY NON-COLOCATION AND HAS BEEN IMPLEMENTED IN THE COMSAT SYSTEM (REF. 1).

THE NUMBERS AND ARROWS REPRESENT CHANNEL NUMBERS AND SENSE OF POLARIZATION. FREQUENCIES ARE REUSED BY MEANS OF SPATIAL ISOLATION AND POLARIZATION DIVERSITY. CHANNEL SEPARATION IS WIDE ENABLING THE USE OF NON-CONTIGUOUS OUTPUT MULTIPLEXERS THUS MAKING THE DESIGN NON-CRITICAL.

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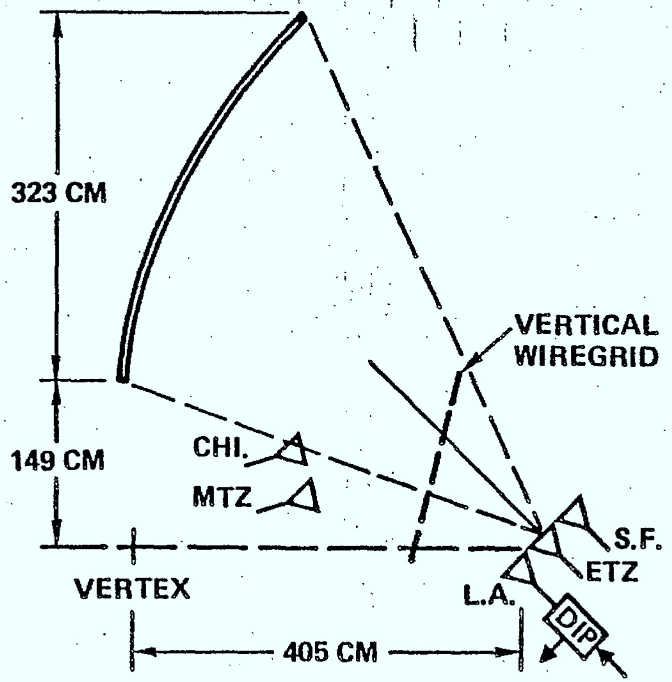
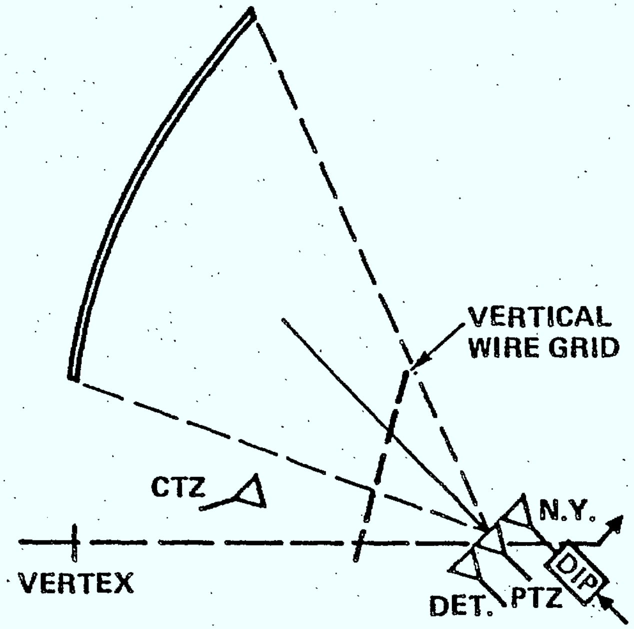
ANTENNA CONFIGURATION

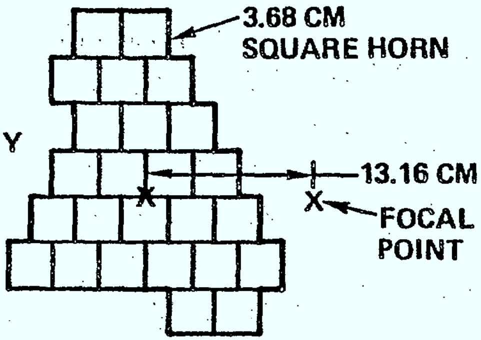
ANTENNA NO. 1

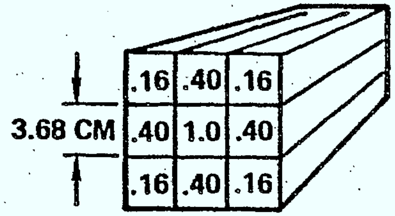


ANTENNA NO. 2



ETZ
FEED GEOMETRY





.16	.40	.16
.40	1.0	.40
.16	.40	.16

SPOT BEAM
FEED APERTURE AMPLITUDE
DISTRIBUTION

ANTENNA CONFIGURATION

A LINEARLY POLARIZED SPACECRAFT ANTENNA CONFIGURATION WHICH CAN IMPLEMENT THE COVERAGE REQUIREMENTS SHOWN ON THE PREVIOUS FIGURE IS ILLUSTRATED. IT IS BASED ON THE ANALYTICAL AND MEASURED RESULTS OBTAINED BY TRW IN A "KU-BAND MULTIPLE BEAM ANTENNA" STUDY PERFORMED FOR NASA LANGLEY (REF. 4). THE STUDY CONSISTED OF DEMONSTRATING CONTIGUOUS CONUS COVERAGE WITH FREQUENCY REUSE (15 BEAMS AND 2 SETS OF FREQUENCIES OR 7.5 TIMES REUSE) AND ALSO DOING A SHAPED BEAM COVERAGE OF THE U. S. EASTERN TIME ZONE (ETZ) WITH 2 SETS OF FREQUENCIES. THE SAME BASIC FEED ELEMENTS AND TECHNIQUES ARE EMPLOYED HERE.

NOTE THAT EXCELLENT SIDELOBE CONTROL IS REQUIRED FOR FREQUENCY REUSE - DOWN APPROXIMATELY 35 dB FROM PEAK TO THE BOUNDARY OF THE NEXT REGION REUSING THE FREQUENCY (i.e., FROM THE CENTER OF THE N. Y. SPOT TO THE BOUNDARY OF THE CHICAGO SPOT). THIS IS ACHIEVED USING THE 9 HORN FEED SHOWN. SIMILARLY, THE 25 HORN ETZ FEED EMPLOYS SPECIAL TECHNIQUES OF SIDELOBE CONTROL SO THAT THE FREQUENCIES CAN BE REUSED IN THE MOUNTAIN TIME ZONE. THE USE OF POLARIZATION DIVERSITY PROVIDES ADDITIONAL INSURANCE PLUS FACILITATING THE FEED CONFIGURATION MECHANIZATION.

TWO REFLECTORS EMPLOYING WIRE GRID POLARIZATION DIPLEXERS AND SETS OF MULTIPLE FEEDS MAKE UP THE ANTENNA CONFIGURATION. NOTE THAT THE WIRE GRID IS REFLECTIVE TO ONE SENSE OF POLARIZATION AND TRANSPARENT TO THE OPPOSITE POLARIZATION. THIS ENABLES FULL REUSE OF THE APERTURE. THE 4 TIME ZONE FEEDS ARE LOCATED ONE ON EACH OF THE FOUR AVAILABLE FOCAL POINTS. THE FEEDS CORRESPONDING TO SPOT BEAMS OVERLAYING VARIOUS TIME ZONES ARE LOCATED IN NON-INTERFERING POSITIONS, i.e., THE N. Y. SPOT BEAM FEED IS LOCATED WITH THE PTZ FEED, ETC.

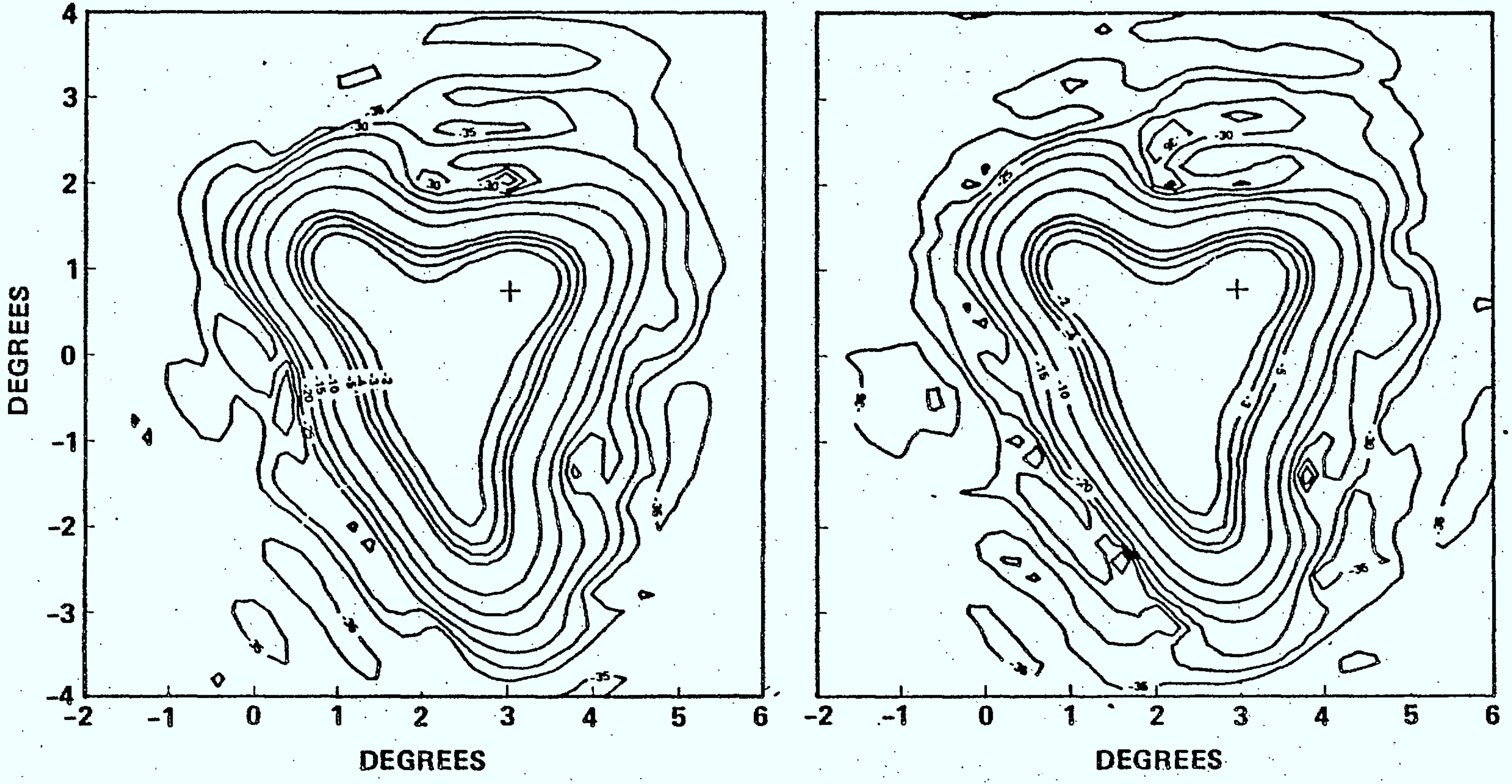
THE NEW YORK AND LOS ANGELES FEEDS ARE DIPLEXED TO PROVIDE UPLINK COVERAGE.

THE 3.2 METER REFLECTOR DIAMETER IS SIZED BY THE 0.6° SPOT BEAM. FOR A TIME ZONE SYSTEM WITHOUT SPOT BEAMS, THE REFLECTOR DIAMETER CAN BE AS SMALL AS 2.3 METERS (REF. 4). FURTHER, AS DEMONSTRATED IN (REF. 4), ALL 4 TIME ZONES (WITHOUT SPOT BEAMS) CAN BE IMPLEMENTED REUSING A SINGLE REFLECTOR.

AN ALTERNATE IMPLEMENTATION USES TWO SETS OF VERTICAL AND HORIZONTAL GRIDDED REFLECTORS AS IN RCA SATCOM AND SBS. TEST RESULTS DEMONSTRATED THAT THE IMPLEMENTATION SHOWN PROVIDES SUPERIOR CROSSPOL ISOLATION (REF. 4).

COMPARISON OF CALCULATED AND MEASURED GAIN CONTOURS

FREQUENCY = 11.7 GHz



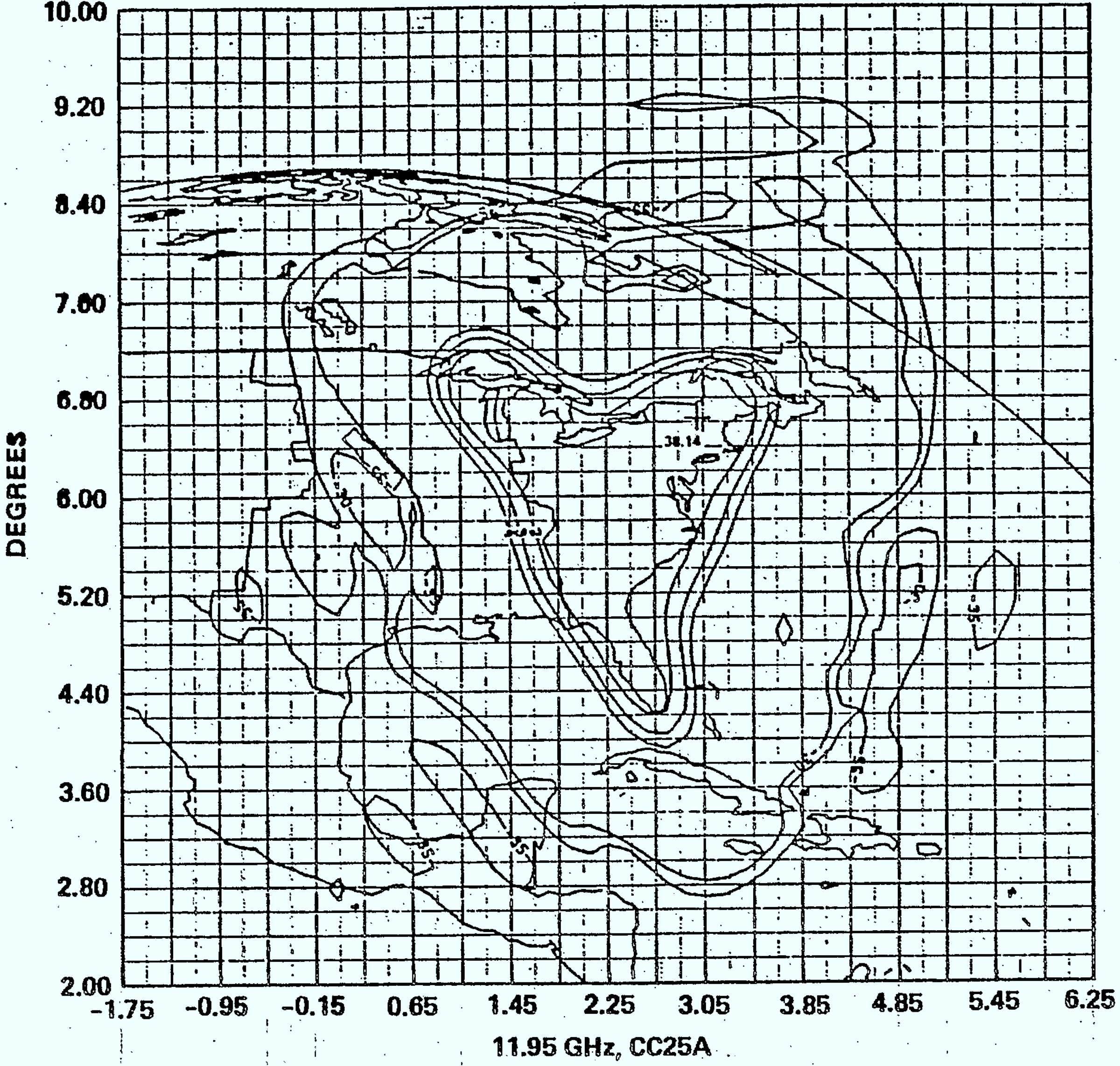
CALCULATED CONTOURS

MEASURED CONTOURS

COMPARISON OF CALCULATED AND MEASURED GAIN CONTOURS

THIS FIGURE IS A COMPARISON OF CALCULATED AND MEASURED GAIN CONTOURS FOR THE EASTERN TIME ZONE EMPLOYING THE 25 HORN FEED SHOWN ON THE PREVIOUS FIGURE. THE SPACECRAFT IS LOCATED AT 98°W. EXCEPT FOR THE DETAILS OF THE SIDELOBE STRUCTURE THERE IS EXCELLENT AGREEMENT BETWEEN COMPUTATION AND TEST RESULTS.

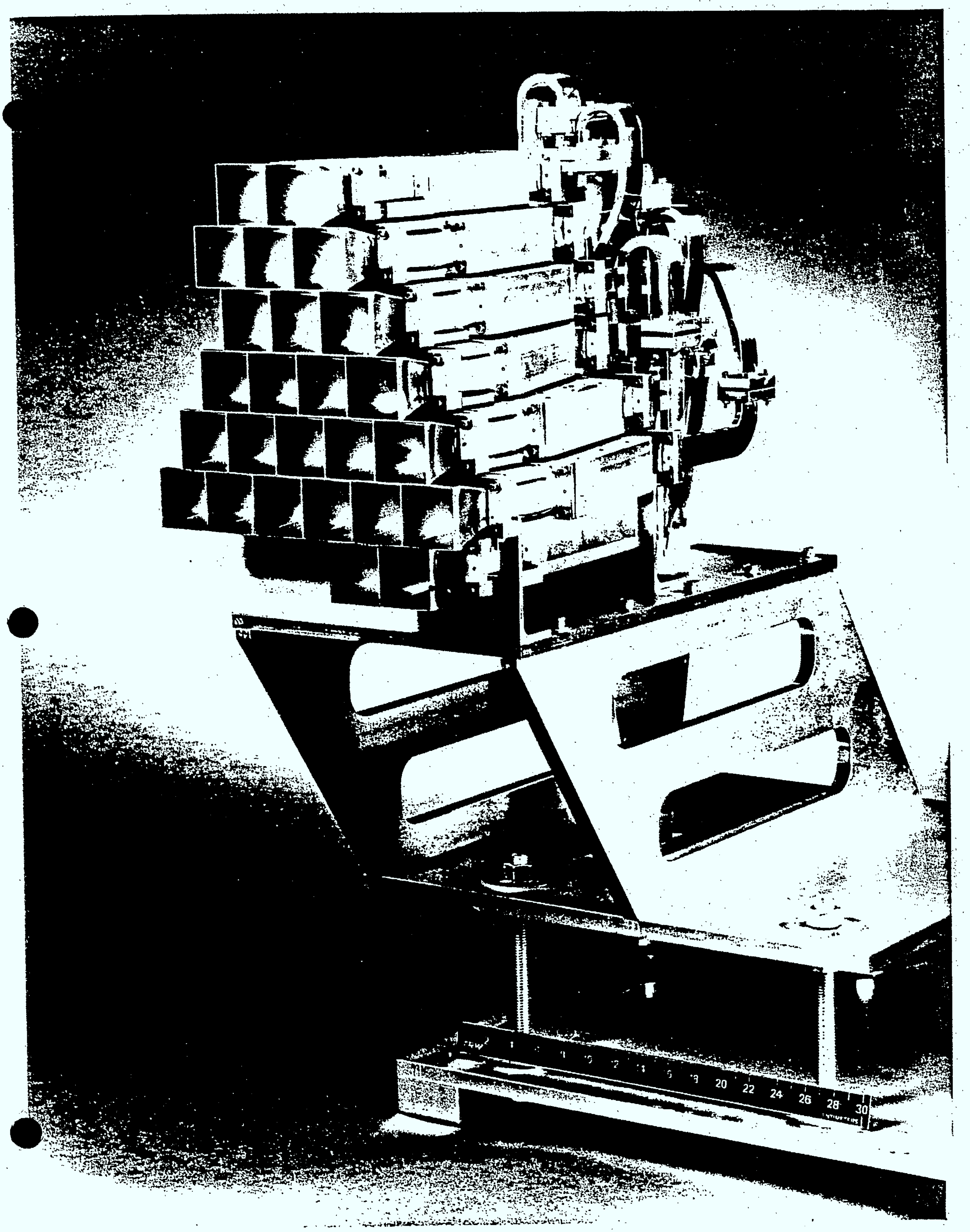
BEAM ISOLATION CONTOURS AT 11.95 GHz



BEAM ISOLATION CONTOURS AT 11.95 GHz

THIS FIGURE SHOWS THE GAIN CONTOURS OVERLAYED ON THE EASTERN TIME ZONE COVERAGE AREA AS SEEN FROM 98° W. NOTE THAT THE COVERAGE PATTERN IS BROAD AND COVERAGE IS ACHIEVED AT ROUGHLY THE -2 dB CONTOUR. THE OVERALL COVERAGE GAIN CAN PROBABLY BE IMPROVED BY USING A LARGER REFLECTOR WITH A HIGHER PEAK GAIN AND MORE PEAKED COVERAGE PATTERN ACHIEVING COVERAGE AT THE -3-4 dB CONTOUR LEVEL. THIS ANTENNA WILL HAVE A HIGHER GAIN SLOPE AT EDGE OF COVERAGE AND BE MORE SUSCEPTIBLE TO POINTING ERRORS.

NOTE THE EXCELLENT ISOLATION ACHIEVED AT THE BOUNDARY OF THE MOUNTAIN TIME ZONE WHERE THE SIDELOBE LEVEL IS -35 dB. THIS ASSURES FREQUENCY REUSE FEASIBILITY.



20
22
24
26
28
30

ETZ FEED CLUSTER

THIS IS A PHOTOGRAPH OF THE 25 HORN FEED CLUSTER BREADBOARD BUILT AND TESTED BY TRW (REF. 4). NOTE THE SCALE IN THE PHOTO. THE MAXIMUM WIDTH IS 22 cm. (8.7 IN.) AND THE MAXIMUM HEIGHT IS 25.8 cm. (10.1 IN.).

NOTE THAT THE STUDY (REF. 4) WAS CONDUCTED FOR THE 11.7-14.5 GHz FREQUENCY BAND AND THAT THE DESIGN PROVIDED QUITE UNIFORM PERFORMANCE ACROSS THE ENTIRE BAND.

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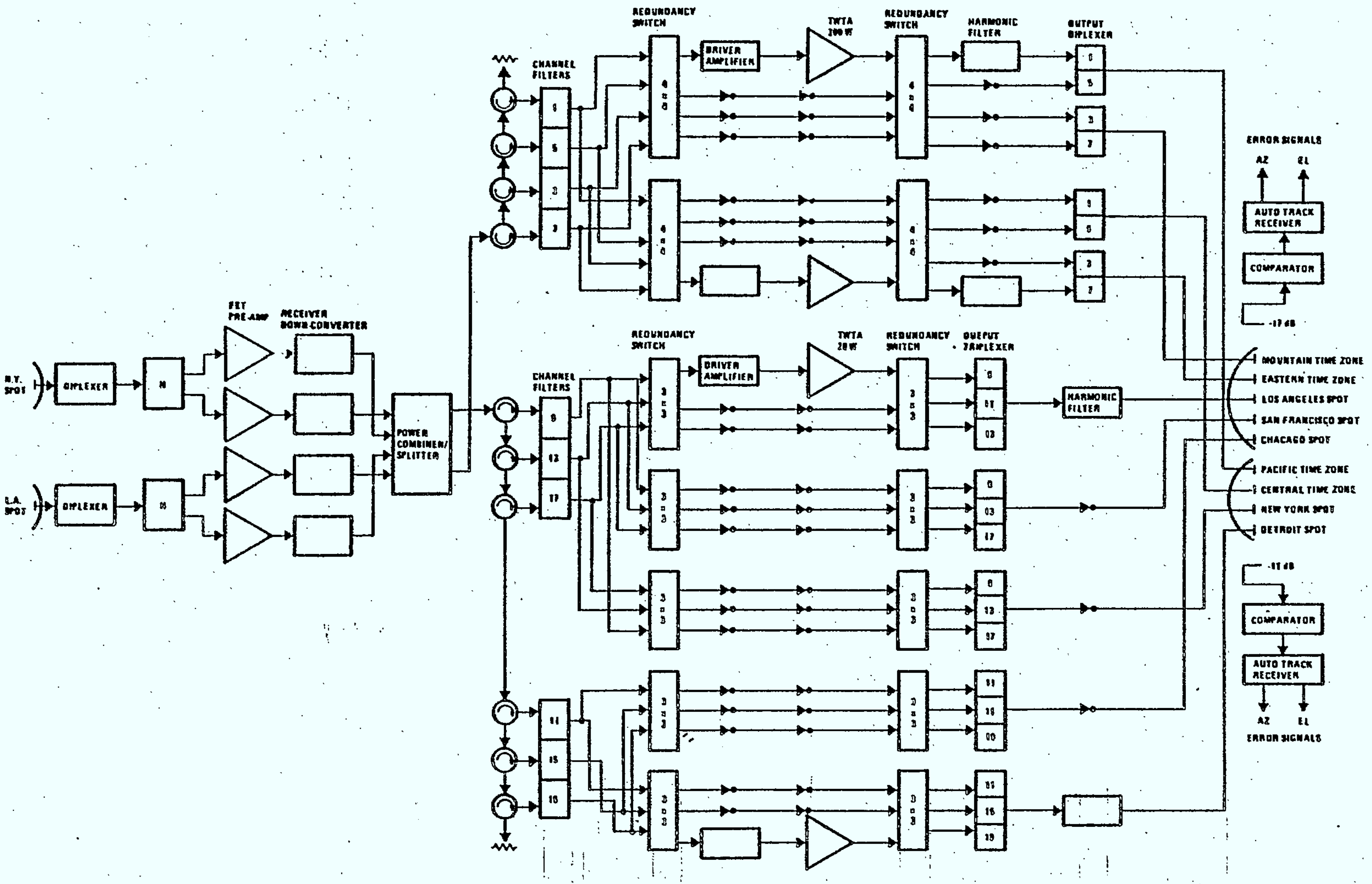
MODEL A COMMUNICATIONS TRANSPONDER



MODEL A COMMUNICATIONS TRANSPONDER

THE MODEL A COMMUNICATIONS TRANSPONDER PROVIDES A COMPLETE NON-REDUNDANT SET OF FULL SERVICE EQUIPMENT. THE CONCEPT AND NOMENCLATURE IS BASED ON THE NORDSAT STUDY (REFs 2, 3). ONLY 1/2 THE SERVICE IS PROVIDED BY A SINGLE SATELLITE. HENCE, THE COLOCATED 2 SATELLITES PLUS SPARE PROVIDE EXCELLENT ON-ORBIT REDUNDANCY. THIS WAS CONFIRMED BY A RELIABILITY, REPLENISHMENT STUDY (REFs 2, 3).

THE TRANSPONDER FOR A DIRECT BROADCAST SATELLITE IS CONCEPTUALLY QUITE SIMPLE. COMPLEXITY IS INTRODUCED ONLY BY THE PROLIFERATION OF TRANSMIT EQUIPMENT. THE UPLINK SIGNALS ARE PRE-AMPLIFIED AND DOWNCONVERTED TO THE TRANSMIT FREQUENCY BAND AND THEN CHANNEL SEPARATED IN THE INPUT MULTIPLEXERS. THE 16-20 Mhz BANDWIDTH SIGNALS ARE THEN AMPLIFIED THROUGH SOLID STATE DRIVERS AND EITHER 20 WATT OR 200 WATT TWTAs, COMBINED IN OUTPUT MULTIPLEXERS AND THEN ROUTED TO THE APPROPRIATE TRANSMIT FEEDS. REDUNDANCY SWITCHES ARE USED IN THE TWTA CHAINS PROVIDING LIMITED AMPLIFIER INTERCHANGEABILITY. HARMONIC FILTERS PROVIDE OUT OF BAND PROTECTION TO SUCH SERVICES AS THE RADIO ASTRONOMY BANDS.

A SET OF 2 RF SENSORS IS SHOWN ON THE RIGHT HAND SIDE OF THE BLOCK DIAGRAM. THESE COULD BE IMPLEMENTED BY COUPLING OFF FROM 4 OF THE 9 HORN FEEDS WITH SIGNALS EMANATING FROM N. Y. AND LOS ANGELES. THE FOUR AZ EL SIGNALS WOULD BE FED TO THE ATTITUDE CONTROL ELECTRONICS WHICH WOULD DERIVE PITCH, ROLL AND YAW ATTITUDE ERROR SIGNALS FOR SPACECRAFT POINTING.

CHANNEL SPACING IS WIDELY SEPARATED, TYPICALLY 50-60 Mhz BETWEEN BAND CENTERS FOR A 16-18 Mhz CHANNEL BANDWIDTH. THIS ENABLES A NON-CRITICAL OUTPUT MULTIPLEXER DESIGN WITH LOW CIRCUIT LOSS. THERE IS FLEXIBILITY IN THE FILTER DESIGN TO HELP CIRCUMVENT HIGH POWER BREAKDOWN (MULTIPACTION) SHOULD IT BECOME PROBLEMATICAL.

RF POWER BUDGETS

ITEM	EASTERN TIME ZONE	NY SPOT (0.6°)
OUTPUT POWER (EOL), dBW	22.9	12.9
OUTPUT LOSSES, dBW	1.3	1.4
ANTENNA PEAK GAIN, dB	38.2	47.6
PEAK EIRP (EOL), dBW	59.9	59.2
RELATIVE GAIN (EOC), dB	-2.0	-3.0
SPACE LOSS (12.5 GHz), dB	206.4	206.4
RECEIVE CARRIER, dBW	-148.5	-150.2
TERMINAL G/T, dB/°K	10.0	10.0
RECEIVE C/N_0, dB-Hz	90.1	88.4
RECEIVER NOISE BW (16 MHz), dB	72.0	72.0
CLEAR WEATHER C/N, dB	18.1	16.4
REFERENCE C/N, dB	14.0	14.0
MARGIN, dB	4.1	2.4

RF POWER BUDGETS

SIMPLIFIED RF POWER BUDGETS ARE SHOWN TO PROVIDE AN OVERVIEW OF THE PERFORMANCE ACHIEVED AND THE LEVELS OF SOME OF THE KEY PARAMETERS. TAKING THE EASTERN TIME ZONE FIRST, NOTE THAT THE USE OF A 200 WATT TUBE IN COMBINATION WITH A SHAPED BEAM RESULTS IN A PEAK EIRP OF APPROXIMATELY 60 dBW. NOTE THAT COMPARATIVE VALUES FOR NORDSAT WERE IN THE 66-68 dBW RANGE (REF. 2). THE OUTPUT LOSSES ARE BASED ON THE NORDSAT STUDY (REF. 2). USING A RELATIVE EDGE OF COVERAGE GAIN OF -2 dB, A TERMINAL G/T = 10 dB/°K AND A RECEIVER NOISE BAND WIDTH OF 16 MHz, THE CLEAR WEATHER C/N IS 18.1 dB. THIS PROVIDES A 4.1 dB MARGIN COMPARED WITH A REFERENCE OF 14 dB FOR ADVERSE SYSTEM TOLERANCES WHICH CAN BE OF THE ORDER OF 0.7 dB, ATTITUDE CONTROL ERRORS OF 0.3-0.5 dB AND RAIN ATTENUATION. THE ADEQUACY OF THIS MARGIN WOULD BE A FUNCTION OF SYSTEM USER REQUIREMENTS. IT APPEARS TO BE REASONABLE ESPECIALLY WHEN COMPARED WITH A THRESHOLD C/N = 10 dB.

A COMPARABLE SET OF NUMBERS FOR THE SPOT BEAM USING A 20 WATT TUBE RESULTS IN A SMALLER MARGIN. A 30 WATT TUBE WOULD PROVIDE APPROXIMATELY THE SAME 4 dB MARGIN WITH RESPECT TO 14 dB.

S/C TECHNOLOGY

ITEM	FEATURES	POTENTIAL SUPPLIERS
ANTENNA	• HIGH GAIN, CONTOUR MATCHING – OVERSIZE REFLECTOR – MULTIPLE FEED • SIDELOBE CONTROL, LOW CROSSPOL	SPACECRAFT CONTRACTOR SPAR
HIGH POWER TWT (50-260W)	• LONG LIFE, DISPENSER CATHODE (7-10 YRS) • MULTIPLE COLLECTOR, HIGH EFFICIENCY (~ 50%) • HIGH COLLECTOR/BODY DISSIPATION (65%/35%)	AEG/TELEFUNKEN HUGHES EDD THOMSON/CSF
TWT EPC	• HIGH VOLTAGE (6-12 KV) • HIGH EFFICIENCY (88-90%) • PACKAGING (POTTED VS OPEN)	SPACECRAFT CONTRACTOR AEG/TELEFUNKEN HUGHES/EDD
HIGH POWER MULTIPLEXER	• HIGH Q (LOW LOSS) • AVOID MULTIPACTION	SPACECRAFT CONTRACTOR SPAR, COMDEV
SOLAR ARRAY (2-6 KW)	• LIGHTWEIGHT (25-30 KG/KW EOL)	SPACECRAFT CONTRACTOR AEROSPATIALE, MBB, SPAR
HEAT PIPE RADIATOR	• SIMPLE OR VARIABLE CONDUCTANCE	SPACECRAFT CONTRACTOR
ASCENT STAGE (PERIGEE/APOGEE PROPULSION)	• FLEXIBLE (VARIOUS S/C WEIGHTS) • EFFICIENT (PERFORMANCE, LENGTH) • MINIMUM AVIONICS (USE S/C)	SPACECRAFT CONTRACTOR

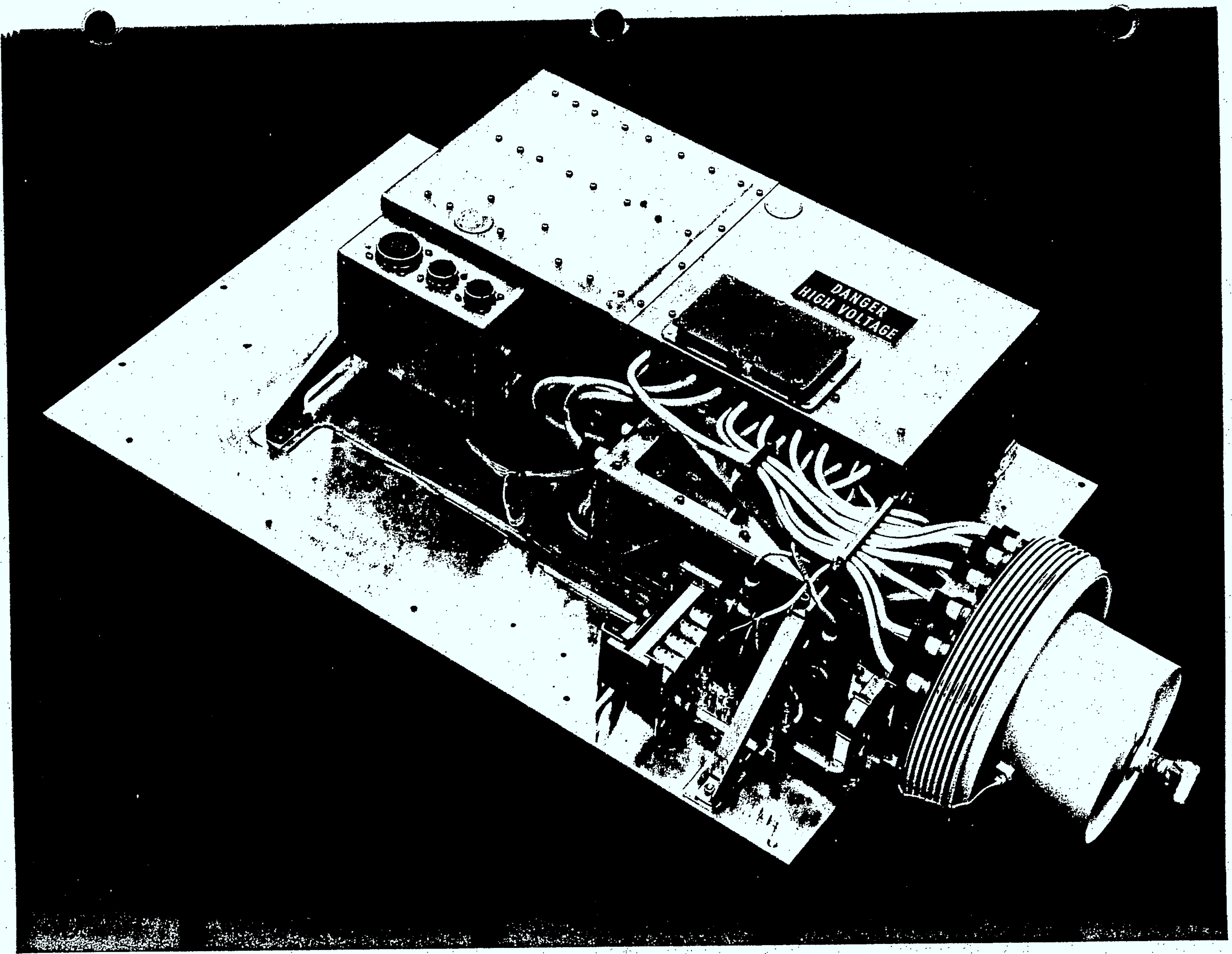
SPACECRAFT TECHNOLOGY

THIS CHART TABULATES THE FEATURES OF AND POTENTIAL SUPPLIERS FOR THE KEY SPACECRAFT TECHNOLOGY FOR A DIRECT BROADCAST SATELLITE. SIGNIFICANTLY, ALL OF THE TECHNOLOGY LISTED IS EITHER DEMONSTRATED OR CAN BE DEVELOPED IN TIME FOR A LAUNCH IN THE 1984-5 TIME FRAME.

THE ANTENNA HAS BEEN DISCUSSED IN DETAIL BELOW. TRAVELLING WAVE TUBES (TWTs) UP TO 260 WATTS POWER OUTPUT ARE IN DEVELOPMENT FOR THE FRANCO-GERMAN DBS PROGRAM. THESE ARE LONG LIFE HELIX TUBES WITH ATTRIBUTES AS LISTED. POWER CONDITIONERS (EPC) FOR THE TWTs ARE AN EQUALLY CRITICAL COMPONENT AND MAY BE SUPPLIED BY THE TWT CONTRACTOR OR THE SPACECRAFT CONTRACTOR. THE MOST SUCCESSFUL EPC FLOWN TO DATE WAS PACKAGED USING AN OPEN CONSTRUCTION TECHNIQUE BY TRW FOR THE CANADIAN TECHNOLOGY SATELLITE PROGRAM. UNQUESTIONABLY, THE HIGH POWER TWTA IS THE MOST CRITICAL COMPONENT ON A DBS SPACECRAFT. THE HIGH POWER MULTIPLEXER IS NOT DIFFICULT ELECTRICALLY BASED ON THE ASSUMPTIONS IMPOSED BUT SHOULD BE TESTED FOR MULTIPACTION BECAUSE OF THE HIGH POWER. SHOULD CHANNEL ASSIGNMENTS REQUIRE CONTIGUOUS MULTIPLEXING AS IN THE CASE OF NORDSAT (REF. 2, 3) - AN EQUIVALENT 10 CHANNEL MULTIPLEXER USING 1977 WARC CHANNELS 22, 24, 26, 28, 30, 32, (34), 36, (38), 40 - THEN THIS BECOMES A MAJOR TECHNOLOGY DEVELOPMENT.

SPACECRAFT BUS TECHNOLOGY IS HIGHLIGHTED BY HIGH POWER AND THERMAL REQUIREMENTS. SUITABLE SOLAR ARRAYS ARE EITHER QUALIFIED OR UNDER DEVELOPMENT BY VARIOUS EUROPEAN AND U. S. SUPPLIERS. A HEAT PIPE RADIATOR FOR THE TWTAs IS VERY DESIRABLE IN ORDER TO SPREAD THE HEAT AND POSSIBLY TO CUT OFF THE RADIATOR DURING ECLIPSE. THE LATTER IS CALLED A VARIABLE CONDUCTANCE HEAT PIPE. HEAT PIPES HAVE BEEN USED SUCCESSFULLY IN SUCH PROGRAMS AS ATS-6 AND CTS. THE LATTER APPLICATION WAS ENGINEERED BY TRW FOR THE 200 WATT TWTA.

AN ASCENT STAGE PROVIDING BOTH PERIGEE AND APOGEE PROPULSION IS REQUIRED FOR SOME SHUTTLE BASED SPACECRAFT CONFIGURATIONS. THESE WOULD UTILIZE EXISTING, QUALIFIED LIQUID BIPROPELLANT ENGINES AND WOULD BE DEVELOPED AS AN INTEGRAL PART OF THE SPACECRAFT.


DANGER
HIGH VOLTAGE

TRAVELLING WAVE TUBE AMPLIFIER - CANADIAN TECHNOLOGY SATELLITE

THIS IS A PHOTOGRAPH OF THE 200 WATT TRAVELLING WAVE TUBE AMPLIFIER (TWTA) USED ON THE CANADIAN TECHNOLOGY SATELLITE. THE AMPLIFIER WAS BUILT AS AN EXPERIMENT AND CONSISTS OF A 200 WATT, 10 COLLECTOR COUPLED CAVITY TWT BUILT BY LITTON AND A 450 WATT ELECTRONIC POWER CONDITIONER BUILT BY TRW. THE TWTA WAS INTEGRATED AND TESTED BY TRW.

THE EPC USED AN OPEN CONSTRUCTION RATHER THAN POTTING IN ORDER TO AVOID ARCING PROBLEMS. THE MAXIMUM HIGH VOLTAGE SUPPLY WAS 11.2 KV AND THE NOMINAL EFFICIENCY WAS 89% WITH A MAXIMUM POWER BUS INPUT OF ROUGHLY 80 VOLTS dc. THE AMPLIFIER PERFORMED FLAWLESSLY IN SPACE AND EXCEEDED ITS ORBITAL LIFETIME GOAL OF 2 YEARS.

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LAUNCH VEHICLE GEOSYNCHRONOUS ORBIT PERFORMANCE COMPARISON

LAUNCH VEHICLE	WEIGHT IN(1) GEOSYNCHRONOUS ORBIT		BEGINNING OF(2) LIFE SATELLITE WEIGHT		MAXIMUM SATELLITE DIAMETER	
	LBS	KG	LBS	KG	FT	M
EXPENDABLE						
DELTA – 3920	2760	1250	1360	620	7.2	2.2
ATLAS – CENTAUR	4860	2200	2340	1060	9.5	2.9
ARIANE 1	3730	1690	1990	900	9.5	3.0
ARIANE 2	4490	2040	2430	1100	10	3
ARIANE 3	5290	2400	2800	1270	10 - 12	3 - 3.65
ARIANE 4	7280	3300	3940	1790	12	3.65
SHUTTLE						
STS/PAM-D	2730	1240	1360	620	9 - 10(1)	2.7 - 3.1(3)
STS/PAM-A	4400	2000	2110	960	14.5	4.4
STS/IUS	—		4670	2120	14.5	4.4
STS/INTEGRATED PROPULSION			10000	4540	14.5	4.4
STS/CENTAUR			14000	6350	14.5	4.4

(1) TRANSFER ORBIT INCLINATION CHOSEN TO MAXIMIZE PAYLOAD AND ADAPT TO AVAILABLE APOGEE MOTOR

(2) USE EXISTING THIOKOL SOLID APOGEE MOTOR WHEN AVAILABLE. INCLUDES ALLOWANCE FOR S/C ADAPTOR, SPIN, DESPIN, ACQUISITION AND INITIAL VELOCITY CORRECTION

(3) MOUNTED VERTICALLY IN SHUTTLE BAY

LAUNCH VEHICLE GEOSYNCHRONOUS ORBIT PERFORMANCE COMPARISON

GEOSYNCHRONOUS ORBIT PERFORMANCE FOR RELEVANT EXPENDABLE AND SHUTTLE BASED LAUNCH VEHICLES ARE TABULATED ON THIS FIGURE. THE RANGE OF BEGINNING OF LIFE SATELLITE WEIGHTS IS POTENTIALLY AN ORDER OF MAGNITUDE - NAMELY FROM 1400 POUNDS TO 14000 POUNDS. MOST OF THE LAUNCH VEHICLES ARE STILL IN THE DEVELOPMENT STAGE, NAMELY THE ARIANE SERIES AND THE SHUTTLE PLUS ALL OF THE ASCENT STAGES.

PERFORMANCE CALCULATIONS ARE NOT DONE UNIFORMLY OR EXHAUSTIVELY. FOR THE FIRST EIGHT LAUNCH VEHICLES LISTED, TRANSFER ORBIT INCLINATION IS CHOSEN TO MAXIMIZE PAYLOAD AND ADAPT TO AN EXISTING OR SLIGHTLY MODIFIED THIOKOL SOLID APOGEE MOTOR. (EUROPEAN MOTORS ARE NOT USED FOR LACK OF DATA.) SPECIFIC IMPULSE (EFFECTIVE) VALUES VARY FROM A LOW OF 283.6 SECONDS FOR THE STAR 37E TO A HIGH OF 293.5 SECONDS FOR THE STAR 30B. FOR THE ARIANE 4 AND THE STS-PAM A, A SMALL APOGEE $\Delta \nabla$ AUGMENTATION IS PROVIDED BY THE SATELLITE HYDRAZINE SYSTEM TO MAKE UP FOR INSUFFICIENT APOGEE MOTOR PROPELLANT.

THE BEGINNING OF LIFE SATELLITE WEIGHT INCLUDES AN ALLOWANCE FOR THE SPACECRAFT ADAPTOR (WHEN APPLICABLE), TRANSFER ORBIT MANEUVERS, ATTITUDE ACQUISITION AND INITIAL VELOCITY CORRECTION. THIS ENABLES A COMPARISON BETWEEN THE DIFFERENT TYPES OF LAUNCH VEHICLES AND UPPER STAGES WITH DIFFERENT MANEUVER REQUIREMENTS. HYDRAZINE IS USED FOR THE MOST PART WITH A CONTINUOUS THRUST SPECIFIC IMPULSE OF 220 SECONDS.

IT IS RECOGNIZED THAT IN SOME CASES THE USE OF A LIQUID APOGEE MOTOR WILL PROVIDE SOMEWHAT BETTER PERFORMANCE. HOWEVER, SOLID APOGEE MOTORS HAVE BEEN USED FOR COMPARISON. THE ONLY EXCEPTION IS IN THE CASE OF THE STS/INTEGRATED PROPULSION WHICH HAS BEEN UNDER STUDY AT TRW AND BY OTHER CONTRACTORS. IN THIS CASE, A LOW ACCELERATION LIQUID BIPROPELLANT SYSTEM IS USED PROVIDING BOTH THE PERIGEE AND APOGEE ΔV IN A MULTI-BURN ASCENT. THIS SYSTEM IS FLEXIBLE AND CAN BE BUILT TO PROVIDE DIFFERENT PERFORMANCE RANGES UP TO THE MAXIMUM SHOWN IN THE CHART. THE LEASAT HYBRID SYSTEM USING A SOLID PERIGEE MOTOR AND A LIQUID APOGEE MOTOR IS ANOTHER EXAMPLE OF AN INTEGRATED PROPULSION SYSTEM.

SPACECRAFT DESIGN REQUIREMENTS

- COMMUNICATION SUBSYSTEM ACCOMMODATION
  - 2-3M ANTENNA REFLECTORS, F/D $\geqslant$1
  - TWTA (POWER AND THERMAL)
  - MINIMUM ECLIPSE SERVICE
  - TWTA REDUNDANCY
- 7-10 YEAR SERVICE LIFETIME
- TRACKING, TELEMETRY AND COMMAND
  - 6/4 GHz ASCENT, 18/12 GHz ON-ORBIT
- NO SINGLE POINT FAILURES FOR ACTIVE COMPONENTS
- TECHNOLOGY CONSISTENT WITH 1984 LAUNCH

SPACECRAFT DESIGN REQUIREMENTS

THE KEY SPACECRAFT REQUIREMENTS FOR THE MODEL A SPACECRAFT ARE LISTED ON THE CHART. THE ACCOMMODATION OF THE ANTENNA SYSTEM AND THE HIGH POWER TWTAs ARE THE PRINCIPAL FACTORS WHICH AFFECT THE CONFIGURATION DESIGN. THE COMBINATION OF HIGH SUNLIGHT POWER, MULTI-MODE OPERATION AND MINIMUM ECLIPSE POWER LEADS TO SPECIAL THERMAL CONTROL REQUIREMENTS INEVITABLY LEADING TO HEAT PIPE RADIATORS FOR THE TWTAs.

OTHER REQUIREMENTS SUCH AS 7-10 YEAR LIFETIME, NO SINGLE POINT FAILURES, ETC., ARE NO DIFFERENT THAN FOR PRESENT COMMUNICATIONS SATELLITES SUCH AS INTELSAT V AND TDRSS.

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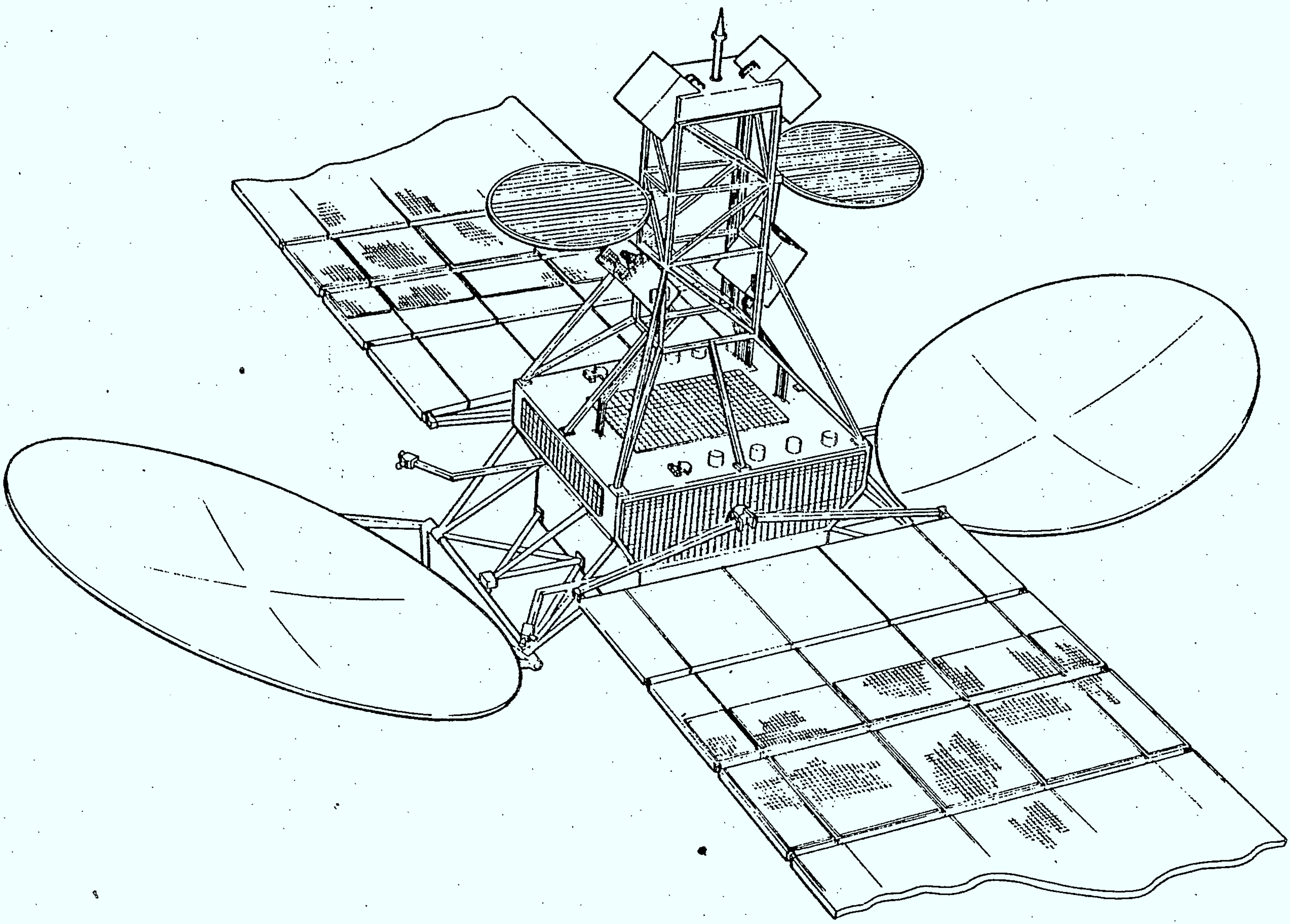
MODEL A SPACECRAFT
ON-ORBIT CONFIGURATION



MODEL A SPACECRAFT

THIS IS AN IN-ORBIT CONFIGURATION DRAWING OF A MODEL A SPACECRAFT. THE SPACECRAFT IS 3-AXIS STABILIZED - THE POWER REQUIREMENT OF OVER 3 kw END OF LIFE IS WELL BEYOND THE CAPABILITY OF A PRACTICAL SPINNER. THE OFFSET FED ANTENNA CONSISTS OF TWO 3.2 METER REFLECTORS WITH ASSOCIATED WIRE GRID POLARIZATION DIPLEXERS AND TWO SETS OF MULTIPLE FEEDS EACH IN FRONT FED AND CASSEGRAIN CONFIGURATION. BOTH THE REFLECTORS EMPLOY EITHER A GRAPHITE OR A COMBINATION GRAPHITE-KEVLAR HONEY COMB CONSTRUCTION PRESENTLY USED BY TRW ON TDRSS AND INTELSAT V RESPECTIVELY.

THE SOLAR ARRAY SHOWN IS A FLEXIBLE FOLDOUT ARRAY SIMILAR TO THAT USED ON CTS AND PRESENTLY BEING DEVELOPED BY LOCKHEED AND TRW FOR ARRAYS UP TO 60 KW. ALTERNATIVELY, AN MBB ULP LIGHTWEIGHT ARRAY USING A GRAPHITE SHEET SUBSTRATE STRETCHED OVER A GRAPHITE FRAME COULD BE USED. BOTH TECHNOLOGIES ARE IN THE 25-30 KG/KW (END OF LIFE EQUINOX) RANGE FOR THE RANGE OF POWERS UNDER CONSIDERATION.

THE SPACECRAFT BODY IS A TYPICAL 3-AXIS MODULAR BOX DESIGN WITH AN UPPER COMMUNICATIONS MODULE AND A LOWER SERVICE MODULE. THE EIGHT 200 WATT TWTA COLLECTORS CAN BE SEEN PROTRUDING FROM THE TOP SURFACE. THEY ARE DESIGNED TO RADIATE ROUGHLY 65% OF THE DISSIPATED HEAT DIRECTLY TO SPACE. IN ADDITION TO THE 200 WATT TWTAs, THERE ARE A TOTAL OF FIFTEEN 20 WATT TWTAs MOUNTED ON THE NORTH-SOUTH RADIATORS (THE SIDE PANELS HOUSING THE SOLAR ARRAY DRIVE MECHANISMS). A SET OF SIMPLE HEAT PIPES (SHOWN BELOW) IS USED TO SPREAD THE HEAT ON EACH RADIATOR.

TWO 30 AMP-HOUR NICKEL HYDROGEN BATTERIES - 28 CELLS EACH - PROVIDE ROUGHLY 1250 WATTS DURING ECLIPSE TO POWER 1 PTZ CHANNEL AND 3 SPOT BEAMS (1/2 SERVICE PER SATELLITE). THIS BATTERY IS SIMILAR TO THAT USED IN LATER MODELS OF INTELSAT V.

FULL 3-AXIS ATTITUDE CONTROL USES 2 RF SENSORS FOR ROLL, PITCH AND YAW SENSING IN COMBINATION WITH 3 OF 4 REACTION WHEELS AND AN ON-BOARD PROCESSOR AS USED ON A RECENT TRW BUILT SPACECRAFT CALLED HEAO.

NORTH-SOUTH STATIONKEEPING EMPLOYS HEATED HYDRAZINE THRUSTERS (HIPEHT) BUILT BY TRW AND RECENTLY SUCCESSFULLY FIRED IN ORBIT ON INTELSAT V. THE AVERAGE SPECIFIC IMPULSE IS 290 SECONDS AND POWER FOR THE HEATERS IS DRAWN FROM THE BATTERIES PRINCIPALLY DURING NON-ECLIPSE SEASONS.

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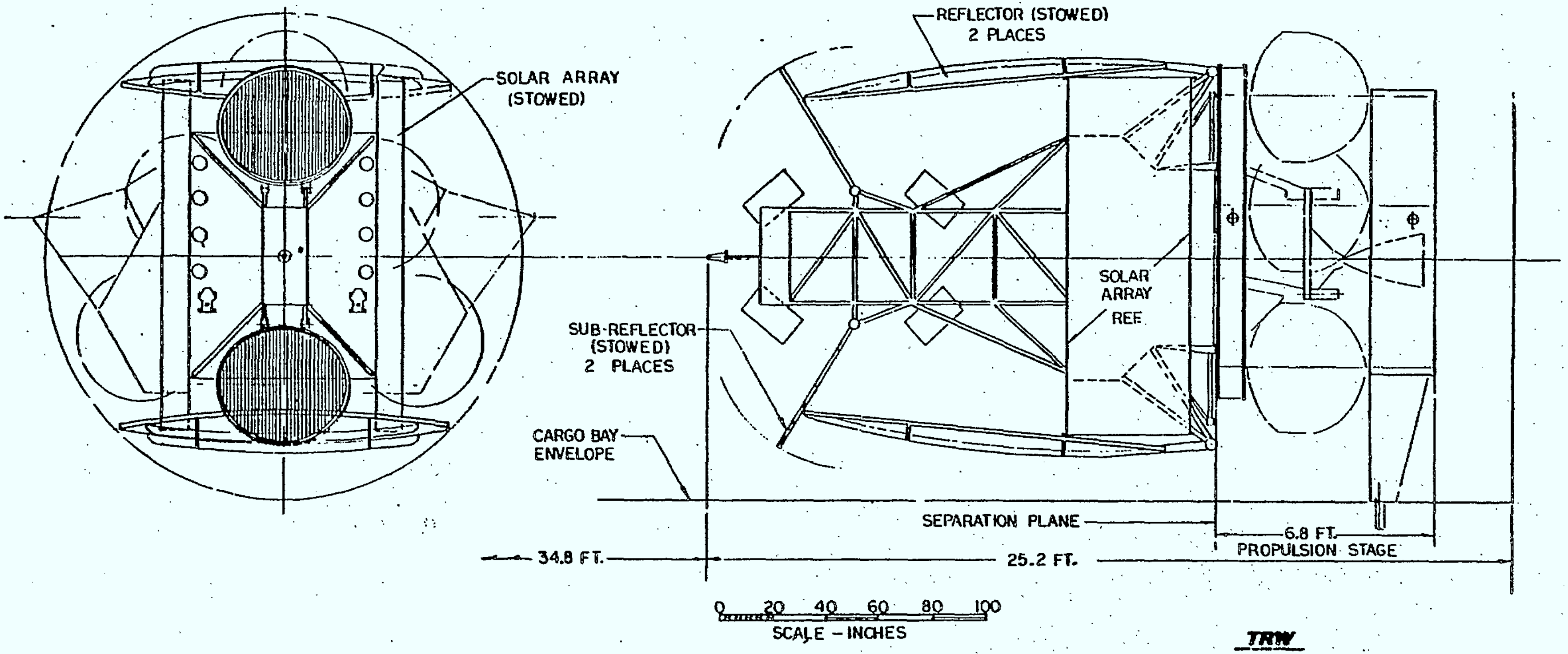
MODEL A SPACECRAFT - LAUNCH CONFIGURATION



TRW

LAUNCH CONFIGURATION
AD 106-2

LAUNCH CONFIGURATION - MODEL A SPACECRAFT

THE LAUNCH OR STOWED CONFIGURATION OF THE MODEL A SPACECRAFT IS SHOWN IN SHUTTLE ORBITER BAY. THE SOLAR ARRAY IS ACCORDIONED (STOWED) NEXT TO THE NORTH-SOUTH RADIATOR PANELS AND PROVIDES POWER FROM A PAIR OF EXPOSED PANELS. THE 3.2 METER (10.5 FOOT) REFLECTORS ARE STOWED ALONG THE EAST-WEST SIDES FOR LAUNCH. THE SUBREFLECTORS ARE ALSO TILTED UPWARDS TO SIMPLIFY THE STOWAGE OF THE LARGE REFLECTORS.

PERIGEE-APOGEE PROPULSION IS PROVIDED BY A LOW THRUST BI-PROPELLANT LIQUID SYSTEM WHICH CONSISTS OF TWO EQUAL WEIGHT STAGES OF 3 TANKS EACH. IN THIS CONFIGURATION, 3 TANKS ARE JETTISONED ALONG WITH ACCOMPANYING STRUCTURE FOLLOWING FIRST STAGE BURNOUT. THE SPACECRAFT IS 3 AXIS STABILIZED THROUGHOUT ASCENT USING A GYRO PACKAGE AND THE SPACECRAFT REACTION CONTROL THRUSTERS. POWERED FLIGHT CONTROL IS PROVIDED BY GIMBALLING THE ROCKET MOTOR (PITCH AND YAW) AND BY THE SPACECRAFT 1 POUND THRUSTERS (ROLL). FOLLOWING FINAL BURNOUT, THE ASCENT STAGE IS JETTISONED. (THIS IS IMPLIED BY ITS ABSENCE ON THE PREVIOUS FIGURE.) A TYPICAL ASCENT SEQUENCE REQUIRES A TOTAL OF 14 BURNS OF ABOUT 10-15 MINUTES DURATION EACH.

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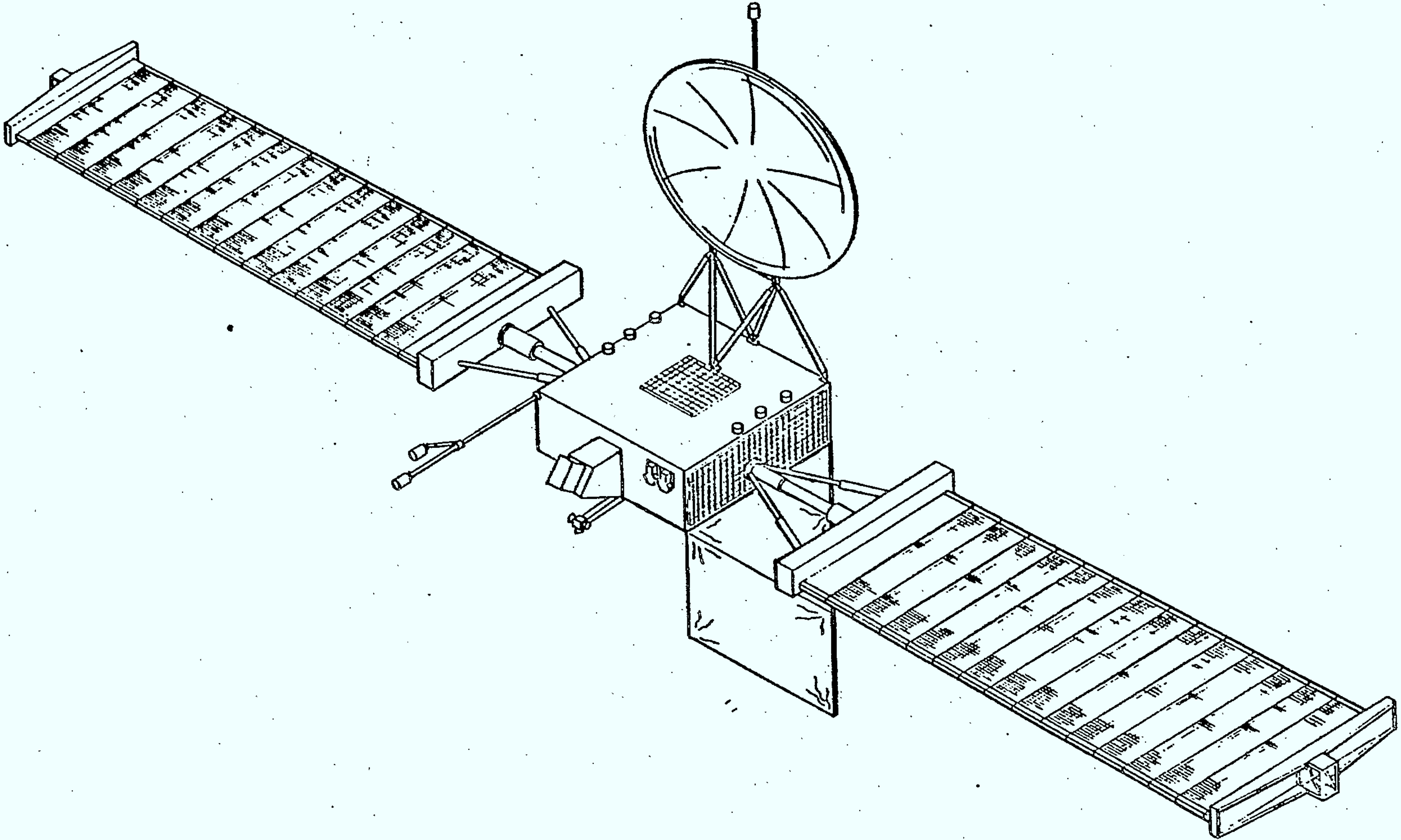
SPACECRAFT FOR COMSAT SYSTEM



COMSAT SPACECRAFT CONFIGURATION

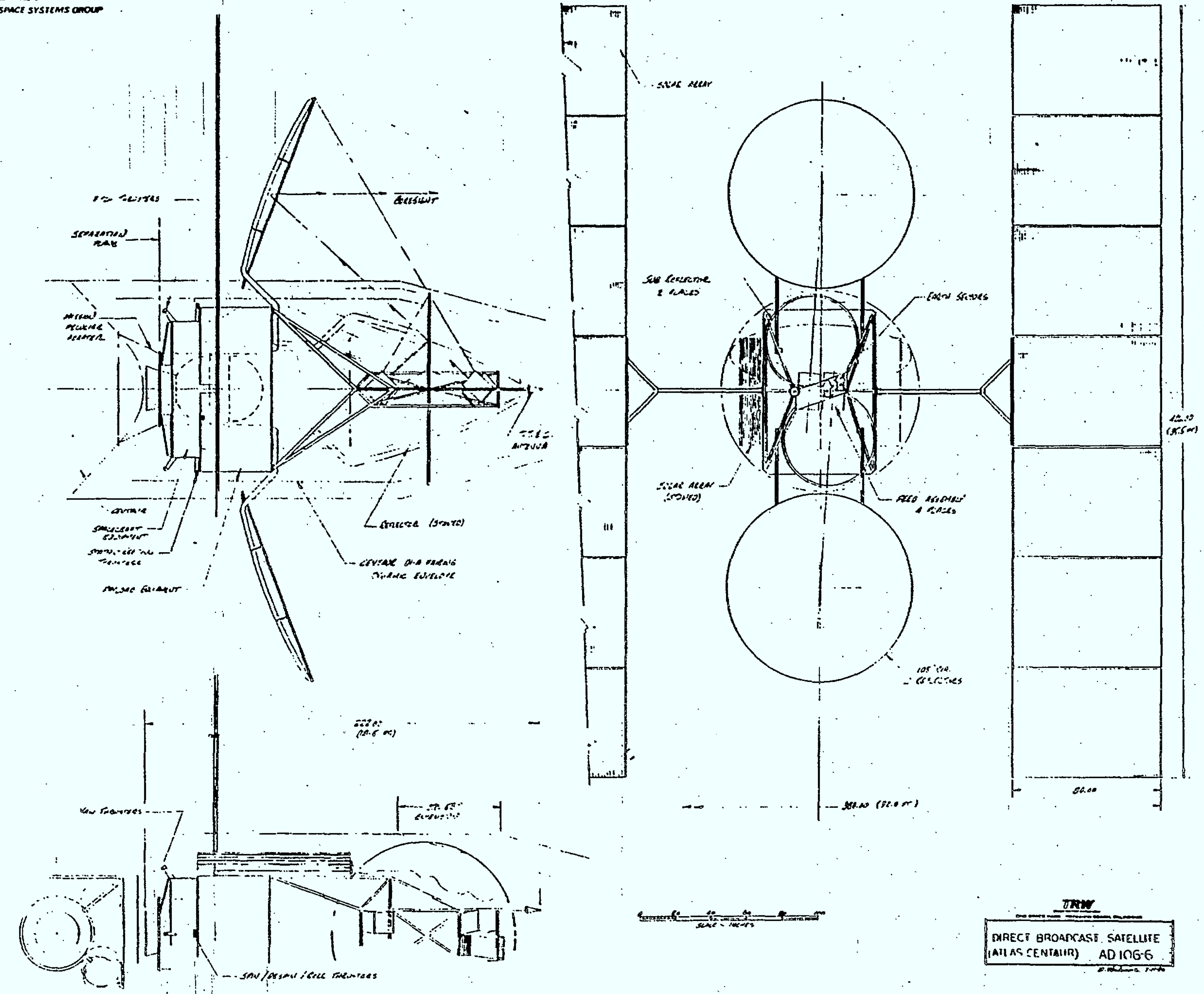
AN ARTIST'S SKETCH OF A SPACECRAFT DESIGN FOR THE PROPOSED COMSAT SYSTEM IS SHOWN.

ITS GENERAL FEATURES ARE SIMILAR TO THE MODEL A CONFIGURATION BUT IT IS QUITE A BIT SIMPLER. NOTE THE USE OF A SINGLE, DEPLOYED REFLECTOR ROUGHLY 2.5-3 METERS IN DIAMETER. THE ANTENNA IS IMPLEMENTED TO COVER ONE OF TWO ADJACENT TIME ZONES IN CIRCULAR POLARIZATION (HENCE NO POLARIZATION GRID). IT IS MECHANIZED HERE WITHOUT THE USE OF AN ANTENNA TOWER. BECAUSE OF THE TORQUE IMBALANCE CAUSED BY A SINGLE REFLECTOR A SOLAR SAIL IS EMPLOYED. THIS TECHNIQUE IS USED ON TDRSS.

THE SOLAR ARRAY MAY BE EITHER ULP OR FLEXIBLE FOLDOUT. A SOLID APOGEE MOTOR, NOT SHOWN, HAS BEEN USED.

TRW
DEFENSE AND SPACE SYSTEMS GROUP

MODEL A SPACECRAFT - EXPENDABLE LAUNCH VEHICLE



MODEL A SPACECRAFT-EXPENDABLE LAUNCH VEHICLE

THIS SET OF ENGINEERING DRAWINGS SHOWS A MODEL A CLASS SPACECRAFT DESIGNED TO BE LAUNCHED ON AN ATLAS-CENTAUR OR AN ARIANE 2-3 BOOSTER. IN GENERAL, THE SPACECRAFT DESIGN IS SIMILAR TO THE SHUTTLE BASED CONFIGURATION. THERE ARE A FEW DIFFERENCES.

THE LAUNCH VEHICLE FAIRING LIMITS THE DIAMETER OF A SOLID REFLECTOR. IN THIS CASE, THE DIAMETER IS ABOUT 2.7 METERS WHICH INCREASES THE SIZE OF THE SPOT BEAM TO ABOUT 0.7°. TIME ZONE COVERAGE IS LARGELY UNAFFECTED BY THE DIAMETER LIMITATION. A SOLID APOGEE MOTOR IS USED AND STOWED WITHIN A CENTRAL CYLINDER WHICH IS CONVENTIONAL. THE SOLAR ARRAY IS SHOWN IN AN "H" CONFIGURATION RATHER THAN AN "I" CONFIGURATION AS PREVIOUSLY DRAWN. DETAILED THRUSTER IMPINGEMENT DURING NORTH-SOUTH STATIONKEEPING STUDIES AS WELL AS ATTITUDE CONTROL STABILITY STUDIES ARE REQUIRED TO DECIDE THE COMPARATIVE MERITS OF THE TWO APPROACHES FOR ANY DESIGN. GENERALLY, IMPINGEMENT CAN BE MORE EASILY MINIMIZED BY CANTING THE THRUSTERS AWAY FROM THE DEPLOYED ARRAY IN AN "I" CONFIGURATION.

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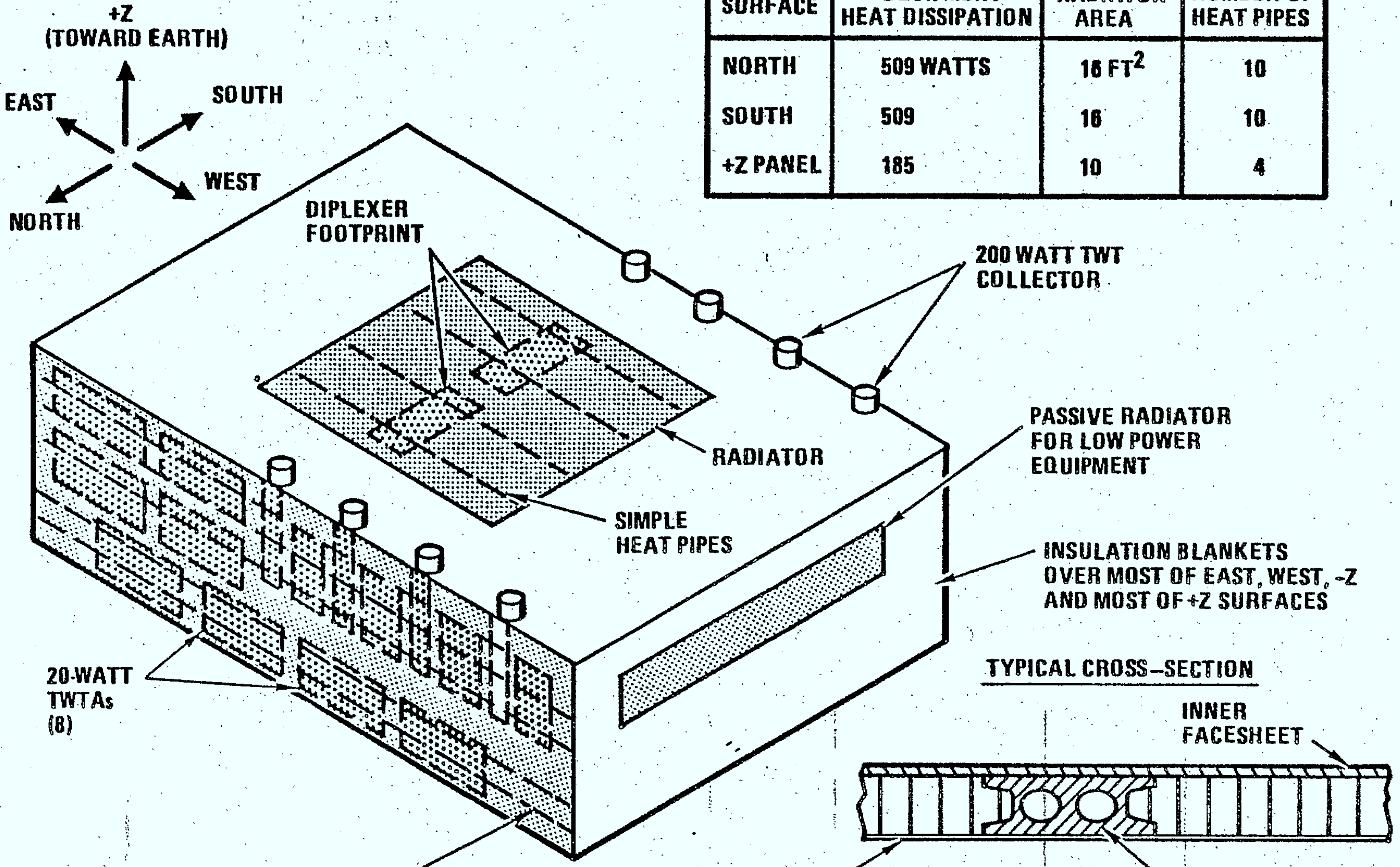
DEFENSE AND SPACE SYSTEMS GROUP

MODEL A THERMAL DESIGN

SURFACE	EQUIPMENT HEAT DISSIPATION	RADIATOR AREA	NUMBER OF HEAT PIPES
NORTH	509 WATTS	16 FT^2	10
SOUTH	509	16	10
+Z PANEL	185	10	4



MODEL A THERMAL DESIGN

THE ACCOMPANYING FIGURE ILLUSTRATES A THERMAL DESIGN IMPLEMENTATION USING SETS OF SIMPLE HEAT PIPES FOR BOTH THE TWTA RADIATORS ON THE NORTH-SOUTH PANELS AND FOR THE OUTPUT MULTIPLEXERS ON THE +Z OR EARTH FACING PANEL. THE HEAT PIPE DESIGN ENABLES THE SHARING OF A LARGE RADIATOR BY SPREADING THE HEAT. THIS IS ESPECIALLY REQUIRED FOR THE MODEL A REDUNDANCY PRINCIPLE WHEREBY ONLY HALF THE TWTAs MAY BE POWERED AT ANY TIME AND FAILURE MODE CONDITIONS CAN RESULT IN SEVERELY UNBALANCED THERMAL MODES (i.e., ONE 200 WATT TWTA ACTIVE ON THE NORTH PANEL AND THREE ACTIVE ON THE SOUTH PANEL).

NOTE THAT FOR A VERY HIGH POWERED, COMPLEX SPACECRAFT SUCH AS NORDSAT WITH 450 WATT AND 200 WATT AMPLIFIERS THE THERMAL REQUIREMENTS MAY RESULT IN COUPLING THE NORTH, SOUTH AND +Z PANELS WITH VARIABLE CONDUCTANCE HEAT PIPES RUNNING VERTICALLY AS WELL AS SPREADING THE HEAT USING HORIZONTAL SIMPLE HEAT PIPES AS IN THE PRESENT DESIGN.

THERMAL DESIGN PRACTICE FOR THE HIGH POWERED TUBES HAS BEEN TO PROVIDE BENIGN CONDITIONS WITH MAXIMUM OPERATING TEMPERATURES BELOW 40°C AND MINIMUM (ECLIPSE EXIT) TEMPERATURES IN THE NEIGHBORHOOD OF 0°C.

ON-ORBIT AVERAGE POWER REQUIREMENTS (WATTS)

	COMSAT		MODEL A		MODEL D	
	SUNLIGHT	ECLIPSE	SUNLIGHT	ECLIPSE	SUNLIGHT	ECLIPSE
LOW VOLTAGE BUS						
COMMUNICATIONS(2)	43	30	118	102	215	185
SPACECRAFT(2)	214	357	304	388	432	624
MARGIN (5%)	13	19	21	25	33	40
	270	406	443	525	680	849
HIGH VOLTAGE BUS						
200W TWTA^{S}	1525	–	2034	508	4067	107
20W TWTA^{S}	–	–	451	169	846	338
MARGIN (5%)	76	–	124	34	246	68
	1601	0	2609	711	5159	1423
SUNLIGHT 7 YEAR EQUINOX(1)	1722		2805		5547	
BATTERY		406		1236		2272
SOLAR ARRAY – 7 YEAR EQUINOX	1992		3248		6227	

(1) SOLAR ARRAY REQUIREMENTS FOR THE LOW VOLTAGE BUS ARE ROUGHLY EQUIVALENT AT SUMMER SOLSTICE AND EQUINOX SINCE THE BATTERY CHARGE NEED AT EQUINOX IS BALANCED BY THE HIGHER ARRAY OUTPUT. THE HIGH VOLTAGE SOLAR ARRAY IS SIZED AT SUMMER SOLSTICE. THIS IS ROUGHLY 7% ABOVE THE EQUINOX REQUIREMENT

(2) TWT HEATERS SUPPLIED BY THE LOW VOLTAGE BUS ARE LEFT ON DURING ECLIPSE. A TOTAL OF 15% OF THE TWTA POWER IS ALLOCATED FOR STANDBY

ON-ORBIT AVERAGE POWER REQUIREMENTS

THE ON-ORBIT AVERAGE POWER REQUIREMENTS FOR THE 3 CLASSES OF DBS SPACECRAFT ARE SHOWN FOR SUNLIGHT AND ECLIPSE IN THE ACCOMPANYING CHART. NOTE THAT POWER IS SUPPLIED BY A LOW VOLTAGE BUS AT AN AVERAGE VOLTAGE IN THE 25-30 VOLT RANGE AND BY A HIGH VOLTAGE BUS IN THE NEIGHBORHOOD OF 100 VOLTS.

CLEARLY, THE OVERWHELMING POWER USER IS THE HIGH POWER AMPLIFIERS. HENCE, THE EMPLOYMENT OF 100 VOLT BUS IN ORDER TO IMPROVE THE EFFICIENCY OF THE TWT EPC AND TO LOWER THE SOLAR ARRAY CURRENT (HENCE THE CABLING WEIGHT).

NOTE THE STANDBY MODE FOR THE NON-OPERATING TWTAs DURING ECLIPSE. THIS CONSISTS OF KEEPING THE TWT HEATERS ON IN ORDER TO MAINTAIN CATHODE TEMPERATURE AT AN OPERATING LEVEL AS A LIFE PRESERVING MEANS. A TOTAL OF 15% OF SUNLIGHT TWTA POWER IS ALLOCATED FOR THE STANDBY MODE.

NOTE THAT THE HIGH VOLTAGE ARRAY MUST BE SIZED TO PROVIDE POWER AT SUMMER SOLSTICE WITHOUT CONTRIBUTION FROM THE BATTERY CHARGE ARRAY. THIS LEADS TO A 7% INCREASE FOR THIS ARRAY ABOVE THE EQUINOX REQUIREMENT.

THE 3 SOLAR ARRAY REQUIREMENTS RANGE FROM ROUGHLY 2 KW to 6 KW.

MASS SUMMARY

A MASS SUMMARY OF THE SPACECRAFT INCLUDING ASCENT STAGE FOR EACH OF THREE SHUTTLE LAUNCHED CONFIGURATIONS IS TABULATED ON THE ACCOMPANYING CHART. THE SUBSYSTEM AND COMPONENT WEIGHTS ARE BASED ON ACTUALS FROM EXISTING SPACECRAFT SUCH AS FLEETSATCOM OR TDRSS WHERE POSSIBLE. THIS IS APPLICABLE FOR EXAMPLE IN THE CASE OF THE ATTITUDE CONTROL AND REACTION CONTROL COMPONENTS. FOR OTHER COMPONENTS, SIMILARITY TO EXISTING EQUIPMENT IS INVOKED OR ACHIEVABLE SIZING FACTORS ARE USED. FOR EXAMPLE, SOLAR ARRAY SPECIFIC MASS OF 30 KG/KW AT 7 YEAR EQUINOX, BATTERY PACKING FACTOR OF 15% IN COMBINATION WITH ACTUAL CELL WEIGHT, ANTENNA REFLECTOR WEIGHT OF 0.5 LBS/FT^2. BASED ON TDRSS AND INTELSAT V HISTORY, ETC. IN THE CASE OF MODEL A AND MODEL D SPACECRAFT, DETAILED STRUCTURE AND THERMAL CONTROL DESIGNS WERE PERFORMED FOR THE NORDSAT STUDY (REF. 2, 3). THAT DATA WAS SUITABLY SCALED FOR THE PRESENT APPLICATION.

THE CONTINGENCY FACTOR FOR THE COMSAT SYSTEM IS ROUGHLY 9% SINCE A FIXED SOLID APOGEE MOTOR IS USED WITH PRESCRIBED CAPABILITY. OTHER TECHNIQUES CAN BE USED TO IMPROVE THE CONTINGENCY SHOULD THIS BE DEEMED NECESSARY. SINCE A LIQUID ASCENT STAGE WITH FLEXIBLE CAPABILITY WAS USED FOR THE MODEL A AND MODEL D DESIGNS THE CONTINGENCY WAS ARBITRARILY SET AT 15%.

THE HYDRAZINE BUDGET INCLUDES 7 YEARS OF LIFETIME WITH NORTH-SOUTH STATIONKEEPING PERFORMED BY HEATED THRUSTERS (HIPEHT) USING A SPECIFIC IMPULSE OF 290 SECONDS. THE SPACECRAFT ON ORBIT VALUES ARE CONSISTENT WITH THE BEGINNING OF LIFE VALUES ON THE EARLIER GEOSYNCHRONOUS ORBIT CHART. BECAUSE OF THE SUMMARY NATURE OF THIS CHART, ALL PROPELLANTS ARE LUMPED IN ONE ENTRY "HYDRAZINE" RATHER THAN BROKEN DOWN AS DONE (BY IMPLICATION) ON THE PREVIOUS CHART.

THE SOLID MOTOR USED FOR THE COMSAT CASE IS A SLIGHTLY STRETCHED THIOKOL STAR 30B AT AN EFFECTIVE SPECIFIC IMPULSE OF 293.5 SECONDS. THE LIQUID ASCENT STAGE PERFORMANCE CORRESPONDS TO A SPECIFIC IMPULSE OF 300 SECONDS, A MASS FRACTION OF APPROXIMATELY 0.9 (INCLUDING RESIDUALS) AND A TWO STAGE VEHICLE.

EXPENDABLE LAUNCH VEHICLES CAN ALSO BE USED FOR THESE CLASSES OF SPACECRAFT. THE COMSAT DESIGN IS COMPATIBLE WITH A DUAL LAUNCH ON AN ARIANE 3. THE MODEL A SPACECRAFT IS IN THE ARIANE 3 CLASS AND THE MODEL D SPACECRAFT IS IN THE ARIANE 4 CLASS. NO EFFORT WAS MADE TO MAKE THESE SPACECRAFT COMPATIBLE WITH SHUTTLE AND EXPENDABLE LAUNCH VEHICLES.

MASS SUMMARY (KG)

	COMSAT	MODEL A	MODEL D
COMMUNICATIONS	128	299	384
SPACECRAFT SUBSYSTEMS	346	568	743
ESTIMATED SPACECRAFT DRY	474	867	1127
CONTINGENCY	43	130	169
SPACECRAFT DRY	517	997	1296
HYDRAZINE	126	182	243
SPACECRAFT ON ORBIT	643	1179	1539
SOLID APOGEE MOTOR	593	–	–
PAM-D STAGE	2183	–	–
LIQUID ASCENT STAGE	–	5973	7666
CRADLE ASSEMBLY	1136	1361	1497
SHUTTLE INSTALLED	4555	8513	10702

CONCLUSIONS

- COMMUNICATIONS AND SPACECRAFT BUS TECHNOLOGY AVAILABLE FOR 1984 LAUNCH
- 1/4 SERVICE, 1/2 SERVICE AND FULL SERVICE SPACECRAFT ALL FEASIBLE
  - LAUNCH VEHICLE CAPABILITY ADEQUATE
  - COMMUNICATIONS TECHNOLOGY EQUIVALENT
  - S/C SIZE SCALING RAISES NO TECHNOLOGY PROBLEMS
- NEW SPACECRAFT DEVELOPMENT REQUIRED REGARDLESS OF OPTION
  - INCLUDES ASCENT STAGE
- STS AND EXPENDABLE LAUNCH VEHICLE COMPATIBILITY DESIRABLE DURING STS TRANSITION PERIOD
- CHOICE OF S/C OPTION DEPENDS ON USER NEEDS
  - GRADUAL SERVICE INAUGURATION (PROLIFERATION OF SATELLITES) VS ECONOMY OF SCALE

CONCLUSIONS

A NUMBER OF CONCLUSIONS MAY BE DRAWN FROM THE BRIEF SURVEY WE HAVE MADE OF ALTERNATIVE SPACECRAFT FOR U. S. DIRECT BROADCAST SYSTEMS.

MOST SIGNIFICANTLY, THERE APPEARS TO BE NO BASIC QUESTION OF FEASIBILITY FROM THE STANDPOINT OF SPACECRAFT TECHNOLOGY. THE TECHNOLOGY EXISTS OR CAN READILY BE MADE AVAILABLE FOR THE EARLIEST FORESEEABLE LAUNCH REQUIREMENT IN LATE 1984 EARLY 1985 TIME FRAME.

WE BELIEVE THAT SPACECRAFT TO PROVIDE ANY OF THE SERVICE NEEDS DELINEATED ARE FEASIBLE FOR THE REASONS CITED. IN ANY CASE A NEW SPACECRAFT DEVELOPMENT IS REQUIRED. THE SOLE QUESTION IS THE DEVELOPMENT OF THE ASCENT STAGE WHICH CAN BE DONE IN PARALLEL WITH THE REMAINDER OF THE SPACECRAFT. THERE IS SOME ADDITIONAL RISK FACTOR SINCE THERE IS AN ADDED SERIES DEVELOPMENT PLUS ADDITIONAL COMPLEXITY WITH THE PROLIFERATION OF COMMUNICATIONS COMPONENTS. HOWEVER, A SYSTEM WITH FEWER SPACECRAFT IS THEORETICALLY MORE RELIABLE SINCE THERE ARE FEWER SPACECRAFT BUSES WHICH MUST BE SUCCESSFUL TO PROVIDE THE TOTAL SERVICE. FOR EXAMPLE, MODEL D vs THE COMSAT APPROACH, THERE IS ONE SPACECRAFT BUS IN SERIES WITH A SET OF REDUNDANT TWTAs COMPARED WITH FOUR SPACECRAFT BUSES IN SERIES WITH AN EQUIVALENT SET OF REDUNDANT TWTAs.

IN THIS ERA OF STS TRANSITION AND UNCERTAINTY (AS WELL AS ARIANE UNCERTAINTY) IT IS HIGHLY DESIRABLE THAT ANY COMMERCIAL SPACECRAFT DESIGNS BE COMPATIBLE FOR LAUNCH WITH BOTH SHUTTLE AND EXPENDABLE BOOSTERS.

FINALLY, AS IS ALWAYS THE CASE, THE CHOICE OF SPACECRAFT OPTION BELONGS WITH THE CUSTOMER. THERE ARE OFTEN PRESSING AND OVERRIDING NON-TECHNICAL CONSIDERATIONS WHICH SWING THE DECISION. GENERALLY, FOR INITIAL COST AND SYSTEM TRIAL PURPOSES, A GRADUAL SERVICE INAUGURATION IS PREFEREBLE TO AN ABRUPT AND IMMEDIATE FULL SERVICE INITIATION. THIS LEADS TO A PROLIFERATION OF SATELLITES WHICH UNFORTUNATELY IS UNAVOIDABLE.

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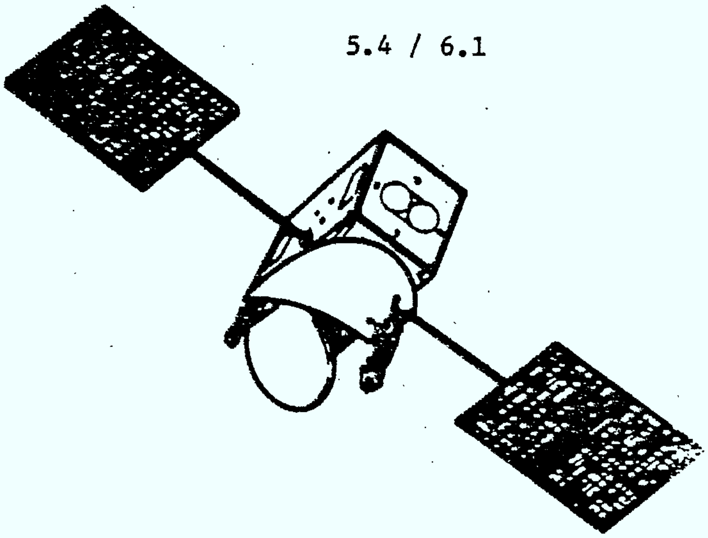
5.4 / 6.1



TITLE : A DIRECT BROADCAST SATELLITE SERVICE FOR THE UNITED STATES
SYSTEM DESCRIPTION AND TRADE-OFFS

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ORGANIZACION DE LOS ESTADOS AMERICANOS
Conferencia Interamericana de Telecomunicaciones

INTERNATIONAL TELECOMMUNICATION UNION

A DIRECT BROADCAST SATELLITE SERVICE FOR THE UNITED STATES - SYSTEM DESCRIPTION AND TRADE-OFFS

by

Ernesto R. Martin*

INTRODUCTION

On December 17, 1980, Satellite Television Corporation (STC) applied for authorization from the U.S. Federal Communications Commission (FCC) to build the first direct broadcast satellite (DBS) system for the United States. STC is a wholly owned subsidiary of the Communications Satellite Corporation (COMSAT), which is the U.S. representative to INTELSAT and is recognized as a pioneer and world leader in satellite communications. At the time of this writing, the FCC was still considering STC's Application.

This Introduction summarizes the broadcast service planned by STC. The remainder of the paper is divided into two parts. Part 1 provides a detailed description of the system and its principal elements. Part 2 defines the reasons behind the system parameters; it identifies the performance versus cost trade-offs, the considerations of orbit/spectrum efficiency and other major factors which influenced the system design. Most of the material contained in this paper is derived from the FCC Application, whose preparation involved the combined efforts of many individuals.

STC's broadcast service will provide three channels of television throughout the contiguous United States (CONUS) and to the major populated areas of Alaska and Hawaii.** For background purposes, Appendix A provides a summary of the television market in the U.S. As currently conceived, STC's television programming will include movies, plays, concerts, night club acts, opera, dance, sports, children's shows, and programs oriented to the interests of minority groups and other

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*The author is Director of Systems Engineering for Satellite Television Corporation. He participated extensively in the design of the system described in this paper.

**In the FCC Application, STC requested authority to implement the first phase of the system for the provision of service to an area approximating the dimension of the Eastern Time Zone in the United States. However, since STC plans to provide nationwide coverage in the future, this paper provides a description of the complete system.

specialized audiences. In addition to entertainment fare, the service will offer public affairs programs, as well as material which is educational or instructional in nature.*

Because the proposed system will be supported by audience subscriptions rather than advertising, satellite transmissions will be scrambled to prevent unauthorized reception. Signals from the spacecraft will be received at subscribers' residences by means of home equipment with both outdoor and indoor units. An addressable descrambler incorporated in the indoor unit can be turned "off" via the satellite signals to disengage non-paying customers.

STC expects to charge approximately $14-18 per month for its program service. In addition, installation and purchase of the home antenna would be required (at a cost to the customer of about $100 if STC does it) and the customer would have to buy or lease the remaining elements of the home equipment. This equipment could be bought or leased from STC or from other competing sources (STC would lease it for about $10 per month).

Figure 1 summarizes the principal characteristics of STC's service.

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*STC also plans to offer a teletext service (which will display on the TV screen textual and graphical information selected by the subscriber) and to provide a high definition television experiment (which would have the enhanced resolution required for large screens such as 1m by 2m). These services/experiments will require special receiving equipment and are not described in this paper.

FIGURE 1

SUMMARY OF STC'S TELEVISION SERVICE

- Three television channels throughout the contiguous United States and to the major populated areas of Alaska and Hawaii.

- Programming will include movies, concerts, opera, sports, children's shows, public affairs and educational material, and programs oriented to specialized audiences.

- Subscription rate for programming is about $14-18 per month (descrambler used to control availability of service).

- Purchase and installation of antenna would cost about $100 if STC does it.

- Remaining equipment can be bought or leased from STC or from competing sources (STC lease at about $10 per month).

PART 1: SYSTEM DESCRIPTION

SUMMARY

The major aspects of STC's nationwide system are depicted in Figure 2. The four operating satellites are spaced 20° apart along the geostationary arc (115°W, 135°W, 155°W, 175°W longitude). The satellites, each independently programmable, serve areas in the CONUS which are approximately the size of the time zones. Satellite downlink transmissions are in the 12 GHz Broadcasting-Satellite service (BSS) band with a typical EIRP of 57 dBW. All operational uplinks are in the 17 GHz band.

Satellite broadcast transmissions are received at individual residences by equipment composed of outdoor and indoor electronic units as shown in Figure 3. Typically, the outdoor unit consists of a 0.75 meter diameter receiving antenna and its attached microwave electronics; in some areas of the U.S. antennae of 0.6 and 0.9 meters are used to equalize grade of reception at minimum cost. These antennae may be mounted on residence rooftops, sidewalls, gable ends or at ground level. Regardless of location, however, the antenna must have an unobstructed view of the satellite. A cable connects the outdoor unit of the home equipment to an indoor unit which amplifies, demodulates, descrambles, and remodulates the receive signal to allow compatible video reception by a conventional television set.

Multiple dwelling units (e.g., apartment buildings, condominiums) normally will use equipment similar to that used for individual reception. It will also be feasible to deliver STC's programs to cable head ends with very simple receiving equipment.

STC intends to utilize PAM-D class satellites.* They are expected to generate prime DC power of approximately 1700 watts at end of life (over 2000 watts at beginning of life). Three operating traveling wave tube amplifiers (TWTAs) will illuminate a shaped beam satellite transmitting antenna. Each TWTA has an RF power output of about 185 watts at end of life (215 watts at

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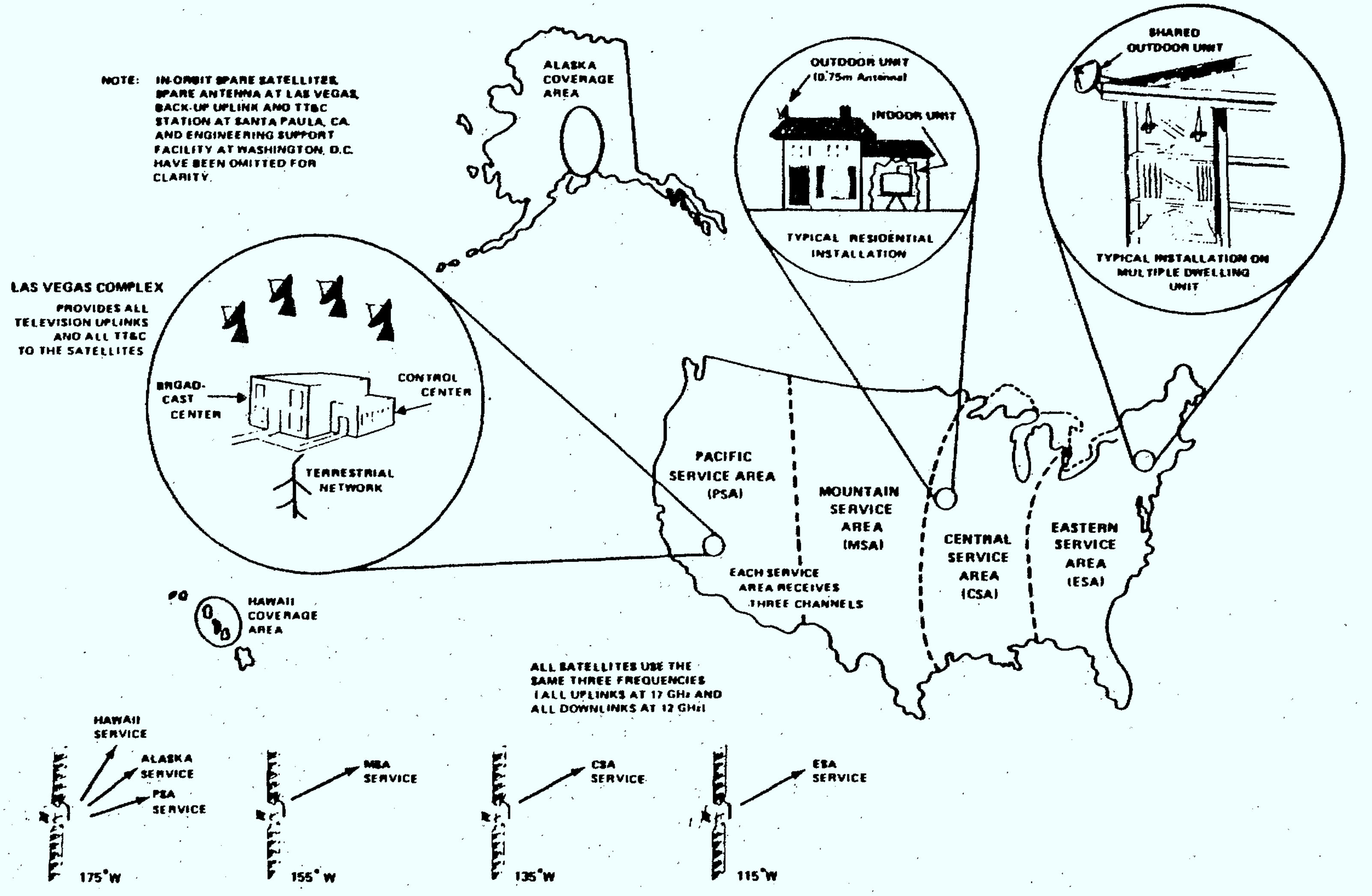
*PAM-D is the smallest booster available for carrying a spacecraft from the Shuttle orbit to geosynchronous transfer orbit. A PAM-D satellite can also be launched on a shared ARIANE III launch.



NOTE: IN-ORBIT SPARE SATELLITES, SPARE ANTENNA AT LAS VEGAS, BACK-UP UPLINK AND TT&C STATION AT SANTA PAULA, CA. AND ENGINEERING SUPPORT FACILITY AT WASHINGTON, D.C. HAVE BEEN OMITTED FOR CLARITY.

ALL SATELLITES USE THE SAME THREE FREQUENCIES (ALL UPLINKS AT 17 GHz AND ALL DOWNLINKS AT 12 GHz)

EACH SERVICE AREA RECEIVES THREE CHANNELS

FIGURE 2 SYSTEM CONFIGURATION

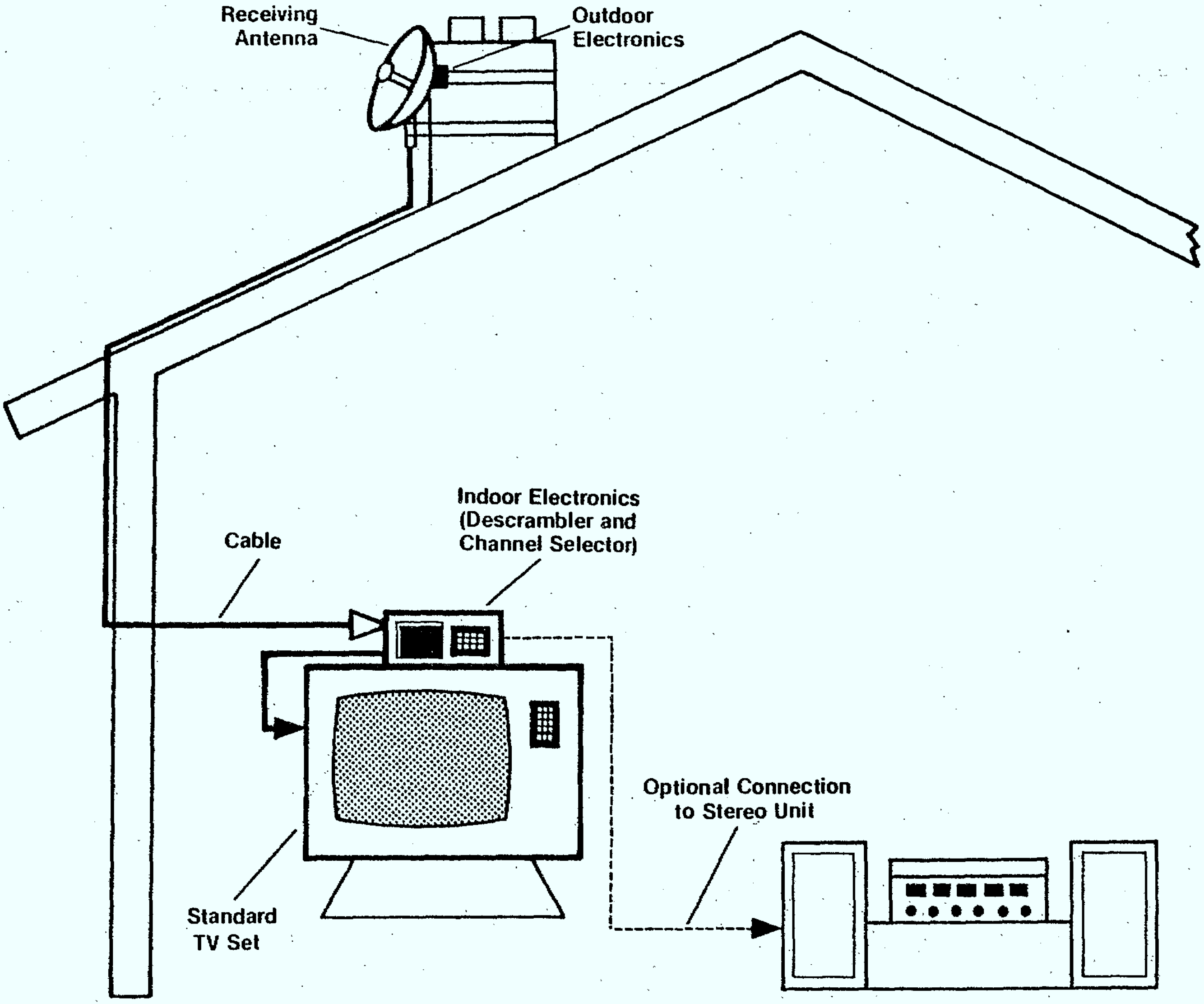


FIGURE 3 TYPICAL RESIDENTIAL INSTALLATION

beginning of life). The transmit antenna patterns are tailored to the contours of the areas served for transmission efficiency reasons and to minimize, to the extent practicable, any signal radiated over foreign territories.

Orbital locations have been selected to permit maximum satellite capacity and spectrum reuse while retaining acceptable eclipse times and elevation angels. As discussed in Part 2 of this paper, the use of four orbital locations was selected largely because it enhances orbit/spectrum utilization efficiency within Region 2.

In addition to the four operating satellites, two in-orbit spare satellites are planned for the nationwide implementation. The spares will be stationed at 115.05°W and at 175.05°W longitude. These locations will allow restoration of service within minutes to the highly populated areas of the East and West Coasts if a satellite malfunction occurs. Failure of the 135°W or the 155°W longitude satellite will require repositioning of one of the spares, a process that would take several days to a week.

All the satellites have a receive coverage area that extends from Los Angeles to Las Vegas. The ground station, which is located near Las Vegas, includes both a Broadcast Center and a System Control Facility. It will have four operating and one redundant 11-meter antennae to feed and control the satellites reliably (the spare satellites are controlled by the same antennae used to feed and control the satellites adjacent to them).

The Broadcast Center provides program uplinks to the satellites and has studio facilities, video tape/film processing equipment and related functional capability. Most programming is expected to be stored on film or tape, but interconnections with the terrestrial network will allow real-time programming to originate from outside the Broadcast Center.

The System Control Facility provides satellite control center and Telemetry, Tracking and Command (TT&C) functions. Additional equipment will be housed at this installation for system testing, to activate home equipment of subscribers, change the level of programming to existing customers and coordinate subscriber billing functions. Collocation of feeder, satellite control and

TT&C functions permits substantial cost savings. Backup feeder and TT&C facilities are planned at Santa Paula, California.

An engineering support facility in Washington, D.C. is also planned for overview of the satellite control, orbital mechanics computations, special analyses and processing of telemetry, and access to specialized personnel in the event of spacecraft malfunction. All ground-based facilities will be connected by terrestrial full-period and dial-up voice/data links.

TRANSMISSION CHARACTERISTICS

STC's transmission plan provides for high quality reception of National Television System Committee (NTSC) color video signals with their associated audio and control subcarrier. Frequency modulation (FM) is used so that home equipment cost and complexity are minimized. Quality objectives and system parameters are generally consistent with those adopted for Region 2 in the Final Acts of 1977 World Administrative Radio Conference (WARC-77) and incorporated in the Final Acts of WARC-79. Changes in technical characteristics have been made from those described in Annex 8 of WARC-77 in order to achieve STC's quality objectives at minimum cost and maximize power and spectrum efficiency; these changes are described in more detail in Part 2 of this paper.

STC's currently planned transmission parameters are summarized in Table 1. Since achievement of acceptable home equipment manufacturing costs is so crucial to STC's proposed offering, certain of these parameters may change in order to minimize costs. However, any such changes are not expected to affect overall transmission characteristics upon which STC's interference analyses have been based. Notice the provision of a second audio channel which may be used for stereo sound in some television programs (by using the customer's stereo amplifier and speakers as shown earlier in Figure 3) or for a second language track (e.g., spanish). The access control channel is used to address the home descramblers.

TABLE 1

Planned Transmission Parameters

Video Baseband:	CCIR Standard M with NTSC color
Audio/Control Subcarrier:	
Inputs:	1 ea. Basic Program; Audio Bandwidth = 13 kHz
	1 ea. Stereo or Second Language; Audio Bandwidth = 13 kHz
	1 ea. Access Control Channel; Bit Rate = 62 kbps
Audio Encoding:	PCM, Bit Rate = 315 kbps/channel
Composite Bit Rate:	692 kbps
Modulation:	QPSK
Frequency:	5.5MHz
Amplitude:	0.12 volts r.m.s. before emphasis at 1 volt p-p video reference point
Emphasis:	525 line per CCIR Rec. 405-1
Video Deviation:	10 MHz p-p
IF Bandwidth:	16 MHz
Uplink Frequency:	In the band 17.3 - 18.1 GHz
Downlink Frequency:	In the band 12.2 - 12.7 GHz

The color video signal is combined with a digital subcarrier and then frequency modulated onto an RF carrier. The deviation selected is consistent with the link quality objectives presented in the following paragraph. Relative power levels of the video and digital subcarrier have been balanced to provide comparable thresholds. The composite signal deviation is greater than implied by Carson's Rule for a 16 MHz bandwidth. The level of "overdeviation" selected gives the 16 MHz channel bandwidth improved clear sky S/N without noticeable degradation of the video performance by impulse noise.

STC's overall quality objective is to provide an excellent picture normally, while assuring an acceptable picture under all precipitation conditions except the heaviest downpour. Baseline link objectives are defined in terms of both pre-detection filtered carrier to noise (C/N) over a 16 MHz radio frequency bandwidth and demodulated video (peak-to-peak luminance) signal to (rms weighted) noise (S/N) using the recommended deemphasis and weighting characteristics for system M as specified in CCIR report 637-1. See XII Recommendations and Reports of the CCIR (Kyoto 1978). The link quality objectives are:*

(a) for 99 percent of the month having the worst precipitation

$$C/N \geq 14 \text{ dB}$$
$$S/N \geq 42 \text{ dB}$$

(b) for 99.8 percent of the month having the worst precipitation

$$C/N \geq 10 \text{ dB}$$
$$S/N \geq 37 \text{ dB}$$

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*The viewer ratings reported in the TASO Report suggest that more than 50 percent of the viewers would rate a 42 dB S/N picture as "excellent". Since this performance would be obtained for 99 percent of the time during the month having the heaviest rain, an "excellent" rating is expected for virtually all of the time from the majority of STC's customers throughout the U.S. Simulations of planned link operating characteristics have confirmed its generally excellent quality. The TASO results also imply that a 37 dB S/N picture would be rated as "passable" by more than 95 percent of the viewers.

Worst month statistics are normally related to average year statistics by a factor of four (i.e. 99 percent worst month equates to 99.75 percent average year and 99.8 percent worst month equates to 99.95 percent average year). Since the second quality objective ($C/N \geq 10$ dB) corresponds to the nominal threshold of an FM demodulator, the receive C/N is expected to be above threshold for all but about 4.4 hours per year (0.05 percent of the year) for locations where these minimum objectives are just met. Periods below threshold will generally consist of degraded but viewable television. Actual outages (e.g., loss of picture synchronization or a virtually unintelligible picture) are expected to occur for a much smaller period of time.

To account for the wide variations in precipitation existing throughout the country (all 5 of the rain climatic zones are present in the U.S.), STC has specified satellite EIRP on an area-by-area basis with due consideration given to the performance expected from STC's baseline home receiver with 0.75m antenna. (Information on home receiver performance is presented later and a discussion of the trade-offs between satellite EIRP and home receiver performance is presented in Part 2 of this paper.) The EIRP requirements are illustrated in Figures 4 through 7. These requirements vary commensurate with rain attenuation and with range loss from the satellites to the points shown in the figures. Rain attenuation has been based on the 0.25% precipitation exceedance for the points shown; these statistics are based on data available for about 125 cities in the U.S. The 0.25% exceedance corresponds to the link quality objective (a) expressed earlier (i.e., to 99% of the worst month or 99.75% of the year).

To further equalize the grade of sevice and to account for satellite EIRP variations from beam center to beam edge, three home antenna sizes are planned in the range between 0.6m and 0.9m diameter. For the typical location, a 0.75 meter antenna will provide adequate margin at an achievable level of satellite transmitter RF power. If additional margin is needed (for example, in a rainy part of the country near the edge of coverage of a satellite), a larger antenna can be used. In dry parts of the country, particularly those which are well inside the satellite coverage area and receive more than the minimum EIRP, a smaller less expensive antenna may be preferred to reduce home equipment costs and provide a greater degree of protection against wind damage.

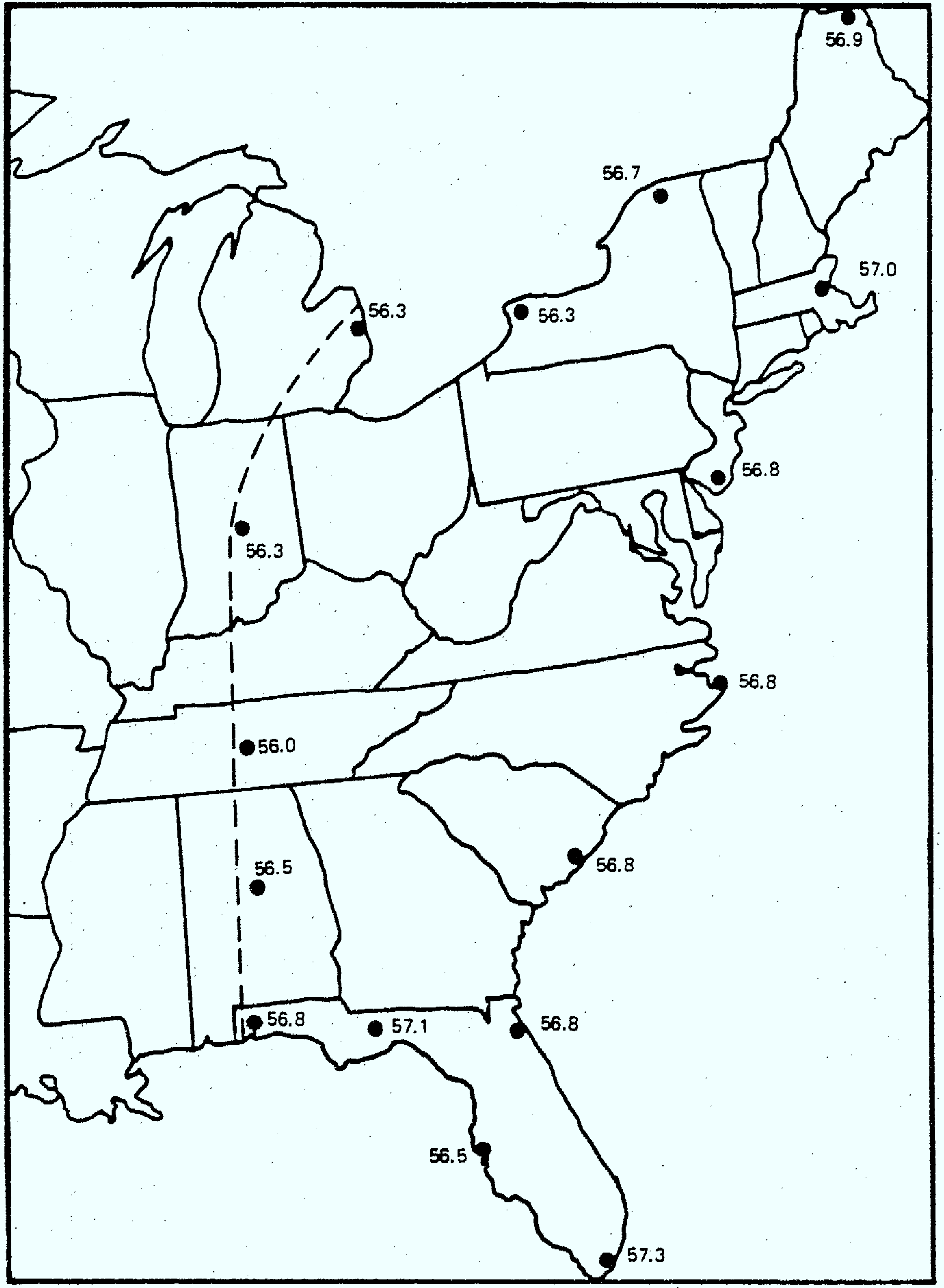

FIGURE 4 MINIMUM EIRP (dBW) FOR EASTERN SERVICE AREA LOCATIONS

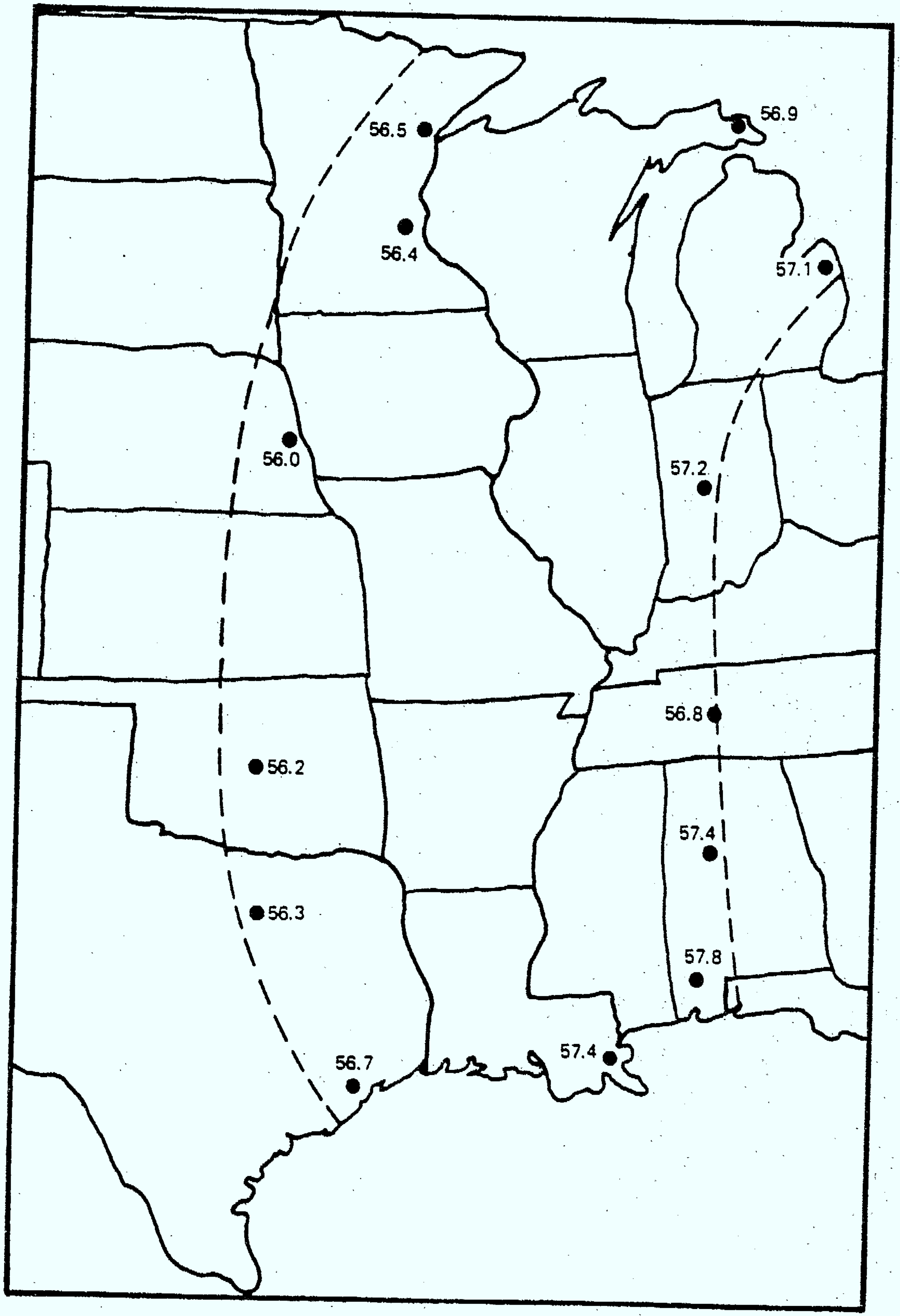

FIGURE 5 MINIMUM EIRP (dBW) FOR CENTRAL SERVICE AREA LOCATIONS

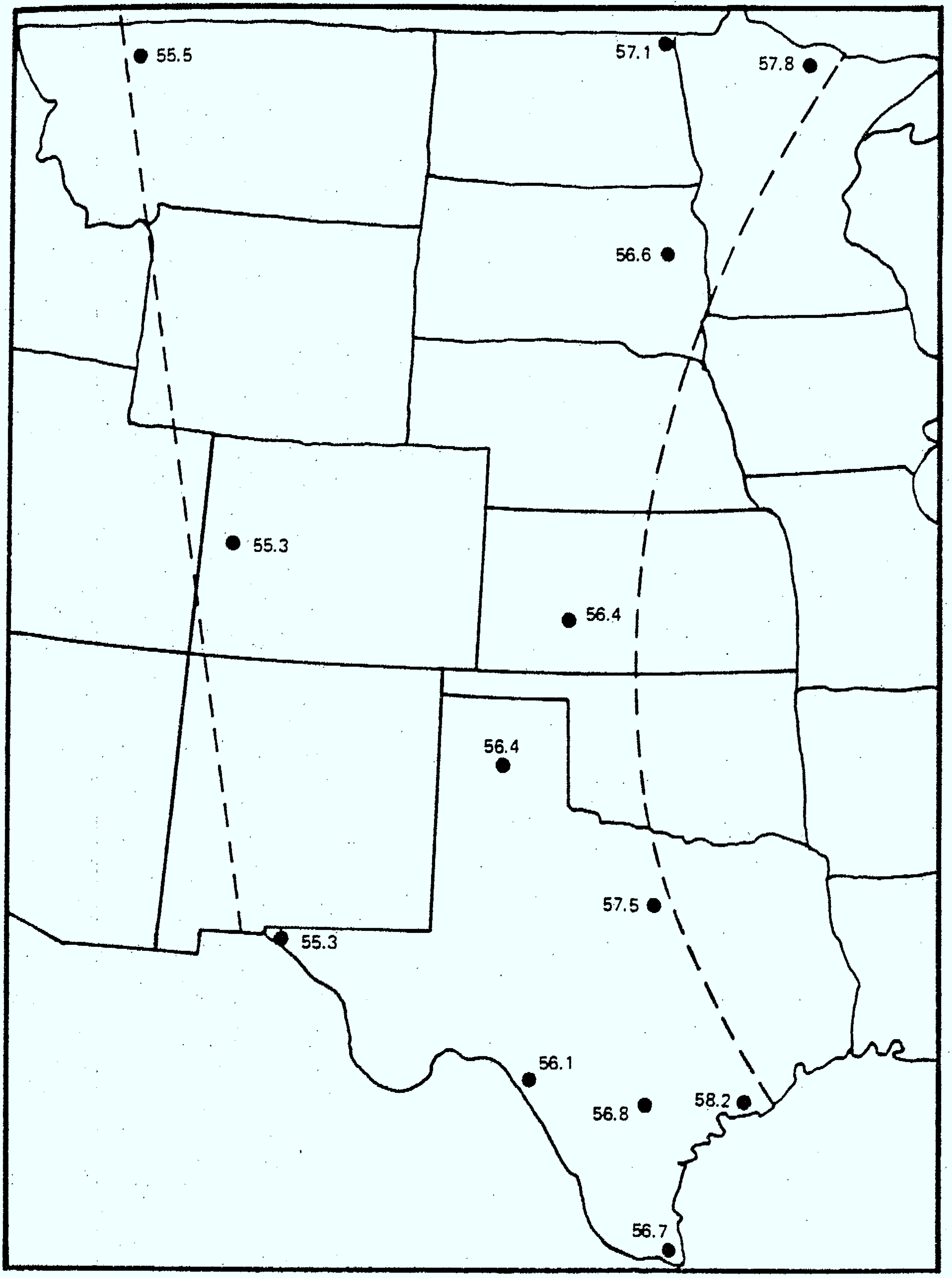

FIGURE 6 MINIMUM EIRP (dBW) FOR MOUNTAIN SERVICE AREA LOCATIONS

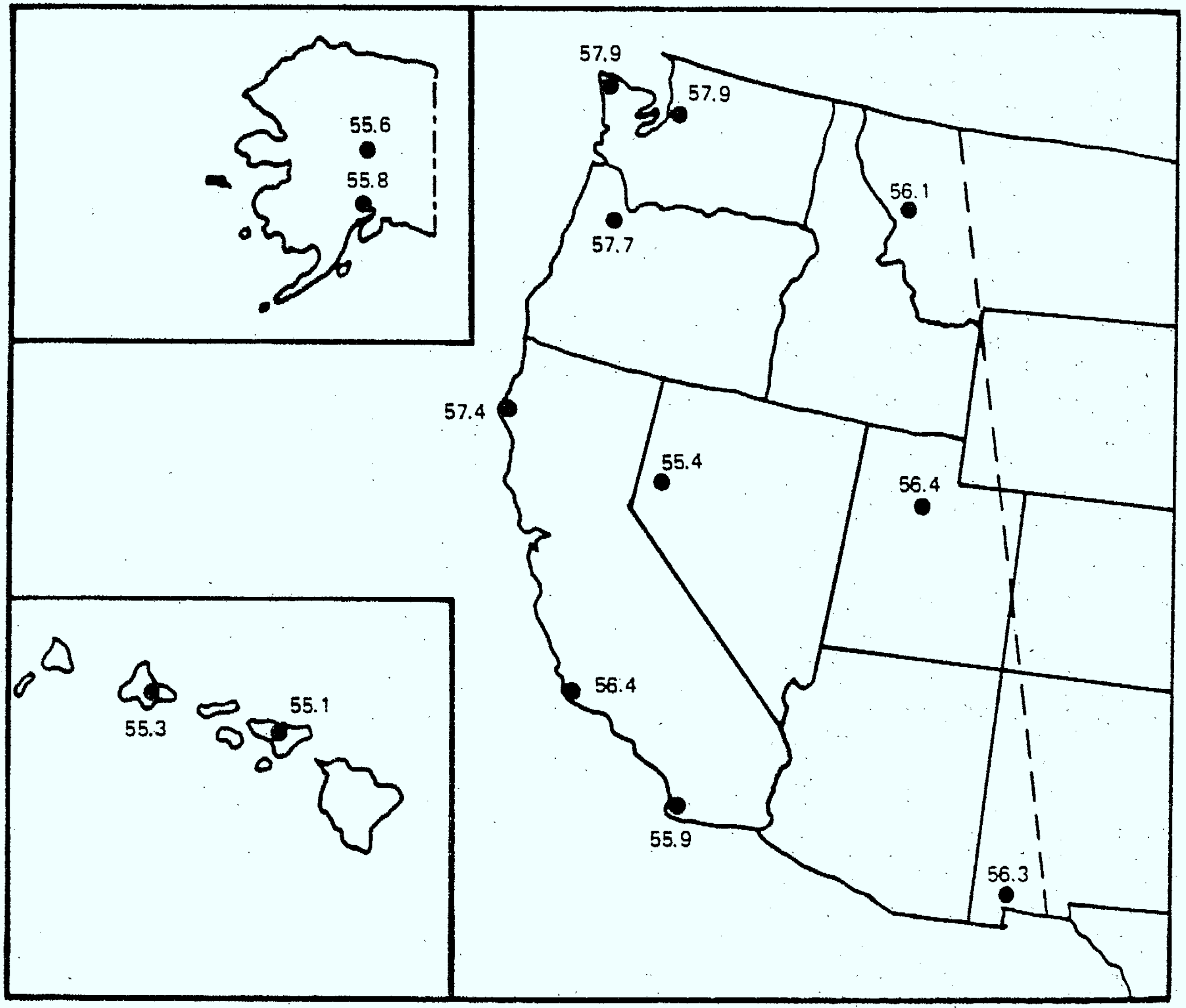

FIGURE 7 MINIMUM EIRP (dBW) FOR LOCATIONS IN THE PACIFIC SERVICE AREA, ALASKA AND HAWAII

The amount of satellite power required to satisfy the link quality objectives is directly proportional to the gain-to-noise temperature ratio (G/T) of the home receiver. Therefore, G/T is a key consideration in the system design. Expected (clear weather) values of G/T versus antenna diameter are presented in Table 2.

STC's reference link design is shown in Table 3. It assumes the baseline 0.75m diameter antenna for the home equipment and the typical satellite transmit EIRP of 57 dBW.

The satellite transponder and feeder station uplinks will provide constant downlink EIRP even in the presence of uplink fading. The receiving antenna for the satellite uplink will have a G/T of at least +7.7 dB/K. With this uplink performance, reasonable earth station EIRP can provide substantial margin against fading that may occur in the 17 GHz band. Table 3 shows the uplink budget for Las Vegas, Nevada to the 115°W satellite. On this link, an EIRP of 86.6 dBW assures that the downlink noise budget is degraded by less than 0.2 dB except for a few minutes per year.

Under clear sky conditions there is a total link margin above threshold of 5.9 dB. However, since under fading conditions signal level decreases are accompanied by sky noise increases and reduction in the G/T of home equipment, an atmosphere attenuation of only 5 dB is allowable before threshold is reached (see the "5 dB Rain Attenuation" column of Table 3).

Expected satellite EIRP in many areas of the country will be greater than required since the satellite antenna is expected to provide minimum EIRP near the edge of coverage and excess EIRP well inside the coverage areas. Because of this, the margin above threshold in many locations will be greater than required to achieve link quality objectives.

For example, the expected EIRP over Cincinnati, Ohio is approximately 58 dBW, more than 1 dB greater than the EIRP required to meet the link quality objectives. The resulting clear sky downlink margin above threshold is 7.0 dB. With this margin, a 5.6 dB fade would cause a 1.4 dB increase in receiver noise temperature, and the link would operate at threshold. A 5.6 dB fade is expected to occur or be exceeded near Cincinnati for only about 2.6 hours per year.

TABLE 2

Clear Weather Home Equipment G/T

Antenna Diameter (m)	0.6	0.75	0.9
Peak Gain, dB	34.9	36.8	38.4
Noise Temperature, db-K	27.4	27.4	27.4
Boresight G/T, dB/K	7.5	9.4	11.0
Pointing Loss (0.5° pointing error), dB	0.4	0.6	0.9
Net G/T, dB/K	7.1	8.8	10.1

Assumptions:

Antenna efficiency	50 %
Noise temperature (at antenna flange)	
Clear weather sky noise	9 K
Background antenna noise	10 K
Receiver noise (NF = 4.5 dB)	527 K
Total Noise Temperature	546 K

TABLE 3

Reference Link Budget

Uplink:

Earth Station EIRP	86.6 dBW
Free Space Loss (17.6 GHz, 48° elev.)	208.9 dB
Assumed Rain Attenuation*	12.0 dB
Satellite G/T	+7.7 dB/K
Uplink C/KT	102.0 dB-Hz

	Atmospheric Condition	
Downlink	**Clear**	**5 dB Rain Attenuation**
Satellite EIRP	57.0 dBW	57.0 dBW
Free Space Loss (12.5 GHz, 30° elev.)	206.1 dB	206.1 dB
Atmospheric Attenuation	0.14 dB	5.0 dB
Home Receiver G/T (0.75 meter)	9.4 dB/K	8.1 dB/K
Receiver Pointing Loss (0.5° error)	0.6 dB	0.6 dB
Polarization Mismatch Loss (average)	0.04 dB	0.04 dB
Downlink C/KT	88.1 dB-Hz	82.0 dB-Hz
Overall C/KT	87.9 dB-Hz	82.0 dB-Hz
Overall C/N (in 16 MHz)	15.9 dB	10.0 dB
Reference Threshold C/N	10.0 dB	10.0 dB
Margin Over Threshold	5.9 dB	0.0 dB

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* Extrapolation of rain attenuation data can only be meaningfully performed down to about 0.005% exceedance. The 0.005% exceedance for Las Vegas at 17.6 GHz is 6.5 dB (*i.e.*, rain fades will exceed 6.5 dB only 0.005% of the year, or about half an hour per year). Since the system is designed for 12 dB of uplink rain fade, the uplink is expected to degrade below design value for less than a few minutes per year.

The 99 percent worst month (99.75 percent average year) rain attenuation estimate for Cincinnati is 1.6 dB. A fade a this level would cause a 0.6 dB increase in receive system noise temperature reducing overall link performance by 2.2 dB. Since the clear sky C/N for Cincinnati is 17.0 dB, the C/N in a 16 MHz bandwidth would exceed 14.8 dB for 99.75 percent of an average year. This C/N corresponds to a post-detection weighted S/N of 42.8 dB. Therefore, the 99 percent worst month link quality objective is exceeded and an excellent picture normally results.

The Cincinnati example characterizes expected signal quality under typical environmental conditions and the effects of heavy precipitation on expected periods of operation below threshold, assuming a 0.75m diameter receiving antenna. Other locations have been similarly analyzed to determine the duraions of below-threshold reception expected in an average year as a function of home equipment antenna diameter. The results are presented in Table 4. Below-threshold durations were calculated based on the expected satellite EIRP contours that are presented later, and assuming the maximum expected pointing errors by the satellite antenna (±0.1°) and the home equipment antenna (±0.5°).

To achieve above-threshold operation for 99.95 percent of an average year, the below-threshold duration must be less than 4.4 hours per year. Table 4 shows that this objective is satisfied at most locations using a home equipment antenna with a 0.75m diameter. At other locations, the objective can be satisfied with 0.6m or 0.9m diameter antennae. For rainy areas like the Gulf Coast and Florida, this objective does not appear to be achievable with small antennae; a more realistic objective for these areas would seem to be operation above threshold in excess of 99.8 percent of an average year.

OPERATING FREQUENCIES

STC's satellites can be designed to transmit normal 16 MHz television programming on ractically any three center frequencies in the 12.2-12.7 GHz band, and to receive on practically any three center frequencies in the 17.3-18.1 GHz band. The design contemplated by STC assumes a single translation frequency.

TABLE 4

Hours of Operation Below Threshold in an Average Year

Home Equipment Antenna Diameter	0.6m	0.75m	0.9m
Location			
Eastern Service Area			
Atlanta, GA	5.2	3.7	2.9
Boston, MA	4.6	3.2	2.2
Buffalo, NY	2.4	1.8	1.4
Caribou, ME	8.5	3.0	1.7
Charleston, SC	18.0	13.1	9.5
Cincinnati, OH	4.0	2.6	2.0
Detroit, MI	7.7	3.0	2.0
Lexington, KY	5.1	3.5	2.7
Miami, FL	19.3	14.9	11.4
New York, NY	4.5	3.2	2.3
Washington, DC	5.4	3.7	3.0
Central Service Area			
Chicago, IL	6.0	3.4	2.4
Dallas, TX	11.6	7.0	5.2
Duluth, MN	6.7	2.6	1.9
Houston, TX	18.1	12.3	8.5
Memphis, TN	7.7	5.3	4.0
Mobile, AL	18.3	13.4	9.5
St. Louis, MO	5.6	3.8	3.0
Topeka, KS	8.1	5.0	3.8
Mountain Service Area			
Albuquerque, NM	2.0	<1	<1
Austin, TX	8.4	4.9	3.8
Denver, CO	<1	<1	<1
El Paso, TX	3.5	1.4	<1
Fargo, ND	7.0	4.0	3.1
Helena, MT	6.3	2.0	<1
Wichita, KS	16.0	7.1	4.3
Pacific Service Area			
Boise, ID	1.6	<1	<1
Los Angeles, CA	4.8	1.9	<1
Portland, OR	4.3	2.1	1.6
San Francisco, CA	5.2	1.8	1.0
Seattle, WA	7.6	3.0	1.9
Tucson, AZ	7.4	3.2	1.9

STC has selected a single translation frequency to minimize the mass and complexity of the satellite communications subsystem. Virtually every provider of DBS services in Region 2 undoubtedly will be motivated similarly, and the Plan developed at the 1983 Regional Administrative Radio Conference (RARC-83) relating uplink to downlink frequencies is expected to reflect that common interest.

STC has tentatively selected specific center frequencies for its three channels based on compatibility with existing Fixed Service (terrestrial) assignments in the U.S. and with a high definition television (HDTV) experimental package that will be incorporated in the satellites. However, in order to allow the use of any three channel frequencies allocated to the U.S. at the RARC-83, STC will be able to change the satellite RF filters and translation frequency after RARC-83 while still providing an HDTV testing capability. A channel-to-channel center frequency separation of 40 MHz or more would be required because of satellite output filter design constraints which impact satellite mass, power and thermal control. WARC-77 (see Final Acts, Annex 8, para. 3.5.3) recognized this for purposes of Region 1 and 3 planning.

ORBIT LOCATIONS

The factors which led to STC's selection of orbit locations at 175°W, 155°W, 135°W and 115°W longitude are presented in detail in Part 2 of this paper.

To account for RARC-83 results, the STC satellite construction program will have sufficient flexibility so that the satellites will be able to accomodate any likely outcome from RARC-83 in terms of U.S. orbit locations. In the FCC Application, STC shows the ability of the satellites to operate from different orbit locations.

SERVICE AREAS

The service areas in the CONUS and in Alaska and Hawaii are shown in Figure 8. A detailed discussion of the factors which led to the selection of these service areas is included in Part 2 of this paper.

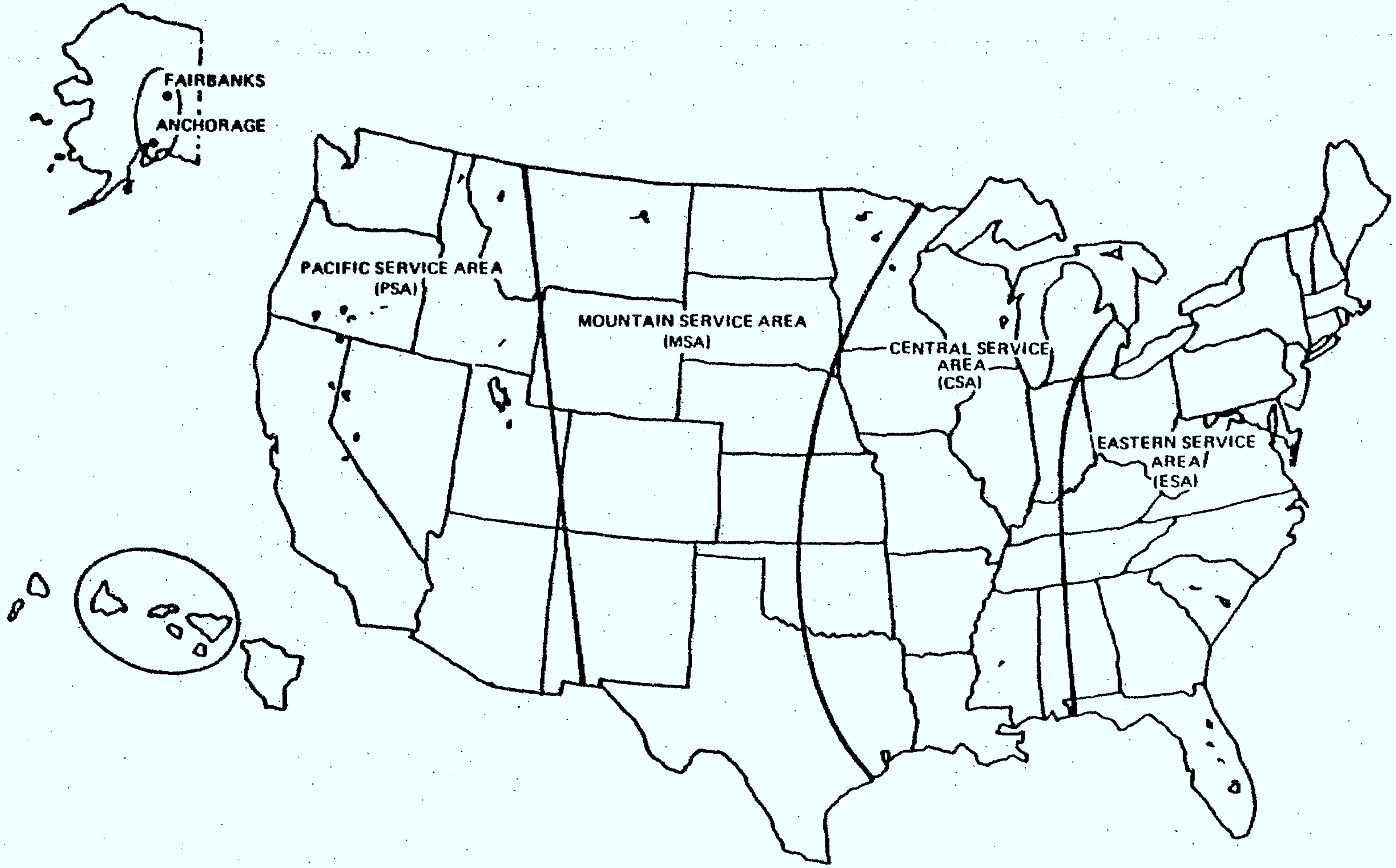

FIGURE 8 CONUS SERVICE AREAS AND COVERAGE OF ALASKA AND HAWAII

SYSTEM COMPATIBILITY WITH WARC-77 AND RARC-83

Within the flexibility allowed by Article 12, para. 12.5 of the WARC-77 Final Acts,* STC's system implementation is fully consistent with Annex 8, WARC-77 (and WARC-79) technical characteristics adopted for Region 2. That flexibility has permitted system parameters to be optimized for the specific offering envisaged. The resultant technical characteristics lead to interference levels in other DBS systems that are less than the levels which would result if the technical charactertistics of Annex 8, WARC-77 were used without change (for example, the EIRP of STC's system is expected to be approximately 3 dB lower).

An important point that needs to be emphasized is that STC is not suggesting or recommending that its technical parameters (e.g., 16 MHz bandwdith, 0.75 meter antenna, 57 dBW EIRP, 9 dB/K G/T) be used for Region 2 planning purposes at RARC-83. STC believes that conservative parameters like those adopted for Region 2 at WARC-77 along with the type of flexibility afforded by para. 12.5 of WARC-77 is the best approach for planning and allow different DBS operators the ability to optimize their system for the service envisioned.

The 1983 RARC will establish a detailed plan for the BSS for Region 2 under the terms of Article 12 and the Principles of Annex 6 of the WARC-77 Final Acts. The conference is expected to review and perhaps modify some of the technical characteristics which were adopted at the 1977 WARC, and to assign orbit locations and frequencies to Region 2 administrations. STC is confident that its planned technical characteristics (e.g., satellite EIRP, channel bandwidth) will be consistent with RARC-83 parameters. In addition, as discussed earlier, the satellite construction program is sufficiently flexible to accomodate any likely outcome from RARC-83 in terms of U.S. orbit locations and frequencies.

INTERSYSTEM INTERFERENCE

STC's system will operate well within the established intersystem, interservice and inter-regional interferene criteria set forth at the 1977 WARC and extended at the 1979 WARC. This is demonstrated in an appendix submitted with the FCC Application.

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*Paragraph 12.5 states: "Administrations may implement systems which utilize values for the technical characteristics different from the values in Annex 8 of the Final Acts, provided that such action does not result in interference to operational or planned systems of other administrations in excess of that determined in accordance with Annex 9."

SATELLITE CHARACTERISTICS

The satellites will be procured under a contract stipulating firm fixed-prices and delivery schedules. The initial flight model spacecraft (F-1) is expected to be delivered three years after start of construction and broadcast operation to the Eastern Service Area should be possible three months thereafter. Additional satellites will be delivered and launched on a schedule which could be as early as every three months.

Satellite specifications will be based predominantly on performance (e.g., EIRP, G/T) and not design requirements. Therefore, spacecraft contractors will have considerable flexibility in the design of the satellites. For the purpose of characterizing the system, STC has synthesized a baseline spacecraft design and has analyzed it sufficiently to ensure that all projected performance requirements can be met. Elements of the baseline spacecraft are described herein to illustrate a typical implementation. Any such representation, however is only one of many alternatives by which contractors may meet STC's performance requirements.

All satellites will be essentially the same. A capability will exist by ground command so that each satellite can be reconfigured to serve either of two services areas, provided it is located at the correct orbital location. Therefore, the satellite design used to serve the ESA from 115° can be reconfigured by ground command and relocated to 135° in order to serve the CSA, and visceversa; similarly, the satellite used for MSA service can also be used to provide PSA service, and visceversa. The only difference between these two types of satellites is in the antenna beam forming networks; this is explained in greater detail later. For the nationwide implementation, then, two operational satellites and a spare of one type will be used for ESA/CSA service, and two operational stellites and a spare of a slightly modified type will be used for PSA/MSA service.

The satellite mission life will be specified to be at least seven years. Performance requirements have been carefully selected so that the satellites can be built without reliance on unproven technology. Although substantial engineering development is required for certain spacecraft elements, it should be possible for contractors to build most of the satellite components from existing, flight-qualified designs. This approach allows the satellites to be procured under a fixed-price contract and minimizes the probability of delayed satellite deliveries and satellite in-orbit anomalies.

The satellite TT&C system for launch and transfer orbit maneuvers will operate in the 4 and 6 GHz frequency bands to provide compatibility with existing ground facilities. After the satellites have been positioned in synchronous orbit, the TT&C function will be accomplished from the Las Vegas System Control Facility operating in the 12 and 17 GHz BSS bands. The same facility will be capable of monitoring and controlling all in-orbit satellites, including the spares.

A summary of the satellite characteristics is presented in Table 5. The following paragraphs identify the most important elements of the satellite.

The satellites will be designed to be compatible with two different launch vehicles. One is NASA's Space Transportation System (STS, also referred to as the Shuttle), using a PAM-D booster to carry the spacecraft from the Shuttle's orbit into geostationary transfer orbit. The present STS flight availability may not be able to accommodate the launch schedule of all the satellites, particularly the early ones. Accordingly, the satellite design will also be compatible with a shared launch (i.e., an STC satellite and another satellite launched together) on the ARIANE launch vehicle. Although the mass of STC's satellites is compatible with a Delta launch vehicle, the satellite volumetric configuration is expected to exceed dimensional constraints of the Delta launch vehicle.

After a satellite is injected into geosynchronous transfer orbit by the launch system, final injection into a nominally geostationary orbit will be accomplished by means of an apogee kick motor (AKM) incorporated in the satellite.

STC does not expect to specify the satellite configuration to be used. Spacecraft manufacturers will be allowed to proposed spin-stabilized or body-stabilized designs, which must meet all specified performance requirements. STC's baseline spacecraft has assumed a body-stabilized design because the high power required (about 1700 watts) appears somewhat easier to achieve with the large, deployed solar arrays typical of

TABLE 5

Satellite Characteristics

Mission	Television Broadcast for Individual Reception
Launch Vehicle	STS/PAM-D and ARIANE
Initial Mass on Station	650 kilograms
Satellite Mission Life	7 years
North-South Stationkeeping	± 0.1 degree or better
East-West Stationkeeping	±0.1 degree or better *
Prime Power	1700 watts end of life
Redundancy	100% all active electronic elements
Stabilization	Spin or body stabilized
Broadcast Channels	Three standard video - 16 MHz Bandwidth. Two (Alternative) HDTV Channels 28 MHz and 100 MHz Bandwidth
Emission Designators	Standard Video - M16 F5/9 HDTV 1 - M100 F5/9 HDTV 2 - M28 F5/9
Eclipse Capability	None
Receive Service Area Transmit Service Areas	L.A./Las Vegas *See* Figure 8
Frequency Bands	Transmit: 12.2 to 12.7 GHz Receive: 17.3 to 18.1 GHz

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* Stationkeeping of each in-orbit spare relative to its nearby operating satellite will be adequate to maintain nominal intersatellite spacing of 0.05°.

Satellite Characteristics—(Continued)

Minimum EIRP per Channel	Varies locally commensurate with rain attenuation statistics and range loss. Ranges between 58.2 dBW and 55.1 dBW.	
Minimum Broadcast RF Output Power per Channel	185 watts (EOL)	
Saturation Flux Density per Channel	-88.1 dBW/m^2 at 17.3 GHz	
Satellite Communications Subsystem G/T	7.7 dB/K minimum	
TT&C Frequencies		
4 & 6 GHz Band (Transfer Orbit Operations)	Transmit:	In the band 4198 to 4200 MHz
	Receive:	6 GHz Band
12 & 17 GHz Band (Synchronous Orbit Operations)	Transmit:	In the band 12.200 to 12.212 GHz *
	Receive:	17 GHz Band
TT&C EIRP		
4 GHz Band	0 dBW minimum	
12 GHz Band	15 dBW normally, 10 dBW during mispointing condition	
Total TT&C RF Power		
4 GHz Band	2 watts	
12 GHz Band	Normal operation: 100 milliwatts Mispointing condition: 10 watts	
TT&C G/T		
6 GHz Band	-32.1 dB/K minimum	
17 GHz Band	-37.5 dB/K minimum	
Polarization (Communications and TT&C)	Transmit:	RHCP for ESA LHCP for CSA RHCP for MSA LHCP for PSA
	Receive:	Orthogonal to transmit

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* Dependent upon outcome of RARC-83

body-stabilized spacecraft. However, techniques exist that would allow spin-stabilized spacecraft to meet STC's requirements.

Spacecraft mass and size are limited by launch vehicle constraints. The STS/PAM-D will place a maximum mass of approximately 1247 kilograms into geosynchronous transfer orbit. The ARIANE Type III launch vehicle will be capable of launching two satellites simultaneously, each weighing approximately this amount. Based on the performance of applicable AKMs and assuming the maximum hydrazine propellant required to achieve the desired geosynchronous orbit, spacecraft mass at the start of service (after apogee motor firing) will be approximately 650 kilograms.

The dimensions of the spacecraft are constrained both by the ARIANE shroud dimensions and by STC's requirements that it be capable of configuration for a vertical launch in the STS (i.e., PAM-D and apogee motor thrust axes orthogonal to the STS Orbiter longitudinal axis). The satellite is expected to have an approximately cylindrical envelope during launch with a maximum diameter of about 2.9 meters and a height of about 2.3 meters.

In geosynchronous orbit the dimensions of the satellite are expected to be dominated by the antenna and the solar arrays. STC's baseline satellite has one deployed antenna reflector measuring 2.9 meters in diameter and two symmetrically deployed solar arrays, each measuring about 7 meters by 1.5 meters.

A representative mass budget for the satellite is presented in Table 6. For the assumed STS/PAM-D launch, the AKM mass is approximately 595 kilograms with a propellant loading of 560 kilograms (for an ARIANE launch the apogee motor would carry about 100 kilograms less propellant). The antennae weigh 44 kilograms, of which about half is budgeted for the reflector and its deployment mechanism, and the other half is budgeted for the feeds and beam forming networks necessary to produce the desired antenna beams. For all subsystems except communications and power, the mass estimates are based on existing hardware being used or being proposed for use on other satellite programs. Therefore, the contingency mass carried in the budget provides margin primarily for the communications and power subsystems.

TABLE 6

Representative Satellite Mass Budget

Item	Mass (Kgs)
Launch Vehicle Capability*	1236
AKM Consumables	560
Hydrazine Propellant (Plus Pressurant)	129
Dry Satellite	547
Communications Electronics	93
Communications Antenna	44
Telemetry, Tracking and Command	20
Electric Power	104
Attitude Control **	49
Reaction Control (Dry)	23
Structure	70
Thermal Control	25
AKM Case at Burnout	35
Balance and Miscellaneous	38
Contingency	46

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* Assumes an optimized STS/PAM-D launch with modified transfer orbit characteristics.

** Includes 5 kgs. budgeted to offset solar torques induced by single antenna reflector.

Sufficient hydrazine propellant will be loaded on each satellite to permit at least one repositioning maneuver at a rate of three degrees per day, or more than one repositioning maneuver at slower rates.

The design requirement for the mission life of the satellites is seven years. This estimate is determined by a conservative evaluation of the effect of the synchronous orbit environment on the solar cell arrays, charge-dischargre cycling on the life of the batteries, and the mass allocated to propellant for spacecraft station-keeping. To suport the probability of survival throughout seven years, all spacecraft equipment will be redundant where possible. Parts will be derated in their applications, and materials and processes will be selected so that aging or wear-out effects will not adversely affect spacecraft performance over its life.

A typical block-diagram of the communications subsystem of the ESA/CSA satellite, excluding redundancy, is presented in Figure 9. The satellite design for MSA/PSA service would differ only in the receive and transmit antenna beam forming networks. The block diagram depicted shows a single conversion transponder, with the receiver translating the 17 GHz uplink signals directly to the 12 GHz downlink frequency band.

Uplink communications signals are received through the beam covering the Los Angeles-Las Vegas area and pass through a wideband receiver. At least two redundant wideband receivers are expected to be provided. All receivers will have high sensitivity, good linearity characteristics and excellent translation frequency stability. Net translation frequency error, including initial setting tolerance, will be better than $\pm$ 10 parts in 10^6 over the operating lifetime of the satellite. Short-term stability will be better than $\pm$ 1 part in 10^6.

Following amplification and downconversion by the receiver, the signals are fed to the input multiplexer where each channel is individually filtered prior to amplification by a TWTA.

Each satellite will have three operating transmitters whose individual outputs can be turned on and off by ground command for emission control purposes. The TWTAs are expected to have a maximum output power of around 215 watts at beginning of life and a minimum output power of about 185 watts at end of life. At least

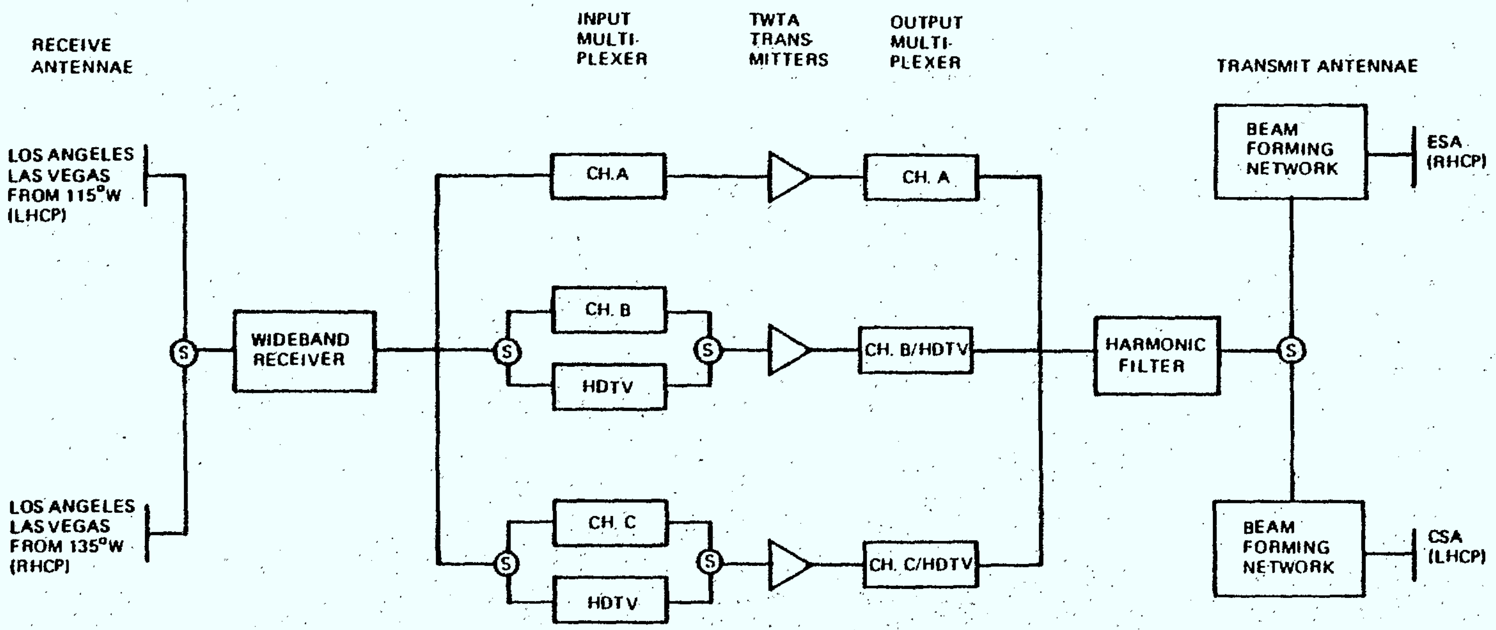


FIGURE 9 REPRESENTATIVE COMMUNICATIONS SUBSYSTEM BLOCK DIAGRAM (ESA/CSA SPACECRAFT)

three additional TWTAs will be provided for redundancy. The power level of these TWTAs is approximately the same as that of the CTS satellite. In addition, considerable work is currently underway by TWTA manufacturers on units of this power level. Despite this, STC considers the TWTAs the most critical aspect of the satellites and will take intensive measures to ensure the timely availability of satisfactory units.

The TWTAs will not be needed for broadcasting during eclipse periods. However, because of concerns related to the effect of on/off transients on TWT life, the TWTAs wil incorporate an eclipse standby mode which keeps the cathode at near operating conditions.

The outputs of the TWTAs are combined in the output multiplexer. The multiplexer filters are sources of potentially large RF losses. These losses, however, can be minimized by adequately separating the channels. High passband efficiency is particularly important because excessive losses would require TWTAs with higher power levels (which have reliability/lifetime implications for the TWTA and mass/power implications for the satellite) and create increased thermal loads on the output filters.

The multiplexed RF is passed through a harmonic filter to attenuate out-of-band emissions and through a beam forming network to develop the requisite shaped beam transmit pattern.

The beam forming networks are part of the antenna assembly, which provides shaped beams to CONUS service areas. Compared to simple beams of circular or elliptical cross section, shaped beams provide more efficient use of RF power because their patterns can be tailored to closely follow irregular contours, and because the power is spread more uniformly over the coverage area. This technology allows STC to design its system so that the radiation falling over other countries is reduced to the maximum extent praticable.

The baseline antenna configuration employs a parabolic reflector with a diameter of approximately 2.9 meters. This reflector is fed by a cluster of feed horns, and the horns are in turn connected to the two beam-forming networks which were shown in Figure 9. All communications receive and transmit functions are performed with this reflector. Although final characteristics of the satellite antenna are subject to variation depending on the selected spacecraft contractor's design, is baseline antenna is typical of approaches that may be implemented.

Operation of the baseline antenna is best described by considering one of its shaped beams, for example, that covering the ESA. The pattern is created by a beam forming network which splits the power at the output of the harmonic filter into 16 parts and feeds these individually to the RHCP (right hand circular polarization) input port of 16 feed horns. In illuminating the parabolic reflector, each of these horns generates a circular beam of about 0.6 degree beamwidth. When the weighted illumination of the 16 contiguous horns is combined, the resulting pattern has a shape that closely follows the contours of the ESA. Within the coverage area the gain is more evenly distributed than it would be for an elliptical beam.

The 16 feed horns used for the ESA beam are part of a feed cluster assembly which is also used to generate the CSA shaped beam. Most of the horns in the feed cluster assembly are shared, with the RHCP port of these horns connected to the ESA beam forming network and the LHCP port connected to the CSA beam forming network. When the satellite is placed in service at 135°W longitude, the switch at the output of the harmonic filter is commanded into the CSA mode, thereby channeling all the satellite's transmit power into the CSA beam forming network.

The use of polarization reversal between the ESA and CSA beams allows these beams to use a single feed cluster assembly at the focal point of the reflector, thereby reducing antenna mass and increasing antenna gain. Because the incorporation of four beam forming networks would significantly increase the mass and complexity of the satellite, STC plans to allow the spacecraft contractor to provide some spacecraft equipped with ESA and CSA beam forming networks and other spacecraft equipped with MSA and PSA beam forming networks, rather than requiring a single design which could accommodate (by ground command and orbit repositioning) any U.S. service area.

Receive functions are provided using the same 2.9 meter reflector by incorporating appropriate receive feed horns.

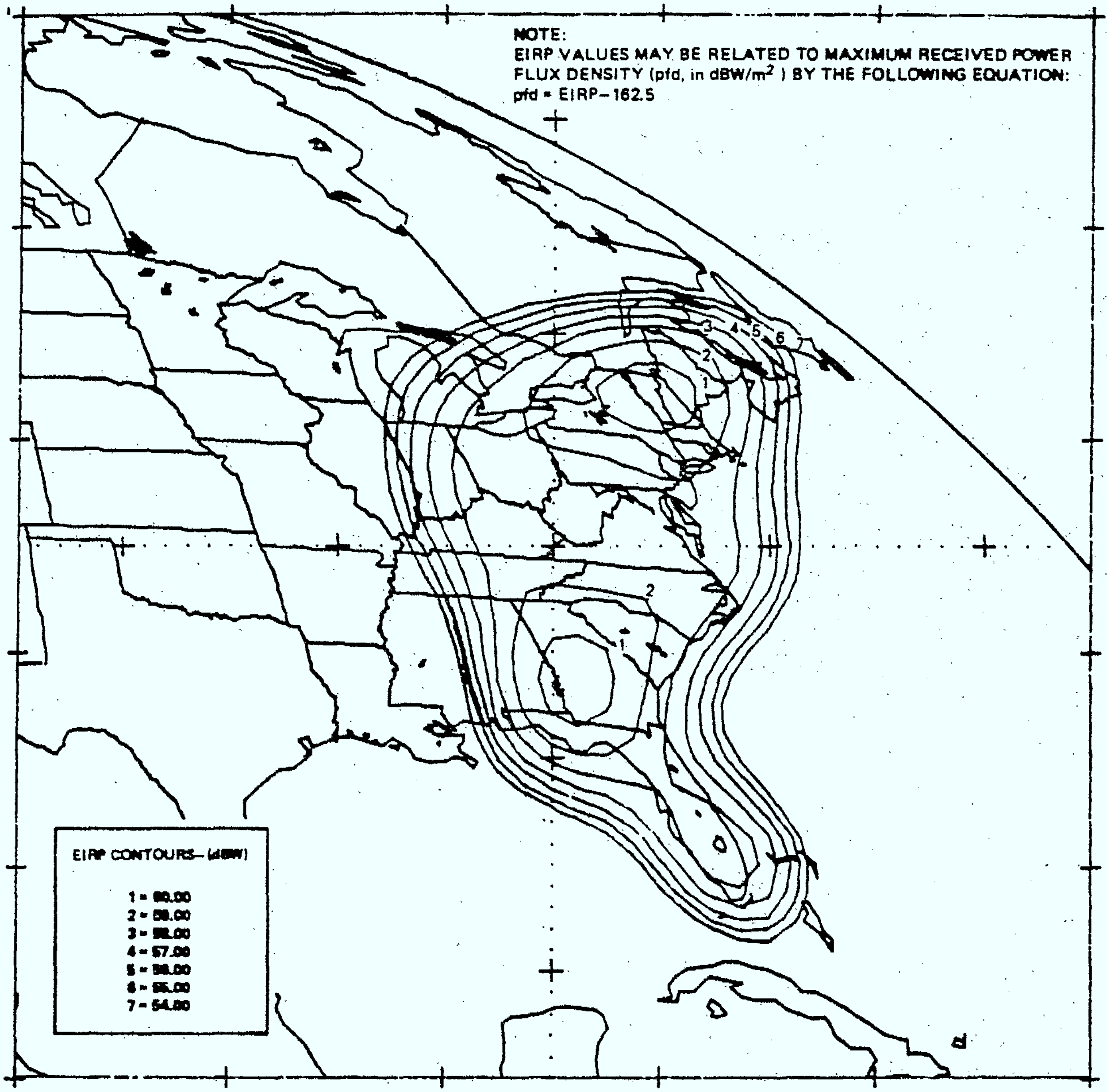
Computer-predicted performance of the baseline antennae, in the absence of pointing errors, are depicted in Figure 10 through 13. The figures show antenna EIRP contours (and maximum power flux densities received at the earth's surface) in 1 dB increments near the four CONUS coverage areas, as viewed from the satellite.

The EIRPs over the service areas range between 60 dBW and 55.1 dBW. Higher values are more likely to occur near the center of the transmit beams, while lower values are expected near the edges. Since the locations on the edge of the transmit beams will receive at least the minimum EIRP necessary, the vast majority of locations will obtain EIRPs greater than the specified values (Figures 4 through 7). For instance, with proper consideration given for expected satellite antenna pointing errors, the tip of Cape Cod in Massachusetts will get the minimum EIRP for the area (i.e., 57 dBW), while Boston will get about 1 dB more and Albany, N.Y. about 2 dB more. In the PSA, these margins are likely to be much greater, with the western edges of the CONUS getting the minimum required EIRPs of 56 to 58 dBW, while Reno gets about 3 dB more than its required EIRP.

To account for satellite pointing error, the baseline design assumes an error tolerance of 0.1 degree in any direction and provides the minimum required EIRP over a larger area than the service area. For example, Maine, Cape Cod and the east coast of Florida have a minimum EIRP requirement of 57 dBW. In Figure 10, the 57 dBW contour is seen to be well beyond these areas to assure achievement of this EIRP even when the satellite is at the extremes of its pointing error tolerance.

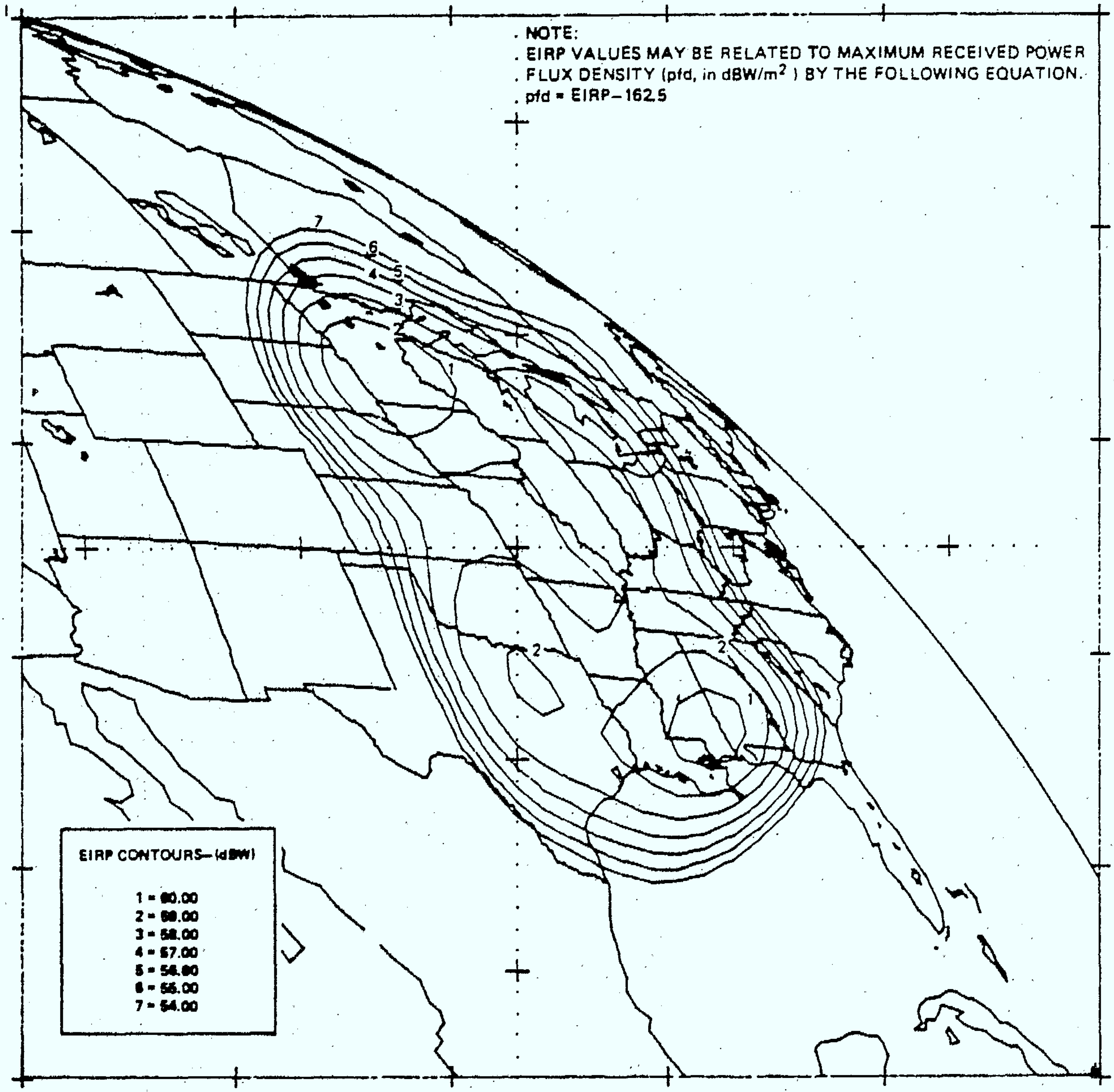
The baseline antennae have been designed to take advantage of the reduced EIRP requirements in areas with low rain attenuation. Predicted EIRP at the tip of Maine (Figure 10), for example, is about 2 dB higher than over the northwest corner of the MSA (Figure 12).

As noted earlier, an important advantage that the shaped beam satellite antenna exhibits is the reduction to the maximum extent practicable of unintentional



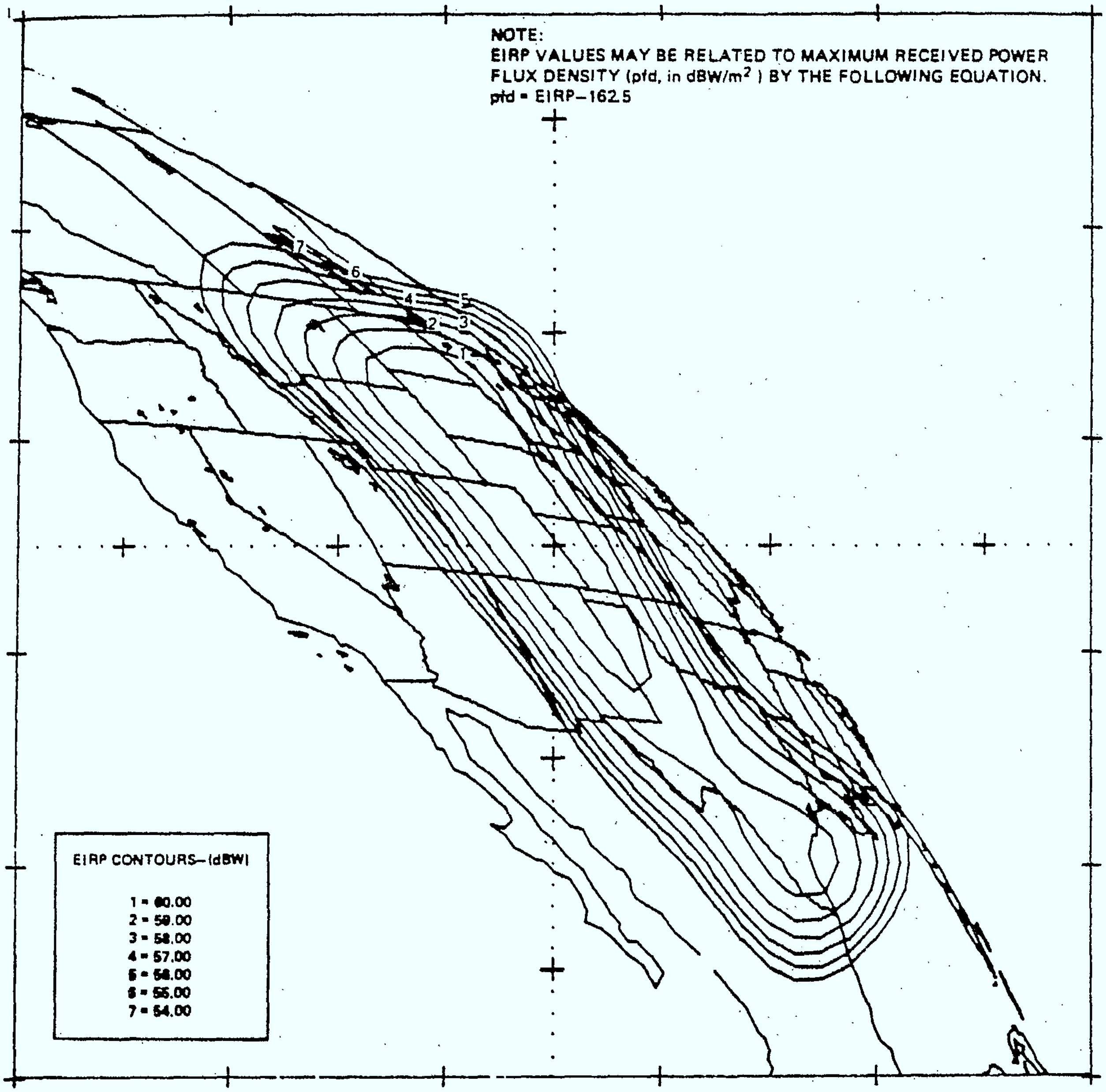
NOTE:
EIRP VALUES MAY BE RELATED TO MAXIMUM RECEIVED POWER FLUX DENSITY (pfd, in dBW/m^2) BY THE FOLLOWING EQUATION:
pfd = EIRP−162.5

FIGURE 10 COMPUTER PREDICTED EIRP CONTOURS FOR ESA BEAM



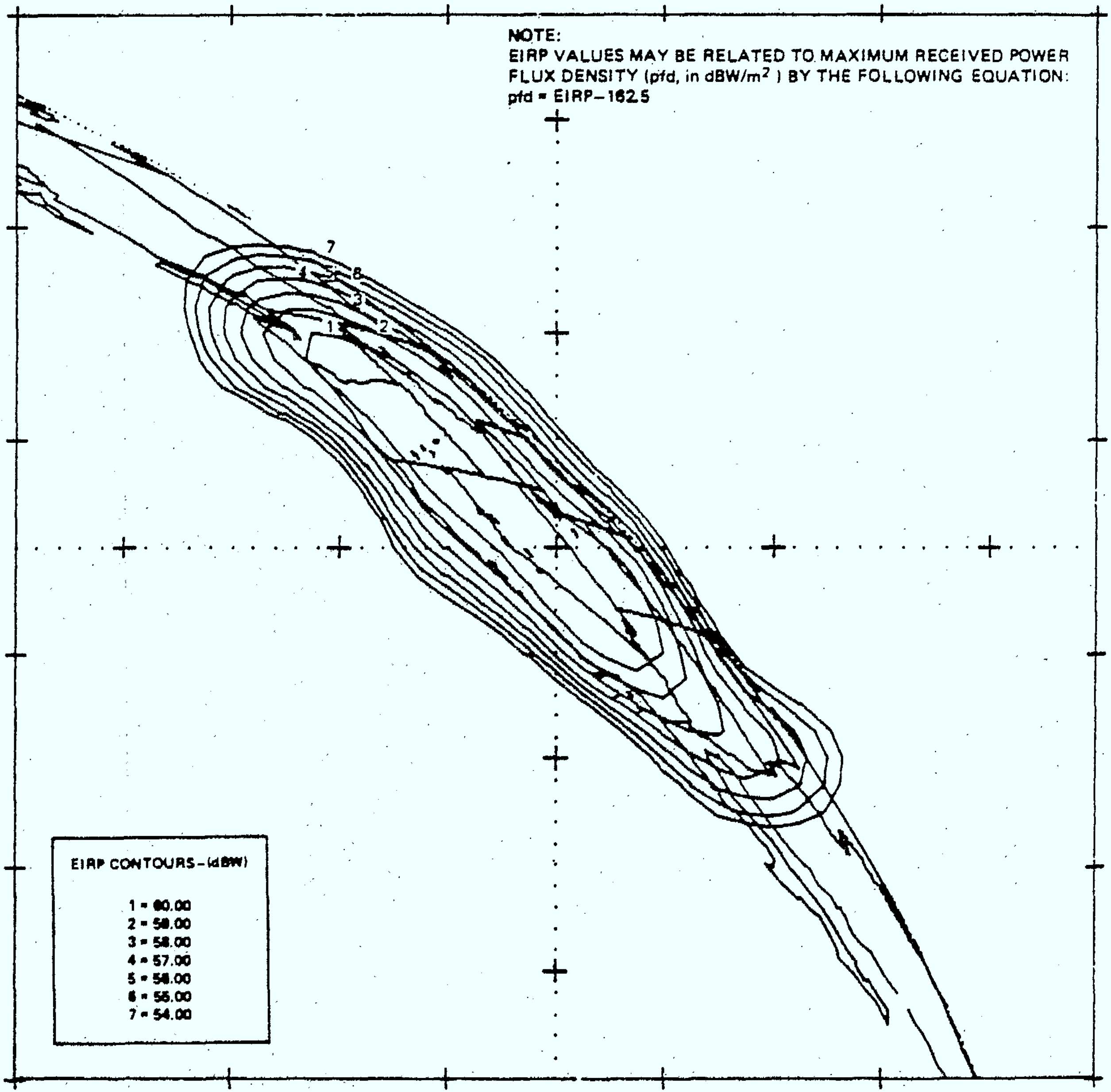
. NOTE:
. EIRP VALUES MAY BE RELATED TO MAXIMUM RECEIVED POWER
. FLUX DENSITY (pfd, in dBW/m^2) BY THE FOLLOWING EQUATION.
. pfd = EIRP − 162.5

FIGURE 11 COMPUTER PREDICTED EIRP CONTOURS FOR CSA BEAM



NOTE:
EIRP VALUES MAY BE RELATED TO MAXIMUM RECEIVED POWER FLUX DENSITY (pfd, in dBW/m^2) BY THE FOLLOWING EQUATION.
~~pfd~~ = EIRP−162.5

FIGURE 12 COMPUTER PREDICTED EIRP CONTOURS FOR MSA BEAM



NOTE:
EIRP VALUES MAY BE RELATED TO MAXIMUM RECEIVED POWER FLUX DENSITY (pfd, in dBW/m^2) BY THE FOLLOWING EQUATION:
pfd = EIRP−162.5

FIGURE 13 COMPUTER PREDICTED EIRP CONTOURS FOR PSA BEAM spillover into other nations.* In this respect, a comparison of shaped and elliptical beams is made in Appendix B to this paper.

Table 7 shows the EIRP power budget, including all losses from the TWTA to the antenna, for the typical ESA edge-of-coverage EIRP of 57 dBW.

The transmit antenna polarizations were defined in Table 5. The reversal of polarization from one service area to the next is not intended to enhance interference protection, since adequate isolation exists by virtue of the 20° separation between the satellites (see the section entitled "Orbit Locations" in Part 2 of this paper). As indicated earlier, it is introduced so that a single set of feed horns can be used, thereby reducing satellite mass and complexity. The polarization reversal causes no reduction in the spectral efficiency of the implementation and in fact parallels the BSS Plan for Regions 1 and 3 where adjacent service areas used cross-polarized channels.

The remainder of the satellite subsystems are generally similar to those of other communications satellites. Noteworthy variations include the large power level (about 1700 watts at end of life), the comparatively low battery mass (because eclipse power is used only for housekeeping loads and to keep the TWTAs warm) and the fairly tight attitude control expected (of the order of ± 0.07° for roll and pitch and 0.5° for yaw) to maximize antenna gain (and thus minimize the TWTA power level).

FEEDER AND TT&C STATION CHARACTERISTICS

The Las Vegas facility is a major complex which provides video operations, feeder links, system control center functions and TT&C capabilities.

The video operations area will control all aspects of program production, scheduling, editing, reproduction, evaluation, control and airing. Program produc-

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*ITU Radio Regulation No. 428A provides that: "In devising the characteristics of a space station in the broadcasting-satellite service, all technical means available shall be used to reduce, to the maximum extent practicable, the radiation over the territory of other countries unless an agreement has been previously reached with such countries."

TABLE 7

Satellite EIRP Budget (Typical)

End of Life TWTA Output Power	22.7 dBW
Output Multiplexer and Harmonic Filter Losses	-0.7 dB
Line and Switch Losses	-0.5 dB
Antenna Losses (beam forming network, feeds, etc.)	-1.5 dB
Minimum Edge of Coverage Antenna Gain (includes pointing error losses)	37.0 dBi
Minimum EIRP	57.0 dBW

tion is expected to involve extensive use of film and recorded video media. Occasionally real-time material will be obtained for broadcast through an interface with the terrestrial microwave network. Complete facilities will be included for program storage, review, production, time base correction, monitoring, introduction of video font and special effects, switching, test, monitor and program transmission control. A modest studio facility will also be created to accommodate local program production.

Feeder links to the satellites will require baseband, intermediate frequency and radio frequency equipment necessary to channelize, scramble, modulate, upconvert, amplify and transmit the video signals. Five 11-meter antennae operating in the 12/17 GHz BSS bands are planned, four for use with the satellites and one for redundancy. They will be equipped with auto track, program track and manual positioning capability and will be controlled from the RF operations area. Planned antenna characteristics are shown in Table 8. Each antenna is fed by three 200 watt transmitters (one for each TV channel).

The equipment in Las Vegas is designed so that normal TV programming and TT&C operations can occur simultaneously without impairment or interruption of either function.

The Las Vegas complex also includes a system control center from where all the satellites are monitored and controlled. Command and ranging signals originating at the control center are modulated, upconverted and amplified by equipment dedicated to command functions and fed to the 11-meter antennae used for feeder links. Similarly, these antennae are used for reception of telemetry and ranging signals from the satellites for processing and limit checking in the control center.

HOME EQUIPMENT

The individual home reception equipment consists of three basic elements: a receiving antenna with its supporting mount, an outdoor microwave unit and an indoor unit (IDU) as shown in Figure 14. The receiving antenna taken with its universal mount and the microwave unit comprise the outdoor unit (ODU). The IDU and ODU are connected by a cable. ODU mounting will vary depending on home architecture and the extent of foliage

TABLE 8

Antenna Characteristics

Electrical	
Operating Frequency Range	
Transmit	17.3 - 18.1 GHz
Receive	12.2 -12.7 GHz
Antenna Gain	
Transmit	63.5 dBi @ 17.5 GHz
Receive	60.5 dBi @ 12.5 GHz
Half-Power Beamwidth	
Transmit	0.11°
Receive	0.15°
VSWR	≦1.3 to 1
Polarization	RHCP/LHCP selectable Receive—orthogonal to transmit
Axial Ratio, (Voltage)	≦1.4 to 1
Noise Temperature @ 30° Elevation	20K
Mechanical	
Antenna Size	11 meters
Mount Type	Elevation over Azimuth
Antenna Pointing Range	Azimuth, 110° Elevation, +15° to +60°
Pointing Accuracy	0.03° RMS in 30 mph winds gusting to 45 mph 0.11° RMS in 60 mph winds gusting to 85 mph
Survival Wind Loads	125 mph any direction
Steering Modes	Auto Track Program Track Manual Slew Manual Position

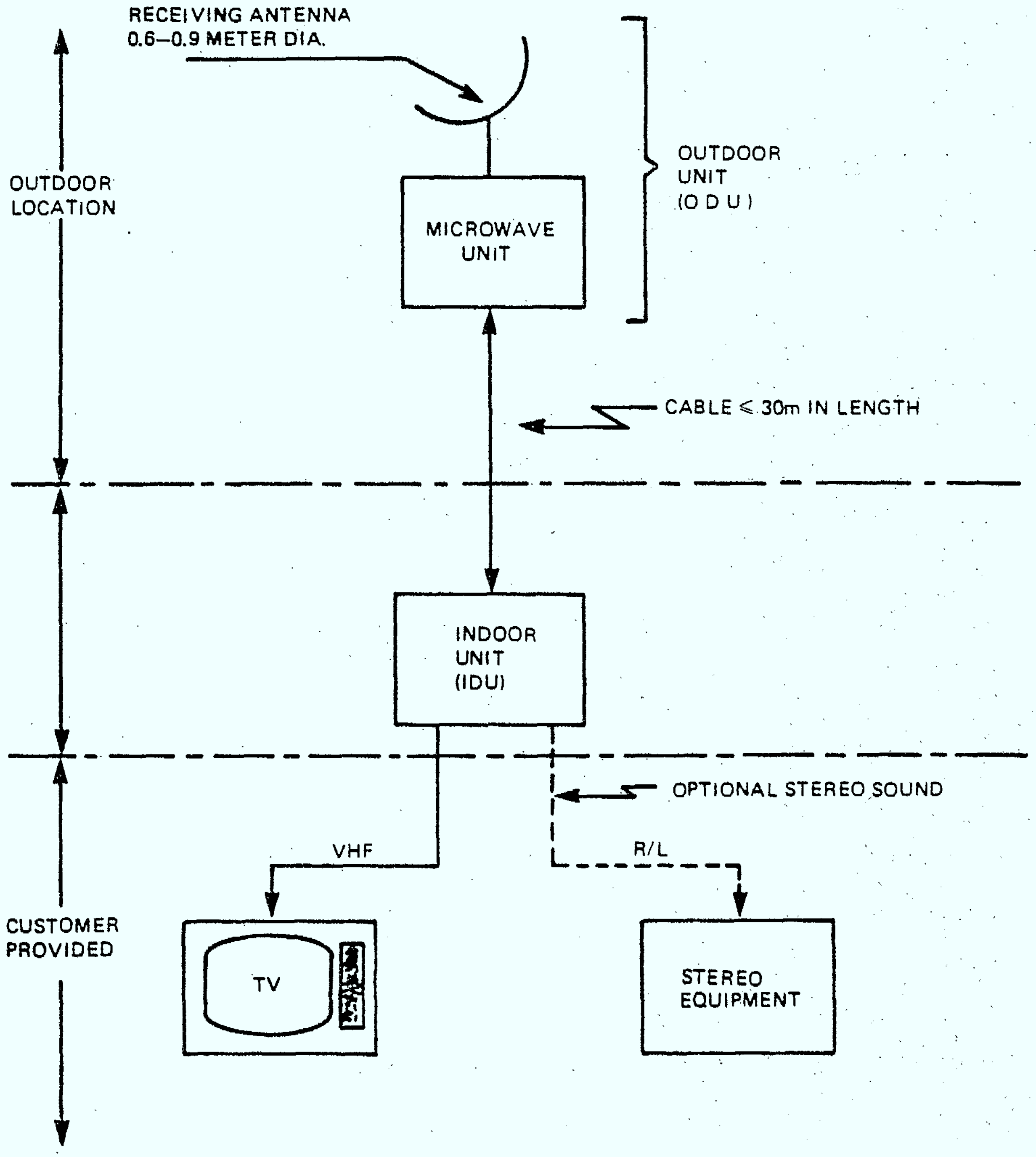

FIGURE 14 INDIVIDUAL RECEPTION EQUIPMENT–BASIC ELEMENTS

or structural blockages in the direction of the satellite, see Figure 15.

The antenna (0.6 - 0.9 meters) and microwave unit are basically broadband devices which may be operated across the full BSS operating frequency band and would be suitable for operation with any conceivable 12 GHz U.S. DBS system implementation. The microwave unit will contain the necessary amplifiers, mixers, filters, and oscillators to downconvert the received 12 GHz signal to an intermediate frequency, nominally in the 800-1300 MHz range. Expected overall ODU performance characteristics are shown in Table 9. Final specifications will be determined after further detailed discussions with hardware suppliers.

The IDU, located in proximity to the viewer's conventional television set, will contain the necessary electronics and controls to allow subscriber channel selection, FM demodulation, descrambling and AM remodulation. Normal channel reception is expected to be either on VHF channel 3 or 4. The IDU provides a standard NTSC formatted signal with the usual adjustments of color, hue, volume and tone retained in the viewer's TV set.

Considerable use of modular construction is anticipated for the IDU to permit cost effective introduction of new technology. For example, it is anticipated that the IDU will be constructed to allow the easy introduction of a new descrambler should improved techniques be developed. Similarly, designs are contemplated which would make changes of channel frequencies, addition of new channel frequencies and modification in the second IF bandwidth possible at minimum cost. This construction concept will guard against obsolescence for units leased by STC, and allow subscribers who purchase similar home equipment to modify it when desired. Figure 16 shows a block diagram of the home equipment, including the principal elements of the IDU.

When second language transmissions are programmed, a switch on the IDU permits their reception using the viewer's TV audio channel. Low level stereo output jacks will also allow connection of the IDU to subscriber-owned stereo equipment suitably located for reception of stereo broadcast transmissions. The subscriber would turn the sound down on his television receiver when stereo transmissions are broadcast.

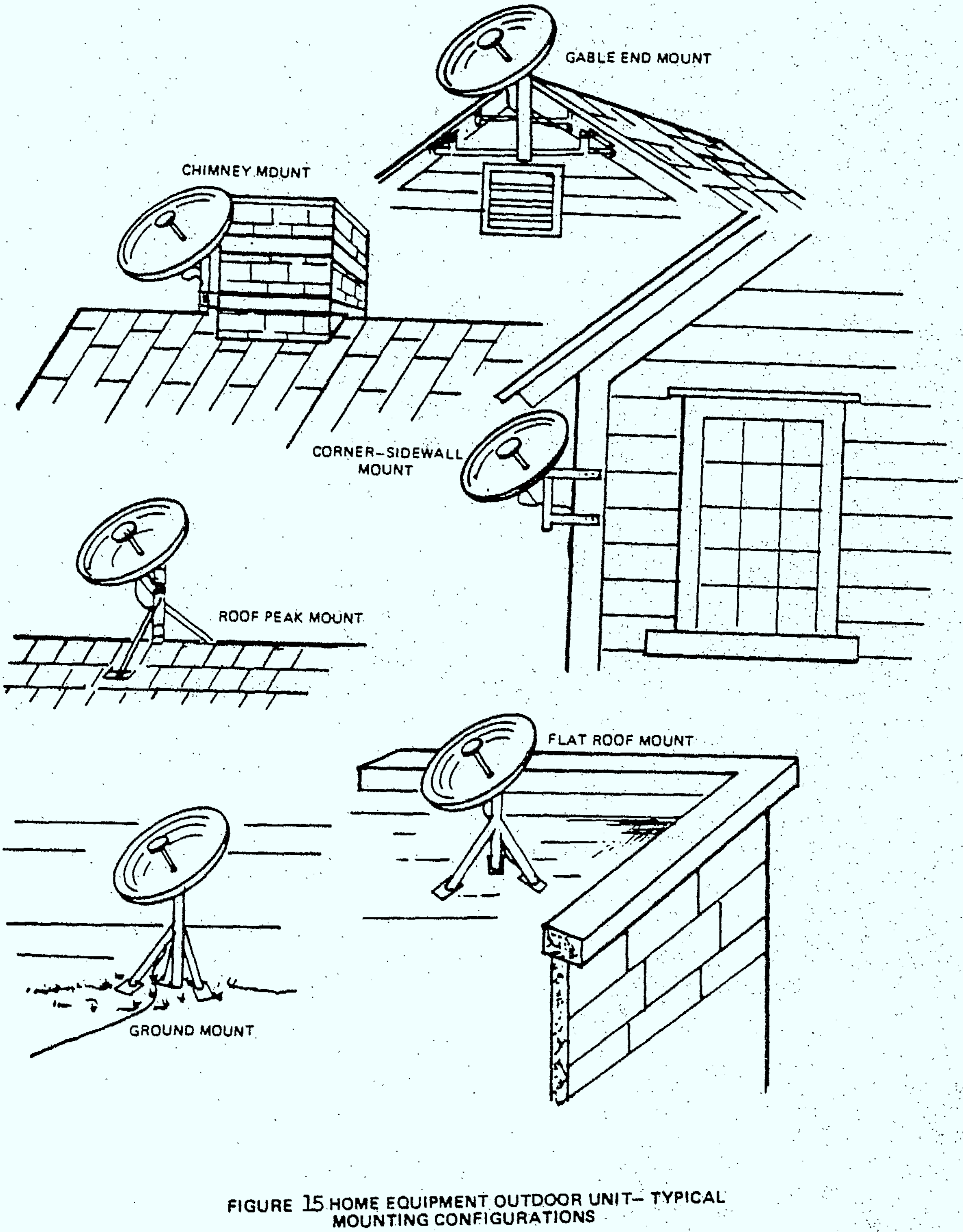

FIGURE 15 HOME EQUIPMENT OUTDOOR UNIT– TYPICAL MOUNTING CONFIGURATIONS

TABLE 9

Outdoor Unit Performance (Nominal)

Antenna/Mount			
Frequency Range	12.2–12.7 GHz maximum *		
Antenna Diameter (m)	.6	.75	.9
Gain dB @ 12.5 GHz	34.9	36.8	38.4
Polarization	circular, selectable**		
Adjustment	10°–80° elevation ± 70° Azimuth		
Wind Survival	123 kph (80 mph)		
Mounting	universal		
Weight	approximately 26 kg.		
Microwave Unit			
Noise Figure	$\leqq$ 4.5 dB		
Bandwidth IF	same as Frequency Range above		
Frequency IF	in range 800-1300 MHz		
Stability	$\pm 1.0 \times 10^{-5}$		
Temperature Range	$-40°$ to $+60°$C		

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*Frequency range expected to accommodate full band available in U.S. for BSS.

**Selectable at time of installation.

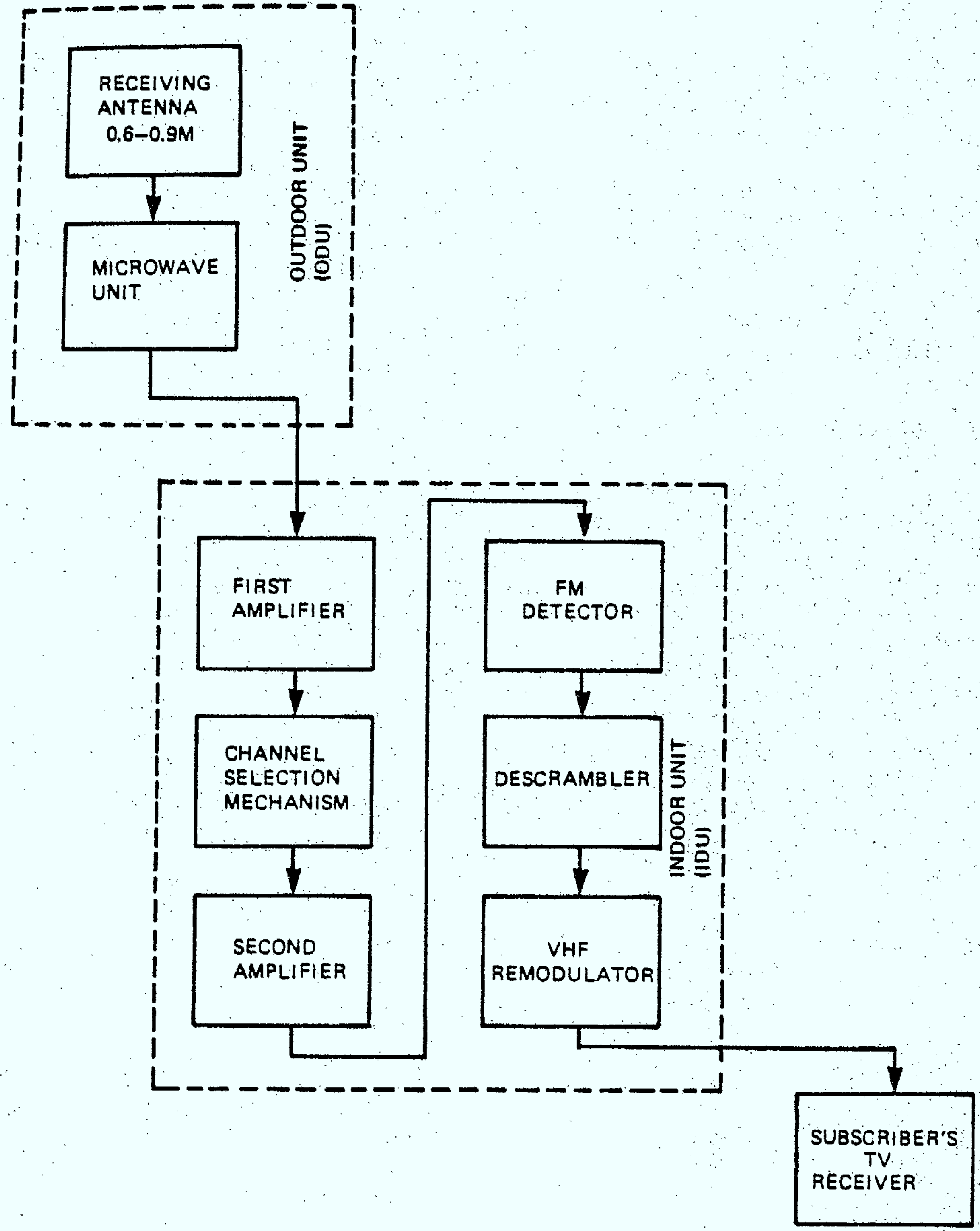


FIGURE 16 HOME EQUIPMENT BLOCK DIAGRAM

Each IDU will be uniquely addressable in order to allow control of individual subscriber service level over the air from Las Vegas. Presently planned performance characteristics of the IDU are shown in Table 10.

Multiple dwelling units (e.g., apartments, condominiums) will be provided with service similar to the individual residences through use of a slightly different outdoor unit and distribution system as shown in Figure 17. This configuration provides scrambled service to each dwelling resident and uses IDUs at each set location identical to those used for individual residence reception. A somewhat larger receive antenna and high gain IF distribution amplifier is expected for multiple dwelling unit installations.

High quality link performance can be provided for cable head ends through use of a somewhat larger receiving equipment antenna than the 0.75 meter baseline individual reception equipment. Head end receiving equipment would down convert, demodulate and descramble all channels simultaneously. Channelizers and regenerators would be used thereafter to condition the signals for transmission over the cable system, using the local cable security system to protect the service.

TABLE 10

Indoor Unit Performance Characteristcs

Input Frequency	in the range 0.8 to 1.3 GHz nominal
Selectable Channels	3 (capacity expandable with module change)
Input Level	-50 dBm ± 10 dBm nominal
Second IF Bandwidth	16 MHz
Output:	
Frequency	VHF channels 3 or 4 60—72 MHz
Signal Level	7dBmv ± 3 into 75 $\overline{\Omega}$
Video-Audio Ratio	approximately + 12 dB
Connector	F type
Audio (Stereo)	150 mv/channel unbalanced
Power	115 Vac. 50-60 Hz approximately 16 watts
Weight	approx. 3.2 kg
Dimensions	approx. 60 × 200 × 120 (mm)

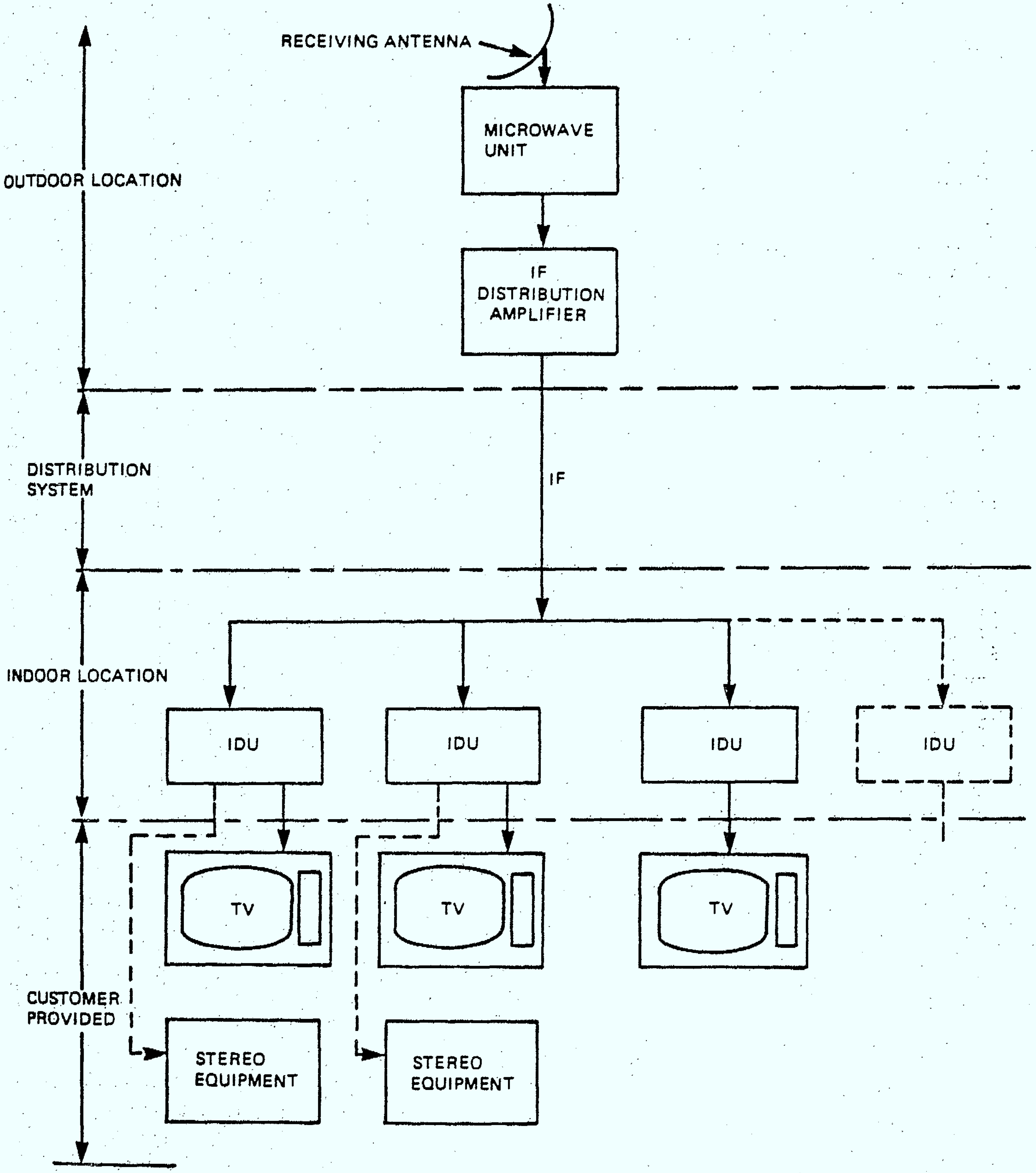


FIGURE 17 MULTIPLE DWELLING UNIT RECEIVING EQUIPMENT–BASIC ELEMENTS

PART 2: SYSTEM TRADE-OFFS

NECESSARY BANDWIDTH

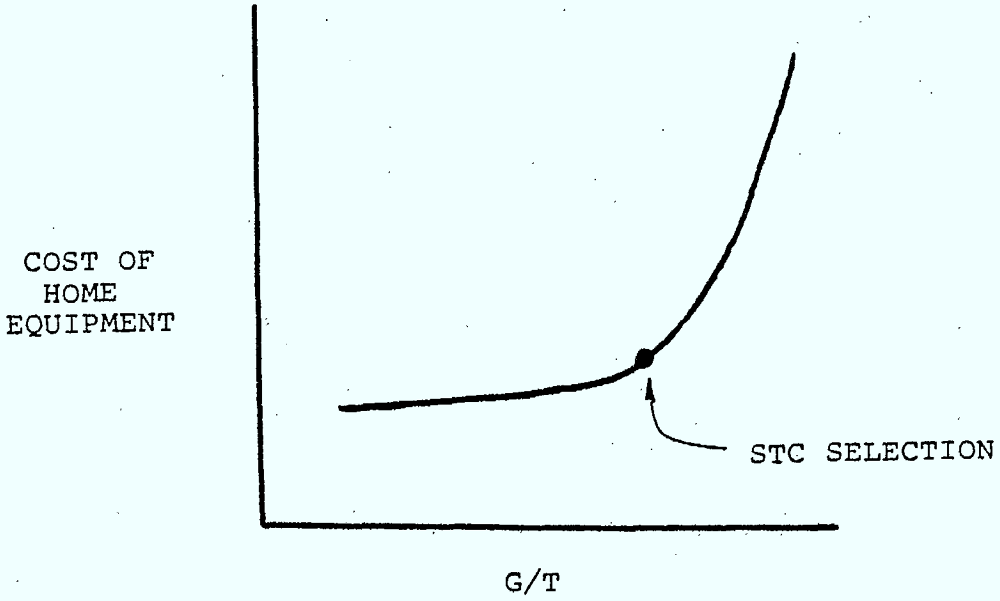
The channel bandwidth has to accomodate the color video signal and the digital subcarrier which carries the two audio channels and one control channel. STC performed a parametric analysis to find the optimum bandwidth required to satisfy the link quality objectives expressed in Part 1 of this paper and to assess the impact on system parameters.

The bandwidth of 16 MHz was selected in preference to a wider bandwidth in order to minimize the satellite power required to ensure a reasonable fade margin above the receiver threshold of the home equipment. Notice that the 16 MHz bandwidth is narrower than, and can therefore be accomodated within, the 18 MHz bandwidth adopted for Region 2 at WARC-77.

SATELLITE EIRP AND HOME EQUIPMENT G/T

One of the principal, if not the principal, trade-off dealing with STC's system is that of satellite EIRP vs home equipment G/T. Based on the link quality objectives and considering the channel bandwidth and signal charactersitics, STC performed a link analysis for a U.S. location with average rain precipitation (0.25% exceedance of 2 dB) to determine what the composite value of G/T + EIRP should be. That analysis showed that the average location should be served with a system whose satellite EIRP (in dBW) and home equipment net G/T (in dB/K) adds up to a value of approximately 66. For example, a satellite EIRP of 60 dBW and a home equipment G/T of 6 dB/K meet this requirement.

In the interest of minimizing overall system cost, including the cost of millions of home equipment units which STC would have to purchase for lease to subscribers, STC conducted a wide-ranging study that considered home terminal technology versus cost and satellite technology versus capacity versus cost. Because of the large number of home terminals involved, the cost picture was dominated by the investment in home terminals which far exceeded the investment in launched satellites. Accordingly, the principal criterion was to find the value of G/T (which depends on home antenna size and microwave receiver noise figure) whose equipment cost cannot be appreciably reduced by futher reductions in G/T. For a given antenna size, the relationship between G/T and cost is approximately shown in the figure below along with the point desired by STC.



Following extensive meetings with equipment manufacturers and other experts, and studies to determine the near-term and far-term outlook for receiver technology, STC concluded that a combination of 4.5 dB receiver noise figure and 0.75 meter antenna represented the desired point. This noise figure can be achieved with receivers using a direct converter approach or a GaAs FET preamplifier approach (both types are currently exhibiting comparable noise figure performance), and includes a manufacturing margin that should allow high manufacturing yields with highly automated production methods (i.e., zero or minimal manual operations).

In some locations use of a 0.75 meter (or 0.6 meter) antenna, which is smaller than the 1 meter unit assumed at WARC-77, will provide slightly less interference protection than that required to achieve the 35 dB C/I single entry objective adopted for planning at WARC-77. However, STC's analysis indicates that the increased interference has a negligible effect on system performance and that its effect would be imperceptible in terms of picture quality.

The selection of a net G/T of approximately 9 dB/K for STC's baseline receiver led to a baseline EIRP of 57 dBW (i.e., the 66 value expressed earlier minus the 9 dB/K G/T) in order to meet the desired link quality objectives. Fortunately, this EIRP is about the maximum value which STC believes can be considered for coverage of a CONUS time zone because of satellite TWTA considerations (see next section).

Because the link is based on presently achievable values of G/T, further improvements in receiver noise figures (improvements which are certain to come, especially after the DBS market matures and the high demand for home terminals solidifies) would result in improved link margins (thereby reducing further the periods below receiver threshold) or allow smaller home antennae which are less expensive, less obtrusive and less susceptible to wind damage.*

SIZE OF SERVICE AREA

STC selected service areas approximately the size of a CONUS time zone in order to allow DBS implementations with existing space technology and to better accommodate audience preferences (developed over thirty years of conventional television broadcasting) to see certain types of programming at certain times.

A service area generally the size of a time zone will require satellite transmitter RF power per channel in the order of 150-200 watts, and a 200W TWTA is about the largest, based on current information, that STC can predict will be available in the near future with adequate (7 year) long life and reliability characteristics. If a service area equal in size to two time zones (or the size of half-CONUS) were considered, the RF power requirement would approximately double and there would be a far more serious question as to the near term availability of such a TWTA from a lifetime and reliability viewpoint.

Another way of providing half-CONUS coverage would be to parallel two 150-200W TWTAs. While this is conceptually possible and was done years ago with low power TWTAs, it leads to reduced reliability and increased operational complexity.

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*Use of smaller antennae may not be possible in some areas when interference criteria are considered.

Although small spot beams serving part of a time zone (or a combination of spot beams and time zones) might be considered for planning, a spot beam implementation, by its nature, does not use a frequency over its full potential coverage area. Thus, planning on this basis would arguably permit inefficient use of spectrum. Also, there are coverage inefficiencies assocated with the use of spot beams that become larger as the spot beam width narrows and approaches the satellite pointing capability. A 1° beam in the presence of a ±.1° pointing error covers 78% more area per watt of satellite RF power than a 0.5° beam in the presence of the same pointing error.

In addition, as a practical matter, the scope and complexity of the planning process grow rapidly when spot beams are considered, particularly because the number of spot beams required and their dimensions and orientations require numerous judgements which are difficult to make without specific knowledge of the service offering planned. For all these reasons, STC adopted time-zone-size service areas and believes that spot beams should not be used for CONUS planning purposes. This would not prevent U.S. operators from actually implementing systems with spot beams, however, so long as the off-axis EIRP of the spot beams was maintained generally below that of any beam covering the entire service area.

Having concluded that CONUS service areas should be approximately the size of a time zone, STC analyzed what their exact size should be in order to optimize the system. For reliability and cost reasons, STC found that the exact size of the four service areas should be selected consistent with the goal of achieving comparable minimum performance to each service area using the same size spacecraft transmitter amplifier. Giving due consideration to limitations imposed by minimum acceptable elevation angles at which home terminals would operate, the coverage areas should be nearly the same size when projected back to the satellite, except that a correction should be made to accommodate excess rain attenuation statistics and range differentials.* With such a performance equalization objective, the optimum partitioning of CONUS is dependent on the particular

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*Inclusion of rainfall statistics tends to make service areas projected to the satellite covering predominately arid territory somewhat larger than those containing heavy precipitation.

satellite orbital locations assumed. For the orbital locations chosen (see next section) and considering the planned use of shaped beams and the required area-by-area EIRP, the four service areas that meet the aforementioned goal are those that were shown in Figure 8.

The PSA is limited by elevation angle constraints (the home terminals along its eastern edge have an elevation angle of about 10°), and its projected normalized area is smaller than that of the other three service areas. This permits some of the power from the PSA satellite transmitter to be used to provide 0.6° spot beam service to Alaska and Hawaii, respectively. A 0.6° spot beam over Alaska and another over Hawaii, plus the CONUS Pacific coverage area, result in a composite coverage area which, when normalized, is about equal to the normalized coverage area of each of the other three CONUS service areas.

While implications of modest changes in the service areas might appear at first to be small, spacecraft design, particularly in the near term, is by its nature power-limited, and very small deviations from an optimum design can, in our judgement, have significant effects on extremely important service parameters (i.e., coverage, service, quality, receiving system cost).

ORBIT LOCATIONS

STC adopted the four orbit locations of 175°, 155°, 135° and 115°W on the basis that this set represents:

1) a very cost efficient implementation from the point of view of spectrum and orbital arc utilization;
2) a practically achievable implementation in terms of its required technology, and
3) a cost effective approach for a fixed level of service and an approach that is comparable in cost to other possible system configurations.

Several generic system configurations were studied with differing orbit location requirements, but each having the common requirement of acceptable home equipment elevation angles and a westward satellite location for eclipse protection. Table 11 is a comparison of the attributes of three different system approaches which were considered to provide three channels to each service area in CONUS.

Table 11 Comparison of Attributes of Three Possible DBS Implementations*

System Approach	No. Useful Arcs	No. Locations per System	No. Frequencies	Remarks
Single satellite centrally located (e.g., 100°W) provides 3 channels to each of four time zones in U.S.	1	1	12	Probably not practical implementation in near term. Excessive growth in satellite mass/power required beyond present larger commercial communications satellites (Atlas Centaur class). Half-capacity satellite possible. Good elevation angles to CONUS; eclipse occurs in prime time on West Coast.
Two satellites located west of areas served (e.g., 115°W satellite provides 3 channels to ETZ and CTZ, 143°W satellite provides 3 channels to MTZ and PTZ).	2	2	6	Can likely be achieved with growth version of present larger commercial communications satellites of Atlas Centaur class. Generally good elevation angles; good eclipse times. Unit satellite and launch costs significantly higher than case below but fewer production models (3) and fewer launches (3) required. One in-orbit spare satellite is assumed.
Four satellites located west of areas served (e.g., 115°W serves ETZ, 135°W serves CTZ, 155°W serves MTZ and 175°W serves PTZ). Three channels provided by each satellite.	4	4	3	Can likely be achieved with growth version of present smaller commercial communications satellites of Thor Delta class. Generally good elevation angles; good eclipse times. Unit satellite and launch costs significantly lower than case above but greater number of production units (6) and launches (6) compensates to give approximately same space segment cost overall as above case. Two in-orbit spare satellites are assumed.

*All channels same sense polarized; WARC-77 satellite and receive antenna characteristics and interference criteria used.

It can be seen from Table 11 that the number of frequencies required to produce three independently programmable channels nationwide is reduced to a minimum for the four-satellite approach and doubles progressively as the number of satellites is halved. As a corollary, note that, for a fixed number of frequencies available to the U.S., individual subscribers will be able to access a number of channels equal to the number of frequencies if a four-satellite implementation is employed (given access to the required number of orbit locations), but will only be able to access half as many channels if a two-satellite implementation is employed. These conclusions would apply for any specified number of channels.

When the U.S. is partitioned into service areas similar to time zones, the approach of covering progressively fewer service areas from progressively more orbital locations creates new portions of the orbital arc that become useful for U.S. coverage. For direct satellite broadcast applications the more westerly arcs tend to be favored for eclipse reasons. This process is clearly demonstrated in Figure 18, which depicts useful orbital arc for CONUS coverage by one satellite, two satellites and four satellites, where coverage is defined by a 15° elevation angle at the receiver. Portions of the arc which assure a 1:00 a.m. earliest eclipse time to served areas are also shown in Figure 18, and here again the four-satellite implementation is clearly preferable.*

It is also important to note that the selected four orbit location should not adversely affect other countries in Region 2, and in fact, should prove beneficial when orbit/spectrum efficiency considerations are introduced. Given the more northerly latitude of Canada relative to the U.S. (which leads to lower elevation angles) and Canada's more easterly extension, and given that most of the other countries in Region 2 are east of the U.S., it can be shown that the preferred orbit locations for these countries are in the orbital band between approximately 70°W and 145°W. A two-satellite approach for the U.S. would place all the channel requirements for all CONUS service areas inside this

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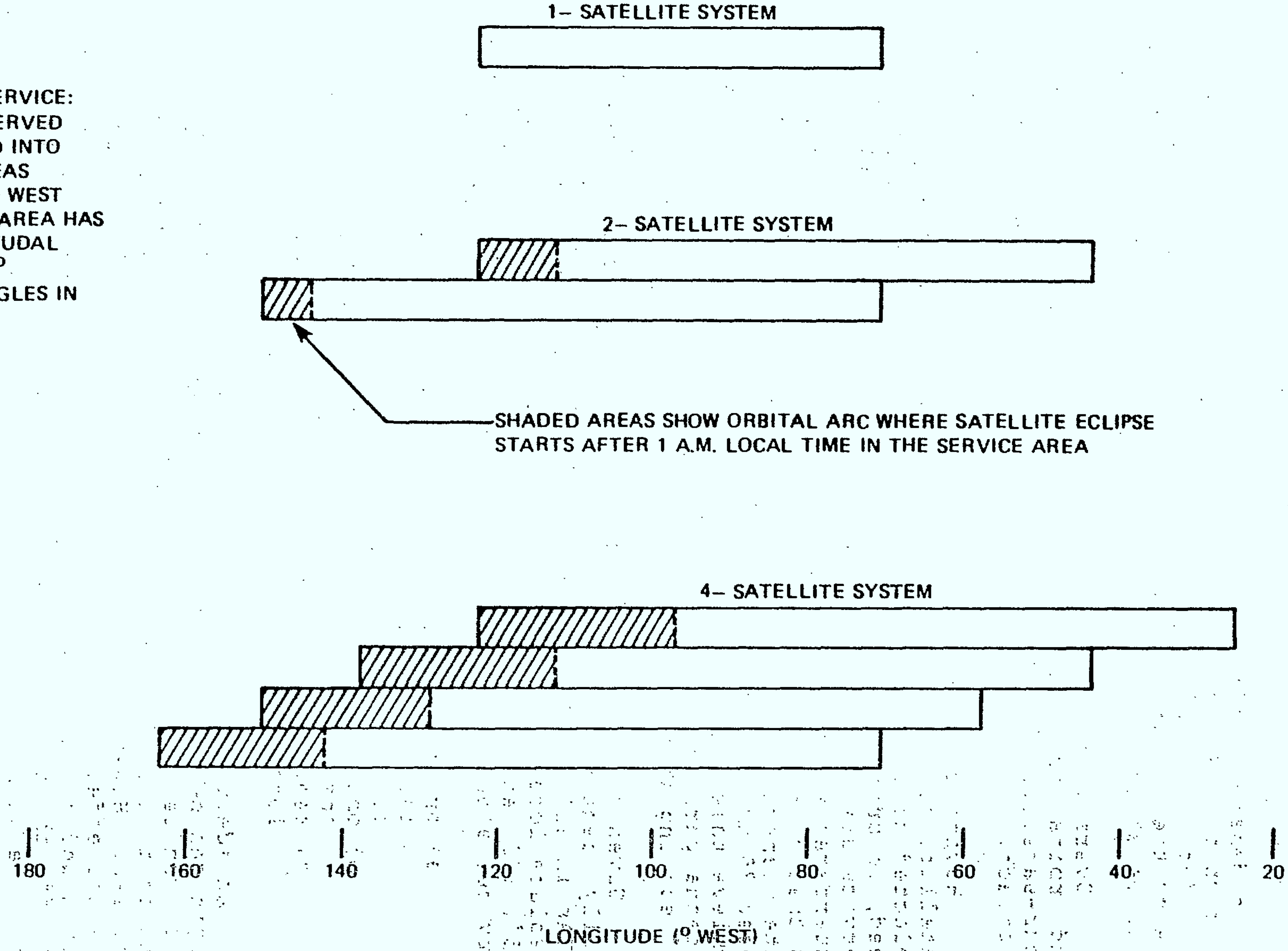
*Figure 18 is based on partitioning the U.S. into quadrants of equal longitudinal width at the northern extremes of CONUS. While time zones could be used and would give similar results, the actual coverage areas will undoubtedly not follow time zones exactly.

FIGURE 18
ORBITAL ARCS FROM SYSTEMS CONSISTING OF 1, 2, AND 4 SATELLITES FOR HYPOTHETICAL SERVICE*

*HYPOTHETICAL SERVICE:
- ONLY CONUS SERVED
- CONUS DIVIDED INTO 4 SERVICE AREAS FROM EAST TO WEST
- EACH SERVICE AREA HAS EQUAL LONGITUDAL WIDTH OF 14.2°
- ELEVATION ANGLES IN EXCESS OF 15°



SHADED AREAS SHOW ORBITAL ARC WHERE SATELLITE ECLIPSE STARTS AFTER 1 A.M. LOCAL TIME IN THE SERVICE AREA virtually 100% of the time (as indicated in Part 1 of this paper, below-design conditions are expected only a few minutes per year). The ability to operate at the 18 GHz frequencies with modestly-sized transmitters and without a diversity site reduces cost and enhances the system's operational efficiency.

SATELLITE CHANNEL CAPACITY

Why did STC choose three channels? Such a capacity was sufficient to meet STC's programmatic and business considerations, but there were technical and cost implications as well.

Today, the overall requirements of a satellite system are seldom selected without early consideration of the types of satellites that are available. An organization does not simply decide, based on telecommunications studies, that it needs a certain number of channels and then selects the class of satellite that meets the requirement. Instead, considerations of available satellite mass/power enter the process very early so that the system needs are optimized with the satellite class in mind.

Figure 19 is an example of the satellite information that needs to be considered from the outset during the system design. Using similar information, STC was aware during its studies that a 3-channel system without eclipse operation could be accommodated in an STS/PAM-D type spacecraft, while an STS/PAM-A type spacecraft could accommodate approximately 6 such channels. Clearly, it would have been inefficient for STC to adopt a four-channel approach based strictly on telecommunications studies, since such an approach would have to use STS/PAM-A class satellites whose cost, including launch, can be twice as high as that of an STS/PAM-D class satellite, while only providing one-third more channels.

SUMMARY

Considerable efforts have been made during the design of STC's system to ensure that it represents a near optimum approach of providing high quality direct broadcast television in the most cost effective manner and with high orbit/spectrum efficiency. Figure 20 summarizes the salient trade-offs that influenced the design. Figure 21 compares STC's system parameters with values recommended in CCIR documentation or used at WARC-77.

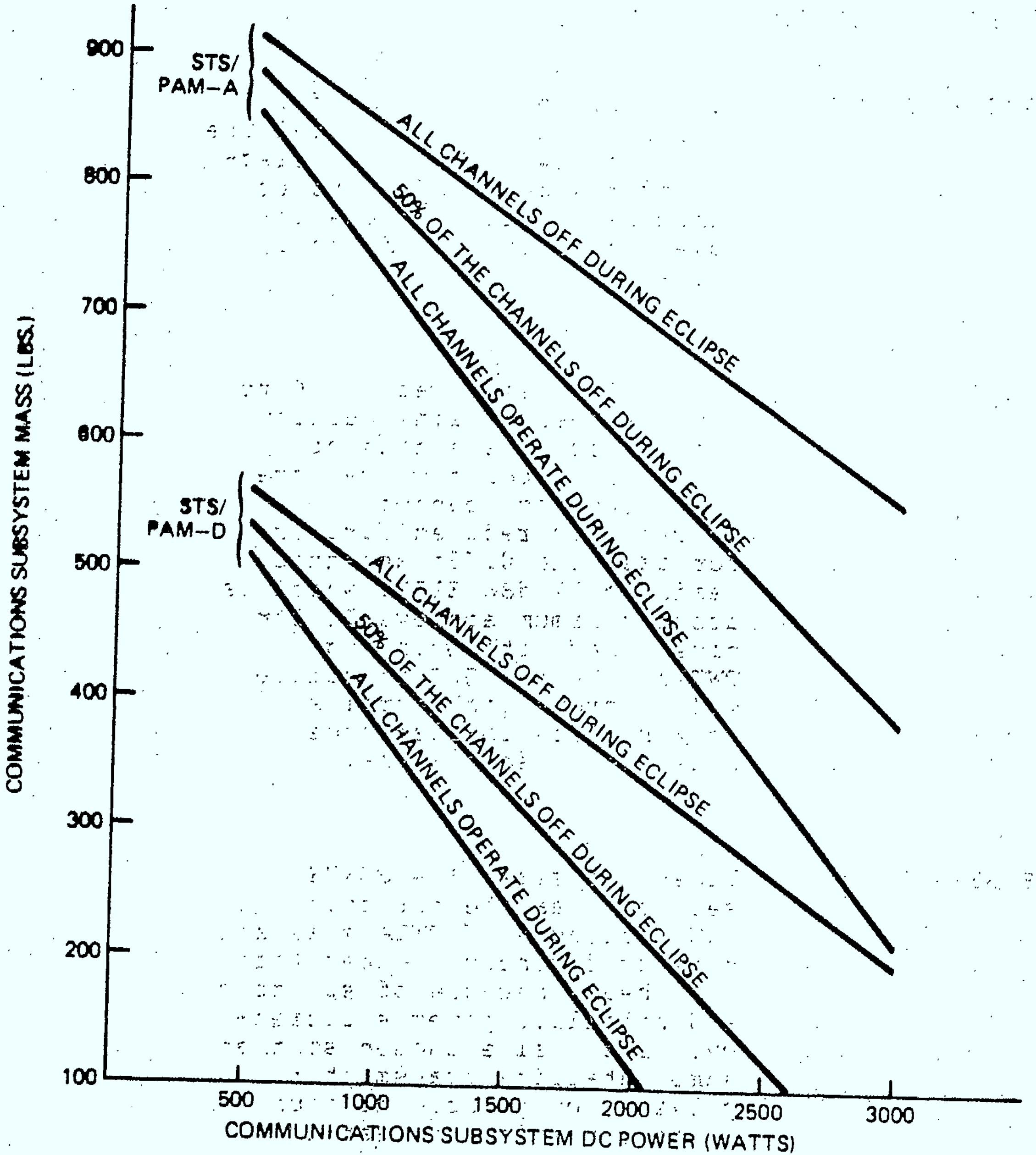


FIGURE 19

TYPICAL STS COMMUNICATIONS MASS & POWER TRADEOFF "high demand" orbital band, while a four-satellite approch places the MSA and PSA requirements outside this band (at 155° and 175°W). Thus, STC anticipates that use of these four rather than two or one orbit locations will be at no cost to other countries in Region 2.

Overall then, from the point of view of spectrum and orbital arc utilization, STC believes that the four-satellite implementation is clearly the preferred approach.

Having chosen a four-satellite implementation, the satellite separation and the absolute locations were selected to satisfy various requirements. A principal need, in order to reuse frequencies from service area to service area without exceeding established single entry interference criteria (Final Acts of WARC-77, Annex 9), is that a transmission received from any adjacent satellite transmitter operating at the same frequency be at least 35 dB below the wanted transmission. In order to achieve this, using standard receiving patterns and antenna parameters adopted for Region 2 at WARC-77, a 20° spacing is required between satellites.

Given the requirement for four satellites of essentially identical design (e.g., same number and size TWTAs in all satellites) separated by 20° in arc, the absolute location of the set has been selected at 175°, 155°, 135° and 115°W, and the normalized coverage (and service) area of each satellite has been determined to:

a) provide three channels of an acceptable threshold quality within the mass constraints of the type satellite planned,
b) obtain acceptable elevation angles from the home terminals, and
c) keep satellite solar eclipse after 1 a.m. local time.

An adequate, but not excessive, satellite mass margin can be forecast for such a 3-channel spacecraft, which can be launched in a very cost-effective manner both on available expendable and planned reusable launch vehicles. However, more easterly orbit locations would have the effect of increasing the projected areas to be served and reducing the necessary spacecraft antenna gain for the broader subtended coverage, resulting in a satellite with either fewer channels or lower quality performance than the design value.*

The most important effect of orbit locations more westerly than the preferred locations identified above would be a reduction in elevation angles at the home receiver below those otherwise obtained. Although the elevation angles for the preferred locations are acceptably high (they are generally consistent with those recommended in Annex 8 of WARC-77), it is important that they not be lowered because of potential blockages of service, particularly in the PSA.

SATELLITE RECEIVE COVERAGE AREA

STC's type of programming, much of which is on video tape or film, is well suited to the concept of a single, small satellite coverage area for the receipt of all feeder links. However, there are technical and cost advantages as well.

Because the small coverage size leads to high satellite antenna gains (and a correspondingly high satellite G/T) and because it is in rain climatic zone 5, the earth station can utilize transmitters of modest power level (e.g., 200 watt per channel) and provide sufficient power margin to operate satisfactorily for

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*Of course, more easterly locations result in higher home equipment elevation angles with lower rain attenuation, but STC found that the decrease in rain and range attenuation per degree of easterly motion was smaller than the decrease in satellite antenna gain. Thus, for a given link quality, the selected set of orbit locations results in the smallest satellite transmitter. This consideration is the subject of a recent Canadian contribution to CCIR (Doc. 10-11S/44-E) submitted as a modification to Report 811. The Canadian document reports on an analysis to find the home equipment elevation angle which minimizes satellite transmitter power for any given link quality. The analysis shows that transmitter power (and thus spacecraft mass and cost) is minimized when the elevation angle is approximately 18° for locations in rain climatic zone 1, 12° for those in zone 2, 9° for those in zones 3 and 4 and 6° for those in zone 5. These elevation angles are considerably lower than those suggested by WARC-77, and the Canadian contribution suggests that these lower values should be used to minimize spacecraft requirements, along with considerations of signal blockage due to buildings, trees, etc.

FIGURE 20

SUMMARY OF STC'S SYSTEM TRADE-OFFS

- NECESSARY BANDWIDTH	Considerations of type of signal, link quality and satellite transmit power. 16 MHz selected over wider bandwidths to minimize satellite transmit power under threshold conditions.
- EIRP AND G/T	EIRP + G/T has to equal 66 to achieve desired link quality objectives. Selection of 9 dB/K G/T is point where home equipment cost cannot be appreciably reduced further for baseline 0.75m antennae. Leads to 57 dBW EIRP, which is about maximum achievable for time zones with existing TWTAs. Better G/T in future will improve link margins and/or allow smaller home antennae in some areas.
- SIZE OF SERVICE AREA	Time-zone-size (1/4 CONUS) service areas better than 1/2 CONUS because of TWTA size and time preferences, better than spot beams because of spectrum and satellite power efficiency. Exact size chosen so that same satellite transmitter provides comparable minimum performance in each service area.

FIGURE 20 (cont'd)

SUMMARY OF STC'S SYSTEM TRADE-OFFS

- ORBIT LOCATIONS	Four satellites for U.S. most efficient from Region 2 viewpoint because half of the service areas served from outside "high demand" orbital band. Satellite separation chosen to reuse frequencies. Locations chosen to provide acceptable elevation angles (more westerly leads to very low angles), eclipse protection (more easterly leads to earlier eclipses), and to maximize number and quality of satellite channels (more easterly decreases antenna gain).
- SATELLITE RECEIVE COVERAGE AREA	Small coverage area (which increases satellite G/T) and rain climatic zone 5 reduces earth station transmitter and permits essentially 100% operation without diversity site.
- SATELLITE CHANNEL CAPACITY	Three channels is optimum use of PAM-D spacecraft, a factor which was considered during the system design.

FIGURE 21

COMPARISON OF STC PARAMETERS WITH CCIR/WARC VALUES

- LINK QUALITY OBJECTIVES	Generally consistent with CCIR/WARC values.
- NECESSARY BANDWIDTH	STC's 16 MHz is lower than, and can be accommodated within, the WARC value of 18 MHz.
- HOME EQUIPMENT G/T	STC's baseline value of 9 dB/K is about 3 dB greater than used at WARC-77, largely because of better noise figure of new receivers.
- ANTENNA SIZE	STC's 0.6, 0.75 and 0.9 meter antennae are smaller than 1 meter used at WARC-77. Decreased C/I protection (to STC subscribers only) is imperceptible.
- SATELLITE EIRP	STC's required EIRP is about 3 dB less than that used at WARC-77 because of STC's higher home equipment G/T.
- HOME EQUIPMENT ELEVATION ANGLES	Generally consistent with WARC values.

<u>NOTE:</u> STC DOES NOT SUGGEST THAT ITS PARAMETERS BE USED FOR RARC-83 PLANNING. CONSERVATIVE PARAMETERS LIKE THOSE USED AT WARC-77 ALONG WITH FLEXIBILITY PROVIDED BY PARA. 12.5 OF WARC-77 ALLOW DBS SYSTEMS TO BE OPTIMIZED FOR THE PARTICULAR SERVICE ENVISIONED.

APPENDIX A

SUMMARY OF TELEVISION MARKET IN CONUS*

-	TOTAL NUMBER OF HOMES	78 million
-	HOMES WITH NO ACCESS TO TELEVISION	1 million
-	HOMES WITH ACCESS TO 1 OR 2 CHANNELS	4.5 million
-	HOMES WITH ACCESS TO 5 OR MORE CHANNELS	42 million
-	HOMES WITH ACCESS TO CABLE	33 million
-	HOMES THAT SUBSCRIBE TO CABLE	19 million

* Based on latest information available in early 1981. All figures are approximate and some are based on a study performed in 1973-1974.

APPENDIX B

COMPARISON OF SHAPED VERSUS ELLIPTICAL SATELLITE BEAMS

STC has synthesized the shaped beam patterns of a 2.9 meter satellite reflector used to generate STC's ESA coverage and compared its off-axis performance with that of an elliptical beam optimized for the same service area and generated by a 1 meter reflector. These results represent only one particular implementation, but provide information which STC believes typifies possible off-axis evelope improvements given similar geometric conditions.

Figures B1 and B2 show analytically predited gain contours for the shaped beam antenna (operating from a satellite at 115°W) over specific segments of the earth's surface along with the WARC-77 gain contours of the optimized elliptical antenna beam (which is a 3° by 2° ellipse with semi-major axis 20° counterclockwise from a North-South direction). Edge of coverage (EOC) gain is 35 dB for the shaped beam and 33.5 dB for the elliptical beam. A pointing error of 0.1° has been accounted for in the contours shown.

To compare relative EIRP of the elliptical and shaped beam implementations, the shaped beam antenna gain contours should be reduced by 1.5 dB, on the assumption that the minimum EOC EIRP for both implementations would be equalized. The resultant modified gain values are proportional to EIRP for each approach. As an example, contour no. 4 of the shaped beam should be reduced to 6.5 dB for the purpose of comparison with the elliptical beam contours.

It is evident from the figures that the shaped beam offers substantial improvements. For example, over Colombia the shaped beams highest comparative gain is near 0 dB (1.7 minus 1.5) while the elliptical beam highest gain is about 17 dB; over Haiti/Sto. Domingo and Venezuela the improvement is around 22 dB.

These figures represent only one case, namely a particularly shaped beam compared with a particular ellipitcal beam covering a particular service area from a particular orbital position, and the results only apply over the earth segments shown. While the results provide some measure of trends, and while STC believes that a properly designed shaped beam will always provide improved off-axis envelope (out to a gain about 35 dB below the antenna's maximum gain) over an equivalent elliptical antenna, analysis of a different case may lead to comparative results which are more or less pronounced than shown here.

It should be noted that large service areas are well suited for shaped beams because their size is much larger than the individual "beamlets" used to form a shaped beam (STC's 2.9 meter reflector generates sixteen 0.6° beamlets to form the ESA shaped beam). A shaped beam for a smaller service area, such as one of the Central American countries, would probably not be practical, since it would require an extremely large satellite reflector.

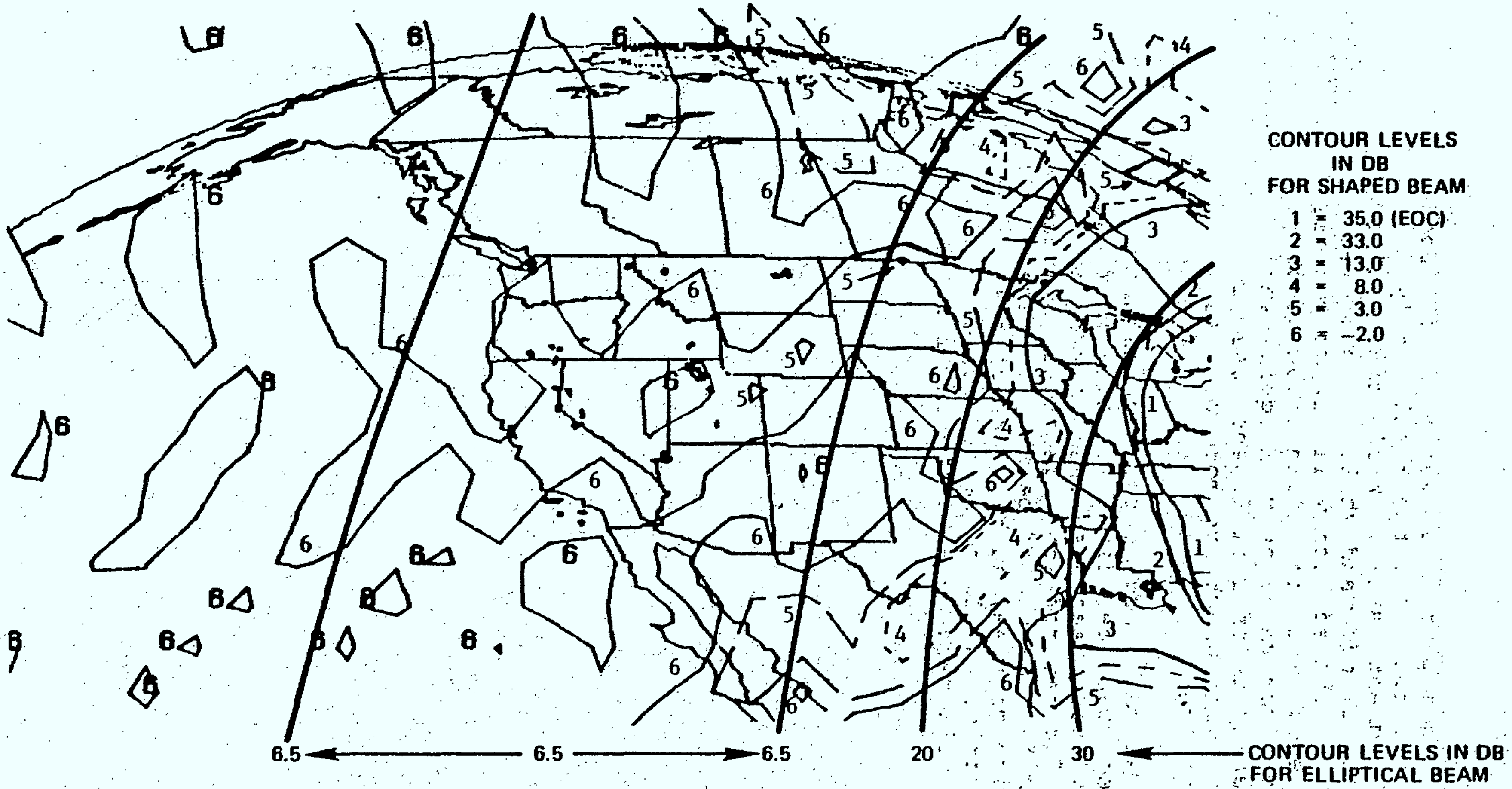
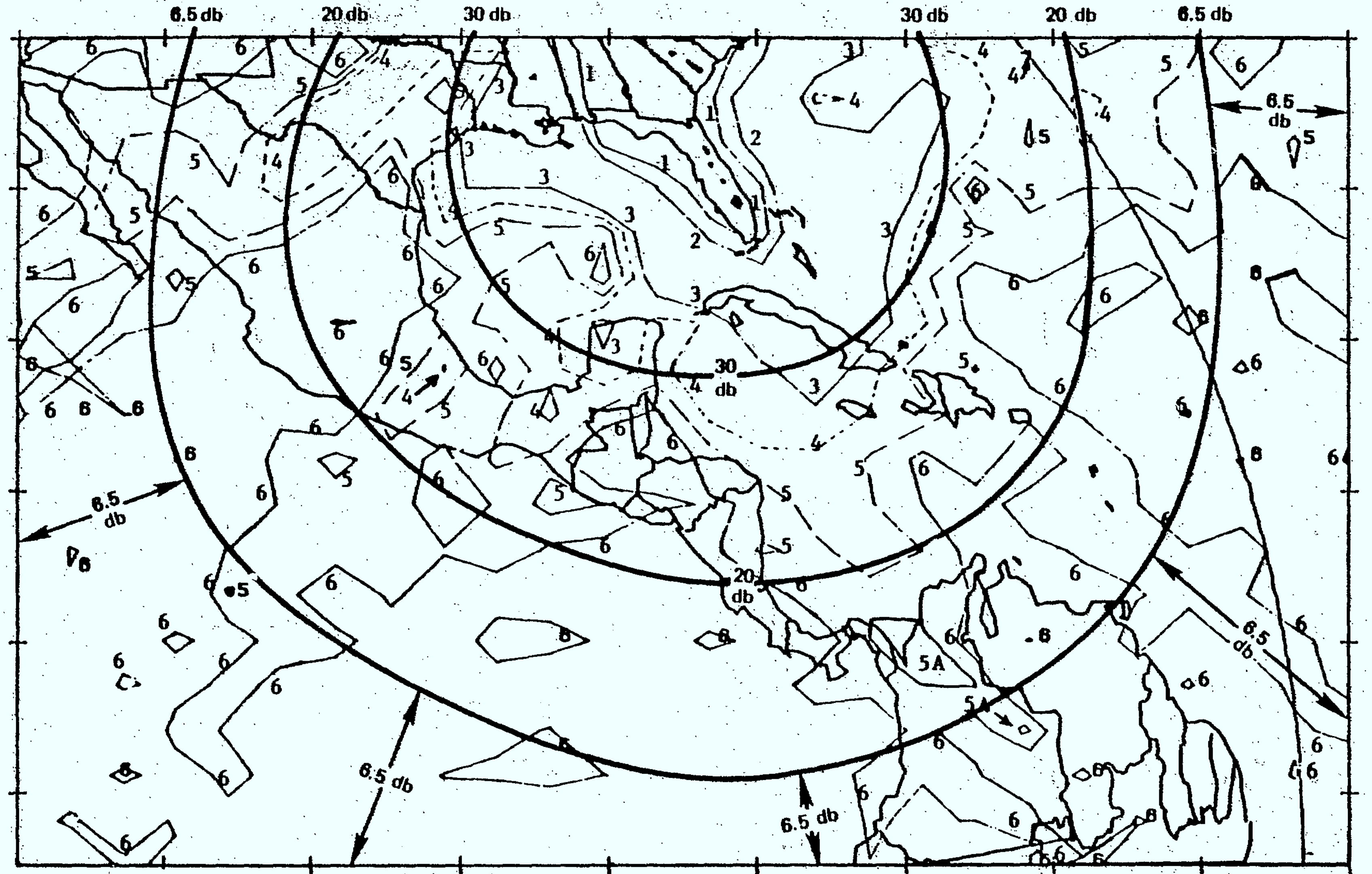


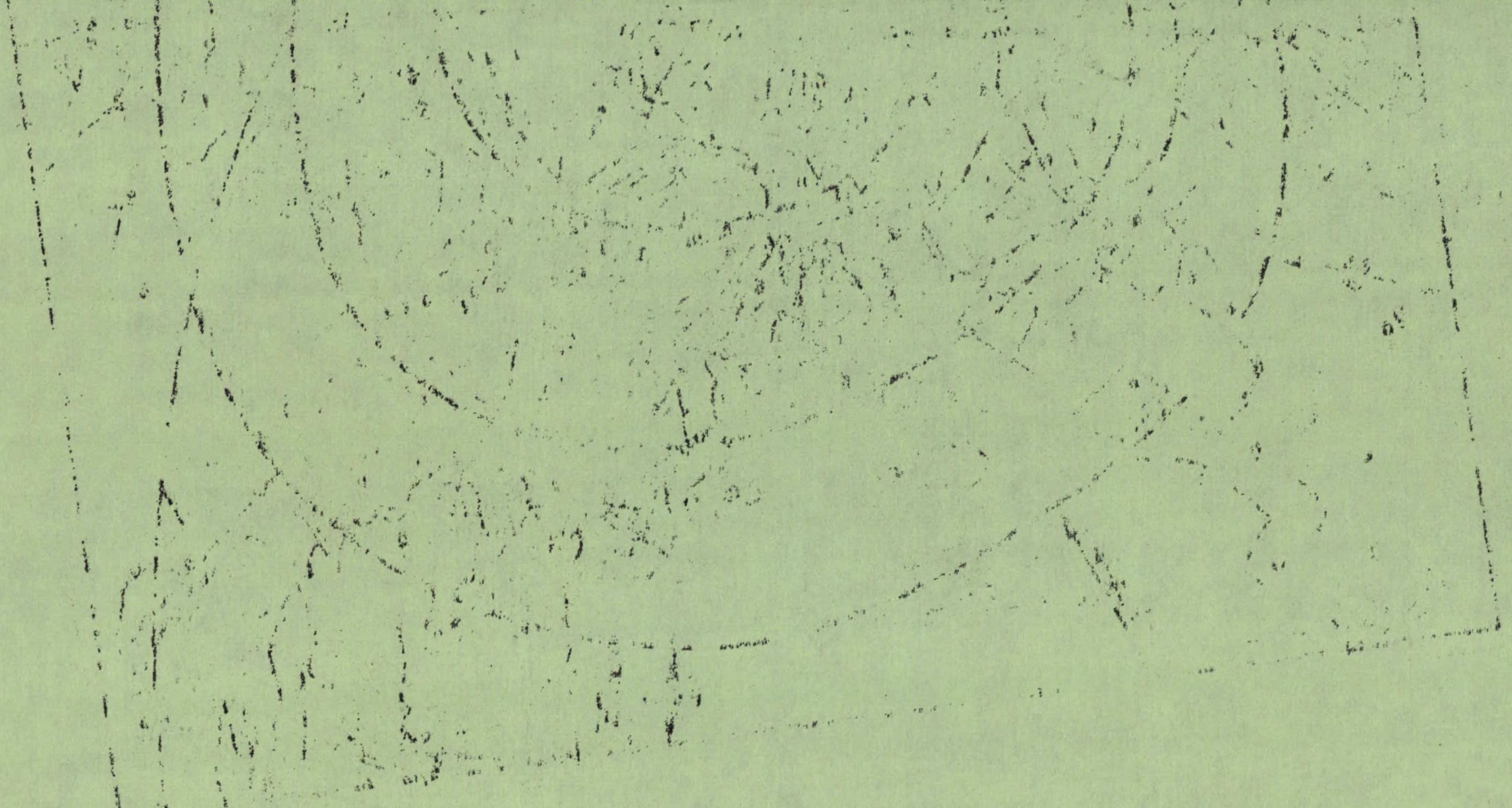
FIGURE B1 ESA–SHAPED BEAM AND ELLIPTICAL BEAM GAIN CONTOURS OVER CANADA AND CENTRAL/WESTERN U.S.



CONTOUR LEVELS
IN DB
FOR SHAPED BEAM

1 = 35.0 (EOC)
2 = 33.0
3 = 13.0
4 = 8.0
5 = 3.0
5A = 1.7
6 = −2.0

FIGURE B2 ESA–SHAPED BEAM AND ELLIPTICAL BEAM GAIN CONTOURS OVER TERRITORIES SOUTH OF THE U.S.



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