SATELLITE BROADCASTING STUDY

APPENDICES

JHC

FINAL REPORT
OF THE
SYSTEMS TECHNOLOGY STUDY GROUP

December 1970

Government of Canada | Gouvernement du Canada

JUL / JUIL 26 1989

H. Baskin/M. Perrier

I see no reason why this report should not be declassified. However, since other broadcasting agencies e.g. the CRTC, were involved, you might want to check with A/DGBP (M. Helm) as well.

J.G. Chambers

I agree with Dr. Chambers. There is no reason not to declassify this report.

M. Helm

CANADIAN SPACE PROGRAM • PROGRAMME SPATIAL CANADIEN

Canada

APPENDIX I

TECHNICAL FACTORS AFFECTING THE CHOICE OF FREQUENCY AND EFFICIENCY OF ORBIT UTILIZATION FOR TELEVISION BROADCASTING FROM SATELLITES

1. Satellite broadcasting st...

ISSUE 4

TECHNICAL FACTORS AFFECTING THE CHOICE OF FREQUENCY AND EFFICIENCY OF ORBIT UTILIZATION FOR TELEVISION BROADCASTING FROM SATELLITES

September 9, 1970

PREFACE

This report was prepared for Ad Hoc Group "C" of the Canadian Preparatory Committee for the 1971 WARC for Space Telecommunications and in support of departmental studies.

The first draft was written jointly by G. Courtemanche (DOC/DTI) and R.F. Zeitoun (DOC/DTR) with very valuable contributions from Dr. C.A. Siocos (C.B.C.), W.R. Wilson (C.R.T.C.) and H. Treffers (DOC/DTR).

This draft was then amended to reflect the comments and suggestions of Dr. B.C. Blevis (DOC/CRC), J.R. Marchand (DOC/DTI), W.J. Wilson (DOC/DTR) and M.L. Card (DOC/DRD). The report was further revised and approved as Issue 3 at a meeting of Ad Hoc Group "C" on April 21, 1970.

On September 9, 1970, G. Courtemanche proposed some additional amendments to the report as a result of further studies within CNO/CCIR Working Party 1011/1. Issue 4 includes these amendments.

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TECHNICAL FACTORS AFFECTING THE CHOICE OF FREQUENCY AND EFFICIENCY OF ORBIT UTILIZATION FOR TELEVISION BROADCASTING FROM SATELLITES

1. INTRODUCTION

At its second meeting on December 3, 1969, the Canadian "WARC" Preparatory Ad Hoc Group "C" formed a technical sub-group with the following terms of reference:

- to review channel requirements for satellite broadcasting;
- to develop proposals for the forthcoming WARC for Space Telecommunications based upon technical criteria and feasibility for spectrum sharing which would meet Canadian satellite broadcasting requirements;
- to coordinate Administrative Regulations with the chairman of Ad Hoc Group "B" and the Frequency Management Group of the Telecommunications Regulation Branch.

Four meetings were held. The participants were:

Mr. G. Courtemanche	DOC/DTI	(Chairman)
Mr. G.J. Clowes	DOC/CRC	(attended first two meetings only)
Mr. W.R. Wilson	CRTC	
Dr. C.A. Siocos	CBC	
Mr. R.F. Zeitoun	DOC/DTR	
Mr. H. Treffers	DOC/DTR	(secretary)

This report deals with the video portion of monochrome and colour television broadcasting from satellites using standard modulation and demodulation techniques.

Further study on a number of items would be very desirable, especially if completed in time for the CCIR Joint Study Group Meeting preceding the Space Conference in February, 1971. Some of these items are:

- the most suitable frequency bands for the earth-to-satellite circuit;
- the improvement that can be obtained from the use of pre-emphasis for colour television;

- the techniques which can be used for the transmission of the sound portion of the television signal;
- the use of threshold extension demodulators in FM television receivers;
- the use of bandwidth compression techniques for television transmissions;
- the feasibility of frequency sharing between satellite broadcasting and the Earth Exploration Satellite service.

In the meantime, the following points are worth consideration:

- for FM television:
  - the sound could be transmitted during the synchronizing and blanking periods of the video signal in a suitable time-division multiplex arrangement. For this method, the data contained in the Appendices would be valid to cover both the video and sound signals but the receivers would require special circuitry to extract the sound.
  - the sound and video signals could be carried as a composite signal with 4.5 MHz offset. This would necessitate the use of a larger frequency deviation and thus a higher transmitter power. Detailed study would be required to determine all the consequences.
  - the sound and video signals could be carried on separate carriers. This would necessitate the use of separate receivers, which might be be acceptable for community reception. It would also affect the spacecraft design.
- for AM/VSB television, the inclusion of the sound signal would necessitate a 2% increase of the required transmitter power based on a conclusion of Reference [7]. No change in receiver design concepts would be required.
- the use of threshold extension demodulators could reduce the required satellite e.i.r.p. and thus lower the cost of the space segment.
- the use of bandwidth compression techniques could also reduce the required channel bandwidth and thus improve the efficiency of spectrum and orbit utilization.

Members of the technical sub-group also attended meetings of Ad Hoc Group "B" responsible for the development of Administrative Radio Regulations for space services other than broadcasting. They were satisfied that the Administrative Regulations being developed for these other services would also cover the requirements of the broadcasting satellite service.

2. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions:

This section gives a detailed list of all the conclusions contained in this report. Appendix IV gives a table of comparison of some of these conclusions for quick reference.

a) Community reception of FM television from satellites

i) Frequency sharing feasibility:

- sharing with terrestrial UHF TV in the band 614-890 MHz is marginally feasible (see § 6.2) provided that:
  - a discrimination angle of 33° can be achieved. This angle would have to be increased if more than one interference entry were present;
  - areas of mutual interference to both the terrestrial and satellite services can be tolerated;
  - areas of interference created by the terrestrial UHF TV station inside the satellite coverage area can be tolerated.
- sharing with tropospheric scatter systems in the band 614-890 MHz is marginally feasible (see § 6.3) provided that:
  - the tropospheric scatter antenna is beamed more than 28° away from the satellite direction, assuming no satellite antenna discrimination;
  - the satellite e.i.r.p. at the center of the beam does not exceed 47 dBW;
  - there is no more than one interference entry.
- sharing with terrestrial ITV systems in the band 2548-2686 MHz is feasible (see § 7.2) provided that:

- a discrimination angle of 4^{o} can be achieved. This angle would have to be increased if more than one interference entry were present;
- areas of mutual interference to both the terrestrial and satellite services can be tolerated;
- areas of interference created by the terrestrial ITV station inside the satellite coverage area can be tolerated.

ii) Frequency re-use

On satellites located within a 90^{o} orbital arc and beamed at the same coverage area, the same frequency can be re-used:

- only once in the band 614-890 MHz
- up to 3 times in the band 2548-2686 MHz
- up to 6 times in the band 11700-12200 MHz

iii) Estimated number of independent programs

Assuming an equal distribution of the estimated number of potential independent programs between Canada and the United States in a fixed 90^{o} orbital arc, the number of independent programs available to Canada vary as follows:

- from a low of 8 for a two-beam coverage and 16 MHz bandwidth to a high of 26 for a six-beam coverage and 20 MHz bandwidth in a 276 MHz shared band between 614 and 890 MHz. These values are 3 and 10 respectively for a 100 MHz exclusive band.
- from a low of 9 for a two-beam coverage and 20 MHz bandwidth to a high of 27 for a six-beam coverage and 20 MHz bandwidth in the band 2548-2686 MHz.
- from a low of 68 for a two-beam coverage and 16 MHz bandwidth to a high of 220 for a six-beam coverage and 22 MHz bandwidth in the band 11700-12200 MHz.

b) Individual reception of FM television from satellites

i) Frequency sharing feasibility

- sharing with terrestrial UHF TV in the band 614-890 MHz is not feasible.
- sharing with tropospheric scatter systems in the band 614-890 MHz is not feasible.
- sharing with terrestrial ITV systems in the band 2548 to 2686 MHz is feasible (see § 7.2) provided that:
  - a discrimination angle of 10° can be achieved. This angle would have to be increased if more than one interference entry were present;
  - areas of mutual interference to both the terrestrial and satellite services can be tolerated;
  - areas of interference created by terrestrial ITV stations inside the satellite coverage area can be tolerated.

ii) Frequency re-use

Within a 90° orbital arc, the same frequency:

- can be re-used once but the adjacent satellite must be beamed at least 3 coverage areas away from the coverage area of the wanted satellite in the band 614 to 890 MHz.
- can be re-used once on satellites beamed at the same coverage area in the band 2548 to 2686 MHz.
- can be re-used up to 4 times on satellites beamed at the same coverage area in the band 11,700 to 12,200 MHz.

iii) Estimated number of independent programs

Assuming an equal distribution of the estimated number of potential independent programs between Canada and the U.S. in a fixed 90° orbital arc the number of independent programs available to Canada vary as follows:

- from a low of 2 for a 2-beam coverage and 22 MHz bandwidth to a high of 5 for a 6-beam coverage and 16 MHz bandwidth in a 100 MHz exclusive band between 614 and 890 MHz.
- from a low of 5 for a 2-beam coverage and 22 MHz bandwidth to a high of 18 for a 6-beam coverage and 20 MHz bandwidth in the band 2548 to 2686 MHz.
- from a low of 42 for a 2-beam coverage and 16 MHz bandwidth to a high of 132 for a 6-beam coverage and 20 MHz bandwidth in the band 11,700 to 12,200 MHz.

c) Community reception of AM/VSB television from satellites

i) Frequency sharing feasibility

- sharing with terrestrial UHF TV and tropospheric scatter systems is not feasible in the band 614 to 890 MHz;
- sharing with terrestrial ITV systems in the band 2548 to 2686 MHz is not feasible.

ii) Frequency re-use

Within a 90° orbital arc, the same frequency:

- cannot be re-used in the band 614 to 890 MHz.
- can be re-used once but the adjacent satellite must be beamed 3 coverage areas away from the coverage area of the wanted satellite in the band 2548 to 2686 MHz. The same applies to the band 11,700 to 12,200 MHz, but the adjacent satellite must be beamed 2 coverage areas away instead of 3.

iii) Estimated number of independent programs

Assuming an equal distribution of the estimated number of potential independent programs between Canada and the U.S. in a fixed 90° orbital arc, the number of independent programs available to Canada is as follows:

- 8 for a 100 MHz exclusive band between 614 to 890 MHz.
- from a low of 12 for a 2-beam coverage to a high of 23 for a 6-beam coverage in the band 2548 to 2686 MHz.
- from a low of 42 for a 2-beam coverage to a high of 125 for a 6-beam coverage in the band 11700-12200 MHz.

d) Individual reception of AM/VSB Television from satellites

i) Frequency sharing feasibility:

- sharing with terrestrial UHF TV and tropospheric scatter systems is not feasible in the band 614 to 890 MHz.
- sharing with terrestrial ITV systems in the band 2548 to 2686 MHz is not feasible.

ii) Frequency re-use:

Within a 90° orbital arc the same frequency:

- cannot be re-used in the band 614 to 890 MHz.
- can be re-used once but the adjacent satellite must be beamed 4 coverage areas away from the coverage area of the wanted satellite in the band 2548 to 2686 MHz. The same applies to the band 11,700 to 12,200 MHz but the satellite must be beamed 2 coverage areas away instead of 5.

iii) Estimated number of independent programs

Assuming an equal distribution of the estimated number of potential independent programs between Canada and the U.S. in a fixed 90° of orbital arc the number of independent programs available to Canada is as follows:

- 8 for a 100 MHz exclusive band between 614 to 890 MHz.
- from a low of 12 for a 2-beam coverage to a high of 23 for a 6-beam coverage in the band 2548 to 2686 MHz.
- from a low of 42 for a 2-beam coverage to a high of 83 for a 6-beam coverage.

e) If portions of the UHF television band were allocated to the land mobile service (see § 6.5), further study would be required to determine the feasibility of frequency sharing with satellite broadcasting.

f) The United States and Canada are considering the possibility of using the band 2550-2690 MHz for the satellite-to-earth link of the Earth Exploration Satellite service. Present indications are that, under certain conditions (see § 7.5), satellite broadcasting in the same band could cause unacceptable interference to the Earth Exploration Satellite Service but this requires further investigation.

g) There are indications that some countries will propose the use of the band 2500-2690 MHz for satellite broadcasting in Region 3 but it is unlikely that such systems would interfere with neither ITV systems nor the Earth Exploration Satellite service in our country.

h) The impact of deleting the present terrestrial UHF TV allocations of, for example, Channels 53 to 70 and replacing them with allocations for television broadcasting from satellites would be as follows:
   - approximately 100 out of the total 600 Canadian UHF allocations would have to be deleted and could not be replaced;
   - 136 allocations in the United States would have to be deleted and only a very small number of these could be replaced;
   - 9 operating stations in the United States would have to change channels provided one can be made available for each in the particularly community;
   - the total cost of changing the operating channels of the 9 USA stations might be somewhat in excess of one million dollars;
   - a two language service in Canada and a three program service in the U.S.A. could conceivably be provided to the entire area of both countries as it would not be related to the economic viability of many small stations;
   - the frequency sharing constraints mentioned in § 2.1 a) for tropospheric scatter systems would either have to be met or these stations would have to change frequency.

i) If all of Canada's future demands for television broadcasting from satellites which are presently estimated at 64 independent programs are to be met in a single frequency band, this will have to be done in the band 11700-12200 MHz.

j) If it is found that only a few independent programs are required and if the constraints given in h) above can be alleviated or accepted, then the 614-890 MHz band would show promise because receivers covering that band are already in the hands of the public.

k) If, after further investigation, it is found that:

- the Exploration Satellite service can either accept the necessary sharing constraints imposed by the Broadcasting Satellite service or can be accommodated in another frequency band;
- the Broadcasting Satellite service can accept the constraints listed in a) above for sharing with terrestrial ITV systems;
- it is acceptable to accommodate less than the estimated number of independent programs required in a single frequency band;

then, the 2548-2686 MHz band would show promise for television broadcasting from satellites bacause this band is attractive from a technical and economic point of view.

2.2 Recommendations:

Based on the above conclusions, it is recommended that:

a) Canada propose the addition of a footnote to the allocation table of Article 5 of the ITU Radio Regulations in the band 614 to 890 MHz, in Region 2, which would permit television broadcasting from satellites, subject to agreement among administrations whose territories are affected and which would read as follows:

"ADD 324B The broadcasting satellite service also may be authorized in the band 614-890 MHz for television broadcasting, subject to agreement among Administrations whose territories are affected.

REASON: To provide for the development of television broadcasting within the appropriate space service, within a band where television receivers are now in the hands of the general public, keeping in mind the existence of established terrestrial services in that band."

b) The possibility of using the frequencies 2548 to 2686 MHz as the companion Earth-to-Satellite band for the 614 to 890 MHz Satellite Broadcasting band be investigated further.

c) The desirability and feasibility of proposing a frequency allocation in the band 2548-2686 MHz for television broadcasting from satellites in Region 2 be investigated further in the light of conclusion 2.1 k)

d) Canada not oppose proposals in either Regions 1 or 3 for satellite broadcasting in the band 2500-2690 MHz.

e) Canada propose a primary allocation for the satellite broadcasting service in the band 11,700 to 12,200 MHz and a secondary allocation for the communication-satellite service (limited to the distribution of television programme material) in that band.

f) The possibility of using the frequencies 14,575 to 15,025 MHz as the companion Earth-to-Satellite band for the 11,700 to 12,200 MHz Broadcasting Satellite band be investigated further.

g) The existing primary allocation for terrestrial broadcasting on a shared basis with the fixed and mobile services in the band 12,200 to 12,700 MHz be retained.

3. ALTERNATIVES

This report covers the following alternatives:

3.1 Methods of reception*:

- individual reception
- community reception

3.2 Frequency bands:

- 614-890 MHz
- 2548-2686 MHz
- 11700-12200 MHz

3.3 Types of modulation:

- AM vestigial sideband
- FM

3.4 Coverage zones:

- four-beam coverage (2 in Canada, 2 in U.S.A.): 3° equivalent circular beamwidth.
- seven-beam coverage (4 in Canada, 3 in U.S.A.): 2° equivalent circular beamwidth.
- eleven-beam coverage (6 in Canada, 5 in U.S.A.): 1.7° equivalent circular beamwidth.

3.5 Grades of Service:**

a) for AM/VSB:

S/N***	Picture Quality
45 dB	Halfway between "fine" and "excellent" for 75% of viewers
40 dB	"Fine" for 75% of viewers
35 dB	Approaching halfway between "passable" and "fine" for 75% of viewers

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* as defined in Reference [1]

** see Table 2-4 of Reference [7]

*** luminance signal-to-r.m.s. weighted noise ratio

b) for FM:

S/N *	Picture Quality
50 dB	"Excellent" for 65% of viewers
45 dB	Halfway between "fine" and "excellent" for 75% of viewers
40 dB	"Fine" for 75% of viewers

3.6 Equivalent rectangular bandwidth:

- for AM vestigial sideband: 4 MHz
- for FM: 16-18-20-22 MHz.

4. ASSUMPTIONS

The conclusions contained in this report are based on the following assumptions for the satellite system:

4.1 Threshold C/N:

10 dB

4.2 Minimum margin above the threshold C/N: (exceeded for 99% of the time)

4 dB

4.3 Improvement in S/N from the use of pre-emphasis:

2.5 dB

4.4 Receiver noise factor: **

- for individual reception: 6 dB
- for community reception: 4 dB

4.5 Video bandwidth:

4.2 MHz

4.6 Bandwidth allowance for guard bands:

2 MHz

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* luminance signal-to-r.m.s. weighted noise ratio

** in the system noise temperature calculations, no allowance has been made for the presence of indigenous noise.

4.7 Type and gain* of receiving antenna:

These are summarized in Table 1 below:

Type of reception	Frequency (MHz)		
	750	2600	12000
Individual	crossed yagi 17 dB	1.5 paraboloid 29.7 dB	1m paraboloid 39.2 dB
Community	3.4 paraboloid 26 dB	3m paraboloid 35.7 dB	1.7m paraboloid 43.9 dB

Table 1 - Type and gain of receiving antenna

4.8 Sidelobe response of both the satellite and terrestrial antennae:

a) for parabolic antennae:

- mean sidelobe response: $30-20 \log_{10} \theta$ **
- r.m.s. variations in mean sidelobe level: 4 dB
- minimum sidelobe response: -10 dB relative to isotropic

b) for crossed yagi:

minimum discrimination at peak sidelobe level is as per CCIR Recommendation 419 "Directivity of antennae in the reception of broadcast sound and television."

* Antenna gain is relative to an isotropic source

** θ is the angle in degrees from the main beam axis

5. NUMBER OF INDEPENDENT PROGRAMS REQUIRED

CBC, CTV and CAB were requested to give an estimate of their channel requirements for future satellite broadcasting and their replies may be summarized as follows:

- CBC: 9 channels for one service, plus
  9 channels if second service is required.
  These requirements allow for a certain amount of regional and provincial broadcasting as well as national service in English and French.
- CTV: for CTV network: 60 hrs/week } 0700-2400 hours
  for education: 50 hrs/week } 0700-2400 hours
  for CATV distribution: 50 hrs/week during off hours
- CAB: 20 channels based on competitive services in both French and English considering 4 time zones and possible pre-emption of present UHF channels for use in direct-to-home service.

This, based on these estimates, a total of 38 channels might be required for CBC and CAB plus possibly 16 channels for CTV to fulfill the above programming hours, assuming service in both English and French. This still does not include requirements for educational TV which has been hard to assess at the present time. However, if Canada were to be divided into five regions for educational purposes it might be logical to think of a requirement of two channels per region, i.e. 10 channels total. This puts up the total channel requirements for Canada to 64.

It should be noted that this does not mean a total of 64 different channels but rather a requirement for 64 independent programs which means that one channel might be allocated several times for different time zones depending on the technical restrictions. Thus the total number of distinct channels required might be significantly less.

6. SATELLITE BROADCASTING IN THE UHF TELEVISION BAND

This study will consider only that portion of the UHF band above 614 MHz (i.e. 614-890 MHz) since at the lower UHF frequencies the required antenna size becomes excessively large. Moreover, this is the band normally considered in recent CCIR studies.

6.1 Examples of television system parameters

Based on the assumptions made in §4 above, the television system parameters of a number of examples have been calculated and are given in Appendices I-a, b, c, d, and e. For convenience, a summary of the required field strengths and e.i.r.p.'s at the satellite beam edge is included in Table 2 for FM television and Table 3 for AM/VSB television.

Equivalent Rectangular Bandwidth (MHz)	S/N (dB)	40		45		50	
	Type of reception	Community	Individual	Community	Individual	Community	Individual
16	Field Strength (dBu)	26.6	37.6	31.6	42.6	36.6	47.6
	e.i.r.p. (dBW)	43.6	54.6	48.6	59.6	53.6	64.6
18	Field Strength (dBu)	*	*	29.6	40.6	34.6	45.6
	e.i.r.p. (dBW)	*	*	46.6	57.6	51.6	62.6
20	Field Strength (dBu)	*	*	27.9	38.9	32.9	43.9
	e.i.r.p. (dBW)	*	*	44.9	55.9	49.9	60.9
22	Field Strength (dBu)	*	*	*	*	31.6	42.6
	e.i.r.p. (dBW)	*	*	*	*	48.6	59.6

Table 2 - FM television from satellites - Summary of system parameters.

* not considered since C/N is less than 14 dB.

Equivalent Rectangular Bandwidth (MHz)	S/N (dB)	35		40		45	
	Type of Reception	Community	Individual	Community	Individual	Community	Individual
4	Field Steength (dBu)	42	53	47	58	52	63
	e.i.r.p. (dBW)	59	70	64	75	69	80

Table 3- AM/VSB television from satellites - Summary of system parameters

6.2 Feasibility of frequency sharing between satellite and terrestrial broadcasting services

This section deals with terrestrial UHF broadcasting as it exists in Canada and the United States and the feasibility of sharing the same frequencies with FM and AM/VSB television broadcasting from satellites.

6.2.1 Standards and Allocation Criteria for UHF Terrestrial TV

Two grades of signals are required in Canada for UHF TV service. These are the Grade "A" contour which is the boundary of the 74 dBu signal, and the Grade "B" contour which is the boundary of the 64 dBu signal. Grade A is considered necessary for metropolitan areas and Grade B is considered the outer limit of a station's service area within which interference from other stations would not be acceptable. These values were based on the figures in Table 4 below. More details are given in Reference [2]

	Unit	Grade A	Grade B
Noise voltage at receiver terminals (300 ohm input)	dBu	7	7
Receiver noise factor	dB	15	15
Ratio of r.m.s. carrier during sync peak to r.m.s. noise unweighted in a 6 MHz channel (equivalent to a passable picture or better)	dB	30	30
Dipole factor	dB	-16	-16
Antenna gain *	dB	8	13
Transmission line loss	dB	5	5
Factor for 90% of time	dB	3	4
Factor for 70% of locations	dB	6	0
Required field strength	dBu	74	64

Table 4 - Factors considered for Grade A and Grade B contours

* gain is above half-wave dipole

A channel allocation plan for the utilization of the UHF TV band by terrestrial stations has been developed on the basis of geographical mileage separations. These separations were established from protection to the 64 dBu contour 90 percent of the time at 50% of receiving locations for stations with 1000 KW ERP and 1000 feet effective antenna height. The co-channel protection ratio considered was 28 dB for 2/3-line offset operation (45 dB non-offset), and the adjacent channel protection ratio was taken as 0 dB. Table 5 shows the geographical separations used for allocation purposes. It is to be noted that for each channel allocated there are 18 "taboos" or channels which cannot be allocated to the same community or to communities within certain distances from it. With this number of "taboos" for each channel, allocation planning becomes a very complex undertaking.

Channel position relative to allocated channel	Separation (Miles)	Reason or type of interference
Co-channel	175	Co-channel S/I
∓ 1st Adjacent	55	Adjacent Channel S/I
∓ 2, 3, 4, 5 channels	20	Intermodulation
∓ 7 channels	60	Oscillator radiation
∓ 8 channels	20	I.F. beat
∓ 14 channels	60	Sound image frequency
∓ 15 channels	75	Picture image frequency

Table 5 - Geographic separations for UHF channel allocation.

6.2.2 Required protection ratios

a) AM/VSB Terrestrial TV service - protection from FM satellite TV signals

Reference [3] describes the only published experimental work in this field. According to this reference the required basic protection ratio is 37 - 48 dB depending mainly on the program content and recommends the use of 43 dB as a good average for planning purposes. Add to this a -3 dB allowance for polarization discrimination (circular for satellite, linear for terrestrial) and the required protection ratio becomes 40 dB.

b) FM satellite TV service - protection from AM/VSB terrestrial TV signals

Again according to Reference [3] the required basic protection ratio is 16 - 26 dB depending mainly on the program content. A figure of 21 dB could be considered as a good average for planning purposes. Considering the following additional factors which affect signal reception, the required protection ratio becomes:

Basic protection ratio	21 dB
Linear-to-circular polarization discrimination	-3 dB
Possible pointing error of earth and satellite antennae	1 dB
r.m.s. variations in mean sidelobe level of earth receiving antenna	4 dB
Required Protection Ratio	23 dB

c) AM/VSB terrestrial TV service - protection from AM/VSB satellite TV signals

As explained earlier in § 6.2.1 the basic protection ratio for two co-channel terrestrial stations for a TV picture of "passable" quality is 28 dB with 2/3 line offset operation or 45 dB with non-offset operation.

Because of the ubiquity of the satellite signal, frequency-offset operation is impracticable. Also, because of Doppler frequency shifts of satellite transmission, it is believed that, at present, carrier frequency tolerances of 1.5 Hz (see footnote to § 2.1.1 of CCIR Recommendation 418-2) are impracticable. Thus, the protection ratio of 45 dB, given in CCIR Recommendation 418-2 for carriers separated by less than 1000 Hz but not synchronized, would apply for planning purposes but only for a small percentage of the time. When interference is present for a large percentage of the time, as is the case for satellite transmissions, the criterion of "just perceptible interference" should be used (see CCIR Report 479) and the required protection ratio would then be 10 to 20 dB higher (see CCIR Recommendation 418-2). Actually, for system M and worst-case carrier separations of less than 1000 Hz, Reference [4] shows a ratio of 53 dB for a picture quality half way between "excellent" and "fine", for 50% of the observers. This quality would result from just perceptible interference. Therefore, for this case, a basic protection ratio of 53 dB has been selected. Add to this a -3 dB allowance for polarization discrimination and the required protection ratio becomes 50 dB.

d) AM/VSB satellite TV service - protection from AM/VSB terrestrial TV signals

In this case, the interference would be present for a small percentage of the time and the 45 dB figure mentioned in § 6.2.2c) above has been selected for the basic protection ratio. Considering the following additional factors which might affect signal reception, the required protection ratio becomes:

Basic protection ratio	45 dB
Linear-to-circular polarization discrimination	-3 dB
Possible pointing error of earth and satellite antennae	1 dB
R.m.s. variations in mean sidelobe level of earth receiving antenna	4 dB
Required protection ratio	47 dB

It should be noted that the above values are for co-channel operation only, but there are also limitations for adjacent channels. However the effect of the other "taboos", which depend mainly on receiver characteristics, has not been established and it would be assumed that they would have no effect on or from satellite service due to better receiver characteristics. However, this is

* See reference [4]

an area which requires further study.

6.2.3. Sharing Considerations

(a) AM/VSB terrestrial TV service - sharing with FM satellite TV signals

As explained in § 6.2.2. a), the required protection ratio is 40 dB.

If we take as a limiting condition, a minimum C/N of 14 dB or a minimum S/N of 40 dB, whichever comes first, it can be seen from Appendix I that the required field strength at the edge of the beam is 26.6 dBu for community reception. This is equivalent to a required field strength of 29.6 dBu at the center of the beam. For that case, the required discrimination angle between the direction of the satellite and the receiving antenna main beam axis can be derived as follows:

Minimum signal to be protected in terrestrial service (dBu)	64
Less required protection ratio (dB)	-40
Maximum permissible satellite signal (dBu)	24
Minimum required satellite signal at the center of the beam (dBu)	29.6
Less maximum permissible satellite signal (dBu)	-24
Required antenna discrimination (dB)	5.6
Required discrimination angle between the direction of the satellite and the receiving antenna main beam axis (see CCIR Rec. 419).	33°

For individual reception, a minimum field strength of 40 dBu is required and sharing is definitely not feasible. The required discrimination angle must be increased when there is more than one interference entry. Furthermore, satellites positioned inside the longitude of Canada and the United States are visible at an elevation angle of 33° in most of the United States and in the southern portions of Canada. Therefore, for community reception, sharing can be considered marginally feasible to achieve in these areas provided there is only one interference entry. For individual reception, a minimum field strength of 40 dBu is required and sharing is definitely not feasible.

(b) <u>FM satellite TV service - sharing with AM/VSB terrestrial TV signals</u>

Due to the nature of terrestrial broadcasting, the terrestrial signal strength varies from several V/m near the transmitter to an insignificant signal at distances far away from the transmitter. These distances are dependent on the power and antenna height of the terrestrial station and on the nature of the intervening terrain. Thus, the terrestrial stations will always create an area of interference in the satellite service. The size of this area is dependent on the satellite receiving antenna discrimination (which is dependent on the elevation angle) and on the power and height of the terrestrial station.

As an example, if we take 50° Latitude as an average location in Canada and assume the satellite position at the same longitude as the earth station, the satellite elevation angle will be 33° and for community reception, the receiving antenna discrimination at this angle will be 26 dB. The maximum permissible terrestrial signal level can be derived as follows:

Minimum satellite signal to be protected at the edge of the beam (dBu)	26.6
Less required protection ratio (dB)	-23
Plus receiving antenna discrimination (dB)	26
Maximum permissible terrestrial signal (dBu)	29.6

For a UHF station of ERP 1000 KW and effective antenna height of 1000 feet the 29.6 dBu terrestrial signal falls at a distance of approximately 170 miles from the transmitter (using curves for 50% of the locations, 10% of the time). This means that beyond a radius of 170 miles from a co-channel terrestrial station, satellite service would be received without harmful interference; within a radius of 44 miles (location of the 64 dBu signal) from the terrestrial station, the terrestrial service would be received without harmful interference; however, in the area between the 44 and 170 miles radii from the terrestrial station, harmful interference could occur for both services. Within this area, use of still better antennas with better discrimination could contribute to solve this problem.

c) AM/VSB terrestrial TV service - sharing with AM/VSB satellite TV signal

If we take as a limiting case, a minimum S/N of 35 dB, it can be seen from appendix I-e that the minimum required field strength at the edge of the beam is 42 dBu for community reception. This is equivalent to 45 dBu at the center of the beam. The required antenna discrimination between the direction of the satellite and the receiving antenna main beam axis can be derived as follows:

Minimum signal to be protected in the terrestrial service (dBu)	64
Less required protection ratio (see § 6.2.2. c) (dB)	-50
Maximum permissible satellite signal (dBu)	14
Minimum required satellite signal at the center of the beam (dBu)	45
Less maximum permissible satellite signal (dBu)	-14
Required receiving antenna discrimination (dB)	31

Since, from CCIR Rec. 419, the maximum available receiving antenna discrimination is 16 dB, it can be concluded that sharing is definitely not feasible under these circumstances, and there is no need to examine the effect of terrestrial signals on AM/VSB satellite TV service.

6.2.4 Conclusion

It can be concluded from the above considerations that, for Canada:

a) FM television broadcasting from satellites for community reception will not cause more than just perceptible interference to AM/VSB terrestrial TV provided that:

- a discrimination angle of 33° can be achieved. This angle would have to be increased if more than one interference entry were present;
- areas of mutual interference of both the terrestrial and satellite services can be tolerated;
- areas of intereference created by the terrestrial UHF TV station inside the satellite coverage area can be tolerated;

b) FM television broadcasting from satellites for individual reception cannot share frequencies with AM/VSB terrestrial TV.

c) AM/VSB television broadcasting from satellites for either community or individual reception cannot share frequencies with AM/VSB terrestrial TV.

6.3 Feasibility of Frequency Sharing with Tropospheric Scatter Systems:

6.3.1 Status of frequency allocations:

In Region 1, stations of the fixed service using tropospheric scatter may and do operate in the band 790-960 MHz subject to agreement between the Administrations concerned and affected. Such operations in the band 790-860 MHz are on a secondary basis to those of the broadcasting service.

In Region 2, Canada has made frequency allocations to tropospheric scatter systems in the band 614-890 MHz on the condition that it would not cause harmful interference to the broadcasting service.

In Region 3, stations of the fixed service using tropospheric scatter have primary status with the broadcasting and mobile services in the band 610-890 MHz except for India and Pakistan in the band 610-960 MHz and Australia in the band 610-820 MHz where these bands are allocated only to the broadcasting service.

6.3.2 Typical tropospheric scatter system parameters

This study is based on the following parameters:

- receiver noise bandwidth at -3 dB points: 7 MHz
- receiver noise power in the occupied bandwidth: -132 dBW
- feeder cable loss: 1.5 dB
- peak sidelobe response: the receiving antenna is normally not designed to minimize the sidelobe response to the same extent as for earth station antennae. The minimum peak sidelobe response can usually be taken as 0 dB. An examination of typical tropospheric scatter system antennae indicate that this isotropic level of peak sidelobe response falls around 28° off the main beam.

6.3.3. Potential interference from satellite:

If we take as a limiting case, for community reception of FM television, a minimum C/N of 14 dB or a minimum S/N of 40 dB, whichever comes first, it can be seen from Appendix I that the required e.i.r.p. from the satellite at the edge of the beam is 43.6 dBW. This is equivalent to an e.i.r.p. of 46.6 dBW at the center of the beam. For that case, the co-channel satellite interference noise power at the point of minimum peak sidelobe response and into the troposcatter system receiver input can be derived as follows:

- satellite e.i.r.p. at center of beam (dBW):	46.6
- free space attenuation (dB):	-182.0
- circular-to-linear polarization loss (dB):	- 3.0
- peak sidelobe response (dB):	0
- feeder and filter losses (dB):	- 1.5
- satellite interference noise power (dBW)	-139.9 dBW

This is -139.9 + 132 = -7.9 dB below the receiver noise level or a decrease in the threshold margin of 0.65 dB which can be considered marginally acceptable. However, additional interference entries could reduce the threshold margin even further.

6.3.4 Conclusion:

Co-channel sharing between FM television from satellite for community reception and tropospheric scatter systems is therefore marginally feasible provided the following conditions are met:

- assuming no satellite antenna discrimination, the tropospheric scatter antenna system is pointed more than 28° off beam from the satellite.
- the satellite e.i.r.p. at the center of the beam does not exceed 47 dBW.
- there is no more than one interference entry.

6.4 Effects of Exclusive Allocations for Satellite Broadcasting on Terrestrial UHF TV Allocations

6.4.1. Review of existing situation

There are close to 600 allocations in Canada on UHF channels 14-83 with only one low power station operating on channel 73. In the United States there are close to 1250 allocations including 280 stations on channels 14-70.

Channels 70-83 are not included in the U.S. allocation plan and they are for low power stations (translators) on a non-interfering, no protection basis. There are about 800 translators in operation which provide in some cases the only service to their communities.

The possibilities of exclusive allocations for broadcasting from satellites have been considered on the basis of Canada being allocated channels 63-70 and the U.S. channels 53-62, for either community or individual reception. In that case, generally channels 53-70 would have to be reserved in both countries for the space service. It is conceivable that if these channels could be made available a service in both English and French for Canada and a three program service for the U.S.A. could be provided.

Such a space system would eliminate 121 allocated channels in Canada and 136 allocated channels in the U.S.A. In Canada we have one low power station operating on channel 73 and in the USA there is one operating station between channels 63-70. There are no Canadian stations operating between channels 53-62 whereas in the USA there are 8 operating stations. Other channels could probably be located for these operating stations, but not for most of the allocations which would have to be deleted. As service to the communities where the channels are presently allocated would be provided through a space system rather than a terrestrial system, these communities would not necessarily lose service. However, the space service would be more national in scope while the terrestrial service could be more local in character.

The total cost of changing the operating channels of the 9 US stations might be somewhat in excess of one million dollars. Other costs would probably be involved for commercial injury. Compared to the substantial satellite broadcast costs for development, production and launch, the cost of changing channels for the nine operating stations may not be excessive.

6.4.2 Conclusions

Based on the above considerations on the exclusive use of channels 53 to 70 for television broadcasting from satellites we can draw the following conclusions:

- approximately 100 out of the total 600 Canadian UHF allocations would have to be deleted and could not be replaced;
- 136 allocations in the United States would have to be deleted and only a very small number of these could be replaced;
- 9 operating stations in the United States would have to change channel provided one can be made available for the particular community;
- the total cost of changing the operating channels of the 9 USA stations might be somewhat in excess of one million dollars;
- a two language service in Canada and a three program service in the U.S.A. could conceivably be provided to the entire area of both countries as it would not be related to the economic viability of many small stations.

6.5. Television broadcasting from satellites and land mobile services

In the past few years it has become increasingly difficult to assign frequencies to land mobile services in major centres in the United States. As a result the land mobile users have been exerting pressure for the use of parts of the UHF band allocated for television. The F.C.C. is presently studying several proposals such as the use, by land mobile, of Channels 14-21 exclusively or on the basis of geographic sharing with UHF-TV, or Channels 70-83 exclusively. A decision on this problem is expected sometime this year. It should be noted that this has not yet become a problem in Canada.

Should land mobile services be alloted part of the UHF band which would be of interest to satellite broadcasting a study would have to be made to determine sharing possibilities.

6.6 Required angular separation between satellites

6.6.1 Required protection ratios between satellite systems for television broadcasting

a) AM/VSB to AM/VSB

In the present case, there will be a nearly constant ratio of signals. As a result, the criterion of "just perceptible interference" ought to be used. Therefore, the basic protection ratio can be taken as 53 dB as proposed in § 6.2.2 c) above.

For adjacent channels, the basic protection ratio can be taken as -6 dB.

b) FM to FM

Reference [5] states that the basic protection ratio required between two co-channel colour FM television signals with 8 MHz peak-to-peak deviation is 30 dB for just perceptible interference. Furthermore, this protection ratio is approximately inversely proportional to the square of the peak-to-peak deviation. For the four bandwidths considered in 6.1 above, the following basic protection ratios are required:

- for 16 MHz occupied bandwidth: 30.4 dB
- for 18 MHz occupied bandwidth: 28.4 dB
- for 20 MHz occupied bandwidth: 26.8 dB
- for 22 MHz occupied bandwidth: 25.4 dB

For adjacent channels, the basic protection ratio can be taken as -6 dB.

6.6.1 ... Cont'd

c) Allowances required in addition to the basic protection ratio

They include the following:

- reduction in the level of the wanted signal at the edge of the beam: 3 dB
- possible pointing error of the earth and satellite antenna: 1 dB
- r.m.s. variations in mean sidelobe level: 4 dB
- allowance for a number of interference entries:

one entry	0 dB
two entries	3 dB
four entries	4 dB
six entries	4.4 dB
eight entries	4.6 dB
ten entries	4.7 dB
twenty entries	4.9 dB

6.6.2 Method of Calculation

Reference [5] proposes the following expression for the mean sidelobe levels of small antennae well outside the main beam:

$$10 \log_{10} G(\Theta) = 30 - 20 \log_{10} \Theta \text{ dB} \qquad (1)$$

where G (Θ) is the gain, at an angle Θ from the axis, of the antenna relative to an isotropic radiator.

From that equation, we can derive the following expression for the discrimination at any angle Θ:

$$10 \log_{10} G(\Theta = 0^{\circ}) - 10 \log_{10} G(\Theta) = 14 + 20 \log \frac{\Theta}{\phi} \qquad (2)$$

where Ø = satellite half-power beamwidth in degrees.

Θ = angle from the axis in degrees.

Furthermore, it is unlikely that the minimum mean sidelobe response will fall lower than - 10 dB.

6.6.2 ... Cont'd

Equation (2) will apply only for community reception. For individual reception, the discrimination given in CCIR Recommendation 419 will be used.

Assuming a lattice of circular coverage areas, as described in Reference [5] the angle γ subtended at the satellite between the center of a given coverage area and the edge of another coverage area can be given by the following expression:

$$\gamma = \left[(N + 1)\sqrt{3} - 1\right] \frac{\phi}{2} \qquad (3)$$

where N = number of intervening coverage areas between the two coverage areas considered.

ϕ = half-power beamwidth in degrees.

<u>Example</u>: Let us calculate the required angular separation between two co-channel FM satellites aimed respectively at the 1st and 3rd coverage areas (e.g. one intervening coverage area between the two coverage areas considered). The required protection ratio can be derived as follows:

- basic protection ratio (assuming 18 MHz equiv. rec. bandwidth) (dB):	28.4
- allowance for reduction in the level of the wanted signal at the edge of the beam (dB):	3.0
- allowance for possible pointing error of the earth and satellite antenna (dB)	1.0
- allowance for r.m.s. variations in mean sidelobe level (dB)	4.0
- allowance for a number of interference entries (assuming four entries in the present case) (dB)	4.0
- required protection ratio (dB)	40.4

6.6.2 ... Cont'd

The available protection from the satellite antenna can be derived as follows:

Using equation (3):

$$\gamma = \left[(1 + 1)\sqrt{3} - 1\right] \frac{2}{2} = 2.46^{\circ}$$

Using equation (2): where $\theta = 2.46^{\circ}$

satellite antenna discrimination $= 14 + 20 \log \frac{2.46}{2} = \underline{\underline{15.8 \text{ dB}}}$

The required protection from the receiving antenna is, therefore, 40.4 - 15.8 = 24.6 dB.

For community reception, the required angle of satellite separation can be derived as follows:

Using equation (2):

$$26 - 10 \log_{10} G(\theta) = 24.6 \text{ dB}$$

$$10 \log_{10} G(\theta) = 1.4 \text{ dB}$$

Using equation (1):

$$1.4 = 30 - 20 \log_{10} \theta$$

$$\theta = \underline{\underline{27^{\circ}}}$$

For individual reception, the required protection of 24.6 dB cannot be achieved since from CCIR Rec. 419, the maximum discrimination available is 16 dB. Therefore, the adjacent co-channel satellite must be beyond radio line of sight of the receiving antenna. This would still apply if only one interference entry had been assumed.

6.6.3 <u>Required angular separation between satellites for AM/VSB systems</u>

Table 6 gives a summary of results based on the method of calculation in § 6.6.2 for a number of cases applicable to the Canada/U.S.A. situation.

6.6.3 ... Cont'd

		Required Angular separation (degrees)	
Equivalent rectangular bandwidth (MHz)		4	
Types of reception		Community	Individual
	No. of Interf. Entries**		
Case 1: Two adjacent co-channel satellites aimed at the same coverage area	1	*	*
Case 2: Two adjacent co-channel satellites aimed respectively at the 1st and 5th coverage areas	1	*	*
Case 3: Two adjacent co-channel satellites aimed respectively at the 1st and 6th coverage areas	1	96	*
Case 4: Two adjacent satellites on adjacent channels aimed at the same coverage area	1	0	0

Table 6: Required angular separation between satellites for AM/VSB systems

* adjacent co-channel satellite must be beyond radio line of sight of the receiving antenna.

** maximum number of potential interference entries is always assumed.

6.6.4 Required angular separation between satellites for FM systems

Table 7 gives a summary of results based on the method of calculation in § 6.6.2 for a number of cases applicable to the Canada/U.S.A. situation.

		Required angular separation (degrees)							
Equivalent Rectangular bandwidth (MHz)		16		18		20		22	
Type of reception		Com.	Ind.	Com.	Ind.	Com.	Ind.	Com.	Ind.
	No. of interf. entries**								
Case 1: Two adjacent co-channel satellites aimed at the same coverage area	1	93	*	74	*		*		*
	2					87		74	
Case 2: Two adjacent co-channel satellites aimed respectively at the 1st and 2nd coverage areas	1	*	*	83	*	69	*		*
	2							83	
Case 3: Two adjacent co-channel satellites aimed respectively at the 1st and 3rd coverage areas	1		*		*		*		*
	4	34		27					
	6					23			
	8							20	
Case 4: Two adjacent co-channel satellites aimed respectively at the 1st and 4th coverage areas	1		*		60		55		
	2								60
	8	21							
	10			17		14.6		12.2	
Case 5: Two adjacent co-channel satellites aimed respectively at the 1st and 5th coverage areas	1		57						
	2				60		56		52
	10	15.3		12.2		10.3		8.6	
Case 6: Two adjacent co-channel satellites aimed respectively at the 1st and 6th coverage areas	2		58		53		51		45
	10	10.9		9.4		8		6.7	
Case 7: Two adjacent satellites on adjacent channels aimed at the same coverage area	1	0	0	0	0	0	0	0	0
	2					3		3	

Table 7: Required angular separation between satellites for FM systems

* adjacent co-channel satellite must be beyond radio line of sight of the receiving antenna.
** maximum number of potential interference entries is always assumed.

6.6.5 Conclusion

Based on the above results, we can conclude that:

- for community reception of AM/VSB television broadcasting from satellites, the first adjacent unwanted co-channel satellite must be beamed at least 5 coverage areas away from the coverage area of the wanted satellite.
- for individual reception of AM/VSB television broadcasting from satellites, all adjacent unwanted co-channel satellites must be beyond radio line of sight of the receiving antenna.

- for community reception of FM television broadcasting from satellites, the same frequency can be re-used once within the longitudes of Canada and the United States on adjacent co-channel satellites beamed at the same coverage area provided there is adequate angular separation between the satellites. The required angular separation decreases as the equivalent rectangular bandwidth increases.
- for individual reception of FM television broadcasting from satellites, the first adjacent unwanted co-channel satellite must be beamed at least 3 coverage areas away from the coverage area of the wanted satellite.

6.7 Estimated number of potential independent programs

6.7.1 On a frequency-shared basis:

If the constraints given in § 6.2.4 for frequency sharing with UHF terrestrial TV could be met, then the estimated number of potential independent programs available in a fixed 90° of orbital arc would be as given in Table 8 for community reception of FM television from satellites in the band 614-890 MHz.

Number of Coverage areas		2				4				6			
	Canada	2				4				6			
	U.S.A.	2				3				5			
Channel bandwidth (MHz)		18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)		16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available		15	13	12	11	15	13	12	11	15	13	12	11
Estimated number of potential independent programs		15	26	24	22	33	41	38	35	45	52	48	44
Minimum number of orbital positions required		1	2	2	2	3	4	4	4	3	4	4	4

Table 8: Frequency-shared allocation - FM satellite - Community reception

6.7.2 On an exclusive allocation basis:

If a 100 MHz portion of the band 614-890 MHz was made available on an exclusive allocation basis, then the estimated number of potential independent programs in a fixed 90° of orbital arc would be:

a) for FM television from satellites:
   - as in Table 9 for community reception
   - as in Table 10 for individual reception

6.7.2 ... Cont'd

b) for AM/VSB television from satellites:

- as in Table 11 for community reception
- as in Table 12 for individual reception

Number of Coverage areas: Canada	2				4				6			
Number of Coverage areas: U.S.A.	2				3				5			
Channel bandwidth (MHz)	18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)	16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available	5	5	4	4	5	5	4	4	5	5	4	4
Estimated number of potential independent programs	5	10	8	8	11	16	13	13	15	20	16	16
Minimum number of orbital positions required	1	2	2	2	3	4	4	4	3	4	4	4

Table 9: Exclusive allocation - FM satellite - Community reception

Number of Coverage areas: Canada	2				4				6			
Number of Coverage areas: U.S.A.	2				3				5			
Channel bandwidth (MHz)	18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)	16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available	5	5	4	4	5	5	4	4	5	5	4	4
Estimated number of potential independent programs	5	5	4	4	5	7	6	6	10	10	8	8
Minimum number of orbital positions required	1	1	1	1	1	2	2	2	2	2	2	2

Table 10: Exclusive allocation - FM satellite - Individual Reception

Number of Coverage areas	Canada	2	4	6
	U.S.A.	2	3	5
Channel bandwidth (MHz)		6	6	6
Equivalent rectangular bandwidth (MHz)		4	4	4
Number of channels available		16	16	16
Estimated number of potential independent programs		16	16	16
Minimum number of orbital positions required		1	1	1

Table 11: Exclusive allocations - AM/VSB satellite - Community reception

Number of Coverage areas	Canada	2	4	6
	U.S.A.	2	3	5
Channel bandwidth (MHz)		6	6	6
Equivalent rectangular bandwidth (MHz)		4	4	4
Number of channels available		16	16	16
Estimated number of potential independent programs		16	16	16
Minimum number of orbital positions required		1	1	1

Table 12: Exclusive allocations - AM/VSB satellite - Individual reception

6.7.3 Conclusion

Based on the above results and assuming an equal distribution of the estimated number of potential independent programs in a 90^{o} of orbital arc between Canada and the United States, the following conclusions can be drawn:

- for AM/VSB television from satellites whether for community or individual reception and independent of the number of coverage

6.7.3 ... Cont'd

areas, the estimated number of independent programs for Canada would be 8 for a 100 MHz exclusive band.

- for FM television from satellites for community reception, the estimated number of independent programs for Canada varies from a low of 8 for two-beam coverage and 16 MHz bandwidth to a high of 26 for a six-beam coverage and 20 MHz bandwidth in a 276 MHz shared band. In a 100 MHz exclusive band, these values are 3 and 10 respectively.

- for FM television from satellites for individual reception, the estimated number of independent programs for Canada varies from a low of 2 for a two-beam coverage and 22 MHz bandwidth to a high of 5 for a six-beam coverage and 16 MHz bandwidth in a 100 MHz exclusive band.

6.8 Recommendations

a) Canada should propose a footnote to the allocation table, in the band 614-890 MHz, in Region 2, which would permit television broadcasting from satellite, subject to agreement among the administrations whose territories are affected for the following reasons:

- frequency sharing with the existing terrestrial services in that band might be workable within the limitations given in § 6.2.4.
- there is a need for more study to determine whether these conditions are realizable for a viable satellite system.
- there is a need for further study to determine if the impact of exclusive allocations for the broadcasting satellite service on existing terrestrial services prevails over the need for such a satellite service.

6.8 ... Cont'd

b) The Canadian proposal should read as follows:

"ADD 324B The broadcasting satellite service also may be authorized in the band 614-890 MHz for television broadcasting, subject to agreement among Administrations whose territories are affected.

REASON: To provide for the development of television broadcasting within the appropriate space service, within a band where television receivers are now in the hands of the general public, keeping in mind the existence of established terrestrial services in that band."

7. SATELLITE TELEVISION BROADCASTING IN THE BAND 2548-2686 MHz

7.1 Examples of television system parameters

Based on the assumptions made in 4 above, the television system parameters of a number of examples have been calculated and are given in Appendices II - a, b, c, d and e.

For convenience, a summary of the required field strength and e.i.r.p.'s at the satellite beam edge is given in Table 13 for FM television and Table 14 for AM/VSB television.

Equivalent Rectangular Bandwidth (MHz)	S/N	40		45		50	
	Type of Reception	Community	Individual	Community	Individual	Community	Individual
16	Field Strength (dBu)	27.6	35.6	32.6	40.6	37.6	45.6
	e.i.r.p. (dBW)	45	53	50	58	55	63
18	Field Strength (dBu)	*	*	30.6	38.6	35.6	43.6
	e.i.r.p. (dBW)			48	56	53	61
20	Field strength (dBu)	*	*	28.9	36.9	33.9	41.9
	e.i.r.p. (dBW)			46.3	54.3	51.3	59.3
22	Field strength (dBu)	*	*	*	*	32.6	40.6
	e.i.r.p. (dBW)					50	58

Table 13: FM television from satellites - Summary of system parameters.

* Not considered since C/N is less than 14 dB

Equivalent Rectangular Bandwidth (MHz)	S/N	35		40		45	
	Type of Reception	Community	Individual	Community	Individual	Community	Individual
4	Field strength (dBu)	43	51	48	56	53	61
	e.i.r.p. (dBW)	60.4	68.4	65.4	73.4	70.4	78.4

Table 14: AM/VSB television from satellites - Summary of system parameters.

7.2 Feasibility of frequency sharing with terrestrial ITV systems

7.2.1 Status of frequency allocations:

In Canada, the band 2548-2686 MHz is allocated to the terrestrial ITV system for which systems are already in operation. In the United States, the band 2500-2690 MHz is allocated for the same type of system.

7.2.2 Typical terrestrial ITV system parameters:

This study is based on the following parameters:

- minimum received carrier power at the input of the receiver: -83 dBW
- receiving antenna gain over an isotropic source: 31 dB
- mean sidelobe level response: 30-20 log θ*
- minimum mean sidelobe response over an isotropic source: 0 dB
- receiving antenna polarization: Linear
- r.m.s. variations in mean sidelobe level: 4 dB
- waveguide and connector losses: 0.5 dB

7.2.3 Required protection ratios:

The required protection ratios are identical to the ones given in 6.2.2

* θ is the angle from the main beam axis.

7.2.4 Conditions for sharing with FM television from satellites

a) Community reception:

If we take as a limiting condition, a minimum C/N of 14 dB or a minimum S/N of 40 dB, whichever comes first, it can be seen from appendix II that the required e.i.r.p. from the satellite at the edge of the beam is 45 dBW. This is equivalent to an e.i.r.p. of 48 dBW at the center of the beam. Let us analyse the situation for a condition of just perceptible interference in the ITV receiver. The required discrimination angle between the direction of the satellite and the ITV receiving antenna main beam axis can be derived as follows:

Satellite e.i.r.p. at center of beam (dBW)	48
Free Space loss (dB)	-192
Atmospheric attenuation (1% of the time) (dB)	-0.4
Circular-to-linear polarization loss (dB)	-3
Mean sidelobe response (dB)	X
R.m.s. variations in mean sidelobe response (dB)	4
Waveguide and connector losses (dB)	-0.5
Interfering carrier power at the input of the receiver (dBW)	-143.9+X

Minimum received carrier power at the input of the receiver (dBW)	-83
Less required basic protection ratio (dB)	-43
Permissible interfering carrier power at the input of the receiver (dBW)	-126

Since the permissible interfering carrier power and the actual interfering carrier power are equal we can conclude that:

Permissible mean sidelobe response (dB)	17.9
Required discrimination angle between the direction of the satellite and the LTV receiving antenna main beam axis (degrees)	4°

The required discrimination angle must be increased when there is more than one interference entry.

b) Individual reception

For individual reception, the required satellite e.i.r.p. will be 8 dB higher than for community reception. Therefore, the required angle between the direction of the satellite and the receiving antenna main axis can be derived as follows:

Permissible mean sidelobe response (dB)	9.9
Required angle between the direction of the satellite and the receiving antenna main beam axis (degrees)	10°

The required discrimination angle must be increased when there is more than one interference entry.

c) Potential interference from the ITV transmitter into the earth station receiver:

Conditions similar to the ones described in 6.2.3 b) also apply here.

7.2.5 Conditions for sharing with AM/VSB television from satellites

For the limiting case of S/N = 35 dB, it can be seen from appendix II-e that the required e.i.r.p. from the satellite at the edge of the beam is 60.4 dBW for community reception. This is equivalent to an e.i.r.p. of 63.4 dBW at the center of the beam. Using the same method as in 7.2.4 above, the required discrimination angle can be derived as follows:

Satellite e.i.r.p. at center of beam (dBW)	63.4
Free Space Loss (dB)	-192
Atmospheric attenuation (1% of the time)	-0.4
Circular-to-linear polarization loss (dB)	-3
Mean sidelobe response (dB)	X
R.m.s. variations in mean sidelobe level (dB)	4
Waveguide and connector losses (dB)	-0.5
Interfering carrier power at the input of the receiver (X) (dBW)	-128.5+X
Minimum received carrier power at the input of the receiver (dBW)	-83
Less required basic protection ratio (dB)	-53
Permissible interfering carrier power at the input of the receiver (dBW)	-136

Since the permissible interfering carrier power and the actual interfering carrier power are equal we can conclude that the permissible mean sidelobe response X is -7.5 dB.

The minimum mean sidelobe response having been assumed to be 0 dB, the receiving antenna cannot provide sufficient discrimination at any angle. Therefore, frequency sharing is definitely not feasible with AM/VSB television from satellites.

7.2.6 Conclusion

It can be concluded from the above considerations that:

a) FM television broadcasting from satellites from community reception can share frequencies with terrestrial ITV systems provided that:

- a discrimination angle of 4^{o} can be achieved. This angle would have to be increased if more than one inteference entry were present;
- areas of mutual interference to both the terrestrial and satellite services can be tolerated;
- areas of intereference created by the terrestrial ITV station inside the satellite coverage area can be tolerated.

For individual reception, the required discrimination angle is larger but might still be considered feasible to achieve.

b) AM/VSB television broadcasting from satellites for either community or individual reception cannot share frequencies with terrestrial ITV systems.

7.3 Required angular separation between satellites

7.3.1 Required protection ratios between satellite systems for television broadcasting

Similar to the ones given in Section 6.6.1

7.3.2 Method of Calculation

Similar to the one described in Section 6.6.2

7.3.3 Required angular separation between satellites for AM/VSB systems

Table 15 gives a summary of results based on the method of calculation in Section 6.6.2 for a number of cases applicable to the Canada /USA situation.

		Required angular separation (degrees)	
Equivalent rectangular bandwidth (MHz)		4	
Type of reception		Community	Individual
	No. of interf. entries **		
Case 1: Two adjacent co-channel satellites beamed at the same coverage area.	1	*	*
Case 2: Two adjacent co-channel satellites beamed respectively at the 1st and 3rd coverage areas	1	*	*
Case 3: Two adjacent co-channel satellites beamed respectively at the 1st and 4th coverage areas	1	56	*
Case 4: Two adjacent co-channel satellites beamed respectively at the 1st and 5th coverage areas	1 2	 56	78
Case 5: Two adjacent co-channel satellites beamed respectively at the 1st and 6th coverage areas	1 2	 43	61
Case 6: Two adjacent satellites on adjacent channels beamed at the same coverage area	1	0	0

Table 15 - Required angular separation between satellites for AM/VSB systems

* adjacent co-channel satellite must be located beyond radio line of sight of the receiving antenna.

** maximum number of potential interference entries is always assumed

7.3.4 Required angular separation between satellites for FM systems

Table 16 gives a summary of results based on the method of calculation in Section 6.6.2 for a number of cases applicable to the Canada/USA situation.

		Required angular separation (degrees)							
Equivalent rectangular bandwidth (MHz)		16		18		20		22	
Type of reception		Com.	Ind.	Com.	Ind.	Com.	Ind.	Com.	Ind.
	No. of Interf. entries *								
Case 1: Two adjacent co-channel satellites aimed at the same coverage area	2	43	86		68		57		48
	4			38		32			
	6							29	
Case 2: Two adjacent co-channel satellites aimed respectively at the 1st and 2nd coverage areas	1		68						
	2	48			72		64		54
	4			43		36		31	
Case 3: Two adjacent co-channel satellites aimed respectively at the 1st and 3rd coverage areas	6		23						
	8				19				
	10	12		9.5		8	15.9	6.8	13.5
Case 4: Two adjacent satellites on adjacent channels aimed at the same coverage area	1	0	0	0	0	0	0	0	0
	2	0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
	4							0.8	

Table 16 - Required angular separation between satellites for FM systems.

7.3.5 Conclusion

Based on the above results, we can conclude that:

- for community reception of AM/VSB television broadcasting from satellites, the first adjacent unwanted co-channel satellite must be beamed 3 coverage areas away from the coverage area of the wanted satellite. For individual reception the unwanted satellite must be beamed 4 coverage areas away instead of 3.

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* maximum number of potential interference entries is always assumed.

- for community reception of FM television broadcasting from satellites, the same frequency can be re-used up to three times within the longitudes of Canada and the Unites States on adjacent co-channel satellites beamed at the same coverage area provided there is adequate separation between the satellites. The required angular separation decreases as the equivalent rectangular bandwidth increases. For individual reception, the same frequency can be re-used only once instead of three times.

7.4 Estimated number of potential independent programs

7.4.1 FM television from satellites:

If the conditions for sharing given in Section 7.2.4 can be met then the minimum number of potential independent programs available in a 90° of orbital arc in the 138 MHz band between 2548 and 2686 MHz is as given in Table 17 for community reception and Table 18 for individual reception.

Number of Coverage areas	Canada	2				4				6			
	U.S.A.	2				3				5			
Channel bandwidth (MHz)		18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)		16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available		7	6	6	5	7	6	6	5	7	6	6	5
Estimated number of potential independent programs		21	18	18	20	37	38	39	38	49	48	54	50
Minimum number of orbital positions required		3	3	3	4	7	8	9	10	7	8	9	10

Table 17 - Frequency-shared allocation - FM satellite - Community reception.

Number of Coverage areas	Canada	2				4				6			
	U.S.A.	2				3				5			
Channel bandwidth (MHz)		18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)		16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available		7	6	6	5	7	6	6	5	7	6	6	5
Estimated number of potential independent programs		14	12	12	10	22	25	26	22	28	30	36	30
Minimum number of orbital positions required		2	2	2	2	4	5	6	6	4	5	6	6

Table 18 - Frequency-shared allocation - FM satellite - Individual reception.

7.4.2. AM/VSB television from satellites:

Since sharing is impossible to achieve, exclusive allocations will be required and the minimum number of potential independent programs in a 90° of orbital arc in the 138 MHz band between 2548 and 2686 MHz is as given in Table 19 for community reception and Table 20 for individual reception.

Number of Coverage areas	Canada	2	4	6
	U.S.A.	2	3	5
Channel bandwidth (MHz)		6	6	6
Equivalent rectangular bandwidth (MHz)		4	4	4
Number of channels available		23	23	23
Estimated number of potential independent programs		23	31	46
Minimum number of orbital positions required		1	2	2

Table 19 - Exclusive allocations - AM/VSB satellite - Community reception.

Number of Coverage areas	Canada	2	4	6
	U.S.A.	2	3	5
Channel bandwidth (MHz)		6	6	6
Equivalent rectangular bandwidth (MHz)		4	4	4
Number of channels available		23	23	23
Estimated number of potential independent programs		23	23	46
Minimum number of orbital positions required		1	1	2

Table 20 - Exclusive allocations - AM/VSB satellite - Individual reception.

7.4.3 Conclusion

Based on the above results and assuming an equal distribution of the estimated number of potential independent programs in a 90° of orbital arc between Canada and the United States, the following conclusions can be drawn:

- for AM/VSB television from satellites for either community or individual reception, the estimated number of potential independent programs for Canada varies from a low of 12 for a two-beam coverage to a high of 23 for a six-beam coverage in a 138 MHz exclusive band.

- for FM television from satellites for community reception, the estimated number of potential independent programs for Canada varies from a low of 9 for a two-beam coverage and 20 MHz bandwidth to a high of 27 for a six-beam coverage and 20 MHz bandwidth in a 138 MHz shared band. For individual reception, these values vary from a low of 5 for a two-beam coverage and 22 MHz bandwidth to a high of 18 for a six-beam coverage and 20 MHz bandwidth,

7.5 Feasibility of frequency sharing with earth exploration satellites

7.5.1 Sharing considerations

Both Canada and the United States have expressed a need to develop earth exploration satellites either individually or on a joint basis. One band which appears suitable and available for space-to-earth transmissions for that purpose is between 2550 and 2690 MHz but this aspect is still being investigated.

The United States intends to submit a proposal to the WARC allowing the use of that band for space-to-earth transmissions in the earth exploration satellite service. Canada would also like to make a similar proposal pending study of the implications of sharing with terrestrial ITV and Satellite Broadcasting systems. The proposal would read as follows:

"ADD 363A In the band 2550-2690 MHz space-to-earth transmissions in the earth exploration satellite service may be authorized, subject to agreement among Administrations concerned and those having services operating in accordance with the Table, which may be affected"

There is presently very little data available on the future characteristics of the space-to-earth link of the Earth Exploration Satellite service. However, indications are that the satellites would operate in near-polar orbits with approximately 50% of the data being read out in real time thus requiring tracking by the readout stations over the required coverage area. Therefore, in portions of the orbit, severe interference could be experienced by the earth receiving antenna in the Earth Exploration Satellite service from the Broadcasting Satellite transmissions. The possibility exists, however, that for the section of the polar orbit within range of interference from the broadcasting satellite in the equatorial orbit, the Earth Exploration satellite data could be recorded on board the spacecraft and read out later but this requires further investigation. Another possible solution would be for the Earth Exploration Satellite service to be accommodated in another frequency band if such a band can be found.

7.5.2 Conclusion

Based on the above considerations, it would appear that:

- the space-to-earth link of the Earth Exploration satellite service as presently conceived might not be able to share frequencies with the Broadcasting satellite service.
- further investigation is required to determine the constraints required to enable such sharing.

7.6 Recommendation

a) Canada should investigate further the desirability and feasibility of using the band 2548-2686 MHz for television broadcasting from satellites in Region 2 because of its attractiveness from a technical and economic point of view.

b) Canada should not oppose satellite broadcasting in the band 2550-2690 MHz in either Regions 1 or 3 since it is unlikely that it would interfere with both terrestrial ITV systems and the earth exploration satellite service in our country.

c) Canada should study the possibility of using the band 2550-2690 MHz as a companion up band for satellite broadcasting in the band 614-890 MHz.

8. SATELLITE BROADCASTING IN THE BAND 11700-12200 MHz

8.1 Examples of television system parameters

Based on the assumptions made in Section 4 above, the television system parameters of a number of examples have been calculated and are given in Appendices III - a, b, c, d and e.

For convenience, a summary of the required field strengths and e.i.r.p.'s at the satellite beam edge is given in Table 21 for FM television and Table 22 for AM/VSB television.

Equiv. rect. bandwidth (MHz)	S/N	40		45		50	
	Types of reception	Community	Individual	Community	Individual	Community	Individual
16	Field strength (dBu)	33.6	40.3	38.6	45.3	43.6	50.3
	e.i.r.p. (dBW)	52.8	59.5	57.8	64.5	62.8	69.5
18	Field strength (dBu)	x	x	36.6	43.3	41.6	48.3
	e.i.r.p. (dBW)			55.8	62.5	60.8	67.5
20	Field strength (dBu)	x	x	34.9	41.6	39.9	46.6
	e.i.r.p. (dBW)			54.1	60.8	59.1	65.8
22	Field strength (dBu)	x	x	x	x	38.6	45.3
	e.i.r.p. (dBW)					57.8	64.5

Table 21 - FM television from satellites - Summary of system parameters.

x not considered since C/N is less than 14 dB.

Equiv. rect. bandwidth (MHz)	S/N	35		40		45	
	Types of reception	Community	Individual	Community	Individual	Community	Individual
4	Field strength (dBu)	49	55.7	54	60.7	59	65.7
	e.i.r.p. (dBW)	68.2	74.9	73.2	79.9	78.2	84.9

Table 22 - AM/VSB television from satellites - Summary of system parameters.

8.2 Required angular separation between satellites

8.2.1 Required protection ratios between satellite systems for television broadcasting

Similar to the ones given in Section 6.6.1 except that the allowance for possible earth and satellite pointing error has been taken as 2 dB.

8.2.2 Method of calculation

Similar to the one described in Section 6.6.2

8.2.3 Required angular separation between satellites for AM/VSB systems

Table 23 gives a summary of results based on the method of calculation in Section 6.6.2 for a number of cases applicable to the Canada/USA situation.

Equivalent rectangular bandwidth (MHz)		Required angular separation (degrees) 4	
Types of reception	No. of interf. entries **	Community	Individual
Case 1: Two adjacent co-channel satellites beamed at the same coverage area	1	*	*
Case 2: Two adjacent co-channel satellites beamed respectively at the 1st and 2nd coverage areas	1	*	*
Case 3: Two adjacent co-channel satellites aimed respectively at the 1st and 3rd coverage areas	1 2	 58	71
Case 4: Two adjacent co-channel satellites beamed respectively at the 1st and 4th coverage areas	2	34	59
Case 5: Two adjacent satellites on adjacent channels beamed at the same coverage area	1	0	0

Table 23 - Required angular separation between satellites for AM/VSB systems.

* adjacent co-channel satellite must be located beyond radio line of sight of the receiving antenna

** maximum number of potential interference entries is always assumed.

8.2.4 Required angular separation between satellites for FM systems

Table 24 gives a summary of results based on the method of calculation in Section 6.6.2 for a number of cases applicable to the Canada/USA situation.

		Required angular separation (degrees)							
Equivalent rectangular bandwidth (MHz)		16		18		20		22	
Types of reception		Com.	Ind.	Com.	Ind.	Com.	Ind.	Com.	Ind.
	No. of interf. entries *								
Case 1: Two adjacent co-channel satellites beamed at the same coverage area	4		36		29				
	6	22					25		
	8			18					22
	10					15		13	
Case 2: Two adjacent co-channel satellites beamed respectively at the 1st and 2nd coverage areas	4		41		32				
	6	25					28		24
	8			20					
	10					17		14	
Case 3: Two adjacent co-channel satellites beamed respectively at the 1st and 3rd coverage areas	10	5.2	9	4.2	7.2	3.5	5.9	3	5.1
Case 4: Two adjacent satellites on adjacent channels aimed at the same coverage area	1	0	0	0	0	0	0	0	0
	10	1	1	1	1	1	1	1	1

Table 24 - Required angular separation between satellites for FM systems

* maximum number of potential interference entries is always assumed.

8.2.5 Conclusion

Based on the above results, we can conclude that:

- for either community or individual reception of AM/VSB television broadcasting from satellites, the first adjacent unwanted co-channel satellite must be beamed 2 coverage areas away from the coverage area of the wanted satellite.

- for community reception of FM television broadcasting from satellites, the same frequency can be re-used up to six times within the longitudes of Canada and the United States on adjacent co-channel satellites beamed at the same coverage area provided there is adequate separation between the satellites. The required angular separation decreases as the equivalent rectangular bandwidth increases. For individual reception the same frequency can be re-used only four times instead of six.

8.3 Estimated number of potential independent programs

8.3.1 FM television from satellites

The number of potential independent programs in a fixed 90° of orbital are in a 500 MHz exclusive band between 11700 and 12200 MHz. will be:

- as in Table 25 for community reception
- as in Table 26 for individual reception

Number of Coverage areas — Canada	2				4				6			
USA	2				3				5			
Channel bandwidth (MHz)	18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)	16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available	27	25	22	20	27	25	22	20	27	25	22	20
Estimated number of potential independent programs	135	150	154	160	259	295	310	321	351	400	418	440
Minimum number of orbital positions required	5	6	7	8	13	16	19	22	13	16	19	22

Table 25 - FM satellite - Community reception.

Number of Coverage areas — Canada	2				4				6			
USA	2				3				5			
Channel bandwidth (MHz)	18	20	22	24	18	20	22	24	18	20	22	24
Equivalent rectangular bandwidth (MHz)	16	18	20	22	16	18	20	22	16	18	20	22
Number of channels available	27	25	22	20	27	25	22	20	27	25	22	20
Estimated number of potential independent programs	81	100	88	100	174	187	192	192	243	250	264	260
Minimum number of orbital positions required	3	4	4	5	9	10	12	13	9	10	12	13

Table 26 - FM satellite - Individual reception

8.3.2 AM/VSB television from satellites

The number of potential independent programs in a fixed 90° of orbital arc in a 500 MHz exclusive band between 11700 and 12200 MHz will be:

- as in Table 27 for community reception
- as in Table 28 for individual reception

Number of Coverage areas	Canada	2	4	6
	USA	2	3	5
Channel bandwidth (MHz)		6	6	6
Equivalent rectangular bandwidth (MHz)		4	4	4
Number of channels available		83	83	83
Estimated number of potential independent programs		83	166	249
Minimum number of orbital positions required		1	2	3

Table 27 - AM/VSB satellite - Community reception

Number of Coverage areas	Canada	2	4	6
	USA	2	3	5
Channel bandwidth (MHz)		6	6	6
Equivalent rectangular bandwidth (MHz)		4	4	4
Number of channels available		83	83	83
Estimated number of potential independent programs		83	166	166
Minimum number of orbital positions required		1	2	2

Table 28 - AM/VSB satellite - Individual reception

8.3.3 Conclusion

Based on the above results and assuming an equal distribution of the estimated number of potential independent programs in a 500 MHz exclusive band and in a 90° of orbital arc between Canada and the United States, the following conclusions can be drawn:

- for AM/VSB television from satellites for community reception, the estimated number of potential independent programs for Canada varies from a low of 42 for a two-beam coverage to a high of 125 for a six-beam coverage. For individual reception, the values are 42 and 83 respectively.
- for FM television from satellites for community reception, the estimated number of potential independent programs for Canada varies from a low of 68 for a two-beam coverage and 16 MHz bandwidth to a high of 220 for a six-beam coverage and 22 MHz bandwidth. For individual reception, these values are 42 and 132* respectively

8.4 Recommendation

a) Canada should propose a primary allocation for broadcasting from satellites in the band 11700-12200 MHz for the following reasons:
   - this band is presently not in use in Canada for terrestrial services;
   - the available bandwidth would be sufficient to cover all foreseeable Canada/USA requirements;
   - a primary allocation would permit the use of higher e.i.r.p.'s for individual reception of broadcasting from satellites.

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* for 20 MHz equivalent rectangular bandwidth instead of 22 MHz.

b) Canada should propose a secondary allocation for the communication-satellite service (limited to the distribution of television programme material) in the band 11700-12200 MHz for the following reasons:

- this would preserve the right for the broadcasting satellite service to use higher e.i.r.p.'s for individual reception;
- this would give more incentive for these other services to design their systems in such a way as to tolerate more interference from the broadcasting satellite service.

c) The possibility of using the band 14575-15025 MHz as the companion earth-to-satellite band for the 11700-12200 MHz broadcasting satellite band should be investigated.

d) The existing primary allocation for terrestrial broadcasting on a shared basis with the fixed and mobile services in the band 12200-12700 MHz should be retained for the following reasons:

- this is the only allocation for terrestrial broadcasting above 1 GHz;
- this band could be used to complement the cable distribution service provided the definition of broadcasting could be amended to cover this aspect of broadcasting.

9. REFERENCES

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BROADCASTING FROM SATELLITES

FM TELEVISION SYSTEM PARAMETERS AT 750 MHz

	Equivalent rectangular bandwidth 16 MHz (equivalent to 18 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	14.6						19.6						24.6						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth	dBW	-128.0			-126.0			-128.0			-126.0			-128.0			-126.0			6
7	Required carrier power	dBW	-113.4			-111.4			-108.4			-106.4			-103.4			-101.4			7
8	Type of receiving antenna		3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			8
9	Rx. antenna gain above isotropic (55% effective)	dB	26			17			26			17			26			17			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	6			-3			6			-3			6			-3			11
12	Required flux (99% time)	dBW/m^2	-119.4			-108.4			-114.4			-103.4			-109.4			-98.4			12
13	Equivalent field strength	dBu	26.6			37.6			31.6			42.6			36.6			47.6			13
		uV/m	21			76			38			135			68			240			
14	Free space attenuation between isotropic sources 39000 km apart	dB	182			182			182			182			182			182			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0			0			0			0			0			0			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	43.6			54.6			48.6			59.6			53.6			64.6			16
		kW	23			288			72			912			229			2880			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	8.0	9.5	12.9	19.0	20.5	23.9	13.0	14.5	17.9	24.0	25.5	28.9	18.0	19.5	22.9	29.0	30.5	33.9	22
		W	6.3	8.9	19	79	112	245	20	28	62	250	355	775	63	89	195	795	1120	2450	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 750 MHz

	Equivalent rectangular bandwidth 18 MHz (equivalent to 20 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	12						17						22						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-127.4			-125.4			-127.4			-125.4			-127.4			-125.4			6
7	Required carrier power	dBW	-115.4			-113.4			-110.4			-108.4			-105.4			-103.4			7
8	Type of receiving antenna		3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			8
9	Rx. antenna gain above isotropic (55% effective)	dB	26			17			26			17			26			17			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	6			-3			6			-3			6			-3			11
12	Required flux (99% time)	dBW/m^2	-121.4			-110.4			-116.4			-105.4			-111.4			-100.4			12
13	Equivalent field strength	dBu	24.6			35.6			29.6			40.6			34.6			45.6			13
		uV/m	17			60			30			107			54			190			
14	Free space attenuation between isotropic sources 39000 km apart	dB	182			182			182			182			182			182			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0			0			0			0			0			0			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	41.6			52.6			46.6			57.6			51.6			62.6			16
		kW	14			182			46			575			145			1820			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	6.0	7.5	10.9	17.0	18.5	21.9	11.0	12.5	15.9	22.0	23.5	26.9	16.0	17.5	20.9	27.0	28.5	31.9	22
		W	4.0	5.6	12	50	71	155	13	18	39	158	224	490	40	56	123	500	708	1540	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 750 MHz

	Equivalent rectangular bandwidth 20 MHz (equivalent to 22 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	9.9						14.9						19.9						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-127.0			-125.0			-127.0			-125.0			-127.0			-125.0			6
7	Required carrier power	dBW	-117.1			-115.1			-112.1			-110.1			-107.1			-105.1			7
8	Type of receiving antenna		3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			8
9	Rx. antenna gain above isotropic (55% effective)	dB	26			17			26			17			26			17			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	6			-3			6			-3			6			-3			11
12	Required flux (99% time)	dBW/m^2	-123.1			-112.1			-118.1			-107.1			-113.1			-102.1			12
13	Equivalent field strength	dBu	22.9			33.9			27.9			38.9			32.9			43.9			13
		uV/m	14			49			25			88			44			157			
14	Free space attenuation between isotropic sources 39000 km apart	dB	182			182			182			182			182			182			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0			0			0			0			0			0			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	39.9			50.9			44.9			55.9			49.9			60.9			16
		kW	9.8			123			31			389			98			1230			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	4.3	5.8	9.2	15.3	16.8	20.2	9.3	10.8	14.2	20.3	21.8	25.2	14.3	15.8	19.2	25.3	26.8	30.2	22
		W	2.7	3.8	8.3	34	48	105	8.5	12	26	107	151	331	27	38	83	339	478	1050	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 750MHz

	Equivalent rectangular bandwidth 22 MHz (equivalent to 24 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	8.2						13.2						18.2						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-126.6			-124.6			-126.6			-124.6			-126.6			-124.6			6
7	Required carrier power	dBW	-118.4			-116.4			-113.4			-111.4			-108.4			-106.4			7
8	Type of receiving antenna		3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			8
9	Rx. antenna gain above isotropic (55% effective)	dB	26			17			26			17			26			17			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	6			-3			6			-3			6			-3			11
12	Required flux (99% time)	dBW/m^2	-124.4			-113.4			-119.4			-108.4			-114.4			-103.4			12
13	Equivalent field strength	dBu	21.6			32.6			26.6			37.6			31.6			42.6			13
		uV/m	12			43			21			76			38			135			
14	Free space attenuation between isotropic sources 39000 km apart	dB	182			182			182			182			182			182			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0			0			0			0			0			0			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	38.6			49.6			43.6			54.6			48.6			59.6			16
		kW	7.2			91			23			288			72			912			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	3.0	4.5	7.9	14.0	15.5	18.9	8.0	9.5	12.9	19.0	20.5	23.9	13.0	14.5	17.9	24.0	25.5	28.9	22
		W	2.0	2.8	6.2	25	35	78	6.3	8.9	19	79	112	245	20	28	62	250	355	775	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES

AM/VSB TELEVISION SYSTEM PARAMETERS AT 750 MHz

	Equivalent rectangular bandwidth 4 MHz (equivalent to 6 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	35						40						45						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	36						41						46						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-134			-132			-134			-132			-134			-132			6
7	Required carrier power	dBW	-98			-96			-93			-91			-88			-86			7
8	Type of receiving antenna		3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			3.4m paraboloid			crossed yagi			8
9	Rx. antenna gain above isotropic (55% effective)	dB	26			17			26			17			26			17			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	6			-3			6			-3			6			-3			11
12	Required flux (99% time)	dBW/m^2	-104			-93			-99			-88			-94			-83			12
13	Equivalent field strength	dBu	42			53			47			58			52			63			13
		uV/m	126			447			224			795			400			1410			
14	Free space attenuation between isotropic sources 39000 km apart	dB	182			182			182			182			182			182			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0			0			0			0			0			0			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	59			70			64			75			69			80			16
		kW	795			10000			2500			31600			7950			100000			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	16.4	14.0	9.3	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	23.4	24.9	28.3	34.4	35.9	39.3	28.4	29.9	33.3	39.4	40.9	44.3	33.4	34.9	38.3	44.4	45.9	49.3	22
		W	219	308	675	2750	3890	8500	692	978	2140	8700	12300	26900	2180	3090	6750	27500	38900	85000	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 2600MHz

	Equivalent rectangular bandwidth 16 MHz (equivalent to 18 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	14.6						19.6						24.6						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-128.0			-126.0			-128.0			-126.0			-128.0			-126.0			6
7	Required carrier power	dBW	-113.4			-111.4			-108.4			-106.4			-103.4			-101.4			7
8	Type of receiving antenna		3.4m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	35.7			29.7			35.7			29.7			35.7			29.7			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	5			-1			5			-1			5			-1			11
12	Required flux (99% time)	dBW/m^2	-118.4			-110.4			-113.4			-105.4			-108.4			-100.4			12
13	Equivalent field strength	dBu	27.6			35.6			32.6			40.6			37.6			45.6			13
		uV/m	24			60			43			107			76			190			
14	Free space attenuation between isotropic sources 39000 km apart	dB	192			192			192			192			192			192			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0.4			0.4			0.4			0.4			0.4			0.4			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	45			53			50			58			55			63			16
		kW	32			200			100			630			316			2000			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	9.4	10.9	14.3	17.4	18.9	22.3	14.4	15.9	19.3	22.4	23.9	27.3	19.4	20.9	24.3	27.4	28.9	32.3	22
		W	8.7	12	27	55	78	170	28	39	85	174	246	536	87	123	269	550	775	1700	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 2600 MHz

	Equivalent rectangular bandwidth 18 MHz (equivalent to 20 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	12						17						22						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth	dBW	-127.4			-125.4			-127.4			-125.4			-127.4			-125.4			6
7	Required carrier power	dBW	-115.4			-113.4			-110.4			-108.4			-105.4			-103.4			7
8	Type of receiving antenna		3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	35.7			29.7			35.7			29.7			35.7			29.7			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	5			-1			5			-1			5			-1			11
12	Required flux (99% time)	dBW/m^2	-120.4			-112.4			-115.4			-107.4			-110.4			-102.4			12
13	Equivalent field strength	dBu	25.6			33.6			30.6			38.6			35.6			43.6			13
		uV/m	19			48			34			85			60			151			
14	Free space attenuation between isotropic sources 39000 km apart	dB	192			192			192			192			192			192			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0.4			0.4			0.4			0.4			0.4			0.4			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	43			51			48			56			53			61			16
		kW	20			125			63			363			200			1250			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	7.4	8.9	12.3	15.4	16.9	20.3	12.4	13.9	17.3	20.4	21.9	25.3	17.4	18.9	22.3	25.4	26.9	30.3	22
		W	5.5	7.8	17	35	49	107	17	25	54	110	155	349	55	78	170	347	490	1070	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

APPENDIX II-c

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 2600 MHz

	Equivalent rectangular bandwidth 20 MHz (equivalent to 22 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	9.9						14.9						19.9						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth	dBW	-127.0			-125.0			-127.0			-125.0			-127.0			-125.0			6
7	Required carrier power	dBW	-117.1			-115.1			-112.1			-110.1			-107.1			-105.1			7
8	Type of receiving antenna		3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	35.7			29.7			35.7			29.7			35.7			29.7			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	5			-1			5			-1			5			-1			11
12	Required flux (99% time)	dBW/m^2	-122.1			-114.1			-117.1			-109.1			-112.1			-104.1			12
13	Equivalent field strength	dBu	23.9			31.9			28.9			36.9			33.9			41.9			13
		uV/m	16			39			28			70			50			125			
14	Free space attenuation between isotropic sources 39000 km apart	dB	192			192			192			192			192			192			14
15	Total atmospheric attenuation ** exceeded for less then 1% of the time	dB	0.4			0.4			0.4			0.4			0.4			0.4			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	41.3			49.3			46.3			54.3			51.3			59.3			16
		kW	13			85			43			269			135			850			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	5.7	7.2	10.6	13.7	15.2	18.6	10.7	12.2	15.6	18.7	20.2	23.6	15.7	17.2	20.6	23.7	25.2	28.6	22
		W	3.7	5.2	11	23	33	72	12	17	36	74	105	229	37	52	115	234	331	725	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES

FM TELEVISION SYSTEM PARAMETERS AT 2600 MHz

	Equivalent rectangular bandwidth 22 MHz (equivalent to 24 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	8.2						13.2						18.2						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth	dBW	-126.6			-124.6			-126.6			-124.6			-126.6			-124.6			6
7	Required carrier power	dBW	-118.4			-116.4			-113.4			-111.4			-108.4			-106.4			7
8	Type of receiving antenna		3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	35.7			29.7			35.7			29.7			35.7			29.7			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	5			-1			5			-1			5			-1			11
12	Required flux (99% time)	dBW/m^2	-123.4			-115.4			-118.4			-110.4			-113.4			-105.4			12
13	Equivalent field strength	dBu	22.6			30.6			27.6			35.6			32.6			40.6			13
		uV/m	13			34			24			60			43			107			
14	Free space attenuation between isotropic sources 39000 km apart	dB	192			192			192			192			192			192			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0.4			0.4			0.4			0.4			0.4			0.4			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	40			48			45			53			50			58			16
		kW	11			72			36			229			115			725			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	4.4	5.9	9.3	12.4	13.9	17.3	9.4	10.9	14.3	17.4	18.9	22.3	14.4	15.9	19.3	22.4	23.9	27.3	22
		W	2.8	3.9	8.5	17	25	54	8.7	12	27	55	78	170	28	39	85	174	246	537	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1 m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES

AM/VSB TELEVISION SYSTEM PARAMETERS AT 2600 MHz

	Equivalent rectangular bandwidth 4 MHz (equivalent to 6 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	35						40						45						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	36						41						46						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-134			-132			-134			-132			-134			-132			6
7	Required carrier power	dBW	-98			-96			-93			-91			-88			-86			7
8	Type of receiving antenna		3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			3m paraboloid			1.5m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	35.7			29.7			35.7			29.7			35.7			29.7			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	5			-1			5			-1			5			-1			11
12	Required flux (99% time)	dBW/m^2	-103			-95			-98			-90			-93			-85			12
13	Equivalent field strength	dBu	43			51			48			56			53			61			13
		uV/m	141			315			250			630			447			1120			
14	Free space attenuation between isotropic sources 39000 km apart	dB	192			192			192			192			192			192			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	0.4			0.4			0.4			0.4			0.4			0.4			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	60.4			68.4			65.4			73.4			70.4			78.4			16
		kW	1100			6920			3470			21900			11000			69200			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	4.8	4.0	2.7	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	24.8	26.3	29.7	32.8	34.3	37.7	29.8	31.3	34.7	37.8	39.3	42.7	34.8	36.3	39.7	42.8	44.3	47.7	22
		W	302	426	933	1900	2690	5880	955	1350	2950	6020	8500	18600	3020	4260	9330	19100	26900	58900	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

APPENDIX III-a

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 12000 MHz

	Equivalent rectangular bandwidth 16 MHz (equivalent to 18 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	14.6						19.6						24.6						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-128.0			-126.0			-128.0			-126.0			-128.0			-126.0			6
7	Required carrier power	dBW	-113.4			-111.4			-108.4			-106.4			-103.4			-101.4			7
8	Type of receiving antenna		1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	43.9			39.2			43.9			39.2			43.9			39.2			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m² *	dB	-1			-5.7			-1			-5.7			-1			-5.7			11
12	Required flux (99% time)	dBW/m²	-112.4			-105.7			-107.4			-100.7			-102.4			-95.7			12
13	Equivalent field strength	dBu	33.6			40.3			38.6			45.3			43.6			50.3			13
		uV/m	48			104			85			184			151			327			
14	Free space attenuation between isotropic sources 39000 km apart	dB	206			206			206			206			206			206			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	2.2			2.2			2.2			2.2			2.2			2.2			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	52.8			59.5			57.8			64.5			62.8			69.5			16
		kW	190			890			603			2820			1900			8900			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	17.2	18.7	22.1	23.9	25.4	28.8	22.2	23.7	27.1	28.9	30.4	33.8	27.2	28.7	32.1	33.9	35.4	38.8	22
		W	52	74	162	245	347	758	166	234	513	775	1100	2400	525	740	1620	2450	3470	7580	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to 1m² includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES

FM TELEVISION SYSTEM PARAMETERS AT 12000 MHz

	Equivalent rectangular bandwidth 18 MHz (equivalent to 20 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	12						17						22						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-127.4			-125.4			-127.4			-125.4			-127.4			-125.4			6
7	Required carrier power	dBW	-115.4			-113.4			-110.4			-108.4			-105.4			-103.4			7
8	Type of receiving antenna		1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	43.9			39.2			43.9			39.2			43.9			39.2			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	-1			-5.7			-1			-5.7			-1			-5.7			11
12	Required flux (99% time)	dBW/m^2	-114.4			-107.7			-109.4			-102.7			-104.4			-97.7			12
13	Equivalent field strength	dBu	31.6			38.3			36.6			43.3			41.6			48.3			13
		uV/m	38			82			68			146			120			260			
14	Free space attenuation between isotropic sources 39000 km apart	dB	206			206			206			206			206			206			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	2.2			2.2			2.2			2.2			2.2			2.2			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	50.8			57.5			55.8			62.5			60.8			67.5			16
		kW	120			562			380			1780			1200			5620			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	15.2	16.7	20.1	21.9	23.4	26.8	20.2	21.7	25.1	26.9	28.4	31.8	25.2	26.7	30.1	31.9	33.4	36.8	22
		W	33	47	102	155	219	478	105	148	323	490	692	1510	331	468	1020	1550	2190	4780	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 12000 MHz

	Equivalent rectangular bandwidth 20 MHz (equivalent to 22 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	9.9						14.9						19.9						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth	dBW	-127.0			-125.0			-127.0			-125.0			-127.0			-125.0			6
7	Required carrier power	dBW	-117.1			-115.1			-112.1			-110.1			-107.1			-105.1			7
8	Type of receiving antenna		1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	43.9			39.2			43.9			39.2			43.9			39.2			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	-1			-5.7			-1			-5.7			-1			-5.7			11
12	Required flux (99% time)	dBW/m^2	-116.1			-109.4			-111.1			-104.4			-106.1			-99.4			12
13	Equivalent field strength	dBu	29.9			36.6			34.9			41.6			39.9			46.6			13
		uV/m	31			68			56			120			99			214			
14	Free space attenuation between isotropic sources 39000 km apart	dB	206			206			206			206			206			206			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	2.2			2.2			2.2			2.2			2.2			2.2			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	49.1			55.8			54.1			60.8			59.1			65.8			16
		kW	81			380			257			1200			812			3800			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	13.5	15.0	18.4	20.2	21.7	25.1	18.5	20.0	23.4	25.2	26.7	30.1	23.5	25.0	28.4	30.2	31.7	35.1	22
		W	22	32	69	105	148	324	71	100	219	331	468	1020	224	316	692	1050	1480	3240	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
FM TELEVISION SYSTEM PARAMETERS AT 12000 MHz

Equivalent rectangular bandwidth 22 MHz (equivalent to 24 MHz total channel bandwidth)

1	S/N (luminance signal to r.m.s. weighted noise)	dB	40						45						50						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	8.2						13.2						18.2						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-126.6			-124.6			-126.6			-124.6			-126.6			-124.6			6
7	Required carrier power	dBW	-118.4			-116.4			-113.4			-111.4			-108.4			-106.4			7
8	Type of receiving antenna		1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	43.9			39.2			43.9			39.2			43.9			39.2			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	-1			-5.7			-1			-5.7			-1			-5.7			11
12	Required flux (99% time)	dBW/m^2	-117.4			-110.7			-112.4			-105.7			-107.4			-100.7			12
13	Equivalent field strength	dBu	28.6			35.3			33.6			40.3			38.6			45.3			13
		uV/m	27			58			48			104			85			184			
14	Free space attenuation between isotropic sources 39000 km apart	dB	206			206			206			206			206			206			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	2.2			2.2			2.2			2.2			2.2			2.2			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	47.8			54.5			52.8			59.5			57.8			64.5			16
		kW	60			282			190			890			603			2820			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	12.2	13.7	17.1	18.9	20.4	23.8	17.2	18.7	22.1	23.9	25.4	28.8	22.2	23.7	27.1	28.9	30.4	33.8	22
		W	17	23	51	78	110	240	52	74	162	245	347	758	166	234	513	775	1100	2400	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

BROADCASTING FROM SATELLITES
AM/VSB TELEVISION SYSTEM PARAMETERS AT 12000 MHz

	Equivalent rectangular bandwidth 4 MHz (equivalent to 6 MHz total channel bandwidth)																				
1	S/N (luminance signal to r.m.s. weighted noise)	dB	35						40						45						1
2	C/N before demodulation (exceeded for 99% of the time)	dB	36						41						46						2
3	Type of reception		Community			Individual			Community			Individual			Community			Individual			3
4	Receiver noise factor	dB	4			6			4			6			4			6			4
5	Corresponding noise temperature	°K	725			1160			725			1160			725			1160			5
6	Noise power in equiv. rect. bandwidth)	dBW	-134			-132			-134			-132			-134			-132			6
7	Required carrier power	dBW	-98			-96			-93			-91			-88			-86			7
8	Type of receiving antenna		1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			1.7m paraboloid			1m paraboloid			8
9	Rx. antenna gain above isotropic (55% effective)	dB	43.9			39.2			43.9			39.2			43.9			39.2			9
10	Misc. receiver losses *	dB	1			1			1			1			1			1			10
11	Effective ant. area rel. to 1 m^2 *	dB	-1			-5.7			-1			-5.7			-1			-5.7			11
12	Required flux (99% time)	dBW/m^2	-97			-90.3			-92			-85.3			-87			-80.3			12
13	Equivalent field strength	dBu	49			55.7			54			60.7			59			65.7			13
		uV/m	282			610			500			1080			890			1930			
14	Free space attenuation between isotropic sources 39000 km apart	dB	206			206			206			206			206			206			14
15	Total atmospheric attenuation ** exceeded for less than 1% of the time	dB	2.2			2.2			2.2			2.2			2.2			2.2			15
16	Required e.i.r.p. from satellite (at edge of beam)	dBW	68.2			74.9			73.2			79.9			78.2			84.9			16
		kW	6600			30900			20900			97800			66000			309000			
17	Sat. antenna beamwidth	°	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	1.7	2	3	17
18	Sat. antenna diameter	m	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	1.04	.88	.58	18
19	Earth coverage diameter	mi	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	660	780	1170	19
20	Sat. ant. gain (beam edge)(55% eff.)	dB	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	36.6	35.1	31.7	20
21	Sat. filter and feeder losses etc.	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
22	Sat. transmitter power	dBW	32.6	34.1	37.5	39.3	40.8	44.2	37.6	39.1	42.5	44.3	45.8	49.2	42.6	44.1	47.5	49.3	50.8	54.2	22
		W	1820	2570	5620	8500	12000	26300	5750	8130	17800	26900	38000	83200	18200	25700	56200	85000	120000	263000	

* Circularly polarized antennae are assumed at both the transmitting and receiving ends. The losses in this item include ellipticity losses due to antenna imperfections, movement of the supporting structure, etc., and perturbations of the satellite position. The effective antenna area relative to $1m^2$ includes the miscellaneous losses.

** See reference (6).

COMPARISON OF CONCLUSIONS*

Types of reception	Frequency band	F M		A M	
		Sharing feasibility	Estimated number of independent programs	Sharing feasibility	Estimated number of independent programs
Community	614-890 MHz shared	extremely difficult to achieve (see § 2.1 a)	8 - 26	not feasible	nil
	exclusive 100 MHz between 614 and 890 MHz	NA	3 - 10	NA	8
	2548-2686 MHz shared	relatively easy to achieve (see § 2.1 a)	9 - 27	not feasible	nil
	exclusive 138 MHz band between 2548 and 2686 MHz	NA	9 - 27	NA	12 - 23
	11700-12200 MHz exclusive	NA	68 - 220	NA	42 - 125
Individual	614-890 MHz shared	not feasible	nil	not feasible	nil
	exclusive 100 MHz band between 614 and 890 MHz	NA	2 - 5	NA	8
	2548-2686 MHz shared	somewhat difficult to achieve (see § 2.1 c)	5 - 18	not feasible	nil
	exclusive 138 MHz between 2548-2686 MHz	NA	5 - 18	NA	12 - 23
	11700-12200 MHz exclusive	NA	42 - 132	NA	42 - 83

* sharing feasibility in the band 11700 - 12200 MHz was not studied

APPENDIX 2

PROPAGATION AND ANTENNA NOISE CONSIDERATIONS IN THE DESIGN OF SATELLITE BROADCASTING SYSTEMS

PROPAGATION AND ANTENNA NOISE CONSIDERATIONS
IN THE DESIGN OF
SATELLITE BROADCASTING SYSTEMS

B.C. BLEVIS

1. INTRODUCTION

This report presents a preliminary discussion of propagation and noise factors affecting the design of satellite broadcasting systems intended for operation at frequencies of 0.8, 2.5 and 12 GHz. It considers attenuation and noise contributions due to absorption and scattering by atmospheric gases and hydrometeors as well as noise received by the antenna from discrete sources and in the sidelobes due to emission from the warm earth. It does not consider any effects which may occur as the result of using a radome. Neither is it concerned with those factors, such as forward scattering from precipitation, transhorizon propagation by partial reflection, turbulent scattering or ducting, which may affect the sharing of frequencies between different services if such sharing is found necessary.

Unfortunately, little is known of what effects the occurrence of turbulent irregularities or elevated layers may have on the fading of signals at low elevation angles. While there is general concurrence that such effects will not be significant at elevation angles much greater than about 5^{o}, there is evidence of the occasional occurrence of peak signal deviations from the mean of the order of 2 dB at 7 GHz for elevation angles of about 5 degrees.

2. GASEOUS ABSORPTION

The zenith attenuation due to oxygen and water vapour has been calculated [1] as a function of frequency using the U.S. Standard Atmosphere for July at latitude 45^{o}N, and recent values of the line breadth constants for oxygen and water vapour. These data may be used to derive the attenuation for other elevation angles by multiplying by the secant of the zenith angle. This approximation has been shown to be valid to an accuracy of better than 1% for zenith angles less than 85^{o} and for an atmosphere associated with an effective earth's radius of 4/3[2].

Derived values of total gaseous absorption through the atmosphere are given in dB in the following table for 12 and 2.5 GHz as a function of elevation angle.

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f GHz	elevation angle 90°	30°	10°	5°
12	0.06	0.12	0.35	0.69
2.5	0.035	0.07	0.20	0.40

The values for an elevation angle of 5° are in substantial agreement with values obtained using the method of Holzer [3], although they are somewhat less than those proposed by Benoit [4].

3. ATTENUATION IN CLOUD OR FOG

The attenuation coefficient of cloud and fog can be obtained easily from theoretical considerations and is simply proportional to the liquid water content (since the particle size is small compared to the wavelength for all frequencies of interest). However, little is known statistically of the horizontal and vertical extent of clouds of given water content and their occurrence.

For calculations of attenuation due to cloud, Holzer [3] has assumed, as a worst case for temperate latitudes, a frontal zone cloud cover having a liquid water content of 0.3 g/m^3 and 6 km vertical extent. On this basis, the attenuation at an elevation angle of 5° can be shown to be approximately 2.7 dB and 0.2 dB at frequencies of 12 GHz and 2.5 GHz respectively. The corresponding figures for an elevation angle of 10° are 1.4 and 0.1 dB.

On the other hand, observations made near Boston [5] of the absorption of solar radiation during the winter of 1967 and the spring and summer of 1968 showed that, during the occurrence of cumulus and cumulonimbus cloud along the path, the attenuation lay between 0.2 and 0.6 dB for 97% of the time at 15 GHz and between 0.15 and 0.25 dB for 97% of the time at 8 GHz. Attenuations observed during the occurrence of other types of clouds were significantly less. On this basis, it is concluded that an allowance of 1.0 dB and 0.1 dB for attenuation in cloud at 12 GHz and 2.5 GHz respectively should be more than adequate for elevation angles greater than about 5° taking into consideration the percentages of the time involved.

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It has been assumed frequently that this margin should be added to that obtained for precipitation and gaseous absorption in order to obtain an overall allowance for atmospheric effects. There seems to be no particularly valid reason for this, and certainly this margin may be accommodated by the greater margin generally assumed for rainfall. In particular, if the system margin for rainfall can be derived from direct measurements of attenuation, the effects of cloud which occurs simultaneously will be included.

It should be noted that, at these frequencies, attenuation due to ice cloud will be about two orders of magnitude less than that due to water cloud of equivalent water content.

4. ATTENUATION DUE TO PRECIPITATION

There is a notable lack of information on attenuation due to precipitation which has been obtained from direct measurements along elevated paths. Such information would be useful in deriving figures for the attenuation expected to be exceeded for a given percentage of the time at any given frequency and elevation angle. In fact, only three such studies have been uncovered. Other studies have postulated coarse models or used meteorological or weather radar data to derive these figures. Unfortunately, even aside from the variation from year to year, with elevation angle and frequency, and with climatology, there appears to be no consistency among the various studies.

The most extensive of the studies involving direct measurement of the attenuation due to precipitation is that carried out in Japan [6,7] at three frequencies, 9.4, 11.8 and 17 GHz, using solar radiometers. The studies covered a four-year period, from 1965 to 1968 inclusive, at 9.4 GHz. The data at 11.8 and 17 GHz were for 1968. All data were normalized to an elevation angle of 45°. A similar study, involving daytime measurements of the attenuation of solar radiation and nighttime measurements of atmospheric noise temperature, was carried out in New Jersey [8] during 1968 at 16 and 30 GHz. At Ottawa, observations were made during the summer of 1967 at 7.3 GHz, for elevation angles between 10° and 20° using beacons on the DCSP satellites [9].

Among the studies of attenuation statistics involving models of precipitation based on meteorological considerations, there are a number of particular interest including those by LeFande [10], Holzer [3], Benoit [4] and the Air Weather Service, MATS [11]. An extensive study has also been carried out in the USSR [12], but insufficient information is available to permit adequate interpretation of the data.

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Studies by Austin [13] and Rogers and Rao [14] have used backscatter data obtained from weather radars to derive attenuation statistics but these studies have also involved a number of assumptions to obtain a precipitation model.

Of course, the phenomenon, and therefore the appropriate model, changes depending on the percentage of time of specific interest. For example, for very small percentages of the time, such as 0.01%, it would be expected that, at least in Canada, precipitation during thunderstorms would be of greatest interest and that the variation of attenuation with elevation angle would be less than that for greater percentages of the time when precipitation from stratiform cloud would be more significant.

It seems appropriate to try to relate attenuation statistics to climatology, and therefore to be able to extrapolate data obtained for one location to any other, by correlating the attenuation information with some generally available meteorological parameter. It is suggested that, depending on the percentages of the time involved, some correlation might exist between the attenuation at any given frequency and the number of thunderstorm days or the total annual rainfall divided by the number of days of measurable precipitation. However, the amount of data available is clearly insufficient to attempt such a correlation.

In analyzing the available information, the various data were first related to a single frequency, in this case 12 GHz, for the purpose of removing at least one variable in the rationalization of the data. This was done by making assumptions on the rainfall rates corresponding to the various percentages of the time being considered. These assumptions can be justified since the purpose is only to establish the form of the dependence of attenuation on frequency, a relation which changes only slowly with rainfall rate.

In this way, the data obtained in New Jersey at 16 and 30 GHz during 1968 indicate that at 12 GHz an attenuation due to rainfall of 2.6 dB would be expected for 0.1% of the time for all elevation angles between 26° and 73°. The Japanese data, normalized to an elevation angle of 45°, give values for 0.1% of the time at 12 GHz of between 1.1 and 3.8 dB. The Ottawa data, which were obtained at 7.3 GHz during 1967 at elevation angles between about 10° and 20°, result in a value of attenuation of 1.8 dB at 12 GHz for 0.1% of the time.

The model studies have by and large given values much in excess of those above. For example, the model corresponding to 0.1% of the time, proposed by LeFande, yields a value of 5.7 dB at 12 GHz for an elevation angle of 5°, and that used by Holzer, and adopted by Benoit, but using instead the dependence of attenuation on rainfall rate due to Medhurst [15], predicts values of 3.5 dB and 6 dB at 5° elevation angle for Paris and Washington, respectively.

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While the model studies are informative, one must necessarily apply more weight to those few direct measurements which have indeed been made. Furthermore, the climatology of much of Canada is such that the attenuations corresponding to small percentages of the time might be rather less than those derived for Washington.

On the basis of this discussion, it is concluded that a value of 3 dB would provide a more than adequate margin for rainfall for 0.1% of the time at a frequency of 12 GHz and an elevation angle of 5° for most locations in Canada. Furthermore, it should be noted that, while higher values of attenuation may be expected to be encountered for 0.1% of the time at a few locations in Canada where the total annual precipitation is significantly greater than at Ottawa, lower values would apply generally throughout the Canadian north, where elevation angles would be also generally lower than elsewhere except perhaps for the east coast (depending on the location of the satellite).

For attenuations corresponding to 0.01% of the time (53 minutes per year), the situation is rather more difficult. For the very small percentages of the time, it is expected that, for Canada at least, the precipitation during thunderstorms is of greatest interest. As a result, the variation from year to year and from location to location would be considerably greater than that for larger percentages of the time. In fact, studies at Montreal [14] using weather radar data show a large variation with azimuth of the attenuation expected for 0.01% of any year.

Referring to the studies described above, the three-frequency data obtained in Japan indicate an average attenuation of between 7 and 8 dB for 0.01% of the time at 12 GHz, except that, over the four-year period from 1965 to 1968 inclusive, a variation of from 5 to 11 dB was obtained. The 7.3 GHz data for Ottawa give a corresponding value of less than 4 dB, but did not include thunderstorms. The New Jersey data for 1968 give a value of about 14 dB at 12 GHz.

In connection with the model studies, the model used by LeFande corresponding to 0.01% of the time would suggest an attenuation of between 9 and 16 dB depending on the elevation angle. The model used in the analysis of the weather radar data at Montreal give, for an elevation angle of 10°, a value between 20 and 35 dB depending on the azimuth. These values may be in doubt because of difficulties associated with the absolute calibration of the radar and enhanced backscatter from hail.

If the interpretation of the data in terms of convective rainfall is valid, it would be expected that any system margin determined for Ottawa or

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Montreal would be more than sufficient for virtually all of the rest of Canada. The choice of an actual value, for the attenuation to be expected for 0.01% of the time at an elevation angle of 5^{o}, however, remains somewhat arbitrary. In the absence of more complete information, a value of 10 dB appears reasonable. This would correspond to negligible attenuation at 2.5 GHz.

It is worthwhile mentioning, at this point, the experience of CRC that, during periods for which the rainfall attenuation might be expected to be greatest, it is not rare to have a complete loss of primary power from the rural mains.

For 1.0% of the time, the direct measurements made in New Hersey for elevation angles between 26^{o} and 73^{o} give a value of about 0.5 dB attenuation at 12 GHz. The Japanese data at 45^{o} elevation support a value of between 0.8 and 2 dB. The model used by LeFande gives a value of 1.5 dB at an elevation angle of 5^{o} or 0.2 dB at 90^{o}. Since the attenuation expected for 1% of the time is expected to vary with elevation angle according to some relation approaching the normal secant law for zenith angles less than 85^{o}, and model studies may be more easily justified, a value of 1.5 dB for 1% of the time at 12 GHz and an elevation angle of 5^{o} is suggested. No margin would be required for the other frequencies considered.

4. ANTENNA NOISE TEMPERATURE

In determining the antenna noise temperature contribution to the overall noise temperature of a receiving system, it is necessary to consider a number of sources. The principal contribution is due to atmospheric absorption and reradiation into the main beam of the antenna. Additional contributions result from atmospheric radiation into the side lobes and energy radiated into the side and back lobes from the warm earth. Sky radiation reflected by the ground into the side and back lobes is considered to be negligible when systems with all but the lowest noise temperatures are considered.

The antenna noise temperature is obtained by multiplying the effective noise temperature as a function of direction by the normalized antenna radiation pattern and integrating over a complete sphere. For convenience, and well within the accuracy required, a simplified antenna radiation pattern is generally assumed. For example, it is possible for most large Cassegrain antennas to assume four beam regions [16] with the relative power responses as follows:

Main lobe	0.70
Side lobes, $0-3^{o}$	0.23
Side lobes, $3-7^{o}$	0.05
Side lobes, $7-180^{o}$	0.02

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The beam regions, other than the main lobe, may be divided into a number of segments appropriate to the variation of the noise temperature with elevation angle. It will be assumed [17] that side lobes at elevation angles less than -10° see a temperature of 290°K and at elevation angles between -10° and 0° a temperature of 150°K. (This essentially means that the contribution to the antenna noise temperature for all elevation angles below the horizon is independent of frequency and equal to about 5°K). Above the horizon, the sky noise temperature is that due to an absorbing medium (including atmospheric gases and precipitation) assumed to be of finite thickness and having a mean radiating temperature, T_r $^{\circ}$K, which is a function of the elevation angle. The sky noise temperature is then given by

$$T_b = (1 - 1/L)T_r$$

where L is the power loss factor of the absorbing medium.

For an elevation angle of 5°, in the absence of rain, the antenna noise temperature is then calculated to be approximately 49°K at 12 GHz, and 28°K at 2.5 GHz.

In the presence of rain or cloud, the absorption by the rain or cloud must be added to the absorption by atmospheric gases in order to determine the sky noise temperature as a function of angle (and therefore the antenna noise temperature). When the attenuation due to rain or cloud is much greater than that due to atmospheric gases, and for elevation angles of about 5° or more, an approximation can be made. Within the accuracy required for the present purposes, it will be sufficient to assume that the power response of the antenna is confined to the main beam. The antenna noise temperature in $^{\circ}$K is then simply

$$(1 - 1/L)290 + 5$$

where L is the combined loss factor due to absorption by atmospheric gases and liquid water. The constant term is an approximate correction for the contribution from all angles below the horizon.

The additional noise temperature contribution from losses in the waveguide connecting the antenna to the reciver is not considered here.

5. NOISE CONTRIBUTIONS FROM DISCRETE SOURCES AND THE COSMIC BACKGROUND

Discrete sources, such as the more intense radio stars, the sun and the moon, may also contribute to the antenna noise temperature. However, the discrete sources are distributed over the celestial sphere and have small angular dimensions. They are therefore only rarely intercepted by the main beam of the antenna and, with the exception of the sun, which has a relatively

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high equivalent noise temperature, will not be considered further.

The apparent temperature of the quiet sun (brightness temperature, T_b) varies from about 1.2×10^4 °K at 12 GHz to about 5×10^4 °K at 2.5 GHz and 3×10^5 °K at 800 MHz. The antenna noise which results from the sun in the main beam is given approximately by:

$$T_a = T_b/L \qquad \text{for } \Omega \leq \omega$$

$$T_a = (\omega/\Omega)\ (T_b/L) \qquad \text{for } \omega < \Omega$$

where Ω (= $4\pi/G$) is the solid angle occupied by the main beam and ω is the solid angle subtended by the sun, of angular width 0.5°. Thus, for an 8 ft receiving antenna at 12 GHz and an elevation angle of 5° (L = 1.17 for the clear sky) the maximum antenna noise contribution from the quiet sun in the main beam would be approximately 5000°K. However, the total duration of interference for a geostationary satellite would only be about 25 minutes per year (18) of which less than half would be at the maximum value. For a 10 ft receiving antenna at 2.5 GHz, the maximum contribution from the quiet sun would be approximately 1500°K, although the total duration of maximum interference would be about two hours per year. In both cases, the interference is divided between two daytime periods occurring near the equinoxes.

The effects of radio bursts and the slowly varying component of solar emission become increasingly important at the lower frequencies. At 2800 MHz an increase in solar noise, due to the slowly varying component, of a factor of 3 over the level of the quiet sun has been observed at sunspot maximum.

Noise due to the cosmic background radiation should be taken into consideration for the lowest frequencies. At 800 MHz, the contribution due to the cosmic background can reach 40°K for an antenna directed toward the galactic centre, although in general the value will be considerably lower. The background cosmic noise decreases as the reciprocal of the frequency raised to a power between about 2.3 and 2.8 and may be neglected in comparison with receiver noise at all frequencies much above 1 GHz.

6. MAN-MADE NOISE

The contribution to the antenna noise temperature due to man-made or, as it is frequently known, indigenous noise can be approximated by the expression:

$$\frac{1}{4\pi} \int_{2\pi\beta} G\ T_i\, d\Omega$$

for small β , where β is the maximum elevation angle from which indigenous noise is received (assumed here equal to 10 degrees or 0.174 radians), G is the gain factor of the antenna as a function of angle, T_i is the effective brightness temperature due to indigenous noise, and $d\Omega$ is an element of solid angle.

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If the gain factor and brightness temperature can be replaced by their average values over the region between the horizon and β, this expression can be simplified further to

$$\frac{\beta}{2} \; \overline{T_1} \; \overline{G}$$

There is however little information on which to base a value of the effective brightness temperature particularly at UHF frequencies and above. One continuing study [19], involving aerial and ground surveys of urban area, has concluded that, at these frequencies, the major source of man-made noise is automobile ignition.

At 950 MHz, the measurement showed an average (over 900 seconds) antenna noise temperature for urban noisy locations of about 3700 °K (for 90% of the time, the antenna noise temperature was less than 7200 °K) and for urban quiet locations of about 1200 °K. The latter figure should also provide some sort of an upper limit for the average antenna noise temperature for suburban residential areas. The above values were obtained with a corner reflector having a 10 dB gain (referred to a depole) directed horizontally at a height of 12 feet above ground. For an antenna having, on the average, a gain equivalent to that of an isotropic antenna over the region from which indigenous noise is received the corresponding values of antenna noise temperature would be somewhat less.

The average gain factor for a parabolic antenna intended for direct reception from a broadcast satellite, having an equivalent diameter of 10 feet (25 and 35 dB gain at 800 MHz and 2.5 GHz, respectively) and directed well away from the horizon, is approximately 0.3 at 800 MHz and 0.15 at 2500 MHz [20]. The average antenna noise contributions at 800 MHz due to indigenous noise under these circumstances would therefore be about 1100 °K for urban noisy locations and about 400 °K for urban quiet locations. For 10% of the time the antenna noise contributions due to indigenous noise for urban noisy locations could be as much as twice as great as the average value.

For many locations in Canada, however, receiving antennas would not necessarily be directed well away from the horizon as assumed in the calculations of average gain factor. Fortunately, where this occurs the density of automobiles would be expected to be correspondingly less and the values derived for the antenna noise contributions can be assumed therefore to include these locations as well.

No consideration is given here to any reduced effects of impulsive noise in an FM receiving system.

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Antenna noise temperatures due to man-made noise will be lower at 2.5 GHz than at 800 MHz by a factor of about ten. Man-made noise for rural locations is considered to be negligible at all frequencies above about 200 MHz.

7. CONCLUSIONS

In considering the propagation and noise factors affecting the design of satellite broadcasting systems for Canadian domestic service, it is assumed that operation at elevation angles of 5° will be required. While reliability of the order of 99.99% for virtually all receiver locations may represent a target for a sophisticated operational system, it is possible that a reliability of 99.9% may be acceptable, in which case the system margins at 12 GHz may be reduced considerably. It may even be possible, in the first instance, for a demonstration system to accept a reliability due to propagation effects for most locations of only 99% allowing a still further reduction in the system margin. Of course, whatever system margin is chosen, it is important to note that for most locations in Canada, because of climatology or elevation angles more favourable than those considered in this study, the reliability may be somewhat greater than indicated.

In respect to the attenuation and antenna noise contributions due to absorption by atmospheric gases, the margins necessary will be largely independent of the required reliability and will be as given in the following table which includes the effects of emission from the warm earth.

	Attenuation dB	Antenna Noise °K
12 GHz	0.7	49
2.5 GHz	0.4	28

For precipitation, the system margins required at 12 GHz for various percentages of any year, are as follows:

Percent of Time	12 GHz Margin dB
0.01%	10
0.1%	3
1.0%	1.5

No allowance for signal attenuation is necessary at the other frequencies.

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Combining the above, the following table gives, for 2.5 and 12 GHz, the proposed system margins in dB for propagation effects. These margins are necessary to achieve reliable operation for the indicated percentages of any year. The corresponding antenna noise temperatures in ^{o}K are also indicated.

	12 GHz		2.5 GHz	
	Margin dB	Noise Temp ^{o}K	Margin dB	Noise Temp ^{o}K
99.99%	10.7	270	0.4	30
99.9%	3.7	170	0.4	30
99%	2.2	120	0.4	30

At 800 MHz, the effects of atmospheric gases and condensed water can be neglected but cosmic background radiation will contribute a maximum of $40^{o}K$ to the antenna noise temperature for an antenna directed toward the galactic centre. It will also be necessary to consider at this frequency and at 2.5 GHz the effects of solar noise and of man-made noise, as indicated above, and of Faraday rotation if antennas of other than circular polarization are used.

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APPENDIX 3

ATMOSPHERIC FADING MARGINS FOR UHF AND SHF SATELLITE BROADCASTING SYSTEMS

ATMOSPHERIC FADING MARGINS FOR UHF AND SHF SATELLITE BROADCASTING SYSTEMS

by

L.A. Maynard and K.S. McCormick

1. INTRODUCTION

Consideration is being given to the potential use of UHF and SHF Satellite Communications and broadcasting to provide service to the Canadian North. In this region, low elevation angles must be employed by ground terminals operating in systems employing 24-hour synchronous satellites. At these low angles of elevation, the effects of tropospheric and ionospheric scattering become pronounced. An additional system margin must be provided to allow for the amplitude fading which results from these scattering phenomena.

This report discusses results derived from several experimental programs undertaken over the last several years in both Canada and the U.S.A., and have employed satellite systems over a broad frequency range from 136 to about 7300 MHz.

Figure 1 shows a north polar view of the earth. Superimposed on this view are the elevation angle contours from a geostationary satellite with a sub-orbital longitude of 90°. The coverage zone included in the 0 to 15 degree elevation angle interval is of obvious importance to Canada. This same region is, of course, a region that is most subject to ionospheric disturbances which affect the lower portion of the range of frequencies which may be used in satellite communications systems.

2. ATMOSPHERIC EFFECTS ON PROPAGATION

When radio waves propagate through the earth's atmosphere from satellite to the ground, interaction can occur in two regions: these are the ionosphere, and the troposphere. This interaction, in turn, can be divided into three categories. These are: (1) regular refraction

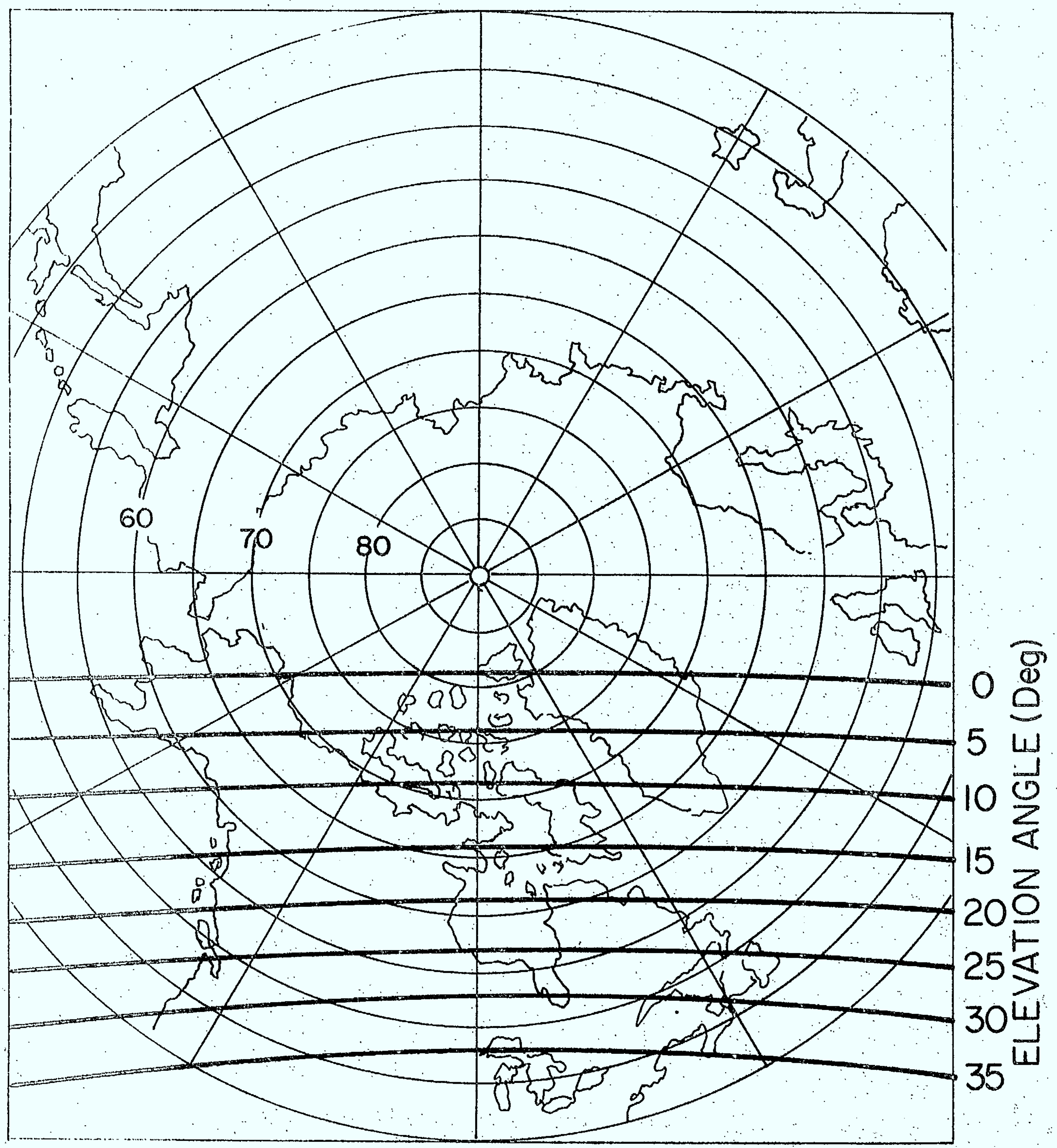


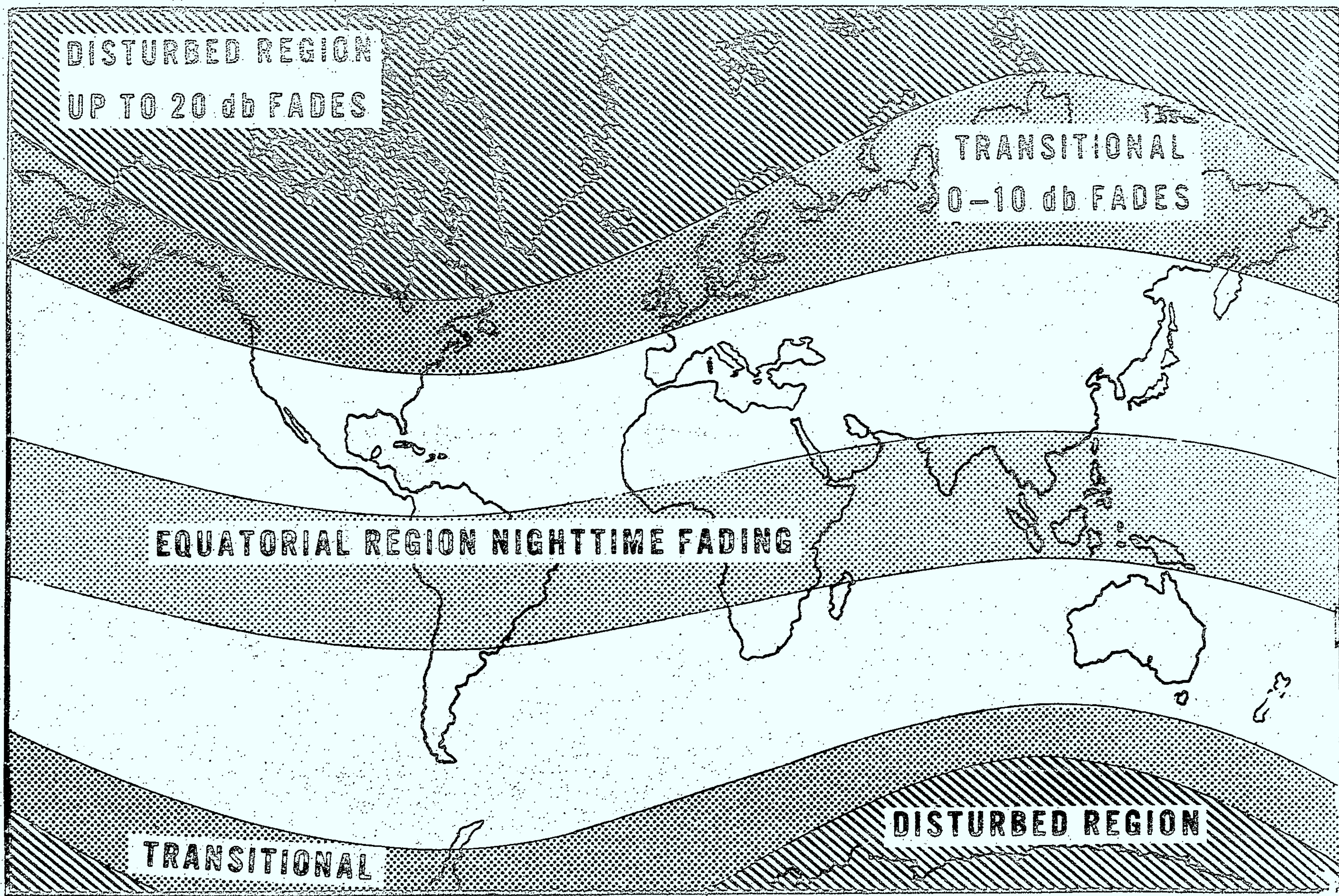
FIG. I

which gives rise to smooth bending of the radio waves passing through the region; (2) irregular refraction resulting in amplitude fluctuations of the received signals, and (3) attenuation of the signals.

Regular refraction results from a smooth variation with height of the refractive index in the atmosphere. This ray bending is almost always observed and generally results in an extension of the radio horizon and an associated increase in the coverage region of an earth satellite.

Irregular refraction, often associated with turbulence in the atmosphere, results in signal fading and is of primary concern in this paper.

The degree and type of interaction with the medium depends on frequency. At frequencies below a few hundred MHz, irregular structure in the troposphere has negligible effect, while irregularities in the ionosphere have pronounced effects. However, in the SHF range, the converse is true, in that ionospheric effects can be virtually ignored, while tropospheric effects, particularly at low elevation angles, become pronounced.



REGIONS OF DISTURBED UHF SATELLITE COMMUNICATIONS

FIG. 2

3. SIGNAL FADING MEASUREMENTS

3.1 Introduction

Canadian measurements of fading signals received from synchronous or near synchronous satellites have covered the frequency range between 136 MHz and 7300 MHz. Satellites employed in this program over the past three years have included the LES-5, the LES-6, the ATS-5, the DCSP Phase-I series, and the TACSATCOM-I satellite. The measurements have been made over a wide range of latitudes varying from Ottawa, (latitude 45°) up to Resolute Bay, N.W.T. (latitude 74°) and include experimental measurements at Churchill, Man., located near the visual auroral zone maximum.

At frequencies below about 1500 MHz, as pointed out previously, the ionosphere is the main cause of signal fading while above this frequency, signal fading is mainly due to tropospheric irregularities. The frequency range below 1500 MHz will be discussed first.

3.2 Frequencies Below 1500 MHz

Figure 2 shows the geographic distribution of regions associated with ionospheric fading at 250 MHz. The intensity of the ionospheric fading is related to the geomagnetic latitude of the region under consideration. This figure shows the region north of about 65° invariant latitude as a region that is subject to a large amount of ionospheric fading in the VHF/UHF frequency range. South of this area is a region that is termed transitional and it is here that ionospheric fading of a sporadic nature may occur. In addition to these polar regions of intense ionospheric fading there is a second region near the equator where the probability of ionospheric fading increases again. Much of the data published to the present time has been confined to the regions of low amplitude ionospheric fading or to the transitional region shown here. This published data, in general, indicates generally that system designers frequently specify inadequate margin allowances for communication systems used in the polar regions.

3.3 Auroral Effects

It has been generally assumed that auroral activity should have a significant effect on signals in the VHF and UHF range. Part of the experimental program at Churchill included an attempt to deduce such effects on the fading amplitudes of signals at these latitudes. Signal fading measurements using the LES-6 satellite were undertaken during periods in which visual auroral activity was observed at Churchill. The results of many measurements of the peak-to-peak fading amplitude as a function of visual aurora activity indicated that there is little or no direct relationship between high fading amplitude and the presence of visual aurora on the transmission path.

3.4 Frequencies above 1500 MHz

At frequencies in excess of 1000 to 2000 MHz, the refractive index of the ionosphere rapidly approaches unity and the inhomogeneous ionospheric structures that affect propagation at lower frequencies become essentially transparent. In the upper SHF region, however, the effects of the troposphere become more and more pronounced, particularly at low elevation angles. In addition to this, absorption mechanisms associated with oxygen and water vapour becomes more significant.

Fig. 3 shows a signal amplitude recording of the beacon signal received from a DCSP-1 satellite over a period of about two days. The received frequency, in this case, was near 7300 MHz. Three phenomena are observed in this slide. The first is a decrease in signal level occurring at an elevation angle of about 15^{o}. This attenuation of approximately 1 dB is related to rainfall over the propagation path. Secondly, a decrease in the median level of the signal is noted as the elevation angle goes below 5^{o}. This is a result of the increasing length of the signal path through the absorbing atmosphere at low elevation angles. Finally, there is a rapid increase in the fading amplitude for elevation angles below about 5^{o}, associated with the turbulent structure of the troposphere along the transmission path.

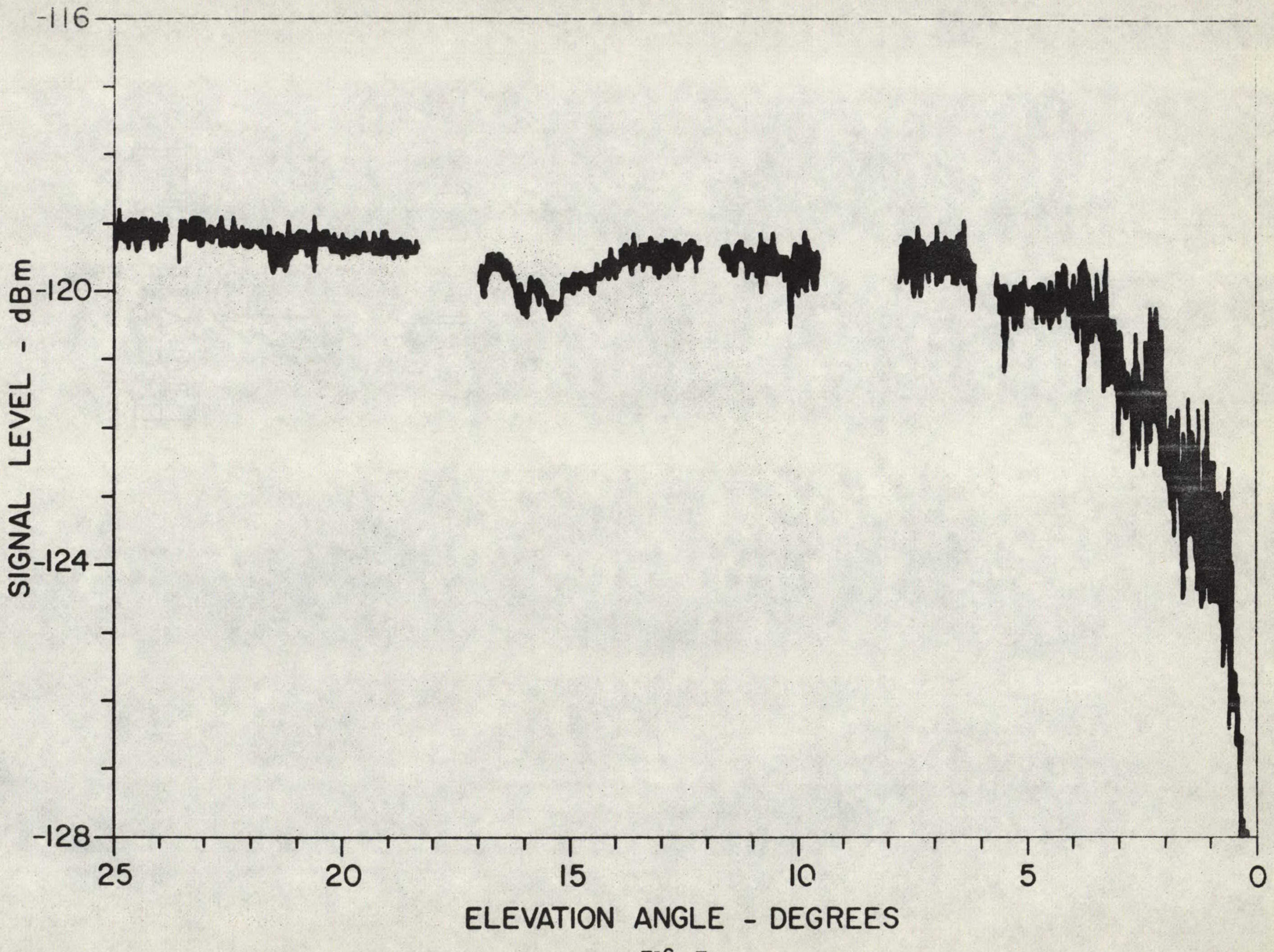

-116
-120
-124
-128
SIGNAL LEVEL - dBm
25
20
15
10
5
0
ELEVATION ANGLE - DEGREES

FIG. 3

4. REQUIRED SYSTEM MARGINS AT HIGH LATITUDES

Margin requirements, based on the results of these measurements can be deduced for the frequency range between 100 and 20,000 MHz. F^{-2} and F^{+1} frequency dependence laws were assumed for ionospheric and tropospheric scattering respectively. Figure 4 shows system margins required for 99% reliability as a function of both frequency and geographic latitude. Geographic latitudes from 40° to 80° are considered. An 80° latitude represents a 1° elevation angle for a geostationary satellite located directly south of a ground terminal. This data is based on information collected at several locations which include some of the AFCRL results at 136 MHz from Boston and data recorded at Canadian stations at Ottawa, Churchill and Resolute Bay. As stated previously, at frequencies below about 1500 MHz, the margins shown are mainly the result of ionospheric fading. It can be seen here that at 136 MHz, a margin of approximately 10 dB is required for a system operating at 75° latitude. At 40° latitude and the same frequency, a margin of approximately 5 dB is required for 99% propagation reliability. At higher frequencies and in the latitude range between 40 and 75 degrees, the margin requirements are seen to rise gradually, approaching something of the order of 3 dB at 12 GHz for 75° latitude. This margin includes atmospheric absorption due to water vapor and oxygen in addition to the margin associated with tropospheric fading. The effects of rainfall are not included in these curves but must be considered in the final analysis, particularly at frequencies above about 8 GHz.

At the extreme limits of the coverage zone, the margin requirements are large. From the curve shown for 80° latitude (which represents the latitude corresponding to the limit of coverage normally considered for geostationary satellites), the margin requirements at SHF are seen to increase rapidly with frequency. In these very high latitude regions, it can be seen that optimum frequencies (from a propagation point of view) occur in the 800 - 2000 MHz range. At lower latitudes, optimum frequencies cover a broad range from about 1 to 5 GHz or more.

Figure 5 shows a similar set of curves plotted for a 99.9% propagation reliability. Here, approximately the same conclusions are

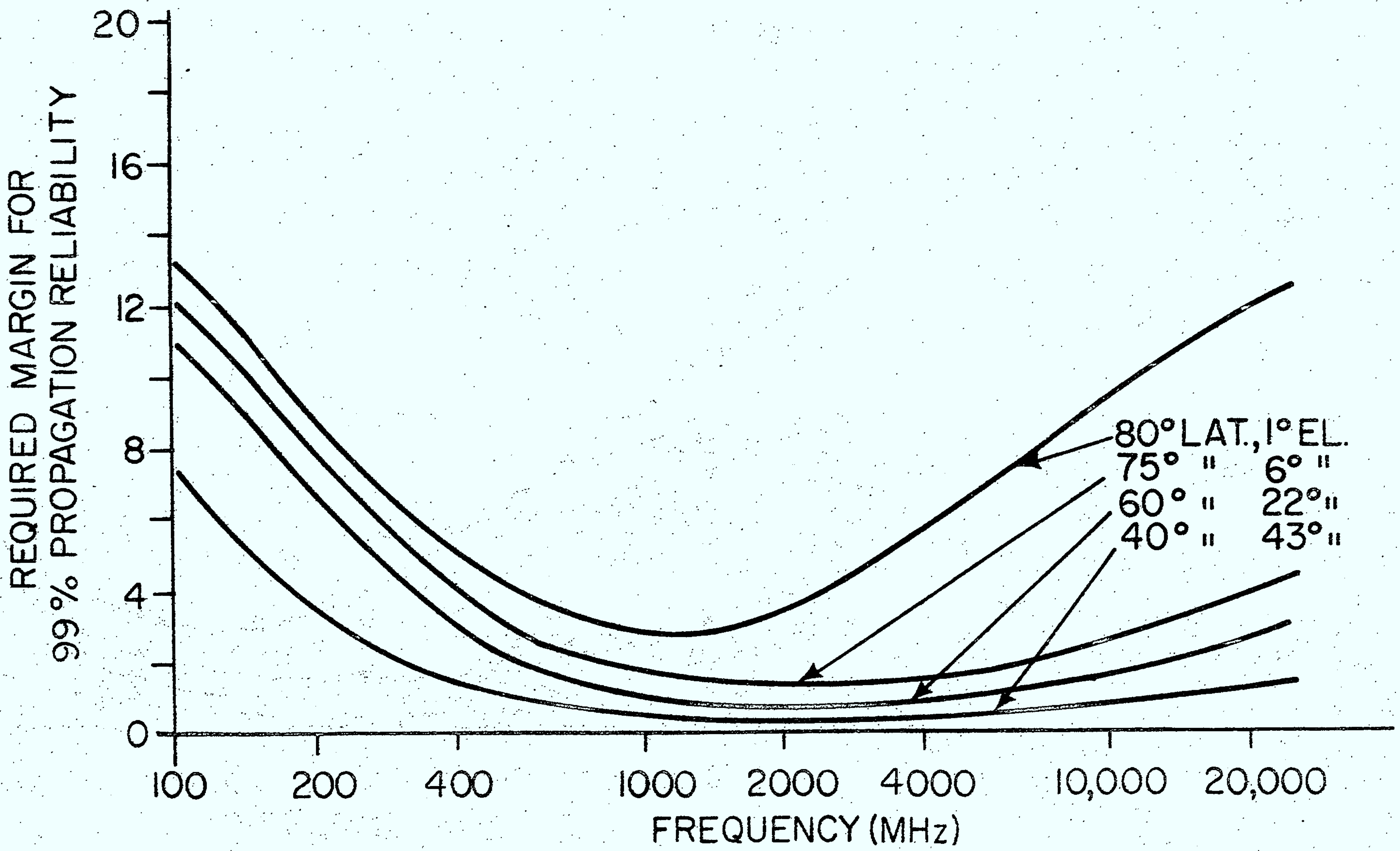
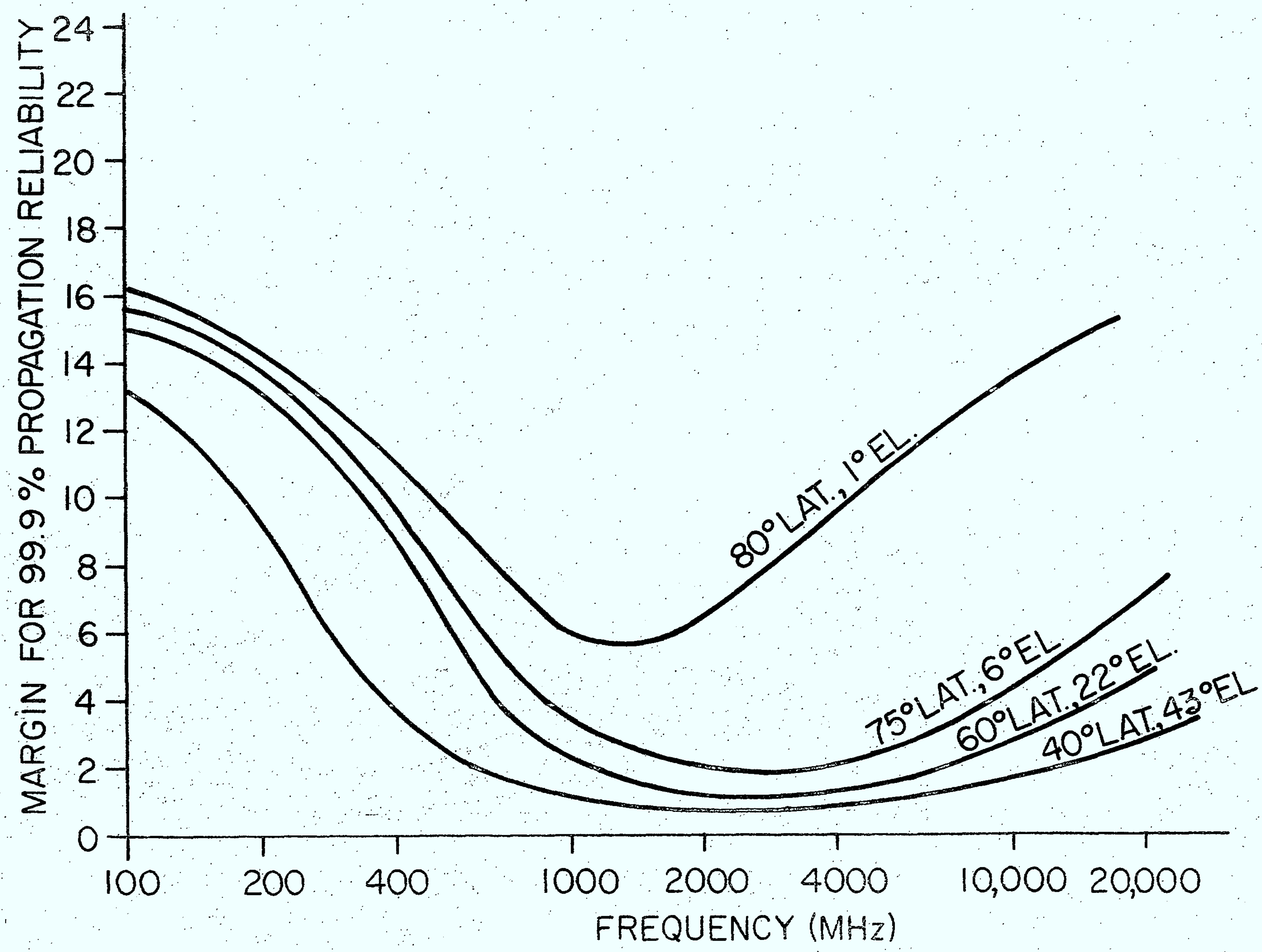

REQUIRED MARGIN FOR
99% PROPAGATION RELIABILITY
20
16
12
8
4
0
80° LAT., 1° EL.
75° " 6° "
60° " 22° "
40° " 43° "
100
200
400
1000
2000
4000
10,000
20,000
FREQUENCY (MHz)

FIG. 4



MARGIN FOR 99.9% PROPAGATION RELIABILITY
24
22
20
18
16
14
12
10
8
6
4
2
0
80° LAT., 1° EL.
75° LAT., 6° EL
60° LAT., 22° EL.
40° LAT., 43° EL
100
200
400
1000
2000
4000
10,000
20,000
FREQUENCY (MHz)

FIG. 5

reached except that in all cases, the required margins are considerably larger. For example, the margins required at 8 GHz at 80° latitude approach 12 dB.

5. SUMMARY AND CONCLUSIONS

1. At low elevation angles, such as are encountered in the high latitude regions of the earth's surface, systems employing geostationary satellites suffer from ionospheric and tropospheric fading. This fading necessitates system margin allowances that become quite large at the extreme limits of the coverage zone. For 99.9% propagation reliability in the lower VHF range, fairly large margins (of the order of 12-16 decibels) are required. The required margin decreases rapidly with increasing frequency until tropospheric rading becomes important.

2. Visual aurora activity appears to have negligible additional effects on signal fading in the VHF/UHF range.

3. SHF frequencies require smaller margins over a broad range of frequencies from 1000-10,000 MHz for all latitudes except at the extreme limits of the coverage zone where elevation angles fall below 5°.

APPENDIX 4

GROUND TERMINAL ANTENNA SYSTEM CONSIDERATIONS FOR SATELLITE TELEVISION BROADCASTING

GROUND TERMINAL ANTENNA SYSTEM CONSIDERATIONS
FOR SATELLITE TELEVISION BROADCASTING

by

L.A. Maynard

INTRODUCTION

In this note, ground terminal antenna systems will be considered in relation to the three general categories of satellite television broadcasting. These include (1) satellite broadcasting intended for direct to home reception, (2) community viewing, and (3) community reception and redistribution. Three frequency ranges will be considered in this study, namely 800 MHz, 2500 MHz and 12,000 MHz.

In each of the three major system categories considered above, it turns out that, to a first approximation, the required effective apertures for any of these services are more or less independent of frequency. In general, paraboloidal antenna diameters of about 8 to 15 feet for television reception and redistribution, 4 to 6 feet to community viewing and 2 to 4 feet for home reception are suitable. These represent near optimum sizes from a cost effectiveness point of view for each of these services.

EIRP AND ANTENNA SIZE CONSIDERATION

A large number of system analyses have been performed for television broadcasting from space. Some of these are included in the listing of references attached. Information relating to antenna size derived from systems analyses have been summarized in Fig. 1. This figure shows a plot of the required antenna diameter in feet as a function of the effective radiated power of the satellite. The results are categorized for systems with various weighted signal-to-noise ratios varying from 40 to 50 dB SNR. It can be seen here that for an assumed value of required weighted signal-to-noise ratio, a linear relationship between the logarithm of the required antenna diameter and the satellite effective radiated power appears to exist. This is not surprising in itself except that it is interesting to note that a large number of different workers appear to come up with remarkably similar relationships between antenna diameter and satellite EIRP.

In this paper, antenna system considerations will be based on the assumption of a 41 to 45 dB peak signal to weighted r.m.s. noise ratio requirement. Antenna systems can be directly scaled up or down if the final required signal noise ratio differs from this.

The straight line approximation for a 41-45 decibel SNR shown in Fig. 1 can be reinterpreted in terms of required gain of the antenna system for the various frequencies being considered, including the 800, 2500 and 12,000 MHz frequency bands. Figure 2 shows a plot of this required antenna gain and beamwidth based on a 43 dB weighted signa-to-noise ratio for these three frequencies. This figure shows a plot of the required satellite EIRP as a function of antenna gain in decibels. Three regions are considered here. Region A includes antennas with gains varying between 10 and 20 decibels. Region B includes antenna systems with gains varying from 20 to 44 decibels, and Region C includes antennas with gains in excess of 44 dB. The reasons for this apparently arbitrary division of antenna gain into these three regions will be discussed further below.

ANTENNA DESIGN

Some general statements can be made concerning the comparison of reflector type paraboloidal antenna with other antennas used for producing directive beams. At VHF frequencies and above, where directive beams become practical, the designer has a choice of many types of possible antennas, including end fire arrays, broadside arrays, corner reflector arrays, various other slow-wave structure antennas, and paraboloidal antennas. A common type of end-fire array, the Yagi antenna, can be designed to produce gains up to 18 to 20 decibels (Region A of Fig. 2) and perhaps a few dB more when grouped in arrays of two or more units. The Yagi antenna itself, however, has a relatively narrow bandwidth and, thus, has a somewhat limited range of application. A view of a circularly polarized Yagi antenna is shown in Fig. 3.

Broadside arrays can also be used at UHF and have the potential of producing greater gains than the end-fire arrays but achievable gains are generally limited by the number of elements required to produce gains equivalent to those of reflector type antenna. In the broadside array, at least four array elements must generally be placed in each square wavelength of aperture. Thus, the number of elements required to approximate the pattern of a reflector type system may be of the order of a few thousand at the higher SHF frequencies, and the feed system becomes unreasonably complex. Because of this, few array type antennas have been used at gains greater than about 30 dB. The helical antenna has similar capabilities to that of the Yagi and gains up to 20 decibels can be achieved with little difficulty. The helical antenna has the advantage of much broader bandwidth than the Yagi, and, from this point of view, when bandwidth becomes an important consideration, this antenna system does offer some potential advantage. Figure 4 shows a plot of antenna length in wavelengths as a function of antenna gain in decibels compared to a isotropic radiator. This curve shows this relationship for both Yagi and helical antenna types. For gains of the order of 20 decibels it can be seen that array lengths in excess of 6 wavelengths are required. At 800 MHz, Yagi or helical antenna lengths approach 8 feet. Figure 5 shows a typical helical antenna.

Two other potential contenders for low gain antenna systems include the orner reflector and the triangular dipole or bowtie antennas. These antennas are illustrated in Figs. 6 and 7. Gains of the order of 14 decibels are achievable using relatively simple corner reflector antenna designs. Similar gains can be achieved using bowtie type UHF antennas placed in front of a ground screen. Either of these are quite suitable for use in the UHF range and indeed, already find wide application in normal TV UHF broadcast reception. Circular polarization is assumed to be a requirement here.

Thus, the gain requirements represented by Region A of Fig. 2, (that is, antenna gains of the order of 10 to 20 decibels), can be achieved in a variety of ways and include parabolic antennas with diameters of a few feet or less, Yagi antennas with lengths ranging from 3 to 8 feet, helical antennas, bowtie type antennas, and corner reflectors. Careful economic studies would have to be made in order to assess the most cost effective antenna system for this frequency range.

Region B, covering the antenna gains from 20 decibels to 44 decibels, generally is a region for which the gain is difficult to achieve using many of the antenna system designs discussed above. It is this region for which required gains are best achieved by using the conventional parabolic antennas. The beamwidth of such antennas employing paraboloidal surfaces varies from about 15 degrees at the low gain end of the region down to about 1 degree at the upper end. This range of beamwidths represents an approximation to the physical stability that must be achieved by the mounting structure of an antenna system. It is generally accepted that the range from 1 to 15 degrees can be achieved using standard, rather simple physical mounting procedures. Region C which represents antenna beamwidths less than one degree is a region that is again best met by paraboloidal antenna systems, but is considered separately since physical mounting stability becomes an important consideration for antennas having these gains. In addition to this, of course, installation and orbit stability become a problem when physical alignment within a fraction of a degree must be achieved. It can be seen then that, broadcast systems with satellites of relatively low EIRP must be implemented with caution in the 12,000 MHz frequency range.

COST OF ANTENNA SYSTEMS

Shown in Table 1 is a tabulated comparison of the cost estimates given in two independent NASA reports. One was produced by the G.E. Co.(5) and the other by the T.R.W. System Group(4). There are also some results reported by other sources.

The G.E. antenna estimates were higher than the corresponding T.R.W. ones, but their converters and detection networks were lower. Aside from the G.E. antenna estimates for 2.5 GHz, which seem comparatively high, the totals for complete receiver systems agreed surprisingly well.

Other independent reports dealt with the manufacture of the receiving system in under-developed countries. Due to lower manufacturing and labor costs, estimates in this area were normally about one half of the corresponding G.E. and T.R.W. estimates.

Parabolic antennas were assumed in all cases except one, but no discussion was given as to the factors affecting the choice of antenna type.

Following are a few general comments in reference to these tables.

1. It appears both surprising and unrealistic that the antenna costs shown are independent of frequency. Extreme precision in manufacturing and mounting is required for antenna systems operating in the 12 GHz band.

2. The unit cost of antenna, converter, and detection systems shown here do not reflect the actual delivered and installed cost to the consumer. Present VHF and UHF terrestrial T.V. receiving antenna systems often cost up to $100.00 or more by the time they are installed. There is little doubt that the installation of a parabola and mount would cost considerably more than this. This is, of course, particularly true in the 12 GHz range, where mounting stabilities of the order of a fraction of a degree are necessary.

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10. C.C.I.R. Doc. IV/232 (Canada), Period 1966-1969.

11. Report of the Working Group on Direct Broadcast Satellites, U.N. Committee on Peaceful Uses of Outer Space, A/AC, 105/51, 26 February 1969.

TABLE I

RECEIVER COSTS

(Antenna only, no converter for 10^6 Production Quantities)

FREQ.	DIA.	COST ANTENNA	COST INSTALLATION	COST GE TOTAL	TRW SYSTEMS GROUP EST.	OTHERS (Refer).
.8 MHZ	2	$ 8.	$ 26.	$ 34.	$ --	$50.- 75. (3) (yagi array)
	4	13.	40.	53.	40.	
	6	24.	80.	104.	78.	
	10	63.	200.	263.	130.	$50. in India (1)
	15	160.	400.	560.	--	
2.5 MHZ	2	110.	26.	136.	--	
	4	130.	40.	170.	80.	
	6	200.	80.	280.	105.	$50. Brazil (2) (Duty Free)
	10	400.	200.	600.	230.	
	15	900.	400.	1300.	--	
2.4 GHZ	2	110.	26.	136.	163.	
	4	130.	40.	170.	180.	
	6	200.	80.	280.	220.	
	10	400.	200.	600.	430.	
	15	900.	400.	1300.	--	
12.2 GHZ	2	110.	26.	136.	190.	
	4	130.	40.	170.	210.	
	6	200.	80.	280.	265.	
	10	400.	200.	600.	710.	
	15	900.	400.	1300.	--	

CONVERTER & DETECTION COSTS

(for 10^6 Production Units)

NASA - G.E. & NASA - T.R.W.

FREQ.	PREAMP	A.M. COST		F.M. COST	
		NASA - G.E.	NASA - T.R.W.	NASA - G.E.	NASA - T.R.W.
.8 GHZ	None	$	$ 24.00	$ 9.00	$ 45.00
	Preamp	7.50	26.00	9.75	47.00
	Paramp	105.00	224.00	108.00	245.00
2.5 GHZ	None	7.50	24.00	9.75	45.00
	Preamp	8.25	26.00	10.50	57.00
	Paramp	106.00	224.00	109.00	245.00
8.4 & 12.2 GHZ	None		30.00	9.75	51.00
	Preamp		80.00	10.50	101.00
	Paramp		230.00	109.00	251.00

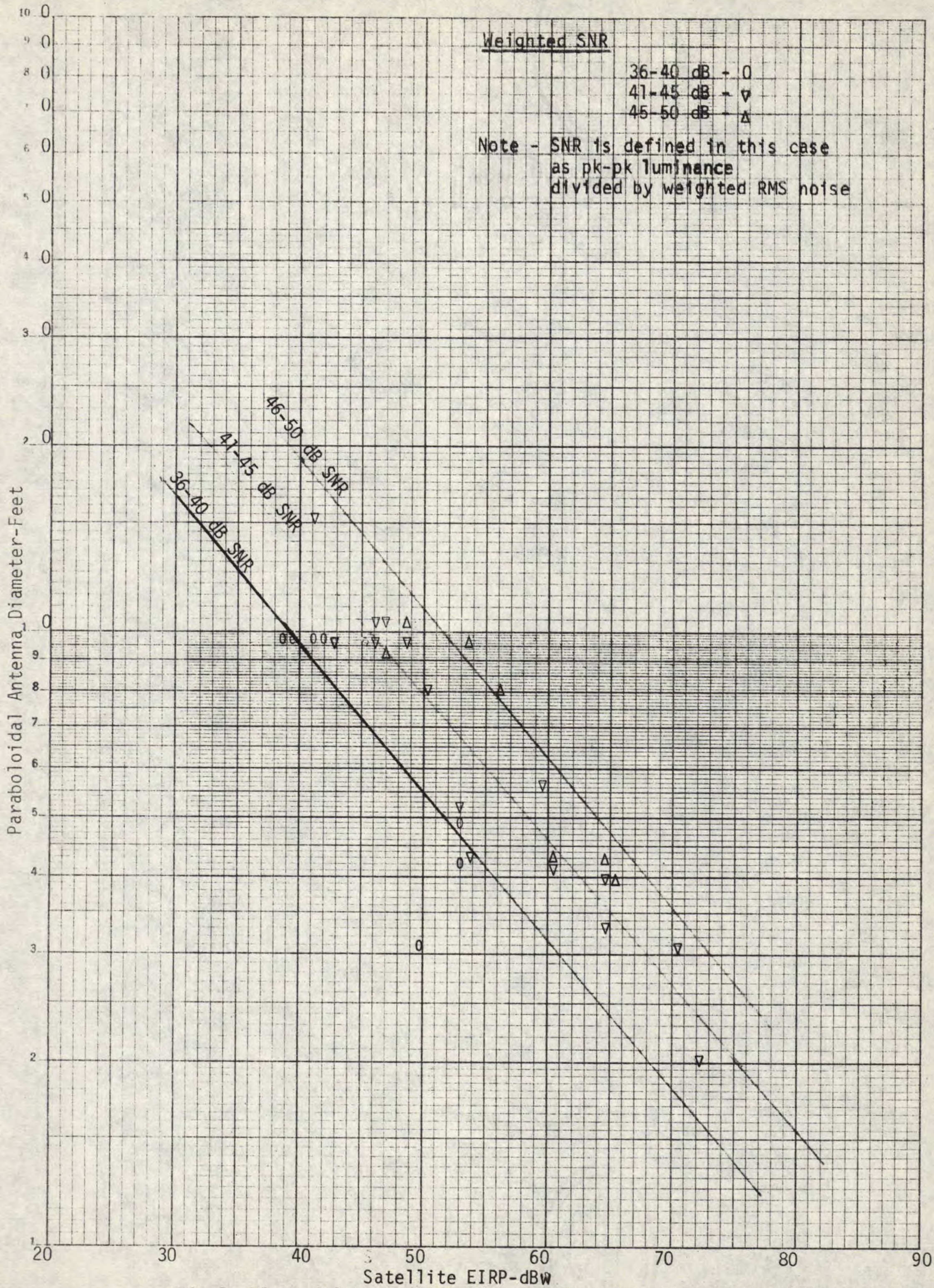

Fig.1 Plot of Antenna Diameter as a Function of Satellite EIRP

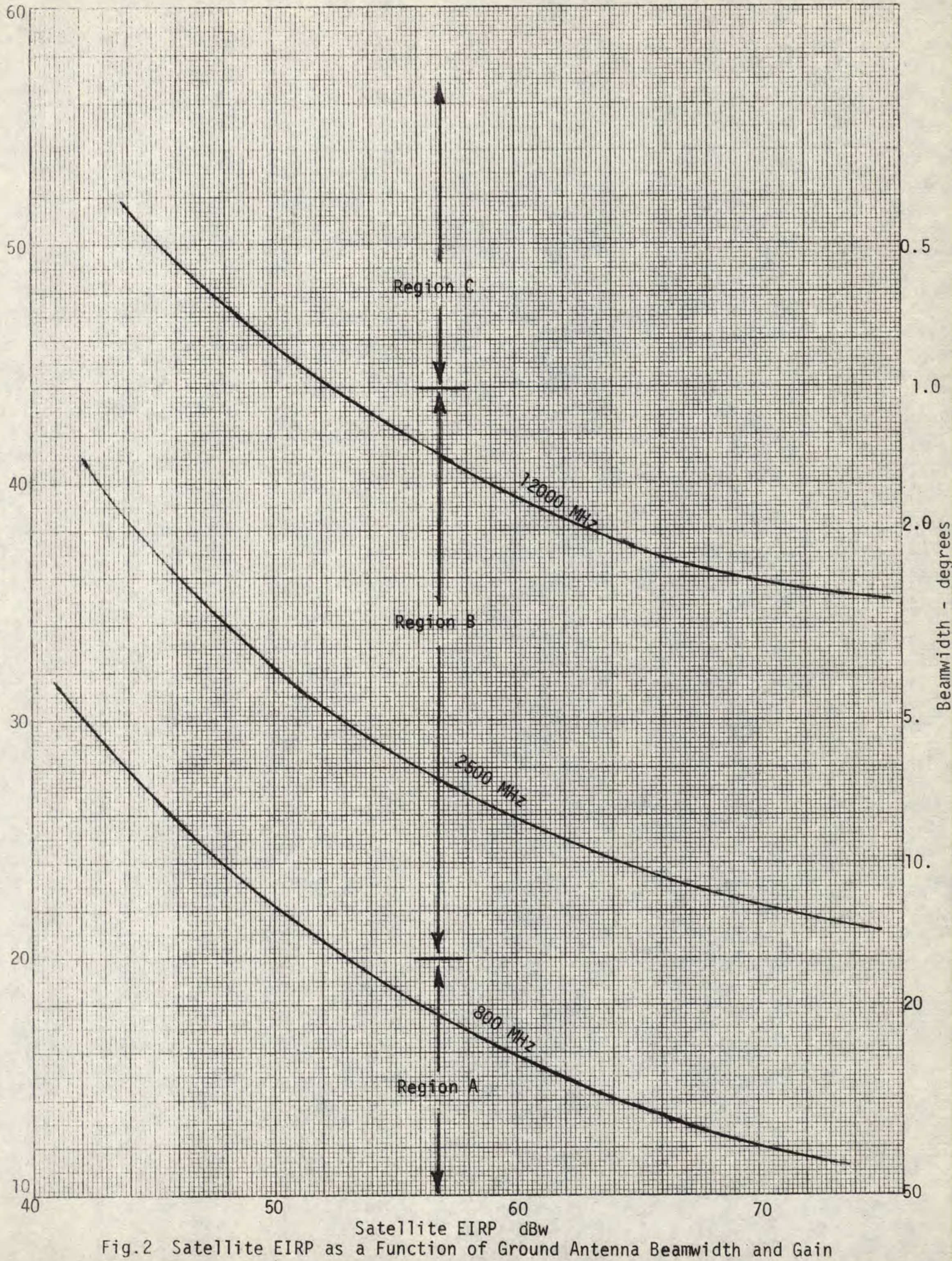

Fig.2 Satellite EIRP as a Function of Ground Antenna Beamwidth and Gain

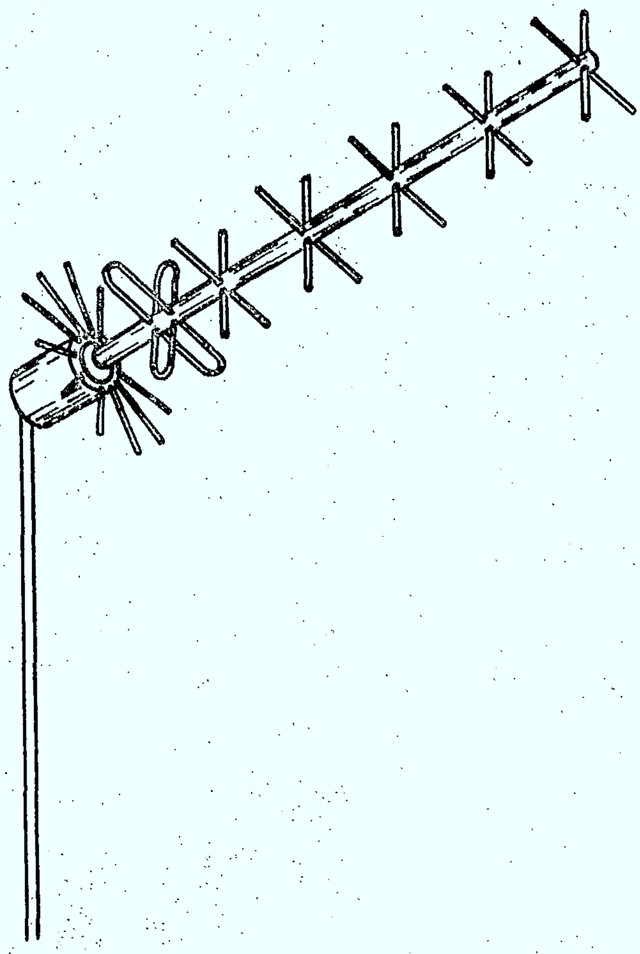

Fig. 3. A Circularly Polarized
Yagi Antenna

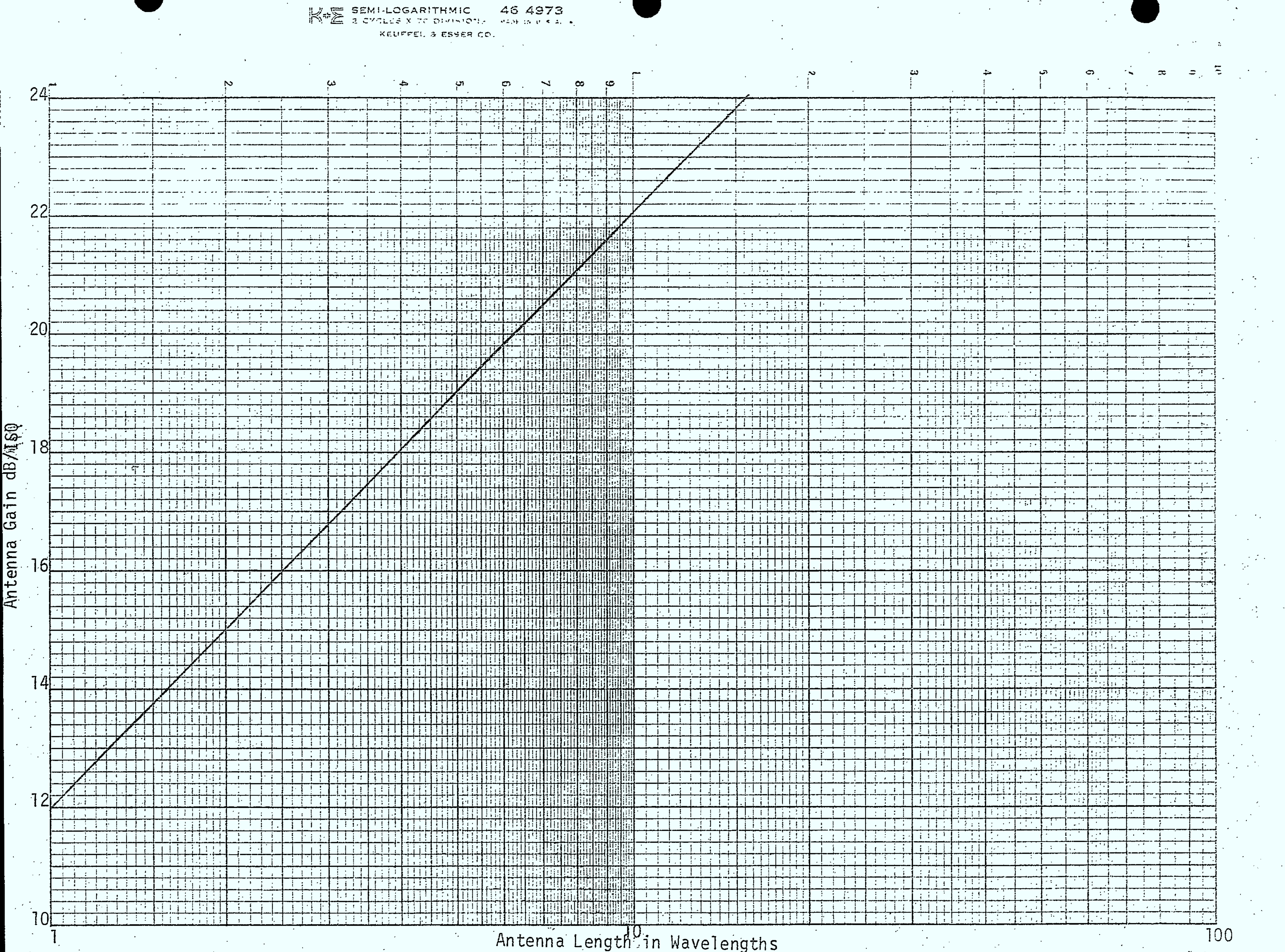

Fig. 4 Antenna Gain is a Function of Antenna Length for Yagi and Helical Antennas

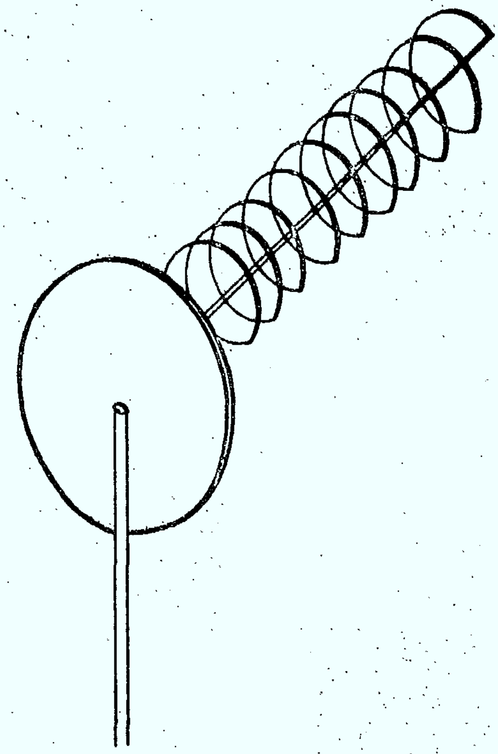

Fig.5. A Helical Antenna

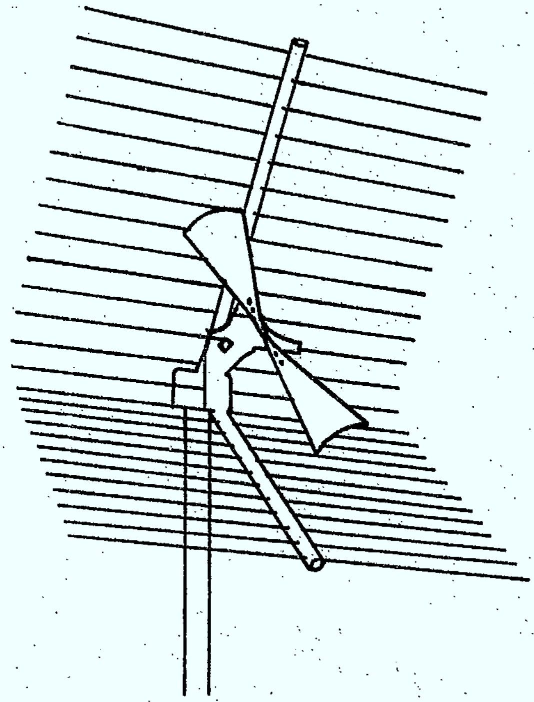

Fig.6. Circularly Polarized
Corner Reflector Antenna

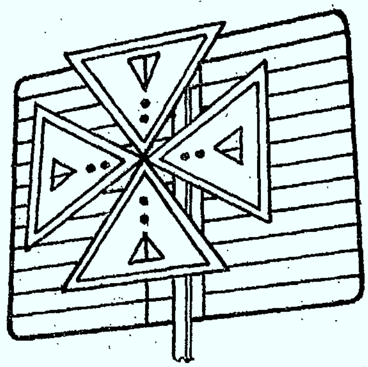

Fig. 7. A Circularly Polarized
"Bow-tie" Antenna

APPENDIX 5

SOLID STATE MICROWAVE POWER AMPLIFIERS FOR BROADCAST SATELLITE TRANSMITTERS

15 April, 1970.

SOLID STATE MICROWAVE POWER AMPLIFIERS FOR BROADCAST SATELLITE TRANSMITTERS

R.J. Bonnycastle and R.G. Aiken

ABSTRACT

Three solid-state devices, the bipolar transistor, the varactor diode and the impatt (avalanche) diode are discussed in terms of available output power, efficiency and power gain, over the frequency range from UHF to Ku Band. The applicability of these devices in solid-state amplifiers for high power broadcast satellite transmitters is then assessed, for a spacecraft launch date of 1977. It is concluded that the solid-state transmitter is a viable contender for both FM and AM/VSB systems at 800 MHz and for FM at 2.5 GHz.

1. INTRODUCTION

As a guideline for this paper a spacecraft launch date for 1977 or later has been chosen. This means that only those hardware concepts already proven experimentally, or currently being tested as part of a high priority programme, need be considered. This paper considers only solid state devices and their application in broadcast satellite transmitters. Two further papers currently being prepared will consider "Microwave Tube Power Amplifiers for Broadcast Satellite Transmitters" and "Power Conditioning Requirements for High Power Broadcast Satellite Transmitters".

2. BIPOLAR TRANSISTORS

For transistors the available output power, the collector efficiency and the power gain per device, decrease as the frequency increases, with a very sharp drop in available output power at 3 GHz. See figures 1,2,3. Typical values are given in Table 1.

TABLE 1

PARAMETERS FOR BIPOLAR TRANSISTORS

FREQUENCY GHz	POWER OUT Watts	POWER GAIN db	CLASS C COLLECTOR EFFICIENCY %
1	20	10	60
2	10	7	40
3	5	5	30

There are ultimate theoretical limitations to the power available per device as a function of frequency, (See reference 1), but the total output power of a solid state transmitter can be made arbitrarily large by combining the outputs of individual amplifiers with special coupling and isolating networks. For example a 1 kW amplifier with 33 db of power gain at 400 MHz has been built using 90 transistors with ratings of 16 watts per device (reference 2). A second example - that used in the 120 watt 250 MHz UHF Transmitter of LES6 uses an "overdriven Class B" mode of operation as an alternative to Class C (references 3 and 4). In this example the transmitted RF power is maximized by:

(a) directly matching the final amplifiers to a solar cell array thereby obviating the need for regulators and DC converters, and

(b) using the "overdriven Class B" mode of operation which has a load impedance looking like a short circuit to all even harmonics of the fundamental. This "optimum power" case theoretically achieves 1.46 times the conventional Class B value of output power, with 88 percent collector efficiency and has the added advantage for FM systems in that the output power and collector efficiency are essentially constant over a predetermined range of drive level.

At the higher frequencies viz S. Band, where the device gain is low, losses in the coupling devices can reduce the overall transmitter gain drastically. However microwave power transistors have been improving very rapidly during the past year so improvements are to be expected.

Heat transfer and removal with solid state does not appear to be a major obstacle. The use of many small amplifiers instead of one large one, allows a relatively large area to be utilized. The supply voltage required is normally limited to about 30 volts by the device collector thickness, and hence V_{cb}, thus avoiding many high voltage breakdown problems. However at the higher powers especially above 500 watts, higher supply voltages may be needed to keep the supply current and hence I^2R loss to a reasonable value.

3. VARACTOR DIODES (MULTIPLIERS)

Strictly, the varactor multiplier circuit cannot be classified as a power amplifier, since it does not have positive power gain and can only produce frequency multiplication. In addition, by virtue of the multiplication process, it cannot be used for processing amplitude modulated signals such as AM/VSB, TV, i.e. its usefulness is strictly limited to FM transmission.

In general, power output and efficiency drop as output frequency and multiplication ratio are increased (see figures 1 and 2). Typical values for 3X frequency multiplication are given in Table 2.

TABLE 2

PARAMETERS FOR VARACTOR MULTIPLIERS

Output Frequency GHz	Power Output Watts	Conversion Efficiency %
1	40	65
2	25	65
4	10	55
8	4	50
10	3	50
12	1.5	50

For transmitter output frequencies above 3 GHz varactor multipliers could be used in the final stages, driven by transistor amplifiers operating at lower frequencies. The outputs of varactor multipliers can be combined in a similar way to transistor amplifiers.

4. IMPATT (AVALANCHE) DIODES

These diodes can be used as negative resistance amplifiers, but their efficiency is very low, typically 5% or less with a theoretical efficiency of about 25%. See Table 3 and figures 1 and 2.

TABLE 3

PARAMETERS FOR IMPATT (AVALANCHE) DIODES

FREQUENCY GHz	POWER OUTPUT Watts	EFFICIENCY %
2.8	1.2	5.0
4.4	1.2	5.0
5.0	1.0	4.0
10.0	1.0	5.0
12.5	0.5	4.5
15	0.4	5.0
18	0.25	4.5
25	0.1	2.5
40	0.05	1.0

A different mode of operation of impatt diodes, called the "high efficiency" mode is capable of efficiencies in the order of 50% but requires special circuits with multiple resonators and is only imperfectly understood at present.

5. APPLICATION OF SOLID STATE AMPLIFIERS IN BROADCAST SATELLITE TRANSMITTERS

In the Television Broadcast Satellite Studies prepared for NASA-LEWIS, solid state transmitters are not mentioned in the TRW Study (reference 5) and only briefly in the GE Study (reference 6). What follows is essentially a summary of paragraphs 5.2.3 and 5.2.4 of the GE Study.

Two frequencies only were considered viz UHF (800 MHz) and S-Band (2.5 GHz) with a range of power outputs from 200 watts to 20 kW. The RF sections of all transmitters were assumed to be based on standard modules containing 4 transistors per stage. This corresponds to a power gain of 4 per stage (i.e. 6 db) since each module is capable of driving 4 more. The individual module output powers for the frequency/circuit combinations are:

	UHF (800 MHz)	S Band (2.5 GHz)
Class B	119 Watts	47 Watts
Class C	159 Watts	59 Watts

Efficiency is not greatly influenced by module size and circuit bandwidth is greater than required. 10 MHz AM video, and 36 MHz FM with Class C operation can be accommodated without difficulty.

The efficiency, weight and cost versus power curves of figures 4, 5 and 6 are based on the standard modules, and include the effects of power combiners. In Figure 4 the peak sync powers for the solid-state AM transmitter have to be converted to average in order to permit the power conditioner to be sized. Thus the 35% efficiency transmitter may provide only about 20% average efficiency for Class B operation. This highlights the basic problem with high power solid-state transmitters viz the transistors used have low gain and only moderate efficiency so that a large number are required for the driver as well as the final stages, with a large consequent loss in combining networks.

The transmitter weights shown in Figure 5 are the sum of:

(a) module weights

(b) power combiner weights

(c) a 25% additional factor to cover supporting structures. This covers all mechanical requirements for mounting transmitter components in cabinets, available for mounting in the spacecraft. Weights with and without power combiners are shown, the latter being representative of transmitters driving array-type antennas having one antenna element per transistor.

Costs are shown in U.S. dollars in Figure 6. Engineering costs taper off at high power (see Figure 6) on the assumption that the transmitter engineering model will not use more than about 10 engineering modules. Above about 1 kW when more than 10 modules are required, the additional units taken will be fabricated production modules, charged to fabrication costs.

The power combiners are wave guide devices (or other transmission line types at lower powers) for combining identical signals from more than one source. Figure 7 shows the estimated nominal insertion loss of these networks versus the number of ports to be summed. For the various types of power combiners considered, weight (Figure 8) and cost (Figures 9 and 10) become excessive for large numbers of ports and lower frequencies. Hence if a large number of ports should be required, it appears preferable at UHF to consider leaky-guide types rather than the hybrids used here for power dividing.

6. CONCLUSIONS

Consistent with a 1977 spacecraft launch, using hardware concepts already proven experimentally or currently being tested as part of a high priority programme, the authors have drawn the following conclusions:

(a) Solid state power amplifiers will not be available at 12 GHz for AM/VSB operation

(b) For 12 GHz FM varactor diodes will be available but their power output and efficiency; remembering that they must be driven by high power transistor stages at sub-harmonic frequency, are such that they will be completely uncompetitive with microwave tubes

(c) For 2.5 GHz AM/VSB - one must use bipolar transistors in their Class B linear mode. However as such transmitter average efficiencies will only be of the order of 20%. This again can be bettered by microwave tubes, e.g. the klystron, TWT or CFA.

(d) For 2.5 GHz FM we can use bipolar transistors in Class C or overdriven Class B to gain a very useful increase in efficiency - provided multicarrier, single channel, operation is not required. Solid-state must now be considered a viable contender.

(e) At UHF - 800 MHz solid state must be considered a contender for both AM and FM as the power conditioning requirements are much less severe than for microwave tubes or gridded triodes. These conclusions are presented in Table 4.

TABLE 4

EXPECTED AVAILABILITY OF SPACE QUALIFIED HIGH POWER
SOLID STATE TRANSMITTERS IN 1977

	800 MHz	2.5 GHz	12 GHz
FM	YES	YES*	NO
AM/VSB	YES	NO	NO

* Not Single Channel Multicarrier Operation

7. REFERENCES

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2. "An All-Transistor 1 kW High Gain UHF Power Amplifier", R.L. Bailey et al IEEE Trans. Microwave Theory and Techniques, Vol. MTT-17, No. 12 December 1969, p 1154.

3. "Transmitted Power Maximization in Communications Satellites" Alvise Braga-Illa and David Snider, Lincoln Laboratory, MIT, AIAA Paper No. 68-437, AIAA 2nd Communications Satellite Systems Conference, San Francisco, April 8-10, 1968.

4. "A Theoretical Analysis and Experimental Confirmation of the Optimally Loaded and Overdriven RF Power Amplifier", David M. Snider, Lincoln Laboratory, MIT, IEEE Trans. on Electron Devices., Vol. ED-14, No. 12, December 1967, p 851.

5. "Television Broadcast Satellite Study", J. Jansen, P.L. Jordan, et al TRW Systems Group, NASA Report No. CR-72510, October 24, 1969, Contract NAS3-9707.

6. "Television Broadcast Satellite Study", R.W. Hesselbacher, General Electric Company, Space Systems Organization, Contract No. NAS3-9708, Vol. III, TVBS Technical Report, November 15, 1969, NASA Report No. CR-72579.

FIGURE 1.

COMMERCIALLY AVAILABLE DEVICES MARCH 1970

POWER VERSUS FREQUENCY.

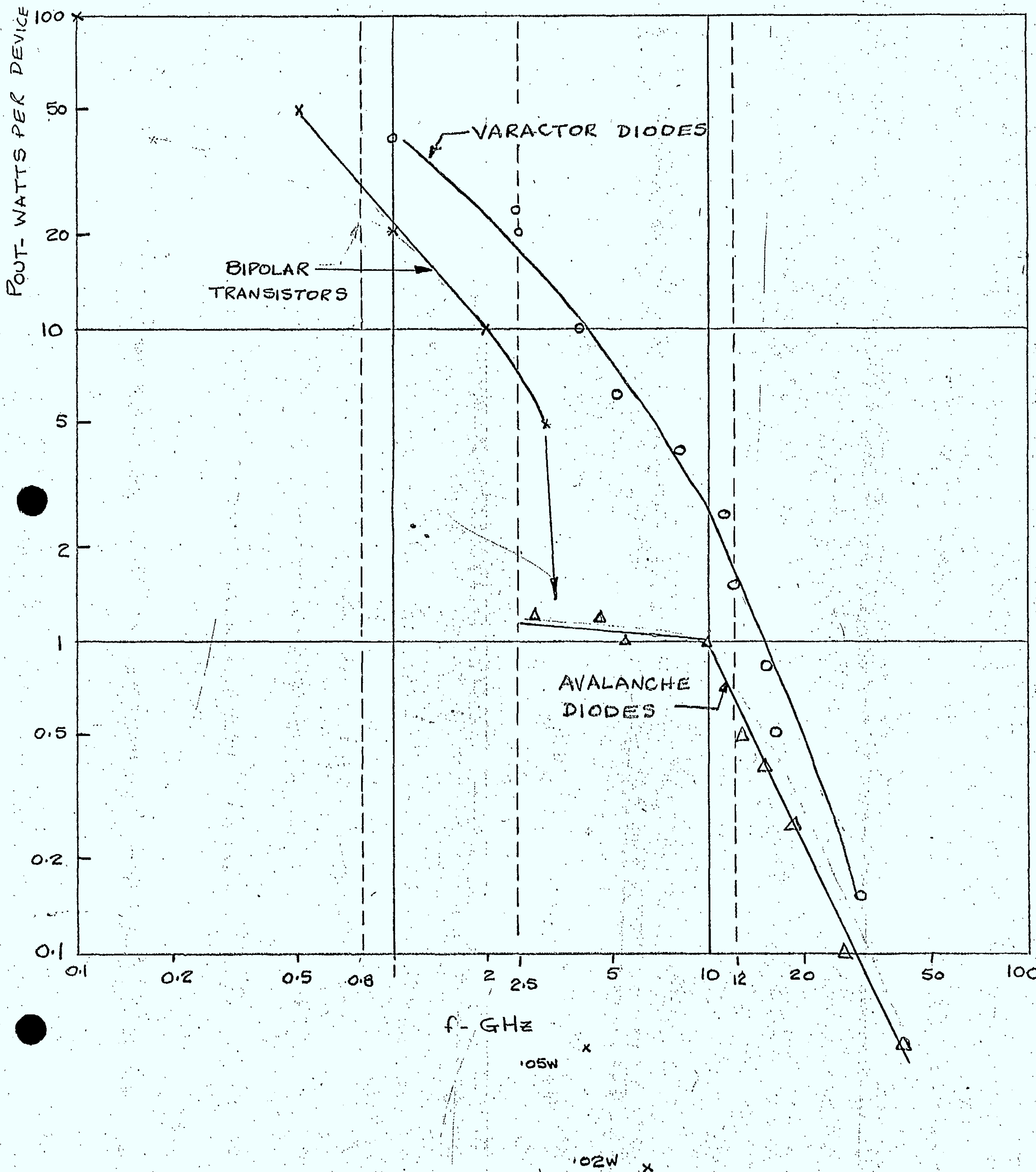


FIGURE 2.

DEVICE EFFICIENCY VERSUS FREQUENCY.

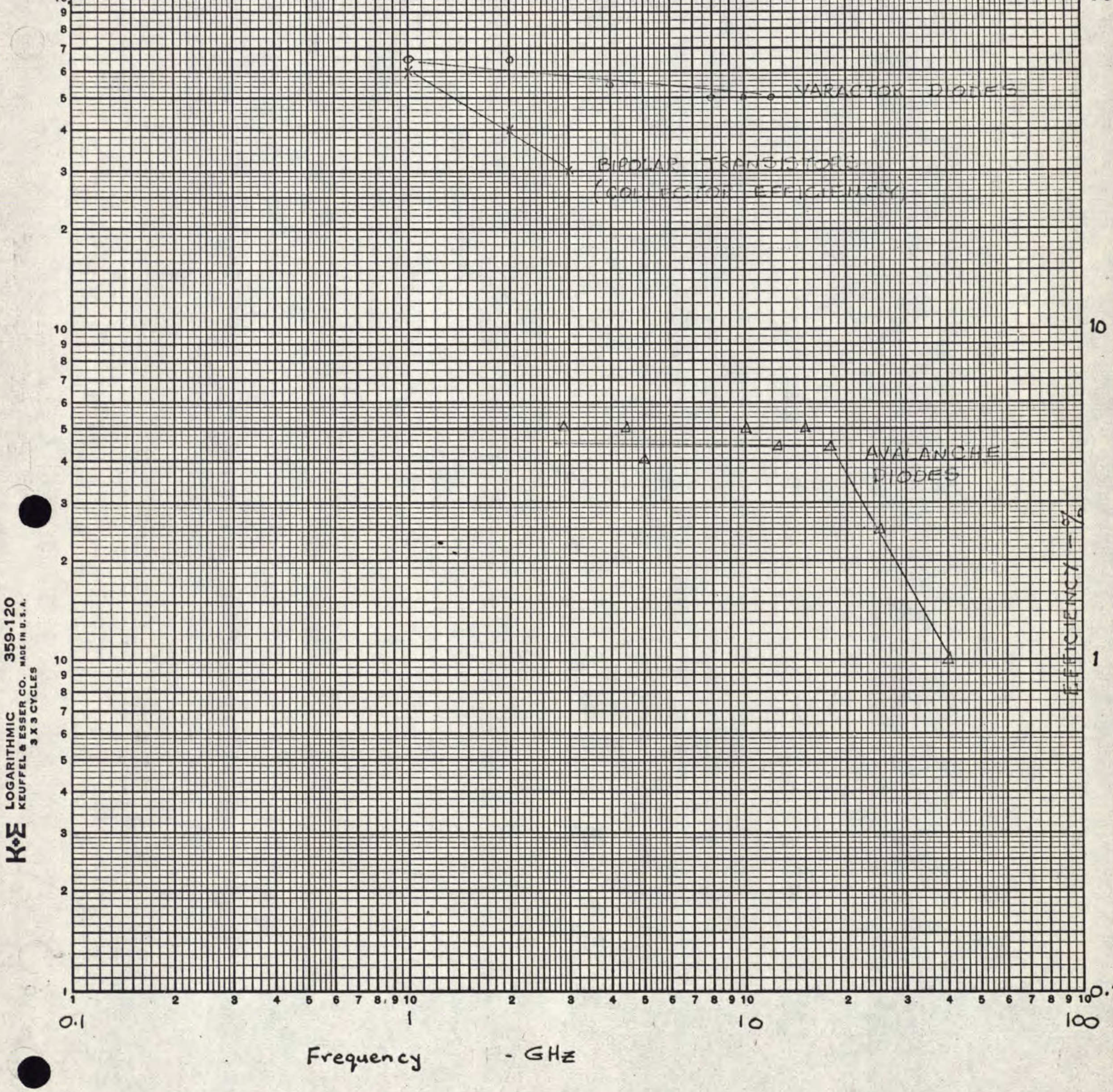
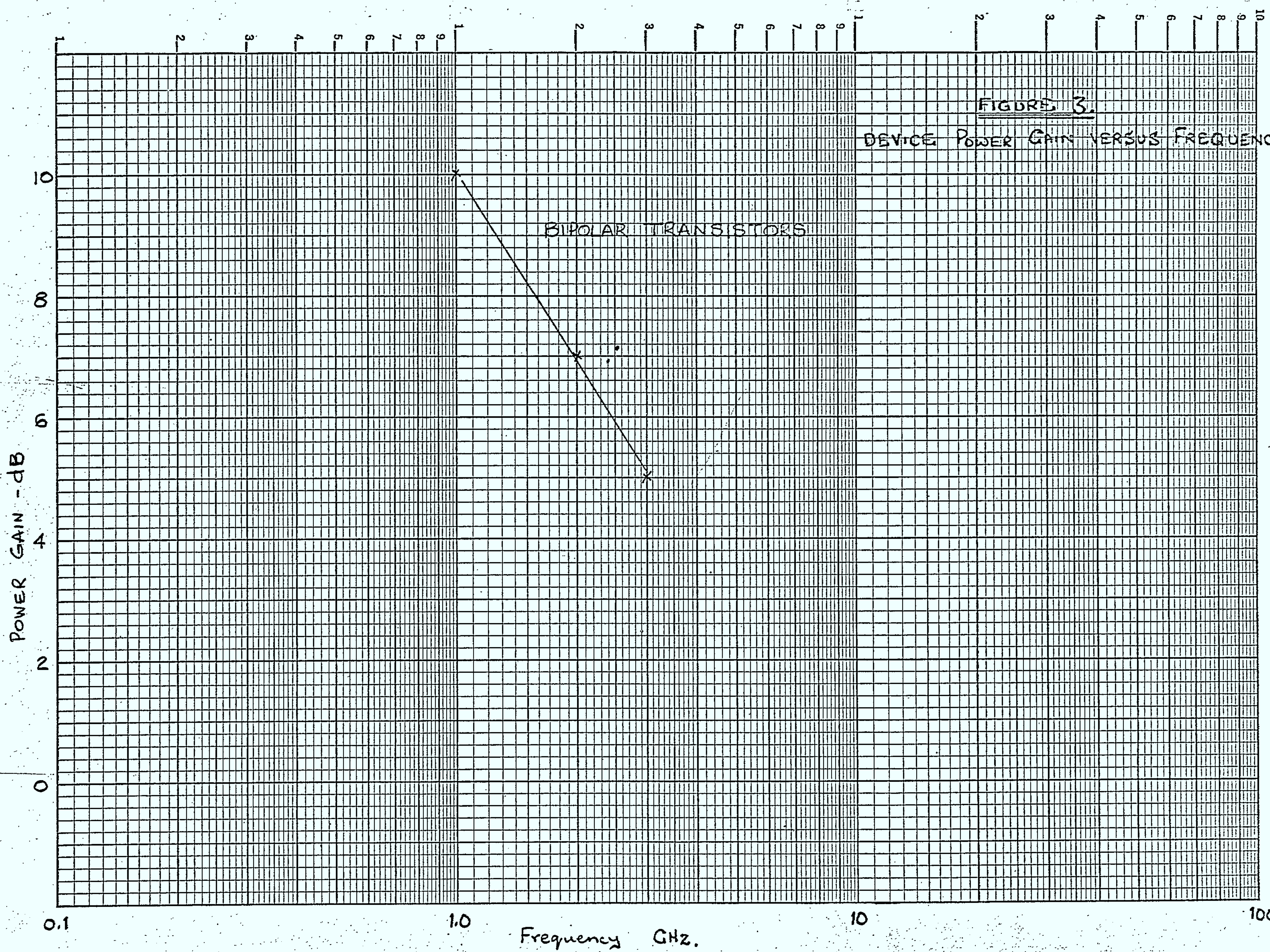


FIGURE 3.

DEVICE POWER GAIN VERSUS FREQUENCY.



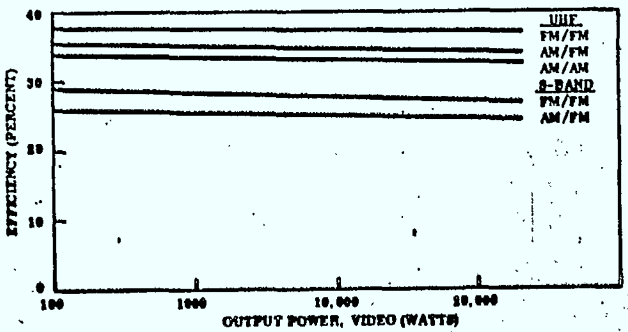


Figure 4. Transistor Transmitter Efficiency

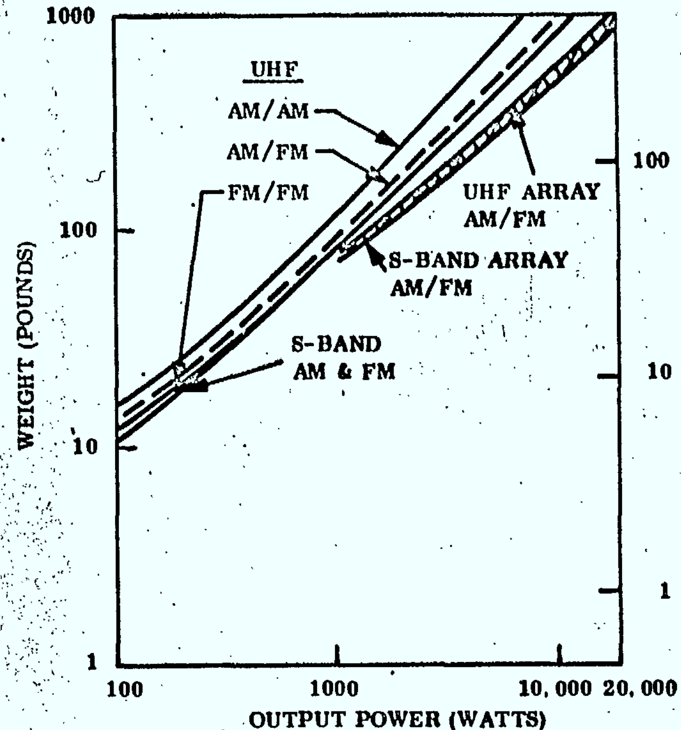


Figure 5. Transistor Transmitter Weight

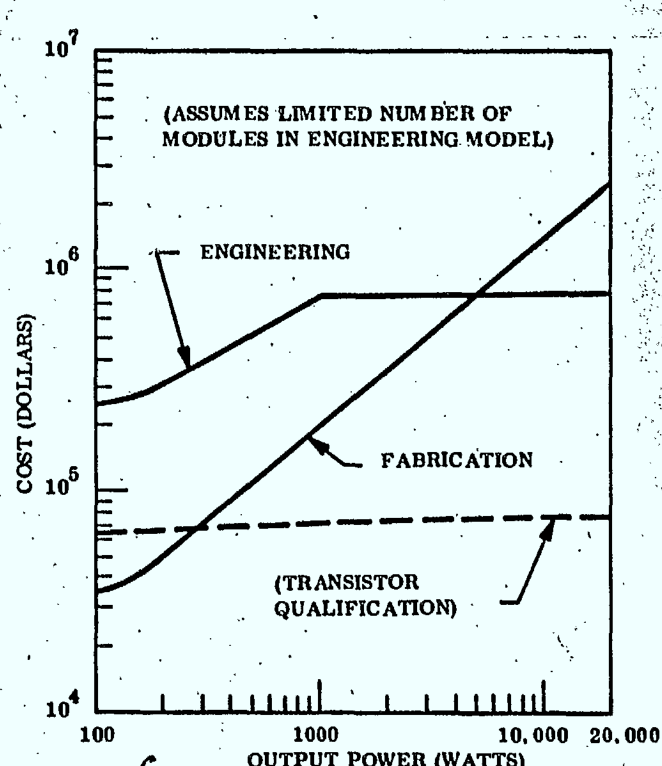


Figure 6. Transistor Transmitter Costs

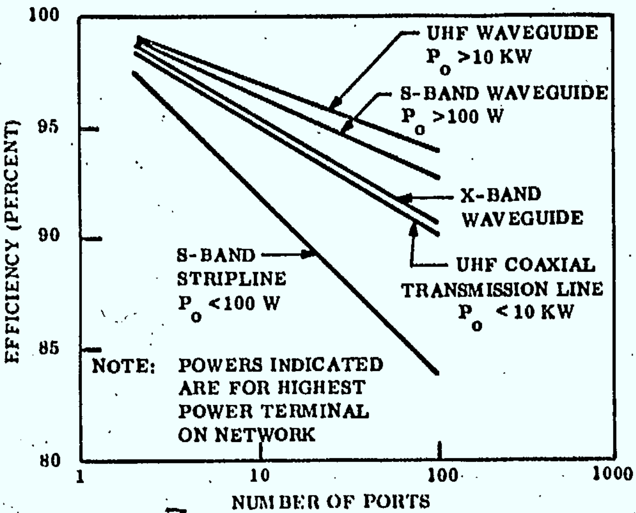


Figure 7 ~~5-2-16~~. Power Divider/Combiner Efficiency

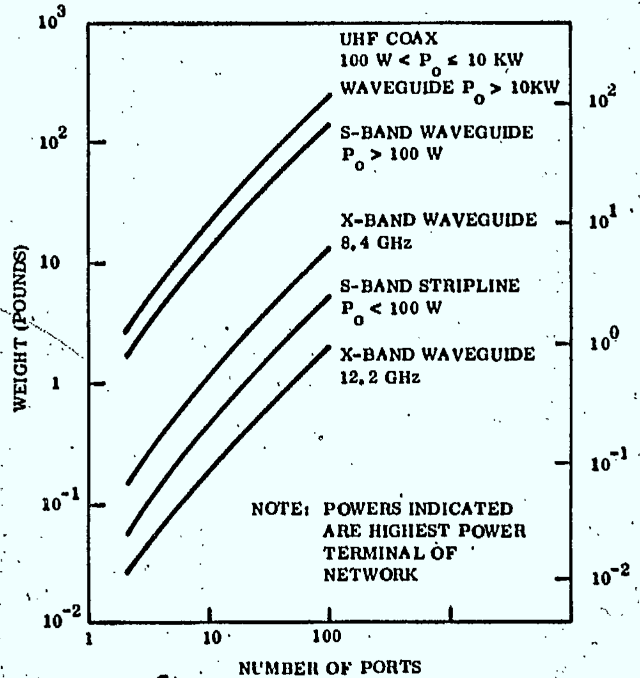


Figure 8 ~~5-2-17~~. Power Divider/Combiner Weight Versus Number of Ports

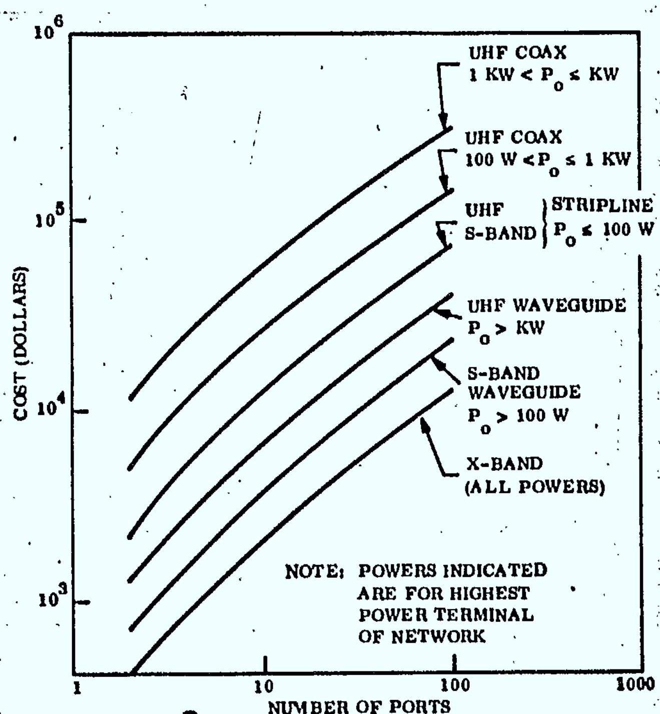


Figure 9 ~~5-2-18a~~. Power Divider Network Engineering Cost

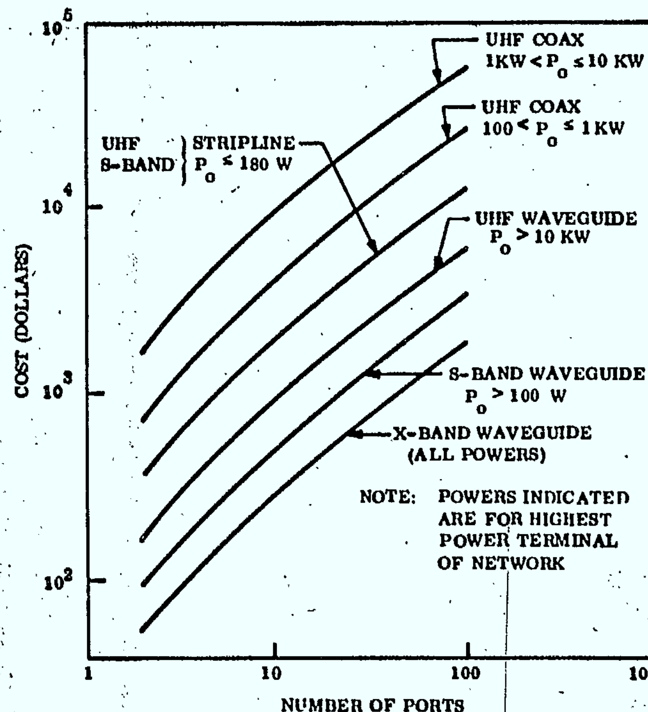


Figure 10 ~~5-2-18b~~. Power Divider Network Fabrication Cost

APPENDIX 6

UPLINK CONSIDERATIONS IN THE DESIGN OF SATELLITE BROADCASTING SYSTEMS

UPLINK CONSIDERATIONS
IN THE DESIGN OF
SATELLITE BROADCASTING SYSTEMS

Introduction

This report presents considerations in the design of the uplinks for satellite broadcasting systems operating at frequencies of 0.8, 2.5 and 12 GHz from satellite to ground. It is based on the following assumptions:

(a) For downlink frequencies of 0.8 and 2.5 GHz the uplink will operate in the 6 GHz band.

(b) For downlink frequencies in the 12 GHz band the uplink will operate at 18 GHz.

(c) The satellite will be maintained in position in the synchronous orbit to within $\pm$ 0.1° in longitude and inclination.

(d) Each channel will operate in a bandwidth approximately 22 MHz wide with guard bands of approximately 10 per cent giving a spacing between channels of 25 MHz.

(e) The method of transmission will use frequency modulation.

(f) The system will only be used for the transmission of television so all carriers in the up-path will have equal amplitude.

(g) The receiving antenna on the satellite will cover Canadian territory so transmissions can enter the satellite from any location in Canada.

General Considerations

An earth station to provide the up-path link in a satellite broadcasting system will consist of the following items:

antenna sub-system;

transmit sub-system;

high power amplifier sub-system.

It may also include the following:

low noise amplifier sub-system;

receiver sub-system;

tracking sub-system.

The number of transmitter chains and high power amplifiers will depend on the number of broadcast channels in the system. The low noise amplifier and the receiver chains may be included if it is considered necessary to monitor the transmission from the satellite. The tracking sub-system may be required if it is decided to use an antenna with a gain high enough to permit the use of low powered transmitters, and which has a beamwidth sufficiently narrow that the satellite will not be illuminated while it moves within its prescribed limitations in the synchronous orbit unless the antenna is operated in an auto-tracking mode.

Technical Considerations

In the case of a communication satellite limited exclusively to a number of individual RF channels each carrying one television transmission there is no intermodulation developed in the output to the satellite, and the total carrier noise in the system is the sum of the carrier noise in the up-path and the down-path. The only problem is to ensure the up-path carrier to noise does not seriously degrade the down-path carrier to noise. It is possible, therefore, to adjust the total gain in the satellite to minimize up-path illumination subject to the generation of intermodulation and degredation of the overall carrier to noise ratio. This would be much more difficult and complicated if the system were handling simultaneously a large number of carriers to various amplitudes.

In the case of satellites broadcasting in the 0.8 GHz or the 2.5 GHz bands where it has been assumed that the uplink will be in the 6 GHz band, the design can follow that already in use in existing communication satellites. These systems operate with a wideband receiver which is capable of simultaneously amplifying all the signals at the input, converting them to the down-path frequency and amplifying them again before passing them to a diplexer which separates out the various channels for individual amplification in a high powered travelling wave tube. The wideband front end is designed so that it contributes essentially no intermodulation into the system. The front end of the satellite will have a $\frac{G}{T}$ of about -7 db.

These systems operate with a single carrier saturating flux density in the order of -80 dbw/meter squared when equipped with a receiving antenna which just covers Canadian territory. This could be increased to -85 dbw/meter squared without running the risk of increasing the intermodulation in the front end. An illumination of -85 dbw/meter squared would be provided at the satellite from the EIRP at the ground station of +78.3 dbw for all elevation angles above 5° at the ground station.

A fixed ground station antenna which has a beamwidth of 0.5° in order to continuously illuminate a satellite which is maintained with 0.1° in longitude and inclination, will have a gain of 51 db at 75 per cent efficiency and a diameter of approximately 23 feet. With an antenna gain of 51 db it would require a power of 27.3 dbw to produce an EIRP of 78.3 dbw. This is about 540 watts and is well within the state-of-the-art at the present time.

This would be a recommended first approach to the problem. There would be a potential increase in intermodulation and a potential reduction in the anticipated life of the satellite if another stage of amplification were added in the wideband front end. The potential reduction in life time comes about through the introduction of additional components in the amplification chain.

If a system were to be produced with an extremely large number of broadcast channels then it might be more economical to produce an earth station with a larger antenna with resulting higher gains and narrower beam fitted with automatic tracking so it would continuously follow the satellite and then use lower powered transmitters to produce the necessary EIRP per channel.

The costs of the various components of earth stations are contained in Table 1 and Table 2.

Based on the information in Tables 1 and 2 the cost of an earth station as described would be as follows:

LIMITED MOTION NO AUTOTRACK

25 foot Antenna (Installed)	$ 51,000
System Installation	52,000
Program Management	52,000
Power	20,000
Building	50,000
Site Survey	10,000
Site Improvement	10,000
Water and Sewage	10,000
Spare Parts	52,000
Basic Cost	$ 307,000

Add per transmit channel - $ 90,000

In U.S. dollars purchased in U.S.A.

In the case of a satellite operating in the 12 GHz band, with up-path transmission at 18 GHz there are a number of problems which would appear to increase the cost of the up-path links.

Packaged tunnel diode amplifiers exist with a noise figure of 8 db at 18 GHz, compared to db at 6 GHz. There will be a slight increase in the thermal noise in the satellite and a large reduction in the gain of the satellite antenna relative to a square meter - approximately 9 db. If the system were designed for a carrier to noise ratio on the down path of 13 db a carrier to noise ratio on the up-path of 19 db would degrade the overall system carrier to noise by an additional 1 db and this is as far as one should go. This would require an up-path single carrier saturation flux density of -80 $dbw/meter^2$.

An antenna with a 0.5° beamwidth at 18 GHz will have a diameter of 7.5 feet and a gain of 51 db. With this size of antenna the requirements would be for each transmit chain to be equipped with a high powered transmitter of about 3,000 watts. The alternative again would be to construct a larger antenna with a higher gain and equip the station as an auto-tracking facility which would permit the use of smaller transmitters.

There are commercially available water cooled klystrons which are capable of this amount of power output, however, the transmitter becomes very expensive because of the high power, the large power supplies and the water cooling. Two estimates follow, one for an antenna in the order of 7.5 feet which would be fixed with high power transmitters and one for an antenna in the order of 25 feet with auto-tracking capability and would require transmitters with output powers of approximately 300 watts. There are commercially available water cooled travelling wave tubes which have this capability.

Table 3 contains some costs of fixed antennas of various sizes with capability of operating at 18 GHz.

ITEM	OPERATION AT 18 GHz LIMITED MOTION	
	7.5 Feet Fixed	25 Feet Auto-Track
Antenna (Installed)	$ 9,650	$ 391,000
System Installation	31,000	81,000
Program Management	31,000	81,000
Power	70,000	33,000
Building	50,000	50,000
Site Survey	10,000	10,000
Site Improvement	10,000	10,000
Water and Sewage	10,000	10,000
Spare Parts	10,000	60,000
Basic Cost	231,650	726,000
TV Transmit Chain	30,000	30,000
High Power Amplifier plus Spares	180,000	80,000
Add per TV Transmit Chain	210,000	110,000

All prices U.S. dollars purchased in U.S.A.

TABLE 1

COST OF EARTH STATION ITEMS WHICH VARY WITH
ANTENNA SIZE IN THOUSANDS OF DOLLARS
4 and 6 GHz Operation
U.S. Prices Delivered in U.S.A.

ITEM	LIMITED MOTION WITH AUTOTRACK				LIMITED MOTION - NO AUTOTRACK		
Antenna Diameter (Feet)	85	60	42	30	30	25	16
Installed Costs	825	520	385	368	66	51	33.5
System Installation and Test	113	91	82	81	52	52	38
Program Management	113	91	82	81	52	52	38
Electric Power	42	36	34	33	20	20	18
Building	100	100	100	100	50	50	50
Site Survey	25	25	25	25	10	10	10
Site Improvements	25	25	25	25	10	10	10
Water and Sewage	25	25	25	25	10	10	10
Spare Parts	113	91	82	81	52	52	38

TABLE 11

COST OF EARTH STATION ITEMS
WHICH DO NOT VARY SIGNIFICANTLY
WITH EARTH STATION SIZE

ITEM - 6 Gc or 4 Gc OPERATION	COST US Prices Delivered in USA
Low Noise Amplifier Cooled - Temp. 20°K	$ 180,000
Low Noise Amplifier Uncooled - Temp. 160°K	$ 32,000
Tunnel Diode Amplifier Temp. 530°K	$ 7,000
High Power Amplifier 30W	$ 14,000
High Power Amplifier 800W	$ 70,000
TV Receive Chain (Single)	$ 20,000
TV Transmit Chain (Single)	$ 20,000
97 Foot Fully Steerable Antenna with Tracking System (Installed)	$ 1,200,000

TABLE 3

Cost of antennas for operation at 18 GHz.

Canadian Dollars delivered in Canada.

Fixed antennas adjustable ±5 degrees in aximuth and elevation.

Manufactured prices - not installed.

Size	Cost
15 ft.	$ 10,200
12 ft.	$ 7,800
10 ft.	$ 6,600
8 ft.	$ 6,150

APPENDIX 7

TELEMETRY AND COMMAND CONSIDERATIONS IN THE DESIGN OF SATELLITE BROADCASTING SYSTEMS

TELEMETRY AND COMMAND CONSIDERATIONS
IN THE DESIGN OF
SATELLITE BROADCASTING SYSTEMS

Introduction

This report presents considerations in the design of the tracking, telemetry, control and monitoring system required to:

(a) establish and maintain a satellite in the synchronous orbit to within ± 0.1 degrees in longitude and inclination.

(b) provide the housekeeping services necessary to guarantee the life of the satellite.

(c) monitor the system operation in order to ensure satisfactory overall system performance.

Tracking Data Requirement

There does not appear to be at the present time any practical experience in maintaining a synchronous satellite in position in the synchronous orbit to within ± 0.1 degrees in longitude and inclination. With existing communication satellites it has been found that the accuracy of the tracking data is approximately 1/20th of the beamwidth of the tracking antenna. It has also been found that there is a large incremental error introduced each time the tracking antenna is switched to another satellite and then returned to the satellite under consideration. This incremental error can be as high as 0.1 degrees for an antenna with a beamwidth of 0.4 degrees. This large incremental error would make it very difficult to maintain a synchronous satellite to within ± 0.1 degrees unless either the tracking station operates continually with one satellite, or the tracking data from the telemetry and command station is supplemented by tracking data from other antennas in the system which are operating in the auto tracking mode. In this report it is assumed that a single tracking antenna will be used on a continuous basis to provide tracking, telemetry, command and monitoring services for one satellite. Tracking data accurate to ± .02 degrees and ranging data accurate to 0.05 miles is expected to permit maintenance of a satellite location in the synchronous orbit to within ± 0.1 degree in both longitude and inclination.

Equipment Required

A tracking, telemetry, command and monitoring station will consist of the following:

(a) antenna sub-system;
(b) low noise amplifier sub-system;
(c) receiver sub-system;
(d) transmitter sub-system;
(e) tracking sub-system;
(f) ranging sub-system;
(g) telemetry sub-system;
(h) command sub-system;
(i) time base generator sub-system;
(j) data transfer sub-system.

Technical Characteristics

In addition to providing tracking, telemetry, command and monitoring services when the satellite is located in the synchronous orbit the station must be capable of providing simultaneous tracking, telemetry and command functions during launch and orbit injection.

Antenna Sub-system

The antenna should be fully steerable with rates compatible with satellite launch and orbit injection requirements. The beamwidth should be not more than 0.4 degrees. The elevation travel should be at least 0 to plus 92 degrees and azimuth travel should be ± 270 degrees. Tracking and pointing velocity should be variable at rates up to 1 degree per second. Tracking and pointing accelerations should be at least 0.01 degree per $second^2$ at pointing accuracies of 0.04 degrees and tracking accuracies of 0.02 degrees. The feed system should be capable of covering the full RF transmit and receive bands with polarization to match the transmission to and from the satellite.

Low Noise Amplifier Sub-system

The low noise receiver must be capable of operating over the frequency band used by the satellite in order to permit not only reception of the beacon signals but also the information channels, in order to make it possible to monitor the overall system performance.

Receiver Sub-system

The receiver sub-system must provide simultaneous reception and demodulation of beacon, telemetry and ranging signals from the satellite. It must also be capable of demodulating as required the information channels broadcast from the satellite.

Transmitter Sub-system

The transmitter sub-system must be capable of simultaneously transmitting command signals and ranging signals at different power levels.

Tracking Sub-system

The tracking sub-system must be capable of acquiring and automatically tracking satellites in both the synchronous and transfer orbit mode. It must also be able to accept pointing data from the data transfer sub-system and operate in a program tracking mode.

Ranging Sub-system

Ranging equipment is required to generate multiple range tones which are transmitted to the satellite and measure the phase delay in the received tones to determine the distance to the satellite with an accuracy of at least 0.05 nautical miles.

Telemetry Sub-system

This equipment is required to interface the antenna sub-system with command signals from the command console.

Time Base Generator Sub-system

All operations associated with tracking data collection must be referred to a time base generator located at the station.

Data Transfer Sub-system

This sub-system accepts tracking, ranging and telemetry data which is then processed into a form suitable for transmission to the spacecraft control centre. It also provides programmed pointing data to the antenna while the antenna is operating in the program mode. It will continuously measure and formulate actual azimuth and elevator data for transmission to the control centre.

Costs

A tracking, telemetry, command and monitoring station of the type described here, for operation with satellite receiving in the 6 GHz band and transmitting in the 4 GHz band costs approximately $1,000,000. The antenna is 42' in diameter giving a beamwidth of 0.4 degrees at 4 GHz. For operation at 2.5 GHz a slightly larger antenna would be required with an increase in cost of approximately $250,000.

For operation with a satellite in the frequency bands of 12 GHz and 18 GHz the antenna on the station would be only about 15' in diameter. On the other hand the requirements for increased surface accuracy and the cost of developing parametric amplifiers, high stability local oscillators for up and down converters and high power transmitters would probably use up any saving from the reduction in the size of the antenna so it is considered that a good estimate of the cost of this facility is still $1,000,000.

APPENDIX 8

SPACECRAFT DESIGN CONCEPTS AND REQUIREMENTS OF FUTURE HIGH-POWER BROADCAST SATELLITES

15 December, 1970

APPENDIX 8

SPACECRAFT DESIGN CONCEPTS AND REQUIREMENTS OF HIGH POWER BROADCAST SATELLITES

by

JOHN MAR

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1. INTRODUCTION

This paper is a report on spacecraft mechanics and control design considerations for future broadcast satellites. Design concepts and features discussed in the following are considered important, and in some instances, key technologies which must be achieved in order to meet requirements of future high power TV broadcast satellites.

The information presented is in large part based on background research and systems design studies carried out by the Space Mechanics Section, CRC, in defining program objectives for the proposed DOC/NASA Communications Technology Satellite project (Ref. 1). The CRC Space Mechanics' delineation of key technology areas is also confirmed in various publications, as for example Ref. 2.

2. ATTITUDE CONTROL CONCEPTS

(a) General Approach

The desirable requirement to avoid the use of a rotary joint between the main satellite body or payload platform and the communication antenna or between large components of the structure such as solar cell sails eliminates the dual spin or tri-spin as eminently useful potential attitude stabilization systems. Dual spin spacecraft have limited application as they are practical only on small, low-powered types of satellites.

There are three current general methods of controlling a satellite's attitude which should be capable of providing control to 0.1° about the three principal axes. These are:

i) a system of reaction wheels (ref. 3)

ii) the Commandable Gravity Gradient System, COGGS (ref. 4)

iii) a system of control moment gyros (ref. 3), and possibly coupled with an RF interferometer.

For the reaction wheel system there are several possibilities:

i) three reaction wheels plus a low thrust propulsion system for momentum dumping

ii) two reaction wheels plus a low thrust propulsion system for momentum dumping and attitude control about the third axis. This method supposedly reduces cross coupling between the reaction wheels.

iii) one large reaction wheel along the pitch axis plus a low thrust system for momentum dumping and attitude control about the roll and yaw axes (RCA Stabilite system).

The COGGS employs a 2-axis-gimbaled gravity gradient boom about which the satellite is torqued for pitch and roll control. Control of the yaw angle is accomplished using only momentum wheel control with saturation prevented by the orbital rate coupling of yaw momentum into the roll axis. The momentum wheels about the roll and pitch axes are used only to provide a damping torque. It is estimated that the weight of the damping wheels required by COGGS would be less than one third of that of the wheels required by a reaction wheel jet system.

The control moment gyro, CMG, system employs one or two constant speed wheels which are gimbaled about one or two axes. Attitude control is obtained by gimballing the wheels. Momentum dumping would be effected with a thruster system. The CMG system is likely to be a serious contender if bearings and gimbal designs can be made with a high degree of reliability. Although it has the advantage of not needing a yaw sensor (usually a Polaris star tracker), the CMG system does not have the inherent control systems accuracy which is achievable in the 3-reaction wheel system.

(b) <u>Control Thrusters</u>

The thrusters to be used would probably comprise one of the following low thrust devices depending on thrust level and duty cycle required:

i) ammonia or hydrazine resistojets

ii) cesium contact ion engines

iii) cesium or mercury ion bombardment engine

iv) pulsed plasma thrusters

v) colloid thrusters

The low thrust systems described above range in specific impulse from about 1000 sec to about 4000 sec, and are suitable for use in maintaining station.

A main high-level thrust system must also be incorporated in the spacecraft to perform the guidance task during transfer from sub-orbit to geostationary orbit and placement on station.

When using a hydrazine (N_2H_4) gas jet system for this, it is possible to also use the same fuel source for the long term low thrust job provided a N_2H_4 resistojet engine is chosen.

(c) Station-Keeping

Station-keeping manoeuvers will in general entail:

i) an initial removal of E-W drift residual caused by apogee motor or launch booster dispersion.

ii) long term periodic removal of N-S and E-W drifts caused by the earth's gravitational potential, lunar and solar gravitational perturbation, and solar radiation pressure force.

Use of low thrust devices described previously or in combination with passive devices such as steerable adjustable solar sails would be required to counteract the disturbing forces acting on the spacecraft as just described.

The calculation of satellite position for station-keeping will be made from measurements of range (150 m), aximuth (0.01°) and elevation (0.01°).

The use of RF monopulse systems or some form of laser system for range measurement appears to provide greatest promise for accurate determination of satellite position. To enable the station-keeping manoeuvers to be carried out automatically would require a complex of data conditioning and data reduction facilities on the ground working in conjuction with software describing the environment. These would typically be dynamics programs on earth gravitational potential (e.g., Tesseral and Zonal harmonics), lunar and solar forces, etc. Such data and computations would provide continuous accurate mathematical prediction of the orbital elements.

(d) Attitude Sensing and Control

The attitude sensing requirements of the satellite will depend on the method of attitude stabilization and the method of injection of the satellite into synchronous orbit. If an apogee motor is required for injection, then the spacecraft will need to be spinning during the apogee motor burning stage in order to overcome rocket motor thrust misalignment (spin may not be a requirement for the CMG system, because of its large angular momentum storage capabilities).

To control the attitude of the spacecraft during a short term spin phase and the normal long term or on-station non-spinning mode will require the use of two distinct attitude sensing systems using:

i) For the spinning phase
   - earth horizon sensors of the scanning type
   - sun sensors

ii) For the non-spinning phase
   - earth sphere detectors
   - Polaris star sensor for yaw control
   - sun sensors (required for attitude manoeuvers after injection into synchronous orbit and for solar array pointing control).

The actual method of control would make use of a digital controller. A digital approach has the very obvious advantages that one controller using multiplexing can handle the sensing channels of roll, yaw, and pitch, makes rate feedback easier to handle, provides long time constant for better accuracy, and has adaptive features such as for command override, easier decoding, and is amenable to the utlimate prospects of on-board satellite control using a small computer on the satellite. Higher reliability may be achieved with a digital approach than with an analogue.

Of a more immediate time frame a programmer or clock for automatic performance of control functions should be designed into the spacecraft. A programmer could perform repetitive functions such as:

i) sequencing-reaction wheel momentum dumping (achieved by firing thrusters about proper axes, possibly as often as once per day).

ii) biasing star tracker error (constant sine)

iii) where no N-S control capability is provided, programmer could bias antenna pointing on a daily basis (circular periodic) and also bias earth sensor, etc.

iv) step or rotate solar cell panels to track the sun

v) control digital sampling for digital controller

vi) initiate earth eclipse mode operations on commencement of eclipse conditions.

The degree of spacecraft pointing accuracy that is possible to achieve today is very much dependent on the state of development of sensors. At the present, sensor technology sets the limits on achievable accuracy. When sensor noise can be reduced significantly (and there is much evidence of good progress in that direction), then the spacecraft dynamics such as relative flexing of parts etc. will dictate achievable pointing accuracy.

On the subject of sensors, there appears a real need to develop a good yaw sensor (the yaw axis referred to here is the satellite to earth vector). At present, the most practical way to achieve yaw sensing is by use of a Polaris star tracker. Perhaps future developments in bearing technology would make possible a good long lifetime inertial gyro suitable for sensing yaw.

3. SPACECRAFT STRUCTURAL DESIGN

In designs of spacecraft structures, use of advanced composites such as carbon fiber reinforced plastics will be made to achieve improvements in strength to weight ratio.

In the area of expandable structures, the satellites may require

i) roll out solar cell arrays with a total electrical output of several kilowatts and up depending on mission requirements

ii) large unfurlable dish antennas for a UHF band broadcast

New and improved methods of deploying large structures will have to be devised. At present, use is made of telescoping, STEM type, and pantograph actuators. Unfortunately, such mechanisms are heavy and do not provide the desirable degree of structural stiffness.

Structural flexibilities of large erectable appendages and of antenna dishes can also cause problems in spacecraft control. To name a few examples, large structures give rise to problems in the following areas:

i) shadowing of control sensor fields of view (e.g. star tracker in the case of a solar cell panel oriented in a N-S direction)

ii) creates optical reflections that interfere with normal performance of optical sensors and thereby making necessary the design and use of effective light baffles.

iii) natural low frequency modes excited by thruster firing or manoeuvres produces low frequency vibrational motion that are difficult to filter out have to be accounted for in the design and operation of the attitude control system.

iv) problems related to thermal distortion are magnified.

v) can obstruct the optimum placement of thrusters (e.g. considerations of ion engine expellent deposits on solar cell panels, shadowing, etc.)

vi) can create electromagnetic induced torques that are significant and need to be counteracted with expenditure of control fuel.

vii) solar radiation pressure torques are magnified and requires greater expenditure of control fuel for maintaining station and attitude.

4. FLEXIBLE SATELLITE ATTITUDE CONTROL

This area of design is a key technology, and has been a subject of CRC research in flexible body dynamics for some years. The following description of the problem includes some paraphrasing of pertinent statements from ref. 2.

The spacecraft structure is made up of three major components: the solar array, antenna, and spacecraft body. The solar array must be constantly oriented to face the sun, and the antenna must always be pointed towards the Earth. When high power levels are used in conjunction with large antennas, the available space within the launch shroud must be shared between spacecraft body, antenna and solar array. Generally, some structural stiffness and mechanical stability may be sacrificed to reduce the packaging volume. Since the solar array and antenna may be the heaviest subsystems, attempts are made to save weight by reducing the thickness of structural members. Furthermore, when deployed, the solar array may be extended by booms at some distance from the spacecraft body in order to be sufficiently clear of the large antenna. The booms of the foldable array structure would generally be lightweight and semi-flexible.

All of the large flexible structures have little of their total mass allotted for structural stiffness because not much stiffness is ordinarily required in the relatively mild space environment. However, when a large antenna is rotated relative to the spacecraft, for example, an interaction with the attitude control system can occur which may detrimentally affect the attitude control pointing accuracy. Projected TV broadcast satellite requirements anticipate solar array areas up to 3300 square feet and antenna areas up to about 1250 square feet.

Space vehicle motion involves the highly non-linear coupling of rigid body motions with flexible spacecraft deflections. Flexible appendages, such as long rods and hinged members which are usually erected in space, exhibit low natural frequencies which may lie within the attitude control filter bandwidth, resulting in command errors to the attitude controller.

Many studies have been conducted to determine the effects of structural flexibility on spin stabilization and cross-product coupling effects of vehicle parameters. Most aerospace companies and government agencies have expended some level of effort on flexible structure and attitude control interaction. The major problems in this technology area are:

i) minimizing the influence on attitude control accuracy.

ii) application and improvement of current analytical and computational tools to treat this non-linear problem.

iii) study of flexible structure modes of vibration.

iv) definition of structure to assess problems in solar array deployment, antenna beam pointing, beam shaping and deployment, and in attitude control and station-keeping.

v) conducting verification test programs to confirm theoretical predictions (on ground and in space).

Only by adequately developing this technology for high-power broadcast satellites can reliable high performance be assured.

A mission goal might be to develop an attitude and station-keeping capability for highly flexible spacecraft. This task will require that the body of the satellite be instrumented with low level accelerometers for the measurement of the responses, i.e. deformations of the structure, due to control torques and external force fields. These measurements and those from the solar arrays will be used to assist in the development of a tractable mathematical model, convenient for operational use, of the satellite and force field system (including damping from solar arrays and fuel sloshing).

5. THERMAL CONTROL

The slow rotation of the satellite relative to the sun of once every 24 hours, and the heat outputs of the high power SHF and UHF transponders and other high power units will create thermal control problems. The solution to these problems will require the use of advanced temperature control devices.

Thermal control is necessary to maintain proper performance of the two main concentrated heat-producing components of the broadcast satellite; the output transmitter tube (TWT) and its high-voltage power conditioning subsystem. Thermal control in space is restricted by the fact that heat transfer can take place only by direct radiation to space or by a combination of conduction and radiation. In an enclosed heat transfer device such as a heat pipe, convection is also employed; however, such a device is used only as a low temperature-drop technique for transferring the heat from the source to the radiating surface. At higher broadcast frequencies like X-band, additional design difficulties arise because tube electrodes (such as the RF structure and collector segments), which are the primary generators of heat, have extremely small areas from which the heat must be carried away. In addition there is the problem of conduction interface resistance. Active fluid loop methods are unsuitable due to excessive weight and poor long life reliability. The use of copper or aluminum thermal conduction masses generally requires large volume and weight, both of which are undesirable. Alternate approaches might involve direct radiation to space or a suitable heat sink from the high-power tubes or the use of heat pipes.

The heat pipe is an extremely effective, enclosed, thermal conducting device which transfers heat by means of vaporization and convection. Heat pipes have been demonstrated at temperatures ranging from -200°C to 2000°C. Power densities up to 300 watts/in^2 are possible with water as the working fluid. Such heat pipes have been flight proven in several applications, among which were a short duration experiment with an Agena booster for the ATS-A, several months in orbit on GEOS/B, and the cooling of a TWT in the 1969 Mariner launch. Ground-operated heat pipes have been used in tests over a broad range of temperatures and power levels. It is expected that TV broadcast satellite requirements will involve dissipated powers up to 15 kW at a maximum operating temperature of about 500°C, with power densities as high as 2 kW/in^2. By use of high thermally conductive materials between the high-power transmitter tube and the heat pipe to spread the heat over a large area, such high heat flux densities can be reduced down to a level within the capability of heat pipe evaporators.

Current effort consists primarily of thermal design for microwave tubes. All these tube designs have considered the use of heat pipes as the primary means of heat transport. Major problems still existing are the need for better data on maximum heat pipe evaporator capability, heat pipe burnout mechanisms, the electrical interface between tube and heat pipe because of extremely high electrical voltages customarily on the tube electrode or structure being cooled, and the mechanical stresses on the tube due to thermal expansion. Additional effort is therefore necessary in the areas of:

i) Evaporator optimization.

ii) Mechanical alignment of interface between tube and heat pipe (potential damage due to installation, launch vibration, and thermal expansion).

iii) Electrical isolation of high tube potentials.

The most promising technique for the last effort is the use of a ceramic section brazed between tube and heat pipe: however, differential thermal expansion between materials creates a new problem which must first be solved.

6. IMPROVED CONTROL FUEL CARRYING CAPACITY

The obvious trend to use of ion propulsion, or more generally electric propulsion devices, for spacecraft positioning and orientation is aimed at increasing control lifetimes in orbit. In cases needing conventional gas, considerations of storing fuel in structural members and even consuming of structural members as fuel need to be investigated.

7. LAUNCH VEHICLES

The future broadcast satellite will undoubtedly weigh in the vicinity of about 2000 - 3000 lbs. The implication is that launch vehicles like the Titan III-C will become economically competitive (cost $16-20 million in 1970 dollars) and will replace smaller vehicles like the Thor-Delta. Use of the Titan III-C will permit injection of satellites directly into synchronous orbit without the need of an apogee motor and will simplify the complex control systems. Consequently, the full payload capacity of the launch may be utilized for the spacecraft itself.

8. TV BROADCAST SATELLITE TECHNOLOGY PRIORITIES

A technology priority list encompassing all subsystems is conveniently summarized in Fig. 23 of ref. 2. The table is reproduced below for easy reference.

PRIORITY CATEGORY \ SATELLITE CLASS	LOW SOLAR ARRAY POWER (1-3 KW; MID-1970'S)	MEDIUM SOLAR ARRAY POWER (3-10 KW; LATE 1970'S)	HIGH SOLAR ARRAY POWER (10-30 KW; EARLY 1980'S)
FIRST	* High Efficiency Microwave Tube * Ground Receiving Systems * High Voltage Power Conditioning * High Efficiency Gridded Tube * UHF Transmitter Circuits	High Efficiency Microwave Tube Ground Receiving Systems High Voltage Power Conditioning Attitude Control of Flexible Structures Solar Array Deployment High Efficiency Gridded Tube UHF Transmitter Circuits	Attitude Control of Flexible Structures High Efficiency Microwave Tube Ground Receiving Systems High Voltage Power Conditioning Solar Array Deployment High Efficiency Gridded Tube UHF Transmitter Circuits High Voltage Handling High Voltage Solar Array Thermal-Transmitter Interface
SECOND	* Solar Array Deployment High Voltage Handling * Thermal-Transmitter Interface * Heat Pipes * DC Rotary Joint RF Rotary Joint	High Voltage Handling Thermal-Transmitter Interface Heat Pipes DC Rotary Joint RF Rotary Joint High Voltage Solar Array High Power RF Components 2-Axis Solar Array Drive	Heat Pipes DC Rotary Joint RF Rotary Joint High Power RF Components 2-Axis Solar Array Drive Solar Cell & Array Manufacture Reflector Antenna Power Handling Reflector Antenna Beam Pointing Reflector Antenna Multi-Beams Microwave Transmitter Circuits
THIRD	* High Voltage Solar Array * High Power RF Components * Reflector Antenna Power Handling * Reflector Antenna Beam Pointing Reflector Antenna Multi-Beams Microwave Transmitter Circuits	Reflector Antenna Power Handling Reflector Antenna Beam Pointing Reflector Antenna Multi-Beams Microwave Transmitter Circuits Mechanically Steerable Antenna Array	Mechanically Steerable Antenna Array Electronically Steerable Antenna Array

* NOW IN DEVELOPMENT OR BEING STUDIED

REFERENCES

1. "Space Mechanics Program Objectives for the Canadian Applied Technology Satellite" (CRC internal report, November 1969).

2. "Key Technologies for High Power Broadcast Satellites", I. Rutstein, AIAA Paper No. 69-1069, AIAA 6th Annual Meeting and Technical Display, Oct. 20 - 24, 1969.

3. "Auxiliary Propulsion Survey" - AFAPL-TR-68-67 Part III Survey of Secondary Propulsion and Passive Attitude Control System for Spacecraft, Air Force Aero Propulsion Lab., Wright Patterson Air Force Base, Ohio, July 1968.

4. "Satellite Attitude Control Using a Torqued, 2 - Axis - Gimbaled Boom as the Actuator", J.A. Gatlin et al, J. Spacecraft, Vol. 6, No. 9, Sept. 1969, pp. 1013 - 1018.

5. "The SAINT Project", Eugene V. Shapurenko, Editor, NASA - Stanford University Summer Training Program in Systems Engineering, August 1967.

REFERENCES

1. "Space Mechanics Program Objectives for the Canadian Applied Technology Satellite" (CRC internal report, November 1969).

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APPENDIX 9

FM TELEVISION BROADCAST SATELLITE SYSTEM COSTS

NATIONAL COMMUNICATIONS LABORATORY

SATELLITE COMMUNICATIONS SECTION

Dec. 1970

FM Television Broadcast Satellites System Costs

by

P.J. Davidson
B.C. Blevis

FM TELEVISION BROADCAST SATELLITES SYSTEM COSTS

1.0 INTRODUCTION

The purpose of the present study, which was carried out largely during the summer of 1970, was to provide a cost analysis for a television broadcasting system using synchronous satellites in order to permit determination of the relative costs of various systems with varying parameters.

Consideration was given to the frequency range from about 800 MHz to 12 GHz.

A computer programme was developed, modelled on the programme given in a report prepared by the Stanford Research Institute for the Agency for International Development (1). This programme operates in a "conversational" mode deriving, from the typed input values assigned to various parameters, a cost estimate for any given system within the constraints of the programme.

The following sections describe the information, and limitations thereto, on which various portions of the costing programme were based.

2.0 EARTH STATIONS

2.1 Antenna:

A number of reports were studied and considered in respect to their predictions of the cost of various antennas relative to their performance. The variation of cost with antenna diameter and frequency, as given in these reports for quantities of 10^6, is plotted in figure 1. As can be seen, there are large differences among the many curves based on data contained in these reports. The problem thus becomes one of deciding which set of curves was the most likely to be representative of the true costs.

The curve as given by SRI (1) was regarded as being low and takes no account of the variation in cost with frequencies. This variation in cost arises because of the variation in type of construction and cost of installation required at the different frequencies. At UHF, a wire or mesh parabola (or Yagi or helical antenna) can be used, whereas, at X-band, parabolic antennas with solid surfaces having much closer tolerances must be used because of the shorter wavelength. For this same reason, it was felt that the G.E. data (3), for which the same curve was used at 2.5, 8.4, and 12.2 GHz, were unreasonable, a spread such as represented by the TRW curves (2) being more nearly as expected. While the Jansky and Bailey curves (4) did show a variance with frequency, their estimates were considered to be too low when viewed in the light of the more recent TRW and G.E. reports and other information available.

Taking all these factors into consideration, it was concluded that the TRW curves constituted perhaps the most realistic set, having the required frequency variation while still agreeing fairly closely with the G.E. curves at 12 GHz and UHF.

2.2 <u>Receiver</u>:

Various reports were agian studied to try to obtain a realistic cost estimate for the receiver front end and converter which accept the signal picked up by the antenna and allow it to be applied to the RF terminals of a standard television receiver. The problem, as before, was one of having as many different values as there were reports.

The receiver considered was comprised of a front end and frequency (if appropriate) and modulation converter, the basic configuration being that shown in Figure 2.

The cost was expected to vary drastically with receiver noise figure. All of the reports showed such a variation, with the cost increasingly very rapidly for noise figures less than approximately 3 dB. This increase in cost is due to the more sophisticated preamplifier required to obtain a lower noise figure. Figure 3, taken from the Jansky and Bailey (4) report, gives an indication of the various types of receivers which are needed to obtain particular noise figures, ranging from a relatively inexpensive configuration using a balanced mixer with matched diodes to obtain a noise figure of 9-10 dB, to an expensive cooled paramp to achieve noise figures of less than a half dB.

It was also expected, as in figure 3, that receiver cost would increase with frequency. Figure 4, taken from Jansky and Bailey (4), shows the dependence of noise figure on frequency for the various receiver types considered.

Once more, it became a problem of deciding which predictions were most likely to be realistic. The G.E. figures (3) seemed to be inexplicably low when compared with the TRW (2), SRI (1) and Jansky and Bailey (4) reports and were therefore eliminated from further consideration. The SRI figures (1) appeared to be low at higher noise figures and high at lower noise figures. They also showed very little variation in cost with noise figure at UHF. As well, the SRI (1) report showed no variation in cost with frequency above 6 GHz. For these reasons the SRI (1) figures were also considered not representative.

The TRW (2) values appeared fairly realistic as far as they went, but unfortunately the data did not extend to sufficiently low values of the noise figure and a realistic extrapolation could not be made from the few points given.

The Jansky and Bailey (4) report appears to exaggerate the variation in cost with frequency when compared to the variation given by G.E. (3) and TRW (2); particularly as this variation will depend to a large extent on the advancement of technology within any specific frequency band.

It was finally decided to accept for the cost analysis in this study the functional variation given by the Jansky and Bailey curves which seemed not only realistic but justifiable in terms of the various techniques examined by the authors. They went into considerably more detail than the other studies although their data appear to be somewhat dated (1966).

The set of curves used were Jansky and Bailey's 2 GHz, 4 GHz and 6 GHz curves but, due to the exaggerated frequency variation mentioned above, these were applied at .8 GHz, 2.5 GHz and 12 GHz respectively to more closely coincide with the TRW (2) values.

Although this procedure is somewhat arbitrary, it was the only way of arriving at a set of values which yield curves of the expected shape and variance with frequency as well as costs which seemed to be reasonable and possible.

3.0 SATELLITE

The most important consideration from the viewpoint of cost in the design of a satellite is the weight and therefore the solar array power. This determines the size of satellite which must be lifted using present boosters, whose cost increases very rapidly, but discontinuously, with increasing payload in synchronous orbit.

To determine the total launch expense of the space segment, a detailed parametric analysis of each subsystem which goes into the final orbiting satellite should be carried out. In this study some consideration was given to a number of the subsystems including the antenna, power supply, transmitter, attitude control, thermal control and basic structure.

The most critical of these is the power supply as it contributes the greatest proportion to the satellite weight. For this reason, and due to time limitations, it was finally decided that the satellite weight could be calculated with sufficient accuracy for the present purposes from the empirical equation (6):

$$W\ (\mathrm{kg}) \simeq 250 + 110\ P$$

where P is the solar array power in kilowatts. The weight calculated in this manner is intended to take into account the contributions from all subsystems. While the use of this equation may seem arbitrary, it gives results which are in close agreement with the weights calculated from detailed examination of a number of particular FM television broadcasting systems by General Electric [3] and TRW [4].

In calculating the cost of the space segment, use was made of another empirical equation proposed by TRW [4]:

$$C_S\ (\$10^6) = 7.8\ P^{0.405}$$

This model is stated to be reasonably accurate for general planning purposes for satellites having solar array powers of between 2 and 20 kw. As expected, the equation is in close agreement with the detailed calculations carried out by TRW, but gives values somewhat higher than those obtained by

G.E. (3) and less than those in the original SRI program based on spacecraft weight.

Due to the critical importance particularly of the latter equation, a closer look at the weights and costs of individual subsystems might be warranted.

4.0 COMPUTER PROGRAMME

The purpose of the computer programme is to provide a quick method of performing the link calculations for a satellite broadcasting system which satisfied the given requirements, and determining and minimizing the system cost.

The programme can be broken down into two basic portions which comprise the earth station segment and the space segment and the associated cost determination.

The earth station costs are fixed by the system requirements and depend solely on these and the number of stations to be established. These costs are therefore fixed and cannot be optimized.

The space segment costs on the other hand, while fixed to a certain extent by system requirements, vary greatly with the satellite size and number of launches. Thus by distributing the system requirements over more than one satellite the space segment cost can often be substantially reduced. For example, it is more cost effective to use two $20 M boosters from the standard inventory, each with a $10 M satellite than it is to put all the system requirements on one $15 M satellite if it requires a larger standard booster costing $225 M.

The programme thus takes the number of transponders required and optimizes the number of identical satellites which will carry these transponders with the most cost effective number of launches.

Section 4.1 shows a block diagram of the programme; Section 4.2 is a computer listing of the programme; Section 4.3 gives a line by line breakdown of the programme; Appendix B is a sample run of the programme.

4.1 Block Diagram of Computer Programme:

A. Earth Station

1. Receiver Cost
2. Antenna Cost

B. Space Segment

1. Power per channel
2. Power per transponder
3. Weight per transponder
4. Optimization of number of satellites and number of launches

C. Printout

1. All transponders on one satellite
2. Optimum space segment
3. Option to print out other configurations analysed.

4.2 Programme Listing

```
      DIMENSIØN NØRBIT(15,15),BØØSTER(15,15),BØØSDØ(15,15),LIFT(15,15)
      DIMENSIØN SATDØ(15,15),NSATPER(15,15),SWØRBIT(15,15)
      DIMENSIØN ALAUNCHCØST(15,15),NTRAPER(15)
      P=3.14159
  111 WRITE(5,1010)
 1010 FØRMAT(///'         FM TELEVISIØN BRØADCAST SATELLITE CØSTS')
      WRITE(5,1040)
 1040 FØRMAT(/'EARTH STATIØN ANTENNA DIA(FT) ')
      READ(5,1050)DIA
      WRITE(5,1060)
 1060 FØRMAT(/'DØWNLINK FR(MHZ) ')
      READ(5,1050)DFR
      GAIN=.55*P**2*DIA**2*DFR**2/((186*5.28)**2)
      DBGAIN=10*ALØG10(GAIN)
      WRITE(5,1061)DBGAIN
 1061 FØRMAT(/5X,'GAIN ØF EARTH STATIØN ANTENNA =',F6.2,' DB')
 1050 FØRMAT(F10.2)
      WRITE(5,1070)
 1070 FØRMAT(/'TYPE-IN RX NØISE FIGURE IN DB')
      READ(5,1050)RXNØISEFIGURE
      WRITE(5,1320)
 1320 FØRMAT(/'NUMBER ØF RECEIVER STATIØNS')
      READ(5,1050)ST
      EXPØ=0
      IF(ST-1)778,778,776
  776 K=1
      DØ 777 N=1,20
      K=K*2
      IF(K.EQ.ST)GØ TØ 778
  777 IF(K.GT.ST)GØTØ 779
  779 KD=K/2
      STD=ST-KD
      FRACT=STD/KD
      EXPØ=N-1+FRACT
  778 CØNTINUE
      RXNF=RXNØISEFIGURE
      IF(RXNF.LE.4)GØ TØ 9002
      RXCØST=26-.2*(RXNF-4)
      GØ TØ 9005
 9002 IF(RXNF.LT.1)GØ TØ 9003
      RXCØST=.5673214E03-.7175465E03*RXNF+.3663939E03*RXNF**2
     X-.8357576E02*RXNF**3+.7090909E01*RXNF**4
      GØ TØ 9005
 9003 IF(RXNF.LT..5)GØ TØ 9004
```

```
          RXCOST=330-380*(RXNF-.5)
          GO TO 9005
    9004  RXCOST=330+158680*(.5-RXNF)
    9005  IF(DFR.GT.800)GO TO 9006
          GO TO 9998
    9006  LRXCOST=RXCOST
          DFRDIF=(DFR-800)/(2500-800)
          IF(RXNF.LT.6)GO TO 9007
          RXCOST=29-(5/8)*(RXNF-6)
          GO TO 9009
    9007  IF(RXNF.LT.1)GO TO 9008
          RXCOST=.7309714E03-.5516818E03*RXNF+.1650000E03*RXNF**2
         X-.2184848E02*RXNF**3+.1069697E01*RXNF**4
          GO TO 9009
    9008  RXCOST=330+780*(1-RXNF)
    9009  IF(DFR.GT.2500)GO TO 9010
          GO TO 9999
    9010  LRXCOST=RXCOST
          DFRDIF=(DFR-2500)/(12000-2500)
          IF(RXNF.LT.9)GO TO 9011
          RXCOST=32-.4*(RXNF-9)
          GO TO 9999
    9011  IF(RXNF.LT.2)GO TO 9012
          RXCOST=.6863720E03-.3597744E03*RXNF+.7692093E02*RXNF**2
         X-.7401199E01*RXNF**3+.2665720E00*RXNF**4
          GO TO 9999
    9012  RXCOST=220+520*(2-RXNF)
          GO TO 9999
    9998  RXCOST=2*RXCOST
          GO TO 9997
    9999  RXDIF=RXCOST-LRXCOST
          RXCOST=2*(LRXCOST+DFRDIF*RXDIF)
    9997  CONTINUE
          RXCOST=RXCOST/(.85**(19.93156856-EXPO))
          WRITE(5,1380)RXCOST
    1380  FORMAT(/5X,'COST OF RECEIVER = $',F8.1)
          ANTENNA$=29.74603+4.310847*DIA-1.042659*DIA**2+.1608796*DIA**3
          IF(DFR.GT.900)GO TO 451
          GO TO 456
     451  HFANT$=43.96825+12.60582*DIA-2.073413*DIA**2+.2662037*DIA**3
          IF(DFR.GT.2500)GO TO 452
          LFANT$=ANTENNA$
          DFRDIF=(DFR-900)/(2500-900)
          GO TO 453
     452  LFANT$=HFANT$
```

```
      HFANT$=158.2381+2.896825*DIA-.5208333*DIA**2+.2951389*DIA**3
      IF(DFR.GT.8500)GO TO 454
      DFRDIF=(DFR-2500)/(8500-2500)
      GO TO 453
454   LFANT$=HFANT$
      HFANT$=183.9048+1.984127*DIA-1.845238*DIA**2+.6944444*DIA**3
      DFRDIF=(DFR-8500)/(12000-8500)
453   ANT$DIF=HFANT$-LFANT$
      ANTENNA$=LFANT$+DFRDIF*ANT$DIF
456   QUANTITY=ANTENNA$/(.85**(19.93156856-EXPO))
      WRITE(5,1370)QUANTITY
1370  FORMAT(/5X,'COST OF AN ANTENNA BOUGHT IN QUANTITY= $',F8.1)
      STADO=RXCOST+QUANTITY
      WRITE(5,1390)STADO
1390  FORMAT(/5X,'COST OF ONE STATION= $',F10.2)
      TEMP=((EXP(RXNOISEFIGURE*.230259))-1)*290
      IF(DFR.GT.890)GO TO 1504
      WRITE(5,1080)
1080  FORMAT(/'SPECIFY RX ENVIRONMENT'/'TYPE 1 FOR COUNTRYSIDE 2 FOR SUB
     1URBS 3 FOR URBAN NOISY')
      READ(5,1031)NOISE
      GO TO(501,502,503)NOISE
1031  FORMAT(I1)
501   TEMP=TEMP+50
      GOTO 504
502   TEMP=TEMP+400
      GOTO 504
503   TEMP=TEMP+1100
      GO TO 504
1504  WRITE(5,1089)
1089  FORMAT(/'SPECIFY ANTENNA NOISE TEMP IN DEGREES KELVIN')
      READ(5,1050)ANTEMP
      TEMP=TEMP+ANTEMP
504   WRITE(5,1090)
1090  FORMAT(/'REQUIRED PEAK TO PEAK/WEIGHTED RMS NOISE RATIO '/'BROADCA
     1ST QUALITY:32=PASSABLE,40=GOOD,50=EXCELLENT')
      READ(5,1050)REQSN
      WRITE(5,1101)
1101  FORMAT(/'SPECIFY MINIMUM CARRIER/NOISE INCLUDING THRESHOLD MARGIN)
     1')
      READ(5,1050)CNMIN
      WRITE(5,1102)
1102  FORMAT(/'SPECIFY BASEBAND IN MHZ E.G.4.2 MHZ FOR A 525 LINE SYSTEM)
     1M')
      READ(5,1050)BBAND
```

```
      BBAND=BBAND*1E6
      WRITE(5,1103)
 1103 FØRMAT(/'SPECIFY WEIGHTING FACTØR AND ALLØWANCE FØR PREEMPHASIS AS
     1 TØTAL'/'E.G.10.2+2.5=12.7 FØR 525 LINE MØNØCHRØME',
     2/,'     10.0 FØR 525 LINE CØLØUR')
      READ(5,1050)WFPRE
      WRITE(5,1104)
 1104 FØRMAT(/'SPECIFY ALLØWANCE FØR PRØPAGATIØN ATTENUATIØN IN DB')
      READ(5,1050)ATTEN
      FMI=REDSN-CNMIN-WFPRE-6.0
      PD=1E6
  100 PD=PD*1.1
      FMØD=(PD/BBAND)
      FMIMP=10*ALØG10(3.)+20*ALØG10(FMØD)+10*ALØG10(1+FMØD)
      IF(FMI-FMIMP)110,110,100
  110 CØNTINUE
      RB=2*(BBAND+PD)
      RADIØBAND=RB/1E6
      R1=RADIØBAND
      WRITE(5,1111)R1
 1111 FØRMAT(/5X,'VIDEØ RF BANDWIDTH-MHZ=',F9.2)
      XKTB=-228.6+10*ALØG10(RB*TEMP)
      VICARRIER PØWER=XKTB+CNMIN+ATTEN
      WRITE(5,1100)
 1100 FØRMAT(/'NØ.ØF VIDEØ CHANNELS PER TRANSPØNDER ')
      READ(5,1050)V
      WRITE(5,1105)
 1105 FØRMAT(/'NØ. ØF TRANSPØNDERS (LIMIT ØF 15)')
      READ(5,1050)TR
      WRITE(5,1110)
 1110 FØRMAT(/'NUMBER ØF AUDIØ CHANNELS PER UIDEØ')
      READ(5,1050)PR
      B=15E3*PR+12E3
      U=15E3*PR/4E3
  180 RMS=-1+(4*.4343)*ALØG(U)
      PF=13+6/U
      PP=RMS+PF
      TD=1E4
   11 TD=TD*1.1
      PD=TD*SQRT(EXP(PP*.230259))
      RB=2*(PD+B)
      XM=(TD/B)**2
      FR=RB/6200
      EXTRA=4.343*ALØG(FR*XM)
      XKTB=-228.6+4.343*ALØG(RB*TEMP)
```

```
      IF(PD-B)22,20,20
   20 F=PD
      GØ TØ 77
   22 F=B
   77 T=10-4.343*ALØG(RB/(2*F))
      AUDIØPWR=X*TP+T
      SN=T+EXTRA+2.5
      IF(SN-45.)11,11,10
   10 TD=TD/1000
      RADIØBAND=RB/1E6
      R2=RADIØBAND
      RADIØBAND=V*(R1+R2)
      WRITE(5,1120)RADIØBAND
 1120 FØRMAT(/5X,'TRANSPØNDER RF BANDWIDTH-MHZ=',F8.1)
      SBB=V*(R1+R2+5)*TR
      WRITE(5,1330)SBB
 1330 FØRMAT(/5X,'SATELLITE RF BANDWIDTH-MHZ=',F8.1)
      RXGAIN=8.686*ALØG(P*DIA*30.5*DFR/3E4)-3
    2 H=22289
    3 XN=3E4/(DFR*30.5)
      DEN=4*P*H
      XISØTR=74.44+8.686*ALØG(DEN/XN)
      WRITE(5,1139)
 1139 FØRMAT(/'ANTENNA CØVERAGE  TYPE 1 IF ELLIPTICAL BEAM;'
     X'2 IF CIRCULAR BEAM')
      WRITE(5,1138)
 1138 FØRMAT('NØTE: IF MØRE THAN ØNE TRANSPØNDER,ALL ANTENNAS HAVE '
     X'SAME CØVERAGE')
      READ(5,1031)NØPTIØN
      GØ TØ (4,5)NØPTIØN
    4 WRITE(5,1140)
 1140 FØRMAT(/'TYPE ANTENNA BEAMWIDTH IN DEGREES X DEGREES'
     X' (ØN SEPARATE LINES')
      READ(5,1050)X
      READ(5,1050)Y
      SG1=10*ALØG10(27000/(X**2))
      SG1=EXP(SG1*.230259)
      SG2=10*ALØG10(27000/(Y**2))
      SG2=EXP(SG2*.230259)
      SDIA1=SQRT(SG1*((186*5.28*1E6)**2)/((P**2)*(DFR**2)*1E12*.55))
      SDIA2=SQRT(SG2*((186*5.28*1E6)**2)/((P**2)*(DFR**2)*1E12*.55))
      THETA=SQRT(X*Y)
      GØ TØ 6
    5 WRITE(5,1151)
 1151 FØRMAT(/'TYPE ANTENNA BEAMWIDTH IN DEGREES(CIRCULAR BEAM)')
```

```
          READ(5,1050)THETA
      6   SG=10*ALØG10(27000/(THETA**2))
          SG0=EXP(SG*.230259)
          SDIA=SQRT(SG0*((186*5.28*1E6)**2)/((P**2)*(DFR**2)*1E12*.55))
          GØ TØ (4001,4002),NØPTIØN
   4001   WRITE(5,4003)SDIA1,SDIA2
   4003   FØRMAT(/5X,'SATELLITE ANTENNA SIZE= ',F6.2,' FT. X ',F6.2,' FT.')
          GØ TØ 4004
   4002   WRITE(5,1171)SDIA
   1171   FØRMAT(/5X,'SATELLITE ANTENNA DIAMETER=',F6.2,'FT')
   4004   PLØSS=XISØTR+3-RXGAIN-SG
          VIPWR=VICARRIER PØWER+PLØSS
          VICHN=EXP(VIPWR*.230259)
          WRITE(5,4005)VICHN
   4005   FØRMAT(/5X,'VIDEØ PØWER PER CHANNEL= ',F8.1,' WATTS')
          AUDPWR=AUDIØPWR+PLØSS
          AUDCHN=FR*EXP(AUDPWR*.230259)
          WATTS=(VICHN+AUDCHN)*V*EXP(2*.230259)
          WRITE(5,1170)WATTS
   1170   FØRMAT(/5X,'SAT PØWER PER TRANSPØNDER=',F8.1,'WATTS',
         X/,5X,'(INCLUDES 2DB BACKØFF ALLØWANCE)')
          IF(DFR.LE.1500)RHØ=.2260714E02+.2161905E02*ALØG10(WATTS)-.2523810E
         X01*ALØG10(WATTS)**2
          IF((DFR.LE.5000).AND.(DFR.GT.1500))RHØ=.1217857E02+.2494048E02*ALØ
         XG10(WATTS)-.2880952E01*ALØG10(WATTS)**2
          IF(DFR.GT.5000)RHØ=.1492857E02+.2205952E02*ALØG10(WATTS)-.2690476E
         X01*ALØG10(WATTS)**2
          RHØ=(RHØ/100)*.85
          WP=WATTS/(1000.*RHØ)
          TRWEIGHT=550.+240.*WP
          WRITE(5,1174)TRWEIGHT
   1174   FØRMAT(/5X,'WEIGHT PER TRANSPØNDER, INC. ANTENNA=',F8.1,'LBS.')
          KØUNT=1
          IBEST=1
          NNTR=TR
          DØ 8099 ISAT=1,NNTR
          NTR=TR
   8003   NTR=NTR-ISAT
          IF(NTR)8001,8002,8003
   8001   NTRAPER(ISAT)=TR/ISAT+1
          GØ TØ 8004
   8002   NTRAPER(ISAT)=TR/ISAT
   8004   CØNTINUE
          DØ 8099 IB=1,ISAT
          NSAT=ISAT
```

```
3003  NSAT=NSAT-IB
      IF(NSAT)3001,3002,3003
3001  NSATPER(ISAT,IB)=ISAT/IB+1
      GØ TØ 3004
3002  NSATPER(ISAT,IB)=ISAT/IB
3004  CØNTINUE
      SWØRBIT(ISAT,IB)=(NTRAPER(ISAT)*(TRWEIGHT)+50)
      WØRBIT(ISAT,IB)=SWØRBIT(ISAT,IB)*NSATPER(ISAT,IB)
      SATDØ(ISAT,IB)=7.8*((WP*NTRAPER(ISAT))**0.405)
      IF(WØRBIT(ISAT,IB).LT.45)BØØSTER(ISAT,IB)=1
      IF(WØRBIT(ISAT,IB).GT.45)BØØSTER(ISAT,IB)=2
      IF(WØRBIT(ISAT,IB).GT.700.)BØØSTER(ISAT,IB)=3
      IF(WØRBIT(ISAT,IB).GT.1200)BØØSTER(ISAT,IB)=4
      IF(WØRBIT(ISAT,IB).GT.2.E3)BØØSTER(ISAT,IB)=5
      IF(WØRBIT(ISAT,IB).GT.4500)BØØSTER(ISAT,IB)=6
      IF(WØRBIT(ISAT,IB).GT.50E3)GØ TØ 8005
      GØ TØ (8011,8012,8013,8014,8015,8016),BØØSTER(ISAT,IB)
8011  BØØSDØ(ISAT,IB)=3.5
      LIFT(ISAT,IB)=45
      GØ TØ 8017
8012  BØØSDØ(ISAT,IB)=6
      LIFT(ISAT,IB)=700
      GØ TØ 8017
8013  BØØSDØ(ISAT,IB)=10
      LIFT(ISAT,IB)=1200
      GØ TØ 8017
8014  BØØSDØ(ISAT,IB)=16
      LIFT(ISAT,IB)=2E3
      GØ TØ 8017
8015  BØØSDØ(ISAT,IB)=20
      LIFT(ISAT,IB)=4500
      GØ TØ 8017
8016  BØØSDØ(ISAT,IB)=225
      LIFT(ISAT,IB)=50E3
8017  ALAUNCHCØST(ISAT,IB)=IB*(SATDØ(ISAT,IB)*NSATPER(ISAT,IB)+BØØSDØ(IS
     XAT,IB))
      IF(ALAUNCHCØST(ISAT,IB).LT.ALAUNCHCØST(KØUNT,IBEST))GØ TØ 8888
      GØ TØ 8099
8888  KØUNT=ISAT
      IBEST=IB
      GØ TØ 8099
8005  WRITE(5,8088)NTRAPER(ISAT)
8088  FØRMAT(//'NØ STD. BØØSTER CAN LIFT',F3.0,'TRANSPØNDERS ØN 1 SAT.')
8099  CØNTINUE
      WRITE(5,6001)
```

```
6001  FØRMAT(//,22X,'******************************')
      KK=1
      NNB=1
      KKT=1
      GØ TØ 6002
7000  KK=KØUNT
      NNB=IBEST
      KKT=2
      WRITE(5,7001)
7001  FØRMAT(22X,'***ØPTIMUM SPACE SEGMENT***')
      WRITE(5,7002)KØUNT,NTRAPER(KØUNT),NSATPER(KØUNT,NNB)
7002  FØRMAT(/'CØNSISTS ØF ',I4,' SATELLITES WITH',I4,
     X' TRANSPØNDERS PER SATELLITE AND',I4,' SATELLITES PER BØØSTER')
      WRITE(5,7003)
7003  FØRMAT(/'FØR EACH SATELLITE:')
      GØ TØ 6003
6002  WRITE(5,6004)
6004  FØRMAT(/,'FØR ALL TRANSPØNDERS ØN ØNE SATELLITE:')
      GØ TØ 6003
7777  WRITE(5,7077)
7077  FØRMAT(//'DØ YØU WISH TØ HAVE DATA PRINTED ØUT FØR ØTHER',
     1' CØNFIGURATIØNS  ',/,'TYPE 1 IF YES, 2 IF NØ.')
      READ(5,1050)CHØICE
      GØ TØ (6011,999),CHØICE
6011  DØ 6666 KK=2,NNTR
      DØ 6666 NNB=1,KK
      IF((KK.EQ.KØUNT).AND.(NNB.EQ.IBEST))GØ TØ 6666
      WRITE(5,6009)KK
6009  FØRMAT(//,10X,'BASED ØN MINIMUM ØF ',I3,' SATELLITES')
6010  WRITE(5,6012)NNB,NTRAPER(KK),NSATPER(KK,NNB)
6012  FØRMAT(//'FØR ',I3,' LAUNCHES WITH ',I3,' TRANSPØNDERS PER '
     1'SATELLITE AND',I4,' SATELLITES PER BØØSTER')
      KKT=3
6003  TWATTS=NTRAPER(KK)*WATTS
      WRITE(5,1173)TWATTS
1173  FØRMAT(/,7X,'TØTAL PØWER PER SATELLITE=',F8.1,' WATTS')
      WRITE(5,1172)SWØRBIT(KK,NNB)
1172  FØRMAT(/,7X,'USEFUL SPACECRAFT WEIGHT=',F8.1,'PØUNDS')
      WRITE(5,1190)SATDØ(KK,NNB)
1190  FØRMAT(/,7X,'SATELLITE CØST $MILLIØNS=',F8.1)
      WRITE(5,1191)WØRBIT(KK,NNB)
1191  FØRMAT(/,7X,'BØØSTER USEFUL PAYLØAD= ',F8.1,' PØUNDS')
      PØUNDS=2.25*WØRBIT(KK,NNB)
      WRITE(5,1180)PØUNDS
1180  FØRMAT(/,7X,'PAYLØAD TRANSFER ØRBIT WEIGHT=',F8.1,' PØUNDS'/)
```

```
          GØ TØ (7011,7012,7013,7014,7015,7016),BØØSTER(KK,NNB)
   7011   WRITE(5,7021)
   7021   FØRMAT(7X,'BØØSTER: THRUST AUGMENTED DELTA')
          GØ TØ 7017
   7012   WRITE(5,7022)
   7022   FØRMAT(7X,'BØØSTER: THØR DELTA')
          GØ TØ 7017
   7013   WRITE(5,7023)
   7023   FØRMAT(7X,'BØØSTER: ATLAS-AGENA')
          GØ TØ 7017
   7014   WRITE(5,7024)
   7024   FØRMAT(7X,'BØØSTER: ATLAS-CENTAUR')
          GØ TØ 7017
   7015   WRITE(5,7025)
   7025   FØRMAT(7X,'BØØSTER: TITAN IIIC-TRST')
          GØ TØ 7017
   7016   WRITE(5,7026)
   7026   FØRMAT(7X,'BØØSTER: SATURN V')
   7017   CØNTINUE
     28   WRITE(5,1270)LIFT(KK,NNB)
   1270   FØRMAT(/,7X,'BØØSTER CAN LIFT',F8.0,' PØUNDS INTØ SYNCHRØNØUS ØRBI
         XT')
          WRITE(5,1310)BØØSDØ(KK,NNB)
   1310   FØRMAT(/,7X,'THE BØØSTER CØSTS',F8.1,'$ MILLIØNS FØR ØNE')
          TØTAL=ALAUNCHCØST(KK,NNB)+(STADØ*ST/1E6)
          STADØ$=STADØ*ST/1E6
          WRITE(5,1430)TØTAL
   1430   FØRMAT(/,'SYSTEMS CØST (EXCLUDING UPLINK AND DEVELØPMENT)='
         X,F8.1,'$ MILLIØNS')
          WRITE(5,1432)ALAUNCHCØST(KK,NNB),NNB,STADØ$,ST
   1432   FØRMAT('INCLUDES:',F9.2,' $M FØR',I4,' LAUNCHES',
         1/,9X,F9.2,' $M FØR',F8.0,' STATIØNS'//)
          IF(TR-1)999,999,5555
   5555   GØ TØ (7000,7777,6666),KKT
   6666   CØNTINUE
    999   CØNTINUE
          WRITE(5,1431)
   1431   FØRMAT(///,5X,'DØ YØU WISH TØ GØ AGAIN '/'TYPE 1 IF YES'/
         1'      2 IF NØ')
          READ(5,1031)IQUERY
          IF(IQUERY-1)998,111,998
    998   CØNTINUE
          STØP
          END
```

4.3 Description of Cost Programme

Line Number	Description
1-3	Sets up the matrices to be used in the cost optimization routine.
4	The value of π is equal to 3.14159.
5-6	Title is typed out.
7-12	User types in the earth station antenna diameter in feet (DIA) and the downlink frequency in MHz (DFR).
13-16	The gain of the earth station antenna is calculated, converted to dB and typed out on the terminal.
18-23	User types in the receiver noise figure in dB (RXNØISEFIGURE) and the number of receiver stations (ST).
24-35	A number, EXPØ, is established corresponding to the exponent to the base 2 of the quantity procured (i.e. the number of times the quantity is doubled). This is used in converting back to a given quantity of a component given the cost for a quantity of one million. (see lines 78 & 99)
36	RXNF is set equal to RXNOISEFIGURE for convenience in the following calculations.
37-80	The cost of the receiver is calculated as a function of the receiver noise figure and the downlink frequency. The different equations at different frequencies correspond to the Jansky & Bailey curves as discussed in section 2.2 of this report. (see Fig. 4). Curve fitting was used to obtain these equations by breaking each curve into several segments and using the method of least squares to fit a polynomial to the curved portions. The equations are for 800 MHz (lines 37-47), 2.5 GHz (lines 52-59) and 12 GHz (lines 64-71). For frequencies less than 800 MHz, the cost is taken to be the same as for 800 MHz. For frequencies between 800 MHz and 12 GHz, and not falling on any of the three

curves, a linear interpolation is done between the two nearest frequencies. For values greater than 12 GHz a linear extrapolation was used to obtain cost figures.

The values obtained from these equations are the production cost for a quantity of 10^6 receivers. To arrive at the retail cost for the given quantity requires two more steps. First, the production cost is doubled to give the retail cost. Next an 85% learning curve is applied to arrive at the cost of the given quantity from a quantity of 10^6 (line 78). [19.93157 represents the exponent to which the base 2 must be raised to reach 10^6]. An 85% learning curve was considered to be used most frequently by electronics manufacturers (see Jansky & Bailey (4)].

Lines 79-80 then type out the cost of a receiver on the user terminal.

81-101 A similar procedure was used to arrive at the cost of the antenna for the earth station as a function of frequency and antenna diameter. The equations used are a least squares fit to the curves as chosen in section 2.1 of this report and shown in tabled 10.1 to 10.4 of the TRW report (2) and plotted in Figure 5. Note however that the cost calculated by the equations in this case is the actual retail cost of an installed antenna so the factor of 2 is omitted. Also, in this case, a single equation was found to adequately fit the data over its entire length. Calculated points shown on Figure 3 indicate the closeness of fit obtained with these equations.

Lines 100 and 101 then cause the cost of an antenna bought in the given quantity to be typed out on the user terminal.

102-104 The cost of one station is calculated as the sum of the cost of the receiver and the earth station antenna and typed out on the user terminal.

105 The receiver noisefigure in dB is converted to receiver noise temperature in degrees Kelvin.

106-118 If the downlink frequency is less than or equal to 890 MHz the user is asked to specify the receiver environment. If the environment is rural, 50^{o} is added to the receiver noise temperature, if suburban 400^{o}, if urban noisy 110^{o}.

119-122 If the downlink frequency is greater than 890 MHz, the programme goes to line 119 where the user is asked to specify antenna noise temperature in degrees Kelvin. This is then added on to the receiver noise temperature to arrive at the system noise temperature.

123-126 The user is asked to specify required peak-to-peak luminance signal to weighted r.m.s. noise ratio in dB. The broadcast quality used is 32 for an acceptable picture (TASO 3), 40 for a good picture (TASO 2) and 50 for an excellent picture (TASO 1).

127-130 The minimum carrier-to-noise ratio including any required threshold margin is typed in.

131-135 The baseband is specified in MHz and this is then converted to Hz.

136-140 The user is asked to specify the weighting factor and allowance for pre-emphasis as a total (dB). 12.7 is suggested for 525 line monochrome; 10.0 for 525 line colour.

141-143 The allowance for propagation attenuation is specified in dB.

144 The required FM improvement factor (FMI) is calculated as (the required peak-to-peak signal weighted r.m.s. noise ratio) minus (the minimum carrier/noise including threshold margin) minus (the weighting factor plus allowance for pre-emphasis) minus (6 dB, which is the conversion between peak-to-peak and r.m.s. values less an allowance for the sync peaks.

145-150 Statement 100 is the beginning of a loop in which the peak deviation (set to be 1 MHz as a starting value in line 145) is gradually increased until the FM improvement factor, calculated by using the peak deviation (lines 147-148), is greater than or equal to the required FM improvement.

151-155 The video r.f. bandwidth is then calculated using Carson's rule. This is then converted to MHz and displayed on the user terminal.

156 The thermal noise in the r.f. bandwidth is then calculated.

157 The video carrier power is calculated as the sum of the receiver noise power, the minimum C/N ratio including threshold margin, and the allowance for propagation attenuation.

158-160 User is asked to specify the number of video channels per transponder.

161-163 The number of transponders is then given. There is a limiting value of 15 due to the dimensions of the array used.

164-166 User is asked to input the number of audio channels required for each video channel.

167-168 The total audio baseband is then calculated as (15 KHz times the number of audio channels per video) plus (12 KHz at the bottom of the baseband). The number of equivalent voice channels is determined by dividing the baseband (above 12 KHz) by 4 KHz.

169-171 Statement 180 calculates RMS, the CCITT loading formula, 4 log (no. of channels) -1. The peak factor is established as 13 dB plus an allowance for small numbers of channels which is then added to RMS to obtain the peak power.

172-173 The test deviation is first set at 10 KHz in preparation for a loop that increases the test deviation until the user requirements are met.

174-176 The peak deviation is then given as the amplitude of a sinewave, the peak power of which is equal to the peak power of all the audio channels. Carson's rule is used to calculate the audio bandwidth, and the square of the modulation index, XM, is determined.

177-178 The bandwidth improvement, FR, is calculated. This is equal to the audio bandwidth divided by twice the bandwidth of the voice channels and is multiplied by the square of the modulation index.

179 The noise power is calculated from the audio bandwidth.

186-183 The threshold improvement is calculated according to the paper by Enloe (<u>Proceedings of IRE, 50</u>, Jan. 1962) which says that the audio bandwidth must be greater than the larger of either (1) twice the baseband, or (2) twice the peak deviation.

184 Threshold (T) is 10 dB minus the threshold improvement, which is ten times the logarithm of the ratio of radio bandwidth to twice the filter bandwidth.

185 The required audio power is then the sum of the noise power and threshold.

186 The signal to noise ratio is calculated as the sum of threshold, the modulation improvement, and a 2.5 dB weighting factor.

187 Checks to see if the calculated signal-to-noise ratio is larger than the required test tone to noise ratio of 45 dB. If it is, the programme is sent out of the loop to statement 10.

188 The test deviation is converted to KHz.

189-190 The audio bandwidth is converted to MHz and saved as R2.

191-193 The transponder RF bandwidth is then calculated as the number of video channels per transponder times the sum of the video and the audio r.f. bandwidths. This is displayed at the user terminal.

194-196 The required satellite bandwidth, in MHz, is calculated as the product of the number of video channels, per transponder, the number of transponders, and the sum of the video bandwidth, the audio bandwidth and a 5 MHz guard band for each channel. This is then typed out on the user terminal.

197 The gain of the receiving antenna is calculated.

198 The height of synchronous orbit (H) is set as 22, 289 statute miles.

199-201 The free space path loss between isotropic radiators is then calculated.

202-209 The user is given the option of specifying either an elliptical or circular satellite antenna beam.

210-214 If the user chooses to use an elliptical beam the programme goes to statement 4 and the user is requested to type in the beamwidth in degrees by degrees.

215-220 The gain of the equivalent circular antennas having beamwidths corresponding to that of each axis is calculated. These gains are then used to calculate the diameters of the equivalent circular antennas.

221-222 The beamwidth of an equivalent circular antenna is calculated as the square root of the two beamwidths of the elliptical antenna. The programme then skips over the circular beamwidth calculations and continues.

223-225 If the user chooses a circular beam instead, the programme skips lines 210-222 and goes to statement 5 where the user is requested to type in the beamwidth in degrees.

226-227 In either case the programme then arrives at statement 6 where the gain of the satellite antenna is calculated in dB and then converted to a power ratio.

228 The diameter of a circular antenna having this gain is then calculated.

229-234 If an elliptical beam was chosen, the programme goes to statement 4001 and types out the size of the elliptical antenna.

If a circular beam was chosen, the programme goes to statement 4002 and types out the diameter of the circular antenna.

235 The path loss is calculated as the sum of the path loss between isotropic antennas plus a 3 dB allowance for loss of gain at the edge of the antenna beam minus the sum of the two antenna gains.

236-239 The required video r.f. power per channel at the satellite is calculated as the sum of the sum of the video carrier power plus the path loss, converted to watts and printed out.

240-241 The power per audio channel is calculated as the sum of the audio carrier power plus the path loss. This is then converted to watts and multiplied by the number of audio channels per video to arrive at the audio power per video channel.

242-245 The satellite power per transponder is then the sum of the video power and the audio power per video channel times the number of video channels per transponders. This is then increased by a 2 dB TWT margin for power amplifier back-off and printed out.

246-252 The required solar array power depends on the conversion efficiency from the D.C. power at the input to the transmitter to the total RF power output to the antenna.

The values used in the programme are based on data taken from the curves in Figure 5.2.9 of the G.E. study (3). These curves were fitted using using least squares techniques.

The curve for crossed field amplifiers (UHF/FM) was used for downlink frequencies less than or equal to 1500 MHz; the curve for LINEAR BEAM S-BAND FM was used for downlink frequencies less than or equal to 5000 MHz but greater than 1500 MHz; the curve marked LINEAR BEAM X-BAND AND FM was used for downlink frequencies greater than 5000 MHz.

In line 252 this is converted to a decimal and multiplied by .85, to account for the efficiency of the power converter.

253-256 The required solar array power is calculated and the weight per transponder is determined using the empirical equation

$$W \text{ (Pounds)} \simeq 550 + 240 P \text{ (kilowatts)}$$

taken from CCIR Report 215-2 (5) and including the contributions of all subsystems. The transponder weight is then printed out.

257-259 The programme prepares for a loop (lines 260-313) which will optimize the number of satellites and number of launches to be used.

KOUNT is an integer used to keep track of the optimum system from the point of view of number of satellites to be used.

IBEST is an integer used to keep track of the optimum system from the point of view of number of launches to be used.

NNTR is the integer value of the number of transponders and serves as a limit on the loop.

The basic philosophy of this optimization routine was that all satellites should be identical and therefore all should have the same number of transponders. This can lead to more transponders than required, but it is considered to be cheaper to make all satellites identical than to attempt to fit different numbers of transponders on different satellites particularly when regard is given to the large initial outlay in designing specific satellites.

An additional advantage of this was the possibility of having a spare transponder in the event of failure.

The loop starts with all transponders on one satellite and increments the number of satellites by one until there is one transponder per satellite.

For each number of satellites there is a loop within the loop which optimizes the number of satellites to be put on a booster; starting with all satellites on one booster and incrementing the number of boosters by one until there is one satellite per booster.

All these possible combinations are stored in an array for later examination if wished, and the optimum cost system is stored as (KOUNT, IBEST).

260 Line 260 is the starting point in the loop and begins by setting ISAT (the number of satellites) equal to one and terminates the loop when the number of satellies equals NNTR (the number of transponders) i.e. when there is one transponder per satellite.

261 Line 261 prepares for a loop (lines 262-267) to calculate the number of transponders per satellite (NTRAPPER) by setting an integer NTR equal to the total number of transponders which has been inserted by the user.

262-267 The number of transponders per satellite is calculated by subtracting the number of satellites (ISAT) from the total number of transponders required (NTR) until the result (NTR) is either zero or negative. If the answer is zero it means the number of satellites will divide evenly into the number of transponders (line 266). If it is negative, the number of satellites will not go evenly into the number of transponders and the number of transponders per satellite must be set equal to the next highest integer in order to get at least the minimum required number of transponders (line 264). In these cases, there will be extra transponders but this is in keeping with the decision to have identical satellites as explained above.

269 Line 269 is the start of a second optimization routine (lines 269-313) within the main optimization routine, in which the optimum number of satellites to go on each booster is calculated. It starts with all satellites on one booster and ends when there is one satellite per booster (i.e. when the number of boosters equals the number of satellites).

270-275 Lines 270-275 utilize a similar procedure to that used in lines 261-267, to calculate the number of satellites per booster.

276 The weight of one satellite (SWØRBIT) is calculated as the transponder weight times the number of transponders plus an allowance of 50 lbs. of basic structure weight.

277 The useful payload of the booster is then the weight of one satellite times the number of satellites per booster.

278 The cost of one satellite (SATDØ) is calculated as a function of the solar array power using the equation

$$C_S = 7.8\ P^{0.405}$$

derived in the TRW report (2).

279-284 A booster number is assigned based on the useful payload.

285 If the useful payload exceeds the carrying capacity of the largest booster (50,000 lbs) the programme is sent to statement

8005 (line 311) where a message is typed out on the user terminal to indicate that no standard booster can lift the payload. The programme then goes back to the beginning of the loop (line 269).

286-303 The cost of the booster (BØØSDØ) and the maximum lift capacity (LIFT) of the booster is assigned depending on the booster number determined in lines 279-284.

304-305 The launch cost of the total system (ALAUNCHCØST) is then the number of boosters (IB) times the sum of the cost per satellite times the number of satellites per booster and the cost of the booster.

306-310 The launch cost of the present system (ALAUNCHCØST (ISAT,IB)) is compared with that of the most cost effective system to that point in the loop (ALAUNCHCØST (KØUNT, IBEST)). If the cost of the present system is less than the cost of the previously most efficient system, the programme is sent to statement 8888 where the integers KØUNT and IBEST are set equal to the values of the present system. If not, the programme retains the values of KØUNT and IBEST and steps to the next point in the loop.

316-319 KK is a subscript corresponding to the first subscript established by line 260 of the programme; NNB is a subscript corresponding to the second subscript established by line 269 of the programme; KKT is an integer used to keep track of the stage of printout. All of these are set equal to one for the first stage of the printout which starts at statement 6002 (line 331).

331-332 The first stage of the printout (KKT = 1) is for all transponders on one satellite (i.e. the first loop of the optimization procedure which has one satellite (KK=1) and one booster (NNB=1). The system printout calculations and statements begin at statement 6003 (line 348).

348-350 The total power per satellite is calculated as the number of transponders per satellite times the number of watts per transponder and printed out.

351-352 The useful spacecraft weight is printed out.

353-354 The satellite cost in millions of dollars is printed out.

355-356 The useful payload on one booster is printed out.

357-359 The payload transfer orbit weight which includes the apogee kick motor is taken to be 2.25 times the booster useful payload. This is then calculated and printed out as payload transfer orbit weight.

360-378 The name of the booster corresponding to the booster number given in lines 279-284 is printed out.

379-381 The maximum payload the booster can lift into synchronous orbit is printed out.

382-383 The booster cost is printed out.

384 The total system cost is then the sum of the space segment and earth segment.

385 The earth segment cost, in millions of dollars, is the cost per station times the number of stations divided by 10^6.

386-391 The total systems cost is printed out along with a breakdown as to the total space segment and total earth segment costs.

392 If only one transponder was specified the programme is sent out of the printing procedure to statement 999 (line 395).

If more than one transponder was specified the programme is sent to statement 5555 (line 393).

393 The programme is sent to statement 7000 (the start of the second stage of printout); to statement 7777 (the start of the third stage of printout); or to statement 6666 (a continuation of the third stage) depending on the value of KKT. After the first stage of printout if there were more than one transponder specified the programme goes to statement 7000 (line 320).

320-322 Lines 332-334 prepare the programme for the second stage of printout, the printout of the optimum system (most cost effective system) by setting the first subscript of the print loop equal to KØUNT and the second subscript equal to IBEST. KKT is set equal to two to indicate that the programme is in the second stage of printout.

323-327 Lines 335-341 indicate that the following printout is to be for the optimum system and indicates the minimum number of satellites on which it is based, the number of transponders on each satellite and the number of satellites on each booster.

328-330 Line 340-342 indicate that, for each satellite, the parameters are as in lines 348 ff. and send the programme to the printout procedure as outlined in lines 348-394 above.

When the programme again reaches line 393 it is sent to statement 7777 (line 334).

334-337 The user is asked if he would like to have the data printed out for the other configurations considered in the analysis.

338 If he does not the programme is sent to statement 999 (line 395); if he does the programme is sent to statement 6011 (line 339).

339-347 A loop is started which will loop thru all the configurations (starting with 2 satellites) considered in the optimization loop (lines 260-313) and, with the exception of the optimum system which is skipped over by line 341, will print out 1) the system under consideration (lines 342-344) and 2) the parameters for each system as in lines 348 ff.

396-403 When all the desired data have been printed out the user is asked if he wishes to enter another system. If he does, the programme is sent to statement 111 (line 5) which begins the programme again; if he does not, the programme is sent to statement 998 (line 401) and the programme is terminated.

5.0 REFERENCES

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2. *Television broadcast satellite study*, J. Jansen, P.L. Jordan et al., TRW Systems Group, Prepared for NASA, Contract NAS 3-9707, NASA CR-72510, October 24, 1969.

3. *Television broadcast satellite (TVBS) study, TVBS Technical Report, Volume III*, R.W. Hesselbacher, General Electric Company, Prepared for NASA, Contract NAS3-9708, NASA CR-72579, 15 November 1969.

4. *Technical and cost factors that affect television reception from a synchronous satellite*, Jansky and Bailey Systems Eng. Dept., Atlantic Research, Prepared by NASA, Contract NASN-1305, June 30, 1966

5. *Feasibility of sound and television broadcasting from satellites*, C.C.I.R. Report 215-2, Documents of the XIIth Plenary Assembly, New Delhi, 1970

6. *Useful applications of earth-oriented satellites--Panel 10, Broadcasting*, Prepared by the Summer Study on Space Applications, NAS/NRC, for NASA, 1969

APPENDIX A: SAMPLE RUN OF PROGRAMME

Shown below is a sample run of a cost analysis of a system consisting of 5 transponders with 5 video channels per transponder and 1 audio channel per video.

```
       FM TELEVISION BROADCAST SATELLITE COSTS

EARTH STATION ANTENNA DIA(FT)?
?4.

DOWNLINK FR(MHZ)?
?12000.

     GAIN OF EARTH STATION ANTENNA = 41.13 DB

TYPE-IN RX NOISE FIGURE IN DB
?4.0

NUMBER OF RECEIVER STATIONS
?5000.

     COST OF RECEIVER = $   508.2

     COST OF AN ANTENNA BOUGHT IN QUANTITY= $   724.0

     COST OF ONE STATION= $   1232.19

SPECIFY ANTENNA NOISE TEMP IN DEGREES KELVIN
?170.

REQUIRED PEAK TO PEAK/WEIGHTED RMS NOISE RATIO?
BROADCAST QUALITY:32=PASSABLE,40=GOOD,50=EXCELLENT
?45.

SPECIFY MINIMUM CARRIER/NOISE INCLUDING THRESHOLD MARGIN)
?14.

SPECIFY BASEBAND IN MHZ E.G.4.2 MHZ FOR A 525 LINE SYSTEMM
?4.2

SPECIFY WEIGHTING FACTOR AND ALLOWANCE FOR PREEMPHASIS AS TOTAL
E.G.10.2+2.5=12.7 FOR 525 LINE MONOCHROME
    10.0 FOR 525 LINE COLOUR
?10.0

SPECIFY ALLOWANCE FOR PROPAGATION ATTENUATION IN DB
?4.5

     VIDEO RF BANDWIDTH-MHZ=    24.68

NO.OF VIDEO CHANNELS PER TRANSPONDER?
?5.

NO. OF TRANSPONDERS?(LIMIT OF 15)
?5.

NUMBER OF AUDIO CHANNELS PER UIDEO
?1.

     TRANSPONDER RF BANDWIDTH-MHZ=   129.3

     SATELLITE RF BANDWIDTH-MHZ=   771.3

ANTENNA COVERAGE? TYPE 1 IF ELLIPTICAL BEAM;2 IF CIRCULAR BEAM
NOTE: IF MORE THAN ONE TRANSPONDER,ALL ANTENNAS HAVE SAME COVERAGE
?2.
```

```
TYPE ANTENNA BEAMWIDTH IN DEGREES(CIRCULAR BEAM)
?1.7

     SATELLITE ANTENNA DIAMETER=  3.40FT

     VIDEO POWER PER CHANNEL=     86.4 WATTS

     SAT POWER PER TRANSPONDER=   688.9WATTS
     (INCLUDES 2DB BACKOFF ALLOWANCE)

     WEIGHT PER TRANSPONDER, INC. ANTENNA=   898.2LBS.

                         **************************

FOR ALL TRANSPONDERS ON ONE SATELLITE:

        TOTAL POWER PER SATELLITE=  3444.3 WATTS

        USEFUL SPACECRAFT WEIGHT=  4540.8POUNDS

        SATELLITE COST $MILLIONS=    17.4

        BOOSTER USEFUL PAYLOAD=   4540.8 POUNDS

        PAYLOAD TRANSFER ORBIT WEIGHT= 10216.9 POUNDS

        BOOSTER: SATURN V

        BOOSTER CAN LIFT  50000. POUNDS INTO SYNCHRONOUS ORBIT

        THE BOOSTER COSTS   225.0$ MILLIONS FOR ONE

SYSTEMS COST (EXCLUDING UPLINK AND DEVELOPMENT)=   248.6$ MILLIONS
INCLUDES:   242.40 $M FOR   1 LAUNCHES
              6.16 $M FOR   5000. STATIONS

                         ***OPTIMUM SPACE SEGMENT***

CONSISTS OF    2 SATELLITES WITH   3 TRANSPONDERS PER SATELLITE AND   1
SATELLITES PER BOOSTER

FOR EACH SATELLITE:

        TOTAL POWER PER SATELLITE=  2066.6 WATTS

        USEFUL SPACECRAFT WEIGHT=  2744.5POUNDS

        SATELLITE COST $MILLIONS=    14.2

        BOOSTER USEFUL PAYLOAD=   2744.5 POUNDS

        PAYLOAD TRANSFER ORBIT WEIGHT=  6175.1 POUNDS

        BOOSTER: TITAN IIIC-TRST

        BOOSTER CAN LIFT   4500. POUNDS INTO SYNCHRONOUS ORBIT

        THE BOOSTER COSTS    20.0$ MILLIONS FOR ONE

SYSTEMS COST (EXCLUDING UPLINK AND DEVELOPMENT)=    74.5$ MILLIONS
INCLUDES:    68.30 $M FOR   2 LAUNCHES
              6.16 $M FOR   5000. STATIONS
```

Fig. 1. Retail Antenna Cost as a function of Diameter for various Frequencies (in quantities of 10^6)

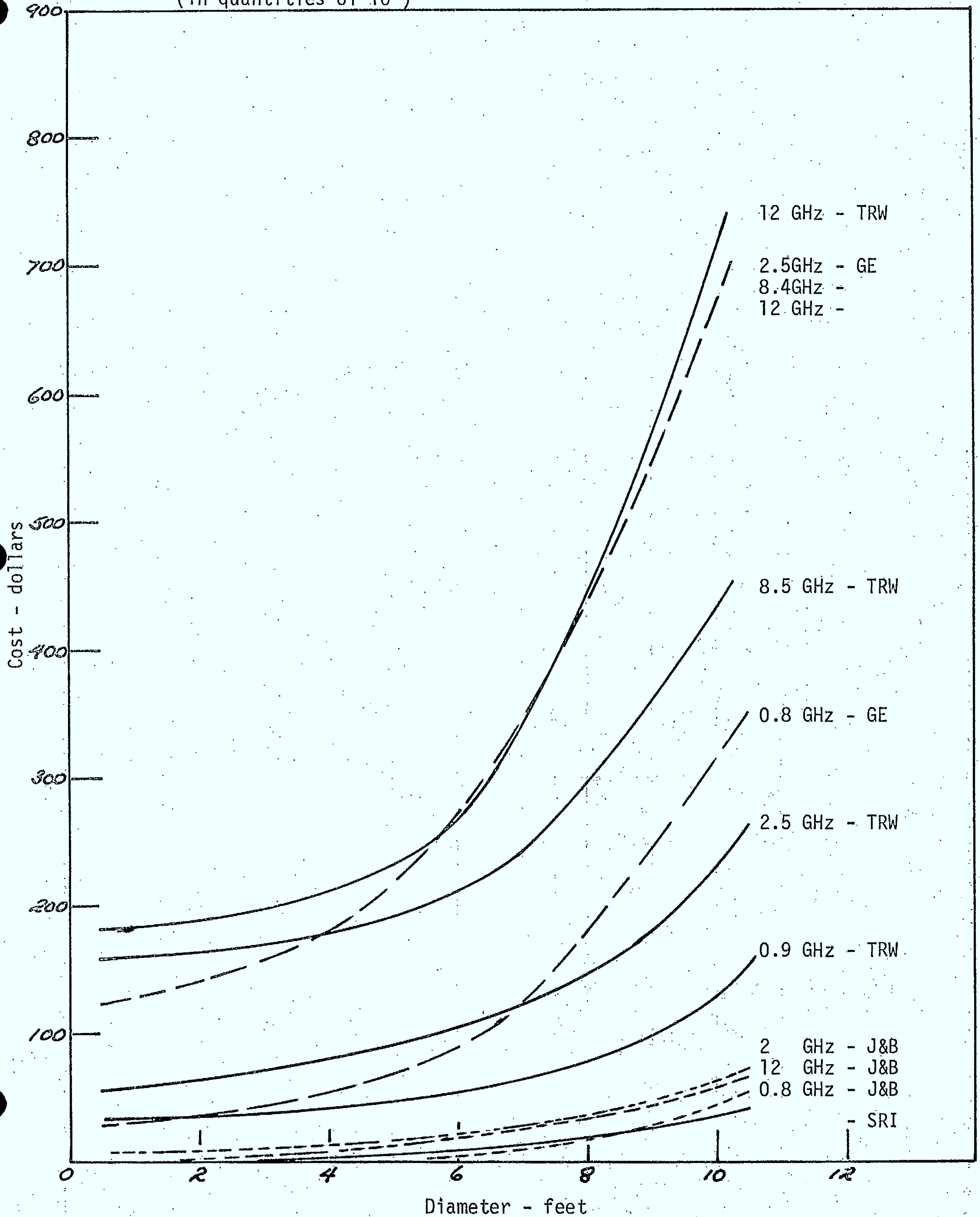
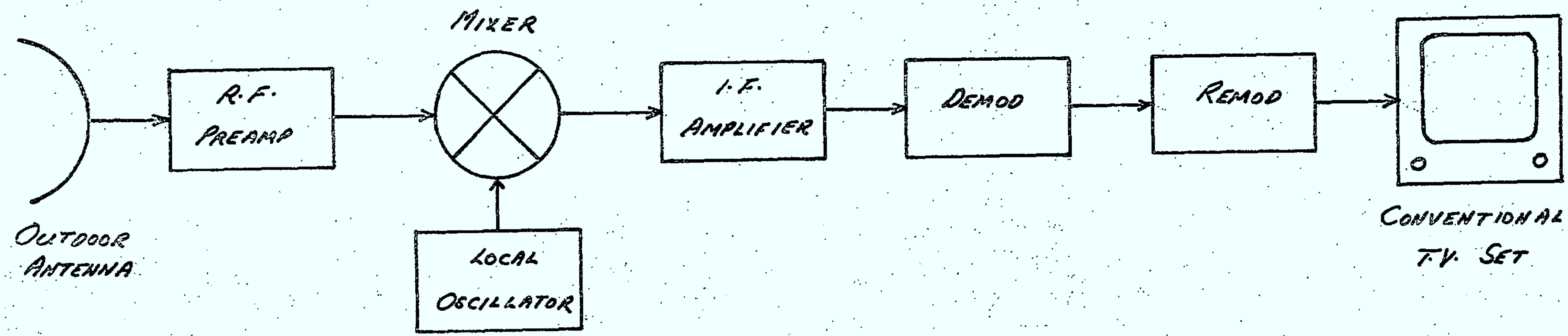


FIG. 2. RECEIVER CONFIGURATION



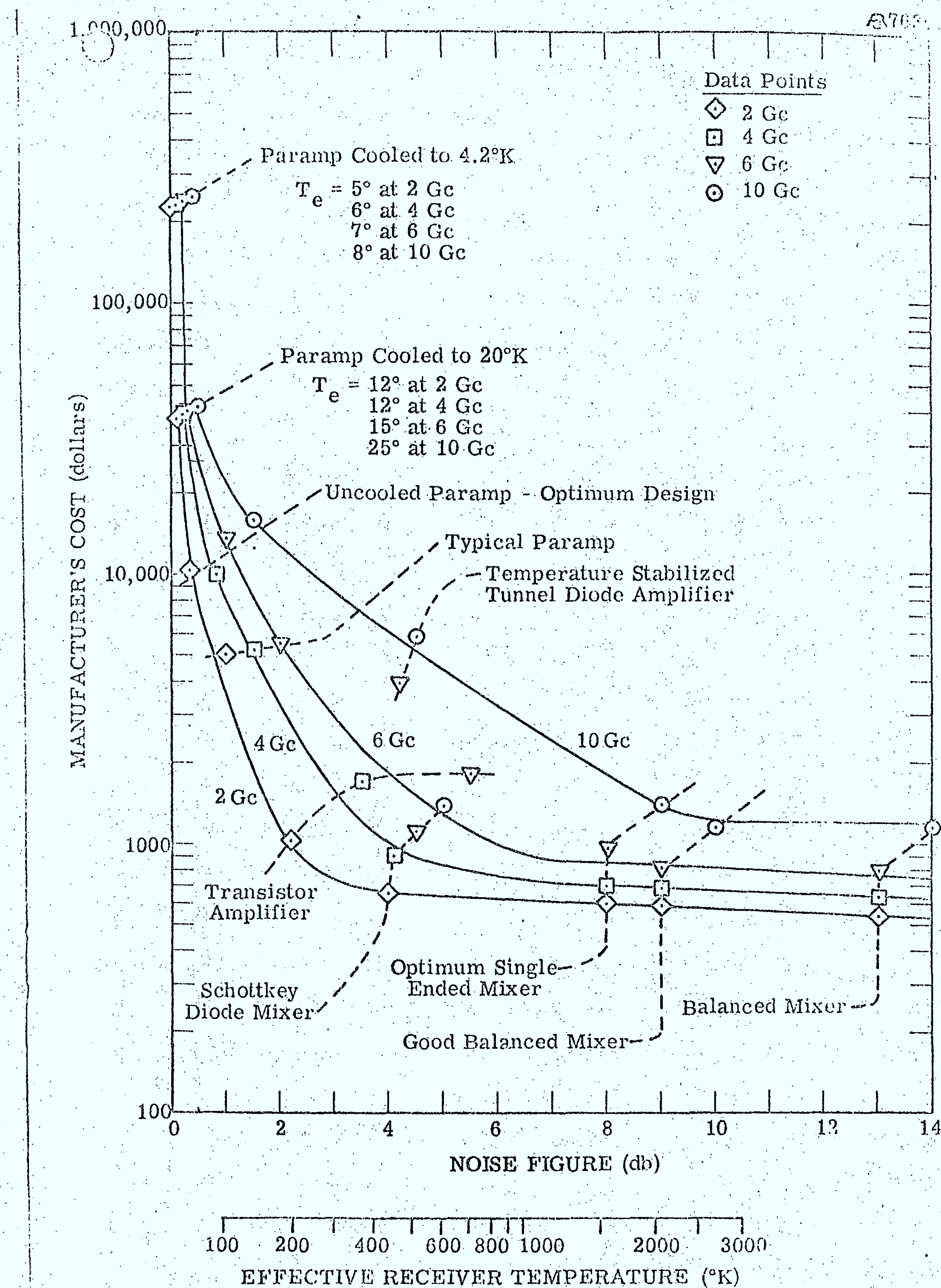


Figure 3 Cost Versus Noise Figure, Microwave, Quantity of One.

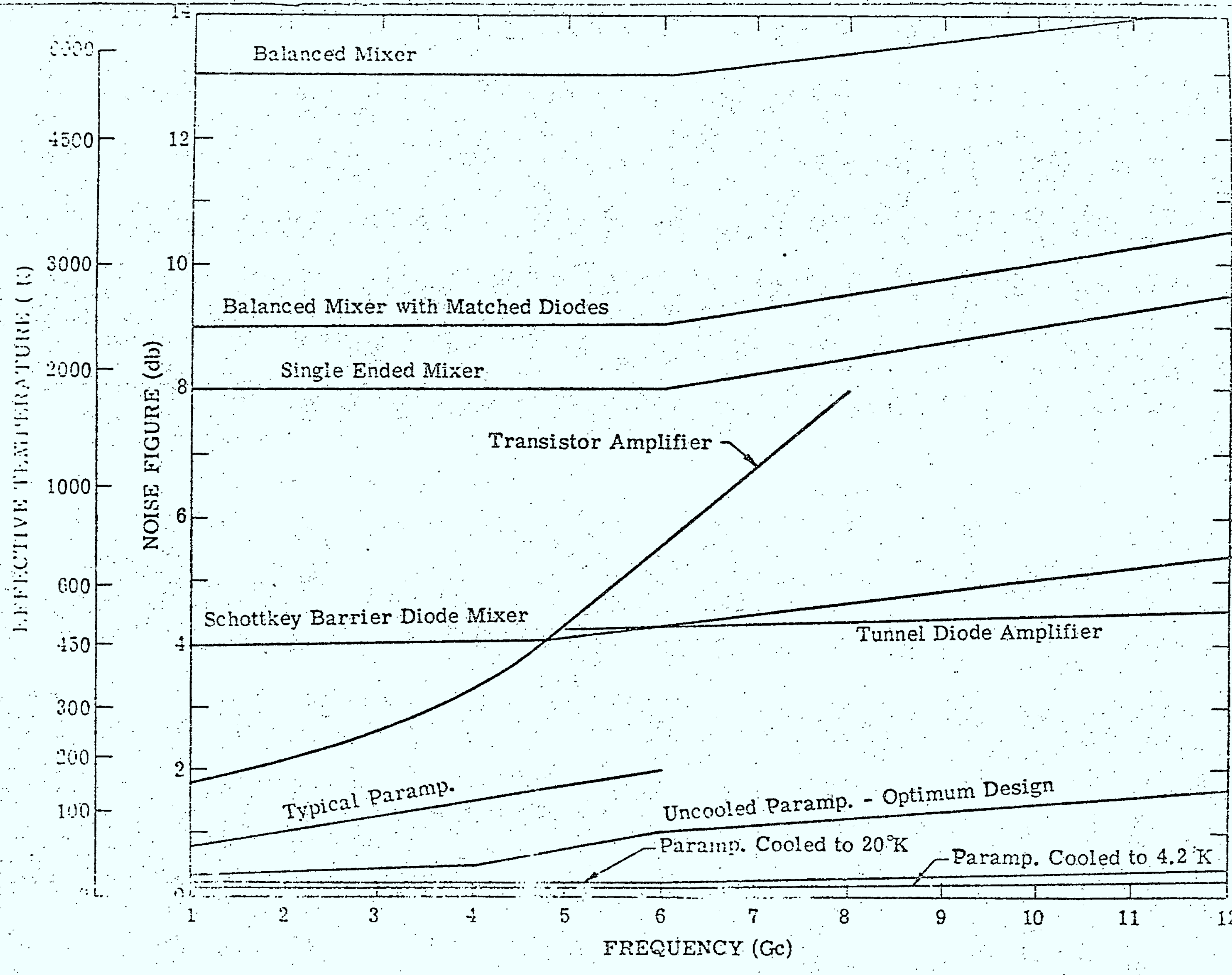


Figure 4 Noise Figure of Various Receivers as a Function of Frequency.

G37957

Fig. 5. Receiver Production Costs as a function of Noise Figure

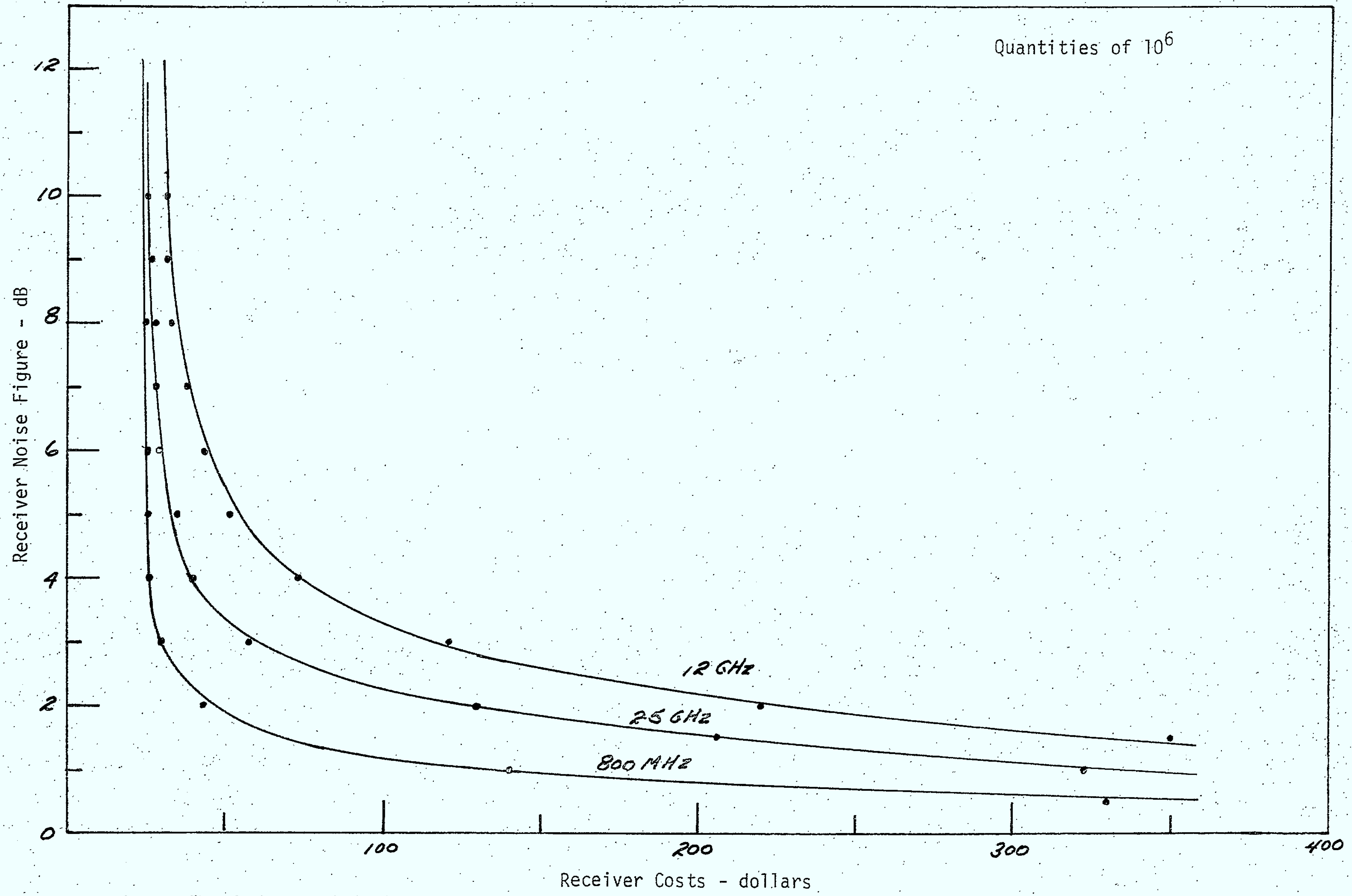
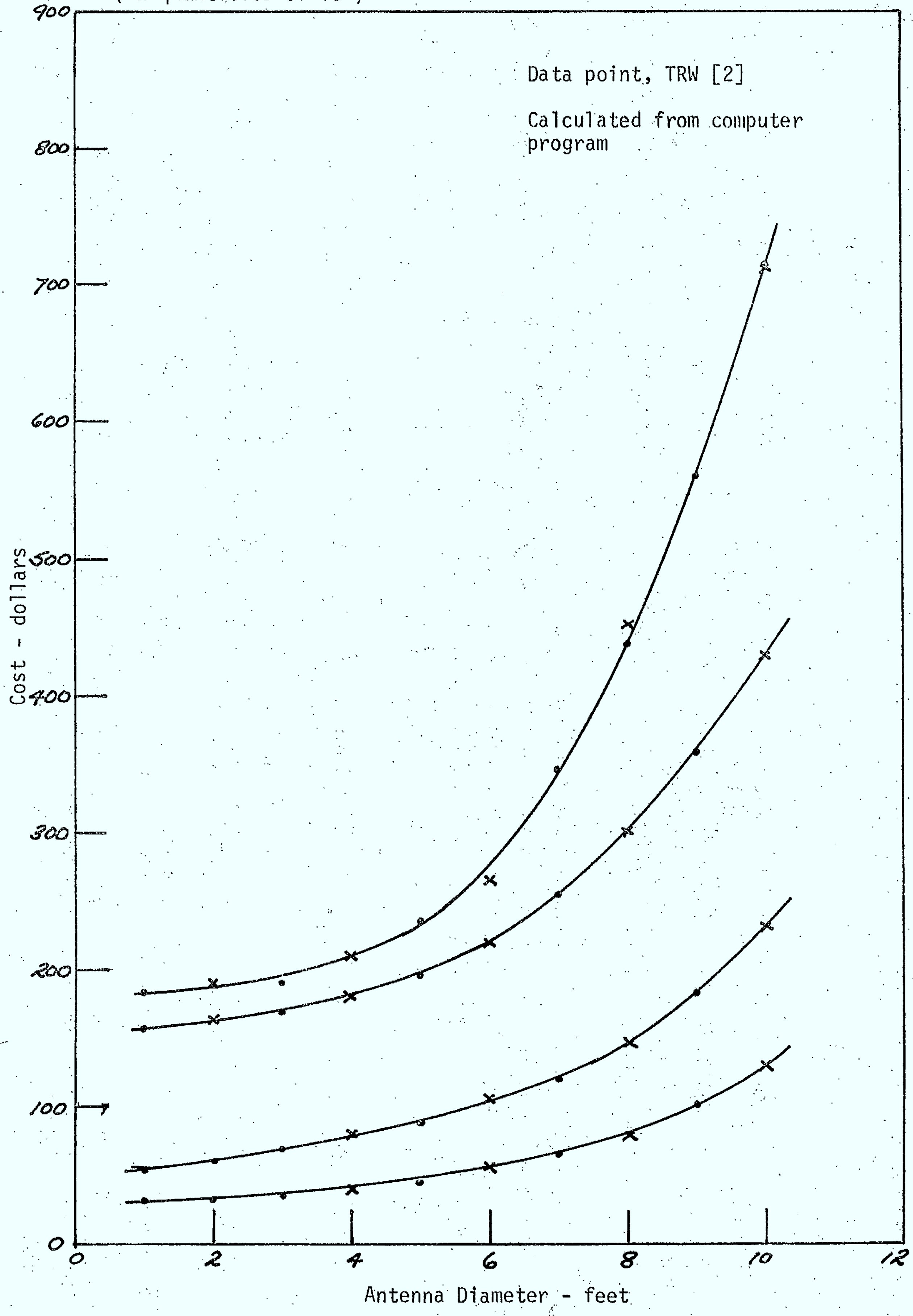


Fig. 6 Costs for installed Antenna as a function of Antenna Diameter (in quantities of 10^6)



SATELLITE BROADCASTING STUDY