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This is Volume 6 of Contribution No. 4 to Telecommission Study 8(c).

The complete documentation for the Telecommission Study is:

Contribution No. 1 - Report: "Communications in the Canadian North"

Contribution No. 2 - Catalogue: "Communications Systems in Northern Canada"

Contribution No. 3 - Report: "Yellowknife Northern Communications Conference"

Contribution No. 4 - Northern Communications Study

- Vol. 1 - Synopsis
- Vol. 2 - Prospects for Northern Development
- Vol. 3 - Northern Communications Requirements
- Vol. 4 - General Information and Broadcasting Services for the North
- Vol. 5 - Terrestrial Systems
- Vol. 6 - Communication Satellite Systems
- Vol. 7 - Northern Communications Co-ordination and Planning.

D.S. Loftus
Liaison Officer
Telecommission STudy 8(c)

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SATELLITES FOR COMMUNICATIONS IN NORTHERN CANADA

SYNOPSIS

Introduction

The recent attention focused on the development of Canada's North has stimulated a review of the communications requirements to both existing and future population centres in this region.

At the present time many communities in the central and eastern Arctic and northern extremities of the provinces are dependent upon HF radio links provided by common carriers or private users. The same general situation applies in the Western Arctic except that the leased circuits are provided on common carrier terrestrial facilities, open wire lines, and military tropospheric scatter systems.

The mode of operation of the HF radio links makes this type of service marginal at best, especially when the problems generated by limited hours of availability, crowded channels, and queing are coupled with poor transmission performance and heavy utilization. The access to existing military systems is limited and the capacity available for message traffic restricted.

An additional factor to be considered is the fluid nature of the population centres. It is expected that there will be a migration from outlying centres to larger centres like Frobisher Bay stimulated by Government policy, economics and natural evolution. This would mean that small centres could eventually disappear in the next decade. Any expenditures for communication systems must take these factors into consideration.

A review of the communication requirements in the Canadian North related to the early plans for the Canadian Domestic Satellite System revealed that the initial application was limited to those population centres generating requirements for approximately twelve intertoll trunks. On the basis of one dedicated North-South

RF channel providing this type of service, up to seven of these stations might be used before the channel is fully loaded. The exact number of stations will depend on the quality of service required. Additional locations could be served if more RF channels were assigned to this service.

In addition to certain large centres which might conceivably have a communications requirement sufficiently large to justify no less than 12 intertoll traffic circuits, there are many small communities in the Canadian Arctic which at present have no service or very limited service using high frequency communications. These could conceivably be much better cared for if an arrangement could be found to provide them with one near commercial grade telephone channel on a 24-hour basis.

An analysis of the situation indicates that there is a large number of such locations. Some of these locations could conceivably have a requirement for two voice channels. Also there appears to be a requirement for a single teletype or telex channel at some of these locations.

In searching for a good technical solution to this problem it was natural to examine the use of communication satellites. Their ability to provide direct high quality communication channels to locations without consideration of the intervening terrestrial barriers make them a most attractive solution to this problem. The nature of the Canadian Arctic is such that it does not appear that it will ever be possible to provide an acceptable service to most of these locations using microwave, open-wire, or high frequency communications.

The first communication satallites had extremely limited effective radiated powers. Consequently their first application was in the international service where through international agreement the cost of channels is heavily inflated and through the construction of extremely large sensitive earth stations it appeared possible to produce a system which might be economically attractive. As technology advanced, the launchers became more powerful, the satellites could become larger, which in turn made it possible to increase their effective radiated power and the use of small earth stations to provide a limited number of voice channels became more attractive. At the present time experiments are under way in this area in at least two countries (Australia and the United States). While it does not appear that these services could be economically viable because of technical limitations associated with sharing the operating frequencies with line-of-sight microwave system the possibility of providing services in areas where this is the only potential technology could make the question of economics of lesser importance.

A Working Group was established consisting of representatives from the Trans-Canada Telephone System, Telesat Canada, and the Department of Communications to look into the matter. Appendix 1 is the list of the individuals who participated in the discussions. It was concluded that the concept should be investigated from two different approaches. The first approach would be to investigate what could be done using the first series of satellites planned for the Canadian Domestic System. This would provide communications at the earliest moment. The second approach would be to investigate what might be done in the future if a system were developed which was specially designed for this type of service, operating in a different frequency band.

In order to estimate the cost of providing service into Northern Canada using the first series of satellites in the Canadian Domestic System the working group developed a model on which the estimate would be based. Appendix 2 is the specification for the model.

The model on which the estimate is based provides only for service between the isolated areas and the earth station connecting the service into the existing national telecommunications network. This means that communications between two isolated areas may use a double hop in the communication satellite. The abnormal transmission delay experienced from this type of operation is considered to be objectionable by a large percentage of the telecommunications industry. However, some work has been done in evaluating the user objections to this type of service, and there is reason to believe that the users in isolated areas would accept this type of service. Item 3 in Appendix 3 contains a discussion of this problem with encouraging conclusions.

The use of a communications satellite to provide service to individual subscribers in isolated areas carries with it a number of problems which will require considerable effort before satisfactory solutions can be worked out. New and sometimes unique solutions will have to be obtained to the problems of operating, signalling, billing, numbering, switching, supervision, local distribution, interfacing between the common carriers and Telesat, and potentials for expansion.

For instance there is a problem of providing bilingual operators for this type of service. In order to provide bilingual service it is necessary to backhaul all of the circuits to the Montreal area. So the cost of integrating the service into the domestic network becomes a significant item in the total cost of the service. Furthermore the proposed technique of providing the service is not compatible with the present arrangement between Telesat and the common carriers for the interface between their facilities.

Another problem is related to the reluctance on the part of the telecommunication common carriers to provide facilities which cannot be easily expanded in the future. If, through the provision of a new type of service, there is an abnormal increase in the use of the facility, it must be expanded. It turns out that there are significant incremental increases in system costs when the amount of service being provided is increased and there is always a danger that the facility originally installed in the isolated area may rapidly become obsolete.

Another item which can be significant in the cost of implementing the service is the local distribution system in the area to be served.

The present arrangement for billing the customer is to charge in terms of who made what call and where to. A new and radical billing system may be needed before the facility is placed in operation.

Another problem which must be solved relates to the location of the master station providing the connection into the domestic system. It may be more appropriate to terminate circuits from the Western sector of the Arctic at a station on the West Coast, depending on traffic flow patterns.

On the basis of the work which has been done it is easy to conlude that economics alone will not bring communications to Northern Canada.

In Table 1 of the contribution to Telesat Canada (Appendix 4, item 1) the cost of providing the service in the form of one dedicated voice channel per community is estimated to be $88,000 annually. The annual cost to the common carriers to link the service to the customer and provide the necessary toll centres has been estimated to be $600,000 for 50 sites. This breaks down to $12,000 per year per voice channel. The total cost, therefore, of providing one dedicated voice channel per community in lots of 50 communities is estimated to be $100,000 per year.

On Page 3 of the contribution from the Communications Research Centre (Appendix 4, item 2) the estimated annual cost per community to provide one voice channel in a UHF satellite communication system, specifically tailored for this type of service, is estimated to be between $13,000 and $37,000 per circuit for a system with 100 terminals, assuming a non-profit situation for operation of the system.

NOTE:

This report has been under preparation for about one year. Over one year there are many significant improvements in communication satellite technology. During that period a number of events have taken place which made significant changes to the work which had previously been completed. For instance, the contribution from Telesat Canada is dated June 17, 1970. After that date Telesat Canada contracted for a space craft with different technical characteristics in the communications sub system than were contemplated at the time they completed their report. As a presentation of the overall picture the report is considered to be correct. However, certain details in the report should be used with care.

APPENDIX I

MEMBERSHIP IN WORKING GROUP

APPENDIX I

Membership in Working Group

P.M.M. Norman, P.Eng.	Telesat Canada
Gordon R. Peterkin, P.Eng.	Bell Canada
H.P. Chamberlain, P.Eng.	Bell Canada
O.S. Roscoe, P.Eng.	Department of Communications
O.L. Britney, P.Eng.	Department of Communications

APPENDIX II

System Model

APPENDIX 2

System Model

Satellite Communications into Northern Canada

At a meeting held with representatives of TCTS and Telesat it was agreed that the estimates for the cost of a system would be based on the following model.

Number of locations - 50, 100, 200, 400.
One estimate will be prepared on the basis that there is one dedicated channel to each location.

Another estimate would be based on the assumption that there would in each case be 20 locations each with a dedicated channel. The remaining locations would share a pool of channels on the ratio of four locations per channel.

In other words - the total number of channels in the system would be $20 + (\frac{N - 20}{4})$ where N = the number of locations.

All channels would operate between the northern stations and the national telecommunication network - channels between northern points would use double hops over the satellite.

75% of the traffic would be within any particular region.

25% of the traffic would be between any subscriber within a region and the national telecommunications network.

Performance between the national telecommunications network and the North would be 44 dBrnCo.

Performance from the North into the national telecommunications network would be 37.5 dBrnCo.

Each remote earth station would have two transmitters and receivers.

The maximum acceptable outage is two to three days twice per year.

The 20 dëdicated channels would each carry one full-time teletype channel.

The system would be managed by an operator where it connects into the national telecommunications network.

Appendix III

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APPENDIX 3

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APPENDIX 4

ATTACHED CONTRIBUTIONS

1. Utilization of the Telesat Canada Initial Domestic Satellite System for Telecommunication Services to the Far North - Telesat Canada.

2. Cost Estimates for a UHF Satellite Communication System - O.S. ROSEOE(CRC).

3. A Satellite Communication System for their Rout Traffic - O.S. ROSCOE - National Communications Laboratory - CRC.

4. Estimate of the Capacity of a Domestic Satellite Channel Using Small Earth Terminals - J.S. Butterworth - CRC.

5. Addendum to Item 4.

6. The Use of Small Earth Stations for Voice Communications to Northern Canada - O.L. Britney.

7. Satellite for Communication in Northern Canada - G.R. Peterken - Bell Canada.

No. 1

Utilization of the Telesat Canada Initial Domestic Satellite System for Telecommunication Services to the Far North

Submitted by

Telesat Canada

In Response To

Telecommission Study No.8(c)

Ottawa

June 17, 1970

Utilization of the Telesat Canada Initial Domestic Satellite System For Telecommunication Services To the Far North

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1. INTRODUCTION

This brief provides a survey of the various system concepts that may be applied to the provision of telecommunication services to the Canadian Far North utilizing the first generation of Telesat Canada satellites.

Planning for the initial domestic satellite system has been based on the provision of six satellite RF channels, allocated to potential users as follows:

1. - CBC, French Language Television
2. - CBC, English Language Television
3. - CBC, English Language Television
4. - CN/CP and TCTS, Toronto-Vancouver Telephone Message Traffic
5. - TCTS, Telephone Message Traffic to the North
6. - Bell Canada, Experimental Use

The satellite channel assigned to Northern telephone service is expected to initially provide circuits to Frobisher Bay and Resolute. This application will utilize about 30 of the 130 2-way circuit capacity of this R.F. channel in the FDM/FM frequency division multiple-access mode. The remaining capacity will be available for growth and if warranted the experimental R.F. channel could also provide further expansion of this service. In addition, alternative satellite designs are presently under evaluation which if implemented could provide additional flexibility and growth potential.

Television network service will be available to some 25 communities throughout the North initially by the provision of "Remote T.V. Receive-Only" earth stations. These stations will require a 25 foot diameter antenna (G/T = 25.5 dB) and will have the capability to accept additional equipment for telephone message service if this is required. Since the satellite has full countrywide coverage, the television service may be extended to any location by the simple addition of an earth station where required.

Unlike the television service in which each television channel utilizes a full satellite R.F. channel, many telephone message circuits may be derived from one satellite R.F. channel in numerous ways, with each transmission method displaying its own cost and performance characteristics. The remainder of this brief is devoted to an examination of these methods for providing telephone message circuits to the North.

Early studies in the application of a Canadian satellite system for telephony to the North suggested it would find its primary use in serving communities requiring a minimum of 6 - 12 telephone trunks. The early studies also proposed that the most economic way of serving the smaller communities having even smaller requirements in the order of 1 or 2 circuits, would continue to be H.F. radio, either directly to the South or indirectly through the satellite earth stations located in the North. The Frobisher Bay and Resolute service mentioned earlier are a result of this planning.

Although early studies were correct in assuming that H.F. radio provided the lowest cost means of serving the smaller communities requiring only one circuit, it did not take into account the growing demand from these communities for a reliability and grade of service better than that available with H.F. radio. The Department of Communications has indicated strong interest in determining the extent to which economic support of this demand might be required, and as a result, Telesat Canada is currently undertaking an extensive evaluation of the technical means which could be used to provide one or two telephone or data channels to such locations in addition to providing trunk facilities to the larger centres such as Frobisher Bay and Resolute. The objective is to select the most economic system which could be implemented within the first few years of operation of the Telesat satellite system. This brief provides an interim view of the work undertaken to date by Telesat Canada in this field.

2. THE PLANNING PHILOSOPHY

In the planning of improved telecommunications to the North, Telesat Canada has considered it important that the approach used be one that recognizes and takes into account the long term implications of providing this service. For example, when a new service is provided by an operating agency, that agency assumes a responsibility to the populace concerned to continue the service and to reasonably meet growth demands over the years. To do so effectively, the source of revenue to meet these committments must be established. Since telecommunication services to the North are unlikely to be commercially viable for some years, a realistic economic analysis and evaluation will provide an equitable basis for any assistance that may be agreed upon.

This approach underlines the need for decision making based on total annual charges taken over a planning period extending over seven to ten years. Total annual charges would include the major factors of return on investment, depreciation based on expected plant retirement from service, and operating and maintenance expenses as well as the other miscellaneous economic factors. These annual charge factors should be assessed based on provision of the total service, that is, Telesat's satellite link and the Common Carrier or telephone company's associated facilities and services. The long term view recommended here should also take into account the economic effects of early equipment retirements resulting from possible proposals to introduce new techniques.

The pertinent planning factors of traffic forecasts, service quality, cost and capacity of various system choices are discussed in the following paragraphs and appendices attached to this brief.

3. FORECAST OF TRAFFIC REQUIREMENTS

The preparation of a forecast of traffic requirements in the North is a pre-requisite to the choice by Telesat Canada of a suitable communication satellite system configuration to meet them. It is recognized that the forecast of requirements for the North is a difficult process and is affected by many factors including the cost of the service. Telesat Canada is sufficiently advanced in the study of alternative systems to be able to discuss the relationship between the costs, circuit quantities, traffic routing and growth capability. Furthermore, traffic forecasts should be established in consultations between the Department of Communications, the Common Carriers and Telesat Canada and planning or action should be implemented on the basis of such forecasts in consultation with all parties concerned.

Some of the major factors affecting the system design include the potential growth of telephone traffic over the initial 5 and 10 year period and the likelihood for the need of television in the future to these small communities. In the Appendix, systems are shown with capacities of from 15 to 400 two-way voice circuits per satellite channel according to the modulation scheme and type of earth station utilized.

Clearly, the numbers of circuits per location, numbers of locations, the need for inter-Arctic communications and forecasted growth should be carefully assessed if wasteful or inadequate designs are to be avoided.

4. QUALITY OF SERVICE

The systems for the North described in the Appendix are capable of a wide range of performance, ranging from that usual in Southern Canada to lower grade systems. The choice of the noise performance of a telephone circuit affects the satellite channel capacity and therefore has a direct bearing on the cost to customers. Results are shown in the Appendix of the variation of capacity with noise performance. This is intended to assist potential customers in making a choice between grade of service and costs. For example, one system (FDM/FM/FDMA) using 15 ft. diameter antennas and an uncooled receiver can provide 12 voice circuits to each of 10 locations with a noise performance of 38 dBrncO or to each of 20 locations with a noise performance of 44 dBrncO. The noise of 38 dBrncO is typical of 2000 mile link in southern Canada whereas a lower performance of 44 dBrncO is typical of present tropospheric scatter systems to the North. A similar change in noise performance for a one voice channel per location system (FM/FDMA, voice activated) using the same earth station design would increase the number of remote communities served from 40 to 65.

Service availability, that is the percentage of the time the facility is working satisfactorily, is another quality factor directly affecting the cost of service to remote Northern locations. Service availability is directly dependent on the maintenance effort expended at earth stations, the logistics of spare parts, and the built-in equipment redundancy. All these factors affect the operating cost.

For example, one of the stations whose costs are provided in the Appendix, has an estimated availability of 98.2% or an estimated outage of 160 hours per year for unattended operation. The cost to reduce this outage to 3 hours per year would require an increase of 30 - 40% of the station first cost by providing equipment redundancy. Alternatively, a similar improvement may be achieved through having selected on site spares and having available a trained technician on site. Therefore, considerable care must be exercised in developing a scheme to ensure that both the quality of service is acceptable to the users and the costs are reasonable.

5. INTEGRATION WITH THE TELEPHONE NETWORK

Planning of a communication satellite system to serve the Far North requires that proper consideration be given to the technical integration with existing communication facilities. In addition, the cost of a service to the end user must take account of the cost of both the satellite and terrestrial services. To this end Telesat Canada is in regular consultation with the Common Carriers with the objective of providing a good and cost effective overall system design.

6. ALTERNATIVE SYSTEM PLANS

Telesat Canada has examined some five alternative modulation and multiple-access systems for serving the Canadian North. Three of the most attractive systems are reported on in the Appendix, including FDM/FM/FDMA, FM/FDMA and PCM/PSK/FDMA systems. This includes several variants of these basic systems, including preassigned, and demand assigned systems. All of these systems are compatible with the initial satellite design.

The systems described in the Appendix were studied in detail with respect to their suitability for meeting the telecommunications needs of the North. These studies have included the relative cost advantages of the systems in meeting different assumed traffic requirements and growth rates, traffic routing flexibility, system operation and maintenance. Other systems which are being examined are a Delta modulation scheme and a PCM/PSK/TDMA system. However, these are not considered to be strong contenders for an initial system.

7. ANNUAL COSTS

Preliminary annual charge studies have been undertaken to determine the order of magnitude of the annual costs for the satellite system portion of various alternatives. The space segment portion of the satellite system costs may vary widely over approximately $1 to $3 million per year per R.F. channel depending on the satellite design chosen, the procurement policies followed and the commercial agreements negotiated, all of which, at this time of writing, are under review. The per channel cost for an expansion of the initial satellite system could be substantially lower than those for the initial system.

To illustrate the relationships between annual cost, service provided and system design examples typical of a small size station design are shown in Table 1.

The examples quoted here demonstrate the normally expected lower cost per circuit when a larger antenna (higher G/T value) is used. However, to realize fully this economic advantage, the circuit capability associated with the larger antenna must approximate the traffic requirements forecast.

It should be realized that the larger system "C" may also be instituted utilizing only a portion of a satellite R.F. channel and serving a corresponding fewer communities and requiring a lower initial capital expenditure.

It is also of interest to note that the larger antenna, used in the example, is about the smallest size suitable for T.V. reception. This offers the possibility for reduction in charges by sharing of certain costs between the telephone and T.V. services. The Appendix provides preliminary data and costs on a wide range of other system designs.

8. TIMING OF INITIAL SERVICE

Telesat Canada can provide service to remote locations in the North during the first year of operation of the domestic satellite system. This timing is dependent on potential customers identifying their forecasted requirements by the end of 1970.

9. SUMMARY

(i) All agencies concerned have agreed upon plans for the provision of network television distribution and telephone trunk requirements (minimum 6-12 circuits) to the far North utilizing Telesat's initial satellite.

(ii) A plan to utilize the satellite system for improving telecommunications to very small communities in the far North has not yet been agreed upon.

(iii) This brief provides preliminary information on the satellite link planning factors necessary to the formulation of an acceptable plan.

(iv) Annual charge information provided here is for illustration purposes only since determination of space segment charges must await a decision on satellite procurement policy and total charges must await formation of a commercial policy.

(v) The initial satellite system is capable of providing in a variety of ways a significant and expanding "small community" telecommunication service to the North.

(vi) Formulation and implementation of a sound plan can best be achieved through realistic and practical long range economic comparison studies of the various alternatives.

(vii) Telesat Canada recognizes the special importance of satellite communication techniques in the North and is prepared to cooperate fully with all agencies in the formulation and implementation of a suitable plan.

TABLE 1

TYPICAL SYSTEM ANNUAL COSTS

	System A[1] x $1,000	System B[2] x $1,000	System C[3] x $1,000
Number of Communities Served	26	26	65
Number of Circuits/Community	1	Shared[4]	4
Total Circuits through 1 R.F. Channel	26	26	260
First Costs (earth segment)	$ 2,100	$ 2,600	$ 26,000
Annual Cost (earth segment) [5]	$ 700	$ 900	$ 8,700
Total annual cost (assuming $3 M./year/ satellite R.F. Channel)	$ 3,700	$ 1,900	$ 11,700
Total annual cost/community	$ 142	$ 73	$ 180
Total annual cost/circuit	$ 142	-	$ 45

NOTES:

(1) System A is a voice activated, single voice channel per carrier FM system with 10 ft. diameter earth station antennas and G/T = 16 dB.

(2) System B is similar to A except that improved circuit utilization is achieved through the use of a simple demand assigned system.

(3) System C is a modified Spade System with 30 ft. diameter antennas and G/T = 26 dB.

(4) Eight circuits through the satellite channel are shared between all stations.

(5) The factors that have been assumed in computing annual costs are for illustration purposes only. For example, depreciation rate is based on an assumed life of 10 years for earth stations and capital expenditures all occur at the same time. Maintenance expense is assumed to be 10% of first costs rather than a figure arrived at by assessing maintenance problems in the far north, etc. The study will be refined in future weeks as the necessary data is developed.

APPENDIX

THE CAPABILITY OF ALTERNATIVE SYSTEMS TO PROVIDE TELECOMMUNICATIONS IN THE NORTH

A. INTRODUCTION

This Appendix describes the characteristics of systems using each of four modulation and multiple-access techniques which are regarded as suitable for application in the Canadian North. Section B describes each of the several possible technical means for providing service in the North. A comparison of the capability of the different modulation techniques and their variants is made in Section C.

B. DESCRIPTION

1. FDM/FM/FDMA SYSTEMS

This form of system which is currently proposed for the provision of 6 or more circuits to individual locations in the North uses separate FDM/FM carriers sharing satellite R.F. channels on a frequency division basis. This is a proven technique which can be implemented with a minimum of development effort and is presently used successfully by Intelsat. This is the means which Telesat Canada plans to use initially to serve Frobisher Bay and Resolute.

The system is so arranged that each earth station transmits one FM carrier. In order for a station to communicate with other locations, a separate receiver is required for each transmitting station with which communication is desired. Thus, a station in the North which needs to communicate with three other stations, say one in the South and two in the North, requires one FM transmitter and three FM receivers.

If these stations were equipped for 6 circuits, they might be assigned in any proportion to the other three stations. One of the features of this system is that all circuits are usually pre-assigned, although demand-assigned schemes may be implemented.

In the variable destination demand assigned system, specific channels are assigned from the transmitting earth station to the satellite. The downcoming portion from the satellite is assigned on demand to any receiving earth station. Thus a variable destination circuit is composed of two oppositely directed variable destination channels. Variable origin systems are also possible and are analagous to the variable destination system. In addition these two techniques may also be combined to provide a variable destination system in one direction and a variable origin of capability in the opposite direction. These systems offer advantages where the traffic requirements are low, with increasing benefits as the circuit requirements to one station decrease below 12. Where the requirement is for less than one fully dedicated circuit per location a demand assigned system becomes essential.

2. FM/FDMA ONE-VOICE CHANNEL SYSTEMS

The concept of this system is based on the assignment of one FM carrier to each voice channel. Such a system is best suited to providing service to remote locations requiring only one or a few voice channels. This scheme may be used for a pre-assigned system where all voice channels are dedicated or for a demand assigned system. In the demand assigned system, both variable destination, variable origin and fully variable systems are feasible.

3. PCM/PSK/FDMA SYSTEMS

The best known system of this type has been developed by Comsat Laboratories for Intelsat and is called the SPADE system. This is a fully variable demand-assignment multiple-access system. In this system individual voice channels are PCM/PSK modulated and located on separate R.F. carriers within the bandwidth of one satellite R.F. channel. The demand-assigned scheme is fully variable so that an earth station can select any of the unused frequency slots in the R.F. channel and communicate with any other station. This provides the greatest possible operating flexibility of any system. One further feature is that the carriers are voice activated, thus conserving satellite power. Variants of the SPADE System are also possible, including in its simplest form, use as a pre-assigned single voice channel per carrier system or else as a variable destination or variable origin demand assigned system controlled from one central location.

4. PCM/PSK/TDMA SYSTEMS

For the frequency-division multiple-access systems discussed previously there are penalties in R.F. channel capacity caused by the effect of intermodulation of the various FM carriers passing through the same power amplifier in the satellite. For this reason an alternative system of time sharing with PCM/PSK carriers is being investigated. For a system requiring 12 to 24 telephone message channels per location this offers a significant improvement in system capability. It is expected that systems similar to the Intelsat MAT-1, which has demand assigned features, could find particular application in the North. However, for locations requiring less than 6 channels such a system becomes inefficient due to the large proportion of carrier burst time used for preamble and guard bands.

C. SYSTEM CAPABILITY

1. SATELLITE R.F. CHANNEL CAPABILITY

(a) Circuit Capacity

The circuit capacity of satellite R.F. channels in terms of the equivalent number of 4 KHz channels which the system can carry is shown in Fig 1-5 for different earth station G/T ratios and channel noise performance. This includes all the systems described in Section B except for TDMA systems since it is unlikely they could be implemented during the first year of operation of the satellite system.

Of the systems shown, it is clear that the FDM/FM/FDMA system offers the greatest capability and most efficient utilization of the satellite for earth station G/T ratios less than or equal to 26 dB, the number of locations served is 20 or less and the circuits are pre-assigned. For more than about 20 locations or for G/T ratios of 26 dB or greater a voice activated PCM/PSK/FDMA and single channel FM/FDMA systems offer the greater circuit capacities. Of these two systems, which both use one voice channel per carrier the capacities are comparable. However, there is a greater confidence in meeting the capacities for the PCM/PSK/FDMA system since voice activation has been more successfully applied to it in the past than for the FM/FDMA system. The SPADE System which uses a voice activated PCM/PSK/FDMA technique is planned for service early next year by Intelsat.

(b) Traffic Capacity

The traffic capacity of each of the alternative systems is illustrated in Table 1 for different earth station G/T ratios and a noise performance of 44 dBrncO. The capacity is expressed in CCS/HR/satellite R.F. channel for the modulation schemes described in Section B and using them in pre-assigned and demand assigned modes of operation.

The capacity of some systems is more sensitive than others to variations in the required noise performance. Therefore, any comparison of traffic capacity must be qualified by a statement on noise performance. Similarly, a proper comparison between pre-assigned, variable destination, variable origin and fully variable demand-assigned systems cannot be made until a traffic forecast is established for communication requirements in the North. The following assumptions are used in this comparison:

(a) The grade of service assumes a probability of 0.01% for encountering all trunks in a group busy.

(b) A Poisson model is used for the network in determining traffic capacity.

(c) The noise performance is 44 dBrnc0.

(d) The traffic configuration for the FDM/FM/FDMA pre-assigned and all variable destination/variable origin systems assumes all traffic is between one Southern earth station and remote communities in the North and that inter-Arctic communications is negligible. If a traffic model is assumed where there is significant inter-Northern communications a further advantage would be shown for a fully-variable demand assigned system over the variable destination/variable origin system. Where individual stations require 1-2 channels to each of 3 or more other remote locations the traffic handling capability of the fully variable systems would be almost twice that of the variable destination/variable origin systems.

(e) In the variable destination/variable origin demand assigned system the traffic capacities shown are for the case where all traffic between the North and Southern Canada is routed through one Southern earth station. If traffic were to be routed via two Southern stations, say one in Western Canada and the second in Eastern Canada, the traffic capacity would be slightly less.

Fig.

SYSTEM CAPACITY VS EARTH STATION G/T

AND NOISE PERFORMANCE

FDM/FM/FDMA 6 CARRIERS

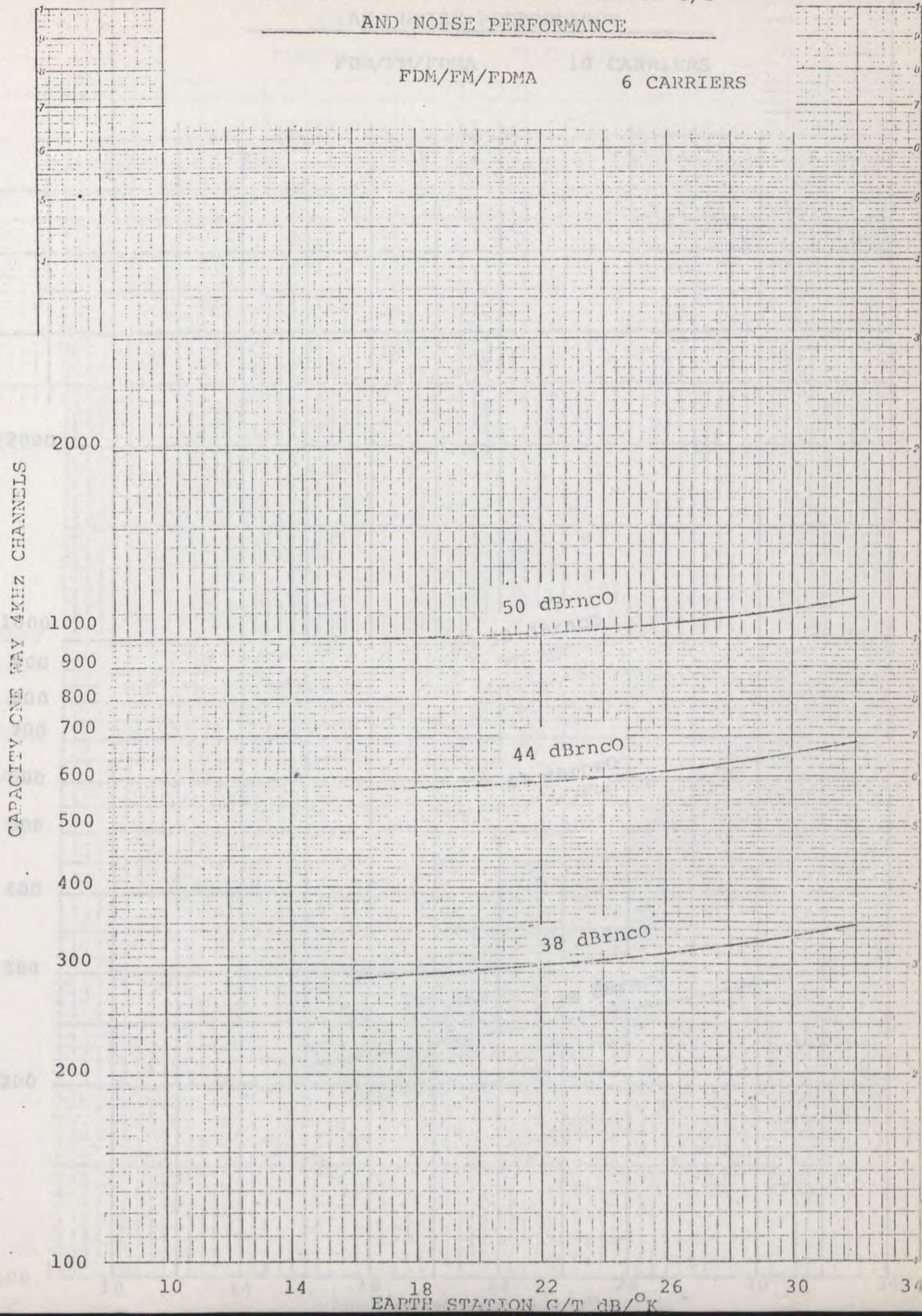


Fig. 2

SYSTEM CAPACITY VS EARTH STATION G/T

AND NOISE PERFORMANCE

FDM/FM/FDMA 10 CARRIERS

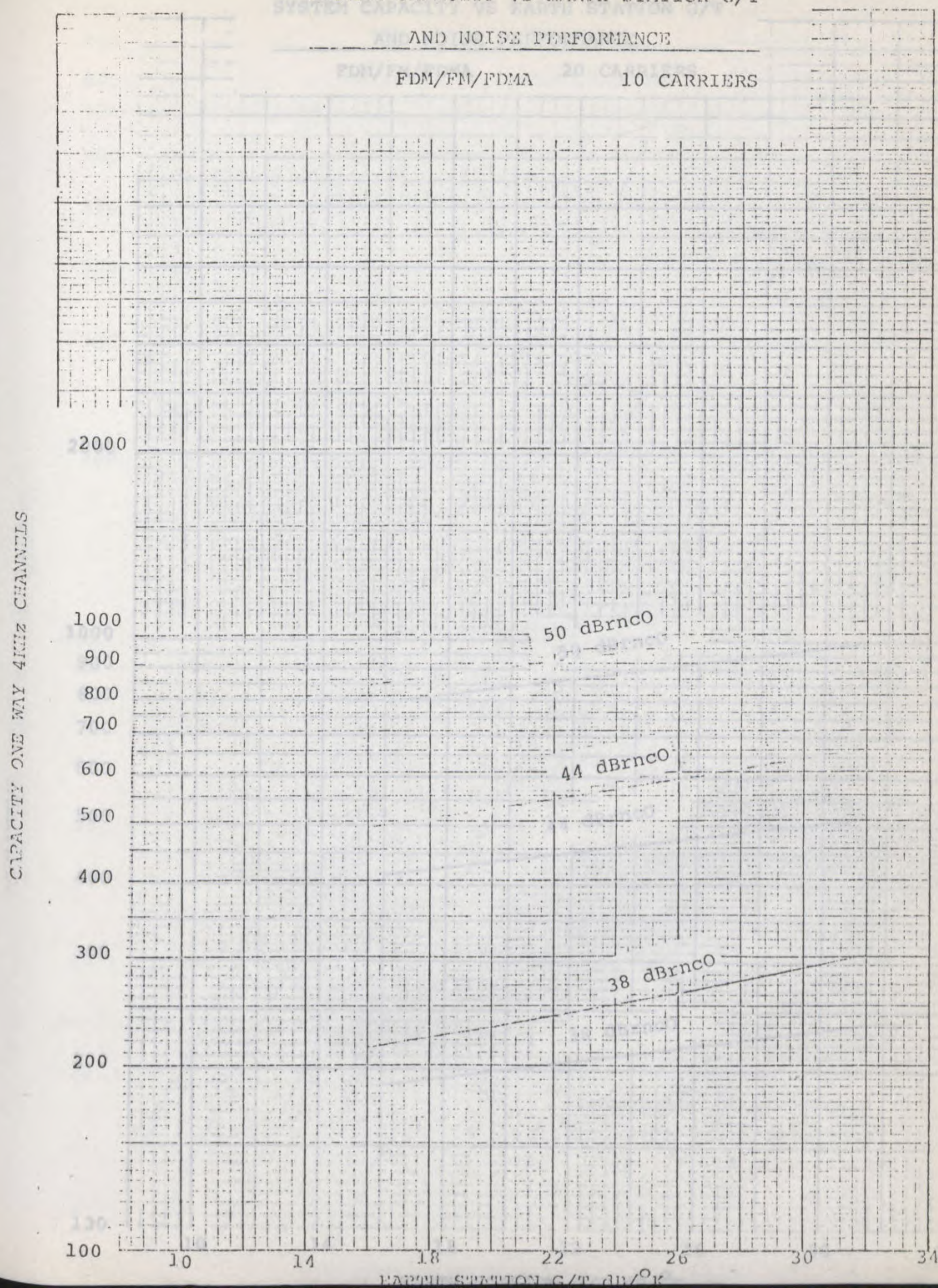
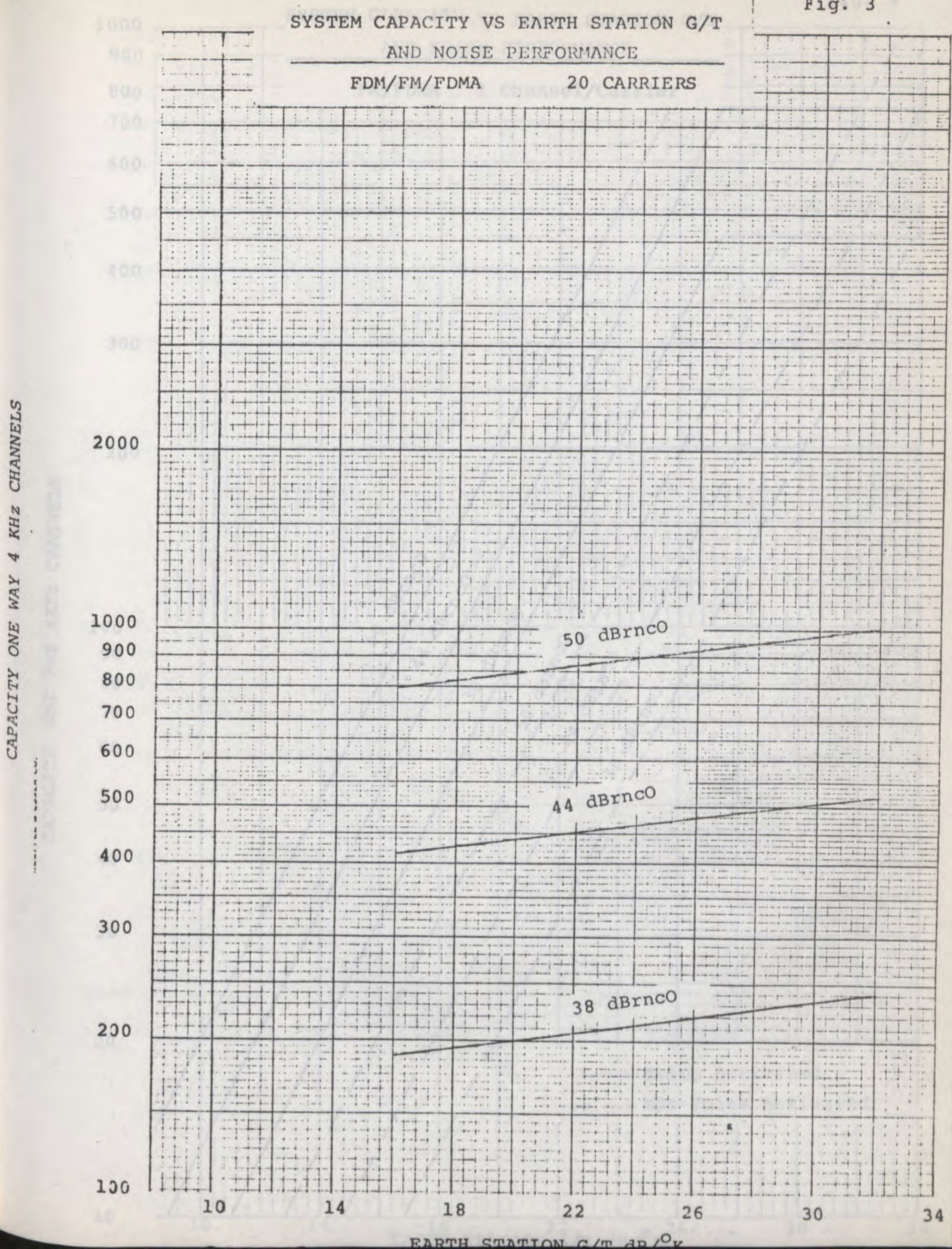


Fig. 3


SYSTEM CAPACITY VS EARTH STATION G/T
AND NOISE PERFORMANCE
FDM/FM/FDMA 20 CARRIERS
CAPACITY ONE WAY 4 KHz CHANNELS
2000
1000
900
800
700
600
500
400
300
200
100
50 dBrncO
44 dBrncO
38 dBrncO
10
14
18
22
26
30
34
EARTH STATION G/T dB/°K

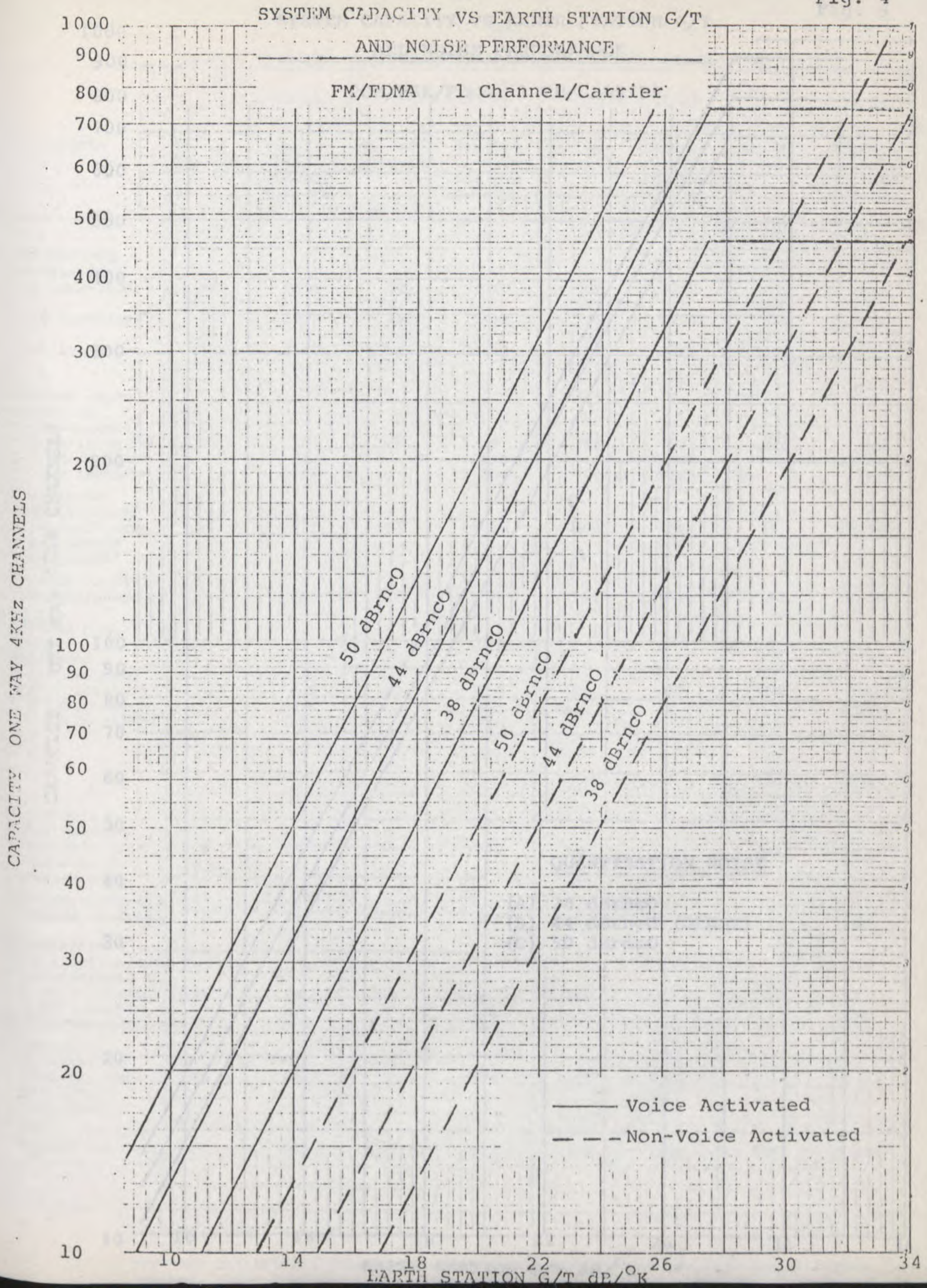

SYSTEM CAPACITY VS EARTH STATION G/T
AND NOISE PERFORMANCE
FM/FDMA 1 Channel/Carrier
CAPACITY ONE WAY 4KHz CHANNELS
EARTH STATION G/T dB/°K
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
10
14
18
22
26
30
34
50 dBrncO
44 dBrncO
38 dBrncO
50 dBrncO
44 dBrncO
38 dBrncO
Voice Activated
Non-Voice Activated

Fig. 5

SYSTEM CAPACITY VS EARTH STATION G/T

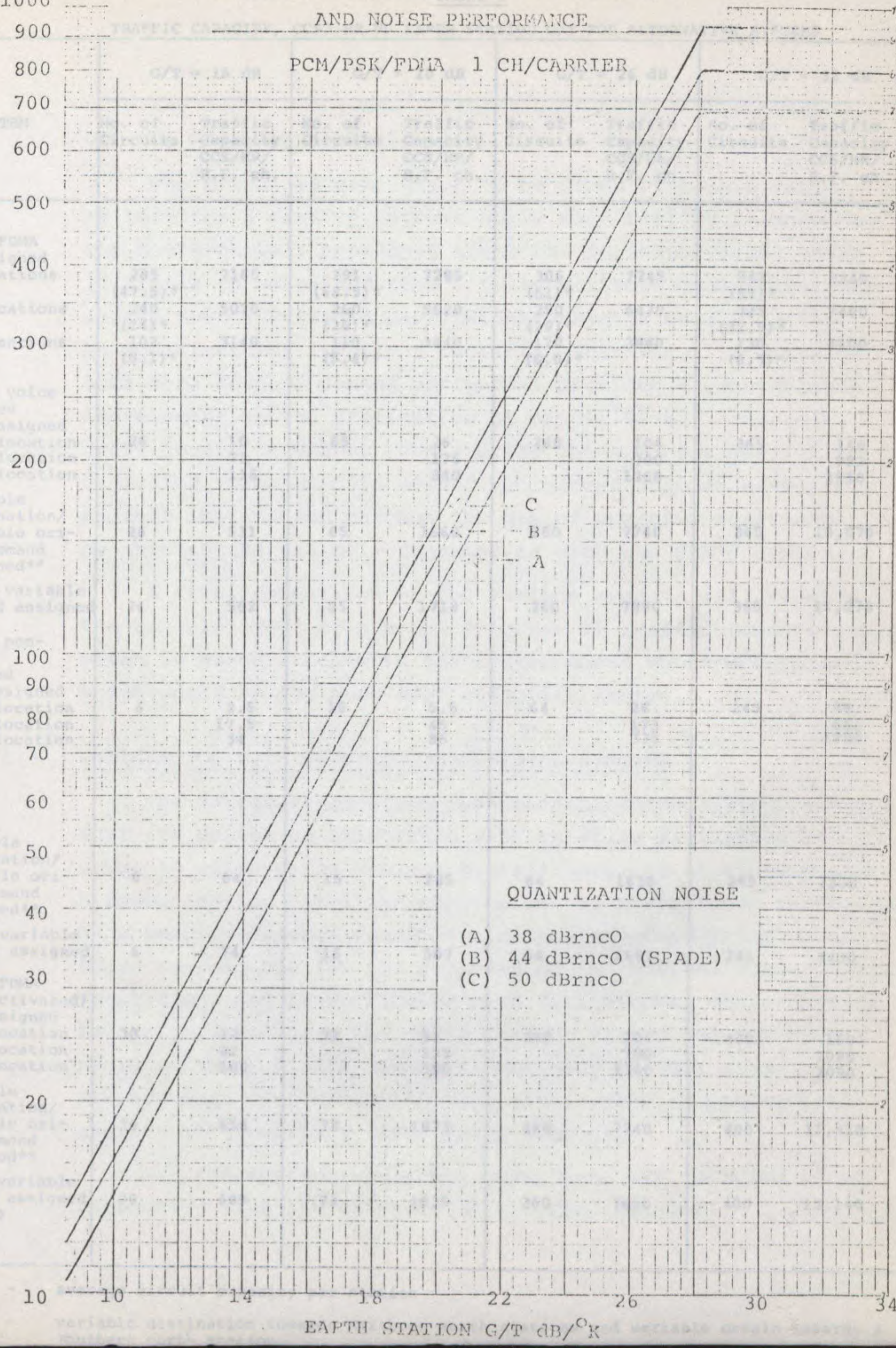


TABLE 1

TRAFFIC CAPACITY, CCS/ HR VS EARTH STATION G/T FOR ALTERNATIVE SYSTEMS

SYSTEM	G/T = 16 dB		G/T = 20 dB		G/T = 26 dB		G/T = 32 dB	
	No. of Circuits	Traffic Capacity CCS/HR/ R.F. ch.	No. of Circuits	Traffic Capacity CCS/HR/ R.F. ch.	No. of Circuits	Traffic Capacity CCS/HR/ R.F. ch.	No. of Circuits	Traffic Capacity CCS/HR/ R.F. ch.
a) FDM/FM/FDMA pre-assigned								
- 6 locations	285 (47.5)*	7165	291 (48.5)*	7285	306 (51)*	7745	342 (57)*	8840
- 10 locations	240 (24)*	5070	260 (26)*	5620	290 (29)*	6470	325 (32.5)*	7460
- 20 locations	102 (5.1)*	3140	110 (5.4)*	3440	120 (6.0)*	3840	130 (6.5)*	4400
b) FM/FDMA voice activated								
- pre-assigned								
- 1 CH/location	26	10	65	26	260	104	365	146
- 2 CH/location		72		176		700		982
- 3 CH/location		136		340		1360		1910
- variable destination/ variable origin demand assigned**	26	531	65	1660	260	7740	365	10,870
- fully variable demand assigned	26	562	65	1718	260	7890	365	11,070
c) FM/FDMA non-voice activated								
- pre-assigned								
- 1 CH/location	6	2.5	16	6.5	64	26	245	98
- 2 CH/location		17.5		45		173		660
- 3 CH/location		34		86		335		1280
- variable destination/ variable origin demand assigned**	6	64	16	285	64	1630	245	7350
- fully variable demand assigned	6	74	16	307	64	1687	245	7430
d) PCM/PSK/FDMA (voice activated)								
- pre-assigned								
- 1 CH/location	30	12	72	29	260	104	400	160
- 2 CH/location		82		196		700		1080
- 3 CH/location		160		380		1360		2090
- variable destination/ variable origin demand assigned**	30	654	72	1873	260	7740	400	11,910
- fully variable demand assigned (SPADE)	30	689	72	1935	260	7890	400	12,140

* - average circuit capacity per station

** - variable destination towards Northern earth stations and variable origin towards a Southern earth station

(f) Any traffic between Northern communities is routed via the Southern earth station.

The principal conclusion to be drawn from this table is that for a traffic network where most traffic is between the Southern well populated areas and Northern Canada there is little to be gained from a fully variable demand assigned system over a variable destination/variable origin system. In addition, for locations requiring less than 12 circuits each, some form of demand assignment provides a considerable improvement in the utilization of satellite R.F. channels. Where locations cannot even justify the need for one fully dedicated voice circuit demand assignment becomes essential whether implemented through the use of operator assistance or through the use of a computer as with the SPADE system.

A final comparison of the various systems will require the establishment of a model forecast of traffic requirements, which in association with the system costs would determine which would be the most cost effective choice.

2. INTEGRATION WITH EXISTING TERRESTRIAL SYSTEMS

The introduction of any new communication system requires that its design be integrated with existing facilities in order to achieve the maximum overall benefits at minimum cost. A communication satellite service to the North is no exception. As a result, Telesat Canada is in regular consultation with those responsible for the planning of terrestrial communications facilities, and in particular with Bell Canada, whose network is designed to serve the north-eastern Arctic and Sub-Arctic regions. Many of the concepts discussed in this study have already been discussed with them with a view to proper integration with existing terrestrial systems.

All the systems which are considered are designed to be integrated with the existing terrestrial network.

With respect to the interconnection between the satellite system and terrestrial network, the single voice channel, demand-assigned or pre-assigned systems may all be interconnected at voice frequency on a 4-wire basis. In addition, FDM/FM/FDMA systems may be interconnected either at voice frequency or in standard groups, supergroups, or entire basebands. Signalling used for the operation of the demand-assigned systems may also be made compatible with the existing terrestrial network. However, proper integration will require continuing consultation between the common carriers and Telesat Canada during the implementation of systems to serve the Far North to ensure compatibility between the terrestrial and satellite networks.

3. INTEGRATION WITH THE INITIAL SATELLITE SYSTEM

The initial Telesat Canada satellite system will be providing service to Frobisher Bay and Resolute using a small portion of one satellite R.F. channel which is being leased in its entirety by the Trans-Canada Telephone System. All the alternative systems described in this Appendix for providing service to the North would be compatible with the presently planned FDM/FM/FDMA system and could share the same satellite R.F. channel. In addition, should further traffic warrant it, other R.F. channels could be made available for service to the North, whether by the use of spare R.F. channels on the first satellite or by launching additional satellites.

4. R.F. INTERFERENCE

One of the major potential restrictions on the use of any of the systems considered for the North could result from radio interference. The use of earth stations with small antennas, typically 10-15 feet in diameter, will require considerable care to avoid interference into adjacent satellite systems. Our preliminary estimates for interference from a single-voice channel earth station using small antennas show that interference into other satellites spaced 3^{o}-5^{o} from the satellite in use would be tolerable.

However, this assumes that other satellites sharing the orbit will have similar receiving system characteristics. It is anticipated, therefore, that the use of any earth station in northern Canada having antennas with discrimination characteristics worse than those of an equivalent 30-foot paraboloid may require international co-ordination with other users of the portion of the geo-stationary orbit of interest to Canada.

Although the estimates made of interference of single channel/carrier systems into adjacent satellites may be tolerable with antennas as small as 10-15 feet in diameter, the transmission of larger capacity carriers with, for example, an FDM/FM/FDMA system would require careful co-ordination with other systems, including other satellites in use by Telesat Canada.

One further means by which interference could be introduced into the Canadian Satellite System would be due to signals from other systems received at the remote Northern earth stations. Depending on the discrimination characteristics of the receiving antenna, other satellites radiating at the maximum permissable flux density of $-152 + \theta/15$ $dBW/4KHz/M^2$ may impose limitations on the system design if interference is to remain tolerable. Telesat Canada is currently examining the potential modes of interference into the system in detail to determine these limitations.

In addition to the question of interference from remote Northern earth stations into adjacent satellites, there is the need to control the flux density at the earth within the limits established by the CCIR. It is assumed at the present time that for all the voice activated single carrier per channel systems that this would pose no difficulty since the carrier will always be loaded when it is transmitted.

This includes both the FM/FDMA voice activated systems and the PCM/PSK/FDMA voice activated (e.g. SPADE) systems. For non-voice activated FM/FDMA systems some form of a carrier dispersal will be required to avoid exceeding the flux limits. Similarly, carrier dispersal would be required for the FDM/FM/FDMA system to serve small remote earth stations in a similar way to that already planned for communications to Frobisher Bay and Resolute.

5. SYSTEM PERFORMANCE

All the systems investigated are capable of a transmission performance which would be competitive with existing terrestrial systems in southern Canada. As shown in Fig. 1-5, there is a considerable variation in satellite R.F. channel capability according to the noise performance assumed. The value of 38 dBrncO would provide a service equivalent to existing 2,000 mile terrestrial radio relay systems in Canada. Existing tropospheric scatter systems offer a transmission performance of from 44-50 dBrncO and HF radio systems, a performance often lower than this. Since the capacity of an R.F. channel is so strongly dependent on the transmission performance required, the final choice will depend on the system economics and particular needs of Telesat Canada's customers. Therefore, this report considers a broad range of noise performance, from 38-50 dBrncO so as to give an indication of the large variations in system capability possible. In paragraph 7 the effect of the choice of noise performance on costs may be assessed with reference to Fig. 1-5.

In addition to the use of Northern systems for voice communications, it should be remembered that future plans may require the provision of television to these areas. It has already been mentioned in the brief that Telesat Canada will be providing television for the CBC to some 25-30 remote northern communities.

This will be achieved through the use of antenna receiving systems having a G/T of approximately 25.5 dB, using antennas having a nominal diameter of 25 feet and an uncooled receiver. These earth stations are capable of modification to provide message traffic if the service is required and frequency coordination with 6 GHz terrestrial microwave systems is achieved. The combination of antenna size and type of receiving system are the minimum required to achieve a satisfactory quality television signal with the initial satellite system. Therefore, it is to be recognized that any system established in the North to provide voice communications and having earth stations with a G/T of less than 25.5 dB would require replacement when television is required.

6. MAINTENANCE

The difficulty and expense of retaining skilled labour in the Far North requires that communication satellite systems developed have earth stations which may be operated unattended and not require skilled maintenance. Thus, systems requiring complex test equipment and sophisticated maintenance techniques are not suited to the environment. Careful consideration must also be given to the logistics of spare parts. Telesat Canada is currently examining the means for maintaining remote earth stations for the various possible systems in order to determine the nature of the maintenance required and the costs involved.

7. COSTS

An assessment of the cost to implement a communication satellite service to the remote areas of the Canadian North requires that costs for the space segment, earth segment and their operation be considered. Estimates of costs for implementing several of the modulation and multiple-access schemes which have been described, including both pre-assigned and demand assigned modes of operation have been prepared. These costs are based on the procurement of lots of 30 earth stations over a short enough period to enable continuity of production by the manufacturer. For 5-15 stations, the costs would be 10-20% higher. The cost estimates were prepared for earth station G/T ratios of 16, 20, 26 and 32 dB, as represented by nominal antenna diameters of from 10-50 feet in diameter, using both tunnel diode amplifier receivers and uncooled parametric amplifiers. The range of earth station costs is shown in Fig. 6-10, using the type of receiving system which results in the lowest overall annual charges for the earth station, including maintenance. The costs are shown as a range of values for the individual earth stations which reflect the variation in cost according to the location where installed. This range accounts for such factors as the differing cost of foundations, installation, shipping and the applicability of provincial sales tax. In addition, some stations may require the provision of prime power, a building and more extensive site preparations. The following notes give additional information concerning the costs in Fig. 6-10.

(a) FDM/FM/FDMA SYSTEMS

This system is characterized by its well proven capability in Intelsat operation and low per circuit incremental cost In addition, the costs for equipment and space requirements at the Southern earth station are a minimum. This system, although limited in its flexibility for demand assigned operation would, with the PCM/PSK/FDMA pre-assigned system, require the least expenditure on development and probably be capable of the earliest implementation.

(b) FM/FDMA 1 CHANNEL PER CARRIER

For the FM/FDMA single channel per carrier system the upper range of costs shown is for a voice activated system. A non voice activated system would have an upper range of costs which is lower by up to $3000 per channel.

The electronics has been priced on the basis of a minimum performance system which would require modifications to the existing hardware to make it suitable for demand assignment. The cost of an FM/FDMA single channel per carrier system to have the same features and performance as the PCM/PSK/FDMA system whose costs are shown would be approximately the same.

(c) PCM/PSK/FDMA PRE-ASSIGNED SYSTEMS

The costs given are for a voice activated system using SPADE channel and IF units. No allowance has been made for any contribution that may be required to Intelsat in order to share the results of their research and development. Such a system would require less modification for demand assigned operation than the FM/FDMA system described since the SPADE channel units are already designed for that purpose.

(d) SPADE

The cost for a fully variable demand assigned system using existing SPADE hardware has been included as an example of one of the most sophisticated systems possible. No allowance has been made for any sharing required with Intelsat of their development expenditures.

Fig. 6

TOTAL EARTH STATION COST VS NO VOICE CIRCUITS

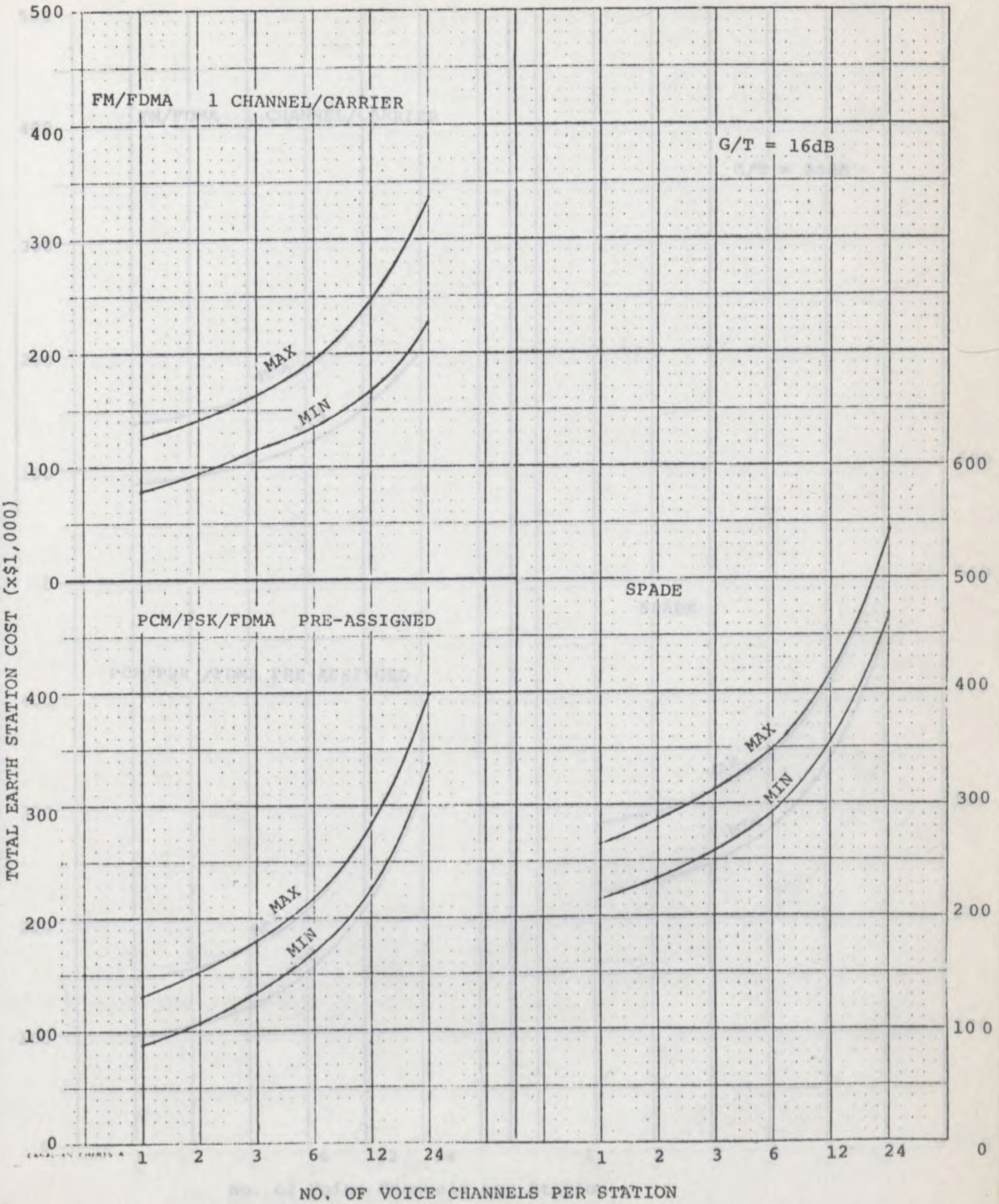


Fig. 7

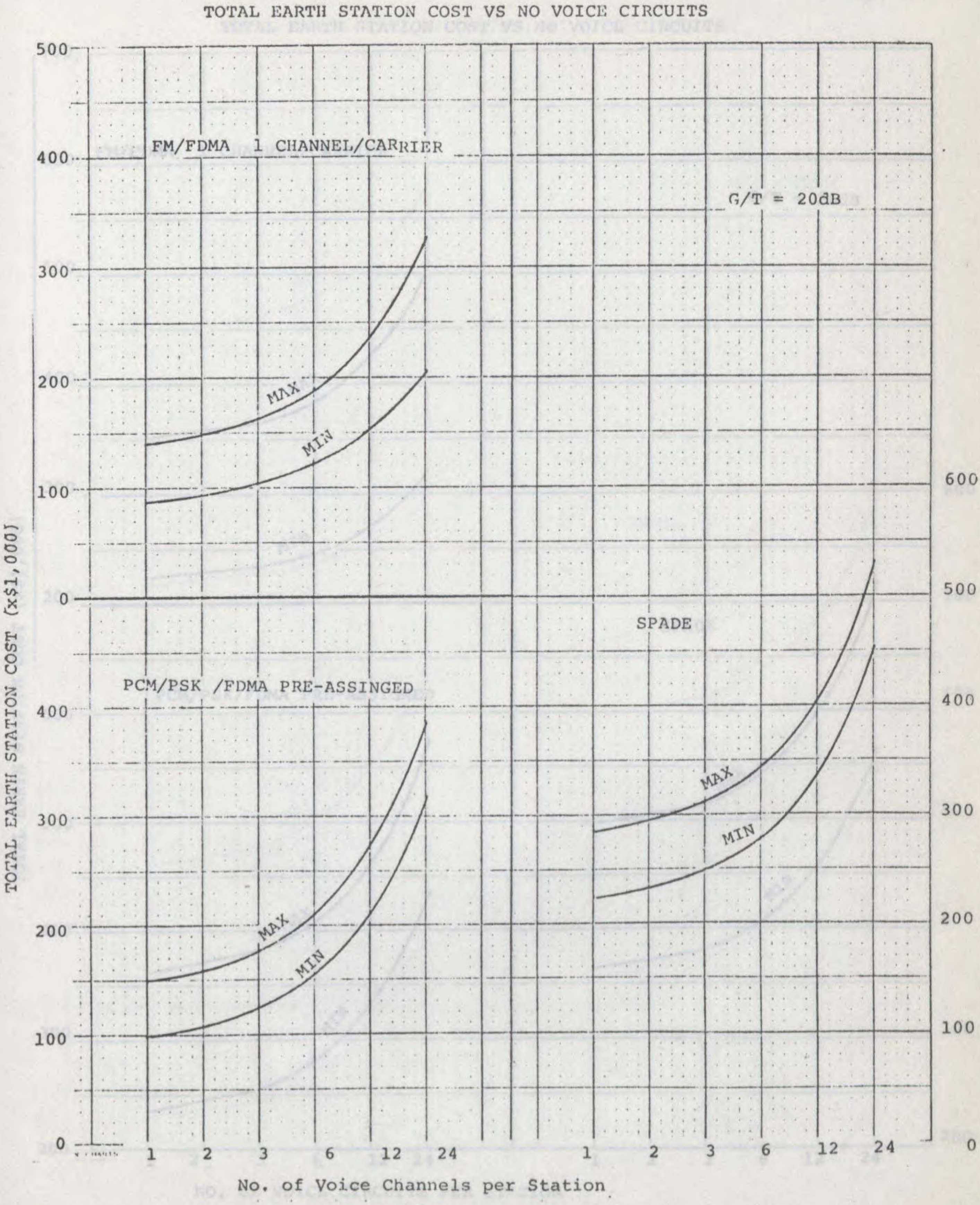

TOTAL EARTH STATION COST VS NO VOICE CIRCUITS
FM/FDMA 1 CHANNEL/CARRIER
G/T = 20dB
MAX
MIN
SPADE
PCM/PSK /FDMA PRE-ASSINGED
MAX
MIN
MAX
MIN
TOTAL EARTH STATION COST (x$1,000)
500
400
300
200
100
0
400
300
200
100
0
600
500
400
300
200
100
0
1 2 3 6 12 24
1 2 3 6 12 24
No. of Voice Channels per Station

Fig. 8

TOTAL EARTH STATION COST VS NO VOICE CIRCUITS

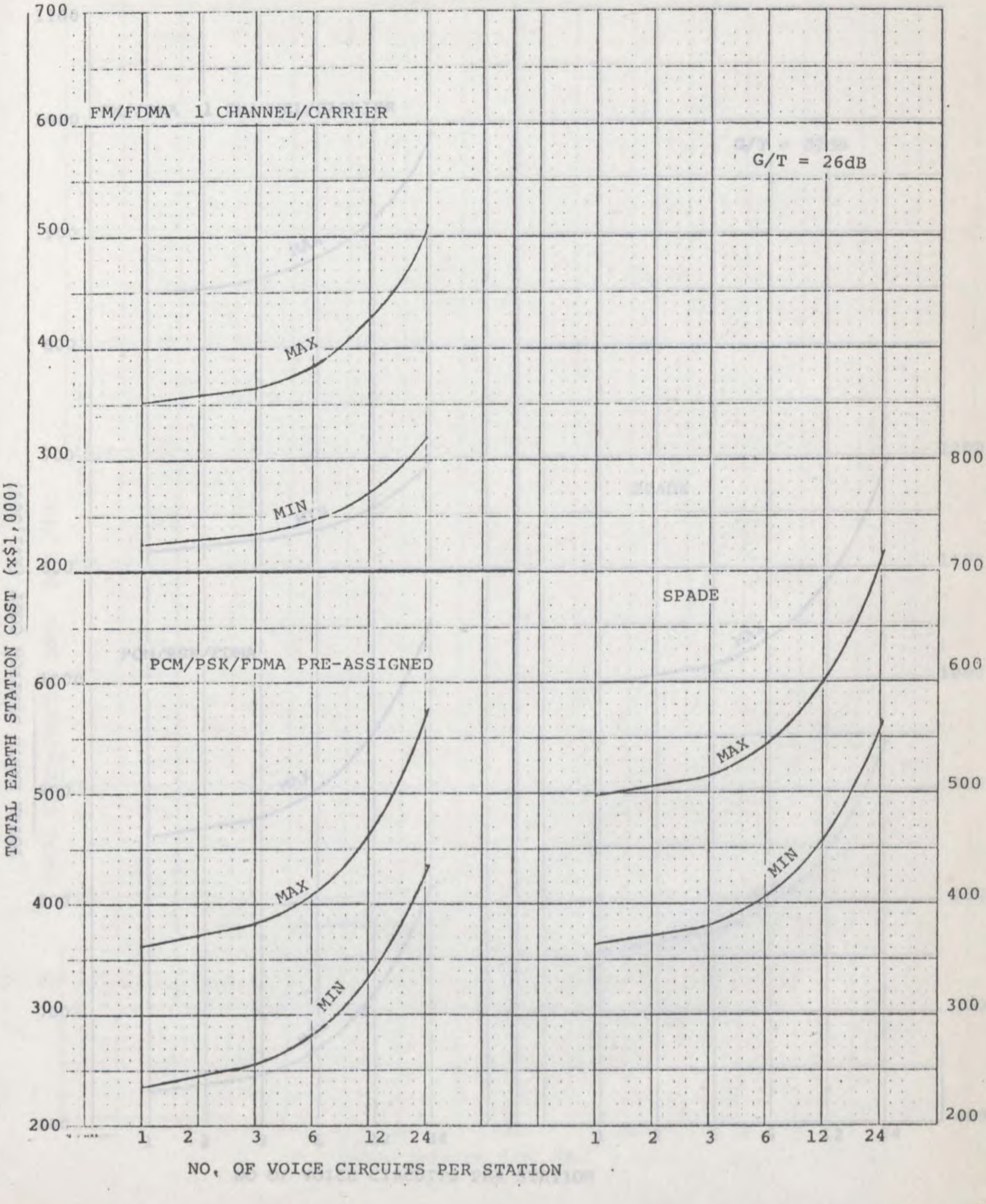


Fig. 9

TOTAL EARTH STATION COST VS NO VOICE CIRCUITS

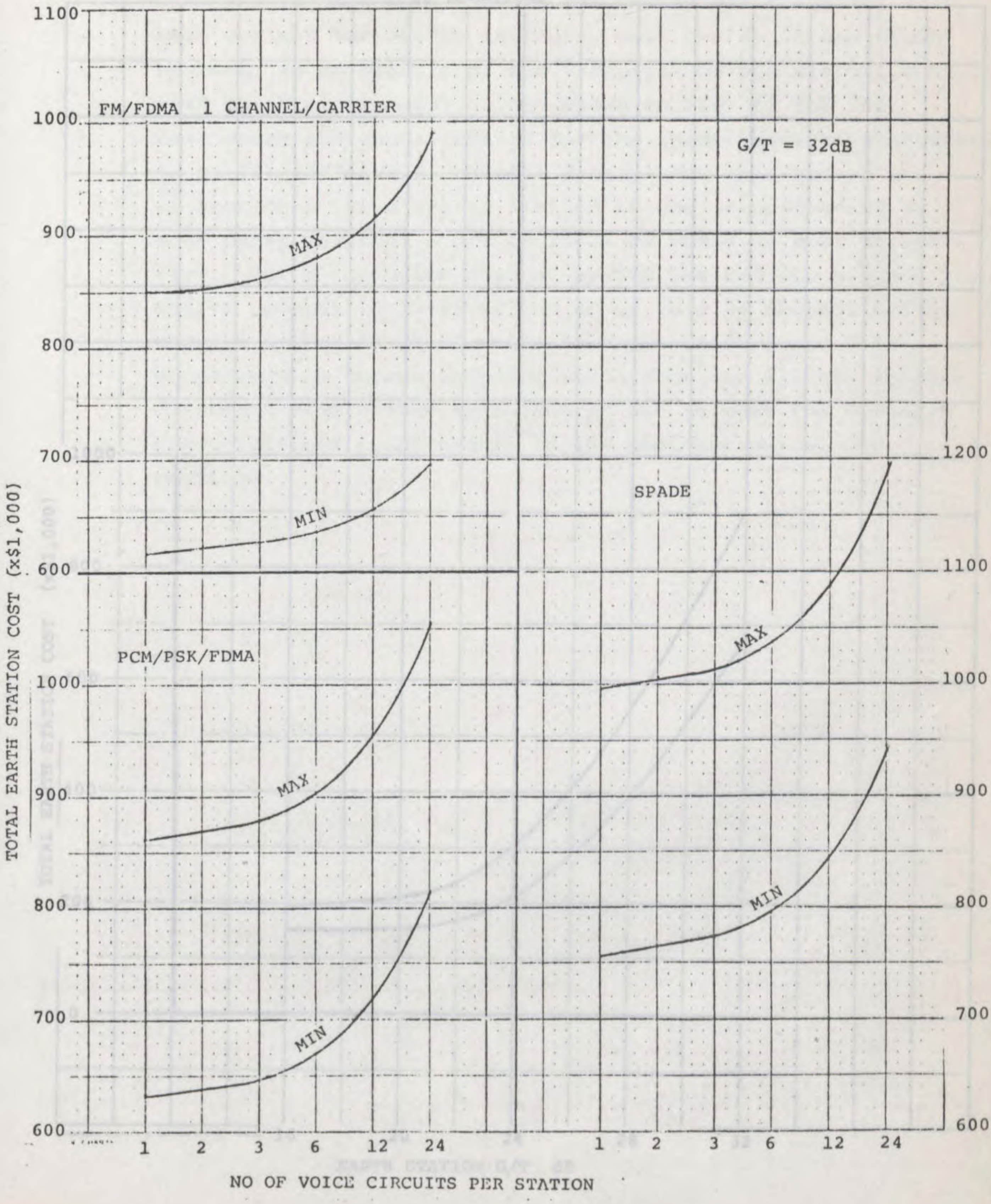
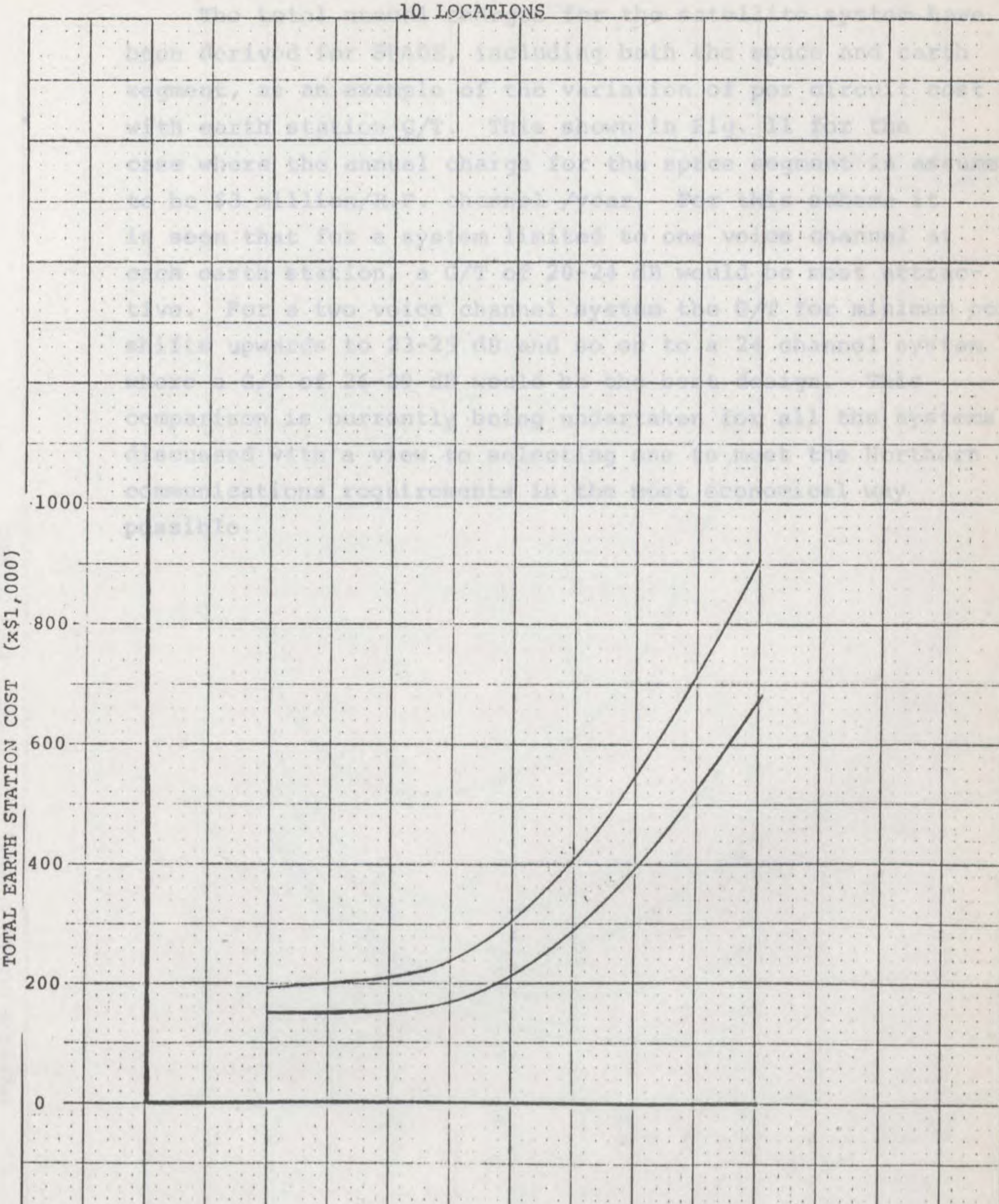


Fig. 10

EARTH STATION COST VS G/T FOR FDM/FM/FDMA SYSTEM SERVING 10 LOCATIONS

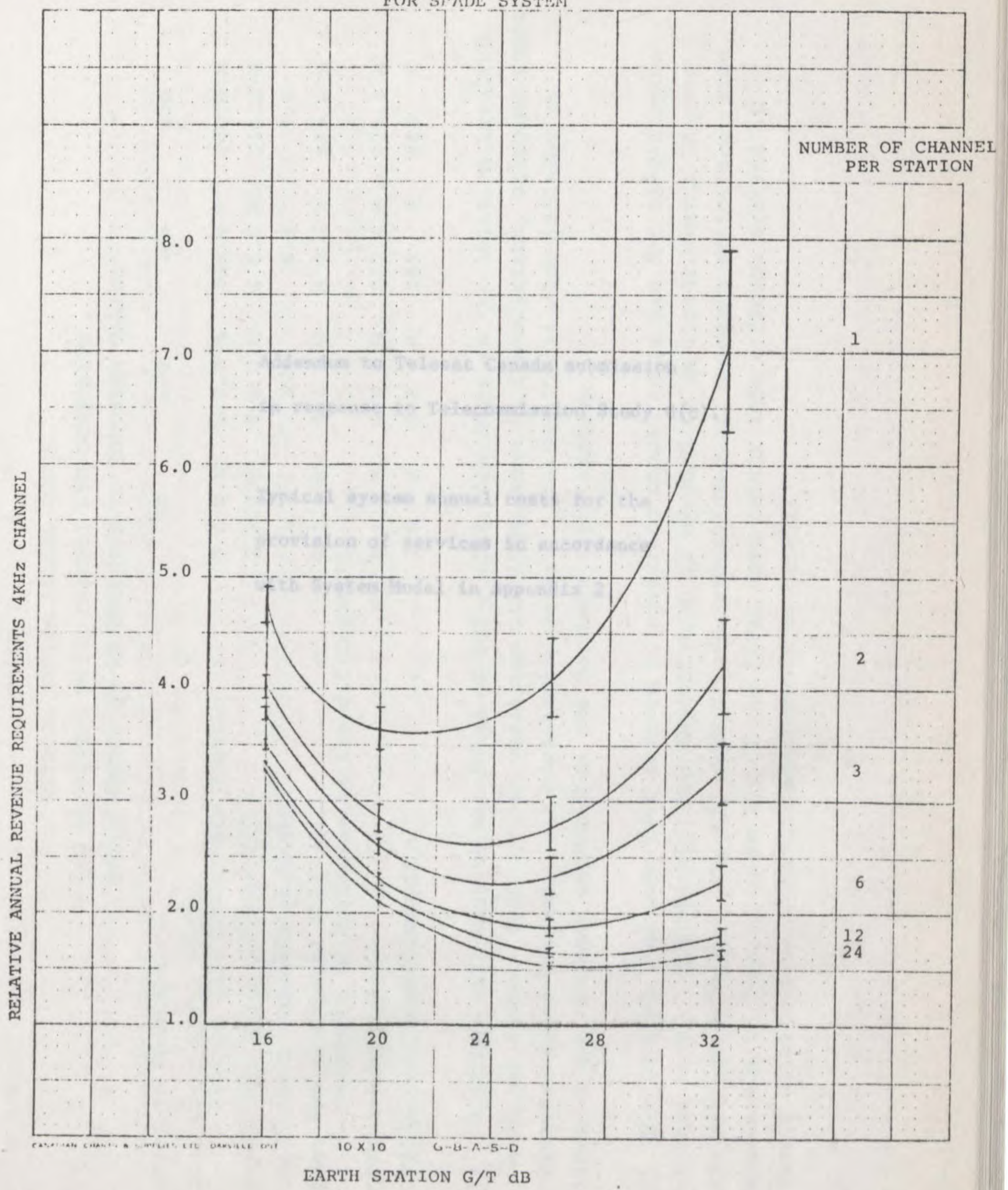


The total annual charges for the satellite system have been derived for SPADE, including both the space and earth segment, as an example of the variation of per circuit cost with earth station G/T. This shown in Fig. 11 for the case where the annual charge for the space segment is assumed to be $3 million/R.F. channel /year. For this scheme it is seen that for a system limited to one voice channel at each earth station, a G/T of 20-24 dB would be most attractive. For a two voice channel system the G/T for minimum cost shifts upwards to 23-25 dB and so on to a 24 channel system where a G/T of 26-29 dB would be the best design. This comparison is currently being undertaken for all the systems discussed with a view to selecting one to meet the Northern communications requirements in the most economical way possible.

Fig. 11

RELATIVE ANNUAL REVENUE REQUIREMENTS VS EARTH STATION G/T

FOR SPADE SYSTEM



Addendum to Telesat Canada submission
in response to Telecommission Study 8(c).

Typical system annual costs for the
provision of services in accordance
with System Model in Appendix 2.

TABLE I

TYPICAL SYSTEM ANNUAL COSTS

- ONE DEDICATED VOICE CHANNEL PER COMMUNITY
- CALLS ROUTED BY AN OPERATOR IN SOUTHERN CANADA

Number of Communities	50	100	200	400
First Costs Earth Segment Average $120 K/Northern Station (1)	$ 6.0 M	$12.0 M	$24.0 M	$48.0 M
Annual Cost Earth Segment (2)	$ 2.0 M	$ 4.0 M	$ 8.0 M	$16.0 M
Satellite RF Channels Required	1.2	2.4	4.8	9.7
Space Segment Annual Cost (4) (assuming $2 M/year/Satellite r.f.Channel)	$ 2.4 M	$ 4.8 M	$ 9.6 M	$19.4 M
TOTAL Annual Cost	$ 4.4 M	$ 8.8 M	$17.6 M	$35.4 M
TOTAL Annual Cost/Community	$88 K	$88 K	$88 K	$88 K

(1) Stations will cost in the range of $90 - 150K, depending on the location involved. Some of the factors causing this variation are items such as installation, shipping costs, Provincial Sales Tax and civil engineering works. The total cost also includes an allowance for the cost expended at the Southern earth station.

(2) The factors that have been assumed in computing annual costs are for illustration purposes only. For example, the depreciation is assumed to be linear over a 10 year life with no salvage. Capital expenditures are assumed all to occur at the same time. Maintenance is assumed to be 10% of the first cost rather than a figure arrived at through assessing maintenance requirements in detail.

TABLE I (Cont.)

(3) All calls between Northern locations are routed via the Allan Park earth station to enable them to be handled by operators in Southern Canada. This requires two satellite hops for calls between the North and therefore introduces round trip delays of 1200 milliseconds. The quality of such calls with this delay are likely to be unacceptable to users unless 4 wire telephone sets are used in the Northern communities. The use of 4 wire telephone sets would incur an additional cost.

(4) The space segment portion of the satellite system may vary over approximately $1 - 3 million per year per RF channel depending on the procurement policies followed and commercial agreements negotiated.

(5) The costs quoted exclude those which would be incurred by the Common Carriers.

TABLE II

TYPICAL SYSTEM ANNUAL COSTS

- ONE DEDICATED VOICE CHANNEL PER COMMUNITY
- CALLS AUTOMATICALLY SWITCHED BETWEEN NORTHERN COMMUNITIES (3)

Number of Communities	50	100	200	400
First Costs Earth Segment				
Average $155 K/Station (1)	$ 8.2 M	$ 15.5 M	$ 31.0 M	$ 62.0 M
Annual Cost Earth Segment (2)	$ 2.7 M	$ 5.2 M	$ 10.3 M	$ 20.7 M
Satellite RF Channels Required	0.7	1.4	2.8	5.6
Space Segment Annual Cost (5)	$ 1.4 M	$ 2.8	$ 5.6 M	$ 11.2 M
(assuming $2.0 M/year/Satellite r.f.Channel)				
TOTAL Annual Cost	$ 4.1 M	$ 8.0 M	$ 15.9 M	$ 31.9 M
TOTAL Annual Cost/Community	$80 K	$ 80 K	$ 80 K	$ 80 K

(1) Stations will cost in the range of $130 - 180K, depending on the location involved. Some of the factors causing this variation are items such as installation, shipping costs, Provincial Sales Tax and civil engineering works. The total cost also includes an allowance for the cost expended at the Southern earth station.

(2) The factors that have been assumed in computing annual costs are for illustration purposes only. For example, the depreciation is assumed to be linear over a 10 year life with no salvage. Capital expenditures are assumed all to occur at the same time. Maintenance is assumed to be 10% of the first cost rather than a figure arrived at through assessing maintenance requirements in detail.

TABLE II (Cont.)

(3) The costs include the provision for forwarding information to Southern Canada concerning calls originated, duration of calls etc., but not the recording and processing of such information.

(4) Calls between Northern locations require one satellite hop. The feasibility of achieving this is dependent on suitable coordination between users of the orbit of interest to Canada in order to reduce adjacent system interference.

(5) The space segment portion of the satellite system may vary over approximately $1 - 3 million per year per R.F. channel depending on the procurement policies followed and commercial agreements negotiated.

(6) The costs quoted here exclude those which would be incurred by the Common Carriers.

(7) The system considered here uses some demand assigned features. It is to be recognized therefore that although communities are shown to have the capability of receiving one dedicated voice channel per location there would in fact be an improvement in the use of r.f. channels which is not reflected in the space segment costs here.

TABLE III

TYPICAL SYSTEM ANNUAL COSTS

- 20 COMMUNITIES WITH ONE DEDICATED VOICE AND TELETYPE CIRCUIT EACH.
- REMAINING COMMUNITIES SHARING VOICE CIRCUITS IN THE PROPORTION 1:4.
- CALLS ROUTED BY AN OPERATOR IN SOUTHERN CANADA

Number of Communities:	50	100	200	400
First costs Earth Segment	$ 6.0 M	$12.0 M	$24.0 M	$48.0 M
Average $120K/Station (1)				
Annual Cost Earth Segment (2)	$ 2.0 M	$ 4.0 M	$ 8.0 M	$16.0 M
Satellite RF Channels Required	0.7	1.0	1.6	2.8
Space Segment Annual Cost	$ 1.4 M	$ 2.0 M	$ 3.2 M	$ 5.6 M
(assuming $2.0 M/year/satellite r.f. channel)				
TOTAL Annual Cost	$ 3.4 M	$ 6.0 M	$11.2 M	$21.6 M
TOTAL Annual Cost/Community	$68 K	$60 K	$56 K	$54 K

(1) Stations will cost in the range of $130 - 180K depending on the location involved. Some of the factors causing this variation are items such as installation, shipping costs, Provincial Sales Tax and civil engineering works. The total cost also includes an allowance for the cost expended at the Southern earth station.

(2) The factors that have been assumed in computing annual costs are for illustration purposes only. For example, the depreciation is assumed to be linear over a 10 year life with no salvage. Capital expenditures are assumed all to occur at the same time. Maintenance is assumed to be 10% of the first cost rather than a figure arrived at through assessing maintenance requirements in detail.

TABLE III (Cont.)

(3) All calls between Northern locations are routed via the Allan Park earth station to enable them to be handled by operators in Southern Canada. This requires two satellite hops and therefore introduces round trip delays of 1200 milliseconds. The quality of such calls with this delay are likely to be unacceptable to users unless 4 wire telephone sets are used in Northern Communities. The use of 4 wire telephone sets would incur an additional cost.

(4) The space segment portion of the satellite system may vary over approximately $1-3 million per year per r.f. channel depending on the procurement policies followed and commercial agreements negotiated.

(5) The costs quoted exclude those which would be incurred by the Common Carriers.

TABLE IV

- 20 COMMUNITIES WITH ONE DEDICATED VOICE AND TELETYPE CIRCUIT EACH
- REMAINING COMMUNITIES SHARING VOICE CIRCUITS IN THE PROPORTION 1:4
- CALLS AUTOMATICALLY SWITCHED BETWEEN NORTHERN COMMUNITIES (3)

Number of Communities	50	100	200	400
First Costs of Earth Segment				
Average $155K/Station (1)	$ 8.2 M	$15.5 M	$31.0 M	$62.0 M
Annual Cost Earth Segment (2)	$ 2.7 M	$ 5.2 M	$10.3 M	$20.7 M
Satellite RF Channels Required	0.4	0.6	0.9	1.6
Space Segment Annual Cost	$ 0.8 M	$ 1.2 M	$ 1.8 M	$ 3.2 M
(assuming $2.0M/year/satellite r.f. channel)				
TOTAL Annual Cost	$ 3.5 M	$ 6.4 M	$12.1 M	$23.9 M
TOTAL Annual Cost/Community	$70 K	$64 K	$60 K	$60 K

(1) Stations will cost in the range of $130 - 180K depending on the location involved. Some of the factors causing this variation are items such as installation, shipping costs, Provincial Sales Tax and civil engineering works. The total cost also includes an allowance for the cost expended at the Southern earth station.

(2) The factors that have been assumed in computing annual costs are for illustration purposes only. For example, the depreciation is assumed to be linear over a 10 year life with no salvage. Capital expenditures are assumed all to occur at the same time. Maintenance is assumed to be 10% of the first cost rather than a figure arrived at through assessing maintenance requirements in detail.

TABLE IV (Cont.)

(3) The costs include the provision for forwarding information to Southern Canada concerning calls originated, duration of calls etc., but not the processing of such information.

(4) Calls between Northern locations require one satellite hop. The feasibility of achieving this is dependent on suitable coordination between users of the orbit of interest to Canada in order to avoid adjacent system interference.

(5) The space segment portion of the satellite system may vary over approximately $1 - 3 million per year per R.F. channel depending on the procurement policies followed and commercial agreements negotiated.

(6) The costs quoted here exclude those which would be incurred by the Common Carriers.

(7) The system considered here uses some demand assigned features. It is to be recognized therefore that although communities are shown to have the capability of receiving one dedicated voice channel per location there would be in fact an improvement in the use of r.f. channels which is not reflected in the space segment costs here.

No. 2

Cost Estimate for a UHF Satellite Communication System

by O. S. Roscoe

National Communications Laboratory

Communications Research Centre

Department of Communications

COST ESTIMATES FOR AN UHF SATELLITE COMMUNICATION SYSTEM

GENERAL

This note details an attempt to determine the annual cost of a thin route multiple access satellite communications system. Since such a system would not likely be implemented until the late 1970's or early 1980's, it is extremely difficult to arrive at the cost of the space segment of the system, because a prediction of the state of satellite technology is involved. For this reason a bracketing range of costs for the space segment is derived which should represent minimum and maximum conditions.

Several assumptions have been made in estimating costs. It is assumed that the parameters of the space segment and the ground station are as given in the CRC description of a typical system. It is also assumed that the space segment is not implemented in a dedicated satellite, but is only part of a communication satellite system providing other services. For example, in a 1980 time frame, a UHF transponder might share a satellite with several very high powered (upwards of 1 kW) 12 GHz transponders used for TV distribution or for other communication purposes. In comparison with current satellites, such a satellite would have much greater primary power, and generally would be larger and heavier. It would be an application of techniques developed in technology-type satellites launched in the early 1970's. The cost of the UHF transponder in such circumstances would then be a portion of the cost of the space segment of the system, based on the portion of the total primary power consumed, total spacecraft weight and the portion of the total spacecraft launch costs which might be allocated to the UHF section on the basis of weight. The cost of certain required items, such as an unfurable antenna and any special development would, of course, be charged against the UHF system.

In determining the annual cost, the principle of "return or invested capital" as used in other communications studies has been applied. "Invested

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capital" can be taken to be the appropriate portion of the capitalized cost of the satellite, the launches, development, the operation control terminal and the ground terminals. The annual revenue required to fund depreciation on the capital investment over the lifetime of the system to pay for maintenance and operation, overhead, etc., is taken as the annual cost of the system. Profit and taxes have not been included, since the system would likely require subsidization and should therefore operate on a non-profit basis.

Assuming a 5 year lifetime for the space segment and a 10 year lifetime for the ground portion of the systems, annual cost of the system, based on the principle described, can be shown to be 20.25% of the invested capital.

SPECIFIED COST ESTIMATES

In a fully implemented system for 1980, it is assumed that 400 ground terminals will be served by 100 duplex voice channels in the satellite in a fully variable, demand assigned multiple access mode. (i.e., any ground station will be capable of direct one-hop connection with any ground station) Channel assignment will be automatically controlled from a central control terminal. Channel switching will be carried out at each individual ground station under control of the central control terminal. Therefore special switching of channels within the control terminal will not be required. The central control terminal will also provide receivers and transmitters for 25% of the channels in the satellite for connection to the national trunk system.

Ground terminals are estimated to cost $20,000 each, installed in locations in northern Canada. Costs of buildings and power, etc. are not included in the above figures because of the small space requirement and low power consumption.

The cost of the space segment is estimated to fall in the $5M to $20M bracket for the full 100 channel capacity transponder. Reducing the capacity by about 50% or more will reduce the cost only slightly.

A central control terminal, fully equipped, is estimated to cost $1M,

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with this cost dropping as the number of channels for connection to the national trunk system is reduced.

The costs are summarized in the table below.

THIN ROUTE SATELLITE SYSTEM COST ESTIMATE

	No. of Ground Terminals		
	400	200	100
Space Segment	\$5-20M	\$4-16M	\$4-16M
Annual cost of Space Segment	\$1-4M	\$0.8-3.2M	\$0.8-3.2M
Ground Terminals (\$20,000 each)	\$8M	\$4M	\$2M
Central Control Terminal	\$1M	\$0.7M	\$0.6M
Total Ground Segment Costs	\$9M	\$4.7M	\$2.6M
Annual Cost of Ground Segment	\$1.8M	\$0.9M	\$0.5M
Total Annual Cost of System	\$2.8-5.8M	\$1.7-4.1M	\$1.3-3.7M
Annual Cost per Community (1 Ground terminal in each)	\$7,000. to \$14,000	\$8,500. to \$20,500	\$13,000. to \$37,000

O.S. Roscoe

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Revised 9/7/70
NGD/kam

No. 3

A Satellite Communication System

for Thin Route Traffic

by O. S. Roscoe

National Communications Laboratory

Communications Research Centre

Department of Communications

A SATELLITE COMMUNICATIONS SYSTEM FOR THIN-ROUTE TRAFFIC

Introduction

Satellite communications systemsfor high volume traffic between major population centers are now an operational reality on an international basis. The development of a domestic system for high volume telephony and distribution of wideband signals is also well underway in Canada. In several quarters consideration is now being given to the use of satellite systems for thin-route traffic. Such systems are particularly attractive for use in sparsely populated, undeveloped, and environmentally rugged areas, such as the northern regions of Canada and Alaska, the outback areas of Australia, or the interior of South America.

Communications via satelliteshave a number of characteristics which make them well suited for providing service to regions such as those above. Among the most important of these characteristics is the flexibility with which new links can be established. After a suitable satellite is in orbit, communications can be extended to new areas simply by placing ground stations in these areas. For small stations, the cost of doing this is relatively independent of distance, or terrain, making satellite systems especially attractive where large distances must be covered. Another characteristic is that direct multi-point communications may be easily established using multiple access techniques. This is important where settlements are widely scattered and transportation is by diverse air routes rather than by fixed land based routes. The requirement for direct contact between diverse areas becomes even more necessary in regions of extensive exploration and development of natural resources.

Several types of service can be postulated for a thin-route system. The major one is voice telephony. Usually, one duplex channel is sufficient because of the small size of most remote communities, although some communities undoubtedly will require several channels. Requirements for data transmission are also developing because of mineral exploration and mining development. In addition, there is an increasing use of centralized computer based medical diagnostic facilities requiring transmission of patient data.

Voice and data transmission services are required from mobile as well as fixed stations. For example, reliable communications to commercial vessels and ice breakers are becoming more important with increased traffic in Canadian arctic waters. Communication to aircraft is another example of a mobile application.

Another potential use is with unattended stations for data read-out from remote sensors. Examples are the read-out of meteorological data or other scientific data from automatic monitoring stations located in remote areas. This may be done by interrogation from a central station, or in a self-clocked periodic fashion. The remote stations may be fixed, or may be, in fact, mobile, as on buoys or on the floating ice pack.

Finally, the system may be used for one-way communications for dissemination of information to the entire area of coverage. This may be facsimile or printer data transmission or broadcast of items of news or of educational interest. Broad and reliable coverage, difficult to obtain by any other means, could be readily achieved.

The following sections deal with a thin-route satellite communications system specifically for northern Canada. The discussion is based on the major requirement for single channel telephony. This does not, however, preclude the use of the system for other types of services and some aspects of the implementation of these other types of services are also discussed.

II) General Requirements

A thin-route multiple access satellite communications system for the remote regions of Canada must have the potential of serving with one voice channel approximately 500 settlements or stations. Many of these would be fixed, but some would be portable and others, located on ships or aircraft, would be completely mobile. In the discussion which follows only the fixed stations will be considered. Much of the same discussion can be applied to mobile stations as well, however. These will differ basically by requiring the added complexity of a tracking antenna.

Generally, the operation of the stations would be left to technically unskilled personnel, dictating that their operation should be as simple as possible. Tracking of a satellite by the antenna must not be necessary. Antenna pointing problems must be minimized. All stations in the network should be able to connect directly to each other and, where such facilities are available, the stations should be connected to local telephone exchanges. Access to the trunk networks should be possible through the system. Above all the cost of ground stations must be low. A cost of not more than about $20,000 for the antenna and the associated receiving and transmitting electronics would be a reasonable target.

Based on the general requirements for a thin-route system for domestic use in the Canadian north, the choice of system parameters can be considered. Some can be concluded directly from the requirements. Others require more extensive analysis.

III) Choice of System Parameters

Several conclusions can be drawn immediately from the stated requirements. To eliminate the necessity for tracking, the satellite should be in geostationary orbit. To reduce antenna pointing problems, the beamwidth of the ground station antenna should be not less than about 10°. The required capacity of the satellite transponder can be obtained from the number of potential stations and the expected usage. If a 20% usage factor is assumed, the transponder must have a capacity of 100 full duplex voice channels. Since the ground stations greatly outnumber this figure, it is mandatory that channels be assigned to the stations on a demand basis.

From a consideration of propagation, a broad range of frequencies, from about 0.4 GHz to 12 GHz, can be used for satellite communications systems. The lower end of this window is limited at low elevation angles by ionospheric fading effects, the upper end by atmospheric absorption and attenuation by rain. In addition to these effects on propagation, the signal flux density undergoes the normal decrease in free space with increasing distance and frequency. Distance is a constant and therefore does not have a variable effect on system parameters. Signal loss in free space increases as the square of the frequency, however, and the effect of this on the system parameters is determined by the constraints placed on the antennas used on the spacecraft and on the ground. The spacecraft antenna gain will ideally be independent of frequency because of the fixed coverage area required on the earth's surface. The ground station antenna will be small to meet the requirements of simplicity and low cost and will essentially have a fixed aperture until the minimum beamwidth is reached. Under these conditions the increase in free space loss is counterbalanced by the increase in gain of a fixed aperture. A gain limit is reached, however, when the minimum beamwidth is reached, and beyond this point the increase in free space loss must be compensated for by an increase in the e.i.r.p. of the satellite, indicating that it would be desirable to operate at a frequency below this point. The beamwidth and gain limit is reached between 2 GHz and 3 GHz. From these considerations, it is the UHF portion of the satellite communications frequency range that is most suitable for a thin-route system.

Other advantages also accrue from the use of this part of the spectrum. A choice can be made from several types of antennas such as yagis, helices, paraboloids, or others, up to about 1.5 GHz. Electronic component costs are also considerably lower than at the upper end of the range. Solid state components for use at UHF frequencies are well within the current state of the art, making it relatively easy to build the spacecraft transponder and low cost ground terminals.

For Canadian domestic use, the spacecraft antenna should be shaped to provide Canadian coverage. This means that it should have ideally a $3^{\circ} \times 8^{\circ}$ beamwidth, with a resultant beam edge gain from this directivity of at least 26 dB. A spacecraft antenna with these parameters is technically achievable, with the problems of implementation becoming less as frequency is increased and the required size becomes smaller.

The quality of speech desired on the circuits using the satellite link determines the bandwidth and power required per voice channel. A post detection signal-to-noise ratio of 33 dB has been recommended by the CCIR[1] for a 'good' quality circuit. A 23 dB signal-to-noise ratio would represent a 'fair' quality circuit. Assuming a frequency modulated carrier, it is shown in appendix A that for a 3400 Hz voice bandwidth, the carrier-to-noise density ratios and FM bandwidths are as given in Table 1.

Table 1

C/N_o and Bandwidth vs. Speech S/N for F.M.

S/N (dB)	C/N_o (dB.Hz)	B (kHz)
33	56.9	53
23	53.6	28.4

Assuming a constant aperture antenna of small size (3 ft.) until the minimum beamwidth constraint is reached (see figure 1), a receiver system noise temperature of 1000°K, and the carrier-to-noise density for the first case in Table 1, the required satellite e.i.r.p. per channel is shown in figure 1. Range is that for an elevation of 0° to the satellite. It can be seen that up to a frequency of 2.2 GHz, a transmitted power of 0 dBw per channel is required for a satellite antenna with a beamedge gain of 26 dB.

Figure 2 shows the antenna gains vs frequency required to meet the signal-to-noise ratios specified in table 1, assuming a satellite e.i.r.p. of 26 dBw. Detailed calculations from which figures 1 and 2 are derived are given in appendix B.

For a transmitted power of 0 dBw per channel, the transponder is required to radiate a maximum of 200 watts when all channels are occupied. For efficiency of operation it has been common to operate transponder broadband power amplifiers as close to saturation as possible. Operation in this non-linear region, however, results in intermodulation products which can interfere with wanted signals. Analysis (2) has shown that, with a large number of carriers, the level of interference to FM modulated carriers would be intolerable and operation at reduced power where the amplifier is linear would be necessary. Up to 4 or 5 dB of back-off from saturation may be necessary to reduce the intermodulation interference to a tolerable level. A power amplifier giving an output power at saturation in excess of 500 watts would therefore be necessary. Alternatives to one broadband amplifier can be considered, however. These include several amplifiers of narrower bandwidth or even the use of a channelized repeater with a discrete 1 watt amplifier per channel. This latter alternative is attractive because it eliminates the intermodulation distortion problem, and again allows operation at saturation, where high efficiencies can be achieved. Use of a channelized repeater would also eliminate operational problems that may be created if there is poor control of transmitted power from ground terminals or significant signal fading.

Using a constant aperture antenna in the ground station and a constant gain antenna in the spacecraft makes the power required for the uplink independent of frequency. Assuming channel bandwidth to be 50 kHz, satellite receiver system noise temperature to be 1000°K and a carrier-to-noise ratio of 20 dB as adequate to overcome front-end noise at the satellite receiver, uplink power is 10 dBw and 13.4 dBw for the two downlink post detection signal-to-noise ratios. Detailed uplink calculations

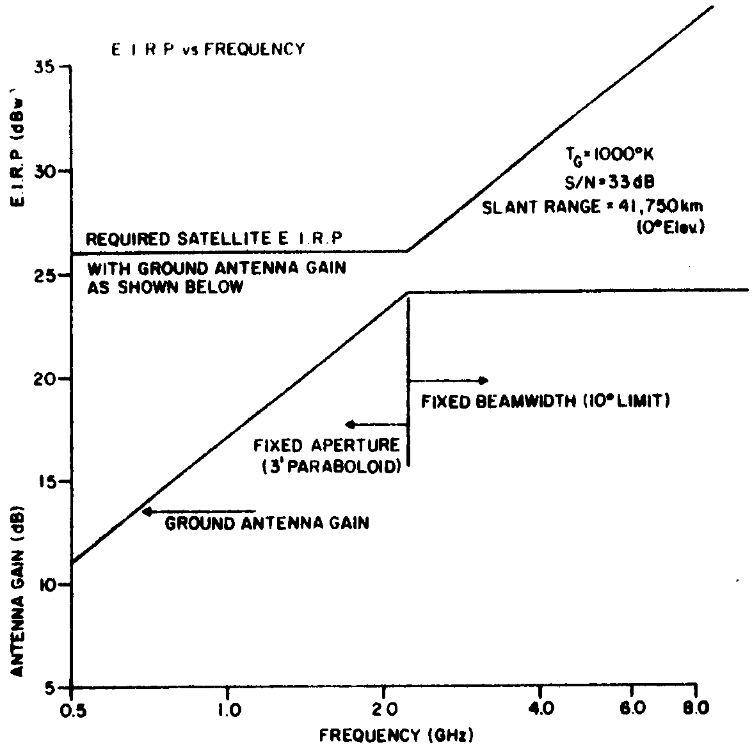


Figure 1

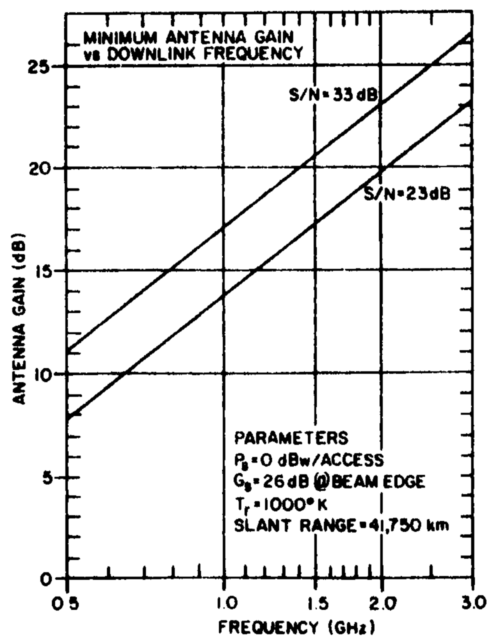
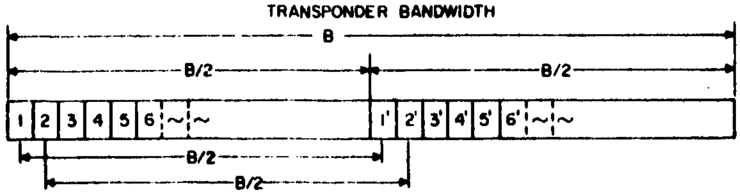


Figure 2



CHANNEL PAIRING FOR DUPLEX OPERATION

Figure 3

are also included in appendix B.

A significant propagation phenomenon at UHF frequencies is the rotation in polarization that a signal suffers in traversing the ionosphere. This is the so-called Faraday effect. It is readily circumvented, however, by the use of circularly polarized signals.

Provision must be made for variations in the system parameters. These can arise because of signal strength variations, antenna gain variations and antenna pointing errors. In the UHF band signal strength variations are primarily due to ionospheric fading, particularly at northern latitudes. The depth of fading varies with frequency approximately following an inverse squared dependence. Interpolating from measurements at 300 MHz and 1.5 GHz, fading amplitudes of up to several dB can be expected at 500 MHz. At 1 GHz and above, such fading decreases to the point where it is virtually negligible. Tropospheric effects can also be neglected in the UHF range at elevation angles above a few degrees.

Antenna gain variations can arise for several reasons. Ellipticity of circularly polarized antennas and deviation from the boresight axis can result in a polarization loss. Antenna gain can also vary because of Fresnel zone reflections. The gain variations here depend on the beamwidth of the antenna, its height, the elevation angle, and the reflection coefficient of the ground in the first Fresnel zone. The antenna can be adjusted in height to maximize its gain, but it can still be expected to vary because of changes in ground level due to ice and snow accumulation or tides if the reflection point is on the sea. The margin is also required to greater elevation angles at lower frequencies because of the generally broader beamwidths of the antennas.

Margin for antenna pointing error is required for possible mechanical misalignment of the ground station antenna.

Estimates of margin that should be provided are tabulated below.

Table 2

f (GHz)	Ionospheric fading (dB) (1% of time)	Ellipticity loss (dB)	Reflection loss (dB)	Mechanical Misalignment (dB)	Total (dB)
0.5	2.0	1.0	4.0	0.5	7.5
1.0	0.5	1.0	3.0	0.5	5.0
1.5	0	1.0	2.0	0.5	3.5
2.0	0	1.0	1.0	0.5	2.5
2.5	0	1.0	0	0.5	1.5

These margins can be met in numerous ways, the most practical of which are increasing antenna gain, reducing ground receiver noise temperature, increasing transmitter power, accepting lower performance for some percentage of the time or at some locations or a combination of any of the above.

The values for the various parameters discussed in this section indicate that all of the components required are within the current state-of-the-art and that little new development would be required. The design is also conservative in that it is based on a high quality of service. Several techniques for increasing capacity and improving quality have not been considered at this point. These include the use of pre-emphasis networks and companding,both of which can improve speech signal-to-noise ratios. Use of these techniques can further ease some of system parameter values. Because of these factors, the system should be relatively easy to implement from a technical point of view.

The prospect of applying forthcoming new developments should not be overlooked, however. In some cases these may ease system parameters without an undue increase in cost or decrease in reliability. One such development which may be expected in the near future is the integrated circuit parametric amplifier. This would result in a significant improvement in system noise temperature.

IV) Network Operation and Control

Efficient multiple access usage of a satellite transponder in a thin-route system where the individual stations do not use a channel full time requires that channels be assigned on demand to stations requiring connection. In a domestic system this can be conveniently done under a central control which pools all unused channels. This section outlines a method of network control and discusses the implications of this method on ground station features and satellite usage.

Two of the requirements for the system, namely that there be simplicity of operation and that it be capable of connection to telephone exchanges, can be met by making the ground station fully automatic, with the channel selection performed by internal logic and external commands from the central control. Current technology makes this possible and economically feasible through the use of digital logic and inexpensive integrated circuit, digitally controlled,frequency synthesizers.

Assuming the inclusion of control logic and a frequency synthesizer the procedure in operating a ground station can be reduced to that followed in operating a telephone. The further addition of touch-tone calling can make the ground stations compatible with telephone exchanges so equipped and can provide the means for signalling between the station and central control.

For assignment purposes, the bandwidth of the satellite transponder can be divided in two, with channels in each half paired for duplex operation between two ground stations. All pairs would have a fixed frequency separation so that the frequency synthesizer could be the basic tunable source for both the transmitter and receiver. The separation between the duplex channel pairs would then be an IF frequency. The bandwidth division and channel pairing are illustrated in Figure 3. In the figure the primed number indicates the pair to the channel with the same number.

One duplex channel must be dedicated for control purposes. It is over this channel that ground stations make their requests to a controlling terminal for connection to another station. The controlling terminal also uses this channel to issue channel assignments to stations and the stations in turn transmit status messages to the control terminal on this channel. Details on how connections are initiated, how control is exercised by the central control terminal and how signalling is accomplished are given in Appendix C.

The central assignment control terminal consists of a ground station monitoring the assignment control channel. A mini-computer at this terminal is used to maintain the pool of available channels, issue assignments, and issue other controlling signals to the logic incorporated in each ground station. The logic in each ground station exercises local control over the frequency synthesizer based on the status of the station (i.e., whether a call is being initiated,or has been terminated), decodes messages received over the assignment control channel, switches the frequency synthesizer accordingly, and sends status messages to the central terminal.

V) A Thin-Route Satellite Communications System Configuration

A satellite communications system based on the general requirements outlined in section II and the analysis carried out in section III is described in this section. Included are features required by the network control system discussed in section IV. A frequency of 1.5 GHz has been chosen, but it must be emphasized that a system need not be restricted to this frequency and may be within a fairly broad UHF range. Figure 4 is a pictorial representation of a typical ground station.

The system described is based on the calculated parameters required to provide a post detection speech signal-to-noise ratio of 33 dB, without the use of speech pre-emphasis techniques. Improvements to some of these parameters have been included to provide for system margins. The parameters chosen for improvement are the ground station receiver noise temperature and antenna gain. A receiver system noise temperature of $800^{o}K$ is easily and economically achievable at 1.5 GHz, providing 1 dB improvement over the assumptions used in the analysis of section III. The antenna gain of 22 dB provides a further 1.5 dB improvement over the value used in the analysis. The analysis was also based on the beam edge gain of the satellite antenna. Its pattern, however, is such that maximum gain falls approximately at the point of 1^{o} elevation to the satellite, providing additional gain where it is needed most for margin losses. For most ground station locations greater than about 55^{o} latitude about 2 dB can be assumed to be gained here. The total available margin for system losses is therefore about 4.5 dB.

A description of a system for multiple access use in the Canadian north is given below.

Frequency : 1.5 GHz, up and downlinks separated by 3 percent

Spacecraft :

Orbit - geostationary

Antenna - shaped paraboloid 3^{o} x 8^{o} beam, circular polarization
beam edge gain 26 dB

Transponder - 200 channels
channel bandwidth 50 kHz
input noise temperature $1000^{o}K$
output power 0 dBw/channel

Ground Station :

Antenna - dual/quad helices or yagis or 3.5' paraboloid-gain
22 dB
circular polarization

Receiver - tunnel diode r.f. amplifier
system noise temperature $800^{o}K$
frequency synthesizer tuning

Transmitter - output power 10 watts

Modulation - FM

Voice channel bandwidth - 3400 Hz

Control - by remote signalling and internal logic
calling by tone signalling
automatic channel selection

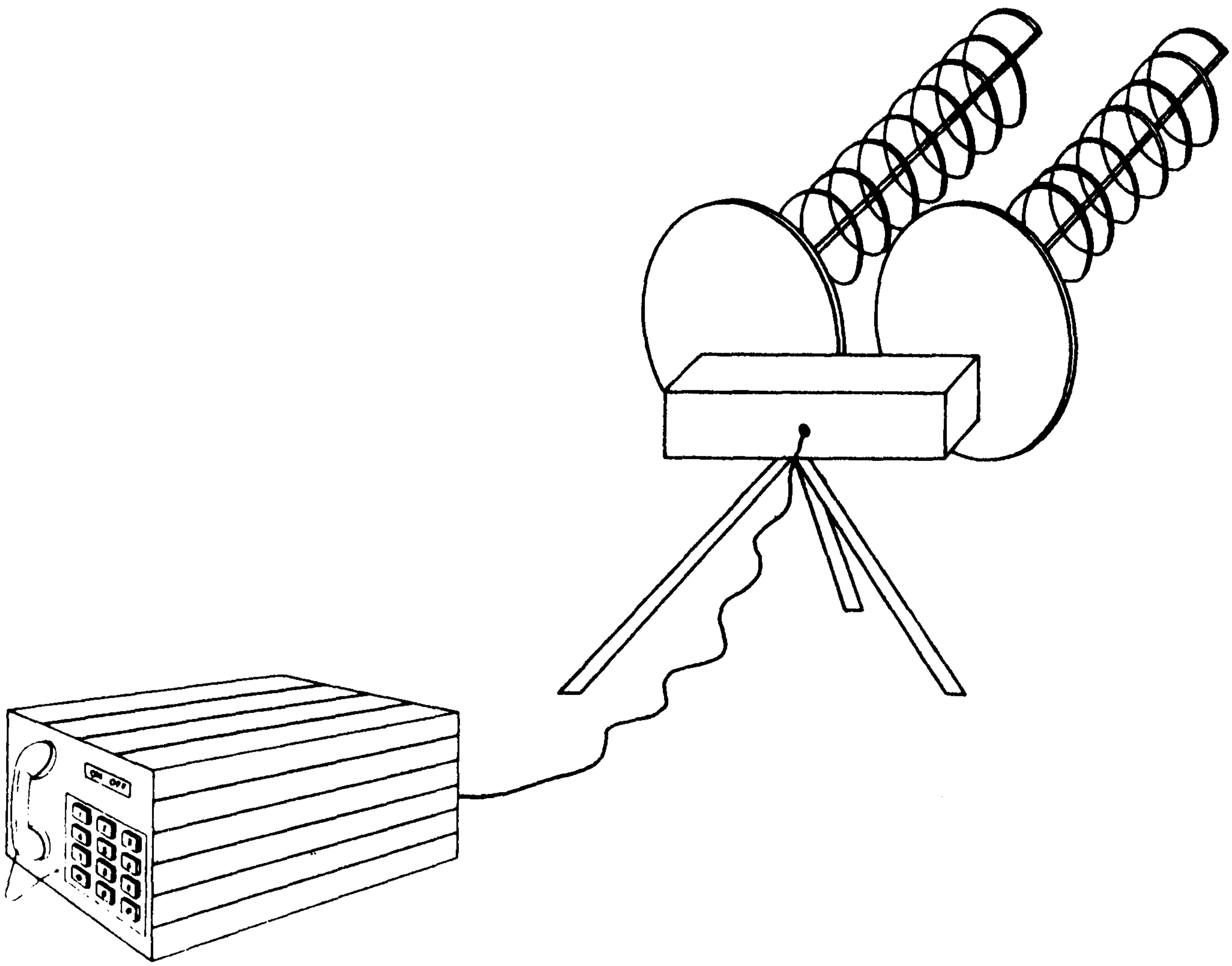
Multiple Access System:

Frequency division multiple access, single channel per carrier
Channels demand assigned
Central control by computer from a channel assignment and control terminal
Demand and control via dedicated channel

The ground station configured above must be modified to provide service other than voice telephony to a fixed station. For mobile applications a tracking antenna is required. A physically tracking antenna, perhaps using monopulse circuitry, would be suitable for ship use, whereas a phased array would be more suitable for aircraft. The unattended fixed readout terminals would not require the extensive demand assignment circuitry, and may also operate at reduced e.i.r.p. at lower data rates. The mobile unattended readout terminals would require omni-directional antennas, and would be required to operate at reduced data rates. In general, the system is sufficiently flexible to handle the range of services discussed in the introductory paragraphs of this report.

VI) System Implementation

A domestic system to meet the requirements described has not yet been implemented anywhere. Australia is planning experiments using an



Typical UHF Satellite Communications

Ground Station

Figure 4

existing NASA satellite to provide a service having some of the characteristics discussed, but because it must use an existing satellite, it does not have complete freedom in system design. Before an operational system is established, the feasibility of design based on theoretical studies must be demonstrated. Propagation measurements must be made. Experiments must be carried out with various modulation methods and network control procedures. This can be done by first implementing an experimental system designed to have some flexibility so that a variety of ideas can be tested. The results of these tests can lead to suitable designs of a thin-route UHF system for inclusion in future domestic communications satellite systems.

The prospect of both UHF and SHF transponders being on board the same satellite raises the possibility of using the two types of transponders in combination. This can be advantageous for providing connections to circuits on the trunk networks from remote UHF terminals. A portion of the UHF transponder can be permanently coupled to a portion of an SHF transponder. UHF terminal users desiring connections to the trunk network would be assigned an appropriate cross-coupled channel. The advantages of such a system are that trunk connections would be made at an SHF terminal which would already have the necessary equipment and that bandwidth in the UHF range would be conserved.

One obstacle in the way of implementing an UHF satellite communications system is that at the present time there is no international frequency allocation for this purpose. This matter is being pursued at the present time and it is hoped that a suitable allocation will be made available by the World Administrative Radio Conference on Space Telecommunications to be held in 1971.

Acknowledgments:

The author wishes to acknowledge the many helpful discussions held with members of CRC staff and the ideas obtained from them, in particular, Messrs. N.G. Davies and L.A. Maynard.

References

1. CCIR Documents of the Ninth Plenary Assembly, Los Angeles, 1959 Vol. 3, p. 28. Recommendation 339-1

2. P.M. Boudreau, FM-FDMA Through A Hard-Limiting Satellite Repeater, Sat. Com. Section TM 2/70, April 1970

Appendix A

Signal-to-Noise Ratio Requirements for Speech Modulated FM Systems

Speech Signal-to-Noise Ratio Requirements

Several recommendations for signal-to-noise ratios for speech have been found. The CCIR(1) has recommended 33 dB for radio systems connected to public telephone networks. For space links, CCIR(2) recommends that the mean noise power on a telephone channel be less than 10,000pWpO. This is equivalent to a test-tone to noise ratio of 47.5 dB, where flat weighting is used for the noise. The average talker on a telephone circuit has been found to have a speech power of -14 dBmO(3). The resulting speech signal-to-noise ratio is then 33.5 dB. Desired objectives for noise levels on public telephone networks have also been quoted by the Bell Telephone Laboratories(4). These objectives are

short haul (100-200 mi)	Noise = 38 dBrn = -52 dBmO
2000 mile system	41 dBrn = -49 dBmO
4000 mile system	44 dBrn = -46 dBmO

where noise power level = -90 dBm + dBrn = dBmO. Taking speech power level as -14 dBmO results in the following signal-to-noise ratio requirements

Short Haul system	39 dB
2000 mile system	35 dB
4000 mile system	32 dB

Data from the three sources generally agree. Therefore a 33 dB signal-to-noise ratio will be assumed to be adequate for a good quality circuit. A still usable, but only fair quality circuit, would be one providing a 23 dB signal-to-noise ratio.

2. Post-Detection Signal-to-Noise Ratio

For FM systems operating above threshold, the detected signal-to-noise ratio is related to the carrier-to-noise ratio in the I.F. bandwidth by:

$$S/N = 3\ C/N_o \left(\frac{f_r^2}{f_m^3}\right) \qquad (1)$$

where S/N = post detection signal-to-noise ratio, unweighted by telephone handset and human ear response

C/N_o = Pre-detection signal-to-noise power density ratio;

f_r = r.m.s. frequency deviation of the F.M. signal;

f_m = post detection bandwidth.

If clipping for 1% of the time is assumed, the peak-to-r.m.s. amplitude ratio is $\sqrt{10}$. Therefore, the peak deviation of a speech-modulated FM carrier is given by:

$$\Delta f_{pk} = \sqrt{10}\ f_r \qquad (2)$$

Substituting this in (1):

$$S/N = 3\ C/N_o\ \frac{\Delta f_{pk}^2}{f_m^3} \cdot \frac{1}{10} \qquad (3)$$

Using Carson's rule for the required FM signal bandwidth:

$$B = 2\ (f_m + \Delta f_{pk})$$

Therefore

$$\Delta f_{pk} = \frac{B}{2} - f_m \qquad (4)$$

Substituting (4) in (3):

$$S/N = 3\ C/N_o\ \frac{(B/2 - f_m)^2}{f_m^3} \cdot \frac{1}{10} \qquad (5)$$

Figure A 1 shows the relationship between C/N_o and B for signal-to-noise ratios of 33 dB and 23 dB, without and with an additional 8 dB improvement possible by the applications of pre-emphasis to the voice signal. Also shown in figure A 1 is the C/N_o at threshold vs. bandwidth. This is considered to be the point where a 0.5 dB departure from linearity occurs and is given by:

$$\frac{C}{N_o B} \left(1-\mathrm{erf}\sqrt{\frac{C}{N_o B}}\right) = \frac{0.122}{\sqrt{3}\ (B/f_m)}^{2}$$

From figure A 1, it can be seen that a given S/N can be maintained with decreasing C/N_o by increasing the bandwidth, with the limit at the threshold of the FM receiver. The minimum C/N_o requirements are summarized in Table A 1, obtained from figure A 1.

Table A 1

S/N (dB)	C/N_o (dB.Hz)	B (kHz)
33, no pre-emphasis	56.9	53
23, no pre-emphasis	53.6	28.4
33, with pre-emphasis	54.2	32
23, with pre-emphasis	51.0	18.3

Acknowledgments:

This appendix has been prepared from material published by

J.S Butterworth and N.G. Davies in Communications Research Centre internal memoranda.

References

1. CCIR Documents of the Ninth Plenary Assembly, Los Angeles, 1959 Vol. 3, p. 28. Recommendation 339-1

2. CCIR Documents of the Eleventh Plenary Assembly, Oslo, 1966, Vol. 4, p. 205. Recommendation 353-1

3. 'Transmission Systems for Communications' by the staff of Bell Telephone Laboratories, Third Edition, 1964 p. 242

4. Ibid. p. 39

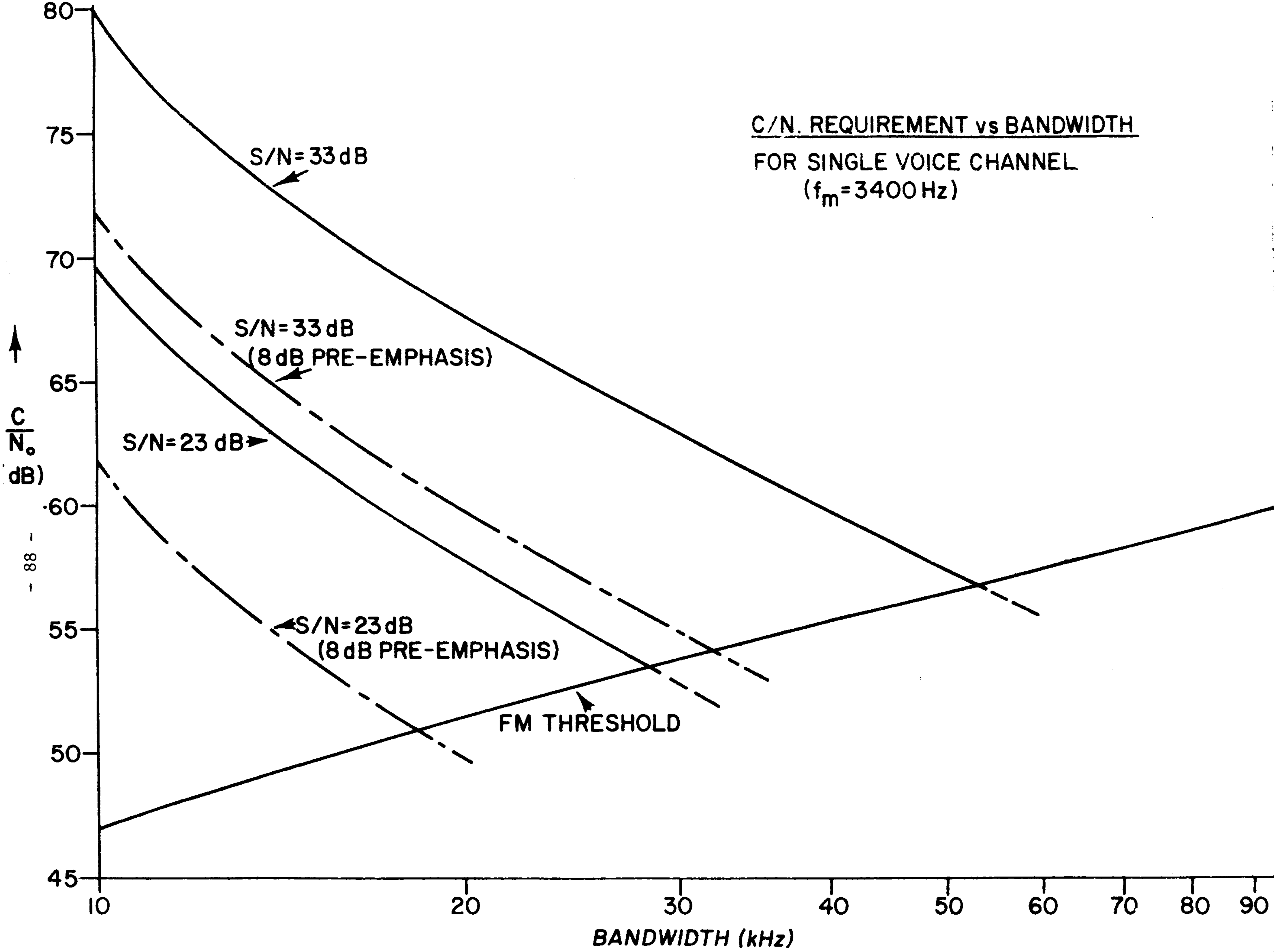

C/N. REQUIREMENT vs BANDWIDTH
FOR SINGLE VOICE CHANNEL
(f_m=3400 Hz)
S/N=33 dB
S/N=33 dB
(8 dB PRE-EMPHASIS)
S/N=23 dB
S/N=23 dB
(8 dB PRE-EMPHASIS)
FM THRESHOLD
$\frac{C}{N_o}$ (dB)
80
75
70
65
60
55
50
45
10
20
30
40
50
60
70
80
90
BANDWIDTH (kHz)

Figure 4.1

Appendix B

Link Calculations

Variation of Ground Station Antenna Gain with Frequency

The carrier-to-noise power density ratios required to provide the voice signal-to-noise ratios listed in Appendix 'A' will be used in these calculations. These are listed in Table B 1 below.

Table B 1

S/N (dB)	C/N_o (dB)
33, no pre-emphasis	56.9
23, no pre-emphasis	53.6
33, with 8 dB pre-emphasis gain	54.2
23, with 8 dB pre-emphasis gain	51.0

The carrier-to-noise density ratio on the downlink is given in dB by

$$C/N_o = P_s + G_s - L_p + G_g - (kT) \quad (1)$$

where P_s = transmitted power from the satellite

G_s = satellite antenna gain

L_p = free space path loss

G_g = ground station antenna gain

kT = receiver noise power density

Assume the following parameters:

P_s = 0 dBw per access

G_s = 26 dB at beam edge ($3^o \times 8^o$ beamwidth)

$T = 1000^oK$. Therefore $kT = -198.6$ dBw/Hz

Rearranging (1) and using the parameters above, G_g becomes

$$G_g = C/N_o + L_p - 224.6 \quad (2)$$

L_p is a function of frequency and distance, and is given in dB by

$$L_p = 92.45 + 20 \log_{10} (f.d) \quad (3)$$

where f = frequency in GHz

d = range in kilometers

Assume that the satellite is in geostationary orbit. Maximum distance to the satellite occurs when the elevation angle to it from the earth's surface is 0^{o}. This distance is approximately 41,750 km. L_p is plotted for this distance as a function of frequency in Figure B 1.

Using the values of L_p from Figure B 1 and C/N_o from Table B 1, G_g can be calculated. G_g is plotted as a function of frequency in Figure B 2 for the four values of S/N.

Uplink Transmitter Power Requirements

Uplink power is given by

$$P_g = P_r - G_g + L_p - G_s$$

where P_g = uplink transmitter power

P_r = power level at the satellite receiver

P_r = -kTB +C/N

where C/N in this case is the carrier-to-noise ratio at the satellite receiver. It must be high enough to overcome front-end noise at the satellite receiver. C/N = 20 dB can be assumed to be adequate. Assume also that the satellite receiver noise temperature is $1000^{o}K$ and that channel bandwidth is 50 kHz. Therefore,

$$P_R = (-228.6 + 30 + 47) + 20$$

$$= -131.6 \text{ dBw}$$

Uplink frequency can be assumed to be within a few percent of the downlink frequency. Therefore, uplink satellite antenna gain equals the downlink gain. Then

$$P_g = -157.6 + L_p - G_g$$

In figure B 2, the increase in required antenna gain with frequency is solely due to increase in path loss with frequency. Therefore, $L_p - G_g$ as a function of frequency is a constant and P_g does not change with frequency. This is a consequence of the use of a fixed gain antenna on the satellite and a fixed aperture antenna on the ground. P_g for each case shown in figure B 2 is given below in table B 2.

Table B 2

Required Transmitter Power

with antenna required to give downlink S/N of	P_g dBw	P_g watts
33 dB	10.1	10

23 dB	13.4	22
33 dB, with pre-emphasis	12.8	19
23 dB, with pre-emphasis	16.0	40

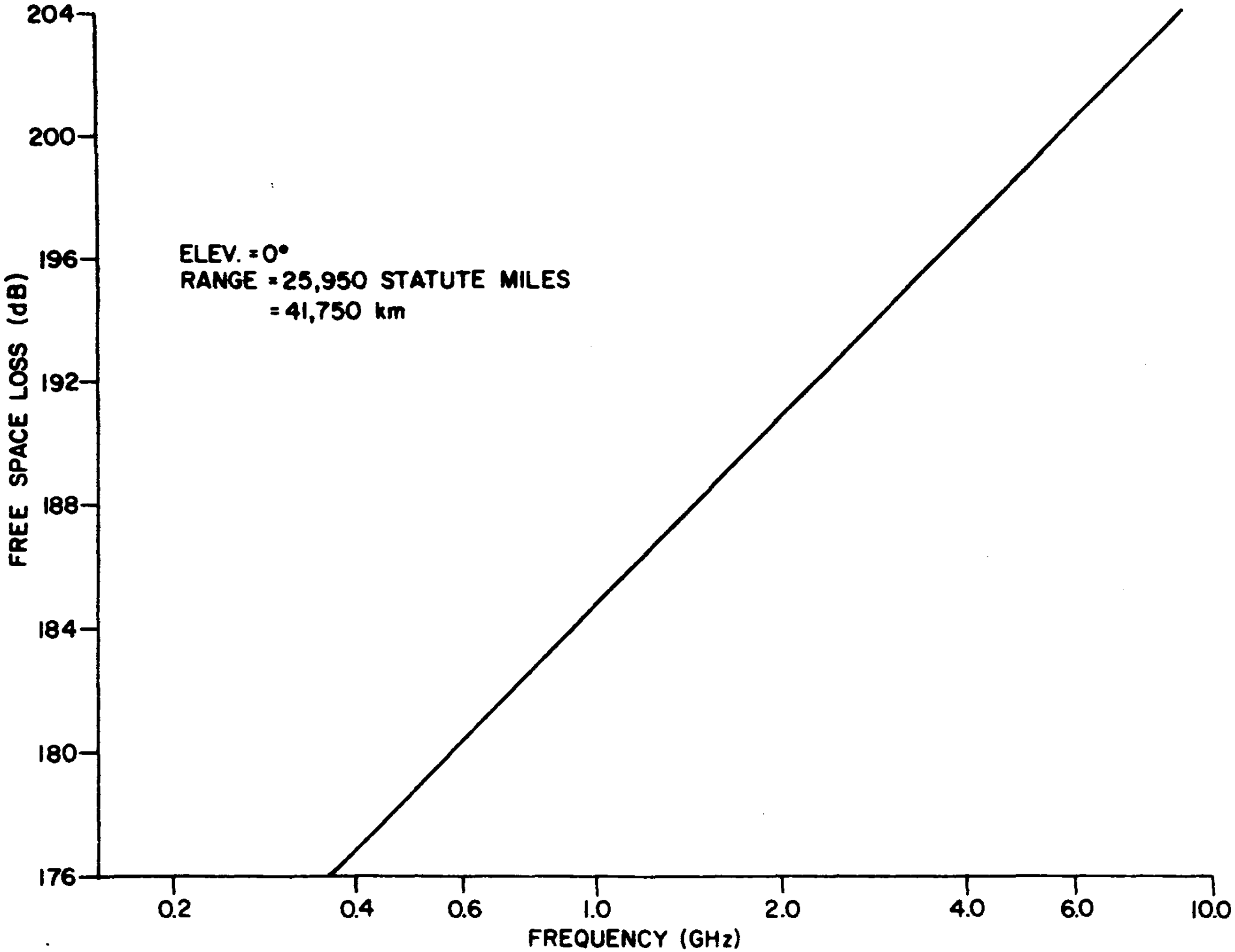
Margin Requirements

The link calculations shown in this appendix do not include allowances for propagation degradation. They show the minimum requirements. Downlink and uplink margins are identical if the frequencies are close to each other. Providing margins by increasing downlink power or decreasing ground station receiver temperature means that uplink margins must be supplied by increasing ground transmitter power. Increasing antenna gain, on the other hand, provides the same amount of margin for both directions.

The most practical way of providing for margins is by a combination of the several possible ways. Firstly, ground station antenna gain should be increased as much as practicable. Secondly, ground station receiver noise temperature should be reduced. Thirdly, pre-emphasis should be employed to improve the speech signal-to-noise ratio. Ground station transmitter power can be increased as required.

Increasing spacecraft power is not recommended because of the problem of exceeding international standards for flux density on the earth's surface and because of the high cost of providing this power.

Margin requirements become greatest as the elevation angle from the ground station to the satellite approaches 0°. About 2 dB for margin is automatically provided in this situation by the spacecraft antenna. For a $3^{\circ} \times 8^{\circ}$ antenna, if the beamedge is assumed to lie along Canada's southern border, the antenna boresight is near the northern extremity of coverage.



MAXIMUM FREE SPACE LOSS TO A GEOSTATIONARY SATELITTE

Figure B 1

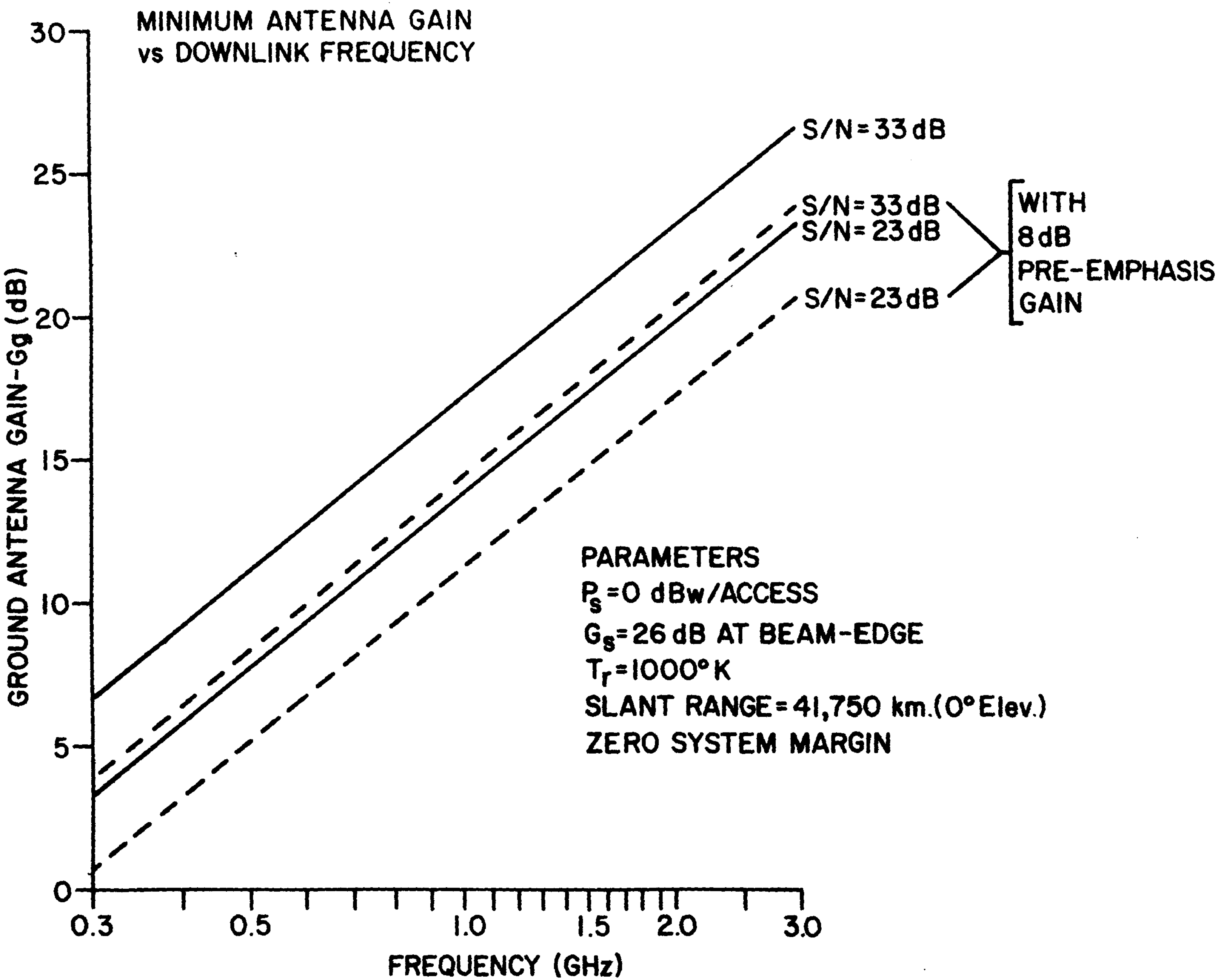

MINIMUM ANTENNA GAIN
vs DOWNLINK FREQUENCY
GROUND ANTENNA GAIN-Gg (dB)
30
25
20
15
10
5
0
S/N=33dB
S/N=33dB
S/N=23dB
S/N=23dB
WITH
8dB
PRE-EMPHASIS
GAIN
PARAMETERS
Ps=0 dBw/ACCESS
Gs=26 dB AT BEAM-EDGE
Tr=1000°K
SLANT RANGE=41,750 km.(0° Elev.)
ZERO SYSTEM MARGIN
0.3
0.5
1.0
1.5
2.0
3.0
FREQUENCY (GHz)

Figure B 2

Appendix C

Demand Assigned Multiple Access Control

Introduction

A method for demand assignment of channels in a thin-route satellite communications system is proposed in this appendix. Foremost among the requirements are that the addition of a demand assignment system does not unduly increase the cost of the ground stations or complicate their operation. For this reason, it is proposed that the communications receiver and transmitter in the ground station be used also for channel demand and assignment purposes. The addition of some logic circuitry and a frequency synthesizer can make channel selection at the ground station completely automatic, requiring no operator intervention.

It is envisaged that the ground stations will be connected to small local telephone switchboards or will have operator controls similar to a telephone. The controls are assumed consist of a telephone handset on a switch actuating cradle, a touch-tone dial, and a power on-off switch. Operation is identical to operation of a telephone.

The satellite bandwidth is assumed to be divided into paired channels so that all pairs have the same frequency separation. The two channels of each pair are assigned to stations wishing to communicate. In this way, only one tunable frequency source is necessary to provide both the transmit carrier and receive local oscillator. This tunable frequency source is a frequency synthesizer suitable for direct digital control.

Network Control

Central control of channel assignments to all of the ground stations in the system is basic to the network control plan. Network control is exercised through the use of a specially equipped Channel Control Terminal (CCT) probably located at a main communications base. The CCT receives a request from a ground station for connection to another ground station, determines whether this connection can be made, assigns a channel pair to the two parties, provides channel control signals for the two parties, and monitors channel usage. The CCT also controls connection to and from trunk circuits where these interface with the system. All bookkeeping and control functions at the CCT are performed by a mini-computer.

One channel pair in the satellite is dedicated as an Assignment Control Channel (ACC). When in a standby condition, the frequency synthesizer (FS) in each ground station is switched automatically to the ACC. A second dedicated channel, a Confirmation Channel (CC), is used by ground stations for message confirmation purposes. The two channels would likely be incorporated within one of the standard voice channels of the system.

A tone signalling system is incorporated in each ground station for requesting a connection and CCT control of the ground station. The signalling system is assumed to be compatible with telephone system requirements.

The procedures at the calling station, the called station, and the CCT are shown in flow chart form in figures C1, C2 and C3. To make a call to another ground station, a 3 digit number assigned to that station is selected on the station keyboard. This selection is stored by the logic in the ground station until the third digit is selected. This is combined with the calling station's number, encoded in an error detecting code and then transmitted as a short tone burst, to conserve channel occupancy time, to the CCT. The calling station switches its FS to monitor its own transmission on the ACC and, if received correctly, then switches its FS to the CC. Correct reception of its own transmission by the calling station is assumed to indicate that there was no simultaneous multiple use of the ACC.

At the CCT the received signal is checked for errors. If it is error-free, a check is made at the CCT if the desired station is free and if a channel pair is available. If free, an addressed channel assignment is transmitted by the CCT on the ACC. All ground stations on standby will decode the address and the addressed station will switch its FS to the CC, transmit a confirmation to the CCT via the confirmation channel, and then switch its FS to the assigned channel. The CCT will then transmit the channel assignment, suitable addressed, to the calling station via the CC, which will switch its FS to the designated channel. The established connection between ground stations can now be used to select the desired number at the local exchange by regular touch tone keying. The ground station itself can be one of these local numbers, or if no exchange is connected, the secondary keying could be eliminated.

Under the condition that the desired station is occupied, an address busy signal would be transmitted by the CCT to the calling station. If a confirmation is not received from the calling station or if a channel pair is not available, this information would also be relayed to the calling station.

Upon termination of the call, the FS in both stations would revert to the ACC. The calling station would then transmit a termination message to the CCT. In the situation where the called station is active but there is no answer, termination of signalling is treated as a call termination.

The system depends on call attempts being made on a random basis. Simultaneous attempted use of the ACC would produce errors. Some protection is available because of the short burst system and the error detecting code. Signals received in error would be ignored and would require repetitioh by the calling ground station. This condition would be detectable by the calling ground station monitoring its own transmission and checking the Error Detecting Code for correspondence with the transmitted signal. Repetition would be automatic after a short random delay. The CCT would also monitor its own transmissions and take necessary repetitive action in cases of simultaneous usage of the ACC. It is assumed that if a calling station or the CCT receives its own signal correctly, then the signal has been received correctly by the called station.

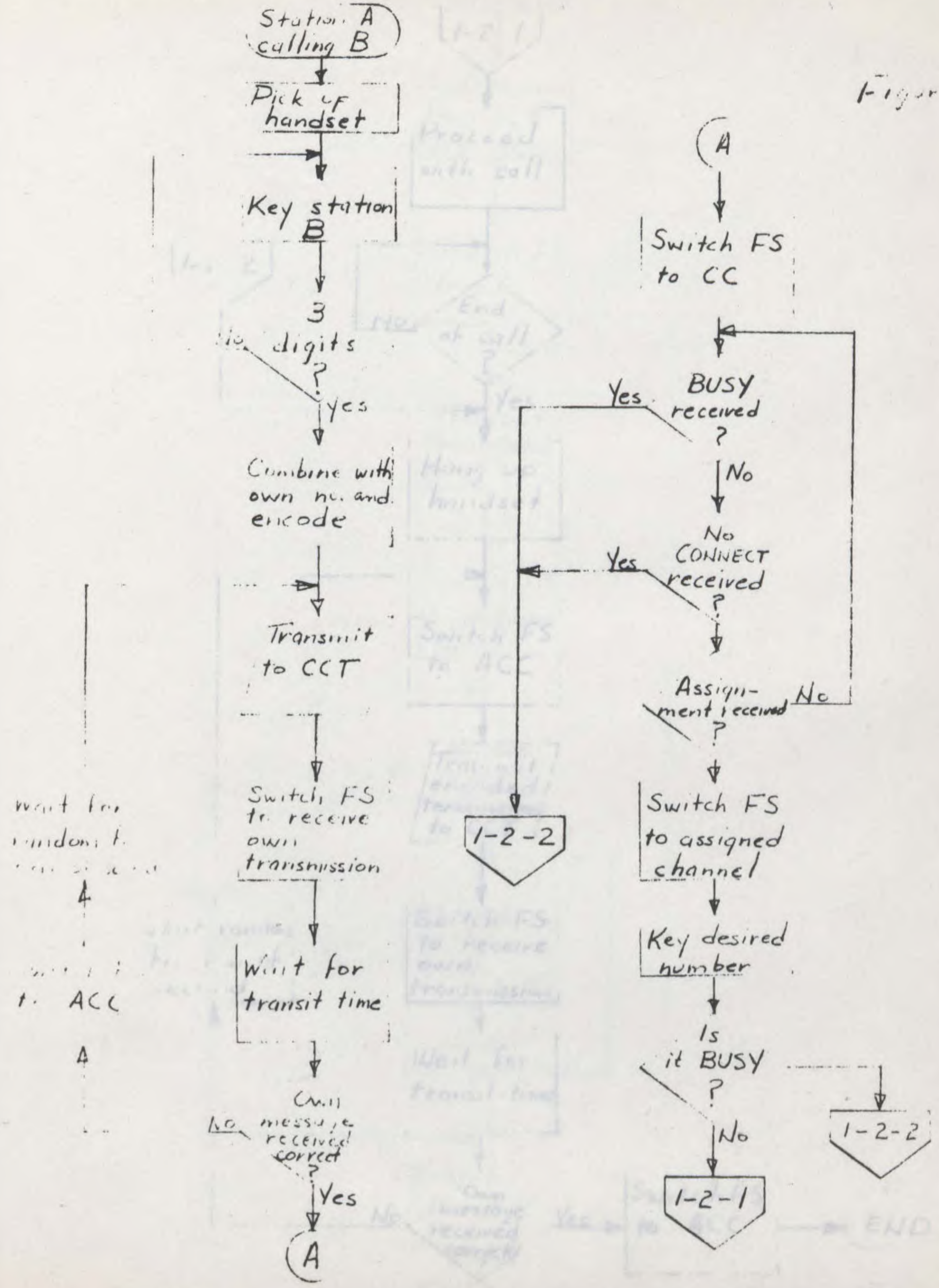
No errors can arise in the use of CC because confirmation on this channel would be time ordered by the CCT.

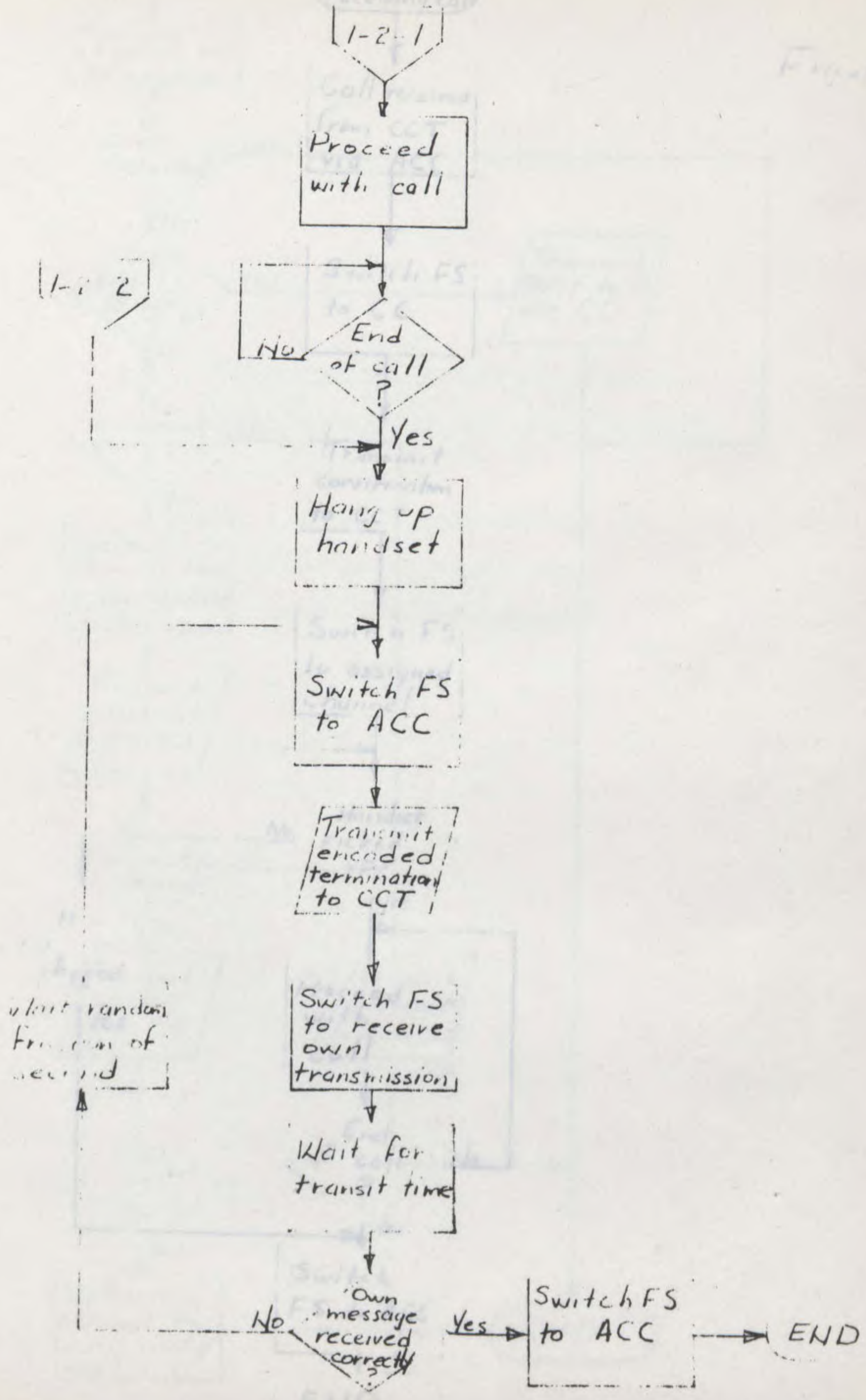
It should be noted that the control concept described is a proposal only and must be tested by means of a computer simulation using practical traffic models and incorporating appropriate time delays and circuit loading statistics before the control system can be finally specified.

Flow Diagram - Demand Assigned Multiple Access Control

1-1

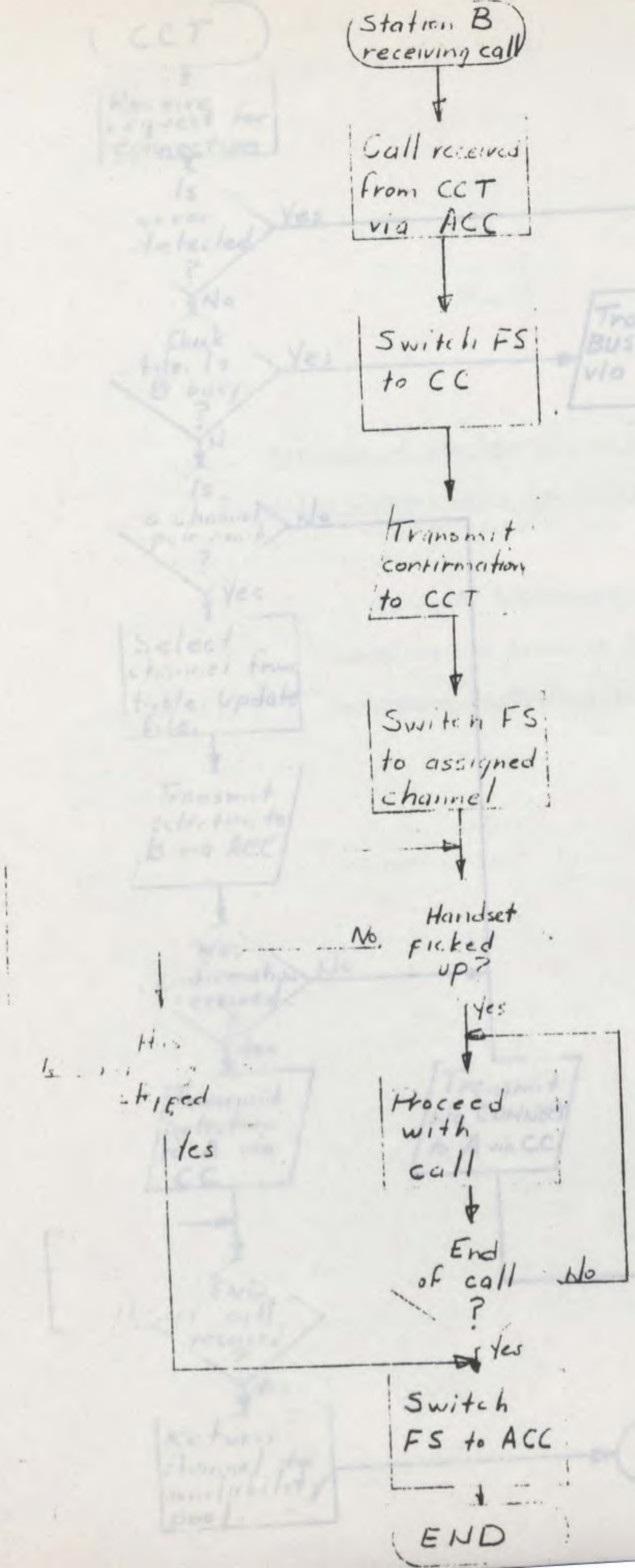
Figure C1




1-2-1
Proceed with call
1-2-2
End of call ?
No
Yes
Hang up handset
Switch FS to ACC
Transmit encoded termination to CCT
Switch FS to receive own transmission
Wait for transit time
Own message received correctly ?
No
Yes
Switch FS to ACC
END

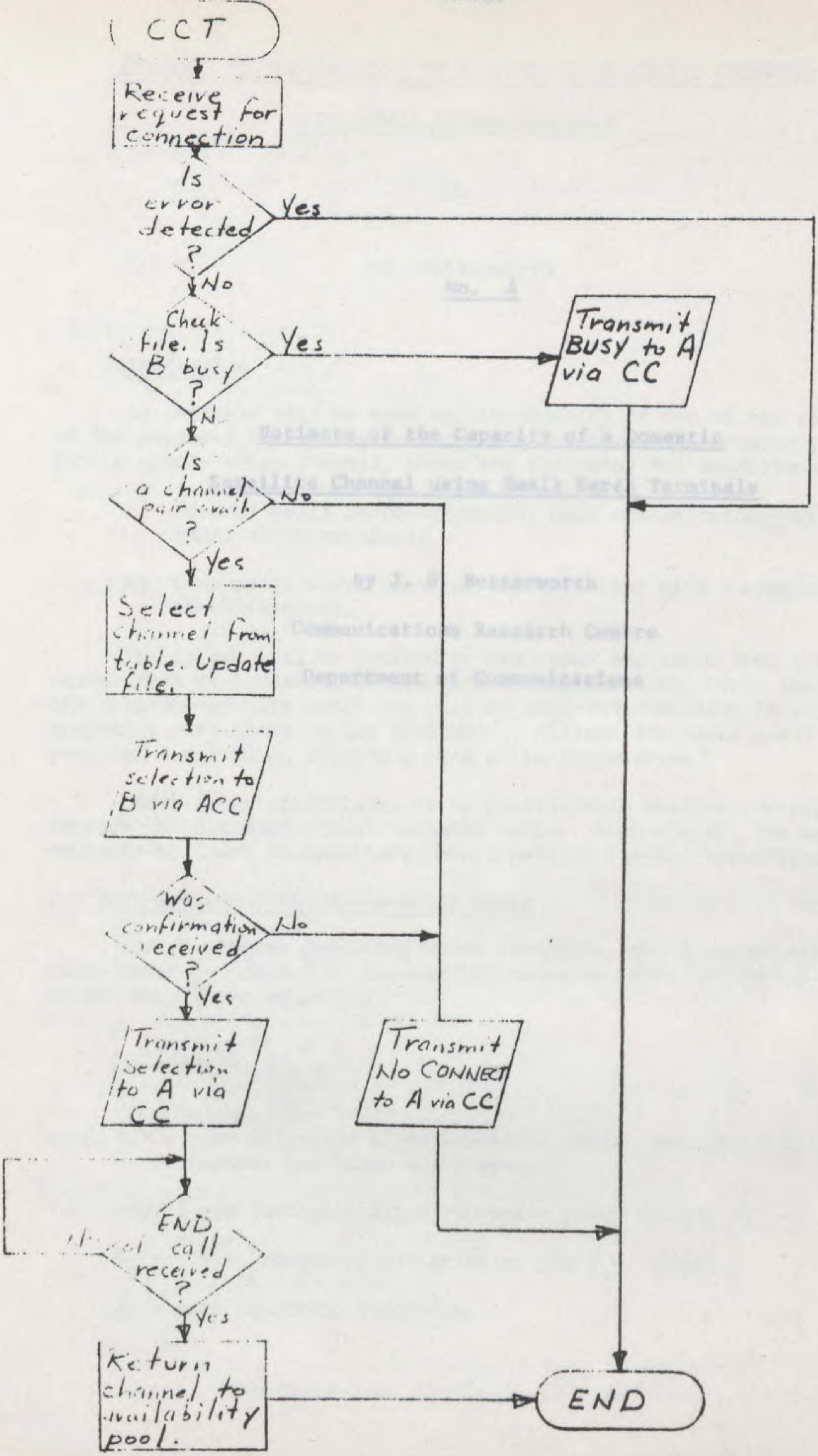
1-3

Figure C2


Station B receiving call
Call received from CCT via ACC
Switch FS to CC
Transmit confirmation to CCT
Switch FS to assigned channel
Handset picked up?
No.
Yes
Yes
Proceed with call
End of call ?
No
Yes
Switch FS to ACC
END

1-4

Figure C3


CCT
Receive request for connection
Is error detected ?
Yes
No
Check file. Is B busy ?
Yes
N
Transmit BUSY to A via CC
Is a channel pair avail. ?
No
Yes
Select channel from table. Update file.
Transmit selection to B via ACC
Was confirmation received ?
No
Yes
Transmit selection to A via CC
Transmit NO CONNECT to A via CC
END call received ?
Yes
Return channel to availability pool.
END

No. 4

Estimate of the Capacity of a Domestic Satellite Channel using Small Earth Terminals

by J. S. Butterworth

Communications Research Centre

Department of Communications

ESTIMATE OF THE CAPACITY OF A DOMESTIC SATELLITE CHANNEL, USING SMALL EARTH-TERMINALS

by

J.S. Butterworth

1. Introduction

An estimate will be made of the capacity of one of the six channels of the proposed domestic satellite, for carriers each frequency modulated with a single voice channel, under the following two conditions:

a) Several small earth-terminals, each communicating with another small earth-terminal;

b) Each small earth-terminal communicating with a single large earth-terminal.

The system will be limited by the power available from the satellite, rather than by bandwidth or some other consideration. This implies that the maximum-capacity condition will be achieved when each FM receiver is operating very close to its threshold. Minimum down-link power is then required for a given receive system noise temperature.

Under these conditions, it is questionable whether pre-emphasis would improve the detected signal-to-noise ratio. Accordingly, the use of pre-emphasis will not be considered here, pending further investigation.

2. Post-Detection Signal-to-Noise Ratio

For FM systems operating above threshold, the detected signal-to-noise ratio is related to the carrier-to-noise ratio in the I.F. bandwidth by the well-known equation:

$$S/N = 3\ C/N_o \left(\frac{f_r^2}{f_m^3}\right) \qquad (1)$$

where S/N = post detection signal-to-noise ratio, unweighted by telephone handset and human ear response;

C/N_o = pre-detection signal-to-noise power density ratio;

f_r = r.m.s. frequency deviation of the F.M. signal;

f_m = post detection bandwidth.

.../2

For a speech signal, the peak-to-r.m.s. amplitude ratio, exceeded only 0.1% of the time, is 7.67 (see Ref. 1). Therefore, the peak deviation of a speech-modulated FM carrier is given by:

$$\Delta f_{pk} = 7.67 f_r \qquad (2)$$

Substituting this in (1):

$$S/N = 3\, C/N_o \frac{\Delta f_{pk}^{\;2}}{f_m^{\;3}} \times \frac{1}{7.67^2} \qquad (3)$$

Using Carson's rule for the required FM signal bandwidth:

$$B = 2\,(f_m + \Delta f_{pk})$$

therefore

$$\Delta f_{pk} = \frac{B}{2} - f_m \qquad (4)$$

Substituting (4) in (3);

$$S/N = 3\, C/N_o \frac{(B/2 - f_m)^2}{f_m^{\;3}} \cdot \frac{1}{7.67^2} \qquad (5)$$

For a single voice channel, f_m will be taken as 3400 Hz.

Equation (5) enables the derivation of the relationship between S/N, C/N_o, and B shown in Fig. 1

From Fig. 1, it will be seen that, as the bandwidth is increased, a lower C/N_o is required to maintain a given S/N. The limit to this improvement is the threshold of the FM receiver.

As a wide range of deviation ratios will be considered, it is essential to know the exact value of C/N_oB at threshold, over the expected range, rather than assuming the customary 10 dB.

If threshold is considered as the point at which a 0.5 dB departure from linearity occurs, then, from an analysis by Rice[2], we have the following condition at this point:

$$\frac{C}{N_oB}\left(1 - \mathrm{erf}\sqrt{\frac{C}{N_oB}}\right) = \frac{0.122}{\sqrt{3}\,(B/f_m)^2} \qquad (6)$$

From this one can find the value of C/N_o at threshold, for a given bandwidth, B. This is plotted in Fig. 1. For reference, C/N_oB as a

.../3

function of B/f_m is shown in Fig. 2.

With FM-feedback (FMFB) receivers, a threshold extension of 8 dB is possible[3] and would obviously be very desirable for the situation under consideration. This extended threshold has also been plotted in Fig. 1.

From Fig. 1, it will be seen that the following conditions occur at threshold.

Table 1

a) Normal receiver:

S/N (dB)	48.2	40.	30.
C/N_o (dB.Hz)	65.	62.	58.5
B (kHz)	260.	146.	72.

b) FMFB receiver:

S/N (dB)	48.2	40.	30.
C/N_o (dB.Hz)	59.8	56.9	53.5
B (kHz)	460.	260.	127.

48.2 dB is the CCIR recommended unweighted S/N for satellite FM telephone links.[4]

Note that N_o includes noise from all sources, but principally receiver thermal (kT_s) noise and intermodulation (IM) noise produced due to multi-access use of the satellite.

3. Determination of Intermodulation Noise

The carrier-to-intermodulation noise ratio (C/IM) at the output of the satellite is determined almost entirely by the output travelling-wave tube.

Westcott has produced graphs[5] showing C/IM as a function of the number of accesses and the output backoff of the TWT from single-carrier saturation. These are reproduced in Fig. 3.

As these graphs represent non-linear relationships, it will be difficult to determine the number of accesses starting from a knowledge of the total C/N_o.

Accordingly, it will be useful to make a first estimate by assuming that the required value of C/kT_s is 2 dB higher than the overall C/N_o. Cases of potential interest can then be checked out accurately.

One can now re-write Table 1 in terms of C/kT_s:

Table 2

a) Normal receiver:

S/N (dB)	48.2	40.	30.
C/kT_s (dB.Hz)	67.	64.	60.5
B (kHz)	260.	146.	72.

b) FMFB receiver:

S/N (dB)	48.2	40.	30.
C/kT_s (dB.Hz)	61.8	58.9	53.5
B (kHz)	460.	260.	127.

4. Small-Terminal to Small-Terminal Situation

4.1 Down-Link

For this situation, C/kT_s will be determined in terms of the number of accesses, N, using known system parameters.

The multi-access saturated EIRP of the satellite, near the edge of the coverage pattern, is (per access):

$$(34-1.4-10 \log N) \text{ dBw} \quad (N \geq 4) \qquad (7)$$

1.4 dB = TWT output compression factor, for $N \geq 4$.

The down-link path-loss at the edge of the coverage zone is 197 dB. The received power at an isotropic antenna would therefore be:

$$\text{EIRP/access} - 197 = -(164.4 + 10 \log N) \text{ dBw}.$$

Three different sizes of antenna will be considered: 4, 6, and 10 ft. diameters. It will be assumed in each case that a tunnel-diode R.F. amplifier is used, leading to a receive system noise temperature, T_s, of about 1000° K; kT_s is therefore -198.6 dBw/Hz, where k is Boltzmann's constant.

Table 3

Ant. Size (ft.)	4	6	10
Receive antenna gain, G_r (dB)	31.6	35.2	39.6
Received power, C (dBw)	-(132.8+10logN)	-(129.2+10logN)	-(124.8+10logN)
C/kT_s	65.8-10logN	69.4-10logN	73.8-10logN

Comparing these last figures with the values of C/kT_s actually required (Table 2),we can obtain the number of accesses, N:

a) 4 ft. terminal

S/N (dB):	48.2	40	30
Normal receiver, N =	0	1	3
FMFB receiver, N =	2	4	16

b) 6 ft. terminal

S/N (dB):	48.2	40	30
Normal receiver, N =	1	3	7
FMFB receiver, N =	5	11	38

c) 10 ft. terminal

S/N (dB):	48.2	40	30
Normal receiver, N =	4	9	21
FMFB receiver, N =	15	30	107

Examination of these results shows that the 4 ft. terminal does not provide enough circuits to merit further consideration (number of circuits equals number of accesses divided by two), the 6 ft. terminal even with FMFB receiver only provides a reasonable number of circuits at lower signal-to-noise ratios, and the 10 ft. terminal only provides reasonable results with an FMFB receiver.

.../6

More detailed calculations have therefore been completed for the latter case, for the three signal-to-noise ratios. Using the initial estimates of capacities as a starting point, the variation of carrier-to-intermodulation noise ratio with backoff was obtained from Fig. 3. When combined with the carrier-to-thermal noise ratio, C/kT_sB, which decreases linearly with backoff, the resultant C/NoB has a maximum at a specific value of backoff. This backoff was typically in the range 1.8 to 2.1 dB.

The results of this detailed calculation are shown in the following table, for different values of operating margin above receiver threshold:

10 ft. dia. antenna S/N = 48.2 dB, FMFB receiver

Margin (dB)	C/N_o(dB.Hz)	B (kHz)	C/N_oB(dB)	N
0	59.8	460	3.2	18
1	60.4	430	4.1	15
2	61.0	400	5.0	13
3	61.7	370	6.0	10
4	62.4	345	7.0	8

10 ft. dia. antenna S/N = 40 dB, FMFB receiver

Margin (dB)	C/No(dB.Hz)	B (kHz)	C/NoB(dB)	N
0	57.0	260	2.8	34
1	57.7	240	3.9	28
2	58.3	225	4.8	23
3	59.0	210	5.8	18
4	59.5	195	6.6	15

10 ft. dia. antenna S/N = 30 dB, FMFB receiver

Margin (dB)	C/No(dB.Hz)	B (kHz)	C/NoB(dB)	N
0	53.5	126	2.5	78
1	54.0	117	3.3	66
2	54.7	110	4.3	54
3	55.5	102	5.3	42
4	56.0	95	6.2	34

4.2 Up-Link

4.2.1 Power Requirement

The total flux density required at the satellite, to drive the output to saturation, is -80 dBw/m^2. From the edge of the coverage zone, the range, d, to the satellite will be approximately 39,500 km. Therefore

$4\pi d^2$ = 162.9 dB (m^2), and the required total ground station EIRP is 82.9 dBw.

The required ground station EIRP per access will be:

(82.9-10logN-input backoff) dBw.

For the 10 ft. diameter antenna, with a transmit frequency gain of 43.1 dB, the required values of transmit power will be as given below:

a) S/N = 48.2 dB.

N	Output Backoff (dB)	Input Backoff (dB)	Power (watts)
18	1.8	4.0	210
15	1.9	4.5	220
13	1.9	4.5	260
10	2.0	5.1	300
8	2.2	5.9	310

b) S/N = 40 dB.

N	Output Backoff (dB)	Input Backoff (dB)	Power (watts)
34	1.8	4.0	110
28	1.9	4.5	115
23	2.1	5.6	120
18	2.2	5.9	140
15	2.2	5.9	160

c) S/N = 30 dB.

N	Output Backoff (dB)	Input Backoff (dB)	Power (watts)
78	1.8	4.0	50
66	1.9	4.5	50
54	2.0	5.1	55
42	2.1	5.6	60
34	2.3	6.2	70

The values of input backoff were obtained from a typical TWT transfer characteristic.

4.2.2 Up-Link Signal-to-Noise Ratio

All estimates made so far have assumed that the up-link signal-to-noise ratio is sufficiently high to be neglected, compared with other factors. This assumption will now be checked for the worst case: 78

accesses, which uses the lowest up-link power per access. The EIRP will be 60 dBw. The up-link signal-to-noise ratio is obtained from the following expression, where all the quantities are in dB:

EIRP - (path loss) + (Satellite receive G/T) - k - B =

60 - 200 - 8.1 + 228.6 - 51 = 29.5 dB.

This is certainly negligible, compared with the overall C/N_oB of 2.5 dB.

5. Small-Terminals to Large-Terminal Situation

In order to achieve euqal signal-to-noise ratio in each direction and at the same time use the minimum of satellite output power, the receivers at both large and small terminals should be operating close to threshold.

This results in unequal signals at the satellite; the prediction of intermodulation noise under these conditions will be difficult, as one cannot use Westcott's curves. The smaller signals will suffer the worst relative effect.

The EIRP of the satellite under these conditions will be (per access):

To each small terminal: $\{34-1.4-10 \log (N/2)\}$ dBw (8)

To the large terminal: $\{34-1.4-10 \log (N/2)\}- \Delta G/T$ dBw (9)

where $\Delta G/T$ is the difference in receive G/T of the large and small terminals.

(8) and (9) are approximate and only true if $\Delta G/T$ is large. This, however, will almost certainly be true; if the large terminal is a 30-ft. diameter antenna with a receive system noise temperature of 200^oK, then, with a 10 ft. "small" terminal, $\Delta G/T$ is about 17 dB.

The implication of this is that the output power of the satellite is virtually given by equation (8). Comparing this with equation (7), it will be seen that the system capacity will be approximately twice that of the small-terminal to small-terminal situation.

6. Conclusions

The effect of telephone handset and human-ear frequency response will subjectively increase the unweighted signal-to-noise ratios considered here by a factor of 2.5 dB. Normally, the use of pre-emphasis would lead to roughly a further 8 dB of improvement. It has been pointed out, however,[6,7] that the use of pre-emphasis in systems operating close to

.../9

receiver threshold changes the relative threshold for different frequency components of the baseband signal. This may put the lower frequency components below threshold, thereby at least partially annulling the pre-emphasis improvement.

Secondly, there is some controversy about the amount of threshold extension actually obtainable in practical FMFB receivers. It has been suggested[7] that the deviation reducation factor, K, is given by:

$$K = \frac{6 \times 10^6}{f_m + 4.1 \times 10^5}$$

For f_m = 3400 Hz, K is therefore 11.6 dB, which appears to be somewhat optimistic.

Because of these large uncertainties in systems parameters, it must be emphasized that the capacity figures in this report can only be regarded as a preliminary estimate.

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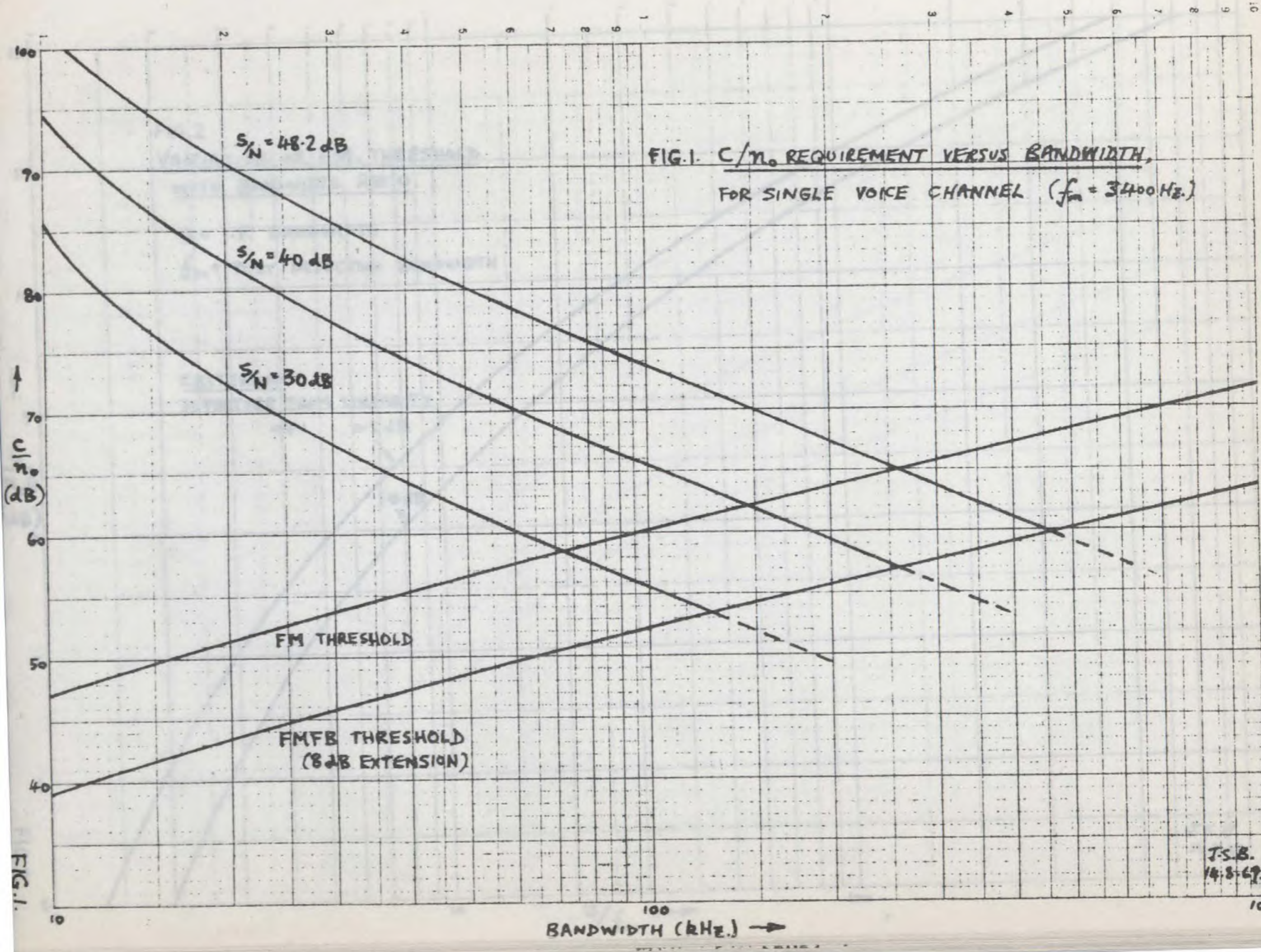

FIG.1. C/n₀ REQUIREMENT VERSUS BANDWIDTH,
FOR SINGLE VOICE CHANNEL (f_m = 3400 Hz.)
S/N = 48.2 dB
S/N = 40 dB
S/N = 30 dB
FM THRESHOLD
FMFB THRESHOLD
(8 dB EXTENSION)
C/n₀ (dB)
100
90
80
70
60
50
40
10
100
1000
BANDWIDTH (kHz.)
J.S.B.
14.8.69.

FIG.1.

FIG.2

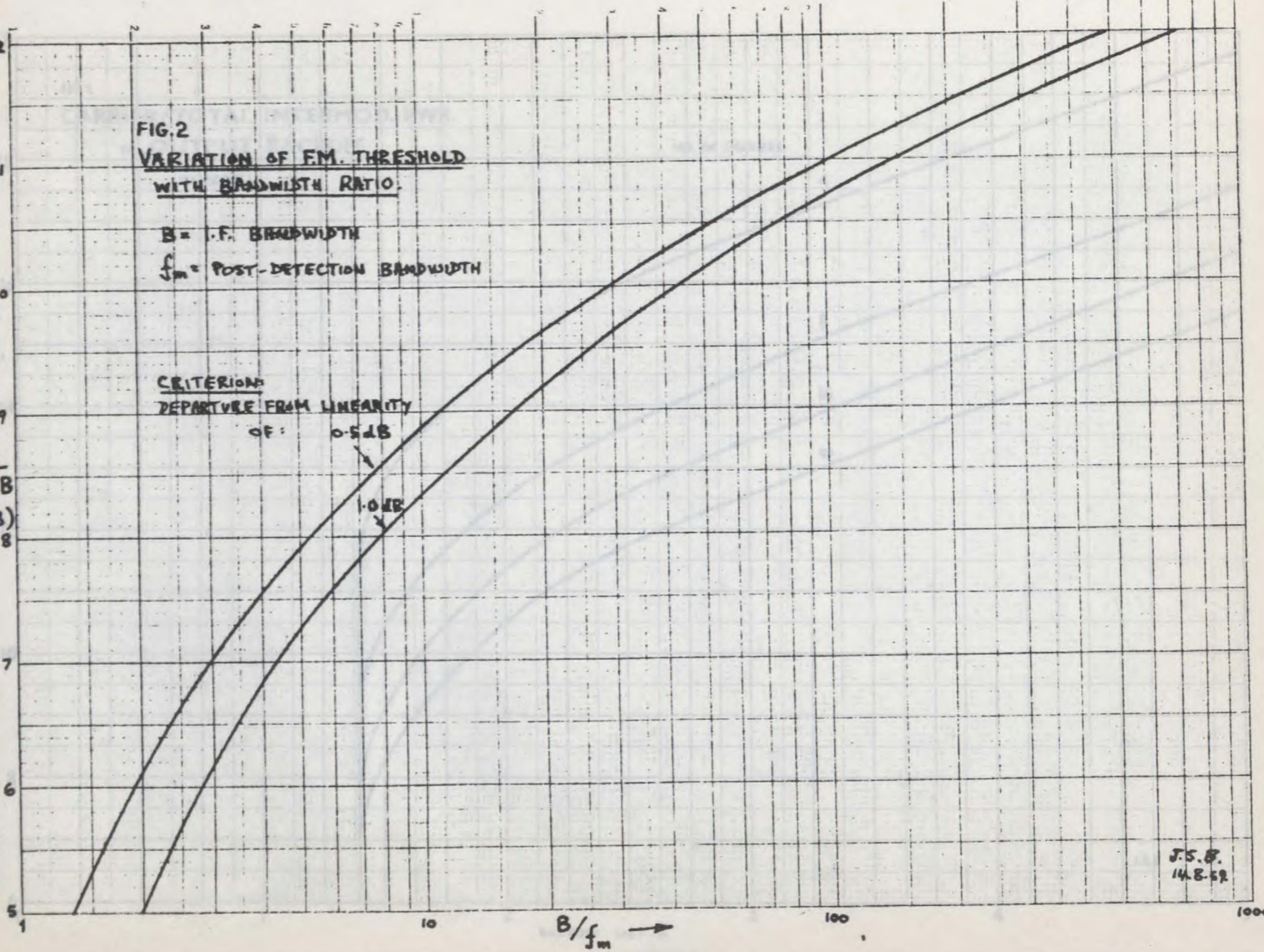
FIG. 2
VARIATION OF F.M. THRESHOLD
WITH BANDWIDTH RATIO.
B = I.F. BANDWIDTH
fm = POST-DETECTION BANDWIDTH
CRITERION:
DEPARTURE FROM LINEARITY
OF: 0·5 dB
1·0 dB
C / n₀B (dB)
B/fm
1
10
100
1000
5
6
7
8
9
10
11
12
J.S.B.
14.8.59.

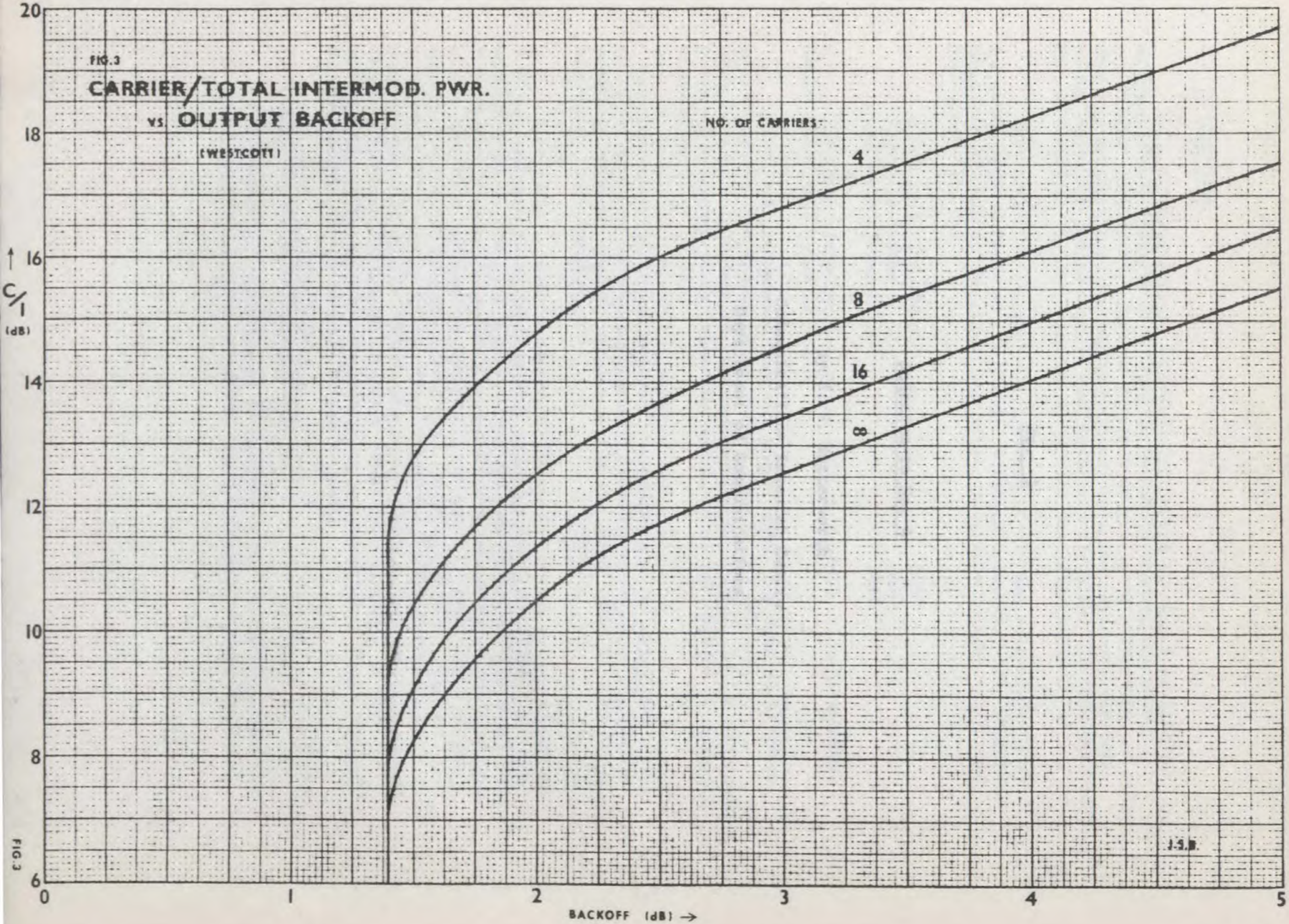
FIG. 3
CARRIER/TOTAL INTERMOD. PWR.
vs. OUTPUT BACKOFF
(WESTCOTT)
NO. OF CARRIERS
4
8
16
∞
C/I (dB)
BACKOFF (dB) →
0
1
2
3
4
5
6
8
10
12
14
16
18
20
J.S.B.
FIG. 3

No. 5

Addendum to No. 4

by J. S. Butterworth

Communications Research Centre

Department of Communications

1. INTRODUCTION

In a previous report, Technical Memorandum No. 26, a preliminary estimate of the capacity of a Domestic Satellite channel was made, for various conditions. Further research in published literature has shown that the values chosen for detected signal-to-noise ratio and for peak-to-rms ratio for speech signals were unnecessarily high. In this memorandum, the calculations will be repeated using more realistic values.

With regard to signal-to-noise ratio, CCIR[1] has recommended 33dB for radio systems connected to public telephone networks. Bell Telephone Laboratories[2] quotes the objectives of the telephone network (with some interpretation) as:

Short haul (120-200 mi)	39dB
2000 mile system	35dB
4000 mile system	32dB

The same reference also quotes 35dB as a "good" signal-to-noise ratio, while 20dB would be "usable".

CCIR[3] also recommends that for space links, the mean noise power on a telephone link should be no greater than 10,000 pWpO, which is equivalent to a test-tone to flat noise ratio of 47.5dB. Taking the speech power of an average-power talker as -14dBmO, this corresponds to a signal-to-noise ratio of 33.5dB.

Consequently, it was decided to consider the following two values of signal-to-noise ratio, (unweighted): the higher value of 33dB would represent a "good" quality circuit, while the lower value of 23dB would represent "fair" quality.

Previously a peak-to-rms amplitude ratio for the speech signal of 7.67 was assumed, which implies peak clipping for 0.1% of the time. The work of Holbrook and Dixon[4] showed that this was necessary for multi-channel FDM signals in order to reduce the probability of several signals clipping at the same time and causing severe distortion. However, for a single channel system, it has been stated that clipping for 1% of the time introduces virtually no perceptible distortion.[5] This corresponds to a peak-to-rms ratio of $\sqrt{10}$, which will be used here. Even infinite speech clipping reduces intelligibility only slightly, especially if pre-emphasis is used[6], however, the resulting unnatural sound would probably be unacceptable to the average telephone user.

2. DETERMINATION OF CAPACITY FIGURES

Following the methods used in Memorandum No. 26 and using the new values of parameters described above, the relationships shown in Fig. 1

were obtained.

The maximum-capacity data obtained from Fig. 1 is summarized in Table 1.

TABLE 1

	S/N(dB)	C/N_o (dB.Hz)	B(kHz)	β
a) No pre-emphasis:				
	33	56.9	53	6.8
	23	53.6	28.4	3.2
b) With pre-emphasis:				
	33	54.2	32	3.7
	23	51.0	18.3	1.7

The pre-emphasis gain assumed was 8dB. As explained in the previous report, it is doubtful if this can be realized when operating within 2 to 3dB of threshold.

The use of threshold extension demodulators was not considered as no reliable information has yet been discovered as to the amount of threshold extension achievable in practice for this type of situation. The last column in Table 1 gives the deviation ratios ($\Delta f_{pk}/f_m$); these are now much smaller than obtained previously, and therefore presumably the amount of threshold extension available would be smaller.

Tables 2 and 3 show the actual capacity figures obtained, using the same method as previously.

Also shown is the required ground station transmit power. Values of down-link margin of from 0 to 4dB above threshold have been considered.

TABLE 2

a) S/N = 33dB, no pre-emphasis

Operating margin (dB):	0	1	2	3	4
4 ft antenna					
Number of accesses	4	-	-	-	-
Power (watts)	3470				

TABLE 2 (Cont'd)

Operating margin (dB):	0	1	2	3	4
6 ft antenna					
Number of accesses	8	6	5	4	-
Power (watts)	540	780	890	1120	
10 ft antenna					
Number of accesses	18	14	10	8	6
Power (watts)	58	87	100	118	160

b) S/N = 33dB, with 8dB pre-emphasis gain

Operating margin (dB):	0	1	2	3	4
4 ft antenna					
Number of accesses	7	6	4	-	-
Power (watts)	1740	2090	2890		
6 ft antenna					
Number of accesses	15	11	8	6	4
Power (watts)	330	380	480	590	800
10 ft antenna					
Number of accesses	35	26	18	13	9
Power (watts)	38	40	49	63	76

TABLE 3

a) S/N = 23dB, no pre-emphasis

Operating margin (dB):	0	1	2	3	4
4 ft antenna					
Number of accesses	8	6	4	-	-
Power (watts)	1590	1820	2950	-	-
6 ft antenna					
Number of accesses	16	12	9	7	5
Power (watts)	300	350	400	480	650

... 4

TABLE 3 (Cont'd)

Operating margin (dB): 10 ft antenna	0	1	2	3	4
Number of accesses	42	30	21	15	11
Power (watts)	33	39	43	52	62

b) S/N = 23dB, with 8dB pre-emphasis gain

Operating margin (dB): 4 ft antenna	0	1	2	3	4
Number of accesses	14	11	8	7	6
Power (watts)	776	960	1200	1250	1410
6 ft antenna					
Number of accesses	31	22	16	12	9
Power (watts)	150	180	210	250	290
10 ft antenna					
Number of accesses	82	55	37	27	19
Power (watts)	20	22	24	27	35

3. CONCLUSIONS

Capacity figures have been presented which should be much more realistic than the preliminary estimates given in Technical Memorandum No. 26.

As pointed out previously, the capacity figures for the situations with pre-emphasis are open to question for operating margins of less than 2 to 3dB.

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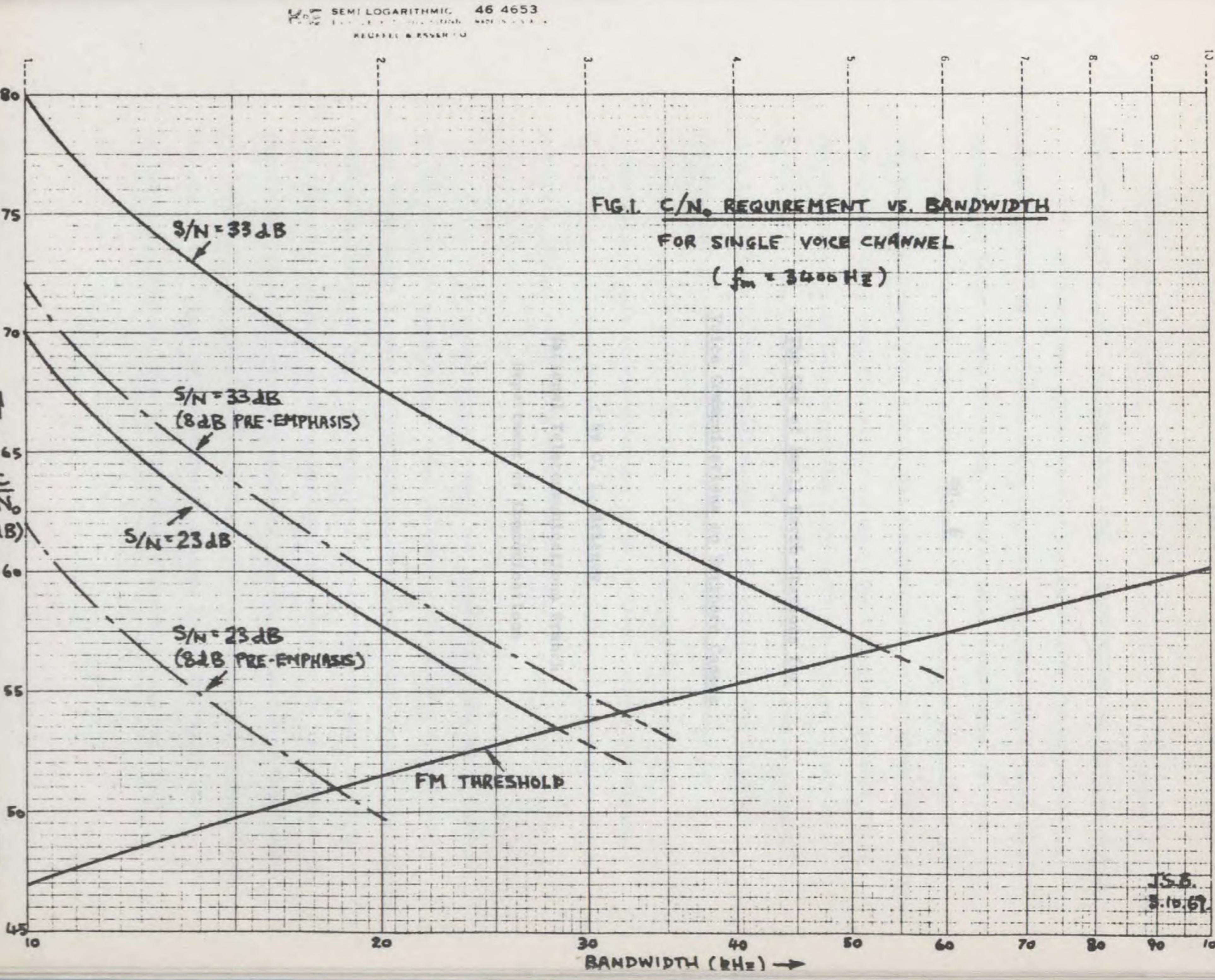

SEMI LOGARITHMIC 46 4653
FIG.1. C/N₀ REQUIREMENT VS. BANDWIDTH
FOR SINGLE VOICE CHANNEL
(fm = 3400 Hz)
S/N = 33 dB
S/N = 33 dB
(8 dB PRE-EMPHASIS)
S/N = 23 dB
S/N = 23 dB
(8 dB PRE-EMPHASIS)
FM THRESHOLD
C/N₀ (dB)
BANDWIDTH (kHz)
80
75
70
65
60
55
50
45
10
20
30
40
50
60
70
80
90
100
J.S.B.
3.10.69.

FIG.1.

No. 6

The Use of Small Earth Stations for Voice Communications to Northern Canada

by O. L. Britney

National Telecommunications Branch

Department of Communications

December 10, 1969

THE USE OF SMALL EARTH STATIONS FOR VOICE COMMUNICATIONS TO NORTHERN CANADA

The first application of the satellites for commercial communications was to provide voice circuits and television between North America and Europe where there was an established requirement for the services. These early satellites operated at synchronous altitude in a spin stabilized mode with a spin axis perpendicular to the plane of rotation. The antenna had a radiation pattern shaped like a doughnut so that while the satellite and the antenna rotated, the earth was always illuminated by the satellite. This extremely inefficient radiation system together with limitations in the overall weight of the satellite due to launcher characteristics resulted in the satellite having an extremely low effective radiated power. In order to make the system in any way economically viable it was necessary to go to large, expensive antennas on the ground in order to obtain a reasonable number of voice channels or provide a circuit which would handle television.

As technology advanced, the launchers became more powerful so the satellite power system could be larger. Larger output travelling wave tubes could be used. Satellite antennas were despun so that they always pointed to the earth while the satellite rotated and it became possible to add directive antennas which concentrated the power of the satellite on a particular portion of the earth surface. Through these improvements and new techniques the effective radiated power of the satellite increased and the use of small less expensive earth stations tended to become more attractive. However, even now it is not possible to say that they would be economically viable. In the international service the high cost of launchers and satellites still make the large ground station antennas mandatory. However, several countries have now looked into the possibilities of using earth stations much smaller than those used in the international service for communications for domestic purposes.

The object of this memorandum is as follows:

1) Present a concept for a system which would provide a limited number of communications channels into northern Canada within the terms of responsibility of the Department of Communications to plan new communication services and assess new developments in terms of needs and requirements of the Canadian North. The system is planned around the limitations of present communications satellites of the type planned for the Canadian Domestic Satellite System.

2) Explain the practical limitations to the service that can be provided due to the state of existing technology, international agreements of the use of frequency and the need to share the synchronous orbit with other users.

3) Outline the work which would be necessary in order that the feasibility of the proposal could be verified and the system design parameters established to the extent necessary for implementation.

4) Recommend certain development projects which are within the state of the art and which should result in significant increases in the capacity of the system.

System Concept

1) The system will provide single voice channels on individual carriers to individual subscribers or small communities.

2) The system will use a single dedicated RF channel in the Canadian Domestic Satellite to provide the service. This RF channel will be divided into a number of small carriers each with one voice circuit.

3) These individual voice channels will be available to all the subscribers on a party line basis. The subscriber would search for a vacant circuit or if all circuits were busy would wait his turn.

4) The system would only provide communications between northern locations and a central station in the south where it would be connected to the existing domestic network. Communications between two northern stations would only be available on a "two-hop" basis with additional transmission delays. Recently received information indicates that subscribers can use this type of service if necessary. This arrangement makes a significant reduction in the cost of the earth stations in remote areas. The transmitter only needs to provide enough power into the small antenna to illuminate the satellite to the extent necessary to provide a voice channel into the big antenna at the master station in the south.

5) The system could be integrated with the domestic network circuits. From the north to south it would have noise levels comparable with existing terrestrial facilities. Circuits from south to north would not meet the same objectives but should be acceptable to the northern subscriber.

6) Even with the satellites planned for the domestic system with effective radiated powers of 34 dbw, when relatively small antennas are used the system becomes power limited on the down-path. In other words, all of the power of the satellite is used in order to provide useable circuits before the total bandwidth in the channel is used up. This situation is aggravated by the use of extremely small antennas which capture a very small amount of the radiated power from the satellite. In order to make the system in any way attractive and obtain a reasonable number of channels, this report only discusses the channel capacity with 10 to 16 foot diameter antennas for the remote stations.

7) Each individual voice channel is voice controlled. The carrier is only on when the user is talking. This technique gives an advantage with respect to the intermodulation developed in the space segment. It also provides for a more economical use of the RF power available for the system because in normal conversation between two individuals about 20% of the time the circuit is not being used and the other 80% of the time is split between the individuals at each end of the channel.

8) At the remote terminals the connecting circuit will be provided on a four-wire basis. This will eliminate echos for this end of the circuit and reduce the overall system requirements for echo suppressors by 50%. There would of course be a problem if a system of this type were

used to provide service in a fairly large community in the North where there could be a number of extensions from the system to different subscribers. It would mean that the extensions would all be provided on a four-wire basis.

Technical Assumptions

1) The system will have one voice channel per individual RF carrier.
2) Frequency modulation is used.
3) The up-path frequency band is 5295 - 6425 GHz.
4) The down-path frequency band is 3700 - 4200 GHz.
5) Satellite EIRP = 34 dbw.
6) Satellite single carrier saturating flux density -80 dbw/square meter.
7) Threshold improvement 0 db.
8) Pre-emphasis/de-emphasis improvement 0 db.
9) Phosphometric weighting factor 2.5 db.
10) Fade margin 3 db.
11) 10 foot antenna system $\frac{G}{T}$ = 16 db.
12) 16 foot antenna system $\frac{G}{T}$ = 20 db.
13) The weighted noise contribution from the satellite circuit into the northern terminal at a point of zero reference level will not exceed 31,600 pW.
14) At a point of zero reference level the weighted noise contribution from the satellite circuit into the domestic system would not exceed 6246 pW.
15) Speech would be inserted into the system at -15 dBm0 so that normal network loadings could be used.

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System Capacity Based on Above Technical Assumptions

Based on the use of 10 foot antennas on the northern terminals the system would have 35 circuits. Based on the use of 16 foot antennas on the northern terminals the system would have 90 circuits.

The small earth stations could require transmitters with power up to 20 watts for the 10 foot antennas. The 16 foot antennas could require transmitters up to 5 watts.

Projects for Further Development

1) The system calculations have been based on the use of a low noise front end in the northern terminals operating at room temperatures with a noise temperature not exceeding 150°K. It is now claimed that it is possible to obtain completely solid state low noise amplifiers operating at room temperature with a noise temperature not exceeding 90°K. The use of these devices would increase the system capacity by about 20%. This should be investigated.

2) The system is based on a standard FM discriminators (threshold $\frac{C}{N}$ = 10 db) because there does not appear to be in existance a demodulator for a single voice channel which provides any threshold improvement (except in advertising brochures). If a demodulator with a 3 db threshold improvement could be obtained this would almost double the number of channels in the system.

3) An investigation might establish some improvement even on a single voice channel from the use of pre-emphasis/de-emphasis.

4) Compandors offer a means of improving the quality of the voice channel in the system. Further study would be required to assess the desirability of using compandors in the system at the northern terminals.

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5) As the size of the antenna at the remote station is increased the gain increases and the power of the associated transmitter decreases. An optimization study should be made to determine the best over-all solution with respect to these parameters in order to produce the most effective system.

6) It is standard procedure in communication systems to have more subscribers than channels on the basis that all the customers will not want to use the system at the same time. The usual ratio is between 3 and 4. So if there were 35 circuits it should be possible to have between 105 and 140 subscribers. This needs a detailed analysis before deciding exactly how many subscribers could be accommodated.

7) The system calculations have been based on a number of parameters which have been selected from past experience with communication satellite systems. These must be worked out in detail before the transmission parameters can be specified to the extent necessary to ensure accurate fixed price bids for small earth stations. As an example, the intermodulation developed in the output stage of the satellite with a large number of small carriers must be calculated in order to optimize the noise budget between the ground station equipment, the up-path thermal noise, the noise contribution from the satellite itself and the thermal noise in the down path. The computer program to do this must take into account the amplitude compression and the load dependent phase shift in the output tube in the satellite. It takes an IBM model 360-65 about 20 minutes to do the calculation for a band 36 MHz wide and a number of runs are required to optimize the system. The computer program does not yet exist in Canada.

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8) COMSAT as agent for Intelsat has developed a demand assignment system using pulse code modulation where any participating station has access on demand to the facilities of any other station through a pool of satellite channels. The system operates in a similar manner to the one described in this memo where a chosen RF channel is divided into a large number of individual RF carriers and each individual carrier carries one digitized voice channel. Recently COMSAT issued a request for quotations (RFQ) for enough of this equipment to make installations in all their ground stations. The system is far more complex than required for domestic use because each earth station in the system is complete with its own control. It would be possible to modify the equipment to use a central control at the main earth station and make it much simpler and much cheaper. It has been estimated that it would take four engineers with digital experience about six months to make such a modification. This could be a worthwhile improvement to the system described in this memo which uses FM.

9) At the recent International Conference on Digital Satellite Communications the Australian Post Office Research Laboratories presented a paper describing a system somewhat similar to the one in this memo except that it used delta modulation. They claimed that delta modulation was a significant improvement over pulse code modulation (PCM). If it were decided to use a modulation system other than FM this item should be further investigated.

10) It would appear that the system described here would not present any problems with respect to the use of orbital slots or interference to other systems by virtue of the fact that each small antenna would not be equipped with a transmitter greater than 20 watts and a carrier of this

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size would not represent an interference problem particularly when these installations are located in isolated Arctic locations. On the other hand this matter should be carefully examined by individuals with experience in this particular problem.

11) The question of signalling and switching in a system of this type has not been investigated. Here again there is a need for an expert in this type of problem. It might be necessary to use one communication channel as a common signalling channel in order to make it possible to call remote stations from the master station. In this case the system capacity would be reduced by one voice channel.

L Boutrey
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No. 7

Satellites for Communications in Northern Canada

by G. R. Peterkin

Bell Canada

Satellites for Communications in Northern Canada

Preface

The recent attention focused on the development of Canada's north has stimulated a review of the communications requirements to both existing and future population centres in this region.

At the present time in the Eastern Arctic, Nouveau Quebec and the Coast of Labrador communities are dependent upon H.F. radio links provided by private users or by Bell Canada and by leased circuits on Military Tropospheric Scatter systems.

The mode of operation of the H.F. radio links (simplex operation) makes this type of service marginal at best, especially when the problems generated by limited hours of availability are coupled with poor transmission performance and heavy utilization. The access to existing military systems is limited and the capacity available for message traffic restricted.

A review of the communications requirements in the Canadian North related to the Domestic Satellite project reveals that the present design is limited in application to those population centres generating requirements for approximately twelve intertoll trunks. This limitation is a reflection of the cost of the Earth Stations plus the limited number of points that can access the North - South Transponder without unduly reducing the total number of channels available.

An additional factor to be considered is the fluid nature of the population centres. It is expected that there will be a migration from outlying centres to main points like Frobisher Bay stimulated by Government policy, economics and natural evolution. This will mean that centres like Grise Fiord and Broughton Island could disappear in the next ten years. Any expenditures for communication systems must take these factors into consideration.

It would appear that some means must be found to improve communication in the Eastern Artic at a reasonable cost.

Possible Solution

A satellite system having the following characteristics to provide a limited number of communications channels to Northern Canada.

- Single voice circuits to small communities available to subscribers on a party line or time sharing basis.
- Low cost earth terminals in the range of $60 - 80,000.

Other factors to be included in design considerations are:

a) Maintenance - The remote terminals should be simple to maintain and employ solid state technology with plug-in design for replacement of units.

b) Reliability - Because of the remote applications of these units a high degree of reliability should be a design objective.

c) Power Requirements - Since locally generated power is usually 115/230V single phase of small capacity and subject to surges and frequency variations, the power design should take these factors into consideration.

Candidates for Satellite Service

At the present time Bell Canada has a number of locations now served over single channel simplex operated H.F. radio that would be candidates for improved service.

There are approximately thirty-two locations now served by H.F. radio that have associated exchanges. In addition there are nineteen locations served by H.F. radio without associated exchanges.

Other locations exist where private H.F. systems are utilized by private companies and new locations requiring communications will develop as mining activity progresses.

All of these locations would be candidates for improved service and should be given consideration in the decision to develop a multiple access type of system.

Network Planning

The utilization of this type of system implies a central "operator" location to handle operator assistance requirements. To facilitate direct access to locations served by the "Northern Satellite" service consideration should be given to a new N.P.A. code so that these points can be accessed by DDD.

When considering the economic viability of such a system the cost of the separate operator location and circuit backhaul should be included.

The overall design criteria must consider the integration of this service into the telephone network and must give full consideration to billing requirements and the need to provide both trunk and subscriber loop circuits.