Cost Effective Options For The Thin Route And TV Broadcasting Network Of Northern Canada

VOLUME I

PREPARED BY MILLER COMMUNICATIONS SYSTEMS LTD.

COST EFFECTIVE OPTIONS FOR THE THIN ROUTE AND TV BROADCASTING NETWORK OF NORTHERN CANADA

FINAL REPORT

The work reported here was performed by Miller Communications Systems Limited for Research Sector, Department of Communications (contract officer Dr. Roger Kaye) under DSS Contract No. OST5-0051

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COST EFFECTIVE OPTIONS FOR THE THIN ROUTE AND TV BROADCASTING NETWORK OF NORTHERN CANADA

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EXECUTIVE SUMMARY

The prime objective of this study is to evaluate alternative methods of improving the cost-effectiveness of the Thin Route and TV/Radio Program Distribution satellite communications systems serving remote communities in Canada in the short and medium term (next 5-7 years). Given this time frame and the existing investment in satellites, as well as the desirability for simple, reliable and low cost remote terminals, the following constraints were placed on the scope of study:

- An Anik I type 4/6 GHz satellite is assumed, although some attention is paid to the possible impact of future 4/6 GHz satellites possessing higher EIRP.

- Only single carrier per transponder FM is considered for the distribution of television.

The main thrust of the report is an in-depth examination of the complex trade-offs involved in choosing the most appropriate single channel per carrier (SCPC) modulation and access technique and the cost sensitive parameters of the remote terminal. Preassigned and demand assigned SCPC systems employing either delta/PSK or FM modulation are considered.

The following factors necessary to the development of cost-effective solutions have been studied in detail:

The existing Telesat/Bell Canada Thin Route Network - The investment in the existing Thin Route Network and the constraints it imposes are recognized.

Circuit Requirements and Traffic Statistics - Since these have not been provided, the study is largely a parametric one.

Transponder Utilization Trade-offs - The number of SCPC circuits which can be carried over the satellite transponder is computed as a function of earth station G/T and desired circuit noise objective.

Remote Earth Station Cost/Performance Trade-offs - The earth station antenna/low noise receiver/high power amplifier combination is optimized for each G/T and number of circuits considered, and overall earth station costs are provided.

Maintenance Philosophy and Operating Costs - have significant impact on the cost and reliability of Northern Service.

Present and Near Term Technology and Cost Trends - has impact on planning for network growth.

Specifically, the study addresses the major aspects identified in the statement of work:

- immediate cost reduction of ground stations
- eventual improvement of the efficiency of utilization of the satellite transponders
- elimination of double-hop operation for north-north calls.
- provision of fully automatic calling and billing.
- graceful growth of the network as traffic increases, including growth beyond the capacity of a single transponder.
- sensitivity of ground station and total network cost to reduction of transmission standards from those required in the south to reasonable modified standards which might be applicable in remote communities.
- possible connection to multiple points in the network of southern Canada.

- cost versus network size relationships.

- high reliability and ease of maintenance.

With regard to these items, the study has concluded that:

1. The remote stations presently being purchased for North-Western Ontario (Thin Route) and the Yukon (TV receive) are the result of several cost reducing cycles since the inception of the Telesat operational system in 1973. Further dramatic reductions in ground station capital and operating costs are not anticipated in the near term. Assuming a continuation of the current world rate of installation of small stations, typically 200-400 per year, a drop of between 5% and 10% per year can be reasonably assumed for planning purposes.

2. Cost reductions on a per service basis, however, can still be achieved through the development and use of an integrated multi-purpose remote earth terminal providing thin route voice, television, and radio program services. When only one service is provided, it must bear the total cost of the station. The subsequent addition of either or both remaining services attracts other costs due to separate planning and engineering, separate procurement, additional shipping and installation expenses, and additional management costs. If remote locations could be served

simultaneously with all three services, some of these costs could be avoided and the tarrif per service therefore reduced. The introduction of a cost-effective multipurpose facility must be prefaced by careful and co-ordinated planning among Telesat and its customers.

The following table summarizes estimated costs for the multipurpose terminal:

	QTY 10	QTY 100
Cost of basic non-redundant Thin Route earth station (1 circuit provided)	$104,910	$ 72,384
Cost of basic redundant Thin Route earth station (2 circuits provided)	161,130	109,031
Cost of non-agile TV receiver	10,000	7,000
Cost of radio program receiver (radio program assumed transmitted via Thin Route transponder and a modified channel unit implemented).	5,000	3,500
Implementation Costs	25,000	25,000
Total Costs: (1 circuit provided)	$144,910	$107,884
(2 circuits provided)	$201,130	$144,531

For example, 50 multipurpose terminals each providing one non-redundant voice circuit could be installed for about $6,000,000.

3. Among the techniques available to improve the efficiency of utilization of the satellite transponder, voice activation (already being implemented in the existing system) provides the greatest improvement at minimum cost. Demand assignment results in a significant increase in the cost of the remote terminal and imposes the requirement of compatible SCPC equipment at all participating stations. The double hopping of North-North calls using preassigned circuits to Allan Park provides network interconnectivity with a minimum of earth station facilities and operational complexity. When all RF channels become assigned and additional users cannot be accommodated, however, demand assignment offers a more economically attractive means of increasing network capacity than the utilization of additional transponder(s). Demand assignment improves transponder capacity in two ways: firstly, by permitting the shared use of SCPC RF channels it essentially removes the bandwidth limitation on the number of users which can be served, and secondly, by eliminating double hopping it improves the utilization of transponder power by up to 24%. Demand assignment also permits the introduction of multiple access points in the South without the depletion of satellite resources or limited interconnectivity that would result with a preassigned system, and facilitates the implementation and associated cost benefit of a centralized control and monitoring system.

[Because of transponder cost.]

A preassigned configuration has the advantage of permitting the successive introduction of new and possibly more efficient SCPC techniques without affecting the operation of existing links. For example, 32 kbps Δ-modulation phase shift keying or emphasized companded FM with a standard channel spacing of 45 kHz offers higher transponder capacities, international (i.e. 10,000 pWpO) circuit quality, and a wider choice of suppliers than the existing 40 kbps/60 kHz equipment serving Canada's North. At the moment, however, these advantages are not compelling reasons to deviate from the present Thin Route parameters in future extensions.

Transponder capacity can be increased by about a factor of 2 if circuit quality is allowed to degrade to the 44 dBrnCo (22,400 pWpO) objective already providing satisfactory service to Frobisher Bay and Resolute Bay using FDM/FM/FDMA techniques. Both 20 kbps delta modulation and reduced bandwidth (22.5 kHz) FM systems can satisfy the Northern Service requirement. However, since they are subject to further degradation, satellite circuits to the Southern switched network are expected to meet toll quality standards (37.5 dBrnCo or 5000 pWpO). Unlike an FDM/FM/FDMA system, a demand assigned SCPC system cannot easily accommodate different noise objectives for the South and North. Furthermore, a digital SCPC system employing a common voice encoding rate (e.g. 40 kbps) severely limits the range of noise performance obtainable, and virtually precludes the provision of two circuit qualities even in a preassigned network. In conclusion, then, a substantial lowering of Thin Route circuit quality as a means of increasing transponder capacity is limited by the requirements of the Southern public switched network, and is considered feasible only for preassigned N-N or private N-S circuits.

Finally, investigation has revealed that as far as the earth segment is concerned, both preassigned and demand assigned SCPC systems can grow gracefully into <u>additional transponder(s)</u> as traffic increases, but at the present rate of growth an additional transponder will not be required within the time frame under consideration.

4. For a centrally controlled demand assigned or a preassigned system in which all calls are routed through or terminated at a single earth station, <u>automatic dialling and billing</u> can be introduced with the simple addition of appropriate supervisory equipment at the single Southern controlling node.

A preassigned system with multiple access points in the South necessarily decentralizes automatic dialling and billing functions which in turn increases the cost of providing these services.

5. An earth station figure of merit (G/T) in the vicinity of 18 dB/°K appears to be the most cost effective for the multipurpose remote terminal. Using G/T's below 15 dB/°K results in

little cost advantage in the earth station but a significant penalty in transponder capacity (and hence space segment charge per circuit); furthermore, the reception of good quality TV even over the higher power dual-band Anik 4 satellite would be precluded. Due to the 36 MHz transponder bandwidth limitation, increasing earth station G/T above 20 dB/°K does not increase the number of voice activated circuits that can be carried over the transponder, and therefore is not recommended. The recommended 18 dB/°K G/T is most economically provided using a 15' antenna and a reliable 260°K transistor low noise amplifier (LNA). An SCPC system exclusively employing earth stations of this type and 45 kHz channel spacing can provide at least 300 simultaneous 10,000 pWpO duplex circuits; with the 40 kbps encoding rate and 60 kHz channel spacing presently employed, the transponder capacity is about 275 circuits.

6. Depending on the number of circuits provided and the required transmitted EIRP per carrier, high power amplifier costs at the remote terminal can be the controlling factor in earth station costs. This as well as the proposed CCIR off-axis EIRP/4 kHz limitations mitigate against the use of 12' (and smaller) antennas when direct N-N calling is desired.

There is little capital cost advantage in choosing an antenna below 15' diameter, and this should probably be reserved for cases in which station transportability is required or access to the site is extremely difficult.

8. Since January 1, 1975, redundantly configured Thin Route terminals have provided a circuit availability of better than 99.6%. With improved fabrication and quality control, an availability of 99% can reasonably be expected for a non-redundant configuration providing a single circuit. As indicated in the previous table, the cost differential between redundant and non-redundant stations is $36,500 - $56,200 (depending on quantity); however, it should be emphasized that a parallel redundant configuration in the unfailed condition provides two circuits.

9. In choosing the deviation and receive bandwidth of a satellite FM video link to serve remote users, one has the opportunity to trade-off the effects of thermal noise and picture distortion. It is clearly desirable to balance these to arrive at the best picture quality for a given G/T available. The deviation employed and corresponding minimum video S/N available over the Telesat/CBC TV channels may exceed the needs of remote viewers while imposing a rather high minimum required G/T. Excess margin in the baseline system, notably 2-3 dB excess satellite EIRP, mean that CBC's performance requirements could be met with video deviations reduced from their present value. Such a reduction, on the other hand, would greatly enhance the capability of small remote terminals to receive a lower quality version (video S/N = 40 to 45 dB) of the same video signal(s).

1. INTRODUCTION

This study identifies and evaluates alternative methods of improving in the short and medium terms the cost-effectiveness of the Thin Route and remote TV distribution satellite network serving remote communities in Northern Canada. Specifically, the following major aspects are addressed:

- earth station capital costs and future trends
- efficiency of utilization of the satellite transponder versus modulation/access technique employed
- implementation of demand assignment and elimination of double-hop operation for north-north calls
- provision of fully automatic calling and billing
- impact of reduced circuit performance standards on earth station cost and transponder utilization
- cost versus network size relationships
- graceful growth of the network including growth beyond the capacity of a single transponder

- maintenance philosophy, operating costs, and service availability.

The report contains a main body, which concentrates on the key issues, together with six technically detailed supporting Appendices:

A Description of Existing Thin Route System

B Single Channel Per Carrier System Performance Analysis

C SCPC Network Control and Demand Assignment Techniques

D Maintenance Philosophy, Operating Costs, and Service Availability

E Earth Station Technology and Trends

F Earth Station Subsystem Costs and Trade-offs

The body of the report consists of seven chapters and an Executive Summary.

The Executive Summary states the objectives of the study and the most important results and conclusions.

Chapter 2 describes the evolution and outstanding features of the existing Thin Route system. The technical constraints imposed by this system and the valuable experience gained in developing it serve as both necessary and useful starting points in planning for future expansion.

Chapter 3 identifies the factors to be considered in providing new SCPC communications facilities to the North, including environmental considerations, satellite coverage, and constraints imposed by the existing Thin Route system and CCIR regulations pertaining to adjacent satellite interference.

Chapter 4 summarizes the noise performance and transponder utilization efficiency of contending single channel per carrier SCPC modulation/ access techniques, namely preassigned and demand assigned 40 kbps, 32 kbps, and 20 kbps variable slope delta-modulation/coherent phase shift keying and emphasized companded FM with and without threshold extension demodulation. A detailed comparative evaluation of SCPC performance for both voice and data, as well as transponder capacity for a mix of earth station types is given in Appendix B. In addition to supporting the body of the report and the key objectives of the study, this appendix serves as a self-contained in-depth analysis of SCPC transmission techniques currently proposed for domestic systems.

Chapter 5 considers TV performance vs G/T both with the present video deviation unaltered and reduced to facilitate the distribution of lower quality TV to remote communities.

The objective of Chapter 6 is to develop hypothetical but realistic network configurations showing how the existing Thin Route network can be extended in a graceful manner. This requires consideration of complex and interelated factors which are difficult to weigh; however, several possible types of networks are presented and their advantages and disadvantages examined. Two hypothetical earth station types having 15 dB/°K (12' diameter) and 18 dB/°K (15' diameter) G/T's are presented for purposes of further discussion.

Chapter 7 identifies and quantifies the cost trade-offs associated with the design of the remote earth terminal, including capital costs and installation and maintenance costs. Total earth station costs are estimated for the two types introduced in Chapter 6. This is followed by an examination of expected cost trends over the next five years. A supporting subsystem cost data base and detailed examination of developing remote terminal technology are given in Appendices F and E respectively. These were largely based on visits and letters to manufacturers undertaken over the course of the study.

Finally, Chapter 8 deals very briefly with maintenance philosophy, operating costs and service availability. A detailed discussion of this subject is given in Appendix D.

2. DESCRIPTION OF EXISTING THIN ROUTE SYSTEM

2.1 Introduction

At an early stage in the planning of the Telesat system it was recognized that the need for communications to and from small communities in the North could best be served using single channel per carrier techniques. Such techniques, together with judicious use of the available space segment permitted graceful growth of the network and the utilization of small aperture terminals requiring modest transmitter sizing and relatively simple communications equipment. It was therefore possible to realize a low cost, highly reliable design permitting unattended operation - important pre-requisites of any communications facility for remote location applications.

Another aspect simplifying the design of both the system and the equipment was the decision to proceed with a traffic configuration where all circuits are operator handled in Ottawa for switching and billing purposes. This scheme, however, leads to the need for "double hopping" when two northern locations are in communication via satellite, with a decrease in both satellite utilization efficiency and circuit performance.

Other requirements for the initial thin route system which significantly affected the early designs included:

1. that television and radio programs could be added without major effort, such as antenna replacement

2. that up to eight channels could be added by plugging in the appropriate equipment

3. that the station could be upgraded to permit the ready retrofitting of demand assignment equipment to allow direct north to north calling.

The circuit quality objectives, transponder utilization objectives and operational requirements agreed between Telesat and Bell Canada led to the implementation of a system using delta encoding, bi-phase phase shift keying transmission techniques to establish the initial system serving seventeen locations in the Bell territory of the Eastern Arctic. This system has now become well established providing an excellent grade of service to remote communities. It is currently being extended to serve North West Ontario and several other locations.

All extensions implemented thus far use the system configured essentially in the North-South, South-North mode. Figures 1 and 2 indicate the rate of growth of the Thin Route System and the locations currently served or planned to receive service by 1977. With the G/T's presently employed and the planned introduction of voice activation (see subsequent section 2.2), the capacity of the Thin Route channel will not be reached before the early 1980's at the present rate of growth. As seen in Figure 2, with the exception of the CNT stations T-21 to T-23 homing on Lake Cowichan, Thin Route service has thusfar been provided only in Bell Territory, specifically the Eastern Arctic and Northern Ontario and Quebec.

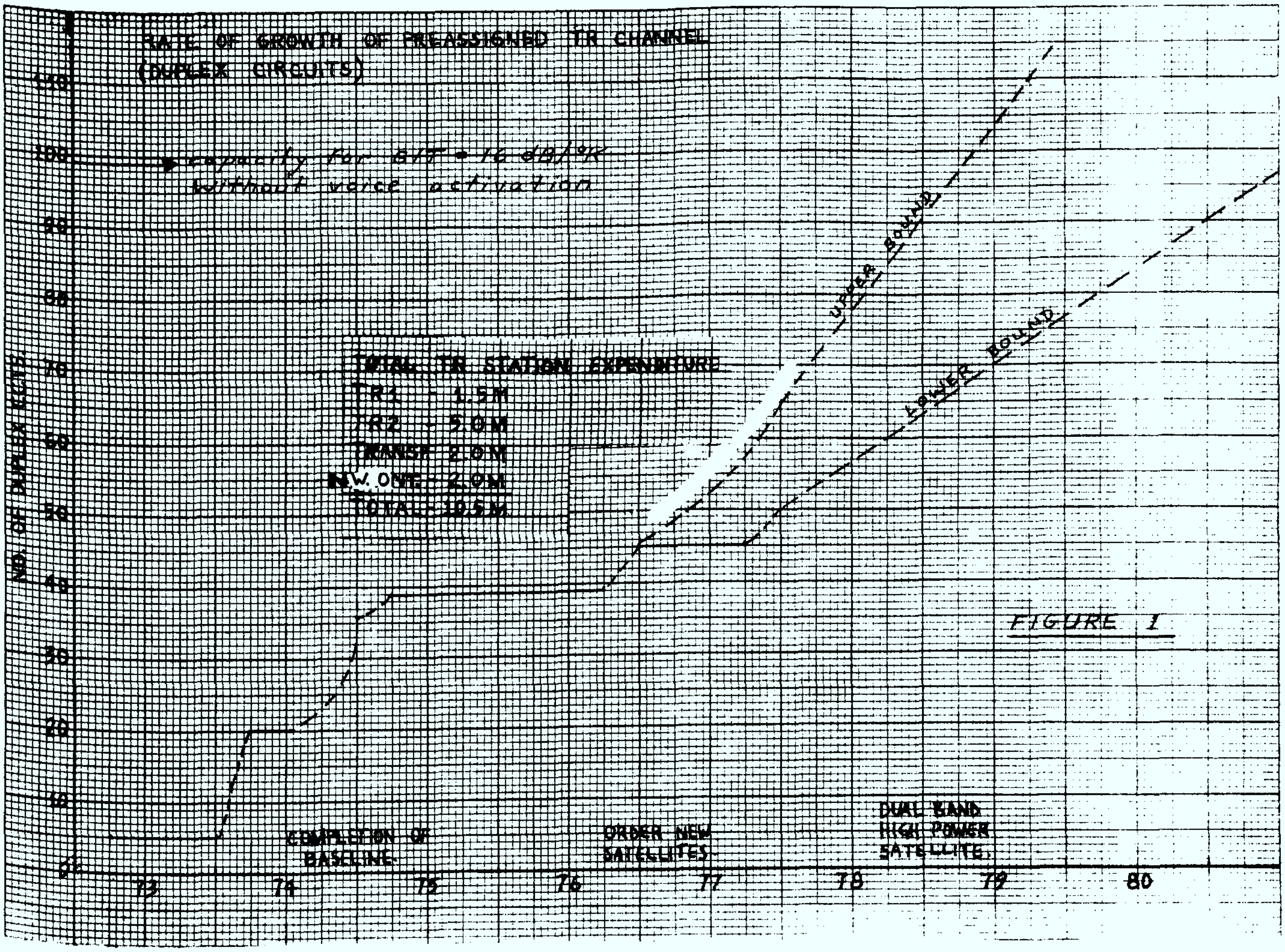

FIGURE 1

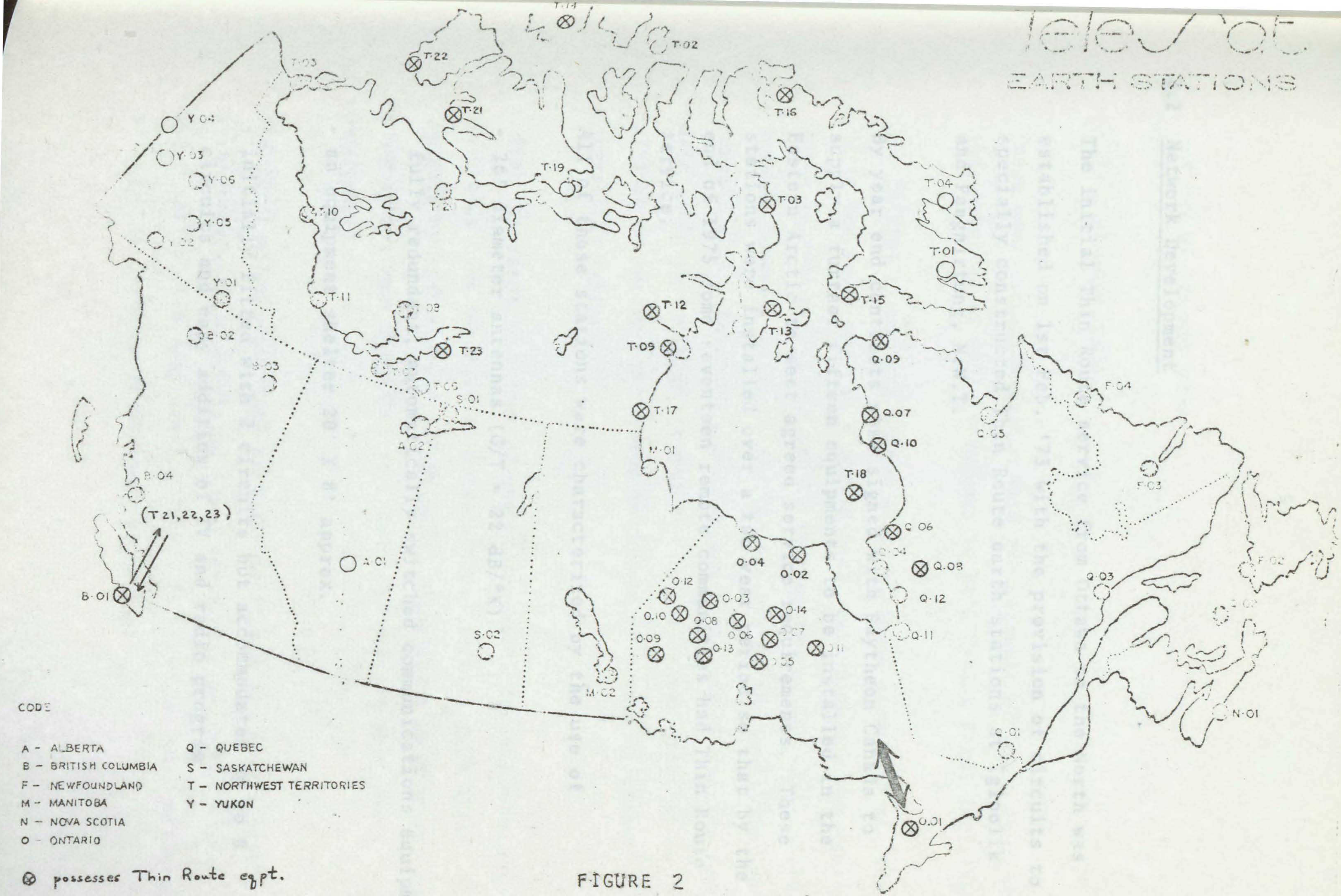
T-14
T-02
T-22
T-03
T-16
Y-04
T-21
Y-03
T-19
T-04
Y-06
T-03
T-20
T-10
Y-05
T-01
Y-01
T-11
T-15
T-12
T-08
T-13
B-02
T-23
T-09
Q-09
B-03
T-06
S-01
F-04
T-17
Q-07
C-05
A-02
Q-10
M-01
T-18
F-03
B-04
(T 21,22,23)
Q-06
O-04
Q-08
O-02
A-01
Q-03
Q-12
F-02
O-12
O-03
B-01
O-10
O-14
O-08
O-06
O-07
Q-11
S-02
O-09
O-13
O-05
O-11
M-02
N-01
Q-01
O-01
CODE
A - ALBERTA
B - BRITISH COLUMBIA
F - NEWFOUNDLAND
M - MANITOBA
N - NOVA SCOTIA
O - ONTARIO
Q - QUEBEC
S - SASKATCHEWAN
T - NORTHWEST TERRITORIES
Y - YUKON
⊗ possesses Thin Route eqpt.

FIGURE 2

2.2 Network Development

The initial Thin Route service from Ottawa to the North was established on 1st Feb. '73 with the provision of circuits to specially constructed Thin Route earth stations at Igloolik and Pangnirtung, N.W.T.

By year end contracts were signed with Raytheon Canada to supply a further fifteen equipments to be installed in the Eastern Arctic to meet agreed service requirements. These stations were installed over a two year period so that by the end of 1975 some seventeen remote communities had Thin Route service.

All of these stations were characterized by the use of

- 26' diameter antennas (G/T = 22 dB/°K)

- fully redundant, automatically switched communications equipment

- an equipment shelter 20' X 8' approx.

- initially fitted with 2 circuits but accommodates up to 8 circuits and easy addition of TV and radio program

- 4 hrs of standby power

- full climate control

These were initially fitted with two channels of voice equipment and connected at voice frequency to Bell Canada local facilities.

The initial signalling method using a single frequency at 2600 Hz in the voice band is a conventional telephone company standard which is well proven and can be implemented at low cost. This method, however, leads to inefficient use of the available space segment since the 2600 Hz carrier and hence the RF carrier remain on in the on-hook condition. As the system grows it is planned to retire this system in favour of a more efficient signalling system.

After the baseline system of seventeen remote locations homing on Ottawa (via terrestrial private line circuits from Allan Park earth station) was established, significant development and promotional work continued to reduce the cost of Thin Route terminals.

The first major out-growth of this effort was the transportable earth terminal now providing fixed service to Rea Point - a major oil industry exploration site. This service was initiated in Aug. '74 using an earth terminal having:

- a 12' diameter antenna (G/T = 12 dB/°K)

- a redundant transistorized low noise amplifier manually switched

- readily available, system compatible equipment

- a 6' X 6' equipment shelter

- standby power by customer

In Feb. '75 Telesat acquired on lease a quantity of five small 12' earth terminals (G/T = 14 dB/°K) from Hughes Aircraft to fill the gap prior to delivery of a quantity of fifteen transportable earth terminals contracted from Raytheon after competitive bidding in Sept.'74. The Hughes stations use frequency modulation techniques and necessitated the addition of special terminal equipment in Allan Park to allow system interconnection. Three of these stations are currently providing service to Bell Canada at Strathcona Sound, Sandy Lake and a Bay James location. These stations are of compact construction and readily fulfill a transportability requirement. They have, however, limitations on circuit extension since they were initially designed to serve a single circuit application. The 15 stations currently under construction by Raytheon and employing 40 kbps Δ-2Ø PSK modulation are expected to replace the leased Hughes stations. Neither the Hughes nor the Raytheon transportables possess sufficient G/T nor the facilities to allow the easy addition of TV service.

It may be worthy of note that there have arisen to date few - if any - short term communications needs requiring a transportable facility. However, the ability to readily pack, ship and set up a station to institute service rapidly may give an edge to this type of facility under "high need" circumstances.

The transportable stations soon to be delivered by Raytheon Canada are characterized by:

- a 12' diameter Cassegrain antenna ($G/T = 14.2$ dB/°K)

- a non-redundant transistorized low noise amplifier

- a non-redundant communications equipment package

- a small equipment shelter

- a sophisticated channel unit permitting operation in voice, voice plus teletype, and voice plus data modes. This channel unit also represents the first implementation of voice activation and improved signalling methods overcoming the disadvantages of the existing signalling systems.

The next phase in evolution of the Thin Route system is the facilities currently under construction for Canadian National Telecommunications. Three communities in CNT territory - Sachs

Harbour, Holman Island and Snowdrift - will soon be served by satellite communications (15' antenna, G/T = 22.5 dB/°K).

These remote stations are unusual in that single channel per carrier techniques are used to transmit to Lake Cowichan, B.C. which has been equipped with the appropriate receiving equipment, whilst the receivers operate on the high density W-E 960 message FDM/FM carrier transmitted from Lake Cowichan. The received baseband is then de-multiplexed by equipment fitted by CNT.

This action has permitted a portion of the Thin Route channel to be assigned to another telephone company (CNT) thus establishing a new service configuration.

During 1976 four communities in the Northern part of Ontario will receive service using stations characterized by:

- 15' Cassegrain antenna of new design (G/T = 19 dB/°K)

- a redundant state of the art low noise transistorized amplifier

- a redundant communications equipment package

- a new generation of channel units designed to be system compatible with original designs.

This project will be extended in 1977 to include a further five Northern Ontario communities. The stations utilised for these smaller communities are similar to those provided for the first four communities except that the communications equipment is non-redundant. This decision permits a significant cost reduction whilst still enabling a high grade of operational service to be provided using second generation designs.

Further discussion of the development of the existing Thin Route system and a more detailed description of its technical characteristics are given in Appendix A.

2.3 Operations and Maintenance

The operations and maintenance strategies presently employed have evolved harmoniously with the system growth. This has been accomplished largely by maintaining high calibre remote earth station maintenance staff in Ottawa and Frobisher Bay with appropriate spare equipment holdings.

Significant attention has been paid to training of not only the permanent staff but also complementary telephone company remote area maintenance staff and local agents in the communities.

The deployment of skilled staff and spares is of crucial importance. As described in some detail in Appendix D, great attention is paid to the interaction among staff deployment and skills, spares deployment and serviceability, and the design philosophies inherent in system expansion.

2.4 Summary

The existing Thin Route System has developed after three years of commercial operation to provide service from some twenty-four remote communities to a large Southern terminal and thus into the national network. The satellite earth segment portion of this network has evolved towards smaller and lower cost earth stations and now comprises a mix of antenna sizes (and thus G/T) and equipment configurations and manufacturers. The network contains only circuits preassigned in the N-S direction - although N-N connections are easily accomplished by appropriate selection of transmit/receive frequencies and some increase in carrier EIRP.

With the need to extend the system to permit improved utilization of the satellite and improved user access, great care must be taken if this is to be accomplished gracefully.

3. FACTORS TO BE CONSIDERED IN PROVIDING NEW NORTHERN COMMUNICATIONS FACILITIES

3.1 Implementing an Arctic Communications System

It is advantageous to consider the more significant problems associated with the installation and operation of any communication system in the Arctic environment. These problems have a common basis in that all are related to the severe climate, the expensive and restricted transportation, and the lack of local resources. Costs for implementing any system may thus become many fold the cost of implementing a similar system in a more temperate region. Some of the basic considerations are listed below and briefly discussed.

i Transportation

Transportation in the Arctic is more expensive and less reliable than in more temperate climates.

ii Prime Power

Prime power in Arctic locations may be nonexistent or inadequate in voltage regulation and reliability or in capacity. Frequently power generators must be constructed at communications sites to ensure reliable power for communications equipment. In such cases it is often desirable to design the communication system to have minimum power consumption.

iii Civil Works

In addition to the problems relating to the transport of personnel, materials, and machinery to sites, consideration must be given to special designs for civil works.

iv Maintenance

It is desirable to design communications equipment to operate unattended to minimize operating expenses.

3.2 Coverage of Arctic Regions by Geostationary Satellites

Although geostationary satellites permit the use of fixed antennas and hence more economical earth stations, they do not provide communications visibility of the entire earth.

This limitation has, however, proven to be a minor one since recent experimental tests in Canada have shown that reliable communications can be provided to earth stations located as far north as 80°N latitude, providing some additional allowance is made for fading due to tropospheric scintillation.

3.3 Extending the Existing Thin Route System

The existing Thin Route system consists of a pre-assigned network operating in a North-South (N-S) mode with Allan Park as the main Southern terminal. The remote fixed terminals and transportables currently operating or scheduled for introduction consist of a mix of designs that include the use of:

- primarily 40 kbps delta modulation-2 phase CPSK, but also FM SCPC techniques

- redundant and non-redundant configurations

- earth station G/T's varying from 12 dB/°K to 22 dB/°K

- a hybrid SCPC transmit-FDM/FM receive scheme at three locations

- 3 different manufacturers of 40 kbps delta modulation channel equipment: G.E., Raytheon, and Canadian Digital Communications Corporation.

Thus the system has evolved to meet needs using a variety of techniques and configurations which have not been standardized. If the future network - existing one plus hypothetical extensions is to achieve N-N compatibility in a demand assigned mode, several technical constraints must be addressed.

3.3.1 Compatibility Standards

In a network for which maximum interconnectivity is a major objective, a fundamental requirement is for performance compatibility of equipments used for each phase of expansion.

With no CCITT or accepted international standard for SCPC systems (except for the 7-bit PCM 64 kbps SPADE system which provides a grade of service in excess of domestic requirements) and specifically no international standard for Δ-mod/PSK equipment, the compatibility issue assumes a major importance.

Assuming the desired circuit performance and associated encoding/modulation scheme have been determined, this problem can be solved by:

- issuing a comprehensive interface specification that places the onus of compatibility on the supplier

- owning the design rights and leasing them as required to competing suppliers

Otherwise the carrier becomes locked into a single supplier or takes risks with regard to the compatibility of equipment procured from different suppliers.

3.3.2 Constraints on the Use of New SCPC Encoding/Modulation Techniques

In the future, it may be desirable for reasons of reduced station cost or improved transponder utilization to introduce encoding/modulation techniques different from the 40 kbps delta-2Ø CPSK presently employed. If this is done the ability to interconnect with existing stations can either be achieved by "double hopping" or fitting the appropriate equipment at the time of the extension. Such a retrofit at the existing twenty-five stations and Allan Park could cost up to $500,000, most of which is non-recoverable. If the function of the fifteen or so transportables planned for service is to provide dedicated pre-assigned N-S links these would not require any retrofitting.

The fine division of satellite power and bandwidth in an SCPC/FDMA system permits the effective use of both even when different types of SCPC systems share a satellite RF channel. However a future extension not employing the present 60 kHz channel spacing would preclude the possibility of sharing synthesizers and common IF equipment for both types of SCPC systems at an earth station, and might also complicate frequency planning in the RF channel. Whether or not compatibility is achieved, it is therefore desirable to arrive at a common SCPC channel spacing. Simple multiples or sub-multiples of a fundamental spacing are permissible for wider (e.g., radio program) or narrower band (i.e., lower quality voice) carriers.

The successive procurement and operation of incompatible "sub-networks" within the total thin route system can be visualized through the use of a simple network matrix. Letting A, B, C, etc. denote successively installed, possibly demand assigned sub-networks, the following binary square matrix describes both the development and interconnectivity of the total network.

$$
\begin{array}{c} \\ A \\ B \\ C \\ \vdots \end{array}
\begin{array}{c}
\begin{array}{ccccc} A & B & C & \cdots & \end{array} \\
\begin{pmatrix} 1 & 0 & 1 & & \\ 0 & 1 & 0 & & \\ 1 & 0 & 1 & & \\ & & & \ddots & \end{pmatrix}
\end{array}
$$

A '1' entry in the ij'th row/column implies direct interconnectivity between terminals in the i'th and j'th sub-networks, a '0' implies double hopping must be used. The diagonal elements are necessarily all '1'. The satellite utilization efficiency of any such arrangement trades-off with the cost of making two or more sub-networks compatible, and should be examined in terms of prevailing and anticipated traffic statistics.

3.3.3 Constraints Imposed by Continuing the Use of 40 kbps Δ-modulation

In considering the continued use of 40 kbps Δ-2Ø CPSK it should be remembered that the first two stations (Pangnirtung and Igloolik) contain G.E. delta equipment which is not compatible with the follow-on Thin Route II system designed by Raytheon. Due to filter matching required in both a delta coder/decoder (codec) and PSK modulator/demodulator (modem), as well as the variety of compression/expansion (compandor) laws and voice activation/squelch circuits possible, there exists a difficulty in making two channel units of different designs compatible. This has been examined closely and equipment currently under manufacture for the stations in Northwest Ontario has been specified to be compatible with the Thin Route II equipment.

3.3.4 The Addition of Voice Activation and Demand Assignment Circuitry

Most SCPC equipment currently manufactured, including that installed throughout most of the baseline system, is equipped to operate in the voice activated, demand assigned mode. Voice activation will be employed in the new transportable stations and the fixed stations for Northern Ontario. The effective addition of demand assignment hinges on the prior development and testing of an appropriate centralized control and signalling scheme (reference Appendix C).

3.3.5 Constraints Imposed by Adjacent Satellite Interference and CCIR Off-axis EIRP Regulations

For FM telephony systems, the CCIR (Rec. 466, Rev. 72) stipulates that 1000 pWpO is the maximum total allowable contribution of adjacent satellite interference and 400 pWpO is the maximum interference from any one adjacent satellite system.

The stated CCIR interference criteria were developed for and are strictly applicable only to multichannel FM systems. While companded SCPC FM systems are not excluded, it is unlikely that they were anticipated at the time recommendation 466 was prepared. Interference criteria for digital links, in particular variable-slope Δ-mod/CPSK systems, have not been finalized and are presently under review in Study Group 4.

Telesat employs antennas of smaller diameter (as low as 12') than those proposed for use in the Intelsat and

U.S. domestic networks. To ensure that its existing and planned future satellite communications systems are not subject to unacceptable levels of interference, Telesat tries to moderate proposed increases in allowable interference into small stations and limitations on off-axis EIRP, and has opposed the reduction of orbital spacing to less than 5°. However, as the demand for orbit space grows the pressure to use it efficiently increases. This pressure may conflict with the desirability of low cost 4/6 GHz satellite earth terminals to provide communications into remote parts of Canada.

Of most immediate concern are proposed limits on off-axis EIRP from an earth station. It is well recognized that these limits are required to protect administrations from interference over which they have no design control. Restrictions on off-axis EIRP may preclude the use of 12' antennas with normal sidelobe characteristics for direct N-N communications.

With the present 5° orbital spacing, the issue of downlink interference is of little concern to administrations planning to implement high capacity systems using large diameter antennas (33' or greater). To ensure that the

400 and 1000 pWpO maximum allowable interference limits previously mentioned do not constrain their system designs, it is likely that U.S. domestic administrations will support proportional increases in interference allocations for earth stations having antenna diameters less than 25'. However, no direct pressure to limit antenna diameter for receive purposes is anticipated, and individual administrations will largely be left to make their own judgements and co-ordinate their channel planning to minimize interference. In this regard, SCPC systems should avoid co-channel TV in an adjacent satellite (see discussion in section 3.4.3.3, Appendix B). Assuming the continuation of 5° satellite spacing and the avoidance of co-channel TV, calculations (see Figures 16, 19, 20, Appendix B) indicate that antenna diameters as low as 12' are acceptable as far as interference into the SCPC system is concerned.

It appears likely that the following adjacent satellite interference criteria will be adopted for both analog and digital message systems:

1. For antenna diameters greater than 100λ (λ = receive wavelength) the 1000 pWpO and 400 pWpO limits will apply. For diameters less than 100λ (25' at 4 GHz)

the interference allocations will increase in proportion to $(100/\lambda D)^2$

2. Off-axis EIRP transmission at an angle $\theta > 1°$ will be limited to 38.5 -25 log θ dBW/4kHz (Canadian position) or less.

The following table indicates proposed maximum allowable noise contributions from adjacent satellite interference vs antenna diameter.

ANTENNA DIAMETER	MAXIMUM ADJACENT SATELLITE INTERFERENCE CONTRIBUTION	
	PER SATELLITE	TOTAL
≥ 25'	400 pWpO	1,000 pWpO
18'	770 pWpO	1,930 pWpO
15'	1,110 pWpO	2,780 pWpO
12'	1,740 pWpO	4,340 pWpO

If these limits are exceeded, the onus of responsibility for rectifying the situation theoretically falls on the interference producing administration. In practice, CCIR limits such as these are applied in designing and licencing satellite communications systems.

Under worst case conditions, a 12' earth station will receive 4300 pWpO total noise due to adjacent satellite interference, small compared to the standard 22,400 pWpO Northern Service objective. In practice, however, and certainly in the foreseeable future, much less interference is anticipated.

The off-axis EIRP restriction may impose more serious constraints on the design of the SCPC system. For example, for direct communications between 12' Thin Route earth stations (G/T = 15 dB/°K, transmit gain = 45 dB), transmitted EIRP's per carrier of about 54 dBW are required (see Figure 12, Appendix B). Assuming the CCIR reference radiation pattern given in recommendation 465 (Rev. 72) and Report 391-2,

$$G(\theta) = \begin{cases} 32 - 25 \log \theta, \text{ for } D/\lambda > 100, \theta > 3° \\ 52 - 10 \log (D/\lambda) - 25 \log \theta \text{ for } D/\lambda < 100, \theta > 3° \end{cases}$$

the off-axis EIRP from a 12' antenna at an angle θ is given by:

$$\text{EIRP}(\theta) \simeq 44.5 - 25 \log \theta$$

To meet the suggested off-axis EIRP/4 kHz requirement, then, about 6 dB of energy dispersal is required. A non-voice activated SCPC carrier does not nearly meet this objective; the modulation present with a voice activated FM or PSK carrier should give 5-8 dB of dispersal.

It is therefore re-iterated that off-axis EIRP restrictions,* as well as increased power amplifier costs, mitigate against the implementation of a fully variable demand assigned SCPC system using a 12' antenna. These limitations could be made less significant if the power required to saturate the satellite transponder were reduced. Increasing the gain of future 4/6 GHz satellites by 5 dB (i.e. specifying a saturating flux density of -86 dBW/m^2 rather than the present -81 dBW/m^2) would give corresponding reductions in HPA size and off-axis EIRP at the expense of a very small reduction in transponder capacity due to an increased up-link noise contribution.

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* Some relaxation in off-axis EIRP restrictions in this case might be argued on the basis that remote terminals located in the North are well down on the receive gain contours of proposed U.S. domestic satellites covering the contiguous 48 states.

ALTERNATIVE SINGLE CHANNEL PER CARRIER (SCPC) MODULATION AND ACCESS TECHNIQUES

Over the last few years several SCPC systems have entered service or have been proposed. To determine the most appropriate type of system to satisfy future Canadian requirements, the following important parameters should be considered:

- number of circuits provided per transponder
- compatibility with existing Thin Route system
- earth segment capital costs and costs of operating the network.

With regard to modulation and access techniques the fundamental options available are:

- FM vs Δ-delta-modulation
- fixed vs voice activated carrier
- preassigned vs demand assigned circuits.

This section compares the important characteristics of each of the contending modulation/access schemes; such a comparison provides a reasonable basis for selecting the most cost-effective.

4.1 Key Results From SCPC Performance Analysis

Appendix B gives a detailed discussion and analysis of the performance of two contending SCPC modulation techniques, namely

1. emphasized companded FM, and

2. variable slope delta-modulation (Δ-mod), 2 or 4 phase coherent phase shift keying (CPSK)

Delta modulation was chosen for evaluation over pulse code modulation (PCM) because

- it is simpler and cheaper

- it degrades gracefully in the presence of noise

- it is more efficient in terms of transponder power required.

Figure 3 summarizes the transponder capacity versus earth station G/T of 20 kbps, 32 kbps, 40 kbps Δ-mod CPSK systems and several FM systems. Voice activation has been assumed in all cases to increase the transponder capacity by a factor of 2.5.

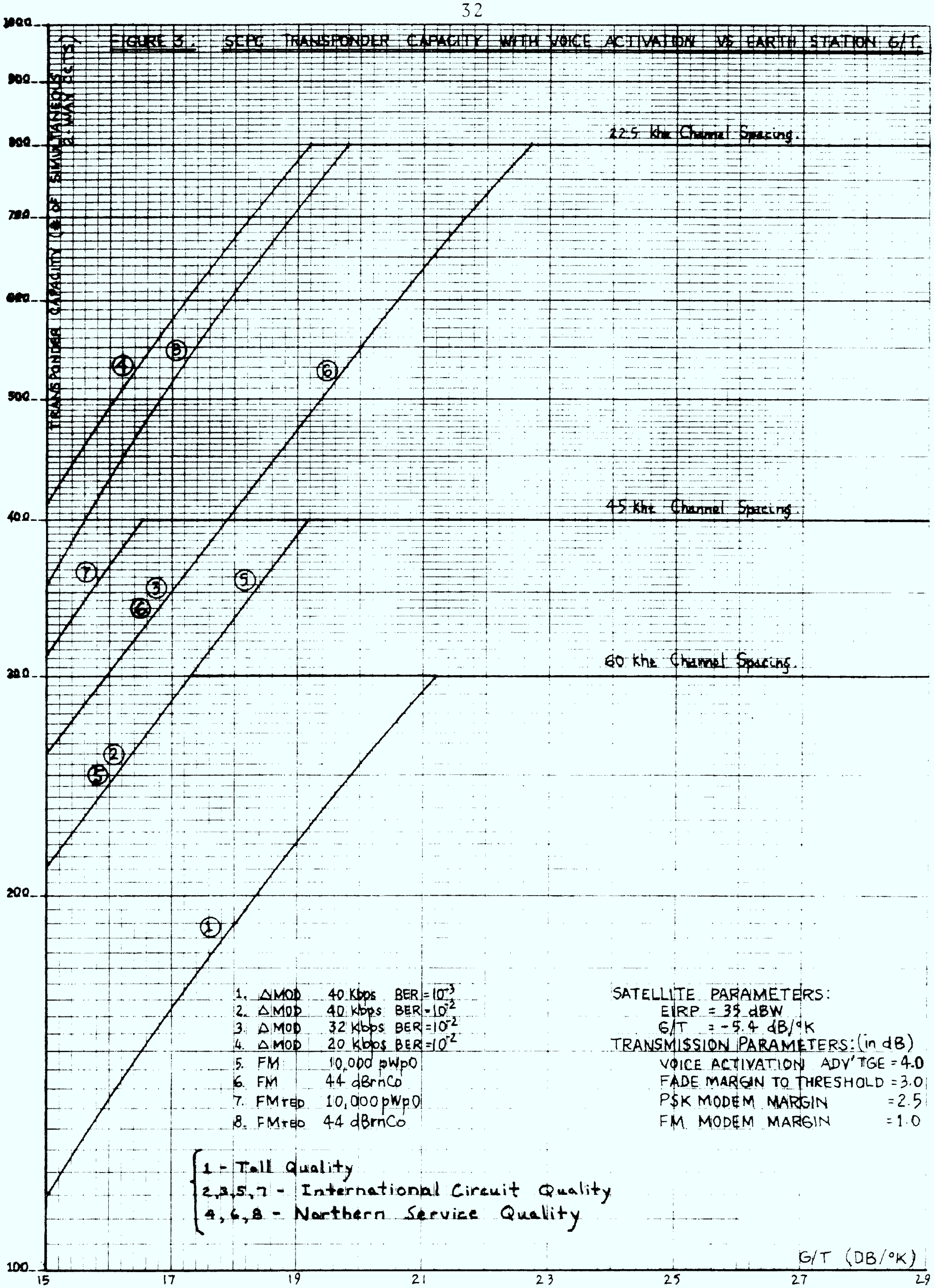

FIGURE 3. SCPC TRANSPONDER CAPACITY WITH VOICE ACTIVATION VS EARTH STATION G/T.

The following key results provide a reasonable basis for evaluating and comparing the performance of the analog and digital schemes:

1. Due to the companding action, the subjective performance of both the Δ-mod and FM systems cannot immediately be related to the normal idle noise specification for circuit quality. Accepted international standards for the "subjectively equivalent" performance of these systems have not been arrived at, and it has been necessary in this study to rely on the results of subjective tests reported in the open literature.

2. On this basis, a 32 kbps Δ-mod CPSK system and a companded FM system employing threshold extension demodulation provide 10,000 pWpO international circuit quality at approximately equal carrier-to-noise density ratios and RF bandwidths.

3. Δ-mod CPSK circuit performance degrades more gracefully than FM circuit performance as the carrier-to-noise ratio drops below threshold. Since relatively small margins can ensure operation above threshold for a very high percentage of time in the 4/6 GHz band, this is not a major consideration.

4. For a voice-activated system with equal G/T's the bandwidth limited capacity of the satellite channel is reached for earth station G/T's in the vicinity of 18-20 dB/°K. Larger G/T's at all stations cannot increase the transponder capacity but will increase the link margin or reduce the required up-link EIRP per carrier.

5. A G/T in the 18-20 dB/°K range can also provide a high quality TV receive performance (video S/N $\geq$ 45 dB-wtd). G/T's below about 16 dB/°K cannot be expected to receive good quality TV over the present Anik, but might over the higher EIRP Anik 4.

6. Both 20 kbps Δ-mod CPSK and reduced bandwidth FM SCPC systems can provide the accepted Northern service quality of 44 dBrnCO (22,400 pWpO). Once again the transmission efficiencies are about the same, with the Δ-mod system perhaps having a slight advantage. This lowering of circuit quality from that obtainable with 40 kbps Δ increases the power limited transponder capacity by a factor from 1.6 to 2.0, or alternatively permits a reduction of up to 3 dB in the sum of receive G/T and transmitted EIRP per carrier. This will permit a significant saving in earth segment cost and/or space segment utilization.

7. When operating on an analog (i.e. voice band) signal, FM offers clear advantages over Δ-mod in many special applications such as the transmission of voice band data, voice plus teletype or low speed data, and radio programs. With appropriate modification of deviation and carrier-to-noise ratio if necessary, an FM SCPC system can be designed to give the degree of channel transparency required to transmit any combination of signals over (and even above) the 300 to 3400 Hz voice band.

8. When a digital interface is available the Δ-PSK system permits the synchronous transmission of data at the link rate. Forward error correcting coding can be used to improve bit error rate performance without necessitating an increase in transmit carrier EIRP. This may decrease required earth station power amplifier size and certainly eliminates a control function. Digital multiplexes can allow the simultaneous transmission of voice and high speed data over a Δ-PSK SCPC link with only a modest accompanying reduction in speech quality due to a reduced encoding rate.

9. FM is more amenable to a network in which more than one circuit quality is desired. An equal carrier demand

assigned FM/SCPC system will automatically provide improved performance into the higher G/T southern terminus, whereas a Δ-mod CPSK system under fair-weather conditions will not.

For a "two circuit quality" network*, a digital solution is less efficient for two reasons:

i The encoding rate is determined by the higher (Southern) circuit quality implying the need for excess C/N_o into the remote terminals.

ii For an equal carrier system, excess carrier power into the Southern terminal(s) reduces transponder capacity.

10. The Δ-mod/PSK and FM SCPC systems are about equally sensitive to most types of wide band adjacent satellite interference. For cochannel FM-TV transmission in an adjacent satellite, it may be necessary or desirable to avoid using the centre 1 MHz or so of the SCPC transponder. A Δ-mod/PSK system may offer significant advantages over FM with regard to narrow band inter-

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* An FDM/FM/FDMA satellite system providing two circuit qualities (44 dBrnCO into the North, 37.5 dBrnCO into the South) has been implemented to serve Frobisher Bay and Resolute Bay. In addition to the concept of "Southern vs Northern" user requirements it must be remembered that the satellite link to the South must allow for subsequent circuit degradations over terrestrial links.

ference of the type produced, for example, by a co-channel SCPC system. However, FM can achieve at least equal immunity to narrow band interference if carrier frequencies are limited.

11. Both Δ-mod/PSK and FM equipment can be equipped with voice activation and echo suppression circuitry and can operate in a pre-assigned or demand assigned mode. The digital approach may offer some advantages in the design of voice detection circuitry and the demand assignment communications system.

12. The hardware complexity and hence size, weight, power consumption and reliability performance of the two approaches are essentially equal.

13. The equipment costs for the two approaches are competitive, although prices may vary depending on non-technical as well as technical factors. FM equipment was quoted at somewhat lower cost for the Alaska system, and might perhaps have the current edge in cost.

14. The trend of higher integration levels for digital building blocks is expected to lead to less complexity and cost for digital SCPC channel units. On the other hand FM is the "newer" SCPC technique, and improvements

TABLE 1

COMPARISON OF Δ-MOD AND FM SCPC TECHNIQUES

	Variable Slope Δ-Mod/CPSK	Companded Emphasized FM with Threshold Extension Demodulation
Circuit Quality	Limited by quantization noise. Under fairweather conditions depends only on encoding rate.	Limited by thermal noise. Determined by C/N_0 and deviation.
Transmission Efficiency	C/N_0 and RF bandwidth requirements for given circuit quality approximately equal	
Transponder Capacity	e.g. 300 simultaneous voice-activated 10,000 pWpO duplex channels for G/T = 18 dB/°K (15' antenna with 260°K transistor amplifier)	
Network Flexibility	Digital format permits efficient digital multiplexing of voice & data and possibly more efficient demand assignment (d.a.) signalling. Circuit quality is not greatly dependent on earth station G/T - this implies non-optimum utilization of satellite resources if a 2 circuit performance network is required.	FM offers better voice channel linearity and amplitude vs frequency rolloff, and hence can be used to transmit high speed voice band data and radio programs. For an equal carrier d.a. SCPC system, FM provides lower circuit noise into the higher G/T Southern terminal(s), thereby efficiently matching space/earth segment resources to a 2 circuit quality requirement.
Sensitivity to Fades and Degraded Transmission Performance	Digital system degrades gracefully and provides intelligibility to error rates of 10^{-1}.	Emphasized companded FM system degrades very quickly below threshold.
Sensitivity to Transmission Distortion and Interference	A PSK carrier possesses amplitude fluctuations and is therefore sensitive to limiting and AM/PM conversion in earth station TWT. The associated backoff penalty with single carrier operation increases earth station TWT size by 1-2 dB. A CPSK carrier is somewhat insensitive to co-channel interference.	Constant amplitude nature of FM meansTWT can be operated at saturation for a single carrier input. For multicarrier d.a. operation required backoff is determined by both intermodulation and intellibible crosstalk requirements. Interleaving can be used to reduce effects of narrowband interference from adjacent satellite SCPC systems.
Cost (Canadian $ per channel unit, Quantity 100)	$4,100	$3,300

in performance, reliability, and cost would not be unexpected.

Table 1 compares the outstanding features of FM and Δ-mod SCPC systems. Since there are no dramatic differences in cost or transponder utilization efficiency for a homogeneous configuration, the continued use of digital SCPC technology seems reasonable providing there is one circuit performance objective throughout the network. However, Figure 3 does reveal the following more significant aspects to be considered in the expansion of the existing Thin Route system:

(1) With voice activation and the present 60 kHz channel spacing, the bandwidth limited capacity (300 duplex channels) of the system is reached for a G/T of less than 18 dB/°K. Since G/T's of 19 dB/°K and 22 dB/°K are used, it is therefore possible that the system will become <u>bandwidth</u> limited before it becomes power limited. This conclusion is reinforced by the fact that adjacent channel multipath* effects might reduce the useable SCPC bandwidth from 36 MHz to 32 MHz, and its bandwidth limited capacity to only about 267 duplex channels.

* Due to non-ideal input multiplex filters, signal energy at frequencies near the edge of a nominal 36 MHz transponder band may be amplified by both the wanted and adjacent transponders. For the HS-333 spacecraft the resulting distortion appearing at the satellite output is time-varying; in an SCPC system it causes a slow variation in the transponded carrier powers.

(2) The unnecessarily large 60 kHz channel spacing may therefore ultimately penalize the capacity of the Thin Route network. Using 4∅ CPSK modulation, 40 kbps Δ-mod links can be accommodated with RF channel spacings as little as 25 kHz and little or no penalty in transmission performance. Even the standard Intelsat spacing of 45 kHz would increase the ultimate Thin Route channel capacity by a factor of 1.33.

(3) Lower quality FM or Δ-mod link requiring about 3 dB less C/N_o and half the RF bandwidth can nearly double transponder capacity in either the bandwidth or power limited modes. The 44 dBrnCo performance of such systems is equivalent to the highly satisfactory service presently provided to Frobisher Bay and Resolute Bay using FDM/FM/FDMA techniques, and still represents a significant improvement in both noise performance and circuit availability over hf radio communications.

4.2 Demand Assignment Multiple Access (DAMA) Techniques

The introduction of demand assignment in an SCPC system permits the satellite to become, conceptually at least, an exchange office providing a voice channel between any two accesses on demand. In the terrestrial network, a large number of telephone lines are 'fanned in' to a modestly sized local exchange, but a high grade of service is maintained. In a similar manner the satellite's broadcasting capability together with the controlled assignment of SCPC channel frequencies on demand allow a transponder to serve a large number of users, as well as provide interconnectivity using a minimum of earth station facilities. A large number of accesses can be served at the expense of a small but non-zero probability of call blockage. The problem of determining the probability of call blockage or system capacity for a given grade of service has been well studied in the terrestrial network, and is really no different in the satellite case. The increased capacity offered by demand assignment depends on the statistics of traffic demand during the busy hour(s); however, long distance rates directly proportional to normal demand can spread user demand, thereby resulting in more efficient utilization of the RF channel.

Demand assignment does not constrain the choice of SCPC encoding/modulation technique and can easily be made compatible with the public switched network using accepted telephone system signalling and supervisory interfaces.

The subjects of automatic call billing and call routing are treated in depth in Appendix C for a demand assigned system. It is shown that a numbering scheme for the satellite system users of identical form to that used in the DDD network greatly simplifies the provision of these services. In particular, if a single area (NPA) code is assigned to the satellite system not only is the provision of automatic billing and call routing made simple but also the impact on the public switched network is minimized.

The provision of automatic call routing is efficiently handled via the demand assignment control system. Communication between nodes of the system for call set up and call supervision is via a separate (i.e. independent of the voice path) signalling channel. In this manner the maximum system flexibility is realized. Automatic call billing for calls originating within the system requires the automatic identification of the calling number to the billing facility. This is simple to provide when the remote terminal serves a single user. However when a telephone switch lies behind the satellite terminal the telephone equipment must be modified to provide this function.

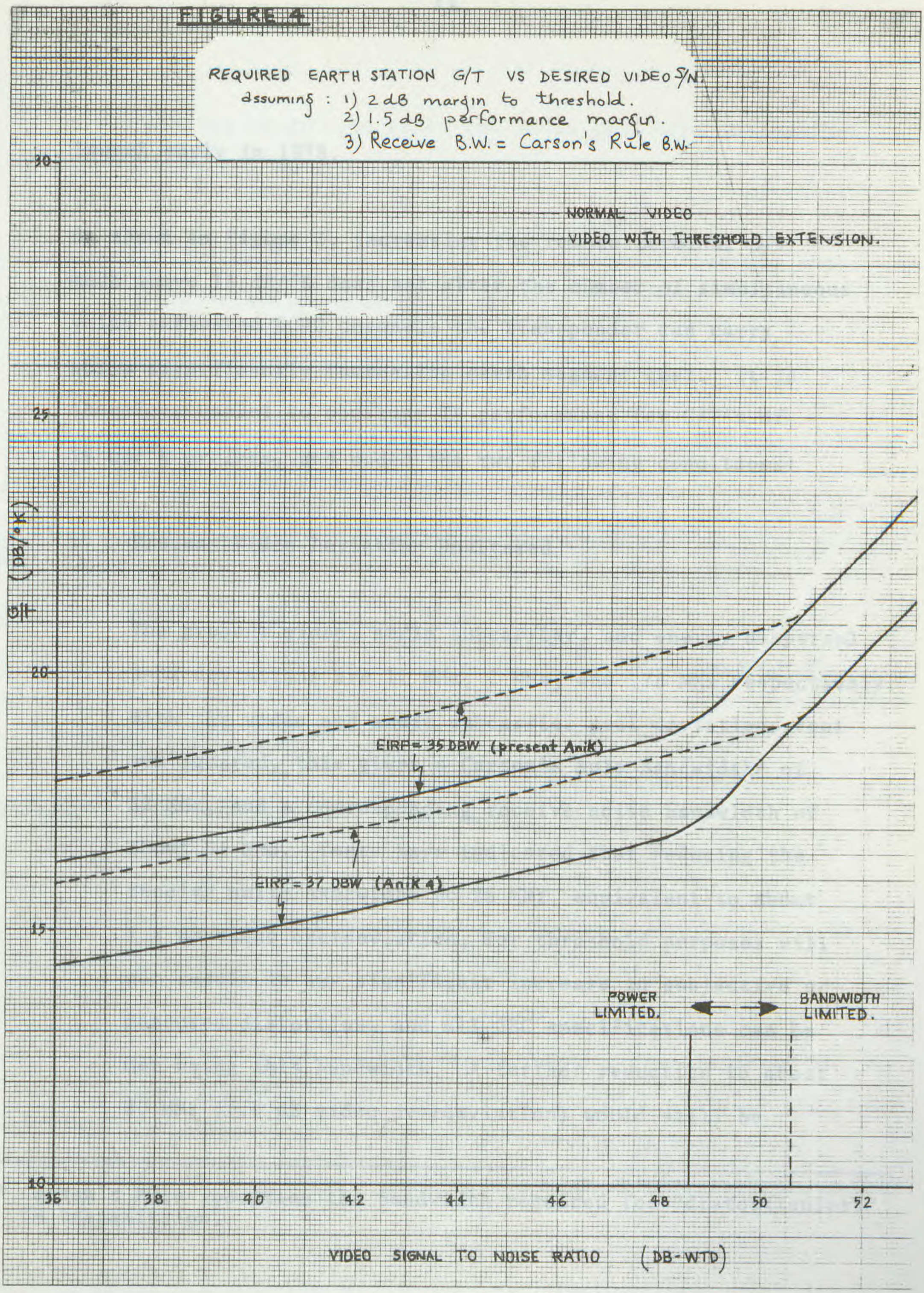
5. TV PERFORMANCE CONSIDERATIONS

While this study concentrates on the more complex cost/performance trade-offs associated with extending the Thin Route message system, the design of the remote terminal must also consider the objective of providing television and radio program services. TV and radio program carriers are received using separate down chains and demodulators, with only the antenna and low noise amplifier subsystems being shared with the SCPC service. Therefore the inclusion of a TV and radio program receive capability simply impacts on the G/T required to provide the desired video and audio qualities. Other practical considerations facilitating the easy addition of these services at an earth station, such as space, power, and environmental control, are identified in Chapter 7.

5.1 Video S/N vs G/T

Figure 4 plots the required remote terminal G/T vs desired weighted video signal-to-noise ratio assuming video deviation and corresponding Carson's Rule Bandwidth are reduced as required to ensure operation above FM threshold. A 2 dB threshold margin and a 1.5 dB performance margin have been used in FM link calculations, and both conventional and threshold extension (2 dB advantage) demodulation considered. The 35 dBW and 37 dBW EIRP's assumed correspond to those of the present Anik and the dual band Anik satellite due for

FIGURE 4


REQUIRED EARTH STATION G/T VS DESIRED VIDEO S/N
assuming : 1) 2 dB margin to threshold.
2) 1.5 dB performance margin.
3) Receive B.W. = Carson's Rule B.W.
NORMAL VIDEO
VIDEO WITH THRESHOLD EXTENSION.
EIRP = 35 DBW (present Anik)
EIRP = 37 DBW (Anik 4)
POWER LIMITED.
BANDWIDTH LIMITED.
G/T (DB/°K)
VIDEO SIGNAL TO NOISE RATIO (DB-WTD)
30
25
20
15
10
36
38
40
42
44
46
48
50
52

launch early in 1978.

As shown in Figure 3, increasing the remote terminal G/T much above 18 dB/°K does not alter the number of simultaneous voice activated SCPC channels the transponder can carry while significantly increasing earth segment cost. It is therefore useful to consider TV performance for G/T's of 18 dB/°K or less, and under the two following conditions:

i Present Video Deviation Unaltered

The present video, audio subcarrier, and energy dispersal peak deviations are 11 MHz, 2 MHz, and .78 MHz respectively. With the video and audio subcarrier peak deviations root sum squared, this gives a Carson's Rule Bandwidth* of 32 MHz, and a corresponding receive noise bandwidth of about 34 MHz. Tests have indicated that reducing the receive noise bandwidth to 26 MHz, equivalent to about 1.8 dB video overdeviation, for threshold purposes will not result in any significant increase in subjective or measured distortion, and all CBC specifications can be met using this bandwidth. A further reduction to about 20 MHz (3.9 dB video overdeviation) would still be

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* Carson's Rule specifies the bandwidth required for "distortionless" FM transmission.

expected to provide video and audio qualities subjectively acceptable to viewers.

The following table indicates the video performance that could be achieved assuming the existing video, audio subcarrier and energy dispersal deviations are left unchanged.

G/T	SATELLITE EIRP	RECEIVE NOISE BANDWIDTH	EXCESS VIDEO DEVIATION	FAIRWEATHER C/N	VIDEO S/N (INDLUDING 1 dB FADE MARGIN)
18 dB/°K	35 dBW	30.6 MHz	.5 dB	10.0 dB*	46.6 dB
		20.0 MHz	3.9 dB	11.8 dB	48.0 dB
	37 dBW (Anik 4)	30.4 MHz	.5 dB	12.0 dB	48.4 dB

* Threshold extension demodulation required

The large deviation and corresponding 32 MHz transmission bandwidth employed in the present Telesat - CBC system limits the minimum required conventional earth station G/T to about 20.5 dB/°K, and provides a minimum weighted video S/N of 48.6 dB. Threshold extension demodulators are available which can reduce these to 18.5 dB/°K and 46.6 dB respectively, but at the expense of a $4,000 - $5,000 increase in receiver cost.

The existing system, then, is not well suited to meeting anticipated lower quality video (40 to 44 dB S/N) requirements in remote communities not presently served. One technique that has been used is to reduce the receive bandwidth and accept some increase in distortion. As indicated in the previous table this permits the use of a conventional demodulator and a G/T of 18 dB/°K, possibly as an interim solution till the advent of a second series of higher power Aniks permits the reception of high quality video.

ii Optimized Video and Audio Subcarrier Deviations

It has been pointed out that using a receive bandwidth less than that predicted by Carson's Rule permits a reduction in the G/T required to receive a TV picture not plagued by subjectively disturbing threshold noise. The consequence of this reduction, however, is increased signal distortion, appearing as:

- colour distortion (i.e. increased differential gain and phase)

- impulsive noise when the picture signal contains high-amplitude, high frequency information as in highly saturated colour information

- interfering tones in video baseband resulting from intermodulation of the line synchronizating signal and audio and colour subcarriers.

Up to 4 dB of excess video deviation may be considered practicable; beyond this the distortions introduced cause serious degradations in picture quality.

In choosing the deviation and receive bandwidth of a satellite FM video link to serve remote terminals, one has the opportunity to trade-off the effects of thermal noise and picture distortion. It is clearly desirable to balance these to arrive at the best picture quality for a given G/T available. There is little advantage, for example, in achieving a high signal-to-noise ratio when signal distortion is the limiting factor. In the case of distortion due to a bandwidth limiting receive filter, a lowering of FM deviation (and video S/N) to alleviate this source of degradation would be desirable.

The deviation employed and corresponding minimum video S/N available in the Telesat system may exceed the needs of remote viewers while imposing a rather high minimum required G/T. Excess margin in the baseline system, notably 2-3 dB excess satellite EIRP, mean that CBC's performance requirements into existing stations could be met with video deviations reduced from their present value. Such a reduction, on the other hand, would greatly enhance the capability of small remote terminals to receive a lower quality version of the same video signals.* The following table indicates one possibility.

G/T	SATELLITE EIRP	RECEIVE NOISE BANDWIDTH	EXCESS VIDEO DEVIATION	FAIRWEATHER C/N	VIDEO S/N (INCLUDING 1 dB FADE MARGIN)
18 dB/°K	35 dBW	20.0 MHz	1.7 dB	11.8 dB	42.0 dB
16 dB/°K	37 dBW	as above			

Since present and possible future radio program carriers occupy a relatively small portion of the space segment, and their down-link EIRP's are largely arbitrary†, it is reasonable to design the radio program transmission parameters to match the G/T's of the large number of remote terminals, rather than the converse. Unlike the case of TV and SCPC voice, therefore, radio program requirements do not theoretically enter into the selection of remote station G/T.

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* An additional advantage of reduced video bandwidth would be a lessening of the mutual interference between the TV and radio program carriers.

† The technique presently employed for CBC's accelerated coverage plan is to locate a 200 kHz radio program carrier about 16 MHz below the centre frequency of the video transponder and with an output EIRP approximately 20 dB below the video carrier. The use of the Thin Route transponder for radio program distribution would offer the following technical advantages over the present scheme:

- 10 dB less up-link EIRP provides the same down-link EIRP; this facilitates the use of multiple origination points in the North.
- There is greater freedom to increase radio program carrier EIRP to match system performance requirements and remote terminal G/T's selected.
- Radio program receiver could be designed to make use of SCPC downconverter and common IF equipment.

6. SYSTEM CONFIGURATIONS AND GROWTH STRATEGIES

This Chapter develops hypothetical but realistic network configurations showing how the existing Thin Route network can be extended in a graceful manner. The following major aspects are addressed:

- network topologies

- the efficiency of utilization of the satellite transponder, including the introduction of demand assignment

- graceful growth of the network as traffic increases, including growth beyond the capacity of a single transponder.

Cost trade-offs are identified and quantified, and several viable system models compared.

6.1 Objective

Many different types of SCPC satellite networks can be visualized, each having its own traffic topology, transponder utilization efficiency, circuit performance, and adaptability to growth or change. The objective here is not to determine the theoretically most efficient earth segment/space segment combination per se, but rather to explore means of extending the existing Thin Route network and deriving benefit from presently unused satellite resources in an optimum manner. To achieve this goal the following basic factors must be considered:

1. Characteristics of Existing Thin Route System

   It is clear that constraints imposed by the existing Thin Route system with regards to interfaces, performance standards, interconnectivity, and operations and maintenance should be considered carefully in future extensions.

2. Circuit Requirements and Traffic Statistics

   The rate of growth of the system may have impact on the most appropriate system configuration. Larger networks favour the use of demand assignment, automated control and supervision, and possibly the exploitation of new technology. Preassigned circuits or limited demand assignment might be more appropriate for small networks or when fixed point-to-point calling predominates. In particular, a N-S preassigned circuit arrangement has the following important features:

- compatability with existing telephone company signalling, switching, and billing facilities

- complete interconnectivity (even between stations possessing incompatible equipment) achieved through double hopping

- a minimum of up-link EIRP required from the remote stations

A continuation of the preassigned SCPC system implies

- a minimum of sophistication in the new remote terminals (i.e. no DAMA equipment)

- no modifications to the existing Thin Route and Allan Park stations

- no alterations to the associated telephone plant

and is clearly favoured at least until the capacity of the transponder is close to being reached.

3. Earth Station Cost/Performance Trade-offs

The final aspect that must be examined in the light of the first two are the cost/performance trade-offs associated with the design of the remote station. Factors such as circuit quality, circuit availability, transponder capacity, capital and operating costs, and flexibility for growth must be weighed as to relative importance. Since the actual requirements of any future extensions have not been specified, a precise evaluation is difficult and perhaps premature. Emphasis is therefore placed on clearly identifying the trade-offs involved rather than recommending a specific system. However, several hypothetical cost effective contenders are developed in order to exemplify the trade-offs and give the study a more concrete value.

6.2 Types of Networks

The following categories serve to describe the types of SCPC networks that could be envisaged.

6.2.1 Preassigned/Demand Assigned

There are two access techniques most commonly employed in

SCPC systems at the present time. These are fixed assignment and demand assignment systems.

Fixed assignment access employs preassigned frequencies for transmitting and receiving RF carriers at each earth station. Thus each voice circuit between any two nodes requires a dedicated pair of frequencies and transmitters and receivers, and the number of possible connections is limited by the 36 MHz satellite RF channel bandwidth. The interconnectivity capability of a preassigned system can be augmented by the use of double hopping through a single common node, as in the present Thin Route system, but this results in reduced circuit performance, double delay, and inefficient utilization of both satellite resources and channel units. Figure 5 graphically illustrates how transponder power and bandwidth utilization efficiencies drop as the percentage of north to north calls increases - due to the higher G/T at Allan Park, with 100% N-N calling the power limited capacity of the transponder is only reduced by about 24%.

A preassigned system having more than one access point to the public switched network places important demands on the terminal equipment required for call routing and billing purposes. In addition, terminating preassigned

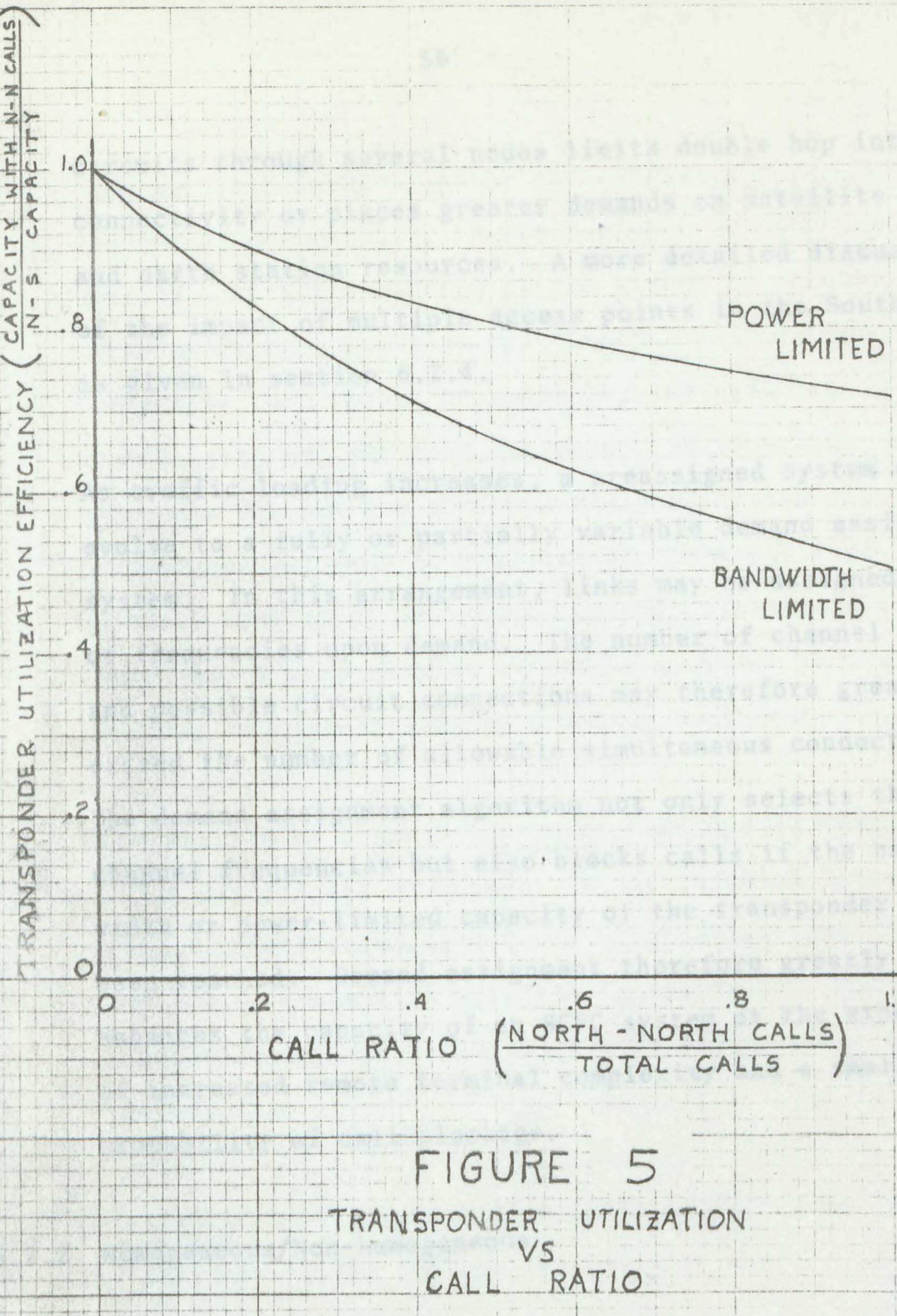

FIGURE 5

TRANSPONDER UTILIZATION VS CALL RATIO

circuits through several nodes limits double hop interconnectivity or places greater demands on satellite and earth station resources. A more detailed discussion of the impact of multiple access points in the South is given in section 6.2.4.

As traffic loading increases, a preassigned system can evolve to a fully or partially variable demand assigned system. In this arrangement, links may be assigned pairs of frequencies upon demand. The number of channel units and possible circuit connections may therefore greatly exceed the number of allowable simultaneous connections. The demand assignment algorithm not only selects the channel frequencies but also blocks calls if the bandwidth or power-limited capacity of the transponder has been reached. Demand assignment therefore greatly enhances the capacity of an SCPC system at the expense of increased remote terminal complexity and a small probability of call blockage.

6.2.2 Homogeneous/Non-homogeneous

A homogeneous SCPC system implies equal carrier levels and a single performance standard throughout the network. Non-homogeneous systems do not satisfy these constraints. Homogeneity offers advantages in a demand assigned system, and may also reduce capital and operating costs due to equipment commonality. A pre-assigned non-homogeneous system with G/T's matched to the number of circuits terminated at a location may theoretically be more cost effective with regard to space segment utilization and total earth segment cost (reference Section 3.3, Appendix B), but for a demand assigned system these advantages can only be realized at the expense of increased complexity or reduced network flexibility. Non-homogeneity also permits tailoring a system to meet special requirements using existing equipment.

One example of a non-homogeneous SCPC system that can offer significant advantages is one in which there is a single remote terminal G/T and a larger antenna diameter and G/T at connection point(s) in the South. This configuration largely reflects that of the existing system, and permits:

- reduced EIRP or improved circuit quality from the remote stations to the South

- for pre-assigned N-S operation, N-N calling achieved by double hopping with only a modest reduction in power limited transponder capacity

- multi-carrier operation of modestly sized southern terminal HPA.

6.2.3 Compatible/Non-compatible

The question of channel unit compatibility has already been introduced. Two terminals in the network are defined as compatible if a satisfactory voice circuit between them can be established. This requirement impacts not only on channel unit compatibility, but also on the EIRP per carrier - G/T combination necessary to ensure acceptable performance.

In general, the existing SCPC network can be divided into compatible sub-networks which cannot directly communicate with each other. This constraint reduces the theoretical advantage of demand assignment applied to the entire network and must be adhered to in devising the control algorithm. Communications between non-compatible sub-networks may still be arranged by double hopping through an intermediate 'translating' station. (A terminal can be part of more than one sub-network if it possess the requisite equipment).

6.2.4 Multiple Access Points in the South

6.2.4.1 Preassigned System

In a preassigned system each satellite link is analgous to a very long subscriber loop, or, when both ends terminate on a telephone switch, a trunk with each end of the link pre-determined. The presence of multiple access points in the South therefore introduces constraints on both call routing and call billing.

i Call Routing

In order to take advantage of the availability of several access points to the switched network, each remote earth station must have at least one satellite link to each access point <u>and</u> the associated telephone equipment must be capable of translating the dialled information and choosing the appropriate link. Both of these conditions can be eliminated if double-hopping of both N-S and N-N calls is allowed. Then all links from the North can be terminated on one large switch in the South which selects the appropriate second link based on the dialled information. The other access points to the switched network have satellite links only to this central location.

In either case above the utilization of the satellite resource is poor and is decreased with increasing connectivity due to the fact that in the absence of some form of inhibiting control, the physical number of channel units in service must be limited by the transponder capacity. In addition, to provide interconnectivity in the preassigned system an inordinate amount of earth station facilities must be provided. For example, if there were three access points in the South, then to provide single-hop calling to any one of these from an earth station say at Pangnirtung would require a minimum of three channel units at Pangnirtung with a corresponding dedicated channel unit at each of the access points. Clearly, satellite resources can be rapidly depleted as the number of Southern access points increases while in fact the actual traffic carried over the satellite may decrease as a result of the rapid drop in the system efficiency!

If each access point is to accept calls originating within the switched network, then double-hop operation may be mandatory. The alternative is (as stated above) to have at least one channel unit at the access point for every other earth terminal in the system.

ii Call Billing

Call billing for calls internal to the system is a very real problem if single hop calls are possible. In effect, each earth terminal in the system must perform the functions of a toll office. These include recording of calling and called numbers, duration of the call, etc. and necessitate a degree of sophistication approaching that of a demand assigned system yet having none of the advantages.

iii Conclusions

It is to be concluded that in a preassigned system single-hop calling between remotes or between remotes and multiple access points to the switched network is undesirable due to the rapid depletion of the satellite resources which results.

6.2.4.2 Demand Assigned System

In a demand assigned system, the presence of several access points to the public switched network need have no deleterious effect on the utilization of the satellite resource. The impact of such a configuration with respect to call routing and billing has been investigated in Appendix C. Two points about this configuration are worth noting.

Firstly, the number of channel units required at a given access point is a function of the traffic expected to flow through that point.

Secondly, if all traffic to/from the switched network flows through only one access point, then the number of channel units required to serve this traffic can be significantly reduced and call routing from the switched network to the satellite system considerably simplified.

As regards billing it has been noted that any telephone switch lying behind an earth station must be equipped for automatic number identification (ANI) if automatic call billing is implemented in the system.

6.2.5 Special Configurations

In addition to the previously described types of SCPC networks, special configurations can be developed to more economically satisfy the particular needs of private users. Some of these are:

i Simplex Channel (s) Shared by Several Users

- like mobile radio, useful for broadcasting and time shared channel utilization.

ii Party Line Service

- minimizes use of space segment resources and terminal complexity in a small sub-network.

iii Distributed PBX Service

- can provide for special routing procedures in a private satellite/terrestrial network.

6.3 System Expansion Techniques and Associated Cost Trade-offs

6.3.1 Introduction

The utilization of the Thin Route transponder is being gradually increased as indicated in Figure 1. At the present rate of growth, it appears that within about 3 years techniques will have to be implemented and service re-arrangements made to permit an increase in capacity.

The techniques available are:

1. Introduction of voice activation

2. Increase of G/T of remote terminals and/or southern terminal(s)

3. Use of demand assignment

4. Use of new SCPC modulation techniques which are more efficient or reduce voice quality

5. Growth into second transponder

These techniques can be instituted with varying degrees of ease and cost. The way in which the service grows and the rate of growth will have major bearing on implementation strategies.

6.3.2 Capacity Expansion Techniques

1. Voice Activation

Since the application of voice activation can increase the capacity of the transponder by a factor of 2.5 at relatively small cost, it is extremely attractive.

The channel units used in the existing system posses the characteristics required for voice activated operation (e.g. fast modem lock-up time) and even have provision for a voice activation unit to be plugged in at a cost of several hundred dollars.

Thus if the pre-assigned capacity of the existing system were say 100 duplex channels (i.e. 200 channel units), then at a hardware cost of about 200 X \$500 = \$100,000 the transponder capacity could be more than doubled. Voice activation in a pre-assigned system can be implemented gradually over a convenient period of time in order to minimize installation costs. The power limited transponder capacity of a partially voice activated pre-assigned system is

$$N' \simeq (1 + \frac{1.5X}{2.5-1.5X} N)$$

where

N = transponder capacity without voice activation

X = fraction of channels which are voice activated

and XN, the number of voice activated channels, is sufficiently large to justify using a central limit statistic.

For example, a half voice activated SCPC system has a capacity 1.43 times greater than that of a non-voice activated system. In general, voice activation can be made to increase transponder capacity in a graceful manner - for every 2 circuits which receive voice activation equipment the transponder capacity is increased by 3 voice activated (or 1 non voice activated) channels.

2. Increase of G/T

Figure 3 plots SCPC capacity with voice activation vs G/T. It is observed that the bandwidth limited capacity of the transponder is reached for a G/T less than 20 dB/°K; there is therefore little advantage in increasing the G/T of most existing terminals.

In the case of future extensions there may be cost advantages in starting service with a relatively low G/T and upgrading it as requirements dictate.

The main advantages of this approach are:

- investment is applied only to real needs, and never to predicted growth which fails to materialize.

- the cost of providing the increased G/T is deferred and possibly reduced through the development of earth station technology or increased EIRP from new satellites.

Based on information developed in Appendix E, Table 2 indicates the saving in capital cost due to a lowering of G/T from 20 dB/°K versus the number of circuits terminated. Each antenna-LNA-HPA combination has been optimized for the specific G/T and number of circuits considered. Compared to the total cost of the remote SCPC earth station, in the order of $100,000 (see Chapter 7), the reduction in cost due to a lowering of G/T below about 15 dB/°K is small, and therefore does not appear justified.

REDUCTION IN G/T	NO. OF N-N CCTS.	TYPICAL REDUCTION IN EARTH STATION CAPITAL COST (ANTENNA + LNA + PA)	TYPICAL % REDUCTION IN TRANSPONDER CAPACITY WITH VOICE ACTIVATION
20 → 18	1	$20,000	0%
	2	$18,200	
	4	$16,600	(i.e. bandwidth limited)
	1	$ 2,300	
18 → 15	2	$ 860	31%
	4	*	

* Cost actually increases due to 100 watt PA's required to provide increased EIRP per carrier

TABLE 2

If the G/T must subsequently be increased, however, the following factors must be considered:

- recovery of the cost of the original higher noise figure LNA may be difficult

- refurbishing remote terminals is costly and possibly disruptive.

Upgrading the G/T of the Allan Park earth station (and other possible Southern Terminals) might seem a cost-effective means of both increasing transponder capacity and reducing the required EIRP from the remote terminals for preassigned N - S operation. Developments in uncooled parametric amplifier technology since the installation of the Heavy Route stations makes a 2 or 3 dB improvement in G/T quite feasible at a cost of about $30,000 - $40,000 for a redundant LNA configuration. However, since links into Allan Park tend to be limited by up-link thermal noise and intermodulation noise produced in the satellite transponder, such improvements in G/T would not greatly alter transponder capacity, and would reduce the required EIRP from the remote terminals by only .5 - 1.0 dB. Such a course of action does not therefore appear to be cost effective.

3. Demand Assignment

The introduction of demand assignment provides dramatic improvements in the number of users (or terminals) which can be served although it does not alter the number of channels the transponder can simultaneously handle. While demand assignment is a well-proven technique, extensive study, development work and field testing would be required to arrive at the most suitable hardware/software configuration. The lead time and cost required to develop a centrally controlled fully variable demand assignment might be considerable. Discounting development, the capital cost of adding demand assignment equipment to a remote terminal is estimated at $3,500; the hardware and software cost of a redundantly configured central processing facility to handle calling and recording would be in the order of $500,000. Furthermore, unlike the case of voice activation, demand assignment normally offers little advantage until it is implemented over much of the network.

In a fully variable demand assigned (d.a.) mode the variation of G/T will not represent a problem provided a single carrier level determined by the minimum G/T is employed. Such an implementation results in excess margin on links into the higher G/T stations, and can make rather inefficient use of the space segment when there is a wide range of G/T's. Two alternatives to this are available:

- lower the carrier level and accept reduced performance into the lower G/T stations, or

- adopt d.a. controlled carrier power per channel (reference section 2.2.1, Appendix C)

At the expense of increased terminal complexity, the latter approach ideally matches the transmitted carrier power to the G/T of the receiving station, resulting in unequal carriers in the satellite transponder.

The introduction of demand assignment has the further disadvantage of increasing by 3 to 5 dB the required EIRP per carrier from the remote terminals to permit direct N-N calling. Most of the existing Thin Route stations possess sufficient EIRP to permit this, but at the expense of reduced ultimate circuit capacity. Considering for example that a non-redundant 50 watt TWT is about $2,000 more than a 20 watt TWT, the excess EIRP requirement associated with a demand assigned system has a significant cost impact. An additional cost consideration mitigating against the implementation of direct N-N calling is the proposed CCIR off-axis EIRP restriction discussed in section 3.3.5 . This could increase remote terminal antenna costs through the imposition of side lobe suppression requirements.

4. Alternate Modulation Techniques

As indicated in section 4.1, emphasized companded FM and lower rate delta modulation techniques exist which can give moderate improvements in the capacity of the satellite transponder, possibly at the expense of reduced circuit noise performance. Some of these systems have been proposed for use in Intelsat, Marisat and domestic systems (e.g. Algeria, Alaska, Indonesia, and Brazil). They all use a standard 45 kHz channel spacing (or 22.5 kHz for lower quality systems), thereby achieving a higher bandwidth limited transponder capacity than the Canadian Thin Route system which employs 60 kHz. In most proposed Δ-mod systems, 4Ø CPSK modulation is preferred over 2Ø CPSK because it halves the transmission bandwidth required, although the latter offers some advantages in terms of modem performance and cost.

As discussed previously the introduction of a new encoding/modulation scheme will result in incompatibility with the existing system or costly retro-fitting at all the present remote sites.

5. Multiple Satellite Transponders

It has thusfar been implicitly assumed that the entire SCPC system is contained in a single satellite transponder. With present space segment charges, results of this study indicate that a second transponder would be added only after voice activation and demand assignment had been implemented and an essentially bandwidth limited capacity reached. Since such a system could provide in the order of 1000-2000 two-way circuits (see Figure 14B, Appendix B) with an earth station G/T of less than 20 dB/^{o}K, the use of a second transponder in fact seems unlikely. However, for the sake of completeness, networks that use more than one transponder are considered.

Due to its finely partitioned use of satellite power/bandwidth and a common access/transmission technique, an SCPC system lends itself to graceful growth into additional transponder(s). The only basic restriction imposed by this development is the requirement for a wide band (i.e. 500 MHz) front end low noise amplifier, normally employed in any event for purposes of flexibility. The introduction of a second transponder into the system implies the need for additional up and/or down chains at stations wishing to communicate in both transponders. Baseband and common IF equipment and the AFC pilot and demand assignment signalling equipment could be shared.

In a pre-assigned network up- and down-chains could simply be added to stations successively as required. A most cost-effective approach might be to reconfigure the entire system in a way that most terminals accessed only one transponder, thereby minimizing the total number of additional chains ultimately required. In this case, an "old" chain could be configured as "new" chain (and conversely) with simple replacement of crystals in the up or downconverters.

To maintain total flexibility in a demand assigement system one would theoretically have to refurbish all stations the moment a new transponder were added to serve the network. In this regard, note that complete single hop interconnectivity can be obtained by replicating <u>either</u> the transmit or receive chain at each station; e.g., if all stations can transmit over both RF channels they need only receive on one or the other.

More graceful growth strategies could be applied in the demand assigned case with little sacrifice in operational flexibility. For example, it is possible to introduce second channel equipment successively at those stations among which there is heaviest traffic; this unburdens the first transponder thereby allowing it to satisfactorily serve the other terminals. With this arrangement, most of the accesses in the network do not initially even have to know that a second transponder is being used.

While not considered in detail here, it is theoretically possible to use single wide band up-chains with a higher frequency IF to simultaneously transmit into more than one transponder, thereby avoiding replication when transponders are added. This, however, would require significant new equipment development, and is not presently considered practicable.

6.3.3 Extension of Thin Route and Television Service at a Remote Terminal

The first and most logical extension would be an increase in the number of circuits terminated. With some SCPC earth station designs this can be accomplished simply and quickly by the addition of channel units. (Typically a shelf unit might accommodate up to eight channel units). Neither the installation nor the subsequent maintenance costs associated with such additions would be large, although the initial extra capital (especially due to HPA, see Table 3, Appendix F) required to make provision for increasing the capacity would have to be considered carefully vs the likelihood of this occurrence.

The second possible area for growth is a television receive capability. Assuming the earth station G/T is sufficient to receive TV and that sufficient space, power, and environmental capability exists, a non-agile TV receiver with one audio channel could be added for about $12,000 installed. Frequency agile receivers with two channels of audio and a cue and control channel which permits the remote command of frequency can be purchased and installed for about $40,000.

6.4 Hypothetical System Models

Based on examination of the performance/cost trade-offs identified in Chapters 4, 5, and 6, two basic earth station types having the following characteristics are proposed for more detailed costing in Chapter 7.

TYPE	G/T	ANTENNA	LNA	HPA SIZE/CONFIGURATION FOR N-N CALLING
1	18	15' focal	260°K transistor amplifier	1X20 watt for 1 cct 2X20 watt for 2 ccts (parallel redundancy) 2X35 watt for 4 ccts (parallel redundancy)
2	15	12' focal	360°K transistor amplifier	1X20 watt for 1 cct 2X35 watt for 2 ccts (parallel redundancy)

TABLE 3

As indicated in Table 4, each of these basic earth station types can provide several circuit qualities/transponder capacities. The Type 1 earth station can receive good quality TV over the present Anik system using either threshold extension FM demodualtion or reduced IF bandwidth to avoid threshold noise.

The Type 2 station will be able to receive similar quality TV over the higher EIRP dual-band Anik 4 satellite due for launch in 1978.

TABLE 4

ENCODING/MOD.	CHANNEL SPACING	NOISE PERFORMANCE (EQUIV. SUBJECTIVE)	G/T	TRANSPONDER CAPACITY (ONE-WAY CHANNELS)		REQUIRED EIRP PER CARRIER
				36 MHz USEABLE*	32 MHz USEABLE*	
40 kbps Δ-20 (baseline)	60 kHz	11,200 pWpO at threshold, 1100 pWpO fairweather	18.0	600	534	50.8 dBW
FM	45 kHz	10,000 pWpO at threshold		800	712	49.1 dBW
32 kbps Δ-40	22.5 kHz	14,100 pWpO at threshold, 1400 pWpO fairweather		840	840	49.9 dBW
32 kbps Δ-20	45 kHz			800	712	
40 kbps Δ-20 (baseline)	60 kHz	as above	15.0	425	425	54.3 dBW
FM	45 kHz	as above		760	712	52.6 dBW
32 kbps Δ-40 32 kbps Δ-20	22.5 kHz 45 kHz	as above		620	620	53.4 dBW
20 kbps Δ-20	30 kHz	22,400 pWpO at threshold, 5000 pWpO fairweather		820	820	51.4 dBW
FM	22.5 kHz	20,300 pWpO		760	760	51.7 dBW

Satellite Parameters:

EIRP = 35 dBW
Earth Station Saturating EIRP = 81.7 dBW
G/T = -5.4 dB/°K

Transmission Parameters:

Voice Activation Advantage = 2.5
FM Threshold Extension Advantage = 2.5 dB
Δ-mod threshold BER = 10^{-2}
Fade margin to threshold = 3.0 dB

* Reference footnote on page 39

7. EARTH STATION DESIGNS AND COSTS

7.1 Introduction

Earth stations to provide improved communication service to remote communities in Canada have to meet the following key objectives:

- they must provide a voice circuit quality adequate for connection into the national telephone network

- they must have extremely high reliability

- they must be low cost and economical to operate

- they must allow for additional services

It has been shown that earth terminals in the range 15 to 18 dB G/T provide excellent utilisation of the satellite transponder. This range of G/T's also permits the design of highly reliable earth station meeting the communications requirements of small communities in the North.

The major system parameters which control the cost of the earth stations are G/T, EIRP per carrier, number of carriers to be simultaneously transmitted, and service availability.

The design requirements of the earth station where trade-offs must be carefully affected to control costs include: the need to ensure reliable operation over an exceptional range of environmental conditions, the provision for growth of additional services, and the need to design for ease of maintenance by unskilled personnel.

Although trade-offs can be made on the choice of subsystems to meet an initial system requirement, the total cost of the station is also quite dependent on limits placed on growth provision. For instance, space and power requirements have a significant effect on system cost and should be considered carefully.

Implementation costs are very high for earth stations in remote locations. Earth station designs must respond to the need to keep such costs as shipping, installation and testing to a minimum.

This chapter addresses some of these points and presents costs of two earth station designs responsive to the hypothetical system models described in Chapter 6.

7.2 Subsystem Trade-offs

The system parameters amenable to trade-off which dominate the cost of an earth station designed to provide a given number of circuits include:

G/T - which permits trade-offs between antenna size (receive gain) and receiver noise temperature

EIRP - which permits trade-offs between antenna size (transmit gain) and power amplifier size

Availability - which controls the need for redundancy, higher reliability designs, type of device, etc.

7.2.1 Choice of Antenna Size

A given G/T can be achieved with a wide range of antennas and low noise amplifiers (LNA's). As the antenna size increases the cost of the receiver to provide the required G/T is reduced. Increasing the antenna size also lowers the cost of the power amplifier (PA) since increased antenna gain at the transmit frequency makes it possible to fit a lower power amplifier.

The non-tracking antenna is a highly reliable passive component. Increasing its size to the maximum extent practicable generally results in improved LNA and PA reliabilities, and therefore lowers operating cost. On the other hand, the larger the antenna the larger the cost of foundation, shipping and installation.

It has been shown that an earth station antenna of 15' diameter can be used when not more than four circuits are required.

7.2.2 PA Size vs Number of Carriers

It might be anticipated that a cost effective earth station for small community use would contain only one circuit. Such a requirement can be readily accommodated using a 12' or 15' antenna and a 20 W travelling wave tube power amplifier.

A second circuit capable of N-N connection can be commissioned by:

a. adding a second complete upconverter and high power amplifier plus RF hybrid combiner (4 dB combining loss precludes this option if 12' antenna is used).

b. increasing the antenna diameter.

c. multiplexing two channels on one RF carrier, i.e. up-grading 2Ø CPSK modem to 4Ø CPSK modem.

d. increasing the high power amplifier size.

If more than four circuits are to be fitted at a remote earth terminal a more capital cost effective solution might be to start service using a 26' antenna. This alternative is even more economically attractive when one considers the operating cost differential associated with terminals possessing 20W and 100 watt TWT's, typically as shown in the following table.

	ANNUAL OPERATING COST PER STATION	
	20 W TWT	100 W TWT
Tube replacement	$1,000 (MTBF=20,000 hr)	$6,000 (MTBF=10,000 hrs)
Power consumed	$ 219 (20% Effy)	$1,095 (20% Effy)
Spares holding charge (10% capital value)	$ 150 (One tube held) for every 4 stations)	$1,000 (One tube held) for every 2 stations)
	$1,369	$8,095

Such a large annual cost differential provides significant incentive to look at the utilisation of larger antennas to reduce operating costs (power and tube replacements) and maintenance costs (higher reliability).

7.3 Designing for Growth

Failure to design for reasonable growth can be costly when the need for system extension arises. Conversely, over-designing for growth can greatly increase the capital and operating cost of an earth station.

These costs arise through:

- incorrect sizing of key station components

- incorrect space and power requirements

It is therefore important to clearly identify system growth requirements if a cost effective design is to result.

7.4 Designing for Maintenance

The provision of a central processor to effect call assignment and billing permits the provision of improved supervisory and control equipment in future stations to automatically report status to the maintenance staff. Such automatic techniques will speed up reporting of faults, reduce mean time to repair and increase availability.

Future designs will also be significantly smaller allowing not only modular replacement of sub-units to be undertaken by local agents but even complete subsystems which can be flown in to the local agent. Such reduction in the need for skilled maintenance effort and associated costs is a difficult trade-off to quantify but clearly desirable.

7.5 Earth Station Costs

To meet the requirements of the system models envisaged two types of remote earth stations are considered as shown below:

TYPE	G/T	ANTENNA	LNA	HPA	NO. OF N-N CCTS
1	18	15'	260°K	20W Tube fitted	1 non-redundant 2 parallel redundant
2	15	12'	360°K	35W Tube fitted	1 non-redundant 2 parallel redundant

In order to provide an indication of cost sensitivity with quantity we have estimated costs for quantity 10 and 100. These costs have been derived from visits and discussions with manufacturers.

To get from the subsystem level to the prime contractor's selling price F.O.B. plant, we have used the 'rule of thumb' of multiplying the subsystem total by 1.5 in the case of quantity 10 and 1.3 in the case of quantity 100.

To a first order of accuracy any quantity between 10 and 100 may be estimated by simple proportion.

The results of Table 7, Appendix F can be summarised as follows:

	QUANTITY 10		QUANTITY 100	
	REDUNDANT*	NON REDUNDANT†	REDUNDANT*	NON REDUNDANT†
Type 1 Station G/T = 18 dB/°K	$161,130	$104,910	$109,031	$72,384
Type 2 Station G/T = 15 dB/°K	$159,075	$101,250	$107,680	$69,680

* Provides 2 circuits with parallel redundancy

† Provides 1 non-redundant circuit

This is at the integrated hardware level FOB plant including 12% Federal Sales tax.

The type 2 station would be somewhat lower in cost to install due to the smaller antenna size. A 12' antenna takes only a few hours to erect and needs a simpler, lower cost foundation.

It should be noted that these cost predictions are in 1976 dollars and assume relatively near term procurement (within next two to three years). Costs beyond that can be reasonably expected to drop at somewhat less than the characteristic rate of the last three years. Assuming a continuation of the current world rate of installation of small stations, typically 200-400 per year, a drop of between 5% and 10% per year can be expected as competition increases and development costs are written off. Further cost reductions might result from the implementation of system (s) that increase this rate by an order of magnitude.

The cost to add a non-agile TV receiver to a Type 1 station would be in the range $7,000 to $12,000 in the next few years, while a frequency agile receiver would cost $30,000 to $40,000. In the case of the Type 2 station an improved low noise amplifier would also be required at a cost of $3,000 to $5,000 although a reduced performance service could be provided without altering the low noise amplifier.

It is worthy of note that real cost benefits for remote community service can be realised if a multipurpose facility including thin route voice, television and radio program capability is planned and implemented concurrently.

The total cost of such a multipurpose earth terminal facility could then be:

	QTY 10	QTY 100
Cost of basic TR earth station	104,910	72,384
Cost of non-agile TV receiver	10,000	7,000
Cost of radio program receiver	5,000	3,500
Implementation Costs	25,000	25,000
	$144,910	$107,884

It is assumed that the radio program would be transmitted via the Thin Route transponder and a modified channel unit implemented.

7.6 Impact of Technology on Cost

Over the first three years of commercial domestic satellite communications there has been a significant favourable trend towards lower cost earth stations for single channel per carrier and for television applications.

Such a trend has accelerated under the rapid growth in U.S. domestic satellite systems: the Marisat system, the Indonesian system and several domestic systems based on the utilization of one half or all of an Intelsat transponder e.g. Algeria, Norway, Nigeria, Brazil, Saudi Arabia, etc. Most of the successful suppliers have been from the U.S.A. In the near term the extension of the U.S. systems and the promise of new domestic systems planned in the 4/6 GHz band indicate a continuation and expansion of the market with a consequent response from industry in terms of technological advancement.

In our review of technology we noticed many developments likely to lead to reduced cost in the areas of:

- low noise amplifiers

- up and downconverters

- single channel per carrier channel units (both FM and digital)

- TV receivers

In parallel with this, operating companies have expended much effort in finding ways to reduce cost. This is exemplified by successive design iterations by Telesat from relatively high cost stations using 26' diameter antennas, full redundancy and extensive growth provisions to low cost non redundant configurations using a 12' diameter antenna.

However, it is worthy of note that with the slow growth of satellite communication service in Canada we will be increasingly dependent on the technology derived by other nations - notably U.S.A.- and the cost benefits of technology will be determined by market forces beyond our reasonable control.

In terms of specific promising technology the area of low noise transistor amplifiers has brought the most spectacular rewards; what was 'state of the art' in parametric amplifiers five years ago at $20,000 should be achievable using a more reliable transistorized amplifier of less than $2,000.

Up and downconverters, have also dropped significantly in the same time frame.

Even the mature technology implicit in the small aperture antennas of 15' diameter selling at $25,000 four years ago can be purchased at half that price, although this drop is more a function of competition and consequent productivity improvements rather than advancement of the technology.

An examination of cost breakdowns of earth station subsystems designed for remote unattended application shows that up and downconversion equipment represents a high proportion of station cost. Development effort in this area should bring significant benefits. So also should the improved packaging for ease of maintenance fortunately now being given a lot of attention by most manufacturers.

Possibly the greatest areas of reward for the development dollar is one which usually <u>increases</u> subsystem cost - reliability improvement programs. However the impact in reducing capital cost (by eliminating the need for redundancy) and/or operational and maintenance costs can be dramatic for remote area applications.

7.7 Summary

Earth stations to provide communication service to remote communities in Canada have thusfar given remarkably reliable service. Their designs have evolved through a series of cost reducing cycles from the initial stations using 26 foot diameter antennas with fully redundant communication hardware and generously sized buildings to 12 foot non-redundant stations with equipment housing of modest proportions. The cost per channel per community has dropped proportionately.

In three years the cost to install a Thin Route earth terminal in a remote northern community has dropped from about $400,000 to less than $200,000. Within a similar time frame an installed cost of less than $100,000 for a station providing one demand assigned voice activated channel would appear a viable goal. Such a station would also make very efficient use of the satellite transponder allowing about 250 simultaneous voice activated duplex circuits.

New technology and the desire for lower cost per channel per community will bring designs of even lower cost to install and maintain.

8. MAINTENANCE PHILOSOPHY, OPERATING COSTS AND SERVICE AVAILABILITY

The introduction of satellite technology has for the first time made it possible to bring to the North a communication/s channel having an availability in the order of 99.99% and greater. Even with the high equipment reliability implicit in modern commercial hardware the precise service availability specified to meet telecommunication service requirements can have a significant impact on the cost of the facilities subsequently installed.

It is, therefore, of the utmost importance that the design of a satellite ground terminal carefully addresses the need to optimize reliability and reduce maintenance and operating costs.

Before attempting such a design a clear understanding is essential not only of hardware reliability, but also of the trade-offs possible in maintenance and operating. The following factors must be considered:

- Maintenance staff deployment

- Spares deployment and quantity

- Transportation costs and schedules

- Training of staff and local agents

In addition, the need to design to assist maintenance is of the utmost importance. In this regard modular construction and control and monitoring equipment which provides clear local indications of equipment status is necessary. In addition, as the system grows it becomes increasingly necessary to slave these indications to a central location to permit rapid assessment and optimum corrective action to be taken.

The Telesat operations and maintenance techniques have evolved over several years and have shown that two men in a strategically placed maintenance location (Frobisher) can successfully service and maintain more than twenty remote Eastern Arctic stations with the support of local agents and occasional help from Ottawa Headquarters staff.

Some typical figures for service availability achieved under these circumstances are summarised in the following table:

SERVICE AVAILABILITY

	1974 (12 months)	1975 (3 months)
Individual Thin Route Circuit	97.37%	98.42%
One of Two Thin Route Circuits at Given Location	98.10%	99.65%
Remote TV	99.86%	

The maintenance philosophy strategies adopted to meet the growing system will be affected by the following factors:

- Number of stations and rate of growth

- Geographical locations

-Station equipment complexity and content

- Anticipated equipment reliability

- Service availability contracted

8.1 Future Maintenance and Operating Costs

If it is assumed that a significant expansion of service were implemented necessitating the establishment of another regional maintenance centre the following costs to set up the centre might apply:

Establishment of technical facilities to house and service spares	$100,000
Spares to service new region	$ 60,000
Test equipment	$60,000
Total Capital Requirements	$220,000

This centre could be manned by one technician supported by local agents as required and one extra staff in Ottawa. The annual cost of this maintenance effort might then be:

Northern technician salary and benefits	$ 40,000
Housing	10,000
Travel and living expenses	20,000

Additional Ottawa Support	$ 20,000
Local agents (assume 25 locations)	25,000
Total Annual Maintenance	$115,000

A typical small multipurpose station can be run on less than 2 kVa average throughout the year. Assuming 25¢ per kilowatt hour the cost of running the station would then be:

$$0.25 \times 2 \times 24 \times 365 = \$4380$$

In summary, then, to maintain and operate an extended system of up to twenty five locations the following direct annual maintenance and operating costs per station might apply.

Annual Maintenance cost of one station $\frac{(115,000)}{25}$ =	$4,600
Annual cost of power	4,380
Annual cost of parts replacement, say	1,000
	$9,980

A total annual maintenance and operating cost of about $10,000 would apply in a situation where a new regional depot had to be established.