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

VOLUME III

PREPARED BY MILLER COMMUNICATIONS SYSTEMS LTD.

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

FINAL REPORT

APPENDIX C

SCPC NETWORK CONTROL AND DEMAND ASSIGNMENT TECHNIQUES

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1. INTRODUCTION

Implementation of a SCPC satellite system and its incorporation into the public switched network presents problems of compatibility, flexibility and efficiency.

Apart from the delay introduced by the satellite path and the resulting requirement to install echo suppressors in the voice circuit at or near the 2 wire - 4 wire interface, compatibility with the switched network is obtained through the installation of the appropriate signal interface circuitry. This circuitry translates the public switched network signals to a form suitable for the satellite system and vice versa. The problems of flexibility and efficiency of circuit utilization can be solved by implementation of a demand assignment system for satellite circuit allocation and overall satellite system control. Internally, a demand assigned SCPC satellite system is a complete, stand-alone, switched communication system and thus it is easily tailored to the requirements of its users. However, the implementation of demand assignment adds to the complexity of the remote stations and the control and supervisory system. This added complexity and cost may be more than offset by the increased flexibility and reduction in the physical resources necessary to provide interconnection between the users.

2. DEMAND ASSIGNMENT

The term "demand assignment" (DA) is taken to mean that control is exercised such that satellite resources are allocated to each call on demand. Demand assignment is achieved by pooling the traffic on a number of links and sharing the satellite resources between the links to meet this traffic.

Consider a power limited DA SCPC system operating over a satellite such as Anik. The communications topology in this case is analogous to that of a large number of small switching offices each connected by a few trunks to a large switch which provides interconnectivity between the small switches. The switching function is performed at each earth terminal by channel selection. In this manner each terrestrial access circuit at one earth terminal can be routed to any other terrestrial access circuit in the system on a per call basis. In such a system the number of channel units may greatly exceed the number of allowable simultaneous connections. Thus the demand assignment algorithm not only selects the channel frequencies but also incorporates a blocking mechanism to prevent the degradation of calls in progress by the completion of additional calls.

2.1 Advantages of Demand Assignment

The advantages of demand assignment are listed below:

i Full interconnectivity of the earth terminals in the system can be provided with a minimum of satellite and earth station resources.

ii The operational efficiency of the satellite RF channels is maximized.

As a result, the cost of providing service to the user can be reduced.

In a comparison of demand assigned and preassigned service for a large number of low-density traffic terminals, Dill (1) has shown that demand assigned service requires one-half to one-sixth the terrestrial resources and one-fifth to one-fifteenth the satellite resources as the corresponding preassigned service.

2.2 Demand Assignment Techniques

Demand assignment of communications channels to meet the requirements of a number of low traffic density earth terminals of varying G/T may be implemented in several ways. The more important techniques are identified below.

2.2.1 Fully Variable Assignment with Dynamic Power Control

In this system, all the traffic in the network is pooled and all the satellite resources are pooled and assigned on a per call basis. Both the channel frequency and the transmit power are controlled. The transmit power may vary from call to call depending on the voice quality desired and the G/T of the receiving earth station. In a power limited system, this assignment technique permits the efficient use of the available satellite power when calls of various qualities are desired or earth terminals of unequal figures of merit are present. In such a network the number of simultaneous calls which may be supported by a given satellite power is a dynamic quantity, varying with the types of call and the earth terminals involved. (Reference section 3.2, Appendix B).

Blocking occurs in this system when the addition of a call would degrade the calls in progress below the acceptable level. Thus the probability of a call being blocked is a function of the power required to complete the call - the higher the power required the greater the probability of being blocked.

2.2.2 Fully Variable System - No Power Control

This system differs from that of 2.2.1 in that the transmit power per carrier allocated to each earth station is a fixed quantity. This restriction removes control over voice quality from the demand assignment system. The resultant possible inefficiency in satellite power utilization is traded for simplification of the demand assignment algorithm. The number of simultaneous calls in this configuration is a fixed quantity. A call is blocked when the available satellite power has been allocated to calls in progress.

In the case of equal G/T remote terminals and southern station(s) possessing higher G/T, this type of system could provide toll quality performance to the south and a single lower voice quality within the north.

2.2.3 Variable Source / Destination

In a variable source system a portion of the satellite resources is permanently allocated to calls entering a particular earth station and is assigned to specific calls as required. Similarly in a variable destination system a portion of the satellite resource is assigned to calls originating from a particular earth station.

These systems reduce the pool of assignable satellite resources but ensure that certain earth stations are not denied access to the system during periods of high traffic. For example in 2.2.1 and 2.2.2 it is possible that during peak traffic periods some earth stations will be "locked out" of the system due to the fact that all satellite resources are in service when a call request is made. This situation may be unacceptable and 2.2.3 provides one alternative.

This system can be operated on a variable power per call basis or on a fixed power per call basis. Blocking occurs earlier in this system than the others due to the fact that some of the resources are dedicated and not in a common pool.

2.3 Comparison of the Demand Assignment Methods

The fully variable assignment scheme with per call power control offers the greatest system flexibility by making the most efficient use of satellite resources. However this flexibility is obtained at the expense of the most complex control algorithm. When a carrier is added to a system where many carriers at various power levels are being passed through a transponder several parameters must be chosen and/or evaluated to ensure that the desired voice quality is met and that existing calls are not degraded. These parameters include carrier power level, carrier frequency and intermodulation signal power. As the number of carriers grows the calculation and choice of these parameters becomes increasingly complex.

The fully variable assignment system with pre-assigned power to each carrier retains much of the flexibility of the above scheme and is much simpler to implement. Satellite resources are again allocated on a per call basis with the exception of carrier power.

Finally in the variable source/destination system where some portion of the satellite power is pre-assigned to certain earth stations, the system flexibility is further reduced but without a corresponding simplification of operation.

The subject of blocking probabilities for these systems is discussed and some formulae derived in a paper by Frenkell (2).

In choosing a demand assignment system, it is seen that computing power and simplicity of the algorithm can be traded for efficiency in the power utilization. The choice of which scheme to use can only be made on an overall system basis (reference section 3.3, Appendix B).

2.4 Control Systems

A demand assignment system necessitates the implementation of a control mechanism with the attendant data flows for control and monitoring purposes. Two distinct configurations exist for implementing the control function - central control and distributed control.

2.4.1 Central Control

With central control, the allocation of satellite resources to meet user demand is controlled from a "Master" control centre. At the "Master", call requests are accepted, channel grants and acknowledgements are made and a busy/idle map of the system resources constructed and updated. Call billing for the system is performed at the Master.

2.4.2 Distributed Control

In a distributed control system some (or all) of the earth terminals of the system participate in control of the communications resources.

A distributed control stragegy has considerable appeal for international demand assignment systems such as SPADE (3, 4) where political considerations are important, but for an integrated domestic system the increased complexity of housekeeping functions and data flow management over a central control system is unwarranted.

3. EXISTING OR PLANNED DEMAND ASSIGNMENT SYSTEMS

In this section brief descriptions of some demand assignment systems currently in service or proposed for service are given. The systems described were developed by:

- Intelsat (SPADE)
- General Electric
- Scientific Atlanta
- Communications Research Centre

3.1 Intelsat's SPADE

The SPADE (4) demand assignment system is a fully variable system without carrier transmit power control. The system was designed to serve a number of international low density traffic links using a single 36 MHz bandwidth transponder. 64 kbps PCM-4Ø CPSK modulation is used and each voice channel is assigned a single RF carrier. Control of the system is distributed, with each earth terminal selecting the required facilities to complete a call from the common pool of available SCPC channels. The control function is provided at each SPADE terminal by the Demand Assignment Signalling and Switching (DASS) Unit. The terminals are linked by a common signalling channel routed through the satellite. This channel operates at 128,000 bits/sec. and is accessed in a TDMA mode such that during every 50 msecs frame each terminal transmits one burst of data. In this manner terminals are constantly updated on the system status. Note that the signalling channel supports a total of 49 terminals. The DASS units perform the following functions:

- Monitor, process and control the signalling between SPADE terminals

- Monitor, process and control the terrestrial signalling between the SPADE terminals and their associated telephone exchanges

- Control and monitor the terminal operations and subsystems

- Generate maintenance alarms when required.

The SPADE terminal incorporates a Terrestrial Interface Unit tailored to the public switched network facilities. This unit effectively interfaces the internal SPADE signalling and control system to whichever terrestrial system exists at the terminal.

3.2 General Electric

The General Electric system briefly described by Aldrich (5) is a fully variable system without transmit power level control, utilizing centralized control. This system has been under development for a number of years for use in the G.E. private communication system. To date the system has been implemented on a satellite link between Daytona Beach, Florida and Valley Forge, Pennsylvania.

The central control system forms part of the System Routing Centre (SRC) which provides all telephone signalling and supervision functions in addition to performing the channel assignment function. Signalling and supervision functions for all telephone trunk interface circuits (i.e., all telephone terminations) are provided via a common 40 kbps data channel operated in a TDM polling mode from the SRC with responses in a TDMA mode on the return channel. In this manner each trunk interface circuit is monitored once in each 600 msec. interval. The SRC utilizes its capability to address an individual channel unit to perform routine fault recognition and testing of the network via loop-back tests on idle units.

The system is configured to complete all calls without operator intervention including the call billing function.

3.3 Scientific Atlanta

The Scientific Atlanta system is a fully variable system without transmit carrier power control. The system utilizes central control, and communication for signalling and supervision between the terminals and the control centre is via a common signalling channel operated at 2400 bps. The control centre polls each terminal once every 0.8 secs. In the forward path from the control centre to the remote terminals the signalling channel has a frame format of 20 time slots each of 40 msecs. duration. One time slot carries synchronization information and 19 carry data. Each of the 19 data slots is dedicated to a remote station. In the return direction, up to 10 remote stations use one channel in a synchronized TDMA mode.

It is claimed that the use of pre-assigned time slots for each station allows a substantial reduction in the amount of overhead information to be transmitted and also simplifies the assembly and formating of messages. The use of a polled rather than an interrupt mode of data operation is said to result in higher operating efficiency in the central control system.

The system is designed to operate through a manual interface (operator's position) at the interfacing telephone office.

3.4 Communications Research Centre

The system developed at CRC is described in a paper by Campbell and Lambert (6) and is scheduled for field testing on the CTS satellite. The system utilizes central control and is a fully variable demand assignment system without transmit power level control. The system requires three simplex channels for system administration - two are used in a demand access mode from remote terminals to the central station, and one is used in the forward direction from the central station towards the remote terminals. These channels provide the facility for making requests, assigning channels and terminating calls. A later development (7) provides for dynamic reassignment of the control channels to minimize their vulnerability to RF interference due to intentional or fault induced double illumination. Note that although the remote terminals are addressable from the central location, the system does not operate on a polling basis. Each terminal transmits its requests in a random access mode, thus there is a non-zero probability of contention in the use of the request channels. Contention is easily recognized in a system where each terminal can monitor its own transmission as transponded by the satellite but when this is not possible another strategy for retransmission of a request must be implemented. Call set-up and call termination procedures are fully described in (6). Of the systems reviewed, this one has the advantages of flexibility in use of the signalling channels and simplicity of the remote terminal controller. Both of these arise from the fact that the signalling channels are random access.

4. INTERCONNECTION WITH THE SWITCHED NETWORK

It is a requirement that the demand assignment system be integrated into the public switched network and provide fully automatic dialling and billing for all calls. For calls internal to the system the provision of these services is simple in that the numbering system can be made as flexible as required and all call supervision information is readily available. Calls to and from the public switched network require that the system numbering plan be compatible with the public switched network and that call supervision information is passed from one system to the other to enable call billing to be achieved. To explore these topics and prepare methods for implementing solutions several assumptions must be made and a system configuration postulated.

4.1 Demand Assigned System Model

The satellite system is assumed to have the following characteristics:

- several nodes (call them Regional Ports) giving the system access to the public switched network at strategically chosen locations

- a large number of small earth terminals serving local, isolated communities.

- a demand assignment system based on the CRC system i.e. a system which has central control, is fully variable without transmit power control and uses random access signalling channels.

It is assumed that the system is operated by a telephone company (Telco) and that the central control system can be regarded as a toll centre for internal calls and calls to the public network.

4.2 Numbering Plan for the Satellite System Subscribers

A numbering plan is required for subscribers on the satellite system which will permit the provision of the following telephony services:

- Unique identification of each station set

- Access to/from the switched telephone network without operator assistance and without two stage dialling procedures.

- Access to and egress from the system via Regional Ports (strategically located earth stations) engineered to interface directly with the switched network. Incoming and outgoing calls will be so routed through Regional

Ports (R.P.'s) as to minimize telephone company charges.

Two numbering plans will be described in this section. The relative merits of each system will be identified and recommendations, as to the preferred system, made.

4.2.1 Unique Area Code Assigned to the System

The assignment of an NPA* code to the system allows each station to be identified by a unique 10-digit number in an identical fashion to stations in the DDD network. However, whereas an NPA in the DDD network consists of a single geographic area, this NPA can be thought of as consisting of several disjoint geographic areas (i.e.: the Regional Ports) with all the advantages and disadvantages associated with the provision of call routing, operator assistance and other standard services.

4.2.1.1 Station Numbering

To a caller on the switched network the 10-digit number of a subscriber on the satellite system is identical in form to any other number on the DDD network. Thus, from a user's point of view, calls to a number on the system are identical in procedure to any other toll calls and the called

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* NPA CODE - The three digit area code which identifies the numbering plan area.

number remains unchanged regardless of the geographical location in the DDD network of the calling party.

4.2.1.2 Incoming Calls

Incoming calls from the DDD network require 10 digit dialling for completion. Once the above NPA has been assigned to the system paths are set up throughout the DDD network such that on translation of the NPA code a route can be selected towards the destination (the NPA in this case). The problem here is that this NPA is a multi-destination code in itself due to the geographically distributed nature of the access points. Thus internally to Canada routes must be set up and boundaries defined such that the first choice route from any originating office within a boundary results in the call being offered to the 'local' R.P. Provided the protocol of alternate routing (i.e.: a call must proceed towards the destination and cannot proceed up the switching hierarchy after crossing from one final route to another) is not violated it is possible that on en-countering an all trunks busy condition on the first choice route that a second route homing on an adjacent R.P. may be used. This may well be the case for a call originating close to a boundary. In all events, the first choice route must provide the most economic path.

Calls from elsewhere in the DDD network may be handled in a similar manner and it seems obvious that for many such calls more than one final path and destination can exist.

Each R.P. will home on a class 4 or higher order office and will be directly connected to it by dedicated trunk facilities. Seven digits will be forwarded to the RP from the switched network.

4.2.1.3 Outcoming Calls

Calls to the DDD network from a subscriber on the system will enter the switched network via the appropriate R.P. All calls require 10 digit dialling (7 digits may be sufficient for calls to offices which home on the same office as the R.P.) and these digits must be forwarded from the R.P. to the telephone network.

4.2.1.4 Calls Internal to the System

Calls from one subscriber to another on the system can be completed via 7 digit dialling.

4.2.1.5 Information

Information services are provided by the Telcos for all subscribers. Thus incoming calls to the satellite system can be served by the Telco's information operators by dialling 1+NPA+555+1212.

Outgoing calls to the DDD network can be handled in the normal way with the exception that the DAMA must recognize the call as a non (or fixed) tariff call. 1+411 should be used for internal information service.

4.2.1.6 Operator Assistance

Dial '0' service may be required for outgoing and internal person-to-person calls. This service will also be required for trouble reporting.

4.2.1.7 Technical Impact on the Switched Network

1. All toll offices in the DDD network must be modified to translate this new NPA code and set up the appropriate routes through the network. Unless a very large amount of traffic is to be handled via any one RP it is unlikely that any new transmission facilities other than those connecting the RP to its 'home' office will be required.

2. The RP will home on a class 4 office and will be connected to it via trunk facilities. At the RP the interface with the telephone company equipment will be 6 wire - 4 wire voice frequency and 2 wire E & M* lead

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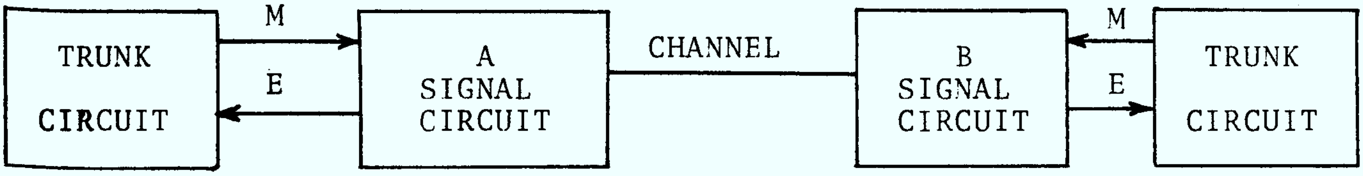
* E and M lead control is a DC signalling system where the potential on the E lead reflects the status of the far end of the circuit and the potential on the M lead reflects the near end status as shown in Figure 1.



SIGNAL	SIGNAL	STATE AT A		STATE AT B	
A → B	B → A	M	E	M	E
On-Hook	On-Hook	Grd	Open	Grd	Open
Off-Hook	On-Hook	Bat	Open	Grd	Grd
On-Hook	Off-Hook	Grd	Grd	Bat	Open
Off-Hook	Off-Hook	Bat	Grd	Bat	Grd

FIGURE 1

E AND M LEAD CONTROL

control. Dialled digit receiving and transmitting equipment (i.e.: registers and senders) compatible with the telco equipment must be provided. Digits may be forwarded across the interface as E & M signals or as MF signals depending on the telco equipment used.

3. Although 4 wire voice frequency interface is provided, the telephone system must inevitably convert at some point from 4 wire facilities to 2 wire facilities. Due to the long propagation delays on satellite circuits echo suppressors must be installed in the 4 wire circuit close to the 2 wire - 4 wire interface to remove the unwanted and unpleasant reflections caused by the 2 wire - 4 wire transition. Echo suppressors are normally required on trunk connections where the round trip delay exceeds 45 msecs.

4. All telephone company Data Centres (the computer centers where the customer bills are prepared from call record details) must be updated to bill for calls for the

new NPA. This requires a software modification to the call billing programs.

NOTE: Items 2 and 3 are common to all numbering schemes and will not be repeated in subsequent sections.

4.2.2 Dedicated Office Code

If a dedicated NPA code cannot be allocated to the satellite system, then a dedicated NNX* code may be used such that each subscriber can be identified by a seven digit number. This number can be reached via the local NPA's of the R.P.'s, i.e.: each subscriber no longer has a single unit 10 digit identifier; on the contrary, from a telephone network point of view each subscriber has as many 10 digit numbers as there are R.P.'s. From a call routing point of view, this system has less impact on the switched network in that only switching machines within the 'local' NPA's need be modified for the office code translation and call routing.

Implementation of the above scheme necessitates a

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* NNX CODE - A seven digit local number consists of a three digit office code (NNX) and a four digit station number. (XXXX) where N = any digit from 2 to 9
X = any digit from 0 to 9

greater knowledge of the system configuration on the part of the user on the DDD network.

4.2.2.1 Incoming Calls

Routing of incoming calls from the DDD network to the 'nearest' R.P. is no longer totally dependent on the switched network. On incoming calls from outside a 'local' NPA, the calling party must have prior knowledge of the NPA code associated with the R.P. through which he wishes the call to terminate. Thus routing is now a function of the subscribers knowledge. If all trunks to the chosen R.P. are busy, the subscriber may dial a new path through some other R.P. if he so desires and wishes to pay the increased toll charges.

Subscribers within the 'local' NPA of an R.P. may call a subscriber using only 7 digits. This can be of considerable importance if a large community of interest exists around an R.P. - e.g.: an R.P. located near Ottawa. The switched network will forward seven digits to the R.P.

4.2.2.2 Outgoing Calls

Outgoing calls require 10 digit dialling to permit proper routing through the appropriate R.P. On calls 'local' to the R.P. area, only 7 digits need be forwarded to the switched network.

4.2.2.3 Calls Internal to the System

Calls internal to the system require 7 digit dialling as in 4.2.1.

4.2.2.4 Information Service

To access a relevant information operator a user on the switched network must know at least one applicable NPA code. This information service would be provided by Telco operators in the 'local' NPA information centres.

Outgoing information calls (i.e.: 1+NPA+555-1212) can be handled as in 4.2.1

4.2.2.5 Technical Impact on the Switched Network

1. All toll centres within each NPA associated with an RP must be modified to translate this NNX code and route calls towards the destination. This procedure is identical to that followed whenever a new NNX code is created within an NPA. Again, new facilities are required to connect the RP to its 'home' office.

2. All data centres in the telephone network must be updated to properly bill calls to the RP's. This is no more complicated than the procedure followed whenever a new office code is introduced to an NPA.

4.2.3 Conclusions Regarding Numbering Plan

Two numbering systems have been presented. For outgoing or internal calls both systems can operate in a virtually identical manner.

For incoming calls it is clear that from a user's viewpoint, the unique 10 digit station number (i.e.: dedicated NPA code) system is the most convenient to use. Convenience to the user on the DDD network is the most important reason in favour of choosing this system. When a dedicated NPA code is assigned to the system, the system can grow, both in subscribers and Regional Ports, independently of and with minimal additional impact on, the switched network.

4.3 Automatic Billing Procedures

The system is to be integrated into the public switched network such that call billing is an automatic function, transparent to the system user. For calls internal to the system, call billing is a simple task as all call supervision information is available to the central control. The central control must, however, record the call billing details in a format consistent with the Telco data centre processing system.

4.3.1 Outgoing Calls

Billing for outgoing calls can be achieved in either of two ways:

i call billing data may be recorded by the central control

ii call billing information may be forwarded to the switched network to be handled by a toll office.

4.3.1.1 Billing Via the Central Control

If billing for space segment use is to be performed in the central control on outgoing calls to the switched network, then the central control must be equipped for Local Automatic Message Accounting (LAMA) operation. This operation requires that the central control store all call billing details on paper tape or magnetic tape in a format consistent with the Telco data centre processing system. With this operation, the switched network returns ANSWER supervision to the satellite system, indicating the start of the call billing period.

4.3.1.2 Billing Via Telco Facilities

The central control must forward both the called and calling number to the RP. The RP forwards these numbers on demand to the toll office equipped for CAMA (Centralized Automatic Message Accounting).

From a telephone company point of view, the RP is a class 5 office equipped with ANI (Automatic Number Identification). In this case, ANSWER supervision is not returned to the RP when the called party answers. Bill preparation is performed at the Telco data centre using the CAMA record tapes.

If the two systems proposed for automatic billing of outgoing calls, billing by the central control is to be preferred for the following reasons:

i The R.P. is much simpler in that it need only handle the dialled digits and does not need to be equipped for ANI

ii Less data is required to be carried by the supervisory system iii The additional requirements on the central control are simply extensions of the capability already required for internal billing purposes

iv The entire satellite system is self contained and appears to the switched network as a new toll area.

4.3.2 Incoming Calls

On incoming calls billing can only be accomplished via the 'home' toll office of the originating subscriber. This is necessitated by the fact that the calling number does not progress through the network part of this 'home' office. Thus the calling number cannot be made available to the RP without operator intervention.

NOTES:

'Billing' in the context used here is limited in meaning to call detail recording. The preparation of actual bills from this data is performed at large, centralized, computer facilities. The magnetic or paper tape containing the data are forwarded periodically to the appropriate data centre.

If a telephone switch exists behind an earth terminal then to permit automatic billing it must be equipped with some form of ANI such that the DAMA controller has access to the originating subscriber's number for all calls using the satellite facilities. For small switches this function could possibly be provided using the DAMA controller.

5. COMPATIBILITY WITH THE EXISTING SYSTEM

The existing preassigned, SCPC system serving the Eastern Arctic is operated by Bell Canada. All calls in the system are routed through Allan Park and bakchauled to Ottawa via terrestrial microwave facilities. There, calls are completed under operator control. In mid 1976 a second preassigned SCPC system sharing the same transponder is due to enter service serving Northern Ontario. In this case all calls are routed through Allan Park and backhauled to an operator position in Thunder Bay. Again call completion is operator controlled. The two systems are designed to be compatible at 40 kbps but there are operational differences between the systems. The Northern Ontario system is designed to operate with the carrier off when a channel is idle whereas the existing system operates with a 2600 Hz tone modulating the carrier during idle conditions. In both systems, the channel units are designed for operation in a demand assigned system in that provision has been made for the channel frequency to be assignable under remote control.

Due to the manual procedure for call set-up it is unlikely that these two systems can be readily interconnected.

In the following sections the term 'existing system' will embrace both of the above systems.

5.1 Introduction of the Demand Assigned System

The existing system operates as two distinct entities both involving substantial terrestrial backhaul facilities to derive switching and billing capability. A demand assignment system may be interfaced with the existing system in one of two ways.

i The demand assigned system may be introduced as a complete system which will co-exist with the pre-assigned system.

ii The existing system can be updated and integrated into the demand assigned system.

5.1.1 The Demand Assigned System as an Add-On

The demand assigned network may be introduced as a discrete add-on to the existing system with a minimum of interaction required between the systems. In such a system, a new voice encoding and modulation can be chosen if it is found desirable.

The existing system may be integrated into the demand assigned system either as its equipment becomes obsolete or as the traffic increases and more resources are required in the assignable pool.

A call from a terminal on the demand assigned system to a terminal on the preassigned system requires no more than that the demand assigned system inject the call into the switched network where it is routed to the appropriate operator position for completion.

Similarly a call going in the opposite direction is routed through the appropriate RP to the demand assignment controller. Such a call appears as an origination from the public switched network. These calls are of necessity double-hop.

5.1.2 Integration of the Existing System with Demand Assignment System

The existing system may be converted to demand assigned operation for simultaneous introduction with the new system. Note that this does not constrain either system to a particular voice encoding or modulation scheme providing DA control recognizes and avoids setting up calls between incompatible equipments (double hopping may be used to complete calls between terminals not possessing compatible equipment). The constraint that demand assignment imposes is that every terminal in the system interfaces with the switched network in the same manner and that signalling and supervisory data is carried on a separate dedicated channel or channels i.e. the signalling function is independent of any voice channel.

5.2 Conclusions

From the brief description given here it is clear that the introduction of demand assigned system need have little or no impact on the existing pre-assigned system.

6. SIGNALLING AND SUPERVISION

Signalling and supervision refer to the operations required to recognize a request for service, assemble the call routing information, apply the necessary call set up signals and recognize call termination.

Signalling and supervision within the satellite system are functions of the demand assignment system design. Call set up information is gathered at the remote terminal initiating the call and forwarded to the central control for processing and translation. All line and trunk supervision is performed at the remotes.

The interface between the satellite system and the public switched network is the trunk circuit. A typical configuration using E&M lead supervision is shown in Figure 2. The E lead reflects the status of the far end (i.e. OFF-HOOK or ON-HOOK) while the M lead indicates the near end status. This supervision system is versatile and is in common use throughout the telephone system. Although dialled information may be transmitted via the E&M leads at 10 pulses per second most modern telephone offices use multifrequency (M.F.) pulsing for trunk dialling, giving a tenfold increase in dialling speed. The signalling necessary to establish a path to/from the public switched network is best illustrated by following the sequence of control signals across the interface for both outgoing and incoming calls.

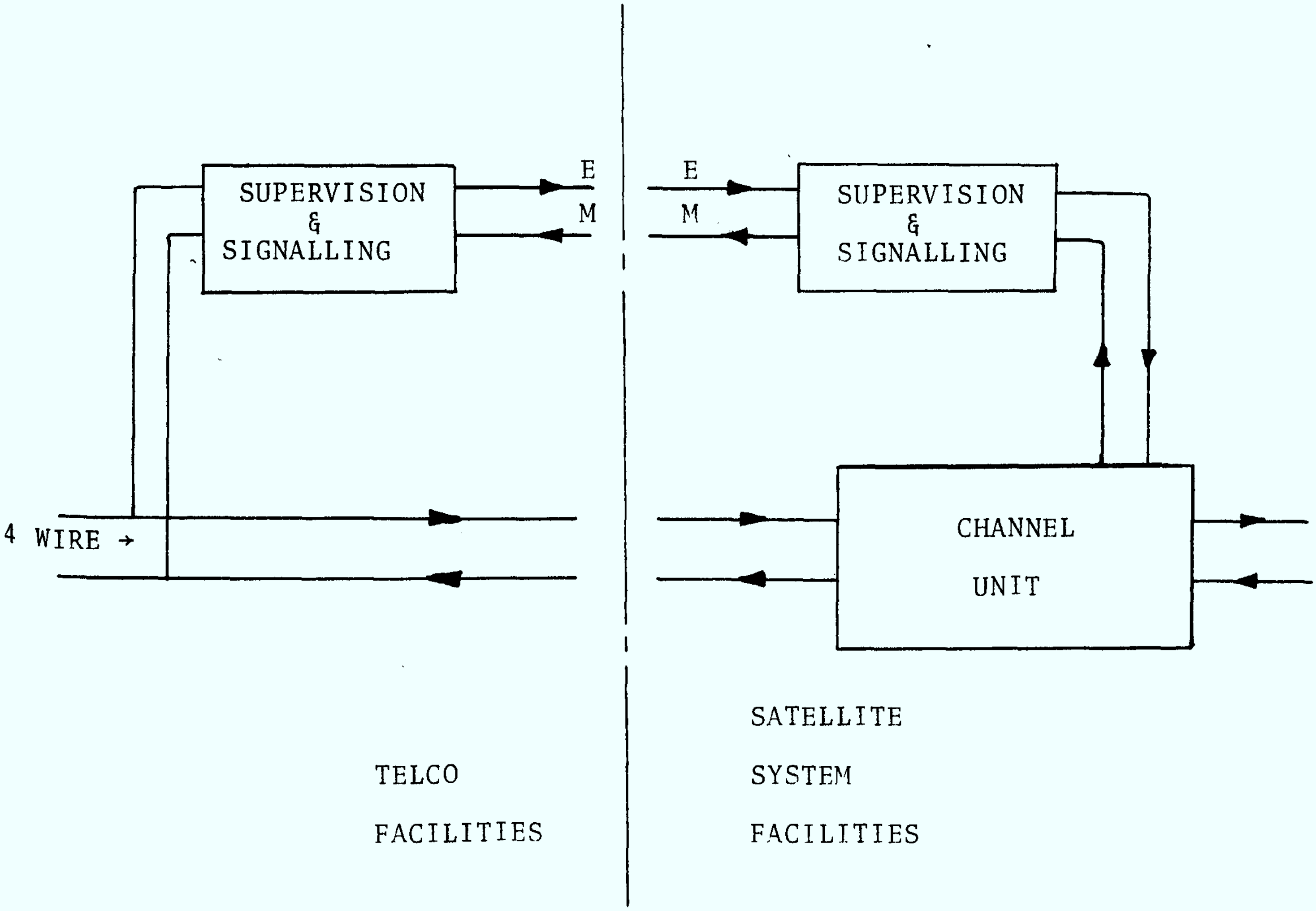

FIGURE 2

SATELLITE SYSTEM - TELCO INTERFACE (6 WIRE)

6.1 Outgoing Calls

The sequence of events on outgoing calls through an RP is as follows:

- The RP sends an OFF-HOOK signal towards the home office via the M lead associated with the chosen trunk. (The trunk must be idle for a minimum of 750 milliseconds before it can be seized. This ensures that the disconnection of any previous call in which the trunk was used, is complete).

- The home office returns a Delay Dialling (OFF-HOOK) signal which is received on the E lead.

- When a digit receiver has been connected to the trunk at the home office, ON-HOOK is transmitted towards the RP. To ensure sufficient time for sending forward the connect signal and the return of the delay dialling signal, the RP should not test for the ON-HOOK, start dialling, signal until 300 msecs have elapsed.

- With MF signalling the RP sends a KP signal followed by the dialled digits and terminated by an ST signal. The KP or Key Pulse signal prepares the digit receiver for the digit stream and the ST or START signal indicates that all necessary digits have been sent.

The procedure from this point is different for CAMA and LAMA operation. First consider LAMA operation.

- When the called party answers, an OFF-HOOK signal (ANSWER) is returned to the RP from the switched network via the E lead. This is the 'start of call' signal for billing purposes and is distinguished from the delay dial signal by the requirement that it must be continuous for a minimum interval of from 2 to 5 seconds.

- When the called party hangs up the OFF-HOOK state is changed to ON-HOOK on the E lead signifying the end of the call.

- The RP changes its M lead signal to ON-HOOK thus releasing the trunk for future service.

CAMA operation requires the following sequency of events:

- After the called number has been forwarded to the home office an OFF-HOOK signal is sent to the RP signifying that the CAMA receiver is ready to receive the calling number. This OFF-HOOK signal is presented to the RP on the E lead of the trunk circuit and is continuous for the duration of the call.

- The RP sends a KP signal, an identification digit, the calling number and finally an ST signal. The identification digit is used to indicate that the identification is automatic or that identification has failed.

- When the called party hangs up, the OFF-HOOK signal sent from the switched network is changed to ON-HOOK signifying the termination of the call.

- The RP changes its M lead signal from OFF-HOOK to ON-HOOK, thus releasing the trunk for future calls.

NOTE:

In the "Bell" system ANSWER supervision is not returned to the originating office when CAMA operation is used.

6.2 Incoming Calls

The sequence of events for an incoming call to an RP from the switched network are as follows:

- The 'home' office sends an OFF-HOOK signal to the RP. This is received on the E lead of the selected trunk.

- The RP returns an OFF-HOOK on its M lead for the time interval required by the equipment to attach a digit receiver. This time interval is clearly a function of the earth station equipment configuration and this signal may be superfluous. The M lead is returned to the ON-HOOK condition.

- The home office forwards a KP signal, sufficient digits for routing purposes within the UHF system and an ST signal indicating that all digits have been sent.

- The RP forwards all digits to the central control. If no channel is available the RP must send an 'all trunks busy' tone towards the switched network.

- When the called party answers, the RP forwards an OFF-HOOK signal to the home office on its M lead. This signal is continuous for the duration of the call.

- When the called party hangs up, the RP forwards an ON-HOOK signal to the home office on its M lead.

The switched network returns an ON-HOOK signal to the RP, thus releasing the trunk for further use.

6.3 Required Equipment

A partial list of the equipment required at the interface is given below.

1. MF tone receivers and tone generators.

2. Logic control unit capable of implementing the necessary logical sequency of events for signalling and control purposes.

3. Tone generating equipment for the tones given in section 6.2.

4. Digit storing and forwarding equipment for ANI purposes.

6.4 Remote to Remote Calling

Supervision and signalling within the demand assigned SCPC satellite system is maintained via communications channels which are independent of the actual voice circuits. This gives the system flexibility in provision of special features such as priority interrupt and also enables the demand assignment controller at the remote to be made as simple as possible.

The following is a possible calling procedure.

The remote station receives a request for service and collects and stores all dialled information necessary to set up the call. The sequency of events is-

- Recognize OFF-HOOK

- Return DIAL TONE and connect a digit receiver

- Receive and store the dialled digits.

When all digits have been received the demand assignment controller sends a request to the central control via a random access signalling channel. The message contains the remote identifier and the dialled information. At the central control the dialled information is translated and a channel frequency selected. This channel assignment is sent to both the calling and called earth stations via a dedicated signalling channel. In addition sufficient routing data to complete the call is sent to the destination when either several users or a telephone switch are terminated in the earth station.

Call supervisory signals such as BUSY or AUDIBLE RINGING are returned to the calling station over the assigned voice channel. In order to provide start of billing information the OFF-HOOK signal from the called party must be returned to the central control. When the call is terminated an ON-HOOK signal is sent to the central control from both remotes. This signal terminates billing and frees the circuit for reassignment.

Contention in the use of the random access channels nullifies any message. If the earth station can monitor the retransmission of its signal from the satellite, then it can recognize any such conflicts and try again. If it cannot monitor its own transmission then an acknowledgement must be sent from the central control within a specified time interval whenever a valid message is received.

When a telephone switch lies behind the satellite earth station, supervision and signalling between the demand assignment system and the telephone system is as described in 6.1 and 6.2.

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

FINAL REPORT

APPENDIX D

MAINTENANCE PHILOSOPHY, OPERATING COSTS AND SERVICE AVAILABILITY

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

April, 1976

APPENDIX D

MAINTENANCE PHILOSOPHY, OPERATING COSTS AND SERVICE AVAILABILITY

APPENDIX D

MAINTENANCE PHILOSOPHY, OPERATING COSTS AND SERVICE AVAILABILITY

1. INTRODUCTION

In order to arrive at a cost-effective means of achieving a required service availability, two basic factors must be considered, namely:

1. Cost vs reliability of earth station hardware and proposed alternate configurations, including the use of redundancy; and

2. Maintenance strategies and their associated costs, including

   - design of monitor, alarm, control and network supervisory systems

   - deployment of Operations staff and spares

   - transportation facilities to unattended earth stations

   - use of local and shared maintenance

   - training and documentation procedures.

The first factor addresses the rate at which failures will occur, the second the time required to repair the fault. These combine to determine service availability. The system design and specification of the equipment ensure that a communications facility can meet the requirements of circuit performance and availability. When the system becomes operational, the objective becomes one of ensuring that it does provide a satisfactory grade of service over a specified period. The maintenance strategy has a prime impact on the achievement of this objective. Operating costs trade-off with a variety of parameters ranging from the initial station configuration through to maintenance policies.

2. EXISTING ORGANIZATION OF MAINTENANCE AND OPERATIONS

2.1 Introduction

Over a three year service period, the Telesat operations and maintenance procedures for remote unattended stations, of which in the order of seventy exist (see map in Figure 1 with associated index in Table 1), have evolved into an efficient approach to providing the grade of service contracted at the lowest operating cost. Any planned extension of the existing system therefore will benefit by fully taking into account present maintenance techniques and staff deployment. To this end, a description of the Telesat Operations and Maintenance organization is included.

2.2 Description of Telesat's Operations Organization

While this report is addressed to stations of the small remote type, any Operations and Maintenance activity must be co-ordinated on such a complete scale that it would seem beneficial to present a brief overview of the entire structure.

2.2.1 General

While two separate Groups - Operations and Maintenance -

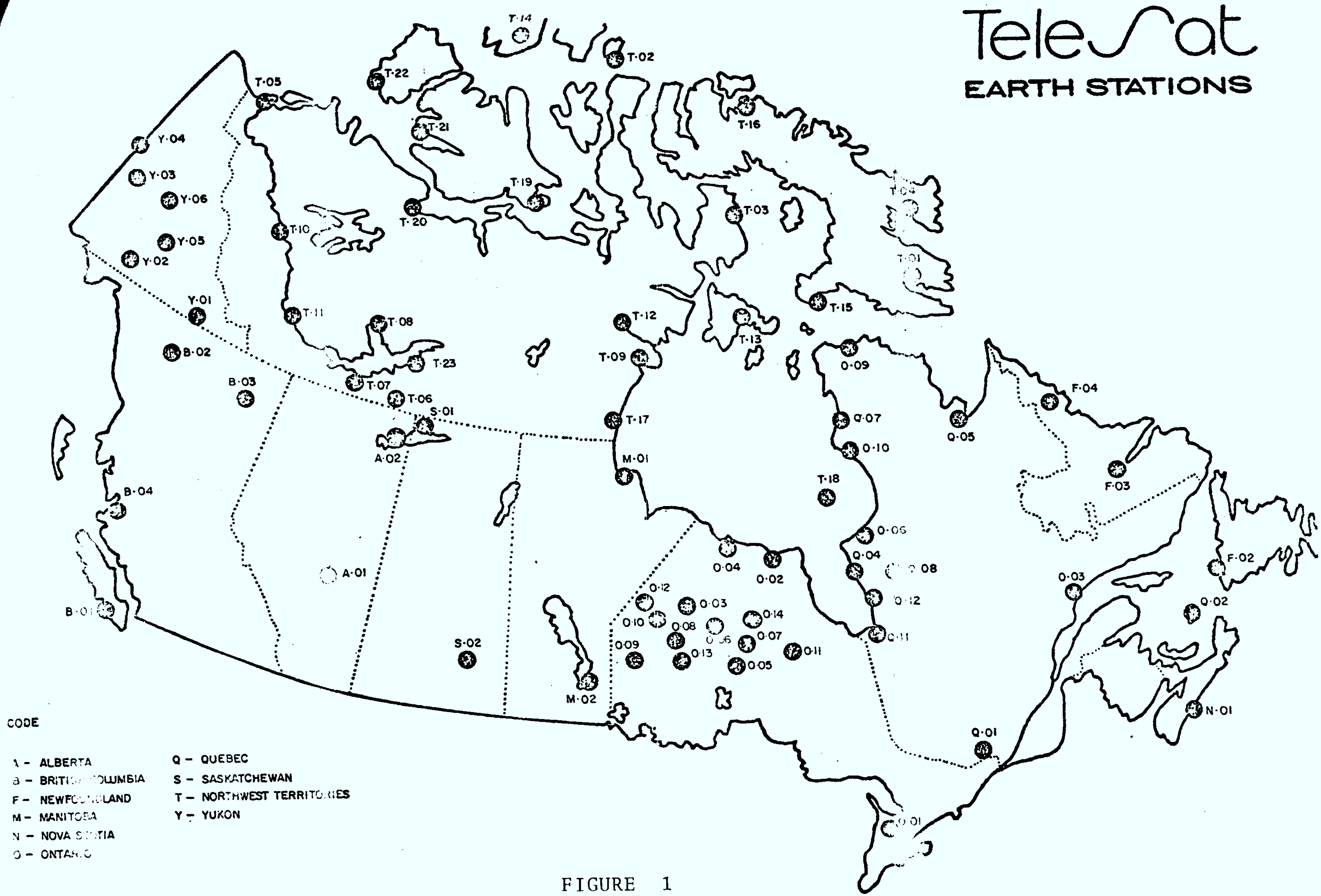

FIGURE 1

14 NOV 75

TABLE 1

EARTH STATION INDEX*

ALBERTA

A-01 Huggett
A-02 Ft. Chipewyan

BRITISH COLUMBIA

B-01 Lake Cowichan†
B-02 Cassiar
B-03 Ft. Nelson
B-04 Bella Bella

MANITOBA

M-01 Churchill
M-02 Belair

NEWFOUNDLAND

F-01 Bay Bulls
F-02 Port au Port
F-03 Goose Bay
F-04 Nain

NOVA SCOTIA

N-01 Harrietsfield

NORTHWEST TERRITORIES

T-01 Frobisher
T-02 Resolute
T-03 Iglookik†
T-04 Pangnirtung†
T-05 Inuvik
T-06 Ft. Smith
T-07 Pine Point
T-08 Yellowknife
T-09 Rankin Inlet†
T-10 Norman Wells
T-11 Ft. Simpson
T-12 Baker Lake†
T-13 Coral Harbour†
T-14 Rea Point†
T-15 Cape Dorset†
T-16 Pond Inlet†
T-17 Eskimo Point†
T-18 Sanikiluaq†
T-19 Cambridge Bay
T-20 Coppermine
T-21 Holman†
T-22 Sachs Harbour†
T-23 Snowdrift†

ONTARIO

O-01 Allan Park†
O-02 Winisk†
O-03 Big Trout Lake†
O-04 Ft. Severn†
O-05 Ft. Hope†
O-06 Kasabonika†
O-07 Landsdowne House†
O-08 Weagamow†
O-09 Cat Lake†
O-10 Muskrat Dam†
O-11 Ogoki†
O-12 Sachigo Lake†
O-13 Slate Falls†
O-14 Webique†

QUEBEC

Q-01 Riviere Rouge
Q-02 Magdalen Is.
Q-03 Sept Isles
Q-04 Ft. George
Q-05 Ft. Chimo
Q-06 Poste de la Baleine†
Q-07 Povungnituk†
Q-08 Radisson†
Q-09 Saglouc†
Q-10 Inoucdjouac†
Q-11 Ft. Rupert
Q-12 Noveau Comptoir

SASKATCHEWAN

S-01 Uranium City
S-02 Qu'Appelle

YUKON

Y-01 Watson Lake
Y-02 Whitehorse
Y-03 Dawson
Y-04 Clinton Creek
Y-05 Faro
Y-06 Elsa

* Stations are numbered by Province in order of start of service
† Stations possessing Thin Route Equipment

have arisen, the organization is configured overall as one.

2.2.2 Operations Sector

Of critical importance in constructing the Operations organization has been the achievement of highly centralized control. The approach taken has been a gross subdivision of work illustrated as follows:

	Satellite Management	Communication Service Management
Central Control and Monitoring (Ottawa)	SCC	NCC
"Hands-on" Control (Allan Park)	TT&C	NOC

Where:

SCC = Satellite Control Centre

TT&C = Tracking, Telemetry & Control

NCC = Network Control Centre

NOC = Network Operations Centre

There are broadly two aspects to operating the communications satellite system - the communications service segment and the satellite segment. Within each of these two areas, two further subdivisions can be identified.

The Network Operations Centre (N.O.C.) located at the Allan Park Heavy Route Station is the direct interface, at the working level, with the customer. A system of "ticketing" various service conditions has been developed here to maintain control, identify status and initiate any action necessary with the system.

For message service, a centralized system of trouble reporting has been established whereby all conditions route initially to the Barrie office of Bell Canada and thence to N.O.C. This system ensures a reliable, efficient trouble reporting scheme and has the added advantage of ensuring compatibility with the customer's records of outages and service availability.

The Network Control Centre (N.C.C.) located in Ottawa is tasked with overall operations management. Service reports and periodic availability calculations are prepared here. Interaction with other sections of the Company are organized. Customer contact at a management level on both a periodic and "as necessary" basis occurs with the N.C.C.

2.2.3 Maintenance Sector

2.2.3.1 General

The responsibility of the Maintenance Group is to ensure continuous, efficient operation of the system. The stations identified in Figure 1 can be broadly categorized in two groups - large and continuously staffed or relatively small and unattended.

A study of the locations of the various stations would reveal a great diversity of operating environments and service applications. The deployment of the maintenance staff has been such as to maximize the support effectiveness in the most economic manner. To this end the following categories have been established.

2.2.3.2 Permanent On-Site Staff

The nature of certain services as well as the complexity of the stations has required that the two so-called Heavy Route Stations - Allan Park (12 maintenance staff) and Lake Cowichan (10 maintenance staff) be continuously manned.

The Allan Park station is also employed as a spares storage and deployment centre and repair workshop. Lake Cowichan maintenance staff have also been used in a support function; e.g., to integrate subsystems for the C.N.T. stations.

2.2.3.3. Remote Stations Group

This section operating from the Head Office in Ottawa basically is responsible for the maintenance of the balance of the network. A very quick look at the distances and locations involved establishes that travelling and living expenses are a chief contributor to the maintenance costs. Bearing this in mind the remote unattended stations are largely maintained on a case by case basis using the most expedient alternative available, yet overall management rests with the Remote Stations Group. The successful installation and maintenance of these stations depends largely on the ability of the staff to react quickly and resourcefully under adverse conditions.

a. On-site staff

Two remote locations have been manned on a daily basis. In Harrietsfield, Nova Scotia, the need arose chiefly due to the addition of the equipment necessary to provide service to Teleglobe Canada after the initial CBC services. Frobisher Bay, NWT, the other manned site, establishes a Northern Canada depot from which spares and/or technical support can be conveniently deployed in the North. In both of these locations, two staff members are retained on a permanent basis.

b. Maintenance agents and shared maintenance

An extremely successful approach to the problem of maintaining remote sites is through the use of contracted maintenance agents. These are skilled technical people who are typically employees of a communications carrier (e.g. CN/CP). They perform regular or as required monitoring and maintenance services for Telesat. Familiarization courses for the maintenance agents have been provided by

Telesat. Often in areas where the Telesat sites are relatively close, the same agent may be responsible fot two or more locations. A good example of the success of this arrangement is the Remote Television station at Fort Nelson in British Columbia which has had no service failures during its first three years of operation.

A similar system of maintenance has been negotiated with a customer. In this case the arrangement decided upon is that the first line of maintenance for certain sites shall be provided by the customer. The logic in such arrangements is again based on minimizing delays and travel expense. Cost-benefits are generally achieved through the sharing of maintenance functions and the use of people resident in a region.

c. Local agent

A relatively novel and useful practice has been to establish a "local agent" at unmanned sites not serviced by contracted staff. In general this person is not a qualified microwave or communications technician. At best the local agent is technically oriented (e.g. Northern Canada Power Commission agent) but where such a person is not available, a responsible citizen may be employed. The primary function of the local agent is one of status reporting and routine surveillance; however, many have been used successfully to make operational changes or module replacements. In general, considering the modest cost involved (typically less than $1000 per year for a site), this is a very advantageous program to pursue once a reasonable initial burn-in reliability has been established.

The remote station staff thus attempts as far as possible to organize work at a local level. When technical support is required from Ottawa, a skilled technician (on a 24 hr. on-call basis) is dispatched with generally prior knowledge based on the status report.

2.2.3.4 Maintenance Categories

Maintenance work generally falls either into the category of a corrective nature in response to service outage or a preventative nature on a more routine basis. The levels of preventative maintenance developed by Telesat for the remote stations are as follows:

a. Status report

Station check lists have been designed and distributed across the network, for completion approximately each 2 weeks. This check involves an examination of the whole station - communications equipment (meter readings, status lights, etc.), battery state, environmental condition. With proper prior familiarization, these checks can easily be performed by local agents. These forms, forwarded to Ottawa, provide the Remote Stations Group with verification of the operational status of the network.

b. System checks

Every three to six months (depending on station type), the systems performance of a station is verified. A scheduling has been drawn up so that the work load for these checks throughout the network is spread uniformly. A scheme has been developed whereby during specific days of each month a reference station automatically transmits test signals during off-air times and thus the maintenance agent/Telesat staff member has some degree of freedom over when the tests may be conducted.

c. Annual checks

On approximately an annual basis each site is visited with a full complement of test gear and the entire station is tested, tuned and modified (if required). These site visits proceed in a logical order thus minimizing overall travel costs.

All types of routine preventative maintenance are of course combined, when practical, with any corrective maintenance trips.

. PROPOSED MAINTENANCE APPROACH

3.1 General

For discussion purposes a network of remote earth stations at least as large as the existing Thin Route system is hypothesized. The hypothetical model is not meant to limit the size or extent of the network, but rather is used to establish certain notions applicable to maintenance policy.

As the market grows and the state of the technology advances, the capital cost of equipment decreases. As transportation and labour costs are increasing rather than decreasing, however, the Maintenance Group faces potentially higher costs expecially in serving the newer and more remote sites. Fortunately, the technological improvements also include an increased reliability factor, thus helping somewhat to balance this effect.

An extended network will be operated at minimum cost if maintenance activities are co-ordinated with those of the existing system. The existing maintenance procedures have evolved in response to the needs of a communications system which has been in commercial operation for over three years, and during that time the Operations staff have developed the greatest appreciation for the tradeoffs and costs involved.

It is useful to describe some of the benefits achieved through integrating maintenance activities with those of the existing system. Of prime importance, perhaps, is the knowledge that has been accumulated (and paid for!) through actual operating experience. Wide ranging inputs would be available to the new operations planners varying from overall structuring down to details of the northern environment. A network which grows logically out of the existing one would realize those economies resulting from common spares and maintenance depots, and collective maintenance and operations personnel.

It is further assumed in this hypothetical "maintenance co-ordinated" network, that the quantity and distribution of stations involved might justify establishment of one or more new Northern regional centre(s).

The maintenance policies proposed in the following sections, then, largely reflect those that have evolved in the existing Telesat system.

3.2 Central Control

To be efficiently managed, this widely dispersed communications network must have a control centre to co-ordinate operation and maintenance. If the control centre posseses maximum network visibility by receiving available up to date information, it can assign priorities and exercise scheduling and deployment decisions in an optimum manner. Central control (as opposed to distributed control) ensures that contradictory actions are not taken and optimum use of made of available resources; it facilitates the recording, accounting and distribution of service availability and operation trend information; and it may also arrange with the customer scheduled service interruptions and other special events.

The control centre, while having overall management authority, could not be expected to make all decisions pertaining to the health of the network. The inevitable delay involved in reporting to the control centre means that corrective action where possible would be taken at the local level and later reported.

The control centre itself would be sub-divided into units having separate responsibilities. Operationally it is necessary to have a group which interfaces with the customer and performs administrative tasks (some of which are specified in customer service agreements). The central maintenance group must respond as quickly as possible to service impairments. With overall network visibility, this group can dispatch personnel/

equipment as the situation requires. Finally, we need a group having the "off-line" function of evaluating the reliability performance of various subsystems based on operational records, identifying recurring trouble spots, and taking corrective action when warranted. The corrective action might consist of engineering modification or replacement of a subsystem.

3.3 Preventative/Corrective Maintenance

Simple statements of work for the maintenance organization of a utility are: "keep the system going" and "minimize inconvenience to the customer". In the case of a communications system to remote unmanned terminals, the objective becomes one of ensuring that system failures are infrequennt, since resulting outages are necessarily prolonged and repair costly. Therefore emphasis is placed on ensuring a large earth station MTBF (mean time between failure) through the use of reliable subsystems, redundancy where necessary, and preventative maintenance. For remote sites, preventative maintenance on a scheduled basis can be undertaken considerably more cheaply than corrective maintenance, which demands fast reaction without great regard to cost.

Preventative maintenance prolongs the useful life of equipment by ensuring it performs well within operating limits, thereby avoiding stress conditions. In some cases failures can be anticipated and corrective action taken; in addition to avoiding outages, this sometimes leads to a cheaper repair bill. The other role which Maintenance encompasses is that of responding to an unforeseen outage in such a way as to minimize the service interruption time; i.e., corrective maintenance.

For both of these activities there is the requirement for a comprehensive reporting scheme from the site. For example, preventative maintenance may be prudent when changes occur in meter readings, etc. Corrective maintenance functions are greatly enhanced by any diagnostic information made available to the central office.

With the possible exception of regional maintenance centres, the remote stations will be unmanned. Therefore, status and surveillance reporting is most conveniently implemented by ensuring that all significant parameters are metered and/or displayed for periodic local examination and transfer to the central office.

The high cost of transportation to these sites will tend to be a dominating factor in the frequency of preventative maintenance trips. After the initial "burn-in" period when a suitable confidence level is gained, the scheduled visits will probably tend to slip further apart limited ultimately by the long term reliability and possibly any contractual obligations to verify performance.

3.4 Maintenance Personnel

Since it impacts on the two most important cost factors in maintaining a network of remote terminals, namely labour and transportation, the deployment of personnel is critical. The first step in developing a maintenance plan is to determine the level of staff required and how they can best be employed. The ultimate service availability performance of the network and operating cost will largely be determined by fundamental decisions with regard to personnel.

A starting point in the process is an examination of commercial transportation routes and costs (see section 4.2). One can quickly conclude that it does not seem feasible to operate an extensive Northern network from the southern control centre. As has been mentioned, a Northern regional centre (in addition to the existing one at Frobisher Bay) is assumed established with the expansion. At an estimated doubling of equivalent southern Canada salaries (including living allowances), a minimal permanent staffing of the regional centre is anticipated.

This still leaves the individual sites in a highly isolated state. The necessary supervision and maintenance must be achieved by routine visits or as required. In this regard it can be very advantageous to designate where possible local maintenance agents, thereby circumventing expensive and time consuming travel, and giving the earth station a degree of stand-alone capability. Contracting of part-time services for "first line" maintenance is a common practice in the North, and has been employed by Telesat.

A corollary of this concept is to engage the customer's (for whom the satellite service is provided) maintenance officer. For public telephone service this would be the telephone carrier; for private circuits the end-user could provide first line maintenance. As well as the advantages of proximity, this approach has two additional benefits, namely:

- the customer gains technical familiarity with the terminal and ultimately some control over its performance.

- responsibility for first line maintenance of the link from the earth station antenna to the telephone exchange or user premises rests with a single authority (e.g. the telephone carrier), thereby avoiding certain ambiguities in outage reporting and restoration of service.

Where a local maintenance agent cannot be located or is not available for a period of time, the local agent in an adjacent community may assume responsibility for routine surveillance and status reporting. To perform these functions he might effectively make use of intercommunity communications facilities (e.g. radio) to reduce the travel required.

In general the local maintenance agents will perform a limited maintenance role, their principal function being of a reporting nature. However, as the technical capabilities of the local agents will typically vary widely, so might the degree of maintenance work they can be expected to perform.

Impacting heavily on the successful functioning of the maintenance agents, and for that matter the Operations staff, is the degree of training provided and the layout of the earth station. A comprehensive training program attended by all local agents and a simple, uncluttered and well documented standard earth station will significantly reduce the cost of operating a large network of remote stations.

As already noted, the Operations personnel (permanent staff) should be deployed in at least two but probably not more than about four locations - Northern regional centre(s) and the control centre. This staff performs "second line" maintenance best described as that which cannot be performed by the local agents. The staff must be prepared to react quickly to many different types of problems, sometimes occurring simultaneously, and also perform routine maintenance and administrative functions such as the careful control of spares inventory. To achieve a smooth running and efficient system, the permanent staff must interact with and guide the local agents, supporting them as required. Costs are minimized if the local agents and Operations staff form a complementary team.

3.5 Spares Deployment

Essential to any maintenance program is rapid access to a stock of equipment spares. Transportation facilities must once again be considered critical in setting up the sparing program. For this reason, Northern regional centre(s) having the most rapid access to the remote sites are a logical choice for any large inventory of spares.

Of particular benefit is a complete equipment rack-up facility for the regional centre, obtained at minimum cost if included as part of an overall hardware procurement. An entire complement of spare modules may be kept in an integrated on-line* condition, ready for shipment to a field location. Shelf items

* "On-line" here does not necessarily imply that integrated equipment remains on continuously, which could reduce ultimate operational life of the modules, but it does mean that it is kept in running order.

would then be used to replace modules removed from the rack-ups. This technique ensures that in most cases modules shipped as replacement items arrive in working order with the minimum of delay. This seemingly trivial constraint that replacement items themselves function properly when installed is in fact a very serious consideration, especially when transportation costs and delays to remote sites are significant.*

A secondary use for a rack-up facility is as a workshop tool and in some cases as a test bed. The opportunity to insert failed equipment into a live environment results in improved diagnostic capability at the regional centre. Perhaps more important is the ability to test and re-align equipment.

The regional centre(s) would provide effective locations as spares depots for two basic reasons:

i they offer reasonable access to the remote sites and the southern control centre, while

ii they minimize <u>total</u> staff and inventory requirements through the use of a shared facility. †

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* It is important to remember here that manufacturers are normally not required to pass spare units through integrated system acceptance tests.

† If failures at the sites occur independently, then on a statistical basis, 1 for n sparing using a shared facility can offer the same backup capability as a 1 for 1 sparing at the local level.

Other factors, however, may favour some departure from this approach. Although small and relatively cheap remote stations are envisaged, equipment categorized as either expendible (e.g. light bulbs, fuses) or particularly troublesome may require on-site storage. This permits immediate access by local agents, and ensures that such spares are available when an Operations staff arrives on-site. Built-up settlements located more or less centrally within a group of remote stations provide an alternative for limited spares caches. Finally, the maintenance staff operating from the southern central office must have a stock from which to draw as the need arises.

3.6 Equipment Design As Related To Maintenance Philosophy

The route to achieving the most cost effective Maintenance Philosophy does not come strictly from the development of operating procedures. The maintainability and operability restrictions must be incorporated early in the design stage.

In order that a communications system provides the required service availability, a reasonable estimated of MTTR must be available during the design phase. Therefore, fundamental operating procedures for a proposed system should be formulated initially, and the resulting MTTR estimated. Given the MTTR, the system is designed to an MTBF consistent with the required service availability. To meet a given availability, there may be some freedom at this point to trade-off MTBF (initial capital cost) and MTTR (expected operating cost), and the most cost effective combination can be determined. However, since there is some uncertainty associated with MTBF evaluation, the system should not be designed to the minimum MTTR achievable.

The modular approach must be emphasized. Neither the working environment nor the expected personnel make the remote station conducive to elaborate on-site repairs. Rather it is expected that the design shall incorporate techniques to localize faults down to the module level. Simple reliable connect/disconnect mechanisms must also complement the modular scheme.

As a general comment, careful consideration at the design stage must be made as regards future growth possibilities versus maintainability. Over and above power, spacing, and environmental control capabilities, any future expansion must be maintainable in all aspects of the term. This brings up an often neglected realm of consideration for any stage of the design - that of human engineering. Briefly, guidelines do exist (1) and should be adhered to.

The preceeding thoughts tend to indicate that a very useful member of the system design team would be a representative from the operations and maintenance group. As well as ensuring that the maintainability concepts are incorporated, a smooth transition would be effected at the time of commissioning.

The intent of this section is not to delve into details of system design, however two key areas are highlighted.

The first is equipment redundancy. Redundancy is employed where the availability requirements of a service are not achievable with single chain operation. There are several factors in the cost/performance trade-off that should be considered:

1. Technological advances have increased the reliability of single chain operation.

2. Northern services may accept a lower availability figure in order to realize lower cost stations.

3. Communications equipment redundancy and an associated automatic switching capability results in a cost increase of a factor of about 2.

4. Prime power back-up may be required as these northern remote communities tend to have relatively primitive power supplies.

The second area of design consideration is local monitor, alarm and control and network supervision. The first level to which local controls and displays must be comprehensible are for the potentially non-technical person. For the more adept maintenance personnel, the equipment should provide easy access for adjustment, calibration, and in-service measurements. The concept of a centralized network supervisory system becomes particularly attractive when considered in conjunction with the demand assignment scheme discussed in Appendix C. This demand assignment system utilizes a centrally located computer as the controller. The additions necessary to the system hardware and computer logic to perform supervisory functions would not be extensive. Envisaged is a scheme whereby, during light traffic loading periods, the supervisory system would activate a routine in the central computer, sequentially "demanding" a carrier for status check. A first-cut approach might simply entail a looped-back continuity check of the circuit. A further state of sophistication would be to time share the remote terminal microprocessor required for demand assignment control. The microprocessor would be continuously scanning and up-dating the status of critical operational parameters. At the time of the supervisory check, this information would be transmitted to the central computer from which it would be displayed to operations and maintenance staff. Included in the scheme could be capability for the central office to access the remote terminal and perform control functions. The network visibility and flexibility provided by such a supervisory system would greatly enhance operations and maintenance efficiency.

4. OPERATING COSTS

4.1 General

Operating and maintenance costs depend heavily on the geographic distribution of the remote terminals. It is reasonable to assume that locations will tend to be added to the network in order of decreasing population/accessibility; i.e. an extension to the existing system will in general face even more difficult operations problems. A basic cost breakdown is developed here for transportation, personnel and the establishment of a regional centre. Also discussed are capital versus operation and maintenance cost trade-offs and their implications in future expansion.

4.2 Transportation Costs

The aircraft has served as the primary means of long range access to and within the North, although barges in some cases can be used to deliver large quantities of supplies during the summer months. As this study does not address specific designated region(s), air transportation costs are examined in a broad context.

Table 2 presents passenger rates for commercial flights to several remote northern locations. These flights are regularly scheduled on a daily basis (e.g. Montreal to Frobisher Bay) up to a weekly or bi-weekly basis (e.g. Montreal to Igloolik), and are sometimes cancelled due to bad weather or insufficient subscription. For comparative purposes, two examples of rates for southern routes are included; using per mile comparison, commercial flights to the North are about double in cost.

Although it is by no means comprehensive, this Table gives an indication of the extent and cost of commercial flights to the larger communities in Canada's north. The transportation costs facing the remote terminal maintenance organization, however, will in general be derived from a much larger base than commercial air fares. Many sites in an expanded thin route system may not be served by scheduled air service. We must therefore consider the accessibility and cost impact of charter air service.

Food, gasoline and other supplies, education and health service, personnel movement, etc. are accommodated as required largely through the use of charter aircraft. Oil exploration and tourism have recently greatly increased the charter business, and there is no shortage of operators providing charter service.

TABLE 2

PASSENGER COSTS (ONE-WAY)

ROUTE	DISTANCE (STRAIGHTLINE MILEAGE)		COST ($)
Montreal, P.Q. - Frobisher Bay, NWT (Baffin Island)	1250		170
Montreal, P.Q. - Fort George, P.Q. (eastern James Bay)	600		135
Montreal, P.Q. - Fort Chimo, P.Q. (northern Quebec)	900	N*	135
Montreal, P.Q. - Winisk (northern Ontario)	850	A/C**	182
Montreal, P.Q. - Hall Beach, NWT	1600		238
Montreal, P.Q. - Resolute Bay NWT	2100		257
Montreal, P.Q. - Fort William, Ont	750	A/C	73
Montreal, P.Q. - Churchill, Man (eastern Hudson Bay) (must be via Winnipeg)	1250		184 (includes fare to Winnipeg)
Montreal, P.Q. - Yellowknife, NWT	1950	A/C	231
Montreal, P.Q. - Whitehorse, Y.T.	2600	A/C	245
Frobisher Bay, NWT - Hall Beach, NWT	500	N	99
Frobisher Bay, NWT - Resolute Bay, NWT	950	N	171
Resolute Bay, NWT - Eureka, NWT (Ellsmere Island, far North)	400		132
Montreal, P.Q. - Winnipeg, Man	1150		97
Montreal, P.Q. - St. John, N.B.	400	A/C	47

* N = Nordair

** A/C = Air Canada

Fixed wing aircraft need a solid surface or water runway to land. Such facilities are generally available on a year round basis to communities in the far North. In the semi-Northern reaches of Canada (e.g. Northern Ontario), often characterized by a more self-sufficient population and vast expanses of muskeg, runway facilities may not be available and even bush plane access during the transition periods of spring break-up and fall freeze-up is prohibited. If on-site repair is required at these times, the maintenance group responsible must seek alternate means of transportation. Helicopters (having a range of about 200 miles and chartered at twice the cost) and Bombardier-type vehicles (at 10 mph, chartered at nearest accessible location) are two possibilities.

Chartering involves a significant increase in transportation cost. For example, typical chartering rates for a Twin Otter aircraft are:

1. $4.40 per hour

2. $2.90 per mile

3. fuel surcharge for fuel costs in excess of $0.30 per gallon.

NOTE: A Twin Otter uses approximately 80 gallons of fuel per hour. Fuel costs in the North range from $0.30 to $5.00 per gallon.

At these rates, some minimum-cost strategy should be developed. At least three techniques are available:

i Charter only from the nearest commercially accessible airfield (i.e. achieve the minimum flying cost by making maximum use of scheduled routes).

ii Charter regularly from a company in a community which has been designated a Regional Centre (i.e. achieve fast reaction time and reduced cost due to special business arrangement with single supplier).

iii Purchase aircraft. This alternative seems least attractive except for an extremely large network of stations since the initial capital investment would be in the order of $900,000 with an annual expenditure of about $200,000.

4.3 Personnel Costs

The following factors must be considered in selecting the source, number and disposition of personnel:

a. preventative maintenance policies

b. magnitude of system and expected earth station failure rate

c. proximity of remote terminals to potential Northern regional centre(s), and access to transportation facilities within the system

d. availability of technical support in the form of contracted maintenance agents

e. rate of change and development of the network.

These factors shall determine the mix of maintenance personnel as well as justification for the establishment of regional centres. The approximate wages expected for maintenance personnel are as follows:

Permanent Staff - Operating from southern central office	$20,000/year
Permanent Staff - Operating from remote regional centre (including living allowance and some guaranteed overtime)	$40,000/year
Maintenance Agent/Shared Maintenance	$ 2,000/year
Local Agent	<$ 1,000/year

4.4 <u>Cost of Establishing and Running a Regional Centre</u>

For discussion purposes, it is assumed that the various factors noted thusfar do indeed justify the establishing of a new Northern regional centre collocated at a required earth station site. The basic costs are as follows:

Expansion of basic earth station to make it suitable for regional centre	$100,000
Spares	$ 60,000
Test Equipment	$ 60,000

Vehicle	$ 10,000
Staff (salary (per man)	$ 40,000/year
Staff Housing (per man/family)	$ 10,000/year
Staff travelling expenses (per man)	$ 20,000/year

4.5 Initial Capital Cost/Operating Cost Trade-offs

From the preceeding sections, it would appear that the remote maintenance organization is faced with travelling/living expenses in the order of 2 to 3 times that expected for more built-up areas. In light of this, the planners should be aware of those areas where an increase in the initial capital cost could result in fewer service trips required and hence lower operating cost. The following are some examples of such trade-offs.

a. Equipment Redundancy

The introduction of redundancy in equipment makes two methods of maintenance available (2):

1. ignore subsystem failures (i.e. respond only to failures causing service outage);

2. respond to subsystem failures.

For remote unmanned stations policy 2 would probably be unacceptable for the following reasons:

- diagnosing subsystem failures which do not impair service requires the ability to remotely switch and test standby equipment, or at the least detect failure induced automatic switching.

- the number of service visits would exceed that required for a non-redundant configuration.

Redundant equipment maintained under policy 1 will achieve a system MTBF of roughly twice that of a nonredundant configuration, neglecting failures due to additional sensing and switching equipment.* This increased MTBF reduces the number of on-site trips required by a factor of two, thereby saving operating dollars.†

Redundancy does imply more initial capital cost. A typical yardstick value to use for the increase is a factor of 2.2. In some cases this figure can drop, even below 2.0 if the manu-

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* It is reasonable to constrain the reliability of such equipment so not to limit the performance of a redundant system.

† In actual fact, maintenance policy 2 would always be applied when convenient; i.e. when subsystem failures are discovered, they would be repaired at a convenient point in time. This further improves service availability without significant increase in operating cost.

facturer is offering a well developed redundant system design or the doubled total unit quantity has a significant impact on cost.

For the reasons stated above, redundancy should be used judiciously at the subsystem or chain level to increase service availability and reduce operating cost. In this regard bear in mind that "the chain is only as strong as the weakest link", i.e., for maximum effectiveness, redundancy should be applied to subsystems in order of increasing reliability!

b. Quality Assurance Programs

Equipment reliability (and thus operating cost) trades-off somewhat with the costs inherent in the quality assurance program in force at the time of procurement. More attention paid to the reliability aspects of the design and manufacture of the subsystems results in more consistently reliable equipment. The need for rigorous quality control programs during the design, manufacturing, and installation phases cannot be over emphasized for remote unattended stations. Such a program might add 10% to the cost of equipment but a retrofit program in the North is extremely expensive.

Thus, the trade-offs which the system planners must make is to balance the long term expected operating costs with the initial capital expenditures. On this point, it is probably advantageous to weigh the operating cost factor with some margin due to a degree of uncertainty as well as steady increases in the components of operating cost.

5. SUBSYSTEM RELIABILITY

To estimate the reliability of a system, statistical data on component, unit, or subsystem failure rate is required. This data may be applied in mathematical expressions for availability under various maintenance strategies (2).

The failure rate function $\lambda(t)$ is the mean number of failures up to time t. For a constant failure rate, $\lambda(t)$ can be written in the form

$$\lambda(t) = \lambda t$$

where λ is the mean number of failures per unit time (i.e. failure rate). Equipment generally has three distinct failure rate periods: initial "burn in", useful life, and the wear-out period. During the burn-in and wear-out periods the failure rate function is not constant and can be quite high. During the time defined as "useful life", the failure rate is approximately constant. Assuming a constant failure rate greatly reduces the complexity of reliability calculations, and is approximately valid providing reasonable preventative maintenance is exercised (see section 3.3).

The Reliability function R(t) is the probability that the unit will operate without failure up to time t; or, for a constant failure rate system, over a time interval t, i.e.

$$R(t) = e^{-\lambda t}$$

The reliability figure of merit for the equipment is the Mean Time Between Failure (MTBF) given by:

$$MTBF = \int_0^\infty R(t)\,dt$$

$$= \frac{1}{\lambda} \quad \text{for a constant failure rate}$$

The MTBF's of units and subsystems provided by manufacturers may simply be based on component failure rates, or they may include allowance for stress, environmental fluctuations, etc.

In order to evaluate the validity and applicability of MTBF data supplied by manufacturers, the following questions should be asked:

- are component screening and/or subsystem burn-in assumed? Are they applied?

- have effects of component stress over operating limits been included in reliability analysis?

- what is the "design life" of the subsystem (i.e. over what period of time is the MTBF data valid)?

- is the statistical sample from which the MTBF data derived truly random and of sufficient extent as to ensure unbiased statistics and a reasonable level of confidence?

- for switches etc. what failure modes are considered?

The following is a list of typical critical unit/subsystem MTBF's for communications equipment applicable to the SCPC Remote Station:

UNIT OR SUBSYSTEM	MTBF (HOURS)
Non Redundant Items	44,300
Parametric LNA and Power Supply	32,600
Transistor LNA and Power Supply	66,700
Downconverter and Regulator	21,000
Receiver Source Unit and Regulator	33,600
IF Common Equipment	22,500
Reference Frequency Unit (RFU) and logic	31,500
Voltage Regulators for RFU and IF Common Equipment	53,200

UNIT OR SUBSYSTEM	MTBF (HOURS)
Channel Unit and Power Supply	16,600
Upconverter and 35W Transmitter and Power Supply	8,900
Demand Assignment and Frequency Selection Unit	33,000 (estimated)
Frequency Agile TV Receiver, 1 Audio	5,600

In addition to outright failure, a combination of degradations in the performance of hardware can lead to an unacceptable level of performance, thus constituting an outage. These outages are not predicted by MTBF data, which describes the rate of catastrophic failure of units and subsystems. In order to compensate variations in the performance of hardware over long term operation, a margin is included in the initial design or specification of the system. This margin is usually sufficient to reduce to insignificance the likelihood of an outage due to non-catastrophic failure.

6. CIRCUIT AVAILABILITY AND MTTR

6.1 Introduction

It is the requirements of the user that should ultimately dictate the level of availability designed into the communication's service offered to him. Availability and performance specifications together determine the quality of service offered, and both have a cost impact. If the service fails to meet the real needs of the customer, it will cause unacceptable inconvenience or not be used effectively. If the service is better than required, the associated extra cost may limit its application.

6.2 Definition of Circuit Availability

Section 5 discusses subsystem reliability. When these subsystems are integrated in an earth station to form part of a satellite communications system, the most important performance parameter becomes circuit availability, defined as the percentage of time a given duplex circuit between two stations is available. Availability in general is defined by:

$A(t)$ = probability of satisfactory operation at time t

Assuming a constant failure rate, the time dependancy can be dropped, giving the following definition of <u>circuit availability</u>:

A = % of time 2 way circuit available to customer

$$= \frac{\text{service period - "outage time"}}{\text{service period}} \times 100$$

However, this definition does not answer the following:

- what level of performance defines the outage threshold (normally "barely intelligible" or "just usable")?

- over what period is availability measured (e.g. per month, per year, per duration of service contract)?

- what duration of performance below threshold is required for a service outage? (What are allowable diagnosis plus switch times in redundant configurations? Are 'hits' in dialling and signalling and other intermittent effects counted in the "outage time"?)

- for parallel redundant configurations are there any limits placed on the allowable number of switches over the service period?

- are outages defined (or measured) only when the circuit is actually required?

- how many outages are expected over the service period? (i.e., What is the mean outage time?) What are the failure rate and time to repair probability distributions and how might they affect operating and maintenance strategies for the service?

- how are outage times measured and recorded (by the user and by the operator)?

- what is the impact of the use of terrestrial and satellite facilities in tandem?

- does the outage time include predictable outages due to sun transit, periodic system testing, etc.?

- what is the degree of inconvenience if the availability requirement is not met and what, if any, penalties are applied to the operator? (i.e.: how are the availability requirements written into the service contract?)

The answers to these questions may depend on the particular requirements of individual users. For example, when circuits are being used to carry data, the number of switches and other short term disturbances must be minimized, and this requirement can be reflected in an availability specification, typically expressed in terms of short term error rate.

Several alternate definitions of availability can be applied in satellite networks possessing alternate circuit connections. For example, "M of N" circuit availability may describe the availability of M out of N circuits between 2 earth stations or among several earth stations.

For a demand assigned system it is more reasonable to consider "half circuit" availability, the percentage of time an earth station can transmit and receive on a given channel unit, and this is the definition used here.

6.3 Effect of Propagation and Interference on Circuit Availability

The earth station to satellite and satellite to earth station radio links are subject to fluctuations in received carrier-to-noise ratio due mainly to:

- earth station pointing error (affected by satellite drift and wind load on the antenna)

- atmospheric attenuation (principally from rain fall)

- tropospheric scintillation (especially at low elevation angles)

- sun and moon transits (predictable occurrences, not considered further here)

- snow and ice accumulations on antennas.

In order to ensure adequate performance for a high percentage of time, a fade margin is included in the link equation. This margin is typically in the 2 to 4 dB range depending on the parameters of the link and the percentage of time the performance must be maintained (3dB has been assumed in the analysis given in Appendix B).

A service contract generally defines both a performance specification (to be exceeded for a given percentage of time) and an availability specification (measured with respect to a given minimum performance threshold). The limiting factor determining fade margin in toll quality systems (e.g. east-west message) has been the performance specification (i.e. outages due to fading do not occur). However, for systems designed to operate near threshold, with relaxed performance requirements, or subject to unusual propagation phenomena (e.g. very low elevation angles), availability requirements will impact on fade margin, and hence on system cost.

The earth station to satellite and satellite to earth station radio links are also subject to interference from adjacent satellite and radio relay systems. Adjacent satellite interference, while a potentially significant contributor to noise, is fairly constant in level and may be calculated with a reasonable degree of accuracy (see section 3.4, Appendix B). Radio relay interferers are subject to wide statistical variations in level, but are not assumed significant in remote areas.

For the link margins assumed, "outages" due to adverse propagation/interference conditions will be of negligible importance compared to those resulting from equipment failure, and have not been considered in availability calculations.

6.4 Mean Time To Repair (MTTR)

The MTTR consists of three terms - fault detection time, travel time, and actual repair time. For this unattended remote stations system the dominating factor will generally be that of the travelling time.

6.4.1 Fault Detection and Diagnosis Time

Assuming an outage starts when a failure occurs (i.e. disrupts service) and not when it is detected by the operator, the mean detection time must be included in the MTTR. This time can be defined as the interval between the occurrence of the failure and the time at which the outage becomes known at the Regional Maintenance Centre.

The mean time between observed loss of service and knowledge of this condition at the control centre might vary from two to eight hours, depending on the number of circuits terminated at the remote station, diagnostic and reporting procedures/local agent(s), alternate communications facilities, etc. For a remote station, MTTR is affected significantly by the detree of reliability with which the fault can be diagnosed when it is detected. If it is correctly diagnosed, the individual dispatched to repair the fault will bring with him the correct spare unit. If not, there is some possibility that the correct unit will have to be shipped to the station after his arrival.

6.4.2 On-Site Equipment Repair Time

Providing diagnosis is sufficiently definitive to ensure the required spare is brought, the mean time to repair is estimated to be 4 hours (reference section 4.3.5). Lack of proper prior diagnosis necessitates a general purpose spares kit to be shipped (would probably cover 80% of the failures) and possibly a second return trip. Under these conditions a reasonable estimate for the mean time to repair, once initially on site would be 10 hours (80% of the failures would still be repaired in about 4 hours, but the other 20% could take about 34 hours due to the wait for additional equipment).

6.4.3 Travel Time

The time between reporting of the fault condition at the control or regional centre and the arrival on-site of an Operations personnel dominates the Mean Time To Repair and is critically dependent on the maintenance philosophy employed (reference sections 4.3 and 4.4.2). Given that a fault occurs which is beyond the repair capability of a local agent, many remote sites are sufficiently inaccessible that "travel time" (here defined as the period required to access transportation and spares plus in-transit time including flying time and miscellaneous delays) will be lengthy regardless of the maintenance philosophy!

In general, travel time depends on:

- scheduling of commercial flights from manned Regional

Centre to commercial airfield at or closest to remote site

- availability and use of charter air service, including effect of weight restrictions

- distance to remote site (i.e. flying time)

- random variables such as

  a. time of occurrence of outage in relation to scheduled flights and availability of operation personnel

  b. weather conditions

  c. time of year

- if applicable, local ground transportation facilities in area of site.

A mean transportation time from the regional centre to a remote Northern site might vary from 8 to 30 hours depending on location, time of year, and chosen means of transportation. It is understood that weather plays a dominant role in increasing the mean transportation time. A figure of 16 to 20 hours however is considered typical under the assumptions given in 4.3.

6.4.4 Total MTTR

The following equation for MTTR is suggested:

$$MTTR = T_1 + (1 + p)\ T_2 + T_3$$

where:

T_1 = mean time between occurrence of outage and its detection (depending on nature of service, this period might not be considered as part of the outage time)

T_2 = mean travel time to remote earth station, including time to inform appropriate personnel, locate spares, and make travel arrangements

p = probability that required hardware is not initially available on site and must be flown to repair personnel after his arrival.

T_3 = mean time required to diagnose and repair trouble on site

Using the "ball-park" estimates for the three stated components, a typical total Mean Time To Repair (including lead time) is:

MTTR = 32 hours

6.5 2-Circuit SCPC Remote Terminal Availability

To demonstrate the impact of redundancy on service availability, three alternate configurations are examined:

a. Completely non redundant

b. Parallel redundancy on transmit, standby redundancy on receive (Thin Route II configuration)

c. Standby redundancy on transmit and receive

In all cases two channel units are assumed (Thin Route II configuration). Both 1 out of 2 and 2 out of 2 circuit availabilities vs MTTR are computed and plotted in Figure 2.

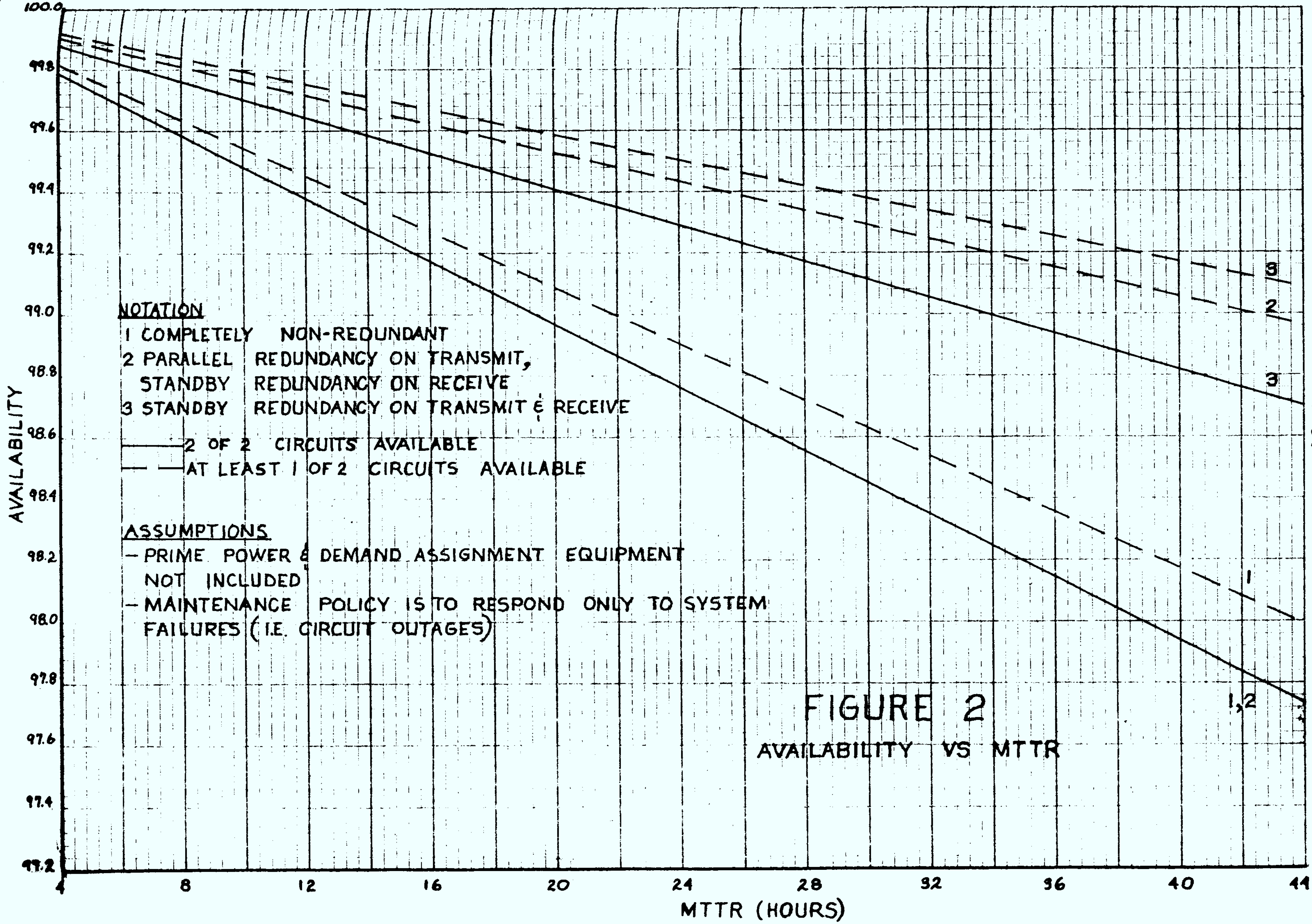
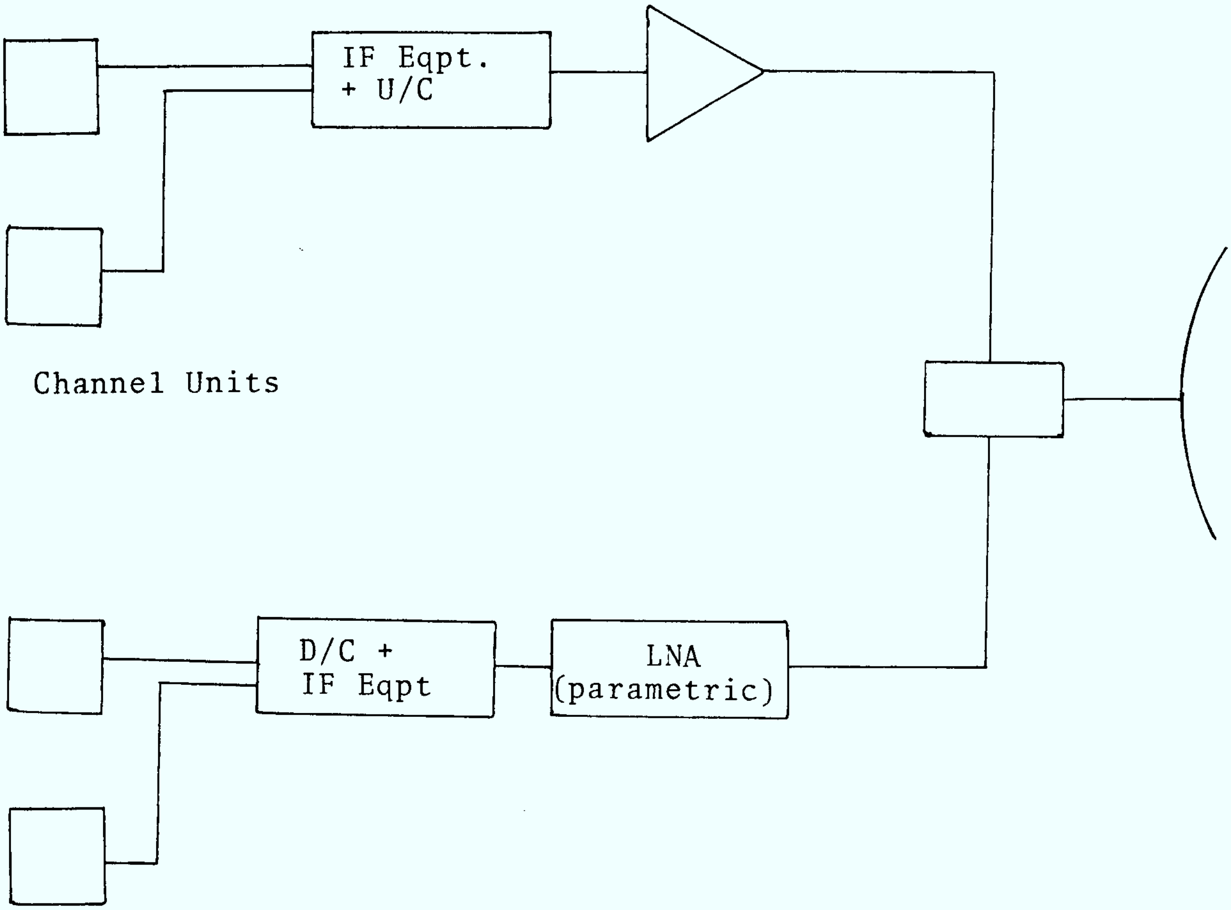
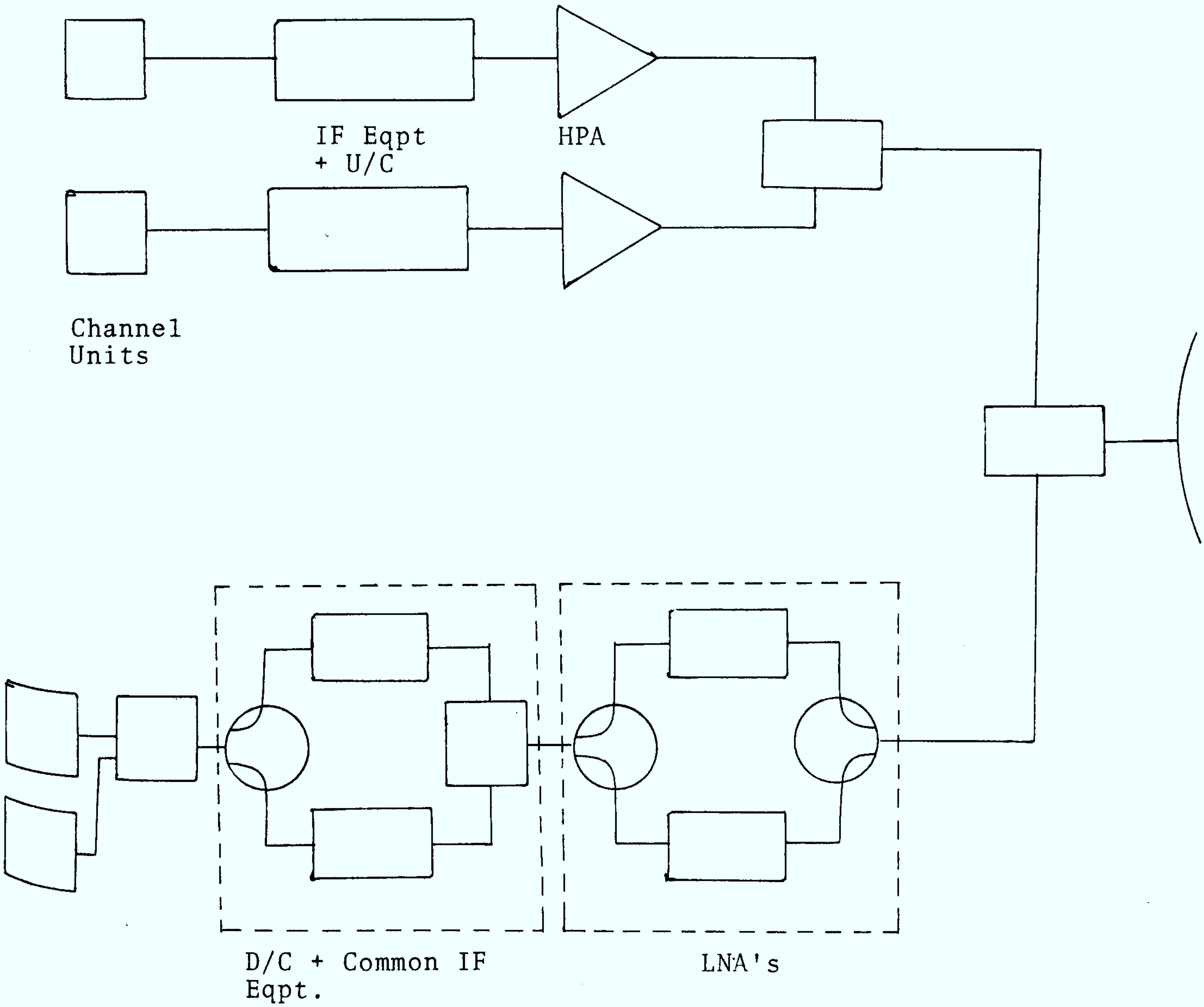


FIGURE 2
AVAILABILITY VS MTTR

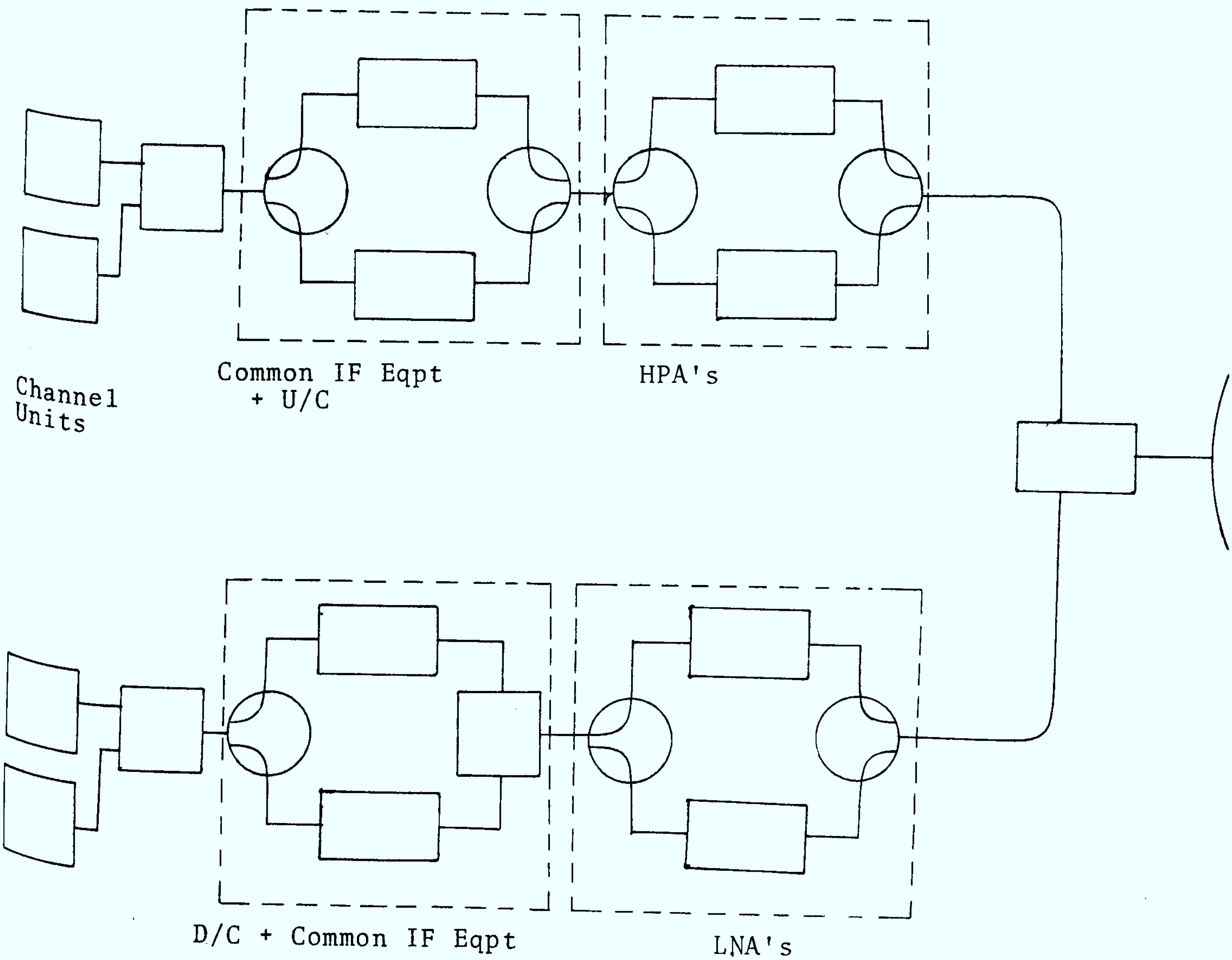
a) COMPLETELY NON-REDUNDANT



b) PARALLEL REDUNDANCY ON TRANSMIT, STANDBY REDUNDANCY ON RECEIVE



c) STANDBY REDUNDANCY ON TRANSMIT AND RECEIVE



6.5.1 Standby vs Parallel Redundancy

The trade-offs between parallel and standby redundancy on transmit are primarily those of 2-circuit availability versus transmitter cost. A standby configuration needs a higher power TWT, due to backoff requirements, as well as high power switches and sensing equipment. (With parallel redundancy little backoff is required since there is only a single carrier in each power amplifier). This cost reduction with parallel redundancy is achieved with a significant reduction in "2 of 2" circuit availability; "1 of 2" circuit availability may be more important, however, because it specifies the % of time the station can communicate.

6.5.2 Conclusions

For an MTTR = 32 hours, the following results are noted:

1. A completely non-redundant system provides a 1 out of 2 circuit availability of only about 98.5%.

2. A standby configuration gives both 1 out of 2 and 2 out of 2 circuit availabilities in excess of 99%.

3. A parallel configuration gives a 1 out of 2 circuit availability in excess of 99%.

These results are based on the assumptions that corrective maintenance of the communications subsystems is not performed at the local level, but that preventative maintenance is exercised and the station is monitored and kept in "running order" (e.g. secondary systems such as prime power, environmental control, etc. are properly maintained, and do not contribute to outages).

REFERENCES TO APPENDIX D

1. Human Engineering Guide for Equipment Designers, University of California Press, 1964.

2. I. Meller, "Dual Systems Reliability Requires Prior Knowledge of Maintenance Programs", Canadian Electronics Engineering, August 1974, pp. 18-21.

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

FINAL REPORT

APPENDIX E

EARTH STATION TECHNOLOGY AND TRENDS

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

April, 1976

APPENDIX E

EARTH STATION TECHNOLOGY AND TRENDS

PAGE

APPENDIX E

EARTH STATION TECHNOLOGY AND TRENDS

1. INTRODUCTION

This section briefly describes current earth station technology on a subsystem by subsystem basis. In addition it attempts to identify near term technological trends which may have significant impact on either performance or cost, or both.

The major subsystems listed by section number are as follows:

2. Antennas
3. Low Noise Amplifiers
4. Up/Down Converters
5. Channel equipment
6. Travelling Wave Tube amplifiers
7. Solid State Microwave Power Amplifiers
8. TV Receivers
9. Power Systems
10. Shelters

2. ANTENNAS

2.1 Current Technology

Antennas currently used in remote Thin Route terminals are paraboloids ranging in size from 26 ft. dia. down to 12 ft. dia. The preferred feed configurations are Cassegrain or Gregorian which can provide high aperture efficiency (55% to 75%) and thus high antenna gain. Ground mounts used are of the Hour Angle/Declination type, and also Azimuth/Elevation type. The main reflectors are fabricated generally from aluminum for reasons of lightness and resistance to corrosion, and may be spun in one piece in the smaller sizes (i.e. up to 15 ft. dia.) or may be fabricated as a set of petals and assembled on site.

When accurate satellite station keeping (e.g. $\pm$ 0.1 deg) is practised, antennas of the sizes currently in use do not require a tracking capability. All that is required is a capability for periodic fine adjustment and an operational sky coverage which includes the operating satellite and its backup.

Table 1 summarizes the primary parameter of some antennas currently in use in 4/6 GHz Thin Route systems.

DIAM FT	FEED TYPE	GAIN 4 GHz	GAIN 6 GHz	COMMENTS
12	Cassegrain	41.3	45.0	Air transportable Twin Otter (800 lbs)
15	Cassegrain	43.7	46.3	Air transportable (DC-3)
26	Gregorian	48.5	51.5	Standard version only

TABLE 1
THIN ROUTE ANTENNAS

2.2 New Developments

Two of the significant new developments in antenna technology which have occured in the last few years:

i Use of metallised fibreglass as a material for the main reflector. This is generally applicable to the smaller antenna sizes and results in a reduced production cost compared with aluminum, especially in large quantities. One U.S. manufacturer of this type of antenna is Prodelin Inc., N.J.

ii Conical horn antennas made, for examply, by AFC Inc. are claimed to have extremely low side lobe levels. This reduces the antenna noise temperature to 3°K at antenna elevation angles as low as 5° above the horizon. This antenna noise temperature reduction is useful only if parametric amplifiers with 40° - 50°K noise temperatures are used in the amplifying chain. When amplifier noise temperatures are of the order of 200 - 300°K then antenna noise does not significantly degrade system noise temperature. The principal advantage of a horn antenna for remote terminal applications is the reduction in interference to and from adjacent satellites.

The AFC antennas employ metallised fibreglass fabrication techniques. Figure 1 shows a 9'6" diameter aperture horn antenna with polar mount for satellite application. AZ-EL mounts are also available.

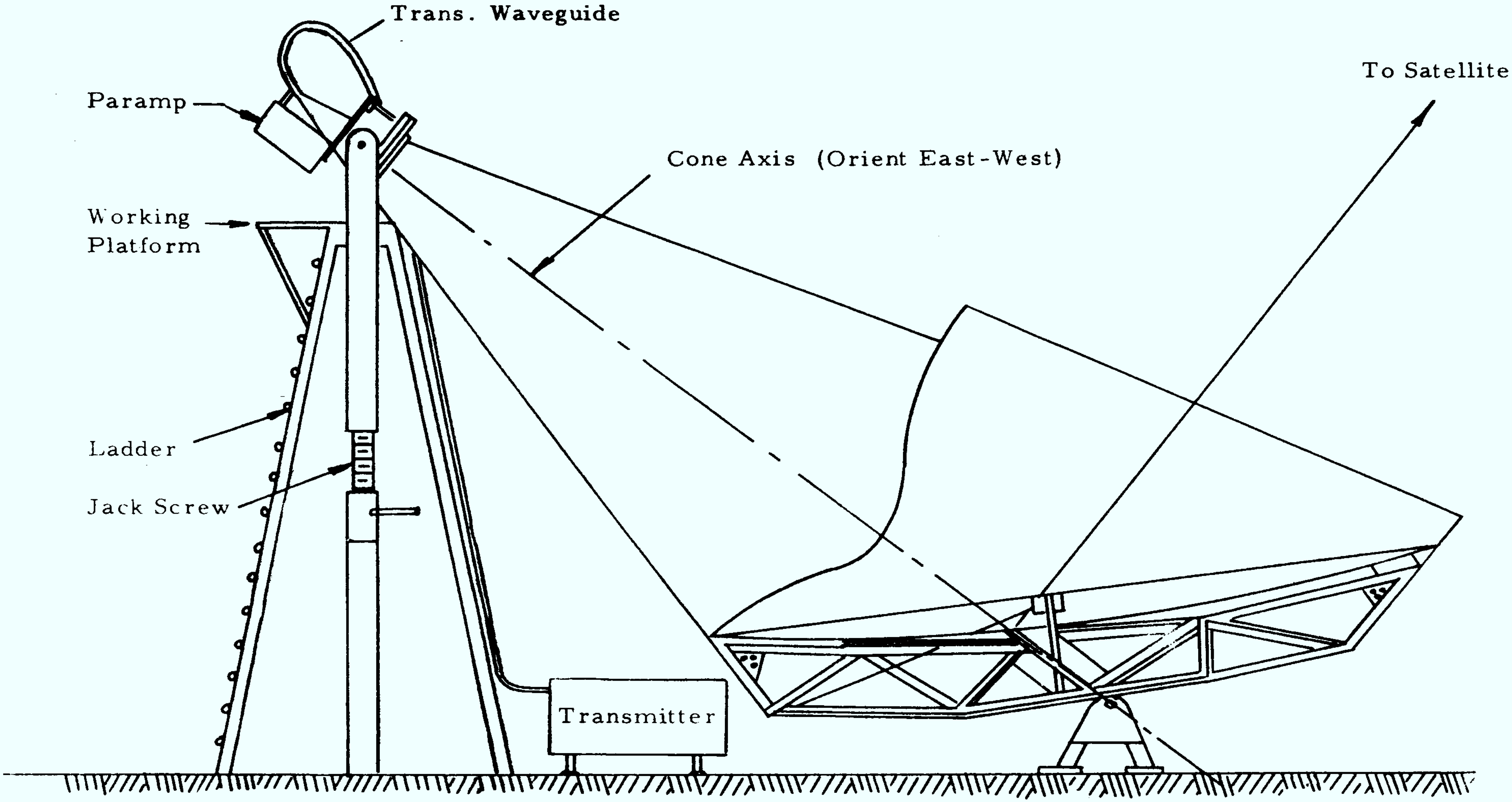


FIGURE 1
CONICAL HORN ANTENNA - POLAR MOUNT

Option: Can be equipped with programmed drive for N-S plane station keeping.

3. LOW NOISE AMPLIFIERS

3.1 General

The noise temperature of the earth station LNA is a major factor in determining the station G/T.

Thin Route stations employ two types of LNA

i Parametric Amplifier

ii Transistor Amplifier

While LNA designs may be temperature stabilized above or below room temperature, cryogenic cooling techniques are not applicable to the type of earth stations being considered due to reduced reliability and increased maintenance requirements.

3.1.1 Parametric Amplifiers

Parametric amplifiers consisting of one or two parametric amplifier stages followed by a transistor post amplifier are used where LNA noise temperatures of 50°K to 150°K are required.

High cut off frequency varactor diodes are used as the negative resistance element and pump sources are generally now solid state Gunn diode oscillators in the 10-50 GHz range. Klystron pumps are obsolete in this application.

Overall LNA gains of 30-50 dB are available. Full 500 MHz operation is generally provided, however if the optimum noise figure is required over one or two adjacent RF channels, narrowband tuning can be effectively used to achieve a reduction in noise figure of a few tenths of a dB.

Present approximate prices range from $30K U.S. for a 55°K unit to $12K U.S. for a 125°K unit.

North American Manufacturers include:

LNR Inc

Comtech

AIL

Northern Telecom

Scientific Communications Inc.

3.1.2 Transistor Amplifiers

Rapid development of GaAs FET (Gallium Arsenide Field Effect Transistor) technology since 1973 has produced major improvements in noise figures available with the transistor LNA.

Currently the state of the art for uncooled GaAs FET amplifiers is NF = 2.0 ± 0.2 dB over the full 3.7 - 4.2 GHz band. Amplica, Avantek, Watkins-Johnson and HP are the major suppliers in the U.S. where the market is dynamic and very competitive. The major advantages that transistor LNA's offer over parametric amplifiers (apart from cost) are small size, (high reliability e.g. 10^5 hours MTBF), simpler power supplies.

The heart of the low noise transistor amp is a GaAs FET device. Presently in use are three different geometries, with a 1.2μm, 1.0μm and 0.5μm gate width. The device noise figure depends largely on the gate width and respective noise figures are 2.9 dB, 2.2 dB and 1.5 dB. These devices are supplied by Nippon Electric and Hitachi, HP has recently supplied samples of FET's with performance between that of 1μm and .5μm gate width ports. In the NF range of 1.8 dB to 2.3 dB

Peltier cooling typically to -18°C may be used. Uncooled FET's are used up to 3.5 dB NF and bipolar transistors throughout are used in the higher NF amplifiers.

All two port amplifying devices exhibit a strong noise figure dependence on source impedance. FET's are particularly difficult to optimize over broad bandwidth because of the high Q at the input of the device. Compared with bipolar transistor, FET's require much closer matching to optimum source impedance for a given noise figure degradation. Therefore better noise figures are achieved only over narrower bandwidths. Present development work is associated with broadbanding the optimization of the device. Prices range from about $4K for the 1.8 dB NF model down to $1K for a 6.5 dB NF model.

4. UPCONVERTERS AND DOWNCONVERTERS

4.1 General

The function of the upconverter is to accept the multicarrier SCPC spectrum at IF (usually 70 MHz) and upconvert this spectrum to the assigned RF channel in preparation for further power amplification prior to transmission.

Similarly, the downconverter accepts the full (normally) 500 MHz satellite carrier spectrum from the LNA output, preselects the required RF channel, and downconverts this channel to IF (70 MHz, or other suitable VHF frequency).

These subsystems are widely manufactured in Canada and the United States both by specialist manufacturers, and by producers of radio relay system components.

4.2 Upconverters

Upconverters are generally one of two types featuring

a. single upconversion

b. double upconversion

Single upconverters are less complex than double upconverters, since only one local oscillator and one stage of mixing is used, frequency selection being performed at RF by waveguide type bandpass filtering, in a manner similar to standard FDM-FM radio relay upconverters.

Double upconverters feature two stages of mixing (and two local oscillators) with an intermediate frequency at VHF or higher e.g. 735 MHz or 1112.5 MHz. The double upconverter is usually selected where convenient frequency agility is required between RF channels since unlike the single upconverter, there is no necessity to change the channel selection filter when changing RF channels.

Particularly important in SCPC systems is the frequency stability of the transmitted carrier. This parameter is established in the design of the upconverter and is determined by the pull-in range of the particular type of channel unit demodulator used. If a typical demodulator can acquire over a $\pm$ 2 kHz range, and assuming all other sources of frequency error i.e. satellite translation, receiver translation are compensated for, then a frequency stability of $\pm$2kHz must be established in the upconverter. For a 6 GHz transmitted frequency this represents an oscillator stability of $\pm$3 parts in 10^7 over the long term. Achievement of these stabilities is well within current high stability crystal oscillator technology (i.e. $5X10^{-10}$/day) however, the requirement does have a major impact on the cost of the upconverter (NB this is two orders of magnitude more stable than radio relay upconverter) as it tends to require that the upconverter L.O. frequencies be synthesized from a low frequency (i.e. 1 MHz or 5 MHz) high stability master crystal oscillator rather than from a 3rd or 5th overtone subharmonically related crystal.

A final parameter which may have a major system cost impact is the upconverter output level. Generally speaking if the upconverter output power level exceeds 0 dBm per carrier, it may be possible to drive the transmitter directly. If the output is low in level e.g. -20 dBm, an intermediate power amplifier, at extra cost, is usually required. Other considerations involved in this choice are

a. the number of carriers to be transmitted

b. the multicarrier intermodulation limitations

4.3 Downconverters

Fundamentally the same trade-offs exist for downconverters as for upconverters except of course, for signal levels.

Frequency agility and improved adjacent RF channel discrimination are achieved at the expense of complexity and cost.

Frequency stability restrictions are usually less exacting than for the upconverter since some form of broadband spectrum centering is often performed at IF. For example the SPADE and Telesat systems employ spectrum centering with the aid of an unmodulated in band reference pilot tone. This technique removes those components of drift associated with the transponder and the earth station receiver.

4.4 Technology Aspects

Cost reduction in the up and downconverter subsystems can be approached in several ways, two of which are:

i Higher level of integration using advanced technologies

ii Reduced performance specifications

i High Level Integration

If the development costs were defrayable over an adequately large production run, integrated subsystems might be realised as follows:

GaAs FET LNA

Microstrip Mixer and 1st IF filter

Thick film IF amplifiers

Surface Acoustic wave IF filter

Oscillators would probably not be included in the integrated subsystem package at present because of size and thermal considerations.

ii Reduced Performance Specifications

Because of the narrowband nature of Thin Route carriers certain specifications can be relaxed in comparison with conventional wideband (video and telephony) up and down-converters e.g.

1. No group delay equalization is normally required

2. Gain ripple and gain slope are less critical especially in receive systems where demodulator AGC is employed and where preassigned transmit frequencies are used.

Currently very few Canadian manufacturers capability encompasses all or most of the above mentioned technologies, and since the demand is not very great we may expect most Canadian sources to supply fairly conventional up and downconverters for the present.

5. SCPC CHANNEL EQUIPMENT

5.1 FM Channel Equipment

FM SCPC systems have been manufactured by Hughes, California Microwave, Scientific Atlanta and RCA. Several systems are in use or planned for both domestic satellite systems and within the Intelsat network, e.g. Algeria, Indonesia, Alaska, Nigeria.

Figure 2 shows a functional block diagram of a California Microwave FM Channel unit which will be described below as representative of this class of commercially available equipment. Most data is extracted from Vandermark (1)

This system includes:

Pre-emphasis/de-emphasis
Compandors
Voice activation
Echo suppressor
Threshold extension demodulation
Demand assignment capability

The primary system parameters are as follows:

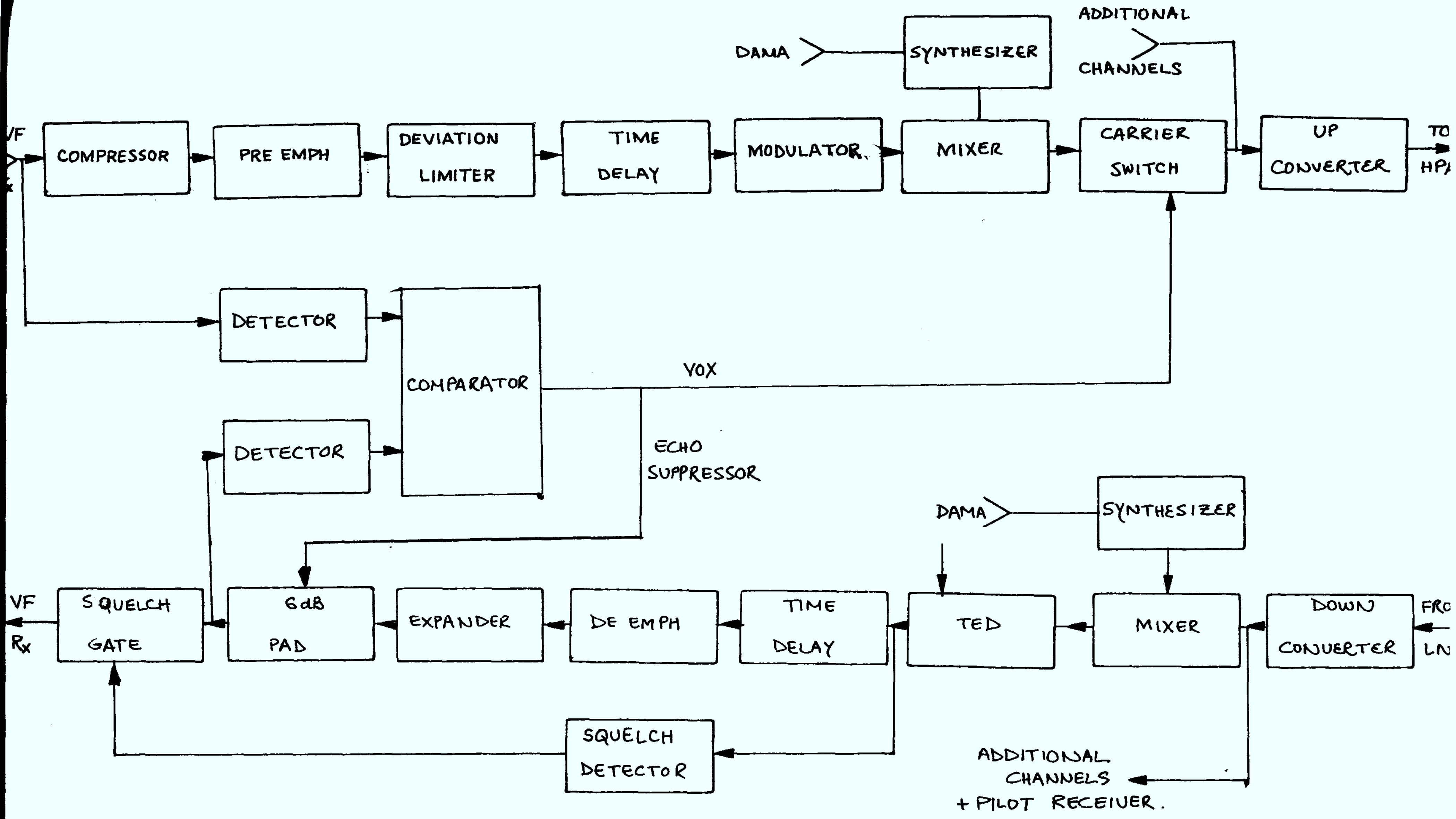


FIG.2 : FM-SCPC CHANNEL FUNCTIONAL BLOCK DIAGRAM.

Carrier Spacing 22.5 kHz or 45 kHz (i.e. 800/1600 ch in 36 MHz)

Test tone deviation 7920 Hz peak

Test tone 1000 Hz

Noise BW 26.7 kHz

Measured static Test Tone to Noise characteristics are shown in Figure 3 for the demodulator. Threshold (1 dB departure from linearity) occurs at 6.5 dB C/N.

Vandermark suggests a subjective compandor improvement of 17 dB be applied to the TT/N results for the case of the average talker, but implies that the full improvement is not realized at C/N's around threshold and below. Intelligibility down to 3 dB C/N is claimed.

The voice activation feature uses analog delay lines (CMOS bucket brigade) to provide 8 mS of unmodulated carrier prior to applying the voice. This prevents speech clipping in the demodulator during acquisition.

The compandor uses a 2:1 and 1:2 logarithmic compression/expansion

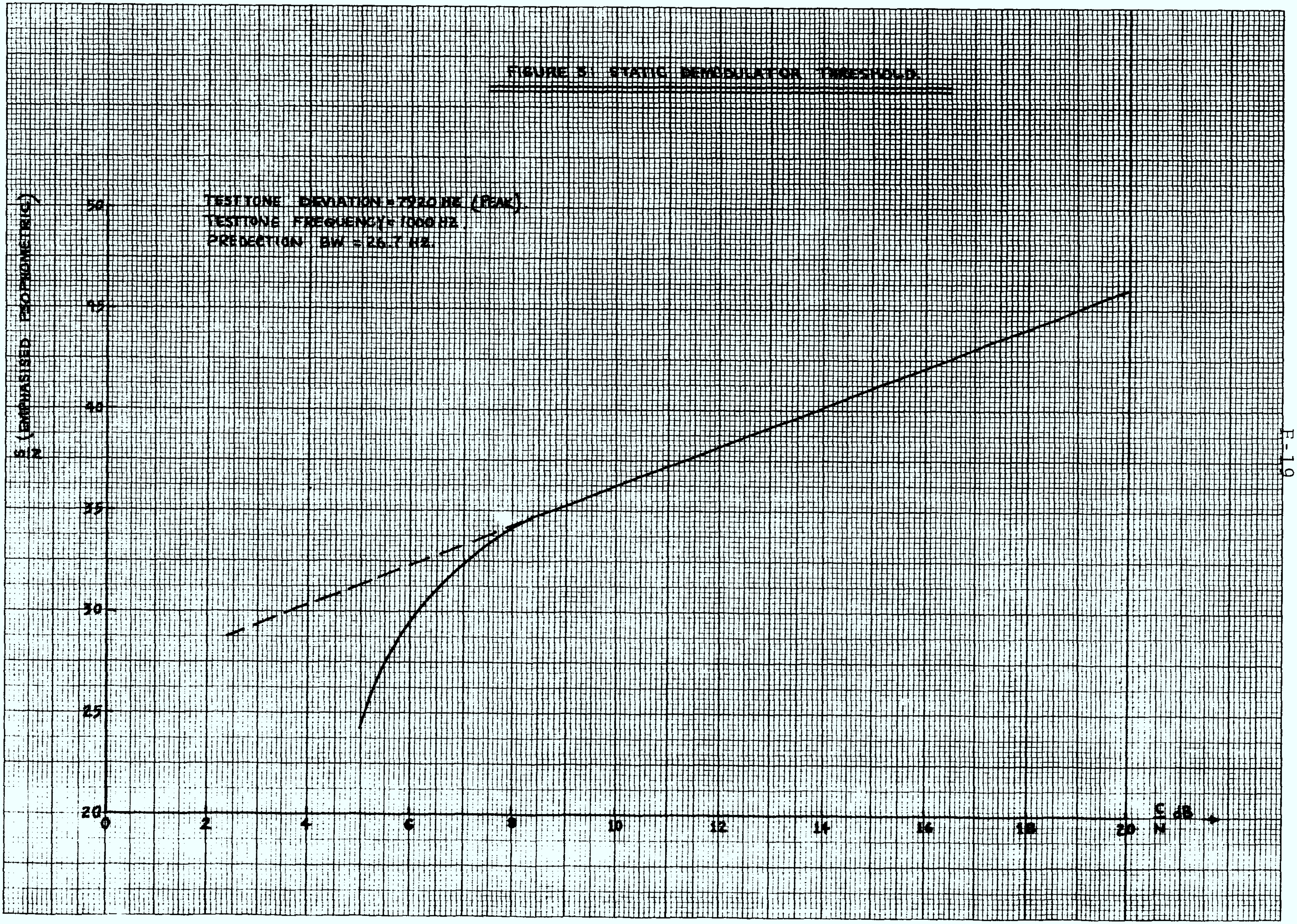


FIGURE 5: STATIC DEMODULATOR THRESHOLD.

laws with the unaffected level set at 0 dBmO.

Peak clipping level is set to the peak of a +4 dBmO test tone.

The built in echo suppressor meets the applicable CCITT recommendations.

Pre-emphasis of 6 dB per octave is used across the full voice band to give a calculated advantage of 6.3 dB.

The demand assignment control sequence is as follows for a shelf of 8 channel units in a DAMA network of 1600 channel units.

1. An 11 bit channel frequency assignment is bussed to all 8 transmit or receive channels ($2^{11} = 2048$) from the DAMA.

2. A 3 bit channel unit address is decoded by the SCPC equipment.

3. On receipt of a strobe pulse from the DAMA to the channel unit decoded by 2 above, the selected channel unit assumes the commanded frequency. The entire operation is performed in 20 mS or less.

Vandermark gives no information on the demand assignment system design.

An 8 channel SCPC terminal with redundant upconverters and downconverters will fit into a 7 ft. high standard radio relay rack.

Other applications for the CMI SCPC equipment are:

Voice Frequency Carrier Telegraphy

Data up to 9600 bps

Program Channel 15 kHz

Minor modifications and strapping changes are necessary for these non-telephony applications.

5.2 Digital Channel Equipment

5.2.1 General

Digital SCPC systems have been manufactured by General Electric, Raytheon Canada, Digital Communications Corp (DCC), SED Saskatoon, Nippon Electric and Fujitsu.

Intelsat's SPADE system is in service using 64 kbps PCM encoding and 4-phase CPSK modulation. Telesat's Thin Route network uses delta-modulation with 2-phase CPSK.

This section briefly describes DCC's STAC (STand Alone Channel Unit) which was specifically designed for earth stations with few channels. Much of the common equipment required to support channel units was reduced or eliminated with the aim of producing a less complex and therefore less expensive installation.

The STAC is available in several optional formats as follows:

5.2.2 STAC Options

Voice encoding:	32/40 kbps delta modulation
Modulation:	2 phase or 4 phase CPSK
Carrier spacing:	25 kHz, 60 kHz or to order
Voice activation:	optional
Signalling:	Interface modules available for E&M or SF signalling.

Echo suppressor: optional

Digital Multiplex: optional for simultaneous transmission of DM voice and data (1200 to 9600 bps) or telegraphy (50 to 300 baud).

5.2.3 STAC Configuration

Figure 4 shows a simplified block diagram of the STAC configured for a typical Thin Route application viz: voice, delta modulation 32 or 40 kbps, voice activation, 2 phase CPSK, without error correcting coding.

Some key features are as follows:

i The voice activation uses a digital speech detector rather than an analog level comparator.

ii A single frequency synthesizer is used to select both transmit and receive channels (NB This requires a paired carrier arrangement but reduces costs).

iii All timing and frequency references are contained in the Timing and Frequency Unit supplied with the first STAC. Subsequent expansion units are equipped

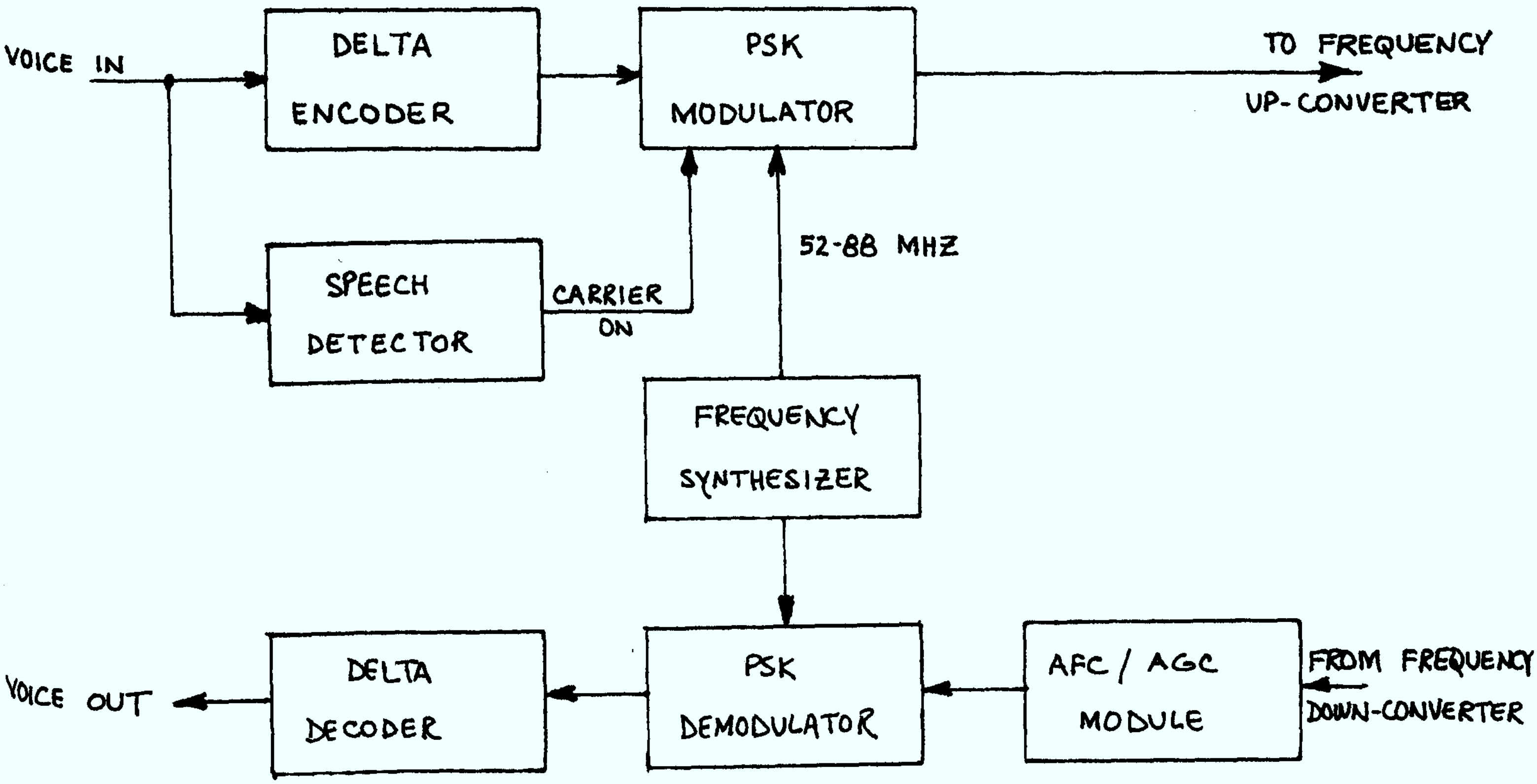


FIG. 4: SIMPLIFIED BLOCK DIAGRAM STAC UNIT.

with buffer amplifiers and use the original TFU references.

A similar arrangement is featured for the AFC/AGC function.

5.2.4 Performance

Claimed channel unit performance is shown in Table 2 and Figure 5.

TABLE 2

SPECIFICATIONS

DELTA CODEC

	Sampling Rate	
	32 kHz	40 kHz
Signal to Quantization Noise over 30 dB dynamic range	>25 dB	>27 dB
Frequency response 300-3400 Hz	±1 dB	± 1 dB
Linearity (1 kHz tone)	± 1 dB	± 1 dB
Intelligibility threshold	$BER=10^{-1}$	$BER=10^{-1}$
Idle noise	-60 dBm0	-60 dBm0

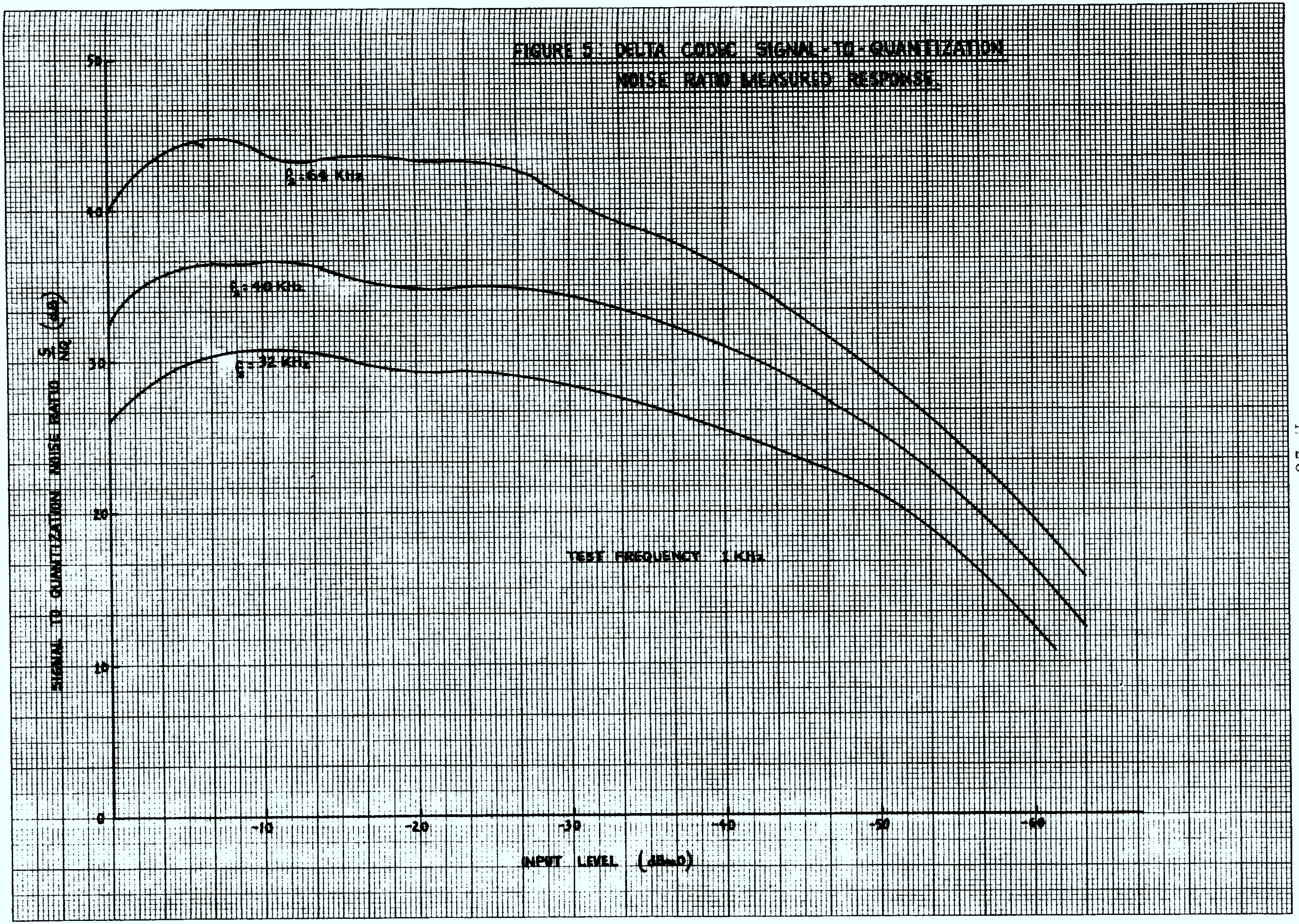


FIGURE 5: DELTA CODEC SIGNAL-TO-QUANTIZATION
NOISE RATIO MEASURED RESPONSE.
fs = 64 KHz
fs = 40 KHz
fs = 32 KHz
TEST FREQUENCY 1 KHz
SIGNAL TO QUANTIZATION NOISE RATIO S/NQ (dB)
INPUT LEVEL (dBm0)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60

PSK MODEM

	Two Phase	Four Phase
Ambiguity resolution	differential encoding	
C/N_o for 10^{-1} BER	46 dB-Hz	46 dB-Hz
Acquisition time	<5 ms	<5 ms
Occupied bandwidth for 32 kbps	50 kHz	25 kHz

FREQUENCY SYNTHESIZER

Operating range	52 - 88 MHz
Spacing between frequencies	Pre-selectable 20 to 60 kHz
Selection	
Manual	Thumbwheels
Auto/remote	Serial bit stream instruction
Stability	± 50 Hz
Impact of spectral purity on performance	<0.1 dB

5.3 New Developments

5.3.1 General

During 1975, published papers indicated that a substantial effort had been applied to the development of all digital channel units with the objectives of:

a. Improving reliability

b. Achieving designs capable of Large Scale Integration (LSI) which could be produced in large quantities at low cost.

Both Harris Electronics Systems, and I.T.T. published reports on these developments. The Harris equipment is briefly described here.

5.3.2 All Digital Channel Unit - Harris

The Harris channel unit (2) includes

i A 16 kbps adaptive delta modulation (ADM) codec on one monolithic integrated circuit chip.

ii Forward acting error correction codec.

iii All digital demodulator capable of operating at rates between 10 bps and 100 kbps.

i Delta Codec

The all digital ADM replaces each analog function contained in a conventional delta codec with a corresponding digital function. e.g.

i The syllabic filter is replaced with a recursive digital low pass filter

ii The multiplier and integrator are replaced by a network composed of an adder-subtractor and digital 10 bit latch.

The performance is claimed to compare favourably with the best syllabically companded ADM currently in use and the following unique features are claimed:

- extremely low power (less than 5 milliwatts)

- very low cost

- increased reliability, through use of a monolithic chip

- very small size, obtained through use of one chip

- stable operation, requiring no timing

- insensitivity to power supply variations.

The ADM encoder/decoder function was realized entirely in digital and resistive technology, all suitable for integration in CMOS I^2R technology. The result was one CMOS chip for one encoder or decoder function. The device was subjected to listener tests, and was found to provide greater intelligibility than other voice processors of comparable complexity and bit rate.

ii Error Correcting Codec

The coder-decoder (Codec) uses a constraint length 7 rate 1/2 convolutional code and a maximum likelihood soft decision decoder based on the Viterbi algorithm. The decoder is physically located in the same chassis as the Modem. The entire unit was designed for general satellite communications applications and can operate at any bit rate up to 100 kbits/sec. The codec provides an additional performance gain of 5 dB at a 10^{-5} error rate and a 3.7 dB gain at a 10^{-3} error rate.

The codec is completely self synchronizing and no additional circuitry or special procedures are required for it to operate properly.

iii Modem Design and Performance

The digital modem is designed to provide with a high degree of reliability, the modulation, demodulation, and coding operations at a low cost. This basic system is a full-duplex biphase PSK modulator/demodulator designed to be continuously tunable from 10 Bits/sec to 99.9 Kbits/sec. with no more than 1 dB degradation from matched filter performance. The modem consists essentially of two portions: carrier tracking loop and a bit synchronizer. The carrier recovery portion of this modem is essentially a digital phased lock synchronous sampler; a block diagram is shown in Figure 6. Coherent demodulation is achieved by first quantizing and sampling the input data stream four times a cycle with alternate samples directed to the data channel and phase channel respectively. Alternate samples are multiplied by plus and minus one and then fed into the corresponding digital channel filter. When the system is in lock, this process strips away the carrier

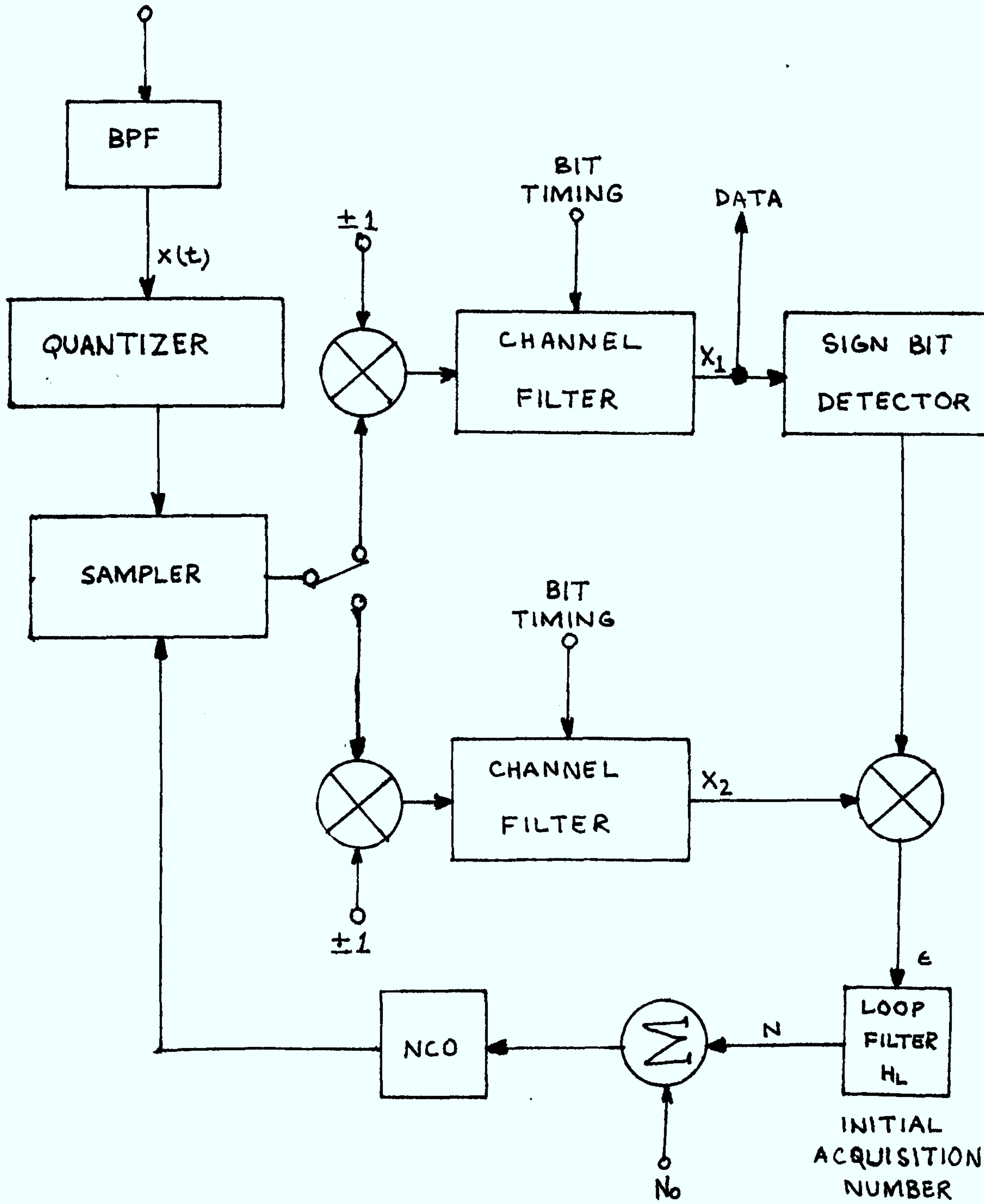


FIG. 6 : BLOCK DIAGRAM OF THE SYNCHRONOUS SAMPLER.

yielding the data stream in one channel and a signal representing the sampled phase error in the other channel. The filters in each channel provide filtering on digital sequences in such a manner as to reduce the broadband noise while passing the modulated data and have outputs which are clocked at the bit rate. The output of the phase channel is then multiplied by the sign of the data channel, to provide sign and magnitude information of the phase error, at which point this product is applied to the loop filter. This filter operates at the bit rate and provides integral plus proportional control of the error signal which drives the NCO. The NCO in turn controls the time at which the samples occur. At lock, the output of the data channel provides a signal on which data decisions can be made.

5.3.3 All Digital PSK Modem - I.T.T.

I.T.T.'s work is described in a paper given at the 1975 EASCON. The paper is not in the Conference record but is believed to be available from the Authors, J.G. Dunn, P.D. Carmichael, I.T.T. Defense Communications Division, Nutley, New Jersey.

6. TRANSMITTERS

6.1 General

This section considers the commonest type of 6 GHz transmitter - the travelling wave tube (TWT) and the solid state transmitter. Klystrons are not discussed as they are seldom used when TWTs are available in the frequency band and power range of interest.

6.2 Travelling Wave Tube Amplifiers

TWT's with power outputs of between 10W and 700W cover virtually all the requirements of Thin Route Systems at 6 GHz. Klystrons find application only where power levels of 700 W and above are required and are limited to instantaneous bandwidths of 40-50 MHz.

The TWT is a broadband (e.g. 500 MHz at 6 GHz) device capable of operating with multiple carriers. Typical gains of 30-40 dB per tube are realized, and the higher power units (100 W up) are often designed with integral TWT driver amplifiers to pro duce an overall unit gain of some 70 dB.

At power levels up to 35 W RF terrestrial TWT's use conventional glass envelopes; above this level metal/ceramic technology is

~~is~~ required for purposes of heat transfer.

Efficiency of a TWT amplifier is described in terms of RF power output divided by prime power input and is typically 10-20% for terrestrial tubes although improved efficiencies are achieved for space tubes.

Cooling is normally by natural convection for low power units, and by forced air for the higher powers. Liquid cooling is not generally used and would not be applicable for remote earth stations.

Manufacturers of TWTs include:

Varian
English Electric
Hughes
Raytheon
Siemens
Telefunken
Thompson CSF

The technology for these devides is quite mature and, with the introduction of the high power 100-600 W units for satellite communications in the last 3 years, would appear to be relatively complete, at least as regards the Canadian requirement where most Thin Route transmitters are 35W or less.

Approximate prices in Canada for TWTs complete with power supplies are currently $6K for 35W and $25-30K for 300 W, both in small quantities.

7. SOLID STATE MICROWAVE POWER AMPLIFIERS

7.1 General

This section identifies four classes of solid state power amplifier and briefly describes the capabilities of several different active devices in these amplifiers.

7.2 Classes of Microwave S.S. Power Amplifier

The four major classes of microwave S.S. power amplifier are:

i Microwave transistor amplifiers

ii Negative resistance amplifiers

iii Phase and Injection locked oscillator - amplifiers

iv Controlled avalanche transit time triode (CATT)

7.2.1 Microwave Transistor Amplifiers

Technology is developing very rapidly in this area both with MESFET's (GaAs Schottky-barrier field effect transistor) and with bipolar transistors and although transistor power amplifiers are not yet commercially available at 6 GHz, near term promise is excellent.

MESFETS are currently being developed for linear power amplification in the 4 GHz - 12 GHz frequency range. They are particularly suited for multicarrier operation where high efficiency at low intermodulation distortion is required. There is a good prospect of the MESFET for replacing medium power TWT's (1-5 W) in the "near" future.

BIPOLAR transistors are capable of providing several watts RF at 5 GHz in laboratory model multicell configurations and are thus currently ahead of MESFET's in power capability in the lower microwave bands. Because of the relatively low efficiency of bipolars, thermal considerations have a profound effect on performance and work is proceeding to improve heat transfer, typically using Beryllium Oxide heat sinks.

Output powers of laboratory devices have been reported as follows:

DEVICE TYPE	FREQUENCY (GHz)	P_{OUT_1}	EFFICIENCY	REFERENCE
MESFET	4.0	670 mW	35%	3
MESFET (balanced pair)	7.5	1 W	37%	4
MESFET	9.0	1.5 W	31.5%	5
MESFET	12.0	610 mW	13%	5
BIPOLAR	5.0	4.0 W	12-15%	6

7.2.2 Negative Resistance Amplifiers

Both Gunn devices and IMPATT devices are used as active elements for negative resistance or reflection type amplifiers (see Figure 7). By proper design of the diode package and mount together with an appropriate matching circuit the transformed input admittance of the device appears to have ~~a~~ negative real components. Hence the reflection coefficient at the input is greater than unity. This factor permits reflected power to exceed input power which is effectively a power gain.

Gunn devices with their lower dc to RF efficiency are limited in power output (e.g. 2W) due to thermal dissipation difficulties. IMPATT devices are capable of much higher power outputs.

Laboratory devices are reported as follows:

DEVICE TYPE	FREQUENCY	P_{OUT}	EFFICIENCY	REFERENCE
IMPATT (4-mesa GaAs)	5 GHz	11W	22%	7
IMPATT	9.2 GHz	4W	13%	8

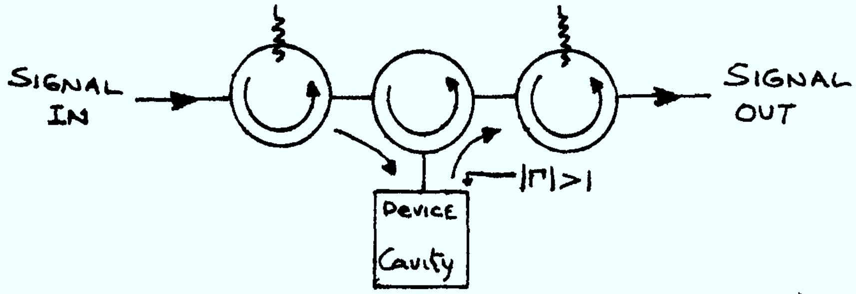


FIG. 7 : BASIC REFLECTION AMPLIFIER.

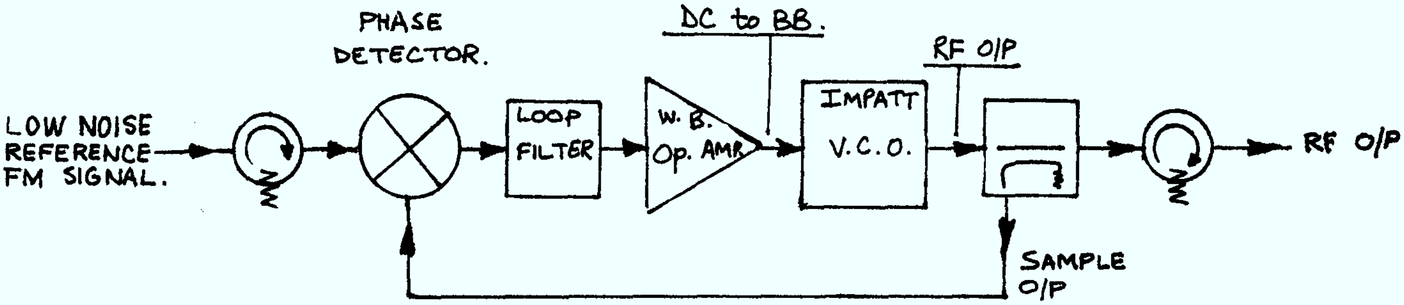
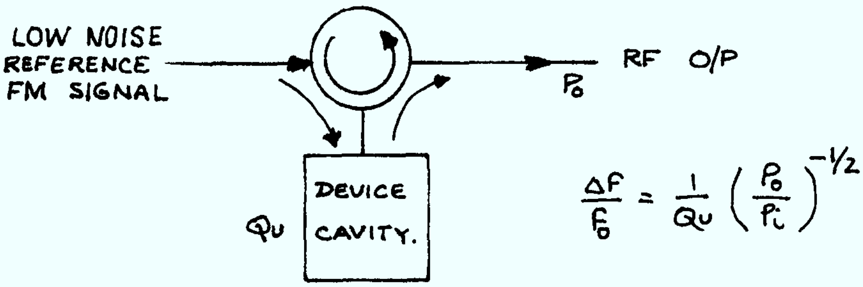


FIG. 8 : THE PHASE LOCKED OSCILLATOR - AMPLIFIER.



$$\frac{\Delta f}{f_0} = \frac{1}{Q_u}\left(\frac{P_o}{P_i}\right)^{-1/2}$$

FIG. 9 : BASIC INJECTION LOCKED - AMPLIFIER.

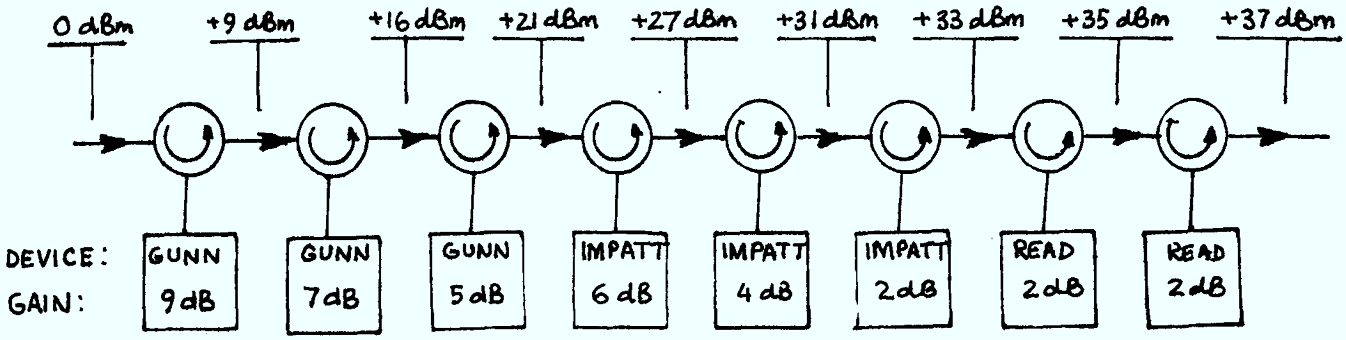


FIG. 10 : RAYTHEON'S ALL SOLID STATE TWT REPLACEMENT.

While the higher power silicon double drift IMPATTs have considerable advantages in terms of power and efficienty over the medium power single drift IMPATTs the latter devices are the more reliable at this time.

Commercially available negative resistance IMPATT amplifiers such as those produced by Hughes employ silicon single drift devices to yield output powers of up to 1.5W (single device) or 2.4 W (two devices hybrid combined) and a typical gain per stage of 4 to 10 dB.

7.2.3 Phase and Injection Locked Oscillator Amplifiers

Phase and injection locked oscillators (see Figures 8 and 9 respectively) are not true amplifiers but are oscillators which are electronically tuned with a varactor or "pulled" by injection phase locking. They are used in FM systems only since they do not possess an input to output power, linear transfer characteristic, only an input to output frequency shift proportionality (usually unity) relationship.

For both types of amplifier a locking bandwidth exists outside which the output frequency does not track the input. The power output of these types of amplifier is roughly equal to the oscillator power output.

The advantages of this type of amplifier are:

i High gains per stage are achievable e.g. up to 30-40 dB

ii The phase noise of the power oscillator can be suppressed (by suitable choice of parameters.) This means that a noisy power oscillator can be locked to a low level, low noise input signal and provide a high level, low noise output signal.

The main disadvantage is that neither type of amplifier is suitable for multicarrier operation.

7.2.4 Controlled Avalanche Transit Time Triode

A new type of solid-state microwave device, constructed with a blend of IMPATT and transistor technologies, promises to offer high power levels at higher frequencies than previous three terminal devices. Similar in structure to an n-p-n bipolar transistor, the CATT incorporates carefully designed avalanche and drift zones between base and collector regions. In a CATT, the charge giving rise to the collector current is primarily generated in the collector depletion region itself by avalanche multiplication of a relatively smaller injected signal. The result of this multiplication is that the collector current is substantially greater than the emitter current, and the E-B junction does not have to be turned on as hard to produce a given level of collector current. The CATT therefore operates with current gain greater than unity, even in a common-base design, leading to increased power gain over a transistor with the same emitter-base geometry. An S-band device reportedly offers a gain improvement of 6 to 9 dB over a similar bipolar transistor at 2 GHz. RF data for this CATT demonstrates a maximum efficiency of 27% at a 13.7 watt output, and a maximum output of 17.7 watts with 11 dB gain and 24% efficiency. RF data represents peak power output under pulsed operation, and was taken with a 70 volt bias. Although the efficiency is somewhat less than one would expect for a bipolar transistor at the same frequency, these CATTs are still in an early developmental stage. Based on simple theory, it appears that the collector efficiency of CATT devices can eventually reach 35 to 50%. The CATT was initially developed by Dr. Se Puan Yu, William R. Cady and Dr. Wirojana Tantraport of General Electric, and announced in the IEEE Transactions on Electron Devices of November, 1974, in a paper entitled" "A New Three-Terminal Microwave Power Amplifier".

7.3 C-Band TWT Replacements

In 1975 Raytheon (see Figure 10) and Bell Laboratories independently published results for development models of multistage C-Band (5.925-6.425 GHz) all solid-state replacements for the 10W TWT's used in 6 GHz FDM/FM Radio relay systems.

The applicability of these amplifiers in remote SCPC terminals is of immediate interest. The main technical considerations are:

a. Reliability
b. Noise performance

A tabular comparison of the two designs (9,10) is presented in Table 3.

PARAMETER	RAYTHEON AMPLIFIER	BELL LABS AMPLIFIER
Frequency	5.925 - 6.425 GHz	5.925 - 6.425 GHz
Power Output	10W	10W
Gain	40 dB	32 dB
No. of Stages	8 - 3 Gunn 3 IMPATT 2 Read	3 - All IMPATT
Noise Figure	20 dB	34 dB
Power	100 v dc 28 v dc	153 w dc

TABLE 3

8. TV RECEIVERS

8.1 General

A TV receiver for earth station use consists of the following major units:

1. Downconverter
2. Main FM Demodulator
3. Audio subcarrier Demodulator
4. Clamping Amplifier

The downconverter and main FM demodulator are the most critical elements as far as determining the receiver cost and performance.

The audio subcarrier demodulator and clamping amplifier are readily available commercial equipments with low cost impact and probably little scope for product improvement resulting in a cost reduction.

8.2 Downconverter

As discussed for SCPC applications the TV downconverter may be single or double downconversion depending on whether or not frequency agility is required. The single downconversion unit has a significantly lower cost.

8.3 Demodulators

8.3.1 Limiter Discriminator

The most commonly used FM demodulator is the Limiter-Discriminator which is often a wideband version of a conventional radio relay demodulator.

The limiter suppresses the A.M. noise during operation above threshold and retains only the zero-crossing information. The discriminator is a voltage to frequency converter which can provide excellent linearity.

The main limitation of the LD is the onset of threshold at 10 to 12 dB input C/N.

8.3.2 Threshold Extension Demodulators (TED)

Threshold Extension demodulators are important to TV receivers in that 2-4 dB of threshold extension (e.g. down to 7 or 8 dB C/N) can directly permit reduction of antenna size or system noise temperature thereby reducing the costs of these elements.

TV TED's are not currently in common use, but it is known that several companies (e.g. Hughes, California Microwave) are actively developing them.

The Hughes TED operates at 4 GHz and is thought to provide a 2 dB threshold extension (i.e. $C/N|_{th}$ = 8 dB) Early indications of price are in the $5-6K range in 100 quantity.

The two basic approaches to threshold extension are the

i Phase Lock Loop Demodulator

ii Phase Lock Loop Tracking Filter

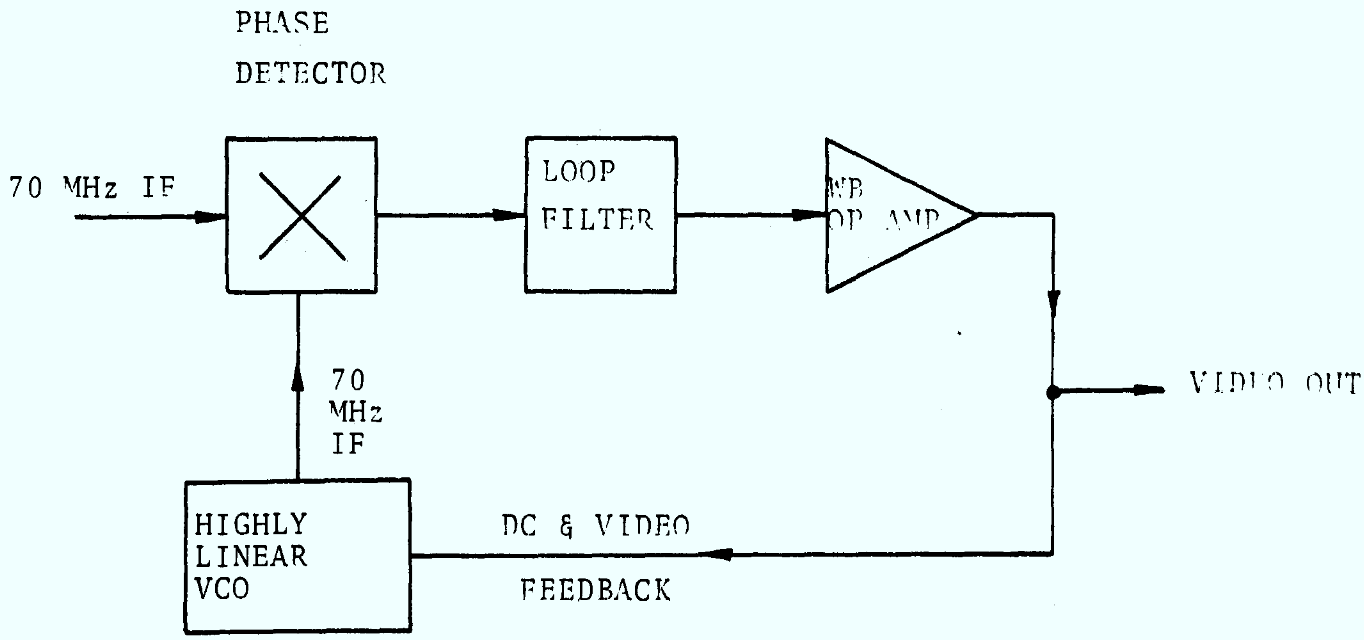


FIGURE 11

GENERAL PLL DEMOD AT I.F.

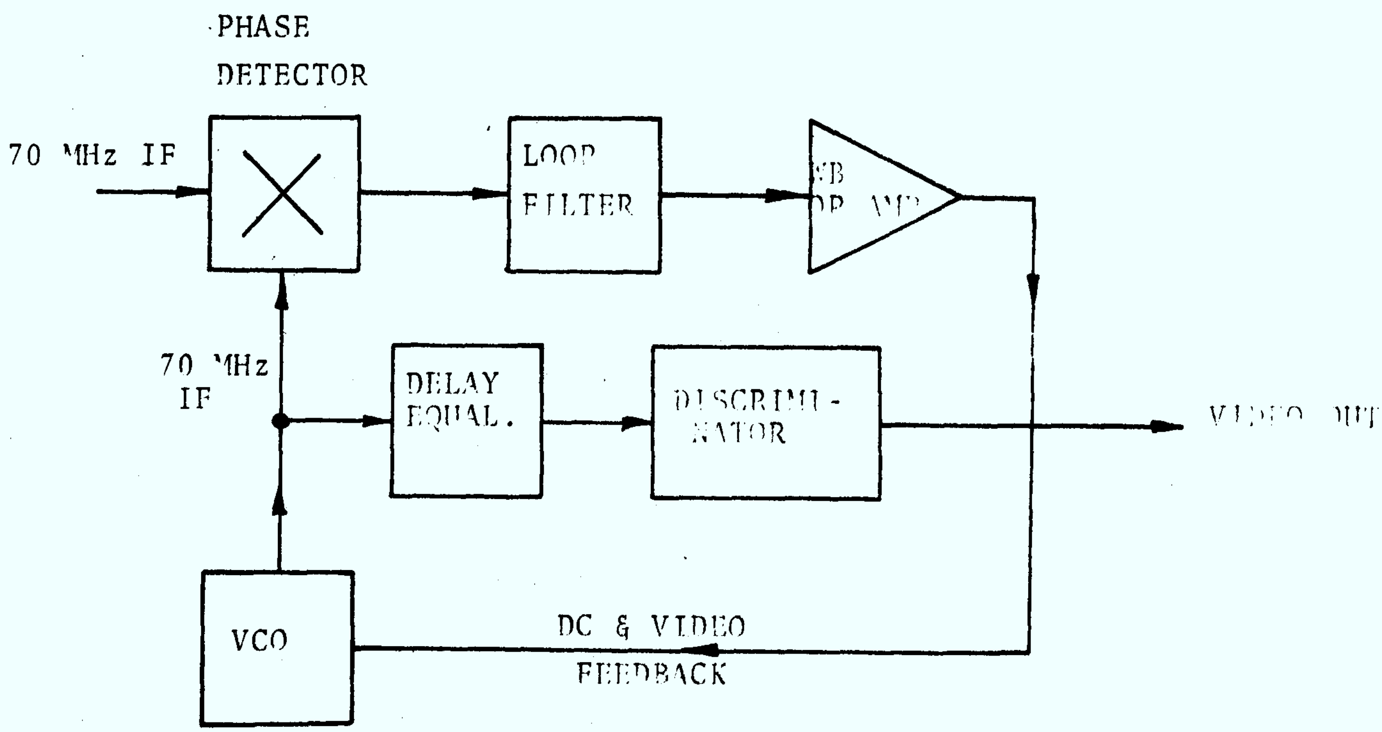


FIGURE 12

GENERAL PLL TRACKING FILTER TYPE
DEMOD AT I.F.

i The General PLL Demod at IF (see Figure 11)

This is just a simple phase-locked loop with a loop bandwidth equal approximately to the top baseband frequency. The VCO must be highly linear and therefore usually a combination of two oscillators at about 500 MHz and 570 MHz beating in a mixer are used to achieve high linearity with varactor tuning. The loop filter places a two times BB bandwidth over the carrier (approximately) and rejects some of the noise from an IF bandwidth that is wider than twice BB bandwidth. The noise power reduction is then proportional to the noise bandwidth reduction, thus threshold extension is attained.

ii General PLL Tracking Filter (see Figure 12)

The VCO in this case does not have to be of the high linearity type and the loop filter may be somewhat less than the baseband bandwidth

This should increase threshold extension even more than 2 dB. An appreciable portion of the distortion due to the VCO non-linearity is removed by the feedback gain in the locked loop, and accumulated group delay due to the reduced loop BW can be equalized prior to entering the discriminator (equivalent to the discriminator mentioned in 8.3.1). In general more complex schemes exist, but so far have not found widewpread use.

9. POWER SYSTEMS

9.1 General

Primary power requirements for small earth stations operating in Northern Canada range from 1 KVA to in excess of 20 KVA depending on the size of station, complexity of equipment, and de-icing provisions.

Most of the larger communities in which permanent earth stations are located will have local diesel generator plant to provide single phase or three phase 60 Hz a.c. supply to the earth station.

It utility a.c. is not available, the earth station must be designed for minimum power consumption from an alternate source.

9.2 Alternate Primary Power Sources

Alternative primary power sources include:

a. small transportable gasoline engine generators capable of providing up to a few kVA.

b. Thermo-electric (e.g. propane fuelled) generators

c. Radioactive isotope generators

d. Wind powered generators

The systems mentioned in a and b above require periodic refuelling and may be somewhat impractical for unattended operation.

Isotope generators are seldom used due to high capital costs and limited (several tens of watts) power capacity.

The most viable of all alternative primary power sources is probably the wind powered generator. Wind power is considered practical in areas with average wind speeds of 8 mph or greater. The generator is usually an alternator with diode rectifier bridge. Storage batteries are used in conjunction with wind generators and perform two main functions:

1. Supply voltage regulation

2. Energy storage for use during calm periods.

In order to obtain a.c. power from the system a d.c. to a.c. inverter is required.

Commercially available wind generators are usually "windmills" rotating about a horizontal axis although recent work at Canada's NRC has produced a vertically oriented windmill with some major advantages.

The largest wind generator in production would appear to be the Swiss Electro model WVG 50G capable of producing 6000W at a windspeed of 30 mph. The average monthly power output of this unit, with a 10 mph average windspeed, is 325 KW-HRS. This unit uses a 3 bladed propeller 16 ft. in diameter.

The cost of a 6000W, 115 V wind generator with automatic controls and voltage regulator suitable for unattended operation in winds up to 120 mph, including 40 ft. tower, 540 AH battery set and 3000 W d.c. to a.c. inverter is approximately $10,000 U.S.

Electro manufacturers other smaller wind generators with average monthly power outputs from 3 to 230 KW-HRS.

Maintenance on the wind driven plant is virtually nil - e.g.lubrication every 5-7 years so that a very high degree of availability should be possible.

10. SHELTERS

The main requirements for earth station shelters are durability, low thermal conductance, and minimum maintenance.

Several materials and construction techniques are used including:

1. Aluminum clad polyurethane foam
2. Steel or aluminum building insulated with polystyrene sheet.
3. Reinforced polyester skins bonded to a polyurethane foam core.

Polyfibre of Renfrew Ont. constructs shelters using nominal 4' X 8' sandwich panels with glass fibre reinforced polyester skins sealing a rigid polyurethane foam core. The overall thickness of the panels is 2 1/4" and the building provides thermal conductance of 0.065 BTU/hr./sq.ft./°F difference. Walls, roof and floor are all constructed in a similar design with the addition on the floor of an encapsulated deck of plywood under a glass fibre reinforced polyester laminate with a non-skid surface. The panels are molded, thus having integral joint configurations as well as molded-in door frames, window openings or other openings through the walls. Surfaces both inner and outer are gelcoated for low maintenance, and long term resistance to weather and the elements. The glass fibre reinforced polyester laminate is manufactured with a fire retardant grade of polyester which produces a flame spread rating of less than 20 using the ASTM-E-84 "Tunnel Test". The building construction is frameless and the structural panels have a load bearing capacity of 600 pounds/inch of length thus providing excellent stiffness and rigidity as assembled. The integrally molded joints fit together in an overlap pattern when assembled. The joint is sealed with a compressed impregnated, sponge type gasket providing excellent water penetration resistance. The double overlap feature of the joint allows the panels to be fastened (or screwed) when assembled eliminating a through wall conductor. The shelters can be erected in factory or on site. Flanges of the double overlap joint are factory drilled for ease of erection. The shelters are normally meant to be mounted on a rigid steel frame which also provides for easy attachment to building foundations as provided by the customer. Typical costs of their Mark 1 shelter (6' by 6' by 7' in height) is $2050 in the 10-20 units quantity range.

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COST EFFECTIVE OPTIONS FOR THE

THIN ROUTE AND TV BROADCASTING

NETWORK OF NORTHERN CANADA

FINAL REPORT

APPENDIX F

EARTH STATION SUBSYSTEM COSTS AND TRADEOFFS

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

April, 1976

APPENDIX F

EARTH STATION SUBSYSTEM COSTS AND TRADEOFFS

APPENDIX F

EARTH STATION SUBSYSTEM COSTS AND TRADEOFFS

1. INTRODUCTION

This Appendix gives a limited presentation of subsystem costs and introduces some of the cost tradeoffs in determining the key parameters of an earth station to meet required SCPC (single channel per carrier) performance.

The major tradeoffs in the design of a small aperture, low cost SCPC earth station are those concerned with the choice of antenna size, system noise temperature, EIRP per carrier, and number of carriers to be transmitted. The operational requirements of number of channels to be simultaneously supported in the satellite transponder and the quality of service to be provided (i.e., noise performance and margin to threshold) control the determination of the basic parameters - G/T and EIRP per carrier (reference Appendix B). Whilst contractual requirements might determine the choice of the number of channels to be initially fitted, design choices based on traffic studies and growth patterns as well as cost tradeoffs determine the provision for future growth. Since traffic studies only estimate growth rates, some arbitrary design choice must be made.

Another design consideration is the desirability that it be possible to add television and/or radio program service by simply installing the appropriate receivers. The initial remote earth station design should account for this in terms of configuration, space provision, power provision and possibly G/T.

Since progressive increases in satellite EIRP from future generation satellites are anticipated, it may be reasonable to provision only the minimum acceptable G/T. Alternatively, the initial design may accommodate a future increase in G/T obtained through a reduction in system noise temperature, replacing a transistor amplifier by an uncooled parametric amplifier, for example. Anticipated reductions in satellite saturating flux densities for SCPC systems might also be an inducement not to greatly oversize the earth station high power amplifier (HPA) to accommodate future growth.

2. BOUNDING OF STATION DESIGN

The plot of SCPC capacities with voice activation vs G/T given in Figure 13, Appendix B, indicates that the bandwidth limited capacity is reached for G/T's in the 17 to 20 dB/^{o}K range. Since a G/T of 20 dB/^{o}K can also provide excellent video quality (S/N $\simeq$ 48 dB-wtd), there is little point in considering G/T's greater than 20 dB/^{o}K. This G/T can be realized using a range of practical designs bounded by:

1. a standard 15' antenna plus 150^{o}K parametric amplifier, or

2. a standard 26.5' antenna plus 600^{o}K transistor amplifier

In order to achieve the lowest cost design meeting the system operational objectives it is necessary to conduct trade-offs to examine the impact on station cost of varying the key cost incurring parameters viz G/T, EIRP and number of carriers to be simultaneously transmitted from the earth station.

The lower bound on antenna size will be limited by adjacent satellite interference considerations and it is considered an antenna diameter below 12' will not be permissible.

Referring to required up-link EIRP vs G/T plotted in Figure 12, Appendix B, then, and assuming 55% antenna efficiency, the following table gives initial bounds on the specification of the remote terminal:

PARAMETER OR SUBSYSTEM	LOWER BOUND	UPPER BOUND
Antenna Diameter	12'	26.5'
G/T	15 dB/°K	20 dB/°K
LNA Temperature	150°K	600°K
Number of Channels per station	1	4
HPA Size	1 watt	100 watts

TABLE 1

In order to arrive at reasonable hypothetical models and a corresponding cost-effective earth station design, it is first required to assemble and present basic subsystem cost data (within bounds given), and examine the cost trade-offs.

3. SUBSYSTEM COST DATA

3.1 Subsystem Trade-offs (Antenna, LNA and HPA)

The tradeoffs surrounding the choice of the antenna, LNA, HPA and a number of SCPC carriers to be simultaneously transmitted are the most critical design/cost tradeoffs to be established. This section presents basic cost data obtained from manufacturers and determines the optimum combination vs G/T and number of channels required.

3.1.1 Cost Data Base

In order to provide a common data base from which capital costs for subsystems can be derived, it is necessary to process the information such that equipment is compared on an equal performance basis. This has not always been possible as equipment specifications have in some cases not been provided with the cost data. However, since costs are subject to change in any event, it is more reasonable for purposes of this study to concentrate on cost trends and tradeoffs, arriving only at "ball-park" figures used to compare various hypothetical models.

Cost data obtained from U.S. manufacturers has been changed to Canadian prices by adding 3% for exchange rate and 17.5% for customs duty. Note that the following have not been included:

- broker's fee
- transportation costs
- Provincial Sales Tax
- Federal Sales Tax

The results of cost data gathering are summarized in the following tables.

TABLE 2

4/6 GHz ANTENNA

DIAMETER (FT)	UNIT COST IN CANADIAN DOLLARS		
	QUANTITY 1	QUANTITY 10	QUANTITY 100
12	8,970	8,800	8,100
15	11,770	11,540	10,590
26	34,940	34,240	31,450
11.5	------	12,100	8,290
18	------	21,780	16,940
26	------	33,890	26,630
11	------	------	8,180
16	------	------	13,550
15	------	------	14,440

TABLE 3

6 GHz POWER AMPLIFIER

(including high voltage power supply)

POWER LEVEL (WATTS)	UNIT COST IN CANADIAN DOLLARS		
	QUANTITY 1	QUANTITY 10	QUANTITY 100
UP TO 20	6,000	5,400	4,890
" " 35	7,000	6,300	5,700
" " 50	8,000	7,200	6,500
" " 100	20,000	18,000	16,300
" " 400	35,000	31,600	28,500
" " 35	------	------	6,700
" " 50	------	------	13,790
" " 100	------	------	14,000
" " 50	------	------	16,700
" " 50	9,100	8,600	------
300/400	30,250	28,750	------

TABLE 4

4 GHz LOW NOISE AMPLIFIER COSTS

TYPE OF AMPLIFIER	NOISE TEMP	NOISE FIGURE	BAND WIDTH	GAIN	UNIT COST IN CANADIAN DOLLARS		
					QUANTITY 1	QUANTITY 10	QUANTITY 100
Transistor	200	2.3	500	48	4,540	4,050	3,300
	226	2.5	500	48	4,050	3,630	2,900
	262	2.8	500	48	3,330	2,970	2,240
	316	3.2	500	48	3.090	2,700	2,060
	375	3.6	500	48	2,720	2,420	1,820
	492	4.3	500	48	2,240	2,000	1,510
	695	5.3	500	48	2,000	1,820	1,390
	1000	6.5	500	40	1,630	1,450	970
Transistor	200	2.3	500	43	3,450	3,100	2,760
	200	2.3	500	57	4,600	4,140	3,680
	289	3.0	500	42	2,330	2,100	1,860
	289	3.0	500	56	3,990	3,590	3,200
	359	3.5	500	45	3,030	2,720	2,420
	527	4.5	500	40	1,720	1,560	1,380
	527	4.5	500	47	1,790	1,610	1,430
Parametric Amplifier	125	1.6	500	50	11,200	11,200	9,000
	150	1.8	250	50	6,800	6,800	4,700
Parametric Amplifier	135	1.7	500	50	------	------	11,320
	160	1.9	500	50	------	------	10,230
Parametric Amplifier	175	2.1	500	50	------	------	8,830

3.1.2 Minimum Cost Antenna - LNA - HPA Combination

Given the performance bounds established in section 2 and "typical" cost data derived from 3.1.1, minimum cost antenna - LNA - HPA combination for a range of system models were determined and are presented in Table 5. The following assumptions apply:

1. Subsystems are purchased in quantity 100

2. A minimum size HPA of 20 watts was used (i.e. solid state HPA's were not considered)

3. Antenna gain figures were calculated assuming 55% efficiency. The relationship between LNA noise temperature and G/T is plotted in Figure 1 for several antenna diameters.

4. The antenna/LNA/HPA's used are those commercially available.

5. Where parametric amplifiers were needed to meet the noise temperature requirement, a redundant configuration was used. This was done to produce a reliability approximately equal to that of single transistor

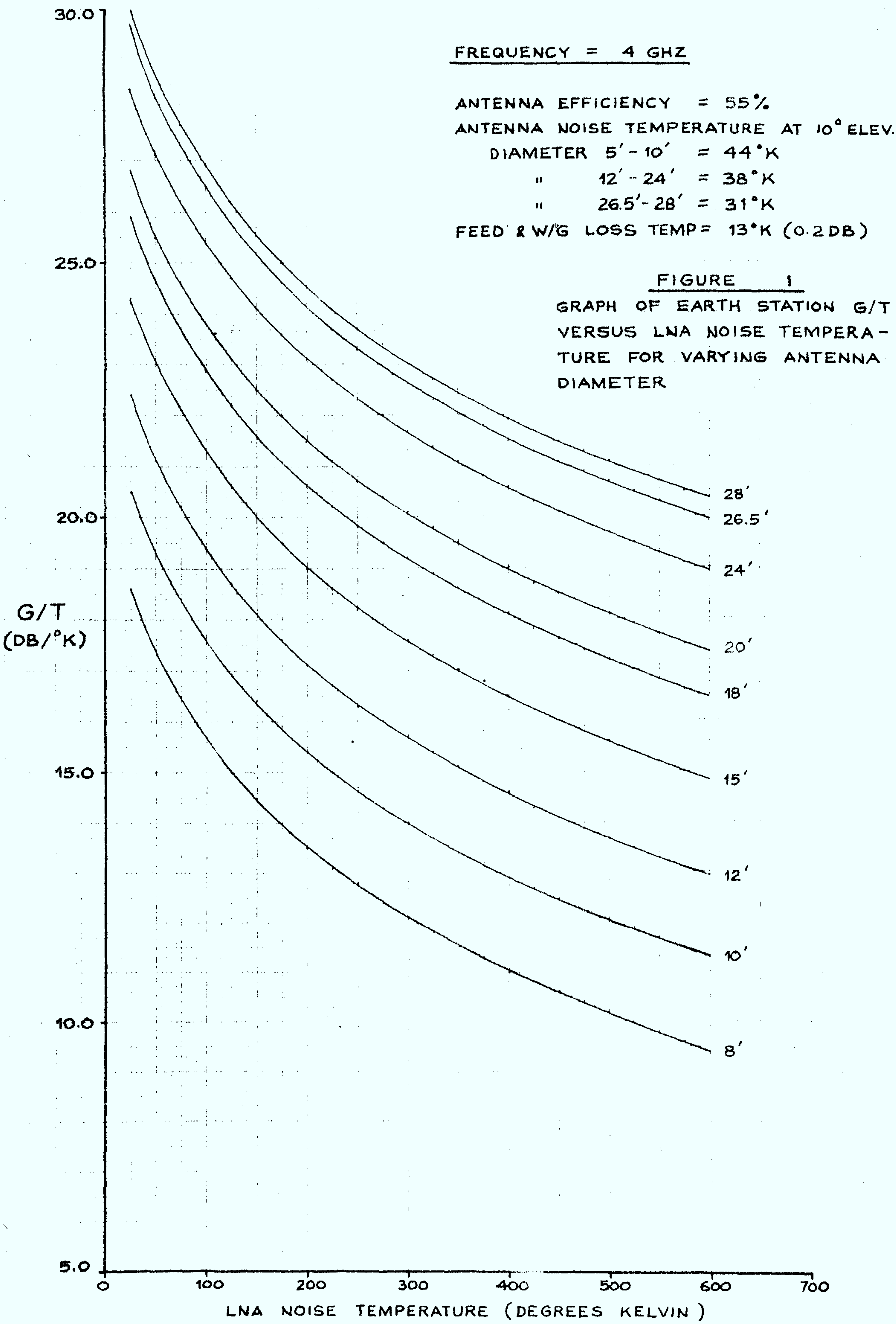


FIGURE 1
GRAPH OF EARTH STATION G/T VERSUS LNA NOISE TEMPERATURE FOR VARYING ANTENNA DIAMETER

TABLE 5

OPTIMUM ANTENNA - LNA - HPA COMBINATION VS G/T AND NO. CIRCUITS

G/T (dB/°K)	PERFORMANCE	NO. CHANNELS	ANTENNA DIAMETER (FT.)	LNA NOISE TEMP (°K)	POWER AMPLIFIER	COST OF ANTENNA + LNA + PA (CANADIAN $) [1]
20	10,000 pWpO	1	26	527	20 (1)[3]	37,720
			15	160 [2]	20 (5)	35,940
		2	26	527	20 (5)	42,610
			15	160 [2]	20 (5)	40,830
		4	26	527	20 (10)	42,610
			15	160 [2]	20 (20)	40,830
18	10,000 pWpO	1	15	262	20 (5)	17,720
		2	15	262	20 (10)	22,610
		4	15	262	35	24,230
15	10,000 pWpO	1	15	527	20 (10)	16,860
			12	359	20	15,410
		2	15	527	20	21,750
			12	359	35	21,920
		4	15	527	100	44,570
	22,400 pWpO	1	15	527	20 (5)	16,860
			12	359	20 (10)	15,410
		2	15	527	20 (10)	21,750
			12	359		20,300
		4	15	527	50	24,970

[1] Quantity 100 assumed

[2] Parametric amplifier in redundant configuration

[3] Calculated PA requirement where less than 20W indicated in brackets.

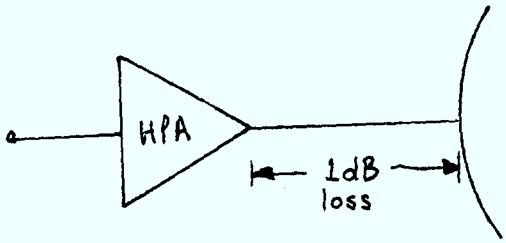
amplifier with system failure corrective maintenance only. The redundant configuration would provide somewhat lower maintenance cost (see section 4.5 Appendix D) but this factor has been ignored.

6. 10,000 pWpO performance using either 40 kbps delta-mod or companded FM with threshold extension is considered for the 18 and 20 dB/^{o}K G/T's. For the 15 dB/^{o}K G/T, 22,400 pWpO obtained with 20 kbps Δ or reduced bandwidth FM is also examined. Note that desired circuit quality influences the required EIRP per carrier into a given G/T, and therefore has impact on earth station HPA cost as well as transponder capacity.

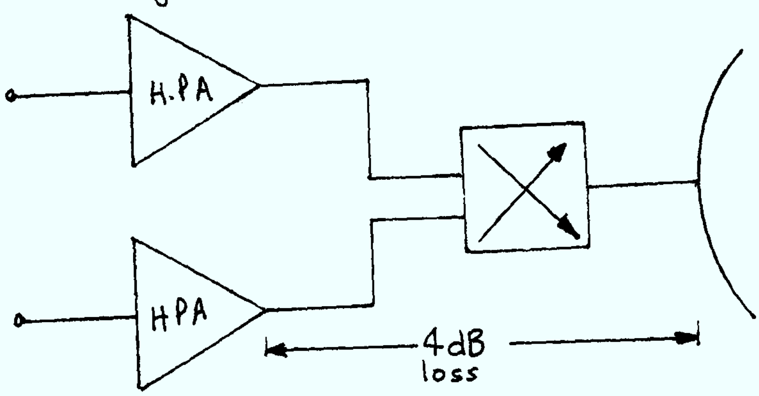
7. The following 1, 2, and 4 circuit configurations are assumed.

TRANSMIT:

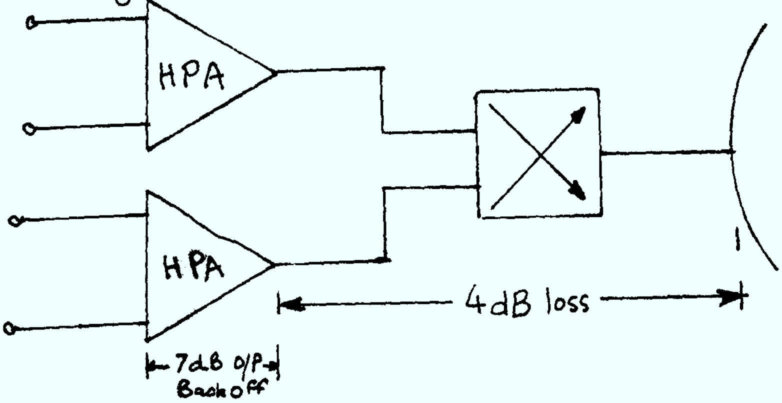
One Channel Configuration.



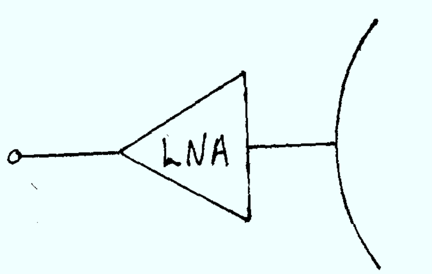
Two Channel Configuration.



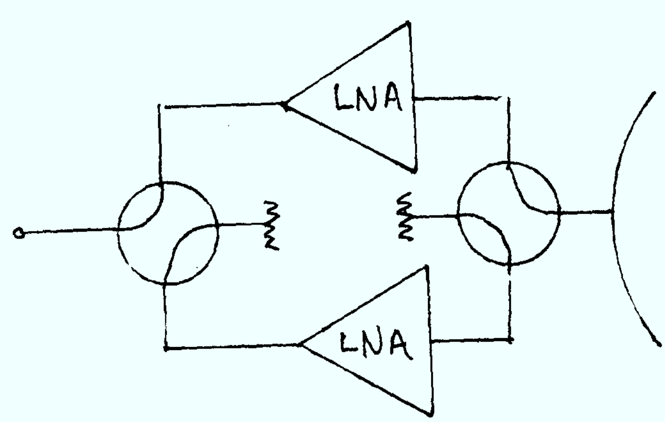
4 Channel Configuration.



Receive:



TRANSISTOR AMPLIFIERS



PARAMETRIC AMPLIFIER

3.2 Common Equipment

3.2.1 Introduction

The previous section 3.1 addressed the trade-offs which can be made to meet the operational and system requirements. In order to complete an earth station the following subsystems have to be considered to complete an SCPC station.

- Upconverters (I.F. to R.F.)
- Downconverters (R.F. to I.F.)
- Common I.F. Equipment (High I.F. to channel unit I.F.)
- Control and Monitoring Subsystems
- Power Systems
- Equipment Housing

In addition, design provision should be made permitting the ready addition of a television or radio program receiver.

3.2.2 Cost Data Base

It has been shown that it is possible to implement an earth station design with a significant portion of the equipment antenna mounted out of doors i.e. on the antenna structure. Since future stations have to account for growth of voice channels; addition of television and radio program receivers; the possible addition of broadcasters and telephone company equipment we have taken the more flexible approach of allowing for a small equipment shelter.

Predicted costs of such common equipment are shown in Table 6.

SUBSYSTEM	QTY 10	QTY 100
Up-downconversion Equipment	22,000	16,000
Common Equipment	7,000	5,000
Control and Monitoring* (including Demand Assignment)	7,000	5,000
Power Subsystem	5,000	5,000
Equipment Housing	6,000	6,000
Channel Units	4,000	3,000

TABLE 6

* The control and monitoring subsystem of a future thin route or multiple purpose earth station would affect the following functions:
  - Internal supervision and display of the communication equipment status to assist local diagnosis
  - The necessary detection, formatting and transmission of signalling information to set up and terminate calls (demand assignment)
  - Assembly and transmission of earth station equipment status for remote monitoring.

  It is perceived that these functions can be readily achieved by a simple microprocessor suitably programmed at low cost. The costs presented assume the above.

3.2.3 Agile and Non-agile TV Receivers

The agile receivers used in the Telesat system are capable of being remotely commanded to switch to any of at least six frequencies. To do this they have to be supported by peripheral equipment and the means of system control.

An audio subcarrier unit provides the means of receiving two program audio and a cue and control channel which interfaces a tone detector and command unit.

Thus the capital cost of a frequency agile receiver compatible with the existing Telesat system is

	QTY 10	QTY 100
Six frequency agile receiver	26,000	23,000
Compatible subcarrier audio unit	8,000	7,000
Tone Detector and Control Unit	4,000	3,500
Total Cost (excluding central control hardware and software rearrangement costs).	$38,000	$33,500

A non-agile receiver with one audio channel could be obtained for $10,000 (Qty 10) or $9,000 (Qty 100).

4. IMPLEMENTATION COSTS

Shipping, construction and installation in the North is extremely expensive. It is, therefore, important that earth station designs should be responsive to these factors to reduce overall implementation costs.

Since most remote communities not currently served by satellite or equivalent grade of service can only be reached by relatively small aircraft the size and weight of the equipment and materials required to construct the earth station has to be given serious consideration. Designs meeting this requirement have already been implemented.

Assuming the design of an earth terminal using typically a fifteen foot diameter and with a small (6'X6') equipment shelter typical direct project costs to implement are as follows:

Shipping of 15' Antenna and construction material*		$4,000	
Shipping of Equipment		$4,000	
Travel Costs	(1)	$2,000	survey
	(2)	$2,000	site development
	(3)	$4,000	equipment installation

Labour Costs	(1)	$2,000	survey
	(2)	$2,000	site development
	(3)	$3,000	equipment installation and testing

These costs are extremely location sensitive, however, a figure of about $25,000 per location for shipping, construction and installation in the North is appropriate for planning purposes.

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* The actual installation of a 15' antenna would cost only a few hundred dollars more than a 12' antenna for a Northern site. However, the transport costs could be significantly different since the 15' antenna has to be specially sectionalized to be carried in a small aircraft such as a Twin Otter. Since not all locations require air transport - some may have sea - or even road access - a suitable average planning figure might be that the 15' antenna could cost about $1000 more to ship and install.

The actual figure would have to be determined on a site by site basis.

5. STATION COST SUMMARY

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

TYPE	G/T	ANT.	LNA	HPA
1	18	15'	260°K	20 W tube fitted
2	15	12'	360°K	35 W tube fitted

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 during visits and discussions with manufacturers of systems and subsystems.

To get from the subsystem level to the selling price ex works we have used the "rule of thumb" of multiplying the hardware subsystem totals 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. Capital costs for the two types of earth stations are broken down in Table 7.

TABLE 7

	TYPE 1 STATION				TYPE 2 STATION			
	QUANTITY 10		QUANTITY 100		QUANTITY 10		QUANTITY 100	
	NR [1]	R [2]	NR [1]	R [2]	NR [1]	R [2]	NR [1]	R [2]
Antenna	11,540	11,540	10,590	10,590	8,800	8,800	8,100	8,100
Low Noise Amplifier	3,000	3,000	2,200	2,200	2,400	2,400	1,800	2,400
Power Amplifier	5,400	11,880	4,890	9,980	6,300	13,850	5,700	11,400
Upconverter Downconverter	22,000	45,000	16,000	33,000	22,000	45,000	16,000	33,000
Common Equipment	7,000	10,000	5,000	7,100	7,000	10,000	5,000	7,100
Channel Units	3,000	6,000	3,000	6,000	3,000	6,000	3,000	6,000
Control & Supervisory [3]	7,000	7,000	5,000	5,000	7,000	7,000	5,000	5,000
Power Equipment	5,000	7,000	4,000	5,000	5,000	7,000	4,000	5,000
Equipment Shelter	6,000	6,000	5,000	5,000	6,000	6,000	5,000	5,000
HARDWARE PACKAGE TOTAL	69,940	107,420	55,680	33,870	67,500	106,050	53,600	82,400
FEDERAL SALES TAX 12%	8,393	12,890	6,682	10,064	8,100	12,726	6,432	9,888
Engineering & Manuf (1.5/10 1.3/100)	104,910	161,130	72,384	109,031	101,250	159,075	69,680	107,120
Profit (Included)								

[1] One non-redundant voice-activated/demand assigned circuit

[2] Two parallel redundant voice-activated/demand assigned circuits. Non reduncant transistor LNA

[3] Includes demand assignment capability

6. CONCLUSIONS

The cost trade-offs indicated in sections 2 and 3 of this Appendix indicate the impact of and need for bounding the design if low cost is to be achieved.

It is also clear that implementation costs are significant and are highly labour and transportation dependent.

Earth stations without redundancy are being implemented in the existing operational system and with constantly improving reliability. There is reason to expect that an even higher grade of service can be cost effectively achieved using highly reliable equipment without redundancy in future earth station designs.