DOMESTIC LONG-DISTANCE COMMUNICATIONS NETWORK STUDY

COMMUNICATIONS SYSTEMS ENGINEERING

TRAFFIC CAPACITIES AND COSTS OF TERRESTRIAL FACILITIES

ASSOCIATED WITH A SATELLITE OF THE ANIK TYPE

USING DIGITAL MODULATION TECHNIQUES

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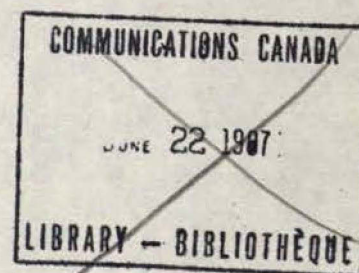
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DLDCNS Report NO.:   5

Date of Issue: July 1973

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USING DIGITAL MODULATION TECHNIQUES

Abstract

The report is of an interim nature and provides early
input to the long haul traffic study on tradeoffs
between the traffic capacity and cost of terrestrial
facilities associated with a satellite system of the
ANIK type using digital modulation techniques.

TABLE OF CONTENTS

1. INTRODUCTION

This report is of an interim nature to present earth station and backhaul costs relating to the 4/6 GHz frequency bands for use in the current Domestic Long-Haul Communications Network Study.

This report is of an interim nature to present cost and traffic handling abilities of the techniques which are felt to be the most viable for 4/6 GHz satellite facilities of the current Telesat type handling long-haul traffic. The information will provide early input to the Domestic Long-Haul Communications Network Study and although the cost and traffic handling figures given are valid for the techniques used, the techniques themselves may require further justification and perhaps modification based on alterate techniques and the ultimate television and message traffic requirements.

The techniques for providing Thin Route service to remote areas are not considered at the present time as the requirements are reasonably well known and may readily be taken into account at a later date.

2. CURRENTLY PREFERRED TECHNIQUE FOR HANDLING SATELLITE VOICE TRAFFIC

On the basis of knowledge to date Time Division Multiple Access (TDMA) has been selected pending further justification as the optimum satellite operational technique for handling voice traffic.

The initial Telesat long-haul satellite system was based on analog FDM-FM-FDMA techniques (FDMA), which are the simplest method of sharing a satellite transponder between three or four earth stations. However, in order to avoid excessive intermodulation noise generated when several carriers are passed through the output travelling wave tube (TWT) in the satellite transponder, it is necessary to operate the TWT in a more linear region by reducing the carrier levels at the input to the TWT. Thus the satellite transmitted power decreases and efficiency, in terms of message circuit capacity, falls off rapidly as the number of accesses to the transponder is increased.

If it is envisaged that in the future several more access points may be added to the current long-haul transponder channel, a digital system using TDMA techniques becomes superior in overall capacity to the previous FDMA techniques. Such a system allows each earth station, in turn, to access the whole satellite transponder for a short period of time. Since only one carrier is passed through the transponder bandwidth at any instant in time the full power of the transponder can be utilized.

Other modulation techniques are, of course, available, however, TDMA currently does appear to provide the most favourable capacity/cost parameters when more than four accesses are required. TDMA equipment can readily

accommodate changes in circuit requirements between different locations and can cater for different service needs such as **voice**, facsimile or data. Recent developments, leading to such capacity enhancement techniques as speech predictive encoding (SPEC)[2.1], and fully variable demand assignment can be added to the system. Fully variable demand assignment requires the addition of a Demand Assignment Controller to apportion access times to the earth stations and set up and control address codes so that circuits between earth stations may be handled on an individual basis in real time.

2.1 REFERENCES

2.1 Speech Predictive Encoded Communications
S.J. Campanella and J.A. Sciulla
Telecommunications Numeriques Par Satellite
Paris 1972   Paper E-4.

3. TECHNIQUES FOR HANDLING TELEVISION SIGNALS

Television signals over a satellite network may be handled in either an analogue or a digital format, but the digital format appears very favourable.

Various requirements and constraints can dictate whether television signals should be transmitted over satellite facilities in an analogue or a digital format. Frequency modulation (FM) is the most widely used today and such equipment is readily available at reasonable cost. However, if a digital type modulation is favoured for handling voice traffic at 4/6 GHz then, because of the terrestrial backhaul facilities, digital transmission may be preferable to analogue transmission. The costs for either mode of television transmission are given in the current report (see Section 11). The variable costs given in Section 15, however, are valid only for digital television techniques.

An F.M. system will degrade smoothly as the system carrier-to-noise ratio degrades provided, of course, the system threshold is not reached. The video performance obtained is, therefore, a function of the system carrier-to-noise ratio and can be adjusted by altering the system deviation and carrier power. Telesat is currently transmitting F.M. television into remote areas through earth stations having a G/T of 26 dB using 26 foot diameter antennas. To carry programme channels along with the video signal, however, sub carriers are necessary, necessitating an increase in the R.F. bandwidths.

A digital system, on the other hand, with error concealment built into the coding/decoding equipment to allow operation over normal transmission paths at error rates down to 1×10^{-4}, will give a quality of performance, provided the system threshold is not reached, which is independant of the carrier-to-noise ratio in the transmission path. Moreoever, digital techniques can achieve very high efficiency in bandwidth utilization compared with F.M. techniques and can readily incorporate programme channels with the video signal without a significant penalty in bandwidth or power. Although such factors may not be of particular significance for the purposes of the present report, these factors do indicate that digital transmission of video is likely to be highly favoured in the future. The digital system which currently is of the greatest interest is the Comsat "Ditec" system[3.1] and this is the system considered in this report (see Section 11). A brief system calculation showing that a "Ditec" system operating in the 4/6 GHz band will operate into an earth station having a G/T of 27.0 dB is given in Section 3.1. In this instance, of course the quality of transmission would be better than in the foregoing FM case. However, in order to be able to receive "Ditec" transmissions in the remote areas it would be necessary either to improve the current Telesat Remote TV station receiver by 1 dB or, since adequate transponder bandwidth is available, apply spectrum spreading techniques to the "Ditec" signal. Thus if the earth station size were to be set purely by television requirements the minimum fixed cost of the earth station required would be $400k (see FIG 8.1 or 9.1). This would correspond to a maximum two-way voice circuit capacity through the earth station of 425 circuits without SPEC or 850 circuits with SPEC.

3.1 CALCULATION OF MINIMUM EARTH STATION REQUIREMENT FOR USE WITH 'DITEC'

The required system carrier-to-noise density $^C/N_0 B$ for the "Ditec" system is given by:

$$(^C/N_0 B) = 10\log R + (^E/N_0) + Mi - 10\log B + 0.4$$

where   R = Transmission bit rate (33.6 M bits/sec)

$(^E/N_0)$ = Energy to bit density ratio (8.4 dB)

Mi   = Implementation margin (4.0 dB)

B   = Required bandwidth (20.4 MHz)

0.4   = Up link contribution to down link.

Thus $(^C/N_0 B)$ = 15.0 dB.

The required earth station $(^G/T)$ is given by

$$(^G/T) = (^C/N_0 B) - EIRP - 228.6 + 10\log B + Lp$$

where EIRP = Satellite isotropic radiated power (33 dBW)

Lp = Down path loss (200.3 dB)

Thus $(^G/T)$ = 26.8 dB.

3.2 REFERENCES

3.1   Ditec - A Digital Television Communications System for Satellite Links
      L.S. Golding   Telecommunications Numerique par Satellite
                                      Paris 1972.

4. METHOD OF PRESENTING COST DATA

The earth station and backhaul costs, as a function of two-way voice circuit capacity, will be split up into fixed and variable costs in order that the fixed costs may be apportioned depending on the number of separate satellite transponders accessed by each earth station.

The report presents costs as a function of the two-way voice circuit capacity of an earth station and includes the cost of the backhaul facilities. The earth station and backhaul facilities will be split up into fixed and variable costs in order that the fixed cost may be apportioned depending on the number of separate transponders accessed by each earth station. The fixed costs for both the earth station and the backhaul take into account such items as:

- Land, access roads, utilities
- Buildings
- Antenna
- Standby Power Equipment.

The variable costs for both the earth station and the backhaul take into account such items as:

- Transmit and receive equipment
- Terminal equipment.

In order, therefore, to determine the cost for a certain traffic requirement the variable cost of the earth station and backhaul equipment for that particular traffic requirement must be summed. The fixed cost of the earth station and backhaul facility, having been apportioned on the basis of the number of separate transponders accessed by the earth station, can then also be summed. The total cost of the earth station and backhaul facilities can then be determined for the particular traffic requirement by adding together the resultant fixed and variable costs.

5. THE ESTABLISHMENT OF EARTH STATION PARAMETERS

As a means of establishing earth station parameters for use in the 4/6 GHz band the current Telesat earth station parameters have been used to establish guidelines.

Ideally the satellite communications network should be designed based on the voice and television traffic requirements separately. Such a procedure would enable an optimum balance to be struck between the space and ground segment costs. Currently the traffic requirements are somewhat undetermined and, therefore, as a means of establishing earth station parameters in the 4/6 GHz band the Telesat earth station parameters have been used as a guideline. These parameters are summarized in Table 5.1. and have been used to establish the parameters of earth stations of different size for use in the current study.

TABLE 5.1.

EARTH STATION PARAMETERS				
Dish Size	Heavy Route	Network TV	Remote TV	Northern Telecom.
	97 ft.	33 ft.	26 ft.	33 ft.
Manned or Supervisory control	20 staff	Supervisory/ 4 staff	Supervisory	Control and Supervisory
Deicing	Yes	Yes	Yes	Yes
Tracking	Simplified Tracking	No Tracking	No Tracking	No Tracking
Primary Power	Uninterrupted Battery + Diesel	Uninterrupted Battery + Diesel	Battery Standby	Uninterrupted Battery + Diesel
Redundant Tx or Rx	Full redundancy	Full redundancy	No redundancy	Full redundancy
G/T	37 (G=59 T=22)	28 (G=50 T=22)	26	28 (G=50 T=22)
EIRP	84dBW (P = 21dBW)	83dBW (P = 30dBW)	---	73dBW (P = 20dbW)

6.   FIXED COSTS DATA FOR EARTH STATIONS

Cost data relating to the fixed costs of earth stations based on the Telesat earth station parameters have been obtained from Telesat press releases, Comsat and various manufacturers.

The fixed costs of the earth stations have been determined in relation to the earth station gain-to-noise temperature ratio (G/T). Costs have been obtained from Telesat press releases, Comsat documents and communications with various suppliers. The results are tabulated in Table 6.1. and covered in more detail in the following paragraphs.

a) The cost of land, buildings and utilities has been obtained from Telesat press releases [6.1, 6.2] and Comsat information on typical relevant earth stations.

b) Antenna tracking requirements are based on the surface finish specified and the possible off-axis allowance from the main beam which will meet the specified satellite drift. At 4/6 GHz some form of tracking would be required for antennas in excess of 40 ft. diameter with a more sophisticated form of tracking required above 60 ft. diameter. The installed cost of an earth station antenna, exclusive of feed and duplexer, is given in Figure 6.1.

c) The cost of wideband redundant low noise amplifiers is given in Figure 6.2. Discussions with suppliers such as AIL Micromega and IMC have tended to confirm the costs given for low quantity production.

d) The cost of power dividers, antenna feeds and duplexer equipment has been determined in conjunction with discussions with Bell-Northern Research personnel.

e) The cost of staff or supervisory equipment has been based on the Telesat staffing or supervisory equipment requirements indicated in Table 5.1. The average cost of staff has been estimated at $13K per annum.

f) The cost of standby power and de-icing equipment has largely been determined from Comsat information with some input from Bell Canada documentation.

6.1   REFERENCES

6.1   Telesat Press Release #8   May 19, 1971.
6.2   Telesat Press Release #11   July 23, 1971.

TABLE 6.1.

| FIXED COSTS OF EARTH STATIONS				
	$G/T = 37$	$G/T = 35$	$G/T = 28$	$G/T = 20$
Land, Building, Utilities	480k	280k	120k	80k
Antenna	(97 ft.) 935k	(75 ft.) 685k	(33 ft.) 35k	(26 ft.) 30k
Low Noise Amplifier	(T=22) 32k	(T=22) 32k	(T=22) 32k	(T=28) 7k
Power Divider, Antenna Feed and duplexer	75k	75k	15k	10k
Staff or Supervisory equipment	260k	175k	60k	15k
Standby Power Supply Equipment	150k	145k	140k	40k
De-icing Equipment	50k	38k	2.5k	2.5k
TOTAL	1982k	1430k	404.5k	184.5k

INSTALLED ANTENNA COST

FIG 6.1

16
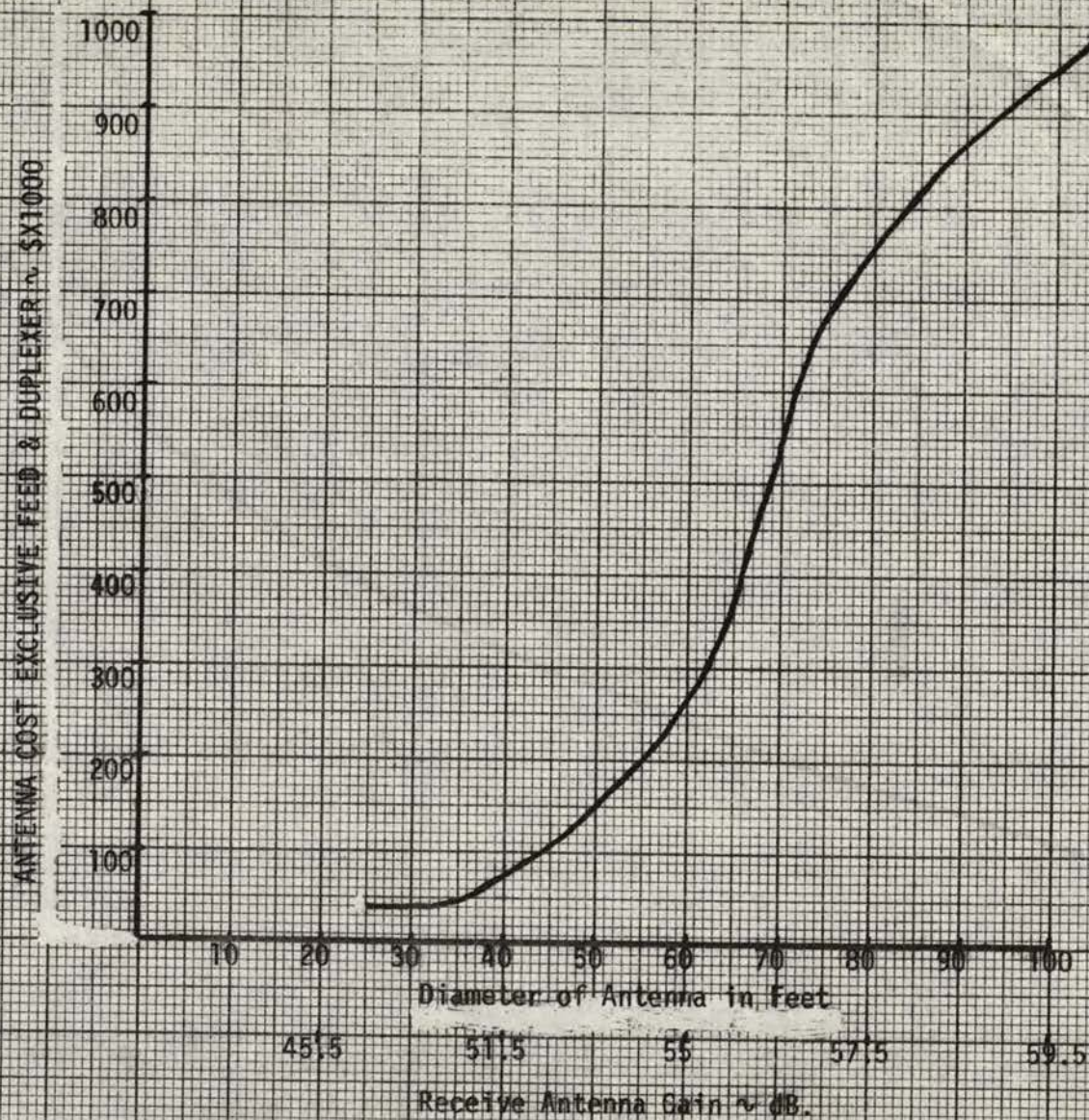
INSTALLED COST OF REDUNDANT LOW NOISE AMPLIFIERS
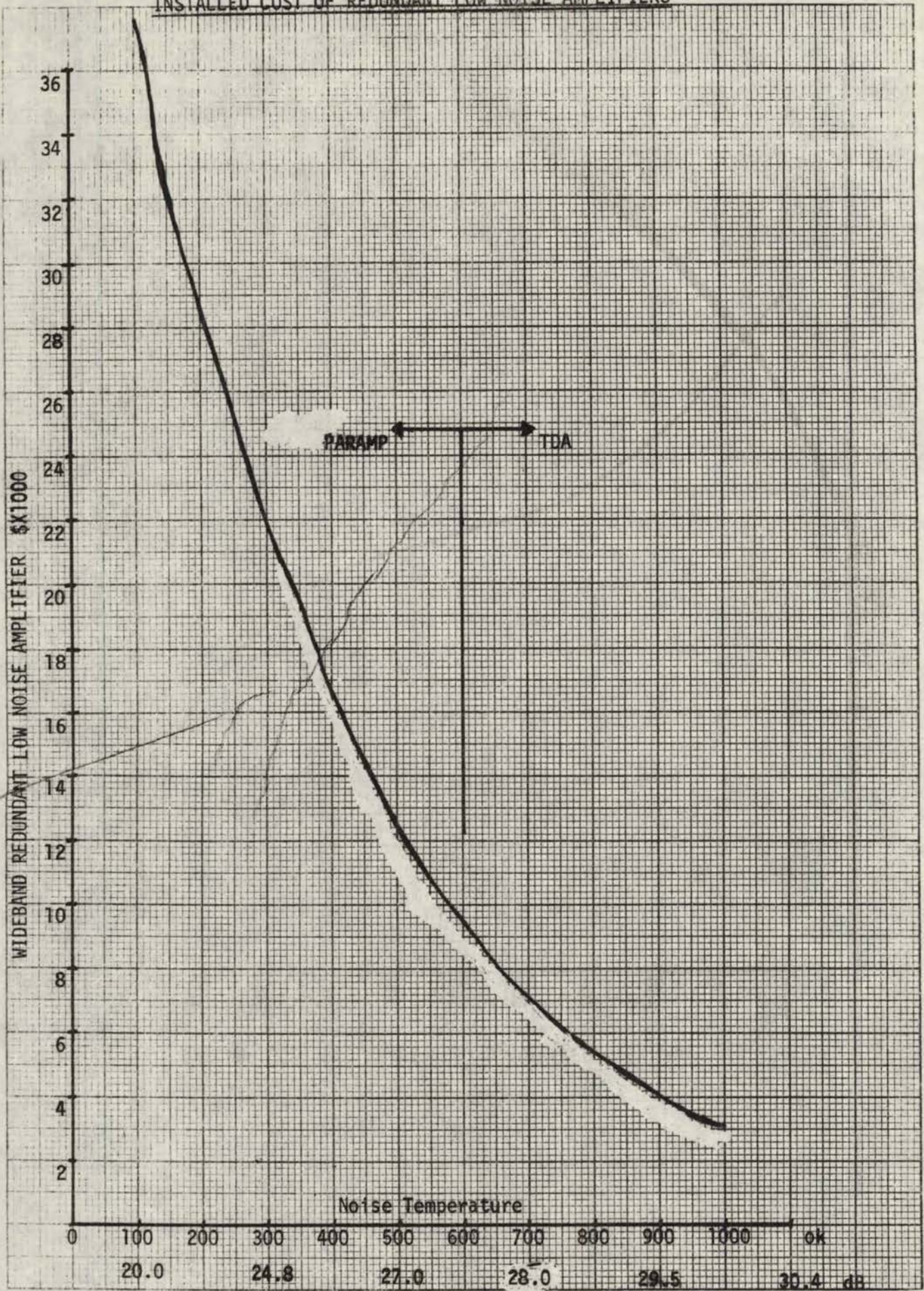
FIG 6.2

7. VOICE CIRCUIT CAPACITY OF PCM-CPSK-TDMA SYSTEMS

Coherent Phase Shift Keying (CPSK) provides the best choice of possible modulation schemes for use with TDMA. The voice circuit capacity versus earth station G/T using this scheme is given here.

In a phase shift keyed system there are two basic equations which govern system performance. These are:

a) Under power limitations

$$10 \log_{10}R = EIRP + (G/T) - (E/N_0) - Mi - (C/I) - Lp - k$$

b) Under bandwidth limitations

$$R = \frac{B \log_2 (L)}{S}$$

where R = transmission bit rate (b/s)

B = system bandwidth (Hz)

EIRP = Satellite effective isotropic radiated power (dBW)

(G/T) = Earth station gain-to-noise temperature (dB)

(E/N_o) = Energy to bit density ratio (dB) [Assumed 8.4 dB for error rate of 1 x 10^{-4} for full rate coding.]

Mi = System implementation margin (dB)

(C/I) = The interference margin allowed (dB)

Lp = Path loss including fade margin (dB)

k = Boltzmanns constant (-228.6 dBW/Hz-^{0}k)

L = Number of phase positions in phase shift keying.

S = Ratio of transponder bandwidth to symbol rate. (Usually taken as 1.2).

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It is not the intention here to discuss these equations further beyond
stating that the critical operating point of the system would be where the bit
rates given under power and bandwidth limitations coincide. Below the critical
value the system will be in the power limited region, whereas above the
critical region the system will be in the bandwidth limited region. A
practical communications system must operate in the bandwidth limited region.
Any given system can, however, be operated in the bandwidth limited region by
suitably reducing the bandwidth and hence the capacity. The net voice circuit
capacity will also be dependent on the number of accesses per transponder: a
reduction of five circuits per access would appear to be a reasonable
assumption.[7.1]

1/2-rate and 3/4-rate convolutional encoding techniques are of
interest in TDMA systems. The former provides better performance and the
latter requires less bandwidth.[7.2] Since Telesat has indicated interest in
such encoding techniques these techniques have been considered in the current
calculations of system capacity when using 4-phase modulation. The results
do differ somewhat from the Telesat figures[7.1] and it must therefore be
assumed that Telesat was adopting a more conservative approach.

The results of 2-way voice circuit capacity available in a 5-node
network versus system (G/T) and carrier-to-noise ratio ($C/N_0\beta$) for a threshold
error rate of 1×10^{-4} is shown in Figure 7.1. The calculations of capacity
based on 1/2 coded 4-phase and 3/4 coded 4-phase operation are given in
Section 7.1.

7.1 SYSTEM CALCULATIONS USING 1/2 RATE AND 3/4 RATE CONVOLUTIONAL CODING[7.3]

7.1.1. Calculations for 1/2 coded 4-phase CPSK

System channel capacity $= \dfrac{B \times \log_2 L}{R \times 1.25}$

where B = Effective RF channel bandwidth

L = Number of phase positions

R = Transmission bit rate for one voice channel.
(128 k bits/sec in this instance)

Hence system capacity = 450 channels.

Allowing for 5 accesses effective system capacity = 425 channels or 213 ccts.

Now $R + {}^E\!/N_0 + Mi + I = EIRP - Lp + {}^G\!/T - k.$

where R = link bit rate = 450 x 128000 x 1.25 bits/sec

= 78.6 dB. or 72 M/bits

$78.6 + 3.9 + 4.0 + 3.0 = 33 - 197 + {}^G\!/T + 228.6.$

${}^G\!/T = 24.9.$

7.1.2. Calculations for 3/4 coded 4-phase CPSK

System channel capacity $= \dfrac{B \times \log_2 L}{R \times 1.25.}$

R = 85 k bits/sec in this instance

Hence system channel capacity = 678 channels.

Allowing for 5 accesses effective system capacity = 312 ccts.

Now $R + {}^E\!/N_0 + Mi + I = EIRP - Lp + {}^G\!/T - k$

where R = link bit rate = 678 x 85000 x 1.25 bits/sec = 78.6 dB

$78.6 + 4.8 + 4.0 + 3 = 33 - 197 + {}^G\!/T + 228.6$

${}^G\!/T = 25.8.$

7.2 REFERENCES

7.1 Communications Capabilities of the Canadian Domestic Satellite System
     J. Almond and R.M. Lester, I.C.C. Digest 1971, p 11.1 to 11.7 inc.

7.2 Integration of Demodulation, Decoding, Buffering and Control for TDMA
     Demand Assignment Systems. I.M. Jacobs, Telecommunications Numeriques
     Par Satellite   Paris 1972   Paper D-7.

7.3 Integration of Demodulation, Decoding, Buffering and Control for TDMA
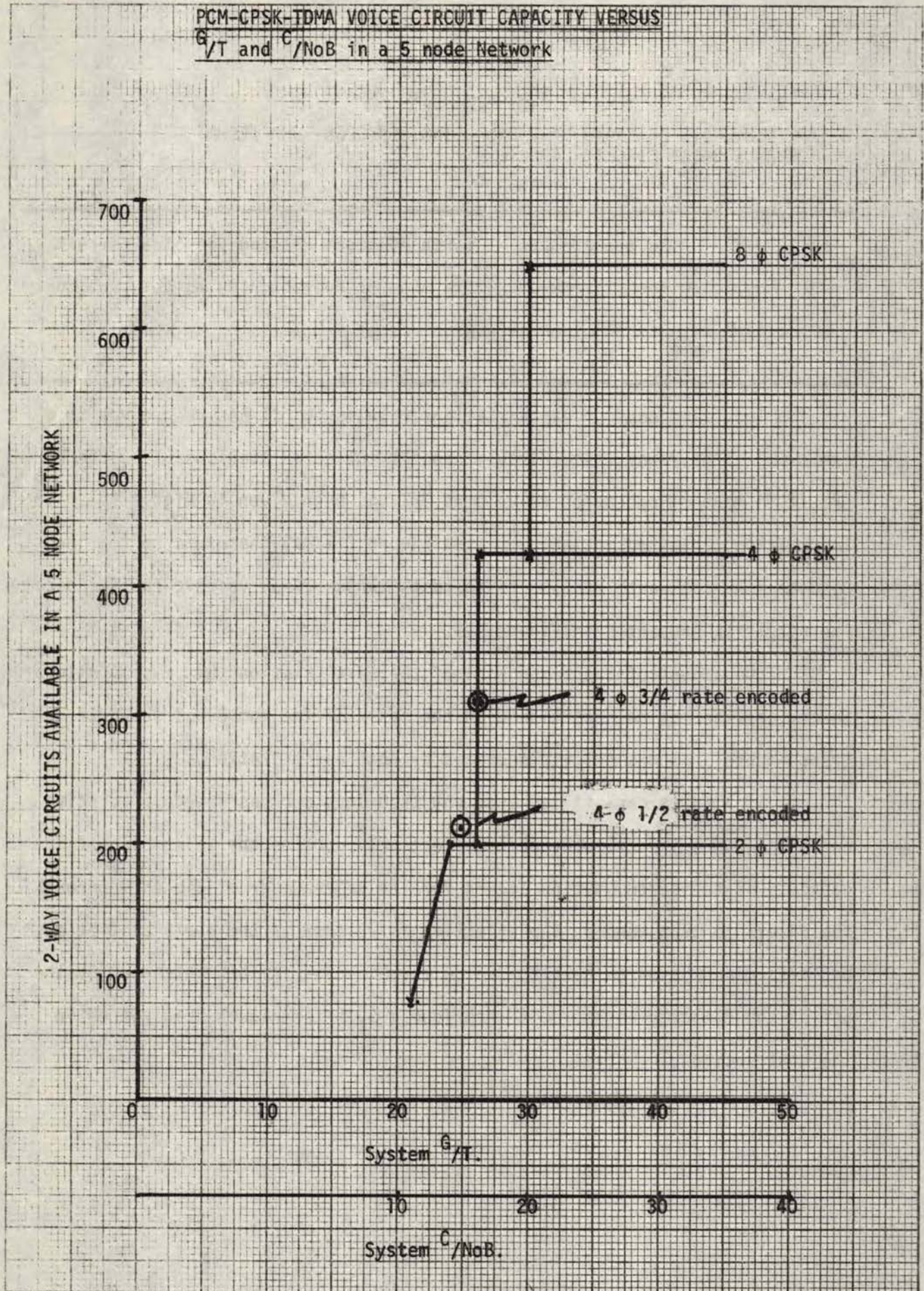   Demand Assignment Systems, I.M. Jacobs, Telecommunications par Satellite.

PCM-CPSK-TDMA VOICE CIRCUIT CAPACITY VERSUS $\frac{G}{}$/T and $\frac{C}{}$/NoB in a 5 node Network

FIG 7.1

8. FIXED COSTS OF EARTH STATIONS USING PCM-CPSK-TDMA TECHNIQUES VERSUS VOICE CIRCUIT CAPACITY


The fixed costs of earth stations related to voice circuit capacity for the PCM-CPSK-TDMA mode of operation using the previously derived data is given here.

The fixed cost of earth stations related to G/T has been given in Table 6.1. The 2-way voice circuit capacity of earth stations using the PCM-CPSK-TDMA mode of operation related to G/T has been given in Figure 7.1. The information contained in Table 6.1 and Figure 7.1 may therefore be combined to determine the earth station fixed costs versus 2-way voice circuit capacity. The result is presented in Figure 8.1.

The amount of the fixed cost of the earth station that may be allocated to any service may be apportioned on the basis of the number of separate transponders in the satellite accessed by that earth station.

If a voice capacity enhancement technique such as speech predictive encoding (SPEC) is utilized, which effectively doubles the voice circuit capacity of the earth station access for the same number of circuits through the satellite transponder, the effective fixed cost of the earth station must be determined based on half the voice circuit capacity brought about by the use of the capacity enhancement technique. Such techniques are covered in the next section.

EARTH STATION FIXED COSTS VERSUS 2-WAY VOICE CIRCUIT CAPACITY/
SATELLITE TRANSPONDER FOR 5 ACCESSES BASED ON PCM-CPSK-TDMA OPERATION
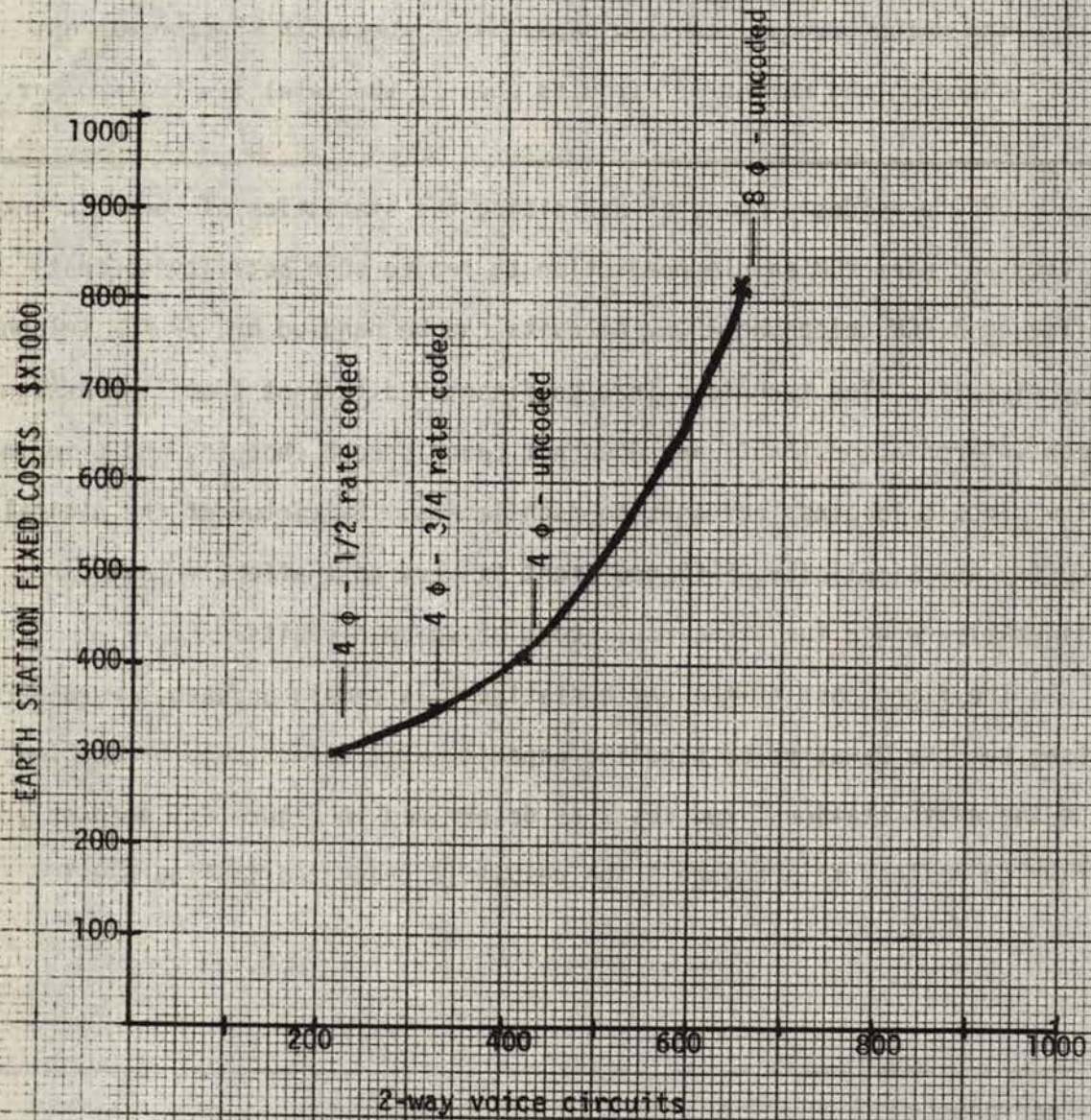
FIG 8.1

9. FIXED COSTS OF EARTH STATIONS USING PCM-SPEC-CPSK-TDMA TECHNIQUES VERSUS VOICE CIRCUIT CAPACITY

The use of speech predictive encoding techniques (SPEC)[9.1,9.2] when used in conjunction with digital systems can effectively double the voice circuit handling capacity of the earth station without changing the number of circuits used in the satellite transponder.

SPEC provides a means of exploiting the statistics of speech trunk activity and uses PCM sample prediction to reduce such activity so that traffic of N PCM telephone 2-way circuits can be handled by $N/2$ PCM telephone 2-way circuits. The technique is significantly different from Time Assignment Speech Interpolation (TASI) and does not cause speech chopping and clipping as the circuit loading increases to high levels. By virtue of the digital circuitry and simplicity, SPEC equipment is very cost effective and can considerably reduce the per circuit cost of voice circuits.

The _fixed_ cost of the earth station will remain unchanged when SPEC is used but the 2-way voice handling capacity will effectively be doubled. Hence the earth station fixed costs as determined in Figure 8.1 need only be redrawn to reflect this change. The result is presented in Figure 9.1.

9.1 REFERENCES

9.1 Speech Predictive Encoded Communications, S.J. Campanella and J.A. Sciulla Telecommunications Numerique Par Satellite, Paris 1972, Paper E-4.

9.2 A Speech Predictive Communication System for Multichannel Telephone, S.J. Campanella and J.A. Sciulla, I.E.E.E. Transactions on Communications, July 1973, pp 827-835.

EARTH STATION FIXED COSTS VERSUS 2-WAY
VOICE CIRCUIT CAPACITY/SATELLITE TRANSPONDER
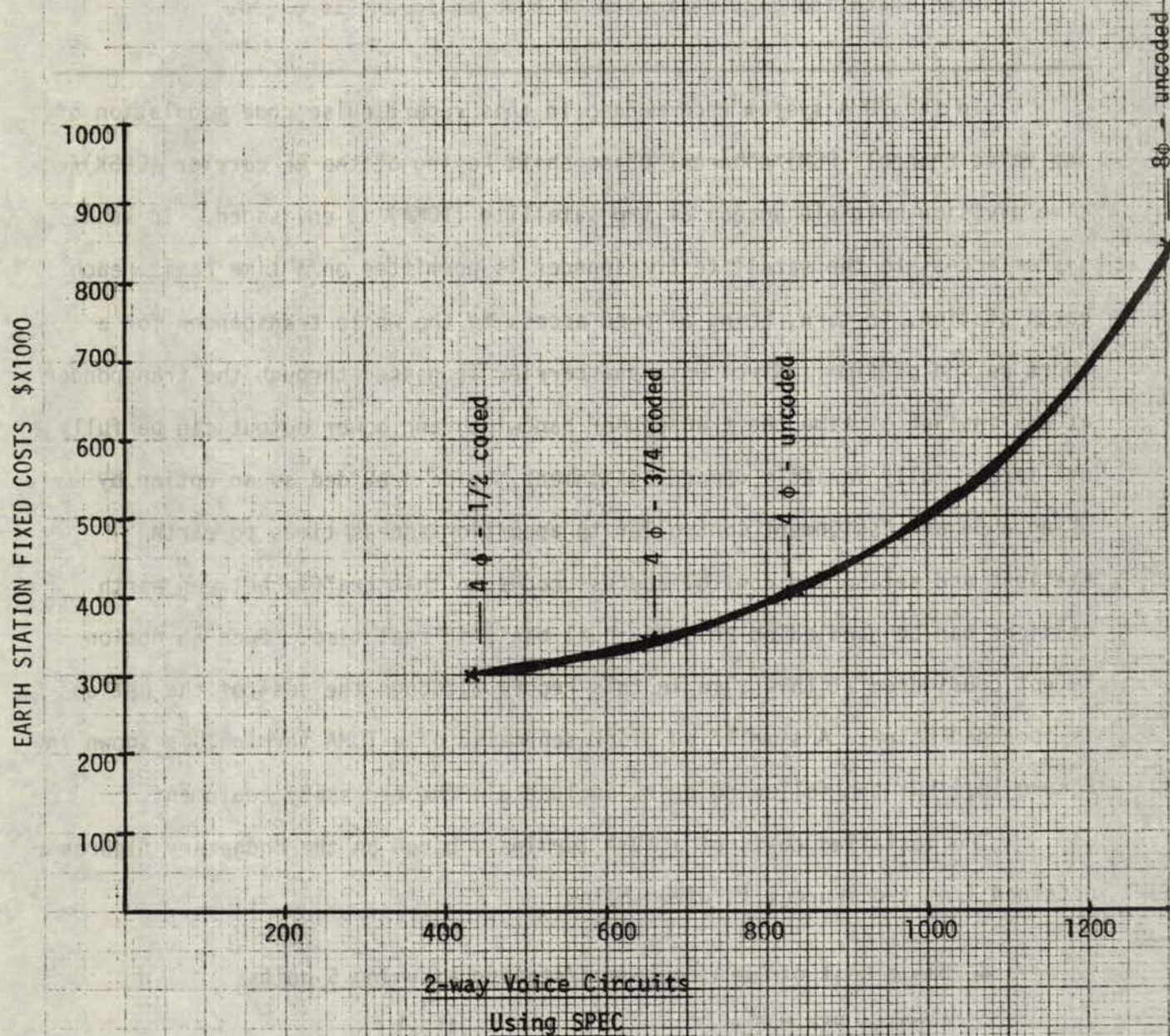FOR 5 ACCESSES BASED ON PCM-SPEC-CPSK-TDMA
OPERATION

FIG 9.1

10. A SIMPLIFIED DESCRIPTION OF TDMA EQUIPMENT WITH COSTS

TDMA allows each earth station in turn to access the whole satellite transponder for a short period of time. A brief description with installed cost estimates of such equipment is given.

In the TDMA system recommended in this report pulse code modulation of the voice channel (PCM)/coherent phase shift keying of the RF carrier (CPSK)/ time division multiple access at the satellite (TDMA) is envisaged. In such a system access to the satellite transponder is permitted on a time basis, each earth station, in turn, being allowed access to the whole transponder for a short period of time. Since only one carrier is passed through the transponder at any instant of time the transponder bandwidth and power output can be fully utilized. Fully variable demand assignment may be provided as an option by using a Demand Assignment Controller to apportion access times to earth stations and set up and control address codes so that traffic between earth stations can be handled on an individual basis in real time. Such an option is not considered at this time in this report although the cost of the option is included below. A simplified block schematic of a TDMA terminal is shown in Figure 10.1 but the following costs include all the necessary equipment.

The installed costs of a TDMA terminal, based on the budgetary figures obtained from two sources is given below:

- Basic Cost of TDMA equipment/station assuming 5 units

4-phase PSK Modem	$ 94.3k	
TDMA Synchroniser	$103.6k	$254.7k
Channel rearranging equipment	$ 56.8k	

- <u>Basic Cost of Demand Assigned TDMA equipment/station assuming 5 units</u>

4-phase PSK Modem	$ 94.3k	
TDMA Synchroniser	$107.0k	$286.4k
Channel rearranging equipment	$ 85.1k	

  In addition 1-Demand Assignment Controller is required at $336.0k.

  Thus based on 5 accesses and exclusive of VF/PCM coder equipment
  the average cost of TDMA equipment/station is:

No Demand Assignment	$254.7k
With Demand Assignment	$353.6k.

The foregoing costs have included channel rearranging equipment, which
strictly speaking is part of the TDMA equipment. However, such equipment is
considerably effected by the type of backhaul system used. The cost of
channel rearranging equipment has, therefore, for the purpose of the remainder
of this report been considered as forming part of the backhaul equipment.
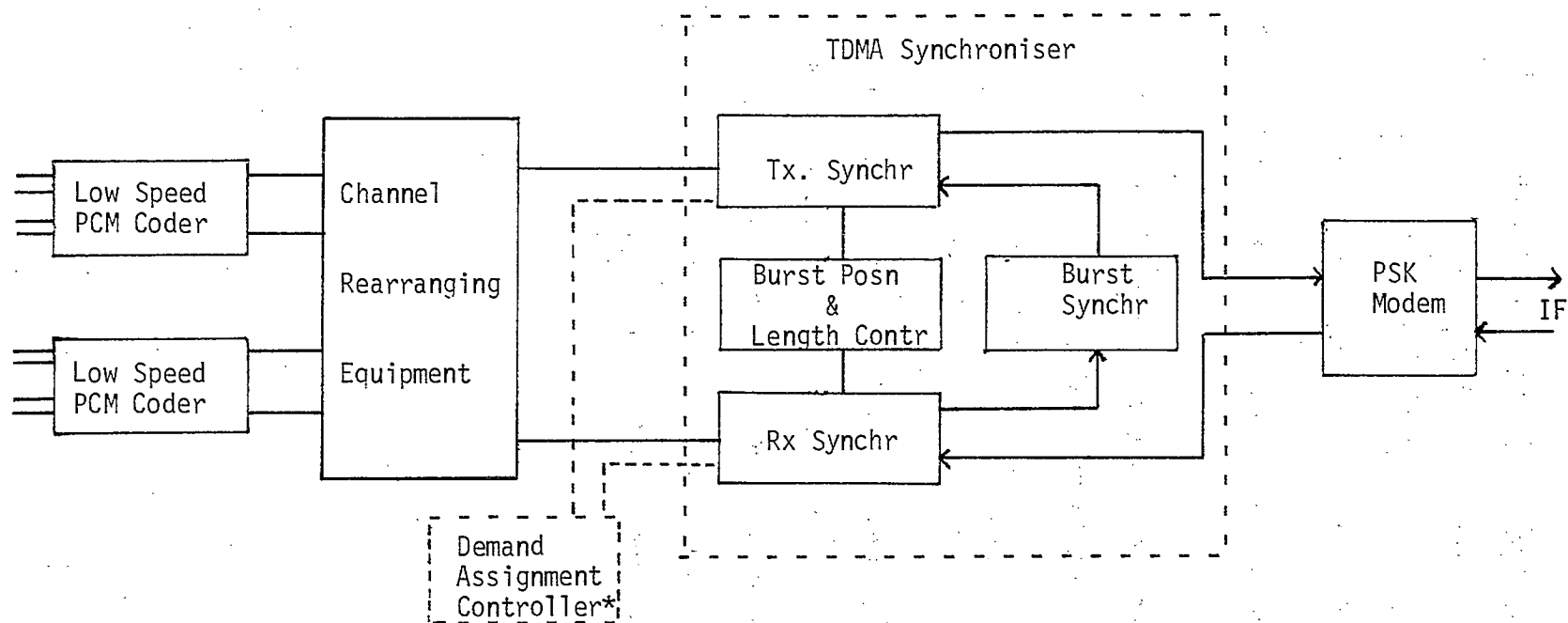
Simplified Block Schematic of TDMA Terminal
Equipment

*Optional Equipment

FIG 10.1

11.   THE COST PARAMETERS OF BACKHAUL FACILITIES

The cost parameters of the backhaul facilities are presented.

Fixed Costs:

The fixed cost of the backhaul facilities is given in Table 11.1. The amount of the fixed cost of such facilities that may be allocated to any service provided through the satellite may be apportioned on the basis of the number of separate transponders in the satellite accessed by the earth station being served. The cost of a protection channel has beeen included.

Variable Costs:

The variable cost parameters of the backhaul facilities are given in Table 11.2. The cost of protection switching and entrance link equipment is included. Costs for both message and video equipment is given. There are many pros and cons for the use of either analogue or digital video transmission and the decision on which method to use cannot readily be made in the current context. Several different video digital coding techniques are possible: the technique of particular interest is the Comsat "Ditec" equipment for which an estimated cost is given.

TABLE 11.1

FIXED COST OF BACKHAUL*		
	REPEATER	TERMINAL
Land, access road, tower (200')	75k	75k
Building	15k	15k
Standby Power Supply & Batteries	65k	60k
Antennas (dishes)	10k	5k
Waveguide	41k	21k
Protection Switch	-	30.4k
Filters & Circulators	10k	5k
Protection Channel	27.8k	14.0k
TOTAL	243.8k	225.4k

*Fixed Cost of backhaul = 450.8 + 243.8 (N-1) $x1000 where N is No. of hops.

TABLE 11.2

| VARIABLE COSTS OF BACKHAUL			
	Repeater	Terminal	Comment
Radio Bay	27.8k	14.0k	
Protection Switching		30.4k	/radio channel
Entrance Link Equipment (both ends)		20.0k	/radio channel
F.M. Terminal Equipment (Message)		3.7k	/term. end
F.M. Terminal Equipment (Video)		7.4k	/term. end inc. 2 prog. chs.
"Ditec" Terminal Equipment (Video)		46.3k	/term. end inc. 2 prog. chs.
VF.FDM/cct		1.2k	
VF/PCM*		62k + $375/cct	
VF/SPEC/PCM*		62k + $462/cct	
FDM/PCM		2.5k + $375/cct	

*When located in Toll Centre.

12.   THE VARIOUS METHODS OF PROVIDING BACKHAUL

The backhaul equipment provided could utilize either analogue or digital modulation. The use of TDMA through the satellite would optimally require digital backhaul equipment and the installation of the voice frequency (VF) and the TDMA channel rearranging equipment in the Toll Centre (OPTION 2).

There are four possible alternative methods of providing the backhaul facilities to the Toll Centre when TDMA is used through the satellite for voice traffic. Such alternatives are presented as Options 1, 2, 3 and 4 in Figures 12.1 and 12.2. The capital costs of equipment, where indicated, are based on the costs given in Section 10 and Table 11.2. The cost of channel rearranging equipment when provided in the Toll Centre instead of in the Earth Station has been estimated at 62.0k.

Figure 12.1

DIGITAL BACKHAUL MODELS
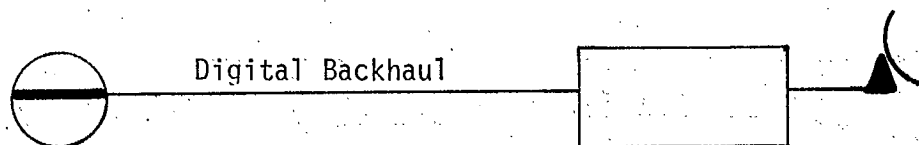
Toll Centre   Earth Station
Contains: Contains:

Option 1.   a) VF/PCM Equipment   a) TDMA Equipment
                 (62k + $357/cct)   (197.9k)*

Option 2.   b) VF/SPEC/PCM   b) TDMA Equipment
                 Equipment plus   less Channel
                 Channel rearranging   rearranging Equipment.
                 Equipment   (197.9k)*
                 (62k + $462/cct)

( ) Capital Costs

*Included in Earth Station Variable Costs.

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Figure 12.2

ANALOGUE BACKHAUL MODELS
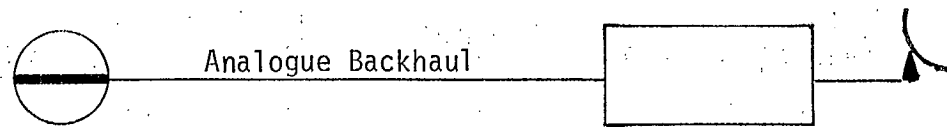
Toll Centre Contains:		Earth Station Contains:

Option 3.   a)   VF/FDM
                  Equipment
                  (7.4k ± 1.2k/cct)

Option 4.*   b)   VF/FDM
                  Equipment
                  (7.4 + 1.2k/cct)

a)   FDM/PCM Equipment
     (2.5k + $375/cct)

     TDMA Equipment
     (197.9k)**

b)   FDM/VF Equipment
     (7.4k + 1.2k/cct)

     VF/SPEC/PCM Equipment
     ($462/cct)

     Interface Equipment
     (56.8k)

     TDMA Equipment (197.9k)**

( ) Capital Costs

*If high capacity were required two radio channels might be necessary.
**Included in Earth Station Variable Cost.

13. THE VARIABLE COSTS OF EARTH STATION EQUIPMENT

Cost data relating to the variable costs of earth stations
based on the Telesat earth station parameters have been obtained from
Comsat and various manufacturers.

The earth station transmitter power will be dependant on the transmit
gain of the associated antenna:

$$\Phi s = EIRP + Lp + Go$$

where Φs = flux density at satellite (-80dBW/m^2 for ANIK)

EIRP = Effective isotropic radiated power

Lp = Path Loss (-200.3 dB @ 6 GHz)

Go = Gain of 1 m^2 antenna (37.3 dB)

Hence EIRP = 83 dBW to fully saturate the transponder.

But EIRP = $Tx + G_{ant}$

where Tx = Transmitter Power (dBW)

G_{ant} = Gain of Transmit antenna (dB)

The above equation gives the required transmitter powers for different
size earth stations to fully saturate the transponder. The results are in
agreement with the Telesat requirements for the larger stations which would be
used to saturate the transponder. For a small station such as one having a
26 foot diameter antenna a transmitter with a power of approximately 3KW would
be required for TDMA operation. The cost of complete redundant transmitters,
including Up converter and power supplies, versus earth station antenna diameter
and transmit gain is given in Figure 13.1.

The breakdown of the variable earth station costs using PCM-CPSK-TDMA in conjunction with either digital or analogue backhaul facilities (OPT 1 and OPT 3 in Section 12) is given in Table 13.1. The variable costs of the earth station are the same in either case although the corresponding variable backhaul costs will be different. The earth station variable costs versus 2-way voice circuit capacity/satellite transponder are shown graphically in FIG 13.2.

The breakdown of the variable earth station costs using PCM-SPEC-CPSK-TDMA in conjunction with either digital or analogue backhaul facilities (OPT 2 and OPT 4 in Section 12) is given in Table 13.2. The corresponding total earth station variable costs versus 2-way voice circuit capacity/satellite transponder are given graphically in FIG 13.3.

It should be noted that the costs of coding equipment given in Tables 13.1 and 13.2 are only estimates as such equipment is not currently available on the market. Further if SPEC is used the fixed cost of the earth station equipment must be determined from FIG 9.1. otherwise the fixed cost of the earth station equipment must be determined from FIG 8.1.
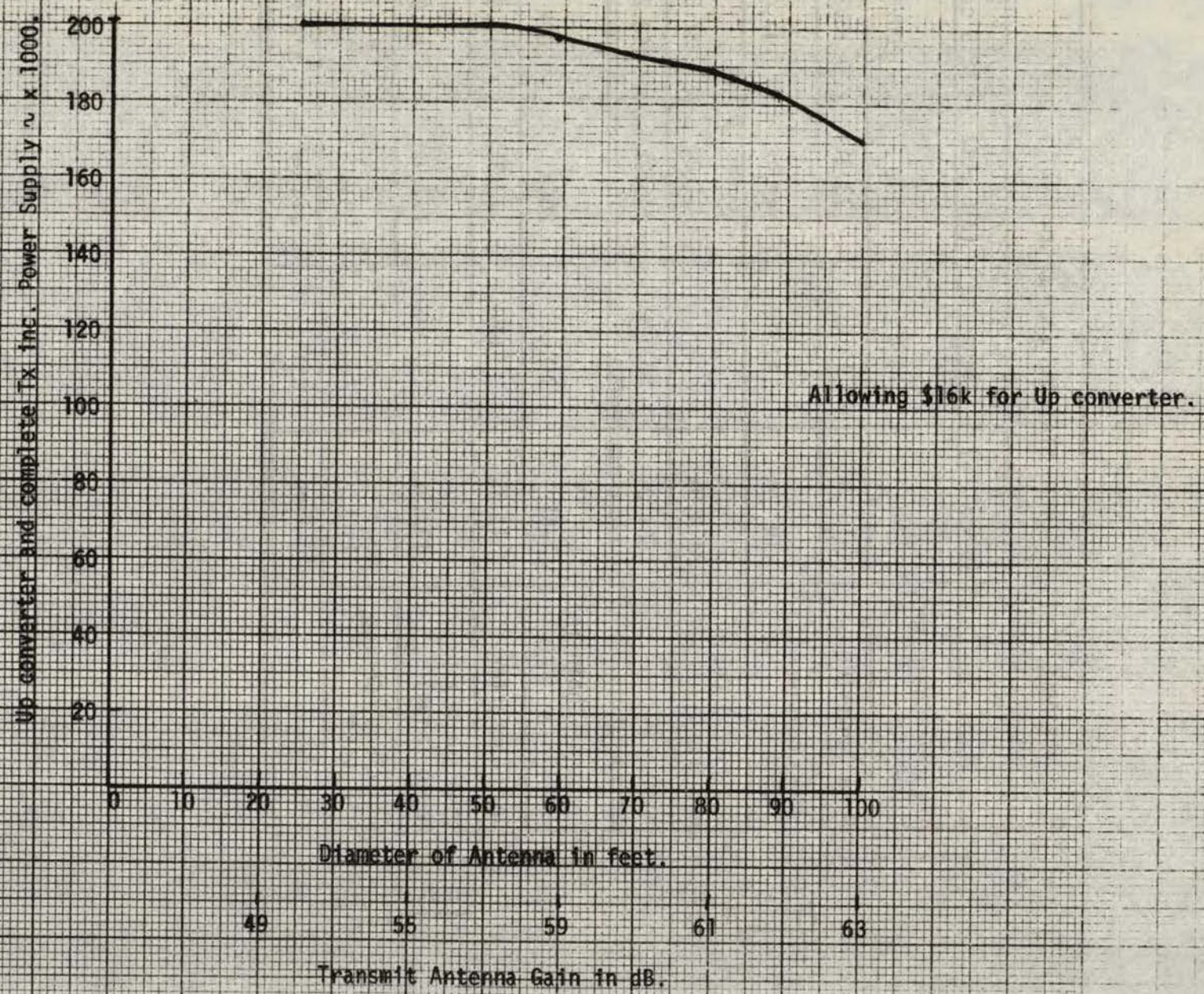
TRANSMITTER COSTS

FIG 13.1

TABLE 13.1

VARIABLE COSTS OF EARTH STATIONS (PCM-CPSK-TDMA)				
	G/T = 37 (650 ccts)	G/T = 30 (425 ccts)	G/T = 26 (315 ccts)	G/T = 25 (215 ccts)
Transmit Chain inc. U/C & P.S.	176k	190k	200k	200k
Down Converter	13.3k	13.3k	13.3k	13.3k
TDMA Equipment (NoDA)	197.9k	197.9k	197.9k	197.9k
Additional Coding Equipment	114.0k	-	37.0k	37.0k
TOTAL	501.2k	401.2k	448.2k	448.2k
Transmit Chain inc. U/C & P.S.	176k	190k	200k	200k
Down Converter	13.3k	13.3k	13.3k	13.3k
TDMA Synch & PSK Modem (NoDA)	197.9k	197.9k	197.9k	197.9k
Additional Coding Equipment	114k	-	37k	37k
TOTAL	501.2k	401.2k	448.2k	448.2k

Using OPT 1 PCM Backhaul (rows 1-5)

Using OPT 3 FDM Backhaul (rows 6-10)

EARTH STATION VARIABLE COSTS VERSUS 2-WAY
VOICE CIRCUIT CAPACITY/SATELLITE TRANSPONDER
FOR 5 ACCESSES BASED ON PCM-CPSK-TDMA
OPERATION

Using either analogue or digital backhaul facilities.
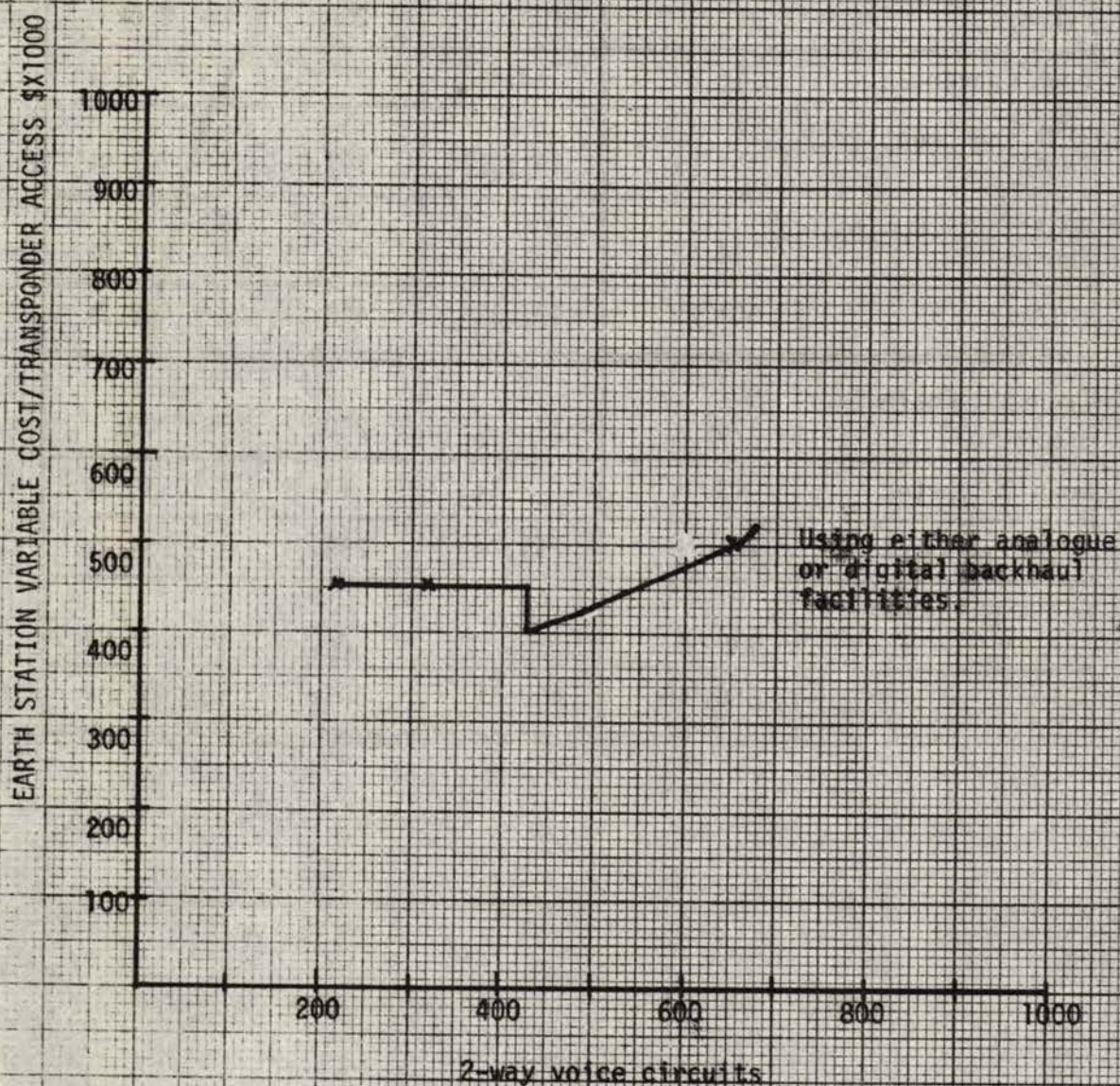
FIG. 13.2

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June 18, 1973

TABLE 13.2

VARIABLE COSTS OF EARTH STATIONS (PCM-SPEC-CPSK-TDMA)				
	G/T = 37 (1300 ccts)	G/T = 30 (850 ccts)	G/T = 26 (630 ccts)	G/T = 25 (430 ccts)
Transmit Chain inc. U/C & P.S.	176k	190k	200k	200k
Down Converter	13.3k	13.3k	13.3k	13.3k
TDMA Equipment (NoDA)	197.9k	197.9k	197.9k	197.9k
Additional Coding Equipment	114.0k	-	37.0k	37.0k
TOTAL	501.2k	401.2k	448.2k	448.2k
Transmit Chain inc. U/C & P.S.	176k	190k	200k	200k
Down Converter	13.3k	13.3k	13.3k	13.3k
TDMA Equipment	254.7k	254.7k	254.7k	254.7k
Additional Coding Equipment	114.0k	-	37.0k	37.0k
TOTAL	558.0k	458.0k	505k	505.0k

Using OPT 2 P.C.M. Backhaul

Using OPT 4 FDM Backhaul

EARTH STATION VARIABLE COSTS VERSUS 2-WAY VOICE CIRCUIT CAPACITY/SATELLITE TRANSPONDER FOR 5 ACCESSES BASED ON PCM-SPEC-CPSK-TDMA OPERATION
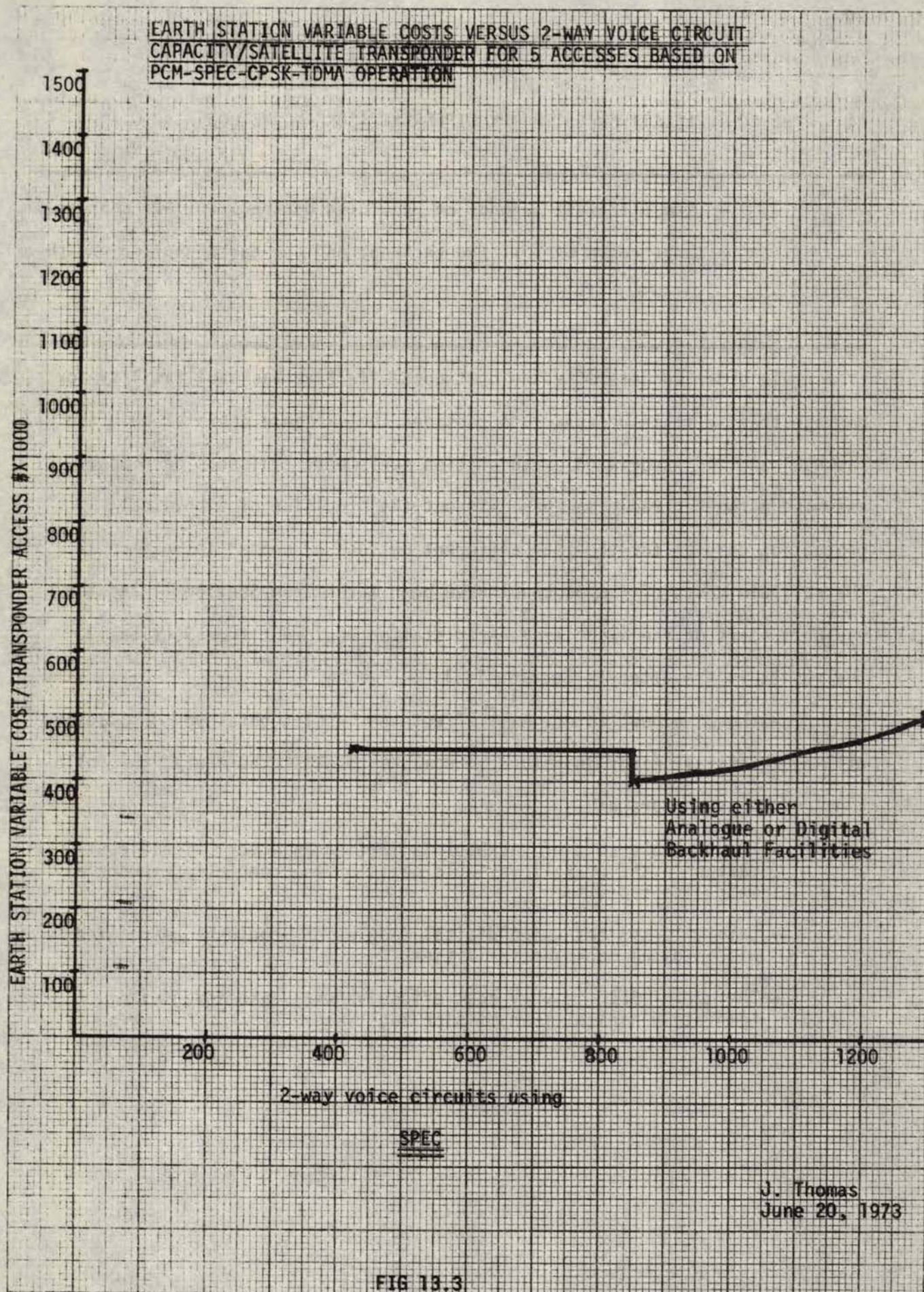
Using either Analogue or Digital Backhaul Facilities

2-way voice circuits using

SPEC

J. Thomas
June 20, 1973

FIG 13.3

14. THE COST EFFECTIVENESS OF THE DIFFERENT BACKHAUL METHODS

The different methods of providing backhaul involve changes in the variable costs of both the backhaul and the earth station equipment necessary.

In order to determine the most cost effective backhaul facility for message traffic it is necessary to consider the variable costs of both the backhaul and the associated earth station equipment. This has been done assuming a two-hop radio backhaul without the provision of a physical protection channel for the four different options presented in Section 12. The variable costs of the backhaul have been taken from Section 11 and the variable costs of the associated earth station equipment from Section 13. The result is presented in Section 14.1.

Although other factors will effect the results obtained such factors will be relatively minor in nature. From the results, therefore, the following conclusions can be drawn:

- The variable cost of backhaul facilities is a very significant factor in the overall variable costs of the complete terrestrial satellite facilities.

- Satellite systems using digital modulation should be associated with digital backhaul facilities.

- The use of SPEC is very cost effective when associated with completely digital transmission facilities.

14.1   EXAMPLE TO SHOW THE COST EFFECTIVENESS OF DIFFERENT BACKHAUL FACILITIES

Assuming a two hop radio system with no physical protection channel provided:

	Digital Only OPT. 1	Digital with SPEC OPT. 2	Analogue Only OPT. 3	Analogue with SPEC OPT. 4
Possible Capacity over Satellite	650 ccts	1300 ccts	650 ccts	1300 ccts
Radio Cost	83.8k	83.8k	83.8k	83.8k
Multiplex & Terminal Equipment	243.8k 62.0k	600.6k 62.0k	780.0k 14.8k	1560.0k 14.8k
Interface Equipment	--	--	--	56.8k
Protection Switching	30.4k	30.4k	30.4k	30.4k
Entrance Links	20.0k	20.0k	20.0k	20.0k
TOTAL VARIABLE COST OF BACKHAUL	440k	796.8k	929.0k	1765.8k
Earth Station Variable Cost from FIGS 12.2 and 12.3	501.2k	501.2k	501.2k	501.2k
TOTAL VARIABLE COST	941.2k	1298.0k	1430.2k	2267.0k
TOTAL VARIABLE COST/CCT	1.4k/cct	1.0k/cct	2.2k/cct	1.7k/cct

15. SUMMARY OF FIXED AND VARIABLE COSTS FOR EARTH STATION AND BACKHAUL FACILITIES

For ready reference the fixed and variable costs of the earth station and backhaul facilities for both message traffic and television are referenced or provided in this section.

15.1 For Message Traffic

a. **Earth Station Fixed Costs**

Using PCM-CPSK-TDMA	FIG 8.1
Using PCM-SPEC-CPSK-TDMA	FIG 9.1

b. **Earth Station Variable Costs**

Using PCM-CPSK-TDMA	FIG 13.2
Using PCM-SPEC-CPSK-TDMA	FIG 13.3

c. **Fixed Cost of Backhaul**

$$F_b = 450.8 + 243.8 \ (N-1)$$

where F_b = Fixed cost of backhaul facilities ($X1000)

N = Number of radio hops in backhaul

d. **Variable Costs of Backhaul**

Digital Backhaul without SPEC (OPT. 1 Section 12)

$$V_b = [168.4 + (N-1) \ 27.8 + (0.375 \times C)]$$

Digital Backhaul with SPEC (OPT. 2 Section 12)

$$V_b = [168.4 + (N-1) \ 27.8 + (0.462 \times C)]$$

Analogue Backhaul without SPEC (OPT. 3 Section 12)

$$V_b = [116.3 + (N-1) \ 27.8 + (1.2 \times C)]$$

Analogue Backhaul with SPEC (OPT. 4 Section 12)

$$V_b = [178 + (N-1) \ 27.8 + (1.7 \times C)]$$

where V_b = Variable cost of backhaul facilities ($X1000)

N = Number of radio hops in backhaul

C = Number of 2-way voice circuits.

15.2 For Television and Program Channel Transmission

a. Earth Station Fixed Cost

If the earth station size were to be established purely by the television requirements the minimum fixed cost required would be that set by a station having a G/T of 27 dB. (See Section 3) The minimum fixed cost therefore, from Table 6.1, would be $400k. This would be equivalent to an earth station capable of handling 425 voice circuits without SPEC or 850 voice circuits with SPEC.

b. Earth Station Variable Cost

The earth station variable cost is dependant on whether transmit facilities are required or not.

i) For transmit facilities the cost would be:

Transmitter	$190k
Downconverter	$ 13.3k
Interface Equipment	$ 15.0k
TOTAL =	$218.3k

ii) For receive only facilities the cost would be:

Downconverter	$13.3k
Interface Equipment	$15.0k
TOTAL =	$28.3k

c. Variable Costs of Backhaul for Television

The backhaul variable costs given below pre-suppose that the television signal is transmitted digitally through the satellite.

Digital Backhaul
(See Section 12)
(Uni- or bi- directional)
$$V_b = [124.7 + (N-1) \, 27.8]$$

Analogue Backhaul
(See Section 12)
(Uni- or bi- directional)
$$V_b = [139.5 + (N-1) \, 27.8]$$

where V_b = Variable cost of backhaul facilities ($X1000)

N = Number of hops in backhaul.

--THOMAS, J.H.
--Traffic capacities and costs of
terrestrial facilites associated
with a satellite of the Anik type
using digital modulation techniques.

DUE DATE			
JUL 24 1996 JUIL			
201-6503			Printed in USA