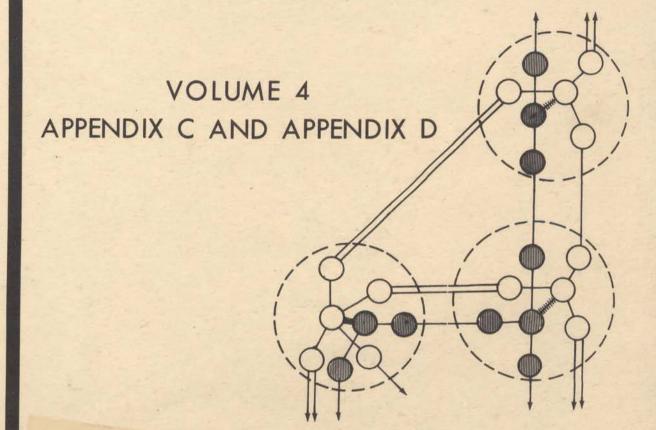
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# Communications Research Centre

DOMESTIC LONG DISTANCE
COMMUNICATIONS NETWORK STUDY



Department of Con

Ministère des Communications CRC REPORT NO. 1274-4

OTTAWA, NOVEMBER 1975



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## DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY VOLUME 4 — APPENDIX C AND APPENDIX D

by

Communications Systems Research and Development Staff

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(Technology and Systems Branch)



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November 1975 OTTAWA

#### NOTE

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#### THE PROJECT TEAM

Rather than attributing authorship of the component parts of this report we have chosen to describe the roles of the various people who have contributed to the project as well as to the writing of the report. Three people have been part of the project from start to finish and have contributed to almost every part of it: Dr. A.R. Kaye (Project Leader), Dr. R.R. Bowen and Dr. G.A. Neufeld. Dr. T.A.J. Keefer was solely responsible for the forecasting of voice circuit requirements. E.A. Walker and R.L. Hutchison contributed to the development of the terrestrial network model and J.L. Thomas to the satellite models. R.V. Baser and P.R. Whalen did a great deal of the computer programming and production work involved in the study.



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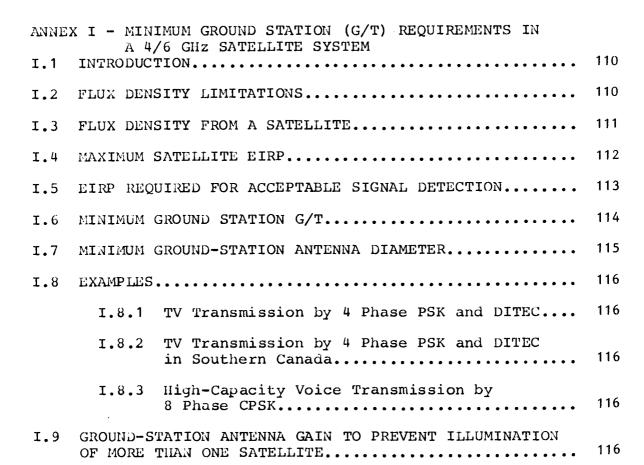


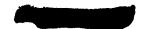
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## APPENDIX C

#### SATELLITE SYSTEM OPTIONS

#### C.1 INTRODUCTION

This appendix is a description of the satellite system options that are likely to be available for use in the Canadian long-haul trunk communications network in the 1980's, and of the probable costs of those options. The range of possible satellites depends on the following factors.

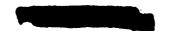
- i) presently available operational satellites and launch vehicles.
- ii) new and expected developments in satellite components and subsystems.
- iii) the development of new launch vehicles,
- iv) the probable requirements and purchases of satellites by other satellite system operators.

These factors are considered and weighed in determining the probable range of satellite options available in the 1980's.

The characteristics and costs of present operational communications satellites, and satellites being developed for possible operational use, are reviewed in section 2. It is likely that any Canadian operational satellite launched for operational use on or before 1980 will be similar to one of these satellites, because of the long lead-time necessary to develop and space-prove a new type of satellite. Moreover, there are many more satellite options available today than there was in the late 1960's when the Anik system was being developed. Even at that time, the Anik satellite was quite similar in many ways to the Intelsat III and Intelsat IV satellites.

Examination of the probable action of other satellite system operators is also important in estimating what satellites will likely be available in the next few years. Included in this list are Intelsat, ESRO, several U.S. domestic common carriers, Brazil, Australia, Japan, etc. Satellite manufacturers will tend to develop satellites to meet the requirements of several of these operators. If a satellite with unique characteristics is required, it is probable that the development costs charged to that system would be quite high.

Any new features that may be available in operational satellites can be predicted by observing current research and revelopment activity in satellite technology. New techniques,





components, and subsystems that are likely to change the character of available satellites in the next few years are discussed in Section C.4.

In evaluating the characteristics and costs of future satellite systems it is necessary to consider the costs and characteristics of the launch vehicle as well as the spacecraft itself, since the cost of the launch is comparable with the cost of the spacecraft, and the weight and volume constraints of the spacecraft are dictated by the capabilities of the launch vehicle. Present and probable future launch vehicles are discussed in Section C.5.

A computer program was written to estimate the weight and cost of a satellite system of a given type. Much of the information presented in sections C.2 to C.5 of this appendix was used in the development of the program, and much was also used in evaluating potential satellite systems with the program. The program itself is described in section C.6, and the way in which it was used to obtain some of the results which were presented in section 4 of the main report are described in section C.7.

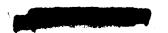
#### C.2 CURRENT AND PLANNED OPERATIONAL COMMUNICATIONS SATELLITES

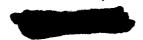
## - THEIR CHARACTERISTICS AND COSTS

There are over twenty types of synchronous geostationary operational communications satellites, not including experimental satellites such as CTS and the ATS series of satellites. Of those, only five types, the Intelsat I to IV satellites, and the Anik-type satellite, has been used operationally. (Military satellites such as the DGCS satellites are not included, since they have characteristics considerably different from commercial satellites.) These twenty-odd types of commercial operational satellites are classified in this appendix into one of the following classes:

- i) spin-stabilized satellites at 4/6 GHz,
- ii) body-stabilized satellites at 4/6 GHz,
- iii) satellites which use the 11/14 GHz and 12/14 GHz bands,
- iv) satellites which use more than one of the 2.5 GHz band, the 4/6 GHz band, the 11/14 GHz band, the 12/14 GHz band, and the 18/30 GHz band.

Satellites in these classes are discussed in sections C.2.1. to C.2.4. respectively, and are summarized in section C.2.5.





## C.2.1 SPIN-STABILIZED SATELLITES AT 4/6 GHz

Satellites in this class include:

- i) the early Intelsat I (Early Bird) to Intelsat III satellites.
- ii) the Intelsat IV satellite,
- iii) the Intelsat IV A satellite,
- iv) the AT&T/Comsat U.S. domestic satellite,
- v) the Anik-type satellite, which includes the Western Union satellite, the American Satellite Corp. phase II satellite, and Hughes Corp. proposals to Brazil, Australia, Iran, etc.,
- vi) the Western Telecom satellite,
- vii) a mini-satellite developed by Fairchild Industries.

The capabilities, weight, and costs of each of these satellite types, except the early Intelsat satellites, is discussed below in sections C.2.1.1 to C.2.1.7. Note that the only satellites which have been used to date in an operational commercial communication system are of this type.

## C.2.1.1 THE INTELSAT III SATELLITE

The Intelsat III satellite was first launched in 1968. Since the launch of the Intelsat IV series of satellites, the Intelsat III has been relegated to a backup role. The satellite has the following characteristics:

1. Satellite Weight: 647 lb. at launch, 334 lb. in

synchronous orbit.

2. Frequency Plan: Two independent channels 225 MHz

wide. 6 GHz uplink and 4 GHz downlink. A single circularly polarized signal

used at each frequency.

3. Antenna System: An 18 circular beam to provide global

coverage. A despun antenna was used for

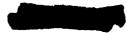
the first time.

4. Communications System: A redundant tunnel-divide amplifier is used for each 225 MHz band. The

output in each band is a TWT with

10 watts at saturation.

5. System Capacity: Each transponder is used in a frequency





division multiple access (FDMA) mode. Satellite capacity is about 2500 simplex voice channels, i.e. 1250 voice circuits.

6. Launch vehicle: Thor-Delta.

7. Costs: i) Non-recurring development costs: = \$13M

ii) Recurring costs to produce

another identical satellite: = \$4M

iii) Launch costs: 
= \$6M

## C.2.1.2 THE INTELSAT IV SATELLITE

At the present time the Intelsat IV is the workhorse of the Intelsat system. It was developed by Hughes Aircraft Co., and first put into service in 1971. At the present time there are two Intelsat IV's over the Atlantic, one over the Pacific, and one over the Indian Ocean. The backup for the Intelsat IV is the much smaller Intelsat III. An Intelsat IV has the following characteristics:

- 1. Satellite Weight: about 3100 lb. at launch and 1585 lb. in synchronous orbit.
- 2. Frequency Plan: The available 500 MHz wide band at 6 GHz and 4 GHz was divided into 12 bands 40 MHz wide. Of this 40 MHz, about 36 MHz was used. Each 40 MHz band is used once with a circular polarized signal.
- 3. Antenna System: There are six antennas on the Intelsat IV, plus an omni antenna for telemetry. These six antennas are:
  - i) Two 6 GHz receive antennas with 170 global-coverage patterns. These are horn antennas.
  - ii) Two 4 GHz horn transmit antennas, again with 170 global coverage. Peak antenna gain is 20.5 dB.
  - iii) Two 4 GHz steerable parabolic reflector antennas with 4.50 coverage and a 31.7 dB peak gain.
- 4. Communications System: two redundant 500 MHz wide TDA receivers, one for each of the two





global antennas.

- Twelve completely redundant 6 watt
  TWT transponders (a total of 24 TWT's).
- Eight of the redundant TWT's can be connected to either one of the parabolic antennas or the global antenna. Four are connected to only one of the global antennas.
- 5. System Capacity: Nominally 6,000 simplex voice channels. If used in a single-carrier FDM mode through the 4.5° antenna, up to 1800 channels can be carried through one transponder. However, many transponders are used in a SCPC mode with spare equipment or in an FDMA mode.
- 6. Launch Vehicle: Atlas Centaur
  - a) Non-recurring costs:
    Prototype Spacecraft
    System Evaluation
    Documentation
    Total
    \$20.13M
    \$2.68M
    \$0.68M
  - b) Recurring costs:
    Flight Spacecraft \$6.85M
    Apogee Motor \$0.42M
    Launch Support Services \$0.21M
    Total \$7.5M
  - c) Launch costs = \$17M

## C.2.1.3 THE INTELSAT IV A SATELLITE

The Intelsat IV A is being developed as a follow-on to the Intelsat IV, because of the rapidly expanding traffic requirements in the Atlantic portion of the network. It has double the capacity of an Intelsat IV. Its characteristics are as follows:

1. Satellite Weight: 3200 lb. at launch, or about 1650 lb. in orbit, very little more than the Intelsat IV.

2. Frequency Plan: The same as that used in the Intelsat IV system, so that the present ground stations can be used without conversion.





3. Antenna System:

The idea of a global beam is rejected. In its place are two disjoint antenna beams. In Atlantic system one covers the Americas, the other covers Europe and Africa. Four antennas on the satellite, one receive and one transmit for each beam. Gain of the 4 GHz antenna is about 22.5 dB. Isolation between antennas is > 27 dB.

- 4. Communication System:
- A redundant 500 MHz wide TDM receiver for each of the two beams.
- Twenty-four operational 36 MHz wide 4.5 watt transponders on the satellite, twelve feeding each transmitting antenna.
- TWT redundancy is one spare TWT for each two active TWT's, a reduction from the one-for-one redundancy of Intelsat IV.
- 5. System Capacity: Double that of an Intelsat IV.
- 6. Launch Vehicle: Atlas Centaur
- 7. Costs: 1. Non-recurring development costs, for Hughes to modify the Intelsat IV \$13.9M
  - 2. Recurring costs for 3 spacecraft:

Basic Cost

\$35.4M

Support Eqpt.

\$ 2.8M

Incentives

\$13.8M

Total

\$52.0M

Total per satellite \$17.4M

Launch costs per satellite

≈ \$17M

## C.2.1.4 THE AT&T/COMSAT U.S. DOMESTIC SATELLITE

AT&T plans to launch three satellites of the Intelsat IV A type in 1976, with a fourth satellite as a terrestrial backup. This system has been planned for several years, but has been delayed by the FCC. The system will have ground stations with 100' parabolic antennas near New York, Los Angeles, Chicago, Atlanta, and San Francisco. The first two ground stations will have 3 antennas each, the latter 3 will have 2 each. The satellite system characteristics area as follows:



1. Satellite Weight: 3100 lb. at lift-off
3032 lb. in transfer orbit
1470 lb. in synchronous orbit

2. Frequency Plan: The 500 MHz wide band at 4/6 GHz is divided into 12 bands 40 MHz apart.

34 of 40 MHz is used. Linear polarization, rather than circular as in Intelsat system, is used.

Both polarizations used. Carriers in opposite polarization separated by 20 MHz.

3. Antenna System: Five fixed-beam parabolic antenna beams used. These are:

- i) A 4.5 ° X 10.5 ° 6 GHz horizontally polarized receive antenna for Alaska and Conus, with peak gain 27.5 dB.
- ii) A 3.5 ° X 7.5 ° 6 GHz vertically polarized receive antenna for Conus only, with peak gain 30.5 dB.
- iii) Two 3.5 ° X 7.5 ° 4 GHz antennas to cover Conus. One vertical, the other horizontal. Peak gain 30.5 dB.
  - iv) One 4.5 ° X 4.5 ° 4 GHz transmit antenna to cover Alaska. Peak gain 30.3 dB. Vertical polarization.

All antennas have >25 dB cross-polarization rejection.

- 4. Communications System: Each antenna has one redundant tunnel dicde amplifier with a 33.3 dB system noise temperature.
  - 24 unprotected TWTA's as output stages. 20 dedicated to Conus, and 4 switchable to either Conus or Alaska.
- 5. System Capacity: 1200 voice channels per transponder when 100' antenna used. Capacity of two satellites is 29,000 voice circuits without an encoding scheme such as SPEC, or 58,000 with SPEC.



- 6. Launch Vehicle: Atlas-Centaur
- 7. Costs: Hughes' cost to Comsat for four spacecraft \$66M
  - Atlas-Centaur launch costs per satellite \$22M
  - Total investment by Comsat to operate space segment of system i.e. complete system except for ground stations carrying customer traffic \$180M
  - For this service, AT&T pays \$272M to Comsat.

#### C.2.1.5 THE ANIK-TYPE SATELLITE

The satellite was developed by Hughes for Telesat in 1972. Since that time, the same satellite, with changes in the antenna reflector, has been purchased by Western Union, by the American Satellite Corp., and by General Telephone and Electronics Corp. As well, it is being considered for domestic satellite communications systems in Australia, Brazil, and Iran. Its characteristics are:

1. Satellite Weight: ≃1200 lb. at lift-off.

≈600 lb. in synchronous orbit.

≈500 lb. at end of life.

2. Frequency Plan:

The 500 MHz band at 4 GHz and 6 GHz is used once. Linear polarization is used. The band is divided into 12 bands, 40 MHz between carriers, with 36 MHz used in each band.

3. Antenna System:

A single reflector is used for both receive and transmit. It is a portion of a parabaloid. Two receive horns at 6 GHz and three transmit horns at 4 GHz are used to achieve an 8° x 3° antenna pattern, with a 26 dB gain at the beam edges, or 29 dB peak gain.

4. Communications System:

- A redundant receiver with a 6 GHz to amplifier and single-stage conversion to 4 GHz is used.
- Twelve unprotected TWTA's with 5 watt saturated power are used.
- Operation during solar eclipse is



## limited to 10 transponders.

- 5. System Capacity: Ten television programs or 4800 voice channels if FM is used.
- 6. Launch Vehicle: Thor-Delta
- 7. Cost: To Telesat: \$30M for 3 satellites. \$7.5M per Thor-Delta launch.
  - To Western Union: \$20M, plus \$5M incentive costs over 7 years, for 3 satellites.
  - Hughes proposal to Brazil: \$15M for 2 satellites.

From these costs it can be seen that Hughes' price is decreasing, because the development costs were absorbed in the early sales.

## C.2.1.6 THE WESTERN TELECOMMUNICATIONS INC. PROPOSAL

#### FOR A U.S. DOMESTIC SATELLITE

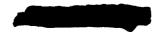
This was an early (1971) proposal to the FCC for a U.S. domestic satellite. It was to be manufactured by North-American Rockwell. The satellite is a more conservative, heavier design than Anik. In view of Anik's widespread use, it is unlikely that it will be produced. Its characteristics are:

- Satellite Weight: 1443 lb. in transfer orbit, 27 lb. in synchronous orbit.
- 2. Frequency Plan: As in the Anik system, the 500 MHz band was divided into 12 bands 40 MHz apart, with about 36 MHz useful bandwidth.
  - Linear polarization was used, as in the Anik system. However, alternate polarization was used in adjacent channels and in adjacent spacecraft to improve isolation. That is, in spacecraft 1, odd channels are vertical, even channels horizontal, with the opposite used in Spacecraft 2.
  - Bad effects of this polarization plan are:





- i) Considerable work must be done in the backup satellite before it can be launched to replace a satellite which has failed in orbit.
- ii) The satellite cannot be used in a system which uses three satellites in orbit, because the satellites are not identical.
- 3. Antenna Pattern: A single elliptical reflector is used, with several feed horns. These feed horns are used to form the following beams:
  - i) A receive-and-transmit 60 x 20 beam to cover Conus. Peak antenna gain is 32.5 dB.
  - ii) Three transmit-only 30 beams to cover Alaska, Hawaii and Peurto Rico. Peak antenna gain is 34.4 dB.
- 4. Communications System: A redundant 500 MHz wide 6 GHz receiver for each polarization.
  - Single-state conversion to 4 GHz.
  - Solid-state 4 watt 4 GHz transmitters are used for each 36 MHz wide signal.
  - Six spare amplifiers are carried in a
     1 for 2 redundancy system.
  - Transmitters are placed in parallel to produce 8 watts output if voice is transmitted (4 watt output is for TV).
- 5. System Capacity: Twelve television signals, on up to 3600 full-duplex voice circuits and six television signals.
- 6. Launch Vehicle: Thor-Delta.
- 7. Costs: The costs presented by Western Telecommunications Inc. to the T.C.C. in 1971 include the following:



i)	Non-recurrant development costs:	\$ <b>1</b> 514
i <b>i</b> )	Production costs of 2 satellites:	\$ <b>1</b> 2%
iii)	Cost to refurbish test model:	\$2M
iv)	Launch vehicles and support services:	\$15M
v)	Launch failure insurance or reserve:	\$3M
	Total cost for two in-orbit spacecraft	
	and one ground spare:	\$47M

#### C.2.1.7 SMALL SATELLITE BEING DEVELOPED BY FAIRCHILD

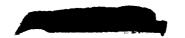
#### INDUSTRIES

Fairchild is developing a small spin-stabilized satellite for "emerging countries". It will have 8 active transponders with 5 watts output per transponder. It is planned that two such satellites would be launched with a single augmented Thor-Delta, similar to the way that two DSCS-II satellites are launched with a single Titan III C launch vehicle. No other information is available on this project directly. Our estimation of the weight and costs of this satellite, with the method described below in Section C.6, are that the satellite would have approximately the following characteristics:

- 1. Satellite Weight: 800 lb. at launch. 400 lb. in synchronous orbit.
- 5. System Capacity: 4,000 voice circuits or 8 television programs if FM is used. Up to 7,000 voice circuits or 16 television programs if 4 phase PSK and source encoding were used.
- 6. Launch Vehicle: An augmented Thor-Delta, of the type being developed by McDonnel-Douglas for RCA, to launch 2 satellites.
- 7. Costs: Non-recurring development costs: \$18M Production costs per satellite: \$4.4M

## C.2.2 BODY-STABILIZED SATELLITES AT 4/6 GHz

The are only two body-stabilized satellite systems being developed at 4/6 GHz exclusively. One of these is the "Sympnonie" satellite being developed by ESRO (now reformed as part of ESA). This is an experimental system in the same sense as CTS and the ATA series, rather than an operational system such as those of Intelsat and Telesat. The other is a body-stabilized





24 channel satellite being developed for U.S. domestic use by RCA Globcom.

## C.2.2.1 THE SYMPHONIE SATELLITE

Development of the Symphonie satellite started as separate French and German satellite development programs in 1960's. They were combined as the Symphonie project in June 1957, for an expected launch by a yet-to-be-developed European vehicle in 1972. Co-ordination and technical difficulties, and the termination of the European launch vehicle program, delayed the Symphonie program over two years. The first Symphonie satellite was launched by NASA with a Thor-Delta in December 1974. The second Symphonie is scheduled to be launched in August 1975.

From a telecommunications system viewpoint Symphonie is in many ways similar to the Intelsat III satellite. Its characteristics are as follows:

1. Satellite Weight: 402 KG. (880 lb.) at launch,

235 KG. (517 lb.) in synchronous

orbit.

2. Frequency Plan: Two 90 MHz wide bands are used at

6 GHz and at 4 GHz.

3. Antenna System:  $18.5^{\circ}$  global reception at 6 GHz, with

a 16.2 dB gain at the beam edge. Two parabolic antennas with 14.5 x 9.4 beams at 4 GHz, one to cover the Americas. Antennas have a 19.5

dB gain.

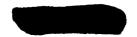
4. Communication System:

Satellite input G/T is -15 dB/ $^{0}$ K satellite EIRP is 28.7 dB. Thus transponders are about 10 watts. The satellite has 2 transponders.

5. System Capacity: Two television programs or 528 voice

circuits.

6. Launch Vehicle: Thor-Delta.



#### C.2.2.2 THE RCA GLOBCOM SATELLITE

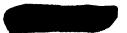
RCA Globcom is purchasing three satellites from RCA for operational U.S. domestic satellite system in 1976. satellites have double the capacity of the Anik-type satellites, and considerably more weight. RCA Globcom paid McDonnell-Douglas dollars to extend the capability of the million several Thor-Delta to be able to put 2,000 lb. in transfer including the apogee motor and fuel. As well, they reviewed proposals from RCA, Fairchild, and Lockheed build to body-stabilized 24 channel satellite at 4/6 GHz which could be launched by the augmented Thor-Delta. RCA was chosen in Montreal contractor, with RCA one of the as subcontractors.

The satellite has the following characteristics:

- 1. Satellite Weight: In transfer orbit 2,000 lb. In synchronous orbit - 1020 lb.
- 2. Frequency Plan: Dual use of the 500 MHz wide band at 4 GHz and 6 GHz by receiving and transmitting at the same frequency both a horizontally and a vertically polarized signal. At each polarization the 500 MHz band is divided into twelve bands 40 MHz apart, with a 20 MHz offset between horizontally and vertically polarized carriers.
- 3. Antenna System: Four reflectors used, two for horizontally polarized signals and two for vertical. Two beams are used, a 8.4 ° x 3.2 ° beam for Conus and Alaska, and a 2.6 ° x 1 ° beam for Hawaii. A total of six feedhorns are used.
- OR THE 12/14 GHz BAND EXCLUSIVELY

There are only two planned operational satellite systems at 11/14 GHz or 12/14 GHz exclusively. One of these is the ESRO operational satellite system at 11/14 GHz, and the other is the GAL system at 12/14 GHz, which has recently been purchased by





IBM. A third satellite system at 12/14 GHz is of course the CTS system, but this system is not an operational one, and is not designed to meet the traffic requirements considered in DLDCNS. As well, several 12/14 GHz satellites have been proposed to DOC by BNR.

## C.2.3.1 EUROPEAN COMMUNICATION SATELLITE

The European Communications satellite system is being developed to carry international telephone and television traffic within Europe in the 1980's. Two possible systems are being considered:

- i) a system with two in-orbit satellites, one operational and one on standby, which achieves an effective 1000 MHz bandwidth by using both horizontal and vertical polarization;
- ii) a system with three smaller satellites, each with a 500 MHz bandwidth. (This system would be used if it becomes unfeasible to achieve enough isolation of the two polarized signals to transmit 4 phase PSK at the same frequency on both polarizations.)

The larger "baseline" satellite system is described below:

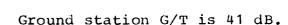
- 1. Estimated Satellite Weight: ≈815 KG in synchronous orbit, 1520 KG in transfer orbit.
- 2. Frequency Plan:

  14.0 to 14.5 GHz for uplink, and 10.95 to 11.2 GHz plus 11.45 to 11.7 GHz for downlink.

  The overall 500 MHz is divided into three 120 MHz wide channels and three 40 MHz wide channels.

  The 40 MHz wide channels are used in a 7° x 3.5° beam, and the 120 MHz wide channels is a 2.9° x 2.9° beam.
- 3. Antenna System: Reception at 14 GHz at both polarizations with an antenna with peak gain of 30.5 dB and a 7° x 3.5° beamwidth.

  Transmission at 11 GHz with a separate antenna system. The 7° x 3.5° beam has 30.5 dB peak gain, and the 2.9° circular spot beam has a 34.8 dB peak gain.
- 4. Communications Systems: Each of 12 transponders has a 20 watt output capability.



5. System Capacity: Each of the six transponders operating through the spot beam will carry 4 phase PSK/TDMA voice traffic exclusively. Two of the transponders in the 7° x 3.5° Eurobeam will carry a television program, and the other four will carry 4 phase PSK/TDMA voice. Total capacity is 2 colour TV channels plus 9,200 full-duplex voice circuits without speech interpolation.

6. Launch Vehicle: Atlas-Centaur.

7. Satellite Costs: An early (1971) estimate of the cost of a satellite was \$11M. However, this estimate is unreliable as a planning estimate because of its early date, and because it is difficult to determine how much ESRO development costs are included.

## C.2.3.2 THE CML SATELLITE CORPORATION'S SATELLITE

In late 1974 CML, a consortium of COMSAT, MCI and Lockheed, announced plans to develop a U.S. domestic satellite system at 12/14 GHz. The primary reason for their using 12/14 GHz rather than 4/6 GHz was so that they could put the satellite ground stations on the site of their customers, and so avoid the interconnect problems with AT&T. (These problems are corporate, rather than technical). Since late 1974 CML has been taken over by IBM. This may result in a change in the requirements and so technical characteristics of the system. However, the best information available is a rather sketchy description of the CML system, given below:

1. Satellite Weight: <1000 lb. in synchronous orbit.

2. Frequency Plan: Single use of the 500 MHz wide frequency band at 12/14 GHz. The band is divided into four radio channels, each 120 MHz wide.

3. Antenna System: A single beam to cover continental U.S., with greater flux density in Eastern U.S. where the attenuation due to rainfall is greater.

4. Communication System: Each of 4 transponders has a 20 watt

output and 120 MHz bandwidth. (This is identical to the ESRO system except use of 12 GHz rather than 11 GHz).

5. System Capacity: In its early stages the system will use FDMA. Later, a TDMA system may be introduced to increase the system capacity.

## C.2.4 OPERATIONAL SATELLITE SYSTEMS WHICH USE MORE THAN

## ONE FREQUENCY BAND

Four satellite systems which use more than one frequency band for operational use have been proposed. These are:

- i) the Fairchild-Hiller proposal for a U.S. domestic satellite,
- ii) the MCI/Lockheed proposal for a U.S. domestic satellite,
- iii) the planned AT&T high-capacity domestic satellite,
- iv) the Intelsat V system.

## C.2.4.1 THE FAIRCHILD-HILLER U.S. DOMESTIC SATELLITE PROPOSAL

Fairchild-Hiller proposed a large satellite system to the FCC for U.S. domestic use in the early 1970's. That proposal was based on the ATS-F satellite; the same satellite bus was to be used. The large parabolic reflector on the satellite was to be used to provide spot beams at 4 and 6 GHz.

The system is no longer actively being considered. It was too large for the available U.S. domestic requirement, and has been superceded by the more modest 24 channel 4/6 GHz system. However, it is described here to indicate the capabilities, weight, and costs of a large system.

- 1. Satellite Weight: i) 2900 lb. is divided into 12 bands
  40 MHz apart in the normal way.
  Opposite polarizations are used
  on adjacent spot beams for additional
  isolation.
  - ii) A 500 MHz band at 13 GHz was to





be used for ground-to-space transmission, and a 500 MHz band at 7 GHz for space-to-ground transmission. Both polarizations were to be used with a conus-wide beam to provide 1000 MHz effective bandwidth, subdivided into 40 MHz bands. (If such a system were designed today, it is likely that the 12/14 GHz band would be used).

- iii) The 2.5 to 2.69 GHz band was to be used for educational television and remote area voice communications.
- 3. Antenna System: i) The 35' reflector was used to provide twelve spot beams 0.40 wide at 6 GHz, 0.60 wide at 4 GHz, and 10 wide at 2.5 GHz.
  - ii) Separate reflectors were used to provide 3.50 x 70 CONUS coverage at 13 GHz and at 7 GHz.
- 4. Communication Systems: i) Ninty-six transponders were to be used at 4 GHz, each 36 MHz wide. Solid state amplifiers were used, some with 0.1 watts output, others with 0.2 watts output.
  - ii) Three watt TWT amplifiers were to be used at 7 GHz.
  - iii) For remote voice communication at 2.5 GHz 100 random-access 100 KHz wide transponders were used, each with 50MW output for a single voice channel.
  - iv) 15 watt 30 MHz solid-state transponders were used at 2.5 GHz for ETV.
- 5. System Capacity: i) A maximum of 57,600 voice circuit capacity by dedicated transponders and FDM/FM through the 4/6 GHz system.
  - ii) Distribution of 24 TV programs through the 13 GHz and 7 GHz





system.

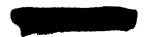
- iii) 50 random access voice circuits at 2.5 GHz.
- iv) Two to four ETV programs at 2.5 GHz.
- 6. Launch Vehicle: Titan IIIC.
- 7. Costs: i) Satellite development costs, over costs of developing ATS-F \$16.6M
  - ii) Recurring costs for 3 satellites \$44.1M
  - iii) Cost of 3 Titan IIIC launches \$77M

## C.2.4.2 THE MCI/LOCKHEED U.S. DOMSAT PROPOSAL

Like Fairchild-Hiller, MCI/Lockheed proposed a large satellite for U.S. domestic use in the early 1970's, and like the Fairchild-Hiller proposal, it was dropped in favour of the smaller system described in section C.2.3.2. However, like the Fairchild-Hiller satellite, it is described as an example of a high-capacity multi-frequency satellite.

It is a body-stabilized satellite with 24 transponders 36 MHz wide at 4/6 GHz, and another 24 transponders 36 MHz wide at 12/14 GHz. Its characteristics are:

- 1. Satellite Weight: ~1500 lb. in synchronous orbit,
- 2. Frequency Plan: Both the 4/6 GHz band and the 12/14 GHz are used twice, once on each polarization. Each 500 MHz wide band is divided into 12 bands 40 MHz apart.
- 3. Antenna System: Separate parabolic reflectors and feedhorns are used at each frequency and each polarization. A total of 10 parabolic reflectors are mounted on the side of the space-craft, 4/6 GHz is used to cover CONUS, 12/14 GHz is used to cover and to cover Alaska and Hawaii with separate spot beams.
- 6. Launch Vehicle: Titan III D/Agena.



## C.2.4.3 THE PLANNED AT&T HIGH-CAPACITY SATELLITE

The AT&T domestic satellite system during the late 1970's is the 4/6 GHz system described in section C.2.1.4. However, development work is being carried out for a high capacity 18/30 GHz system for the 1980's. Included in this development is an 18 GHz and 30 GHz propogation experiment on the 4/6 GHz operational satellite, primarily to determine the attenuation and rotation of 18 and 30 GHz signals in different atmospheric conditions.

The tentative design of the 18/30 GHz satellite system has the following characteristics:

- i) body-stabilized satellite,
- ii) use of 0.1° to 0.2° spot antenna beams, with up to 10 beams per satellite,
- iii) an overall 1500 MHz system bandwidth, divided into three 500 MHz wide radio channels,
- iv) use of 4 phase PSK to transmit up to 1 Gb/s in each 500 MHz wide radio channel,
- v) 20 dB allowance for atmospheric fading.

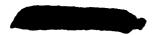
Without the use of source encoding or dual polarization on a given beam, such a system would have a capacity of 120,000 full-duplex voice circuits per satellite.

As well as this 18/30 GHz system, the satellite may have a 12/14 GHz or a 4/6 GHz system for communication to Hawaii and Alaska.

## C.2.4.4 THE PROPOSED INTELSAT V SATELLITE

The Intelsat V system is being planned for use primarily between North America and Europe after the Intelsat IV and Intelsat IVA systems are filled. Because of Intelsat's decision to develop the IVA satellite rather than go directly from the IV to the V, the V will not likely be required until the early 1980's, tentatively 1982.

As presently planned, the Intelsat V will be a body-stabilized satellite using both the 4/6 GHz band and the 11/14 GHz band. Spot beams will be used to achieve multiple use of the spectrum. Details of the Intelsat V design are of course undergoing changes to incorporate new techniques and improved estimates of traffic requirements. As envisaged in 1973, the





1. Launch Vehicle: Atlas-Centaur.

2. Frequency Plan:

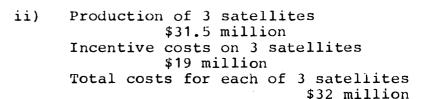
- i) The 4/6 GHz band:
  The 500 MHz wide band is divided into six 40 MHz wide bands and four 60 MHz wide bands. Half the band is to be used for global coverage, and the other half shared by 5 spot beams.
- ii) The 500 MHz wide band at 11/14 GHz is divided into 260 MHz bands to be used for satellite-switched TDMA. As in the 4/6 GHz band, spot beams are used to achieve multiple use of the spectrum.
- 3. Antenna System:
- i) A horn antenna is used for global coverage at 4/6 GHz,
- ii) Five steerable 7' parabolic reflectors are used to provide 2.50 beams at 4/6 GHz.
- iii) Three 44' parabolic reflectors are used to provide 2.50 beams at 11/14 GHz.
- 4. Communications Systems: i)
- i) Transponders with 5 watt output and 40 MHz or 60 MHz bandwidth are provided for global coverage.
  - ii) Transponders with 5 watt output and 250 MHz bandwidth at 4 GHz, and with 10 watts output and 250 MHz bandwidth at 11 GHz, are used.
  - iii) Cross-strapping is provided between the 4/6 GHz and the 11/14 GHz systems.
- 5. Satellite Capacity:

Normally 12,500 full-duplex voice circuits, but up to 20,000 voice circuits if heavy-route traffic is carried exclusively.

- 7. Satellite Costs: Costs presented by Lockheed to Intelsat in 1972 are:
  - i) Development costs

\$45 million





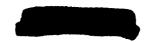
#### C.2.5 SUMMARY OF SATELLITE CHARACTERISTICS AND COSTS

All operational satellites at present, and most of those planned for operational use in the near future use the 4/6 GHz band. These include the Intelsat III, Intelsat IV and Intelsat IVA satellites, Anik-like satellites used by Telesat, Western Union, and others, the AT&T/Comsat satellite, the small Fairchild satellite, and the RCA Globcom satellite. All of these except the last one are spin-stabilized satellites. However, if both the augmentation of the Thor-Delta to place 2,000 lb. in transfer orbit and the RCA Globcom body-stabilized satellite itself are technological successes, it is likely that this type of satellite will be more widely used in the future. It could replace the Intelsat IVA and the AT&T/Comsat satellites, for instance, at considerable saving in cost.

Only four operational satellites are being developed at high frequencies. These are:

- i) The AT&T satellite being developed to use the very high potential capacity of a system which uses the 2.5 GHz wide band at 18 and 30 GHz;
- ii) The Intelsat V satellite which will use both the 4/6 GHz band and the 11/14 GHz band simply because its requirements exceed the capacity of the 4/6 GHz band;
- iii) The CML (now IBM) system, which may use the 12/14 GHz band to avoid the inter-connect problems with AT&T terrestrial systems and the large cost of new backhaul systems;
- iv) The ESRO operational satellite which will use the 11/14 GHz band exclusively, possibly because of the neavy use of the lower frequency bands for terrestrial systems on continental Europe.

It is likely that 4/6 GHz satellite will continue to be used, and that they will be spin-stabilized if a small satellite is required or body-stabilized if a larger satellite such as the RCA Globcom satellite is required. The advantages of the higher frequency satellites are the very high capacity available and the avoidance of interconnect and interference problems.



Available cost information on the above systems is summarized in Table C.1. In some cases these costs are itemized as non-recurring or development costs and recurring or production costs. Such information was taken from submissions to Intelsat and to the FCC in the U.S. In other cases the costs are itemized simply as purchase prices or as basic purchase prices plus incentives for successful operation of the satellite.

#### C.3 PROBABLE DEVELOPMENT OF OPERATIONAL SATELLITE SYSTEMS

#### BY SPECIALIZED AND COMMON CARRIERS

In estimating the characteristics and costs of operational satellites that will be available in the next decade, it is important to examine the likely expansion of other satellite systems such as those of Intelsat, AT&T, Western Union, RCA Globcom and RCA Alascom, American Satellite Corp., etc., because the direction and timing of new satellite development will be geared in part to the requirements of these "customers". In contrast, if a unique satellite system is required for Canadian use, the cost may be quite high because the manufacturer may decide that he must recover a large percentage of his development costs through the one sale.

As shown in Table C.1, development costs of a new satellite design such as Intelsat IV and Intelsat V are quite high. Modifications to other satellites, as in the Intelsat IVA and the Fairchild-Hiller satellite cases (the Fairchild-Hiller proposal was a modification of the ATS-F), result in much lower development costs.

The other factor in determining the probable development costs per system is the number of systems over which the development costs can be averaged or the number over which the manufacturer believes they can be averaged. For instance, the \$30 million cost to Telesat by Hughes Aircraft Co. absorbed a large portion but likely not all of the development costs of Anik. Cost of the next such system, the three Western satellites to Western Union, was \$25 million, substantially less, because much of the development cost was absorbed and because further sales to American Satellite Corp., to Brazil, to Australia, etc. were promising.

The probable development of satellite systems as part of a communication network by several commercial carriers are described below.

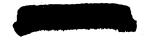


Table C.1
Capital Costs of Satellites

Satellite Type	Waight in Synchronous Orbit, lb.	Development Costs, Millions of Dollars	Costs/Satellite,	Basic Cost, Millions of Dollars per Satellite	Incentive Costs/Satellite, Millions of Dollars	Incentive Costs, Dollars per Transponder Day
Intelsat III	334	13	4	-	-	-
Intelsat IV	1585	23.5	7.5	· <u>-</u>	-	-
Intelsat IVA	1650	13.9	12.7	-	4.6	-
AT&T/Comsat, 4/6 GHz	1470	-	<b>-</b>	16.5	-	-
Anik	630	-	-	10	-	-
Western Union	630	-	-	6.66	1.66	-
Amsat Corp.	630	-	-	6.0	2.3	80
Mini Fairchild	400	18	4.4	_	-	-
RCA Globcom	1020	_	-	7.6	3.3	48
Fairchild-Hiller	2900	16.6	14.7	-	-	-
Intelsat V	1700	45	10.5	-	6.3	-
ESRO	1800	-	-	11	-	-
Western Telecom	730	15	6	-	-	-
Brazil, Anik-like	630	-	-	7.5	-	-
Brazil, Anik-like plus 50w trans- ponders	≃ 630	-	-	17.7	-	-

#### C.3.1 THE INTELSAT SYSTEM

Intelsat is using primarily Intelsat IV satellites at present, with Intelsat III satellites serving as backup in some areas. The Intelsat IVA, with double the capacity of the Intelsat IV, will be put into service in the Atlantic area in late 1975 or 1976, and possibly in the Pacific and Indian Ocean areas at a later date. This will delay requirement for the Intelsat V in the Atlantic area to the 1980 or 1982 time-frame. (Intelsat analyses indicated that Intelsat V would have been required in the Atlantic area by 1978 if the Intelsat IVA program had not been approved).

The Intelsat IVA is very similar to the Intelsat IV, the only new feature being the double use of the frequency band through the use of high-gain antennas.

The Intelsat V will be a much more complex satellite, in that it will use spot beams at both 11/14 GHz and at 4/6 GHz, will use transponders with much wider bandwidth, may use cross-coupling between 11/14 GHz and 4/6 GHz, will use digital modulation techniques and TDMA, and may use satellite switching. It will be a body-stabilized rather than a spin-stabilized satellite.

A Canadian domestic satellite for use by 1980 may benefit from some of the subsystems developed for Intelsat V, but the size and the timing of Intelsat V are wrong for Intelsat V development to be used directly. In contrast, the Intelsat IVA is larger, more expensive, and of older design than several satellites of similar capacity designed recently for U.S. domestic use, i.e. the Amsat, Lockheed, and RCA designs for the RCA Globcom satellite.

#### C.3.2 U.S. DOMESTIC SATELLITE SYSTEMS

After long delay by the FCC, several satellite systems are being constructed and operated in the U.S. These include:

## The AT&T Satellite System

AT&T and Comsat will operate a satellite system for U.S. domestic use in 1976. It will have 3 in-orbit satellites, each very similar to the Intelsat IVA, and be built by Hughes. These are not expected to be used until 1983.

The next AT&T system may be a very high capacity 18/30 GHz system but the timing of this system has not been determined.





## 2. The RCA Globcom System

At present, RCA Globcom/RCA Alascom is leasing Anik transponders. They are constructing a larger system which will use a 24-channel body-stabilized satellite in late 1975 or early 1976. Again, this system will have a seven year life until about 1983.

# 3. The American Satellite Corp. System

The Amsat system is to be developed in three phases. first phase was to have been to Telesat's Anik system, but transponders of action has leased transponders of result of FCC Westar instead. The second phase of the development is launch of two Anik-like satellites, purchased from Hughes, at a basic cost of \$18 million plus incentive costs as great as \$9 million. third stage of the Amsat system development is to launch satellites similar to those of RCA Globcom, but this may not happen until the early 1980's.

# 4. The Western Union "Westar" System

Western Union has two Anik-like satellites in orbit, the first operational U.S. domestic satellite system. This system will not require replacement until about 1981, after replacement of Telesat's Anik system.

## 5. The Hughes/GTE System

GTE is trying to establish a satellite system as part of its U.S. domestic network. The system would use Anik-like satellites, built, owned, and operated by Hughes Aircraft Co. No firm date is available for launch of such a system, so if it does become operational it will be available until about 1982 to 1984.

## 6. The CML (Or IBM) System

CML, (Comsat, MCI, Lockheed), was to have developed a 12/14 GHz satellite system (see Section C.2.3.2). However, the corporation has been purchased by IBM. Whether such a system becomes operational, and in what form, must await the result of court battles between IBM and ATT. Note that the major reason for using 12/14 GHz was to avoid interconnect problems with AT&T.

In summary, it seems that U.S. domestic satellites in the remainder of the 1980's will resemble the Anik, the Intelsat IVA, or the RCA Globcom satellite. The only exception is the CML or IBM satellite, and it may never fly. The next generation U.S. domestic satellites will be required in 1981 to 1984, after the replacement for Telesat's Anik is required.

## C.3.3 DOMESTIC AND REGIONAL GEOSTATIONARY SATELLITE SYSTEMS

#### OUTSIDE NORTH AMERICA

There are several domestic and regional communication satellite systems being developed outside North America. These include:

1. The Brazillian Government System

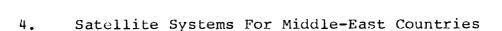
Brazil is considering use of satellites for both telephone traffic and for television broadcast. Hughes has proposed a satellite similar to Anik (the Hughes satellite model HS333), or several other satellites with an Anik bus and a communications package containing a mixture of Anik transponders and 50 watt 2.5 GHz transponders (Hughes satellite models HS336, HS339 and HS340). An alternative is to lease transponders of an Intelsat IV over the Atlantic.

2. The Australian Post Office System

For some time the Australian Post Office has been considering the use of satellites to connect the widely separated areas of Australia. (In many respects the Australian situation is similar to that in Canada). The options they were considering a year ago were either an Anik-like satellite or lease of Intelsat IV transponders.

3. The ESRO Regional European System

An 11/14 GHz body-stabilized satellite system will be launched about 1980 to carry voice and telephone traffic between European countries (see Section C.2.3.1). The system is an interesting one in that it will use a body-stabilized rather than a spin-stabilized satellite, 11 and 14 GHz rather than 4/6 GHz, digital transmission, TDMA and source encoding schemes similar to SPEC and DITEC.



Both Algeria and Iran have indicated plans to develop domestic or regional satellite systems. The available information on the specifications and requirements of these systems indicates that Anik-like satellites would likely be used.

5. Japanese Communications Satellites

Japan is developing a communications satellite system which will use two spin-stabilized satellites weighing about 700 lb. in synchronous orbit, launched with a Thor-Delta 2914 rocket. These satellites are being manufactured by Philoo-Ford for \$30 million. As well, two body-stabilized satellites for television broadcast are being manufactured for Japan, again at a cost of \$30 million. These satellites are also to be launched with Thor-Delta 2914 launch vehicles.

#### C.3.4 SUMMARY

Most of the communications satellites being put into service in the next few years will be of the following three types:

- i) Anik-like spin-stabilized satellites weighing about 600 lbs. and launched with a Thor-Delta 2914. The "standard" communication system in such a satellite is twelve 5 watt transponders at 6 and 4 GHz, but this could be modified, as in the satellite proposals by Hugnes to Brazil.
- ii) Body-stabilized satellites weighing about 1,000 lbs., and carrying about twice the communications payload of the Anik-like satellites. Such a satellite is being manufactured by RCA for RCA Globcom. Similar satellite designs have been developed by Fairchild and Lockheed.
- iii) Spin-stabilized satellites such as the Intelsat IVA or the AT&T/Comsat satellite, with the same communications capability as the RCA Globcom satellite, but weighing about 1500 lbs. and requiring an Atlas-Centaur launch vehicle.

The two main exceptions to the above three classes of satellite are the Intelsat V satellite and the ESRO operational satellite.



Both of these are to be launched in the early 1980's, too late for use as a follow-on to the present Anik satellites.

It is expected that satellite manufacturers will focus their development of new satellite systems first on requirements of Intelsat V, and on requirements for U.S. domestic satellites in the 1981-1984 time-frame, when replacements for present U.S. domestic satellites will be required. An uncertainty which may influence development of such satellites is the shuttle-tug program in the U.S.; a manufacturer would not want to be caught "off base" developing a satellite for conventional launch if the shuttle-tug were available to his customers. Thus it is unlikely that designs other than the three described above will be available "off-the-shelf" for Anik replacement in 1978 to 1980.

#### C.4 EXPECTED IMPROVEMENTS IN THE CHARACTERISTICS OF

#### COMMUNICATION SATELLITES

In the previous two sections currently available satellites and their use in communication networks were described. These satellites are being continuously improved to make them more reliable, and lighter, and at the same time new satellite designs are being produced to make current designs obsolete, or at least limit their market potential. For example, the recent successful design of a body-stabilized satellite in the 1,000 lb. class capable of carrying 24 Anik-like transponders is a major improvement in satellite construction.

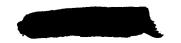
Improvements in the design of communication satellite systems are expected to be in one of the following three areas:

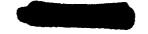
- i) improvements in the satellite bus,
- ii) improvements in the satellite communications subsystem,
- iii) improvements in satellite system use, i.e. use of more cost-effective modulation and encoding techniques.

Improvements in these three areas are discussed below in Sections C.4.1 to C.4.3, and summarized in Section C.4.4.

#### C.4.1 IMPROVEMENTS IN SATELLITE BUS CHARACTERISTICS

Expected improvements in this area include the following:





- a) the introduction of magnetic bearings rather than mechanical bearings with lubricants, which will improve the reliability of the stabilization system;
- b) introduction of ion engines rather than hydrazine jets for station-keeping, to decrease the satellite weight and increase the operational lifetime of the satellite (a major constraint on the satellite lifetime is the on-board supply of hydrazine fuel);
- c) introduction of solar-cells with higher efficiency, expressed as electrical watts generated per pound of solar cell (this improvement is already being introduced to current satellite designs);
- d) introduction of NiH batteries rather than the presently used NiCd batteries, resulting in less danger of damaging the battery system due to over-discharge;
- e) introduction of more accurate attitude-control systems so that communication systems using spot beams and dual polarization can be used.

These are improvements in the various subsystems of the satellite bus. As well, a basic change in design of the bus may take place if the shuttle and tug system is used to launch the satellites. In that case, the satellite will probably be designed as an aggregate of replaceable subsystems rather than as an integrated unit as it is at present.

#### C.4.2 IMPROVEMENTS IN THE SATELLITE COMMUNICATION SYSTEM

Several improvements and new concepts in the communication subsystem are expected to be introduced in the next few years. These include:

- a) use of higher power transponders where applicable; (An example of the capability of high-power tubes is the 200 watt 12 GHz tube on CTS. Note, however, that next-generation satellites may not use such tubes unless the satellite system includes hundreds of ground stations).
- b) use of solid-state amplifiers rather than TWTA's for low-power transponders, which would increase the reliability and lifetime of the amplifiers;





- c) introduction of antenna systems capable of generating several spot beams; (These systems may use large parabolic or spherical reflectors with several feed horns, or may use other systems such as phased arrays or lens antennas if these antennas can compete on a weight basis with the reflector-and-feedhorn system).
- d) development of systems at higher frequencies, at 11 GHz, 12 GHz, 14 GHz, 18 GHz and 30 GHz;
- e) development of on-board signal processing, such as satellite-switching and on-board re-modulation. Satellite-switching may be introduced so that spot beams and very-wide-bandwidth transponders may be used efficiently, and so that the satellite system may be adaptable to diurnal or long-term variations in traffic requirements. On-board remodulation, say from 4 phase PSK to 8 phase PSK, may become a cost-effective method of connecting ground stations with different G/T values. These techniques are not likely to be introduced unless the signal-processing equipment can be made quite large and extremely reliable.

## C.4.3 IMPROVED METHODS OF USING THE SATELLITES TO INCREASE

THE TRAFFIC-HANDLING CAPACITY OF A GIVEN SATELLITE

Several improvements in the modulation, access and encoding techniques used in the satellite system are expected to be introduced to increase the traffic-handling capability of a given satellite system. These include:

- a) introduction of time-division multiple access (TDMA); (TDMA is being introduced on a limited scale in the Anik system to handle COTC traffic between Halifax and Toronto);
- b) a demand assignment system for thin-route traffic that is centrally controlled, and therefore less expensive than the Intelsat SPADE system with distributed control;
- c) higher-capacity digital modulation techniques such as 8 phase PSK and possibly 16 phase PSK;
- d) source-encoding schemes such as DITEC for television distribution and SPEC for voice transmission.





#### C.4.4 SUMMARY

As seen from the above list of possible improvements to communication satellites in the next decade, communication satellite system design is much more "dynamic" or in a "state-of-flux" than the designer of terrestrial communication transmission systems. This is basically because the medium is a much newer one; the first operational communication satellites were launched in the mid and late 1960's. In contrast, microwave radio and coaxial cable systems, still the backbone of terrestrial transmission networks, were introduced in the 1940's.

It is expected, however, that the rate at which new satellites and satellite subsystems are introduced will decrease in the next few years, for the following reasons:

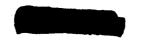
- a) Successful operating "off-the-shelf" satellites are available at present (see Section C.3.4), whereas this was not so ten years ago.
- b) There is a tendency to space-prove major new satellite subsystems on experimental satellites or as additions to more conventional operational satellites. The decision by NASA not to continue development of communication satellites could slow down the rate of introduction of new systems.
- As suggested in Section C.3.4 above, it is not likely that major satellite design changes will be introduced until the timing and extent of the shuttle-tug program is clarified, and until there is the requirement for the next generation of U.S. domestic satellite. The only expected exceptions to this are development of the Intelsat IV and the AT&T 18/30 GHz satellites.

System improvements suggested in Section C.4.3 may come sooner, since they are improvements primarily in ground station electronic equipment, used in conjunction with the same satellites used by earlier equipment.

#### C.5 SATELLITE LAUNCH VEHICLES

#### C.5.1 CONVENTIONAL LAUNCH VEHICLES

The launch vehicle imposes rigid weight and volume constraints on the payload satellite or satellites. The reason for the weight constraint is fairly obvious; the launch vehicle is capable of lifting only so much weight into a circular





synchronous geostationary orbit. The volume constraint imposed because of the shape of the payload cavity, a cylindrical with a definite diameter and height. This volume constraint is a serious one when spin-stabilized satellites used, because the area of the side of the spinning cylinder determines the amount of prime power that can be generated in the satellite. Moreover, the diameter of the payload cavity usually the limiting dimension, because the height-to-diameter ratio of the satellite cannot be greater than a certain amount or it becomes dynamically unstable while in geostationary orbit. volume constraint is much less severe when a body-stabilized satellite is used because the satellite is usually a small cube similar shape during launch, from which the solar sails and antenna reflectors can be unfurled.

The three most widely used launch vehicles communications satellites are the Thor-Delta, the Atlas-Centaur These three launch vehicles are described in and the Titan IIIC. Appendix C of reference [1]. As explained in that report, there are many possible models in the Thor-Delta series, with different payload weight and volume capabilities. The most widely used of these recently for communications satellites has been the 2914 model with a launch capability of about 700 lbs. into synchronous orbit with the aid of an apogee-kick motor (AKM). In 1973 RCA Globcom let a contract to McDonnell-Douglas, manufacturer of the Thor-Delta, to construct the 3914 Thor-Delta with a lift capability of about 1,000 lbs. into synchronous orbit.

Other launch vehicles that could be used to place communications satellites in geostationary orbit are the Atlas-Agena, the Titan IIIB-Agena, and the Atlas-Agena with an apogee-kick motor.

The important salient features of these various launch vehicles, from a communications system viewpoint, are the satellite weight that can be placed in synchronous orbit, the cost of the satellite launch (including the delivery of the launch vehicle to the launch site, use of the launch site and launch staff, and interfacing of the payload and launch vehicle), and whether or not an apogee-kick motor is used. These characteristics are given in Table C.2.

## C.5.2 THE SHUTTLE-TUG

The shuttle is being developed by NASA as a reasonable launch vehicle to put large weights and volumes into low (~100 mile) orbits. It will be capable of placing up to 65,000 lbs. Into a 100 mile orbit at an estimated cost of \$10.5 million. This load may be up to 15 feet in diameter and 60 feet long. The shuttle is expected to be operational by about 1980.



TABLE C.2

Cost and Performance of Conventional Launch Vehicles

Launch Vehicle	Use of AKM	Maximum Wt. into Geostationary Orbit	Launch Cost, Millions of 1973 Dollars
Thor Delta 2914	Yes	710	7.5
Atlas-Agena	No	830	11
Titan IIIB-Agena	No	970	12
Thor-Delta 3914	Yes	1,050 (?)	9.0(?)
Atlas-Agena	Yes	1,430	11
Atlas-Centaur	Yes	1,900	17
Titan IIIC	No	3,270	25
	i	l	Ĭ



NASA plans are to eventually have a reasonable tug to raise communication satellites from the low 100 mile geostationary orbit. Meanwhile, development is underway modify the Delta launch vehicle to be used as a tug. Several Delta combinations are being considered, to raise weights from 1,010 lbs. to 4,500 lbs. into geostationary orbit. The estimated total cost to place a 4,500 lbs. load in synchronous orbit with shuttle and two tandem Deltas is \$9 million. information on the shuttle and tug is based on a seminar given by B.R. Stark of Philco Food Corp. at CRC in 1973 [2]. As stated previously, it is not expected that the shuttle will be used to launch the next generation of Canadian domestic satellites. However, the presence of the shuttle and development of interim expendible tugs is important, in that it is expected to slow development of both conventional launch vehicles and satellites to be launched by conventional means.

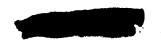
#### C.6 COMPUTER PROGRAM TO DETERMINE SATELLITE WEIGHTS

#### AND COSTS

The weights and costs of most existing satellites were determined from the manufacturers or the users of the satellites; these satellites are evaluated above in Section C.2. However, for the synthesis and evaluation of possible satellite systems as part of the overall network for the 1980's, we required the ability to estimate the weight and cost of modifications to existing satellites, and of completely new satellite types.

A technique developed by COMSAT [3], and used by BNR on their SHF satellite study [1] and also on later multi-beam satellite studies [4,5], proved to be an accurate and flexible one which suited our needs. Basically, Kiesling et al examined the characteristics and costs of communication satellites built or proposed prior to 1972, and from this data determined empirical formulae to estimate the weight and costs of new satellites. The first part of this task was to determine the weight of any given communication satellite based on its communication requirements. The second part of the task was to determine the development costs, production costs, and launch costs of that satellite, based on its weight.

The computer program which was written to make estimates of the weight and costs of many different satellite options was based on the COMSAT empirical technique. In adapting the technique for use in the DLDCNS it was assumed that an operational satellite may include several communication "subsystems", each with its own transponder power and bandwidth, antenna system and redundant transponders, and that these





subsystems would be combined to use the same prime power system and satellite bus. In general, the program was written to carry out the following steps:

- i) to determine the weight requirements of each communications subsystem of the satellite,
- ii) to determine the weight of the complete satellite in synchronous orbit which would carry the communication system "payload" weights determined in (i),
- iii) to determine the development, production and launch costs of a satellite with the total weight determined in (ii),
- iv) to determine the total capital and annual costs of the space portion of a satellite system using the above satellites, taking into account the number of satellites used, satellite lifetime, cost of money, and use of TT&C ground stations.

The required input, calculations, and output of this computer program are described below.

## C.6.1 INPUT REQUIRED

Input data is in general a description of the satellite system of interest. This data consists of two types: data on the satellite system as a whole, and data on each communication subsystem of the satellite. Data on the satellite system as a whole consists of values for the following:

- i) the number of identical satellites required for the system, including in-orbit and ground spares,
- ii) the number of satellites to be launched, assuming no requirement for additional satellites because of satellite failure,
- iii) the number of satellites over which the manufacturer would spread his developmental costs,
- iv) the number of antenna reflectors at 4/6 GHz,
- v) the number of antenna reflectors at 12/14 GHz,
- vi) the number of antenna reflectors at other frequencies,





- vii) the total number of redundant receiver boxes in the satellite for all communications subsystems,
- viii) the total number of antenna feedhorns at all frequencies,
- ix) the number of communication subsystems in each satellite,
- x) the interest rate used in determining the present value of total system costs,
- xi) the planned satellite lifetime,
- xii) the time interval between launches of the in-orbit satellites of the system,
- xiii) the satellite launch insurance cost as a function of the sum of the satellite production cost and launch cost,
- xiv) the voice circuit capacity of the satellite system, and
- xv) the television program capacity of the system.

As well, the following data on each communication subsystem of the satellite is required:

- i) the transponder bandwidth in MHz,
- ii) the east-west and north-south antenna beamwidth in degrees,
- iii) the required subsystem carrier-to-noise ratio in the down path,
- iv) the diameter of the corresponding ground station,
- v) the noise temperature of the corresponding ground station,
- vi) the downlink carrier frequency in GHz,
- vii) the loss in dB between the final output amplifier and the output from the antenna,
- viii) the number of transponders required during a solar eclipse as a fraction of the maximum number of operational transponders,





- ix) the number of transponders per antenna beam,
- x) the number of antenna beams of the subsystem, and
- xi) the number of spare transponders carried in case of transponder failure, as a percentage of the total number of operational transponders.

As the program was written, a maximum of seven subsystems could be included in a given satellite. However, this number could easily be increased by making minor program changes.

#### C.6.2 OUTPUT PRODUCED

The following output is determined by the computer program:

- i) the antenna gain of each satellite antenna,
- ii) the power output requirement of each transponder in the satellite.
- iii) the satellite prime power requirements for each subsystem,
- iv) total "payload" weight of each communications
  subsystem,
- v) total satellite weight,
- vi) satellite development, production, and launch costs, assumed to be a function of the total satellite weight,
- vii) total annual cost of the satellite system, taking into account the cost of money at the specified interest rate,
- viii) marginal annual cost of the space portion of the satellite system per voice circuit for use in Southern Canada.

#### C.6.3 CALCULATION OF THE RESULTS

Both derived relationships between parameters and empirical formulae relating other parameters were used in determining the above results. Both observed and empirical formulae are described below so that the results obtained with the program can



be understood and so that the empirical formulae can be modified if necessary to take into account advances in satellite manufacture and changes in the cost of both satellites and launch venicles.

The following steps and relationships are included in the computer program calculations:

## 1. Satellite Antenna Gain For Each Subsystem:

$$GS = 40.8 - 10 \log_{10} (BW1 * BW2)$$
 (1)

where GS is the antenna gain in db, BW1 and BW2 are the E-W and N-S antenna beamwidths in degrees.

## 2. Antenna Array Weight:

For each antenna with gain GS the weight of the antenna reflector is

$$ARW = \frac{0.14 \cdot 10^{-10}}{F^2}$$
 (2)

where GS is the antenna gain in dB in (1), and F is the carrier frequency in GHz.

## 3. Earth Station Antenna Gain:

The Earth-station antenna gain is

GES = 
$$7.5 + 20 \log_{10} D - 20 \log_{10} F$$
 (3)

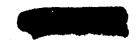
where F is the carrier frequency in GHz,
D is the antenna diameter in feet.

## 4. Transponder Output Power for Each Subsystem:

The required output power of a transponder in dBW is

$$TX = \left(\frac{C}{N}\right)_D + 10\log_{10}B - GS + 20\log_{10}F$$
 (4)

$$- GES + T + 16.8 + LS$$





where  $(C/N)_D$  is the required downlink carrier to noise ratio,

B is the system bandwidth in MHz,

GS is the satellite antenna gain, given by (1),

F is the carrier frequency in GHz,

GES is the Earth-station antenna gain, given by (3),

T is the receiving system noise temperature in  ${\bf dB}$  in the Earth station, and

LS is the satellite output system losses in dB.

# 5. Transponder Prime Power Requirements:

The d.c. prime power requirements of a transponder are assumed to be

$$TX/10$$
 $TXSW = 3.4 * 10$  (5)

# 6. Solar Array Prime Power Requirements for Earth Subsystem

The solar array must generate PAR watts of prime power for a given subsystem, where

PAR = 1.1 \* TXSW \* 
$$\left\{\frac{AK}{13.1} + 1\right\}$$
 \* M \* N (6)

where TXSW is the prime power required per transponder, given by (5),

AK is the eclipse capability of the subsystem,

M is the number of transponders per antenna beam of the subsystem, and

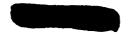
N is the number of antenna beams of the subsystem.

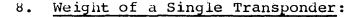
# 7. Battery Prime Power Requirements for Each Subsystem:

The battery prime power requirements PB are

$$PB = AK * TXSW * M * N * 1.24$$
 (7)

where AK, TXSW, M, and N are as defined above for Equation (6).





Weight of a single transmitter tube, as a function of its power output capability, is

$$WTWT = 3.5 + \frac{TX/10}{10}$$
 (8)

where TX is given by (4).

## 9. Combined Weight of All Transponders in a Given Subsystem:

The combined weight of all the transponders in a subsystem, including the multiplexing systems, is

WEM = M \* N \* 
$$\{1.6 + \text{WTWT}(1 + \text{SS})\}$$
 (9)

where M and N are as defined for Eqn. (6),

WTWT is the weight of a transponder, given by (8),

and SS is the subsystem spares ratio of spare transponders for the subsystem.

## 10. Battery Weight for a Given Subsystem:

Battery weight is proportional to battery prime power requirements of the battery system, and is given by

$$WB = 0.2*PB \tag{10}$$

where PB is the battery prime power requirement given by (7).

## 11. Satellite Solar Array Weight:

Solar array weight is a nonlinear function of solar array prime power requirements. The solar array prime power requirement for subsystem i, given by (6), is PAR. The total solar-array prime power requirement, then, is

$$PRR = \sum_{i=1}^{I} PAR_{i}$$
 (11a)

where I is the number of subsystems in the satellite.

The "efficiency" of the solar array system is described by the parameter



$$GA = \frac{PRR}{0.045 * PRR + 90}$$
 (11b)

The weight of the solar array is

WAR = 0.045 \* PRR + 90 (11c)  
= 
$$\frac{PRR}{GA}$$
, (11c)

and the weight allocated to subsystem i is

$$WAR_{i} = \frac{PAR_{i}}{GA}$$
 (11d)

# 12. Additional Communication System Weight:

The additional satellite weight, WCE, is given by

WCE = (number of reflectors at 4/6 GHz) \* ARW4

- + (number of reflectors at 12/14 GHz) \* ARW12
- + (number of reflectors at other freq.) \* ARWO
- + (number of receiver boxes) \* 10.0
- + (number of feedhorns) \* 2.0 (12a)

where ARW4 is the weight of the heaviest reflector at 4/6 GHz, determined with Eqn. (2),

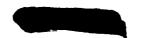
ARW12 is the weight of the heaviest reflector at  $12/14~\mathrm{GHz}$ , and

ARWO is the weight of the heaviest reflector at any other frequency.

The amount of extra weight allocated to subsystem i is arbitrarily stated to be

$$WCE_{i} = \frac{N_{i}^{*M}_{i}}{\sum_{j=1}^{I} N_{j}^{*M}_{j}} * WCE$$
 (12b)

where  $M_i$  and  $N_i$  are as in Eqn. (6) and I is as in Eqn. (11).





As well, additional weight  $AW_i$  of subsystem i may be specified as an input to account for the additional features of the subsystem. Thus the total additional weight associated with subsystem i is

$$ATW_{i} = WCE_{i} + AW_{i}$$
 (12c)

## 13. Total Communications Payload Weight:

The payload weight for each subsystem is the sum of its transponder weights, WEM; given by Eqn. (9), battery weight WB; given by Eqn. (10), solar array weight WAR; given by Eqn. (11d), and additional weight ATW; given by Eqn. (12c). The sum is

$$WSC_i = WEM_i + WB_i + WAR_i + ATW_i$$
 (13a)

The total satellite communications payload weight is

$$WSC = \Sigma_{i=1}^{I} WSC_{i}$$
 (13b)

with I, as before, the number of subsystems on the satellite.

# 14. Total Satellite Weight:

The weight efficiency factor of satellites has been found to be

$$SEF = 1.3 \times 10^{-4} * WSC + 0.3283$$
 (14a)

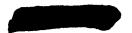
with a minimum of 0.38. The total satellite weight, then, is

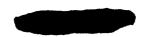
$$WS = WSC$$
 (14b)

## 15. Satellite Development Costs, Production Costs and

## Launch Costs

The development costs, production costs and launch costs of a satellite system are assumed to be proportional to the square root of the total satellite weight, JWS. More precisely, these costs, expressed in millions of 1973 dollars, are approximately;





Development Costs: CD = 0.9√WS (15a)

Production Costs:  $CP = 0.22 \overline{WS}$  (15b)

Launch Costs:  $CL = 0.3 \overline{WS}$  (15c)

## 16. T.T.&C. Ground Station Annual Costs

For a satellite system with one operational and one in-orbit spare satellite, the total TT&C annual costs are approximately

AC1 = 
$$\left(\frac{i}{1 - (1+i)} - 2N + 0.13\right) * 3.0$$
  
+  $\left(\frac{i}{1 - (1+i)}\right) * 2.6 + 1.4$  (16a)

where i is the interest rate,

N is the satellite lifetime in years, and

0.13 is the assumed maintenance cost to capital cost ratio for the ground station.

For each additional in-orbit satellite above two, the annual cost for TT&C is

AC2 = 
$$\left(\frac{i}{1 - (1+i)^{-2N}} + 0.13\right) * 1.5$$
  
+  $\left(\frac{i}{1 - (1+i)^{-N}}\right) * 0.4 + 0.25$  (16b)

# 17. Total Satellite System Annual Cost:

The total satellite system annual cost is

SATAN = 
$$\left(\frac{i}{1 - (1+i)^{-N}}\right) * 0.9 \sqrt{WS} * \frac{NS1}{NS3}$$
  
+  $\Sigma_{j=1}^{NS2} \left(\left(\frac{i}{1 - (1+i)^{-N}}\right)\right) * 0.52 \sqrt{WS} * (1+K) (1+i)^{-(j-1)D}$   
+  $\left(\frac{i}{1 - (1+i)^{-N}}\right) * 0.22 \sqrt{WS} * (1+i)^{-NS2*D} + AC1 + (NS2-2) *AC2$ 



where NS1 is the number of satellites purchased,

NS2 is the number of satellites launched,

NS3 is the number of satellites over which development costs are spread,

K is the increase in percentage launch costs due to launch insurance, and

D is the inter-launch interval in years.

# 18. Marginal Cost Calculations of Cost Per Voice Circuit

Suppose that a satellite system provides the following services:

- i) Thin-route requirements and television distribution in northern Canada and between northern and southern Canada,
- ii) Distribution of NTV television programs in southern Canada only,
- iii) Transmission of NVC voice circuits in southern Canada.

Then the marginal cost per voice circuit for southern services is

$$AVCC = \frac{SATAN2 - SATAN1}{NVC + 500 * NTV}$$
 (18)

where SATAN2 is the total annual cost of the composite satellite system,

SATAN1 is the total annual cost of the small system to meet northern services only.

## C.6.4 PERFORMANCE OF THE PROGRAM

As stated above, the empirical formulae used in the program were based on information available to COMSAT on satellites developed before 1972. To test the usefulness of the program in estimating the performance of later satellites, the program was used to estimate the weight and cost of two modern satellites, the Anik spin-stabilized satellite and the Fairchild 24 channel body-stabilized satellite (a satellite which is very similar to the 24-channel RCA satellite). The results of these tests are shown below in Table C.3.





Table C.3

Evaluation of Computer Program Performance

Satellite Model	Anik Satellite	Fairchild Satellite
Estimated Weight	594	1140
Actual Weight	600	1030
Estimated Capital Cost	52.6	10.1
Acutal Capital Cost	48	10.6

#### C.7 USE OF THE COMPUTER PROGRAM

The program was used several hundred times during the course of the study. When considering satellites for the 1980-87 time-frame, rather conventional satellite systems only were considered, i.e. satellites similar to or at least with similar buses to satellites being produced or planned at the present time. Basically, the satellites considered for operational use in 1980-87 were variations of those described in Sections C.2 and C.3. In contrast, the satellite improvements described in Section C.4 were assumed to be available for operational use in the later 1987-1994 interval.

It may be noted that the satellite launch cost is assumed to be  $0.3\sqrt{\text{WS}}$ , a smooth function of satellite weight. However, only a small number of launch vehicles is available, and so the launch cost is in fact a discrete function of satellite weight. To avoid large errors due to this difference, only satellites with weights close to the capabilities of available launch venicles were considered for the 1980-87 interval. considering satellites for the 1987-1994 interval, no However, it was constraints were placed on satellite weights. assumed that the launch cost of 0.3/WS would continue, i.e. that conventional launch vehicles rather than the shuttle-tug would be used in the late 1980's.



## References

- 1) Bell-Northern Research, "A Super-High-Frequency Satellite Communications System for Canada, (1977-1985)", BNR Report to DOC, Sept. 1971.
- 2) B.R. Stack, of Philo-Ford Corp; CRC Seminar on the Characteristics of Communication Satellites and Launch Venicles, May 1973.
- J.D. Kiesling, B.R. Elbert, W.B. Garner, and W.L. Morgan, "A Technique for Modelling Communications Satellites", COMSAT Technical Review, Vol. 2, No. 1, Spring 1972, pp. 73-103.
- 4) Bell-Northern Research, "A Multi-Beam SHF Satellite Communication System for Canada, (1977-1985)", October 1972.
- 5) Bell-Northern Research, "Feasibility Study of a Broadcast Satellite System for the CBC Post-1978 Requirements", BNR Report to DOC, July 1973.



#### APPENDIX D

# CHARACTERISTICS AND COSTS OF SATELLITE GROUND STATIONS FOR THE CANADIAN LONG-DISTANCE COMMUNICATION NETWORK IN THE 1980's

#### D.1 INTRODUCTION

In this Appendix the characteristics and costs of satellite ground stations which might become part of the satellite system of the Canadian domestic long-distance communication network in the 1980's are described. Four distinct types of ground station are described in this Appendix. They are:

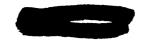
- 1) 4/6 GHz ground stations to carry voice and television traffic,
- 2) 12/14 GHz ground stations to carry voice and television traffic,
- 3) telemetry, tracking, and control (TT&C) ground stations,
- 4) small receive-only ground stations for television reception.

Ground stations for use in northern Canada are not described nere, because their costs are not required in comparing terrestrial and satellite systems for southern Canada.

Considerable information on the characteristics and capital costs of ground stations was presented in DLDCNS Reports 5 [1] and 9 [2]. This Appendix expands on that information, and in some cases supercedes it; all information necessary to model the ground stations from a network viewpoint are presented in this Appendix.

The model of 4/6 GHz and 12/14 GHz ground stations which carry television and/or voice traffic is described in Section D.2. A major difference between ground stations at 4/6 GHz and those at 12/14 GHz is of course the long backhaul systems of the former. As is shown below, this difference is dealt with simply





by changing the cost function of one of the branches of the network model of the ground station.

The modulation techniques that would be feasible on a satellite system in the 1980's, and the necessary signal strengths for the more attractive techniques, are presented in Section D.3. Source encoding techniques which could be used to increase the capacity of the system are described in Section D.4.

The pasic or fixed costs of satellite ground stations are described in Section D.5. Included in these fixed costs are:

- the antenna, its supporting structure, and its feed system,
- 2) the building, access road, and other site costs,
- 3) initial costs of the backhaul system.

The incremental costs of ground stations, i.e. the costs associated with increasing the traffic carried through a satellite ground station, are described in Section D.6. These costs are essentially the cost of the electronic equipment in the ground stations and backhaul links.

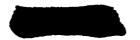
T.T.&C. ground stations and their costs are described in Section D.7.

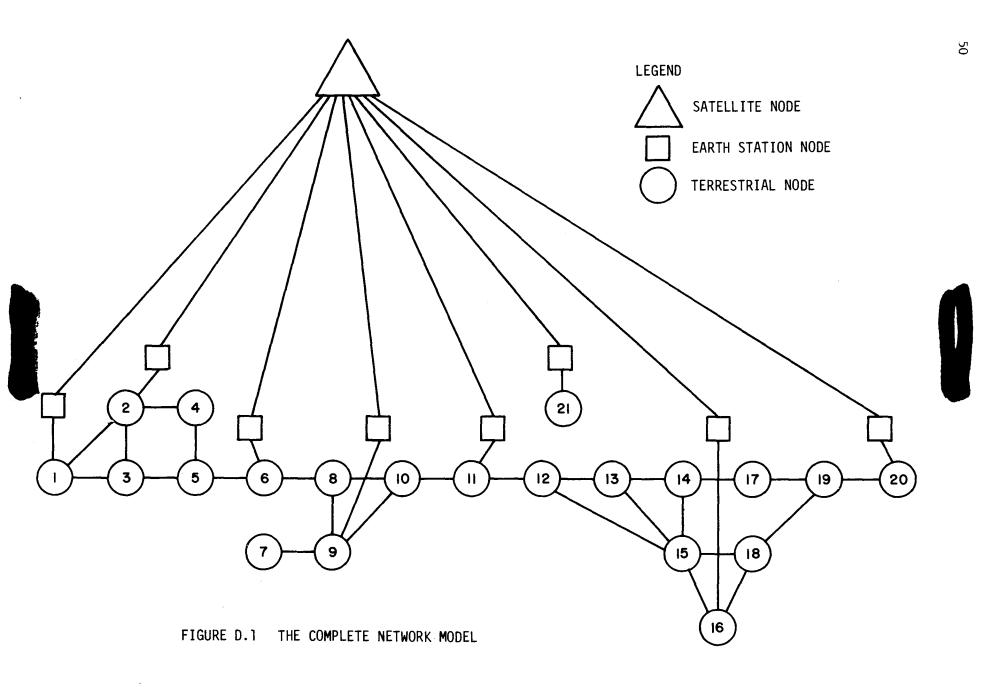
Characteristics and costs of small receive-only ground stations for network-quality regional CBC television signals in southern Canada are described in Section D.8.

Concession of ground station capital costs to annual costs is described in Section D.9, based on the more general conversion formulae of Appendix F. The annual cost functions for each link in the network model of a ground station is summarized in Section D.9.

## D.2 NETWORK MODEL OF A SATELLITE GROUND STATION

The overall satellite/terrestrial network, which includes the TCTS and the CNCP terrestrial networks and the satellite system, has been modelled as a network with a modest number of nodes and links. A simplified network model is shown in Fig. D.1. The locations of satellite ground stations in Fig. D.1 are only those in a feasible network, they were changed during synthesis of the network. The detailed network model in the Toronto-Sudbury-Ottawa area is shown in Fig. D.2. In Fig. D.2 the links within a metropolitan area are artificial links to





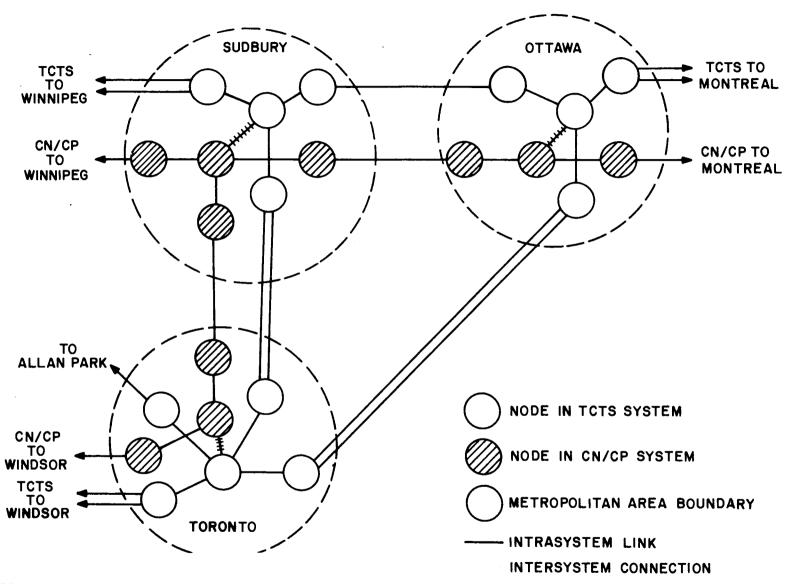


FIG. D.2 DETAILED NETWORK MODEL IN THE TORONTO-SUDDURY-OTTAMA AREA

account for transmission costs within that metropolitan area. A more detailed description of the network model is given in Cnapter 3, in Appendix B and in Appendix F.

As shown in Fig. D.2, the Allan Park satellite ground station is modelled as being connected to a peripheral node of the Toronto metropolitan network. (It is actually joined to the metropolitan network at the Shelbourne microwave repeater site, but that amount of detail is not considered in our model).

In synthesizing a network model of a satellite ground station the following had to be taken into account:

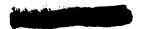
- a) the model must consist solely of network links and nodes,
- b) because of the character of the network optimization algorithms used, ground station costs must be associated with specific links rather than nodes,
- c) the ground stations handle television receive-only traffic, television transmit-and-receive traffic, nigh capacity voice traffic, and medium capacity voice traffic\*, each with its own cost per voice circuit or television signal.

The actual network model of a ground station, and its connection with a metropolitan junction of the terrestrial network, are shown in Fig. D.3. Each of the links shown in Fig. D.3 has a specific network cost associated with it. These costs are:

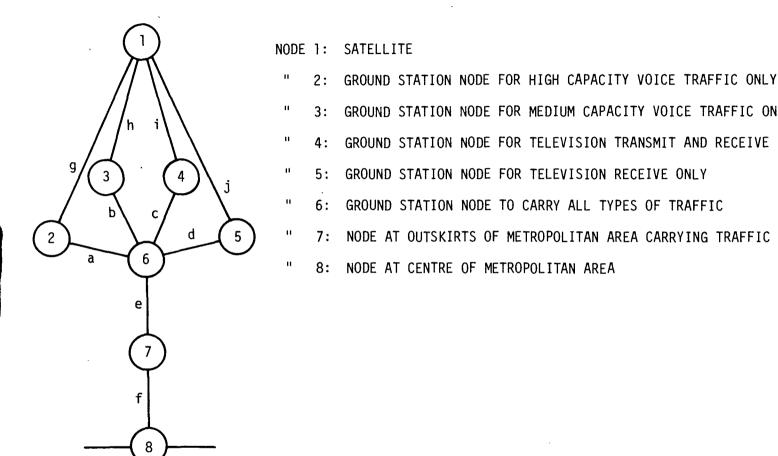
For link f: The metropolitan area costs, as explained in Appendix B.

For link e: All ground station costs which are common to all types of traffic through the ground station. Included are both fixed and incremental costs of the backhaul system, and ground station site and antenna system costs.

For link a: Incremental costs of adding high-capacity voice-circuit capability at the ground station.



<sup>\*</sup>Medium capacity voice traffic is defined to be that traffic which would be carried on the satellite system in a multiple access mode rather than through dedicated transponders.



- GROUND STATION NODE FOR MEDIUM CAPACITY VOICE TRAFFIC ONLY
- GROUND STATION NODE FOR TELEVISION TRANSMIT AND RECEIVE
- GROUND STATION NODE FOR TELEVISION RECEIVE ONLY
- GROUND STATION NODE TO CARRY ALL TYPES OF TRAFFIC
- NODE AT OUTSKIRTS OF METROPOLITAN AREA CARRYING TRAFFIC TO GROUND STATION
- NODE AT CENTRE OF METROPOLITAN AREA

FIG. D.3 NETWORK MODEL OF A SATELLITE GROUND STATION AND ITS NETWORK CONNECTIONS



For link b: Incremental costs of adding medium-capacity

voice circuit capability at the ground

station.

For link c: Incremental costs of adding the capability

to transmit and receive a network-quality

television signal.

For link d: Incremental costs of adding the capability

to receive a network-quality television

signal.

For links q, h, i and j:

the satellite system space portion costs to carry the same traffic carried through

links a, b, c and d respectively.

Note that links a, b, c and d can only carry a specific type of traffic. This complexity in the model was required because of the significant difference in ground station electronic costs for the different types of traffic.

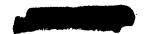
Cost functions for links a, b, c, d and e are described in Sections D.5, D.6 and D.9.

D.3 MODULATION TECHNIQUES AND SIGNAL STRENGTH REQUIREMENTS OF A

TRUNK COMMUNICATION SATELLITE SYSTEM

The present Anik satellite system uses the following types of modulation:

- a) High modulation index analog FM to transmit 960 voice channels or one network quality TV signal per 36 MHz wide transponder.
- b) Single Channel Per Carrier (SCPC) frequency-division-multiple-access (FDMA) for thin-route voice transmission with up to 120 voice channels per transponder and 40 Kb/s delta-modulation of each carrier.
- transmission of 400 voice circuits through a single transponder between Halifax and Toronto. (In this system the 400 voice circuits are frequency-division multiplexed (FDM), quantized at 9 bits to form a 30 Mb/s bit stream, and transmitted by PSK/TDMA).





Frequency-division-multiple-access (FDMA) is also available, and is being used in other operational satellite systems, but is very inefficient compared with TDMA.

It is assumed that in the 1980's the above techniques will still be available, if they prove to be the most cost-effective, and that the following new techniques will also be available:

- a) time-division-multiplexing (TDM) of individual voice circuits,
- b) 4 phase PSK and 8 phase PSK transmission of time-division multiplexed signals,
- c) TDMA of several signals through a single transponder.

Other modulation techniques such as 16 phase PSK and combinations of angle and amplitude modulation with even higher ratios of voice circuits/hertz are being investigated in laboratories, but it is not expected that these will be available for operational use in the early 1980's.

Carrier-to-noise ratios were determined for each of the above types of transmission, based on the following requirements:

- a) a "worst-case" error rate of 10<sup>-5</sup> for digital voice transmission systems, with an outage rate no greater than .01%,
- b) a "worst-case" error rate of 10<sup>-4</sup> for digital television transmission systems, with outage no greater than .05%,
- c) a "system implementation margin" of 4 dB,
- d) in addition to the implementation margin, a propagation attenuation margin of 3 dB at 4/6 GHz and 8 dB at 12/14 GHz,
- e) an uplink carrier-to-noise ratio about ten times that of the downlink, resulting in an overall carrier-to-noise ratio only 0.4 dB lower than the downlink ratio.

Based on these requirements, the required downlink carrier-to-noise ratios for the different transmission systems at both 4/6 GHz and at 12/14 GHz are as shown in Table D.1.

Analog FM transmission of voice, either through dedicated transponders or in an FDMA mode, was not included in Table D.1



Table D.1
Required Downlink Carrier-to-Noise Ratios

Carrier Frequency	Type of Traffic	Type of Modulation	Down Link Carrier-to-Noise Ratio
4/6 GHz	voice	4 phase PSK	17.6 dB
4/6 GHz	voice	8 phase PSK	23.3 dB
4/6 GHz	. VT	4 phase PSK	16.6 dB
4/6 GHz	TV	analog FM	13.5 dB
12/14 GHz	voice	4 phase PSK	22.6 dB
12/14 GHz	voice	8 phase PSK	28.3 dB
12/14 GHz	TV	4 phse PSK	21.1 dB
12/14 GHz	TV	analog FM	17.5 dB
	1	1	1



because digital transmission of voice through the satellite system is much more cost-effective than analog transmission, as is shown below. Moreover, the required carrier-to-noise ratio is a continuous function of the desired system capacity rather than the discrete requirements shown in Table D.1.

# D.4 SOURCE ENCODING TECHNIQUES FOR DIGITAL TRANSMISSION SYSTEMS

Significant developments have been made in the source encoding of voice and television signals for transmission over digital transmission systems. The DITEC system has developed for the transmission of two network-quality television over single Intelsat IV (or Anik) satellite a system is being transponder. At the same time, the SPEC developed to double the number of voice messages to be carried over a given digital voice transmission system. ADDIC, a system similar to SPEC, is being developed in Italy as an alternative to The characteristics and estimated costs of the DITEC and SPEC systems are summarized below.

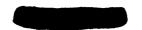
#### J.4.1 THE DITEC SCHEME FOR SOURCE ENCODING OF TELEVISION

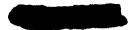
## SIGNALS FOR DIGITAL TRANSMISSION

The DITEC system was reported by Golding at the 2nd International Conference on Digital Satellite Communications [3]. Since that time, in June 1974, the DITEC system underwent a field demonstration in which it transmitted two CBC television programs through the Anik satellite between Vancouver and Montreal.

Basically, the DITEC system is one in which the television audio and video signals are encoded to form a 29.4 Mb/s digital sequence. This sequence is then channel encoded with a 7/8 rate convolutional code to form a 33.6 Mb/s digital sequence transmission. Two such sequences can be time-division multiplexed and the resultant bit stream transmitted over an Anik transponder by using 4 phase PSK modulation. By using error-correcting characteristics of the convolutional code, the system is reputedly able to reproduce a network-quality signal with a random channel error rate of 10-4.

In January 1973 it was estimated by COMSAT, the developer of the DITEC system, that DITEC equipment would cost about \$40,000 for either an encoder or a decoder. Thus if the DITEC equipment is used to transmit a television signal from one location to N others, the capital cost of the encoding equipment is \$(N+1)40,000. Note that the input to the encoder is a baseband television signal, and the output is a baseband 33.6 Nb/s digital sequence.





#### D.4.2 THE SPEC SCHEME FOR SOURCE ENCODING BLOCKS OF

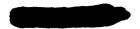
#### VOICE SIGNALS FOR DIGITAL TRANSMISSION

The SPEC system has been reported by Campanella and Sciulli [4,5], Campanella and Suyderhoud [6], and by Suyderhoud, Jankowski, and Ridings. [7] The SPEC system takes advantage of the fact that when two people are conversing over a full-duplex voice circuit, only about 40% of the capacity of the channel is being used, since only one person is talking at once and there are gaps in his speaking. The principle on which SPEC is based 2N voice conversations on N full-duplex voice channels by filling the gaps in a speech waveform with another speech large enough, this can be done with very waveform. If N is little distortion of the transmitted signals.

An earlier speech interpolation system, TASI, is being operationally on intercontinental submarine cable systems. It is an analog system. A major criticism of the TASI system is achieves its that it encoding advantage by dropping low-level high speech signals in traffic conditions, and interruptions are objectionable. The SPEC system reputedly avoids this problem by using an estimate of each speech waveform at the receiver when that waveform is not transmitted, and so degrades much more gracefully in very high traffic conditions.[6]

The SPEC system has been developed and has undergone field trials for use in the Intelsat system. In its present form it is used to transmit 64 voice signals through 32 voice circuits. In the Canadian digital multiplexing hierarchy 32 voice circuits are not used; rather, 24 circuits are used on T-1 systems, and 96 circuits on T-2 systems. In a private conversation with the author, S.J. Campanella stated that SPEC could be modified to be used at either the T-1 or the T-2 rate.

A prototype SPEC system has been developed in the COMSAT Laboratories, and field trials of this prototype system have been Intelsat IV between Hawaii and Brewster Flats, through an Washington, and then by terrestrial transmission to Clarksburg, However, the system has not yet been produced in Because of this, cost estimates of operational quantity. SPEC systems are very tentative. Information available 1974 indicated that a system which reduced 48 voice circuits (two blocks) to 24 circuits would cost about \$9,000, or \$200 per voice More recent information indicates that circuit end, installed. the cost of an installed SPEC system operating at the T-1 or rate will be about \$400 per voice-circuit-end, and may be as high as \$700 per voice-circuit-end.



#### D.5 INITIAL COST OF SATELLITE GROUND STATIONS

The initial cost of a satellite ground station includes the initial cost of the ground station itself, including the building, the antenna system, the prime power supply system, and the low-noise amplifier for the site. As well, the initial cost includes that of the microwave radio or land-line backhaul system to a metropolitan junction node. Costs are quite different for 4/6 GHz systems and 12/14 GHz systems, and so are discussed separately in Sections D.5.1 and D.5.2 respectively. The complete ground station initial costs are allocated to link e of Figure D.3.

#### D.5.1 INITIAL COST OF 4/6 GHz GROUND STATIONS

It is assumed that, if a 4/6 GHz satellite system is used in the 1980's, the present heavy-route and NTV ground stations would be augmented. The two major components of the initial costs of these ground stations are the backhaul initial costs and the initial costs of the ground stations themselves. The initial costs of the ground stations themselves is shown in Table D.2 taken from reference 1.

An important and probable augmentation of the existing 4/6 GHz ground stations is the addition of a second antenna system so that traffic can be routed through two satellites simultaneously. (This is discussed in detail in Chapter 4 of the full report). The capital costs of adding a second antenna system at an established ground station are given in Table D.3.

The backhaul systems from the 4/6 GHz ground stations to the metropolitan areas that they serve vary from one ground station to another, and so must be costed individually. The distances from existing ground stations to their respective metropolitan areas are given in Table D.4. It is assumed that if new ground stations are installed, at Moncton or Sept Iles for instance, the backhaul system would be a one-hop one. The backhaul systems use the upper 6 GHz band, from 6425 MHz to 6590 MHz and from 6770 MHz to 6930 MHz. It is assumed that the same frequency band and frequency plan would be used for radio backnaul systems in the 1980's. Eight full-duplex radio channels, each 20 MHz wide, are used in this band. It is assumed that in such short-haul systems seven operational and one not-standby radio channel would be used.

Cost information on the radio backhaul systems were taken from Appendix B, the description of the terrestrial radio systems, on the assumption that the costs of the backhaul radio links would be very similar to that of long-haul terrestrial

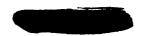


Table D.2

Initial Costs of 4/6 GHz Ground Stations

Parabolic Antenna Diameter, ft.	97	75	33	26
System Noise Temperature, dB <sup>0</sup> K	22	22	22	28
Ground Station G/T, dB/°K	37	35	28	20
Land, Building, Utilities, \$,000	480	280	120	80
Antenna Costs, \$,000	935	685	35	30
De-icing Eqpt., \$,000	50	38	2.5	2.5
Antenna Auxiliary Eqpt., \$,000	<b>7</b> 5	75	15	10
Supervisory Eqpt., \$,000	60	60	60	15
Standby Eqpt., \$,000	150	145	140	40
Low-Noise Amplifier, \$,000	32	32	32	7
Total Capital Cost, \$,000	1,782	1,315	404.5	184.5

Table D.3

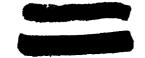
Cost of Adding a Second Antenna
To a Ground Station

Antenna Diameter, ft.	97	75	33	26
Additional Land, Building, Utilities, \$,000	300	200	20	20
Antenna Costs, \$,000	935	685	35	30
De-icing Eqpt., \$,000	50	38	2.5	2.5
Antenna Auxiliary Eqpt., \$,000	75	75	15	10
Supervisory Eqpt., \$,000	10	10	10	5
Standby Power Supply Eqpt., \$,000	40	40	30	10
Low-noise Amplifier, \$,000	32	32	32	7
Total Capital Costs, \$,000	1,442	1,080	144.5	84.5

Table D.4

Radio Backhaul from Existing Ground Stations
To Nearest TCTS Metropolitan Junction Node

Metropolitan Area	Satellite Ground Station	Nearest Metropolitan Junction Repeater	Distance, Miles	Anticipated Number of Hops
Vancouver	Lake Cowichan	Haney	75.3	3
Edmonton	Hugget	Kavanaugh	24.8	1
Regina	Qu'Appelle	Craven	20.4	1
Winnipeg	Grand Beach	Queen's Valley	51.7	2
Toronto	Allan Park	Shelbourne	40.8	2
Montreal	Riv. Rouge	Rigaud	28.6	1
Halifax	Harrietsfield	Gore	37.4	2
St. John's	Bull's Bay	St. John's	17.4	1



radio links. It was assumed that no radio protection equipment or digital radio regeneration equipment would be used at the one or perhaps two intermediate repeaters of a backhaul link. The capital costs of radio terminals is given in Table D.5 as a function of the installed number of operational radio channels, and the cost of intermediate repeaters is given in Table D.6. The installed capital cost of the complete backhaul systems at each of the present heavy-route or NTV ground stations is given in Table D.7. Also included in Table D.7 is the initial cost of the ground station itself; the sum of the two initial costs is the initial capital cost of link e of Figure D.3 for 4/6 GHz systems.

## D.5.2 INITIAL COST OF 12/14 GHz GROUND STATIONS

It is expected that 12/14 GHz ground stations with antennas in the 30' to 60' range, perhaps with dual antenna systems, would be placed near a metropolitan junction node. This would avoid the long backhaul costs associated with 4/6 GHz ground stations. At the same time, it is expected that they would be too large and real estate would be too expensive to place them in the downtown area of large cities. They would likely be connected to a junction node through a short coaxial-cable wire-line-entrance-link.

Costs of 12/14 GHz ground stations themselves are similar to those at 4/6 GHz, with the following exceptions:

- a) Antennas of similar diameter at 12/14 GHz are more expensive than at 4/6 GHz because they have finer surface tolerances and because they have higher gain and so require more tracking capability.
- b) Equipment such as low-noise preamplifiers, power dividers, antenna feed systems, etc, are more expensive at 12/14 GHz. It was estimated that these items would be 50% more at 12/14 GHz than at 4/6 GHz.

The initial costs of 12/14 GHz ground stations is given in Table D.8 for ground stations with different antenna types. Included are the initial costs of a coaxial cable wire-line-entrance-link to a metropolitan junction node. The costs incurred in adding a 12/14 GHz antenna system at an existing ground station are given in Table D.9.



Table D.5

Installed Costs of a Terminal Repeater in an Upper 6 GHz Radio System

	_	acity, Channels Protection	Site, Antenna & Alarm Costs	R.F. Connection Costs	Protection Switch Costs	Prime Power Costs	Transceiver Costs	Modem Costs	Total Costs
_	1	1	\$117,000	\$16,300	\$84,200	\$67,000	\$52,360	\$20,600	\$357,5
	2	1			16,800		26,180	10,300	53,3
	. 3	1			16,800		26,180	10,300	53,3
J	. 4	1		7,100	16,800		26,180	10,300	60,4
	5 .	1			16,800		26,180	10,300	53,300
	6	1			16,800	9,000	26,180	10,300	62,300
	7	1			16,800		26,180	10,300	53,300

Table D.6

Installed Costs of a Regular Repeater in an Upper 6 GHz Radio System

	city, Channels Protection	Site, Antenna & Alarm Costs	R.F. Connection Costs	Prime Power Costs	Transceiver Costs	Total Costs
1	1	\$127,000	\$32,600	\$60,000	\$104,720	\$324,400
2	1				52,360	52,360
3	1				52,360	52,360
4	1	<u> </u>	14,200		52,360	66,560
5	1				52,360	52,360
6	1			9,000	52,360	61,360
7	1				52,360	52,360

Table D.7

Capital Costs of 4/6 GHz Ground Station and Backhaul Systems

Metropolitan Area	Backhaul Initial Costs	Backhaul Full-Load Costs	Backhaul Incremental Costs	Ground Station Initial Costs	Total Initial Costs
Vancouver	\$927,000	\$2,096,000	\$1,169,000	\$1,782,000	\$2,709,000
Edmonton	331,000	720,000	389,000	405,000	736,000
Regina	331,000	720,000	389,000	405,000	736,000
Winnipeg	629,000	1,408,000	779,000	405,000	1,034,000
Toronto	629,000	1,408,000	779,000	1,782,000	2,411,000
Montreal	331,000	720,000	389,000	405,000	736,000
Halifax	629,000	1,408,000	779,000	405,000	1,034,000
St. John's	331,000	720,000	389,000	405,000	736,000
·	,	•			

Table D.8

Initial Costs of 12/14 GHz Ground Stations

Parabolic Antenna Diameter, ft.	60	46	30	<b>1</b> 9
System Noise Temperature, dB <sup>0</sup> K	22	<b>2</b> 2	22	28
Ground Station GK, dB/0K	42	40	36	26
Land, Bldg., and Utilities, \$,000	480	280	120	80
Antenna Costs, \$,000	550	400	320	92
De-Icing Eqpt., \$,000	50	38	2.5	2.5
Antenna Auxiliary Eqpt., \$,000	110	110	22	15
Supervisory Eqpt., \$,000	60	60	60	15
Stand-by Power Supply Eqpt., \$,000	150	145	140	40
Low-Noise Amplifier, \$,000	48	48	48	10
Wire-Line-Entrance Link, \$,000	46	46	46	46
Total Capital Costs, \$,000	1,494	1,127	758.5	300.5

Table D.9

Capital Costs Incurred in Adding a 12/14 GHz Antenna System
To An Existing Ground Station

Antenna Diameter, ft.	60	46	30	19
Additional Land, Bldg., Utilities, \$,000	300	200	35	20
Antenna Costs, \$,000	550	400	320	92
De-icing Eqpt., \$,000	50	38	2.5	2.5
Auxiliary Antenna Eqpt., \$,000	110	110	22	15
Supervisory Eqpt., \$,000	10	10	10	5
Standby Power Supply Eqpt., \$,000	40	40	30	10
Low-Noise Amplifier, \$,000	48	48	48	10
Total Capital Costs, \$,000	1,103	846	467.5	154.5



#### D.6 INCREMENTAL GROUND STATION COSTS

Incremental ground station costs are those costs above the costs discussed above in Section D.5. They are called incremental costs, because they are proportional to the amount of traffic carried by the ground station. All costs of links a, b, c, and d of Fig. D.3 are incremental costs. The fixed costs discussed in Section D.5 are all allocated to link e. As well, the incremental costs of the microwave radio or wire-line-entrance-link systems are allocated to link e.

Calculation of ground station incremental costs is complex because there are several network possibilities to consider, several types of satellite traffic, and several choices of satellite modulation for each of the above. Choice of the most cost-effective satellite modulation scheme is a major result in itself.

Ground station costs are determined for the situation in which the terrestrial network remains an all-analog one, and for that in which it is a hybrid one with both digital and analog systems. The difference in ground station costs in these two cases is the additional multiplex costs to route traffic through the satellite system. This is described in more detail below in Section D.6.1.

A second variation which will affect ground station incremental costs is the choice of satellite frequency, either 4/6 GHz or 12/14 GHz, for a given type of traffic.

The third major variation is whether a given type of traffic is transmitted through the satellite system digitally or by analog means. If an analog system is used, it is assumed that the presently used frequency modulation schemes would continue to be used. If the system is converted to a digital one, it is assumed that 4 phase PSK would be used for most traffic, and possibly 8 phase PSK for high-capacity satellite links through dedicated transponders.

In total, there are eight scanarios to consider for each of the four kinds of traffic, as shown in Fig. D.4. For some combinations in Fig. D.4 and some types of traffic the satellite ground station system is the same, but this is the exception ratner than the rule, as is shown below.

The additional multiplex and source-encoding equipment for the various scenarios shown in Fig. D.4 is described below in Section D.6.1.



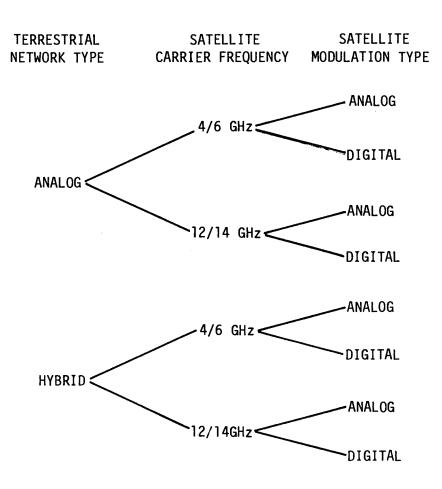


FIG. D.4 NETWORK SCENARIOS TO CONSIDER FOR EACH TYPE OF TRAFFIC





The additional multiplex and source-encoding equipment for the various scenarios shown in Fig. D.4 is described below in Section D.6.1. Note that it is only the additional costs over and above the costs which would be incurred in an all-terrestrial network which is included here, since the basic multiplexing costs would be incurred in network expansion and so need not be considered to meet the objectives of the DLDCNS.

The incremental costs of the backhaul systems for the various network scenarios of Fig. D.4 are given in Section D.6.2. Complete ground station communication systems and their costs for the different scenarios and types of traffic are described in Section D.6.3, and summarized in Section D.6.4.

#### D.6.1 ADDITIONAL MULTIPLEX EQUIPMENT REQUIRED FOR

#### SATELLITE TRANSMISSION

In determining the additional multiplex equipment requirements for voice transmission through the satellite system, we must consider the following four situations:

- An analog terrestrial network and an analog satellite system,
- 2) An analog terrestrial network and a digital satellite system,
- 3) A hybrid (digital and analog) terrestrial network and an analog satellite system, and
- 4) A hybrid terrestrial network and a digital satellite system.

The first situation, in which both the terrestrial and satellite systems are purely analog, is quite simple: there are no additional costs because both systems would use the same multiplexing equipment except perhaps for a different arrangement of supergroups and mastergroups.

Let us now consider the situation in which the terrestrial network is a hybrid one, with all new traffic routed on digital systems, and the satellite system is an analog one. Some of the traffic through the satellite system would originate in the same metropolitan area as the ground station, and so would simply be analog multiplexed for satellite transmission. Other traffic would originate in nearby metropolitan areas, such as in Calgary for satellite transmission at Edmonton or at Ottawa for satellite transmission at Montreal. Such traffic would be routed digitally



on the terrestrial network and then converted D/A for analog transmission at the ground station. An outline of such a system is snown in Fig. D.5a. If such traffic were routed completely through the terrestrial network, it would simply be multiplexed digitally and transmitted through the digital terrestrial system. The <u>additional</u> equipment required for analog satellite transmission is simply the analog multiplex equipment shown in Fig. D.5c.

Let us now consider the alternative in which **voic**e is transmitted digitally through the satellite. cost-effective to use SPEC equipment or other similar equipment in this case to double the capacity of the satellite system at a small percentage increase in satellite system cost. terrestrial network is an all-analog one, the multiplex system requirements at the satellite ground station are as shown in Fig. (See the above discussion of Fig. 5a for an explanation of the two input branches to the system). If the terrestrial network is a hybrid one, with digital terrestrial transmission the use of SPEC as the alternative to without transmission, the multiplex system requirements at the ground station are as shown in Fig. D.6b. Note that in this case the digital multiplexing of voice circuits from other metropolitan areas must be removed to the T-1 or first level so that SPEC equipment be used. In both the digital and can analog terrestrial network cases with a digital satellite system, additional multiplex equipment for satellite transmission is as shown in Fig. D.6c.

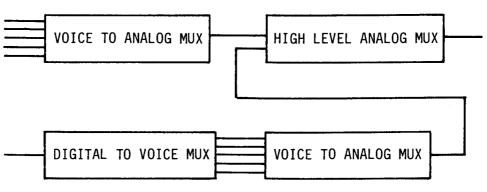
## D.6.2 INCREMENTAL COSTS OF BACKHAUL SYSTEMS

As discussed in Section D.5, the backhaul systems from 4/6 GHz satellite ground stations would be microwave radio systems in the upper 6 GHz band. If a 12/14 GHz satellite system were used with ground stations within the metropolitan areas, short coaxial cable wire-line-antenna-link systems would be used. In considering the incremental costs of these systems four scenarios are considered. These are:

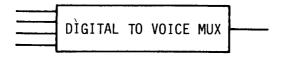
- A 4/6 GHz analog satellite system,
- A 4/6 GHz digital satellite system,
- 3) A 12/14 GHz analog satellite system, and
- 4) A 12/14 GHz digital satellite system.

If a 4/6 GHz analog satellite system were used, such as the present Anik system, the upper 6 GHz radio system would likely continue to be used as it is now, with up to seven full-duplex 20 MHz wide radio channels. As is the case of 4 GHz radio system (see Appendix B), up to 1260 voice circuits are

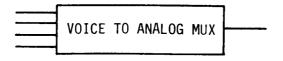




a. MULTIPLEX REQUIREMENTS TO FEED SATELLITE:



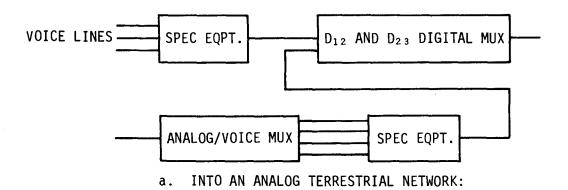
b. REQUIREMENTS FOR TERRESTRIAL NETWORK:

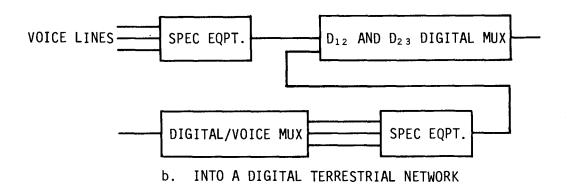


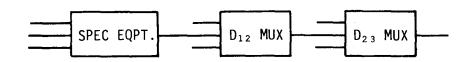
c. ADDITIONAL REQUIREMENTS TO FEED SATELLITE:

FIG. D.5 MULTIPLEX REQUIREMENTS FOR AN ANALOG SATELLITE SYSTEM WITH A DIGITAL TERRESTRIAL VOICE NETWORK









c. EQUIVALENT EQUIPMENT ADDITION

FIG. D.6 USE OF SPEC EQUIPMENT



transmitted at present per radio circuit, and this number may be increased to 1500 in the 1980's, for a total system capacity of 10,500 voice circuits. The backhaul incremental costs per voice circuit is obtained by dividing the backhaul incremental cost estimates of Table D.7 by 10,500. Backhaul incremental costs per television circuit are the costs of Table D.7 divided by seven. These costs are shown in Table D.10.

If a 4/6 GHz digital satellite system were used, it is likely that dual polarization could be used to provide 7 operating and one hot-standby 40 MHz full-duplex radio channels. (Note that the backhaul systems are one or two hop ones except at Vancouver where three are used). If the SPEC equipment were located at a downtown location rather than at the ground station, and if 4 phase PSK with partial response encoding were used, as in the 8 GHz terrestrial digital radio system, the capacity of the system would be 672 x 2 x 2 x 7 or 18,816 voice circuits. A television signal would require the equivalent of 1,344 voice circuits, so the system would be capable of carrying 14 television programs, 18,816 voice circuits or some combination of the two. Incremental costs per voice circuit and television signal are shown in Table D.10.

If a 12/14 GHz satellite were used, it is likely that short coaxial-cable wire-line-antenna-link would be used. satellite system were an analog one, a cable such as L-4 could be used, or a cable such as LD-4 if a digital satellite system were (See Appendix B for details of these systems). A nominal used. mile distance between ground station and metropolitan one junction point was assumed. The incremental capital cost of L-4 system would be about two dollars per voice circuit, considering that two terminals would be required, and about \$1.50 per voice circuit on the LD-4 system, taking into account the increased capacity due to the use of SPEC. These costs are negligible in comparison with other system costs and will not be considered further.

# D.6.3 SATELLITE GROUND STATION ELECTRONIC SYSTEMS

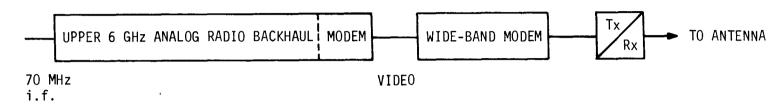
#### AND THEIR COSTS

The information described above in Sections 0.6.1 and 0.6.2 is used below in determining the costs of the electronic communications equipment for each of the eight types of system shown in Fig. 0.4, and for each of the four types of traffic through the ground station.

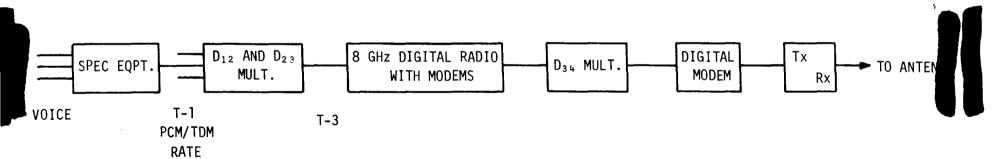
Table D.10

Incremental Capital Costs of
Upper 6 GHz Microwave Radio Backhaul Systems

Metropolitan	Backhaul	Costs Per Circuit				
Area	Incremental	Anal	og System	Digital	-	
	Costs \$ x1,000	per Voice Circuit	per TV Program	per Voice Circuit	per TV Program	
Vancouver	927	88.3	132,000	49.3	66,000	
Edmonton	331	31.5	47,000	17.6	23,600	
Regina	331	31.5	47,000	17.6	23,600	
Winnipeg	629	59.9	90,000	33.4	45,000	
Toronto	629	59.9	90,000	33.4	45,000	
Montreal	331	31.5	47,000	17.6	23,600	
Halifax	629	59.9	90,000	33.4	45,000	
St. John's	331	31.5	47,000	17.6	23,600	

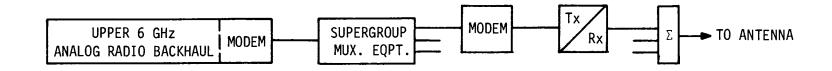


OPTION 1: ANALOG FM SINGLE-CARRIER-PER-TRANSPONDER TRANSMISSION

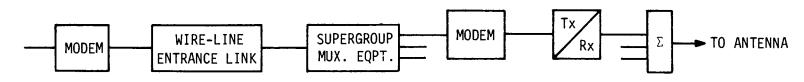


OPTION 2: DIGITAL 8 PHASE PSK SINGLE-CARRIER-PER-TRANSPONDER WITH SPEC

FIG. D.7 HEAVY-ROUTE VOICE TRANSMISSION FROM AN ANALOG NETWORK THROUGH A 4/6 GHz SATELLITE

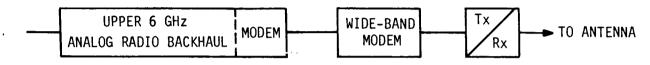


OPTION 1: WITH A 4/6 GHz SATELLITE

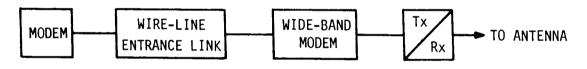


OPTION 2: WITH A 12/14 GHz SATELLITE

FIG. D.8 MEDIUM CAPACITY VOICE TRANSMISSION FROM AN ANALOG NETWORK THROUGH AN ANALOG SATELLITE

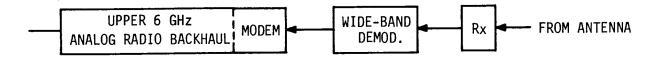


OPTION 1: WITH A 4/6 GHz SATELLITE

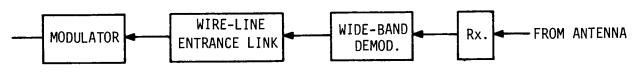


OPTION 2: WITH A 12/14 GHz SATELLITE

FIG. D.9 TELEVISION TRANSMIT AND RECEIVE THROUGH AN ANALOG SATELLITE



OPTION 1: WITH A 4/6 GHz SATELLITE



OPTION 2: WITH A 12/14 GHz SATELLITE

FIG. D.10 TELEVISION RECEIVE ONLY THROUGH AN ANALOG SATELLITE



#### D.6.3.1 SYSTEM COSTS WITH A 4/6 GHz ANALOG SATELLITE AND

AN ANALOG TERRESTRIAL NETWORK

# High Capacity Voice Link:

Total

Such a satellite link would use an FM single-carrier-per-transponder system, as shown as "option 1" in Fig. D.7. The capital costs for this system are:

Transmitter and downconverter \$210K
Wideband modem \$\frac{\\$15K}{\$225K}

Average cost per voice circuit between Toronto and Vancouver would be \$235, where 960 voice circuits could be carried. Similar links between other ground stations with 33 ft. antennas could carry 720 voice-circuits, at a cost of \$312 per voice circuit.

# Medium Capacity Multiple-Access Voice Link:

Total capacity of an Anik-type transponder is 180 to 240 voice circuits with about 4 carriers. Assume an average of 60 voice circuits per carrier. Such a system is shown as "option 1" of Fig. D.8. System costs are the same as for the high-capacity analog 4/6 GHz system, \$225K. However, the cost per voice circuit is much greater, about \$3,750. Because of this high cost per voice circuit, analog FDMA systems are not likely to be used.

## Television Transmit and Receive

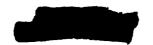
Costs for each television signal are as follows:

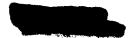
Transmitter and downconverter \$210K

Modem \$ 10K

Total \$220K

The block diagram of this system is shown in Fig. D.9.





# Television Receive-Only:

The cost of receiving a television program without being able to transmit are much less. Costs are as follows:

Down-converter \$15K

Demodulator \$ 5K

Total \$20K

The system block diagram for this service is quite simple, as shown in Fig. D.10.

# D.6.3.2 SYSTEM COSTS WITH A 12/14 GHz ANALOG SATELLITE

#### AND AN ANALOG TERRESTRIAL NETWORK

The block diagram of such a system, shown in Fig. D.11, is very similar to that of a similar system at 4/6 GHz, except for replacement of the radio backhaul system by a wire-line-entrance-link. However, the electronic equipment costs of a 12/14 GHz system is considerably more than that of a 4/6 GHz system. The costs are:

Transmitter and downconverter \$320K

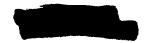
Modem \$ 20K

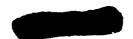
Total \$340K

System capacity would be about 960 voice circuits in a cost-effective system, as in the 4/6 GHz case. Thus costs would be about \$350 per voice circuit.

## Medium Capacity Multiple Access Voice Link:

The block diagram of this system is shown as "option 2" in Fig. D.8. As shown, the system is very similar to that at 4/6 GHz except for the different backhaul system. System costs would be about \$340K, as in the high-capacity 12/14 GHz analog case. If, as in the 4/6 GHz medium capacity analog case, that on the average about 60 voice circuits are carried per transmitter, the capital cost per voice circuit is about \$5,660, a very high cost.





## Television Transmit and Receive:

A block diagram is given in Fig. D.9 as "option 2", the 12/14 GHz analog option. At the block-diagram level the system is the same as the 4/6 GHz analog option except for the backhaul link. However, electronic system costs are again more expensive than at 4/6 GHz. An estimate of these costs is:

Transmitter and downconverter \$320K

Modem \$ 20K

Total \$340K

# Television Receive-Only:

The system block diagram is shown as "option 2" in Fig. D.10. Cost of the specialized equipment in this system are:

Downconverter \$20K

Demodulator \$10K

Total \$30K

# D.6.3.3 SYSTEM COSTS WITH A 4/6 GHz DIGITAL SATELLITE AND

AN ANALOG TERRESTRIAL NETWORK

## High Capacity Voice Link

The block diagram of this system is shown as "option 2" in Fig. D.7. It is assumed that 8 phase PSK would be used if high-capacity dedicated-transponder voice links were used. Installed capital costs of the system are estimated as follows, taking into account the use of SPEC:

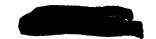
High-level digital multiplex eqpt. \$100/vcct. SPEC equipment \$400/vcct.

Transmitter and downconverter \$210K

8 phase PSK modem \$150K

Total \$360K

If 8 phase PSK is used with SPEC through a 36 MHz wide transponder, the link capacity is about 2700 voice circuits,





resulting in a cost per voice circuit of \$133 per voice circuit for transmitter, downconverter, and modems. Thus the total capital cost per voice circuit is about \$633.

# Medium Capacity TDMA Link:

It is assumed that a medium-capacity link in digital satellite system would use 4 phase PSK, TDMA, and SPEC. A block diagram of the system is shown as the 4/6 GHz system in Fig. D.12. The costs of this system are as follows:

- Costs per voice circuit:

SPEC equipment \$400

High level digital multiplex, taking into account the "gain" of the SPEC system \$120

- Common Costs:

Transmitter and downconverter \$210K

TDMA equipment \$105K

4 phase PSK modem \$95K

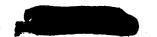
Total common costs \$410K

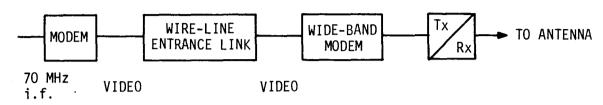
It is assumed that an average of 600 voice circuits would be handled by a TDMA transmitter at a ground station, not necessarily all to the same location. Thus the costs per voice circuit of the common equipment is about \$680, for a total cost per voice circuit of \$1200.

#### Television Transmit and Receive

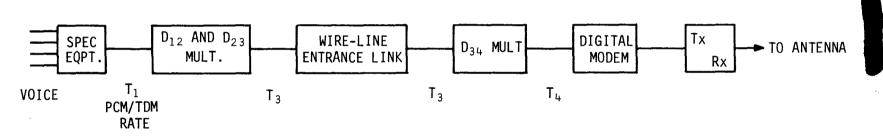
The system block diagrams are shown in Fig. D.13. There are actually two systems of interest, one in which analog transmission in the backhaul system is used, and the other in which a digital radio backhaul system is used, as shown in Fig. D.13. The special link costs when an analog backhaul system is used are as follows:

DITEC Encoder and Decoder \$ 80K 4 phase PSK 33 Mb/s Modem \$ 25K



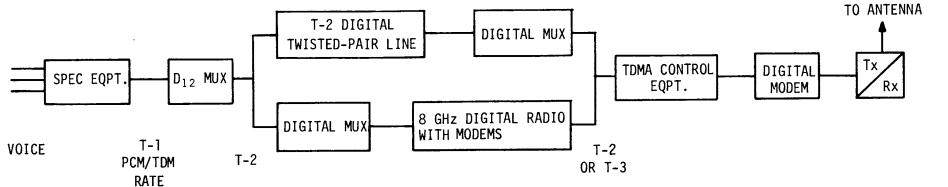


OPTION 1: ANALOG FM SINGLE-CARRIER-PER-TRANSPONDER TRANSMISSION

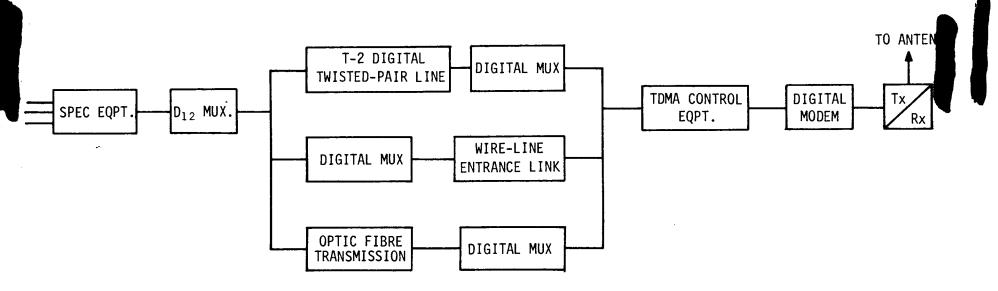


OPTION 2: DIGITAL 8 PHASE PSK SINGLE-CARRIER-PER-TRANSPONDER WITH SPEC

FIG. D.11 HEAVY-ROUTE VOICE TRANSMISSION FROM AN ANALOG NETWORK THROUGH A 12/14 GHz SATELLITE



OPTION 1: WITH A 4/6 GHz SATELLITE

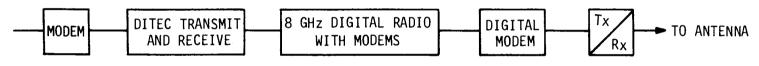


OPTION 2: WITH A 12/14 GHz SATELLITE

FIG. D.12 MEDIUM CAPACITY VOICE TRANSMISSION THROUGH A DIGITAL SATELLITE BY 4 PHASE PSK/TDMA



OPTION 1: WITH A 4/6 GHz SATELLITE AND ANALOG BACKHAUL



OPTION 2: WITH A 4/6 GHz SATELLITE AND DIGITAL BACKHAUL



OPTION 3: WITH A 12/14 GHz SATELLITE

FIG. D.13 TELEVISION TRANSMIT AND RECEIVE THROUGH A DIGITAL SATELLITE



Transmitter and Downconverter	\$210K
System improvement to use DITEC	<u>\$ 5K</u>
Total costs	\$320K

When a digital backhaul system is used an additional analog modem is required, at an additional cost of about \$20K installed, for a total of \$340K. Note, however, that the additional backhaul costs are at least \$20K when an analog backhaul system is used, as shown above in Table D.10. In view of other advantages of a digital satellite system, a special link cost of \$340K and use of a digital backhaul system is assumed.

## Television Receive Only

Block diagrams for two possible 4/6 GHz systems are shown in Fig. D.14, the difference again being the type of 6 GHz backhaul system used. As in the above scenario for transmission and reception of television, it will be assumed that a 6 GHz digital backhaul system is used, and that 4 phase PSK and DITEC or its equivalent is used through the satellite. The costs of that system are:

DITEC Decoder	\$40K
4 phase PSK Demodulator	\$15K
Downconverter	\$13K
System improvement	\$ 5K
Analog Modem	\$20K
Total cost	\$93K

## D.6.3.4 SYSTEM COSTS WITH A 12/14 GHz DIGITAL SATELLITE AND

#### AN ANALOG TERRESTRIAL NETWORK

A block diagram of the system is shown in Fig. D.11. It is shown that 8 phase PSK and SPEC would be used. The costs of such a system are as follows:

Costs per voice circuit:

SPEC equipment

\$400





High-level multiplex costs \$100

## Common equipment costs:

Transmitter and downconverter \$320K

8 phase PSK modem \$150K

Total \$470K

As in the case above for a similar satellite system at 4/6 GHz, capacity of such a subsystem is about 2700 voice circuits. Cost per voice circuit of the common equipment is about \$175, total cost per voice circuit is about \$675.

## Medium Capacity TDMA Voice Link:

A block diagram of the system is shown in Fig. D.12. As shown, the system is very similar to that of a 4/6 GHz TDMA voice system, except for use of a different backhaul system and the requirement for 12/14 GHz transmitters. Costs of the system are as follows:

SPEC	and	multiplex	costs	\$520/vcct.
------	-----	-----------	-------	-------------

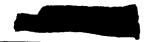
#### Common costs:

Transmitter and downconverter	\$320K
TDMA Equipment	\$105K
4 phase PSK modem	<u>\$ 95K</u>
Total	\$520K

As in the 4/6 GHz TDMA system, an average of about 600 voice circuits per TDMA transmitter is expected, resulting in a cost of about \$870 per voice circuit for the common equipment, or a total of about \$1400 per voice circuit.

# Television Transmit and Receive:

As in the 4/6 GHz digital system, it is expected that 4 phase PSK and DITEC or its equivalent would be used. A block diagram of the system is shown in Fig. D.13. Cost of such a subsystem is as follows:





DITEC Encoder and Decoder	\$ 80K
4 phase PSK 33 Mb/s Modem	\$ 25K
Transmitter and Downconverter	\$320K
Total capital cost	\$425K

# Television Receive Only:

Again, the system is very similar at the block-diagram level to a 4/6 GHz digital system, as shown in Fig. D.14. The costs of a 12/14 GHz system are as follows:

DITEC Decoder	\$40K
4 phase PSK Demodulator	\$15K
Downconverter	\$20K
Analog modem	\$20K
Total capital cost	\$95K

## D.6.3.5 SYSTEM COSTS WITH A 4/6 GHz ANALOG SATELLITE AND

A HYBRID TERRESTRIAL NETWORK

# High-Capacity Voice Link:

The system block diagram is shown as "option 1" in Fig. D.15. The system is very similar to that shown in Fig. D.7 for an analog terrestrial network, except for the additional multiplex requirement. The additional cost of the multiplex equipment, installed, is expected to be about \$1,000 per voice circuit, resulting in a total cost of about \$1300 per voice circuit.

## Medium-Capacity FDMA Voice Transmission:

The system block diagram for this sytem is shown as that for a 4/6 GHz satellite in Fig. D.16. Again, the system is identical to that for an analog terrestrial network except for the addition of digital to analog multiplex conversion, at an added cost of about \$1,000 per voice circuit. Thus total capital cost per voice circuit would be about \$4,750, a very high figure.



OPTION 1: WITH A 4/6 GHz SATELLITE AND ANALOG BACKHAUL

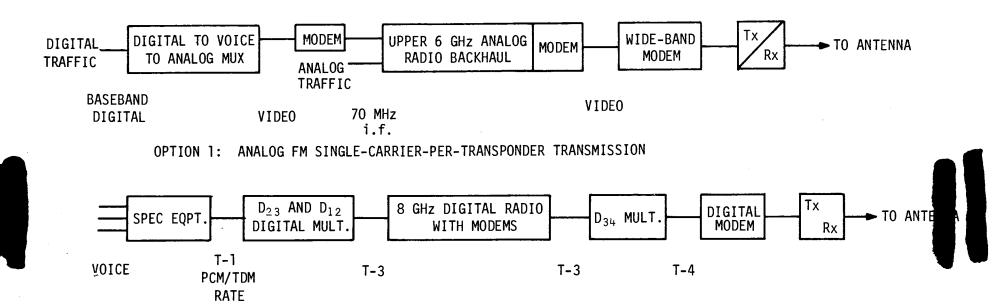


OPTION 2: WITH A 4/6 GHz SATELLITE AND A DIGITAL BACKHAUL



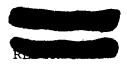
OPTION 3: WITH A 12/14 GHz SATELLITE

FIG. D. 14 TELEVISION RECEIVE ONLY THROUGH A DIGITAL SATELLITE



OPTION 2: DIGITAL 8 PHASE PSK SINGLE-CARRIER-PER-TRANSPONDER WITH SPEC

FIG D.15 HEAVY-ROUTE VOICE TRANSMISSION FROM A HYBRID NETWORK THROUGH A 4/6 GHz SATELLITE



# Television Transmit and Receive

It is expected that, in a hybrid terrestrial network, terrestrial television transmission would continue to be through analog microwave radio systems, and so the television-transmit-and-receive subsystem and its costs would be the same as described above in Section D.6.3.1.

# Television Receive Only

As described above, the television-receive-only subsystem and its costs would be as described above in Section D.6.3.1.

D.6.3.6 SYSTEM COSTS WITH A 12/14 GHz ANALOG SATELLITE AND

A HYBRID TERRESTRIAL NETWORK

# High-Capacity Voice Link

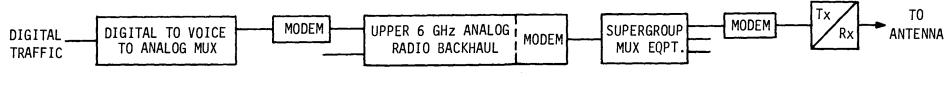
The block diagram for this scanario is shown in Fig. D.17 as "option 1", the analog satellite transmission option. The subsystem is the same as that shown in Fig. D.11, except for the added multiplex equipment that would be required. System costs would be the same as that described above in Section D.6.3.2 except for the added cost of \$1,000 per voice circuit for added multiplexing, for a total of about \$1,350 per voice circuit.

# Medium-Capacity FDMA Voice Transmission

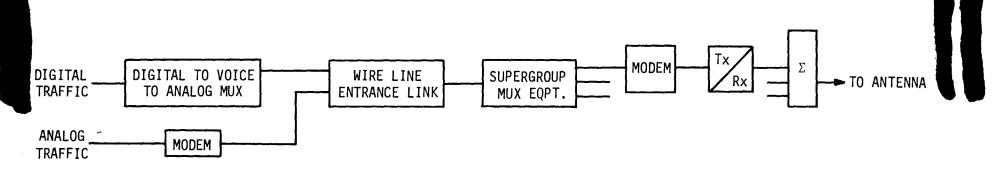
The medium-capacity FDMA subsystem for voice transmission in this network scenario is shown in Fig. D.16. Again, the system is similar to that shown in Fig. D.8, except for the additional multiplex requirements. Cost per voice circuit for this system would be about \$1,000 more than that described in Section D.6.3.2, a total of about \$6,700.

# Television Transmit and Receive

System characteristics and costs are the same as that described in Section D.6.3.2 and Fig. D.9. The cost is \$340K per television signal.

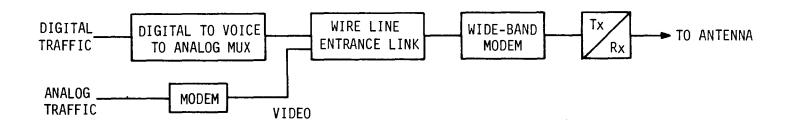


OPTION 1: WITH A 4/6 GHz SATELLITE

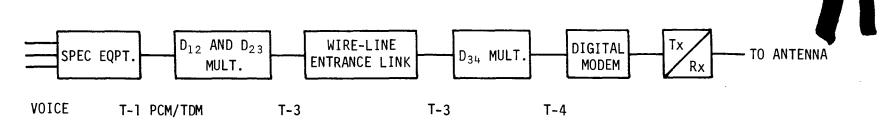


OPTION 2: WITH A 12/14 GHz SATELLITE

FIG. D.16 MEDIUM CAPACITY VOICE TRANSMISSION FROM A HYBRID NETWORK THROUGH AN ANALOG SATELLITE

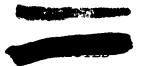


OPTION 1: ANALOG FM SINGLE-CARRIER-PER-TRANSPONDER TRANSMISSION



OPTION 2: DIGITAL 8 PHASE PSK SINGLE-CARRIER-PER-TRANSPONDER WITH SPEC

FIG. D.17 HEAVY-ROUTE VOICE TRANSMISSION FROM A HYBRID NETWORK THROUGH A 12/14 GHz SATELLITE



Again, the system is identical to that described in Section D.6.3.2. Cost per received television signal is about \$30K.

#### D.6.3.7 SYSTEM COSTS WITH A 4/6 GHz DIGITAL SATELLITE AND A

HYBRID TERRESTRIAL NETWORK

# High Capacity Voice Link

The block diagram for this subsystem is shown in Fig. D.15 as the digital option. As in Section D.6.3.3 it is assumed that 8 phase PSK and SPEC would be used. System costs are the same as those interfacing with an analog terrestrial network, about \$630 per voice circuit.

# Medium Capacity TDMA Voice Traffic Television Transmit and Receive Television Receive-Only

The same subsystem and costs as described in section D.6.3.3

# D.6.3.8 SYSTEM COSTS WITH A 12/14 GHz DIGITAL SATELLITE

#### AND A HYBRID TERRESTRIAL NETWORK

Subsystems characteristics and costs for all types of traffic are the same as those described above in Section D.6.3.4 for subsystems which interface with an analog network.

#### D.6.4 SUMMARY OF GROUND STATION CAPITAL COSTS

The initial capital costs and incremental capital costs of the common ground station network link, link e of Fig. D.3, are summarized in Table D.11 for a 4/6 GHz satellite system. Additional costs for a second 4/6 GHz antenna are \$1.08 million 1973 dollars if a 75 antenna is used, or \$144 thousand 1973 dollars if a 33 antenna is used.

Total costs for the common link of a 12/14 GHz ground station is \$1.5 million (1973) if a 60' antenna is used, or \$0.76 million (1973) if a 30' antenna is used. The capital cost of a second 12/14 GHz antenna, or of a 12/14 GHz antenna at a ground station site used originally for 4/6 GHz, is 1.1 million 1973



Table D.ll

Capital Costs of Ground Station Common Links
for a 4/6 GHz Satellite System

Metropolitan	Initial Costs,	Incremental Costs, 1973 Dollars		
Area	Millions of 1973 Dollars	Digital Satellite System	Analog Satellite System	
Vancouver	2.71	49	88	
Toronto	2.41	33	60	
Winnipeg & Halifax	1.03	33	60	
All others and	0.74	18	32	



dollars for a 60' antenna or 0.47 million for a 30' antenna. There are no appreciable incremental costs for the common link of a 12/14 GHz ground station, but if a 12/14 GHz antenna is placed at a 4/6 GHz ground station site the incremental costs are as shown in Table D.11.

In the backhaul system of a 4/6 GHz ground station a television signal has the equivalent of 1500 voice circuits if analog transmission is used, or 1344 voice circuits if digital transmission is used.

Links a, b, c and d of Fig. D.3 are "specialized links" in that they carry only one type of traffic. Capital costs of these links are given in Table D.12 for a 4/6 GHz ground station and in Table D.13 for a 12/14 GHz ground station. The information in these tables was taken from Section D.6.3 above. There are no "initial" costs for the specialized links in this model of a ground station, since the cost of electronic equipment is approximately proportional to the required capacity of the link.

# D.7 TELEMETRY, TRACKING, AND CONTROL (TT&C) GROUND STATIONS

The TT&C ground station is used to control the satellite as it is being placed in orbit and to control and monitor the satellite during its operation. It does not carry any network voice or television traffic, and so is not modelled in the same way as a ground station which does carry such traffic. Rather, its costs are included with the costs of the satellites themselves, and contribute to the cost of links g, h, i and j of Fig. D.3. The costs are described here, and are included with the satellite costs as described in Appendix C.

The cost of a TT&C ground station can be considered to be composed of three types of cost. These are:

- The capital cost of equipment which could be used by several successive satellite systems. This includes the building, the steerable antenna, the transmitters and receivers, etc.
- The capital cost of equipment which is purchased specifically for the launch and control of one satellite, and is not likely to be used in succeeding satellite systems. Such costs include that of the control centre computers, software, and display equipment, of orbit calculations, downrange costs during satellite launch, and of computer software for use during the launch.

Table D.12

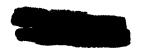
Capital Costs of Specialized Links
of a 4/6 GHz Ground Station in 1973 Dollars

Terrestrial Satellite Transmission Transmission		Capital Cost per Voice Circuit		Capital Cost per Television Signal	
Mode	Mode	High Cap. Link	Medium Cap. Link	Transmit and Receive	Receive Only
Analog	Analog	\$235, Tor-Van. \$310, otherwise	\$3,750	\$220K	\$20K
Ana log	Digital	\$630	\$1,200	\$340K	\$95K
Hybrid	Analog	\$1,300	\$4,750	\$220K	\$20K
Hybrid	Digital	\$630	\$1,200	\$340K	\$93K

Table D.13

Capital Costs of Specialized Links
of a 12/14 GHz Ground Station in 1973 Dollars

Terrestrial Satellite Transmission Transmission		Capital Cost per Voice Circuit		Capital Cost per Television Signal	
Mode	Mode	High Cap. Link	Medium Cap. Link	Transmit and Receive	Receive Only
Analog	Analog	\$350	\$5,700	\$340K	\$30K
Analog	Digital	\$675	\$1,400	\$425K	\$95K
Hybrid	Analog	\$1,350	\$6,700	\$340K	\$30K
Hybrid	Digital	\$675	\$1,400	\$425K	\$95K



3) Annual cost of the salaries of personnel at the TT&C ground station and at the satellite control centre who are responsible for operation of the satellite.

Costs of these items for the control of the first two satellites of the system, and of each additional satellite, are given in Table D.14. The long-term capital purchases are assumed to be amortized over 14 years, and the short-term capital purchases are assumed to be amortized over 7 years. In addition to the above costs, it is assumed that M&O costs of the TT&C ground station antenna, transmitters, etc., i.e. the long-term capital purchases, is 13% of the capital cost of these items. The M&O cost of the short-term capital purchases, item 2 above, is covered under item 3 above.

#### D.8 GROUND STATIONS FOR THE RECEPTION OF CBC REGIONAL TV

#### SIGNALS IN SOUTHERN CANADA

The possibility of using the satellite system for the distribution of network-quality CBC regional television programs is discussed in Section 4.5 of the full report. If such a satellite subsystem were used, it would have the following characteristics:

- a) Transmission from Earth to space would be from an existing ground station, at the same cost as the transmission and reception of a nationwide television signal (see Section D.6 for these costs).
- b) Reception of the television signal would be at the local CBC broadcast stations.

Because of the large number of television-receive-only satellite ground stations at the local CBC broadcast stations in such a network, probably over one hundred, the cost of the receive-only terminal must be kept small. To minimize such costs the antenna system of the terminal would probably be a small fixed parabolic reflector about 15 manually steerable) feet (Seventeen feet is the maximum diameter diameter. 12 GHz [8].) Such an antenna would be non-tracking antenna at placed either beside or on the roof of the television station, and, the electronic equipment placed within the television station, resulting in the reception of the satellite small cost, without the need for an independent ground station shelter or a backhaul system.

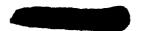
The 12/14 GHz band can be used for this type of service, since it is the type of traffic for which the band is intended,



Table D.14

Costs of TT&C Ground Stations in Millions of 1973 Dollars

·	Capital Cost of Long-term Capital Purchases	Capital Cost of Short-term Capital Purchases	Annual Salaries of Satellite-Control Personnel
Cost for First Two Satellites in Orbit	3.0	2.6	1.4
Cost for each Additional	1.45	0.4	0.25



and because there are no flux-density limitations in the band. Conventional analog transmission of television signals from the satellite to ground stations with small antennas and inexpensive receivers at 4 GHz is not possible because of the flux-density limitations at 4 GHz. However, digital transmission of network-quality television signals at 4 GHz is possible within the flux-density limitations, as is shown in Annex I of this Appendix. Thus the three types of system considered are conventional analog transmission at 12/14 GHz, and digital transmission with DITEC or equivalent at both 4/6 GHz and at 12/14 GHz.

At 4 GHz a low-cost receiver with a transistor preamplifier could be used. Such a system would have a 29 dB<sup>0</sup>K noise temperature, and a G/T of 14 dB/<sup>0</sup>K if a 15' antenna were used. Alternately, a nigher-cost uncooled paramp could be used rather than the transistor preamp to reduce the noise temperature to 24 dB<sup>0</sup>K and increase the G/T to 19 dB/<sup>0</sup>K. Similarly, a tunnel-diode preamplifier could be used at 12 GHz to provide a 29 dB<sup>0</sup>K noise temperature, or an uncooled paramp to provide a 24 dB <sup>0</sup>K system noise temperature. The G/T of these systems would be 23.5 dB/<sup>0</sup>K and 28.5 dB/<sup>0</sup>K respectively.

The cost of the above ground stations were determined by adding the mean installed costs of the antenna system, the receiver, and the DITEC encoding equipment, the major subsystems of such ground stations. The costs of the six ground station options considered are shown in Table D.15.

#### D.9 ANNUAL COSTS OF GROUND STATIONS

Capital costs of various types of satellite ground stations have been given above in Sections D.5 to D.8. These costs were converted to annual costs as described in Appendix F. The following parameters were used in calculating the annual costs:

- a) 14 year lifetimes for both ground stations and their backhaul systems, i.e. two satellite lifetimes,
- b) 10% annual interest rate,
- c) 13% ratio of M&O annual costs to capital cost of installed equipment, the same ratio as that used for terrestrial radio systems.

M&O costs only were allocated to the initial costs of  $4/6~\mathrm{GHz}$  ground stations and their backhaul systems, and both M&O and amortization costs of all other purchases. The composite of M&O and amortization costs is 26.57% of capital costs.

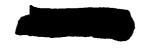
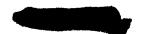


Table D.15

Incremental Capital Costs of
Television Receive-Only Ground Stations
for CBC Regional TV in Southern Canada

Satellite Frequency Band	System Noise Temperature	Use of DITEC	Antenna Costs	Receiver Costs	DITEC Cost	Total Cost
4/6 GHz	29 dB	Yes	\$24,000	\$16,000	\$40,000	\$80,000
4/6 GHz	24 dB	Yes	\$24,000	\$40,000	\$40,000	\$104,000
12/14 GHz	29 dB	Ло	\$24,000	\$18,000	0	\$42,000
-12/14 GHz	29 dB	Yes	\$24,000	\$18,000	\$40,000	\$82,000
12/14 GHz	24 dB	No	\$24,000	\$40,000	0	\$64,000
12/14 GHz	24 dB	Yes	\$24,000	\$40,000	\$40,000	\$104,000



### Common Link Annual Costs:

Based on the above, the annual costs of the common links of the 4/6 GHz ground stations are given in Table D.16. Other common link annual costs are as follows:

- \$0.29 million for an additional 75' 4/6 GHz antenna,
- \$0.038 million for an additional 33' 4/6 GHz antenna,
- \$0.4 million initial costs of a 12/14 GHz ground station with a 60' antenna,
- \$0.2 million initial cost of a 12/14 GHz ground station with a 30' antenna,
- \$0.29 million for an additional 60' 12/14 GHz antenna,
- \$0.12 million for an additional 30' 12/14 GHz antenna.

# Specialized Link Annual Costs

Specialized link capital costs are given above in Table 0.12 and D.13. Annual costs of these links are 0.2657 times the capital costs, as shown in Table D.17.

### TT&C Ground Station Annual Costs

Based on the capital cost information presented in Section D.7 above, the annual cost of the TT&C ground station facilities of a satellite system is 2.7 million 1973 dollars if the satellite system has two satellites in orbit, plus 0.7 million 1973 dollars for each additional satellite in orbit.

# Television Receive-Only Ground Stations for CBC Programs in Southern Canada:

Based on the information presented above in Section D.8, the incremental annual costs of television receive-only ground stations at local CBC television stations for reception of network-quality programs is given in Table D.18.

Table D.16

Annual Costs of Ground Station Common Links for a 4/6 GHz Satellite System

Metropolitan Area	Initial Costs, Thousands of	Incremental Costs Per Voice Circuit, 1973 Dollars		
	1973 Dollars	Digital Satellite System	Analog Satellite System	
Vancouver	350	13.0	23.4	
Toronto	310	8.8	16	
Winnipeg & Halifax	135	8.8	16	
All other existing sites	96	4.8	ð <b>.</b> 5	
New Locations	195	4.8	8.5	

Table D.17

Annual Costs of Ground Station Specialized Links in 1973 Dollars

Satellite Carrier Frequency, GHz	Terrestrial Transmission Mode	Satellite Transmission Mode	Annual per Voice Doll High Cap. Link	Circuit, ars	Annual Cos per Television Thousands of Transmit and Receive	Signal,
4/6	Analog	Analog	62	1,000	58	5.3
4/6	Analog	Digital	170	320	90	25
4/6	Hybrid	Analog	345	1,260	58	5.3
4/6	Hybrid	Digital	170	320	90	25
12/14	Analog	Analog	93	1,500	90	3
12/14	Analog	ມigital	180	370	113	25
12/14	Hybrid	Analog	360	1,800	90	3
12/14	Hybrid	Digital	130	370	113	25



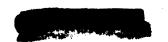
Table D.18

Incremental Annual Costs

of Ground Stations for Reception

of CBC Regional Television Programs in Southern Canada

Satellite Carrier Frequency, GHz	Transmission Mode	Ground Station G/T, dB/°K	Annual Cost Thousands of 1973 Dollars
4/6	Digital/DITEC	14	21
4/6	Digital/DI <b>T</b> EC	19	28
12/14	Analog FM	23.5	11
12/14	Analog FM	28.5	17
12/14	Digital/DITEC	23.5	22
12/14	Digital/DITEC	28.5	28





# References

- 1. J.H. Thomas, "Traffic Capacities and Costs of Terrestrial Facilities Associated with a Satellite of the Anik Type Using Digital Modulation Techniques", DLDCNS Report No. 5, July 1973.
- 2. J.H. Thomas, "Earth Segment Capital Costs", DLDCNS Report No. 9, January 1974.
- 3. L.S. Golding, "DITEC A Digital Television Communications System for Satellite Links", Conference Record, 2nd International Conference on Digital Satellite Communications, pp. 384-397, November 1972.
- 4. J.A. Sciulli and S.J. Campanella, "A Speech Predictive Encoding Communication System for Multichannel Telephony", IEEE Trans. on Communications, Vol. COM-21, No. 7, pp. 827-835, July 1973.
- 5. S.J. Campanella and S.J. Sciulli, "Speech Predictive Encoded Communications", Conference Record, 2nd International Conference on Digital Satellite Communications, pp. 342-347, November 1972.
- 6. S.J. Campanella and H.G. Suyderhoud, "Digital Speech Interpolation for Telephone Communications", EASCON-74, pp. 331-336, September 1974.
- 7. H.G. Suyderhoud, J.A. Jarkowski and R.P. Ridings, "Results and Analysis of the Speech Predictive Encoding Communications System Field Trial", COMSAT Technical Memorandum CL-20-74, June 1974.
- "A Super-High-Frequency Satellite Communications System for Canada (1977-1985)", Bell-Northern Research Study for DOC, September 1971.





#### ANNEX I

# MINIMUM GROUND STATION (G/T) REQUIREMENTS

IN A 4/6 GHz SATELLITE SYSTEM

#### I.1 INTRODUCTION

In a given satellite communication system, the required signal quality is attained by making (G/T + EIRP) for the system greater than some minimum, where (G/T) is the ground station gain to noise temperature ratio in dB, and EIRP is the effective isotropic radiated power transmitted from the satellite in dBW. The tradeoff between EIRP and G/T is determined by the following:

- a) Technical contraints which limit satellite tube characteristics, satellite and ground station antenna diameters, ground station receiver noise figures, etc;
- b) Economic factors, in which the satellite cost increases rapidly as the satellite EIRP is increased and ground station costs increase rapidly with increasing G/T;
- c) Constraints on the flux density on the ground from the satellite, which limits the satellite EIRP.

In this Annex the limitations imposed on the ground station G/T by this third factor are examined.

#### I.2 FLUX DENSITY LIMITATIONS

In the 3.4 GHz to 7.75 GHz band, which includes the 3.7 to 4.2 GHz band used for satellite-to-Earth transmission by satellites such as Anik and Intelsat IV, the flux density  $\psi$  cannot exceed

i) 
$$-1.52 \text{ dBW/m}^2 \text{ for } \delta \leq 5^0$$

ii) 
$$-152 + \frac{\delta-5}{2} \text{ dBW/m}^2 \text{ for } 5^0 \le \delta \le 25^0$$

iii) 
$$-142 \text{ dBW/m}^2 \text{ for } \delta \ge 25^0$$



in any 4 KHz band, where & is the angle of arrival.\*

This can be written as

$$\psi \leq -152 + F(\delta) \text{ dBW/m}^2/4 \text{ KHz} \quad (1a)$$

where 
$$F(\delta) = 0$$
,  $0 \le \delta \le 5^0$  (1b)

= 
$$(\delta-5)/2$$
,  $5^0 \le \delta \le 25^0$ 

= 10, 
$$\delta \geq 25$$

#### I.3 FLUX DENSITY FROM A SATELLITE

The total flux density in watts per  $\mathbf{m}^2$  from a satellite transponder is

$$\phi = EIRP - L_{P} + 10log_{10} \left(\frac{4\pi}{\lambda^{2}}\right)$$

$$= EIRP - L_{P} + 21.45 + 20log_{10}f$$
 (2)

wnere

 $L_{\rm p}$  is the path loss in dB,

f is the carrier frequency in GHz.

Equation (2) is not yet in the correct form, since Equation (1) refers to the maximum flux density in any one 4 GHz band, not the flux density over several MHz. Suppose that the signal transmitted from the satellite has the power spectral density S(f), and that the maximum value of S(f) is  $S_{MAX}$ .

Then from the point of view of flux density limitations, the signal has as effective bandwidth

$$B_{F} = \frac{\int_{0}^{\infty} S(f) df}{S_{MAX}}$$
 (3)

<sup>\*</sup> ITU Radio Regulations, notes 470NL and 470 NM.





Then the maximum flux density per meter<sup>2</sup> in any 4 KHz band is

$$\psi_{\rm m} = \phi - 10\log_{10} \left( \frac{B_{\rm F} \times 10^3}{4} \right)$$

$$= EIRP - L_{\rm p} + 20\log_{10} f - 10\log_{10} B_{\rm F} - 2.53 \tag{4}$$

if  $B_F$  is in MHz.

#### I.4 MAXIMUM SATELLITE EIRP

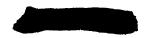
The maximum satellite EIRP can be specified simply by equating (4) and (1). The result is

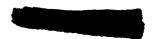
EIRP - L<sub>p</sub> + 
$$20\log_{10}f$$
 -  $10\log_{10}B_F$  - 2.53  
< - 152 +  $F(\delta)$ 

or

EIRP - 
$$L_{p}$$
 + 20log<sub>10</sub>f - 10log<sub>10</sub>B<sub>F</sub> - F( $\delta$ )
$$\leq - 149.5$$
 (5)

Let us now impose a "safety margin" on the maximum allowable EIRP, such that it is 6 dB less than the maximum specified by (5), i.e. such that the ITU regulation is met with a 6 dB margin. In this case (5) becomes





EIRP - 
$$L_p$$
 +  $20log_{10}f$  -  $10log_{10}B_p$  -  $F(\delta)$ 

#### 1.5 EIRP REQUIRED FOR ACCEPTABLE SIGNAL DETECTION

Let us now consider only the down-link noise in clear-air or non-fading conditions. The received carrier strength is

$$C = EIRP - L_p + G$$
 (7)

where G is the gain of the ground station antenna. The down-path noise is

$$N = KTB_{N}$$
 (8)

where T is the noise temperature of the ground station,  $B_{\rm N}$  is the noise bandwidth of the received signal.

The down-path carrier-to-noise ratio in dB, then, is

$$\left(\frac{C}{N}\right) = \left(EIRP + \frac{G}{T}\right) - 10log_{10}B - 10log_{10}k - L_{P} - 60$$
(9)

with  $B_N$  in MHz. Since Boltzman's constant is 1.38 x  $10^{-23}$ , or 10  $\log_{10}k$  is -228.6 dB, Equation (9) becomes

$$\left(\frac{C}{N}\right) = \left(EIRP + \frac{G}{T}\right) - 10log_{10}B_{N} - L_{P} + 168.8 \tag{10}$$

If we now assumed that the up-path (C/N) is 10 dB greater than  $(C/N)_D$ , the overall (C/N) is 0.4 dB less than  $(C/N)_D$ . If, as well, we allow 3.0 dB for atmospheric fading at 4 GHz, we have an





expression for the overall carrier-to-noise ratio in poor atmospheric conditions. It is

$$\frac{C}{N} = \left(EIRP + \frac{G}{T}\right) - 10\log_{10}B_N - L_P + 165.2$$
 (11)

Note that C/N includes any detection equipment margin that is required. Equation (11) can be written in the form

EIRP - L = 
$$\frac{C}{N}$$
 -  $\frac{G}{T}$  +  $10\log_{10}B_N$  -  $165.2$  (12)

# I.6 MINIMUM GROUND STATION G/T

The minimum ground-station G/T can be determined by equating (EIRP -  $L_p$ ) in (12) and (5). Equation (5) can be re-written in the form

EIRP - 
$$L_p \le F(\delta) + 10\log_{10} f - 149.5$$
 (13)

Thus

$$\frac{C}{N} - \frac{G}{T} + 10\log_{10}B_{N} - 165.2$$

$$\leq F(\delta) + 10\log_{10}B_F - 20\log_{10}f - 149.5$$
 (14)

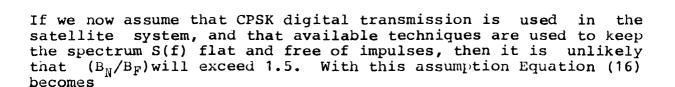
If we now set f = 4 GHz, the centre of the band, we have 20  $log_{10}(f)$  equal to 12 dB, so

$$\frac{C}{N} - \frac{G}{T} + 10\log_{10}\left(\frac{B_N}{B_F}\right) - F(\delta) \le 3.7$$
 (15)

Equation (15) can be re-written in the form

$$\frac{G}{T} = \frac{C}{N} + 10\log_{10}\left(\frac{B_N}{B_F}\right) - F(\delta) - 3.7 \tag{16}$$





$$\frac{G}{T} \ge \frac{C}{N} - F(\delta) - 1.9 \tag{17}$$

It is important to note that this result is independent of the satellite antenna pattern, since the only satellite parameter of interest is its EIRP.

### I.7 MINIMUM GROUND-STATION ANTENNA DIAMETER

From equation (17), the necessary antenna diameter is

$$G \ge \frac{C}{N} + T - F(\delta) - 1.9 \tag{18}$$

The relationship between parabolic antenna gain, diameter, and carrier frequency is

$$G = 5.6 D^2 f^2$$
 (19a)

where D is the antenna diameter in feet and f the carrier frequency in GHz. Expressing (19a) in dB's, we have

$$G = 20\log_{10}D + 20\log_{10}f + 7.5$$
 (19b)  
=  $20\log_{10}D + 19.5$ 

if the carrier frequency f is 4 GHz as before. Equating (19c) and (18), we have

$$20\log_{10}D \ge \left(\frac{C}{N}\right)^2 + T - F(\delta) - 21.4$$
 (20)



#### I.8 EXAMPLES

#### 1.8.1 TV TRANSMISSION BY 4 PHASE PSK AND DITEC

If the TV signal is to be received anywhere in Canada,  $\delta < 5^0$  in several places, so  $F(\delta) = 0$ . The necessary C/N for such a system is 16.6 dB. If low-cost transistor preamplifiers are used, T = 29 dB. Substituting these values into (20), we have  $G \ge 43.7$  dB and  $D \ge 16$ .

#### 1.8.2 TV TRANSMISSION BY 4 PHASE PSK AND DITEC IN

#### SOUTHERN CANADA

If the system considered above is restricted to Southern Canada, the smallest  $\delta$  is about  $10^{\,0}$ , at St. John's from the satellite at  $114^{\,0}$  west longitude. In that case  $F(\delta)$  is 2.5 dB, so  $G \ge 41.2$  dB and  $D \ge 9$ '.

#### 1.8.3 HIGH-CAPACITY VOICE TRANSMISSION BY 8 PHASE CPSK

In this case the smallest look-angle is about  $19^{0}$  from Halifax to the satellite at  $114^{0}$  west longitude, and so F(0) = 7 dB. (Capacity from St. John's is not large enough to require use of 8 phase CPSK). In such a system the required C/N is 23.6 dB, and T would likely be 23 dB. Thus the minimum antenna gain would be 37.7 dB at 4 GHz, requiring an 8 foot antenna. This result is rather academic, since a much larger antenna and lower satellite EIRP would result in a minimum overall satellite system cost.

#### 1.9 GROUND-STATION ANTENNA GAIN TO PREVENT ILLUMINATION OF

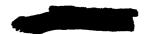
#### MORE THAN ONE SATELLITE

Satellites in the Anik system are  $5^{\,0}$  apart. To prevent illumination of more than one satellite, the beam must be no more than  $2^{\,0}$  wide. Thus the antenna gain must be at least [4]

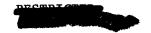
$$G = 40.8 - 10\log_{10} (BW1 \times BW2)$$

$$= 40.8 - 10\log_{10} 4$$

$$= 34.8 \text{ dB}$$
(21)



This is lower than the required gain in the two examples of Section 8, and so they apply, rather than the interference limitation.



# **CRC DOCUMENT CONTROL DATA**

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