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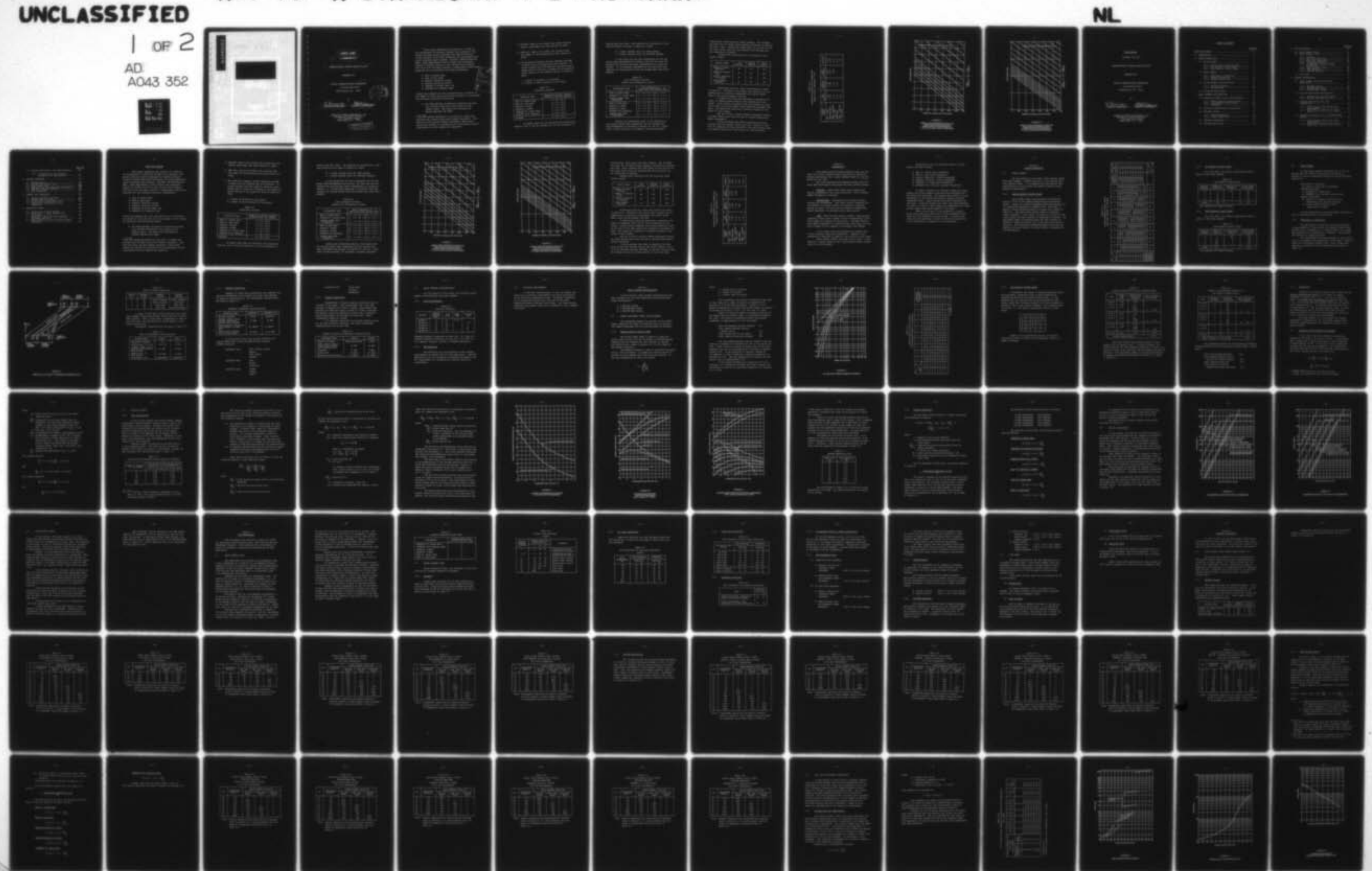

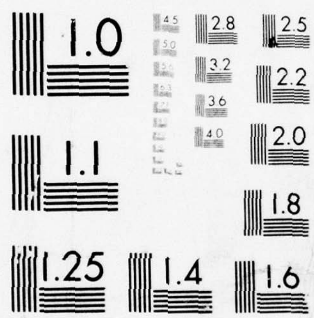


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SUMMARY REPORT

November 26, 1976

# COMMUNICATIONS SYSTEMS MODELING STUDY

PREPARED FOR

DIGITAL COMMUNICATIONS CORPORATION

19 Firstfield Road

Gaithersburg, Md. 20760

by

Reinhard Stamminger Wilbur L. Pritchard

SATELLITE SYSTEMS ENGINEERING, INC.
Bethesda Air Rights Building
7315 Wisconsin Avenue
Washington, D.C. 20014

This report summarizes the results of a study on the transmission of digitally encoded voice channels, with several multiple access techniques and traffic patterns. 16 kb/s variable slope delta modulation and three modulation/access techniques were studied: PSK-SCPC, TDM-PSK-FDMA and TDMA. Three hypothetical traffic models were generated, ranging in traffic from 80 to 1100 one-way voice channels with 10 to over 200 earth stations. Transmission models were generated for six different satellite transponders:

- DSCS II global beam,
- DSCS II spot beam,
- domestic satellite C-band,
- domestic satellite K-band,
- INTELSAT IV global beam, and
- INTELSAT IV-A regional beam.



A model was prepared for cost calculations as a function of the number of earth stations and voice channels in the system. The following conclusions were drawn:

- The TDMA-PSK-FDMA transmission technique provides only limited connectivity and results in the highest costs. The choice will therefore be between PSK-SCPC and TDMA.*

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* The TDMA system considered in this study is simple and provides only variable destination demand assignment. Systems with fully variable demand assignment, where burst lengths are changed in accordance with instantaneous traffic requirements are more complex and expensive.

- PSK-SCPC leads to the lowest cost system when the channel requirement per earth station is small.

- TDMA will lead to the lowest cost solution when the number of voice channels per earth station is large.

- The break-even capacity between PSK-SCPC and TDMA is about 50 to 60 channels per earth station. It varies slightly with the specific satellite transponder that is used and it depends on the number of earth stations in the system as shown in Table S-1, where

  n = number of channels in the system
  m = number of earth stations in the system.

Table S-1
Break-even Formulas

| Satellite Type | Break-even Channel Capacity (Channel Units Per System) |
|---|---|
| DSCS II, Global Beam | n = 11 + 50 m |
| DSCS II, Spot Beam | n = 37 + 44 m |
| Domestic, C-band | n = 37 + 42 m |
| Domestic, K-band | n = 37 + 49 m |
| INTELSAT IV, Global Beam | n = 16 + 79 m |
| INTELSAT IV-A, Regional | n = 32 + 43 m |
| Average | n = 30 + 50 m |

At system loads that are different from break-even capacity, one of the two systems will be less expensive to operate than the other. The formulas for calculation of the cost difference are shown in Table S-2, where

A' = annual systems costs for TDMA systems
A = annual systems costs for PSK-SCPC systems.

It was found that the cost differences for the two global beam transponders are similar, and that the cost differences for the four spot beam transponders as a group are similar. It is therefore reasonable to calculate cost differences for average global beam and average spot beam transponders.

Table S-2
Cost Difference Formulas
Annual Cost Difference in $1000

| Transponder Type | Cost Difference: A' - A<br>TDMA Minus SCPC System Costs |
|---|---|
| DSCS II Global Beam | A' - A = 52 + 230 m - 4.6 n |
| INTELSAT IV, Global Beam | A' - A = 52 + 261 m - 3.3 n |
| Average Global Beam Transponder | A' - A = 52 + 246 m - 4.0 n |
| DSCS II Spot Beam | A' - A = 52 + 62 m - 1.4 n |
| Domestic, L-Band | A' - A = 52 + 60 m - 1.4 n |
| Domestic, K-Band | A' - A = 52 + 69 m - 1.4 n |
| INTELSAT IV-A Regional | A' - A = 52 + 69 m - 1.6 n |
| Average Spot Beam Transponder | A' - A = 52 + 65 m - 1.5 n |

System cost differences based on the formulas for the average global beam transponder and the average spot beam transponder are plotted in Figures S-1 and S-2. These costs include antennas, RF equipment, baseband equipment, installation, spare parts and space segment. Not included are costs for "no break" power systems, buildings or shelters and land. Thus, although the costs shown on S-1 and S-2 are not total costs, they are nevertheless valid measures for the comparison of systems.

Systems were configured for the following three traffic models:

| Traffic Model | Low Capacity | Medium Capacity | High Capacity |
|---|---|---|---|
| Number of earth stations | 26 | 10 | 211 |
| Number of channel units | 80 | 219 | 1100 |
| Traffic intensity in Erlangs | 19 | 133 | 492 |
| Space segment channels | 29 | 152 | 518 |

Normalized costs for these three models are shown in Table S-3. PSK-SCPC is the lowest cost solution for all combinations of satellite transponder and traffic model. TDMA is the second cheapest solution.

A sensitivity study was performed to determine the effect of changing earth station cost assumptions on the result. Earth station equipment costs were doubled as would be the case if Mil Spec rather than commercial equipment was used. The break-even capacities increased slightly as the result of this change.

The use of fully variable demand assignment results in higher system costs than the use of variable destination demand assignment.

It was concluded that TDMA is generally the best solution when the average traffic per earth station is over 50 to 60 channels and that PSK-SCPC is the best solution when the average traffic per earth station is less than that.

Table S-3

Normalized Systems Cost Comparison

Annual Costs, PSK-SCPC = 1.00

| Traffic Model | Low Capacity | Medium Capacity | High Capacity | Average |
|---|---|---|---|---|
| PSK - SCPC | 1.00 | 1.00 | 1.00 | 1.00 |
| TDM-PSK-FDMA | 3.43 | 1.98 | 4.10 | 3.03 |
| TDMA - maximum bit rate | 3.35 | 1.45 | 2.88 | 2.41 |
| TDMA-FDMA | 2.76 | 1.83 | | 2.25 |
| TDMA - reduced bit rate | 3.14 | | | 3.14 |

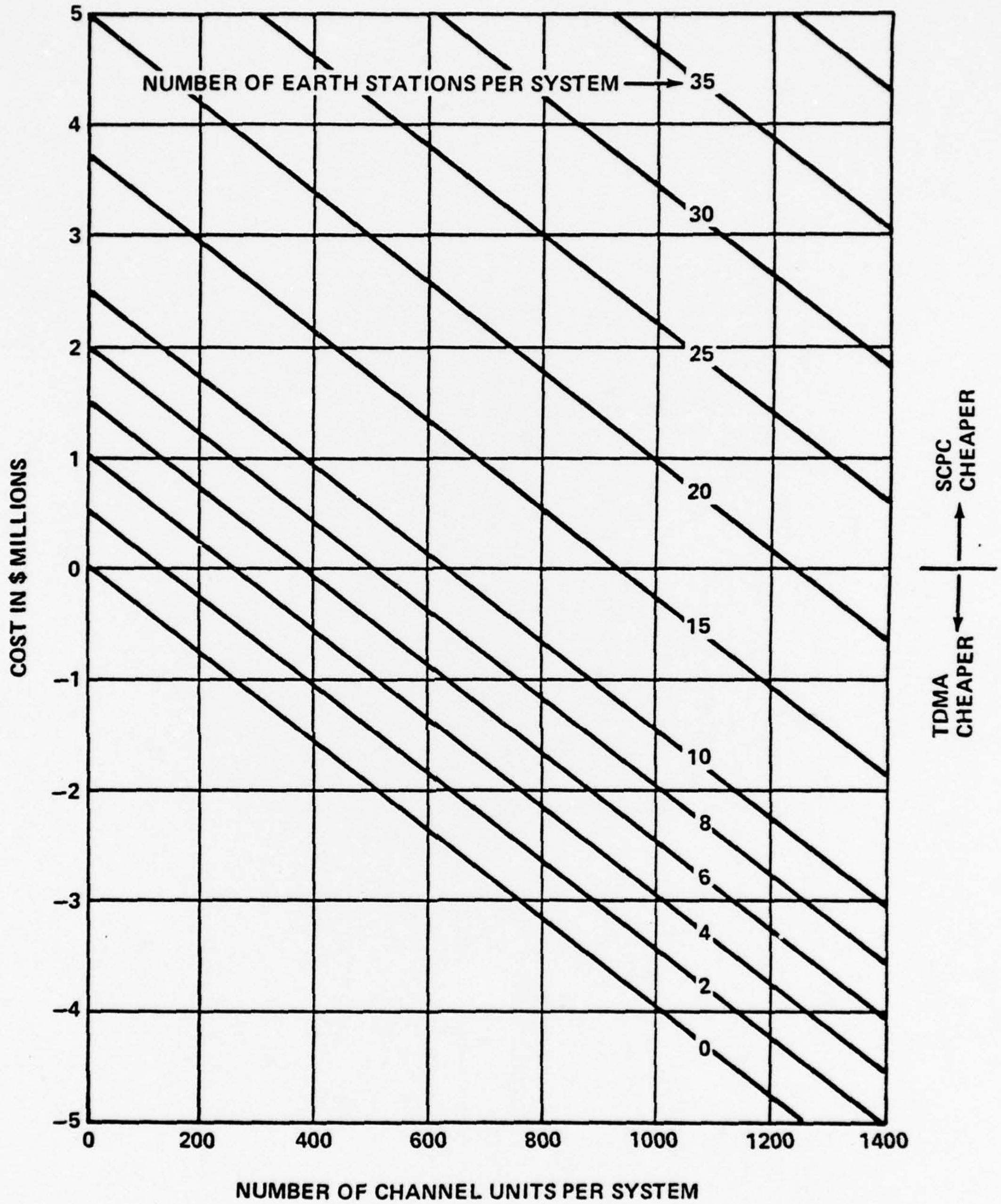


FIGURE S–1

ANNUAL COST DIFFERENCE IN $ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL GLOBAL BEAM TRANSPONDER

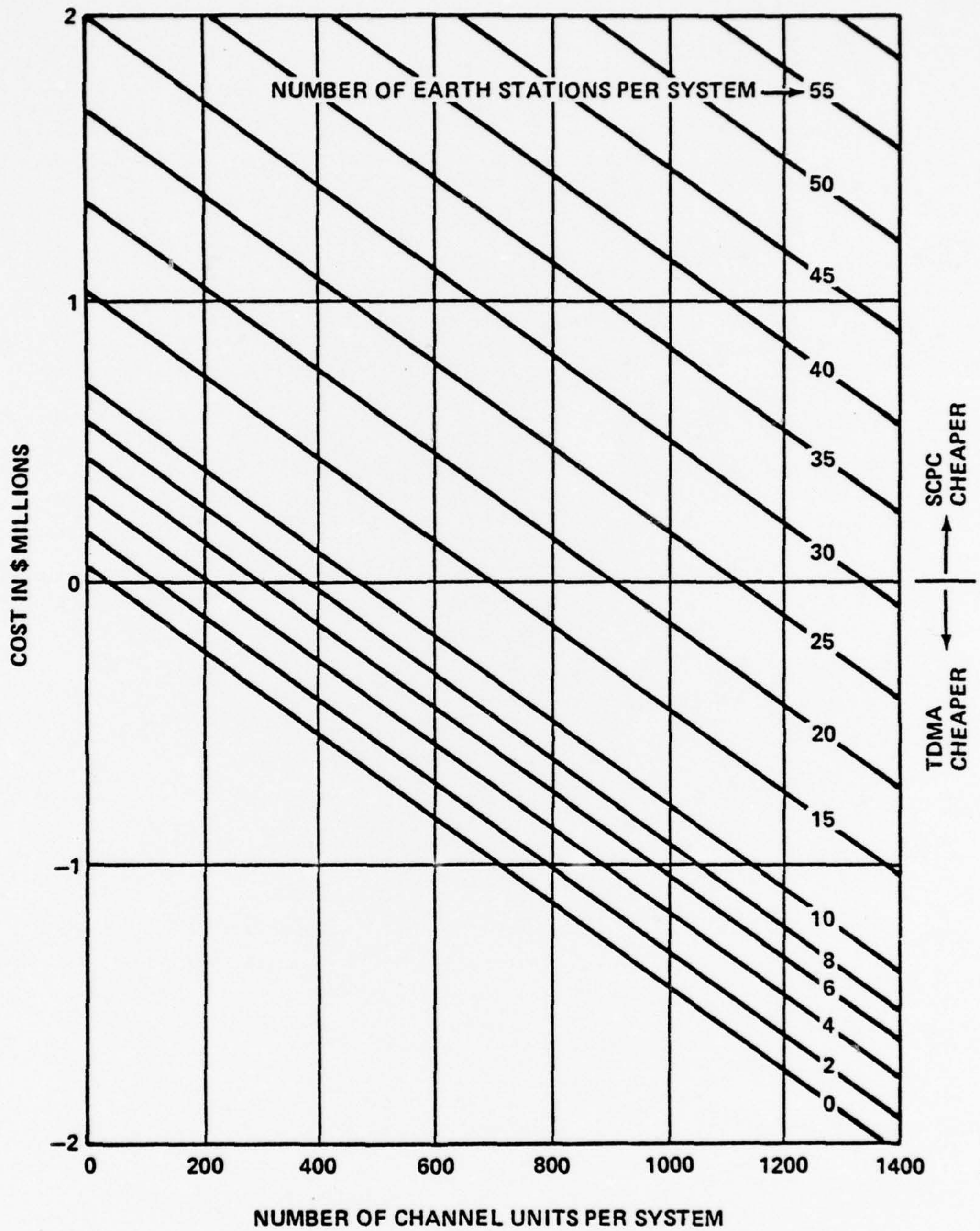


FIGURE S–2

ANNUAL COST DIFFERENCE IN $ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL SPOT BEAM TRANSPONDER

# FINAL REPORT

November 26, 1976

# COMMUNICATIONS SYSTEMS MODELING STUDY

PREPARED FOR

DIGITAL COMMUNICATIONS CORPORATION
19 Firstfield Road
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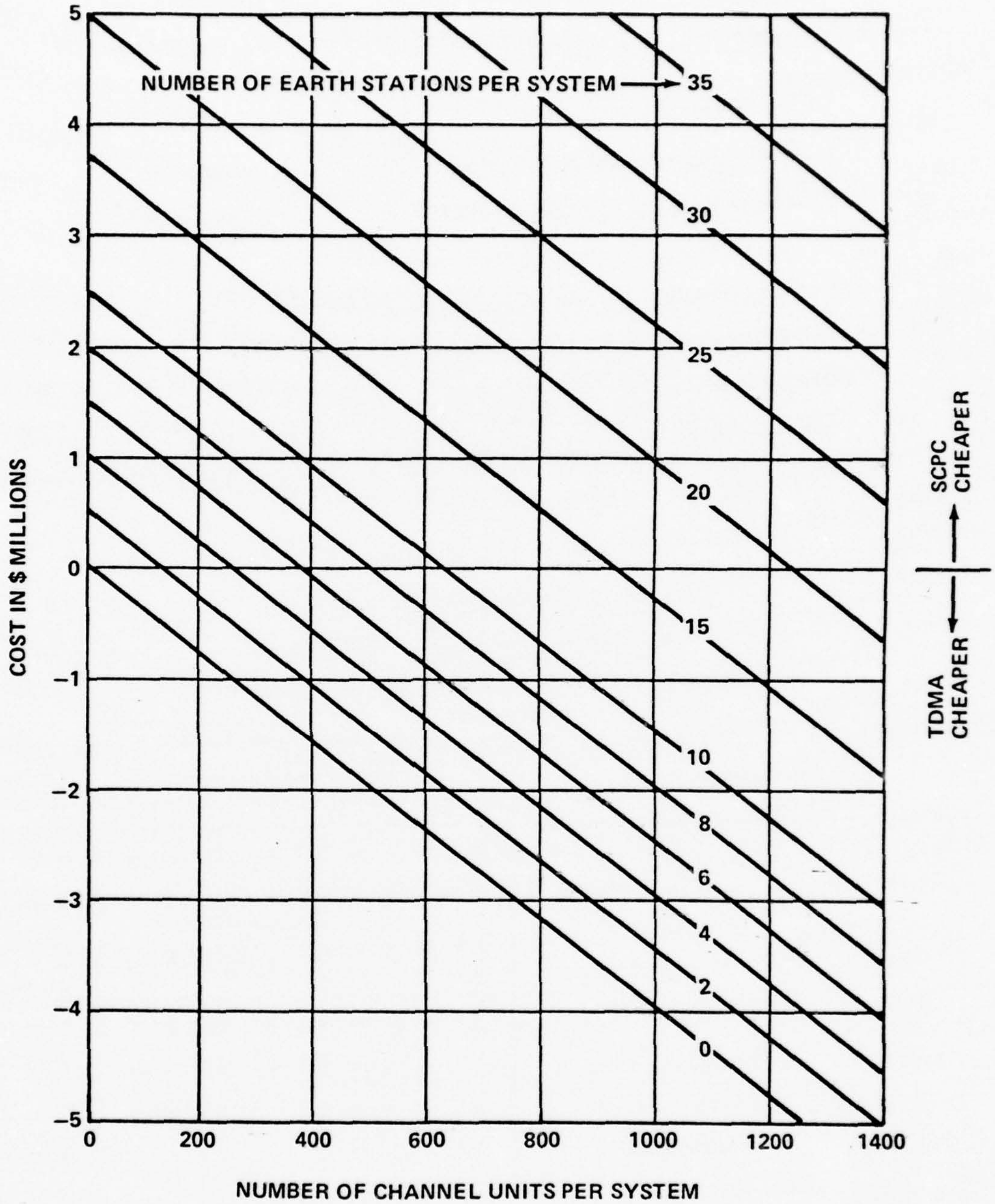


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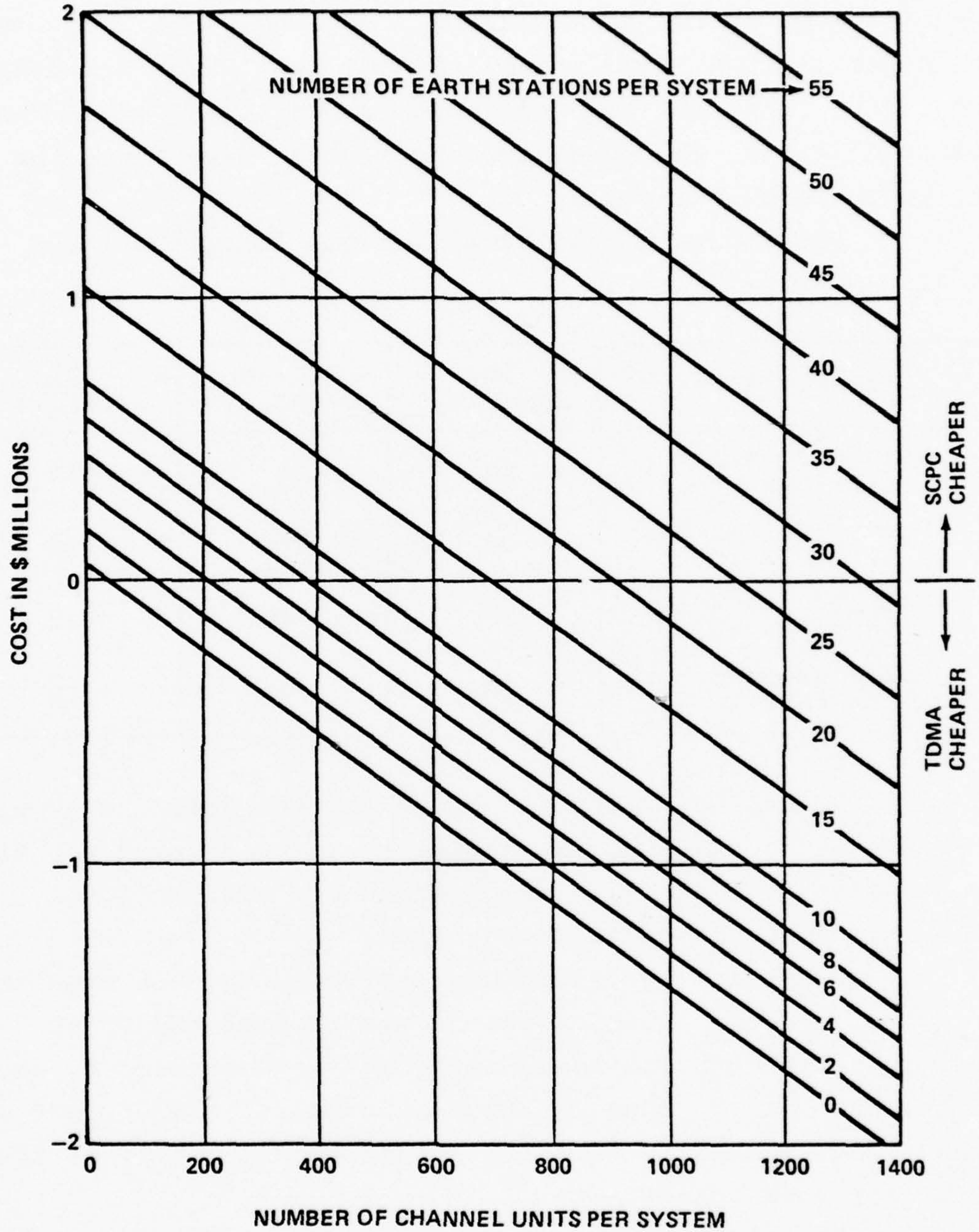


FIGURE S–2

ANNUAL COST DIFFERENCE IN $ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL SPOT BEAM TRANSPONDER

installation, spare parts and space segment. Not included are costs for "no break" power systems, buildings or shelters and land. Thus, although the costs shown on S-1 and S-2 are not total costs, they are nevertheless valid measures for the comparison of systems.

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| TDMA-FDMA | 2.76 | 1.83 | | 2.25 |
| TDMA - reduced bit rate | 3.14 | | | 3.14 |

## Section 1
## INTRODUCTION

This Communications Systems Modeling Study was prepared for Digital Communications Corporation by Satellite Systems Engineering, Inc., under Purchase Order No. 761 830, dated July 26, 1976.

The study developed and compared systems costs for three modulation/access techniques and three traffic models:

PSK-SCPC. Phase shift keyed single channel per carrier transmission with voice activation. Fully variable demand assignment is provided.

TDM-PSK-FDMA. Transmission of multiple digital carriers per transponder. Each earth station transmits all its traffic on a single carrier and receives a separate carrier for each link over which it wishes to communicate. Demand assignment is available within each carrier.

TDMA. Time division multiple access. Each station transmits a burst with a number of bits corresponding to the total number of channels of the station. Variable destination demand assignment is available within the burst, but the burst lengths are not changed in accordance with demand.

In all cases, the voice channels are encoded with 16 kb/s variable slope delta modulation. Whether or not encrypting is used has no impact on the results of this study.

Three traffic models were used in the study: A low-capacity, a medium capacity and a high-capacity model ranging from 80 to 1100 channels.

Transmission over six different satellite transponders has been studied:

- DSCS II, Global beam transponder
- DSCS II, Spot beam transponder
- Domestic satellite, C-band transponder
- Domestic satellite, K-band transponder
- INTELSAT IV, Global beam transponder
- INTELSAT IV-A, Regional coverage transponder.

In order to perform the economic comparison, space segment and ground segment costs have been estimated and a cost model was generated. The optimum earth station G/T was determined for each modulation/access technique and each transponder type. Annual system costs were calculated for each case. A general systems cost model was also developed, in order to be able to make system cost comparisons for other traffic models than those assumed in the study.

Based on this work, it was possible to clearly define the conditions under which a given modulation technique will be preferable over the others. A sensitivity study was also performed in order to check the sensitivity of the conclusions to changes in the assumptions.

# Section 2
# SYSTEM ASSUMPTIONS

## 2.1 TRAFFIC MODELS

For the purpose of this study, three traffic models have been assumed: a medium capacity, a low capacity and a high capacity model. It is assumed that many typical user applications will fall within the range of traffic encompassed by these models.

### 2.1.1 Medium Capacity Traffic Model

This traffic model was extracted from Technical Note No. 39-75 of the Defense Communications Engineering Center: Design of a Demand Assignment Satellite Network, by Dr. Nicholas Kyriakopoulos, December 1975. The model is based on actual switched traffic in Europe and is shown in Table 2-1. The model shows traffic among 10 locations, coded A through L. The traffic for each link as well as the total traffic for each location is expressed in Erlangs. The equivalent number of channels shown for each location is based on a grade of service of 1 in 100 and on the Erlang B equation. The channels are demand-assigned since they are based on the total traffic for each location, regardless of the destination.

Table 2-1
Medium Capacity Traffic Model
Busy Hour Traffic in Erlangs

| From \ To | A | B | C | D | E | F | G | H | K | L | Traffic Offered to Satellite | Required DA Channels |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | 1.10 | 2.70 | .15 | .30 | 1.05 | .35 | .45 | 1.10 | .10 | 7.30 | 14 |
| B | .60 | | 4.85 | .30 | 1.05 | 4.30 | .60 | .85 | .55 | .80 | 13.90 | 23 |
| C | 1.85 | 2.65 | | .95 | 1.30 | 4.25 | 1.30 | 1.90 | .35 | 1.30 | 15.85 | 25 |
| D | .15 | .60 | 3.20 | | 1.70 | 2.90 | 6.00 | .35 | 1.05 | .20 | 16.15 | 26 |
| E | .30 | .35 | 2.50 | 1.30 | | 2.00 | 2.25 | 1.10 | 1.10 | 1.10 | 12.00 | 20 |
| F | 1.25 | 5.30 | 7.00 | 1.45 | 2.00 | | 2.60 | 1.30 | .70 | 1.00 | 22.60 | 33 |
| G | .25 | .35 | 5.45 | 5.90 | 1.30 | 2.90 | | .30 | .40 | .35 | 17.20 | 27 |
| H | .60 | .60 | 3.70 | .20 | .95 | 1.50 | .35 | | 1.00 | .10 | 9.00 | 17 |
| K | 2.40 | .20 | 1.05 | .60 | 1.00 | .50 | .30 | 1.10 | | -- | 7.15 | 14 |
| L | .60 | 2.00 | 4.55 | .25 | 1.00 | 2.50 | .80 | .20 | -- | | 11.90 | 20 |
| Traffic Received | 8.00 | 13.15 | 35.00 | 11.10 | 10.00 | 21.90 | 14.55 | 7.55 | 6.25 | 4.95 | | |
| Receive Channels Required | 15 | 22 | 47 | 19 | 19 | 32 | 24 | 15 | 13 | 11 | | 219 / 217 |

### 2.1.2 Low Capacity Traffic Model

For this model, the channel requirements shown in Table 2-2 have been assumed.

Table 2-2
Low Capacity Traffic Model

| Location Category | Number of Locations | Channels Per Location | Total Number of Channels |
|---|---|---|---|
| A | 1 | 20 | 20 |
| B | 5 | 6 | 30 |
| C | 10 | 2 | 20 |
| D | 10 | 1 | 10 |
| Total | 26 | | 80 |

All channels are demand assigned.

### 2.1.3 High Capacity Traffic Model

For this model, the channel requirements shown in Table 2-3 have been assumed.

Table 2-3
High Capacity Traffic Model

| Location Category | Number of Locations | Channels Per Location | Total Number of Channels |
|---|---|---|---|
| A | 1 | 200 | 200 |
| B | 10 | 20 | 200 |
| C | 100 | 6 | 600 |
| D | 100 | 1 | 100 |
| Total | 211 | | 1100 |

All channels are demand assigned.

## 2.2 SPACE SEGMENT

In generating systems configurations, it will be assumed that the traffic postulated in the models in Section 2.1 may be transmitted through any of the following satellites:

DSCS Phase II satellites
- Global or spot beam transponders

INTELSAT satellites
- INTELSAT IV, global beam
- INTELSAT IV-A, regional coverage beam

Domestic satellites
- Typical U.S. domestic satellite with characteristics similar to Westar
- Future domestic satellite with capability at K-band.

A brief description of the transponder characteristics of these satellites is given below.

### 2.2.1 DSCS Phase II Satellites

The DSCS Phase II satellites are spin-stabilized at approximately 60 rpm and have two steerable narrow beam antennas with a beamwidth of 2.5 degrees each, and a global beam antenna with a beamwidth of 18 degrees. The antennas are mounted on a despun platform.

The transponders are cross-strapped to allow reception by one antenna and transmission by the other. Figure 2-1 shows the transponder frequency plan. Four transmission channels are provided with the characteristics shown in Table 2-4.

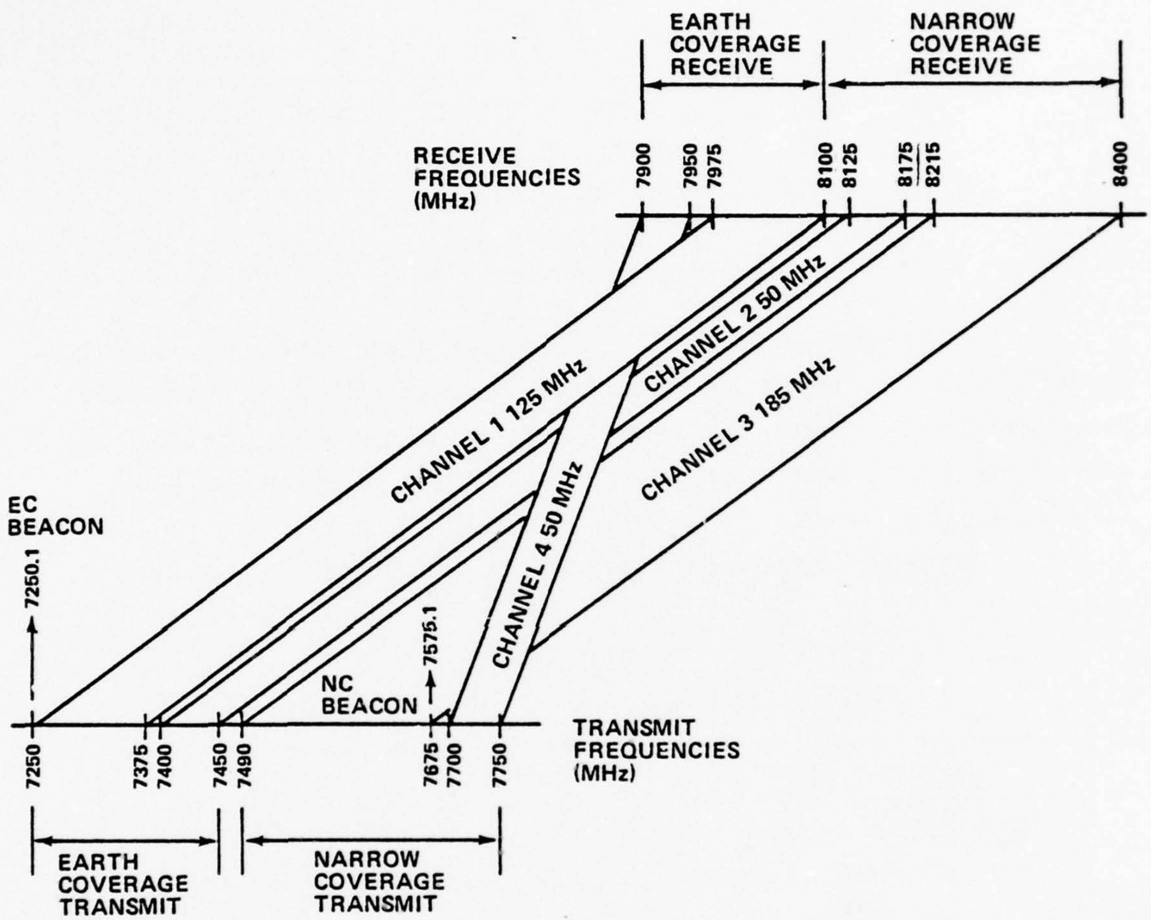



FIGURE 2–1

DSCS SATELLITE, PHASE II TRANSPONDER FREQUENCY PLAN

Table 2-4

DSCS II Channel Bandwidths

| Channel No. | Bandwidth in MHz | Transmit Antenna | Receive Antenna |
|---|---|---|---|
| 1 | 125 | Earth Coverage | Earth Coverage |
| 2 | 50 | Earth Coverage | Spot Beam |
| 3 | 185 | Spot Beam | Spot Beam |
| 4 | 50 | Spot Beam | Earth Coverage |

A single 20 watt TWT is associated with the global beam transmit antenna and another 20 watt TWT with the spot beam antennas. Thus, if more than 1 transponder is used in any given beam, the associated TWT cannot operate in the single carrier mode.

Transponder characteristics are shown in Table 2-5.

Table 2-5

DSCS II Transponder Characteristics

| Antenna Beam | Global | Spot |
|---|---|---|
| Beamwidth, degrees | 18 | 2.5 |
| Antenna gain at 8 GHz | 16.8 dB | 33 dB |
| Transmit EIRP, single carrier saturation at beam center | 28 dBW | 43 dBW |
| Receive G/T, at beam center | -19 dB/K | -3 dB/K |
| Transponder gain | commandable | commandable |

### 2.2.2 INTELSAT Satellites

INTELSAT IV global beam transponders and INTELSAT IV-A regional transponders are available for lease from INTELSAT for domestic communications. The transponder characteristics are shown in Table 2-6.

Table 2-6
INTELSAT Transponder Characteristics

| Satellite Type | INTELSAT IV | INTELSAT IV-A |
|---|---|---|
| Antenna coverage | Global | Regional |
| Transmit EIRP, single carrier saturation, minimum over coverage | 22 dBW | 29 dBW |
| Single carrier saturation flux density, at beam edge | $-73\ dBW/m^2$ | $-75\ dBW/m^2$ |
| Receive G/T, minimum over coverage area | -18 dB/K | -11.6 dB/K |

In the Atlantic area, the regional INTELSAT IV-A antenna beams cover an area bounded by the following INTELSAT stations:

| | |
|---|---|
| Northwest beam | Mill Village, Canada<br>Mexico<br>West Indies<br>Ecuador |
| Southwest beam | Peru<br>Brazil<br>Argentina |
| Northeast beam | Sweden<br>Senegal<br>Sudan |

| | |
|---|---|
| Southeast beam | Ivory Coast |
| | Ethiopia |
| | Mozambique |

### 2.2.3 Domestic Satellites

Transponders of typical domestic satellites will be included in the study. Such transponders use 5 watt TWTs and have a bandwidth of 36 MHz at C-band. With shaped beam coverage for CONUS and Alaska an EIRP of 33 dBW is achieved. The domestic satellite specified by Brazil has a different antenna beam shape, but provides the same EIRP. These transponders operate at C-band.

U.S. domestic satellites with K-band capability have not yet been procured; therefore, the K-band transponder characteristics are not yet firm.

Table 2-7

Domestic Satellite Transponder Characteristics

| Frequency Band | C-Band | K-Band |
|---|---|---|
| Antenna coverage | CONUS and Alaska | CONUS |
| EIRP, single carrier saturation, minimum over coverage area | 33 dBW | 38 dBW |
| Bandwidth | 36 MHz | 54 MHz |
| Receive G/T | -6 dB/K | -6 dB/K |
| Saturation flux density | -83 $dBW/m^2$ | -83 $dBW/m^2$ |

## 2.3 GROUND SEGMENT CHARACTERISTICS

For the purpose of this study, the following ground segment characteristics have geen assumed:

### 2.3.1 Existing Terminals

Table 2-8
Existing Terminals

| Terminal | Antenna Diameter (feet) | G/T (dB/K) | EIRP (dBW) | TX Power (kW) |
|---|---|---|---|---|
| AN/WSC-2 | 4 | 12 | 67.8 | |
| AN/MSC-85 | 8 | 18 | | 0.5 |
| AN/TSC-54 | 18 | 26.5 | | 5 |
| AN/MSC-46 | 40 | 34 | | 10 |
| AN/FSC-78 | 60 | 39 | | 8 |

INTELSAT Standard A Terminals 100 feet dia., 40.7 dB/K G/T.
INTELSAT Standard B Terminals 32 feet dia., 30.7 dB/K G/T.
U.S. Domestic Terminal, similar to INTELSAT Standard B.

### 2.3.2 New Terminals

New terminals will be configured to meet systems requirements at minimum cost for each application. Smallest permissible size will be based on INTELSAT requirements and FCC requirements for limitations on adjacent satellite interference.

## 2.4 SIGNALING REQUIREMENTS

In the basic system design, it will be assumed that there are no signaling requirements that would be affected by the satellite transmission delay. Signaling information can be transmitted equally well with any of the three modulation/access techniques under study. For these reasons, signaling requirements need not be considered in this comparative study.

# Section 3
## BASIC SYSTEMS CONFIGURATIONS

In this section, basic systems configurations have been developed for the three modulation/access techniques under investigation:

- a PSK-SCPC System
- a TDM-PSK-FDMA System
- a TDM-PSK-TDMA System.

### 3.1 DEMAND ASSIGNMENT VERSUS PRE-ASSIGNMENT

This paragraph presents an analysis of the traffic models regarding the number of channels that are required with demand assignment and with pre-assignment of channels.

#### 3.1.1 Medium Capacity Traffic Model

The traffic model shown in Table 2-1 shows the Erlang load for each link and the number of demand-assigned channels that are required for each location to satisfy the traffic with a grade of service of 1 in 100, based on the Erlang B equation.

The Erlang B equation is used to calculate the probability of call blockage. It assumes an infinite source of callers and also assumes that lost calls are cleared. It has been recommended for use by the CCITT.

$$P = \frac{\frac{Y^n}{n!}}{\sum_{o}^{n} \frac{Y^n}{n!}}$$

where:

P = probability of blocking

n = number of channels

y = traffic load in Erlangs.

For convenience, the Erlang B tables have been used in this study and a grade of service or probability of blocking of 0.01 was used throughout. Figure 3-1 is a graphic presentation of Erlang load versus number of channels for grades of service 1 in 20, 1 in 100, and 1 in 1000.

Table 3-1 shows the number of channels required for the medium capacity traffic model, if pre-assigned channels are used. The traffic concentration factor with demand assignment is approximately 2.1 for this model.

| | |
|---|---|
| Total pre-assigned one-way channels | 467 |
| Total demand assigned one-way channel units | 219 |
| Total Erlang load in the system | 133 |
| Total satellite channels required | 152 |

The total demand-assigned one-way channel units are based on a probability of blocking of 0.01 at any earth station. Since a circuit requires a channel unit at two earth stations, the end to end probability of blockage is approximately 0.02. If the satellite is capacity limited to 152 channels, it also introduces a separate probability of blocking of 0.01. Thus the probability of blocking for the overall link is approximately 0.03.

If an overall probability of blocking of 0.01 is required, it is necessary to design each earth terminal and the satellite link for an individual probability of blocking of 1 in 300.

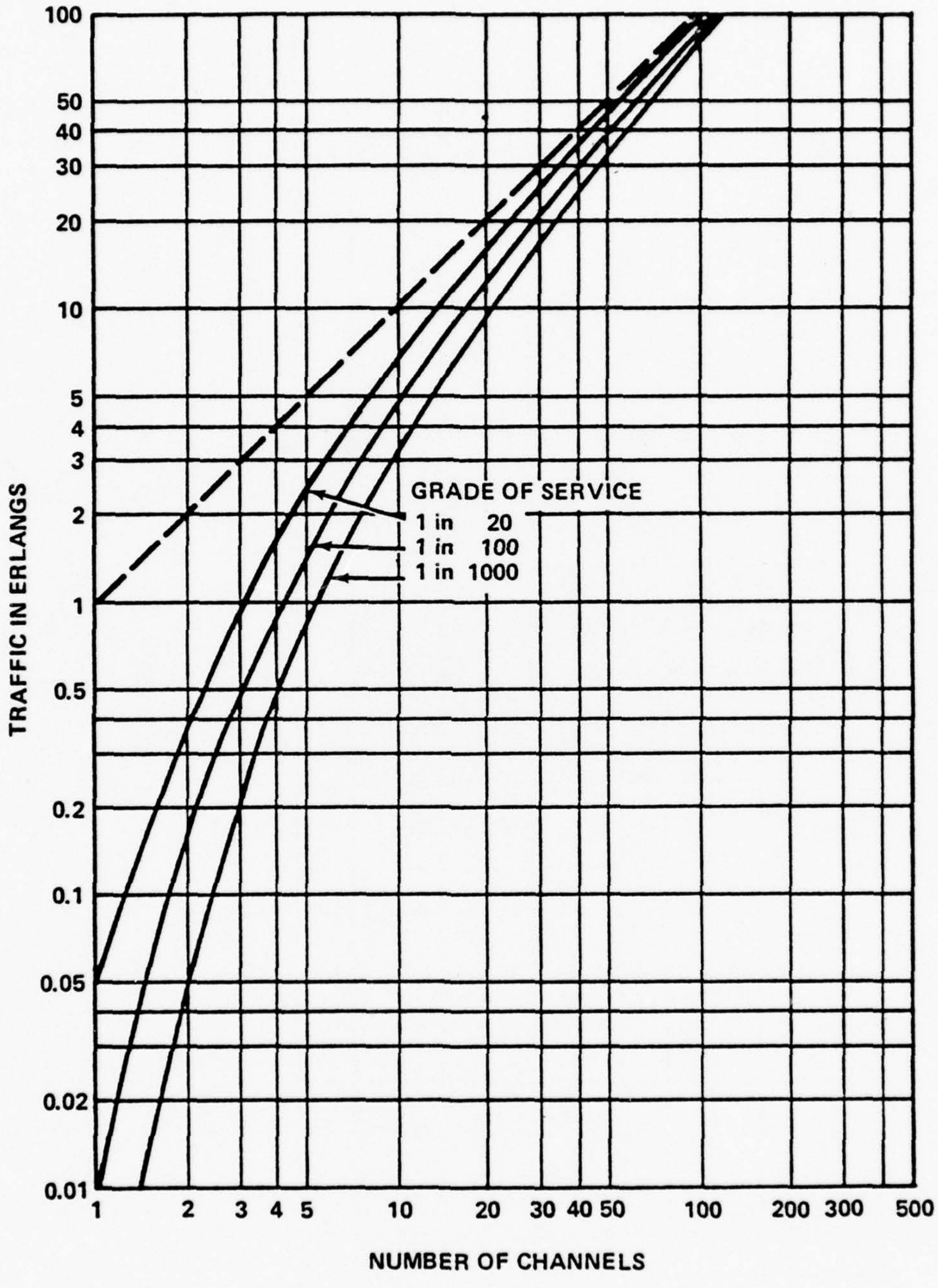



FIGURE 3–1

ERLANG LOAD VERSUS NUMBER OF CHANNELS

Table 3-1

Medium Capacity Traffic Model

(Pre-assigned Traffic in Channels)

| FROM \ TO | A | B | C | D | E | F | G | H | K | L | Required Pre-assigned Channels |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | 5 | 7 | 2 | 3 | 5 | 3 | 3 | 5 | 2 | 35 |
| B | 4 | | 11 | 3 | 5 | 10 | 4 | 4 | 4 | 4 | 49 |
| C | 6 | 8 | | 5 | 5 | 10 | 5 | 6 | 3 | 5 | 53 |
| D | 2 | 4 | 8 | | 6 | 8 | 13 | 3 | 5 | 3 | 52 |
| E | 3 | 3 | 7 | 5 | | 6 | 7 | 5 | 5 | 5 | 46 |
| F | 5 | 11 | 14 | 5 | 6 | | 7 | 5 | 4 | 5 | 62 |
| G | 3 | 3 | 12 | 12 | 5 | 8 | | 3 | 3 | 3 | 52 |
| H | 4 | 4 | 9 | 3 | 5 | 6 | 3 | | 5 | 2 | 41 |
| K | 7 | 3 | 5 | 4 | 5 | 3 | 3 | 5 | | | 35 |
| L | 4 | 6 | 10 | 3 | 5 | 7 | 4 | 3 | | | 42 |
| | | | | | | | | | Total | | 467 |

### 3.1.2 Low-Capacity Traffic Model

To determine the impact of demand-assignment versus pre-assignment, assumptions must be made regarding the required connectivity and traffic distribution. It was assumed that all stations must be interconnected to each other, except that stations category C are only connected to stations A and B, and stations category D are connected only to station A. The station interconnect matrix is shown below.

| | A | B | C | D |
|---|---|---|---|---|
| A | | X | X | X |
| B | X | X | X | |
| C | X | X | | |
| D | X | | | |

Based on this interconnect matrix, the traffic distribution shown in Table 3-2 was developed; traffic is shown in Erlangs.

Table 3-2

Traffic Distribution for Low Capacity Model

| Link | Traffic Per Link | Traffic Per Originating Station | Total Traffic Per Category |
|---|---|---|---|
| A to B | 1.41 | 7.05 | |
| A to C | 0.10 | 1.0 | |
| A to D | 0.01 | 0.1 | |
| | | 8.15 | A 8.15 |
| B to A | 1.41 | 1.41 | |
| B to B | 0.1 | 0.4 | |
| B to C | 0.01 | 0.1 | |
| | | 1.91 | B 9.55 |
| C to A | 0.10 | 0.10 | |
| C to B | 0.01 | 0.05 | |
| | | 0.15 | B 1.50 |
| D to A | 0.01 | 0.01 | D 0.10 |
| Total System Traffic | | | 19.3 |

With this traffic distribution station A would require only 16 channel units. In actual practice, the traffic load on the links between stations D to A and C to A could be higher, thus justifying the 20 channels provided at station A. The equivalent number of pre-assigned channels to satisfy the traffic distribution of Table 3-2 is shown in Table 3-3.

Table 3-3

Number of Pre-Assigned Channels for

Low Capacity Traffic Model

| Link | Channels Per Link | Channels Per Station | Total Channels Per Category |
|---|---|---|---|
| A to B | 5 | 25 | |
| A to C | 2 | 20 | |
| A to D | 1 | 10 | |
| | | 55 | A 55 |
| B to A | 5 | 5 | |
| B to B | 2 | 8 | |
| B to C | 1 | 10 | |
| | | 23 | B 115 |
| C to A | 2 | 2 | |
| C to B | 1 | 5 | |
| | | 7 | C 70 |
| D to A | 1 | 1 | D 10 |
| Total Channels in the System | | | 250 |

The comparison between the pre-assigned and demand-assigned channels for the low capacity traffic model is shown below:

| | |
|---|---|
| Total pre-assigned channels | 250.0 |
| Total demand-assigned channel units at all earth stations | 80.0 |
| Total system Erlang load | 19.3 |
| Total satellite channels needed with demand assignment | 29.0 |

### 3.1.3 Conclusion

Analysis of the medium capacity model shows that the channel concentration factor[1] as the result of demand-assignment is better than 2 to 1. For the low capacity model, the channel unit concentration factor[2] is more than 3 to 1, even though the pre-assigned model does not provide full interconnectivity. The channel concentration factor is approximately 8. For the high capacity model, the channel concentration factor would be even higher and more severe limitations in lack of interconnectivity would have to be accepted if traffic were pre-assigned.

For these reasons, it is concluded that demand-assignment is essential for all the traffic models under study and demand-assignment will therefore be used in all systems models.

### 3.2 CARRIER-TO-NOISE DENSITY REQUIREMENT

In all cases, the voice channels are digitally encoded at bit rates of 16 kb/s or 32 kb/s. In the former case, 2-phase PSK is used, resulting in a noise bandwidth of approximately 20 kHz. In the latter case, 4-phase PSK is used with the same noise bandwidth. All calculations have been performed for the 16 kb/s system; transmission of the 32 kb/s system requires 3 dB higher $C/N_o$.

$$\frac{C}{N} = \frac{E_b}{N_o} + 10 \log \frac{R}{BW} + M_s$$

$$\frac{C}{N_o} = \frac{C}{N} + 10 \log BW$$

[1] - Channel Concentration refers to satellite channels.

[2] - Channel Unit Concentration refers to terminal hardware.

where

$\frac{C}{N}$ = total carrier-to-noise ratio at the normal operating point

$\frac{E_b}{N_o}$ = energy per bit-to-noise density ratio at threshold. For the delta modulation system assumed in this study threshold occurs at BER = $10^{-2}$ which corresponds to $E_b/N_o$ = 6 dB.

R = bit rate, 16 or 32 kb/s

BW = IF bandwidth per channel, approximately 20 kHz

$M_s$ = system margin, assumed to be 5 dB at C-band. This results in normal operation at a BER of better than $10^{-4}$. Such margin is required for all system variations such as antenna pointing errors, power level variations, rain attenuation, etc.

$\frac{C}{N_o}$ = carrier-to-noise density ratio in dB Hz.

For 2-phase operation

$$\frac{C}{N} = 6 + 10 \log \frac{16}{20} + 5 = 10 \text{ dB}$$

and

$$\frac{C}{N_o} = 10 + 10 \log 20{,}000 = 53 \text{ dB Hz.}$$

For 4-phase operation

$$\frac{C}{N} = 6 + 10 \log \frac{32}{20} + 5 = 13 \text{ dB}$$

and

$$\frac{C}{N_o} = 13 + 43 = 56 \text{ dB Hz}$$

## 3.3 PSK-SCPC SYSTEM

### 3.3.1 Link Calculations

In this single channel per carrier system, demand assignment is accomplished by central control, using a separate common control channel. Through this system, full flexibility is accomplished; any station can be interconnected on demand with any other station in the system. Rate 1/2 coding can be employed for the common control channel to achieve low bit error rates. Therefore, in the basic link calculation, only the performance of the voice channels will be determined.

Satellite power is conserved by the provision of a voice operated switch. The voice activity statistics depend on the number of channels in the system. McClure [1] has calculated the relationship shown in Table 3-4.

Table 3-4
Voice Activity Statistics Versus Number of Channels

| Number of Channels in the System | Voice Activity Ratio at Any Given Moment Not to Be Exceeded for: | |
|---|---|---|
| | 90% of the Time | 99% of the Time |
| 12 | 0.60 | 0.75 |
| 20 | 0.55 | 0.66 |
| 50 | 0.48 | 0.55 |
| 100 | 0.44 | 0.50 |
| 800 | 0.40 | 0.42 |

[1] R. B. McClure, Comsat Technical Memorandum CL-12-71, March 31, 1971, Link Power Budget Analysis for SPADE and Single Channel PCM/PSK.

The long-term average voice activity ratio is 0.40. This ratio will be used in the satellite capacity calculations regardless of the number of channels in the system for the following reasons:

(a) The statistics in Table 3-4 assume that the voice switching on all channels in the system is uncorrelated. In actual fact, there is a correlation between each pair of voice channels forming a circuit. In a normal conversation, while one party talks, the other listens. Thus, even for only 2 channels in the system, the voice activity factor is less than 0.5, except for the small percentage of time when both parties talk simultaneously.

(b) An adequate system margin has been allowed to absorb temporary peak power requirements when the voice activity ratio of 0.4 is exceeded.

Total carrier-to-noise ratio is calculated with the following equation, using numerical values:

$$\left(\frac{C}{N}\right)_T = \frac{1}{\dfrac{1}{\left(\frac{C}{N}\right)_u} + \dfrac{1}{\left(\frac{C}{N}\right)_D} + \dfrac{1}{\left(\frac{C}{N}\right)_I}}$$

where:

$\left(\frac{C}{N}\right)_T$ = total carrier-to-noise ratio in the receiving bandwidth

$\left(\frac{C}{N}\right)_u$ = up-link carrier-to-noise ratio

$\left(\frac{C}{N}\right)_D$ = down-link carrier-to-noise ratio

$\left(\frac{C}{N}\right)_I$ = carrier-to-intermodulation noise ratio.

Up-link carrier-to-noise ratio is calculated as follows; all numbers are expressed in dB.

$$\left(\frac{C}{N}\right)_u = W_s - G_{m^2} - BO_I - X + \left(\frac{G}{T}\right)_s - k - 10 \log BW$$

where:

$W_s$ = satellite saturation flux density in $dBW/m^2$

$G_{m^2}$ = gain of a square meter relative to isotropic

$$G_{m^2} = 10 \log \frac{4\pi}{\eta^2}$$

where $\eta$ = wavelength in meters.

At 6 GHz, $G_{m^2}$ = 37 dB;

at 7.5 GHz, $G_{m^2}$ = 39 dB.

$BO_I$ = input back-off, dB

X = 10 log N

N = number of active channels per transponder. With a voice activity of 0.4 the total number of channels per transponder is 2.5 times N.

$\left(\frac{G}{T}\right)_s$ = satellite G/T

K = Boltzmann's constant, -228.6 dB

BW = receive noise bandwidth per channel, 20 kHz.

Down-link carrier-to-noise ratio is calculated as follows; again all numbers are expressed in dB.

$$\left(\frac{C}{N}\right)_D = EIRP_s - BO_o - X - PL_D + \left(\frac{G}{T}\right)_E - k - 10 \log BW$$

where:

$EIRP_s$ = satellite EIRP, single carrier saturation

$BO_o$ = output back-off, dB

$PL_D$ = down-link pathloss. For the frequency of 4 GHz, a pathloss of 196.2 dB was used, which corresponds to an elevation angle of 30 degrees.

$\left(\frac{G}{T}\right)_E$ = earth station G/T.

The carrier-to-intermodulation noise ratio can be determined from Figure 3-2. The curves in this figure were derived from Reference [1]. With voice operated switching, the carrier-to-intermodulation noise ratio is 4 dB higher than without voice switching.

The next step in the channel capacity calculations is the determination of the optimum operating point for a given satellite-earth station combination. Figure 3-3 shows the carrier-to-noise ratios for the example of a domestic C-band transponder and an earth station with a G/T of 32 dB/K.

The down-link carrier-to-noise ratio can be calculated for single carrier saturation. The multi-carrier saturation C/N is 1.5 dB lower. The relationship of input versus output back-off for single and multi-carrier transmission is shown on Figure 3-4 as single and multi-carrier C/N ratios.

The optimum operating point corresponding to the highest carrier-to-noise ratio is at 11 dB input back-off. However, the system provides satisfactory performance over

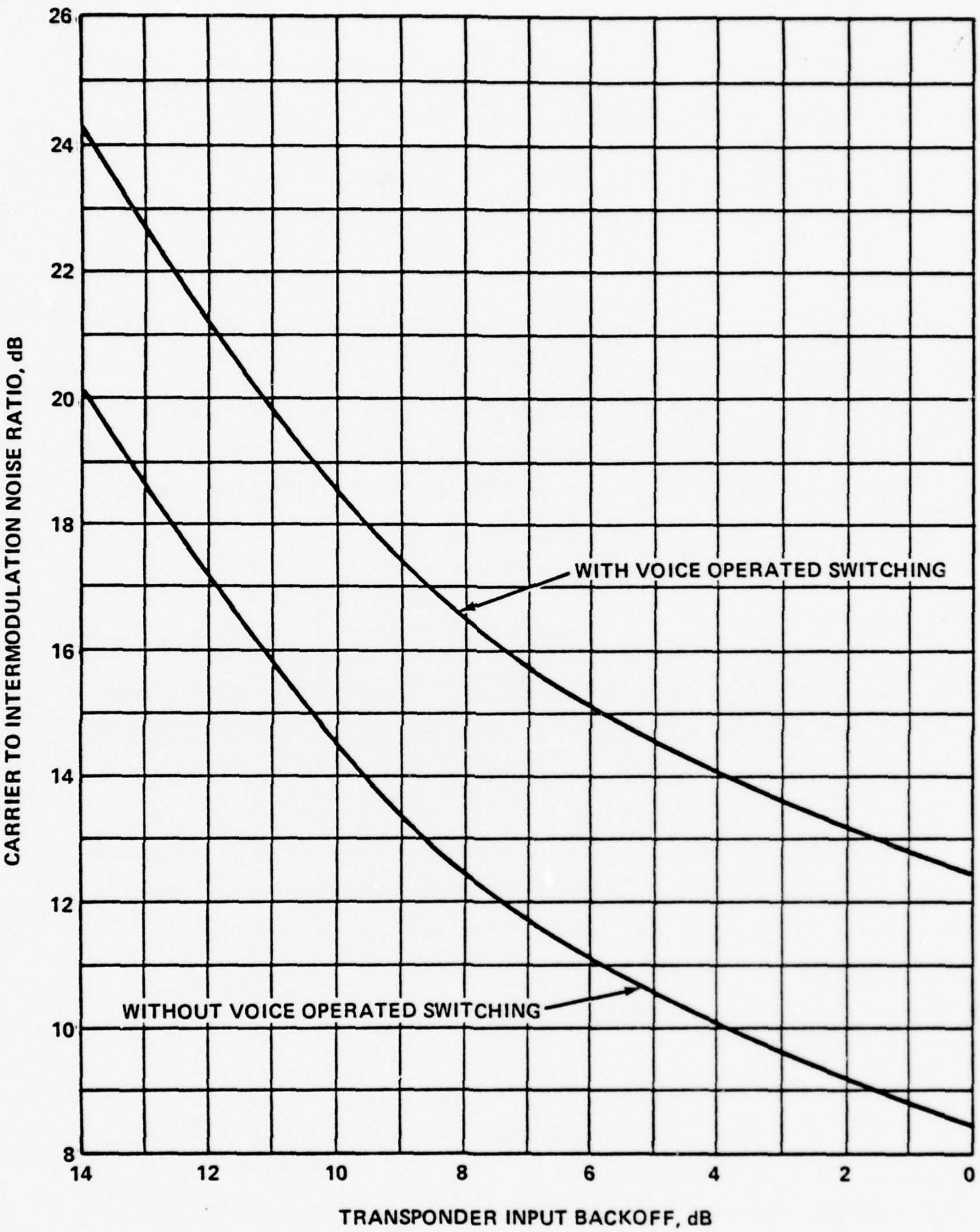



FIGURE 3–2

CARRIER TO INTERMODULATION NOISE RATIO FOR SCPC TRANSMISSION

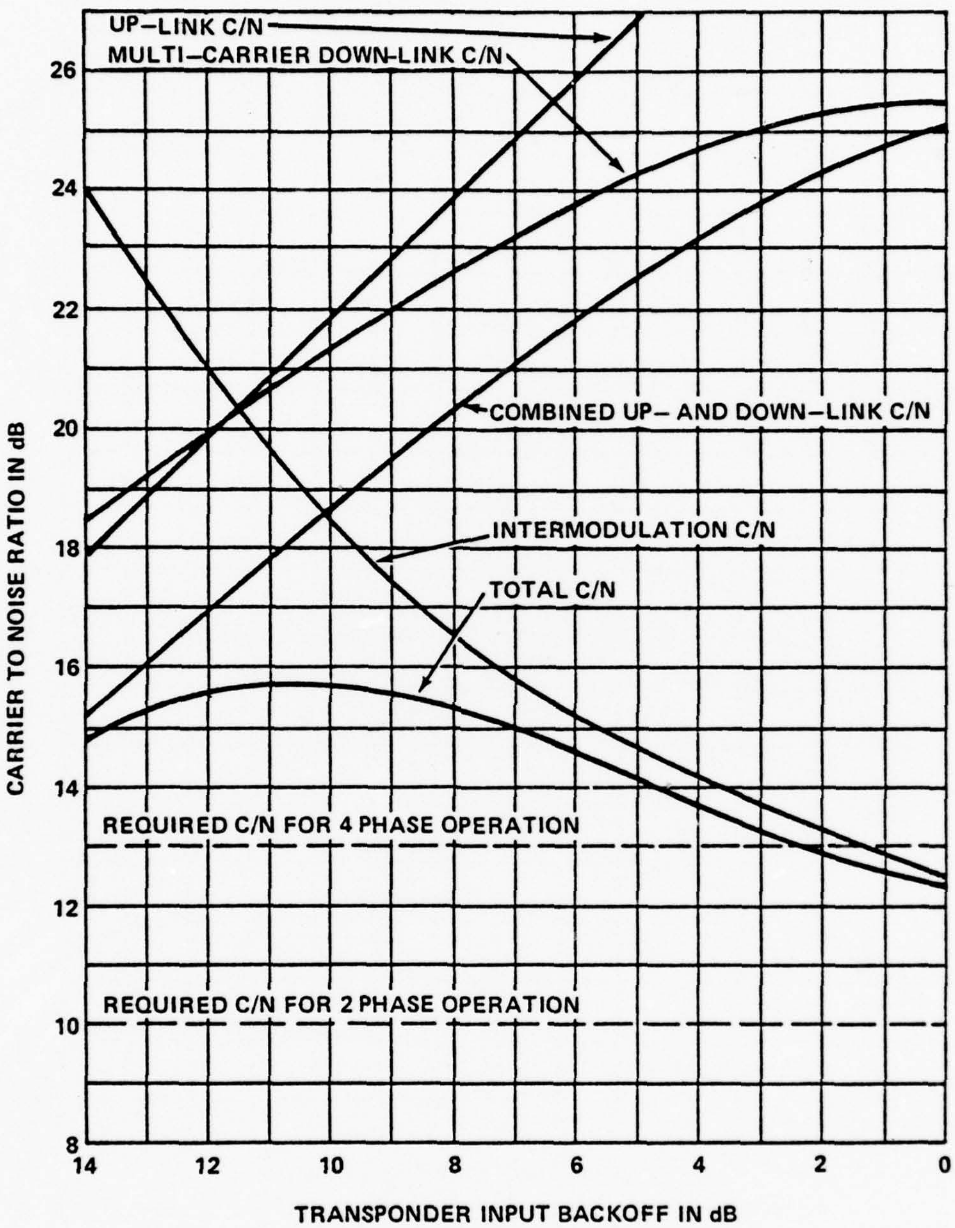



FIGURE 3–3

OPTIMUM OPERATING POINT
FOR SCPC TRANSMISSION
EIRP = 33 dBW, G/T = 32 dB/K

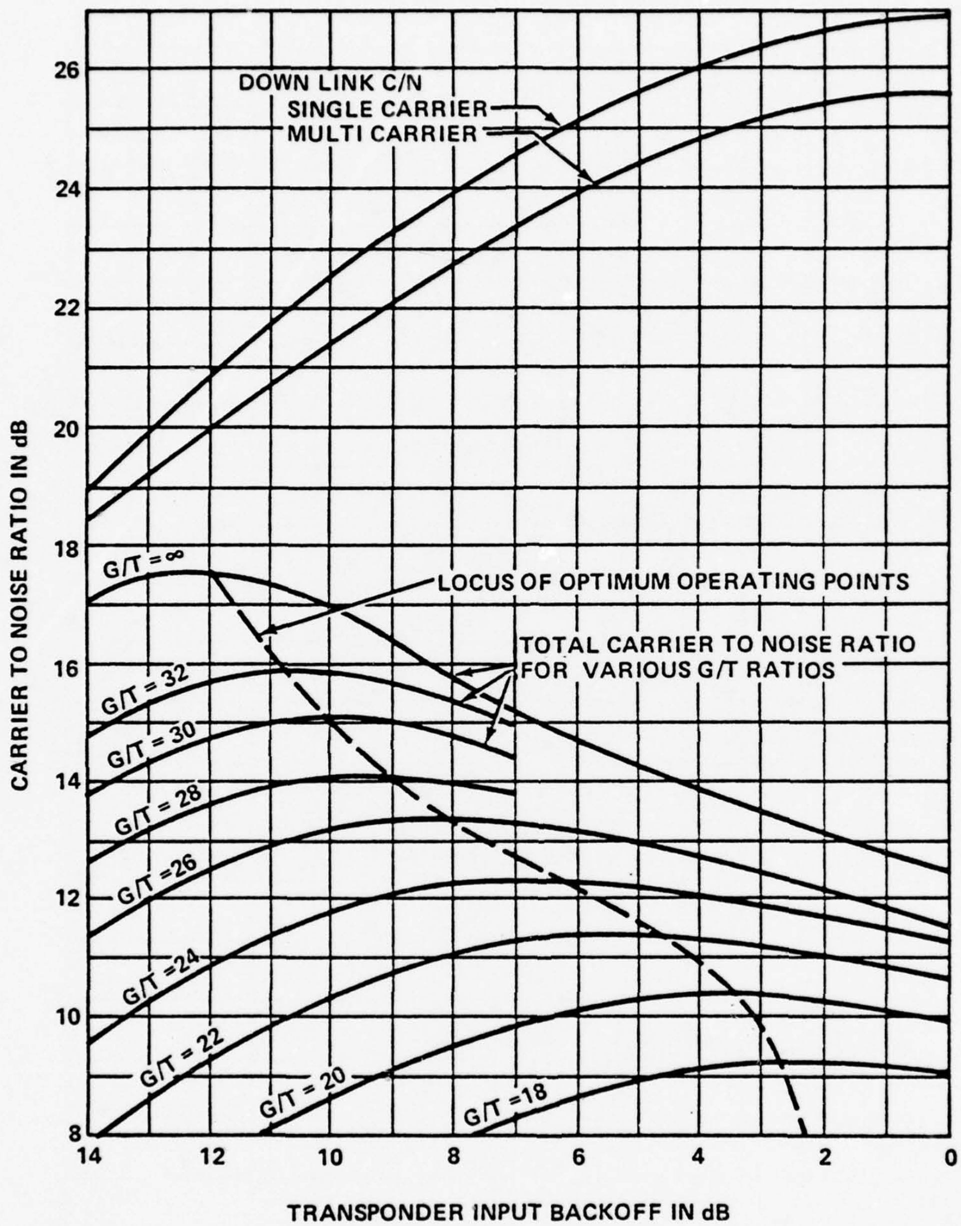



FIGURE 3–4

OPTIMUM OPERATING POINTS FOR SCPC TRANSMISSION
EIRP = 33 dBW, VARIOUS G/T RATIOS

a wide range of back-offs, both for 2-phase and 4-phase operation, indicating that lower earth station G/T ratios are adequate.

Figure 3-4 shows the optimum operating points for SCPC transmission over a range of G/T ratios. With a domestic satellite with 36 MHz bandwidth and 33 dBW EIRP, an earth station G/T of 18 to 20 dB/K is the lowest G/T that will support the full bandwidth capability of 1440 voice operated channels with 16 kb/s delta modulation. An input back-off of 3 dB is optimum for these small earth stations.

The maxima of the curves are quite flat. It is possible to vary the back-off around the optimum by ±2 dB without losing more than 0.2 to 0.5 dB in carrier-to-noise ratio. Therefore, a near optimum operating point can be found from the simplified relationship in Table 3-5.

Table 3-5

Optimum Operating Point

| EIRP + G/T (dB) | Input Back-off (dB) |
|---|---|
| 51 | 2.5 |
| 53 | 3.5 |
| 55 | 4.5 |
| 57 | 6.0 |
| 59 | 8.0 |
| 61 | 9.0 |
| 63 | 10.0 |
| 65 | 11.0 |

The relationship in Table 3-5 is valid for C-band transmission of 36 MHz. For other conditions, the results can be scaled.

3.3.2 Channel Capacities

For the power limited condition, channel capacities are calculated as follows:

$$10 \log n = EIRP_S - BO_o - PL_D + \left(\frac{G}{T}\right)_E - y - \left(\frac{C}{N_o}\right)_R - k + SA + \Delta M$$

where:

n = number of total voice channels

y = dB difference between down-link noise and total noise

$\left(\frac{C}{N_o}\right)_R$ = required carrier-to-noise density ratio at normal operation

= 53 dB Hz for 2-phase operation

SA = voice activity switching advantage, 4 dB

$\Delta M$ = additional margin for use at frequencies higher than 4 GHz.

For the bandwidth limited case, the channel capacity is given by

$$\eta = \frac{\text{Transponder Bandwidth in kHz}}{25}$$

The factor y depends on the selected operating point and on the satellite gain, as well as on the exact intermodulation contribution. For the power limited case, a transponder input back-off of 2.5 dB has been used and the corresponding y factor of 2 dB has been assumed. The small input back-off is due to voice switching, which brings a carrier-to-intermodulation noise advantage of 4 dB as shown in Figure 3-2.

The bandwidth limited capacities are as follows:

| | |
|---|---|
| 36 MHz Transponder | 1440 Channels |
| 50 MHz Transponder | 2000 Channels |
| 54 MHz Transponder | 2160 Channels |
| 125 MHz Transponder | 5000 Channels |
| 185 MHz Transponder | 7400 Channels |

For the power limited case, the following relationship was derived:

<u>INTELSAT IV Global Beam</u>

$$10 \log n = 1.9 + \left(\frac{G}{T}\right)_E$$

<u>INTELSAT IV-A Regional Coverage</u>

$$10 \log n = 8.9 + \left(\frac{G}{T}\right)_E$$

<u>Domestic Satellite, C-Band</u>

$$10 \log n = 12.9 + \left(\frac{G}{T}\right)_E$$

<u>Domestic Satellite, K-Band</u>

$$10 \log n = 5.4 + \left(\frac{G}{T}\right)_E$$

<u>DSCS II, Global Beam</u>

$$10 \log n = 0.9 + \left(\frac{G}{T}\right)_E$$

<u>DSCS II, Spot Beam</u>

$$10 \log n = 15.9 + \left(\frac{G}{T}\right)_E$$

To compensate for the higher rain attenuation and atmospheric absorption above 4 GHz, an additional margin, $\Delta M$, of 1.5 dB was included for DSCS II and 3 dB for the domestic K-band transponder.

The results of the channel capacity calculations are shown in Figure 3-5.

## 3.4 TDM-PSK TRANSMISSION

In this system, the channels of each earth station are time division multiplexed and the composite bitstream is modulated onto a PSK carrier. Carrier sizes are 1, 2, 6, 20 and 200 channels for the low and high capacity traffic models and 14 through 33 channels for the medium capacity model. Each station requires a demodulator for each carrier it receives. Demand assignment is accomplished by switching of the demultiplexed receive channels.

Voice operated switching is not possible, except on the carriers with only one channel. The individual links are too small to permit the use of Speech Interpolation (DSI). Thus, the 4-dB voice activity advantage that was used in the SCPC system is not available with the TDM-PSK system.

The basic $E_b/N_o$ requirement per channel as well as the margin requirements are the same for TDM-PSK transmission and for SCPC transmission. Bandwidth requirements are also identical.

Therefore, the bandwidth limited capacities of this system and the SCPC system are identical, but the power limited capacities of this system are 4 dB lower than those of the SCPC system. The capacities for these systems are shown in Figure 3-6.

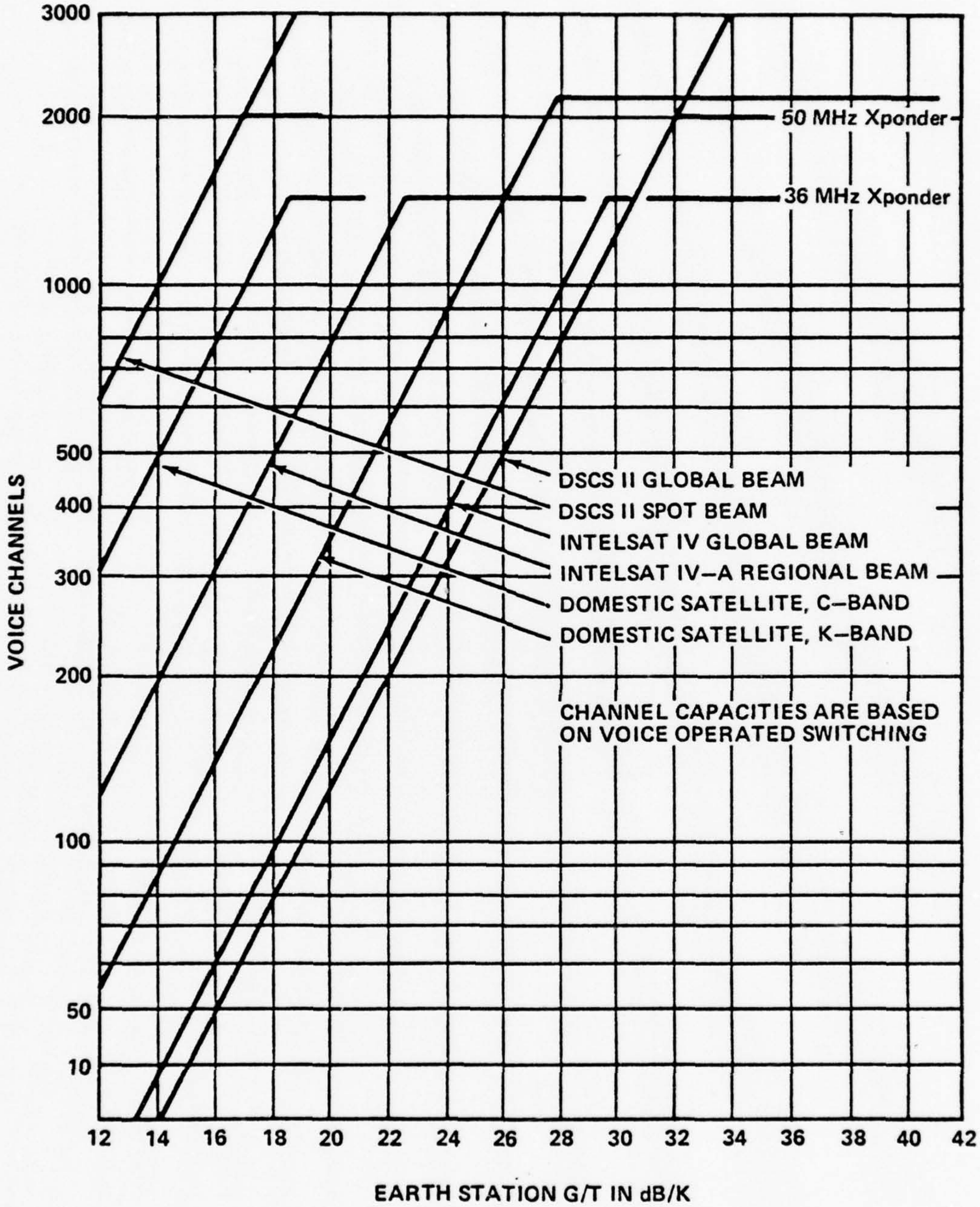



FIGURE 3–5

TRANSPONDER CAPACITY WITH SCPC TRANSMISSION

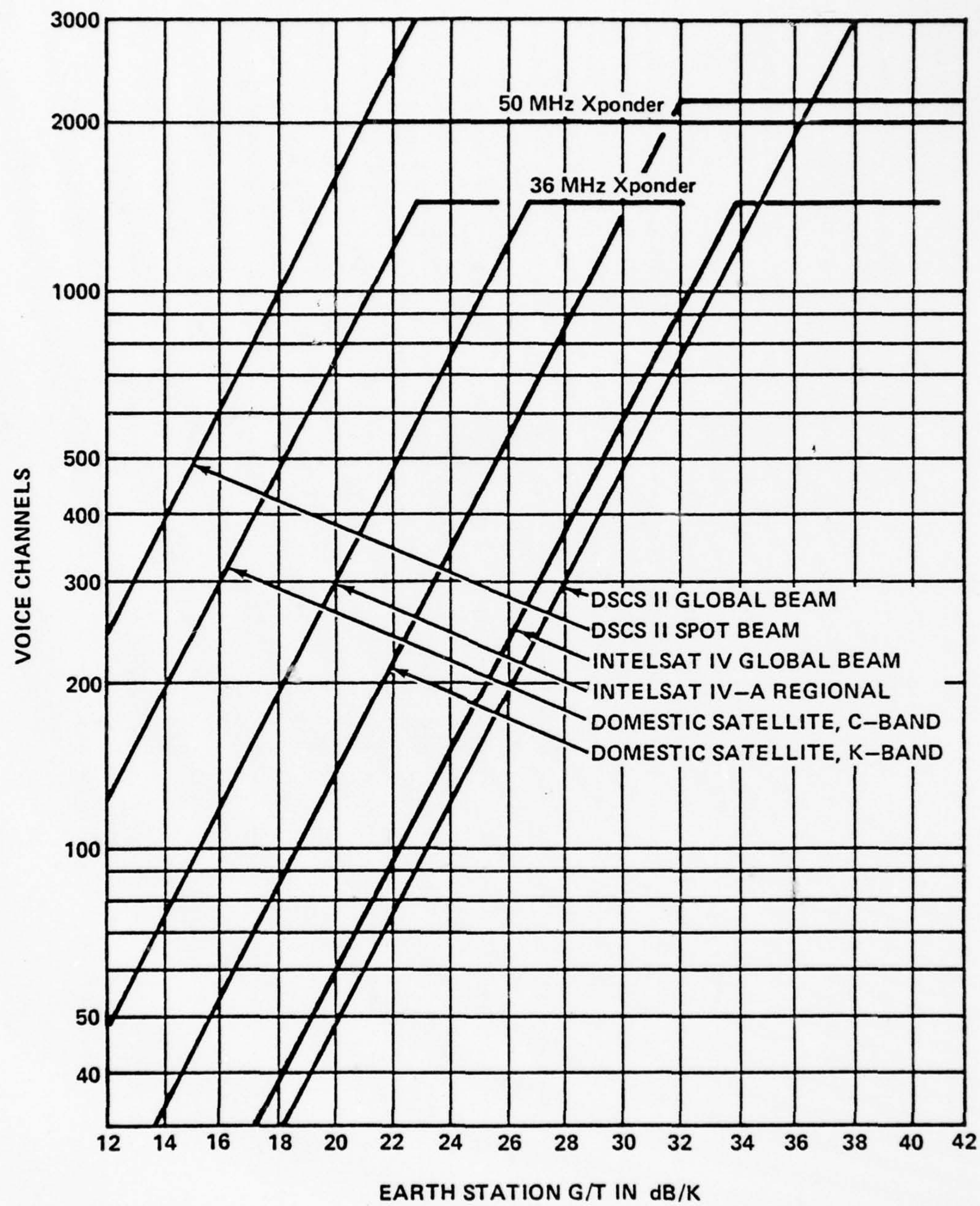



FIGURE 3–6

TRANSPONDER CAPACITY WITH TDM–PSK TRANSMISSION

## 3.5 TDM-PSK-TDMA SYSTEM

In this system, individual channels at an earth station are time division multiplexed and PSK modulated onto a carrier which is transmitted in a burst mode. The advantage of this system is that it eliminates multicarrier intermodulation losses. This would provide a basic power advantage of approximately 3 dB over the multi-carrier systems.

However, if the system works with earth stations which can support the total bandwidth of a transponder, additional losses relative to those with the other systems are incurred, due to intersymbol distortion at the high bit rates used as a result of the earth station HPA and satellite TWT nonlinearities. In a typical system, these losses are about 3 dB.

If the system operates with small earth stations, so that only about one-half of the available transponder bandwidth is occupied by the main lobe of the PSK spectrum, then the intersymbol distortion is reduced because the PSK sidelobes can be transmitted through the HPA and the satellite, thus reducing the envelope variations of the transmitted spectrum.

Voice operated switching is not possible and the individual links are too small to permit the use of Speech Interpolation. Thus, the 4 dB voice activity advantage that was used in the SCPC system is not available with the TDMA system.

A variation of this system is the transmission of individual channels per burst.

A major constraint of the TDMA system is that it requires the use of a full transponder. Sharing of the transponder with other services would require operation at back-off and would result in a carrier-to-noise ratio loss.

Under bandwidth limited conditions, the TDMA system capacity per transponder will be identical to that with the other two systems. In the power limited case, however, the TDMA capacity will be approximately that of the TDM-PSK system shown on Figure 3-6. Exact capacities have to be determined for each specific case.

# Section 4
# COST ASSUMPTIONS

Cost assumptions are required to permit the trade-off among earth station antenna size, earth station cost and transponder capacity. This trade-off will be performed to permit the synthesis of optimized configurations for each application.

## 4.1 SPACE SEGMENT COSTS

The trade-offs will be based on the assumption that a full transponder or a fraction of a transponder would be leased from any of the satellite systems under consideration. INTELSAT, as well as several domestic communications satellite carriers have developed rates for transponder lease. A few examples are given below.

INTELSAT has two rates for transponder lease. One applies for the lease of a protected transponder, i.e., in case of satellite failure a transponder will be made available in a spare satellite. The other rate applies for pre-emptable service, i.e., in case of satellite failure or during other contingencies, the service may be interrupted for prolonged periods.

The present rate for a pre-emptable transponder is $1 Million per year. One-half or one-quarter of a transponder may be leased for $500,000 or $250,000, respectively. It is assumed, however, that the type of traffic considered in this study is too important to permit pre-emption. Therefore, only the rate for a protected transponder will be used.

The rate for a protected transponder is based on 360 units of space segment utilization. One unit corresponds to one CCIR quality telephony channel transmitted to an earth station with a G/T ratio of at least 40.7 dB/K. For 1976, the rate for a unit of utilization was set at $8,280. The corresponding rate for the lease of a transponder is approximately $3 Million per year. No rate has yet been set for the lease of INTELSAT IV-A transponders. However, since the higher EIRP of these transponders permits the transmission of more channels, it may be assumed that the lease rate will be increased accordingly. A rate of $4 Million per year is estimated.

Western Union has leased transponders to American Satellite Corporation for $1.6 Million per year. It is expected that transponder lease costs in the future will be slightly higher, perhaps $2 Million per year.

In determining a lease rate a communications satellite carrier has to consider the following factors: satellite and launch vehicle costs, satellite lifetime, administrative and other applicable costs, required revenues to cover costs and profits and competitive considerations. At times when a satellite is lightly loaded, a carrier may decide to lease transponders at a lower rate to attract additional traffic. At times when the satellite reaches saturation, the fully allocated costs will normally be used to determine charges.

Domestic K-band transponders are not yet available. A lease rate has been estimated which is higher than that of present C-band transponders, since more bandwidth and power is provided. The estimate for DSCS II transponders has been extrapolated from the commercial lease rates; it is not based on DSCS II program costs.

Table 4-1

Assumed Transponder Lease Rates

| Transponder | Assumed Lease Price (in $ Million Per Year) |
|---|---|
| INTELSAT IV, Global Beam | 3 |
| INTELSAT IV-A, Regional Beam | 4 |
| Domestic, C-Band | 2 |
| Domestic, K-Band | 4 |
| DSCS II, Global Beam | 3 |
| DSCS II, Spot Beam | 4 |

## 4.2 GROUND SEGMENT COSTS

Unless otherwise noted, cost estimates in this section are for standard commercial equipment.

### 4.2.1 Antennas

Antenna cost estimates for 4/6 GHz antennas are based on quotations from various antenna suppliers during the year 1975. Actual quotations were averaged and costs were increased by 10% for inflation up to year end 1976 to obtain the data shown in Table 4-2.

Table 4-2
Antenna Cost Estimates
($1000)

| Antenna Diameter (meters) | Antenna Costs for Quantities of: | | | Comments |
|---|---|---|---|---|
| | 1 | 10 | 50 | |
| 3 | 17 | 16 | 14 | Fiberglass antenna without motor control |
| 4.5 | 21 | 18 | 16 | Fiberglass antenna without motor control |
| 8 | 62 | 54 | 48 | Manual motor control |
| 10 | 80 | 67 | 58 | Manual motor control |
| 11 | 96 | 80 | 70 | Manual motor control |
| 13 | 171 | 155 | 134 | Step track |
| 15 | 360 | 335 | - | Step track |
| 32 | 1400 | - | - | Step track |

4.2.2 Low Noise Amplifiers

These cost estimates are also averaged values from 1975 quotations, to which 10% was added to obtain year end 1976 estimates.

Table 4-3
Cost Estimates for Low Noise Amplifiers
($1000)

| Noise Temperature (K) | Non-Redundant | | Redundant | |
|---|---|---|---|---|
| | Quantity: 1 | 50 | Quantity: 1 | 50 |
| 50 | 29 | 24 | 60 | 51 |
| 55 | 28 | 23 | 58 | 48 |
| 65 | 24 | 21 | 50 | 44 |
| 80 | 19 | 17 | 41 | 35 |
| 90 | 18 | 16 | 39 | 34 |
| 130 | 15 | 13 | 32 | 28 |
| 500 | 4 | 3 | 10 | 7 |

### 4.2.3 High Power Amplifiers

Table 4-4

Cost Estimates for High Power Amplifiers

| Saturated Power Rating | Non-Redundant | | Redundant | |
|---|---|---|---|---|
| | Quantity: 1 | 50 | Quantity: 1 | 50 |
| 25 W TWT | 21 | 16 | 47 | 36 |
| 100 W TWT | 23 | 18 | 52 | 40 |
| 400 W TWT | 35 | 26 | 76 | 58 |
| 600 W TWT | 39 | 30 | 87 | 65 |
| 1200 W TWT | 115 | 90 | 254 | 198 |
| 3000 W TWT | 140 | 110 | 309 | 242 |
| 1500 W Klystron | 47 | 41 | 106 | 90 |
| 3000 W Klystron | 53 | 43 | 115 | 95 |

### 4.2.4 Frequency Converters

Table 4-5

Cost Estimates for Frequency Converters

| Type | Quantity 1 | Quantity 50 |
|---|---|---|
| Double conversion, frequency agile up or down converter | 25 | 21 |
| Single conversion, fixed frequency up or down converter | 14 | 11 |

### 4.2.5 RF Equipment Costs at Higher Frequencies

To find RF component costs at 7/8 and 12/14 GHz, the 4/6 GHz component costs were used and multiplied by a factor of 1.3 to account for smaller commercial production quantities at the higher frequencies. Antennas were compared on the basis of equal diameter. Antenna gains were scaled in accordance with the frequencies.

### 4.2.6 SCPC Equipment Costs

(a) Commercial SCPC Equipment

- Central station with redundant common equipment: $105 K + $6 K per channel

- Remote station with non-redundant common equipment: $ 12 K + $6 K per channel

(b) Mil Spec SCPC Equipment

- Central station with redundant common equipment: $215 K + $12 K per channel

- Remote station with non-redundant common equipment: $ 25 K + $12 K per channel

The above figures are known DCC equipment costs. The prices for Mil Spec equipment were adjusted to remove the cost of Tempest associated hardware which is approximately $3000 per channel. The costs do not include documentation, spare parts or non-recurring development.

The above figures show that equipment constructed to Mil Specs costs about twice as much as commercial equipment. The same factor of 2 will be applied to derive cost estimates for other earth station subsystems constructed to Mil Specs.

### 4.2.7 TDMA Equipment

The cost estimates are for commercial equipment. No redundancy is employed in the remote stations, but the central station is fully redundant except for channel equipment.

The system provides partial demand assignment. Each station transmits on all its channel units at all times, but the destination of each channel can be changed on demand. Channel assignment is controlled through a common signaling channel.

- Central station: $340 K + $2.4 K per channel
- Remote station: $124 K + $2.4 K per channel

### 4.2.8 PSK-FDMA Equipment

This system also provides partial demand assignment. Each station transmits one carrier with the allocated number of channels at all times. The destination of each channel can be changed on demand. A separate receive chain is required for each link. Redundancy is provided only at the central station.

- Central Station

| | |
|---|---|
| Transmit Link | \$ 45 K + \$1.0 K per channel |
| Receive Link | \$ 29 K + \$1.7 K per channel |
| Common Equipment | \$ 55 K |

- Remote Station

| | |
|---|---|
| Transmit Link | \$ 20 K + \$1.0 K per channel |
| Receive Link | \$ 29 K + \$1.7 K per channel |
| Common Equipment | \$ 25 K |

## 4.3 COST MODEL

The system optimization for each application will be based on minimum costs. Since space segment costs are expressed in annual lease costs, the earth station investment costs have to be converted to annual costs as well. System optimization will then be based on minimum annual systems costs.

Annual earth station costs will be estimated on the following basis:

(a) Depreciation

An average equipment life of 10 years will be assumed. The annual straight line depreciation therefore, will be 10% of initial equipment costs.

(b) Cost of Money

Cost of money is normally included in the calculation of the annual earth station costs. It is applied to the undepreciated portion of the earth station investment. Assuming a 10% cost of money, the average cost of money over the equipment life will be 5% without applying a present value factor.

(c) Replacement Parts

It will be assumed that the annual cost for replacement parts will be 3% of the initial equipment cost.

(d) Operating Costs

Operating costs are assumed to be proportional to complexity and therefore, cost of the equipment. It will be assumed that operating costs are 10% per year of initial equipment costs.

Based on the above considerations, annual earth station costs are assumed to be 28% of initial equipment costs.

# Section 5
# SYSTEMS OPTIMIZATION

In this section, the optimum systems configuration was determined for each combination of traffic model, satellite type and access technique. The study was limited to the use of a single transponder to satisfy traffic requirements.

## 5.1 SPACE SEGMENT COSTS VERSUS EARTH STATION G/T

The annual space segment cost was determined for each traffic model, satellite type and access technique as a function of earth station G/T. Where a model uses less than a full transponder, the cost allocation was made in proportion to the fraction of transponder power or bandwidth that was used. Bandwidth ratios were used in all bandwidth limited cases and power ratios were used in the power limited cases.

### 5.1.1 PSK-SCPC System

This system provides full demand assignment. Channels are transmitted only when required by traffic. In the power limited cases, the capacity was determined on the basis of satisfying the total Erlang load of the system with a probability of blocking of 0.01. Space segment channel requirements are summarized below:

| Traffic Model | Low Capacity | Medium Capacity | High Capacity |
|---|---|---|---|
| Number of channel units | 80 | 219 | 1100 |
| Erlang load | 19 | 133 | 492 |
| Space segment channels | 29 | 152 | 518 |

Transponder capacities versus G/T and annual space segment costs for the three traffic models are shown in Tables 5-1 through 5-6.

Table 5-1
Annual Space Segment Costs ($1000)
SCPC-DSCS II Global Beam (50 MHz)
($3 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 19 | -- | -- | -- |
| 14 | 31 | 2806 | -- | -- |
| 16 | 49 | 1771 | -- | -- |
| 18 | 78 | 1117 | -- | -- |
| 20 | 123 | 705 | -- | -- |
| 22 | 195 | 445 | 2339 | -- |
| 24 | 309 | 281 | 1476 | -- |
| 26 | 490 | 177 | 931 | -- |
| 28 | 776 | 112 | 587 | 2002 |
| 30 | 1230 | 70 | 371 | 1263 |
| 32 | 1950 | 45 | 234 | 797 |
| 34 | 2000 | 44 | 229 | 777 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-2
Annual Space Segment Costs ($1000)
SCPC-DSCS II Spot Beam (50 MHz)
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 617 | 188 | 986 | 3360 |
| 14 | 977 | 119 | 622 | 2120 |
| 16 | 1549 | 75 | 393 | 1338 |
| 18 | 2000 | 58 | 304 | 1036 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-3
Annual Space Segment Costs ($1000)
SCPC-Domestic Satellite, C-Band
($2 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 309 | 188 | 984 | -- |
| 14 | 490 | 118 | 621 | -- |
| 16 | 776 | 75 | 392 | 1335 |
| 18 | 1230 | 47 | 247 | 842 |
| 20 | 1440 | 40 | 211 | 719 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-4
Annual Space Segment Costs ($1000)
SCPC-Domestic Satellite, K-Band
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 55 | 2111 | -- | -- |
| 14 | 87 | 1332 | -- | -- |
| 16 | 138 | 840 | -- | -- |
| 18 | 219 | 530 | 2779 | -- |
| 20 | 347 | 335 | 1753 | -- |
| 22 | 550 | 211 | 1106 | 3770 |
| 24 | 871 | 133 | 698 | 2379 |
| 26 | 1380 | 84 | 440 | 1501 |
| 28 | 2160 | 54 | 281 | 959 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-5
Annual Space Segment Costs ($1000)
SCPC-INTELSAT IV Global Beam
($3 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 25 | -- | -- | -- |
| 14 | 39 | 2236 | -- | -- |
| 16 | 62 | 1411 | -- | -- |
| 18 | 98 | 890 | -- | -- |
| 20 | 155 | 562 | 2944 | -- |
| 22 | 245 | 354 | 1858 | -- |
| 24 | 389 | 224 | 1172 | -- |
| 26 | 617 | 141 | 740 | 2520 |
| 28 | 977 | 89 | 467 | 1590 |
| 30 | 1440 | 60 | 317 | 1079 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-6
Annual Space Segment Costs ($1000)
SCPC-INTELSAT IV-A Regional Coverage
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 123 | 943 | -- | -- |
| 14 | 195 | 595 | 3118 | -- |
| 16 | 309 | 375 | 1967 | -- |
| 18 | 490 | 237 | 1241 | -- |
| 20 | 776 | 149 | 783 | 2669 |
| 22 | 1230 | 94 | 494 | 1684 |
| 24 | 1440 | 81 | 422 | 1439 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

### 5.1.2 TDM-PSK-FDMA System

This system provides only partial demand assignment. It provides a variable destination capability for all channels, but all channels from all earth stations are always transmitted, regardless of instantaneous traffic requirement. Thus, the required space segment capacity equals the total number of channel units in the system. Transponder channel capacities and space segment costs for the three traffic models as a function of earth station G/T are shown in Tables 5-7 through 5-12.

Table 5-7
Annual Space Segment Costs ($1000)
TDM-PSK - DSCS II Global Beam (50 MHz)
($3 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 8 | -- | -- | -- |
| 14 | 12 | -- | -- | -- |
| 16 | 19 | -- | -- | -- |
| 18 | 31 | -- | -- | -- |
| 20 | 49 | -- | -- | -- |
| 22 | 78 | -- | -- | -- |
| 24 | 123 | 1945 | -- | -- |
| 26 | 195 | 1227 | -- | -- |
| 28 | 309 | 774 | 2127 | -- |
| 30 | 490 | 489 | 1342 | -- |
| 32 | 776 | 308 | 847 | -- |
| 34 | 1230 | 194 | 534 | 2682 |
| 36 | 1950 | 123 | 337 | 1692 |
| 38 | 2000 | 121 | 330 | 1650 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-8

Annual Space Segment Costs ($1000)

TDM-PSK - DSCS II Spot Beam (50 MHz)

($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 245 | 1305 | 3569 | -- |
| 14 | 389 | 822 | 2252 | -- |
| 16 | 617 | 519 | 1421 | -- |
| 18 | 977 | 328 | 896 | -- |
| 20 | 1549 | 207 | 566 | 2841 |
| 22 | 2000 | 160 | 438 | 2200 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-9
Annual Space Segment Costs ($1000)
TDM-PSK - Domestic Satellite, C-Band
($2 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 123 | 1299 | -- | -- |
| 14 | 195 | 819 | -- | -- |
| 16 | 309 | 519 | 1418 | -- |
| 18 | 490 | 326 | 895 | -- |
| 20 | 776 | 207 | 565 | -- |
| 22 | 1230 | 130 | 356 | 1788 |
| 24 | 1440 | 110 | 304 | 1527 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-10
Annual Space Segment Costs ($1000)
TDM-PSK - Domestic Satellite, K-Band
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 22 | -- | -- | -- |
| 14 | 35 | -- | -- | -- |
| 16 | 55 | -- | -- | -- |
| 18 | 87 | 3674 | -- | -- |
| 20 | 138 | 2317 | -- | -- |
| 22 | 219 | 1462 | 4000 | -- |
| 24 | 347 | 924 | 2526 | -- |
| 26 | 550 | 582 | 1594 | -- |
| 28 | 871 | 367 | 1006 | -- |
| 30 | 1380 | 232 | 634 | 3187 |
| 32 | 2160 | 149 | 405 | 2036 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-11
Annual Space Segment Costs ($1000)
TDM-PSK - INTELSAT IV Global Beam
($3 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 10 | -- | -- | -- |
| 14 | 15 | -- | -- | -- |
| 16 | 25 | -- | -- | -- |
| 18 | 39 | -- | -- | -- |
| 20 | 62 | -- | -- | -- |
| 22 | 98 | 2455 | -- | -- |
| 24 | 155 | 1550 | -- | -- |
| 26 | 245 | 977 | 2677 | -- |
| 28 | 389 | 618 | 1689 | -- |
| 30 | 617 | 389 | 1066 | -- |
| 32 | 977 | 246 | 673 | -- |
| 34 | 1440 | 166 | 457 | 2291 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

Table 5-12

Annual Space Segment Costs ($1000)

TDM-PSK - INTELSAT IV-A Regional Coverage

($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 49 | -- | -- | -- |
| 14 | 78 | -- | -- | -- |
| 16 | 123 | 2601 | -- | -- |
| 18 | 195 | 1641 | -- | -- |
| 20 | 309 | 1034 | 2834 | -- |
| 22 | 490 | 654 | 1788 | -- |
| 24 | 776 | 411 | 1128 | -- |
| 26 | 1230 | 259 | 712 | 3576 |
| 28 | 1440 | 223 | 608 | 3056 |

Note: Transponder capacities are based on formulas given in section 3; space segment costs are based on transponder lease rates shown in Table 4-1.

### 5.1.3 TDM-PSK-TDMA System

With this system, it is normally assumed that the total power of a transponder is available to the TDMA system. In this case, the space segment cost is equal to the transponder lease rates as shown in Table 4-1.

However, it is also possible to share the transponder between the TDMA system and other services, although this requires careful study of the resulting interference between the systems. This case is only included for completeness; it is not considered promising, since channel capacities are lower and earth station equipment costs are higher than in the SCPC case.

Channel capacity per transponder is calculated as follows:

$$10 \log n = EIRP_S - BO_o - PL_D + \left(\frac{G}{T}\right)_E - y - M_I - \left(\frac{C}{N_o}\right)_R - k - \Delta M$$

where:

$y$ = degradation of down-link C/N due to up-link and intermodulation noise; an average value of 3 dB* is expected for this mode of operation

$M_I$ = equivalent degradation of C/N due to intersymbol distortion; an average value of 3 dB** is expected for this mode of operation.

---

* This value is higher than that used for SCPC, since TDMA requires a larger backoff to reduce intersymbol distortion and adjacent transponder interference due to spectrum spreading. An input backoff of at least 4 dB is required for TDMA.

** SCPC does not suffer from this degradation due to the low bit rate and small bandwidth used for each carrier.

$\Delta M$ = additional margin at frequencies above 4 GHz; 1.5 dB was used for DSCS II and 3 dB for K-band operation.

Other quantities are as defined in section 3.3.

For the bandwidth limited case, the capacity is given by

$$n = \frac{\text{Transponder bandwidth in kHz}}{25}$$

For the power limited case, the following relationship was derived, based on the above formula:

<u>DSCS II, Global Beam</u>

$$10 \log n = -8.6 + \left(\frac{G}{T}\right)_E$$

<u>DSCS II, Spot Beam</u>

$$10 \log n = 6.4 + \left(\frac{G}{T}\right)_E$$

<u>Domestic Satellite, C-Band</u>

$$10 \log n = 3.4 + \left(\frac{G}{T}\right)_E$$

<u>Domestic Satellite, K-Band</u>

$$10 \log n = -4.1 + \left(\frac{G}{T}\right)_E$$

<u>INTELSAT IV, Global Beam</u>

$$10 \log n = -7.6 + \left(\frac{G}{T}\right)_E$$

INTELSAT IV-A, Regional Beam

$$10 \log n = -0.6 + \left(\frac{G}{T}\right)_E$$

Channel capacities and space segment costs for this mode of operation are shown in Tables 5-13 through 5-18.

Table 5-13
Annual Space Segment Costs ($1000)
TDM-PSK-TDMA-FDMA
DSCS II, Global Beam (50 MHz)
($3 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 26 | 55 | -- | -- | -- |
| 28 | 87 | 2756 | -- | -- |
| 30 | 138 | 1739 | -- | -- |
| 32 | 219 | 1097 | -- | -- |
| 34 | 347 | 692 | 1895 | -- |
| 36 | 550 | 437 | 1196 | -- |
| 38 | 871 | 276 | 754 | -- |
| 40 | 1380 | 174 | 476 | |

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-14
Annual Space Segment Costs ($1000)
TDM-PSK-TDMA-FDMA
DSCS II Spot Beam (50 MHz)
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 12 | 69 | -- | -- | -- |
| 14 | 110 | 2918 | -- | -- |
| 16 | 174 | 1841 | -- | -- |
| 18 | 275 | 1162 | 3181 | -- |
| 20 | 437 | 733 | 2007 | -- |
| 22 | 692 | 463 | 1266 | -- |
| 24 | 1096 | 292 | 799 | -- |
| 26 | 1738 | 184 | 504 | 2532 |
| 28 | 2000 | 160 | 438 | 2200 |

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-15
Annual Space Segment Costs ($1000)
TDM-PSK-TDMA-FDMA
Domestic Satellite, C-Band
($2 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 18 | 138 | 1159 | -- | -- |
| 20 | 219 | 731 | -- | -- |
| 22 | 347 | 461 | 1262 | -- |
| 24 | 550 | 291 | 796 | -- |
| 26 | 871 | 184 | 503 | -- |
| 28 | 1380 | 116 | 317 | -- |
| 30 | 1440 | 111 | 304 | -- |

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-16
Annual Space Segment Costs ($1000)
TDM-PSK-TDMA-FDMA
Domestic Satellite, K-Band
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 26 | 155 | 2066 | -- | -- |
| 28 | 245 | 1304 | -- | -- |
| 30 | 389 | 823 | 2252 | -- |
| 32 | 617 | 519 | 1421 | -- |
| 34 | 977 | 327 | 897 | -- |
| 36 | 1549 | 207 | 566 | 2841 |
| 38 | 2160 | 148 | 406 | 2037 |

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-17
Annual Space Segment Costs ($1000)
TDM-PSK-TDMA-FDMA
INTELSAT IV - Global Beam
($3 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 28 | 110 | 2182 | -- | -- |
| 30 | 174 | 1377 | -- | -- |
| 32 | 275 | 869 | 2389 | -- |
| 34 | 437 | 548 | 1507 | -- |
| 36 | 692 | 346 | 951 | -- |
| 38 | 1096 | 218 | 600 | -- |
| 40 | 1440 | 167 | 456 | -- |

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

Table 5-18
Annual Space Segment Costs ($1000)
TDM-PSK-TDMA-FDMA
INTELSAT IV-A - Regional Coverage
($4 M per Transponder)

| G/T | Transponder Capacity | Space Segment Costs for | | |
|---|---|---|---|---|
| | | Low Cap. Model | Med. Cap. Model | High Cap. Model |
| 22 | 138 | 2318 | -- | -- |
| 24 | 219 | 1463 | -- | -- |
| 26 | 347 | 923 | 2524 | -- |
| 28 | 550 | 582 | 1593 | -- |
| 30 | 871 | 367 | 1005 | -- |
| 32 | 1380 | 232 | 634 | -- |
| 34 | 1440 | 146 | 608 | -- |

Note: Channel capacities are calculated with formulas shown in section 5.1.3; space segment costs are based on transponder lease rates given in Table 4-1.

## 5.2 LNR, HPA AND ANTENNA COMBINATIONS

In configuring an earth station, different combinations of antenna diameter and LNR noise temperature can be considered to obtain the lowest cost combination for a given G/T. Different combinations of antenna diameter and HPA power will produce a given earth station EIRP. The antenna diameter may also determine whether or not tracking is required. The EIRP requirement for the earth station depends on the satellite transponder gain, on the number of channels transmitted and on the G/T of the receive earth station. All these factors have been considered in steps so as to obtain an understanding of the essential relationships.

### 5.2.1 Minimum Cost G/T Combinations

The receive *figure of merit* for earth terminals, the gain-to-noise temperature ratio, is calculated from antenna gain, antenna noise temperature, transmission line losses and receiver noise temperature. The receive antenna gain was based on an efficiency of 60%. The antenna noise temperature is assumed to be 30 K and the transmission line losses are assumed to introduce a loss of 20 K. G/T as a function of antenna diameter and receiver noise temperature is shown in Table 5-19. Quantities of 50 units are assumed. All equipment is non-redundant. The trade-off is performed for a receive frequency of 4 GHz, using commercial equipment.

Antenna gain is calculated as follows:

$$G = 10 \log \eta \frac{D^2 \pi^2}{\lambda^2}$$

where:

$G$ = antenna gain in dB
$\eta$ = efficiency, assumed to be 60%
$D$ = antenna diameter in m
$\lambda$ = wavelength in m; at 4 GHz, $\lambda = 0.075$ m

This formula can be written as:

$$G = 30.2 + 20 \log D$$

The information of Table 5-19 has been plotted in Figure 5-1 to find the lowest cost combinations of antennas and receivers for a given G/T, for the discreet values of noise temperature and antenna gains shown in Section 4.

Figures 5-2 and 5-3 show a continuous plot of antenna cost versus antenna gain and receiver cost versus total systems noise temperature. From this information, the curves in Figure 5-4 have been plotted from which the following lowest cost combination of antenna gain and receiver noise temperature have been developed:

Table 5-19

G/T Versus Antenna Diameter and Receiver Noise Temperature

(at 4 GHz)

| Antenna Diameter (m) | | 3 | 4.5 | 8 | 10 | 11 | 13 | 15 | 32 |
|---|---|---|---|---|---|---|---|---|---|
| Gain (dB) | | 39.7 | 43.3 | 48.3 | 50.2 | 51.0 | 52.5 | 53.7 | 60.3 |
| Cost ($1000) | | 14 | 16 | 48 | 58 | 70 | 134 | 360* | 1400* |
| Receiver** Temperature (K) | Cost ($1000) | | | | | | | | |
| 50 | 24 | 19.7 | 23.3 | 28.3 | 30.2 | 31 | 32.5 | 33.7 | 40.3 |
| 55 | 23 | 19.5 | 23.1 | 28.1 | 30.0 | 30.8 | 32.3 | 33.5 | 40.1 |
| 65 | 21 | 19.1 | 22.7 | 27.7 | 29.6 | 30.4 | 31.9 | 33.1 | 39.7 |
| 80 | 17 | 18.6 | 22.2 | 27.2 | 29.1 | 29.9 | 31.4 | 32.6 | 39.2 |
| 90 | 16 | 18.2 | 21.8 | 26.8 | 28.7 | 29.5 | 31.0 | 32.2 | 38.8 |
| 130 | 13 | 17.1 | 20.7 | 25.7 | 27.6 | 28.4 | 29.9 | 31.1 | 37.7 |
| 500 | 3 | 12.3 | 15.9 | 20.9 | 22.8 | 23.6 | 25.1 | 26.3 | 32.9 |

* Quantity of 1

**Receiving system noise temperature is 50 K higher

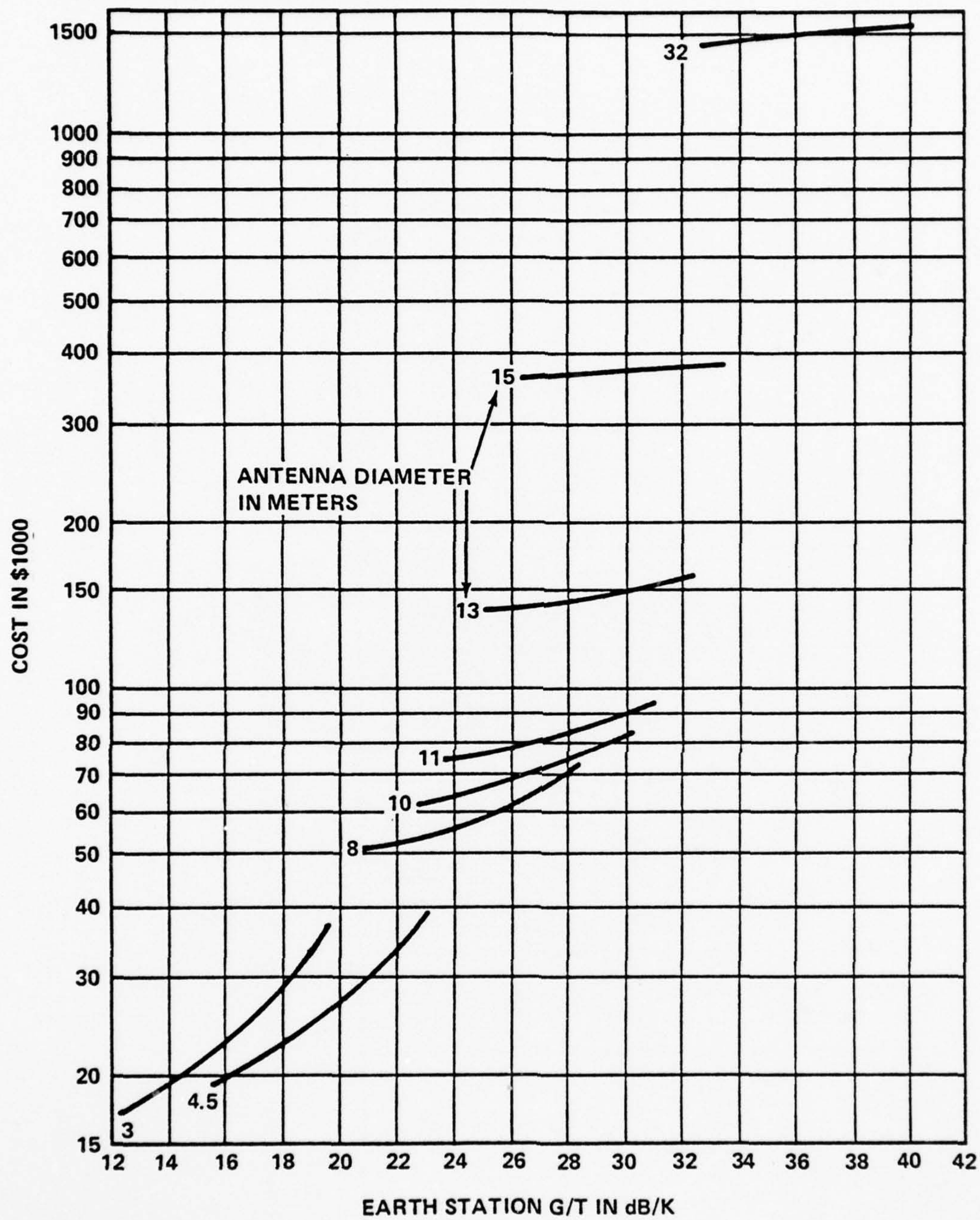



FIGURE 5–1

COST VERSUS EARTH STATION G/T

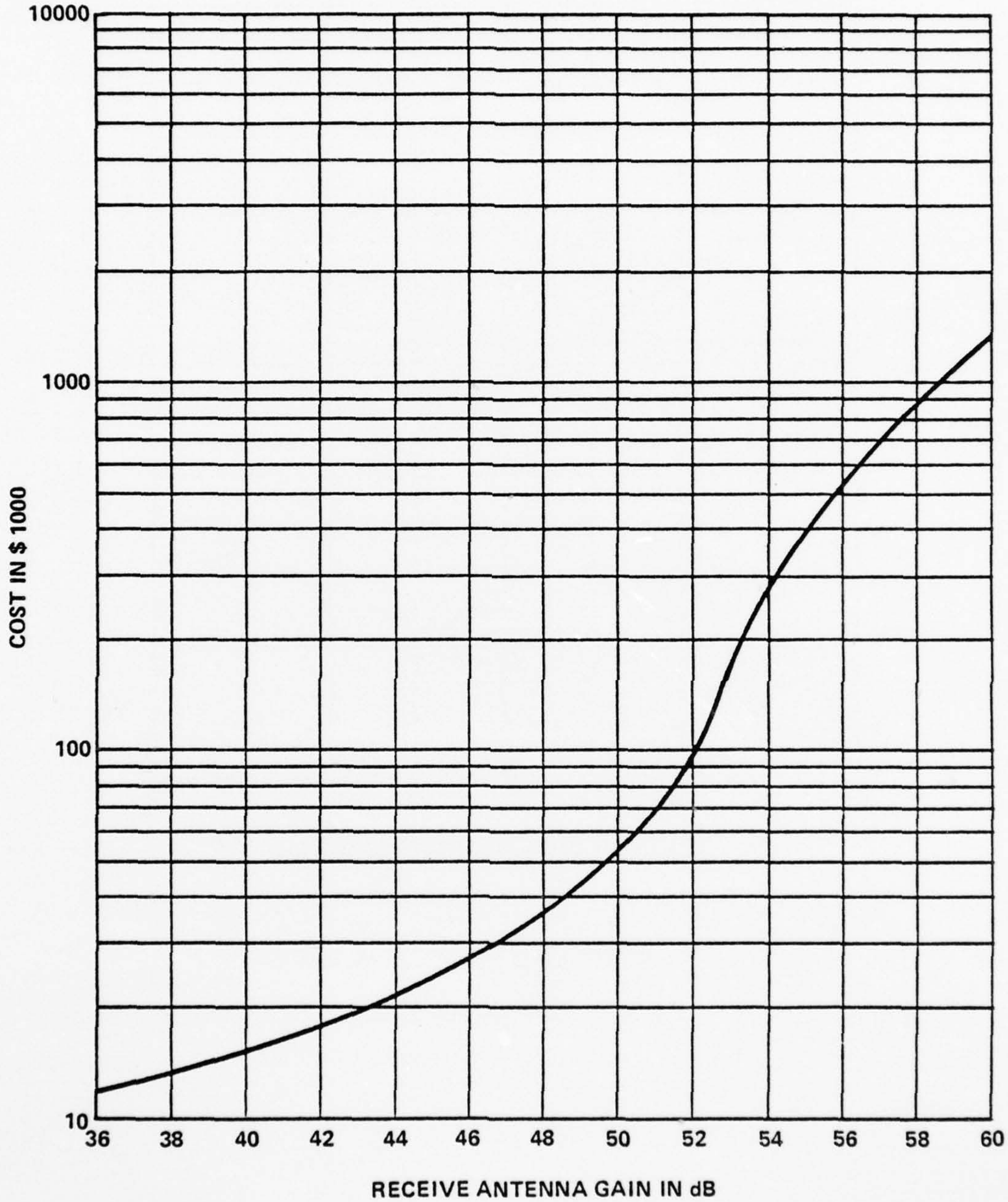



FIGURE 5–2

ANTENNA COST VERSUS ANTENNA GAIN

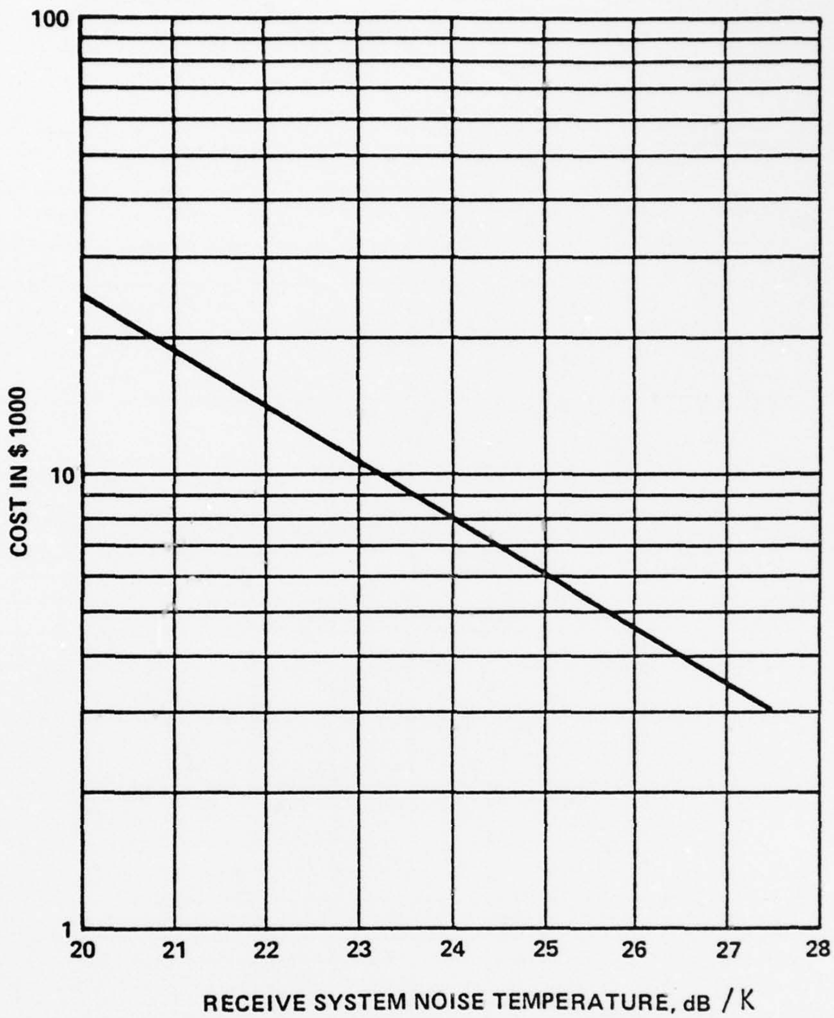



FIGURE 5–3

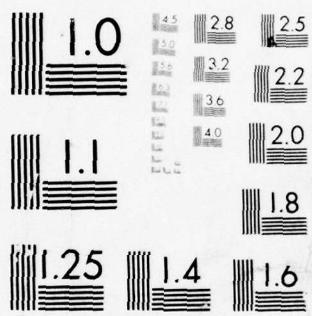
LOW NOISE RECEIVER COST
VERSUS SYSTEM NOISE TEMPERATURE

AD-A043 352 DIGITAL COMMUNICATIONS CORP GAITHERSBURG MD F/G 17/2
COMMUNICATIONS SYSTEMS MODELING STUDY.(U)
NOV 76 R STAMMIGER, W L PRITCHARD

UNCLASSIFIED NL

2 OF 2
AD
A043 352

END
DATE
FILMED
9-77
DDC




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

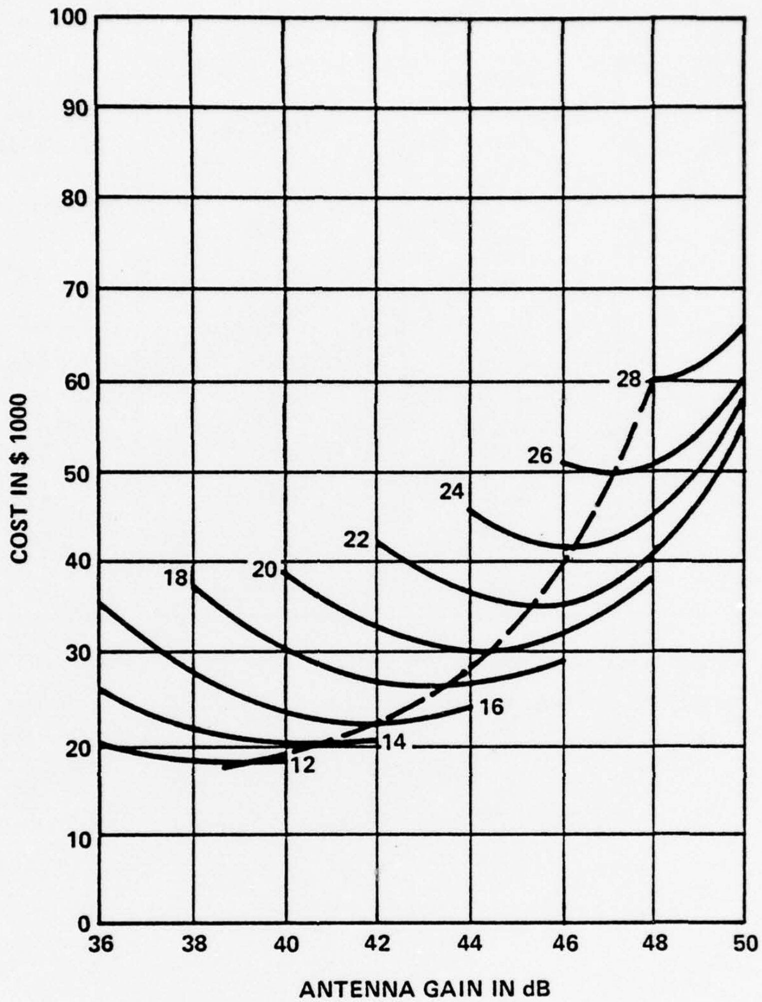



FIGURE 5–4

MINIMUM COST FOR DIFFERENT VALUES OF G/T

| G/T | Antenna Gain (dB) | Antenna Diameter (m) | Receiver* Noise Temperature (K) | Cost of Antenna/ Receiver Combination ($1000) |
|---|---|---|---|---|
| 12 | 39 | 2.8 | 450 | 17.5 |
| 14 | 41 | 3.5 | 450 | 20.0 |
| 16 | 42 | 3.9 | 350 | 22.0 |
| 18 | 43.5 | 4.6 | 300 | 26.0 |
| 20 | 44.5 | 5.2 | 230 | 30.0 |
| 22 | 45.5 | 5.8 | 170 | 35.0 |
| 24 | 46 | 6.2 | 108 | 42.0 |
| 26 | 47 | 6.9 | 75 | 50.0 |
| 28 | 48 | 7.8 | 50 | 60.0 |

Higher G/T ratios are always obtained by using the receiver with the lowest noise temperature.

* The receiving system noise temperature is higher by 50 K, as described in section 5.2.1.

### 5.2.2 Minimum Cost EIRP at 6 GHz

Single carrier saturated EIRP will be determined for different antenna/HPA combinations in order to find the combinations with the lowest cost for a given EIRP. A loss of 2 dB will be assumed between HPA output and antenna.

Costs of HPAs are plotted in Figure 5-5. Minimum cost for a given EIRP is plotted in Figure 5-6. Cost is plotted versus transmit antenna gain minus line losses. For EIRPs above 80 dBW the minimum cost solution would require an HPA with more than 3 kW. For lower values of EIRP, the optimum combinations are shown below:

| EIRP (dBW) | Antenna Gain (dB) | Antenna Diameter (m) | HPA Power (Watts) | Cost ($1000) |
|---|---|---|---|---|
| 48 | 38 | 2.1 | 10 | 25 |
| 52 | 39 | 2.3 | 20 | 27.5 |
| 56 | 40 | 2.6 | 40 | 30 |
| 60 | 41 | 2.9 | 80 | 34 |
| 64 | 42 | 3.3 | 160 | 39 |
| 68 | 43 | 3.7 | 320 | 44 |
| 72 | 44 | 4.1 | 640 | 50 |
| 76 | 45 | 4.6 | 1300 | 57 |
| 80 | 47 | 5.8 | 2000 | 65 |

Since the minimum cost is achieved with relatively large power levels and small antenna diameters, the selection of the antenna diameter will generally be determined by the G/T requirement.

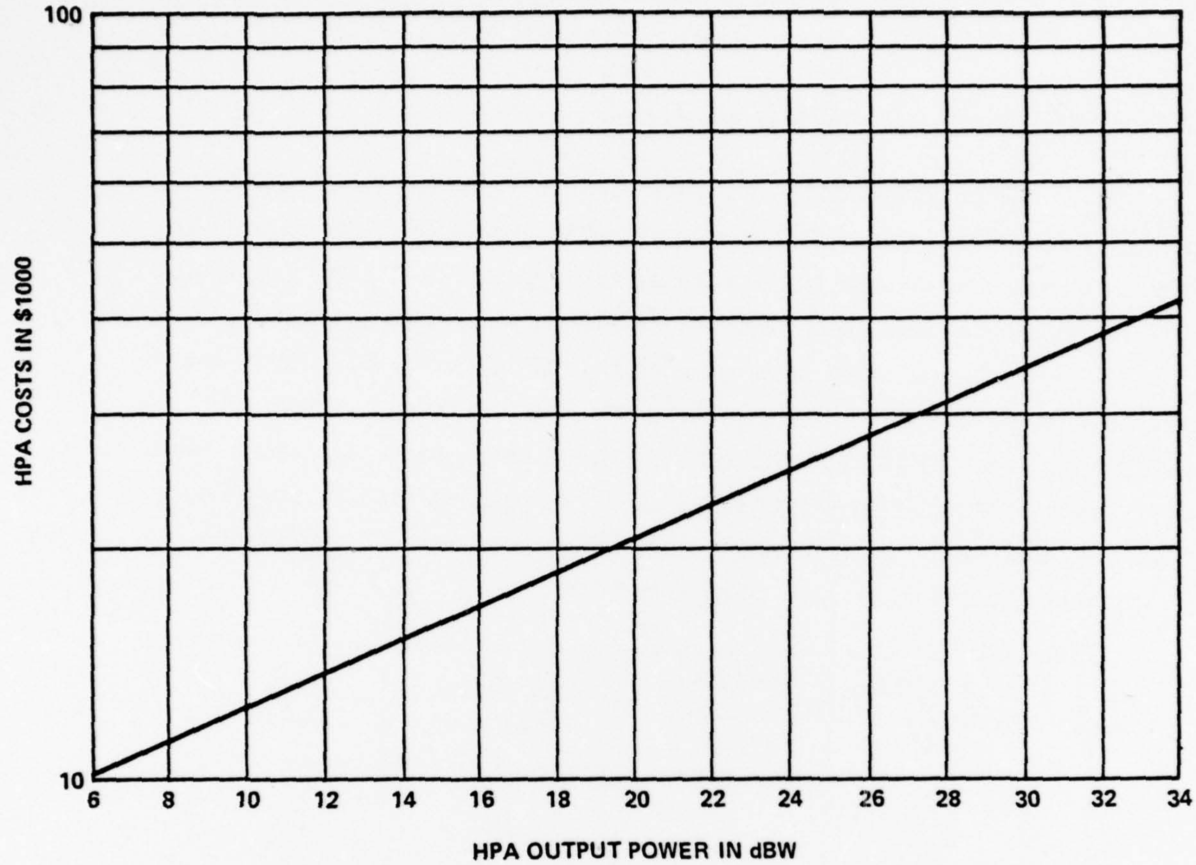



FIGURE 5–5

HPA COST VERSUS OUTPUT POWER
AT 6 GHz

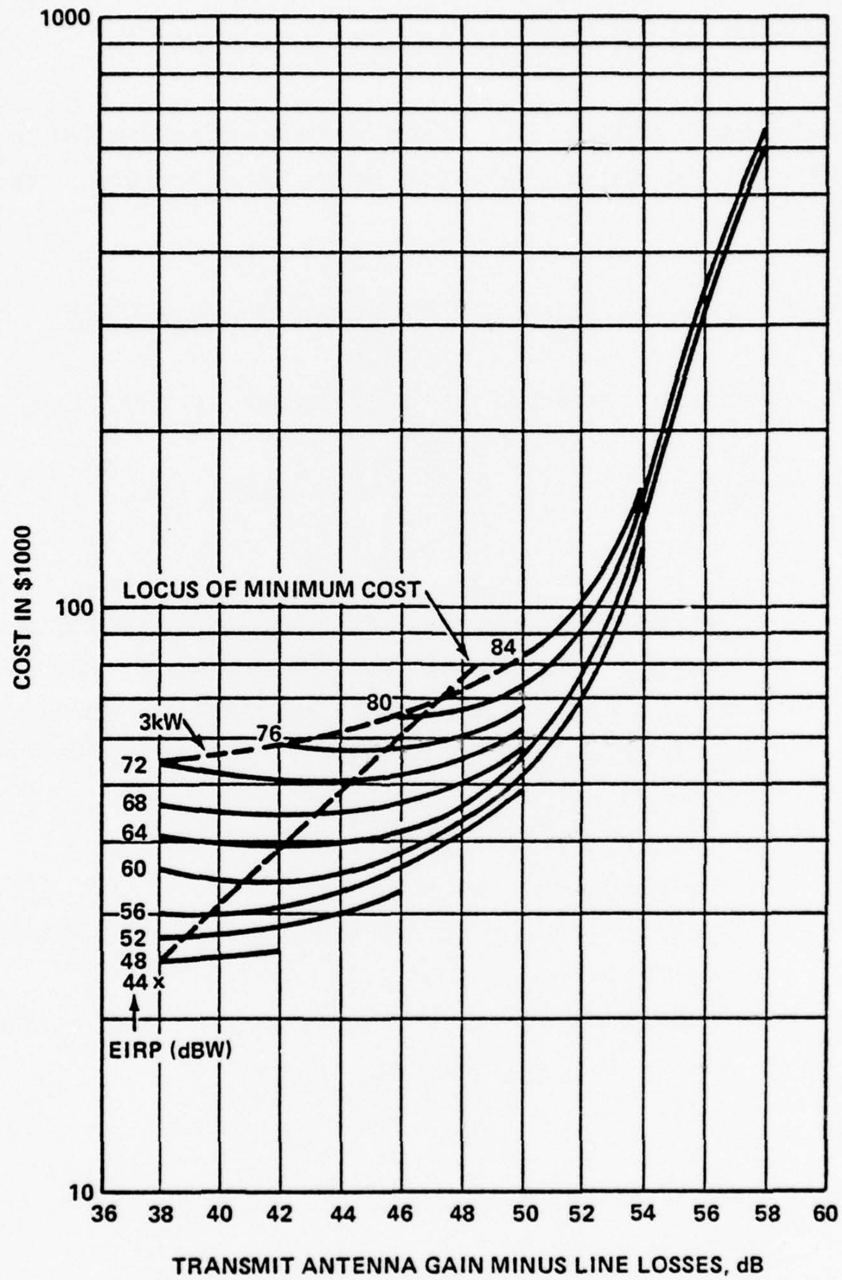



FIGURE 5–6

MINIMUM COST FOR EIRP
AT 6 GHz

## 5.3 SYSTEMS OPTIMIZATION FOR SCPC TRANSMISSION

In this section, the optimum configuration of an SCPC system will be determined for each traffic model and each satellite type.

### 5.3.1 Earth Station EIRP and RF Power Requirements

RF power per channel is calculated as follows:

$$P_c = W_s - G_{m^2} - BO_I - 10 \log n + PL_u - G_T$$

where:

$P_c$ = average RF power per channel at HPA output, dBW

$W_s$ = transponder saturation flux density, $dBW/m^2$

$G_{m^2}$ = gain of one square meter at up-link frequency;
at 6 GHz, $G_{m^2}$ = 37.0 dB,
at 8 GHz, $G_{m^2}$ = 39.5 dB,
at 14 GHz, $G_{m^2}$ = 44.4 dB

$BO_I$ = transponder input back-off

n = number of channels per transponder (transponder capacity)

$PL_u$ = pathloss at up-link frequency; at 30° elevation,
6 GHz, $PL_u$ = 199.7 dB,
8 GHz, $PL_u$ = 202.2 dB,
14 GHz, $PL_u$ = 207.1 dB

$G_t$ = net transmit antenna gain (antenna gain minus line losses).

The power per channel as calculated with this formula is shown in Table 5-20.

Table 5-20
Earth Station HPA Power per Channel
for SCPC Transmission

| Satellite | $W_s$ ($dBW/m^2$) | G/T (dB/K) | n | $BO_I$ (dB) | G (dB) | $P_c$ (Watts) |
|---|---|---|---|---|---|---|
| Domsat C-Band EIRP = 33 dBW | -83 | 12 | 309 | 3 | 40.4 | 13.5 |
| | | 14 | 490 | 3 | 42.5 | 5.4 |
| | | 16 | 776 | 3 | 43.5 | 2.7 |
| | | 18 | 1230 | 3 | 45 | 1.2 |
| | | 20 | 1440 | 3 | 46 | 0.8 |
| | | 22 | 1440 | 4 | 47 | 0.5 |
| | | 24 | 1440 | 6 | 47.5 | 0.3 |
| | | 26 | 1440 | 8 | 58.5 | 0.15 |
| | | 28 | 1440 | 9 | 49.5 | 0.09 |
| | | 30 | 1440 | 10 | 51.5 | 0.05 |
| INTELSAT IV Global Beam EIRP = 22 dBW | -73 | 14 | 39 | 3 | 42.5 | 675 |
| | | 16 | 62 | 3 | 43.5 | 337 |
| | | 18 | 98 | 3 | 45 | 150 |
| | | 20 | 155 | 3 | 46 | 76 |
| | | 22 | 245 | 3 | 47 | 38 |
| | | 24 | 389 | 3 | 47.5 | 21 |
| | | 26 | 617 | 3 | 48.5 | 11 |
| | | 28 | 977 | 3 | 49.5 | 5.4 |
| | | 30 | 1440 | 3 | 51.5 | 2.3 |
| | | 32 | 1440 | 4 | 53.5 | 1.2 |

(Continued)

Table 5-20
Earth Station HPA Power per Channel
for SCPC Transmission (continued)

| Satellite | $W_s$ (dBW/m$^2$) | G/T (dB/K) | n | $BO_I$ (dB) | G (dB) | $P_c$ (Watts) |
|---|---|---|---|---|---|---|
| | | 12 | 123 | 3 | 40.5 | 214 |
| | | 14 | 195 | 3 | 42.5 | 85 |
| INTELSAT IV-A | | 16 | 309 | 3 | 43.5 | 43 |
| Regional Coverage | | 18 | 490 | 3 | 45 | 19 |
| | -75 | 20 | 776 | 3 | 46 | 10 |
| | | 22 | 1230 | 3 | 47 | 4.8 |
| EIRP = 29 dBW | | 24 | 1440 | 3.5 | 47.5 | 3.2 |
| | | 26 | 1440 | 4.5 | 48.5 | 2.0 |
| | | 28 | 1440 | 6 | 49.5 | 1.2 |
| | | 30 | 1440 | 8 | 51.5 | 0.5 |
| | | 32 | 1440 | 9 | 53.5 | 0.2 |
| | | 12 | 55 | 3 | 37 | 170 |
| | | 14 | 87 | 3 | 39 | 68 |
| Domsat | | 16 | 138 | 3 | 41 | 27 |
| K-Band | | 18 | 219 | 3 | 43 | 11 |
| | -83 | 20 | 347 | 3 | 45 | 4.3 |
| EIRP = 38 dBW | | 22 | 550 | 3 | 47 | 1.7 |
| | | 24 | 871 | 3 | 49 | 0.7 |
| | | 26 | 1380 | 3.5 | 51 | 0.24 |
| | | 28 | 2160 | 4.5 | 53 | 0.08 |
| | | 30 | 2160 | 6 | 55 | 0.03 |
| | | 32 | 2160 | 8 | 57 | 0.014 |
| | | 34 | 2160 | 9 | 59 | 0.007 |

(continued)

Table 5-20
Earth Station HPA Power per Channel
for SCPC Transmission (continued)

| Satellite | $W_s$ (dBW/m$^2$) | G/T (dB/K) | n | $BO_I$ (dB) | G (dB) | $P_c$ (Watts) |
|---|---|---|---|---|---|---|
| DSCS II Global Beam EIRP = 28 dBW 115 dB gain | -78 | 14 | 49 | 3 | 39 | 600 |
| | | 16 | 49 | 3 | 41 | 240 |
| | | 18 | 78 | 3 | 43 | 95 |
| | | 20 | 123 | 3 | 45 | 38 |
| | | 22 | 195 | 3 | 47 | 15 |
| | | 24 | 309 | 3 | 48 | 7.6 |
| | | 26 | 490 | 3 | 50 | 3.0 |
| | | 28 | 776 | 3 | 52 | 1.2 |
| | | 30 | 1230 | 3.5 | 54 | 0.4 |
| | | 32 | 1950 | 4.5 | 56 | 0.13 |
| | | 34 | 2000 | 6 | 57 | 0.07 |
| | | 36 | 2000 | 8 | 59 | 0.03 |
| DSCS II Spot Beam EIRP = 43 dBW 105 dB gain | | 12 | 617 | 3 | 37 | 12.1 |
| | | 14 | 977 | 3.5 | 39 | 4.3 |
| | | 16 | 1549 | 4.5 | 41 | 1.4 |
| | | 18 | 2000 | 6 | 43 | 0.5 |
| | | 20 | 2000 | 8 | 45 | 0.19 |
| | | 22 | 2000 | 9 | 47 | 0.09 |
| | | 24 | 2000 | 10 | 48 | 0.059 |
| | | 26 | 2000 | 11 | 50 | 0.030 |
| | | 28 | 2000 | 12 | 52 | 0.015 |
| | | 30 | 2000 | 12 | 54 | 0.009 |
| | | 32 | 2000 | 12 | 56 | 0.006 |

For the calculation of earth station transmit power requirements for different G/T ratios at K-band, it was necessary to define the relationship between G/T and transmit antenna gain. This was based on the SBS filing with the FCC where 5-meter antennas are used with a receiving system noise temperature at 12 GHz of 225 K. This system noise temperature was used for all G/T ratios in the study. It is expected, however, that detailed optimization at these frequencies will also result in higher noise temperature at very low G/T ratios and lower noise temperatures at higher G/T ratios.

For operation with DSCS II, system noise temperatures shown in Table 5-21 were calculated. Earth station characteristics are taken from Table 2-9.

Table 5-21
DSCS II Earth Station Characteristics

| Antenna Diameter (feet) | Antenna Diameter (meters) | G/T (dB/K) | G (dB) | T (dB) | T (K) |
|---|---|---|---|---|---|
| 4 | 1.2 | 12 | 37.3 | 25.3 | 340 |
| 8 | 2.4 | 18 | 43.3 | 25.3 | 340 |
| 18 | 5.5 | 26.5 | 50.5 | 24.0 | 250 |
| 40 | 12.2 | 34 | 57.4 | 23.4 | 220 |
| 60 | 18.3 | 39 | 60.9 | 21.9 | 155 |

$$G = 10 \log \eta \frac{D^2 \pi^2}{\lambda^2} = 35.7 + 20 \log D$$

$\eta = 60\%$

$\lambda = 4$ cm

The transmit power levels calculated in this section are based on the total channel capacity of the transponders which assumes an average voice switching advantage of 4 dB. Accordingly, to find the transmit power level for an individual channel, 4 dB must be added to the power shown in Table 5-20. For an earth station that transmits more than one channel, a voice switching advantage may be used that varies from 0 to 4 dB, depending on the number of channels transmitted. In addition, the HPA must be operating at a back-off that depends on the system operating conditions.

### 5.3.2 Incremental Systems Costs Versus G/T

The optimum systems configuration was determined for different traffic models and satellite types. A detailed example of this determination is shown in Table 5-22 for the case of the low capacity traffic model and the Domestic C-band transponder. The results of the optimization are shown in Figure 5-7.

In the cost comparison, only those cost elements have been entered that change with the change of G/T. This includes antenna costs, HPA costs and LNR costs. These subsystem costs have been multiplied by a factor of 1.5 to obtain installed costs with spares. Annual costs were found by multiplying the total by the annualizing factor of 0.28.

Because of the low traffic requirements and the efficient space segment utilization of the PSK-SCPC system, the space segment costs are low and the ground segment costs dominate in this model. Minimum costs are achieved with a G/T of 18. This corresponds to an antenna diameter of approximately 4.5 meters. Because of FCC sidelobe requirements, a slightly larger antenna would probably be chosen in practice.

**Table 5-22**

**Annual Systems Costs for Low Capacity Model,**

**SCPC Transmission and Domsat C-Band Transponder**

| G/T | Antenna Gain (dBi) | Antenna Cost ($1000) | RX Noise Temp. (K) | RX Cost ($1000) | RX & Antenna Cost for 26 Systems ($1000) | HPA Cost 1 Ch. ($1000) | HPA Cost 2 Ch. ($1000) | HPA Cost 6 Ch. ($1000) | HPA Cost 20 Ch. ($1000) | Total Ground Segment Investment Costs ($1000) | Annual Ground Segment Costs ($1000) | Annual Space Segment Costs ($1000) | Total Annual Costs ($1000) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 39 | 14 | 450 | 3.5 | 455 | 17 | 21 | 33 | 80 | 1080 | 453 | 188 | 641 |
| 14 | 41 | 17 | 450 | 3.5 | 533 | 13 | 18 | 26 | 65 | 1038 | 435 | 118 | 553 |
| 16 | 42 | 18 | 350 | 4.5 | 585 | 11 | 16 | 21 | 55 | 1015 | 426 | 75 | 501 |
| 18 | 43.5 | 21 | 300 | 5.5 | 689 | 10 | 13 | 18 | 45 | 1054 | 443 | 47 | 490 |
| 20 | 44.5 | 23 | 230 | 6.5 | 767 | 10 | 12 | 17 | 45 | 1117 | 469 | 40 | 509 |
| 22 | 45.5 | 25 | 170 | 9.0 | 884 | 10 | 11 | 15 | 45 | 1214 | 510 | 40 | 550 |
| 26 | 46 | 27 | 108 | 14.0 | 1066 | 10 | 10 | 13 | 45 | 1376 | 578 | 40 | 618 |
| 26 | 47 | 31 | 75 | 18.0 | 1274 | 10 | 10 | 12 | 45 | 1600 | 672 | 40 | 712 |
| 28 | 48 | 36 | 50 | 24 | 1560 | 10 | 10 | 11 | 45 | 1870 | 785 | 40 | 825 |
| 30 | 50 | 52 | 50 | 24 | 1976 | 10 | 10 | 10 | 45 | 2286 | 960 | 40 | 1000 |
| 32 | 52 | 100 | 50 | 24 | 3224 | 10 | 10 | 10 | 45 | 3534 | 1484 | 40 | 1524 |
| 34 | 54 | 280 | 50 | 24 | 7904 | 10 | 10 | 10 | 45 | 8414 | 3450 | 40 | 3490 |
| 36 | 56 | 530 | 50 | 24 | 14400 | 10 | 10 | 10 | 45 | 14700 | 6174 | 40 | 6214 |
| 38 | 58 | 860 | 50 | 24 | 23000 | 10 | 10 | 10 | 45 | 23310 | 9790 | 40 | 9830 |
| 40 | 60 | 1400 | 50 | 24 | 37000 | 10 | 10 | 10 | 45 | 37310 | 15670 | 40 | 15710 |

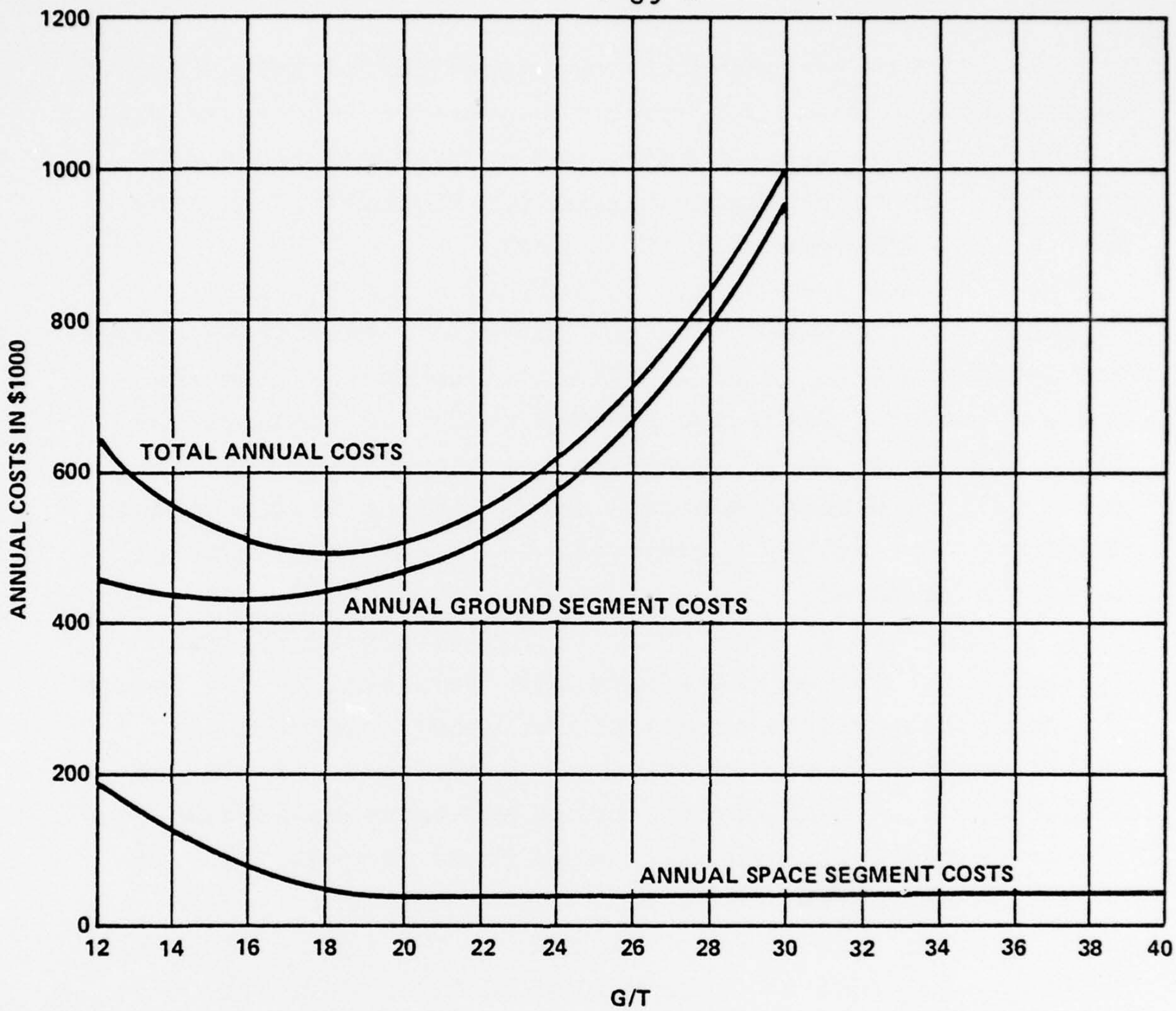



FIGURE 5–7

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK – SCPC TRANSMISSION
DOMESTIC C–BAND TRANSPONDER

Figure 5-8 shows the optimization for INTELSAT IV. Because of the lower EIRP of this satellite and the resulting higher space segment cost, the optimum G/T is 26 dB/K. Figure 5-9 shows the optimization for INTELSAT IV-A, with the optimum C/T occurring at 22 dB/K.

Figure 5-10 is the optimization for the high capacity traffic model with the domestic C-band transponder. The optimum G/T is 18 dB/K, identical to that of the low capacity model. Since the average number of channels per earth station is small in all cases, the optimum operating point will be almost identical for all three traffic models. Therefore, in further optimization only one traffic model need be considered.

For the systems optimization with DSCS II, the C-band earth station costs have been increased by 30%, since the production volume of commercial grade equipment at 7/8 GHz is lower than at 4/6 GHz. The same factor of 30% has been used for K-band earth station equipment to account for the lower production quantities at these frequencies. It should be noted that commercial grade equipment is used throughout in this cost optimization. The impact of using Mil Spec equipment has been evaluated in section 8.1.

Figure 5-11 shows the optimization for DSCS II global beam. The optimum G/T is 26 dB/K, similar to that of INTELSAT IV global beam.

The curves of Figure 5-7 through 5-11 provide enough information to permit scaling of optimum G/T ratios for all conditions of PSK-SCPC operation.

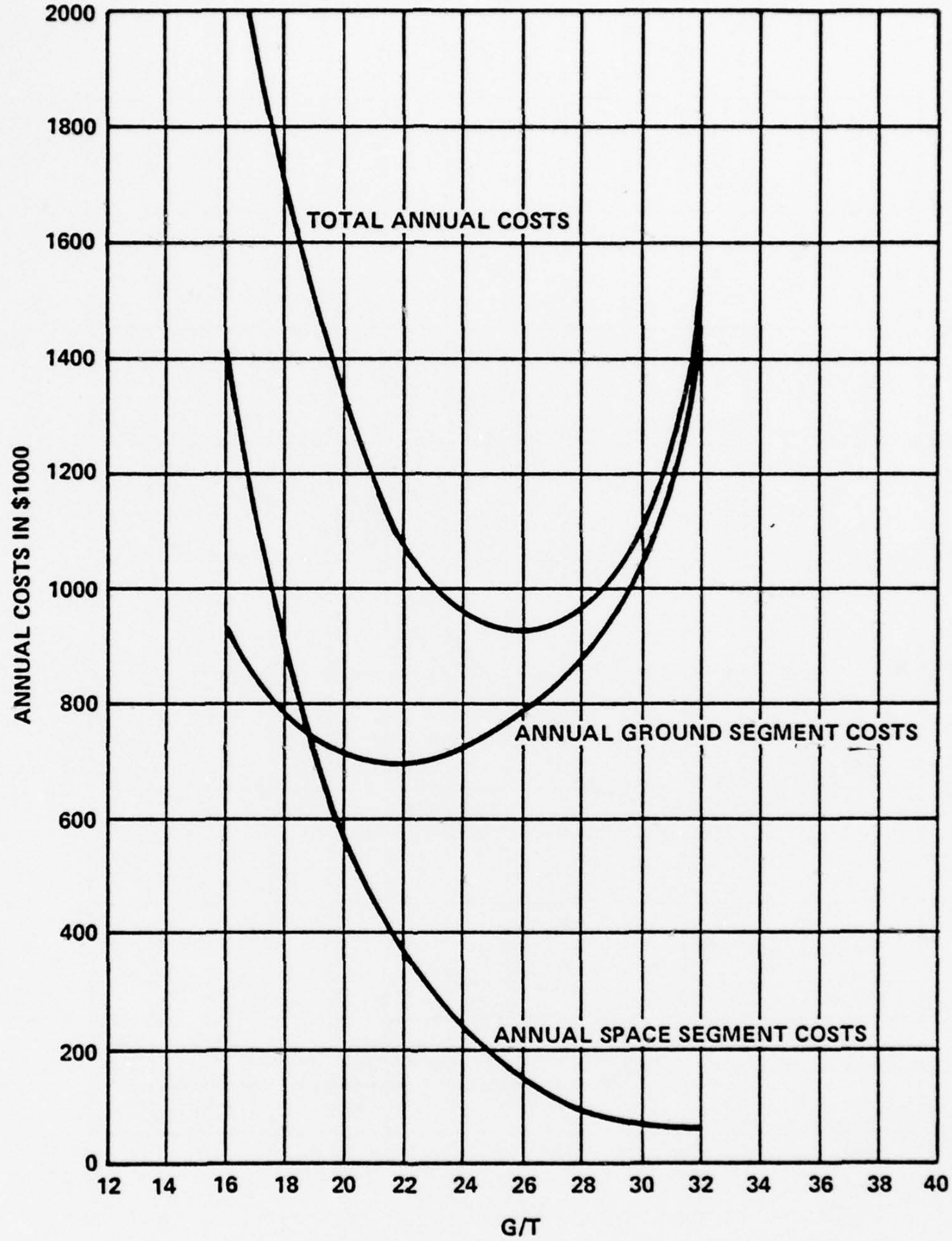



FIGURE 5–8

ANNUAL COST VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK – SCPC TRANSMISSION
INTELSAT IV – GLOBAL BEAM TRANSPONDER

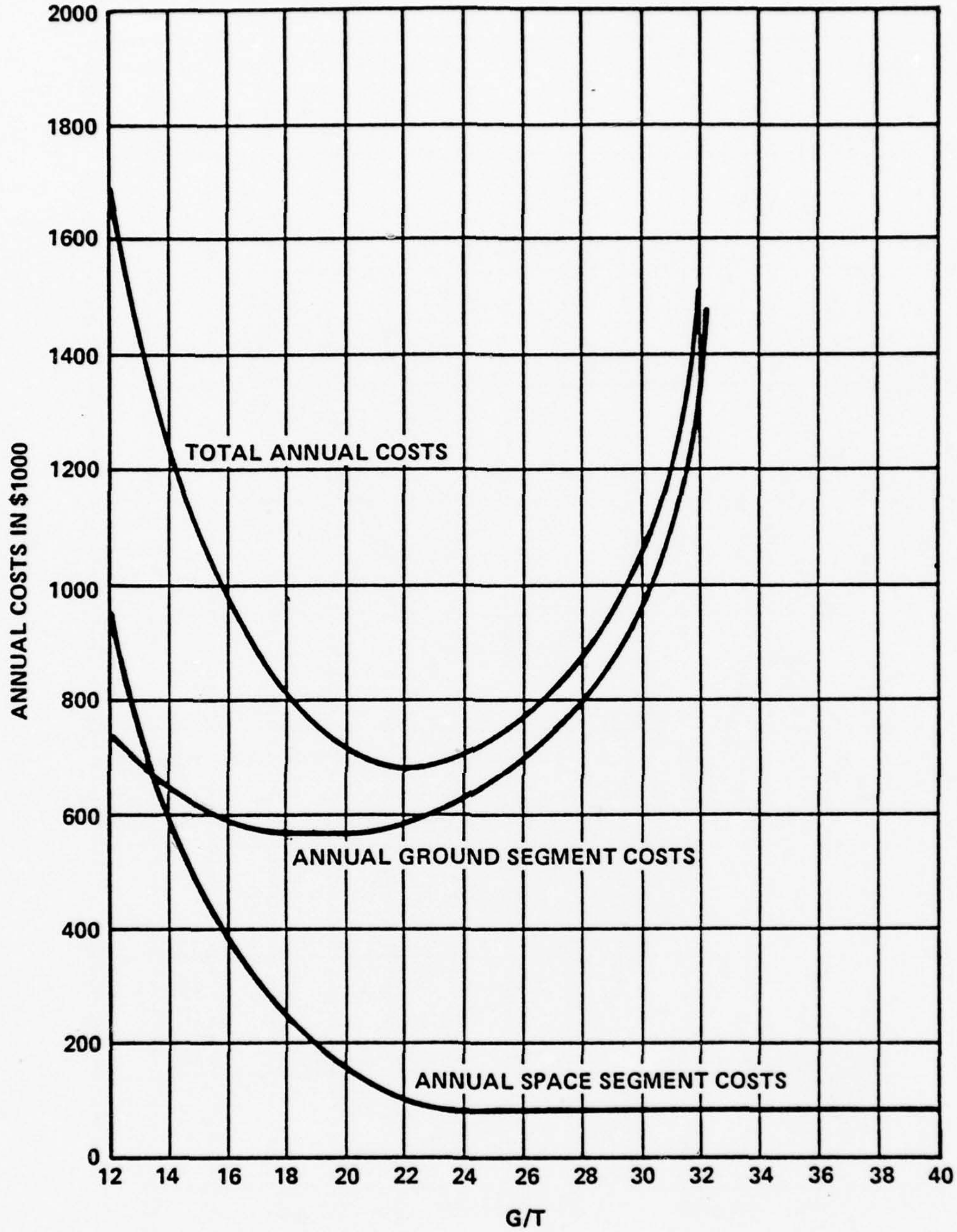



FIGURE 5–9

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK – SCPC TRANSMISSION
INTELSAT IV–A REGIONAL COVERAGE

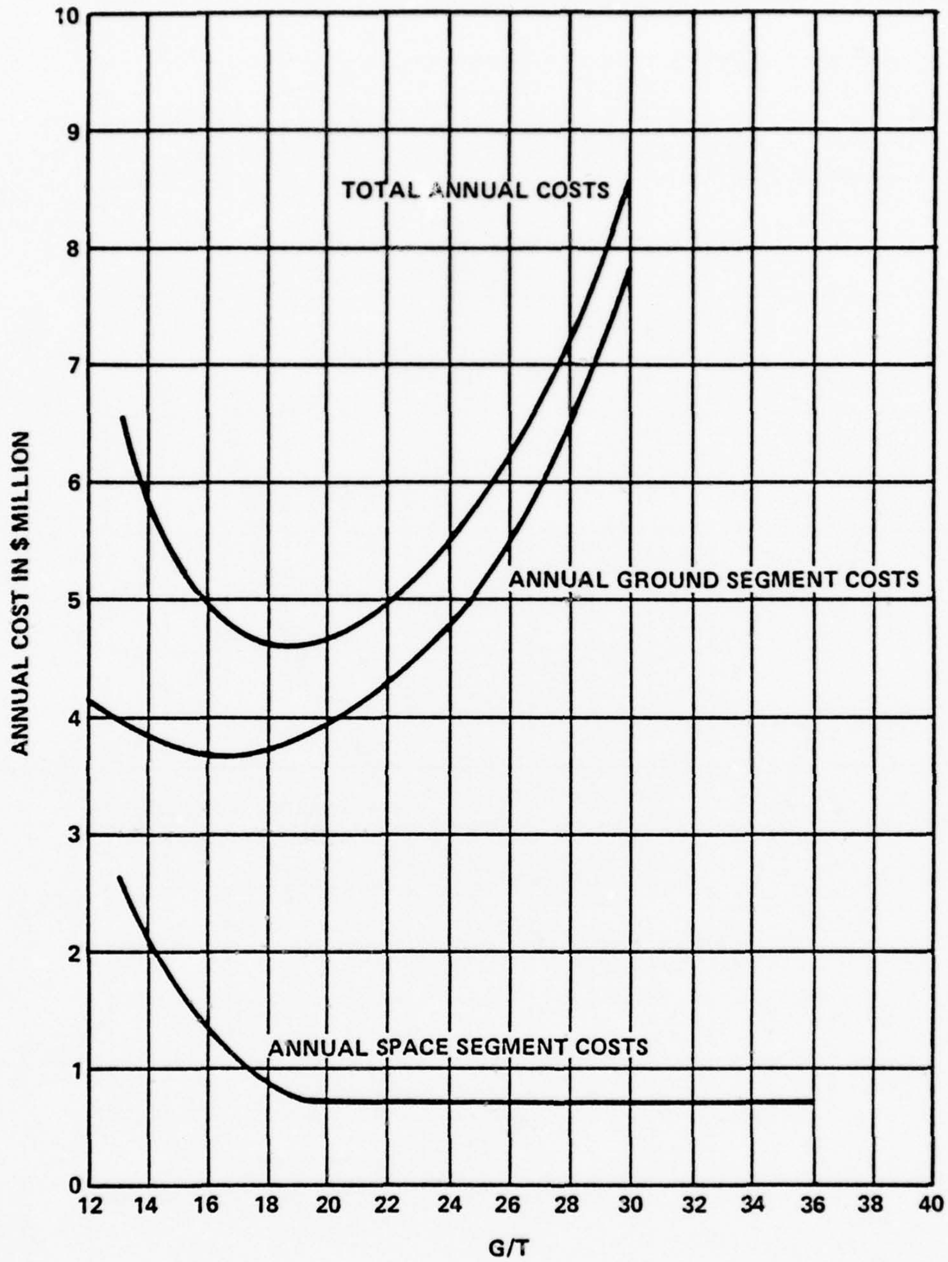



FIGURE 5–10

ANNUAL COSTS VERSUS G/T FOR
HIGH CAPACITY TRAFFIC MODEL
PSK – SCPC TRANSMISSION
DOMESTIC C–BAND TRANSPONDER

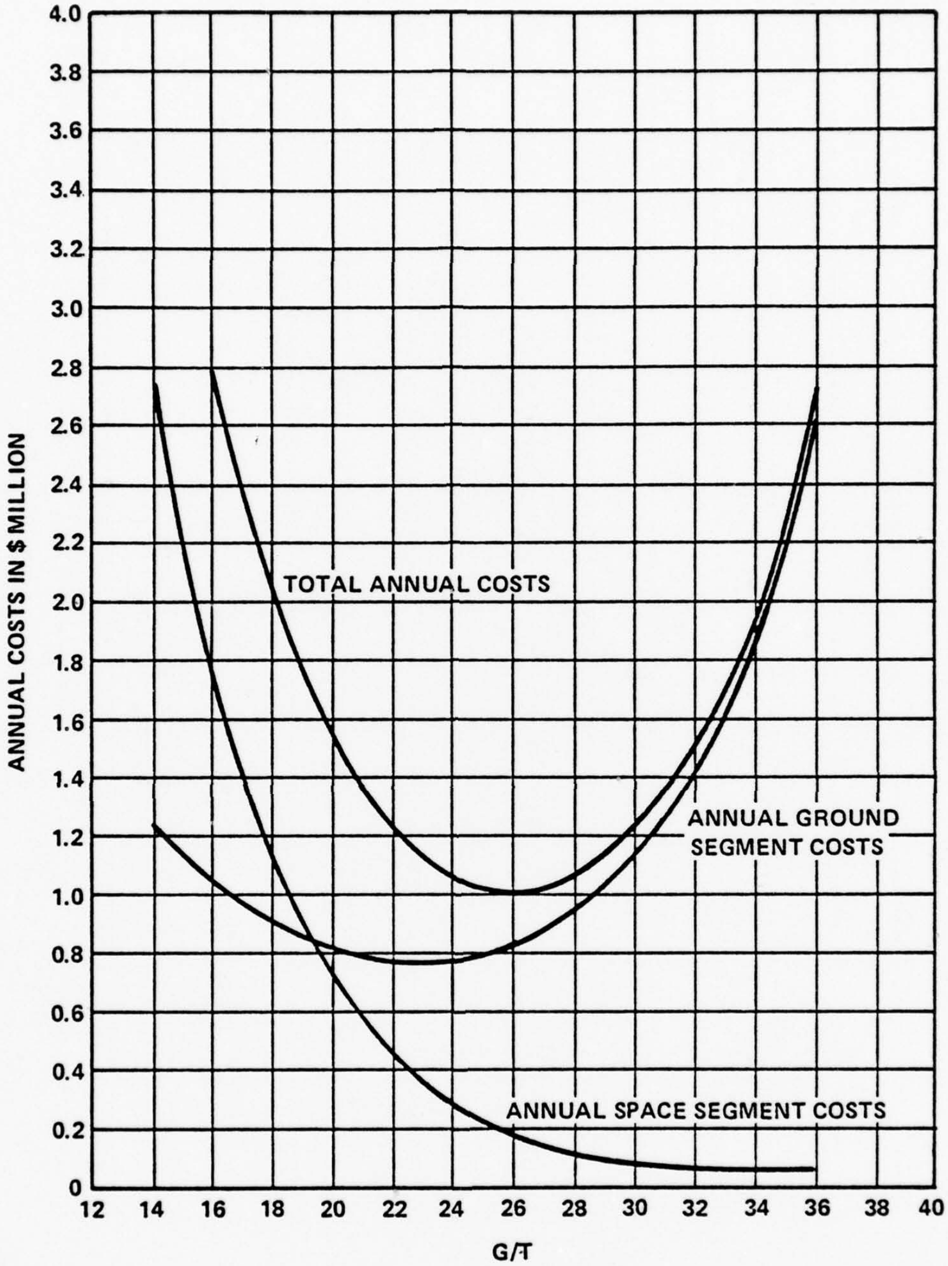



FIGURE 5–11

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
PSK – SCPC TRANSMISSION
DSCS II, GLOBAL BEAM

## 5.4 SYSTEMS OPTIMIZATION FOR THE TDM-PSK-FDMA SYSTEM

In this section the optimum configuration for the TDM-PSK-FDMA system was determined for each traffic model and each satellite type.

### 5.4.1 Earth Station EIRP and RF Power Requirements

In the power limited region, the transponder capacities with this system are 4 dB lower than with the SCPC system. Accordingly, the average transmit power per channel is 4 dB higher than in the SCPC system. For a station with only one channel, the transmit power requirement is identical, since the SCPC transmit power requirement is 4 dB higher during carrier on condition than the calculated average power level. In the bandwidth limited operating mode, the number of channels in the system is identical and the average transmit power requirements are also identical. The resulting power requirements per channel for this system are shown in Table 5-23.

Since each earth station transmits only a single carrier, the earth station HPA does not require a back-off.

### 5.4.2 Incremental Systems Costs Versus G/T

The earth station EIRP requirements per channel for earth stations with only one or two channels are identical to those for SCPC transmission. For larger numbers of channels, the SCPC earth stations benefit from a reduction in average power due to the voice activity factor; however, the HPA must operate at a back-off. The TDMA-PSK-FDMA system does not use voice switching; therefore, the average power per channel is higher. However, since each earth station transmits only one carrier, the HPA can operate with less

Table 5-23
Earth Station HPA Power per Channel
for TDM-PSK-FDMA Transmission
(Power in Watts)

| G/T (dB/K) | Domsat C-Band | Domsat K-Band | DSCS II Global | DSCS II Spot | INTELSAT IV Global | INTELSAT IV-A Regional |
|---|---|---|---|---|---|---|
| 12 | 33.9 | 427 | -- | 30 | -- | 538 |
| 14 | 13.6 | 171 | 1507 | 11 | 1700 | 214 |
| 16 | 6.8 | 68 | 602 | 3.5 | 847 | 108 |
| 18 | 3.0 | 28 | 239 | 1.0 | 377 | 48 |
| 20 | 1.5 | 10.8 | 95 | 0.25 | 191 | 25 |
| 22 | 0.6 | 4.3 | 38 | 0.09 | 96 | 12.1 |
| 24 | 0.3 | 1.8 | 19 | 0.059 | 53 | 5.9 |
| 26 | 0.15 | 0.60 | 7.5 | 0.030 | 28 | 2.3 |
| 28 | 0.09 | 0.20 | 3.0 | 0.015 | 14 | 1.2 |
| 30 | 0.05 | 0.05 | 1.0 | 0.009 | 5.4 | 0.5 |
| 32 | -- | 0.014 | 0.33 | 0.006 | 1.8 | 0.2 |
| 34 | -- | 0.007 | 0.11 | -- | -- | -- |
| 36 | -- | -- | 0.03 | -- | -- | -- |

back-off. As a result, there is little difference in HPA power requirements and therefore in earth station costs between the two systems.

However, the channel capacities of the TDMA-PSK-FDMA system are lower than those of the PSK-SCPC system, resulting in higher space segment cost allocations. Annual costs versus G/T are shown in Figures 5-12 through 5-16.

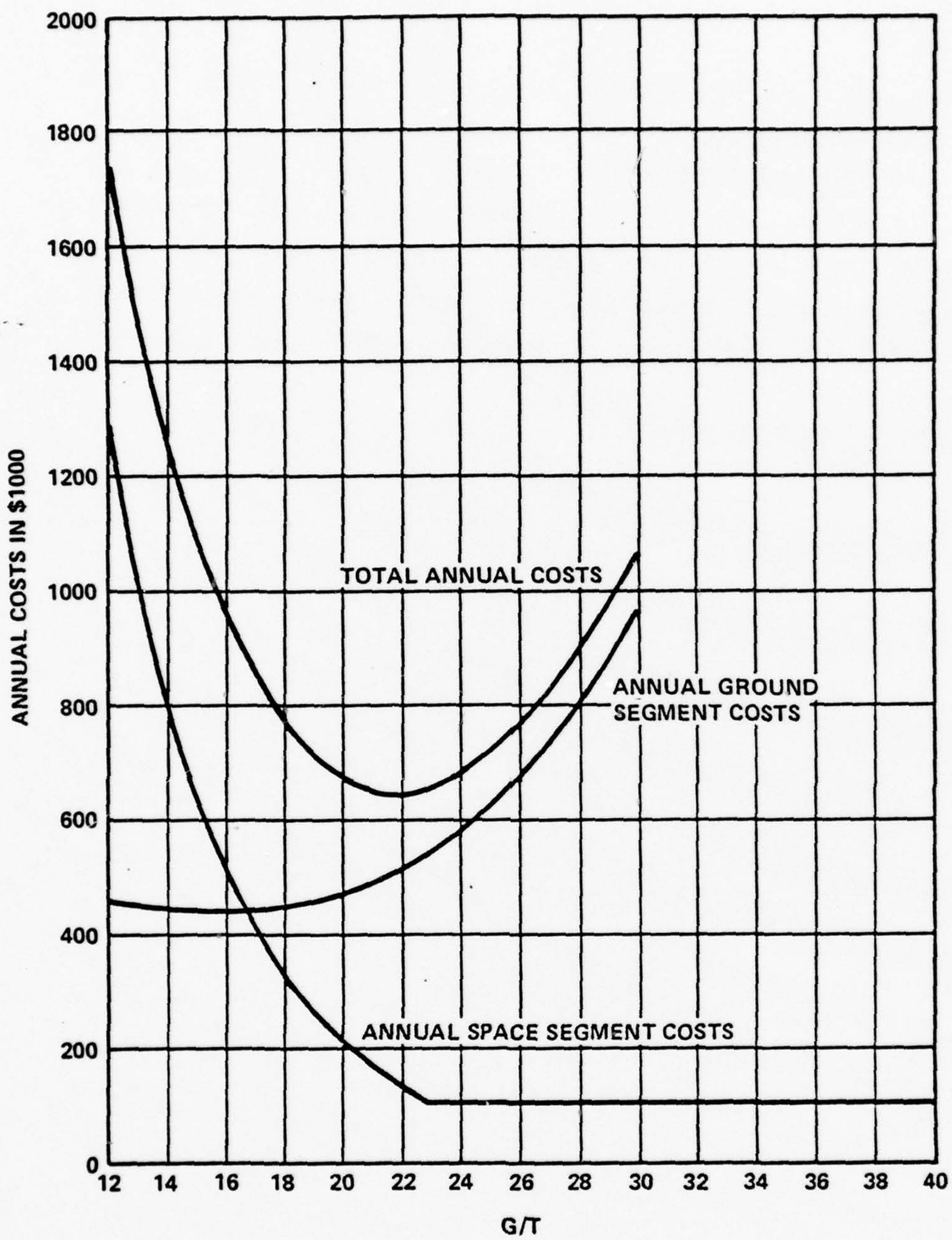



FIGURE 5–12

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM–PSK–FDMA TRANSMISSION
DOMESTIC C–BAND TRANSPONDER

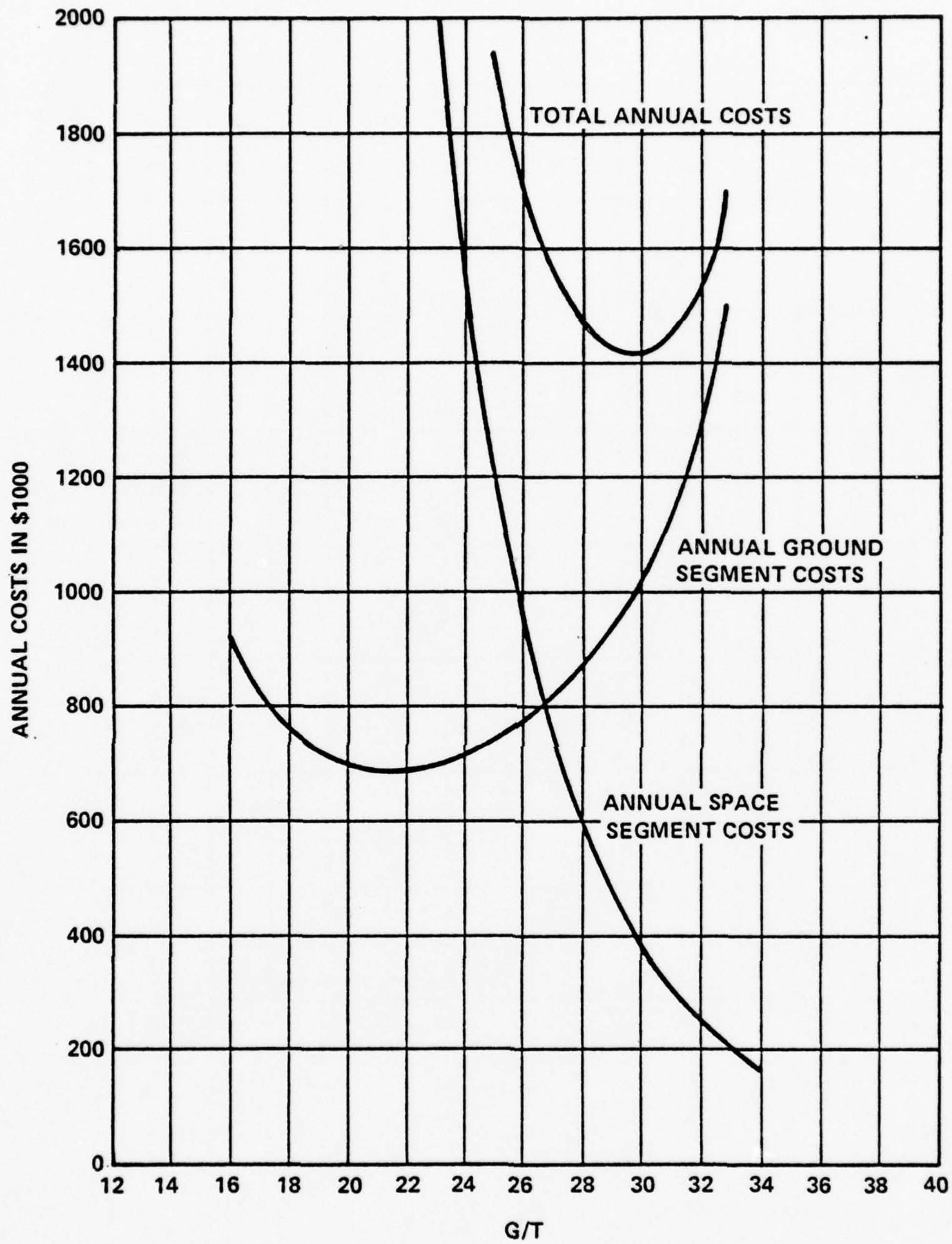



FIGURE 5–13

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM–PSK–FDMA TRANSMISSION
INTELSAT IV – GLOBAL BEAM TRANSPONDER

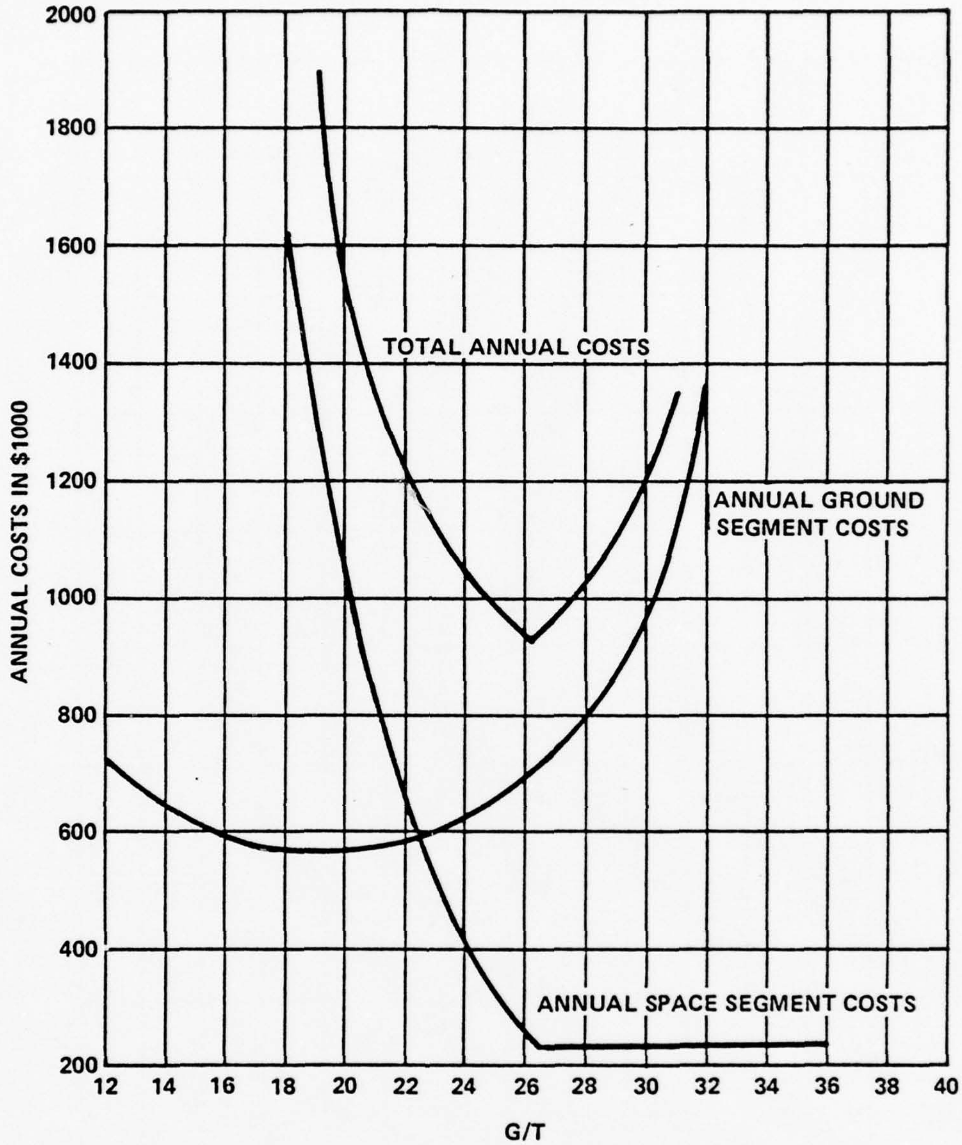



FIGURE 5–14

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM–PSK–FDMA TRANSMISSION
INTELSAT IV–A REGIONAL COVERAGE

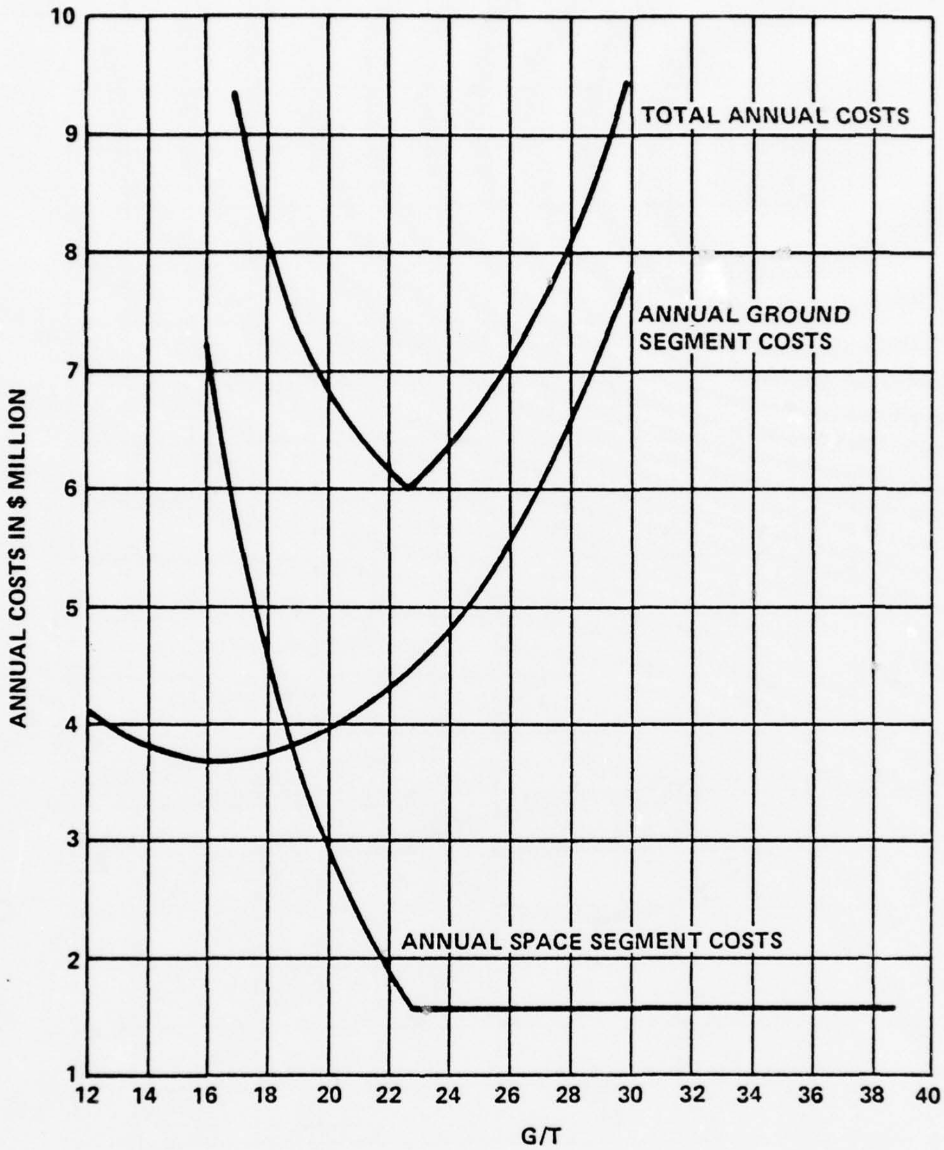



FIGURE 5–15

ANNUAL COSTS VERSUS G/T FOR
HIGH CAPACITY TRAFFIC MODEL
TDM–PSK–FDMA TRANSMISSION
DOMESTIC C–BAND TRANSPONDER

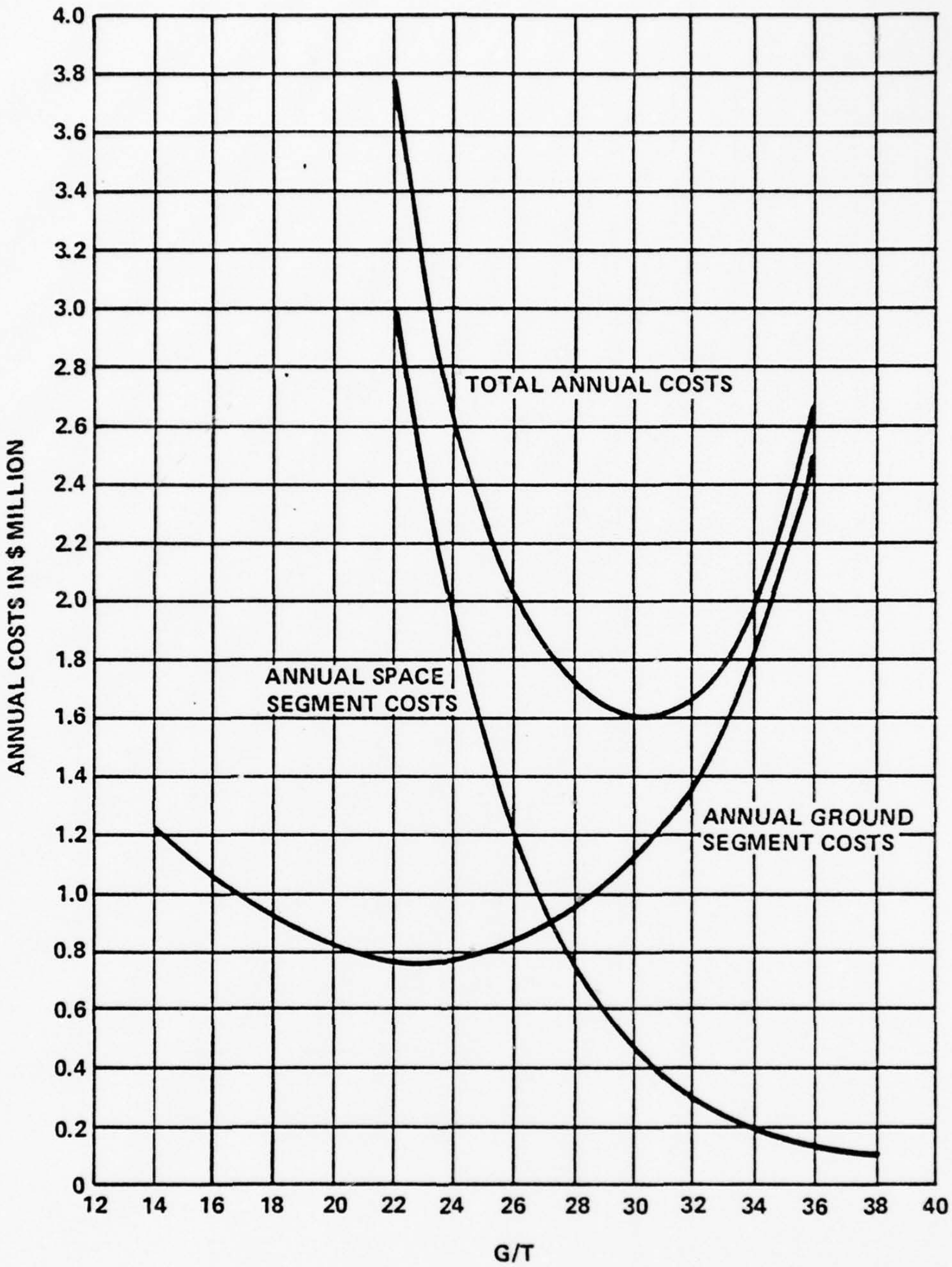



FIGURE 5–16

ANNUAL COSTS VERSUS G/T FOR
LOW CAPACITY TRAFFIC MODEL
TDM–PSK–FDMA TRANSMISSION
DCSC II, GLOBAL BEAM

## 5.5 SYSTEMS OPTIMIZATION FOR TDMA OPERATION

In this section, the optimum configurations for the TDMA system have been determined for each traffic model and each satellite type. Three sub-cases of TDMA operation have been considered:

(a) Operation at maximum achievable bit rate. In this case, the receive G/T and transmit EIRP of the earth station have been chosen so as to provide adequate margins for TDMA operation at the maximum achievable bit-rate. It is assumed that the TDMA time frame is shared with other users, since the requirements for the three traffic models are not sufficient to load a full transponder at maximum bit rate. Space segment costs for each traffic model were pro-rated in accordance with the fractional transponder capacity used.

(b) Operation at the bit rate corresponding to the traffic requirements. In this case, the receive G/T and the transmit EIRP for each earth station were adjusted to provide adequate margins for TDMA operation at the bit rate that corresponds to the traffic requirement of each traffic model. The total transponder cost is allocated to the service, since no other use of the transponder is made. The transponder operates in a backed-off single carrier mode, without intermodulation.

(c) Transponder shared with other services. This case is identical to that of (b) above, except that the transponder is shared with other services. This reduces the space segment cost allocation, but results in operation in an intermodulation environment.

### 5.5.1 Calculation of Earth Station Transmit Power Requirements

(a) Operation at maximum achievable bit rate. Required Receive G/T and transmit power are calculated as follows:

$$\left(\frac{C}{N}\right)_T = \frac{E_b}{N_o} + 10 \log \frac{R}{BW} + M_s + M_I$$

where:

$\left(\frac{C}{N}\right)_T$ = total carrier-to-noise ratio

$\frac{E_b}{N_o}$ = energy per bit-to-noise density ratio at threshold, 6 dB for BER = $10^{-2}$

R = maximum bit rate per transponder, $R = BW \cdot 0.87$

BW = IF bandwidth, equals transponder bandwidth

$M_s$ = system margin, assumed to be 5 dB at 4 GHz, 6.5 dB at 7.5 GHz and 8 dB at 12 GHz

$M_I$ = additional margin for intersymbol distortion due to HPA and satellite nonlinearities, assumed to be 3 dB

$\left(\frac{C}{N}\right)_T$ = 13.4 dB at 4 GHz
14.9 dB at 7.5 GHz
16.4 dB at 12 GHz

$$\left(\frac{C}{N}\right)_T = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_u} + \frac{1}{\left(\frac{C}{N}\right)_D}}$$

$$\left(\frac{C}{N}\right)_u = W_s - G_m{}^2 - BO_I + \left(\frac{G}{T}\right)_s - k - 10 \log BW$$

$$\left(\frac{C}{N}\right)_D = EIRP_s - BO_o - PL_D + \left(\frac{G}{T}\right)_E - k - 10 \log BW$$

where:

$BO_I$ = transponder input back-off, 4 dB
$BO_o$ = transponder output back-off, 0.8 dB
$n = (R/16,000) \times 0.95$
= number of channels
$P_T = W_s - G_T + P_L - G_m{}^2 - BO_I$

Using these formulas, the transmission characteristics for the six satellite types under investigation have been calculated. They are shown in Table 5-24.

(b) Operation at the bit rate corresponding to the traffic requirements. From Table 5-24 it was found that the uplink noise contribution is 1 dB or less. The link calculations can therefore be simplified by calculating only downlink C/N and adding 1 dB of uplink contribution to obtain total C/N. In the power limited mode of operation, the required $C/N_o$ is given by:

Table 5-24

TDMA Link Performance - Maximum Bit Rate

| | | Satellite Type | | | | | |
|---|---|---|---|---|---|---|---|
| | | DSCS II Global Beam (105 dB Gain) | DSCS II Spot Beam (105 dB Gain) | Domsat C-Band | Domsat K-Band | INTELSAT IV Global | INTELSAT IV-A Regional |
| $W_s$ | ($dBW/m^2$) | -68* | -84* | -84 | -73 | -73 | -75 |
| $(G/T)_s$ | (dB/K) | -19 | - 3 | - 6 | - 6 | -18 | -11.6 |
| BW | (MHz) | 50 | 50 | 36 | 54 | 36 | 36 |
| $(C/N)_u$ | (dB) | 21.1 | 21.1 | 23 | 23.9 | 21 | 25.4 |
| $(C/N)_D$ | (dB) | 15.8 | 15.8 | 13.8 | 17.1 | 14.1 | 13.7 |
| $EIRP_s$ | (dBW) | 28 | 43 | 33 | 38 | 22 | 29 |
| $PL_D$ | (dB) | 201.7 | 201.7 | 196.2 | 205.7 | 196.2 | 196.2 |
| $(G/T)_E$ | (dB/K) | 38.7 | 23.7 | 24.8 | 34.3 | 36.1 | 28.7 |
| R | (Mb/s) | 43.5 | 43.5 | 31.3 | 47.0 | 31.3 | 31.3 |
| n | | 2580 | 2580 | 1860 | 2790 | 1860 | 1860 |
| T | (dB) | 21.9 | 24.0 | 22.0 | 24.0 | 20.0 | 20.0 |
| $G_R$ | (dB) | 60.9 | 47.7 | 46.8 | 58.3 | 56.1 | 48.7 |
| $G_T$ | (dB) | 59.9 | 46.7 | 48.3 | 57.6 | 57.6 | 50.2 |
| Antenna Diameter | (m) | 12.0 | 3.3 | 6.8 | 6.0 | 19.7 | 8.4 |
| $P_T$ | (dBW) | 30.8 | 28.0 | 27.4 | 28.1 | 28.1 | 33.5 |
| $P_T$ | (kW) | 1.2 | 0.63 | 0.55 | 0.65 | 0.65 | 2.2 |

*Derived from Technical Note No. 39-75; see section 2.1.1.

$$\frac{C}{N_o} = 10 \log R + \frac{E}{N_o} + M_s + M_I$$

or

$$\frac{C}{N_o} = 10 \log R + M_s + 9$$

$C/N_o$ for the three traffic models and the three operating frequencies is shown in Table 5-25.

Table 5-25

$C/N_o$ Needed to Satisfy Traffic Requirements

| Traffic Model | Low Capacity | Medium Capacity | High Capacity |
|---|---|---|---|
| Number of Channels | 80 | 219 | 1100 |
| Bit rate in Mb/s at 5% overhead | 1.4 | 3.7 | 18.5 |
| $C/N_o$ at 4 GHz, $M_s$ = 5 dB | 75.5 | 79.7 | 86.7 |
| $C/N_o$ at 7.5 GHz, $M_s$ = 6.5 dB | 77.0 | 81.2 | 88.2 |
| $C/N_o$ at 12 GHz, $M_s$ = 8 dB | 78.5 | 82.7 | 89.7 |

$$\frac{C}{N_o} = EIRP_s - BO_o - PL_D + \left(\frac{G}{T}\right)_E - k$$

The specified $C/N_o$ can be obtained with a range of combinations of earth station G/T and back-off.

Table 5-26 shows transmission parameters for the low capacity traffic model and all six satellite types. It was found that a TDMA system is possible with relatively small antennas and low transmit power levels by operating at a transponder output back-off of 10 dB. This reduces the earth station costs, but the full transponder lease rate will be charged to the system, which makes this solution unattractive.

Table 5-26

TDMA Link Performance at Bit Rate to Meet Traffic Requirements for Low Capacity Model

| | | Satellite Type | | | | | |
|---|---|---|---|---|---|---|---|
| | | DSCS II Global Beam | DSCS II Spot Beam | Domsat C-Band | Domsat K-Band | INTELSAT IV Global | INTELSAT IV-A Reg. Coverage |
| $C/N_O$ | (dB-Hz) | 77.0 | 77.0 | 75.5 | 78.5 | 75.5 | 75.5 |
| $(G/T)_E - BO_O$ | (dB) | 22.1 | 7.1 | 10.1 | 17.6 | 21.1 | 14.1 |
| $(G/T)_E$ | (dB/K) | 32.1 | 17.1 | 20.1 | 27.6 | 31.1 | 24.1 |
| $BO_O$ | (dB) | 10 | 10 | 10 | 10 | 10 | 10 |
| $BO_I$ | (dB) | 16 | 16 | 16 | 16 | 16 | 16 |
| $G_T$ | (dB) | 55.1 | 42.1 | 44.1 | 51.6 | 51.1 | 46.1 |
| Antenna Diameter | (m) | 7.2 | 2.4 | 5.2 | 3.3 | 9.5 | 6.3 |
| $P_T$ | (dBW) | 23.6 | 20.6 | 19.6 | 22.1 | 22.6 | 25.6 |
| $P_T$ | (Watts) | 230 | 120 | 90 | 165 | 182 | 360 |

(c) Transponder Shared with Other Services. In this operating mode, the transponder should be driven to an output back-off of 4 to 5 dB, depending on the other services that will be carried. Uplink and intermodulation noise contributions will be similar to those of the TDM-PSK-TDMA system. For this reason, the optimum G/T ratios in the two systems will be similar. Since the TDMA system must transmit higher power levels than the TDM-PSK-TDMA system, the optimum G/T will be slightly higher for the TDMA system. However, the differences are not large enough to warrant a separate optimization.

In all TDMA applications, we have assumed that pulsed HPAs will not be available. The power rating of each HPA, therefore, corresponds to the power needed for the full bit rate of the system.

# Section 6
# SYSTEMS COMPARISON

Based on the optimization carried out in section 5, the three modulation systems under study can now be compared. The systems optimization was important to ensure that each modulation system is used under optimum conditions. All technical data required for the comparison have already been developed and presented in earlier sections. Based on this information, the costs for each case have been tabulated and compared.

## 6.1 PSK-SCPC COSTS

Tables 6-1 through 6-6 show the systems costs for PSK-SCPC transmission for each satellite and traffic model. The first step is the selection of the optimum G/T. This is determined from Figures 5-7 through 5-11. HPA power levels are taken from Table 5-20. Quantities of equipment are selected in accordance with the requirements of the traffic models, sections 2.1 and 3.1. Unit equipment costs are based on sections 4.2 and 5.2. Annual space segment costs are found in Tables 5-1 through 5-6. Total ground segment subsystem costs are multiplied by a factor of 1.5 to allow for cabinets, wiring, installation, spares and documentation. Total costs are annualized by a factor of 0.28. Thus, the factor of 0.42 can be applied to the subsystem costs to find the annual ground segment costs.

For SCPC transmission through a domestic C-band transponder, the optimum G/T is 28 dB/K. This G/T could be accomplished with an earth station antenna diameter of approximately 4.5 meters. Such an antenna may not meet the FCC requirements for sidelobe response; therefore, a G/T of 20 dB/K has been selected in the model. This G/T would be

Modulation System: PSK-SCPC
Satellite Type: Domestic C-Band
Earth Station G/T: 20 dB/K

Table 6-1
System Costs
($1000)

HPA: 0.8 W/Ch. Av.
= -1 dBW/Ch. Av.

| Traffic Model | | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 30 | 26 | 780 | 10 | 300 | 211 | 6330 |
| HPA | Power dBW | | | | | | | |
| 1 Ch. | 3 | 10 | 10 | 100 | - | - | 100 | 1000 |
| 2 Ch. | 9 | 12 | 10 | 120 | - | - | - | - |
| 6 Ch. | 14 | 15 | 5 | 75 | - | - | 100 | 1500 |
| 20 Ch. | 17 | 18 | 1 | 18 | 10 | 180 | 10 | 180 |
| 200 Ch. | 26 | 28 | - | - | - | - | 1 | 28 |
| Up-Converter | | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Common Equipment-Cent. | | 105 | 1 | 105 | 1 | 105 | 1 | 105 |
| " " -Rem. | | 12 | 25 | 300 | 9 | 108 | 210 | 2520 |
| Channel Units | | 6 | 80 | 480 | 219 | 1314 | 1100 | 6600 |
| Total Ground Segment Subsystem Costs | | | | 2550 | | 2227 | | 22905 |
| Annual Ground Segment | | | | 1071 | | 935 | | 9620 |
| Annual Space Segment | | | | 40 | | 211 | | 719 |
| TOTAL ANNUAL COSTS | | | | 1111 | | 1146 | | 10339 |

Modulation System: PSK-SCPC
Satellite Type: IS-IV Global Beam
Earth Station G/T: 26 dB/K

Table 6-2
System Costs
($1000)

HPA: 11 W/Ch. Av.
= 10.4 dBW/Ch. Av.

| Traffic Model | | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 50 | 26 | 1300 | 10 | 500 | 211 | 10550 |
| HPA | Power dBW | | | | | | | |
| 1 Ch. | 14.4 | 16 | 10 | 160 | – | – | 100 | 1600 |
| 2 Ch. | 20.4 | 21 | 10 | 210 | – | – | – | – |
| 6 Ch. | 25.4 | 27 | 5 | 135 | – | – | 100 | 2700 |
| 20 Ch. | 28.4 | 32 | 1 | 32 | 10 | 320 | 10 | 320 |
| 200 Ch. | 37.4 | 50 | – | – | – | – | 1 | 50 |
| Up-Converter | | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Common Equipment-Cent. | | 105 | 1 | 105 | 1 | 105 | 1 | 105 |
| Common Equipment-Rem. | | 12 | 25 | 300 | 9 | 108 | 210 | 2520 |
| Channel Units | | 6 | 80 | 480 | 219 | 1314 | 1100 | 6600 |
| Total Ground Segment Subsystem Costs | | | | 3294 | | 2567 | | 29087 |
| Annual Ground Segment | | | | 1384 | | 1078 | | 12216 |
| Annual Space Segment | | | | 141 | | 740 | | 2520 |
| TOTAL ANNUAL COSTS | | | | 1524 | | 1818 | | 14736 |

Modulation System: PSK-SCPC
Satellite Type: IS-IVA Regional
Earth Station G/T: 22 dB/K

Table 6-3
System Costs
($1000)

HPA: 4.8 W/Ch. Av.
= 6.8 dBW/Ch. Av.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 35 | 26 | 910 | 10 | 350 | 211 | 7385 |
| HPA — Power dBW | | | | | | | |
| 1 Ch. — 10.8 | 12 | 10 | 120 | - | - | 100 | 1200 |
| 2 Ch. — 16.8 | 18 | 10 | 180 | - | - | - | - |
| 6 Ch. — 21.8 | 22 | 5 | 110 | - | - | 100 | 2200 |
| 20 Ch. — 24.8 | 26 | 1 | 26 | 10 | 260 | 10 | 260 |
| 200 Ch. — 33.8 | 41 | - | - | - | - | 1 | 41 |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Common Equipment-Cent. | 105 | 1 | 105 | 1 | 105 | 1 | 105 |
| Common Equipment-Rem. | 12 | 25 | 300 | 9 | 108 | 210 | 2520 |
| Channel Units | 6 | 80 | 480 | 219 | 1314 | 1100 | 6600 |
| Total Ground Segment Subsystem Costs | | | 2997 | | 2357 | | 24953 |
| Annual Ground Segment | | | 1175 | | 990 | | 10480 |
| Annual Space Segment | | | 94 | | 494 | | 1684 |
| TOTAL ANNUAL COSTS | | | 1269 | | 1484 | | 12164 |

Modulation System: PSK-SCPC
Satellite Type: DSCS-II, Global Beam
Earth Station G/T: 26 dB/K

Table 6-4
System Costs
($1000)

HPA: 3 W/Ch. Av.
= 4.8 dBW/Ch. Av.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 65 | 26 | 1690 | 10 | 650 | 211 | 13715 |
| HPA — Power dBW | | | | | | | |
| 1 Ch. — 8.8 | 16 | 10 | 160 | - | - | 100 | 1600 |
| 2 Ch. — 14.8 | 21 | 10 | 210 | - | - | - | - |
| 6 Ch. — 19.8 | 26 | 5 | 130 | - | - | 100 | 2600 |
| 20 Ch. — 22.8 | 29 | 1 | 29 | 10 | 290 | 10 | 290 |
| 200 Ch. — 31.8 | 48 | - | - | - | - | 1 | 48 |
| Up-Converter | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Down-Converter | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Common Equipment-Cent. | 105 | 1 | 105 | 1 | 105 | 1 | 105 |
| Common Equipment-Rem. | 12 | 25 | 300 | 9 | 108 | 210 | 2520 |
| Channel Units | 6 | 80 | 480 | 219 | 1314 | 1100 | 6600 |
| Total Ground Segment Subsystem Costs | | | 3832 | | 2747 | | 33386 |
| Annual Ground Segment | | | 1609 | | 1154 | | 14022 |
| Annual Space Segment | | | 177 | | 931 | | 3000 |
| TOTAL ANNUAL COSTS | | | 1786 | | 2085 | | 17022 |

Modulation System: PSK-SCPC
Satellite Type DSCS II, Spot Beam
Earth Station G/T: 18 dB/K

Table 6-5
System Costs
($1000)

HPA: 0.5 W/Ch. Av.
= -3 dBW/Ch. Av.

| Traffic Model | | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 34 | 26 | 884 | 10 | 340 | 211 | 7174 |
| HPA | Power dBW | | | | | | | |
| 1 Ch. | 1 | 13 | 10 | - | - | - | 100 | - |
| 2 Ch. | 7 | 14 | 10 | - | - | - | - | - |
| 6 Ch. | 12 | 18 | 5 | - | - | - | 100 | - |
| 20 Ch. | 15 | 21 | 1 | - | 10 | - | 10 | - |
| 200 Ch. | 24 | 32 | - | - | - | - | 1 | - |
| Up-Converter | | 11 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Down-Converter | | 11 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Common Equipment-Cent. | | 105 | 1 | 105 | 1 | 105 | 1 | 105 |
| Common Equipment-Rem. | | 12 | 25 | 300 | 9 | 108 | 210 | 2520 |
| Channel Units | | 6 | 80 | 480 | 219 | 1314 | 1100 | 6600 |
| Total Ground Segment Subsystem Costs | | | | 2878 | | 2357 | | 25695 |
| Annual Ground Segment | | | | 1209 | | 990 | | 10773 |
| Annual Space Segment | | | | 58 | | 304 | | 1036 |
| TOTAL ANNUAL COSTS | | | | 1267 | | 1294 | | 11809 |

Modulation System: PSK-SCPC
Satellite Type: Domestic, K-Band
Earth Station G/T: 24 dB/K

Table 6-6
System Costs
($1000)

HPA: 0.7 W/Ch. Av.
= -1.5 dBW/Ch. Av.

| Traffic Model | | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 34 | 26 | 884 | 10 | 340 | 211 | 7174 |
| HPA | Power dBW | | | | | | | |
| 1 Ch. | 2.5 | 13 | 10 | 130 | - | - | 100 | 1300 |
| 2 Ch. | 8.5 | 14 | 10 | 140 | - | - | - | - |
| 6 Ch. | 13.5 | 20 | 5 | 100 | - | - | 100 | 2000 |
| 20 Ch. | 16.5 | 22 | 1 | 22 | 10 | 220 | 10 | 220 |
| 200 Ch. | 25.5 | 36 | - | - | - | - | 1 | 36 |
| Up-Converter | | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Down-Converter | | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Common Equipment-Cent. | | 105 | 1 | 105 | 1 | 105 | 1 | 105 |
| Common Equipment-Rem. | | 12 | 25 | 300 | 9 | 108 | 210 | 2520 |
| Channel Units | | 6 | 80 | 480 | 219 | 1314 | 1100 | 6600 |
| Total Ground Segment Subsystem Costs | | | | 2889 | | 2367 | | 25863 |
| Annual Ground Segment | | | | 1213 | | 994 | | 10862 |
| Annual Space Segment | | | | 133 | | 698 | | 2379 |
| TOTAL ANNUAL COSTS | | | | 1346 | | 1692 | | 13241 |

achieved with an antenna with approximately 5.3 meters diameter which meets the sidelobe requirements.

For a small number of channels, the HPA cannot benefit from the full voice activity advantage. The power rating of the HPA is therefore based on a higher power level than the average power. In addition, the HPA must operate at a back-off for all cases except when a single channel per earth station is transmitted. The following values have been used in determining the HPA power requirement:

| Channels per Earth Station | Ratio of Peak to Average Power (dB) | HPA Output Back-Off (dB) | HPS Power Rating Relative to Average Power per Channel (dB) |
|---|---|---|---|
| 1 | 4 | 0 | 4 |
| 2 | 4 | 3 | 10 |
| 6 | 3 | 4 | 15 |
| 20 | 1 | 4 | 18 |
| 200 | 0 | 4 | 27 |

## 6.2 TDM-PSK-FDMA SYSTEM COSTS

Tables 6-7 through 6-12 show the systems costs for the TDM-PSK-FDMA system for each satellite and traffic model. The optimum G/T was selected from Figures 5-12 through 5-16. Because of the lower transponder capacity and therefore higher space segment cost, this G/T is higher than that for SCPC transmission. Therefore, the antenna costs are higher than with SCPC transmission.

Table 6-13 shows the baseband equipment costs that apply for TDM-PSK-FDMA transmission. Each station needs a receive chain for each transmission link. To keep the equipment requirements within practical limits, it was not possible to provide full interconnectivity between all

Table 6-7

System Costs

($1000)

Modulation System: TDM-PSK-FDMA
Satellite Type: Domestic C-Band
Earth Station G/T: 22 dB/K

HPA: 0.6 W/Ch. Av.
= -2.2 dBW/Ch. Av.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 35 | 26 | 910 | 10 | 350 | 211 | 7385 |
| HPA — Power dBW | | | | | | | |
| 1 Ch. — -2.2 | 10 | 10 | 100 | - | - | 100 | 1000 |
| 2 Ch. — 0.8 | 10 | 10 | 100 | - | - | - | - |
| 6 Ch. — 5.6 | 10 | 5 | 50 | - | - | 100 | 1000 |
| 20 Ch. — 10.8 | 13 | 1 | 13 | 10 | 130 | 10 | 130 |
| 200 Ch. — 20.8 | 22 | - | - | - | - | 1 | 22 |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | 11 | 170 | 1870 | 90 | 990 | 2510 | 27610 |
| Baseband Equipment (see Table 6-13) | | | 6371 | | 3706 | | 85310 |
| Total Ground Segment Subsystem Costs | | | 9700 | | 5286 | | 124778 |
| Annual Ground Segment | | | 4074 | | 2220 | | 52407 |
| Annual Space Segment | | | 130 | | 356 | | 1788 |
| TOTAL ANNUAL COSTS | | | 4204 | | 2576 | | 54195 |

Table 6-8

System Costs

($1000)

Modulation System: TDM-PSK-FDMA
Satellite Type: IS-IV, Global Beam
Earth Station G/T: 30 dB/K

HPA: 5.4 W/Ch. Av.
= 7.3 dBW/Ch. Av.

| Traffic Model | | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 78 | 26 | 2028 | 10 | 780 | 211 | |
| HPA | Power dBW | | | | | | | |
| 1 Ch. | 7.3 | 11 | 10 | 110 | - | - | 100 | |
| 2 Ch. | 10.3 | 13 | 10 | 130 | - | - | - | |
| 6 Ch. | 15.1 | 16 | 5 | 80 | - | - | 100 | |
| 20 Ch. | 20.3 | 21 | 1 | 21 | 10 | 210 | 10 | |
| 200 Ch. | 30.3 | 35 | - | - | - | - | 1 | |
| Up-Converter | | 11 | 26 | 286 | 10 | 110 | 211 | |
| Down-Converter | | 11 | 170 | 1870 | 90 | 990 | 2510 | |
| Baseband Equipment (see Table 6-13) | | | | 6371 | | 3706 | | 85310 |
| Total Ground Segment Subsystem Costs | | | | 10896 | | 5796 | | |
| Annual Ground Segment | | | | 4576 | | 2434 | | |
| Annual Space Segment | | | | 389 | | 1066 | | |
| TOTAL ANNUAL COSTS | | | | 4965 | | 3500 | | |

Modulation System: TDM-PSK-FDMA
Satellite Type: IS-IVA, Regional
Earth Station G/T: 26 dB/K

Table 6-9
System Costs
($1000)

HPA: 2.3 W/Ch. Av.
= 3.6 dBW/Ch. Av.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 50 | 26 | 1300 | 10 | 500 | 211 | |
| HPA — Power dBW | | | | | | | |
| 1 Ch. — 3.6 | 10 | 10 | 100 | - | - | 100 | |
| 2 Ch. — 6.6 | 10 | 10 | 100 | - | - | - | |
| 6 Ch. — 11.0 | 13 | 5 | 65 | - | - | 100 | |
| 20 Ch. — 16.6 | 17 | 1 | 17 | 10 | 170 | 10 | |
| 200 Ch. — 26.6 | 29 | | | | | 1 | |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | 211 | |
| Down-Converter | 11 | 170 | 1870 | 90 | 990 | 2510 | |
| Baseband Equipment (see Table 6-13) | | | 6371 | | 3706 | | 85310 |
| Total Ground Segment Subsystem Costs | | | 10109 | | 5476 | | |
| Annual Ground Segment | | | 4246 | | 2300 | | |
| Annual Space Segment | | | 259 | | 712 | | |
| TOTAL ANNUAL COSTS | | | 4505 | | 2712 | | |

Modulation System: TDM-PSK-FDMA
Satellite Type: DSCS II, Global Beam
Earth Station G/T: 30 dB/K

HPA: 1 W/Ch. Av.
= 0 dBW/Ch. Av.

Table 6-10
System Costs
($1000)

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 66 | 26 | 1716 | 10 | 660 | 211 | |
| HPA — Power dBW | | | | | | | |
| 1 Ch. — 0 | 13 | 10 | 130 | - | - | 100 | |
| 2 Ch. — 3 | 13 | 10 | 130 | - | - | - | |
| 6 Ch. — 7.8 | 14 | 5 | 70 | - | - | 100 | |
| 20 Ch. — 13 | 18 | 1 | 18 | 10 | 180 | 10 | |
| 200 Ch. — 23 | 31 | | | | | | |
| Up-Converter | 14 | 26 | 364 | 10 | 140 | 211 | |
| Down-Converter | 14 | 170 | 2380 | 90 | 1260 | 2510 | |
| Baseband Equipment (see Table 6-13) | | | 6371 | | 3706 | | 85310 |
| Total Ground Segment Subsystem Costs | | | 11179 | | 5946 | | |
| Annual Ground Segment | | | 4695 | | 2497 | | |
| Annual Space Segment | | | 489 | | 1342 | | |
| TOTAL ANNUAL COSTS | | | 5184 | | 3839 | | |

Modulation System: TDM-PSK-FDMA
Satellite Type: DSCS II, Spot Beam
Earth Station G/T: 22 dB/K

Table 6-11

System Costs

($1000)

HPA: 0.1 W-Ch. Av.
= -10 dBW/Ch. Av.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 26 | 1386 | 10 | 530 | 211 | |
| HPA — Power dBW | | | | | | | |
| 1 Ch. — -10 | 13 | 10 | 130 | - | - | 100 | |
| 2 Ch. — - 7 | 13 | 10 | 130 | - | - | - | |
| 6 Ch. — - 2 | 13 | 5 | 85 | - | - | 100 | |
| 20 Ch. — 3 | 13 | 1 | 13 | 10 | 130 | 10 | |
| 200 Ch. — 13 | 18 | - | - | - | - | 1 | |
| Up-Converter | 14 | 26 | 364 | 10 | 140 | 211 | |
| Down-Converter | 14 | 170 | 2380 | 90 | 1260 | 2510 | |
| Baseband Equipment (see Table 6-13) | | | 6371 | | 3706 | | 85310 |
| Total Ground Segment Subsystem Costs | | | 10859 | | 5766 | | |
| Annual Ground Segment | | | 4561 | | 2422 | | |
| Annual Space Segment | | | 160 | | 438 | | |
| TOTAL ANNUAL COSTS | | | 4721 | | 2860 | | |

Table 6-12

System Costs

($1000)

Modulation System: TDM-PSK-FDMA
Satellite Type: Domestic K-Band
Earth Station G/T: 28 dB/K

HPA: 0.2 W/Ch. Av.

| Traffic Model | | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|---|
| | | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | | 51 | 26 | 1326 | 10 | 510 | 211 | |
| HPA | Power dBW | | | | | | | |
| 1 Ch. | -7 | 13 | 10 | 130 | - | - | 100 | |
| 2 Ch. | -4 | 13 | 10 | 130 | - | - | - | |
| 6 Ch. | 0 | 13 | 5 | 65 | - | - | 100 | |
| 20 Ch. | 6 | 13 | 1 | 13 | 10 | 130 | 10 | |
| 200 Ch. | 17 | 23 | - | - | - | - | 1 | |
| Up-Converter | | 14 | 26 | 364 | 10 | 140 | 211 | |
| Down-Converter | | 14 | 170 | 2380 | 90 | 1260 | 2510 | |
| Baseband Equipment (see Table 6-13) | | | | 6371 | | 3706 | | 85310 |
| Total Ground Segment Subsystem Costs | | | | 10779 | | 5746 | | |
| Annual Ground Segment | | | | 4527 | | 2413 | | |
| Annual Space Segment | | | | 367 | | 1006 | | |
| TOTAL ANNUAL COSTS | | | | 4894 | | 3419 | | |

Table 6-13
TDM-PSK-FDMA System
Baseband Equipment Costs

| | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Central Station | | | | | | | |
| Transmit Link | 45 | 1 | 45 | 1 | 45 | 1 | 45 |
| Receive Link | 29 | 25 | 725 | 9 | 261 | 210 | 6090 |
| Common Equipment | 55 | 1 | 55 | 1 | 55 | 1 | 55 |
| Remote Station | | | | | | | |
| Transmit Link | 20 | 25 | 500 | 9 | 180 | 210 | 4200 |
| Receive Link | 29 | 145 | 4205 | 81 | 2349 | 2300 | 66700 |
| Common Equipment | 25 | 24 | 625 | 9 | 225 | 210 | 5250 |
| Transmit Channels | 1.0 | 80 | 80 | 219 | 219 | 1100 | 1100 |
| Receive Channels | 1.7 | 80 | 136 | 219 | 372 | 1100 | 1870 |
| TOTAL | | | 6371 | | 3706 | | 85310 |

earth stations. For the low capacity and the high capacity models, the connectivity between stations type A, B, C and D was limited to that shown in section 3.1.2. For the medium capacity model, full interconnectivity was assumed.

Even with the limited interconnectivity, the high capacity model requires baseband equipment in the amount of $83 million, compared to less than $10 million in the case of SCPC. The former case is therefore not practical and has been shown only on Table 6-7 for reference.

TDM-PSK-FDMA transmission results in higher costs than SCPC transmission in all cases examined. Antenna costs are higher, more down-converters are required, baseband equipment costs are higher and space segment costs are higher.

## 6.3 TDMA SYSTEM COSTS

Tables 6-14 through 6-19 show the systems costs for the conventional TDMA system, where the total bandwidth and power of the transponder is used for TDMA transmission. Since the traffic models always require less than the full bit rate of the transponder in bandwidth limited operation, it was assumed that the TDMA frame would be shared with other users and that only the pro-rated portion of the transponder lease rate would be applied.

Modulation System: TDMA
Satellite Type: Domestic, C-Band
Earth Station G/T: 25 dB/K

Table 6-14
System Costs
($1000)

HPA: 550 W = 27.4 dBW

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 46 | 26 | 1196 | 10 | 460 | 211 | 9706 |
| HPA | 30 | 26 | 780 | 10 | 300 | 211 | 6330 |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | 1 | 340 |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | 210 | 26040 |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | 1100 | 2640 |
| Total Ground Segment Subsystem Costs | | | 6180 | | 2962 | | 49698 |
| Annual Ground Segment | | | 2596 | | 1244 | | 20873 |
| Annual Space Segment | | | 86 | | 235 | | 1183 |
| TOTAL ANNUAL COSTS | | | 2682 | | 1479 | | 22056 |

Modulation System: TDMA
Satellite Type: IS IV, Global Beam
Earth Station G/T: 36 dB/K

Table 6-15
System Costs
($1000)

HPA: 650 W = 28.1 dBW

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 554 | 26 | 14404 | 10 | 5540 | 211 | 116894 |
| HPA | 32 | 26 | 832 | 10 | 320 | 211 | 6752 |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | 1 | 340 |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | 210 | 26040 |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | 1100 | 2640 |
| Total Ground Segment Subsystem Costs | | | 19440 | | 8062 | | 157308 |
| Annual Ground Segment | | | 8165 | | 3386 | | 66069 |
| Annual Space Segment | | | 129 | | 353 | | 1774 |
| TOTAL ANNUAL COSTS | | | 8294 | | 3738 | | 67843 |

Modulation System: TDMA
Satellite Type: IS-IVA, Regional
Earth Station G/T: 29 dB/K

HPA: 2200 W = 33.4 dBW

Table 6-16
System Costs
($1000)

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 67 | 26 | 1742 | 10 | 670 | 211 | 14137 |
| HPA | 41 | 26 | 1066 | 10 | 410 | 211 | 8651 |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Down-Converter | 11 | 26 | 286 | 10 | 110 | 211 | 2321 |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | 1 | 340 |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | 210 | 26040 |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | 1100 | 2640 |
| Total Ground Segment Subsystem Costs | | | 7012 | | 3282 | | 56450 |
| Annual Ground Segment | | | 2945 | | 1378 | | 23709 |
| Annual Space Segment | | | 172 | | 471 | | 2366 |
| TOTAL ANNUAL COSTS | | | 3117 | | 1849 | | 26075 |

Table 6-17
System Costs
($1000)

Modulation System: TDMA
Satellite Type: DSCS II, Global Beam
Earth Station G/T: 39 dB/K

HPA: 1200 W = 30.8 dBW

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 480 | 26 | 12480 | 10 | 4800 | 211 | 101280 |
| HPA | 47 | 26 | 1217 | 10 | 470 | 211 | 9917 |
| Up-Converter | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Down-Converter | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | 1 | 340 |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | 210 | 26040 |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | 1100 | 2640 |
| Total Ground Segment Subsystem Costs | | | 18057 | | 7532 | | 146125 |
| Annual Ground Segment | | | 7584 | | 3167 | | 61373 |
| Annual Space Segment | | | 93 | | 255 | | 1279 |
| TOTAL ANNUAL COSTS | | | 7677 | | 3418 | | 62652 |

Table 6-18
System Costs
($1000)

Modulation System: TDMA
Satellite Type: DSCS II, Spot Beam
Earth Station G/T: 24 dB/K

HPA: 630 W = 28 dBW

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 47 | 26 | 1222 | 10 | 470 | 211 | 9917 |
| HPA | 40 | 26 | 1040 | 10 | 400 | 211 | 8440 |
| Up-Converter | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Down-Converter | 14 | 26 | 364 | 10 | 140 | 211 | 2954 |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | 1 | 340 |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | 210 | 26040 |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | 1100 | 2640 |
| Total Ground Segment Subsystem Costs | | | 6622 | | 3132 | | 53285 |
| Annual Ground Segment | | | 2781 | | 1315 | | 22380 |
| Annual Space Segment | | | 124 | | 340 | | 1705 |
| TOTAL ANNUAL COSTS | | | 2905 | | 1655 | | 24085 |

Table 6-19
System Costs
($1000)

Modulation System: TDMA
Satellite Type: Domsat K-Band
Earth Station G/T: 34.3 dB/K

HPA: 650 W = 28.1 dBW

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 66 | 26 | 1716 | 10 | | 211 | 13926 |
| HPA | 42 | 26 | 1092 | 10 | | 211 | 8862 |
| Up-Converter | 14 | 26 | 364 | 10 | | 211 | 2954 |
| Down-Converter | 14 | 26 | 364 | 10 | | 211 | 2954 |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | 1 | 340 |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | 210 | 26040 |
| Channel Units | 2 | 80 | 192 | 219 | 526 | 1100 | 2640 |
| Total Ground Segment Subsystem Costs | | | 7168 | | 3342 | | 57716 |
| Annual Ground Segment | | | 3011 | | 1404 | | 24241 |
| Annual Space Segment | | | 115 | | 314 | | 1577 |
| TOTAL ANNUAL COSTS | | | 3126 | | 1718 | | 25818 |

## 6.4 SYSTEMS COSTS WITH TDMA-FDMA TRANSMISSION

In this transmission mode, the TDMA carrier shares transponder bandwidth and power with other services. The transponder TWT operates at a back-off, similar to operation with PSK-FDMA. In this case, the transponder capacity is not adequate to satisfy the high capacity traffic model. System costs are shown in Tables 6-20 through 6-25.

## 6.5 TDMA WITH REDUCED BIT RATE

Another alternative for TDMA transmission is the reduction of the TDMA bit rate and the use of a full transponder for the system. This permits reduction of antenna size and operation of the transponder at a large back-off; however, the full transponder charge is applied to the system.

The results of this transmission mode are shown in Table 6-26 for the low capacity traffic model and the domestic C-band transponder. This transmission mode is not promising, since the cost savings from reduced antenna and HPA size are less than the extra space segment costs.

Modulation System: TDM-PSK-TDMA-FDMA
Satellite Type: Domestic, C-Band
Earth Station G/T: 22 dB/K

Table 6-20
System Costs
($1000)

HPA: 0.6 W/Ch.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 35 | 26 | 910 | 10 | 350 | | |
| HPA Power dBW | | | | | | | |
| 18.8 | 18 | 26 | 468 | 10 | 220 | | |
| 21.2 | 22 | | | | | | |
| Up-Converter | 11 | 26 | 286 | 10 | 110 | | |
| Down-Converter | 11 | 26 | 285 | 10 | 110 | | |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | | |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | | |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | | |
| Total Ground Segment Subsystem Costs | | | 5582 | | 2772 | | |
| Annual Ground Segment | | | 2344 | | 1164 | | |
| Annual Space Segment | | | 461 | | 1262 | | |
| TOTAL ANNUAL COSTS | | | 2805 | | 2426 | | |

Table 6-21
System Costs
($1000)

Modulation System: TDM-PSK-TDMA-FDMA
Satellite Type: IS IV, Global Beam
Earth Station G/T: 30 dB/K

HPA: 5.4 W/Ch.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 78 | 26 | 2028 | 10 | | | |
| HPA Power dBW | | | | | | | |
| 26.4 | 29 | 26 | 754 | 10 | | | |
| 30.7 | 36 | | | | | | |
| Up-Converter | 11 | 26 | 286 | 10 | | | |
| Down-Converter | 11 | 26 | 286 | 10 | | | |
| Common Equip.-Cent.. | 340 | 1 | 340 | 1 | 340 | | |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | | |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | | |
| Total Ground Segment Subsystem Costs | | | 6986 | | | | |
| Annual Ground Segment | | | 2934 | | | | |
| Annual Space Segment | | | 1377 | | | | |
| TOTAL ANNUAL COSTS | | | 4311 | | | | |

Modulation System: TDM-PSK-TDMA-FDMA
Satellite Type: IS-IVA, Regional
Earth Station G/T: 26 dB/K

Table 6-22
System Costs
($1000)

HPA: 2.3 W/Ch.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 50 | 26 | 1300 | 10 | 500 | | |
| Hpa — Power dBW 22.6 / 27.0 | 24 / 29 | 26 | 624 | 10 | 290 | | |
| Up-Converter | | 26 | 286 | 10 | 110 | | |
| Down-Converter | | 26 | 286 | 10 | 110 | | |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | | |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | | |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | | |
| Total Ground Segment Subsystem Costs | | | 6128 | | 2992 | | |
| Annual Ground Segment | | | 2574 | | 1257 | | |
| Annual Space Segment | | | 923 | | 2524 | | |
| TOTAL ANNUAL COSTS | | | 3497 | | 3781 | | |

Table 6-23

System Costs

($1000)

Modulation System: TDM-PSK-TDMA-FDMA
Satellite Type: DSCS II, Global Beam
Earth Station G/T: 30 dB/K

HPA: 1 W/Ch.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 66 | 26 | 1716 | 10 | | | |
| HPA Power dBW 19 | 20 | 26 | 520 | 10 | | | |
| Up-Converter | 14 | 26 | 364 | 10 | | | |
| Down-Converter | 14 | 26 | 364 | 10 | | | |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | | |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | | |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | | |
| Total Ground Segment Subsystem Costs | | | 6596 | | | | |
| Annual Ground Segment | | | 2770 | | | | |
| Annual Space Segment | | | 1739 | | | | |
| TOTAL ANNUAL COSTS | | | 4509 | | | | |

Table 6-24

System Costs

($1000)

Modulation System: TDM-PSK-TDMA-FDMA
Satellite Type: DSCS II, Spot Beam
Earth Station G/T: 22 dB/K

HPA: 0.1 W/Ch.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 53 | 26 | 1378 | 10 | 530 | | |
| HPA Power dBW | | | | | | | |
| 9.0 | 16 | 26 | 416 | 10 | 180 | | |
| 13.4 | 18 | | | | | | |
| Up-Converter | 14 | 26 | 364 | 10 | 140 | | |
| Down-Converter | 14 | 26 | 364 | 10 | 140 | | |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | | |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | | |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | | |
| Total Ground Segment Subsystem Costs | | | 6154 | | 2972 | | |
| Annual Ground Segment | | | 2585 | | 1248 | | |
| Annual Space Segment | | | 463 | | 1266 | | |
| TOTAL ANNUAL COSTS | | | 3048 | | 2514 | | |

Modulation System: TDM-PSK-TDMA-FDMA
Satellite Type: Domestic, K-Band
Earth Station G/T: 28 dB/K

Table 6-25
System Costs
($1000)

HPA: 0.2 W/Ch.

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 51 | 26 | 1326 | 10 | | | |
| HPA Power dBW 12 | 18 | 26 | 468 | 10 | | | |
| Up-Converter | 14 | 26 | 364 | 10 | | | |
| Down-Converter | 14 | 26 | 364 | 10 | | | |
| Common Equip.-Cent. | 340 | 1 | 340 | 1 | 340 | | |
| Common Equip.-Remote | 124 | 25 | 3100 | 9 | 1116 | | |
| Channel Units | 2.4 | 80 | 192 | 219 | 526 | | |
| Total Ground Segment Subsystem Costs | | | 6154 | | | | |
| Annual Ground Segment | | | 2585 | | | | |
| Annual Space Segment | | | 1304 | | | | |
| TOTAL ANNUAL COSTS | | | 3889 | | | | |

Table 6-26

System Costs

($1000)

Modulation System: TDMA - Reduced Rate
Satellite Type: Domestic C-Band
Earth Station G/T: 20 dB/K

| Traffic Model | Unit Cost | Low Capacity | | Medium Capacity | | High Capacity | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| Antenna & LNR | 30 | 26 | 780 | | | | |
| HPA 19.6 dBW | 20 | 26 | 520 | | | | |
| Up-Converter | 11 | 26 | 286 | | | | |
| Down-Converter | 11 | 26 | 286 | | | | |
| Common Equip.-Cent. | 340 | 1 | 340 | | | | |
| Common Equip.-Remote | 124 | 25 | 3100 | | | | |
| Channel Units | 2.4 | 80 | 192 | | | | |
| Total Ground Segment Subsystem Costs | | | 5504 | | | | |
| Annual Ground Segment | | | 2312 | | | | |
| Annual Space Segment | | | 2000 | | | | |
| TOTAL ANNUAL COSTS | | | 4312 | | | | |

## 6.6 COST COMPARISON

Tables 6-27 through 6-29 show the summary of annual systems costs of all cases that have been investigated. PSK-SCPC transmission is always accomplished at the lowest systems cost.

Table 6-30 shows a cost comparison for the different modulation techniques, based on average systems costs for all satellite types considered.

Table 6-31 is a normalized systems operation based on the average costs of Table 6-30.

Table 6-27

Systems Cost Comparison

Low Capacity Model

Annual Costs ($1000)

| Modulation System | PSK-SCPC | TDM-PSK-FDMA | TDMA Max. Bit Rate | TDMA-FDMA | TDMA Reduced Rate |
|---|---|---|---|---|---|
| DSCS II, Global Beam | 1786 | 5184 | 7677 | 5409 | |
| DSCS II, Spot Beam | 1267 | 4721 | 2905 | 3048 | |
| Domestic, C-Band | 1111 | 4204 | 2682 | 2805 | 4312 |
| Domestic, K-Band | 1346 | 4894 | 3126 | 3889 | |
| INTELSAT IV, Global | 1524 | 4965 | 8294 | 4311 | |
| INTELSAT IV-A, Regional | 1269 | 4505 | 3117 | 3497 | |
| Average | 1384 | 4746 | 4633 | 3826 | 4312 |

Table 6-28

Systems Cost Comparison

Medium Capacity Model

Annual Costs ($1000)

| Modulation System | PSK-SCPC | TDM-PSK-FDMA | TDMA Max. Bit Rate | TDMA-FDMA | TDMA Reduced Rate |
|---|---|---|---|---|---|
| DSCS II, Global Beam | 2085 | 3839 | 3418 | | |
| DSCS II, Spot Beam | 1294 | 2860 | 1655 | 2514 | |
| Domestic, C-Band | 1146 | 2576 | 1479 | 2426 | |
| Domestic, K-Band | 1692 | 3419 | 1718 | | |
| INTELSAT IV, Global | 1818 | 3500 | 3738 | | |
| INTELSAT IV-A, Regional | 1484 | 2712 | 1849 | 3781 | |
| Average | 1590 | 3150 | 2310 | 2907 | |

Table 6-29

Systems Cost Comparison

High Capacity Model

Annual Costs ($1000)

| Modulation System | PSK-SCPC | TDM-PSK-FDMA | TDMA Max. Bit Rate | TDMA-FDMA | TDMA Reduced Rate |
|---|---|---|---|---|---|
| DSCS II, Global Beam | 17022 | | 62652 | | |
| DSCS II, Spot Beam | 11809 | | 24085 | | |
| Domestic, C-Band | 10339 | 54195 | 22056 | | |
| Domestic, K-Band | 13241 | | 25818 | | |
| INTELSAT IV, Global | 14737 | | 67843 | | |
| INTELSAT IV-A, Regional | 12164 | | 26075 | | |
| Average | 13220 | 54195 | 38088 | | |

Table 6-30
Averaged Systems Cost Comparison
Annual Costs ($1000)

| Traffic Model | Low Capacity | Medium Capacity | High Capacity |
|---|---|---|---|
| PSK-SCPC | 1384 | 1590 | 13220 |
| TDM-PSK-FDMA | 4746 | 3150 | 54195 |
| TDMA-Max. Bit Rate | 4633 | 2310 | 38088 |
| TDMA-FDMA | 3826 | 2907 | |
| TDMA-Reduced Rate | 4312 | | |

Table 6-31

Normalized Systems Cost Comparison

Annual Costs, PSK-SCPC = 1.00

| Traffic Model | Low Capacity | Medium Capacity | High Capacity | Average |
|---|---|---|---|---|
| PSK-SCPC | 1.00 | 1.00 | 1.00 | 1.00 |
| TDM-PSK-FDMA | 3.43 | 1.98 | 4.10 | 3.03 |
| TDM-Max. Bit Rate | 3.35 | 1.45 | 2.88 | 2.41 |
| TDMA-FDMA | 2.76 | 1.83 | | 2.25 |
| TDMA-Reduced Rate | 3.14 | | | 3.14 |

## Section 7
## GENERAL COST COMPARISON

General cost models have been generated to permit determination of the break-even channel capacity for PSK-SCPC versus TDMA transmission. It was found that the TDM-PSK-FDMA transmission technique results in higher costs than SCPC or TDMA transmission, in addition to providing only limited interconnectivity. The TDM-PSK-FDMA technique has therefore been eliminated from further consideration.

### 7.1 GENERAL PSK-SCPC COST MODEL

Based on the work presented in preceding sections, the PSK-SCPC systems costs can be approximated by the following relationship:

$$A = [C_1 + (C_2 + C_3 + C_4 + C_5)m + (C_6 + C_7)n]a + \frac{A_1}{x} \cdot \frac{n}{1.5}$$

where:

- $A$ = total annual systems costs
- $C_1$ = central station common equipment cost minus remote station common equipment cost
- $C_2$ = cost of antenna and LNR
- $C_3$ = fixed portion of HPA cost
- $C_4$ = cost of up- and down- converter
- $C_5$ = cost of remote station common equipment
- $m$ = number of earth stations in the system
- $C_6$ = cost of channel equipment, per channel
- $C_7$ = variable cost of HPA, per channel
- $A_1$ = annual transponder lease cost
- $x$ = transponder channel capacity

n = number of channel units in the system. for SCPC it is assumed that the number of space segment channels is $\frac{n}{1.5}$

a = annualizing factor

The above equation may be rearranged to consist of three terms: A fixed term, a term proportional to the number of earth stations in the system and a term proportional to the number of channels in the system.

$$A = aC_1 + ma\left(C_2 + C_3 + C_4 + C_5\right) + n\left[a(C_6 + C_7) + \frac{A_1}{1.5x}\right]$$

Earth station HPA costs were found to have only a minor impact on the total systems costs. For this reason, they will be approximated by a fixed term for each earth station and a variable term depending on the total number of channels in the system. The result is within the accuracy of the assumptions.

The following terms depend on the specific satellite type selected: $C_2$, $C_3$, $C_4$, $A_1$ and x. The applicable numbers have been listed in Table 7-1.

With PSK-SCPC, the required space segment capacity is lower than the number of channel units. This relationship is shown in Section 5.1.1 for the three traffic models. For these general calculations, a concentration factor of 1.5 has been used. The space segment cost term is reduced by this factor in the above equations.

Table 7-1

Input Values for General Cost Calculations for PSK-SCPC Transmission

Costs in $1000

| | DSCS II Global | DSCS II Spot | Domestic C-Band | Domestic K-Band* | IS IV Global | IS IV-A Regional |
|---|---|---|---|---|---|---|
| $C_1$ | 93 | 93 | 93 | 93 | 93 | 93 |
| $C_2$ | 65 | 34 | 30 | 42 | 50 | 35 |
| $C_3$ | 26 | 18 | 15 | 14 | 27 | 22 |
| $C_4$ | 28 | 28 | 22 | 28 | 22 | 22 |
| $C_5$ | 12 | 12 | 12 | 12 | 12 | 12 |
| $C_6$ | 6 | 6 | 6 | 6 | 6 | 6 |
| $C_7$ | 0.4 | 0.3 | 0.2 | 0.2 | 0.4 | 0.3 |
| $A_1$ | 3000 | 4000 | 2000 | 4000 | 3000 | 4000 |
| x | 490 | 2000 | 1440 | 2160 | 617 | 1230 |

*The G/T was increased from 24 to 28 dB/K to reduce space segment costs. The resulting increase of antenna cost was $8k, the reduction in HPA cost was $4k. The increase in transponder capacity was from 871 to 2,160 channels.

Using the values of Table 7-1, the relationships shown in Table 7-2 have been developed:

Table 7-2

Annual Cost Formulas for PSK-SCPC Transmission

| Satellite Type | Annual Costs in $1000 |
|---|---|
| DSCS II, Global Beam | A = 39.1 + 55.0m + 6.8n |
| DSCS II, Spot Beam | A = 39.1 + 38.6m + 4.0n |
| Domestic, C-Band | A = 39.1 + 33.2m + 3.5n |
| Domestic, K-Band | A = 39.1 + 40.3m + 3.8n |
| INTELSAT IV, Global Beam | A = 39.1 + 46.6m + 5.9n |
| INTELSAT IV-A, Regional | A = 39.1 + 38.2m + 4.8n |

## 7.2 GENERAL TDMA COST MODEL

In this model, it is assumed that the system operates at the maximum transponder bit rate that is possible within 16 kBps delta modulation and 2 phase PSK. The time frame is shared with other services and only that portion of the time required to meet the traffic model is charged to the TDMA systems costs.

$$A' = [C'_1 + (C'_2 + C'_3 + C'_4 + C'_5)m + nC'_6]a + \frac{A_1}{X'} \cdot n$$

The same terminology applies as in Section 7.1, but the TDMA quantities are designated as "prime" (e.g. A'). Again, this equation is rearranged into a fixed term, a term proportional to the number of earth stations in the system and a term porportional to the number of channels in the system. All HPAs must operate at the maximum bit rate, therefore, there is no channel dependent term for HPA costs in the above expression.

$$A' = aC'_1 + ma[C'_2 + C'_3 + C'_4 + C'_5] + n\left[aC'_6 + \frac{A_1}{X'}\right]$$

Cost values applicable to the TDMA system are shown in Table 7-3.

Table 7-3

Input Values for General Cost Calculations for TDMA Transmission

($1000)

| | DSCS II Global | DSCS II Spot | Domestic C-Band | Domestic K-Band | IS IV Global | IS IV-A Regional |
|---|---|---|---|---|---|---|
| $C'_1$ | 216 | 216 | 216 | 216 | 216 | 216 |
| $C'_2$ | 480 | 47 | 46 | 66 | 554 | 67 |
| $C'_3$ | 47 | 40 | 30 | 42 | 32 | 41 |
| $C'_4$ | 28 | 28 | 22 | 28 | 22 | 22 |
| $C'_5$ | 124 | 124 | 124 | 124 | 124 | 124 |
| $C'_6$ | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| $A_1$ | 3000 | 4000 | 2000 | 4000 | 3000 | 4000 |
| $x'$ | 2580 | 2580 | 1860 | 2790 | 1860 | 1860 |

The resulting annual cost formulas are shown in Table 7-4.

Table 7-4

Annual Cost Formulas for TDMA Transmission

| Satellite Type | Annual Costs in $1000 |
|---|---|
| DSCS II, Global Beam | A' = 90.7 + 285.2m + 2.2n |
| DSCS II, Spot Beam | A' = 90.7 + 100.4m + 2.6n |
| Domestic, C-Band | A' = 90.7 + 92.4m + 2.1n |
| Domestic, K-Band | A' = 90.7 + 109.2m + 2.4n |
| INTELSAT IV, Global Beam | A' = 90.7 + 307.4m + 2.6n |
| INTELSAT IV-A, Regional | A' = 90.7 + 106.7m + 3.2n |

## 7.3 CALCULATION OF BREAK-EVEN POINT

The break-even point for PSK-SCPC transmission and TDMA transmission has been calculated based on the formulas in Tables 7-2 and 7-4. The break-even formulas are shown in Table 7-5.

Table 7-5
Break-Even Formulas

| Satellite Type | Break-Even Channel Capacity (Channel Units per System) |
|---|---|
| DSCS II, Global Beam | n = 11 + 50m |
| DSCS II, Spot Beam | n = 37 + 44m |
| Domestic, C-Band | n = 37 + 42m |
| Domestic, K-Band | n = 37 + 49m |
| INTELSAT IV, Global Beam | n = 16 + 79m |
| INTELSAT IV-A, Regional | n = 32 + 43m |
| Average | n = 30 + 50m |

Average break-even capacities are shown in Table 7-6.

Table 7-6
Average Break-Even Capacities

| Number of Earth Stations Per System | Number of Channel Units Per System | Number of Channel Units Per Earth Station |
|---|---|---|
| 3 | 180 | 60 |
| 5 | 280 | 56 |
| 10 | 530 | 53 |
| 100 | 5,030 | 50 |

## 7.4 GENERALIZED CALCULATION OF COST DIFFERENCE

A generalized calculation of cost difference between SCPC systems and TDMA systems is given below for the three satellite types. It will be noted that the cost differences are similar for the systems working with spot beam transponders as a group and are also similar for those systems working with the two global beam transponders. Average formulas have therefore been generated, covering the case of spot beam and global beam transponders.

Table 7-7
Cost Difference Formulas
Annual Cost Difference in $1000

| Transponder Type | Cost Difference: A' - A<br>TDMA Minus SCPC System Costs |
|---|---|
| DSCS II, Global Beam | A' - A = 52 + 230m - 4.6n |
| INTELSAT IV, Global Beam | A' - A = 52 + 261m - 3.3n |
| Average Global Beam Transponder | A' - A = 52 + 246m - 4.0n |
| DSCS II, Spot Beam | A' - A = 52 + 62m - 1.4n |
| Domestic, C-Band | A' - A = 52 + 60m - 1.4n |
| Domestic, K-Band | A' - A = 52 + 69m - 1.4n |
| INTELSAT IV-A, Regional | A' - A = 52 + 69m - 1.6n |
| Average Spot Beam Transponder | A' - A = 52 + 65m - 1.5n |

Figures 7-1 and 7-2 are graphs of cost differences calculated for systems operating with an average global beam or spot beam transponder. In the upper portion of the graphs, the SCPC systems are cheaper; in the lower portion the TDMA systems are cheaper.

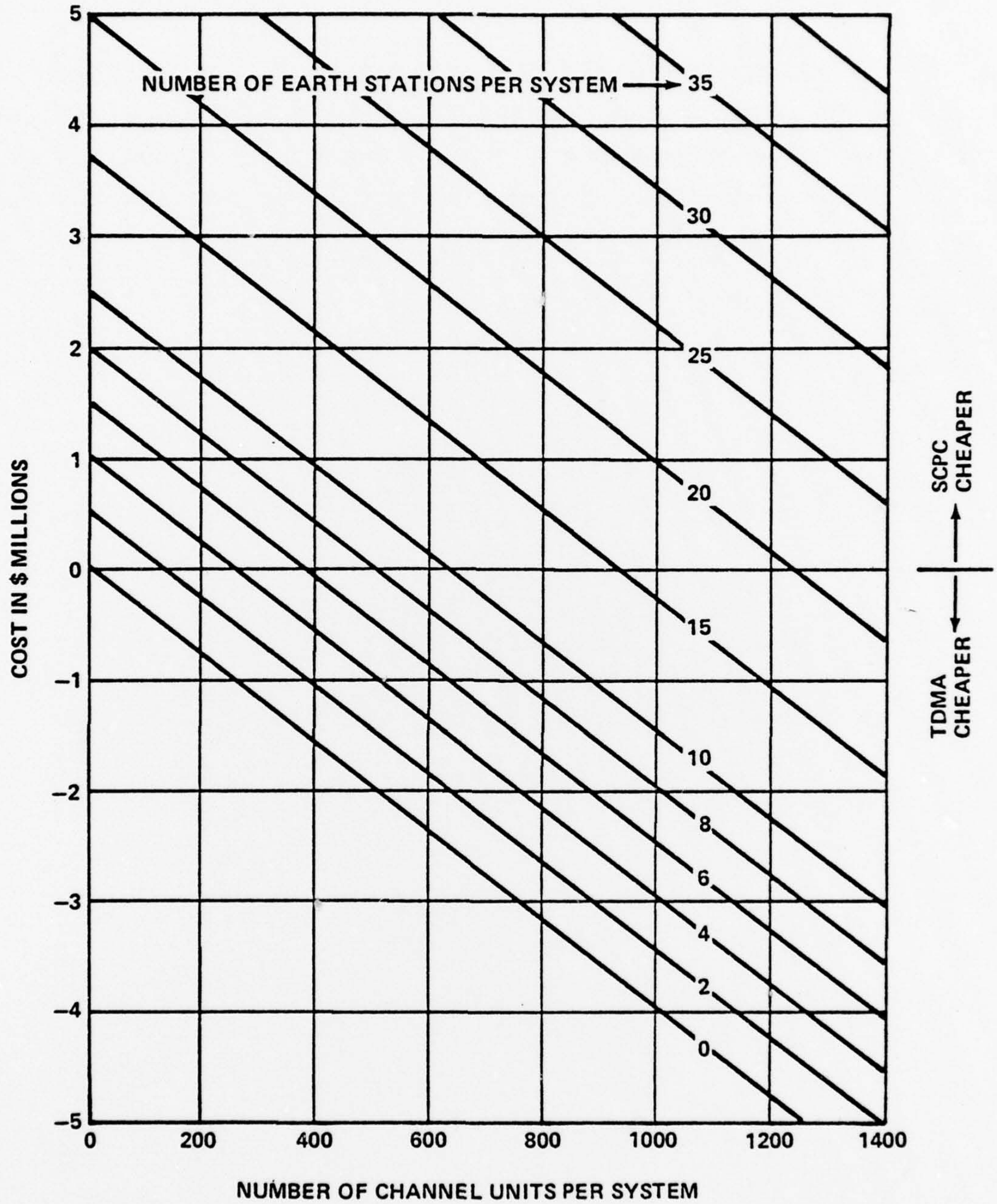



FIGURE 7–1

ANNUAL COST DIFFERENCE IN $ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL GLOBAL BEAM TRANSPONDER

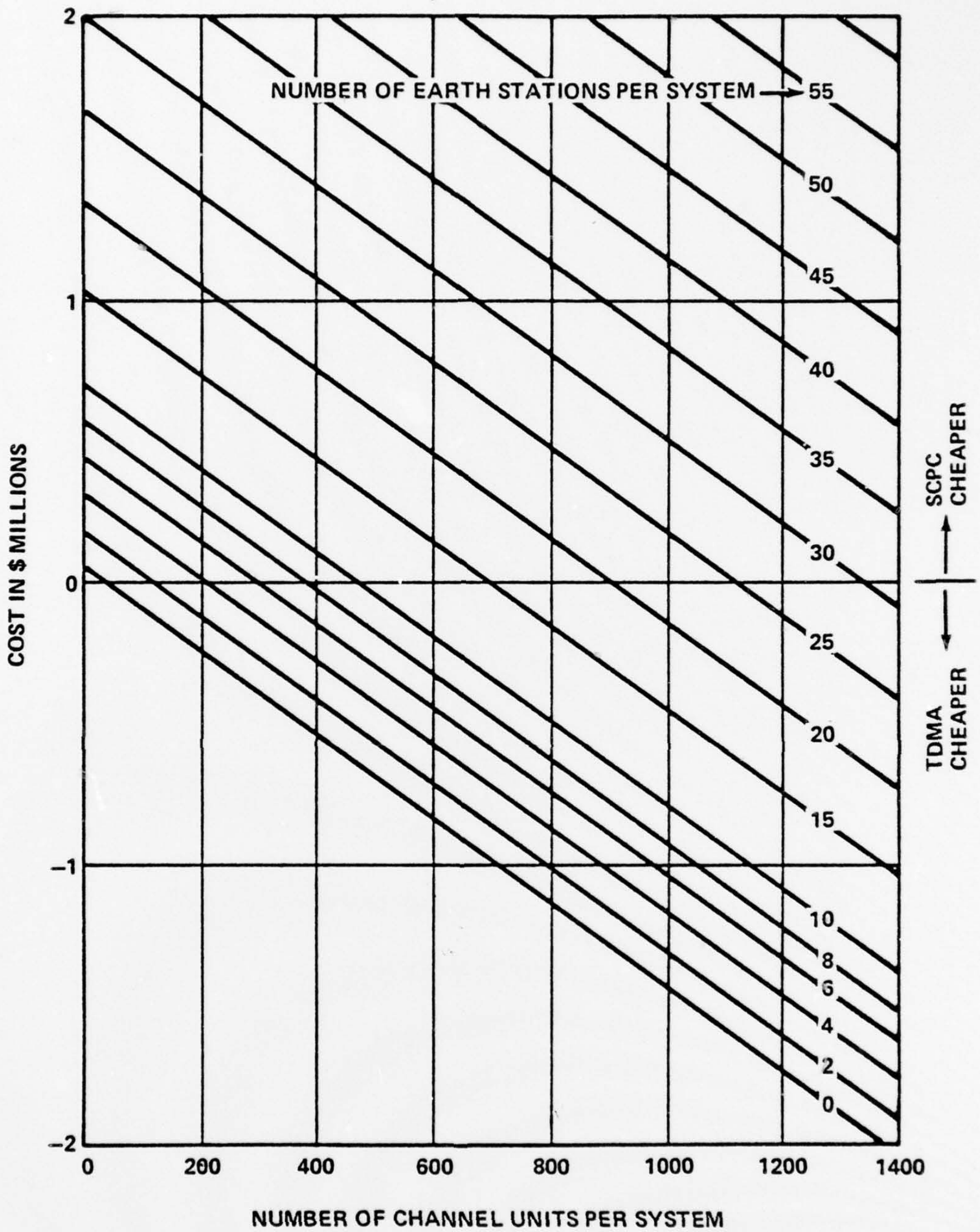



FIGURE 7–2

ANNUAL COST DIFFERENCE IN $ MILLION
TDMA SYSTEM COSTS MINUS SCPC
SYSTEM COSTS FOR OPERATION WITH
A TYPICAL SPOT BEAM TRANSPONDER

# Section 8
## SENSITIVITY STUDY

In this Section, the sensitivity of the study results to the assumptions has been examined.

### 8.1 SENSITIVITY TO EARTH STATION COST VARIATIONS

Earth station cost can vary widely, depending on the type of specifications, quantities of equipment procured and location of installation. For this reason, it is interesting to investigate the sensitivity of the study results to changes in the cost assumptions.

Section 4.2.6 shows that digital baseband equipment procured to Mil Specs costs about twice as must as commercial equipment. It was assumed that the same cost ratio also applies for all other earth station equipment and the break-even capacities were calculated on this basis. The comparison of the results with those for commercial equipment is shown in Table 8-1.

Table 8-1

COMPARISON OF BREAK-EVEN CAPACITIES
(number of channel units in the system)

| Transponder Type | Break-Even Capacity With Mil Spec Equip. | Break-Even Capacity With Commercial Equip. |
|---|---|---|
| DSCS II, Global Beam | n = 16 + 73m | n = 11 + 50m |
| DSCS II, Spot Beam | n = 34 + 41m | n = 37 + 44m |
| Domestic, C-Band | n = 34 + 40m | n = 37 + 42m |
| Domestic, K-Band | n = 28 + 37m | n = 37 + 49m |
| INTELSAT IV, Global Beam | n = 21 + 104m | n = 16 + 79m |
| INTELSAT IV-A, Regional | n = 31 + 42m | n = 32 + 43m |
| Average | n = 27 + 56m | n = 30 + 50m |

In this comparison, it was found that with Mil Spec equipment the break-even capacities for operation with global beam transponders increase by about 25 channels per earth station and that the break-even capacities for operation with spot beam transponders remain about the same. As the result the average break-even capacity for all transponders considered increased by about 10%.

## 8.2 SENSITIVITY TO SPACE SEGMENT COST VARIATIONS

The study uses 6 different transponders with transponder lease rates varying from $2 Million to $4 Million per year. Thus, the results already take into account the above range of transponder space segment cost variations.

In this section, the break-even capacities have been calculated, based on the assumption that space segment would be available free of charge to the system's user. The equipment cost base was kept at Mil Spec equipment level. The break-even capacity increased further to about 140 channels per earth station. This is to be expected, since the per channel space segment requirement for global beam operation is much higher than for spot beam operation. The results are shown in Table 8-2.

Table 8-2

BREAK-EVEN CAPACITIES IN THE ABSENCE OF SPACE SEGMENT CHARGES

| Transponder Type | Break-Even Capacity With Mil Spec Equipment |
|---|---|
| DSCS II, Global Beam | n = 30 + 135m |
| DSCS II, Spot Beam | n = 31 + 38m |
| Domestic, C-Band | n = 32 + 37m |
| Domestic, K-Band | n = 32 + 43m |
| INTELSAT IV, Global Beam | n = 30 + 153m |
| INTELSAT IV-A, Regional | n = 31 + 42m |
| Average | n = 31 + 75m |

## 8.3 BREAK-EVEN CAPACITIES WITH BASEBAND EQUIPMENT COSTS ONLY

In this Section, the break-even capacities are calculated, taking into account only baseband equipment costs.

$$C = C_1 + mC_5 + nC_6$$

$$C = C'$$

$$n = \frac{[C_1' - C_1] + m[C_5' - C_5]}{[C_6' - C_6]}$$

$$n = 34 + 31m$$

Thus, the costs of the baseband equipment alone lead to a break-even capacity of over 30 channels per earth station. The RF equipment costs further increase the break-even capacity.

## 8.4 TDMA SYSTEMS WITH FULLY VARIABLE DEMAND ASSIGNMENT

In such systems the burst length of each earth station is adjusted in accordance with its instantaneous traffic requirement. The cost of a non-redundant terminal is estimated to be $250K, compared with $124K for equipment with only variable destination demand assignment.

The increase of annual cost due to the more extensive TDMA equipment can be compared with the cost saving resulting from space segment cost reduction. The highest cost per channel for all transponders considered, namely that of INTELSAT IV-A, was used. The cost per channel for the six transponder types is shown below.

| Transponder Type | Annual Lease* Cost ($1000) | Transponder** Capacity | Annual Space Segment Cost Per Channel ($1000) |
|---|---|---|---|
| INTELSAT IV, Global | 3000 | 1860 | 1.61 |
| INTELSAT IV-A, Regional | 4000 | 1860 | 2.15 |
| Domestic, C-Band | 2000 | 1860 | 1.08 |
| Domestic, K-Band | 4000 | 2790 | 1.43 |
| DSCS II, Global Beam | 3000 | 2580 | 1.16 |
| DSCS II, Spot Beam | 4000 | 4000 | 1.55 |

* From Table 4-1
** From Table 5-24

The cost reduction due to fewer space segment channels required with fully variable demand assigned TDMA is shown below for the three Traffic Models.

SPACE SEGMENT COST SAVINGS

| Traffic Model | Number of Channels* Variable Destination | Space Seg. with Full Demand Assignment | Difference Number of Channels | Annual Cost Saving for IS IV-A, $1000 |
|---|---|---|---|---|
| Low Capacity | 80 | 29 | 51 | 110 |
| Medium Capacity | 219 | 152 | 67 | 144 |
| High Capacity | 1100 | 518 | 582 | 1251 |

*From executive summary

The increased ground segment cost for fully variable demand assigned TDMA equipment for the three traffic models is shown below. A cost difference of $126k in investment cost applies to each remote ground station, and twice that amount to the central station. An annualizing factor of 0.42 is used, as explained in section 6.1.

GROUND SEGMENT COST INCREASE

| Traffic Model | Number of Terminals | Annual Cost Difference in $1000 |
|---|---|---|
| Low Capacity | 27 | 1,429 |
| Medium Capacity | 11 | 582 |
| High Capacity | 212 | 11,219 |

Thus, the ground segment cost increase exceeds the space segment cost saving by a large factor in all cases.