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COMMUNICATION SATELLITE SYSTEMS FOR ALASKA

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GSFC — GODDARD SPACE FLIGHT CENTER —
GREENBELT, MARYLAND

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COMMUNICATION SATELLITE SYSTEMS FOR ALASKA

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March 1971

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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SECTION 1

INTRODUCTION

The State of Alaska has a real need for improved communication services. Current facilities are overloaded, inadequate, or in many areas of the state, nonexistent.[1,2] The welfare of Alaska's population as well as progressive growth depend upon the acquisition of a responsive communication network.

Specifically, requirements have been identified for: voice circuit coverage to the approximately 250 villages located throughout the state, and educational, instructional and entertainment television coverage.[1,2,3]

The environment of Alaska, with its varied terrain, temperature extremes and vast area, makes satellite service the logical choice for the extension of Alaska's telecommunications. Such a system can give line-of-sight communication coverage to every area of the state. Communications for any point having appropriate visibility of the synchronizing orbit can be established with the placement of an earth terminal. The attraction and utility of a satellite for Alaska are evident.

Alternatives that the State of Alaska may wish to pursue divide into two categories as follows:

a. Procurement of services from a common carrier (RCA Globecom or other to-be-authorized organization).

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[1] "A Plan for Telecommunication Development in Alaska," Office of Telecommunications, October 15, 1969.

[2] "The Need for a Long Range Communication Development Plan for Alaska," Communications Working Group, Federal Field Committee for Development Planning in Alaska, April 1969.

[3] "Summary of Alaska Conference on Satellite Telecommunications," August 28-29, 1969.

b. Procurement of a dedicated Alaska Domestic Satellite System to provide a range of services.

The dedicated system could be entirely state owned or jointly owned. Various possibilities also exist in the organization and operation of the system.

No hard recommendation is possible until the future institutional and financial relationships are resolved. This report constitutes a source of information which planners of a future dedicated Alaska Satellite System may wish to consult in their deliberations. This report does not conclude that a dedicated system is preferable to a common-carrier service.

This study examines the technical and cost factors associated with the implementation of an Alaskan Satellite System. To determine a representative system configuration, it was necessary to analyze the current environment within which a system must operate and to generate requirements that the system will satisfy. In both instances, available information was incomplete. However, an explicit statement of requirements is useful as a frame of reference for further refinement, so a brief analysis is included.

An illustrative example is provided to allow the reader to develop a feel for the relative cost of such a system. The example illustrates the use of the charts and tables presented in this study. A detail design will require refined and updated information from spacecraft and terminal manufacturers.

To assure full consideration of the many potentially useful satellites, a reasonably complete list of all "in orbit" and planned satellites was examined for applicability. It was considered desirable to choose a satellite from among those already developed in order to avoid R and D costs. A number of constraints exist that affect system selection and particularly the allocation of frequency. These are discussed in terms of their influence on system design. Performance and approximate cost were analyzed to illustrate the tradeoffs necessary to achieve cost-effective implementation and operation.

Finally, appendices that treat special problem areas were included for reference and more detailed information.

This report was produced during a short period, precluding an in-depth collection of requirements and a fully supported engineering design. The objective is to provide a data base and an example system to serve as a vehicle for initial planning decisions. With this qualification, the report can be used as a basis for further discussion and continued effort.

SECTION 2

SUMMARY OF RESULTS

This preliminary short-term effort has resulted in the formulation of a data base which can be used to synthesize candidate systems to provide satellite communications for remote areas in the State of Alaska. It was concluded on the basis of an initial examination of postulated requirements and the Alaskan environment that a satellite system could provide an effective means for supplying television and voice communications to such remote areas throughout the State. A need for augmentation of the existing intercity voice communications circuits was also identified. Since intercity telecommunications is within the province of the common carrier and the Alaskan Public Utility Commission, it was therefore considered to be outside the scope of this study.

The candidate satellites that could be employed have been listed along with their principal properties and cost. Various patterns of TV and voice communication have been described for the State and its primary users.

The necessary tradeoff data (cost versus various levels of service and performance) have been developed and presented so that specific system configurations can be easily developed and the associated cost factors generated for evaluation. A number of constraints and potential problem areas (choice of frequency, operation of ground terminals in the "bush") have been identified and discussed, with supporting material placed in a series of appendices to the report.

A system configuration was chosen to be used primarily as an example to illustrate the use of the tables and graphs contained in Section 7 and Appendix B of this report. The example was synthesized to reflect a minimal cost system that might be appropriate to a dedicated system for Alaska. The system provides television to remote areas of the State. An option to add a single telephone circuit to each of the remote ("bush") terminals is available. In all systems considered only the costs of implementation and the tradeoffs between alternate approaches were addressed. Overall economics (including revenues and service charges) and regulatory policies needed to implement the system (FCC regulation and frequency allocation), were considered to be beyond the scope of this effort. Table 2-1 is a summary description of this system. System capability additions may be costed by referring to the appropriate tables in the report.

Choice of frequency was identified early in the study to be a critical parameter. Examination was made of the 650 to 890 MHz band, 2.5 GHz band, 4/6-GHz band and higher frequencies. It was concluded that 4/6-GHz band provided the only basis for proceeding for the following reasons*: 1) it is the only internationally approved frequency; 2) flight qualified hardware is most readily available, therefore minimal satellite hardware developed is needed; 3) ground terminal hardware is being rapidly developed for the U.S. and Canadian domestic systems.

A design, similar to the TELESAT spacecraft being procured as a Canadian domestic communication satellite, was selected for the space segment. An antenna modification which permits the State of Alaska to be more optimally covered plus a reconnection of output tubes to provide the power to transmit to small earth terminal antennas will be required.

TELESAT contains the power to support ten active 36-MHz repeaters. Each repeater services 30-foot diameter ground terminal antennas. In order to support one color television channel and 50 demand-access voice circuits communicating to 15-foot Alaskan ground terminal antennas, the ten 36-MHz repeater output tubes would be reconnected as follows: Four power output tubes would be placed in parallel at the output of one of the repeaters to provide sufficient power for one color television channel; one additional repeater would be employed for the 50 demand-access

*The results of the forthcoming World Administrative Radio Conference (WARC) may justify further examination of the 2.5 GHz band.

TABLE 2-1. A DEDICATED SATELLITE SYSTEM FOR ALASKA

Satellite:	Modified TELESAT Design
Antenna:	5-foot Reflector Covering Most of Alaska with a 3.6° (half-power points) Beam
Repeater:	Two Independent Sections, Each Capable of 1 Color TV Channel Plus 1 Multiple-Demand-Access Telephony Channel for 50 or more Simultaneous Users.
Transmitter:	Installed RF Power = 50 watts, 25 watts/Section
Life Expectancy:	7 years
Frequency:	4/6 GHz
User Terminals:	Low Cost "Bush" Design
Antenna:	15-foot Diameter Reflector, Manual Pointing
Preamp:	Uncooled Paramp
Adapter:	Frequency Translates to Standard TV Receiver Channel, Converts from FM to Conventional VSB Modulation to Provide Compatible Signal to TV Receiver Antenna Terminals
Receiver:	Standard Commercial Home TV Instrument
Optional: (incremental)	Single-Voice-Circuit Telephony Add-On to TV-Only System
	Diplexer (transmit-receive switch)
	Voice Transmitter - 5-watt output
	Voice Receiver - Standard FM Receiver Plus Down Converter
Communications Control Terminal:	Provides TV Uplink and Control of Voice Circuits
Antenna:	32-foot Diameter, Autotrack
Transmitter:	100-watt Output (for both TV and 50-voice circuits)

TABLE 2-1. A DEDICATED SATELLITE SYSTEM FOR ALASKA (Continued)

Preamp:	Uncooled Paramp; System Noise Temperature = 200°K
Receivers:	Standard FM Voice Receivers (1 per circuit), TV Monitor
Control:	Switchboard Type Manual Control for Voice Circuits

voice circuits. Since this arrangement uses only five of the ten available power tubes, the remaining five power tubes are reconnected in the same manner. There is, therefore, complete redundancy available for back-up of both television and voice electronics (six repeaters are eliminated in this concept).

Only half of the solar cell energy allocated to the generation of transmitter power is used at any one time. Since solar cell subsystems are not normally designed in sections allowing back-up of one complete set of cells for another, this part of the system is over-designed rather than truly redundant unless a modification is made to the power subsystem. A smaller spacecraft with less solar cell power but with redundant electronics could be employed. The closest such spacecraft is INTELSAT III which would require the addition of four power tubes as well as modifications similar to those for TELESAT. The cost savings involved in using a smaller but more extensively modified spacecraft must be investigated.

A number of alternative approaches are available to provide reliable (continuous) service considering the finite lifetime of spacecraft. One alternative is to employ an orbiting spare plus a spare on the ground. This approach has high probability of providing continuous service but requires the procurement of three spacecraft and two boosters. A second approach might be the use of common-carrier facilities as back-up in the event of satellite failure but such an arrangement, if feasible, would have to be negotiated. No cost estimate of this approach is possible at this time. A third approach, employing only a spare spacecraft stored on ground, is not quite as risk-free as the first but can result in lower acquisition cost if the redundant satellite repeaters are made with a high degree of statistical independence with respect to failures and each repeater has an average life of 7 years. If the replacement satellite is launched within 6 months of the failure of one repeater, the probability of the back-up repeater surviving during the satellite replenishment interval (assuming an $e^{-t/T}$ survival probability) is about 95%. Six months should be a reasonable time to procure a booster and launch the back-up satellite. This would thus defer the initial acquisition cost of a booster and additional satellite until such time as they are required for replacement.

The choice of an alternative is subject to additional economic versus reliability tradeoffs which must, in the final analysis, be made by the State of Alaska. Alternative three was adopted as an example in this report.

The probability of launch failure of either the initial or replenishment launch is a cost item and must be considered. INTELSAT has purchased launch insurance from Lloyds of London to protect against the financial consequences of launch failure. The premium charged for this insurance was 25% of the insured amount, however the insurance did not take effect until a number of successful launches with a given configuration had been demonstrated. An arrangement to cover the particular circumstances of the launch of an Alaskan satellite would have to be negotiated between the insurer and the operator or manager of dedicated systems for the State of Alaska if this form of protection is desired. The premium cost may vary greatly from the INTELSAT premium and the form of protection desired may be different, thus a specific cost for launch failure is not included in the overall system costing.

The ground segment selected in the example consisted of one central earth terminal, which serves to transmit television programming and acts as the Central Control for the voice-circuit assignments, plus 30, 150 or 250 "bush" terminals which receive television. In Table 2-2 the costs for TV-only terminals and incremental costs for one full-duplex voice circuit per terminal are shown.

Each "bush" terminal is assumed to operate within an existing housing structure such as a school, which has light, heat and power. Television viewers and voice circuit users are required to visit the facility for service. A "bush" terminal was selected

TABLE 2-2. SUMMARY COSTS OF A DEDICATED SATELLITE SYSTEM FOR ALASKA

SPACE SEGMENT

Acquisition Cost		Dollars
Satellite[1] (1 satellite in orbit, 1 satellite in storage)		16M
Engineering Modifications to TELESAT design[1] (antenna and TWT)		2M
Launch (1 booster)		7M
	TOTAL SPACE	25M
Annual Capital Recovery Cost[2]		
(7 year amortization, 10% interest)[3]		5M

GROUND SEGMENT ("Bush" Terminals)

Acquisition Cost	Number of Stations		
TV-only terminal (cost in quantity of 1 = 48K)	30	150	250
Unit Cost[4]	29K	19K	17K
TOTAL COST[5]	0.96M	3.2M	4.7M
Telephony "add-on" (1 circuit)			
"Add-on" Unit Cost	5K	3.5K	3.1K
TOTAL COST[5]	0.16M	0.53M	0.78M
TV Receive Plus Telephone Circuit			
Unit Cost	34K	23K	20K
TOTAL COST	1.1M	3.7M	5.5M
Annual Capital Recovery Cost[2]			
(7 year amortization 10% interest)	0.22M	0.74M	1.1M

TABLE 2-2. SUMMARY COSTS OF A DEDICATED SATELLITE SYSTEM FOR ALASKA (Continued)

GROUND SEGMENT
(Satellite Control and Communications Control Facility)

Acquisition Costs		Dollars
Real Estate		150K
Satellite Control Equipment:		850K
RF Equipment Command-Control Encoding T/M Decoding Modems T/M Display Computer		
Communications Control Equipment		760K
RF Equipment TV Receive TV Transmit Voice Channel Receive Voice Channel Transmit Switchboard and Synthesizers		
	TOTAL CONTROL	1.76M
Annual Capital Recovery Cost (2)		0.35M
(7 year amortization 10% interest)		

TABLE 2-2. SUMMARY COSTS OF A DEDICATED SATELLITE SYSTEM FOR ALASKA (Continued)

ANNUAL MAINTENANCE AND OPERATIONS COSTS
(Direct Salaries for Control Center)

Annual Cost	Dollars
Control Operations	0.35M
Communications Operations	0.40M
Shift Supervisors	0.14M
General Maintenance	0.10M
TOTAL M&O/YEAR	1.0 M

GRAND TOTALS

Acquisition Cost	
Space Segment	25 M
Ground Segment	
150 "Bush" Terminals (TV plus voice)	3.7 M
Satellite and Communications Control Terminal	1.76M
GRAND TOTAL ACQUISITION	30.46M

TABLE 2-2. SUMMARY COSTS OF A DEDICATED SATELLITE SYSTEM FOR ALASKA (Continued)

Annual Cost	Dollars
Satellite Annual Capital Recovery (ACR)	5.0 M
Bush Terminal ACR (150 stations)	0.74M
Satellite and Communications Control ACR	0.35M
Maintenance "Bush" Terminals(6) (15% of acquisition cost)	0.56M
M&O Control Center	1.00M
GRAND TOTAL ANNUAL	7.65M

ADDITIONAL COST FACTORS

Possibility of Launch Failure

Utility Costs

Legal Costs - Licenses

Technical Management and Administration

TV Programming

Consulting Engineering

Footnotes:

(1) These costs apply as long as the Canadian version of TELESAT is in production, estimated to be 18 months.

(2) Costs are based on a 7-year ground and space segment capital recovery period (page 8-33).

(3) Ten percent interest was assumed. Annual costs are sensitive to interest rates and amortization rates (page 8-33).

(4) Quantity prices based on learning curve, Figure 8-13.

(5) Costs include 12% for initial spares and test equipment.

(6) Installation costs are assumed included in first year M&O.

which would operate with an Alaskan version of TELESAT using a 15-foot antenna and an uncooled paramp with a system-noise temperature of 200°K resulting in a G/T = 20 dB. The 30, 150 or 250 earth terminals are grouped to share the available demand-assigned voice circuits. For example, assuming 150 earth terminals and 50 available voice channels, each voice circuit would be time shared by three earth-terminal locations.

The yearly operating and maintenance cost of the "bush" terminals was taken as 15% of the acquisition cost. The "bush" terminal would be designed to be operated by local, untrained personnel as a part-time job and the total cost will be allocated to maintenance. The maintenance will be performed by teams of aircraft pilot/electronic technicians servicing the terminals periodically. These teams will also perform the installation, and the costs of installation are thus considered to be included in the first-year maintenance costs.

In addition to the communications-control function performed by the central earth terminal, a satellite-control function is required. The satellite-control function is used to establish and maintain the satellite position in orbit, switch redundant components, adjust antenna pointing, control electrical repeater characteristics and anticipate future problems with the spacecraft from an analysis of the telemetry Performing this function requires a terminal to receive telemetry and transmit commands. The terminal should be staffed by a team of spacecraft specialists to diagnose spacecraft problems using the telemetry and to translate desired actions into specific command instructions to the spacecraft. There are a number of alternatives to providing both the terminal and personnel. The central communications control terminal augmented with an additional transmitter and receiver can be used as the satellite control terminal.

Since satellite control is not a full-time function, arrangements might be made to share facilities with or procure the services from, other spacecraft system operating entities. The personnel required could be provided by the State of Alaska in a shared arrangement or by the other operators providing the terminal, if the services were procured. It is not necessary to collocate the personnel and the terminal. In fact, the U. S. Air Force maintains a worldwide net of control terminals (Remote Tracking Stations) with a single central data reduction and command generation facility in Sunnyvale, California linked to the RTS by telephone circuits. NASA has a similar configuration for the Manned Space Flight Network. The costs derived in Table 2-2 reflect maintenance and operations by the State of Alaska but reflect no overhead charges.

An additional cost element which could be substantial for a dedicated satellite system is the cost of technical management and administration. The number of technical and administrative people required to operate a system and provide technical planning is not linearly related to the number of spacecraft involved. The overhead percentage decreases as more spacecraft are operated thus burdening a single spacecraft system with a high overhead. The actual dollar cost of these services can only be obtained after the State of Alaska has considered the organizational requirements and its resources.

The foregoing is a first-cut, minimal cost system which should be sufficient to support the initial decision-making process by the State of Alaska. Some areas needing further investigation are identified as follows:

1. It is assumed that the FCC will permit the use of 15-foot 4- to 6-GHz ground terminals in Alaska because of the proposed location of the satellite over the Pacific Ocean where the satellite population is expected to be low. This should be verified.

2. The concept of a single satellite with two sections having a high degree of statistical independence requires further study to permit a more meaningful tradeoff between system

reliability and system acquisition costs. The implications of using a spacecraft with less solar cell power as an alternative must be investigated.

3. The probability of launch failure and consequences of such a failure to the State of Alaska require further analysis. The impact on costs remain to be determined.

4. The feasibility of reducing operational costs by having a non-Alaskan agency provide technical control of the satellite segment should be studied.

5. Costs of both technical and non-technical management require further resolution.

6. Assumptions were made that the "bush" terminals would be installed in existing housing having suitable utility service. This should be verified.

7. The costs shown for an Alaskan version of TELESAT are valid only for approximately 18 months, to take advantage of the on-going program. The impact of this condition should be investigated since a dedicated Alaskan system does not seem feasible within this time frame.

8. The installation, operation and maintenance concept for the "bush" terminals requires further study.

Prior to a final choice of alternatives by the State of Alaska the following actions are required:

1. The above questions should be answered.

2. A dedicated satellite communication system, responsive to a firm requirement should be selected and costed in detail.

3. The costs of leasing services meeting the same requirement from a common carrier should be determined for comparison. Proposals for the U. S. Domestic Satellite System are now in the hands of the FCC.

SECTION 3

THE ALASKAN ENVIRONMENT

3.1 INTRODUCTION

An Alaskan Satellite System must interface with an established environment - Alaska in its current status. Any system exists within and reacts with its particular environment. A system design is influenced directly by environmental factors, and any realistic and practical system synthesis includes definition and interface appraisal of the environment. This section presents the principal environmental factors in outline form in order to support a subsequent requirements analysis.

3.2 PHYSICAL FEATURES[1]

Alaska has an east-west span of 2000 miles, a north-south span of 1100 miles and a coastline of 3300 miles. Hundreds of islands exist along the north Gulf Coast, the Alaska Peninsula and the Bering Sea Coast, in addition to the Aleutian Islands. Alaska contains 375 million acres of land and over 3 million lakes.

Two vast mountain systems divide the state into four major physiographic divisions that have greatly influenced human settlement patterns. The two longest mountain ranges are the Brooks Range, which separates the Arctic region from the interior, and the Alaska-Aleutian Range, which extends westward along the Alaska Peninsula and the Aleutian Islands and northward about 200 miles along the peninsula then eastward to Canada.

Permafrost, which covers most of the northern third of the state, is a major factor in the geography and human use pattern of Alaska. Discontinuous or isolated areas of permafrost exist over the central portion in an overall area covering nearly a

[1]"Alaska Natives and the Land," October 1968.

third of the State. No permafrost exists in the south central and southern coastal portions, including southeast Alaska, the Alaska Peninsula and the Aleutian chain.

These features help to form four major climatic zones: (1) the maritime zone, which includes southeastern Alaska, the South Coast, and southwestern islands; (2) the transition zones, comprising a very narrow band along the southern portion of the Copper River, the Chugach Mountains, Cook Inlet, Bristol Bay and the coastal regions of the West Central division; (3) the Continental Zone, which is made up of the remainders of the Copper River and West Central divisions and the Interior Basin; and (4) the Arctic Zone north of the Brooks Range.

In the maritime zone, annual precipitation amounts to 200 inches in the southeast panhandle and up to 150 inches along the north Gulf Coast. Amounts taper to 60 inches on the southern side of the Alaska Range in the peninsula and to 30 inches along the Aleutian chain. Precipitation amounts decrease rapidly to the north with an average of 12 inches in the continental interior zone and less than 6 inches in the Arctic region. Snowfall is a large percentage of total precipitation. For example, Yakutat averages 216 inches of snow annually, with a total precipitation of 130 inches annually. Barrow averages 29 inches of snow with a total precipitation of about 4 inches.

Alaska is exposed to the majority of storms that cross the North Pacific, which results in a variety of wind problems. Winds in excess of 50 mph occur frequently during the winter months, and wind velocities can approach 100 mph under special conditions through narrow mountain passes. The presence of winds can cause extreme winter cold, creating a hazard to human life patterns.

Mean annual temperatures range from the low 40's in the south to 10 degrees on the Arctic Slope. Summer temperatures can exceed 90 degrees and winter temperatures can remain at -50 degrees for 2 or 3 weeks at a time.

3.3 POPULATION FEATURES

The distribution of Alaska native and non-native population is shown in Figure 3-1. It is important to note that of the total 262,000 population, (282,000 as of 1968)[1] 213,000 are located in the Southeast part of the State. The remainder of the State is populated principally by Alaska natives scattered widely in remote villages. Although the requirements for minimum communication service may be uniform throughout the State, the revenue producing element is located in the Southeast corner.

Figure 3-2 shows the Generalized Geographic Distribution of Eskimos, Indians, and Aleuts in Alaska. This distribution of ethnic groups and their languages will influence the design and selection of Instructional Education Television Programs and indicates a time sharing of single channel TV among non-native and native subelements.

The distribution of Alaska natives by size of place in predominantly native places is shown in Table 3-1.[2] The table shows that 178 locations account for a native population of 37,398.

TABLE 3-1. DISTRIBUTION OF ALASKA NATIVES BY SIZE OF PLACE IN PREDOMINANTLY NATIVE PLACES, 1967

Total Size of Place	No. of Places	Native Population	Cumulative Totals	
			No. of Places	Native Population
25-99	50	2,839	50	2,839
100-199	64	8,813	114	11,652
200-299	16	5,735	140	17,387
300-399	15	4,357	155	21,744
400-499	12	4,807	167	26,551
500-599	2	1,021	169	27,572
600-699	2	1,113	171	28,685
700-799	-	-	171	28,685
800-899	1	825	172	29,510
900-999	-	-	172	29,510
1000-2499	6	7,888	178	37,398

[1] "Statistical Abstract of the United States," 1970.

[2] "Alaska Natives and the Land," October 1968.

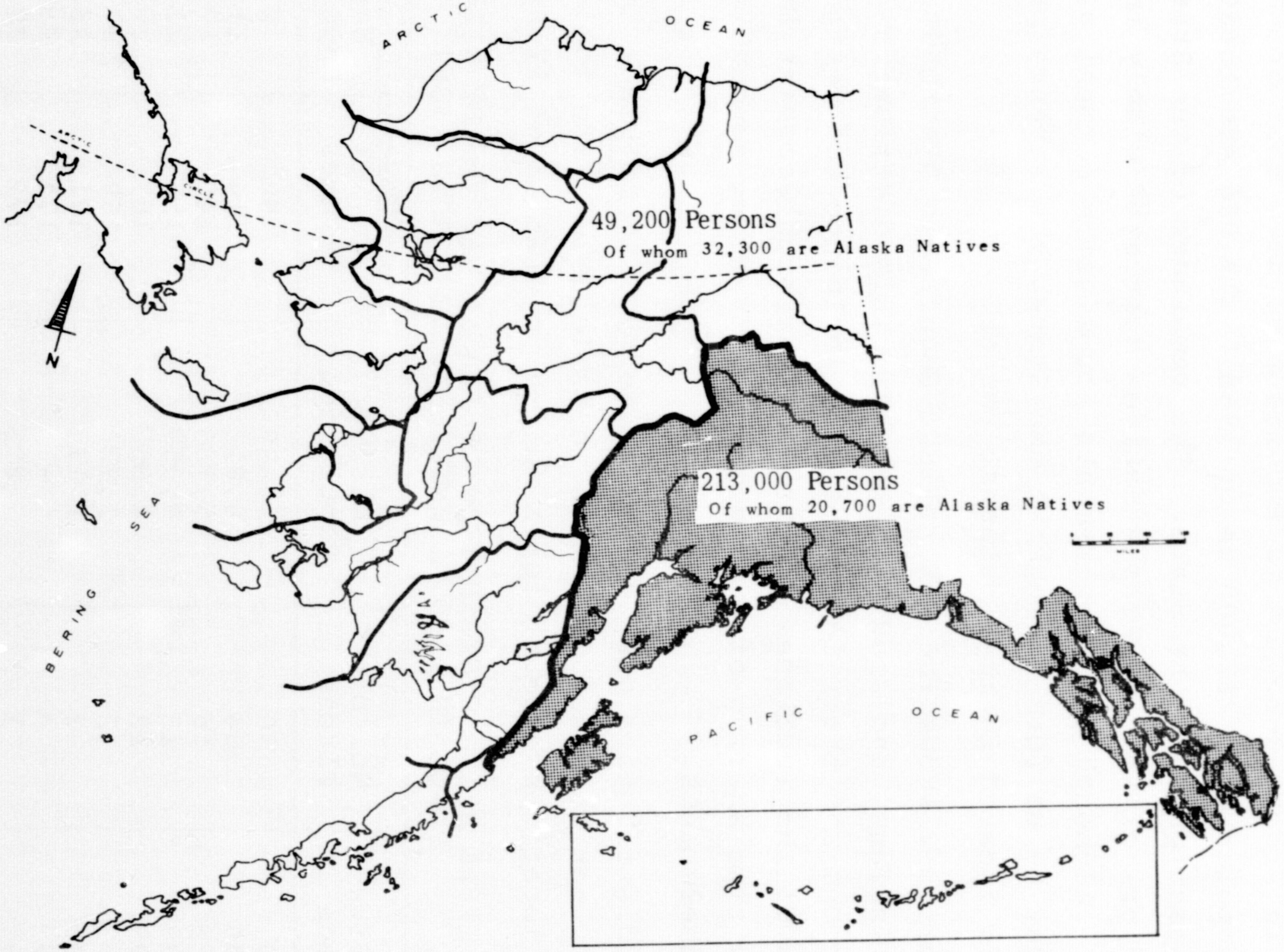


Figure 3-1. Distribution of Alaska Native
and Non-Native Population 1967

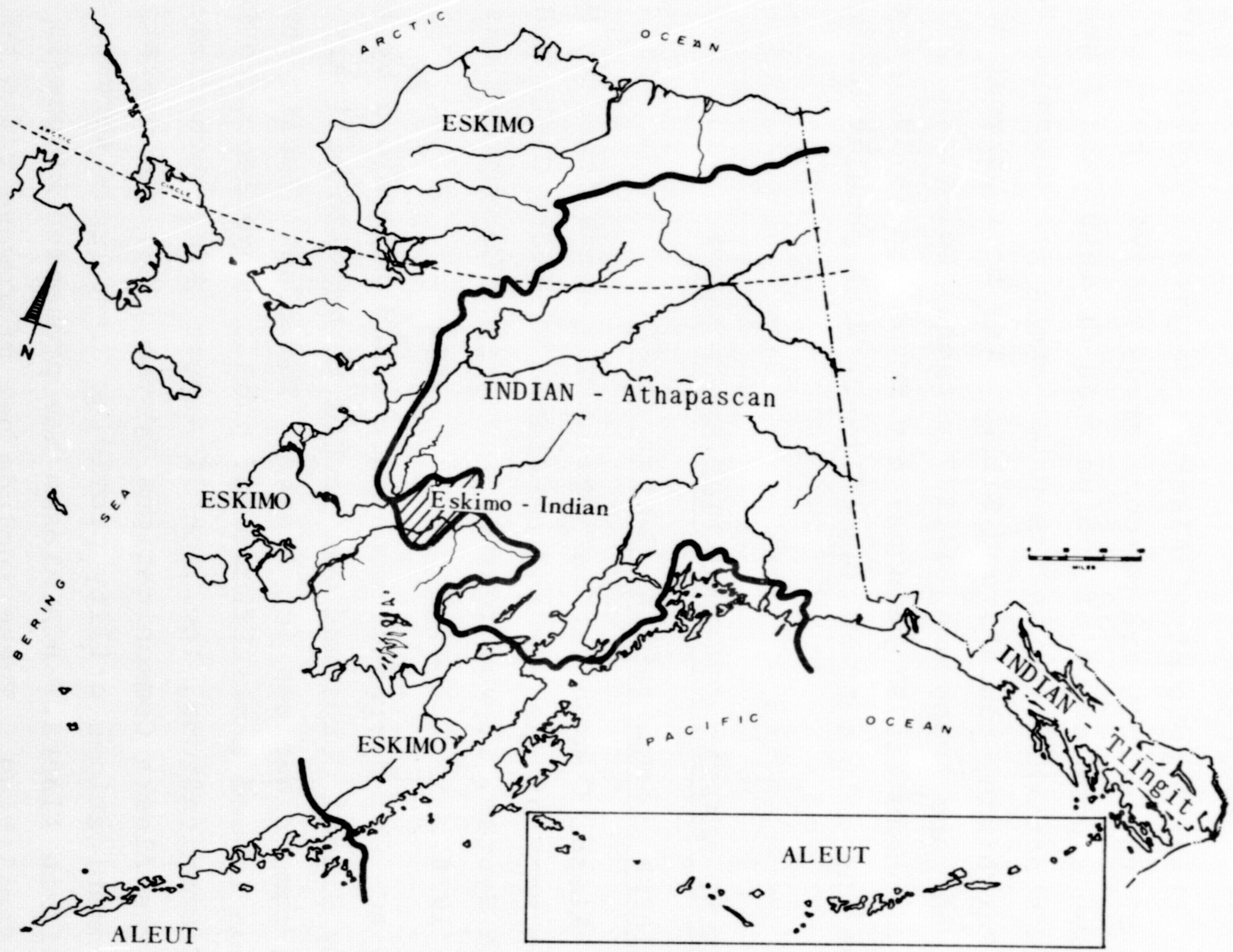


Figure 3-2. Geographic Distribution of Eskimos Indians and Aleuts

Access to the villages is limited. Fewer than a dozen native villages are in the State's limited road network. Two are on the route of the 540-mile Alaska Railroad. Access to the other 170 or so is only by air, or seasonally by boat, snowmobile or dog team.

More than 70 percent of Alaska's natives (37,000) live in 178 villages or towns that are predominately native. Half of these places have a population of 155 persons or less, and a quarter of Alaska's natives live in six urban areas - Anchorage, Fairbanks, Juneau, Ketchikan, Kodiak, and Sitka. The four largest non-native urban areas are Anchorage (44,237 persons) Fairbanks (13,311 persons), Juneau (6,797 persons) and Ketchikan (6,483 persons). These are the only centers (as of 1960) with populations over 5,000.

3.4 CURRENT ALASKAN COMMUNICATION ENVIRONMENT

3.4.1 Alaska Communications System (ACS)

The Alaska Communications System was established in May 1900 under the name of the Washington-Alaska Military Cable and Telegraph System. It was renamed the Alaska Communications System (ACS) in 1936.

The ACS was designed, constructed and maintained by the U.S. Army Signal Corps and was tasked to provide military and civilian communications for Alaska. The Alaska Public Service Commission issued a certificate of public convenience to RCA Alaska Communications, Inc., on 31 August 1970, authorizing it to acquire the Alaska Communications System (ACS) and operate it as a telecommunications utility providing long lines service between points within Alaska. RCA Alaska has presented proposals for its several facilities. These include new microwave radio relay systems and expansion of existing systems at a cost of more than $16.2 million, a direct distance dialing program costing about

$3.3 million, a "bush" program for new and improved service to 142 remote communities costing about $4.5 million and miscellaneous projects totaling $1.4 million. RCA Alaska has awarded a $1 million contract to R.E.L., Inc., to install a troposcatter system from Prodhoe Bay to Barter Island. This system will provide communications service to the oil interests operating on the North Slope. The system is due for completion in the fall of 1970.

Figure 3-3 shows the ACS facilities and toll centers owned by the U.S. Government. The majority of these broadband systems are expected to be sold to commercial interests at later dates.

In addition to the military systems and the RCA Alaska System, there are small independent telephone companies, the FAA, the Alaska Railroad, the U.S. Fish and Wildlife Service and the Native Service providing communications service in the State of Alaska. A detailed on-site field survey would be required to determine the magnitude of existing and pending communication service in Alaska. This survey would facilitate the integration of the proposed system with the present communications systems.

3.4.2 INTELSAT (Talkeetna)

A standard COMSAT earth station was installed at Talkeetna, Alaska, and it has been in operation since the summer of 1970. It uses a 90-foot antenna and is served by a microwave system to Anchorage. It uses INTELSAT III F4 and has an elevation angle of 16°.

3.4.3 TV Broadcast

There are seven existing television broadcast stations in Alaska - stations KENI-TV, KTVA and KHAR-TV in Anchorage; KFAR-TV and KTVF in Fairbanks; KINY-TV in Juneau and KIFW-TV in Sitka. These are shown in Figure 3-4. In addition, military TV for the education and entertainment of service personnel is provided by seven stations which do not transmit beyond the boundaries of military reservations.

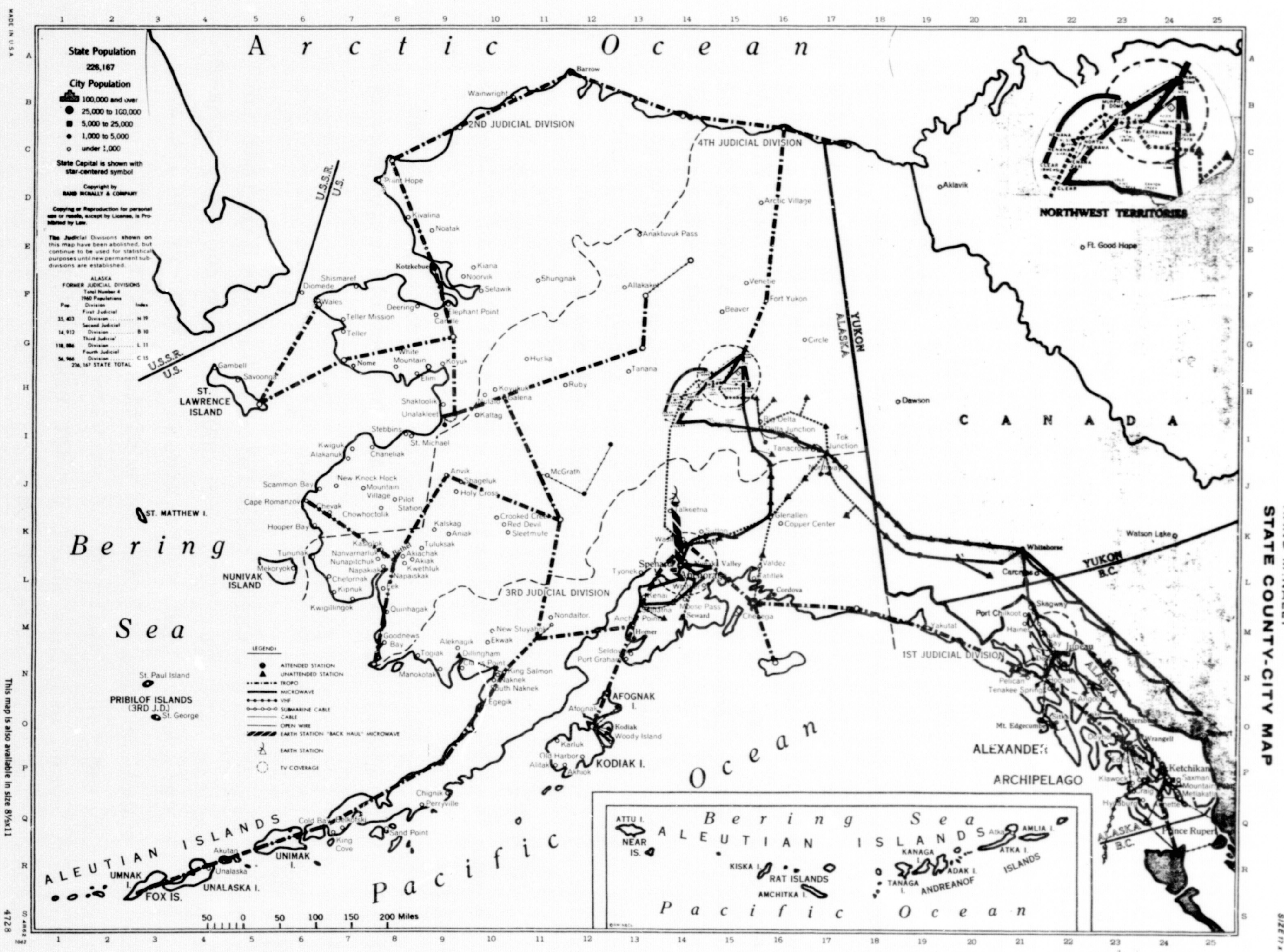
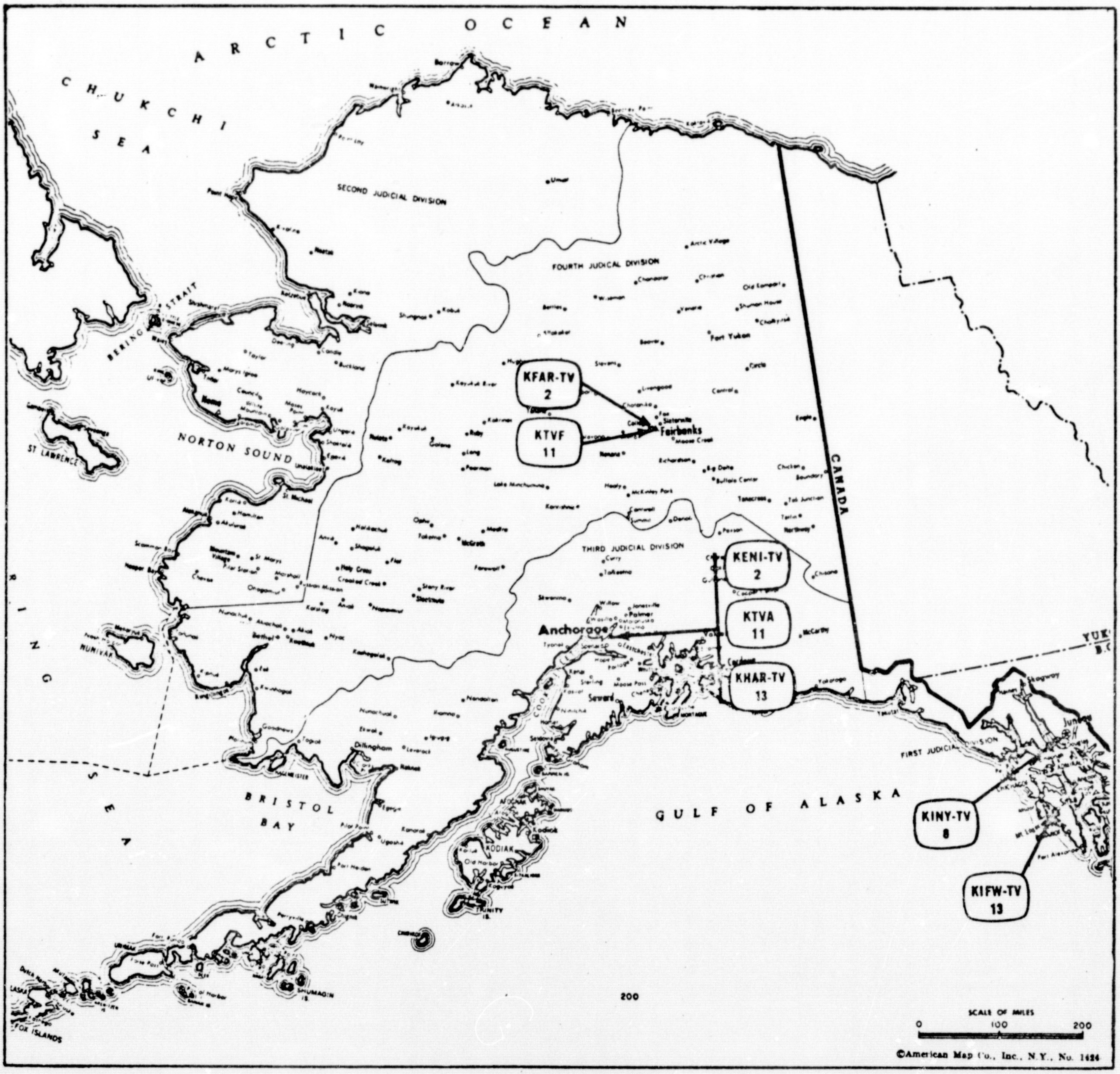


Figure 3-3. ACS Facilities and Toll Centers Owned by the U. S. Government

Alaska



Alaska Station Status as of Jan. 1, 1968

	VHF	UHF	TOTAL
◯ Commercial Television Stations	7	0	7
⬤ Educational Television Stations	0	0	0
			7

Figure 3-4. Alaska TV Stations

SECTION 4

DISCUSSION OF REQUIREMENTS

4.1 INTRODUCTION

The generation of realistic quantitative requirements is essential to a responsive system design. For this preliminary study, the necessary inputs describing current and predicted requirements for service in Alaska were unavailable. However, for gross sizing of the system it is useful to discuss the general requirements associated with communications in Alaska.

It is the purpose of this section to discuss the projected requirements to allow sizing of the satellites capabilities. The projected requirements are summarily divided between television broadcasts (simplex) and voice communications (duplex). The former is rather well described by simply stating whether it is monochrome or color TV. No multiple access problem exists. The latter is far more difficult to describe, but can be subdivided into three requirements: 1) providing service between remote ("bush") locations, 2) providing intercity trunking within Alaska, and 3) providing trunking to the lower 48 states.

Commercial services exist to fulfill the existing latter two requirements; only the first will be considered within the scope of this report. The multiple access problem of providing duplex communications between remote locations does present a considerable problem.

4.2 USER ELEMENTS

Elements in Alaska requiring communication service may be conveniently categorized as individuals, commercial interest and State and Federal agencies.

Commercial industries are concentrated in the city areas of Anchorage, Fairbanks, Juneau and Ketchikan, as well as in rural areas scattered throughout the State. The major portion of city industry is now served by the Alaska Communications Service. Some rural areas located on the established communications routes are also served by ACS. Although no quantitative data were available for this study, it appears that the ACS is currently saturated and expansion of service is urgently required. In addition, many areas that do not access the ACS require service. The commercial development of the State depends to a great extent on the ability to provide communications to rural areas where oil fields, lumber camps and ships at sea create a demand for service.

The State and Federal agencies form the most crucial user elements in the State, since their services offered to the population affect the individual's personal welfare. The agencies may be identified as belonging to the following categories:

a. Public Health and Safety
b. Education
c. Aviation (FAA)
d. National Defense
e. Commercial Development
f. Federal and State Administration

The user elements are normally organized as a headquarters (centrally located) with numbers of remotely located reporting elements throughout the State.

4.3 USER ELEMENT COVERAGE AND DISTRIBUTION

The coverage required by the described user elements ranges over the entire State from Barrow and Prudhoe Bay in the North, to Metlakatla in the South and from Tok Junction in the East to the Aleutians in the West. Figure 4-1 shows the approximately 250 communities distributed over the State that require service.

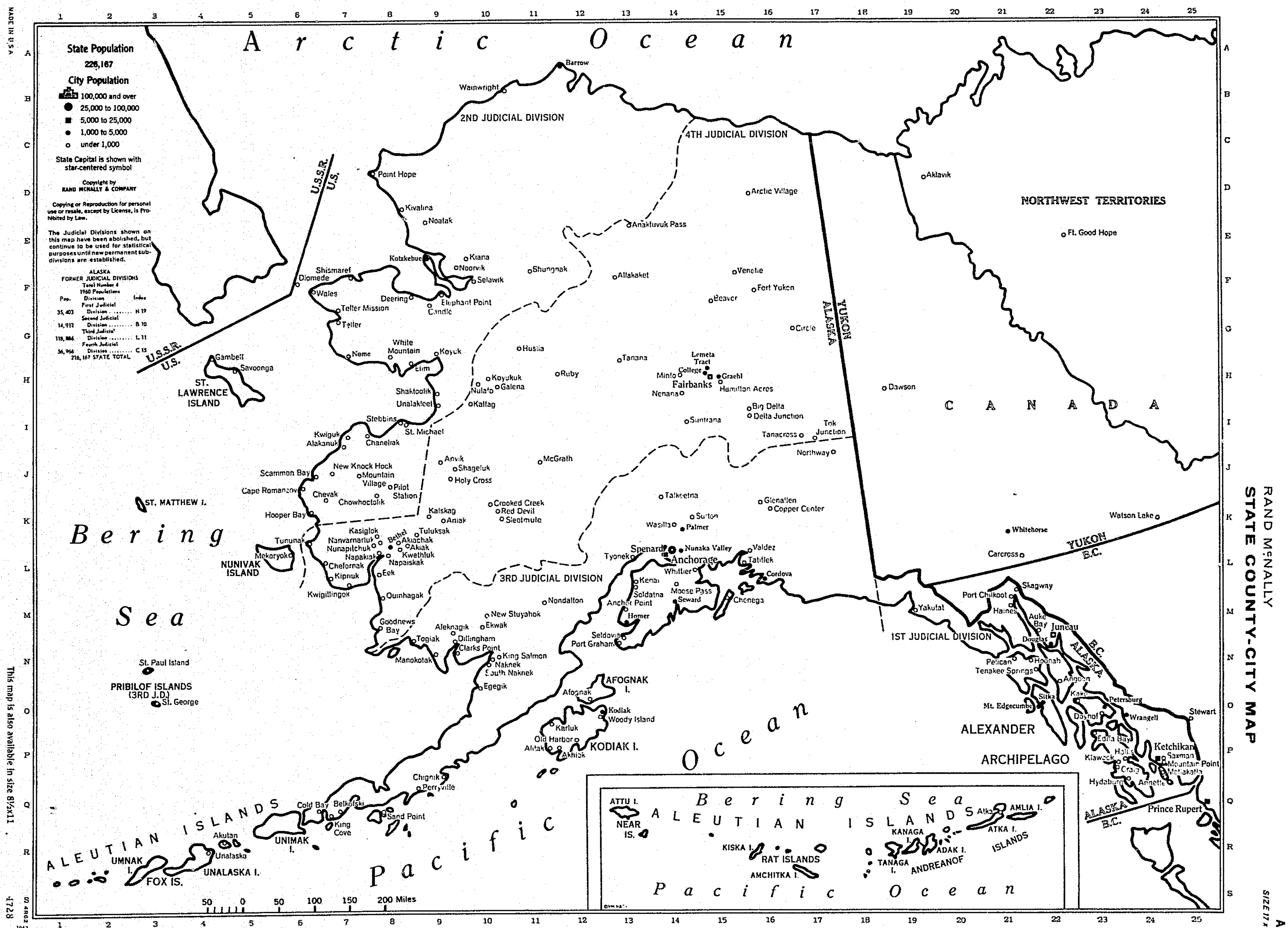


Figure 4-1. Distribution of Alaskan Communities

4.4 TYPES OF SERVICE REQUIRED

The types of service required by the State are identified generally as:

a. Television
b. Telephone
c. Telegraph (Record Communications)
d. Data

4.4.1 Television

Television represents a valuable medium for communications to the State for purposes of education, instruction, cultural development, and entertainment. The television services provided may be categorized as follows:

- Educational Television
- Instructional Television
- Computer-Aided Instruction
- Recreational Television

These would be provided to all the remote locations by satellite broadcast .

a. Educational TV

Educational TV may be employed to improve the general education of adults in a variety of subjects, including:

1. Language
2. Practical Skills
3. Practicing Arts
4. Medicine
5. Mathematics
6. Recreation (sports, dancing, etc.)

b. Instructional TV

Instructional TV is valuable for supporting the local classroom teacher with standardized, high quality material and instruction otherwise unavailable to a local area. Such programs are introduced directly into the schools and colleges of the State. The service may be designed as interactive, providing opportunity for questions and more flexible instruction.

c. Computer-Aided Instruction

Computer-aided instruction is an advanced instructional method based on using computers and interactive displays that students may access individually or in groups. A statewide system may time-share a centrally located computer.

d. Recreational TV

Various classes of entertainment may be locally generated within the State or received from the lower 48 States over commercially available services for satellite rebroadcast. This class of service includes the commercial and network broadcasts of a variety of topics to include general interest programs for news, sporting events, and entertainment. Such programs may be scheduled live or in near-real time for broadcast to the State.

4.4.2 Telephone

The ratio of telephones to people in India is roughly 2 to 1000. In the United States a vast majority of families have one or more telephones. This service is fundamental to the personal welfare of the individual. Telephones in use in Alaska, based on a population of 282,000, number 82,000 (48,000 residential and 34,000 business) as of 1968.[1] Sharing will probably remain with the native population in the ratio of 25-50 families per instrument primarily because of revenue considerations.

[1] "Statistical Abstract of the United States," 1970.

4.4.3 Business Related Services

Business related services such as telex, telegraph and data communications are not specifically treated in this report, but it is of interest to briefly discuss how they can often be accommodated by voice circuits.

Telex and telegraph are essential services that provide the record communications so valuable to an orderly process of business dealings. Record communications may be stored for future reference and provide a record of all effected transactions. Orders and instructions are best transmitted via telex or telegraph to minimize misunderstandings. Lengthy conversations, including alphanumerics, are best transmitted via record communications. Potential telex and telegraph requirements represent a small increment of total equivalent voice circuit requirements, since multiplexing allows 16 telegraph circuits on a single voice circuit.

The installation of computer facilities at various industry offices as well as the advent of computer-aided instruction pose a requirement for data service. Current practice accommodates up to 9600 bits per second (bps) over "voice" circuits with varying degrees of conditioning so that this service may be assumed to be included in the equivalent voice circuit requirement.

4.5 DEMAND FORECAST

From the foregoing discussion four observations pertinent to the system requirements can be made.

First, the satellite should be sized to be compatible with up to 250 "bush" terminals. As these terminals would be of modest cost, they would have a correspondingly limited figure of merit (G/T) and this establish the required satellite effective isotropic radiated power (EIRP).

Second, the system (satellite and bush terminal) must be able to support one broadcast television channel.

Third, it is desirable for each bush terminal to be provided with the capability to support one duplex voice channel.

Fourth, the number of duplex channels (one channel per carrier) that the satellite should be designed to support would normally be determined based upon existing statistical experience. But these statistics do not exist for the small, typically telephoneless, communities of Alaska. It is not envisioned that these satellite circuits will support any significant amount of casual conversations or normal business traffic carried by most voice service, but rather they will primarily provide for emergency services and community logistical support. Therefore, the duty factor on the 250 terminals will be low and dedicated circuits are unadvisable. A preliminary estimate is five users per circuit. In conclusion, 50 circuits will be assumed to be required.

SECTION 5

CANDIDATE SATELLITES

5.1 GENERAL

One of the major premises guiding the selection of candidate satellites for a dedicated Alaskan system is that it must be relatively inexpensive compared to the benefits provided. Since development costs of spacecraft are high in comparison to the costs of an already developed spacecraft, this premise may rule out the possibility of developing a new spacecraft. As a result, only procurement of an additional copy of a satellite which has been developed or which is well advanced is considered here.

Considerations of commercially or militarily sponsored satellites are based on procurement of an additional copy of the particular spacecraft of interest. NASA satellites in orbit are assumed to be available for an Alaskan experiment (assuming an experiment is desired) as long as arrangements can be made for interfacing with other planned experiments. Copies of NASA spacecraft could also be procured for an operational system, however, the cost and final configuration of such a spacecraft is uncertain since the NASA spacecraft considered carry many experimental items not required for a communication system operation.

Within the defined constraints, all presently available and planned NASA, commercial and military communications satellites of the U.S. and its allies are considered potential candidates for the Alaskan satellite system. Selection of a particular satellite will depend upon traffic capabilities desired, ground complex selected, and satellite cost.

Most of the presently available and planned satellites of interest have a geostationary orbit. The satellite employed for the Alaskan Communications Spacecraft should also have a geostationary orbit. The far northern location of Alaska suggests the possibility of an inclined, high elliptical orbit such as that employed by the Russian Molniya spacecraft. However, this type of orbit imposes a requirement for a ground complex with a sophisticated tracking capability. A geostationary orbit supplies adequate Alaskan coverage and allows use of simple, inexpensive pointing systems with the small, wide beamwidth antennas anticipated for an Alaskan ground complex.

Major satellite parameters that should be considered in selecting a suitable spacecraft include in-orbit cost, earliest date of availability, EIRP supplied, bandwidth, and operational frequencies. In-orbit costs include both launch and satellite costs. Obtaining service in existing or presently planned NASA satellites is assumed to be cost free if it can be arranged for an experiment. The costs of copies of NASA satellites are not given because of the uncertainty of their operational configuration. The earliest date of availability of in-orbit NASA satellites for experimental purposes is assumed to be now. The limiting time for such an experiment is the procurement and installation lead time for ground equipment. Obtaining copies of existing commercial, NASA or military satellites would require about 18 months minimum from the time procurement is initiated. Total spacecraft EIRP capability at the frequency of interest should be considered, based on paralleling applicable on-board transmitters. Satellite bandwidths should preferably be wide enough to accommodate FM-TV. Preferred operational frequencies will be discussed in detail in a subsequent section. For the initial determination of candidates, the following four combinations of satellite frequency bands will be considered; 6-GHz up and 860-MHz down,* 6-GHz up and 4-GHz down, 8-GHz up and 7-GHz down and 13-GHz up and 12-GHz down.

5.2 SATELLITES PRESENTLY IN ORBIT

A number of communications satellites currently in orbit could supply a considerable Alaskan communications capability.

*TV only.

These satellites and some of their major parameters are listed in Table 5-1. The table presents the satellites as they presently exist. Minor modifications to the antenna and power amplifier systems should be possible for any new spacecraft procured.

Satellite launch vehicles required are included in the table to provide the basis for estimating satellite launch costs. In the case of experiments involving NASA's ATS-1 and ATS-3, satellite and launch costs are not involved if arrangement can be made for using existing in-orbit spacecraft.

Antenna gains shown in the table are in some cases estimated values based on data specifying power amplifiers and EIRP for these spacecraft. In making these estimates, internal spacecraft losses of from 1 to 2 dB have been assumed. This is typical of the losses encountered in practice. For new procurements where additional TWTs are summed in parallel, the internal losses may be increased.

The two NASA ATS satellites and the commercially sponsored INTELSATs II and III operate in the 6-GHz uplink, 4-GHz downlink frequency bands. The remaining spacecraft have military sponsors and operate in the 8-GHz uplink, 7-GHz downlink frequency bands.

The IDCSP satellite shown in the table has no station keeping capability and is therefore not suitable for a geostationary orbit. The launch vehicle listed for this satellite is based on orbiting multiple satellites on each launch.

In considering satellite and launch costs, note that they are based on past costs for the configurations described. Future costs may be somewhat higher. Further changes to the antenna or power amplifier systems could also affect costs.

5.3 PLANNED AND PROPOSED SATELLITES

A number of new communications satellites are presently being developed and some additional versions of satellites now in orbit have been proposed. These satellites and some of their parameters

TABLE 5-1. SATELLITES PRESENTLY IN ORBIT

SPACECRAFT	ON-ORBIT WEIGHT (LBS)	LAUNCH VEHICLE	AVAILABILITY	FREQ (MHZ)	TRANSPONDER BANDWIDTH (MHZ)	TRANSPONDER POWER AMPLIFIER	TRANSPONDER TYPE	TRANSPONDER NUMBER	ANTENNA TYPE	ANTENNA GAIN	EIRP PER TRANSPONDER	COST ($MILLIONS) SATELLITE	COST ($MILLIONS) LAUNCH
ATS-1	775	ATLAS-AGENA D	NOW - POSITIONED AT 150°W LONGITUDE. LAUNCHED 12/6/66. 3-YEAR DESIGN LIFETIME. LIMITED PROPULSION CAPABILITY LEFT	UP: 6000 DOWN: 4000	25	TWO 4-WATT TWTS INDEPENDENT OR SUMMED	IF TRANSLATION SOFT LIMITER[1]	2	REC: COLLINEAR ARRAY XMIT: ELECTRONICALLY DESPUN PHASED ARRAY	REC: 7.8 DB XMIT: 14 DB[5]	21.7 DBW (2-TWTS)	0	0
ATS-3	798	ATLAS-AGENA D	NOW - POSITIONED AT 63°W LONGITUDE. LAUNCHED 11/5/67. 3-YEAR DESIGN LIFETIME. ACTIVE AND USABLE	UP: 6000 DOWN: 4000	25	TWO 12-WATT TWTS INDEPENDENTLY EMPLOYED	IF TRANSLATION SOFT LIMITER[1]	1	MECHANICALLY DESPUN	17.2 DB[5]	26.2 DBW (1-TWT)	0	0
				UP: 6000 DOWN: 4000	25	TWO 4-WATT TWTS INDEPENDENTLY EMPLOYED	IF TRANSLATION SOFT LIMITER[1]	1			22.1 DBW (1-TWT)		
INTELSAT II	192	THRUST AUGMENTED DELTA	APPROXIMATELY 18 MONTHS AFTER A NEW ITEM PROCUREMENT DECISION. 3-YEAR DESIGN LIFETIME	UP: 6000 DOWN: 4000	126	FOUR 6-WATT TWTS, ANY THREE USED SIMULTANEOUSLY	RF TRANSLATION LINEAR (REDUNDANT BACKUP AVAILABLE)	1	REC: OMNI XMIT: MULTIPLE ELEMENT BICONICAL HORN (12 TORROIDAL	REC: 0 DB XMIT: 6 DB	15 DBW	3.0[2]	4[2]
INTELSAT III	334	THRUST AUGMENTED DELTA	APPROXIMATELY 18 MONTHS AFTER A NEW ITEM PROCUREMENT DECISION, 5-YEAR DESIGN LIFETIME	UP: 6000 DOWN: 4000	225	ONE 10-WATT TWT	RF TRANSLATION LINEAR	2	MECHANICALLY DESPUN	14 DB[5]	22 DBW	6.0[2]	5[2]
IDCSP	102	TITAN IIIC[3]	APPROXIMATELY 18 MONTHS AFTER A NEW ITEM PROCUREMENT DECISION. 3-YEAR DESIGN LIFETIME	UP: 8000 DOWN 7000	26	TWO 2.5-WATT TWTS INDEPENDENTLY EMPLOYED	IF TRANSLATION HARD LIMITER	1	DUAL BICONE (TORROIDAL PATTERN)	3 DB[5]	7 DBW	1.5[2]	3[2][3]
TACSATCOM	1620	TITAN IIIC	APPROXIMATELY 18 MONTHS AFTER A NEW ITEM PROCUREMENT DECISION	UP: 8000 DOWN: 7000	10	THREE 20-WATT TWTS ANY TWO USED SIMULTANEOUSLY	IF TRANSLATION HARD LIMITER	1	MECHANICALLY DESPUN MICROWAVE HORN	15 DB[5]	30 DBW	23[2]	21.5[2]
				UP: 300 DOWN: 250	0.5	200-WATT SOLID STATE	IF TRANSLATION HARD LIMITER	1	MECHANICALLY DESPUN FIVE-ELEMENT HELIX ARRAY	15 DB[5]	38 DBW		
SKYNET	280	THOR-DELTA	APPROXIMATELY 18 MONTHS AFTER A NEW ITEM PROCUREMENT DECISION, 5-YEAR DESIGN LIFETIME	UP: 8000 DOWN: 7000	20[4]	TWO 3-WATT TWTS INDEPENDENTLY EMPLOYED	IF TRANSLATION HARD LIMITER	1	MECHANICALLY DESPUN	15 DB[5]	14 DBW[4]	3.5[2]	4.5[2]
					2[4]						14 DBW[4]		
NATO	280	THOR-DELTA	APPROXIMATELY 18 MONTHS AFTER A NEW ITEM PROCUREMENT DECISION, 5-YEAR DESIGN LIFETIME	UP: 8000 DOWN: 7000	20[4]	TWO 3-WATT TWTS INDEPENDENTLY EMPLOYED	IF TRANSLATION HARD LIMITER	1	MECHANICALLY DESPUN	15 DB[5]	16.3 DBW[4]	3.5[2]	4.5[2]
					2[4]						8.5 DBW[4]		

NOTES: (1) ONE OF THREE MODES POSSIBLE WITH THIS TRANSPONDER. ALSO HAS MODULATION CONVERSION AND SPACECRAFT HIGH RATE DATA TRANSMISSION MODES.
(2) PRELIMINARY ESTIMATES BASED ON PAST COSTS. COSTS OF FUTURE ITEMS MAY PROVE TO BE HIGHER.
(3) EIGHT OF THESE SPACECRAFT HAVE COMMONLY BEEN DEPLOYED INTO NEAR SYNCHRONOUS ORBITS BY ONE LAUNCH VEHICLE.
(4) TRANSPONDER HAS TWO CHANNELS.
(5) ANTENNA PROVIDES EARTH COVERAGE FROM SYNCHRONOUS ALTITUDE.

are listed in Table 5-2. The table presents these satellites as configured in present planning. Minor modifications to the antenna and power amplifier systems should be possible for any additional spacecraft procured. Launch vehicles are included in the table to supply the basis for estimating satellite launch costs.

The ATS Y-1 spacecraft shown in the table is an ATS-1 type satellite. It presently exists in disassembled form within NASA-GSFC. It is estimated that it could be assembled and readied for launching within 12 months.

The contract for the developing ATS-F and G has recently been awarded. Assuming no revision to the current schedule, the ATS-F spacecraft could be launched on, or before, February 1973. ATS-F is already heavily committed to planned experiments. The commitments for ATS-G are much more loosely defined, but it will not be available until considerably later.

Modifications to the INTELSAT III satellite have been proposed. In all cases one of the major changes is varying the antenna pattern, but the proposed spacecrafts should be available within 18 months after the award of contract is made.

Estimates of the availability of a version of INTELSAT IV, TELESAT, and DSCS Phase II suitable for Alaskan service are based on allowing 18 months after the first launch scheduled for each respective program. First launches for INTELSAT IV and DSCS Phase II are expected in the spring of 1971, but the TELESAT launch will probably not occur before late 1972.

INTELSAT IV is similar to proposed versions of a U.S. domestic satellite. Therefore a separate listing for the domestic satellite has not been presented in Table 5-2. First launching of a domestic satellite will be considerably later than that scheduled for INTELSAT IV. Either INTELSAT IV or the U.S. domestic satellite offer considerable channelization and a high EIRP. TELESAT is the planned Canadian domestic

TABLE 5-2. PLANNED OR PROPOSED SATELLITES

SPACECRAFT	ON-ORBIT WEIGHT (LBS)	LAUNCH VEHICLE	AVAILABILITY	TRANSPONDER Frequency (MHz)	Bandwidth (MHz)	Power Amplifier	Type	Number	ANTENNA TYPE	GAIN	EIRP PER TRANSPONDER	COST ($ MILLIONS) Satellite	Launch
ATS-Y-1	775	Atlas-Agena D	Approximately 12 months after an item assembly decision. Three-year design lifetime. (1)	Up: 6000 Down: 4000	25	Two 4-watt TWTs independent or summed	If Translation Soft Limiter	2	Rec: Collinear Array Xmit: Electronically Phased Array	Rec: 7.8 dB Xmit: 14 dB (earth coverage)	21.7 dBW (Two TWTs)	1(1)	11
ATS-F & ATS-G(2)	1600-1900	Titan III-C	Launch of ATS-F expected in February 1973. Five-year design lifetime. Must compete with presently planned experiments.	Up: 6000 Down: 4000	40	Undefined	If Translation Soft Limiter	1	30-foot parabolic dish plus an earth coverage horn used only at C Band	Xmit: 18 dB earth coverage & 47-dB narrow beam	Earth coverage 23.7 dBW, 0.60° beamwidth 51.5 dBW		
				Up: 2300 Down: 2100	40	Undefined	If Translation Soft Limiter	1		41-dB narrow beam	1.2° beamwidth 47.5 dBW	0	0
				Up: 1600 Down: 1500	40	Undefined	If Translation Soft Limiter	1		38.5-dB narrow beam	1.6° beamwidth 48 dBW		
				Up: 6000 Down: 850	40	Undefined	If Translation Hard Limiter	1		Xmit: 33.5-dB narrow beam	2.8° beamwidth 48 dBW		
INTELSAT III 1/2(3)	330	Thrust Augmented Delta	Approximately 18 months after a new item procurement decision. Five-year design lifetime.	Up: 6000 Down: 4000	25	One 7-1/2 watt TWT	RF Translation Linear	2	Mechanically despun parabolic reflector supplying	Undefined(3)	31 dBW at 6° beamwidth points(3)	7.0	5
INTELSAT III (modified)(4)	419	Thor-Delta 303	Approximately 18 months after a new item procurement decision. Five-year design lifetime.	Up: 6000 Down: 4000	38	One 5-watt TWT	RF Translation Linear	6	Earth coverage horn plus two 3.1° x 6.5° beams from one parabolic reflector. Mechanically despun.	Narrow beam Xmit - 27.4 dBW	Narrow beam 32.5 dBW(4)	7.5	6
INTELSAT IV	1584	Atlas-Centaur	Approximately 18 months after first launch scheduled for early 1971. Five-year design lifetime.	Up: 6000 Down: 4000	36	One 10-watt TWT	RF Translation Linear	12	Mechanically despun. Two earth coverage plus two 4.5° spot beam antennas.	Xmit: 15-dB earth coverage & 27-dB spot beam	Earth coverage 23 dBW. Spot beam 34.7 dBW	18	15.5
TELESAT(5)	600	Thor-Delta 904	Approximately 18 months after first launch (expected by late 1972). Five-year design lifetime.	Up: 6000 Down: 4000	36	12 5-watt TWTs independently employed	RF Translation Linear	-	Mechanically despun single 3° x 8° spot beam antenna	Xmit: 26 dB	34 dBW	8	7
Canadian Applications(6)		Titan III-C	Approximately 18 months after first launch (expected by 1974).	Up: 12,200 Down: 11,700	-	Up to 200 watts of power possible	-	-	Multiple beams expected	Up to 43 dB possible	55 to 64 dBW likely	Up to 20 possible	Up to 24 possible
DSCS Phase II	1050	Titan III-C(7)	Approximately 18 months after first launch (expected early in 1971. Five-year design lifetime.	Up: 8000 Down: 7000	125	One 20-watt TWT	RF Translation Quasi-Linear	1	Mechanically despun earth coverage antennas	16 dB	28 dBW Hard limiting	10	11(7)
				Up: 8000 Down: 7000	185	One 20-watt TWT	RF Translation Quasi-Linear	1	Two mechanically despun 3° narrow beams	32 dB	44 dBW hard limiting one beam on, 40 dBW two beams.		

NOTES: (1) This spacecraft exists in disassembled form within NASA/GSFC. Estimates are based on assembling the various subsystems to provide an ATS-1 type spacecraft.

(2) The contract for development of this spacecraft has just been awarded. These characteristics should therefore be considered preliminary.

(3) A NASA-proposed modification to INTELSAT III. Exact antenna beamwidth has not been precisely defined.

(4) A TRW 1 September 1970 proposal for modifying the INTELSAT III spacecraft. Two elliptical beams providing about the same ERIP can be obtained on one parabolic dish.

(5) This is the Canadian Domestic Satellite. The contract for development has just been awarded. The characteristics shown are based on precontract award expectations.

(6) This is a proposed Canadian satellite that is at present only a concept being considered. Its characterization is therefore incomplete.

(7) It is planned to launch two of these spacecraft on one launch vehicle, and estimates are based on employing this approach.

satellite and offers many of the same features as INTELSAT IV, but is a smaller spacecraft.

The Canadian Applications Satellite is a proposed spacecraft whose exact configuration is not well defined at present, but from proposals already made it is expected to be a very large spacecraft supplying a very high EIRP. It is anticipated that at least a Titan IIIC launch vehicle would be required to put this satellite in a geostationary orbit. Another version is smaller and suitable for a Thor-Delta launch.

DSCS Phase II is a military satellite. A Titan IIIC can orbit two of these spacecraft in a single launching. DSCS Phase II operates in the 8-GHz uplink, 7-GHz downlink frequency bands. The Canadian Applications Satellite operates in the 13-GHz uplink, 12-GHz downlink frequency bands and the remaining spacecraft of Table 5-2 have transponders that operate at 6-GHz uplink, 4-GHz downlink. ATS-F and G also have transponders operating at 6-GHz uplink, 0.86-GHz downlink, and 6-GHz uplink, 2.5-GHz downlink.

Antenna beams listed for each satellite are those presently existing at the frequencies of interest. Beam pattern reconfigurations, within limits, may be possible on all of these spacecraft. Certain of these satellites provide, as presently proposed, beamwidths so narrow that complete Alaskan coverage is not supplied. The ATS-F and G satellites, and perhaps the Canadian Applications Satellite, fall into this category. Costs are again preliminary estimates for the configurations indicated that do not account for any modifications to antenna or power amplifier systems that may be desired.

SECTION 6

CONSTRAINTS AND CONSIDERATIONS

6.1 GENERAL

In addition to the performance-cost tradeoffs, there are a number of constraints which tend to narrow the choice of possible candidate systems. There are also considerations which lead to preferred configurations while not prohibiting other choices. This section will discuss the constraints and considerations brought about by

a. The choice of frequency
b. Orbital spacing and interference.

A preferred satellite list will be developed with which the tradeoffs can be performed.

6.2 THE CHOICE OF FREQUENCY

The governments represented in the ITU are presently developing positions for the World Administrative Radio Conference which will take place in 1971. This conference will consider revisions to the present international radio regulations. Table 6-1 lists the existing and proposed frequency bands which are candidates for the satellite distribution of television program material.

Of the two existing bands the 8-7 GHz band at first appears to offer some promise since it is allocated in the U.S. for government use and contains a 50-MHz segment for exclusive satellite use.[1] This segment has no flux density limitation. However, this band is presently being used by the U.S. and allied military, and the characteristics of a military satellite system make it very undesirable as a cohabitant of the frequency spectrum. Specifically, the military has a range of antennas including: 2-ft, aircraft

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[1] International Radio Regulations of the International Telecommunications Union, Article 5, page 76, 1968.

TABLE 6-1. FREQUENCY CANDIDATES COMMUNICATION - SATELLITE SERVICE

Existing:	5925-6425(1) 3700-4200	Up Down
	7900-8400 7250-7700	Up Down
Proposed:(2)	614-890(3)	
	2500-2550 2150-2200	Up Down
	12750-13250 11700-12200	Up Down

Notes: (1) All frequencies in MHz

(2) "Proposal of the United States of America for the WARC-Space Telecommunications (1971)," published by the United States Department of State

(3) TV Broadcast Only

(proposed); 6-ft, ship; 20-ft, transportable; 40-ft, semi-transportable; and 60-ft, fixed. All of these have high power transmitters; consequently, they are likely to cause interference. The small antenna diameters will also make them subject to interference. In addition, the military system design is based on flexibility; therefore, both terminals and satellites are subject to movement as events dictate, making the planning of sharing a frequency band very difficult. For these reasons the 8-7 GHz band is considered a poor candidate.

The other existing satellite communications band 6-4 GHz is used by INTELSAT and is likely to be the frequency band used for domestic commercial service. As opposed to the military design, however, the terminals will all be 42 feet or larger and satellite and terminal locations will remain fixed, making the problem of coordination to reduce interference less difficult. The availability and performance of components is better in this band relative to the 8-7 GHz band or any higher frequency band. Costs should also be relatively lower. A significant factor favoring this band over higher frequencies is that the antenna pointing accuracy is less for a fixed aperture antenna. Over the size apertures of interest, antennas with course manual steering may be employed. For these reasons the 6-4 GHz band is considered a prime candidate.

The other two proposed bands, S-band (2.2 - 2.5 GHz) and the UHF band (614 - 890 MHz) while lower in frequency than C-band (6 - 4 GHz) have restrictions or disadvantages which limit their serious consideration. The S-band proposal is presently limited to demand Assignment Multiple Access for remote areas with limited traffic, although recent discussions indicate its possible use for Institutional Television Fixed Service (ITFS)[1]. While supporting the use of satellite broadcast techniques in the UHF band, the FCC would be concerned with any type of satellite coverage that could restrict their frequency assignments to terrestrial stations; but if the same transmission carried any communications services, in this band that has been designated as a TV broadcast band, this would be a derogation of FCC rules and regulations.*

As shown in Table A-1 no allocation for voice transmission is available at UHF. If this band were chosen, large spacecraft antennas would be required to obtain the desired coverage and gain. The system would be tied to large and complex spacecraft. A significant disadvantage to the use of any of the proposed frequency

[1] "Proposal of the United States of America for the WARC-Space Telecommunications (1971)," published by the United States Department of State.

bands is that should the proposals be modified before adoption or rejected completely, any prior expenditures for equipment would be wasted.

In summary, the choice of frequency band is a most important systems decision from the investment as well as technical viewpoint.

6.3 PREFERRED SATELLITE LIST

Based on the above constraints and considerations, Table 6-2 lists the preferred satellites. The satellite costs are an estimate of the cost to procure a copy of the existing or proposed design.

TABLE 6-2. CANDIDATE SATELLITE COSTS
(in Millions of Dollars)

SPACECRAFT	COST	LAUNCH COST	TOTAL
ATS-1	AVAILABLE IN ORBIT		
ATS-3	AVAILABLE IN ORBIT		
INTELSAT II	3.0	4.0	7.0
INTELSAT III	6.0	5.0	11.0
INTELSAT III-1/2*	7.0	5.0	12.0
INTELSAT IV*	18.0	15.5	33.5
TELESAT*	8.0	7.0	15.0
ATS-F&G**			
INTELSAT III (MOD)*	7.5	6.0	13.5
Canadian Application*	18.5	16.0	34.5

*Costs shown are tentative and subject to change during negotiation of definite specifications.

**Cost figures for these satellites with the experiments they carry deleted are not available.

There is one other version of ATS-1, designated ATS-Y1, which is an existing qualification model. It is estimated that it would cost $1.0 million plus modification costs and $11.0 million launch costs for a total of $12.0 million to place ATS-Y1 in orbit.

6.4 ORBITAL SPACING

In recent years many countries, and organizations within the same country, have become involved in planning and setting up satellite communications systems employing geostationary orbits. Many of these present and planned satellites operate in the same frequency bands. As a result, interference between satellite systems has become a matter of considerable concern on the international communications scene. In response to this concern, CCIR studies have been initiated to determine the minimum allowable orbital spacing, between satellites operating at the same frequency, that still results in a tolerable level of interference.

Basically there are three kinds of interference situations of concern, which can be illustrated by considering two independent communication satellites A&B. A ground terminal communicating with Satellite B can suffer interference from a terminal in System A due to radiations relayed through either of the two satellites of interest. Additionally, the terminal in System B can interfere with itself by having its radiations relayed through the satellite of System A. The latter is a multipath situation.

The levels of interference are a function of a large number of variables in addition to orbital spacing. These include:

- Satellite orbital position, beam pointing, antenna pattern, transmitter power, signal polarization, and type of repeater.
- Ground terminal location, beam pointing, antenna patterns, transmitter power, receive system noise temperature, and polarization.

- Modulation and coding of the desired and interfering signals.
- Type of baseband information transmitted and quality of performance required.

With all these factors to be considered in developing spacing criteria, no officially accepted international standards exist at present. It is expected, however, that such standards may be adopted in the near future. If they are, the use of small ground terminals having wide beamwidth antenna patterns may tend to be eliminated. Alternately, and more likely, the spacing required for satellite systems utilizing small ground complexes may be increased over those with larger ground terminals.

Small ground terminals are highly desirable in an Alaskan ground complex for a number of reasons. First, there is an obvious reduction in cost when smaller antennas are employed. There is also the greater compatibility, from a reliability viewpoint, with the wind, ice, snow, and unskilled maintenance and operating personnel that may exist. More importantly, however, the wider beamwidths of small terminals allow the elimination of sophisticated tracking systems from the ground complex. As the size of the terminal antennas is reduced, advantages are gained in terms of ground complex, cost and reliability.

Essentially, the need for wide beamwidths to minimize pointing difficulties is a result of the fact that even geostationary satellites commonly exhibit a certain degree of north-south and east-west movement from their required positions. This is a result of the excessive station keeping requirements imposed by allowing no satellite movement. Typically $\pm 3^\circ$ of movement in at least the north-south directions is allowed. A 15-foot ground terminal provides about a 1.1° beamwidth when operating at 5 GHz. With this beamwidth and a relatively crude pointing system, successful communications could probably be carried out through occasional manual changes of the antenna pointing angles. Antennas with narrow beamwidths would not allow a manual pointing system to be implemented without constant attention.

The exact satellite orbital spacing that would be required if an Alaskan ground complex composed of 15-foot terminals were employed has not been investigated in detail. Preliminary indications are, however, that there is a potential problem in allowing spacings as close as 7° to any other satellite operating at 6-4 GHz.

With the relatively wide spacings required, there would be considerable difficulty in positioning an Alaskan satellite operating at 6-4 GHz at longitudes corresponding to the lower 48 states. Domestic satellites of both the U.S. and Canada operating at 6-4 GHz will exist at these longitudes. Locations over the Pacific should be more readily available. The major demands for Pacific locations are likely to be by military satellites. These satellites operate in the 8-7 GHz frequency band and would pose no interference problem to an Alaskan satellite operating in the 6-4 GHz band. Fortunately, satisfactory Alaskan coverage can be provided from a considerable range of satellite longitudes that include locations over the Pacific. These Pacific locations improve the prospects for 15-foot antennas, whereas an Alaskan beam on a domestic satellite over the mid-U.S. may require 30-foot antennas.

SECTION 7

TRADEOFFS

7.1 INTRODUCTION

The choice of an Alaskan satellite system will depend upon a large number of interdependent factors; all directly related to cost. Insofar as possible, it is desired to select a least cost system that is fully responsive in terms of performance.

As will be seen in this section, there are parameters that must be identified and fixed for any design to proceed expeditiously. Some of the parameters have a relatively narrow range, which restricts the degree of choice, and other parameters range quite widely. As in any system design, a number of constraints are imposed by the environment, by accepted standards and practices, and by element cost and availability. This section describes the primary factors, comments on the degree of choice, and presents factors that may be optimized according to the requirements imposed.

In order to proceed logically, the various factors are described in terms of satellite systems, ground systems, information systems, and environmental factors.

7.2 INFLUENTIAL FACTORS AND DEGREE OF CHOICE

7.2.1 Satellite System

Candidate satellite systems were discussed in terms of availability, performance, and radio frequency utilized (See Sections 5 and 6), but for the duration of the report attention shall be focused on those satellites operating in the 6-GHz up, 4-GHz down frequency band. This class of satellites exhibits a variety of power and bandwidth parameters which may be traded for an optimum configuration. Thus, two significant factors of choice for the satellite system are:

- EIRP - Effective Isotropic Radiated Power
- B - RF Bandwidth

7.2.2 Ground System

The ground receiving system is described primarily in terms of the receiving antenna gain, G, and the receiving system noise temperature, T. These two factors and, more specifically, their ratio G/T determine a figure of merit for the ground receiving system. For a given B, it is possible to trade EIRP versus G/T. That is, as the power is increased in the satellite, the gain and sensitivity on the ground can be decreased. This is a fundamental tradeoff for system selection. In addition, for a fixed G/T it is again possible to trade antenna gain versus receiving system noise temperature. That is, a high gain (large diameter) antenna may be used with a relatively economical preamplifier (e.g., a tunnel diode amplifier) to achieve a specified G/T. Thus, for the ground system two significant factors of choice are:

- G - Ground Antenna Gain
- T - Receiving System Noise Temperature

It is necessary to note here that G is normally constrained by size restrictions and may practically vary from 10 to 40 feet, depending upon planned location. The primary contribution to the system noise temperature is usually represented by one of three classes of amplifiers:

- Tunnel Diode Amplifier (TDA) - 620° K
- Uncooled Paramp - 200° K
- Cooled Paramp - 68° K

The ground transmitting system is described primarily in terms of the transmitting antenna gain (at the uplink frequency) and the transmitter power. The product of these two (or the sum if expressed in decibels is the Effective Isotropic Radiated Power (EIRP). In designing the uplink parameters it is desirable to insure that the strength of the uplink transmitted signal as received at the satellite is significantly greater than the effect at noise of the satellite referred to that point. That is:

$$(EIRP)_g - L_{pB} + (G/T)_s + K \gg 0 \quad \text{(in dB)}$$

where $(EIRP)_g$ is the Effective Isotropic Radiated Power for a ground terminal

L_{pB} is the power budget loss factor defined by Equation 7 and is expressed in dB

(G/T) is the ratio of satellite receiving antenna gain (G) to system noise Temperature (T); the ratio expressed in dB

K is Boltzmann's constant (-228.6 dB/°K Hz)

7.2.3 Information System

Prescribed parameters that describe the method and quality of transfer exist for the transmission of television and voice signals. It is necessary to specify the method of modulation, the information bandwidth, the receiver sensitivity, and some measure of signal (TV or voice) quality.

7.2.3.1 Modulation

Wideband Frequency Modulation (FM) and Vestigial Sideband Amplitude Modulation (VSAM) have been considered for satellite relay of TV and voice transmissions. The present analysis is based upon use of FM as the preferred modulation because of the freedom from distortion resulting from transponder limiting, less required EIRP, and bandspreading, which allows more total radiated power within the CCIR restrictions on radiated power per unit bandwidth.[1]

7.2.3.2 Information Bandwidth

The present analysis considers both a baseband of 4.5 MHz, which will carry monochrome or color TV, and a baseband of 2.5 MHz, which will carry only monochrome TV.

The TV audio information is transmitted on an FM subcarrier. If a maximum modulating frequency of 15 kHz is employed within a predetection bandwidth of 100 kHz, the resulting voice output signal-to-noise ratio will exceed that of the related TV signal-to-noise ratio by a considerable margin (15 to 20 dB). Therefore, the remainder of the study will concentrate on the TV video performance. The telephone baseband is chosen as 3.4 kHz.

7.2.3.3 Receiver Threshold

Standard FM receivers can be improved by extending the detection threshold through use of FM feedback (FMFB). For the present analysis, it is assumed that a standard FM receiver with a nominal 10.5-dB threshold is used. FMFB receivers can be employed to lower the threshold at increased cost. Threshold extension of receivers used with a large modulation index is difficult to implement.

7.2.3.4 Picture Quality[2]

The Television Allocation Study Organization (TASO) has carried out experiments using TV performance viewing that resulted in a subjective rating of TV picture quality as a function of signal-to-noise ratio. Table 7-1 shows the TASO grades versus the peak-to-peak signal-to-rms noise ratio $\left(\frac{S}{N}\right)_o$.

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[1] CCIR Rec 358-1; Oslo, 1966.

[2] Proceedings IRE, Volume 48, June 1960.

It is possible to relate $\left(\frac{S}{N}\right)_o$ to the carrier-to-noise ratio $\left(\frac{C}{N}\right)$ at the receiver input by means of the FM equation so that one may relate picture quality to signal-to-noise ratio. (see page 7-16).

TABLE 7-1. SUBJECTIVE ASSESSMENT OF SIGNAL-TO-NOISE RATIO FOR TELEVISION

TASO GRADE	DESCRIPTION	MEDIAN OBSERVER (dB)	90% OBSERVER (dB)	MEAN OBSERVER (dB)
1	Excellent	43	--	42
2	Fine	33	41	37
3	Passable	27	33	31
4	Marginal	23	28	25
5	Inferior	17	22	19

(1) Excellent: The picture is of extremely high quality, as good as you could desire.
(2) Fine: The picture is of high quality providing enjoyable viewing, but interference is perceptible.
(3) Passable: The picture is of acceptable quality and interference is not objectionable.
(4) Marginal: The picture is poor in quality and you wish you could improve it; the interference is somewhat objectionable.
(5) Inferior: The picture is very poor, but you could watch it -- definitely objectionable interference is present.

7.2.3.5 Voice Quality

Voice quality is again a subjective measure that ranges between a signal-to-noise ratio $\left(\frac{S}{N}\right)_o = 50$ dB for "high" quality voice to $\left(\frac{S}{N}\right)_o = 38$ dB for "good" quality voice. The analysis for voice transmission has assumed a desired $\left(\frac{S}{N}\right)_o = 50$ dB.

7.2.4. Radiation Limitation

To minimize interference from both satellite and terrestrial systems that may share the frequency spectrum, the CCIR has established a maximum spectral flux density[1] for certain frequencies in the 1- to 10-GHz range.

The maximum spectral flux density produced at the earth's surface by satellite emission should not exceed:

$$-152 + \frac{\theta}{15} \text{ (dB)}$$

relative to 1 watt per square meter per 4 kHz (θ = elevation angle measured in degrees above the local horizontal). The maximum EIRP that any satellite is permitted to radiate is given in dBW by:

$$(\text{EIRP})_{max} = 177 + \frac{\theta}{15} + 20 \log R + 10 \log B$$

where R is the slant range in meters and B is the transponder bandwidth in Hz. This relation is based on a uniform signal spectral density over the entire bandwidth B. The FM TV spectrum exhibits a number of peaks, which results in a non-uniform power spectrum. It may be possible to use standard signal spreading techniques such as the application of saw tooth waveform that deviates the TV signal 2 MHz at a 30 Hz rate to allow conformance with CCIR standards. EIRP_{max} is plotted in Figure 7-1 for the worst case when θ is zero and R takes on its maximum value from synchronous altitude.

7.3 TRADEOFF ANALYSIS

7.3.1 Introduction

As discussed in the previous section, EIRP and $\frac{G}{T}$ are important parameters that essentially determine the satellite earth terminal configuration. Having set the principal RF parameters, it is then necessary to determine the resulting signal

[1] CCIR Rec 358-1; Oslo, 1966.

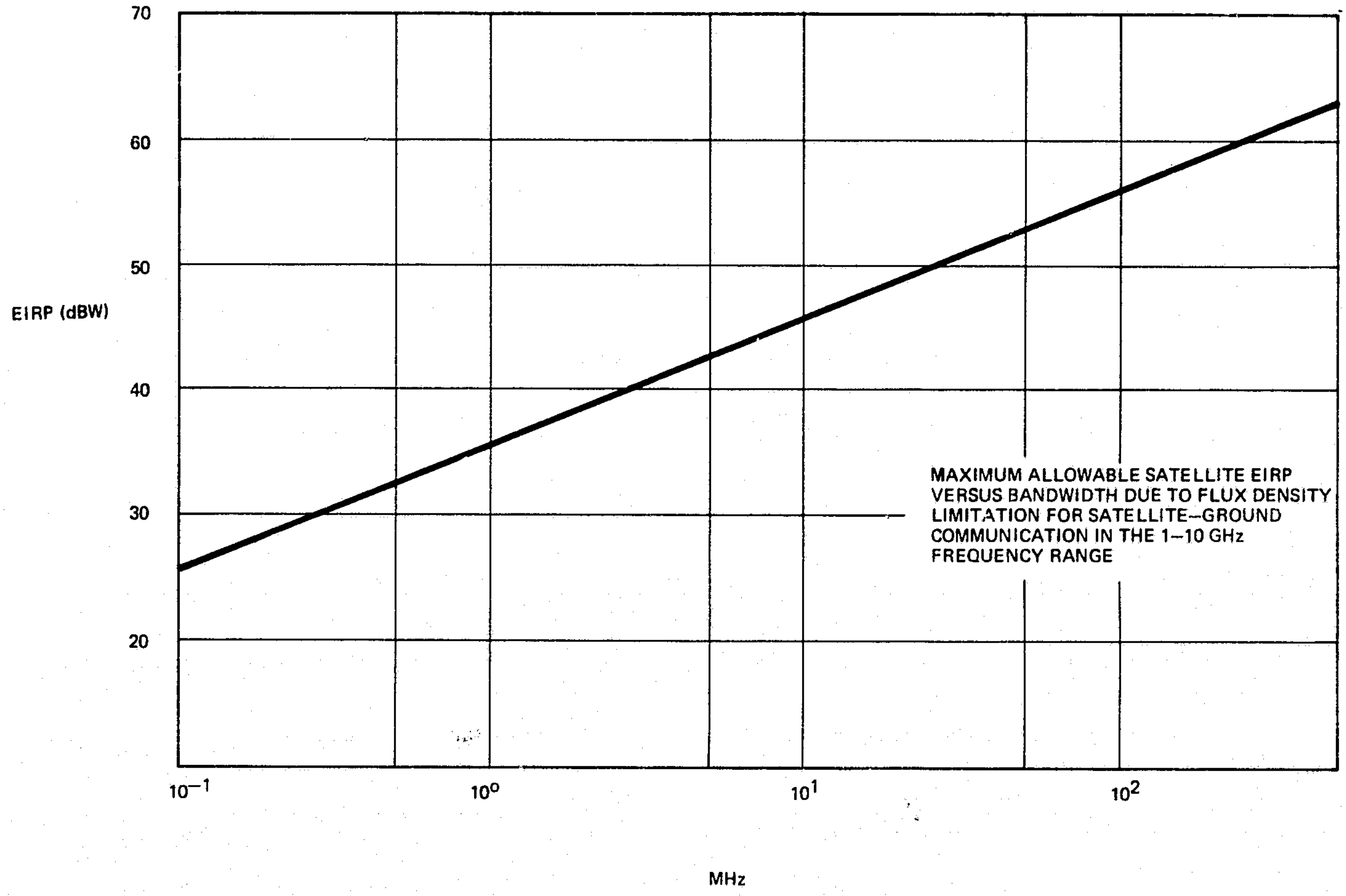

Figure 7-1. Flux Density Limitations on Satellite EIRP

quality for the user. The following paragraphs will present tradeoffs among satellite power, receiving station figure of merit and signal quality for both TV and voice transmission. The figures presented are primarily for the downlink since this is generally the limiting element in a satellite relay system. Representative TV and voice uplink calculations are also included.

7.3.2 Television Tradeoffs

7.3.2.1 Television

Three assumptions for the TV tradeoff analysis were previously discussed in this section.

1. The carrier frequencies analyzed are:
   a. 6 GHz on the uplink
   b. 4 GHz on the downlink
2. Maximum modulating frequencies of:
   a. f_m = 4.5 MHz for color TV
   b. f_m = 2.5 MHz for monochrome TV
3. Frequency Modulation to be employed.

Other assumptions are:

- Synchronous, geostationary satellite
- Single channels
- Radio frequency bandwidth B (15 to 36) MHz
- Carrier-to-noise ratio $\left(\frac{C}{N}\right)$: (10.5 to 19.5) dB
- Use standard FM receiver
- FM·TV (SNR) improvement[1] - noise weighting factor, k_p, of
  $\begin{cases} 10.8 \text{ dB for color TV} \\ 7.3 \text{ dB for monochrome TV} \end{cases}$
- No pre-emphasis or de-emphasis is employed for the specified reason of enhancing the FM performance.

7.3.2.2 TV Video Transmission (Uplink)

This paragraph describes a representative uplink calculation for the ground station-to-satellite to derive a relation between the required ground transmitter power (P_G) and the total antenna gain (station + satellite) ($G_G + G_S$). Two typical transmit terminals are then described.

To provide an adequate margin for establishing the required carrier-to-noise ratio, $\left(\frac{C}{N}\right)_d$, in the downlink, 10 dB is added to the downlink ratio to define the required uplink carrier-to-

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[1] CCIR Rec 421-1; Oslo, 1966.

noise ratio, $\left(\frac{C}{N}\right)_o$. The uplink noise will then contribute 0.4 dB to the total noise. Thus,

$$\left(\frac{C}{N}\right)_u = \left(\frac{C}{N}\right)_d + 10 \text{ dB}$$

This defines the required uplink carrier-to-noise ratio at the satellite receiver. We will employ a middle range value of $\left(\frac{C}{N}\right)_d$.

$$\left(\frac{C}{N}\right)_d = 14 \text{ dB}$$

$$\left(\frac{C}{N}\right)_u = 14 + 10 = 24 \text{ dB}$$

The received carrier level at the satellite is

$$C_u = (P_G + G_G + G_S - L) \text{ dBW}$$

where

P_G = Ground transmitter power

G_G = Ground antenna gain

G_S = Satellite antenna gain

L = Losses

KTB = Thermal noise power in bandwidth B

or

$$\left(\frac{C}{N}\right)_u = P_G + (G_G + G_S) - L - 10 \log (KTB) \text{ dB}$$

This equation can be solved for P_G in terms of $(G_G + G_S)$ in dBW. Selecting the constants as:

$$\left(\frac{C}{N}\right)_u = 24 \text{ dB}$$

$$B = 24 \text{ MHz } (73.8 \text{ dB})$$

$$T = 1000° \text{ K} = 30 \text{ dB}$$

$K = -228.6$ dBW/°K/Hz

$L =$ Total losses which is the sum of Free Space Loss (200.2 dB) and Off Beam Allowance + Diplexer + Miscellaneous losses (2.8 dB); $L = 203.0$ dB

yields a solution for P_G of the form:

$$P_G = \left[102.2 - (G_G + G_S)\right] \text{ dBW}$$

This relation is plotted in Figure 7-2.

Two classes of terminals should be considered, one operating within a narrow beam, which would be typical if Fairbanks were the transmitter and the other operating in an earth coverage beam, which would be typical if the transmitter were in the lower 48 and a narrow beam was not allocated for the operation. In the first case, if the same spacecraft antenna were used for transmit and receive the satellite antenna would have about 36 dB gain (2.6°). If a 32-ft. earth terminal antenna with a 53-dB gain is used, the combined gain is 89 dB. From Figure 7-2, about 11 dBW of transmitter power is required, or 11 watts. From the viewpoint of interference potential, it is probably not wise to go below a 20-ft. antenna, although a 15-ft. antenna with a 125-watt transmitter would achieve the same C/N as the satellite.

The second case would use an earth coverage spacecraft antenna with an 18-dB gain. The same 32-ft. earth terminal antenna now gives a combined gain of 71 dB. From Figure 7-2, a 32-dBW or 2000-watt transmitter is required. This is the equivalent of a 40-ft. antenna with a 1000-watt transmitter. As a benchmark, a 32-ft. antenna with a 10,000-watt transmitter costs approximately $400,000.

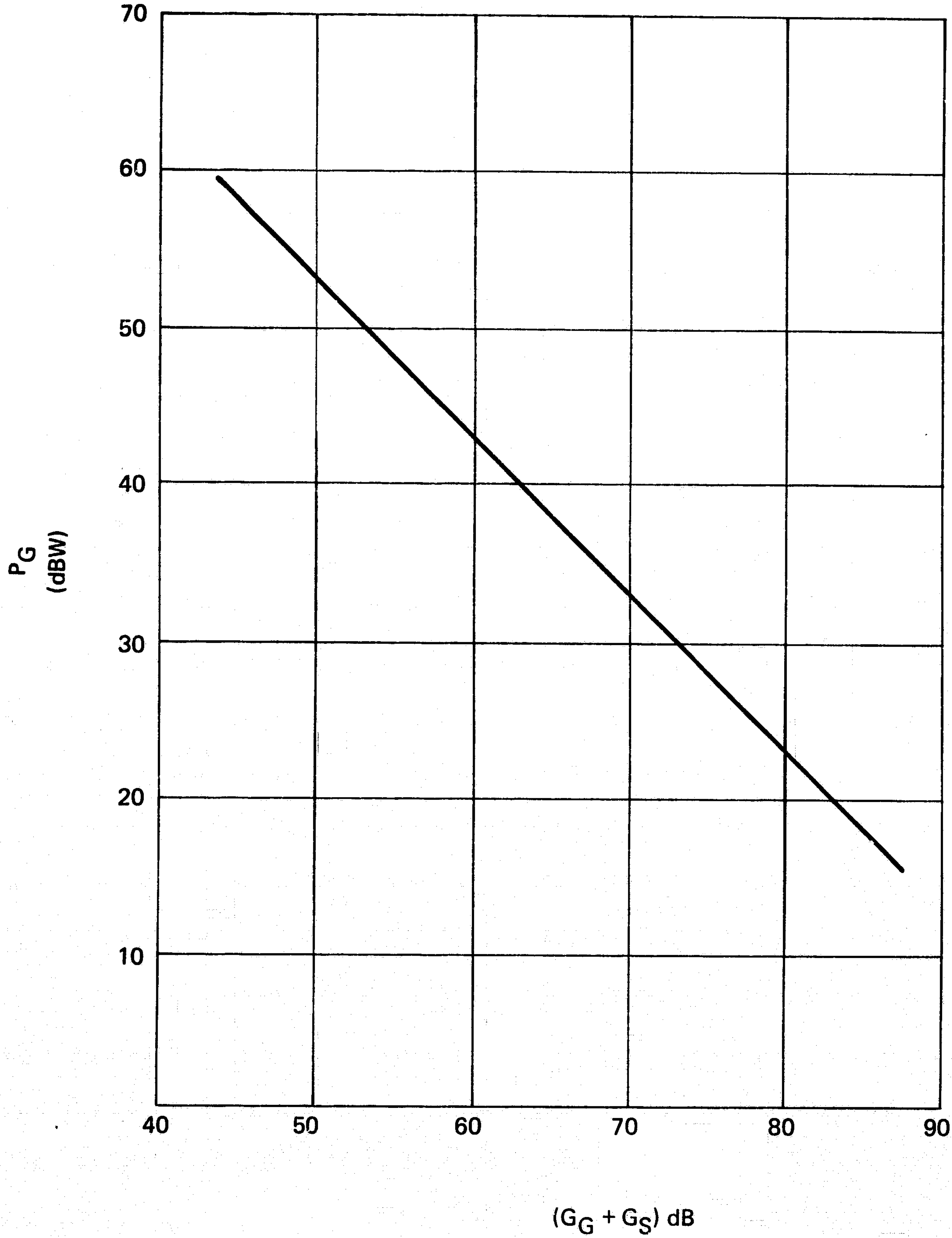

Figure 7-2. Ground Transmitter Power Versus Total Antenna Gain $P_G = [102.2 - (G_G + G_S)]$

7.3.2.3 Downlink Tradeoffs for TV

This paragraph provides a representative analysis of TV downlink parameters.

a. EIRP versus G/T

The received carrier power at an earth terminal is a function of the satellite power, the free-space loss and the earth terminal antenna gain. Expressing these quantities in decibels, the relationship between them is:

$$C = EIRP + G - L$$

or

$$\frac{C}{N} = EIRP + \frac{G}{T} - L - B - K$$

where

$\frac{C}{N}$ = Carrier-to-noise ratio at discriminator input in dB

B = Radio frequency bandwidth expressed in dB

L = Total loss = 201.5 dB at 4 GHz

K = Boltzmann's constant = 228.6 dBW/°K Hz

Thus

$$EIRP = \left(\frac{C}{N} + B\right) - \frac{G}{T} - 27.1 \text{ dB}$$

This equation is plotted in Figures 7-3 through 7-6 for B = 15, 20, 24 and 36 MHz, and various C/N. The maximum allowable flux density calculated for the specified bandwidth is also plotted on these figures.

Table 7-2 shows a few representative examples of the use of the graphs. $\frac{G}{T}$ is illustrated for a few antenna diameters coupled with an uncooled parametric amplifier.

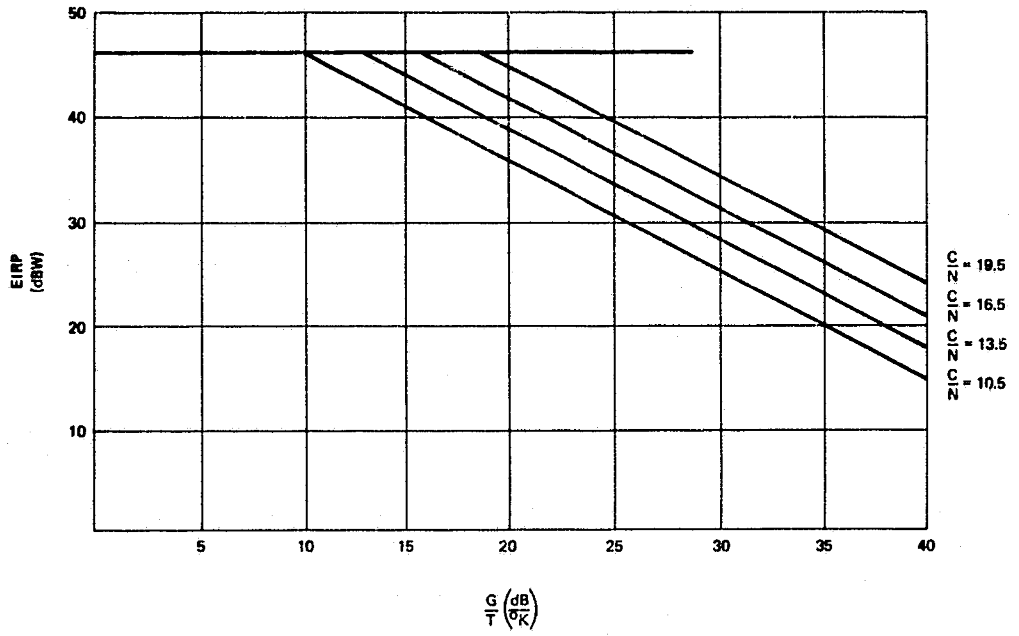

Figure 7-3. EIRP vs. G/T for RF Bandwidth of 15 MHz at 4 GHz

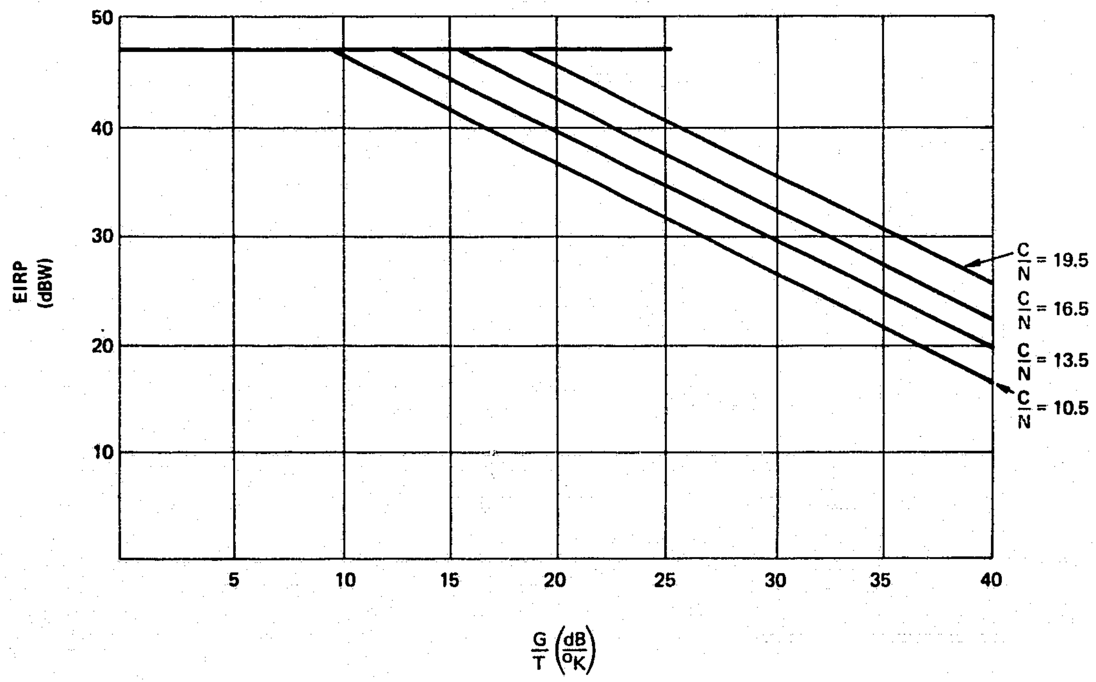

Figure 7-4. EIRP vs. G/T for RF Bandwidth of 20 MHz at 4 GHz

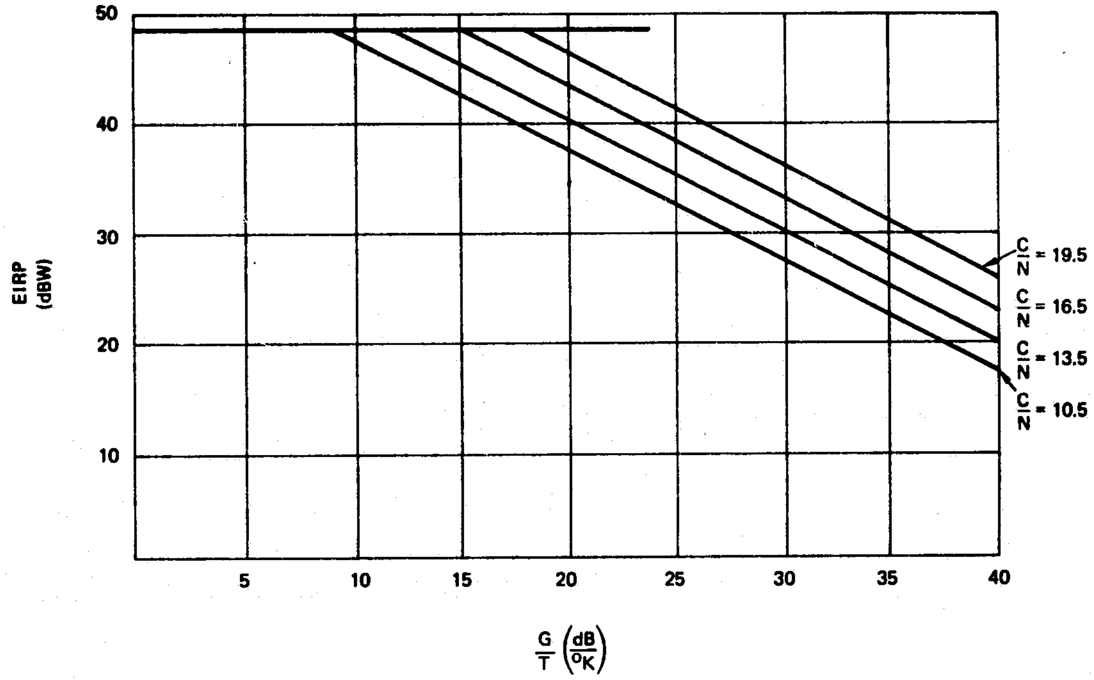

Figure 7-5. EIRP vs. G/T for RF Bandwidth of 24 MHz at 4 GHz

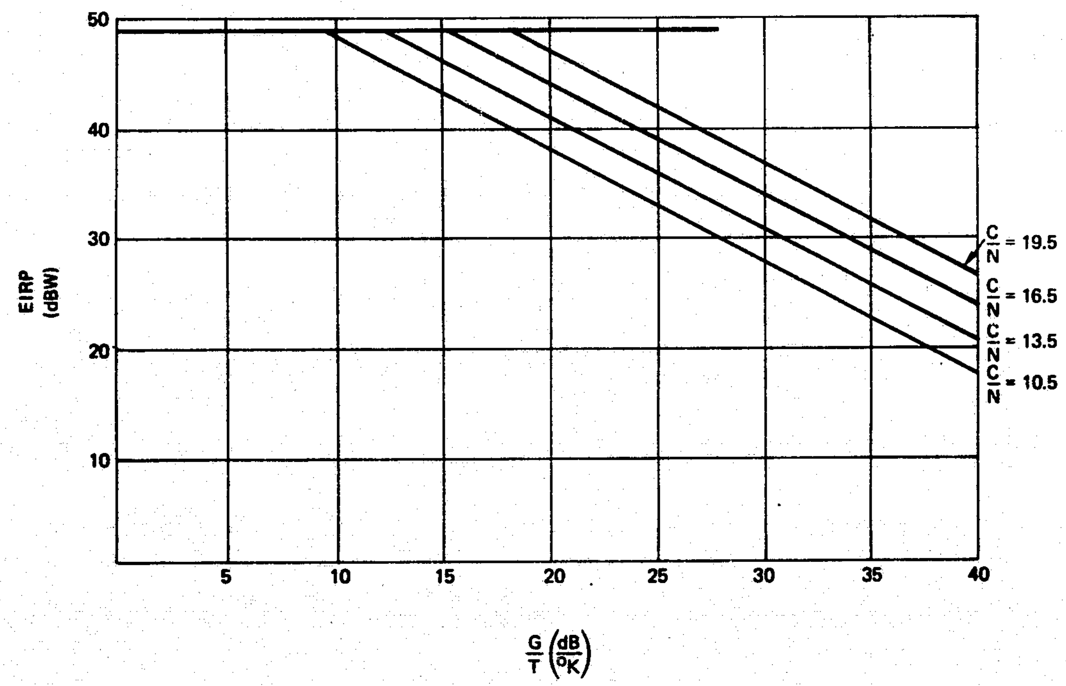

Figure 7-6. EIRP vs. G/T for RF Bandwidth of 36 MHz at 4 GHz

TABLE 7-2. EIRP vs $\frac{G}{T}$ (4 GHz)

EIRP dBw	ANTENNA DIAMETER ft	GAIN eff = 55% dB	EFFECTIVE NOISE TEMPERATURE	$\frac{G}{T}$ dB/°K
45.5	10	39.6	200°K(23dB)	16.6
42.1	15	43.0	200°K(23dB)	20.0
39.6	20	45.5	200°K(23dB)	22.5
36.1	30	49.0	200°K(23dB)	26.0
B = 36 MHz; $\frac{C}{N}$ = 13.5 dB; EIRP = 62.1 - $\frac{G}{T}$				

b. $\left(\frac{S}{N}\right)_o$ versus f_m

Since the carrier-to-noise ratio, $\frac{C}{N}$, is related to the output signal-to-noise ratio $\left(\frac{S}{N}\right)_o$ by the modified FM equation*, it is possible to derive a measure of picture quality from the specified $\frac{C}{N}$ ratios. The TASO quality figures shown in Table 7-1 were measured at a maximum modulating frequency, f_m, of 6 MHz. Below 4 MHz, the TASO grades are probably not representative of picture quality. The present analysis is based on a use of f_m = 4.5 MHz for color TV with its chrominance peak at 3.58 MHz, and f_m = 2.5 MHz for monochrome TV. For illustrative purposes, graphs are included to show the relation between output signal-to-noise ratio $\left(\frac{S}{N}\right)_o$ and maximum modulating frequency. In addition, the number of lines generated by the maximum modulating frequency are shown to demonstrate the

* The modification reflects the video peak-peak signal-to-noise ratio. This is accomplished by the weighting factor k_p.

decrease of resolution of lines with decrease in maximum modulating frequency.[1]

The equation relating $\left(\frac{S}{N}\right)_o$ and $\left(\frac{C}{N}\right)$ is:

$$\left(\frac{S}{N}\right)_o = 6m^2 \left(\frac{C}{N}\right)\left(\frac{B}{f_m}\right) k_p$$

where $\left(\frac{S}{N}\right)_o = \frac{\text{peak-to-peak signal}}{\text{rms noise}}$ at discriminator output

$\left(\frac{C}{N}\right) = \frac{\text{rms carrier}}{\text{rms noise}}$ in receiver bandwidth

B = receiver bandwidth

f_m = maximum modulating frequency = $\begin{cases} \text{4.5 MHz for color TV} \\ \text{2.5 MHz for monochrome TV} \end{cases}$

m = modulation index

k_p = noise weighting improvement factor = $\begin{cases} \text{10.8 dB for color TV} \\ \text{7.3 dB for monochrome TV} \end{cases}$

Since B is known, m can be calculated by Carson's rule as:

$$m = \frac{B}{2f_m} - 1$$

Thus:

$$\left(\frac{S}{N}\right)_o = 6\left(\frac{B}{2f_m} - 1\right)^2 \left(\frac{C}{N}\right)\left(\frac{B}{f_m}\right) k_p$$

Plots of $\left(\frac{S}{N}\right)_o$ vs baseband bandwidth for various $\left(\frac{C}{N}\right)$ are shown in Figures 7-7 through 7-10 for color TV. TASO grades are shown as circled numbers.

[1] Fink, Donald; Television Engineering Handbook, McGraw-Hill, 1957.

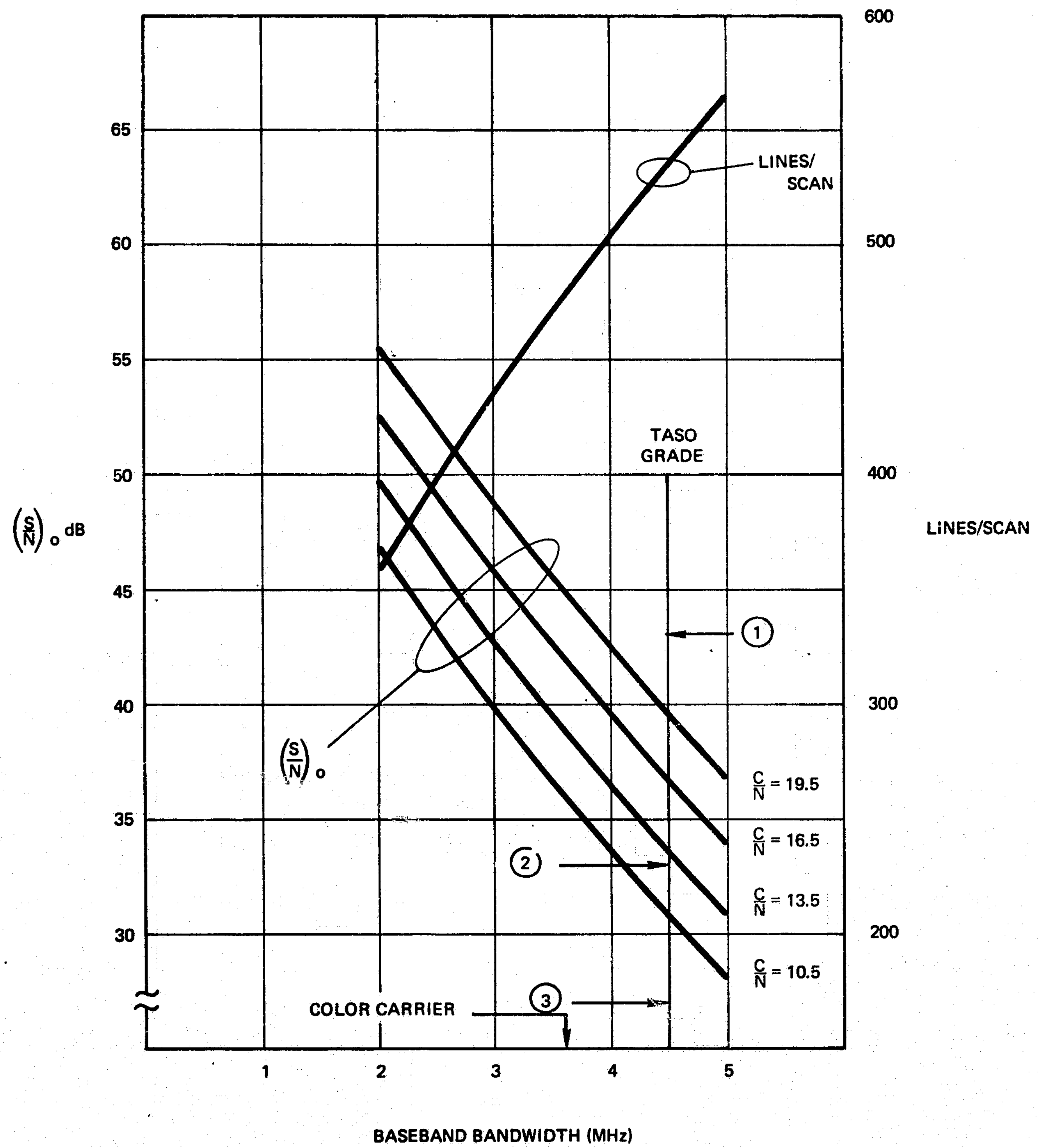

Figure 7-7. $(S/N)_o$ and Lines Per Scan Versus Baseband Bandwidth for RF Bandwidth of 15 MHz

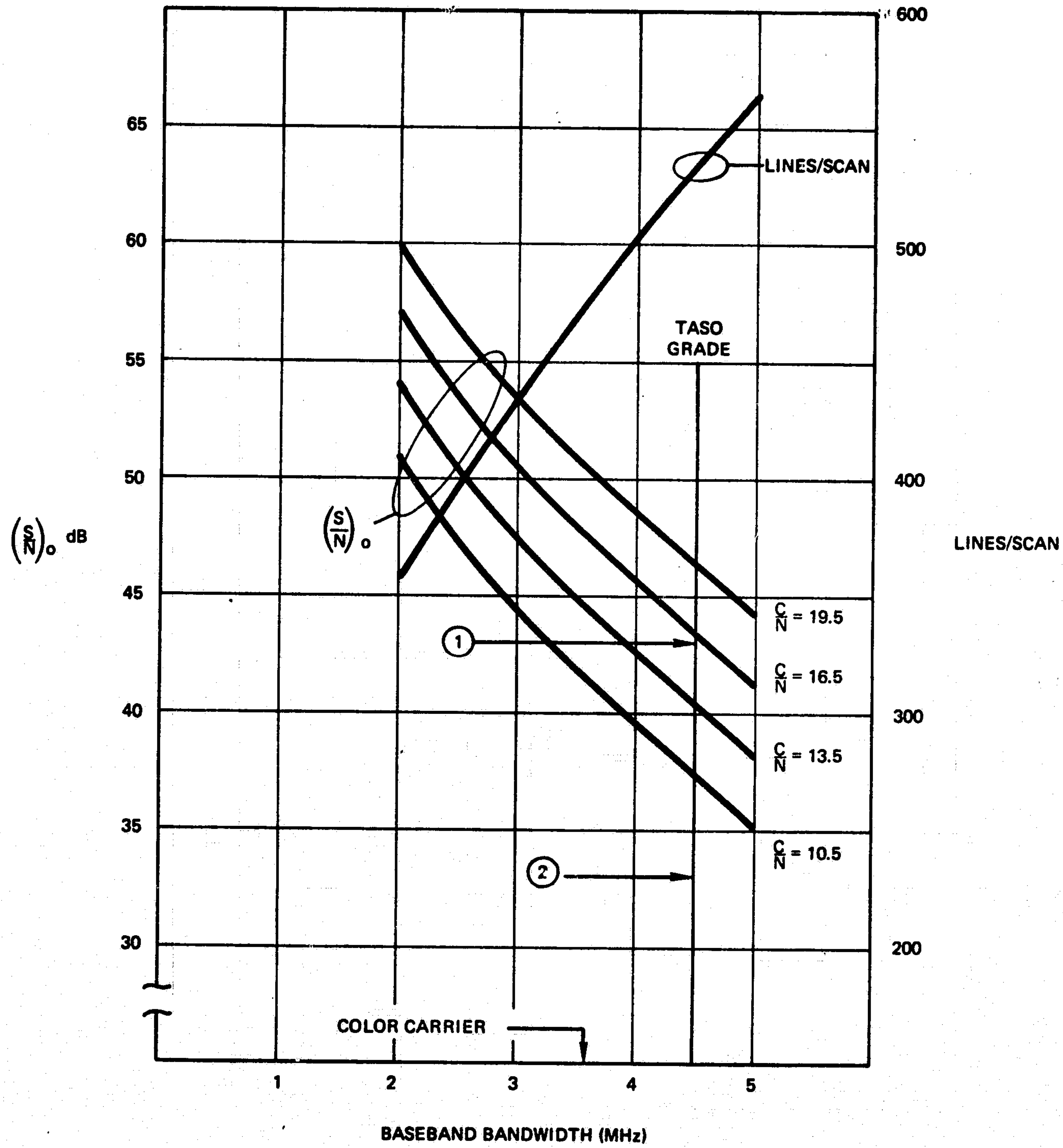

Figure 7-8. $(S/N)_o$ and Lines Per Scan Versus Baseband Bandwidth for RF Bandwidth of 20 MHz

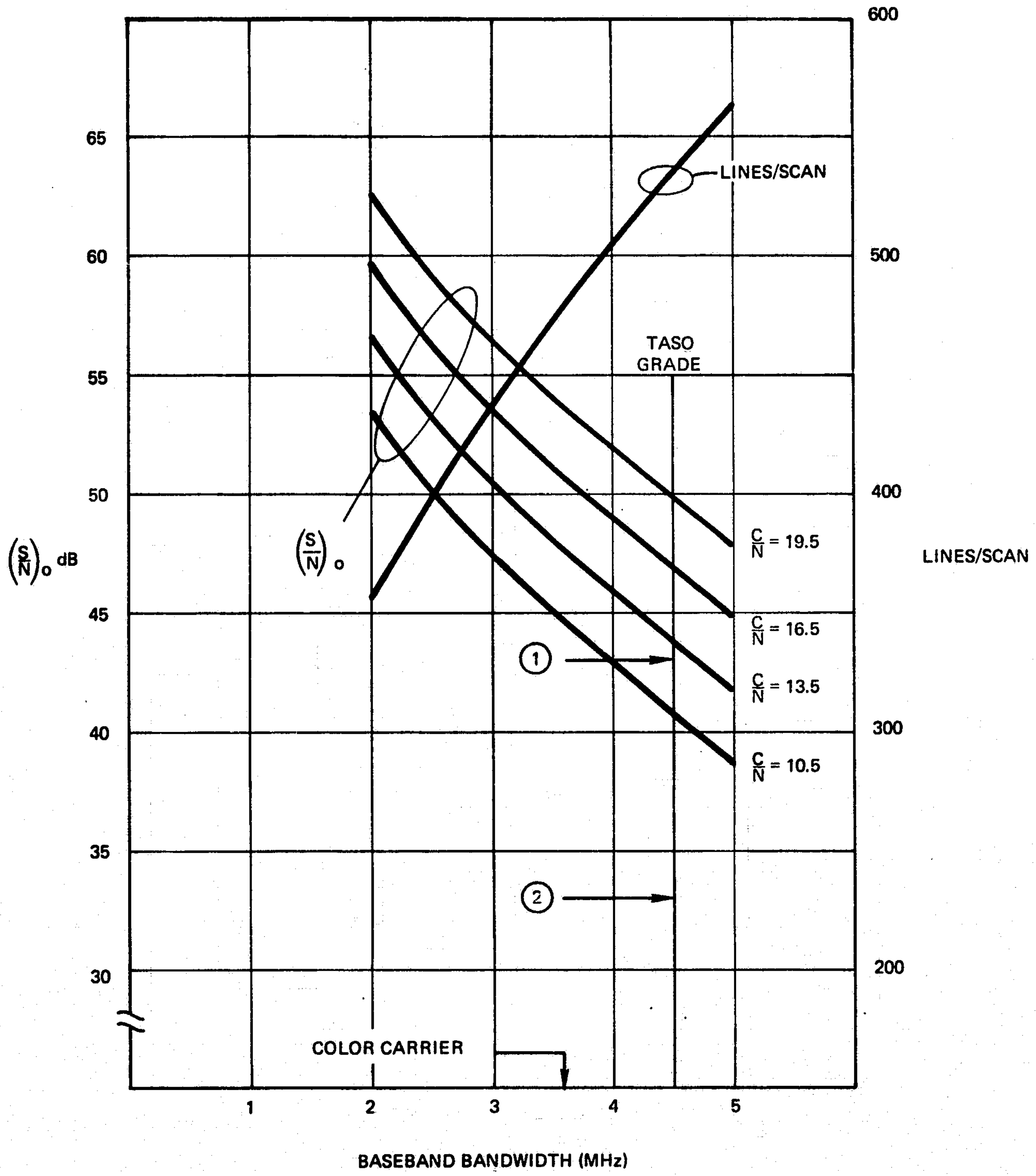

Figure 7-9. $(S/N)_o$ and Lines per Scan Versus Baseband Bandwidth for RF Bandwidth of 24 MHz

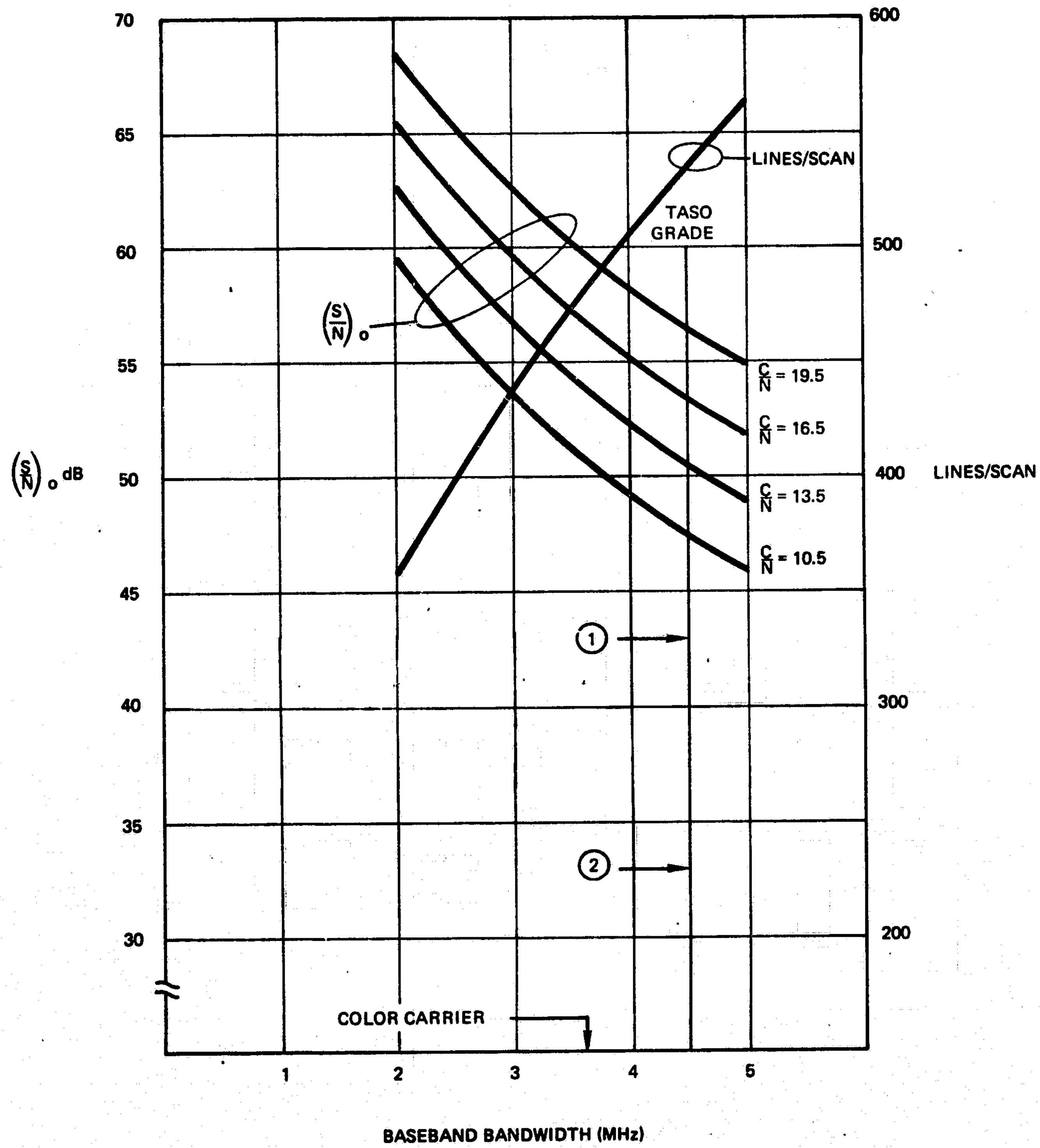

Figure 7-10. $(S/N)_o$ and Lines Per Scan Versus Baseband Bandwidth for RF Bandwidth of 36 MHz

The existence of a threshold $\left(\frac{C}{N}\right)$ ratio for FM signals represents a real and practical limit to flexibility in trading off baseband and RF bandwidth against $\left(\frac{C}{N}\right)$. For example, assume an RF bandwidth of 24 MHz is available and a TASO grade of excellent quality is required $\left(\frac{S}{N}\right)_o$ = 42 dB. If a 4.5-MHz baseband signal is transmitted, using Carson's rule, a modulation index of 1.67 will occupy this bandwidth. Applying the above FM equation, the relationship between $\left(\frac{S}{N}\right)_o$ and $\left(\frac{C}{N}\right)$ is:

$$\left(\frac{S}{N}\right)_o = \left(\frac{C}{N}\right) + 30.3 \text{ (in dB)}$$

Similarly, if a 2.5-MHz baseband signal is transmitted in 24 MHz RF bandwidth, a modulation index of 3.8 can be used and $\left(\frac{S}{N}\right)_o$ is related to $\left(\frac{C}{N}\right)$ by

$$\frac{S}{N}_o = \frac{C}{N} + 36.5 \text{ (in dB)}$$

There is a gain of 6.2 dB due to the additional improvement when a larger modulation index is used with the lower baseband bandwidth, even when the lower noise weighting factor is taken into account. However, this improvement may be available in practice only as a higher $\left(\frac{S}{N}\right)_o$ because the FM threshold may limit the minimum $\left(\frac{C}{N}\right)$ to about 10.5 dB. In this case, if operation at threshold is assumed, the 4.5-MHz signal produces an $\left(\frac{S}{N}\right)_o$ of 40.8dB. This is within 1.2 dB of the required quality. Since a lower $\left(\frac{C}{N}\right)$ cannot be used, the 2.5-MHz signal will produce an $\left(\frac{S}{N}\right)_o$ of 47.0 dB, which is an improved quality. The flexibility to tradeoff quality for $\left(\frac{C}{N}\right)$ and the resultant lower transmitter powers and/or antenna sizes is not available; however, due to the 10.5-dB threshold. If operation well above threshold was required for satisfactory quality with the 4.5-MHz signal, the tradeoff would be available. RF bandwidth was assumed constant in this case. If RF bandwidth is at a premium, the larger modulation index can be traded off for reduced bandwidth.

In addition to S/N ratio, which measures the ratio of wanted to unwanted signals, quality in a video signal is also a function of the ability to resolve line pairs. This is a function of the maximum modulating frequency.

The number of lines is related to the maximum modulating frequency by the relation

$$f_{max} = 15.8\ rn^2$$

where n = Number of lines

r = Ratio of horizontal to vertical resolution ≈ 1.

This relation is also plotted on the graphs in Figures 7-7 through 7-10.

7.3.3 Voice Tradeoffs

The technical factors determining voice channel use are similar to those of TV. The demand for voice grade circuits will require several hundred voice channels. However, a number of the users will have a low usage factor. It is appropriate then that no dedicated channels assignments be made, but rather that the channels be sequentially shared, understanding, of course, that channel availability will not be guaranteed. Appendix D gives a description and performance tradeoffs for a suitable single channel FDMA/FM system. This section illustrates the required EIRP vs number of voice channels which is plotted for three different $\frac{G}{T}$ values.

The assumptions made for the voice channel calculations are as follows:

a. Synchronous, geostationary satellite

b. Frequency - 6-GHz up; 4-GHz down

c. Voice bandwidth f_m = 3.4 kHz

d. Receiver bandwidth B = 102 kHz

e. Modulation - FM

f. Separate carrier for each voice channel

g. Use standard FM receiver *

h. Psophometric weighting factor = 2.5 dB

i. No preemphasis or deemphasis

7.3.3.1 EIRP vs G/T

The equation relating EIRP and G/T has been developed in paragraph 7.3.2.3.

where $\left(\frac{C}{N_o}\right)_{eff} \triangleq$ Effective carrier to thermal noise density ratio (See Equation (E-5)

$L_{PB} \triangleq$ Power budget loss factor (See Equation (E-7)

7.3.3.2 Number of Channels vs EIRP

Figure 7-11 relates the number of channels, M, obtained vs satellite EIRP at a $\left(\frac{S}{N}\right)_{FL}$ ** ~ 51.5 dB, which represents voice quality. This relation is plotted for 3 values of $\frac{G}{T}$ representing 10- , 15- and 30-foot dishes with T = 200°K. Also plotted is the flux density limitation.

*The curves from Appendix D for threshold values of 12 dB were used to allow a 1.5 dB maintenance margin above the 10.5 dB design thresholds anticipated.

**$\left(\frac{S}{N}\right)_{FL}$ is full load rms sine wave power to noise power ratio.

From Appendix D, this is equivalent to a 50.0 dB test tone to noise.

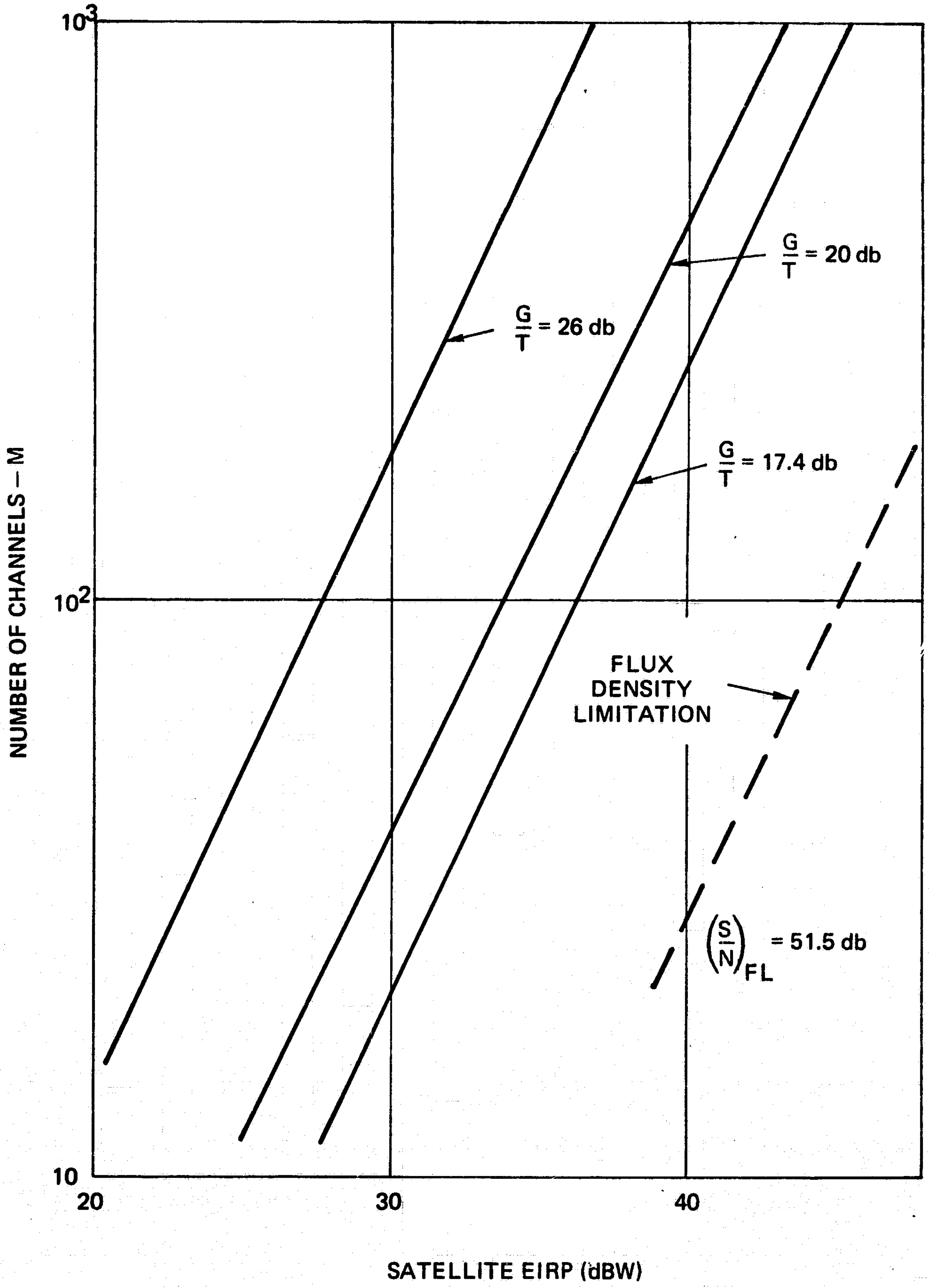

Figure 7-11. Number of Channels Versus Satellite EIRP

As an example, a $\frac{G}{T} = 17.4 \frac{dB}{°K}$ and a satellite EIRP = 32 dBW can support 35 voice channels, while a $\frac{G}{T}$ = 26 dBW, with a satellite EIRP = 32 dBW, can support 300 voice channels.

7.4 TV BANDWIDTH REDUCTION

The "standard" bandwidth of a television transmission in the U.S. (either VSB-AM broadcast or TV distribution) is 4.2 MHz. It can be demonstrated that the video bandwidth required to provide a TV picture that is acceptable for entertainment purposes is only 2 to 2.5 MHz. The main purpose of the 4.2-MHz transmission bandwidth is to support the chrominance information in a color transmission that is centered around 3.58 MHz in the video spectrum.

Figure 7-12 shows the measured average response of TV receivers from RF to viedeo. Since the RF and IF responses must be wide, the plot essentially shows the video response of the receivers.

7.5 SATELLITE ANTENNA

It is advantageous to use a satellite antenna which is directive and radiates signals only to areas of the earth where reception is desired. The satellite power is used more effectively and the chances of interference with outer users of the radio spectrum diminish. Two coverages have been computer generated to illustrate several concepts for coverage of Alaska. Figure 7-13 shows a series of coverage plots for a 4.2° circular beam from a synchronous satellite positioned at 150° west longitude.

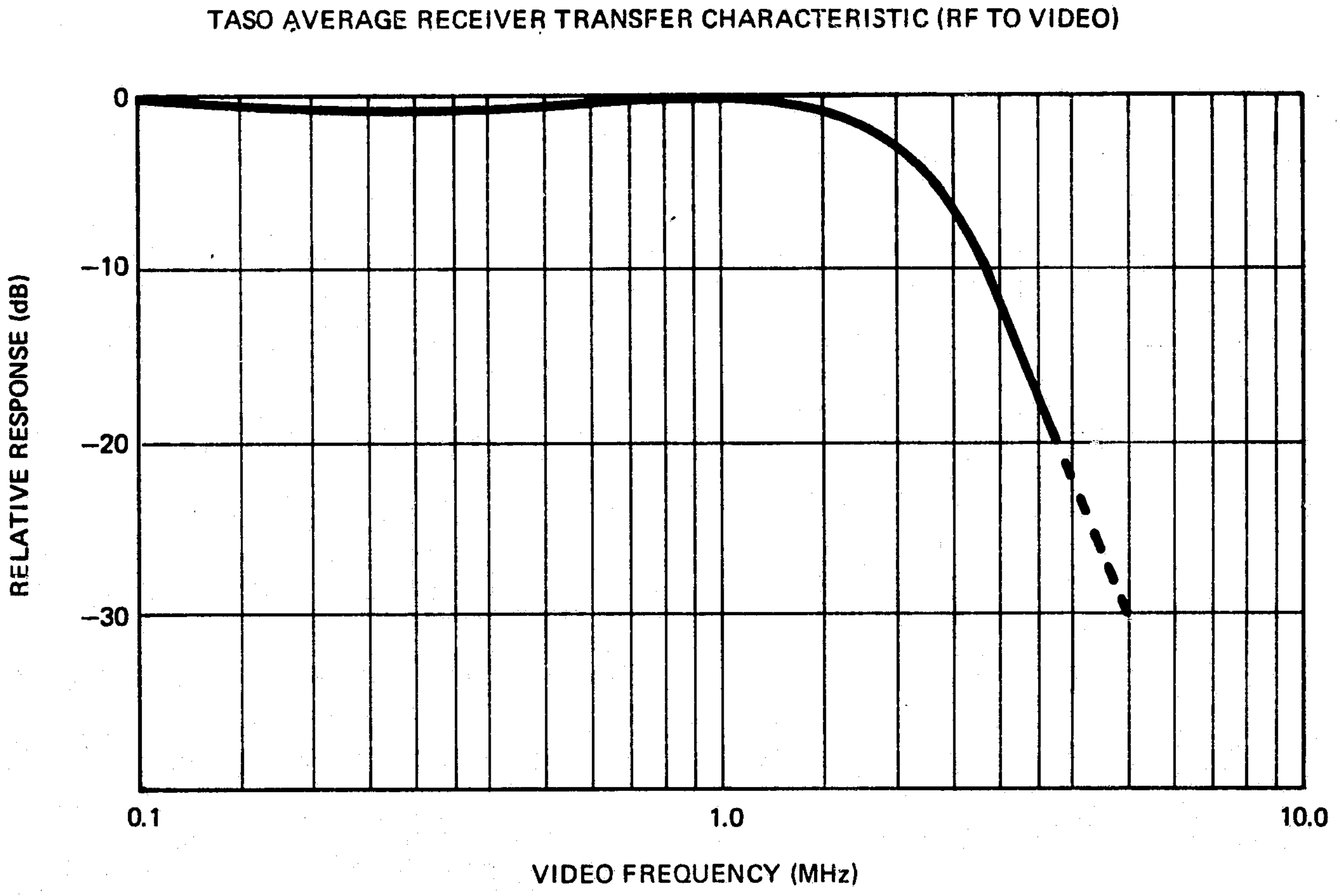

Figure 7-12. TASO Average Receiver Transfer Characteristic (RF to Video)

Figure 7-14 illustrates several further concepts. Here the satellite has been positioned at 125° west longitude, which places the satellite in view of New York for possible interstate communication. The 4.2° circular beam coverage is shown as well as a second contour for a 2° circular beam. The plots show that by reducing coverage of the Aleutian Chain, it is possible to cover Alaska with a 2° spot beam. Halving the required beamwidth generates four times the gain in power over the area, or equivalently, can be expressed as a reduction of spacecraft weight and prime power. Because the satellite antenna beam is tilted, a spreading of coverage results in the axis of tilt.

The use of an elliptical (rather than circular beam) would result in a further gain of efficiency and lessen interference problems.

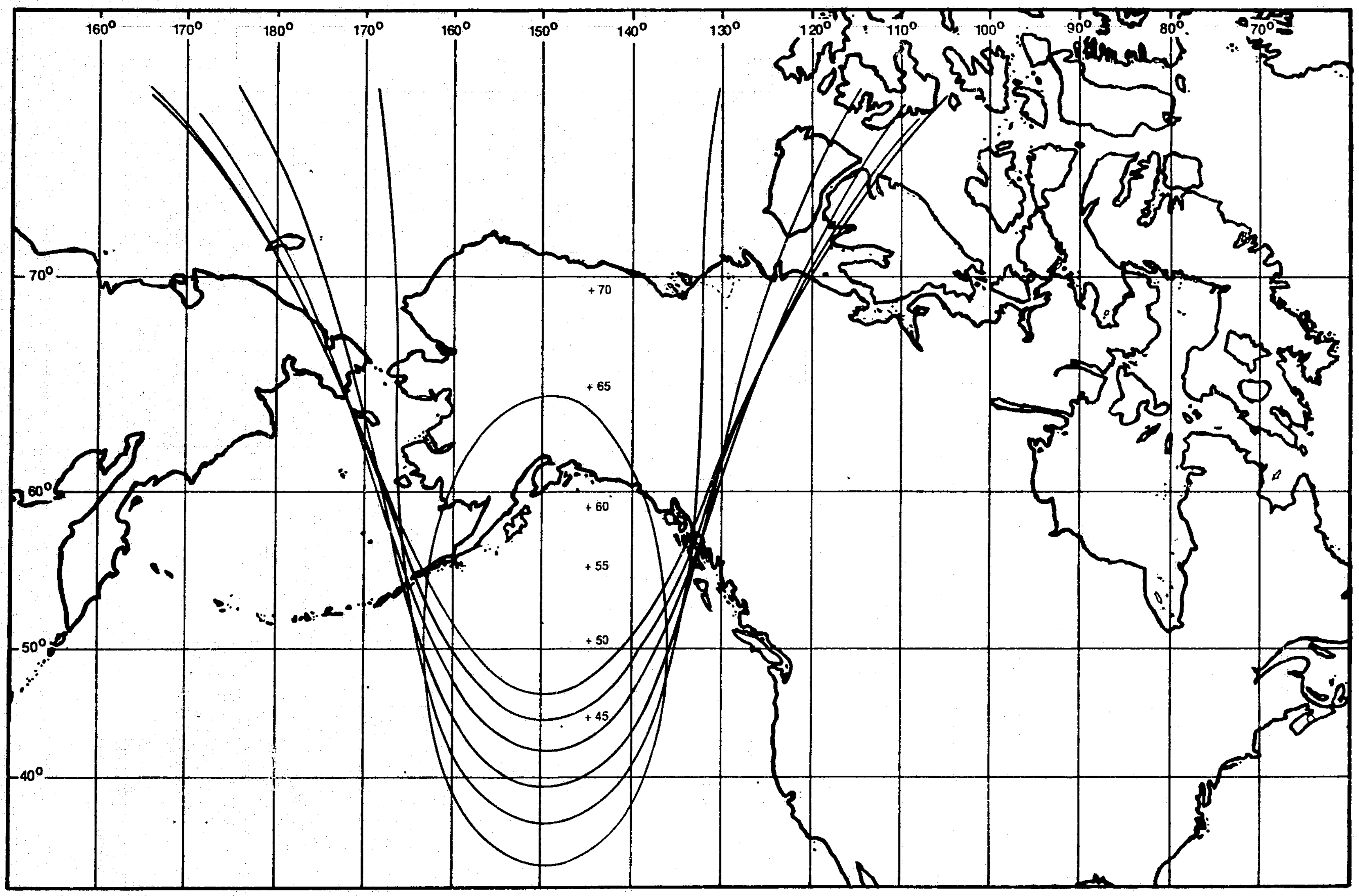

Figure 7-13. Coverage Diagram

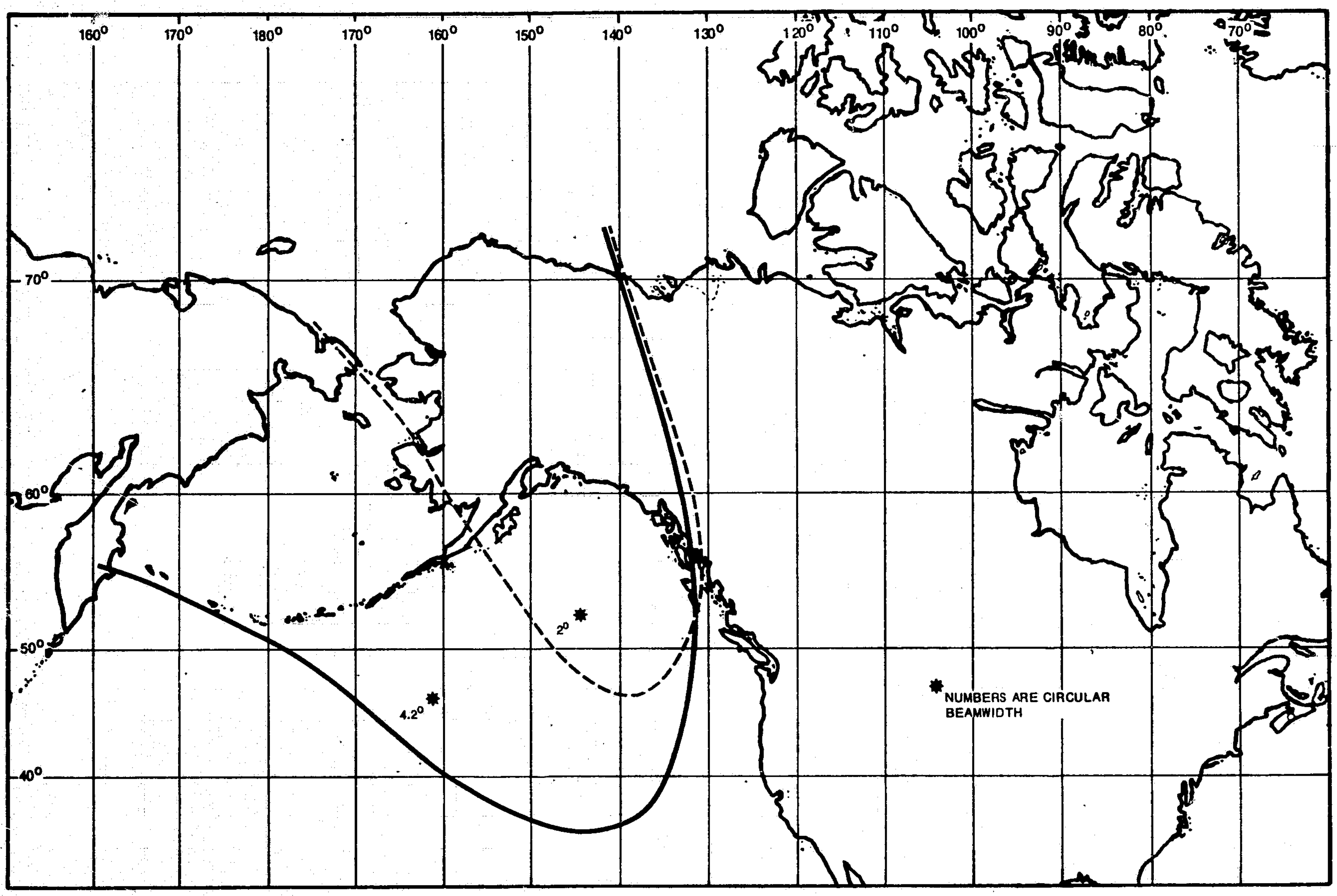

Figure 7-14. Coverage Diagram

7.6 COST FACTORS

In planning a communications satellite system for Alaska there will be a choice of equipment and techniques, each with certain advantages and disadvantages. As the user requirements are developed, it will become apparent that these requirements can be technically met by several alternatives, some of which may permit inexpensive future expansion of services or facilities. A major factor in the selection of one of the alternatives is a cost analysis.

The analysis must account for all costs; the capital as well as the operating costs. The items of cost that are considered capital investment costs are listed as follows:

a. Engineering feasibility study
b. System design and general specification development
c. Preparation of bid requests, bid evaluation, and contract negotiations
d. Management of contract
e. System engineering
f. Communication/TV equipment
g. Site acquisition
h. Transportation
i. Construction of roads, buildings, fences, etc.
j. Equipment installation
k. Ancillary support items
l. Training and training equipment
m. Test facilities
n. Licenses, permits, etc.
o. Legal fees.

The capital costs can be viewed in two ways: (1) the capital costs can be assumed incurred as acquisition costs when the system is installed, and not considered as part of the total annual system cost; or (2) the capital costs can be amortized as capital recovery costs, and considered as part of the total annual system cost.

From the second viewpoint, a capital recovery factor can be defined as follows: The capital recovery is that factor which multiplies the present investment to give the uniform annual payments over n periods of time which are required to recover the investment and the interest to be paid on it. The capital recovery cost is related to the acquisition cost by

$$V = C_A \left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

where C_A = acquisition cost

V = annual payment (capital recovery cost

$$\frac{i(1+i)^n}{(1+i)^n-1} = \text{capital recovery factor}$$

Table 7-3 indicates capital recovery factors for different rates of interest and different time periods. In the formula i is the interest rate and n is the number of time periods (normally years) over which the capital expenditures are to be repaid.

TABLE 7-3. CAPITAL RECOVERY FACTORS

Life (Yrs)	4%	6%	8%	10%
1	1.04	1.06	1.08	1.10
3	0.360	0.374	0.388	0.402
5	0.225	0.237	0.250	0.264
7	0.169	0.177	0.191	0.205
10	0.123	0.136	0.149	0.163
15	0.090	0.103	0.117	0.131
20	0.074	0.087	0.102	0.117

The total annual cost of a system, assuming capital recovery costs, is the sum of the annual cost of capital recovery plus the annual cost of operation.

The following is a list of some of the items that comprise recurring annual operating costs:

a. Wages of operating and maintenance personnel

b. Wages of overhead and administration personnel

c. Outside plant maintenance

d. Fuel

e. Replacement parts

f. Utility Services (water, power, etc.)

g. Transportation (material and personnel)

h. Leased facilities

i. Taxes, insurance, etc.

j. Contingency expenses.

Certain cost factors are estimated on a percentage basis. Initial spare parts and test equipment may be calculated on percent of equipment cost. Labor and installation material is estimated at between 15 and 30 percent depending upon the complexity of the installation.

7.7 SPACE SYSTEM LIFE CONSIDERATIONS

7.7.1 Introduction

In establishing an operational satellite system, consideration must be given to the number of satellites that must be purchased to provide an acceptable probability of the satellite system surviving for the desired operational lifetime. In the succeeding paragraphs the principal factors that determine the life of the space system are discussed and the criteria for determining the number of satellites to be purchased are outlined in general terms.

7.7.2 Spacecraft Wearout Mechanisms

Items that exhibit wearout phenomena have a fairly well defined end of life as well as being subject to random failures. For example, solar cells can fail randomly and, in addition, their output decreases with life in orbit due to solar radiation. Therefore, the solar array should be designed so that its output after some specified time in orbit is sufficient for satellite operation. Other items in this category may be storage battery capacity, mechanical bearings, and amount of propulsion system gas. Wearout causes the reliability to decrease at a greater rate as the wearout lifetime is approached, and the reliability function is usually truncated at the wearout time. This has the effect of lowering the expected life to the satellite because the area under the reliability curve has decreased.

7.7.3 Satellite Random Failure

Expected life of the satellite is a function of its reliability where reliability is the probability that the satellite will operate satisfactorily for a given period of time. In general, the expected life, or mean-time-to-failure, is the integral of the reliability function or the area under the reliability curve. Therefore, expected life will be increased if the predicted reliability is improved. Several methods for improving satellite reliability are available to the designer, and a combination of these methods is generally applied. One method entails careful design of components, selection of parts, and thorough testing prior to launch. Other methods, which are discussed in subsequent paragraphs, involve application of redundancy and design of components which exhibit wearout phenomena so that the wearout occurs after some specified time.

Reliability of an item having a constant failure rate, that is, subject to random failure, is expressed by the exponential form

$$R(t) = \exp(-\lambda t)$$

where $R(t)$ = reliability at time t
λ = failure rate

Reliability of a series circuit, that is one in which all parts must operate for the circuit to operate, is the product of the reliabilities of each part. This is equivalent to replacing the part failure rate in the equation by the sum of the part failure rates, therefore the reliability function is still exponential. An example of a reliability function for a satellite in which all parts must operate, or conversely a satellite having no redundant circuitry or paths leading to success, is shown in Figure 7-15. For the exponential case the expected life or mean-time-to-failure occurs at a reliability $R(t) = 0.37$.

If redundancy is applied to the satellite design so that failure of a particular component does not render the satellite inoperable the reliability function is no longer exponential but tends toward the shape of a normal function. An example of such a reliability curve is also shown in Figure 7-15. The shape of the curve depends on the amount and type (active or standby) redundancy applied, and these considerations depend on such factors as allowable weight and volume, power requirements and availability.

7.7.4 Launch Vehicle Reliability

Launch vehicle reliability can be included in the reliability prediction and expected life calculation. A launch reliability equal to 0.9 for example will lower the reliability curve and the mean-time-to-failure by 10%. This is an appropriate and useful index when numerous launches are involved for system replenishment, but when few launches are involved the results of the prediction may be misleading. A launch vehicle reliability of 0.9 means that one of every ten launches is expected to fail, but if only two launches are scheduled the probability that both are successful is relatively high (0.81). Furthermore, once the satellite has been successfully launched then only the satellite reliability need be considered.

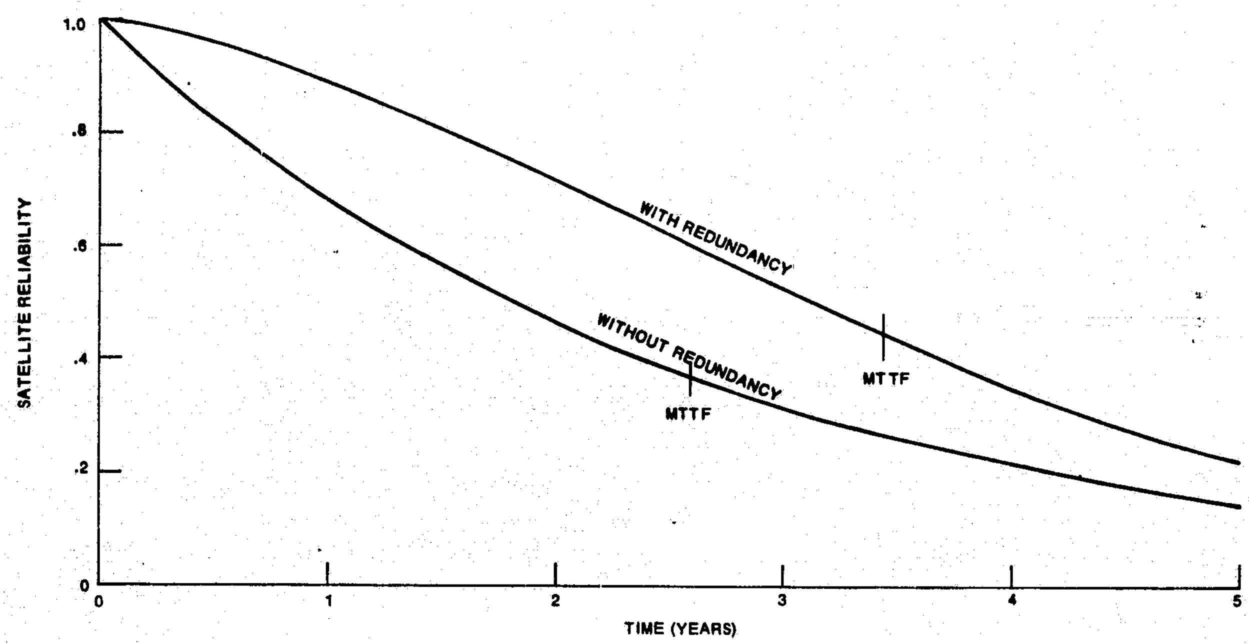

Figure 7-15. Example of Satellite Reliability

7.7.5 System Availability Requirements

In establishing an operational satellite system, a significant investment is required in the ground system as well as the spacecraft and launch vehicle. As a consequence, long outages of the space system constitute a gross waste of available resources. For this reason, provision must be made for replenishing the satellite system in the event of failure. If the satellite system is the only available communications link, a high degree of dependency may be placed upon it, and the outage duration associated with launching another satellite (which will require a minimum of 30 days) may be intolerable. As a consequence, consideration is often given to maintaining an additional spacecraft in orbit as a spare. This would permit a reasonable approach to 100% availability for the space system.

A replenishment strategy for a system involving numerous satellites can be evolved from system reliability or system mean-time-to-failure considerations. In the case of only one operating satellite in orbit and possibly only one spare satellite a better approach might be to launch the spare when a failure seems to be imminent. Although the operating satellite is expected to fail at its mean-time-to-failure it may fail much earlier or much later. With increasing ammounts of telemetry capability designed into the satellite the probability of detecting most types of impending failures tends to increase. Impending failure should be apparent early enough to prepare and launch the spare.

In Figure 7-16, a replenishment strategy is shown for a one satellite system. If a probability of 0.7 is desired of maintaining the satellite system for 5 years, a second launch must be provided for. To extend the satellite system beyond 5 years with the same probability of success will require the launch of an additional satellite.

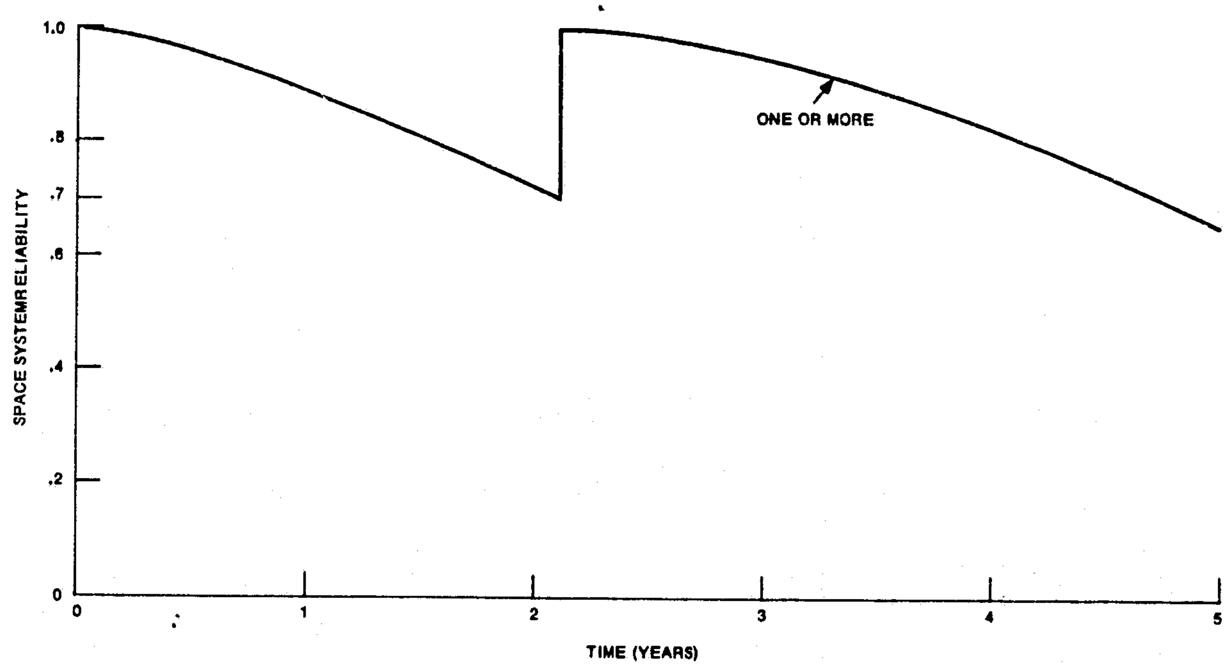

Figure 7-16. Example of Reliability of One Satellite System with Launch of Spare Satellite at 0.7 Reliability of Initial Satellite

7.7.6 Economic Considerations

In the final analysis, the overall allowable cost of the space subsystem will be a major determinant of the degree of reliability that is feasible. In evaluating the number of satellites that should be purchased, the doctrine of marginal utility can be employed as measure of reasonableness. In Figure 7-17, the satellite system reliability is shown as a function of the number of satellites purchased, assuming a desired system life of 5 years. As can be seen from the Figure, the purchase of the second satellite increases the reliability of system from 0.2 to 0.68. However, the "knee" in the curve is such that the purchase of a third satellite increases the reliability to only 0.84. Additional numbers of satellites provide successively decreasing increments of reliability. Since each satellite and launch vehicle cost a comparable amount (exclusive of satellite development), the additional dollars invested in the space system provide an incrementally smaller increase in the reliability of the system. For the system shown in Figure 7-17, the purchase of two or at the most three satellites appears to be the maximum justifiable on economic grounds.

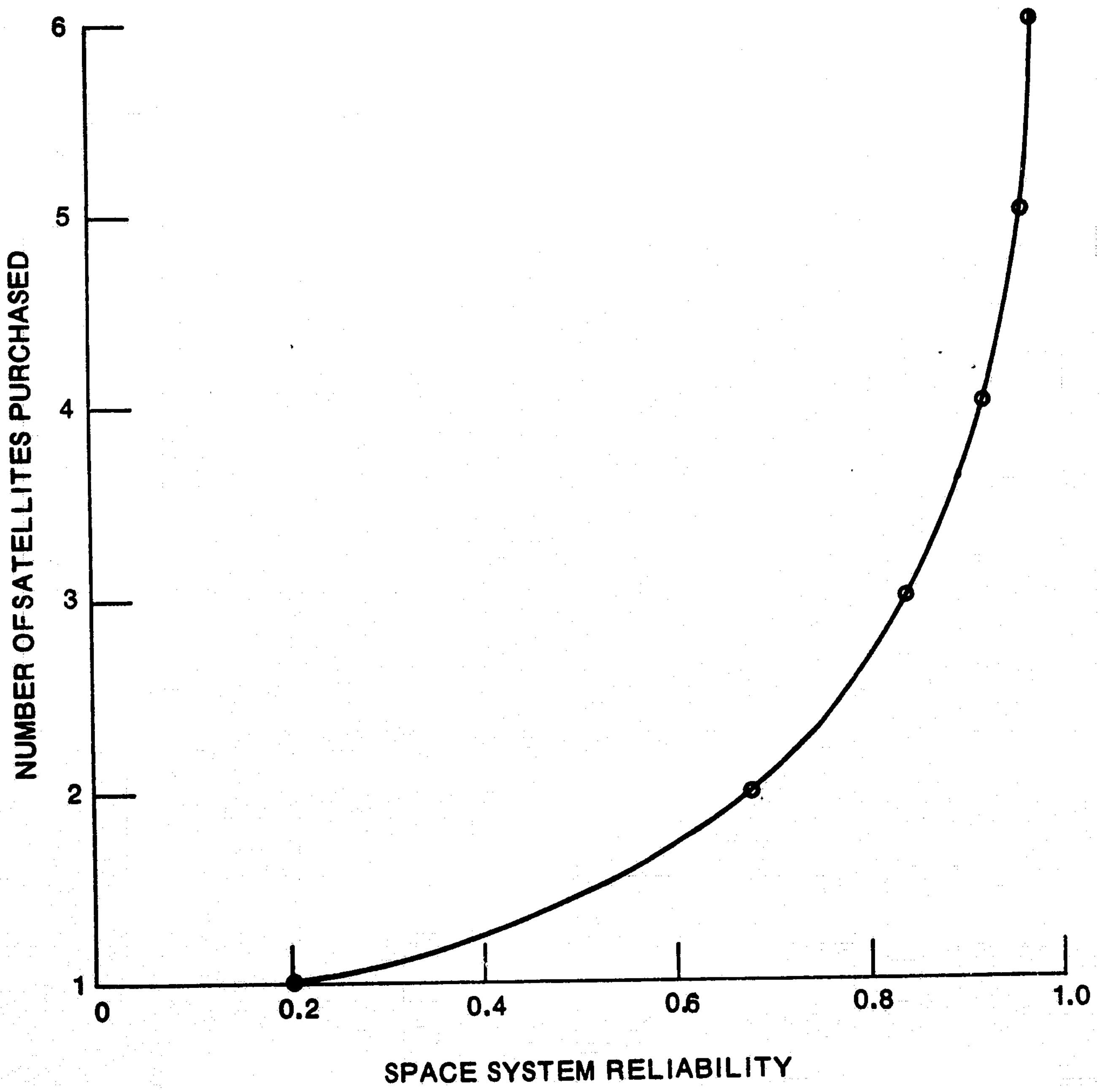

Figure 7-17. Example of Minimum Reliability of a One Satellite System vs. Number of Satellites Purchased

SECTION 8

TABULAR SUMMARY OF CANDIDATE SYSTEMS

The tables in this section present the principal features and properties of the collection of potentially useful satellite systems. The satellite characteristics are identified, along with their capability in terms of service and required ground terminals. Conclusions for each system are also summarized, pointing out problem areas that may affect system implementation.

There are two sets of tables. Tables 8-1 through 8-20 show the principal features and properties of the collection of satellite systems assuming color TV transmission, with f_m = 4.5 MHz. Tables 8-21 through 8-40 give corresponding features and properties of the same collection of satellite systems for monochrome TV transmission, with f_m = 2.5 MHz. It should be noted that these tables are a first order summary and useful for general planning and sizing, but a more detailed analysis considering additional factors is necessary for each specific system and its application before any final plans are decided.

The following satellite configurations are included:

- ATS-1 & ATS-Y-1
- ATS-3
- ATS-F & ATS-G (C-Band Down)
- ATS-F & ATS-G (UHF Down)
- ATS-F & ATS-G (S-Band Down)
- INTELSAT II
- INTELSAT III
- INTELSAT III 1/2
- INTELSAT IV (EIRP - 42 dBW)
- INTELSAT IV (EIRP - 45 dBW)
- INTELSAT IV (EIRP - 48 dBW)
- TELESAT (EIRP - 40.5 dBW)

- TELESAT (EIRP - 43.5 dBW)
- Canadian Applications
- IDCSP
- DSCS Phase II
- TACSATCOM (SHF)
- NATO & SKYNET
- INTELSAT III (Modified)

The major advantages and disadvantages are noted for each configuration. It is premature to identify problem areas realistically, and detailed analyses are better confined to configurations that remain after a first selection.

As will be noted in the tables, a few configurations (e.g., INTELSAT IV) demonstrate excess capacity. This capacity could be employed to interface with the Alaskan Communication System and provide other required services (e.g., intercity communications).

A one-to-one comparison of the two sets of tables (i.e., color and monochrome and TV) reveals some dividends in reduced G/T by transmitting monochrome TV rather than color TV. The advantages result from the smaller required RF bandwidths.

TABLE 8-1. ATS-1 & ATS-Y-1 (Color TV)

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
21.7	25	Greater Than EC	None	None	UP:6000 DN:4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	125	125	125
		RF Bandwidth Required (MHz)	25*	25*	25*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	24	15
Ground Terminal	Required G/T (dB/°K)		47.5	38.5	36
	Antenna Diameter (ft)		--	58	58
	Receive System Noise Temperature (°K)		--	40°	68°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Satellite Segment Cost Frequency Allocation	Large Antenna Required on Ground No Area Coverage Possible Large C/N Required to Meet CCIR of 52 dB

TABLE 8-2. ATS-3 (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
26.2	25	Greater Than EC	None	None	UP:6000 DN:4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	125	125	125
		RF Bandwidth Required (MHz)	25*	25*	25*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	24	15
Ground Terminal	Required G/T (dB/°K)		43	34.1	31.5
	Antenna Diameter (ft)		--	44	56
	Receive System Noise Temperature (°K)		--	68°	200°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Satellite Segment Cost Frequency Allocation	Large Antennas Required on Ground No Area Coverage Possible Large C/N Required to Meet CCIR of 52 dB

TABLE 8-3. ATS-F & ATS-G (C-Band Down) (Color TX)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
58	40	Approx. .6°	None	None	UP:6000 DN:4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40**	40**	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	26*	24*	15*
Ground Terminal	Required G/T (dB/°K)		17	12	16.5
	Antenna Diameter (ft)		19	9.4	18
	Receive System Noise Temperature (°K)		630°	630°	630°

*CCIR Flux Density Limit Exceeded at This Bandwidth

**Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Sufficient Bandwidth & Satellite EIRP Satellite Segment Cost Frequency Allocation	Major Antenna Redesign to Achieve Area Coverage

TABLE 8-4. ATS-F and ATS-G (UHF Down) (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
51	40	Approx. 2.8°	None	None	UP:6000 DN: 850	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		2.5	.5	-4
	Antenna Diameter (ft)		17	13	8
	Receive System Noise Temperature (°K)		630	630	630

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Sufficient Bandwidth & Satellite EIRP for TV Satellite Segment Cost	Frequency Allocation at UHF Marginal Area Coverage w/ Narrow Beam EIRP Requirements Imply Large Antenna Diameter for Voice Operation No Voice Authorized by FCC

TABLE 8-5. ATS-F & ATS-G (S-Band Down) (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
55	40	Approx. 1.2°	None	None	UP:6000 DN:2650 (F) 2500 (G)	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40**	40**	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36*	24*	15*
Ground Terminal	Required G/T (dB/°K)		13	12	12
	Antenna Diameter (ft)		24	21	21
	Receive System Noise Temperature (°K)		630	630	630

*CCIR Flux Density Limits Exceeded at This Bandwidth
**Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Sufficient Bandwidth and Satellite EIRP Satellite Segment Cost	Major Antenna Redesign to Achieve Area Coverage Marginal Ground Antenna Size

TABLE 8-6. ATS-F and-G (C-Band) (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
31	40	EC	None	None	UP:6000 DN:4000	Parallel Two Channels

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		31.5	27.5	26.5
	Antenna Diameter (ft)		56	35	31.5
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Satellite Segment Cost Frequency Allocation	Large Antennas Required on Ground

TABLE 8-7. INTELSAT II (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
15	126	Toroidal Pattern With 12° Beamwidth	3.0	4.0	UP:6000 DN:4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	360	220	130
		RF Bandwidth Required (MHz)	74	44	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		47.8	45.2	42.7
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP

TABLE 8-8. INTELSAT III (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
25	225	Greater Than EC	6.0	5.0	UP:6000 DN:4000	Parallel 2 Existing 10 watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	360	220	130
		RF Bandwidth Required (MHz)	74	44	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		37.8	35.2	32.7
	Antenna Diameter (ft)		51.5	50	37.5
	Receive System Noise Temperature (°K)		40°	68°	68°

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Frequency Allocation	Satellite Segment Cost No Area Coverage Possible Large Antennas Required on Ground

TABLE 8-9. INTELSAT III 1/2 (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
31*	25	---	7.5	4.5	UP:6000 DN:4000	Existing Antenna Replaced with Narrow Beam Antenna & Beamwidth Truncated

*EIRP at 6° Beamwidth

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	123	123	123
		RF Bandwidth Required (MHz)	25**	25**	25**
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	24	15
Ground Terminal	Required G/T (dB/°K)		38.2	28.8	26.7
	Antenna Diameter (ft)		56	41	32
	Receive System Noise Temperature (°K)		40	200	200

** Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Area Coverage Possible Reasonable G/T Required Frequency Allocation	Satellite Segment Cost Large Antennas Required on Ground Low Noise Temperature for CCIR Quality

TABLE 8-10. INTELSAT IV (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
42	36	4.5	18.0	15.5	UP:6000 DN:4000	Parallel 3 Existing 10 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		20.8	17.8	15.7
	Antenna Diameter (ft)		16.5	11.5	9
	Receive System Noise Temperature (°K)		200°	200°	200°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable Ground Terminals Good Area Coverage Frequency Allocation Growth Potential	Satellite Segment Cost Availability - Fall 1972

TABLE 8-11. INTELSAT IV (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
45	36	4.5°	18.0	15.5	UP:6000 DN:4000	Parallel 6 Existing 10 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		17.8	14.9	12.7
	Antenna Diameter (ft)		11.5	8.5	6.5
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable Ground Terminals Good Area Coverage Frequency Allocation Growth Potential	Satellite Segment Cost Availability - Fall 1972

TABLE 8-12. INTELSAT IV (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
48	36	4.5°	18.0	15.5	UP:6000 DN:4000	Parallel 12 Existing 10 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36**	36**	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24*	15*
Ground Terminal	Required G/T (dB/°K)		14.8	12.2	12.3
	Antenna Diameter (ft)		8	6	6
	Receive System Noise Temperature (°K)		200	200	200

*CCIR Flux Density Limit Exceeded at this Bandwidth

**Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable Ground Terminals Good Area Coverage Frequency Allocation Growth Potential	Satellite Segment Cost Availability - Fall 1972

TABLE 8-13. TELSAT (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
40.5	36	4°x8°	8.0	7.0	UP:6000 DN:4000	Parallel 5 Existing 5 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		22.3	19.2	17.2
	Antenna Diameter (ft)		19.5	13.5	11
	Receive System Noise Temperature (°K)		200°	200°	200°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable Ground Terminals Frequency Allocation	Satellite Segment Cost Availability - Fall 1972

TABLE 8-14. TELESAT (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
43.5	36	4° x 8°	8.0	7.0	UP:6000 DN:4000	Parallel 10 Existing 5 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		19.3	16.3	14.2
	Antenna Diameter (ft)		14	10	8
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin	Satellite Segment Cost
Reasonable Ground Terminals	Availability - 1974
Frequency Allocation	

TABLE 8-15. CANADIAN APPLICATIONS (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
55	40	approx. 2 1/4°	18.5	16	UP:12000 DN:12000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		23	22.5	22
	Antenna Diameter (ft)		11	10	9.5
	Receive System Noise Temperature (°K)		200°	200°	200°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Good Spot Area Coverage Reasonable Earth Terminals	Satellite Segment Cost Frequency Allocation Pointing

TABLE 8-16. IDCSP (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
7	26	Toroidal Pattern Giving EC	1.5	3.0	UP:8000 DN:7000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	130	130	130
		RF Bandwidth Required (MHz)	26*	26	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	24	15
Ground Terminal	Required G/T (dB/°K)		62.5	57.5	50
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP. Large Antennas Required on ground. Satellite Segment Cost. Large C/N Required to Meet CCIR of 52 dB. Military Frequency Band

TABLE 8-17. DCSC PHASE II (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
47	185	3°	10.0	10.0	UP:8000 DN:7000	Parallel 2 Existing 20 Watt TWT's on Narrow Beam Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	360	220	130
		RF Bandwidth Required (MHz)	74	44	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15*
Ground Terminal	Required G/T (dB/°K)		20.3	17	16.5
	Antenna Diameter (ft)		9	6	7
	Receive System Noise Temperature (°K)		200°	200°	200°

*CCIR Flux Density Limit Exceeded at This Bandwidth

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Good Growth Potential Good Spot Coverage with 3° Beam Reasonable G/T Costs Reasonable Antenna Size	Satellite Segment Cost Military Frequency Band Interference with Military Satellites Availability - Fall 1972

TABLE 8-18. TACSATCOM (SHF) (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
30	10	Greater Than EC	23	17	UP:8000 DN:7000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	50	50	50
		RF Bandwidth Required (MHz)	10*	10*	10*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	10	10	10
Ground Terminal	Required G/T (dB/°K)		66.5	57.5	47.5
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP Insufficient Bandwidth Military Frequency Band Large Antenna Size on ground. Satellite Cost Segment

TABLE 8-19. NATO & SKYNET (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
17	20	Greater Than EC	3.5	4.5	UP:8000 DN:7000	Disable Narrow Bandwidth Channel and Power Splitting

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	100	100	100
		RF Bandwidth Required (MHz)	20*	20*	20*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	20	20	15
Ground Terminal	Required G/T (dB/°K)		59	50	45
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP Satellite Segment Cost Large Antennas Required on ground. Insufficient Bandwidth Military Frequency Band

TABLE 8-20. INTELSAT III (Modified) (Color TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
35.5 (per channel)	38	3.1°x6.5°	7.5	6.0	UP:6000 DN:4000	Add 2 Spot Beams Downlink EC Uplink. 6-5 Watt Channel

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	185	185	130
		RF Bandwidth Required (MHz)	38*	38*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	24	15
Ground Terminal	Required G/T (dB/°K)		27	24.2	22
	Antenna Diameter (ft)		34	24	19
	Receive System Noise Temperature (°K)		200°	200°	200°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Good Spot Area Coverage Growth Potential Reasonable Earth Terminals	Satellite Segment Cost

TABLE 8-21. ATS-1 & ATS-Y-1 (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
21.7	25	Greater than EC	None	None	Up: 6000 Dn: 4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	125	125	125
		RF Bandwidth Required (MHz)	25*	25*	25*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	15	15
Ground Terminal	Required G/T (dB/°K)		40.4	36	35.5
	Antenna Diameter (ft.)		68	55	52
	Receive System Noise Temperature (°K)		40°	68°	68°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Satellite Segment Cost Frequency Allocation	Large ground Antennas Required No Area Coverage Possible

TABLE 8-22. ATS - 3 (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS)		FREQUENCY (MHz)	MODIFICATIONS
			S/C	LAUNCH		
26.2	25	Greater than EC	None	None	Up: 6000 Dn: 4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	125	125	125
		RF Bandwidth Required (MHz)	25*	25*	25*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	15	15
Ground Terminal	Required G/T (dB/°K)		35.5	32	31.5
	Antenna Diameter (ft)		52	34	32
	Receive System Noise Temperature (°K)		68°	68°	68°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Satellite Segment Cost Frequency Allocation	Large ground antennas Required No area coverage possible

TABLE 8-23. ATS-F AND-G (C BAND DOWN) (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
58	40	Approx. 6°	None	None	Up: 6000 Dn: 4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40**	40**	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36*	15*	15*
Ground Terminal	Required G/T (dB/°K)		11.5	13	11.5
	Antenna Diameter (ft)		10	12	10
	Receive System Noise Temperature (°K)		630°	630°	630°

* CCIR flux density exceeded
**Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Sufficient Bandwidth & Satellite EIRP Satellite Segment Cost Frequency Allocation	Major Antenna Redesign to achieve area coverage

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TABLE 8-24. ATS-F and -G (UHF Down) (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
51	40	Approx. 2.8°	None	None	Up: 6000 Dn: 850	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		.5	-.5	-1
	Antenna Diameter (ft)		13	12	11
	Receive System Noise Temperature (°K)		630°	630°	630°

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Sufficient Bandwidth & Satellite EIRP Satellite Segment Cost	Frequency Allocation at UHF. Marginal area coverage. No voice transmission authorized by FCC

TABLE 8-25. ATS-F AND-G (S-Band Down) (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
55	40	Approx 1.2°	None	None	Up: 6000 Dn: 2650 (F only) Dn: 2500 (G only)	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	195
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36**	15**	15**
Ground Terminal	Required G/T (dB/°K)		7	8.5	8
	Antenna Diameter (ft)		11	13	12
	Receive System Noise Temperature (°K)		630°	630°	630°

*Bandwidth Limits Capability
** CCIR Flux Density exceeded at this Bandwidth

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Sufficient Bandwidth & Satellite EIRP Satellite Segment Cost	Major Antenna Redesign

TABLE 8-26. ATS-F AND-G (C-Band Down) (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
31	40	EC	None	None	Up: 6000 Dn: 4000	Parallel two Channels

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		29.5	27	26
	Antenna Diameter (ft)		44	34	30.5
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Satellite Segment Cost Frequency Allocation	Large ground Antennas required

TABLE 8-27. INTELSAT II (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
15	126	Toroidal Pattern with 12° Beamwidth	3.0	4.0	up: 6000 Dn: 4000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	360	220	130
		RF Bandwidth Required (MHz)	74	44	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		47	42.5	42
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP

TABLE 8-28. INTELSAT III (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
25	225	Greater than EC	6.0	5.0	Up: 6000 Dn: 4000	Parallel 2 Existing 10 Watt TWT's on one Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	360	220	130
		RF Bandwidth Required (MHz)	74	44	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		35.5	31	30.5
	Antenna Diameter (ft)		40	30	29
	Receive System Noise Temperature (°K)		40°	68°	68°

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Frequency Allocation	Satellite Segment Cost No area coverage Large ground Antennas Required

TABLE 8-29. INTELSAT III 1/2 (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
31*	25	--	7.5	4.5	Up: 6000 Dn: 4000	Existing Antenna Replaced with Narrow Beam Antenna & Beamwidth Truncated

* EIRP at 6° Beamwidth

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	123	123	123
		RF Bandwidth Required (MHz)	25*	25*	25*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	15	15
Ground Terminal	Required G/T (dB/°K)		31	27	26
	Antenna Diameter (ft)		53	34	30
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Area Coverage Possible Reasonable $G/_T$. Frequency Allocation	Satellite Segment Cost Large Ground Antennas Required

TABLE 8-30. INTELSAT IV (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
42	36	4.5	18.0	15.5	Up: 6000 Dn: 4000	Parallel 3 Existing 10 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		19	16.3	15.5
	Antenna Diameter (ft)		13	10	9
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable ground Antennas - Good area coverage Frequency allocation Growth potential	Satellite Segment Cost Availability - Fall 1972

TABLE 8-31. INTELSAT IV (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
45	36	4.5°	18.0	15.5	Up: 6000 Dn: 4000	Parallel 6 Existing 10 Watt TWT's on One Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		16	13.2	12.3
	Antenna Diameter (ft)		9.5	7	6
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable Ground Terminals Good area coverage Frequency allocation Growth potential	Satellite Segment Cost Availability - Fall 1972

TABLE 8-32. INTELSAT IV (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
48	36	4.5°	18.0	15.5	Up: 6000 Dn: 4000	Parallel 12 Existing 10 Watt TWT's on one Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	120
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15**	15**
Ground Terminal	Required G/T (dB/°K)		13	13	11.5
	Antenna Diameter (ft)		6.6	6.6	6
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability
** CCIR Flux Density Exceeded at this Bandwidth

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable Ground Terminals Good area coverage Frequency Allocation ~~Growth Potential~~	Satellite Segment Cost Availability - Fall 1972

TABLE 8-33. TELESAT (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
40.5	36	4° x 8°	8.0	7.0	Up: 6000 Dn: 4000	Parallel 5 Existing 5 Watt TWT's on one Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	20
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		20.3	17.3	16.2
	Antenna Diameter (ft)		16	11	10
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable ground terminals Frequency Allocation	Satellite Segment Cost Availability - Fall 1972

TABLE 8-34. TELESAT (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
43.5	36	4° x 8°	8.0	7.0	Up: 6000 Dn: 4000	Parallel 10 Existing 5 Watt TWT's on one Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	176	176	130
		RF Bandwidth Required (MHz)	36*	36*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		13	14.8	14
	Antenna Diameter (ft)		7	8	7.5
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Adequate Power Margin Reasonable earth terminals Frequency Allocation	Satellite Segment Cost Availability - 1974

TABLE 8-35. CANADIAN APPLICATIONS (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
55	40	Approx. 2 1/4°	18.5	16	Up: 12000 Dn: 12000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	195	195	130
		RF Bandwidth Required (MHz)	40*	40*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		22	22	21.2
	Antenna Diameter (ft)		6.5	6.5	6
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Good Spot Area Coverage Reasonable earth terminals	Satellite Segment Cost Frequency Allocation Pointing

TABLE 8-36. IDCSP (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
7	26	Toroidal Pattern Giving EC	1.5	3.0	Up: 8000 Dn: 7000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	130	130	130
		RF Bandwidth Required (MHz)	26*	26	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	24	15	15
Ground Terminal	Required G/T (dB/°K)		50.5	49	48
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP Military Frequency Band

TABLE 8-37. DSCS PHASE II (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
47	185	3°	10.0	10.0	Up: 8000 Dn: 7000	Parallel 2 Existing 20 Watt TWT's on Narrow Beam Transponder

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	360	220	130
		RF Bandwidth Required (MHz)	74	44	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15**	15**
Ground Terminal	Required G/T (dB/°K)		18	16.5	15.5
	Antenna Diameter (ft)		7	6	5
	Receive System Noise Temperature (°K)		200	200	200

** CCIR Flux Density Exceeded

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Good Growth Potential Good Spot Coverage Reasonable Ground Antenna size	Satellite Segment Cost Military Frequency Band Availability - Fall 1972

TABLE 8-38. TACSATCOM (SHF) (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
30	10	Greater than EC	23	17	Up: 8000 Dn: 7000	None

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	50	50	50
		RF Bandwidth Required (MHz)	10*	10*	10*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	10	10	10
Ground Terminal	Required G/T (dB/°K)		47.5	37.5	31.5
	Antenna Diameter (ft)		--	36	19
	Receive System Noise Temperature (°K)		--	68	68

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP Insufficient Bandwidth Military Frequency Band Large ground antennas Satellite Segment Cost

TABLE 8-39. NATO AND SKYNET (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
17	20	Greater than EC	3.5	4.5	Up: 8000 Dn: 7000	Disable Narrow Bandwidth Channel & Power Splitting

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	100	100	100
		RF Bandwidth Required (MHz)	20*	20*	20*
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	20	15	15
Ground Terminal	Required G/T (dB/°K)		50.5	45	44
	Antenna Diameter (ft)		--	--	--
	Receive System Noise Temperature (°K)		--	--	--

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
	Insufficient EIRP Satellite Segment Cost Large ground antennas required Insufficient bandwidth Military frequency band

TABLE 8-40. INTELSAT III (Modified) (Monochrome TV)

SATELLITE CHARACTERISTICS

EIRP (dBW)	REPEATER BW (MHz)	ANTENNA BEAMWIDTH	COST ($ MILLIONS) S/C	COST ($ MILLIONS) LAUNCH	FREQUENCY (MHz)	MODIFICATIONS
35.5 (Per Channel)	38	3.1°x6.5°	7.5	6.0	Up: 6000 Dn: 4000	Add 2 Spot Beams Downlink. EC Uplink.6-5 Watt Channels

SATELLITE CAPABILITY VERSUS GROUND TERMINAL EMPLOYED

Type of Service	Voice (Duplex)	Number of Channels	185	185	130
		RF Bandwidth Required (MHz)	38*	38*	26
	TV	Quality/Channel $(S/N)_o$	(52 dB)	TASO 1 (43 dB)	TASO 2 (33 dB)
		Number of Channels	1	1	1
		RF Bandwidth Required (MHz)	36	15	15
Ground Terminal	Required G/T (dB/°K)		25	22.5	21.5
	Antenna Diameter (ft)		33	20	18
	Receive System Noise Temperature (°K)		200	200	200

*Bandwidth Limits Capability

SYSTEM CONCLUSIONS

ADVANTAGES	DISADVANTAGES
Good Spot Area Coverage Growth Potential Reasonable earth terminals	Satellite Segment Cost

SECTION 9

ILLUSTRATIVE EXAMPLE

9.1 INTRODUCTION

The previous sections of the report along with several of the appendices have formed a compendium of design information. This section is intended to illustrate how the material can be utilized by providing an example.

9.2 CONCEPT RATIONALE AND EXAMPLE PARAMETERS

An illustrative systems configuration consists of one central earth station (at College Alaska), which serves as the television broadcast originator and as control for voice channel assignment. Additional earth terminals are placed at remote and diverse locations throughout the state.

The College terminal comprises a TV uplink as well as the capability to transmit and receive the 50-voice channels. The remote terminals have TV receive capabilities and duplex single channel voice capabilities.

The television and voice have separate satellite transponders. They are designed however to be interchangeable. The satellite transponders must pass a single television channel with a color base bandwidth of 4.5 MHz or up to 50-voice channels with a base bandwidth of 3.4 kHz each. As will be observed in examining the parameters of candidate satellites (Section 5), a typical transponder radio frequency bandwidth is 36 MHz so this will be employed in our example configuration. Two 36-MHz transponders are used to support one TV channel and 50-voice channels.

The choice of radio frequency involves a lengthy process (see Appendix A) and it is premature to make a definite selection. However, for purposes of illustration the 6-4 GHz band (6 GHz up, 4 GHz down) is utilized as being the most probable allocation.

Having set example parameters for the various bandwidths and center frequencies, it is necessary to express a figure which defines the desired quality of signal for both television and voice. For television, subjective assessments have been made and the results are shown in Table 7-1 (Section 7). A television signal TASO grade 1 is equivalent to an excellent quality picture. Our example presents an output signal-to-noise ratio of 50.5 dB which exceeds this grade. High quality voice reception requires a signal-to-noise ratio of 50 dB (see Paragraph 7.2.3). Our example presents a signal-to-noise ratio of 51.5 dB.

These considerations allow a calculation of the power required onboard a satellite to communicate with a ground-based terminal receiver having a prescribed sensitivity.

As was described in Section 7, the satellite power is expressed as EIRP (Effective Isotropic Radiated Power) in dBW. The ground terminal sensitivity is expressed as G/T (Ground Antenna Gain/Receiving System Noise Temperature) in dB. These two numbers are related by an equation which allows an evaluation of different choices associated with, for example, a large amount of satellite power and a reasonable receiving system sensitivity or decreased satellite power and a more sensitive receiving system. Receiving systems may be made more sensitive by employing larger antennas (more gain) and low noise receivers utilizing expensive amplifiers. Since the deployment of the earth terminals will involve remote locations in Alaska with varying degrees of access, it is important to design a ground system that employs low maintenance elements. Low maintenance considerations eliminate the possibility of using cooled parametric amplifiers for receiver preamplification. For our example then, a receiving system with a noise temperature of 200° K and a receiver threshold of 10.5 dB or greater will be employed.

The bush terminal ground-based antenna can be selected as the result of a number of considerations. Practically, the choice is influenced by logistics, ease of pointing, radio interference and gain. These tradeoffs have been discussed in Section 7 and for the purposes of the present example, a 15-foot paraboloid is used.

Table 9-1 presents the parameters chosen for the example.

The configuration shown in Figure 9-1 represents a typical terminal. If the television channel is examined first, a signal-to-noise ratio of, $(S/N)_o$ = 50.5 dB is required. From Figure 7-10, it is determined that, for a television bandwidth of 4.5 MHz and a $(S/N)_o$ of 50.5 dB, a received carrier-to-noise ratio of approximately 13.5 dB results.

A system noise temperature of 200°K and a receiving antenna diameter of 15 feet results in a desired G/T of 20 dB/°K. Figure 7-6 may be employed to relate G/T to EIRP. For a G/T of 20 dB/°K

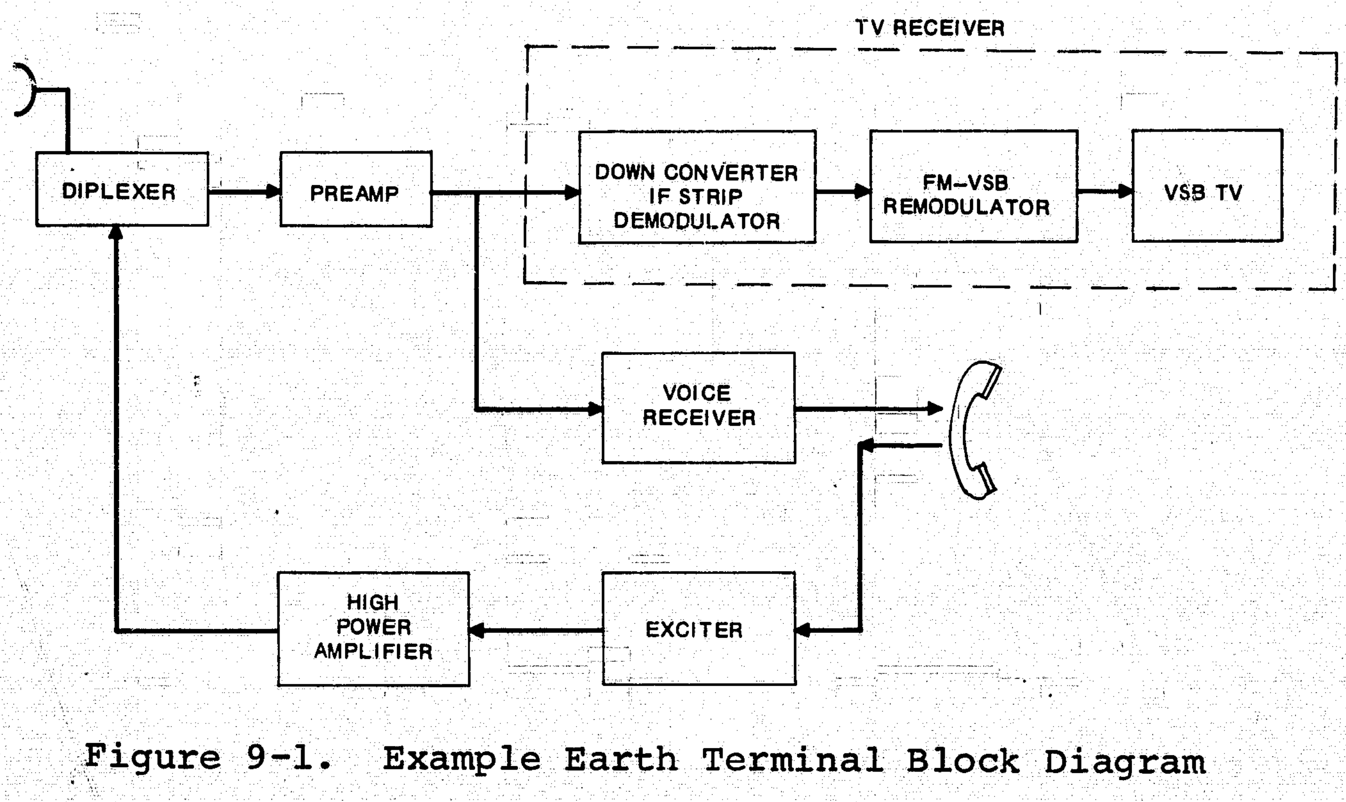

Figure 9-1. Example Earth Terminal Block Diagram

TABLE 9-1. ILLUSTRATIVE EXAMPLE CONFIGURATION AND PARAMETERS

Space Segment

Satellite - TELESAT

Number of Transponders	= 12 - 5 watt TWT (1)
Total Transmit Power	= 17 dBW
RF Bandwidth	= 36 MHz
Antenna Beamwidth	= 3.6° (2)
Antenna Diameter	= 5 ft.
Antenna Gain	= 33.5 dB
Miscellaneous Losses	= 1.5 dB

Alaska Configuration for TELESAT

Color TV (1 channel)	= 4 - 5 watt TWT (3) EIRP = 45 dBW
Voice (50 channels, Demand Assigned)	= 1 - 5 watt TWT (4) EIRP = 39 dBW

Ground Segment

TV Receive Only (Baseline System)

Antenna Diameters	= 15 ft.
Antenna Gain	= 43 dB
System Noise Temperature	= 200°K (23 dB)
Figure of Merit (G/T)	= 20 dB/°K
TV Baseband	= 4.5 MHz
FM Threshold	= 10.5 dB
Carrier-Noise Ratio	= 13.5 dB
Signal-Noise Ratio	= 50.5 dB (5) (6)
Modulation Index	= 3

Incremental Voice

FM Threshold	= 10.5 dB
Carrier-Noise Ratio	= 12 dB
Signal-Noise Ratio	= 51.5 dB (7) (8)
Modulation Index	= 14

(1) Prime power will support 10 - 5 watt TWTs
(2) Modified from 4° x 8° used for the coverage of Canada
(3) Represents 40% of satellite capacity
(4) Represents 10% of satellite capacity
(5) Video peak - peak to weighted RMS ratio
(6) Better than TASO 1
(7) Peak-peak to weighted RMS ratio
(8) Better than "toll" quality

the resulting required EIRP is equal to 45 dBW. Thus, for a single channel of color television reception on the ground, the following example parameters apply:

a. Single Channel TV (4.5 MHz)
b. Quality better than grade 1 (excellent)
c. G/T - 20 dB/°K
d. EIRP - 45 dBW

A similar exercise may be followed to derive the parameters for reception of a single voice channel. The voice system provides 50 voice channels for use by 250 different ground locations which share the use of the channels. A user signals his request to access a channel by communicating a short message on his assigned channel to a control facility (College Alaska). An operator retransmits the incoming message on the receive frequency of the designated recipient. The designated recipient of a particular call is alerted via his assigned channel to activate his transmitter. The user may then engage in voice communication via the satellite. This process of requesting and assigning channels may be manual, semiautomatic or completely automatic, but its cost is computed for manual operation in the example. Two hop transmission is required for this mode of operation and twice as much satellite power is used. However, more than enough power is available since the TV requires a large EIRP and the transponders are designed to be interchangeable.

For voice a quality of 51.5 dB is employed. If Figure 7-12 is examined, it is possible to determine that for a G/T of 20 dB/°K and for 50-channel voice reception, an EIRP of approximately 31 dBw is required single hop and 34 dBW double hop (EIRP available is a minimum of 39 dBW). Since the system should be designed for equal power per voice channel, the required EIRP for a single demand assigned voice channel will be equal to approximately 17 dBW (double hop).

In summary, 36 MHz of transponder bandwidth at an EIRP of 45 dBW is required for one color TV channel; 36 MHz of transponder bandwidth at an EIRP of 34 dBW is required for 50 demand assigned voice channels (double hop). These figures apply to a single earth terminal which will receive both television and voice with a receiving G/T of 20 dB/°K.

9.3 MINIMAL COST EXAMPLE UTILIZING TELESAT

As an example, the approximate costs associated with the procurement are for a space segment, the TELESAT satellite, and a ground segment, one central control earth station and 30,150, or 250 remotely located earth terminals. Each of these has the capability of recieving one color TV channel and of communicating (transmitting and receiving) one voice circuit. The elements are as follows:

a. Earth Stations

   1. One station with a 32-foot antenna capable of TV transmit and duplex service on 50 individual voice circuits.

   2. 30, 150, 250 stations with 15-foot antennas capable of TV receive only and/or one voice circuit.

b. One TELESAT Satellite*

c. One Thor Delta 904 launch vehicle

Costing assumes a system life of 7 years and a satellite lifetime of 7 years. Costing information has been derived from several sources.[1] The results have been presented in Table 2-2.

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*For a minimal cost consideration we are assuming the provisioning of two satellites and one launch vehicle.

[2]AIAA Paper No. 70-49, and Atlantic Research TR-PL-9037; June 196

APPENDIX A

RADIO FREQUENCIES AND RELATED RADIO REGULATORY ASPECTS

A.1 INTRODUCTION

All users of radio frequencies are required to comply with radio regulations and frequency allocations formulated internationally and implemented nationally. These managerial and technical steps subdivide the spectrum among various needs to assist in the control of interference and to guide use. The function being served is identified by service or classes of service. Where several bands are allocated to a particular service, the band selected would depend upon radio propagation, band congestion, and equipment availability factors.

The designation of a specific frequency is accomplished in the assignment process, which must consider interference and sharing criteria of all emissions involved, the performance standards in the geographical area being served, and the technical details of the proposed operation. Since assignment is predicated upon determination of eligibility for the frequency band by the operating agency, eligibility has a controlling influence upon the provision of radio frequencies. It is, therefore, an important step to fully classify both the function and the operating agency.

Radio operations are conducted by private operators, commercial carriers and organizations, as well as by the Federal Government. The radio spectrum is accordingly further divided into Government bands, non-Government bands, and jointly shared bands. This subdivision, however, is within the framework of the service allocations and exists only for services that the Federal Government operates. For example, there is no "government" band for domestic broadcasting or any "non-Government" band for air defense radars.

The radio frequency allocations in the United States are based upon the 1968 revised publication to the International Radio Regulations, Geneva, 1959. It should be noted that preparatory work is underway for a 1971 World Administrative Radio Conference to address space services.

United States proposals for this conference are contained in FCC Docket No. 18294, through the Seventh Notice. If these proposals are adopted internationally, it may be 1973 before they are fully implemented in the United States. The selection of frequencies is therefore discussed in terms of both current and proposed allocations.

Radio regulatory considerations, therefore, affect proposed satellite operations in the following manners:

a. Procedural channel for authorization

b. Choice of radio frequency band and the assignment criteria to be observed

c. Imposition of technical and operational conditions inherent to approval.

These are discussed in this appendix.

A.2 PROCEDURAL CHANNELS

A.2.1 Government Operation

If the operation to be performed is a Federal Government activity, the application would be processed through the Interdepartment Radio Advisory Committee (IRAC) and the Office of Telecommunications Policy (OTP). Since the proposed operation includes domestic broadcasting, an area delegated to the FCC by the Communications Act, no frequency action would be taken by the IRAC until OTP passed upon policy aspects.

A.2.2 Non-Government Operation

If the proposed experiments are conducted by a state, city, or industrial organization, they would be authorized by the Federal Communications Commission. The Federal Communications Commission has, among other roles, the authority to regulate radio transmissions and to issue licenses for radio stations. It exercises these regulatory actions pursuant to the Communications Act of 1934, as amended, and in consonance with the Administrative Procedures Act applicable to all regulatory agencies. Both applications and authorizations are guided by published rules and regulations of the Commission. Functional areas are assigned to operating bureaus oriented to each major subdivision of communications regulation. Since October 1951, the operating bureaus have been Broadcasting, Safety and Special Radio, Common Carrier, and Field Engineering. With the exception of Field Engineering, each Bureau has its own engineering and legal staff, and each Chief exercises delegated authority to grant authorizations. In the last year, the Community Antenna Task Force has been given bureau status to handle the growing community antenna industry.

Each radio operation licensed by the FCC is classified into one of some 381 services and classes, and the available radio spectrum is suballocated to meet requirements of each. The proper identification of the service/class thereby identifies frequency areas that may be used by that service. Although numerous individual steps are involved in the total assignment process, these may be grouped under two parts:

a. Eligibility to qualify for licensing, and the service class in which the proposed operation is to be licensed.

b. Technical aspects of the radiation and its service area, including radio frequency.

A.2.3 International Coordination

Radio frequency uses are in consonance with the Radio Regulations and the Table of Frequency Allocations herein. Where an allocation is not worldwide, the allocations are by regions. Region 2 includes the United States and Alaska. The boundary between Region 2 and Region 3 coincides with the international boundary in the Bering Strait, thence by great circle arc to the intersection of meridian 165° E and parallel 50° N, and southward beyond the area of interest. With a 3° coverage of Alaska, the coverage slightly overlaps into Region 3, but coverage into Region 3 is at sea or below 3° vertical angle.

International radio frequency notifications are handled by the Federal Communications Commission for the Secretary of State. Details of notification are contained in the Radio Regulations, and would be considered during national policy coordination. Flux density limits, coordination distances, and minimum elevation angles of earth terminals are also contained in the Regulations. However, pertinent aspects are contained in national regulatory actions.

A.2.4 Opinion

Subject to interpretations and willingness to handle the frequency requirement through different approaches, it would appear that the proposed satellite operation involving broadcast transmissions is within the purview of the Federal Communications Commission. One of the objectives behind passage of the Communications Act was the need to regulate broadcasting within the United States. The Act expressly addresses the broadcast service as a responsibility of the FCC. Further, since communication services are included in the experiment, both the FCC and the Alaska Public Utilities Commission would be involved in regulatory aspects pertaining to common carrier operations.

Except for international broadcasting by the United States Information Agency, the Federal Government does not engage in radio broadcasting in the United States. An exception is military broadcasting on military troops bases outside the continental United States. There are seven such television stations in Alaska operated by the military. The authorizations for these stations were coordinated with the FCC, and they are authorized under technical provisions to strictly limit any reception off military reservations. In fact, coordination of applicable policy for this type of Federal broadcasting is under the condition that any such broadcasting will be relinquished to commercial operation should an applicant agree to provide the service. For these reasons, it is assumed that processing of regulatory aspects of the proposed operation would be as a non-Government function.

The Radio Regulations currently define the Communications Satellite Service as "A Space Service between earth stations when using active or passive satellites for the exchange of communications of the fixed or mobile service." The existing regulations also provide for the Broadcasting Satellite Service as a "space service in which signals transmitted or retransmitted by space stations, or transmitted by reflection from objects in orbit around the Earth, are intended for direct reception by the general public."

Proposed changes by the United States (Seventh Notice, Docket 18294) include the following footnote explanation of direct reception:

> In the broadcasting satellite service, the term "direct reception" encompasses both individual reception by members of the general public, and by those members engaged in community reception, i.e., group viewing or listening.

A.3 RADIO FREQUENCY PROVISION

A.3.1 Service Classification

The described operation of the Alaska experiment is not presently and specifically defined in terms of existing classes of service. This primarily stems from alternatives in the conduct of the operation, the nature of baseband content (e.g., television and telephone), and alternatives of circuits that may be open to public service.

Viewed in its total baseband package of picture transmission with associated sound, including possible simultaneous sound in two or three languages, and with additional voice channels for public use, it would be classed as a common carrier. Frequency provision today would be from bands available to common carriers, and within the FCC would be processed by the Common Carrier Bureau. The advantages of being classed as a common carrier are the increased flexibility of interconnection and future transition from experimental to established status. The disadvantages are related to competition and economic protection of currently authorized service areas and future disposition of the system.

A.3.2 Frequency Congestion and Geographical Aspects

In controlling interference through frequency sharing techniques, spatial aspects of transmitter and receiver locations and antenna patterns represent a first consideration. The geographical aspect involves two congestion situations - orbital congestion of satellites and the geographically related congestion in the radio spectrum.

The ability to confine the satellite transmissions to a defined geographical area assists in controlling the potential area of interference. The use of an antenna of 3° beamwidth limits coverage generally to Alaska, as shown in Figure 5-2. Frequency provision is aided immeasurably if geographical sharing is concerned only with other operations in Alaska. In fact, frequency congestion in the United States might have an impact upon the proposed operation if the antenna pattern included the continental United States. For example, there are 10,502 authorizations in the frequency band 5925 to 6425 MHz within the 48 contiguous states. The same band in Alaska is estimated to have no authorizations. However, authorizations will increase as RCA Alaska shifts fixed microwave systems from Government to non-Government portions of the Fixed Service bands. If the antenna coverage is confined to Alaska only, the highly congested band in the United States could be avoided, simplifying the frequency coordination problem.

The other geographical aspect of frequency sharing in satellite systems concerns separation in orbital positioning. Since satellites drift about assigned stations, it is important to avoid situations where separate satellites drift into common antenna apertures of their respective earth stations. In current and projected satellites that may require stations between 90° and 120° West, frequency clearance problems would be alleviated by positioning the Alaska Broadcasting Satellite at least as far West as 150°. An additional advantage of a westerly positioning is to limit unnecessary coverage into Canada. Because of curvature, the 3° beam in northern latitudes subtends south of the intended coverage of Alaska. Antenna coverage into Canada and the United States increases the frequency clearance problems and the time to achieve agreement. If the satellite is positioned west of the United States, coverage of this land mass can be avoided.

Table A-1 shows the present and proposed radio frequency allocations.

A.4 POWER FLUX DENSITY

Radio regulatory measures to assist in the control of interference between space emissions and terrestrial radio systems include maximum limits of radiated power directed to the earth. The present and proposed wording is as follows:

Communication-Satellite Space Stations

Present - The total power flux density at the earth's surface, produced by an emission from a communication-satellite space station, or reflected from a passive communication satellite, where wide-deviation frequency (or phase) modulation is used, shall in no case exceed -130 dBW/m^2 for all angles of arrival. In addition,

TABLE A-1. RADIO FREQUENCY ALLOCATIONS
(AVAILABLE TO COMMUNICATIONS - SATELLITES)

FREQUENCY BAND (MHz)	PRESENT (UNITED STATES)	PROPOSED REGION 2
470 - 890	BROADCASTING (UHF TV)	Footnote: The broadcasting satellite service also may be authorized in the band 614-890 MHz for television broadcasting, subject to agreement among administrations concerned.
2150 - 2200	FIXED 2150-2160 Omnidirectional 2160-2180 Domestic public 2180-2200 Operational Fixed	COMMUNICATION - SATELLITE (Earth to Space) FIXED MOBILE
2500 - 2550	FIXED (Portion of 2500 - 2690) Operational Control Instructional Television	COMMUNICATION - SATELLITE (Space to Earth) FIXED MOBILE
3700 - 4200	COMMUNICATION - SATELLITE (Used as Space to Earth)	COMMUNICATION - SATELLITE
5925 - 6425	COMMUNICATION - SATELLITE (NG) (Used as Earth to Space) FIXED (Common Carrier)	FIXED MOBILE COMMUNICATION - SATELLITE May be used for transmission of program material for retransmission in the broadcasting satellite service.

TABLE A-1. RADIO FREQUENCY ALLOCATIONS (AVAILABLE TO COMMUNICATIONS - SATELLITES)
(Continued)

FREQUENCY BAND (MHz)	PRESENT (UNITED STATES)	PROPOSED REGION 2
7250 - 7300	COMMUNICATION - SATELLITE (G)	COMMUNICATION - SATELLITE
7300 - 7750	COMMUNICATION - SATELLITE METEOROLOGICAL - SATELLITE FIXED MOBILE	FIXED MOBILE COMMUNICATION - SATELLITE (Space to Earth) Note: Also tracking and telemetry associated with meteorological satellite.
7900 - 8025	COMMUNICATIONS - SATELLITE	(SAME)
8025 - 8400	COMMUNICATION - SATELLITE (G) FIXED MOBILE	FIXED MOBILE COMMUNICATION - SATELLITE (Earth to Space) Note: 8175 - 8215 primary allocation to meteorological satellite, earth to space.
11.7 - 12.2 GHz	MOBILE (Common Carrier)	BROADCASTING - SATELLITE COMMUNICATION - SATELLITE (Space to Earth) Mobile

TABLE A-1. RADIO FREQUENCY ALLOCATIONS (AVAILABLE TO COMMUNICATIONS - SATELLITES) (Continued)

FREQUENCY BAND (GHz)	PRESENT (UNITED STATES)	PROPOSED REGION 2
12.75 - 13.25	FIXED (CATV, TV Intercity, TV Pickup, TV STL) MOBILE	COMMUNICATION - SATELLITE (Earth to Space) Note: May be used for transmission of program material for retransmission in broadcasting satellite service FIXED MOBILE
17.7 - 19.7	FIXED MOBILE (Radio Astronomy 19.3 - 19.4)	COMMUNICATION - SATELLITE (NG) (Space to Earth) FIXED MOBILE
19.7 - 20.2	(Within Fixed, Mobile, Government)	COMMUNICATION - SATELLITE (Space to Earth)
27.5 - 29.5	FIXED MOBILE	FIXED MOBILE COMMUNICATION - SATELLITE (Earth to Space) (May also be used for telecommand signals to communication - satellites)

TABLE A-1. RADIO FREQUENCY ALLOCATIONS (AVAILABLE TO COMMUNICATIONS - SATELLITES) (Continued)

FREQUENCY BAND (GHz)	PRESENT (UNITED STATES)	PROPOSED REGION 2
29.5 - 31.0	FIXED MOBILE	COMMUNICATION - SATELLITE (Earth to Space) (May also be used for telecommand signals to communication - satellites)
92 - 95	(Not Allocated)	COMMUNICATION - SATELLITE (Earth to Space) (Frequency may be used for telecommand with satellite)
102 - 105	(Not Allocated)	COMMUNICATION - SATELLITE (Space to Earth) (Frequency may be used for tracking and telemetry, with satellite)
140 - 142	(Not Allocated)	COMMUNICATION - SATELLITE (Earth to Space) (Frequency may be used for tracking and telemetry, with satellite)
150 - 152	(Not Allocated)	COMMUNICATION - SATELLITE (Space to Earth) (Frequency may be used for telecommand with satellite)

such signals shall if necessary be continuously modulated by a suitable waveform, so that the power flux density shall in no case exceed -149 dBW/m^2 in any 4 kc/s band for all angles of arrival.

Proposed - The maximum power flux density at the earth's surface, produced by an emission from a communication-satellite space station, or reflected from a passive communication-satellite, for all conditions and methods of modulation, shall not exceed -152 plus $\frac{\emptyset}{15}$ dB relative to 1 W/m^2 in any 4 kHz band, where $\emptyset$ is the angle of arrival of the wave in degrees above the horizontal. This limit shall be assumed to relate to the power flux density under free space propagation conditions.

APPENDIX B

ALASKA SYSTEM COST TABLES

It is useful to calculate first order system costs to obtain a relative scale of employing alternative configurations. The costs of the candidate space segments are shown in Sections 5 and 8 and include the satellite and launch costs. This paragraph will present cost estimates for the ground segment, which includes the complete earth terminal. There was insufficient time to obtain quotations from sampled manufacturers regarding element costs, so the data shown are taken from a recent study on Satellite Communications for less developed countries. For convenience, the assumptions upon which the data is based are also included here.

Basic Design Assumptions. In the consideration of the costs of earth stations for the regional system, the following practical assumptions are made regarding the basic design configuration. Stations for the regional system should use:

a. Antenna diameters no larger than 32'.

b. Only manual positioning capability.

c. Uncooled receiver front ends.

d. A design that permits servicing by relatively untrained personnel (replaceable, throwaway subsystems).

e. The ability to operate from widely varying (voltage and frequency) commercial power sources that may also be interrupted for periods of time.

The earth station costs also assume implementation of the PCM-FDMA (SPADE)[2] demand assigned, multiple access system as described elsewhere in this report. The modem equipment will employ PSK, two phase modulation and coherent phase lock demodulation.

The lower limit on antenna diameter is assumed to be 10' (with a 3 db beamwidth of 1.2° at 6 GHz and a beamwidth to the first null of 2°). This is dictated by the concern that this system should minimize the possibility of interference to other stationary orbit satellite systems sharing the same frequencies, and should minimize the interference received from other systems and by the marginal decrease in cost achieved by using smaller antennas.

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[1] "Satellite Communications and Educational Television in Less Developed Countries," Presidents Task Force on Communications Policy, June 1969.

[2] "Spade," International Conference on Digital Satellite Communications, November 1969.

The availability of commercial power has been assumed.

In the non-critical and supporting subsystems, are stock equipment, the performance of which is not likely to be improved greatly. The auxiliary subsystems are unique to the proposed system design. One-time costs will be high but fortunately there are but a few of these subsystems required.

Earth station costs have been derived by summarizing the costs of the several subsystems and are based upon a production of 250 or more stations. The values presented represent the funding allocation to the using agency necessary to procure the particular subsystem: e.g., a high power amplifier, in an installed, integrated and operating condition at the desired operating location. These values, therefore, are not the factory FOB price; rather, they include all of the shipping, cabling, installation, test and administration necessary to secure as subsystems as part of an operating communications facility. They do include the one time cost of three-quarters to one million dollars for initial system-design, tooling, etc.

Antennas. Conventional and shaped Cassegrain, Dielguide, Hoghorns and Casshorns were considered. Shaped Cassegrains were used as the most representative since their figure of merit (G/T) is close to, or equals, that of the other techniques and more units of this style have been constructed at all sizes so that cost information is relatively accurate.

The primary receiving system includes the main reflector, subreflector, orthogonally polarized transmit and receiver feed (or receive only feed as the application may require), redundant parametric or tunnel diode amplifiers, antenna foundation and mount, and manually operated antenna drive. Tables B-1 and B-2 show the comparative costs of primary receiving systems utilizing several types of antenna and preamplifiers.

TABLE B-1. ANTENNA COST BREAKDOWN*

Antenna Diameter (ft)	10	15	25	32
Reflector	1,000	5,000	8,000	10,000
Pedestal (Foundation)	1,000	5,000	8,000	10,000
Dual Polarized Feed	500	500	1,000	2,000
Manually Operated Drive	500	2,500	5,000	10,000
**Installation	2,000	7,000	8,000	13,000
Total Cost ($)	5,000	20,000	30,000	45,000

*Based on catalog listings for 10 and 15 foot antennas and manufacturers quotations for 25 and 32 feet, factored for quantity production.

**Includes shipping, erection, alignment, testing, and administration.

TABLE B-2. PRIMARY RECEIVING SYSTEM COSTS FOR DIFFERENT ANTENNAS AND PREAMPLIFIERS

Antenna Diameter (ft)	10	15	25	32
Gain at 4 GHz (db)	39.5	43.0	47.5	49.6
Cost (x $1000)	5	20	30	45
With 20°K Paramp (50°K System)				
Cost (x $1000)	135	150	160	175
G/T	22.5	26.0	30.5	32.6
With 90°K Paramp (150°K System)				
Cost (x $1000)	30	45	55	70
G/T	17.7	21.2	25.7	27.8
With 600°K System (Using TDA)				
Cost (x $1000)	15	30	40	55
G/T	11.7	15.2	19.7	21.8

Power Amplifiers. The exciter rf output level is normally increased by a redundant high power amplifier system (HPA) so that the combination of the HPA and antenna gain yields sufficient EIRP to properly illuminate the satellite. These wideband units amplify single or multiple carriers by means of a traveling wave tube (TWT) having a 500 MHz bandwidth.

The development of higher power high frequency (6 GHz) transistors in the near future will tend to eliminate the TWT or klystron requirements for the lower EIRP designs (50-60 dbw). Table B-3 shows the comparative costs of power amplifiers against the number of voice channels transmitted. Standardized increments of power are utilized; i.e., 5, 25, 50, 100, 250, 500, 1000, 1500, 2500, 5000, and 10,000 watts.

TABLE B-3. POWER AMPLIFIER COSTS*** vs CHANNEL CAPACITY

Antenna Diameter (ft)	10	15	25	32
Antenna Gain at 6 GHz (db)	43.0	46.6	51.0	53.0
**Single Channel				
Total Power (watts)	25	5	5	5
Cost (x $1000)	10	3	3	3
**Five Channels				
*Total Power (watts)	250	100	50	25
Cost (x $1000)	50	35	30	20
**Ten Channels				
*Total Power	500	250	100	50
Cost (x $1000)	75	50	35	30
**Fifty Channels				
*Total Power (watts)	2500	1000	500	250
Cost (x $1000)	105	95	75	50
TV Transmit				
Total Power (watts)	10,000	5000	1500	1000
Cost (x $1000)	110	100	80	75

*Includes 6-dB backoff

**Assumes "SPADE" Voice Operated Carrier System

***Assumes 10° Satellite Beamwidth (21-dB gain)

Low Noise Amplifiers. Low noise maser amplifiers are available at very low noise temperatures (approximately 10°K) but are very expensive and complex and are available only with limited bandwidths (approximately 1% or 40 MHz at 4 GHz). Parametric amplifiers are available at noise temperatures down to 20°K with 500 MHz bandwidth. Both of these amplifiers are cryogenically cooled. Uncooled parametric amplifiers are presently available with 500 MHz bandwidth at 150°K. Performance gains are expected by 1972 which will result in 12°K for cryogenically cooled and 90°K for uncooled paramps.

Power Subsystem. The cost of stations using local power includes a half hour capacity battery for power interruptions and the necessary switch-gear and power distribution equipment.

Civil Works. Civil works consists of the equipment building or shelter, site preparation and utilities installation. Costs are related to the traffic handling capacity of the station.

Receivers and Exciters (Voice). A redundant exciter capable of amplifying and converting individual carriers at IF to multiple frequencies in the 6 GHz band at the level sufficient to drive the PA is estimated to cost $3,000 per carrier. The same estimate applies for a receiver employing multiple carrier frequencies which must be converted to individual carriers at IF.

Terminal Equipment. The equipment capable of accepting the individual voice channels, modulating and/or demodulating, and interfacing with the Ground Control Equipment (GCE) is estimated for each station as:

Interface and IF Equipment	$25,000
Demand Assigned Switching and Signaling Equipment	10,000
Channel Equipment	2,000/channel

Control and Monitor Equipment. To maintain an operable station a control and monitoring (remote and local) capability is required. A cost of $3,000 will supply this function as well as general rf cabling and waveguide, etc.

Logistics. Central repair depots and traveling repair teams with large amounts of test equipment and spare parts up to subsystem size are the most economical maintenance philosophies both in cost and in numbers of skilled personnel. Initial spares will cost 7% and test equipment will cost 5% of the cost of the operating station.

Table B-4 shows the summary costs for a variety of earth station configurations based on the above-described assumptions.

Costs for a satellite have been described in Sections 5 and 8.

TABLE B-4. EARTH STATION COST SUMMARY
(all values are in thousands of dollars)

Antenna Diameter (ft)	10		15		25		32	
Temperature (°K) Figure of Merit (G/T)(dB)	600 11.7	150 17.7	600 15.2	150 21.2	600 19.7	150 25.7	600 21.8	150 27.8
TV Receive Only								
• Antenna and Pre-amp	15	30	30	45	40	55	55	70
• Video Receiver	10	10	10	10	10	10	10	10
• Audio Receiver	10	10	10	10	10	10	10	10
• Control and Monitor	3	3	3	3	3	3	3	3
• Civil Works	9	9	9	9	9	9	9	9
• Power	3	3	3	3	4	4	4	4
• Total Cost	50	65	65	80	76	91	91	106
TV Receive Plus One Voice Channel								
• Civil Works	1	1	1	1	1	1	1	1
• Receiver	3	3	3	3	3	3	3	3
• Exciter	3	3	3	3	3	3	3	3
• Power Amplifier	10	10	3	3	3	3	3	3
• Terminal Equipment	37	37	37	37	37	37	37	37
• Power	1	1	1	1	1	1	1	1
• Cost TV Receive Only	50	65	65	80	76	91	91	106
• Total Cost	105	120	113	128	124	139	139	154
Total without terminal equipment	68	83	76	91	87	102	102	117

*This cost is based on the use of a Space type terminal which utilizes a PCM-PSK-FDMA Multiple Access System and control at each station. If a STAR type terminal (FM-FDMA) is planned, this cost will be reduced.

TABLE B-4. EARTH STATION COST SUMMARY (Page 2 of 3)

Antenna Diameter (ft)	10		15		25		32	
Temperature (°K)	600	150	600	150	600	150	600	150
Figure of Merit (G/T)(dB)	11.7	17.7	15.2	21.2	19.7	25.7	21.8	27.8
TV Receive Plus Five Voice Channels								
• Civil Works	3	3	3	3	3	3	3	3
• Power Amplifier	50	50	35	35	30	30	20	20
• Power	1	1	1	1	1	1	1	1
• Receiver	15	15	15	15	15	15	15	15
• Exciter	15	15	15	15	15	15	15	15
• Terminal Equipment	45	45	45	45	45	45	45	45
• Cost TV Receive Only	50	65	65	80	76	91	91	106
• Total Cost	179	194	179	194	185	200	190	205
TV Receive Plus 10 Voice Channels								
• Civil Works	5	5	5	5	5	5	5	5
• Power Amplifier	75	75	50	50	35	35	30	30
• Power	6	6	6	6	6	6	6	6
• Receiver	30	30	30	30	30	30	30	30
• Exciter	30	30	30	30	30	30	30	30
• Terminal Equipment	55	55	55	55	55	55	55	55
• Cost TV Receive Only	50	65	65	80	76	91	91	106
• Total Cost	251	266	241	256	237	252	247	262

TABLE B-4. EARTH STATION COST SUMMARY (Page 3 of 3)

Antenna Diameter (ft)	10		15		25		32	
Temperature (°K)	600	150	600	150	600	150	600	150
Figure of Merit (G/T)(dB)	11.7	17.7	15.2	21.2	19.7	25.7	21.8	27.8
TV Receive Plus 50 Voice Channels								
• Civil Works	9	9	9	9	9	9	9	9
• Power Amplifier	105	105	95	95	75	75	50	50
• Power	10	10	8	8	6	6	5	5
• Receiver	150	150	150	150	150	150	150	150
• Exciter	150	150	150	150	150	150	150	150
• Terminal Equipment	135	135	135	135	135	135	135	135
• Cost TV Receive Only	50	65	65	80	76	91	91	106
• Total Cost	609	624	612	627	601	616	590	605
TV Receive Plus TV Transmit Plus 50 Voice Channels								
• Power Amplifier	110	110	100	100	80	80	75	75
• Civil Works	2	2	2	2	2	2	2	2
• Video Exciter	10	10	10	10	10	10	10	10
• Audio Exciter	10	10	10	10	10	10	10	10
• Power	10	10	8	8	6	6	5	5
• Cost TV Receive Plus 50 Voice Channels	609	624	612	627	601	616	590	605
• Total Costs	751	766	742	757	709	724	692	707

APPENDIX C

MAINTENANCE IN RURAL ALASKA

This appendix discusses a maintenance concept for those ground terminals that will not be located at the major metropolitan centers in Alaska. The concepts are based on experience with satellite communication systems. For discussion purposes these terminals have been categorized into three groups. Group A consists of those terminals that are accessible from a major metropolitan area with surface transportation within 5 hours 98 percent of the time. Group B includes those terminals that are accessible from a major metropolitan area within 24 hours 95 percent of the time. Group C is made up of the remaining terminals that are inaccessible for certain periods of the year because of weather conditions.

The criterion that will be used in developing a maintenance concept is the reliability requirement placed on the terminal, i.e., the outage or downtime that can be tolerated.

There is no preestablished reliability requirement for satellite ground terminals that provide the type of service proposed for the Alaskan Satellite System. For the purpose of this discussion we have arbitrarily assumed that a downtime of 2 days can be tolerated while a downtime of 1 week is unacceptable.

A maintenance program must not only be effective in meeting the reliability requirement but it must also be cost effective. In considering the cost associated with a maintenance program there are two separate areas that must be examined: the maintenance costs when the system is in operation and that portion of the initial procurement costs that is related to maintenance.

As a general rule it can be stated that the more money expended in the initial procurement for training programs, test equipment, performance monitors, maintenance manuals, and terminal design features that provide an operating margin, the less it will cost to maintain the terminal during the operational phase.

The costs associated with maintaining a terminal can be an appreciable percentage of the total ground terminal costs when one considers that they include spare parts cost, costs for replacing major components, salary and per diem costs for contractor personnel to modify or refurbish terminals in the field, and transportation expenses for maintenance personnel and replacement parts.

Because of the remote location of many of the terminals and the severe environment condition under which they will be operating, the cost for maintaining the terminal will be escalated. The availability of transportation, the performance of local prime power systems and the capability of the personnel at the terminal to maintain the terminal will be critical factors in establishing a maintenance program and estimating the maintenance costs.

At this time specific details are not available on these factors and it has been necessary to make the following assumptions: (a) the terminals will be operated by local personnel who have not had experience in operating electronic equipment, (b) the prime power systems at most of the locations will be erratic and there will be frequent power outages (these erratic prime power systems will induce failures in the electronic components of the ground terminals), and (c) there will be a total of 250 terminals located outside major metropolitan areas, 25 percent are accessible within 5 hours by surface transportation, 98 percent of the time (Group A), 50 percent are accessible within 24 hours, 95 percent of the time (Group B), and 25 percent are inaccessible for certain periods of the year (Group C). At certain periods it may be impossible to reach these locations within 2 to 3 weeks. Transportation for heavy and bulky replacement parts may only be possible during specific months of the year.

If we consider these assumptions to be realistic, the two factors that are critical in determining the time to repair a failure are the availability of skilled maintenance personnel and the availability of replacement parts. The most effective approach for keeping the downtime to a minimum would be to have maintenance personnel assigned to each terminal and have the site stocked with 100 percent spare parts. However, the cost for this type of maintenance program would be excessive when we consider that there will be approximately 250 terminals.

An alternate approach which would require fewer maintenance personnel and a small number of spare parts is to have the maintenance personnel and spares located at the major metropolitan areas. The maintenance personnel and parts would be transported to the terminal that had a failure. This approach would not meet the reliability requirement for those terminals that are in Group C.

For the maintenance program to be cost effective and meet the reliability requirements it must be tailored to the specific conditions that exist at each terminal or group of terminals.

Earlier a list of assumptions was presented on the conditions that existed at the terminals. In developing a maintenance program that is directly applicable to specific ground terminals, detailed information will be needed. For example, the maintenance capability of the terminal operators will vary significantly and the failure rate of components at the different terminals will vary.

At this time it is not possible to present a final maintenance plan because of the lack of details concerning the terminal design, personnel and site locations. However, it is possible to describe those elements that are essential to a maintenance program, indicate what should be taken for implementing a maintenance program and a general consent of how the maintenance program would function.

The two basic elements of a maintenance program are the low level routine maintenance performed by an operator and the high level maintenance performed by skilled maintenance personnel. To develop a maintenance plan that will provide for these two levels of maintenance and be adaptable to the environmental and operational conditions under which the Alaskan Satellite System must operate, the following programs must be established:

a. A training program for the operators that will enable them to perform routine maintenance. The extent of this training will depend on the basic technical knowledge of the prospective operators, the complexity of the electronic equipment, i.e., cooled or uncooled paramp, synthesizers, hydraulic system, etc. and the amount of human engineering effort that has been incorporated into the design of the terminal to simplify maintenance.

b. A spare parts program that will establish the level of spare parts to be stocked at depots and at the various terminals. The criteria that would be used in determining what items should be stocked at the terminal are:

1. Failure rate of the components.
2. Capability of the operators to do repair work.

3. Difficulty of transporting the parts because of weight and size.

4. Components critical to the voice mode of operation.

5. Cost of components.

c. A program for establishing a pool of maintenance personnel which will perform the high level of maintenance at the terminal when a failure occurs. These maintenance personnel would be assigned to the terminal in the major metropolitan areas and would be transported to the remote terminals to perform the maintenance.

d. A program that will permit experienced maintenance personnel to submit suggestions and ideas to the engineer who will be designing the terminal. The purpose of this program would be to incorporate features in the terminal that will simplify maintenance procedures.

The following discussion describes how a maintenance program for the remote terminal could be implemented.

In the early phase of the program a group of approximately 15 skilled maintenance personnel would be hired. These maintenance personnel would be given training in the operation and maintenance of the remote terminals.

When the terminals are installed in the field, one or two of these maintenance personnel would be assigned to a terminal for a period of approximately 2 months. During this period the maintenance man would train the local operator in the operation and routine maintenance of the terminal. Performance tests would be performed during this period and a log would be maintained to provide the operator with a measure of performance for the various subsystems in the terminal. A record would be maintained of failures which would be used in determining the number and type of spare parts to be stocked at the site.

It is assumed that the 250 terminals will be installed over a period of 3 years, which provides adequate time for the maintenance personnel to move from site to site as they are installed.

The terminals that are in the Group A and Group B categories would have their high level maintenance performed by the maintenance personnel from the headquarters facilities on an on-call basis. Because of the more remote location of the terminal in the Group B category, a larger number of spares would be stocked at these sites and a more extensive initial training program would be given to the operators.

The terminals in the Group C category would have the largest number of spares stocked on site and the training program would be the most extensive. It may be required to establish a formal training program for these operators at a headquarters facility, to provide the operator with a basic knowledge in electronics. A preventative maintenance schedule would be established for these terminals. Periodically a maintenance man from headquarters would visit the terminal to perform the preventative maintenance. During those periods of the year when transportation to the site is extremely difficult, certain selected terminal sites would have maintenance personnel permanently assigned. The criteria that would be used in determining which terminals would have maintenance personnel are:

a. The maintenance capability of the operator.
b. The maintenance history of the terminal.
c. The probability of providing transportation to the site within 1 week.

The terminals in Group C may also be provided with redundant features that are not included in the terminals in Groups A and B. Special consideration would be given to redundant or backup prime power systems and redundant components for those subsystems that are used in the voice mode of operation.

APPENDIX D

FREQUENCY DIVISION MULTIPLE ACCESS

D.1 INTRODUCTION

Frequency division multiple access (FDMA) is a technique which allows the simultaneous operation of multiple signals through a single channel repeater. The repeater bandwidth is apportioned among the total number of users as depicted in Figure D-1. For example, the available bandwidth, W, is divided into frequency slots with the i^{th} user transmitting with center frequency, f_i.

The purpose of this appendix is to present the system descriptions and performance characteristics of a single channel per carrier fully variable, demand assigned frequency division multiple access (FDMA) technique which may be applicable to the Alaskan communication problem. The technique consists of single channel per carrier frequency modulation of many analog voice channels. The carriers can be chosen with equal or unequal spacing, using a stagger-cosine or a log-log distribution. The system is fully variable in that any station can utilize any idle carrier frequency upon demand. In order to maximize the capacity a voice activation circuit can be used to take advantage of the user-talker activity factor.* A particular implementation of this approach is the one that Nippon Electric Corporation and Hughes Aircraft Company employed in a cooperative project termed STAR (Reference 3). It should be noted that the STAR system employs centralized control methods. The single channel FM/FDMA system under present consideration will also utilize a centralized control technique.

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*This circuit effectively turns the carrier off when there is a pause in the conversation (see Appendix F).

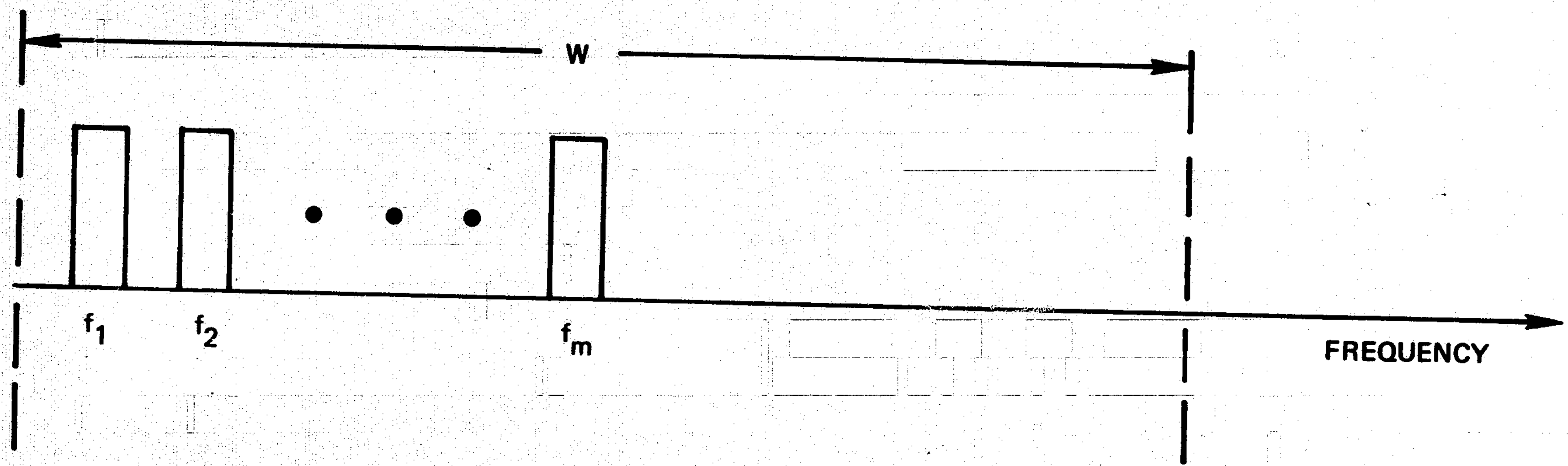

Figure D-1. Frequency Division Multiple Access Repeater Bandwidth Allocation

D.2 FM PERFORMANCE CONSIDERATIONS

The following paragraphs discuss some of the important performance considerations for a single channel per carrier FM/FDMA system.

D.2.1 Channel Quality

The allowable psophometrically weighted total noise power for a high quality mode of operation has been defined to be 10,000 pWOp* (Reference 6). The psophometrically weighted test tone to noise ratio for high quality operation then becomes 50 dB. This is the desired goal of speech quality that is assumed necessary.

a. Speech Measurement

The most appropriate technique for determining the level of a speech signal is with a vu meter. This instrument measures speech volume expressed in volume units (vu). Measurements taken on an identical vu meter can vary over a small range (~1 to 3 dB) for the same signal, depending on the observer and even geographical area. Reference 7 indicates that the average talker volume, V_o, is equal to -12.5 vu with a standard deviation, σ, of 5 (other more recent tests indicate values of -15.8 and 6.4 for V_o and σ, respectively). However, in order to be prepared for the most critical condition (as Reference 7 suggests), the system should be designed on the basis of the compromise -12.5 figure. A more useful measure of average talker volume would be the average power. The average volume can be related approximately to the average speech power, P, of an average talker active channel by (Reference 7)

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*pWOp is the psophometrically weighted mean power at a point of a zero relative level.

$$P = V_o + 0.115\,\sigma^2 - 1.4 \text{ dBm} \qquad \text{(D-1)}$$

where

V_o is the average vu meter reading

σ^2 is the variance of the vu meter readings

Thus, the average speech power for our system becomes -11 dBm . The average speech power is shown in Figure D-2 relative to a 0-dBm test tone.

b. Amplitude Characteristics

In general, speech signals can perhaps vary over quite a wide range (as much as 30 dB). It is important to keep the average power as high as possible without clipping the speech in order to provide the highest S/N without distortion. Experimental measurements reported by Holbrook and Dixon (Reference 8) show that the distribution given in Figure D-3 adequately represents the variation of instantaneous speech power in an active channel. If a speaker makes some reasonable attempt to control his volume, the average power of an active channel can be maintained approximately 18 dB below the clipping level without causing the peaks to be clipped more than one percent of the time. For this system, it is then assumed that the average power of an active channel will be 18 dB below the peak power of a maximum amplitude sine wave. This result is shown in Figure D-2.

D.2.2 FM Power and Bandwidth Considerations

The required amount of receiver signal to noise for a single channel analog FM system is of primary importance. This section is oriented towards analyzing this situation.

General FM performance is given by the well known relation

$$\left(\frac{S}{N}\right)_{FL} = \frac{3}{2} \frac{D_p^2}{f_2^3 - f_1^3} \frac{C}{N_T} \qquad \text{(D-2)}$$

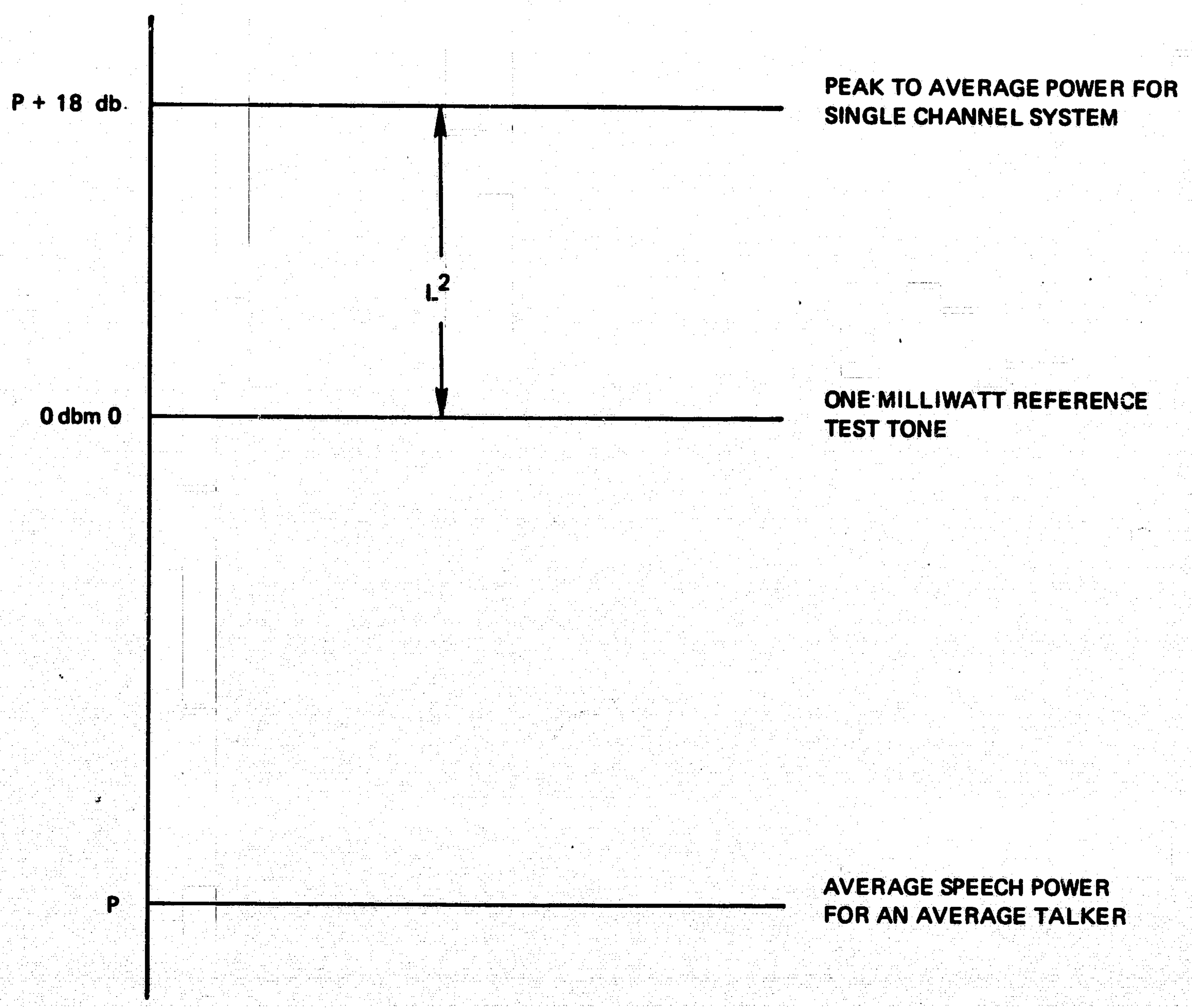

Figure D-2. Speech Power Level Considerations

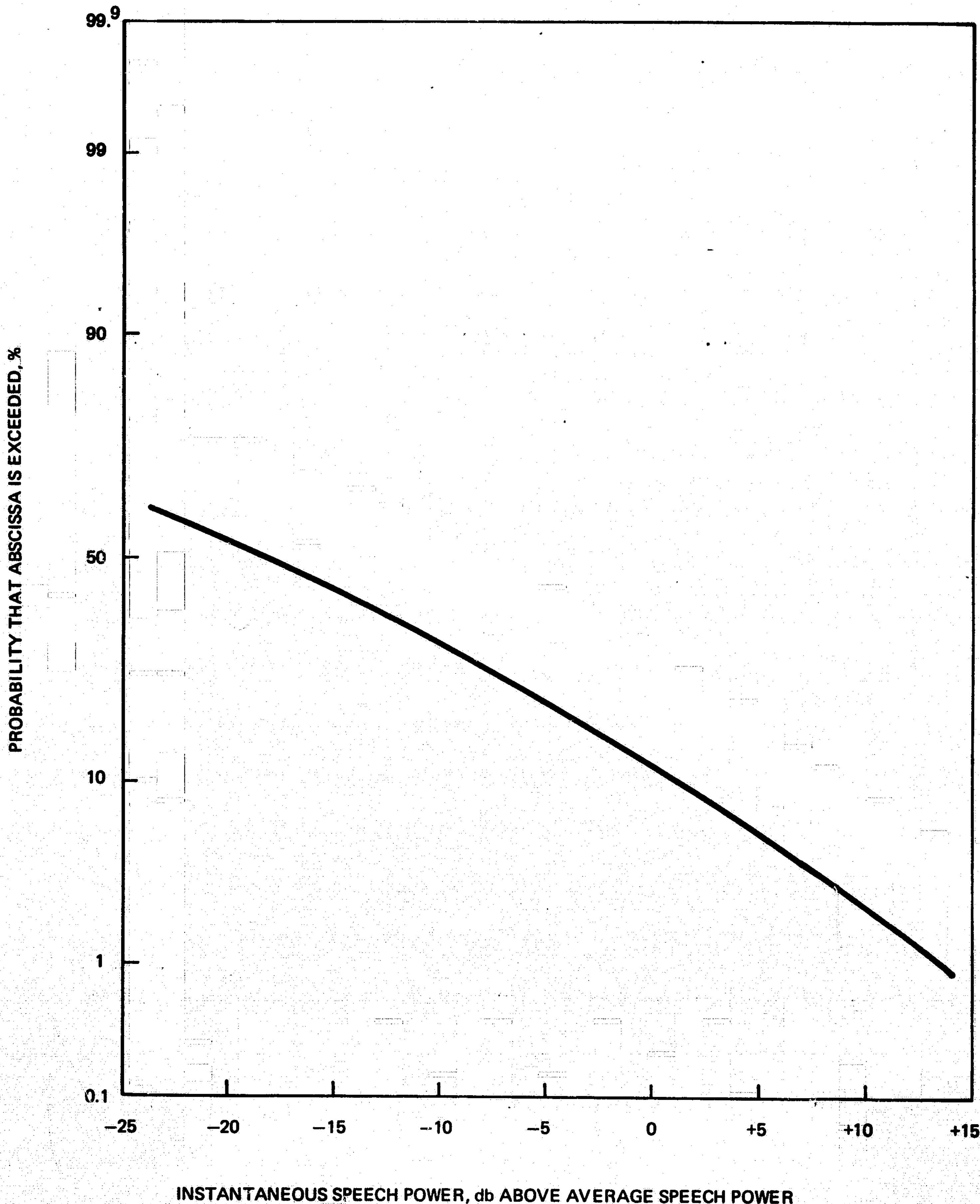

Figure D-3. Distribution of Instantaneous Speech Power for a Single Speaker where

$(S/N)_{FL}$ = full load rms sine wave power to noise power ratio of the baseband signal in the bandwidth $(f_2 - f_1)$

D_p = peak deviation (in Hz)

f_2, f_1 = upper and lower limits of the baseband signal

C/N_T = total carrier power to total noise power density ratio at the receiver

For the single voice channel case f_1 is generally about 300 Hz and f_2 about 3400 Hz (as in the STAR system - Reference 3). However, Equation (D-2) can be very closely approximated by letting $f_1 = 0$.

$$\left(\frac{S}{N}\right)_{FL} = \frac{3}{2f_2}\left(\frac{D_p}{f_2}\right)^2 \frac{C}{N_T}$$

$$= \frac{3}{2f_2} m^2 \frac{C}{N_T} \qquad \text{(D-3)}$$

where

$$m = \text{modulation index} = \frac{D_p}{f_2}$$

Equation (D-3) is plotted in Figure D-4 as a function of C/N_T and is only valid when the system is operating above threshold. The value of threshold, α, can be expressed by the following

$$\frac{C}{N_T} \cdot \frac{1}{2f_2(m+1)} \geq \alpha \qquad \text{(D-4)}$$

For the conventional FM discriminator, α is usually taken to be 12 dB, for an FM feedback discriminator α is taken as 6 dB.

In order to determine the necessary results, it becomes necessary to define some criteria for acceptable speech quality. Paragraph D.2.1 indicates that a 50-dB psophometrically weighted test tone to noise ratio will yield high quality voice communication. Hence Equation (D-2) can be rewritten in terms of test tone to noise

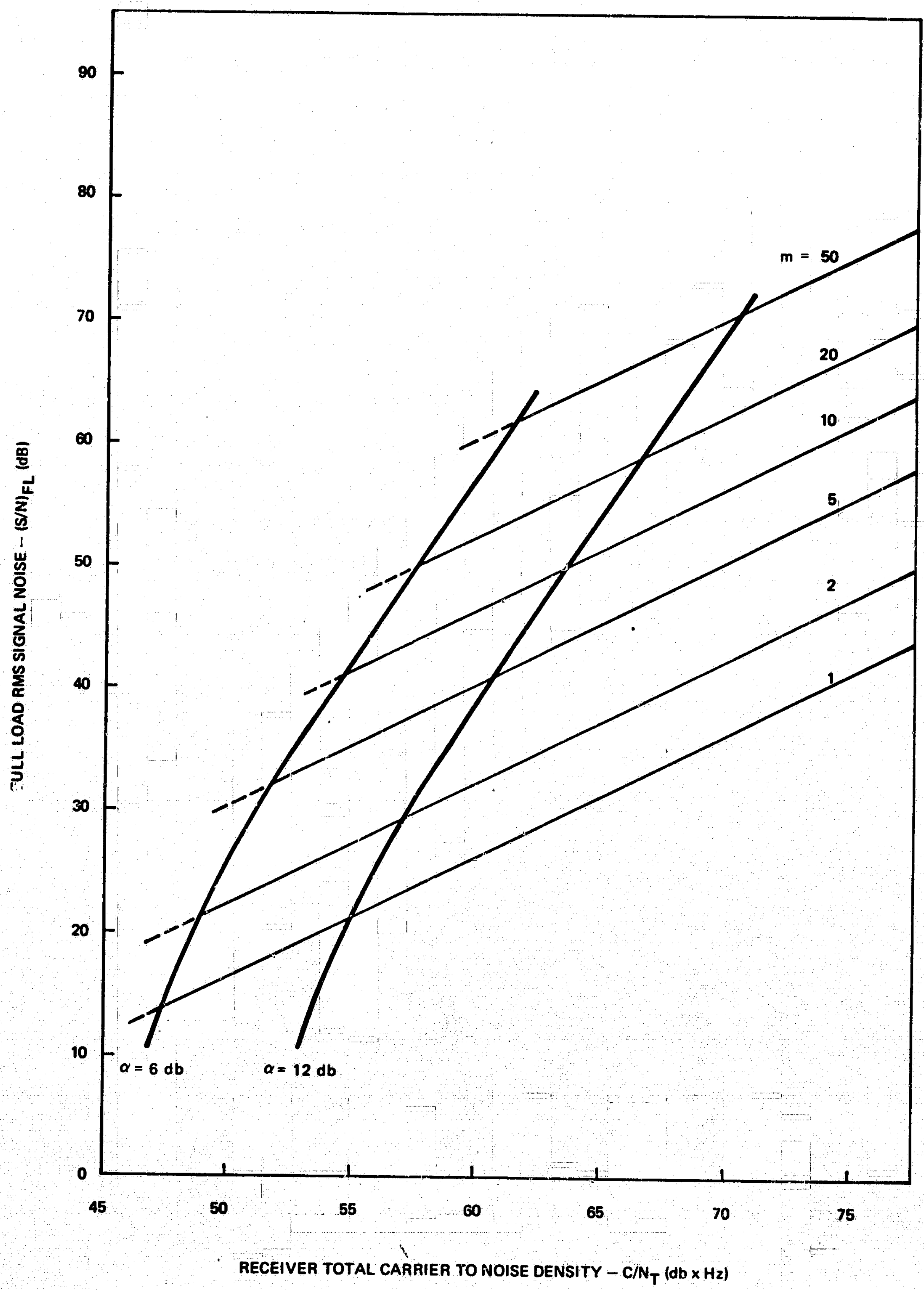

Figure D-4. Full Load RMS Signal to Noise vs. Receiver Carrier to Total Noise Density for FM/FDMA System ratio by examining Figure D-3 and recalling that the peak to average value of a sine wave is 3 dB

$$\left(\frac{S}{N}\right)_{TT} = 2\left(\frac{S}{N}\right)_{FL} \beta/L^2 \tag{D-5}$$

where

$(S/N)_{TT}$ = test tone to noise ratio weighted in baseband channel

β = psophometric weighting improvement (2.5 dB)

L^2 = Load factor (note the fact that if the 2 in Equation (D-5) is retained, L^2 is the peak full load power to test tone reference. If the factor of 2 is omitted in the above equation, then L^2 is the rms load power to test tone reference).

The load factor, L^2, can change as a function of the average speech level, P, as shown in Figure D-2. As mentioned previously in Paragraph D.2.1, two levels of average speech are considered, (P = -11 dBm and -13.5 dBm) to show the variation in different measurements in determining the average power for the average talker. Hence, the load factors are +7 dB and +4.5 dBm respectively. Utilizing these results, Equation (D-5) yields the corresponding values of full load rms sine wave signal to noise ratios of 51.5 dB and 49.0 dB. The value of $(S/N)_{FL}$ = 51.5 dB is the more conservative and is chosen as a practical design goal.

Proceeding from this point, it is desired to next determine both the power and bandwidth requirements for this system. Before doing this, however, it is necessary to calculate the index of modulation, m, for this single channel FM system. The technique used to determine m is to solve Equations (D-3) and (D-4) for m. For this analysis, the following parameters are assumed: (1) 6 dB and 12 dB threshold; (2) test tone to noise ratio (weighted) of 50 dB; and (3) upper baseband frequency of 3400 Hz. Under these assumptions Equations (D-3) and (D-4) are plotted in Figure D-5

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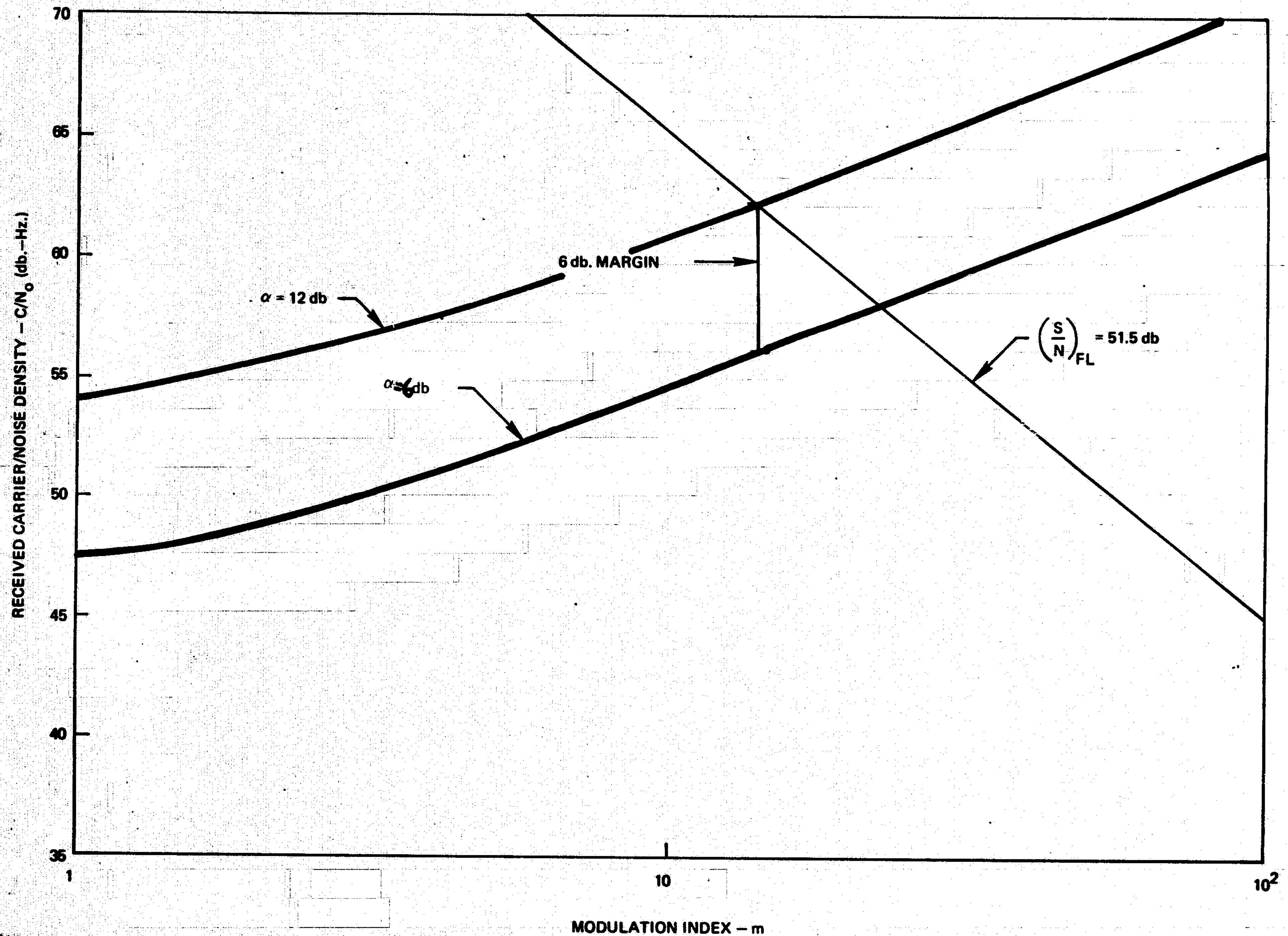

Figure D-5. Received Carrier/Noise Density vs Modulation Index as a function of modulation index and carrier to noise density ratio for the two thresholds. The intersection of these two curves yields the optimum modulation index and the required total carrier to noise density ratio at the receiver. Once this is determined the bandwidth per channel, B_{CR}, can be determined from the familiar Carson's Rule of bandwidth $B_{CR} = 2f_2(m+1)$. Multichannel bandwidth considerations are addressed in Paragraph D.3.3. All of these results in terms of modulation index, required carrier to noise density ratio, and necessary bandwidths are given in Table D-1. Two cases of interest are shown depending on whether or not FM feedback is used. For the case where no FM feedback is used the threshold was assumed to be α = 12 dB. The receiver operating point is shown in Figure D-5 by the intersection of the α = 12 dB curve and the $(S/N)_{FL}$ = 51.5 dB curve. If the receiver does employ FM feedback and no margin is assumed, the receiver operating point is given by the intersection of the α = 6 dB curve and the $(S/N)_{FL}$ 51.5 dB curve. For FM feedback with a 6 dB margin the results of the table were determined by finding the 6 dB spread point between the α = 6 dB and $(S/N)_{FL}$ = 51.5 dB curves as shown in Figure D-5. This increases the operating point by an additional 4.1 dB.

D.3 SYSTEM PERFORMANCE

The following paragraphs discuss the measures of performance of a candidate FDMA/FM system.

D.3.1 Repeater EIRP

The procedure for determining the required satellite effective isotropic radiated power (EIRP) is given in Appendix E. Equation (E-6) is used to calculate the repeater EIRP. The analysis has been done for the single channel per carrier FDMA/FM system and the corresponding downlink power budget is given in Table D-2. Several basic assumptions are necessary to arrive at this power budget.

TABLE D-1. FM PERFORMANCE RESULTS

$(S/N)_{FL}$ (dB)	Threshold (dB)	Margin (dB)	M	C/N_T (dB x Hz)	B_{CR} (kHz)
51.5	6	0	22.2	58.0	158
51.5	6	6	14.0	62.1	102
51.5	12	0	14.0	62.1	102

a. The TWT output backoff, L_{BO}, is assumed to be 4.3 dB. References 14 and 15 indicate that the TWT must be backed off by this amount in order to achieve a desirable carrier to inter-modulation ratio of 20 dB. The TWT backoff was determined as a function of C/IM for M equal amplitude carriers and is shown in Figure E-2 of Appendix E.

b. In calculating the satellite EIRP it is assumed that the average uplink power is the same for each user; the repeate EIRP is then linearly power shared for each user. A 1-dB degradation due to uplink power imbalance is assumed.

c. The free space attenuation factor has been calculated on the basis of an average satellite to earth terminal slant range of 20,800 nautical miles.

d. Voice activation circuits are employed in each earth terminal and the voice activity factor is chosen to be 40 percent.

In addition to these, the following assumptions will be made when selecting quantitative values of EIRP, G/T, and M:

e. An allowance for fluctuations in received signal to noise is given in terms of a system margin.

f. The channel quality is assumed to correspond to a 50-dB psophometrically weighted test tone to noise ratio. This results in a full load rms sine wave signal to noise ratio, $(S/N)_{FL}$, of 51.5 dB.

TABLE D-2. SINGLE CHANNEL FDMA DOWNLINK POWER BUDGET; 4 GHZ

Satellite EIRP (dBW)	EIRP
TWT Backoff (dB)	-4.3
Power Control Loss (dB)	-1.0
Free Space Attenuation (dB)	-196.6
Miscellaneous Losses (Polarization, ellipticity, atmospheric, tracking) (dB)	-1.0
Received Carrier Power (dBW)	EIRP -202.9
Receiver Figure of Merit-G/T (dB)	G/T
Boltzmann's Constant (dBW)	+228.6
Voice Activation Factor; α_v (dB)	+4.0
Effective M Channel Carrier to Thermal Noise Density Ratio; $(C/N_o)_R^{eff}$ (dB/Hz)	EIRP + G/T + 29.7
Number of Channels; M (dB)	-M
Received Carrier to Thermal Noise Density Ratio at a Receiver for a Single Channel; $(C/N_o)_R$ (dB/Hz)	EIRP + G/T -M +29.7

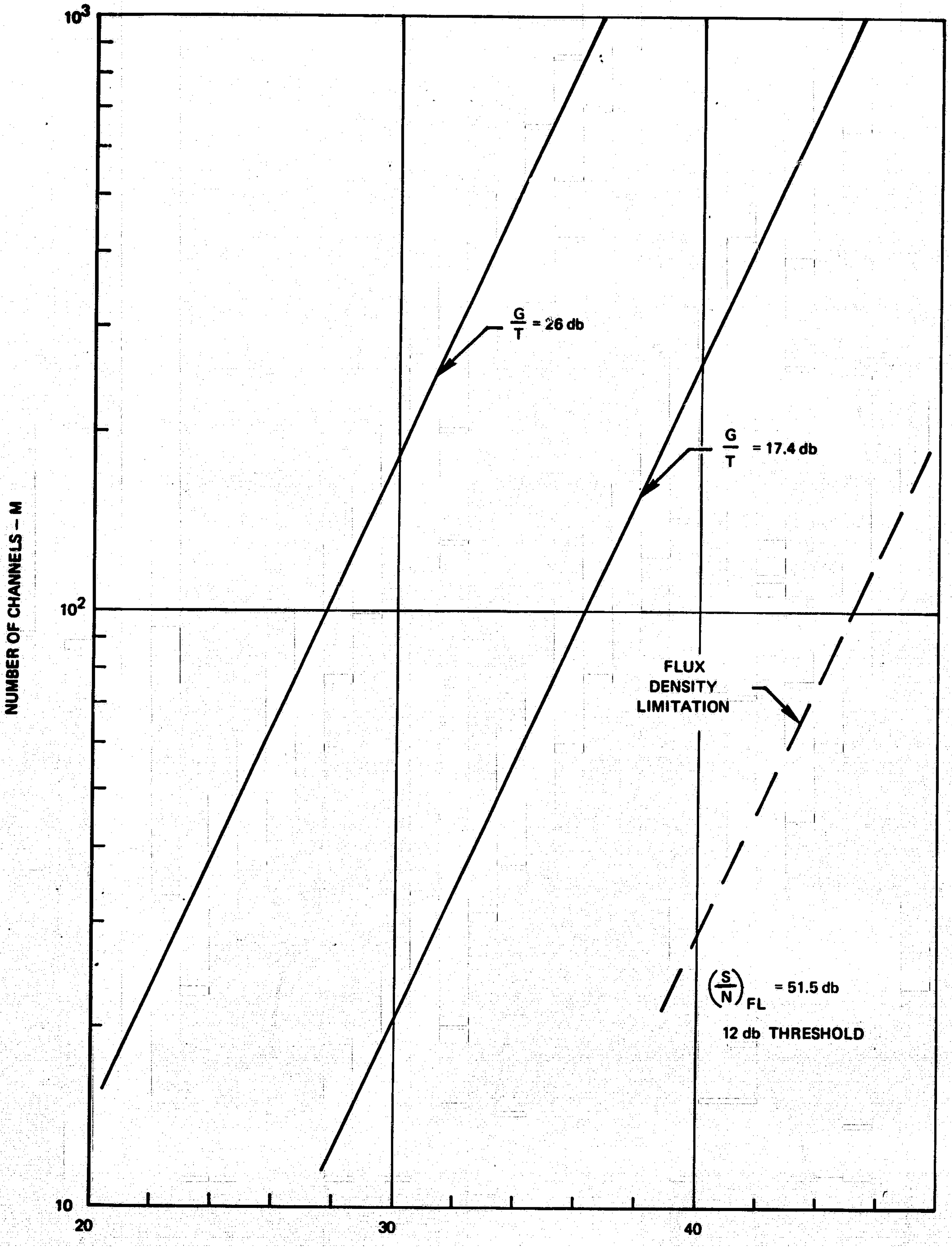

Figure D-6. Number of Channels vs Satellite EIRP

g. The repeater bandwidth, W, is directly related to the number of channels, M, and the Carson's Rule of bandwidth for frequency modulation, B_{CR}, by the relationship $W = MB_{CR}$.

D.3.2 Repeater Bandwidth

The repeater bandwidth, W, is assumed to satisfy the Carson's Rule established for conventional FM performance. More precisely, W is directly proportional to the number of channels, M, and the bandwidth per channel, B_{CR}.

$$\begin{aligned} W &= M\ B_{CR} \\ &= 2M\ f_2\ (m + 1) \end{aligned} \qquad \text{(D-6)}$$

where

f_2 = is the highest baseband frequency (3400 Hz)

m = modulation index

Equation (D-6) is plotted in Figure D-7 as a function of repeater bandwidth for systems with and without margin. It is assumed that the channel quality corresponds to $(S/N)_{FL} = 51.5$ dB and $m = 14$.

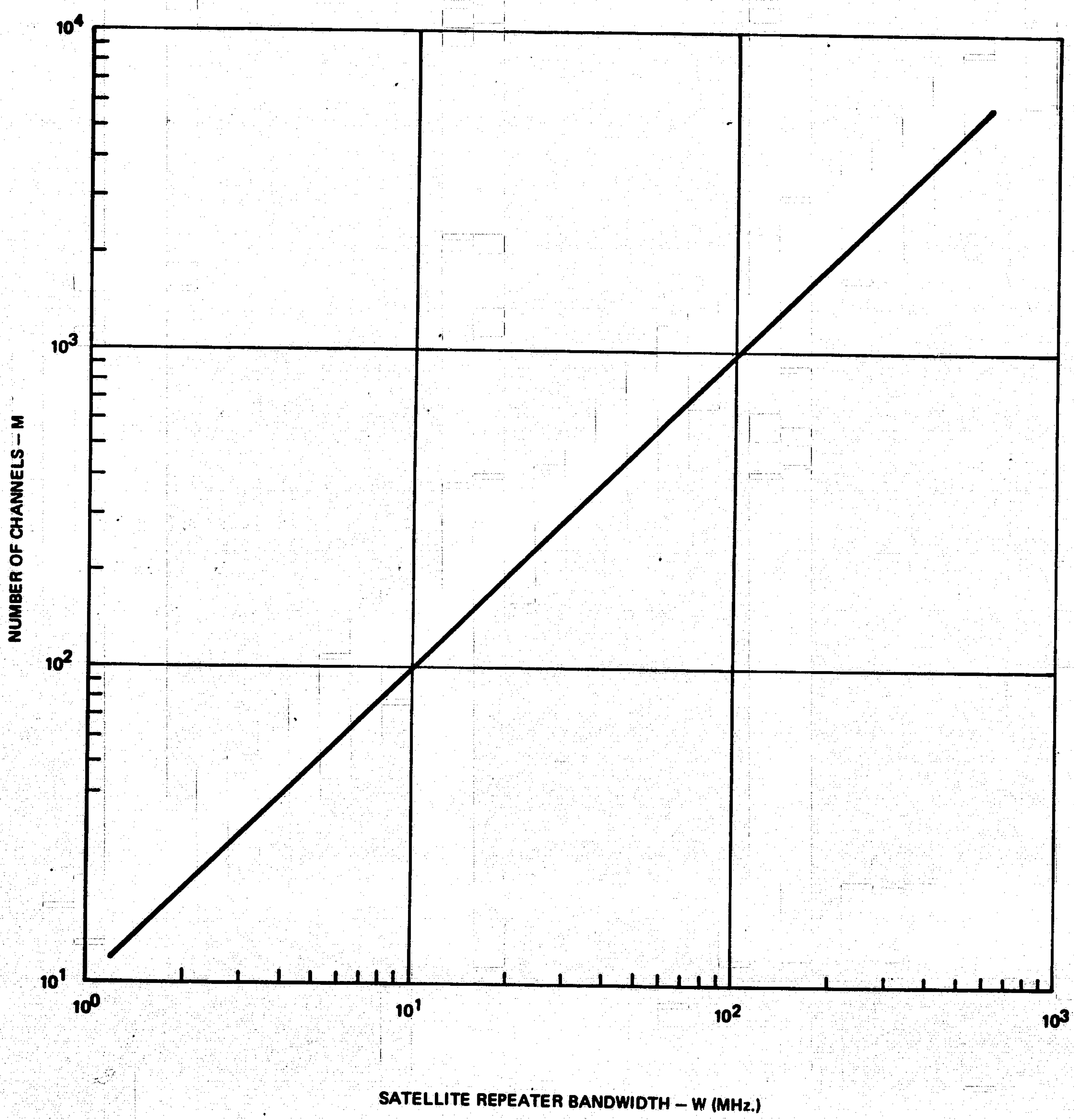

Figure D-7. Number of Channels vs. Satellite Bandwidth

APPENDIX E

FDMA SYSTEM TRANSMISSION PERFORMANCE

The problem of determining the required satellite effective isotropic radiated power (EIRP) necessary to obtain reliable data transmission is analyzed in this appendix. The communications system under analysis is shown in Figure E-1. For this system it is assumed that M independent voice channels are accessing a single wideband satellite transponder that uses a TWT as a final power amplifier. Each uplink signal is transmitted on some frequency, f_u (6 GHz). The satellite repeater retransmits the signals on some other frequency, f_D (4 GHz).

E.1 SATELLITE EIRP

The performance of FDMA through a satellite repeater can be determined by considering the appropriate power division among the relative levels of the input signals and noise. The total carrier power at the j^{th} receiver resulting from a signal transmitted through the repeater from the i^{th} transmitter can be expressed as

$$(C)_{ij} = \frac{S_i (C)_j}{\alpha_i \left\{ \sum_{k=1}^{M} S_k + N_s \right\}} \qquad \text{(E-1)}$$

where

S_i = signal power at the satellite resulting from the i^{th} transmitter

α_i = suppression of the i^{th} signal (if a hard limiter is used)

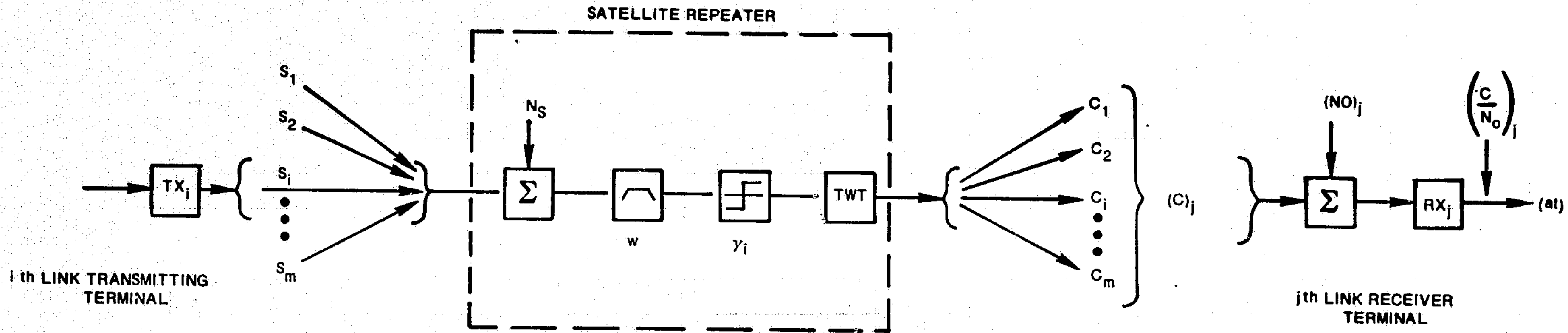

Figure E-1. Communications System

$(C)_j$ = total satellite power received at the j^{th} receiver

N_s = repeater thermal noise

M = number of signals

The suppression term, α_i, is introduced for the purpose of generality. For a linear repeater $\alpha_i = 1$, indicating that there are no suppression effects. For FDMA signals, the total noise density at the j^{th} receiver is the sum of thermal noise density, rebroadcast satellite noise, intermodulation noise density, intersymbol distortion and channel crosstalk noise density (spectrum overlap due to nonideal filters).

$$(N_T)_j = (N_o)_j + \frac{(C)_j \quad N_s}{\alpha_i W \left\{ \sum_{k=1}^{M} S_k + N_s \right\}} + IM_o + I_{s_o} + I_{f_o} \qquad \text{(E-2)}$$

where

$(N_o)_j$ = thermal noise density at j^{th} receiver

W = repeater bandwidth

IM_o = repeater intermodulation noise density

I_{s_o} = Intersymbol distortion noise density

I_{f_o} = channel crosstalk noise density

It should be noted that the inclusion of suppression effects, intersymbol distortion, intermodulation noise and channel crosstalk greatly complicates the computation of the system capacity since general expressions for describing nonlinear systems and nonideal filters are not available. The total carrier power to noise density at the j^{th} receiver due to signal, S_i, and noise effects can then be expressed as

$$\left(\frac{C}{N_T}\right)_{ij} = \frac{S_i \; (C/N_o)_j}{\alpha_i \left\{ \sum_{k=1}^{M} S_k + N_s \right\} \left\{ 1 + \frac{N_s \; (C/N_o W)_j}{\alpha_i \left[\sum_{k=1}^{M} S_k + N_s \right]} + \frac{1}{(N_o)_j} \left[IM_o + I_{s_o} + I_{f_o} \right] \right\}} \quad \text{(E-3)}$$

The first term in the denominator of the above equation shows the repeater power division according to the number and relative power levels of the uplink signals and uplink noise. The second term indicates the degree to which the earth terminal receiver noise is modified by the rebroadcast satellite noise, intermodulation, intersymbol and crosstalk noise effects.

Thus, Equation (E-3) gives the total carrier power to noise density ratio at a receiver in terms of the various link parameters. This ratio must be some specified based upon desired system performance.

On this basis it is now possible to determine the required satellite EIRP. Before proceeding further, several assumptions are made to increase the usefullness of the results.

a. The uplink carrier to thermal noise density ratio is much greater than the downlink carrier to thermal noise density ratio (i.e., $(C/N_o)_{up} = \frac{S_i W}{N_s} >> (C/N_o)_{down}$).

b. The carrier to intermodulation noise ratio, C/IM, will be 20 dB and the corresponding TWT output backoff is 4.3 dB (Reference 2).

c. The channel crosstalk and intersymbol distortion will not be limiting effects (C/I_f and C/I_s > 23 dB; Reference 2).

d. Interference effects caused by other signals are neglected.

Under these assumptions, Equation (E-3) can be used to determine the received carrier to thermal noise density ratio, $(C/N_o)_R$,

$$\left(\frac{C}{N_o}\right)_R = \frac{(C/N_T)_{ij}}{1 - \left(\frac{C}{N_T}\right)_{ij} \frac{IM}{C} \frac{1}{W}} \tag{E-4}$$

where C/IM is the carrier power to intermodulation noise power ratio* and $(C/N_T)_{ij}$ is the required carrier to total noise density at a given receiver for a single channel and is dependent on system performance (FM or PCM/PSK). For a system which employs M channels the effective carrier to thermal noise density ratio becomes

$$\left(\frac{C}{N_o}\right)_R^{eff} = M \left(\frac{C}{N_o}\right)_R \tag{E-5}$$

where

M = number of voice channels

Finally, the repeater EIRP can now be calculated by the following equation:

$$EIRP = \frac{(C/N_o)_R^{eff} \quad L_{PB}}{G/T} \tag{E-6}$$

where G/T is the receiver figure of merit and L_{BP} is the power budget loss factor which is given by

$$L_{PB} = L_{FS} \; L_m \; L_{BO} \; L_{PC} \; k \; \alpha_v \tag{E-7}$$

where

α_v = voice activation factor (i.e., α_v = 1 continuous operation; α_v = .4 burst operation)

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*It is assumed that the intermodulation noise is spread evenly over the repeater bandwidth, W (i.e., $IM_o W = IM$).

L_{FS} = is the free space attenuation

k = is Boltzman's constant (-228.6 dB ^{o}K)

L_{BO} = is the TWT backoff for a given C/IM

L_{PC} = is the power control loss

L_{M} = is the allowance for miscellaneous losses

E.2 SYSTEM CAPACITY

The digital data rate that the j^{th} terminal can receive from a signal from the i^{th} transmitter is

$$R_j = \frac{(C/N_T)_{ij}}{(E_b/N_o)_j} \qquad \text{(E-8)}$$

where $(E_b/N_o)_j$ is the energy per bit to noise density ratio at the j^{th} terminal. The system capacity (or total data rate), R_T, is then obtained by summing all of the individual data rates over the M signals.

For analog modulation techniques, the system capacity is a measure of the maximum number of acceptable quality voice channels. To determine the system capacity, one must consider the particular modulation technique and compute the quality of the analog modulated voice signal on the basis of the demodulator output signal to noise ratio.

E.3 INTERMODULATION (IM) EFFECTS

Under the assumption that a single wideband repeater contains a hard limiting device, certain intermodulation effects will occur. These intermodulation products result because of the nonlinear characteristic of the repeater. The products tend to reduce the amount of useful signal power or produce interference. The loss in useful signal power is called the suppression. Both analytical (Reference 9) and experimental results indicate that the suppression is approximately 1 dB for a large number of signals.

The loss due to interference can be extremely serious. For the case of equal bandwidth and equal amplitude signals Cahn (Reference 10) has shown that, at worst, C/IM in a slot bandwidth is approximately 9 dB when the frequencies are closely packed.

Two methods, however, are available for increasing the C/IM to a level greater than 9 dB. In the first technique, Shaft (Reference 11) has derived the following relationship giving the average C/IM for a system in which M_o carrier frequencies are unequally spaced among M channels.

$$\frac{C}{IM} = 9.2 + 10 \log_{10} (M/M_o) \tag{E-9}$$

It is immediately noted that the reduction in intermodulation is achieved at the expense of increased bandwidth expansion.

The second technique for improving the C/IM ratio would be to reduce the operating level of the repeater TWT to a point at which the intermodulation level is tolerable. Some sacrifice, however, in terms of repeater power is necessary. Doyle (Reference 12) has performed some calculations showing the tradeoff between intermodulation performance and repeater loss. Berman (Reference 13) has obtained a curve of C/IM versus TWT backoff for M equal amplitude carriers using digital computer simulations and the results are shown in Figure E-2. More recent work has been performed by McClure (Reference 14) in terms of optimizing the TWT backoff as a function of margin.

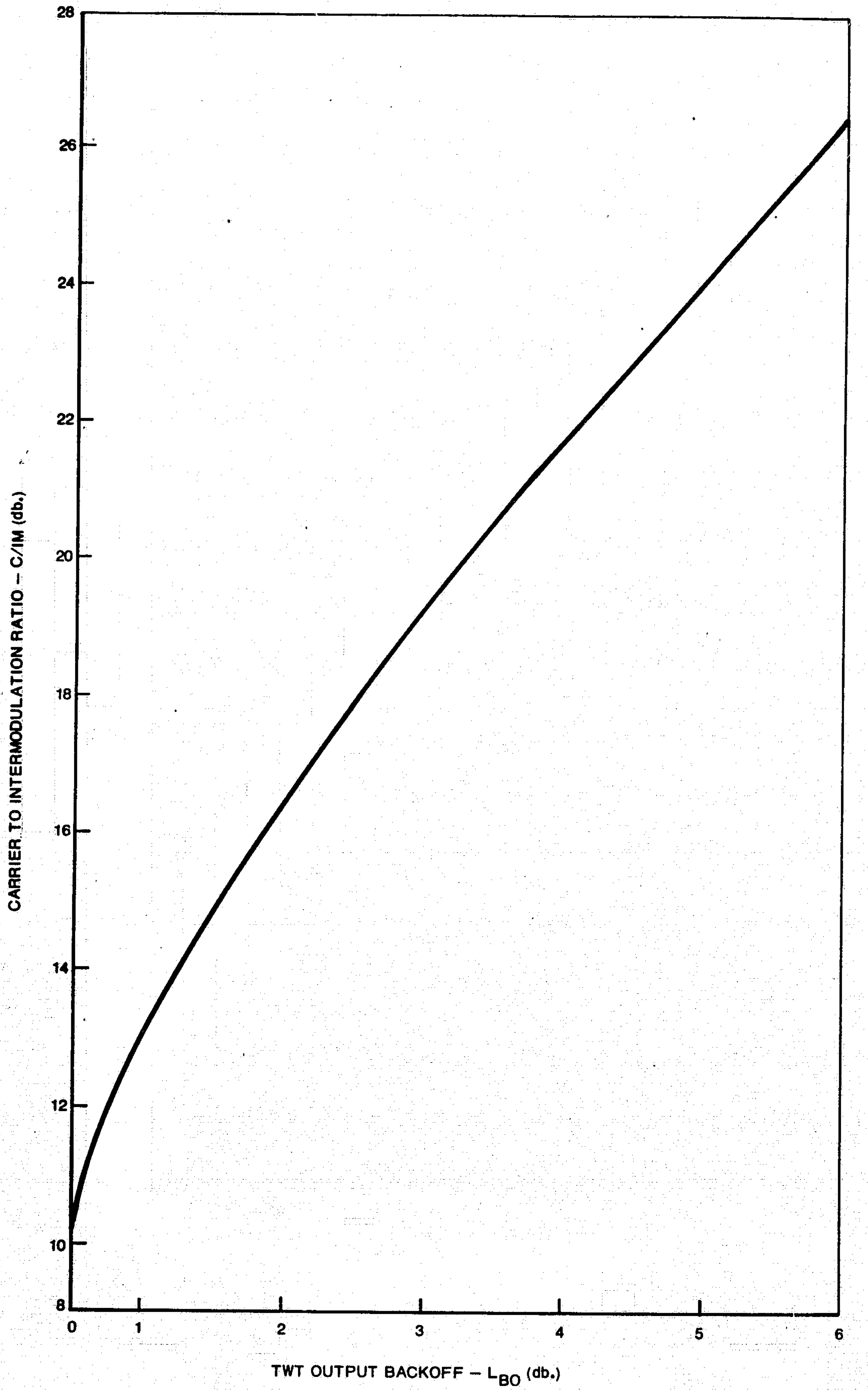

Figure E-2. Carrier to Intermodulation Ratio vs. Output TWT Backoff

APPENDIX F

VOICE ACTIVIATION CONSIDERATIONS

In a conventional two-way telephone conversation each user has the circuit for somewhat less than half the time. Pauses in speech, operator setup time, etc., contribute to a substantial amount of free time. Measurements on working telephone channels (Reference 16) show that the average talker activity* is approximately 35 percent of the total time that the circuit is busy. This is shown in Figure F-1, as taken from Reference 17. Thus, for a duplex circuit it is seen that each one-way channel is free for about 65 percent of the time.

For a system with a large number of channels it is possible to take advantage of this "free" time to: (1) increase the number of users per circuit, or (2) decrease the satellite repeater power per circuit. An example of the first type of scheme is TASI (Time Assignment Speech Interpolation), a transatlantic telephone switching system. Idle time is filled by multiplexing an active user onto a free channel. Thus, a typical telephone conversation may be conducted using many circuits. The STAR and SPADE Systems use the second method. Here the so-called "START-STOP" method is used to turn off circuits in use while they are not active. The aim is to conserve power in the satellite repeater. Thus, the repeater can be designed for the number of <u>active</u> channels, not the number of <u>busy</u> channels. The next paragraph will outline the derivation of the expressions necessary to illustrate the channel savings to be gained by a method similar to the "START-STOP" scheme.

Consider a system with n independent talkers, each with average probability of activity p. At any given time the probability that the number of active users is equal to or greater

*Defined as the percentage of time that energy above a prescribed low threshold is transmitted in one direction.

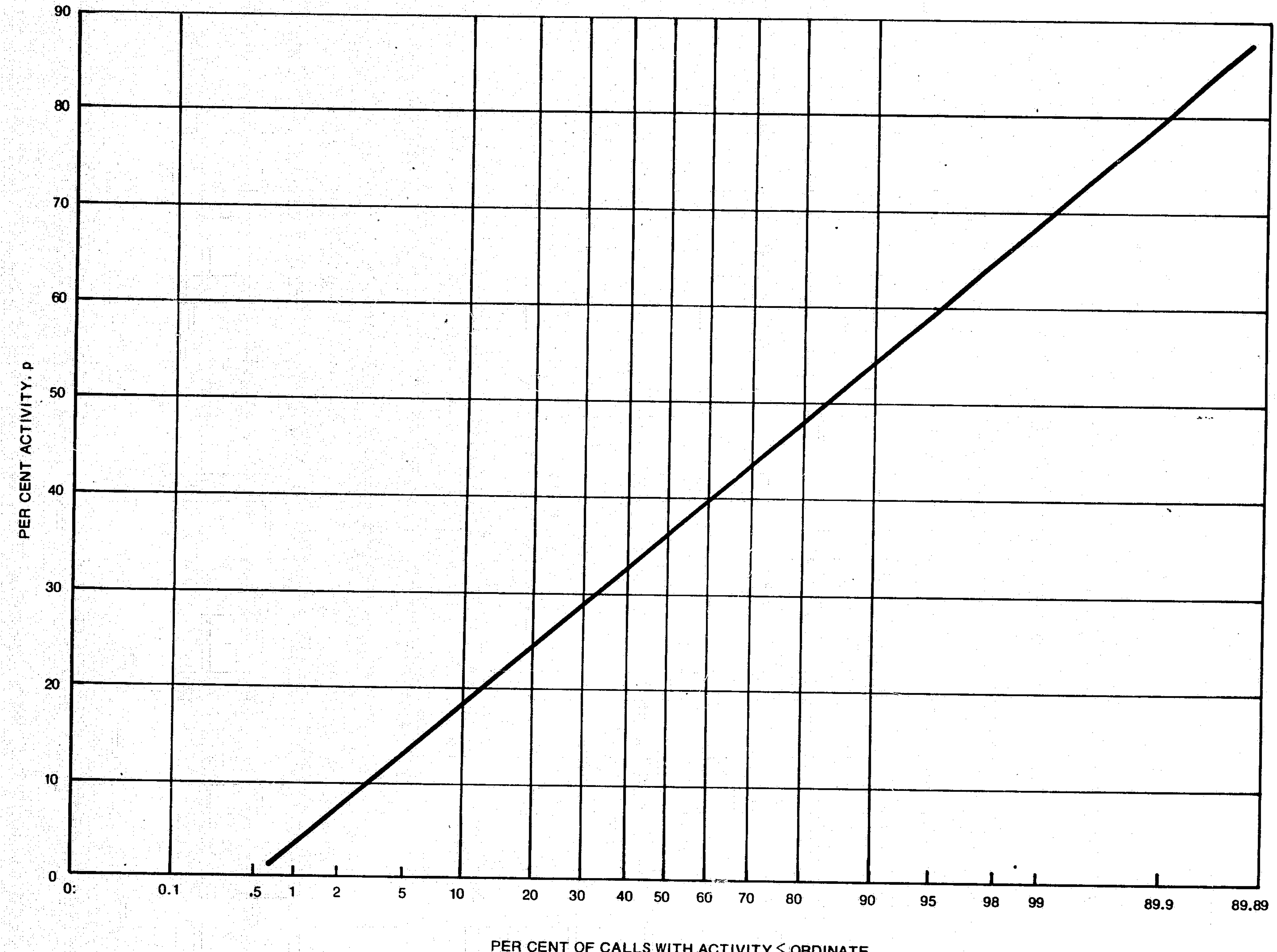

Figure F-1. Measured Activity Distribution than c ($c \leq n$) is related to the binomial distribution, and is given by

$$B(n,c;p) = \sum_{i=c}^{n} \binom{n}{i} p^i (1-p)^{n-i}$$

It is easily shown that, for $n \gg 1$, this relationship is closely approximated by the Gaussian distribution. That is,

$$B(n,c;p) \cong \frac{1}{\sqrt{2\pi}} \int_u^\infty \exp\left\{- \frac{x^2}{2}\right\} dx$$

where

$$u = \frac{c - np - 0.5}{\sqrt{np\,(1 - p)}}$$

Thus, we have a Gaussian random variable with mean $np + 0.5$ and standard deviation $\sqrt{np(1-p)}$. Plots of n versus c for values of $B(n,c;p) = 0.01, 0.5$ and values of $p = 0.3, 0.4$ are shown in Figure F-2. It is seen that if an activity factor of 0.4 is assumed, and one is willing to tolerate overload 1 percent of the time, a $n = 500$ channel system will have $c = 225$ simultaneous active channels. Thus, the satellite repeater need only be designed for 225 channels, even though the system carries 500 channels. This is a 3.3-dB gain in satellite power. If an activity factor of $p = 0.3$ is assumed, the gain for a 500-channel system is 4.5 dB. If one were willing to tolerate greater overload probabilities, the savings can be greater. For example, from Figure F-2, for $B(n,c;p) = 0.5$, the gains are 4.1 dB for $p = 0.4$, and 5.7 dB for $p = 0.3$; both for 500-channel user systems.

While it is unlikely that a 50-percent overload would be acceptable for practical system design, (the 1-percent overload being reasonable),Figure F-2 illustrates the gain to be taken advantage of by voice activation.

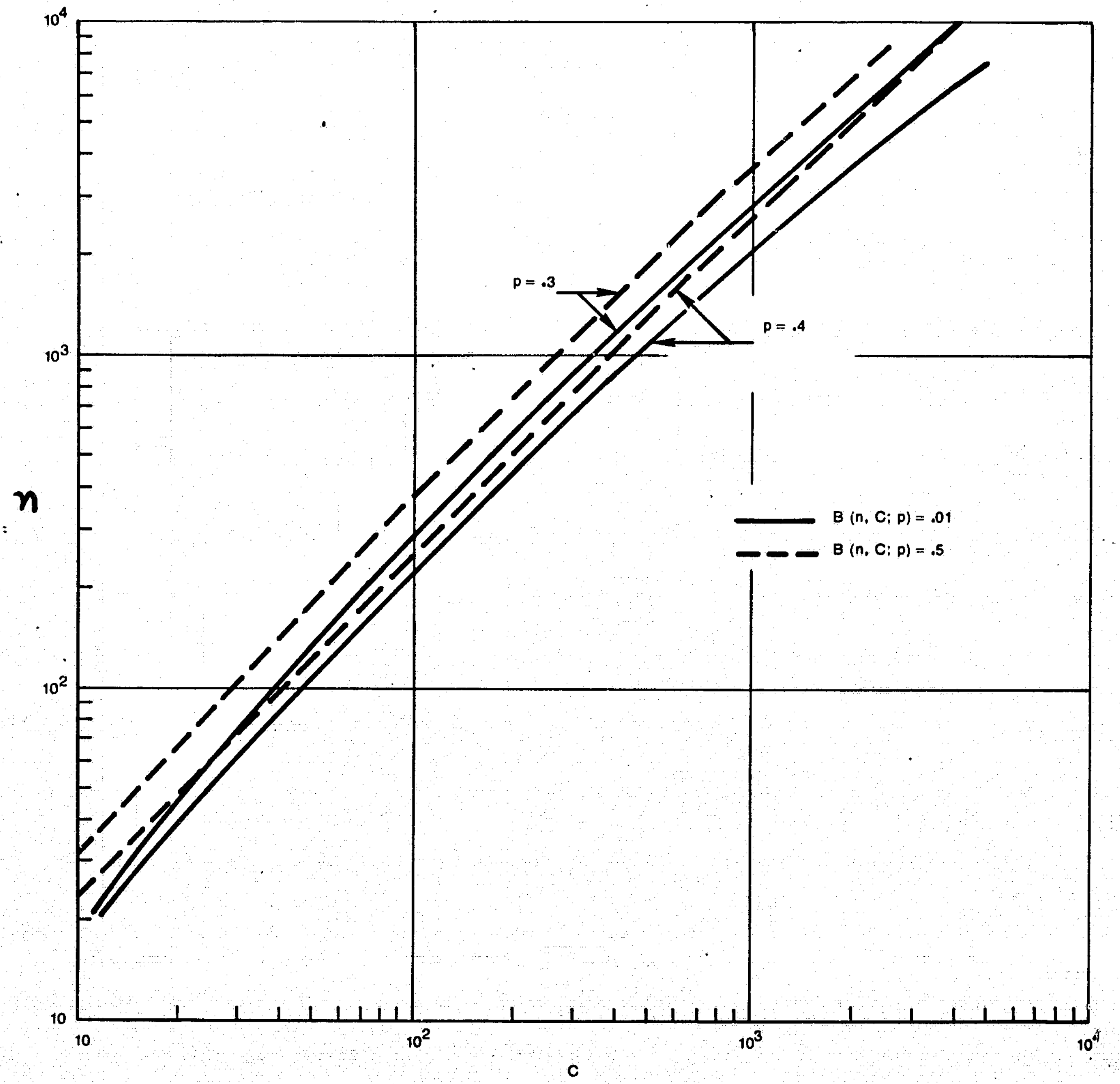

Figure F-2. Voice Activation Advantage

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