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**NASA Contractor Report 165301**

**30/20 GHz COMMUNICATIONS SYSTEM  
FUNCTIONAL REQUIREMENTS**

**C. M. Siperko, M. Frankfort, R. Markham, and M. Wall  
Lewis Research Center  
Cleveland, Ohio**

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Lewis Research Center  
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EXECUTIVE SUMMARY

1.0 INTRODUCTION

This study defines the characteristics of 30/20 GHz satellite systems to be used in support of projected communication requirements of the 1990's. The study encompasses a requirements analysis which develops projected market demand for satellite services by general and specialized carriers, an analysis of the impact of propagation and system constraints on 30/20 GHz operation, development of a set of technical performance characteristics for the 30/20 GHz systems which can serve the resulting market demand, and finally defining the experimental program necessary to verify technical and operational aspects of the proposed systems.

The market analysis in this study takes as its basis previous Western Union and other reports on the addressable and accessible satellite market demand. Data from these studies, together with that derived from additional potential markets identified in the current study, have been combined and analyzed. The specific requirements of each type of traffic were then used to arrive at market projections for the Ka-band in terms of the various types of satellite

carriers and their market interest. The traffic mix identified for each type of carrier results in a projection of three types of Ka-band satellites: An all trunking satellite, an all CPS satellite, and a satellite combining both types of service.

An analysis of propagation factors at Ka-band identified suitable modes of operation for normal and rain affected operation in each region of the U.S. By combining the market and operation mode studies, a set of functional specifications for a satellite applicable to a Western Union class carrier was established. By comparing these specifications with currently available technology and considering the minimum requirements for a useful satellite system, a set of functional requirements for the proposed experimental satellite was obtained. Such a satellite would be used to investigate presently assumed propagation effects, prove out necessary new technology, and provide an experimental system to assess the applicability of the Ka Band to commercial service offerings.

In addition, certain topics requiring further investigation have been identified, and potential uses of an intersatellite link considered.

Discussion of potential uses of Ka-band satellites normally places great emphasis on the channel availability problem due to weather related attenuation

increases. Methods to resolve this problem require considerable investment in additional hardware, loss of system capacity, and complex control procedures. Without any attempt to minimize the importance of the availability problem at Ka-band, it must be realized that in normal use a Ka-band facility will represent only a part of any entity's total communication capability. Typically a carrier using a Ka-band trunking network will have other trunking facilities as well, be they terrestrial, C-band, or Ku-band, interconnected into a single communication network. Similarly, a company served by a network of CPS stations operating at Ka-band will also have available alternate communication facilities for voice and low to medium speed data via the standard telephone network (message telephone system or MTS). Such alternate routing capabilities for both carrier and private networks are routinely used today in all terrestrial systems. Examining the Ka-band availability from the standpoint of the user, loss of the Ka-band facility represents a loss of capacity, not a total interruption of communication. (This is not always true for wide band facilities, but most of these are not used for real-time traffic or represent lower priority "real-time" services which can be delayed if necessary.) Thus the user is faced with either a loss of throughput or increase in blocking probability during a Ka-



band outage, or is forced to use higher cost channels (e.g. MTS), or both. The net result is an increase in cost per unit of traffic. Thus, while the effects of Ka-band outages will certainly be a factor in a decision to implement a Ka-band network, they should not be the overriding factor in determining suitability of Ka-band transmission systems for given services.

A more detailed summary of the report is given below. The sections are keyed to the main sections of the report.

## 2.0 MARKET ASSESSMENT

The three major traffic categories identified in the previous studies--data, voice, and video--were further broken down on the basis of characteristics affected by Ka-band satellite performance limitations. These are primarily availability and lack of global (CONUS) beam coverage. In later sections of this report, designs for trunking and CPS earth stations are shown which will yield availabilities of .9999 and .999, respectively, over the entire continental United States (CONUS). The lack of full CONUS coverage beams can be circumvented by using simultaneous or sequential transmission on many spot beams. Thus it will be possible to install purely Ka band transmission networks to satisfy any reasonable system requirements. There are, of course, cost penalties involved in these solutions and practical Ka-band

networks may not, in fact, achieve these availabilities or provide CONUS coverage. Notwithstanding these problems we feel that even with significantly lower availabilities than those quoted above, only truly real-time data (e.g. airline reservation systems or credit verification) and Network or CATV broadcast video are completely unsuitable for Ka-band services. As noted in the introduction, other services which at first might seem unsuitable actually can effectively use the Ka band when consideration is given to the other communication facilities available to the user. Thus with overall service quality generated by a combination of Ka-band and other facilities, suitably priced Ka-band links can be attractive in almost any network.

The analysis of existing and announced satellite carriers has identified three types of carriers: public carriers carrying primarily switched voice and data between trunking terminals (AT&T, GTE); private carriers using primarily CPS terminals (e.g. SBS, SPCC, etc.) to carry voice and data directly between customer locations; and combination carriers (e.g. WU and RCA) which provide both trunking and CPS service. The projected traffic for each of these carriers in the year 2000 has been estimated at 900 GBPS for the public carriers as a group, 200 GBPS for each of two CPS carriers, and 300 GBPS for each of two combination

carriers. Based on these estimates, practical limitations on spacecraft capacity, and a balance of initial system costs and long term capacity needs, we estimate that the initial satellite for each type of carrier would have a capacity of 10 GBPS for a public carrier, 2.5 GBPS for a CPS carrier, and 4 GBPS of trunking and 2 GBPS of CPS for a combination carrier.

### 3. NETWORK CONNECTIVITY

The connectivity problems of the three types of carriers have been analyzed in terms of the requirements of the traffic they carry. A public carrier can use Ka-band facilities to supplement existing lower frequency band facilities, using its existing terrestrial network to concentrate traffic to high capacity trunking stations. It can also use Ka-band to directly connect high traffic points (e.g. downtown city locations), bypassing higher levels in the switching hierarchy. A public carrier would normally require a satellite providing service to points distributed throughout CONUS. This will require either a centrally located satellite or multiple satellites with direct links between them. A public carrier normally plans its network in advance to integrate all its transmission facilities and can therefore use a predetermined satellite configuration.

A CPS type private carrier is organized to provide corporate- or organization-wide networks which are

normally isolated from each other. These networks are constantly changing as a result of customer actions, both on a long term basis, and dynamically as customer activity varies on a daily or hourly basis. In many cases some of the user locations will be located in remote areas. Thus a satellite for this type of carrier must have the capability of being reconfigured at high and low rates, and must be capable of reaching any portion of CONUS. (Indeed it is precisely the capability of providing a wide range of broadband services to remote locations that makes a satellite system attractive.)

Combination carriers require both heavy traffic trunking capability and CPS capability. They must therefore have all the features identified above.

For all types of carriers the economy of providing CONUS coverage with a single satellite that is, consequently, limited to a small portion of the orbital arc must be balanced against possible improvements in performance obtainable from suitably interconnected satellites with smaller coverage. The problem of orbital arc saturation remains to be addressed.

#### 4. PROPAGATION CONSIDERATIONS

Previous studies of 20/30 GHz propagation have identified seven rain rate climate zones for CONUS. The rainfall statistics in these regions were used to define system power margins needed in each of the re-

tions for various levels of availability and for a well-located satellite. Based on maintaining a reasonable elevation angle over CONUS, the optimum satellite location was determined to be 97°W longitude with a  $\pm 7^\circ$  range allowing reasonable operation. An examination of experimental results of earth station space diversity separation vs. expected diversity gain showed that 8-10 km separation would be sufficient to yield considerable system improvements.

5. TRANSMISSION SYSTEM CONSIDERATIONS

The propagation analysis of section IV was used to derive performance requirements for an operating link. The various methods available to increase system margin considered were:

1. Increased Power
2. Increased Antenna Size
3. Forward Error Control
4. Reduced Rate Transmission
5. Space Diversity

For trunking stations for which a .9999 availability is required, no combination of approaches 1-4 will provide satisfactory service. On the other hand, if space diversity is used, a small amount of adaptive power control (4.9 dB up-link and 8.75 dB downlink) and 5 meter antennas are sufficient to provide the availability needed (if diversity gain is obtained on a dB for dB basis for single site fades greater than 18 dB, which requires verification).

For CPS stations, except in rain zone E (southeast in CONUS), with 32 MBPS uplinks and 256 MBS downlinks, the use of adaptive power control (7.5 db) and forward error correction is sufficient to obtain .999 availability. In rain zone E it would be necessary to go to lower burst rates, increased antenna size, and more uplink power.

A consideration of synchronization techniques has determined that the preferred approach would be an open-loop one in which slant range calculations are made by the master control station and appropriate delay instructions sent to each trunking or CPS station. This will minimize equipment both in the spacecraft and ground stations, as compared to closed loop approaches in which each station determines its own delay.

An investigation of cross-polarization separation-loss problems indicates that rain-induced depolarization should not affect system performance since the rain induced attenuation will make the signal unusable first. There may be some problems with antenna design for cross-polarization (especially in the spacecraft, which has a wide range of beam pointing angles), since maintaining off-axis cross-polarization isolation is harder than obtaining on-axis isolation.

## 6. FUNCTIONAL SPECIFICATIONS

The functional specifications for an operational

Western Union class carrier 20/30 GHz satellite system have been determined. A requirement for 4 GBPS trunking and 2 GBPS CPS service was assumed. For trunking, the spacecraft carries 18 fixed .3° beams operating at 500 MBPS each. These are interconnected by a fully-connected IF switch. Three carrier frequencies are reused six times each.

CPS service uses an additional set of six transponders, each equipped with dual TWT's for the downlink to provide two independent 256 MBPS signals at full power. The uplinks will use multiple 32 and 128 MBPS channels. A Baseband Processing Unit will be used to provide full interconnectivity between all CPS users.

7. EXPERIMENTAL SYSTEM FUNCTIONAL REQUIREMENTS

Recommendations for an experimental system to provide verification of the propagation analysis and a test of the solutions to the hardware problems and to provide a market trial vehicle are given. The proposed system would have a 500 MBPS SS-TDMA, a 274 MBPS FDM and an NTSC analog video (36 MHz BW) capability in the trunking mode. Seven beams covering all rain zones would be available, with one steerable to measure frequency reuse problems. An on-board TDMA switch would be used for interconnection of the beams, with additional FDM switching between some beam pairs. Dual power (10/75 watt) transponders are required.

Antenna size would be 5 meters for trunking earth

stations and 3.5 meters for CPS earth stations (except 5 meters in rain zone E). Uplink power would be 150/450 watts. FEC encoders and decoders ( $R=1/2$ ,  $K=7$ ) would be required in the spacecraft and ground stations for CPS service. A master control station would be required, and full monitoring capabilities should be installed in both the spacecraft and ground stations.

8. ADDITIONAL STUDY RECOMMENDATIONS

Areas for further study identified are:

- a) Rain zone E alternative approaches - Ka-band special design vs. cross-band operation.
- b) CPS mix between semi-permanent and demand assigned channels.
- c) TDMA Synchronization approaches.
- d) Scanning beam vs. Fixed Contiguous beams for CPS.

9. INTERSATELLITE LINKS

Intersatellite links can be used to provide connections between services (e.g. domestic and international) to reduce the multihop delay. They can also be used to interconnect other band (C or Ku) satellites to a Ka band satellite. A third application would be to extend the orbital arc available to Ka band by using two interconnected satellites for CONUS coverage.



Functional requirements for the intersatellite link are given. From a system standpoint it appears as additional ports on the spacecraft switch and Baseband Processing Unit (BPU).

CANDIDATE SERVICES, MARKET DEMAND, AND  
TRANSMISSION CHARACTERISTICS

1.0 STATEMENT OF THE PROBLEM

The requirements of this subtask are to develop a detailed list of candidate services and the following data for each:

- . Performance requirements
- . Availability
- . Transmission characteristics
- . Connectivity requirements
- . Characterization into Trunking/CPS systems
- . Net accessible satellite market for each -  
forecasted for the years 1990 and 2000.

2.0 INTRODUCTION

To determine whether or not the services identified are viable candidates for 30/20 GHz communication systems, key technical and operational data are established for each as it relates to Ka band operation (e.g., quality and availability). The data is evaluated relative to technical and propagation parameters derived in section 4, as well as operational constraints of a 30/20 GHz communication system, to identify those services that are viable 30/20 GHz candidates and those that are more appropriately suited to "C" or "Ku" band systems.

Previous studies developed forecasts for voice, data, and video service categories. The accessible traffic identified in these studies together with some additional traffic identified in the current study has been used to identify the net accessible trunking and Customer Premise Station (CPS) market size and expected carrier market shares. (Note that a typical CPS user is one with a large transmission capacity requirement located far enough from a trunking station to make it economically preferable to install a separate earth station.)

### 3.0 METHODOLOGY

The list of candidate services have been developed using the following sources:

- . 18/30 GHz Fixed Communication System.  
Service Demand Assessment (WU)
- . 30/20 GHz Fixed Communication System.  
Service Demand Assessment (ITT)
- . 30/20 GHz Net Accessible Market Assessment  
(WU).
- . Consultation with the Authors of the above.
- . Existing and planned WU services and other common carrier services as understood by WU business planners.
- . Consultation with product line organizations within Western Union.
- . Informal Discussions with representatives from other common carriers.

The reports prepared by Western Union were the result of an exhaustive market research effort that led to the identification of thirty one services that are candidate market applications. The net traffic addressable by satellite systems operating within each of the three satellite frequency bands was then identified. Subsequent effort further developed the accessible demand based on economic justification of facilities implementation by specialized and public common carriers. These reports form the basis for the present effort along with identification of several additional specialized market areas. The resulting accessible market demand was then categorized with respect to: A) common carriers emphasizing different market thrusts; and B) suitability for CPS or trunking requirements.

Technical and operational requirements for each of the candidate services were identified for subsequent comparison to Ka-band system technical and operational characteristics.

#### 4.0 CANDIDATE SATELLITE SERVICES

The thirty one market applications can be segregated into three basic service categories: Data, voice and video. There are 21 applications within the data category and 5 applications in each of the voice and video categories.

#### 4.1 DATA TRAFFIC

Data traffic may be divided according to its need for immediacy, i.e., real time, packet, and store-and-forward categories. Real-time includes the switched and dedicated traffic, often broadband, where continuous high quality transmission is expected, such as interactive computer service. Although exhibiting real-time characteristics, packet separates users from the medium by nodal intelligence which can:

- (A) Absorb short outages with nodal storage of incoming data;
- (B) Seek alternate routes for longer outages; and
- (C) Defer data transmission when circuits are overloaded due to outage of some of all interconnecting facilities.

Deferred data transmission refers primarily to store-and-forward operation, such as electronic mail, remote job entry, and mailgram/telegram service.

##### 4.1.1 DESCRIPTION OF SERVICE

Satellite services for data transmission will generally require both direct delivery at the customer's premises (CPS), and routing via major trunking stations through local distribution facilities because:

- (A) Customers with CPS stations may need to communicate with customers without CPS terminals.

- (B) Operation at much less than the basic 64 KBPS rate through a CPS terminal may be uneconomic (even where CPS terminals exist) compared with a trunking connection.

Those applications requiring distribution among a wide community of users (e.g., switched network data transmission) will predominantly be handled on a trunking basis because many of these users will not be equipped with CPS terminals. Interconnect to CPS users may be provided at major trunking terminals or within the satellite; some considerations for each approach are discussed in Section III. Interconnection with users on trunking systems will be via local terrestrial switching and local loop distribution. Some applications would additionally benefit from interconnection with Terrestrial or C/Ku band links. Data applications frequently include multi-point (e.g., as in polling) as well as point-to-point transmissions. Facilities for both types of operation are required.

#### 4.1.2 PERFORMANCE REQUIREMENTS FOR DATA

Data transmission as defined at the user interface is characterized by the rate, delay, quality of performance and availability of the service. Data rates range from slow asynchronous through 1.544 MB/S for deferred traffic. Real-time traffic is typically at 300 bps to 1200 bps asynchronous at the lower end and ranges from 2.4 kbps to 1.544 MB/S for higher speed

links, some of which will be in support of nodes serving less than real-time (packet) requirements.

One transmission objective (as proposed by Bell's DDS) for real-time high quality data signals is 99.5% error-free seconds when the circuit is available. In general delays due to data traffic outages should not exceed a few seconds for real-time traffic, one minute for packet traffic and one hour for deferred traffic.

Typical availability specifications for high quality real-time data may also be deduced from DDS service end to end availability which is specified at 99.96%. Other data quality specifications have been proposed, e.g., one part in  $10^7$  error rate for 99.5% of the time with further stipulations as to overall error performance. All of these result in a similar intrinsic quality objective for the end-to-end link of the order of one part in  $10^7$  with some allowance for burstiness of errors and occasional link down time and/or temporary outages.

In point of fact, many data users currently employ analog facilities which offer considerably poorer performance than the above. It would seem that their major considerations are: A) the price of the service; and; B) the net throughput of the facility under some form of ARQ protection (a common feature of most systems). Most data applications are in fact fairly tolerant of short outages and occasional bursty errors.

#### 4.2 VOICE SERVICES

Voice traffic is conveniently categorized under the following headings:

1. Leased-line business;
2. MTS business (including WATS); and
3. MTS residential.

##### 4.2.1 DESCRIPTION OF SERVICES

Leased-line business traffic encompasses point-to-point service between business locations, usually of the same organization. These services may carry either permanent or switched connections. Another type of leased line service is a connection into the MTS system, e.g., FX lines. MTS business and residential traffic arises from connections to the public switched telephone network directly.

Leased connections between business locations can often be served by CPS to minimize cost by eliminating local distribution. All other voice services would primarily be handled via switches which are best served by interconnection via trunking facilities.

##### 4.2.2 PERFORMANCE REQUIREMENTS FOR VOICE

While it is commonly considered that voice applications require very high availability (99.99%), the requirement can often be circumvented in practice. For example, a portion of circuits forming a trunk group may be unavailable without causing complete loss of service and in non-busy hours there might not



even be a noticeable effect on blocking probability. Thus the apparent availability can be 99.99% even if some of the circuits exhibit much poorer availability. Switched voice traffic requires distribution to a wide community of users. The high degree of connectivity required is most readily achieved via trunking modes. It also implies an interface between users with CPS terminals and those connected to local distribution facilities serving a trunking station. Corporate leased line services often in fact do serve as trunks for private switched systems. For this case CPS terminals will find an important role to play.

Studies of the subjective effects of time delays on speech indicate that the long delays associated with round-trip satellite links are not a serious problem for most users. However, the long-delayed echo accompanying the transmission must be eliminated for service to be satisfactory. Modern echo cancellers are expected to solve this problem. Analog message channel objectives are easily met by standard CODEC's used in the conversion to digital traffic. An error rate better than one part in  $10^5$  is generally considered acceptable for voice signals.

#### 4.3 BROADCAST TV

Included in this category are Network TV, CATV and special events broadcasts (sports events, etc.).

#### 4.3.1 SERVICE DESCRIPTIONS

The basic requirement of a broadcast TV network is to transmit signals from a source to a large number of users (for example, CATV head ends, television stations or other distribution centers). In addition to services requiring CONUS coverage, new markets are emerging which could require broadcast service of interest to geographically limited areas. These include local news coverage and sports events, public service information, etc., which could be served by a spot beam capability.

The concept of satellite distribution for these service is based upon the elimination of (expensive) terrestrial facilities and therefore this is an almost entirely CPS application, especially for down-links.

#### 4.3.2 PERFORMANCE REQUIREMENTS

Previous studies have assumed a digital 30-50 MBPS bit stream for each video signal. This requires the use of compression equipment which is currently quite costly, especially in view of the need to equip large numbers of receive-only earth stations. Therefore, broadcast television should preferentially use analog transmission to minimize the cost of receive terminals, unless the cost of the compression equipment can be reduced significantly. Availability requirements for broadcast TV are normally extremely high. However, for some special purpose networks, a tradeoff

may be made between availability and cost. Other signal parameters should satisfy NTC 7 standards for network TV, whereas CATV performance may be relaxed somewhat from these standards. For network quality S/N, the NTC 7 requirement is 53dB while 48dB is acceptable for CATV. Limited distribution TV would fall in between these limits. Since obvious picture degradation occurs at 45dB S/N, video links for limited distribution may be designed without fade margin by allowing the spread between nominal operations and obvious degradation to be used instead.

#### 4.4 SPECIAL PURPOSE VIDEO

This consists of some types of videoconferencing, educational and health services, newsgathering, and other applications of video where point-to-point transmission can provide a useful service.

##### 4.4.1 SERVICE DESCRIPTION

There are two types of special purpose video; interactive and one way. Interactive video is represented primarily by videoconferencing. Other forms of "interactive video" require a video return channel, but the request channels use low speed data.

Most other special purpose video is one way to a single point or multipoint.

Videoconferencing via intracompany networks may be satisfactorily served via CPS stations. However, as

videoconferencing expands toward frequent use of ad-hoc conferences between organizations at least one of which is not equipped for CPS, access to local distribution via trunking becomes more important. In educational video or health networks, newsgathering and other uses of video where geographical flexibility is important, CPS is the preferred mode of transmission because access to wideband local distribution facilities is normally not available.

For special purpose video services there is no time urgency in most cases, so traffic deferral is acceptable. Therefore, availability may not be as important as rapid reconfiguration, geographical area selectivity, and low cost.

#### 4.4.2 PERFORMANCE REQUIREMENTS

Special purpose TV can be divided into full motion and limited motion applications, Educational, medical, newsgathering and full motion videoconferencing require a channel equivalent to broadcast CATV.

Limited motion videoconferencing would be transmitted in a digital mode at 1.6 Mb/s. Freeze frame videoconferencing will operate at 56 Kb/s. Both of these can be treated as data traffic but will tolerate poorer error rates--as low as one part in  $10^5$ .

Because of the data rates involved, freeze frame videoconferencing has been lumped with data traffic in the market analysis.

## 5.0 KA-BAND MARKET FORECAST

The characteristics of Ka-band transmission are reviewed below and then are used to identify those services which are more amenable to Ka-band satellite transmission. Market forecasts for these services are then derived based upon previous work and potential services that have been identified since the previous study was completed.

### 5.1 KA-BAND TRANSMISSION LIMITATIONS

There are three inherent characteristics of Ka-band which impact on the utility of a Ka-band satellite for the services described in Section 4:

- . Limited availability
- . Limited Beam Coverage
- . Analog Transponder Penalties

Ka-band services are subject to weather-induced outages, typically of ten minutes duration. These can be countered by diversity operation, power control, and adaptive forward error control or a combination of these techniques. Diversity operation is generally only feasible economically for trunking stations and possibly for broadcast uplinks. Power control is of only partial benefit (approximately 5dB) due to the limited power increases available and the time required to coordinate changes. FEC will result in a trade of available spectrum for more margin. Both of these techniques combined can serve to enhance availability

for CPS stations through increased margin but will still leave residual outage or partial outage periods. Therefore, in the market assessment which follows, it is assumed that services which cannot tolerate such outages are not prime candidates for Ka-band satellites. As will be described, most services can in fact tolerate such outages and remain candidates for Ka-band transmission.

Limited beam coverage results from the fact that additional power is necessary to transmit at Ka-band compared to the C/Ku bands. Thus services requiring simultaneous CONUS coverage cannot be easily provided.

Services requiring an analog transponder or partial transponder are somewhat limited by the less efficient use of spacecraft transponders for each analog circuit. The number of 36MHz analog transponders which may be placed in a particular spacecraft is limited because of space and power limitations, and will not use the bandwidth fully. However, for multi-ground station applications, efficient transponder utilization may not be of prime importance so that a case can be made for analog transmission (or SCPC for that matter) in a number of cases.

## 5.2 SERVICES ADAPTABLE TO Ka-BAND TRANSMISSION

### 5.2.1 DATA

Of the three types of data delineated in section 4.1,

i.e., real-time, packet, and deferred traffic, deferred traffic is more amenable to Ka-band transmission than the other two. However, there may be users of some "real-time" services who are willing to tolerate occasional outages if the cost of the service is attractive. Similarly, packet networks using Ka-band satellite facilities may be able to cope with occasional outages and/or reduced capacity by virtue of intelligence in the nodes which will to some extent mask these effects from the user. Almost all data is point-to-point, or point to a defined set of other points and therefore is not affected by the lack of simultaneous CONUS coverage.

#### 5.2.2 VOICE

For a public carrier trunking system carrying a small percentage of a trunk group on a Ka-band satellite, only a small penalty (in blocking probability) would be incurred during an outage, and this only if the outage coincides with a busy hour. Thus, a lower cost voice channel could be attractive. The same considerations apply to private lines wherever a significant cross section between two points is provided. The following should be noted with respect to Ka-band voice circuit unavailability for private networks.

A) In many corporate networks, serving trunk groups are undersized for economic reasons so that blocking probability is already high during peak periods. Lack of facilities arising from inclement

weather would thus only extend such high blocking periods affecting service in a similar manner to an unexpected additional load.

B) Where facilities are mixed, one generally has recourse to alternate means of transmission. For example, if intra company tie lines are unavailable due to overload or outages, alternate paths are normally available via MTS. This results in additional costs during Ka-band outage and it will be necessary to develop an economic profile to decide just what the most cost effective combination of facilities would be. Under a scenario in which Ka-band facilities offer significant economic advantage these should dictate their use despite occasional outages.

C) Outages for Ka-band will be area limited, so that an adjacent serving area may be able to communicate. Alternate routing via adjacent facilities coupled by terrestrial facilities could therefore greatly alleviate local circuit outages.

In view of the above it would seem that voice Ka-band services whether by CPS or trunking facilities can be readily sold if the price advantages can be realized. Voice is almost never broadcast and therefore is not amenable by spot beam coverage.



### 5.2.3 BROADCAST TV AND CATV

The TV network and CATV distribution markets have limited ultimate growth capabilities and an already heavy investment in C-band facilities. In addition, except possibly for a few marginally profitable CATV services, Ka band outages are not tolerable for these markets. Limited beam coverage will also make Ka-band transmission unattractive to users with a nation-wide coverage requirement.

Limited area networks, one of the new services identified in this report, would probably tolerate short outages if the overall service cost were low enough. The limited beam coverage at Ka-band is an advantage in this case, allowing extensive frequency re-use. Broadcast TV normally favors the use of analog transmission to minimize the cost of TV receiving equipment. Therefore, due to the analog transponder limitations, effective satellite costs may increase for this type of service offering.

### 5.2.4 SPECIAL PURPOSE VIDEO

These services would tolerate outages if the cost is sufficiently attractive.

The small coverage afforded by spot beams is of no consequence, since these are basically two point services. Full bandwidth video would be easier to handle on an analog basis. Low bandwidth video is almost always digital.

### 5.3 MARKET FORECASTS

#### 5.3.1 BASIS FOR MARKET FORECASTS

The 18/30 GHz Demand Assessment effort developed baseline total market forecast for the data, voice, and video service categories. The baseline forecasts were modified in successive processing steps to develop impacted baseline, net long haul traffic, addressable and accessible satellite market forecasts. During the current study, certain additional services were identified as viable candidates for Ka-band satellite systems. Traffic was estimated for these new services to obtain a total market forecast. The revised market forecasts will be described in terms of two typical carrier traffic scenarios: public carrier and specialized common carriers. The public carriers currently address the voice MTS market primarily while specialized common carriers currently address all major market areas including private line voice, video and data.

#### 5.3.2 NEW SERVICES IDENTIFIED

The new services (all in the video area) are:

- . Video Data Retrieval
- . Limited Area TV Distribution
- . TV Newsgathering

A video data retrieval service has been identified in which video data banks containing current information of primary importance to various industry, institutional, and government groups, can be accessed by an

authorized user. Typical examples would be rare medical procedures for doctors, new analysis procedures for chemists, and repair procedures for complicated electronic or mechanical equipment. The transmission would be on a simplex basis from the data base to the user. Communication for inquiry can be accomplished via either a telephone or a low or medium speed data channel.

Limited area TV distribution would be used for broadcasting local sport or public affairs events to an area lying within a spot beam region.

Temporary video uplinks for newsgathering and similar purposes can be established in the Ka-band without the coordination problems encountered at C band which would very helpful in rapid establishment of such uplinks. This is a point-to-point TV service.

#### 5.3.2.1 MARKET CONTRIBUTIONS FROM NEW SERVICES

Video data retrieval will compete with direct distribution of video information via tape cartridges and video discs. The market potential is thus hard to quantify. As a first attempt, a requirement for six channels has been assumed.

Limited area TV distribution is a potential market whose growth is likely to be highly cost sensitive. The use of satellite capacity installed primarily for other services will thus be very attractive. For these reasons the number of additional transponders

estimated to be needed for this service has been estimated as ten.

Temporary video uplinks would be used for transmission from locations where permanent facilities were unavailable. Considering the number of users of such services and the number of simultaneous events requiring such facilities, a requirement for ten satellite channels would seem to be a good estimate.

All these services would use spot beams to CPS type earth stations.

### 5.3.3 PUBLIC CARRIER

Public carriers currently address the voice MTS market primarily and also a portion of the data between different business establishments. These carriers presently operate exclusively in a trunking mode.

Services provided by the public carriers, e.g., AT&T and GTE, are heavily influenced by the large investment they have in terrestrial plant. Therefore, Ka-band trunking by public carriers would be backed up by terrestrial facilities, resulting in an acceptable level of availability. Business and residential voice services are therefore prime targets for transmission over Ka-band trunks that have been integrated with alternate routing facilities (or that are provided using space diversity terminals).

Based upon present thinking, it is unlikely that public carriers would get significantly involved with

CPS. This is not only from a technical point of view, but because they own the existing local distribution plant.

Newer services such as wideband 1.5-6.0 Mb/s videoconferencing could be captured by public carriers using Ka-band satellites in the trunking mode since the public carriers are expected to have extensive wideband local distribution within this time frame. Narrowband videoconferencing (56 kBits/s and under) will also readily be carried on local distribution networks. It is expected that, in the long term, videoconferencing would benefit from the trunking mode which permits on-demand videoconferencing between unrelated organizations.

#### 5.3.4 SPECIALIZED COMMON CARRIER

Specialized common carriers currently address all major market areas including private line voice, video and data. Despite initial system designs directed toward voice transmission, the dominant satellite service business of the specialized carriers is video and program distribution services where the point to multipoint transmission capabilities of existing satellites are most effectively realized. However, a strong interest in the business and government voice and data market has been maintained and the projections for growth of this type of traffic will assure

that this market will dominate in the time frame of interest for Ka-band satellites. Although the degree of flexibility in routing enjoyed by public carriers with respect to voice and data will not be as great for the specialized carriers, it will be possible to mitigate the effects of outages in much the same manner (e.g., through a mix of transmission media and adaptivity) and by use of the public networks as an alternate transmission medium. Since much business voice traffic is in fact used for trunks between PABX's or tandem switches, outages will have the same effect as increased traffic loads. Under conditions of a properly designed system, the specialized carriers should thus be carrying appreciable amounts of voice traffic on Ka-band satellites. Specialized carriers will use both the trunking and CPS modes in support of voice and data traffic.

The previously completed 18/30 Accessable Market Study tabulated primary and secondary areas of interest for potential specialized common carriers. Based on this, one class of common carrier has been postulated as represented by either RCA, or Western Union with American Satellite (who has long term arrangements for joint use of the satellite). Another class, emphasizing different market areas, would be a SBS or XTEN type of carrier.

### 5.3.5 MARKET SHARE ANALYSIS

Based upon the foregoing, the assumption is that there will be three types of carriers providing ka-band satellite services: Public carriers, Western Union/RCA-type specialized common carriers and the SBS/XTEN-type specialized common carriers. Examination of the WU 18/30 GHz Demand Assessment effort and other sources, such as the SBS filing in support of its application for satellite service, provided the basis for making the assessment of probable carrier market share in the year 2000 as shown in Table 5.3.5-1.

As noted in Section 5.3.3 it has been assumed that no CPS service will be offered by a public carrier. It has also been assumed that SBS/XTEN-type carriers will not offer trunking service. In addition, based on current market trends, it is expected that full bandwidth video will be provided only by an RCA/Western Union-type carrier.

(As noted previously, slow motion videoconferencing is considered as being a data service). The CPS/trunking split for other services was obtained by comparing the SBS traffic predictions with the WU 30/20 GHz Accessible Market study. The trunking split between public and specialized carriers is based upon current market trends. For example, public carriers handle more low speed than high speed data. Division of traffic between carriers in the same category e.g., SBS/XTEN was assumed 50/50.

<u>Service</u>	<u>Public Carrier</u>		<u>Western Union</u>		<u>RCA</u>		<u>SBS</u>		<u>XTEN</u>	
	Trunking	CPS	Trunking	CPS	Trunking	CPS	Trunking	CPS	Trunking	CPS
Broadcast Video	---	50	---	50	---	---	---	---	---	---
Special Video	---	35	15	35	15	---	---	---	---	---
Full Bandwidth	---	16	8	16	8	24	24	24	24	24
Limited Motion	4	4	10	4	10	6	6	6	6	6
Voice	60	16	5	16	5	24	24	24	24	24
Data	10									

Table 5.3.5-1

Market Share for Satellite Carriers - Percent of total Accessible Market.



The service split between types of specialized carriers, i.e., Western Union/RCA vs. SBS/XTEN is based upon the primary/secondary market determination made in the 30/20 GHz Assessible Market study. Sixty percent of the traffic was assigned to primary carriers with the remainder assigned to the secondary carriers. The number of transponders for satellite carriers were calculated from total traffic estimates obtained from the 30/20 GHz Net Accessible Market Study, the SBS satellite filing, and new services identified in Sec. 4. Dividing this traffic among the various carriers using Table 5.3.5-1 resulted in Table 5.3.5-2. The calculations assumed an equivalent transponder providing 50 Mb/s for voice or data or one full-motion video channel. (Note that splitting the analog transponders among the satellites results in about six analog transponders/satellite, which appears practical.) Conversion of transponder capacity to number of satellites involves both technical and economic problems. At the technical end, while total capacity for a trunking satellite is relatively easy to determine from the Hughes and TRW Phase I reports, the reduction in capacity due to the introduction of CPS is much less clear. It will depend on the method of operation (TDMA or FDMA), the manner in which spot beams are interconnected, etc.

From an economic standpoint it is quite likely that

<u>Service</u>	<u>Public Carrier</u>		<u>Western Union</u>		<u>RCA</u>		<u>SBS</u>		<u>XTEN</u>	
	Trunking		CPS	Trunking	CPS	Trunking	CPS	CPS	CPS	
Broadcast Video	---		13	---	13	---				
Special Video										
Full Bandwidth	---		3	2	3	2				
Limited Motion	14		56	28	56	28	84	84		
Voice	660		44	110	44	110	66	66		
Data	22		35	11	35	11	53	53		
TOTAL	894		<u>151</u>	<u>149</u>	<u>151</u>	<u>149</u>	203	203		
			300		300					
No. of Satellites	18			6		6	4	4		

Table 5.3.5-2

Transponders for Satellite Carriers

when service is first established the traffic requirements will be much less than those projected here. It may well be that under such circumstances a lower than possible capacity satellite will prove to be optimum, especially if the savings in space and weight of the communications system can be used to extend the useful life of the spacecraft, modify the performance to reduce earth station costs, or similarly improve over all system performance, as well as reduce initial costs. Additionally, because of the range of variation possible in synchronization techniques, beam scan patterns, channel assignment algorithms, etc., it is unlikely that a single satellite could serve the needs of more than one carrier. This also favors the use of lower capacity satellites since the available customer base will thus be fragmented.

The above considerations will be least applicable to a public carrier, since a trunking system permits the use of a much simpler satellite, and since a public carrier is in a better position to switch a large amount of traffic to Ka-band at one time. We have therefore assumed a 10 GBPS capacity for a public carrier satellite. On the other hand, the size of a SBS/XTEN type satellite will be heavily influenced by the above considerations, and we consider 2.5 GBPS a reasonable size for the initial satellites and 5 GBPS for later models.

U/RCA type satellites would be sized at an intermediate level, for example 4 GBPS for trunking and 2 GBPS for CPS, on the initial satellite, with a heavier emphasis on CPS in subsequent satellites (i.e. 3.5 GBPS for trunking and 5.5 GBPS for CPS).

An examination of Table 5.3.5-2 shows that the three types of satellites may be distinguished not only by the types of service offered but by configuration--all trunking, all CPS, or combined trunking/CPS. It is clear that enough traffic has been identified to justify market entry by each of the assumed carriers, even if the aggregate traffic demand were to fall considerably short of the projected levels.

### III

#### NETWORK CONSIDERATIONS

##### 1.0 STATEMENT OF PROBLEM

To develop typical network topologies, traffic mix, loading and connectivity for a trunking/CPS carrier such as Western Union.

##### 2.0 INTRODUCTION

Two basic types of network are examined, i.e., public and specialized carrier. The public network, exemplified by the Bell system, will offer Ka band satellite services as an adjunct to its terrestrial network, using the additional capacity provided by the Ka band system to augment existing terrestrial facilities. In a specialized carrier network, typical of the type operated by Western Union, limited terrestrial distribution is available for use with the Ka band satellite system.

Connectivity requirements will be described below for each service category expected to be offered by Western Union using Ka band satellite transmission in terms of traffic and performance requirements, service mode (CPS or trunking), and the necessary service availability. Aspects of connectivity explored are the number of satellites and transponders per satellite, the number of spot beams, the probable geographical distribution of service and the need for interconnection with terrestrial and other satellite systems. The impact of advanced satellite technology (e.g. multibeam and multiple

satellite systems) on the achievement of connectivity requirements is discussed.

Satellite capacity and distribution requirements for typical Western Union Network topologies are described. These topologies are related to the growth of specialized carrier traffic, starting from an initial minimum feasible satellite network to a maximum one predicted for the year 2000. This analysis predicts that the cumulative portion of this market ranges from 30 to 84 percent of the net addressable satellite market, depending on the number of SMSA's addressed.

### 3.0 METHODOLOGY

The typical network topologies described are based upon information from the following previous studies:

- 18/30 GHz Fixed Communication System Service Demand Assessment (W.U.).
- 30/20 GHz Net Accessible Market Assessment (W.U.).
- Propagation Effects Handbook for Satellite Systems Design (NASA).

They are based upon a detailed market research effort that led to the identification of thirty one services that are candidate satellite markets, augmented by the following three additional market areas:

- Video Data Retrieval
- Limited Area TV Distribution
- TV Newsgathering

Each candidate service was examined in turn, and the connectivity requirements expected to satisfy most users of that service is described below:

4.0 ANALYSIS

4.1 TYPICAL NETWORKS FOR PROVIDING Ka-BAND SERVICE

Two types of networks may be visualized for providing Ka-band service. These two types of network may be conveniently categorized as either public or specialized, each of which is described in relationship to its application as a Ka-band network.

4.1.1 PUBLIC NETWORK

This refers to a network approach likely to be implemented by a dominant carrier such as AT&T which has a very extensive existing terrestrial network. The Ka-band satellite services would be offered as an adjunct to their terrestrial network, using the additional capacity provided by the Ka-band system to augment existing terrestrial facilities. A public network of this type is likely to consist of a limited number of high volume earth station locations, each serving a large geographical area. Each earth station would serve a region containing a number of large, medium and small size cities, or one or more SMSAs (Standard Metropolitan Statistical Areas).

#### 4.1.2 SPECIALIZED NETWORKS

##### 4.1.2A TRUNKING NETWORK

These networks have more limited terrestrial distribution systems, primarily used for interconnecting with the Ka-band satellite system. In this type of network a number of earth stations are strategically located closed to the major areas of market demand. As before, each earth station location serves a central SMSA, with terrestrial extension to other SMSAs. Terrestrial extensions are used to assemble enough traffic to provide a viable network, but for economic reasons are generally limited to a radius of about 50 miles from the earth station. Earth stations may be small, medium, or large, depending upon the type and quantity of projected traffic. A network of this type is appropriate to the Western Union environment.

##### 4.1.2B CPS NETWORKS

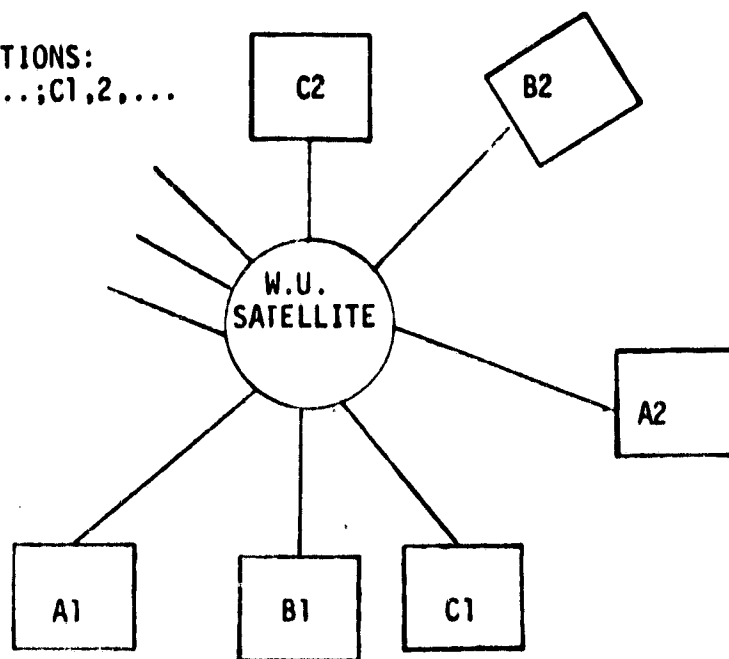
Two possible CPS network configurations are visualized, as illustrated in Figure 4.1.2-1:

- (a) Intra-organization CPS links; and
- (b) CPS links subleased by other carriers.

In the intra-organization type of communication network, illustrated in Figure III-1A, large companies and government organizations lease capacity from a satellite common carrier (e.g., Western Union) to interconnect geographically widely dispersed offices having high traffic volume requirements. Each office

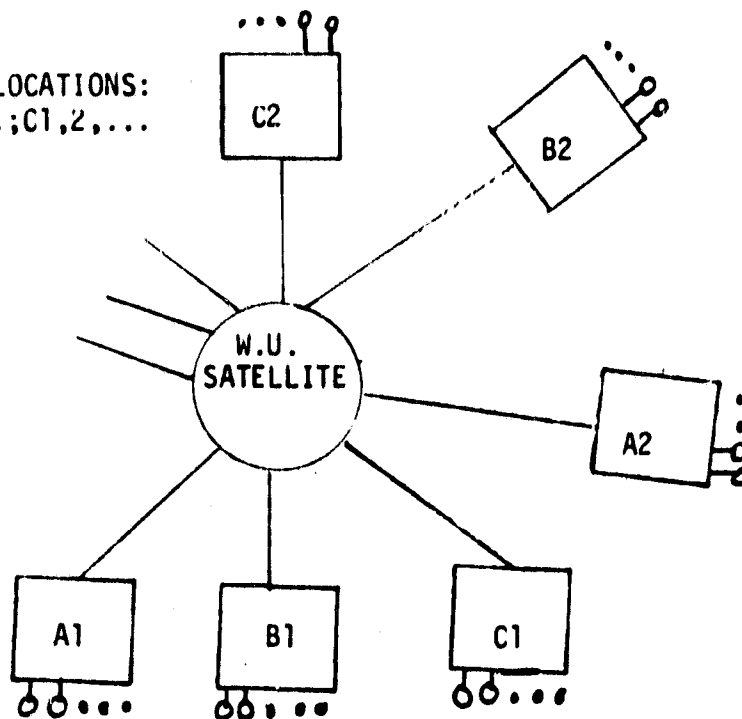


ORGANIZATION LOCATIONS:  
 A1, 2, ...; B1, 2, ...; C1, 2, ...



(a) INTRAORGANIZATION CPS LINKS

OTHER CARRIER CPS LOCATIONS:  
 A1, 2, ...; B1, 2, ...; C1, 2, ...



(b) CPS LINKS SUBLEASED BY OTHER CARRIERS

FIGURE III - 1 POSSIBLE CPS CONFIGURATIONS

has associated with it a separate ground station for communication to the satellite, which links the ground stations. Interconnection between the CPS network and other networks is performed at the ground stations. Sublease by a satellite common carrier (e.g., Western Union) to other specialized carriers (e.g., Tymnet) for satellite capacity sharing to its customers is shown in Figure III-1B. In this case the CPS ground stations act to concentrate traffic from a number of users at each ground station, which are interlinked via satellite. While the carriers A, B & C are providing a trunking service, Western Union is supplying dedicated CPS service to the second tier carriers.

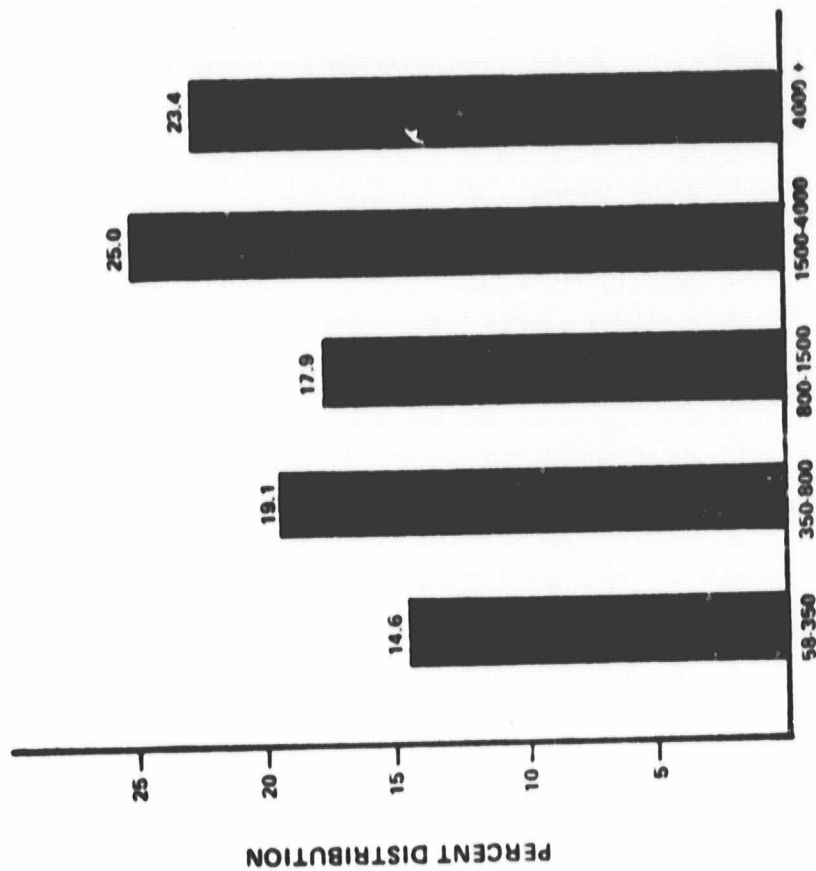
#### 4.1.3 GEOGRAPHIC TRAFFIC PATTERNS

The installation of a trunking Ka-band satellite system by a carrier is based upon an estimate that this system will augment its existing trunking network in a cost effective manner. In the case of a public carrier, the satellite system relieves a portion of any traffic peaks which would tend to overload the existing terrestrial network, or it may be used to provide new services not conveniently handled by the terrestrial network in a cost effective manner (e.g., videoconferencing). A specialized carrier might use a Ka-band trunking system to provide service capacity not currently available with its existing limited network. Therefore, a geographic study of traffic patterns and

the interconnectivity requirements of services are important considerations in determining where earth stations should be located and how they should be interconnected. An estimate of geographic patterns may be obtained from a Western Union study,<sup>4</sup> used to obtain a service demand assessment.

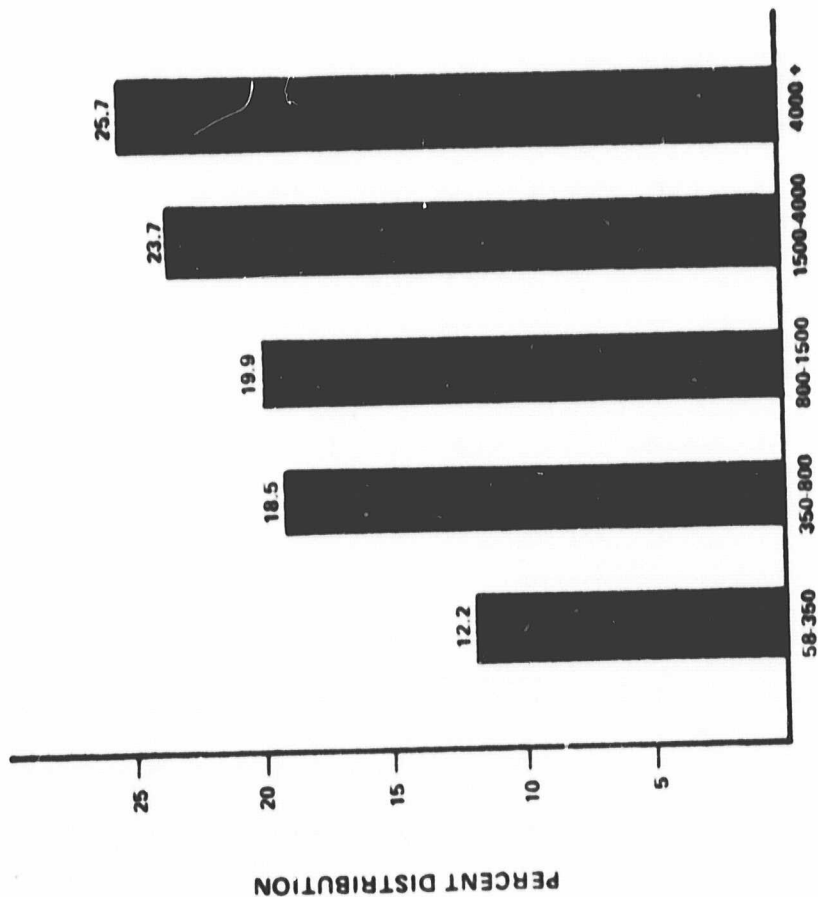
In the studies, traffic volume was estimated by service category as a function of city size, based upon 275 SMSA's grouped into five population categories. Each population category was assigned to a minimum/maximum range that produced five population groupings (quintiles), each with approximately 20% of the total SMSA population (157.3 million). The percentage proportions of the market demand for voice and data traffic by SMSA were determined and assigned to the appropriate population quintile, using weighting factors to indicate the relative importance of market demand per unit population within each SMSA. The distribution of voice and data traffic volume by population quintile, developed in this manner, is presented in Figure III-2. A video service category is not included since a substantial portion of video traffic is broadcast in nature, originating in a limited number of cities and received throughout the CONUS. This is consistent with Section II - 5.2.3, where it was concluded that this service category is not suitable for Ka-band since the TV network and CAIV

### DATA SERVICES



Source: REF. 4

### VOICE SERVICES



POPULATION CATEGORY (000'S)

## TRAFFIC DEMAND/POPULATION DENSITY 1990

FIGURE III - 2

distribution markets already have heavy investment in C-band facilities and Ka-band does not provide the reliability required for this service.

Note that the top 15 SMSAs, having populations ranging from 1.5 to 4+ million, have a predicted demand of 49.4% of the total voice traffic and 48.4% of the total data service for 1990.

Analysis of the economics of operating a communications network in the U.S. indicates that about 30% of the accessible market represents the minimum viable market that a satellite network must serve to attract a sufficient number of customers and subsequent traffic load to its network. Based upon the SMSA population distribution, this coverage will be achieved by addressing the population centers illustrated in Figure III - 3. Therefore, this minimum network will serve as a basis for estimating the traffic requirements for establishing a specialized carrier Ka-band network.

For accurate prediction of the geographic location of CPS networks, a study is required to determine the geographic distribution of the high volume traffic centers for large industrial and government organizations. An estimate of the total CPS networking market size may be obtained by examining the users of long haul traffic. A determination of the major segment of the user population for large organizations was part

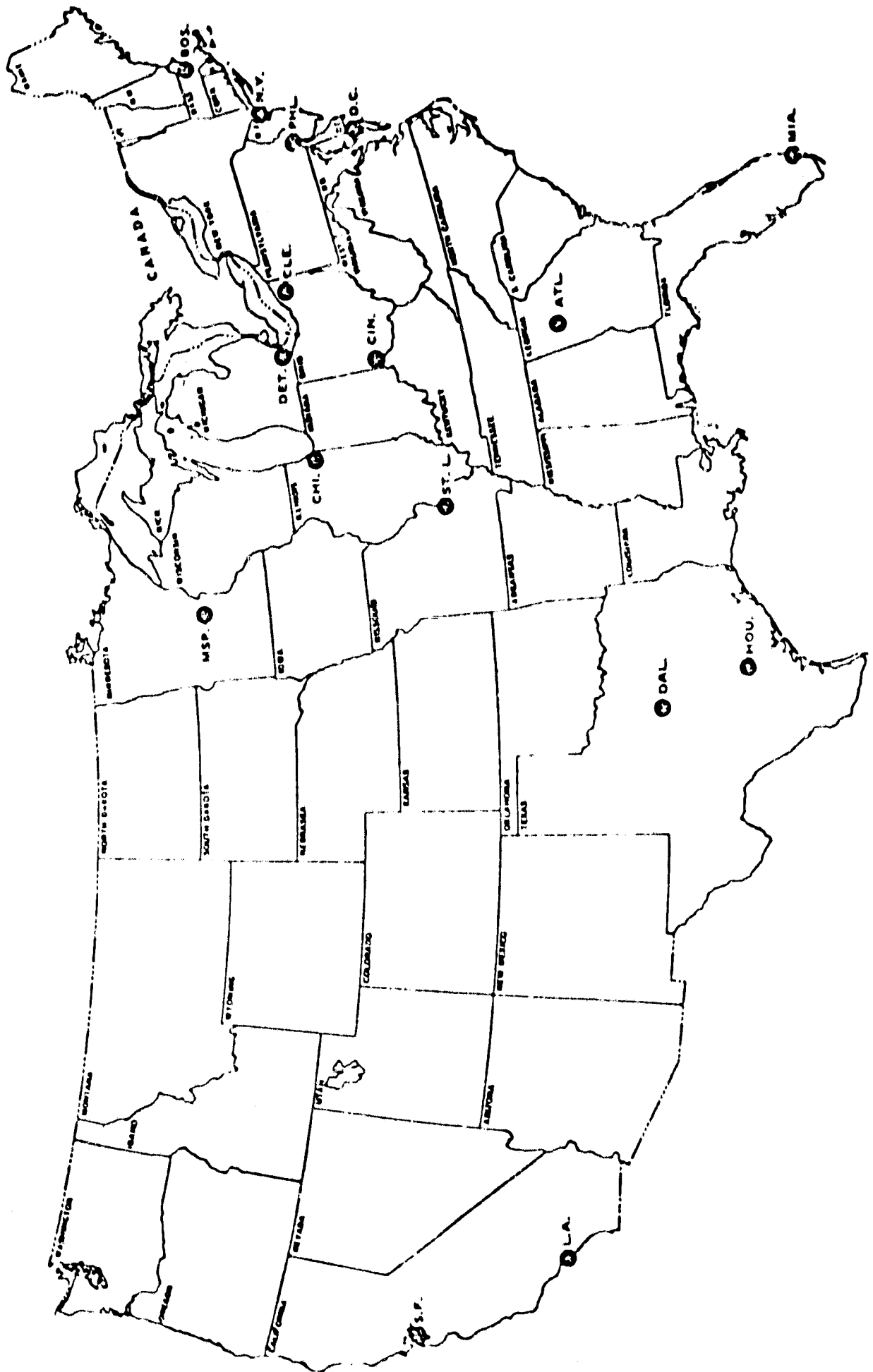


FIGURE III - 3 FIFTEEN TOP SMSAs PROVIDING 30% MARKET COVERAGE FOR YEAR 1990

of the service demand assessment study. A quintile distribution of user population in each user category by traffic volume was obtained from the Fortune Double 500/50 directory, a federal government department and agency list, and a list of major city/local governments, institutions of higher learning, and major hospitals. The conclusions of this study are:

1. About 1,000 (less than .05% of the over 3 million business firms) represent 60% of this category's total transmission expenditures with an average annual transmission expenditure of \$4.6 million.
2. Only 19 federal departments (of the total of 84 departments and agencies), each spending \$12.0 million per year or more on telecommunications service, make up 80% of the federal governments' total transmission expenditure.
3. All state governments, except for Wyoming, and the 18 largest city governments spend over \$1 million each on telecommunication services.
4. The larger institutions of higher learning and hospitals have average annual transmission expenditures of \$229,000 and \$185,000, respectively.

Table III-1 summarizes some typical statistics of organizations which may be candidates for CPS networks. A typical large company is estimated to have four major locations, resulting in annual telecommunication expenditures in excess of \$5 million per location. A typical Federal agency having 20 locations would spend in excess of \$40 million per establishment. At the state level, over \$2 million would be spent per establishment, and over \$0.5 million at hospitals and schools.

	Number of entities	Average yearly expenditure (\$000,000)	Number of locations per entity	Average yearly expenditure per location (\$000,000)
LARGE CORP.	1550	20.8	4	5.2
FED. AGENCY	19	861.8	20	43
STATE GOVERN.	65	6.4	3	2.1
HOSP. & SCHOOLS	1000	.6	1	.6

TYPICAL USER LONG HAUL TRANSMISSION EXPENDITURES--YEAR 2000

TABLE III-1

An estimate of the point at which it might pay for an organization to acquire a CPS earth station may be obtained by calculating the required savings, S, of telecommunications cost using a CPS mode relative to competing service:

$$S = 1 - E/TC$$



where:

E = one-time earth station cost,

C = transmission expenditure/yr. of a typical establishment

T = 5.33 = 10 year amortization period discounted at 20%/yr.

Equation 1 is plotted in Figure III-4 for earth station costs ranging between \$1,000 and \$1,000,000. As illustrated, a large establishment expending one million dollars per year would break-even at virtually no cost reduction if a \$100,000 earth station is used and would require only a reduction to 90 percent of other facility long haul transmission costs to justify the use of CPS with only one-half of this traffic carried by the CPS terminal.

At the lower extreme, schools or medical establishments with typical annual long haul communications expenditures of \$0.6 million (of which one-half was adaptable to a CPS system) would have to receive a 75 percent reduction in annual costs before a \$1 million earth station could be justified but would need a reduction to only 90 percent to justify a \$100,000 earth station.

Thus, earth station costs in the range of \$100,000 to \$1,000,000 appear justifiable to a wide range of potential user organizations who, assuming acceptable quality of service, will find CPS networks a viable

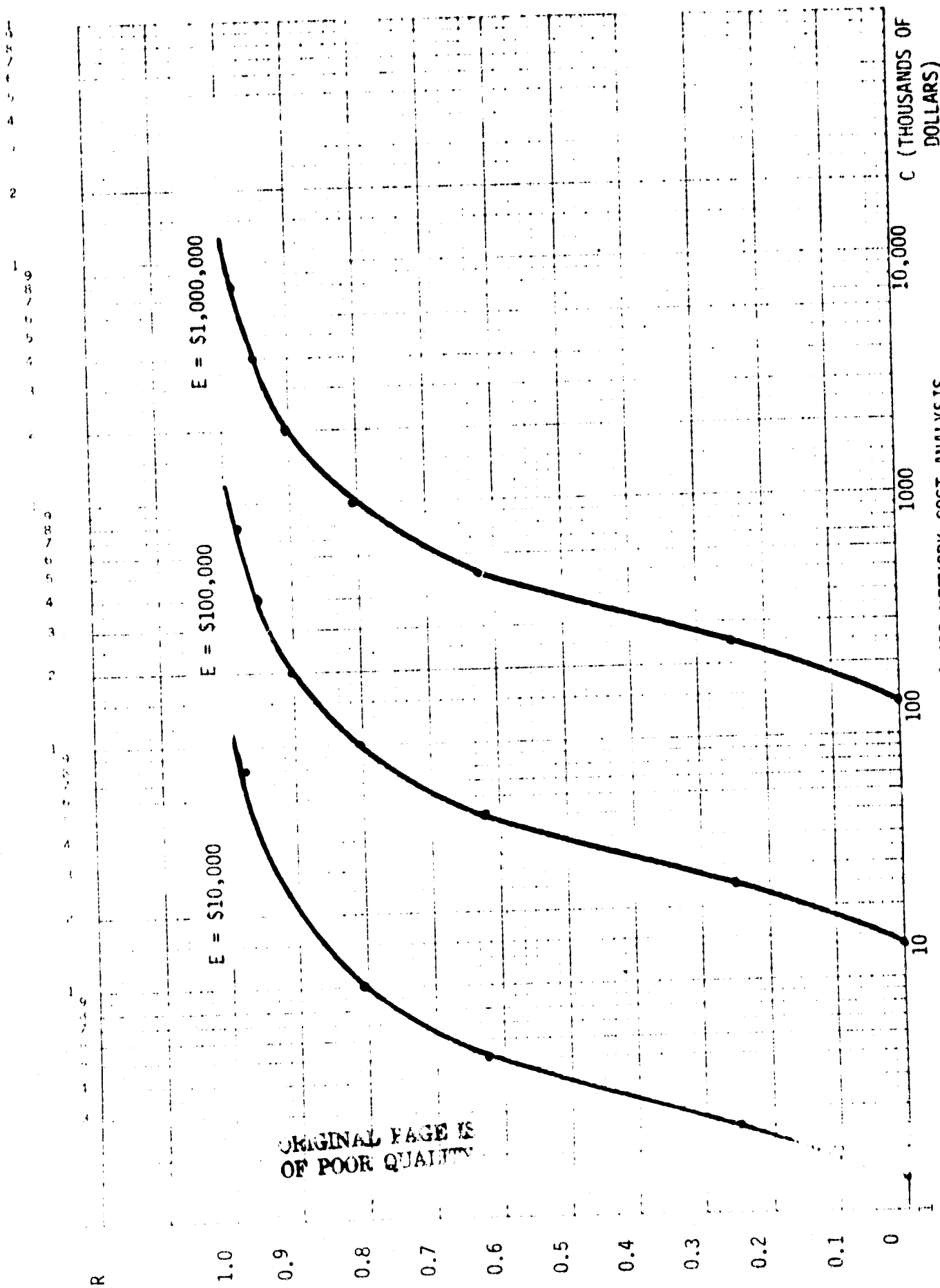


FIGURE III - 4 CPS NETWORK COST ANALYSIS

ORIGINAL PAGE IS OF POOR QUALITY

approach to satisfying their communications needs. Users whose traffic requirements will not justify a CPS earth station at a particular location may be able to join with other users in their geographical vicinity to assemble enough traffic to install one. This will expand the market for CPS networks by making them economical for organizations with many low traffic locations. The costs of the required terrestrial connections must of course be considered in determining the feasibility of such arrangements compared with using trunking service.

#### 4.2 CONNECTIVITY REQUIREMENTS

Connectivity describes the communication links between users and ground stations, between ground stations and satellites, between and within satellites, transponders, and spot beams required to provide data, voice, and video services.

Connectivity requirements for each service are dependent upon traffic and performance requirements, service mode (CPS or trunking), and the necessary service availability. Connectivity is affected by the number of satellites and transponders per satellite, the number of spot beams, the required geographical distribution of service and the interconnection with terrestrial and other satellite systems. It, in turn, impacts on the technology required, e.g., multibeam, multi-hop, intersatellite links, etc.

Other issues which may be affected by connectivity requirements are:

1. Geographic distribution and location of satellites.
2. Deployment of satellites specialized by service, e.g. voice service.
3. Use of reliability improvement techniques, e.g. diversity and adaptive power techniques to improve fade margin.
4. Tradeoff between connectivity and performance requirements, e.g. connectivity vs. delay.

#### 4.2.1 DATA SERVICE CONNECTIVITY

Connectivity requirements for data transmission vary widely among the different data communication applications. It is convenient to distinguish between those applications requiring dedicated service and those requiring switched service.

##### 4.2.1.1 DEDICATED DATA TRAFFIC

A large portion of data traffic requires dedicated service on leased line (or privately owned) networks. These networks link the various remote locations of companies or governmental agencies, and while some need for dedicated intercompany connectivity exists, the more usual requirement is for connection between establishments of the same corporation or agency. While many dedicated data communications links involve

the simple pre-assigned connection of two points, there are also frequent needs (for example, those associated with the polling of remote terminals from a central site) that require multipoint connections.

Dedicated traffic is suitable for transmission via either CPS or trunking configurations. However, CPS configurations in the Ka band are not likely to meet the availability requirements of most real-time data applications and should be reserved primarily for that portion of traffic using deferred or store-and-forward transmissions. An exclusively CPS configuration is practical for data transmission only when the establishments at both ends of the link are large enough to support on-site dedicated earth stations and where availability requirements are not severe. CPS to CPS transmission of this type are likely for applications such as electronic mail. For example, CPS earth stations co-located with large regional post offices may offer an excellent and cost effective means of providing the lower availability dedicated links suitable for the large volume expansion of mailgram-type services planned by the U.S. Postal System.

While a limited number of instances, such as the above, may be cited where CPS to CPS transmission modes provide a cost effective solution to special problems of data transmission connectivity, in the general case requirements will often exist for connec-

tions between two or more small organizations for which on-site earth stations are impractical. It is also necessary to provide for dedicated links between many small organizations (without CPS) and one or more large central locations which may have an on-site earth station (for example, the linking of remote sales offices to a computer system at corporate headquarters). It is therefore highly likely that trunking will be required (even for those establishments capable of supporting CPS earth stations) so that the smaller establishments may be addressed. As a result, the satellite system should provide the means for interconnection of dedicated links between establishments using CPS and trunking modes. This interconnection will most probably be achieved at common ground stations, thus reducing the complexity of the satellite communication subsystems.

Total Ka band satellite traffic far exceeds the capacity of a single transponder. The multiple transponders within the satellite require means for connecting data users assigned to different transponders. This is relatively straightforward as long as all earth stations are addressable by the same satellite. If multiple satellites are used, either an intersatellite link or a ground station connection will be required, with resulting increased delay and system complexity.

The problem of reaching a station, whose antenna points at one satellite, from a station whose antenna points at a different satellite, requires some form of interconnectivity between satellites. Whether this is best established by intersatellite link, or via multiple relay through earth stations involves many complex tradeoffs between costs, flexibility, and the accumulation of time delays (which under some data communications protocols has adverse effects on throughput). Fortunately, for dedicated data service the problems of intersatellite connectivity are lessened by the fact that the origin and destination of channels are pre-assigned. Dedicated users can, with relative ease, be segregated into small communities of users all of whom can (under some system designs) be assigned to the same satellite. While some loss in the flexibility of reconfiguration may be implied, the separation of users into such communities provides an additional method of achieving desired connectivity assignments.

#### 4.2.1.2 SWITCHED DATA TRAFFIC

Connectivity requirements for switched data traffic tend to be similar to, but more demanding than those for dedicated data traffic. Whereas dedicated traffic involves pre-assigned connectivity among limited communities of users, switched traffic involves on-demand connection to a potentially very large community of recipients.

The same considerations relative to interconnection between CPS and trunking users discussed under Dedicated Data Traffic applies even more strongly for switched traffic. Because of the need to address a wide range of possible recipients, independent on the size of the establishment in which they reside, links between CPS and trunking modes are essential.

Polied operation, which might occasion the need for multipoint connectivity among data terminals, is not commonly encountered in switched circuits and therefore switched data traffic tends to be point-to-point (through the switches) rather than multipoint.

There are, however, needs for many-to-one switched data connections as in the case of terminals widely separated throughout a region individually calling in to a central computer (similar to In-WATS) and the reverse (e.g. a computer sequentially dialing remote terminals to accept their accumulated data as in Out-WATS). The essential connection, however, remains point-to-point and the many-to-one nature of these applications is primarily tariff oriented. For switched data traffic, connection to both long haul and local terrestrial facilities will be needed. While the satellite system may ultimately grow to a very large size, and be capable of reaching, through its own facilities, most or all of the significant population centers, it is likely to be a long term



gradual growth. As result, the need to reach a wide range of potential addresses (which is inherent in switched network operation) will initially require routing through terrestrial facilities to cities not yet included in the satellite network. With this pattern of interoperability established at the beginning, it is likely to continue throughout the evolution and maturity of the satellite system.

The connectivity problems, imposed by the multi-beam and/or multisatellite environment expected in some of the high traffic scenarios, are potentially complex for switched data traffic. The need to reach a large number of widely dispersed users on demand requires sophistication in the ability to direct transmissions from beam-to-beam and from satellite-to-satellite without incurring undesirably long transmission delays.

The ability to solve multisatellite connectivity problems by assigning user communities to the same satellite is not a viable option in the case of switched data since wide distribution to all potential users is usually required.

#### 4.2.2 VOICE SERVICE CONNECTIVITY

Connectivity requirements for voice traffic transmitted by Ka satellite depends upon the type of service provided. For the purpose of describing this connectivity, voice traffic will be divided according to

dedicated business, MTS business, and MTS residential voice services.

A voice service network used by a corporation usually contains a combination of dedicated facilities used to reach various corporate or customer locations having a high volume of traffic and MTS facilities used to reach other corporate and non-corporate locations and to provide emergency backup or overflow connections to the locations normally reached by the dedicated facilities. The interconnection between the dedicated and MTS facilities occurs in switching machines which are a part of the overall network. In these networks the dedicated and MTS connections to the switches are functionally distinct, although in the absence of CPS service they may use the same physical facilities. Physical separation of some or all of the dedicated facilities into CPS and non-CPS carried circuits thus presents no special problems.

#### 4.2.2.1 DEDICATED TRAFFIC

The most commonly encountered leased line configurations are:

- (a) Lines connecting two establishments which have a high volume of dedicated traffic.
- (b) Intracompany networks connecting multiple locations.

- (c) Foreign exchange lines connecting an establishment in one city with a central office in a remote city. These are usually used for non-toll customer access, for example, as for airline reservations.

Connectivity requirements for leased line voice traffic are similar to those of dedicated data traffic. That is, connectivity generally requires pre-assigned links between a limited number of locations. The required links are point-to-point only, because of the nature of voice transmission.

Dedicated links often carry switched traffic. For example, many intracompany dedicated networks terminate on PBX's which are used for local distribution within the customer's premises or for dial out to the surrounding local area. Another instance of this is the leasing of dedicated transmission facilities linking switches owned by a specialized common carrier. The SCC provides switched service to the customers served by its network nodes but may use dedicated lines obtained from another carrier (e.g. the Bell System) to provide the needed transmission facilities linking those nodes. As discussed with respect to dedicated data, the achievement of a desired connectivity may be complicated by the use of different spot beams, transponders, and multiple satellites, particularly in view of the requirement to hold delay to a

minimum. Fortunately in the case of dedicated voice traffic the fact that connectivity is pre-assigned and involves a limited number of locations, offers the possibility of solving these problems by grouping the user communities so that each community uses common satellite facilities.

#### 4.2.2.2 MTS TRAFFIC

The general requirement of MTS traffic, whether business or residential, is the need to address a large number of possible recipients. Furthermore, this connectivity must be provided on demand rather than being pre-assigned. This is accomplished by the existing network through a hierarchy of switches and facilities.

Ka-band transmission can be used in two ways in the MTS network. Firstly, trunking routes can be set up between major centers (e.g., New York to Los Angeles) supplementing terrestrial and lower frequency satellite facilities. Such routes will require high availability and large capacity. Secondly, a CPS type network, using earth stations located directly on class 2, 3, or 4 switching centers can be used to directly connect locations with large common interest (e.g., Downtown New York City to Downtown Washington, D. C.). In this case the alternate routing capability of the network can be used to reroute calls if an outage occurs. (With the common channel interoffice

signalling system expected to be in widespread use by 1990, it would be possible to reroute calls in progress if necessary.)

#### 4.2.3 BROADCAST TV

This service category includes Network TV and CATV, both of which have multipoint connectivity requirements from a limited number of origination points to a multiplicity of receive points. As described in Section 11-5.2.3, only limited area networks are feasible using Ka band, and only if the overall cost is low enough for the service to tolerate short outages.

The use of spot beams, multiple transponders, or multiple satellites in various network configurations is not likely to impose important problems for either limited area Network TV or CATV. The limited number of up-links means that each originating site can look at each of several satellites without imposing inordinate increases in overall system costs. The receive-only locations need to look at only the most convenient satellite broadcasting the desired program material.

It is also possible to use multi-hop satellite transmissions to improve connectivity for Broadcast TV. This may be of particular importance in a multisatellite environment where not all earth stations look at each satellite. The one-way nature of the Broadcast TV transmissions eliminates concern over the addition-

al time delays introduced. The only disadvantages appear to be the possible accumulation of transmission impairments and some loss of spectrum efficiency because of the multiple transmissions of the same program.

#### 4.2.4 SPECIAL PURPOSE VIDEO

Special purpose video may be one way or interactive. One way video such as that used in newsgathering and special events, usually requires full bandwidth. For interactive video, such as videoconferencing, narrower bandwidth, limited motion capabilities are generally acceptable.

Although videoconferencing via dedicated intracompany networks may be satisfactorily served via CPS stations, trunking becomes important as videoconferencing expands toward more frequent use of ad-hoc conferences between organizations at least one of which is not equipped with a CPS station.

Delay caused by interconnecting videoconferencing users via multiple satellite hops may be objectionable in videoconferencing because of the two way interactive nature of these conferences. This may limit the usefulness of multi-hop and intersatellite links in this application. Trunking modes of Interactive video require connectivity between transponders, beams, and satellites to which the trunks are connected. Interconnections between transponders and beams in the same

satellite cause small delay effects. However, multi-hop and intersatellite connections are subject to the same delay restrictions as imposed on the CPS mode.

#### 4.2.5 CONNECTIVITY REQUIREMENT SUMMARY

The connectivity requirements for Ka band service categories are summarized in Figure III - 5. Note that the delay limitation category bears on the applicability of connectivity solution via multiple-hop and intersatellite links. It may be concluded from this summary that:

- CPS/Trunking connectivity is often needed.
- Satellite/Terrestrial connectivity is usually needed.
- Multiple-Hop and Intersatellite link delays are to be avoided when possible.

#### 4.3 SATELLITE CAPACITY AND DISTRIBUTION REQUIREMENTS FOR TYPICAL WESTERN UNION NETWORK TOPOLOGIES

Typical topologies for a Western Union network may be visualized by examining the growth of the minimum specialized network discussed in Section 4.1. The minimum specialized network has been estimated to cover about 30% of the total accessible market, which represents the minimum viable coverage. (This minimum portion of the market must be served to attract a sufficient number of customers and subsequent traffic load.) Based upon the estimates made in Section II - 5.3.5, this minimum network could well be

SUMMARY OF CONNECTIVITY REQUIREMENTS

SERVICE	APPLICATION	CONNECTIVITY	USER CONNECTIVITY	DELAY LIMITATIONS <sup>1</sup>	OPS/TRUNKING INTERCONNECTIVITY	SATELLITE/TERRESTRIAL INTERCONNECTIVITY
DATA	DEDICATED	PRE-ASSIGNED POINT-TO-POINT AND MULTIPPOINT	LIMITED	MODERATE	OFTEN NEEDED	SOMETIMES NEEDED
	SWITCHED	ON-DEMAND POINT-TO-POINT	WIDESPREAD	MODERATE	USUALLY NEEDED	USUALLY NEEDED
	DEDICATED	PRE-ASSIGNED POINT-TO-POINT; OCCASIONAL CONFERENCE	LIMITED	MAJOR	OFTEN NEEDED	SOMETIMES NEEDED
VOICE	MTS BUSINESS	ON-DEMAND POINT-TO-POINT; PLUS OCCASIONAL CONFERENCE	WIDESPREAD	MAJOR	USUALLY NEEDED	USUALLY NEEDED
	MTS RESIDENTIAL	ON-DEMAND POINT-TO-POINT	WIDESPREAD	MAJOR	NOT APPLICABLE	USUALLY NEEDED
	BROADCAST TV	PRE-ASSIGNED ONE-WAY BROADCAST (LIMITED AREA COVERAGE)	LIMITED	NONE	SOMETIMES NEEDED	OFTEN NEEDED
VIDEO	SPECIAL	PRE-ASSIGNED ONE-WAY BROADCAST, WITH OR WITHOUT NARROW-BAND RETURN CHANNEL	LIMITED	MINOR	SOMETIMES NEEDED	SOMETIMES NEEDED
		PRE-ASSIGNED (EVOLVING TO ON-DEMAND) TWO-WAY POINT-TO-POINT OR MULTIPPOINT VIDEOCONFERENCE	LIMITED/WIDESPREAD	MAJOR	OFTEN/USUALLY NEEDED	OFTEN/USUALLY NEEDED

FIGURE III-5



served by one satellite for each specialized carrier. (Separate satellites will probably be employed because of the range of variation possible in synchronization techniques, beam scan patterns, channel assignment algorithms, etc.)

The distribution requirements for traffic division among four separate satellites (one for each specialized carrier) are based upon the connectivity requirements given in Section 4.2 for the type of services offered by each specialized carrier. For example, MTS voice traffic, which requires maximum connectivity with all other users of the network, should be assigned a major portion of each satellite capacity, distributed by transponders and spot beams to provide maximum interconnectivity (as described in Section 4.2).

The specialized common network size grows from the minimum to meet additional traffic growth toward a predicted maximum specialized network size of 99 earth stations in the year 2000 (assuming that Ka-band service can be offered at 40% less than Ka-band service). On this basis, it was shown that the cumulative portion of this market captured by Ka-band in the year 2000 is 83.75%, based upon the total market value of the principal SMSA plus all of its subordinates located within a 50+ mile radius for hubbing.

If the market predictions are accurate for the year 2000, each specialized common carrier will have either

two or three satellites, depending upon their capture of the total market, the mixture of traffic, transponder capacity for trunking and CPS, etc. The additional connectivity requirements imposed by multiple satellites (see Section 4.2) impose constraints on the services provided (due to additional delay caused by multiple-hop or intersatellite links).

Since low earth station elevation angles result in higher attenuation due to rain (because of longer path length), satellite locations resulting in higher elevation angles will be sought and used, where available. If not available to both satellites of a specialized common carrier, the one providing a higher elevation angle will be dedicated to the services requiring increased reliability. The other satellite may be used for services which are tolerant of outages (usually deferred traffic). Distribution of satellite capacity, by services, among several satellites for each specialized common carrier will therefore probably depend upon service reliability needs, based upon geographical distribution of rainfall throughout CONUS and the satellite elevation angle.

Interconnectivity between satellites of different carriers, e.g., MTS traffic from one carrier to another, requires appropriate links and standards. These intercarrier links may be located at earth stations or as part of a terrestrial network. Standards will be required to interface differences in synchronization, protocols, etc. between carriers.

## REFERENCES

1. 30/20 GHz Net Accessible Market Assessment, Western Union Report No. CR-159837, February, 1980.
2. 18/30 GHz Fixed Service Communications Satellite System Study, Hughes Aircraft Company, Report No. 159627, September, 1979.
3. 30/20 GHz Mixed User Architecture Development Study, IRW Inc., Report No. NASA CR-159686, October, 1979.
4. 18/30 GHz Fixed Communications System Service Demand Assessment, Western Union Report No. CR-159547 Vol. II, July, 1979.
5. Propagation Effects Handbook for Satellite Systems Design, A Summary of Propagation Impairments on 10-100 GHz Satellite Links, with Techniques for System Design. ORI TR 1679, NASA Communications Division, NASA Headquarters, Washington, D.C., March, 1980.

## IV

### PROPAGATION EFFECTS ON THE TRANSMISSION PATH

#### 1.0 STATEMENT OF THE PROBLEM

The requirements of this subtask are to identify 30/20 GHz propagation characteristics, and provide a basis for establishing expected effects on typical links used in support of candidate services.

#### 2.0 INTRODUCTION

Rain attenuation on the transmission path, and the resulting large link margin requirements required to provide high availability performance, is the most significant factor in identifying the services that can be accommodated by 30/20 GHz satellite communication systems. This section presents the key precipitation data that will be compared to the availability and performance requirements of the trunking and CPS services developed in Section II. The resulting link margin requirements establish the Ka-band system parameters necessary to satisfy service availability/performance criteria and to identify system limitations.

#### 3.0 METHODOLOGY

The most recent NASA handbook on propagation effects at 30/20 GHz and other sources were used to develop the required propagation information.

Using the propagation statistics, fade depths and link margin requirements were computed for each of the CONUS

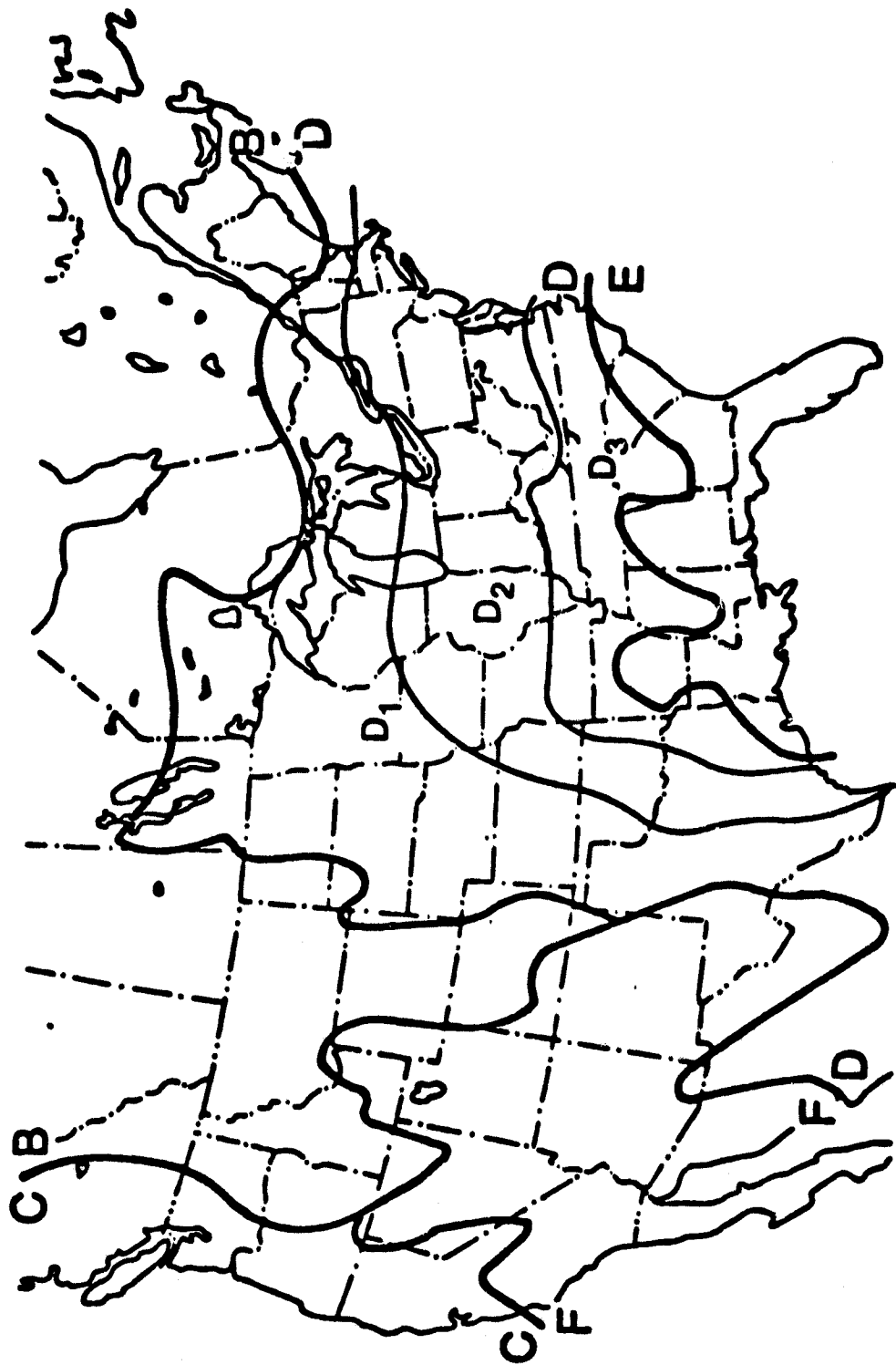
rain zones identified. Pertinent fade duration statistics, rain attenuation characteristics as a function of earth station elevation angle, and space diversity gain data from the referenced publications were used to derive the data presented.

#### 4.0 PROPAGATION CHARACTERISTICS

Figure IV-1 shows the rain rate climate regions for the continental United States (CONUS). Figure IV-2 shows the point rain rate distributions as a function of the CONUS rain regions. Region D is subdivided into three subzones and the rain rate distribution for each of the subzones is shown in Figure IV-2(b). Using the procedures from the NASA Handbook and the point rain rate statistics in Figure IV-2, fade depths as a function of percent of time the fade depth is exceeded were computed for each of the rain zones. To maintain a given level of link availability, the precipitation margin required equals the rain fade depth; thus the data computed is identified as Precipitation Margins for the 20 GHz and 30 GHz Links in Tables IV-1 and IV-2, respectively.

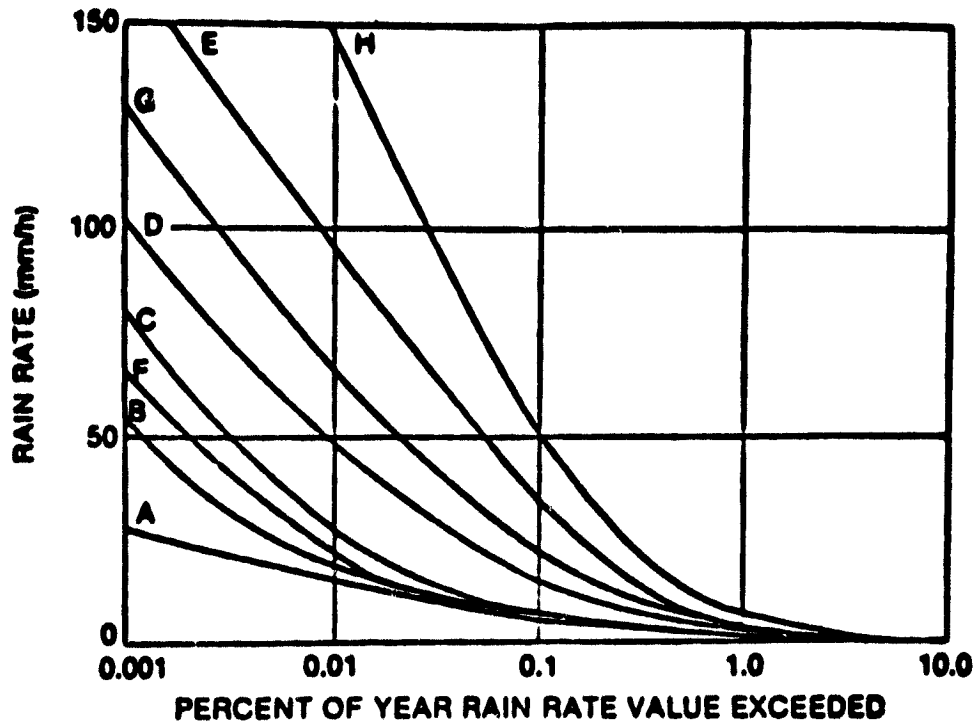
The data has been computed for each rain zone at the appropriate elevation angle, since rain attenuation varies appreciably with earth station elevation angle, particularly in high rain rate regions. Figure IV-3 shows rain attenuation characteristics as a function of earth station elevation angle.

The satellite location can be optimized to provide the

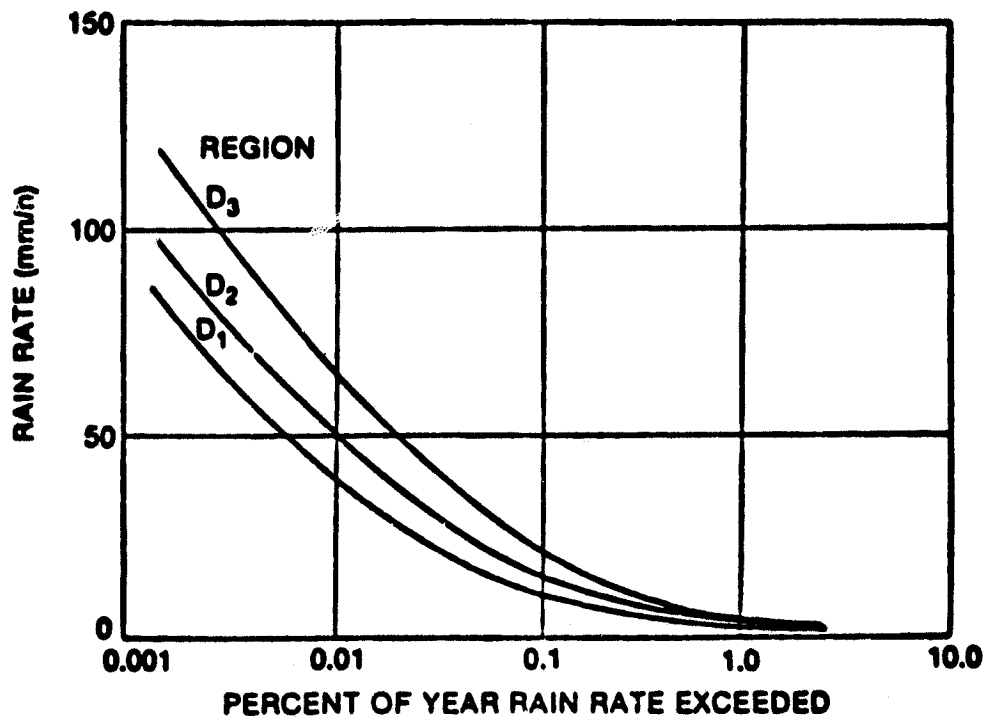


**RAIN RATE CLIMATE REGIONS FOR THE  
CONTINENTAL UNITED STATES SHOWING  
THE SUBDIVISION OF REGION D**

**FIGURE IV - 1**



(a) Climate Regions A to H



(b) Climate Regions D divided into three subregions  
(D<sub>2</sub> = D above)

**POINT RAIN RATE DISTRIBUTIONS AS A  
FUNCTION OF PERCENT OF YEAR EXCEEDED**

FIGURE IV - 2

**Rain Attenuation in dB for Satellite at 90°W**  
**(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	6	4	1	1
C	30	20	8	5	1	1
D <sub>1</sub>	40	23	9	6	2	1
D <sub>2</sub>	45	28	12	8	3	1
D <sub>3</sub>	50	36	17	12	3	2
E	55	55	29	20	4	2
F	40	17	6	4	2	1

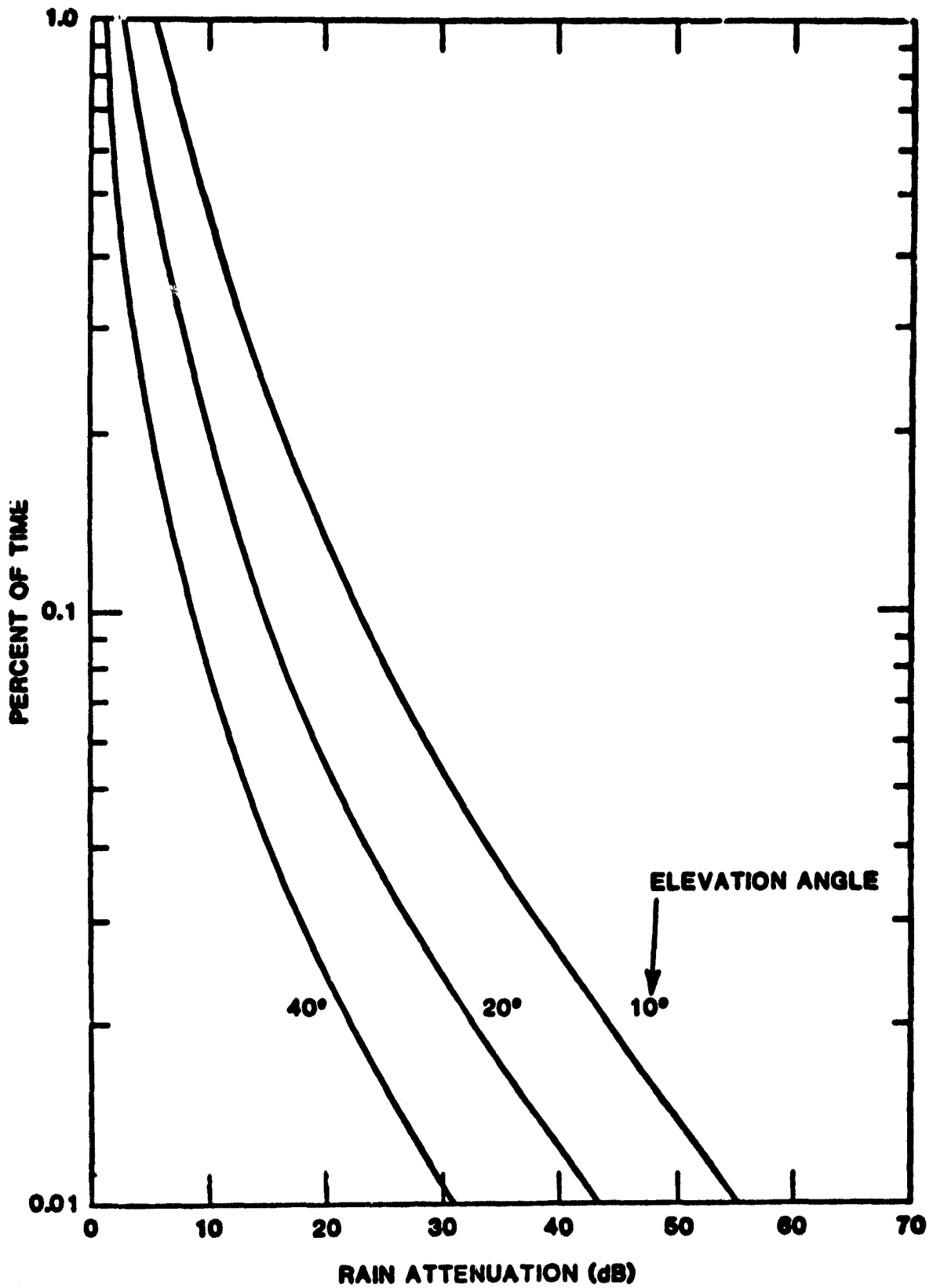
TABLE IV - 1

**Rain Attenuation in dB for Satellite at 90°W**  
**(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	13	9	3	2
C	30	45	17	11	3	2
D <sub>1</sub>	40	50	21	14	4	2
D <sub>2</sub>	45	63	28	18	6	3
D <sub>3</sub>	50	80	39	27	8	4
E	55	120	64	43	10	4
F	40	37	13	9	4	2

TABLE IV - 2





VARIATION OF RAIN ATTENUATION OF A  
FUNCTION OF ELEVATION ANGLE-ZONE D<sub>2</sub>

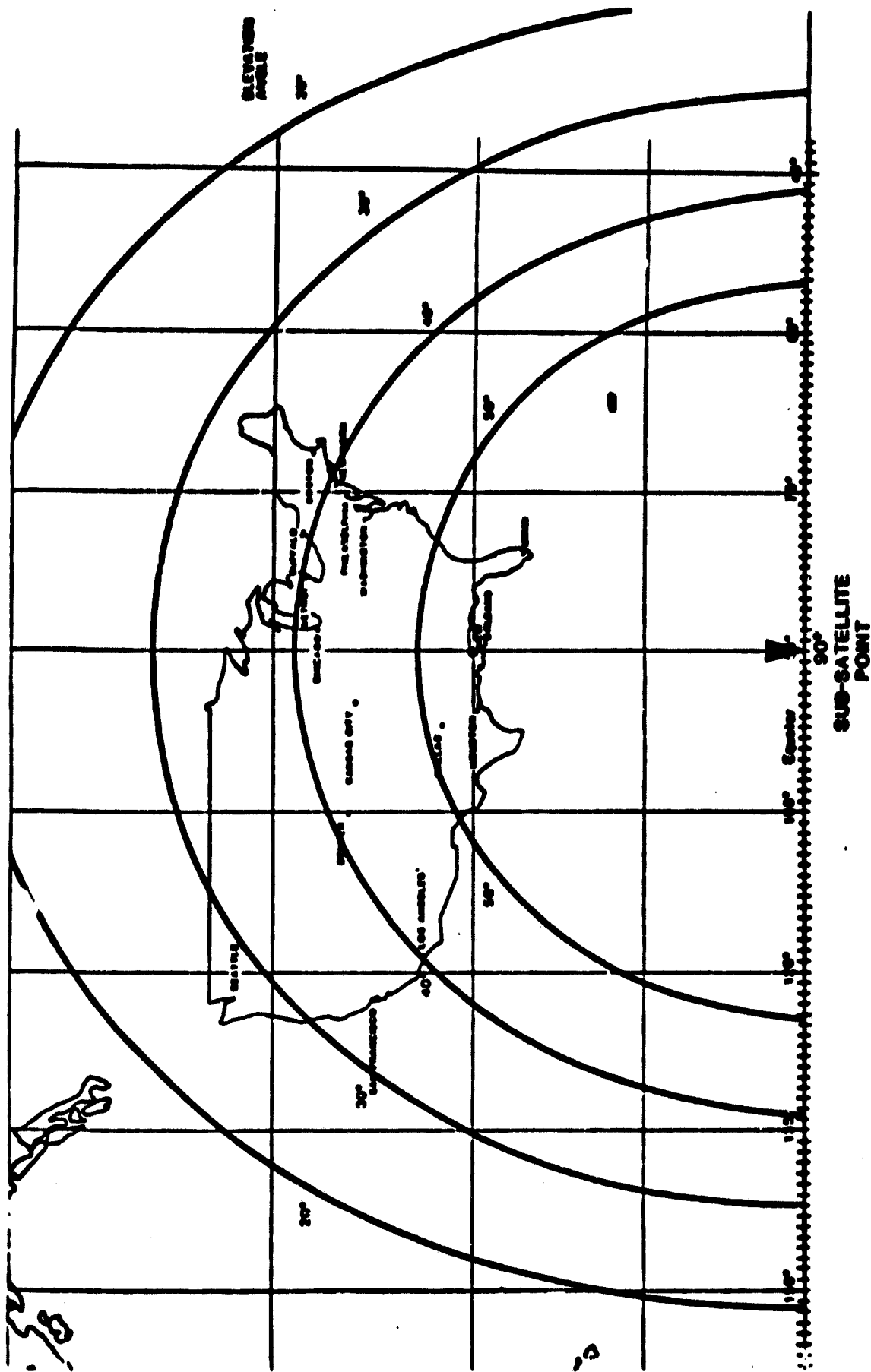
FIGURE IV - 3

best weighted CONUS coverage with the lowest margin requirements. Figure IV-4 and IV-5 show the elevation angle contours superimposed on the CONUS for satellite locations at 90°W and 97°W longitude, respectively. The optimum location is at 97°W. At orbital arc locations below 90°W and above 104°W appreciable performance degradation in major population centers will be experienced.

Of particular interest is the relationship between total annual rain attenuation and the worst month attenuation. Figure IV-6 shows the results of rain attenuation measurements, as a ratio of worst month to total annual attenuation, recorded at Greenbelt, MD. The worst month attenuation exceeded the average annual level by factors of 5 to 7.5.

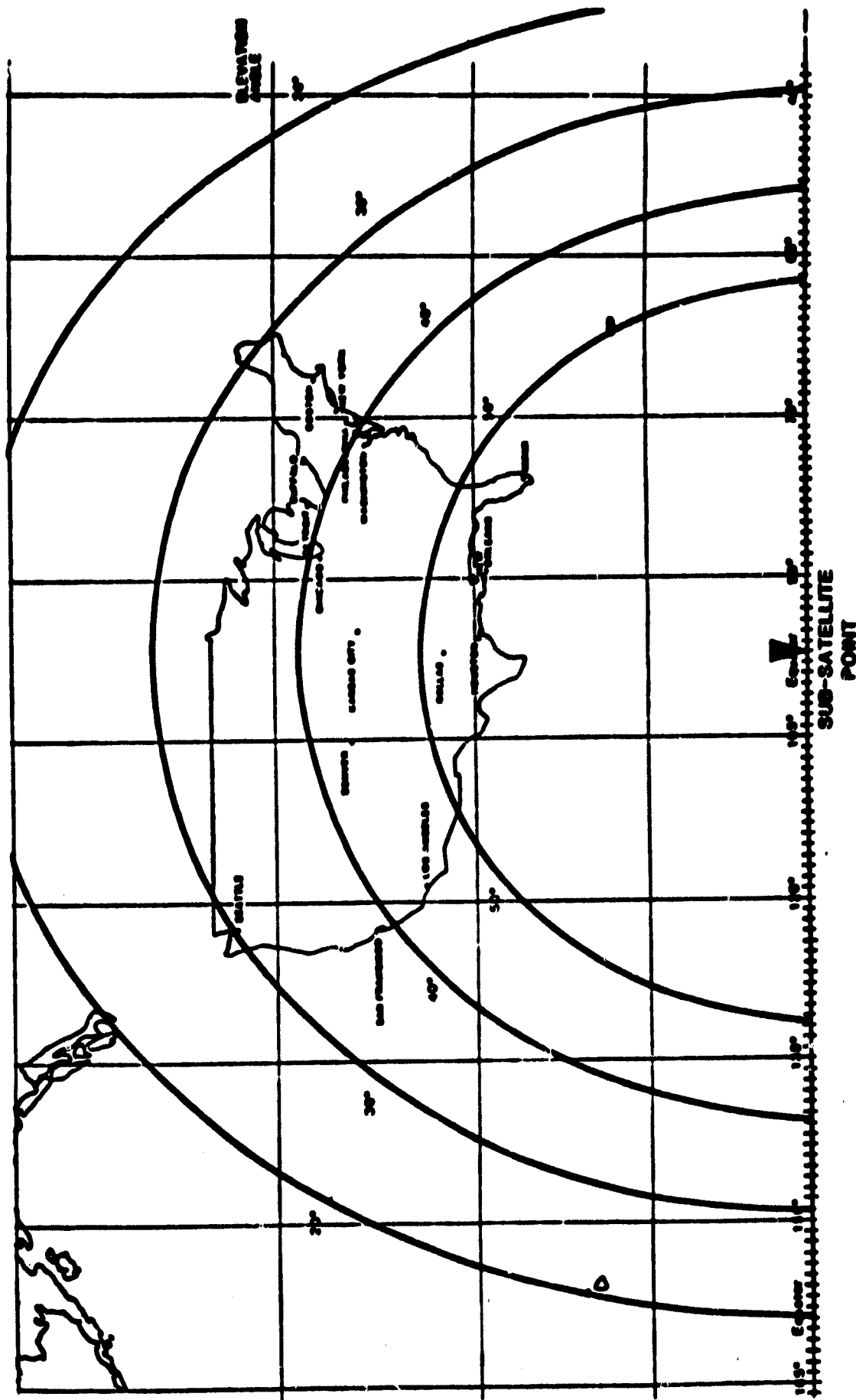
Figures IV-7 to IV-9 show fade duration distributions at three widely separated locations: Holmdel(NJ), Slough (England), and Rosman (NC) respectively. Fade durations and the number of fades vary among the three because the measurement period and the elevation look angle (and consequently the rain path length) were different at the three sites. The distribution characteristics at the three sites are, however, similar.

Figure IV-10 is a histogram showing the percentage of each month the three fade depths indicated were exceeded. The data is the result of measurements made at



SATELLITE AT 90° W LONGITUDE

FIGURE IV - 4



SATELLITE AT 97° W LONGITUDE

FIGURE IV - 5

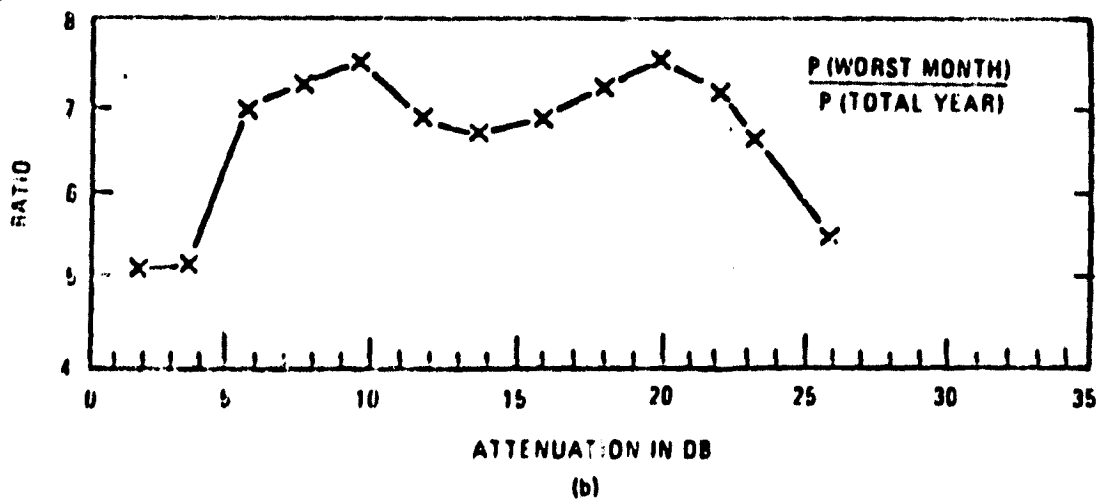


Figure 4-13. Comparison of Worst Month and Annual Attenuation Statistics for 1977.

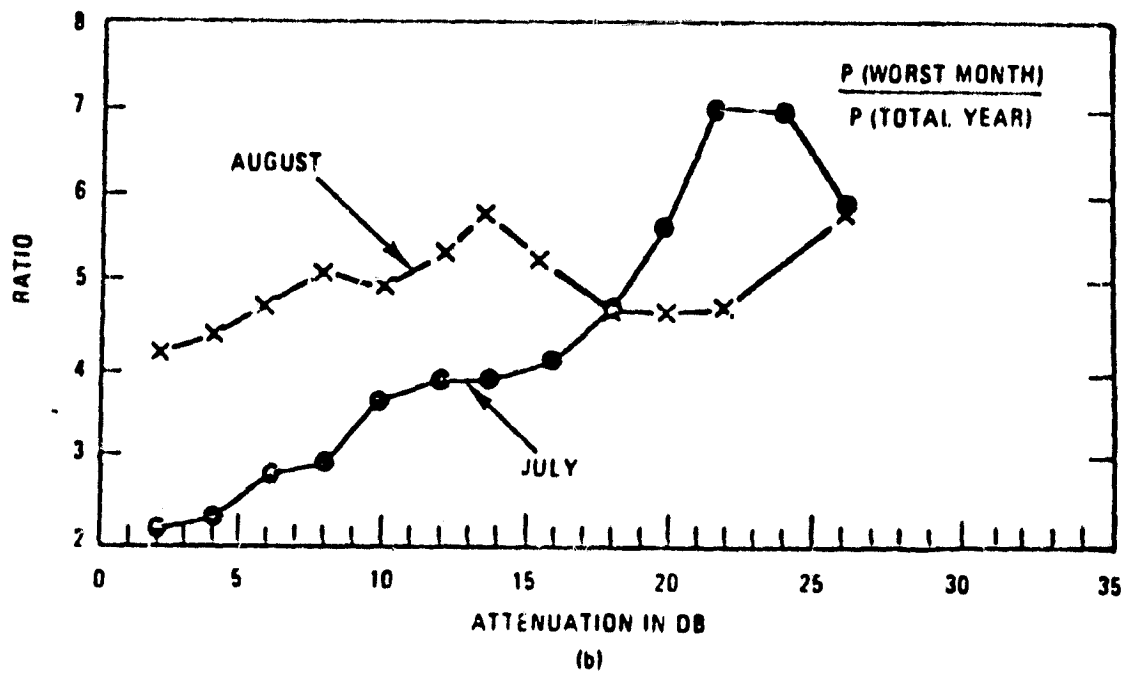


Figure 4-14. 11.76 GHz Attenuation Distributions, Greenbelt, Maryland

FIGURE IV - 6

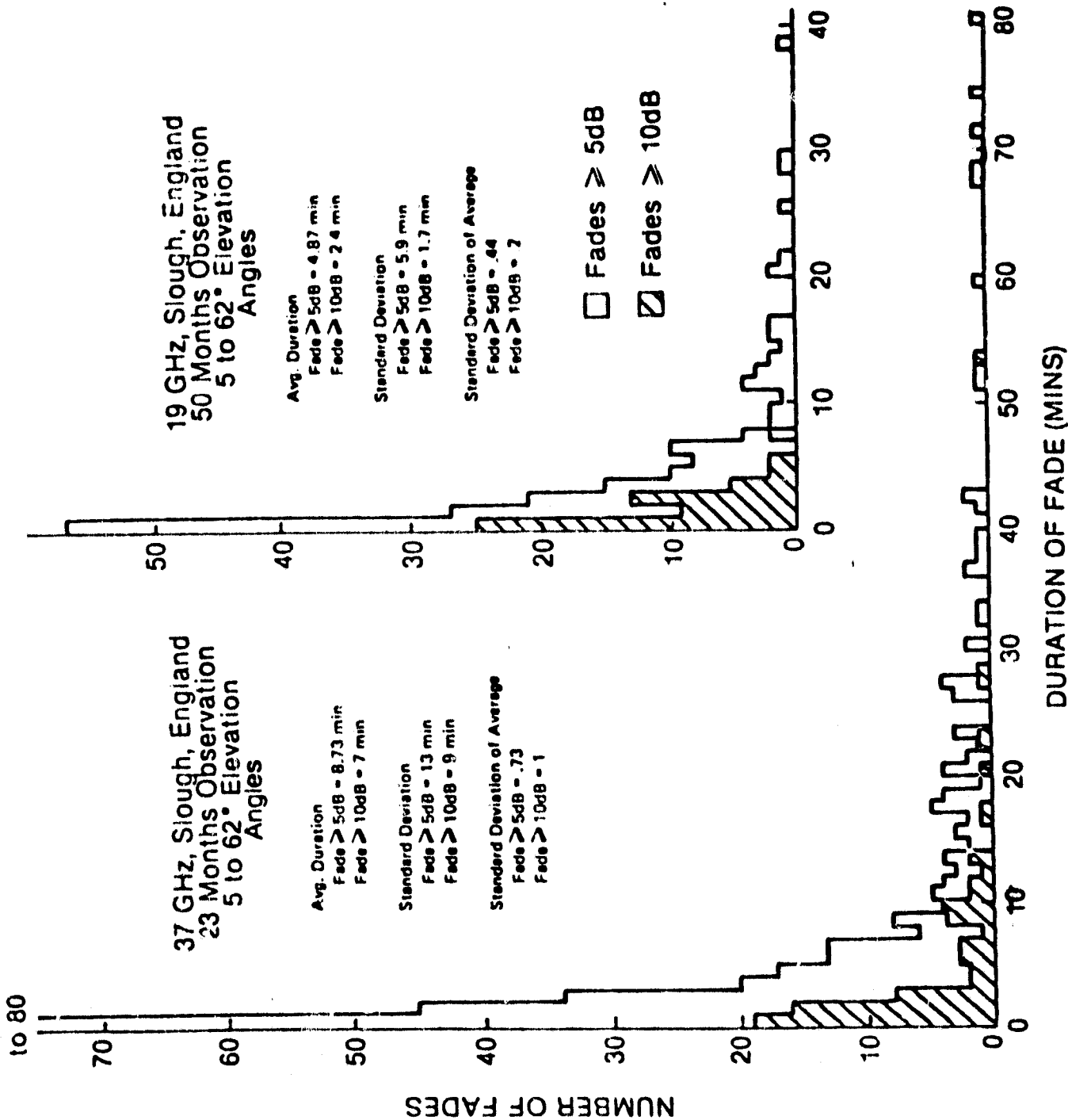
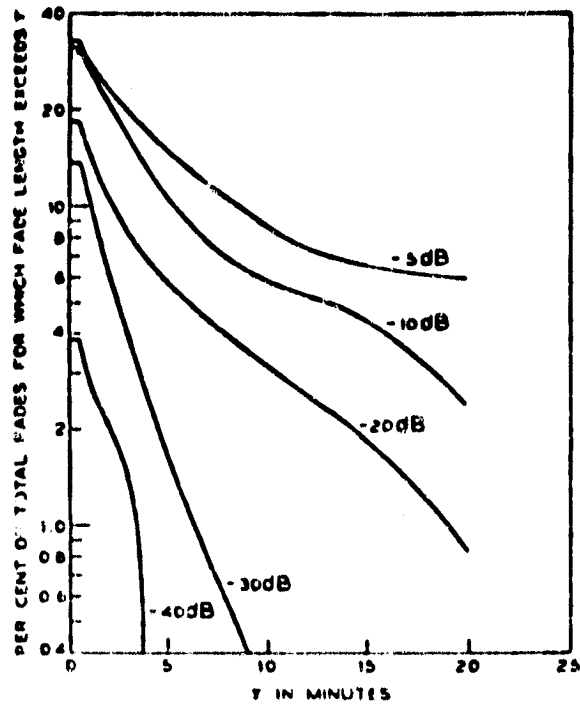


FIGURE IV - 7

HISTOGRAMS OF FADES GREATER THAN 5 AND 10 dB AT 19 AND 37 GHz

Source: Reference 1



HOLMDEL, N. J.

PERCENT OF TOTAL NUMBER OF FADES FOR WHICH THE FADE LENGTH EXCEEDS THE ABSCISSA. BASED ON 178 HOURS OF RAIN DATA AND A TOTAL OF 182 FADES.

FIGURE IV - 8

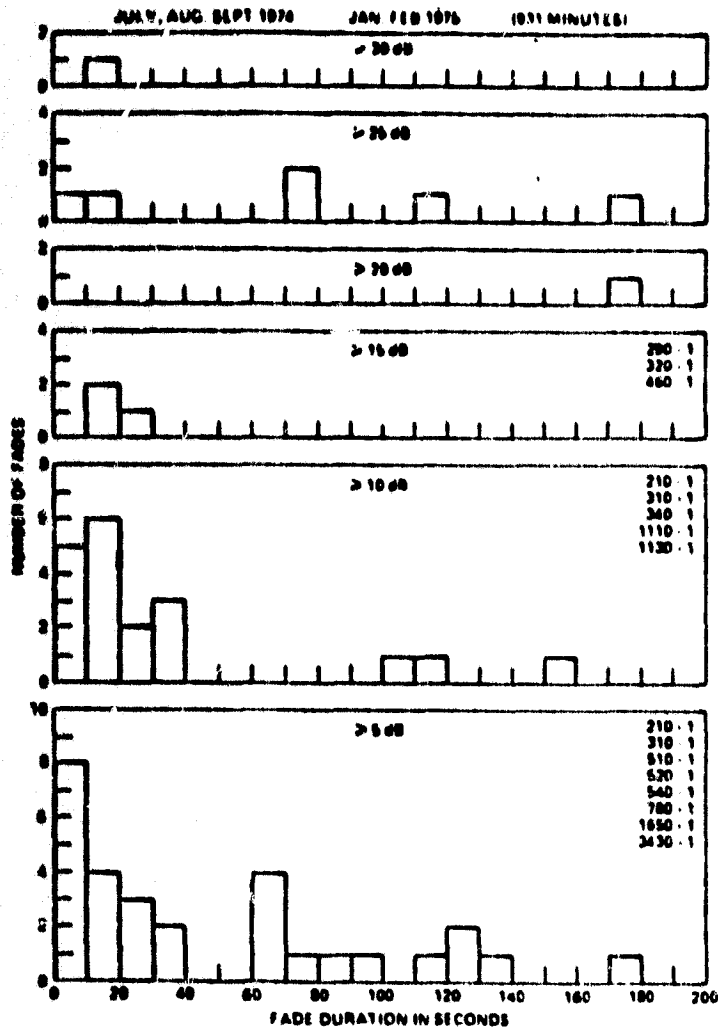


FIGURE IV - 9



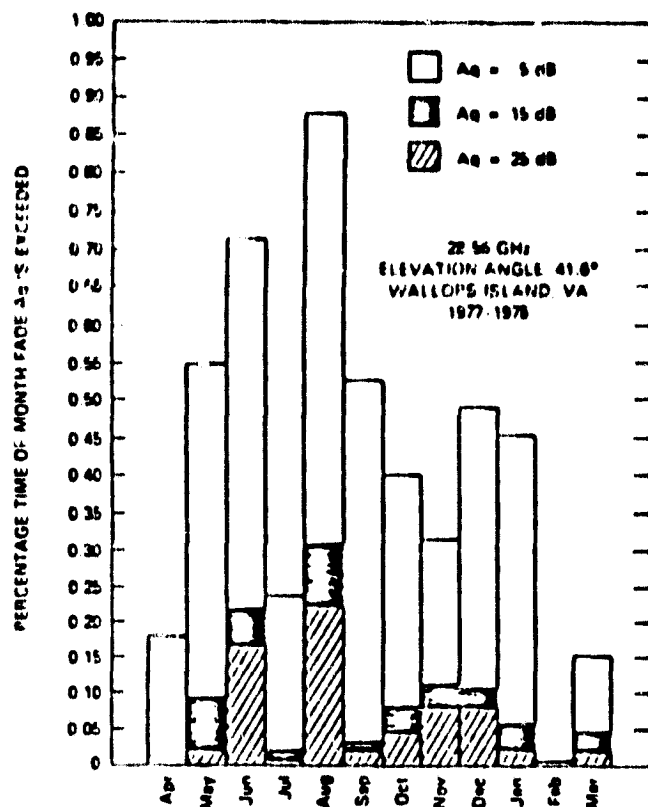


Figure 5.5-1. Histogram denoting percentage times for various months the fades of 5, 15, and 25 dB were exceeded.

FIGURE IV - 10

Wallops Island, VA illustrating typical fade distribution characteristics by month. Monthly distribution varies considerably between sites as can be seen by comparing Figures IV-6 and IV-10, two sites that are approximately 150 miles apart. At Greenbelt the worst month is July whereas August is the worst month at Wallops Island. Additional data for Richland, WA is shown in Figure IV-11 to illustrate variances between sites. Fade duration statistics are useful in estimating blocking probabilities for message switched services on occasions during which adaptive FEC is activated to accommodate severe fading, or other means are used to exchange available bandwidth for performance quality on remaining circuits.

Figure IV-12 shows that fade characteristics are relatively independent of frequency. A reasonably accurate estimate of rain attenuation can therefore be made from data at a single spot frequency.

#### 5.0 SPACE DIVERSITY

Space diversity has been used for a number of years in terrestrial microwave systems. In such systems it is generally used to combat degradations due to ducting, multipath, and other phenomena characteristic of paths near and parallel to the earth's surface. The use of space (or "separation") diversity with satellite links is primarily intended to combat high attenuation due to intense precipitation. The basis for use of a diversity

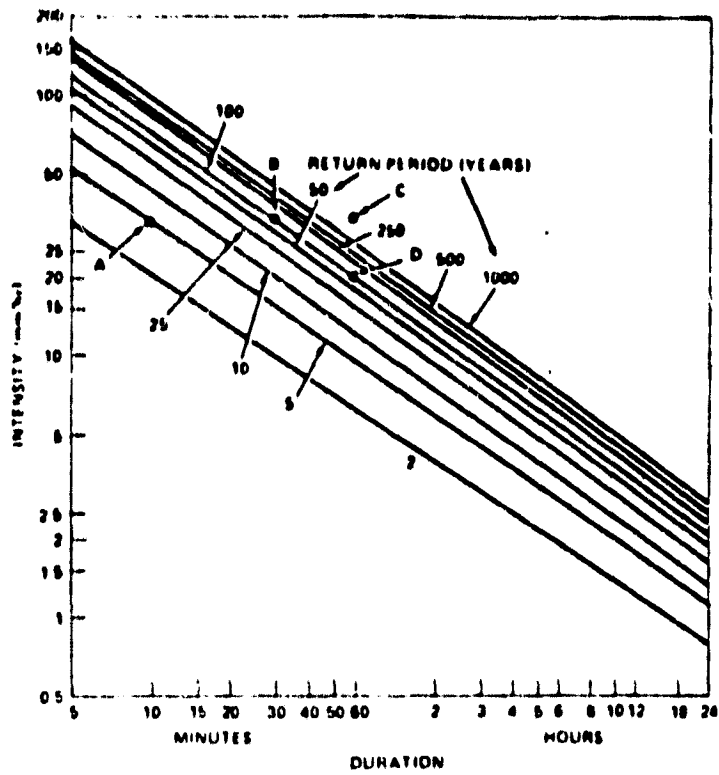


Figure 6. Average total precipitation, Richland, Washington, area.

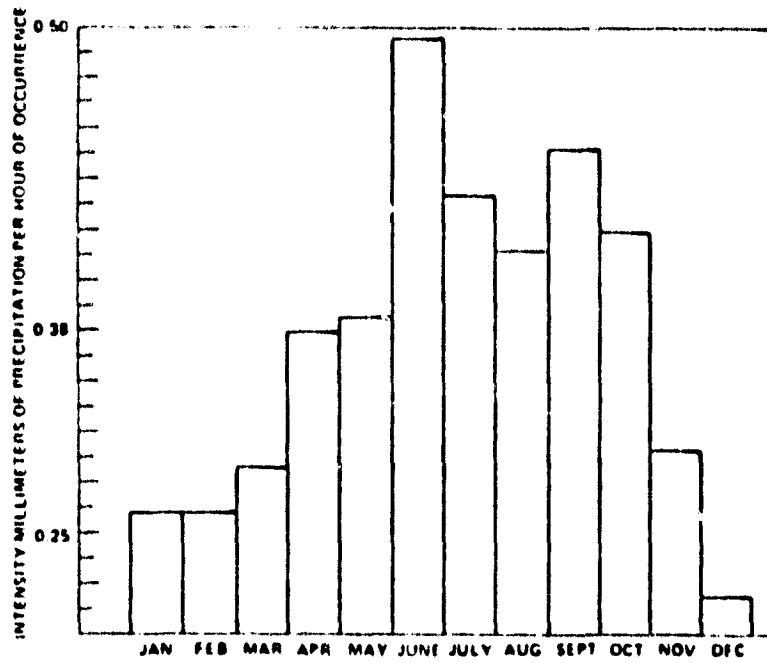
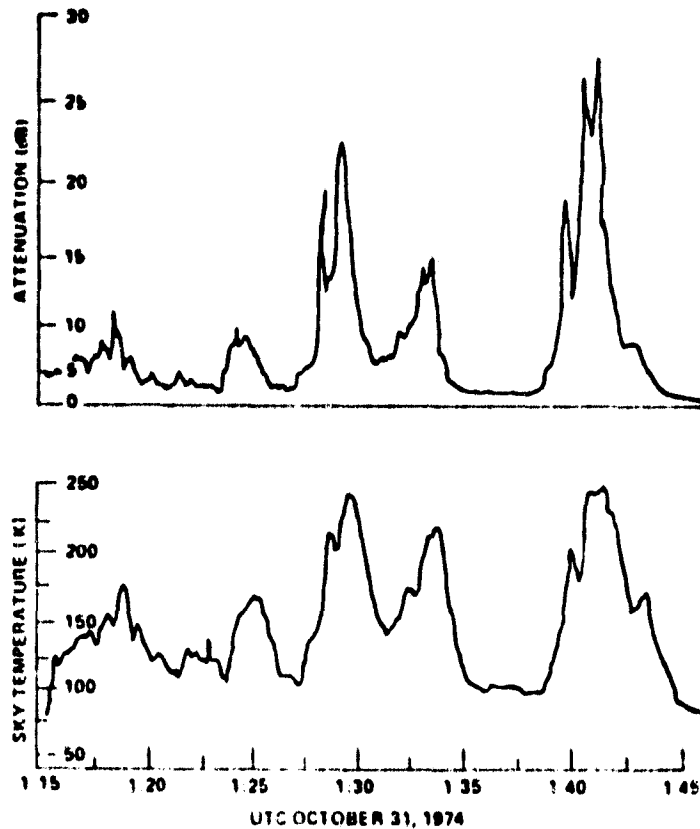


Figure 7. Average monthly precipitation intensity factors based on the period from 1946-1970.

FIGURE IV - 11



30-GHz ATTENUATION AND  
20-GHz SKY TEMPERATURE

FIGURE IV - 12

system is the observation that regions of intense rainfall are generally limited in geographic extent. This is true for temperate climates. The physical separation of the satellite earth stations then serves to reduce the correlation of such heavy rainfall at the sites. Some simple means of choosing the better of the sites at any instant then completes the diversity system.

A useful tool in the study of diversity systems is the concept of "diversity gain," as developed by D. Hodge of Ohio State University. The derivation of diversity gain is best illustrated by a figure. In Figure IV-13 the two curves to the right are the individual cumulative time distributions of attenuation for the two sites operating individually. The single curve to the left is the cumulative time distribution for diversity operation--that is, the better of the two stations at any instant. As shown, the distance between the curves for the same percentage time is the diversity gain in decibels.

Hodge has determined an empirical relationship between the separation distance, fade depth, and diversity gain based on measurements made using ATS-V. These measurements were taken at 15.3 GHz. This relation is as follows:

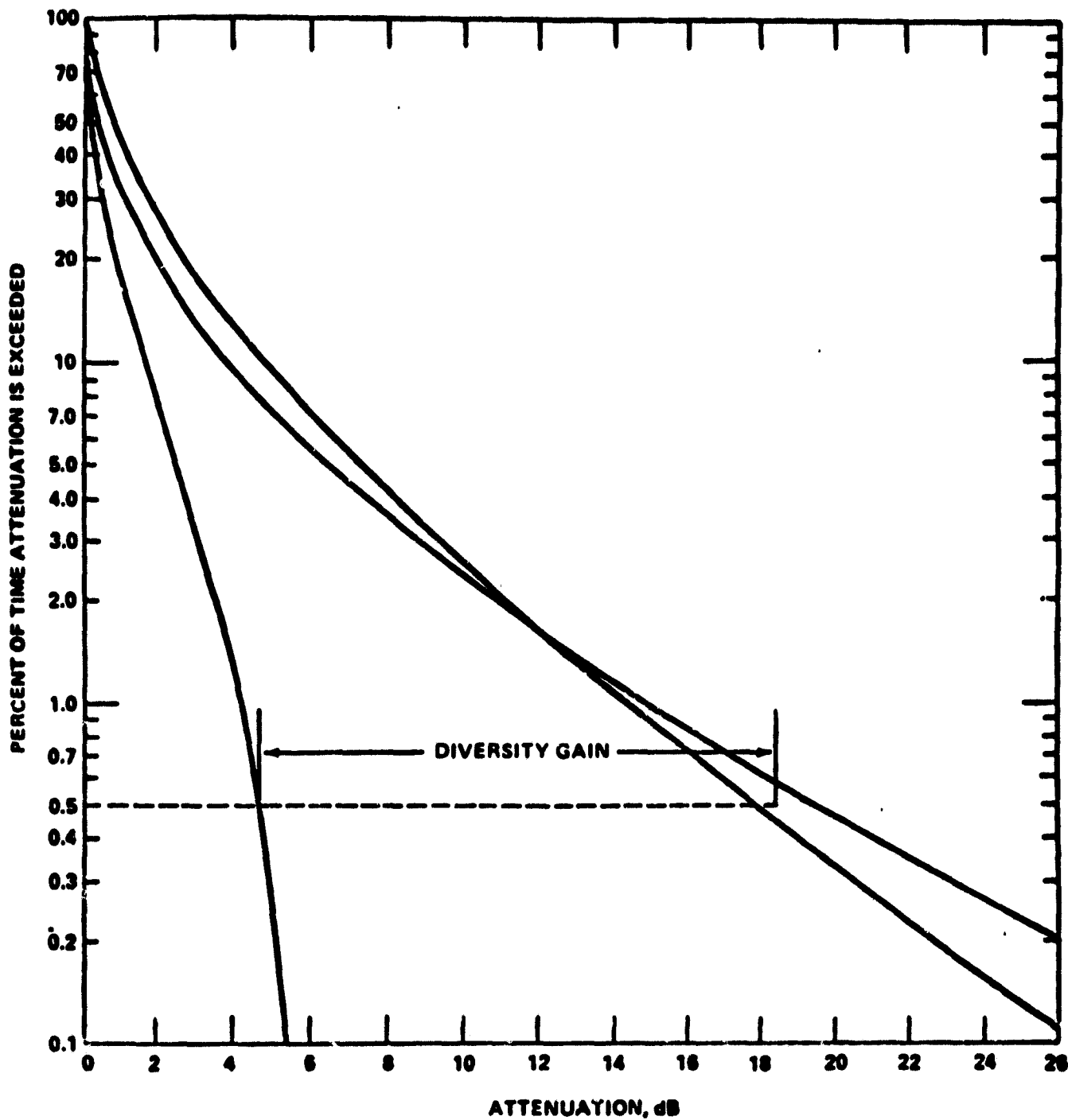


FIGURE IV - 13  
 DIVERSITY GAIN CALCULATION

$$G = a(1 - \exp(-bD))$$

where

G = Diversity gain in dB

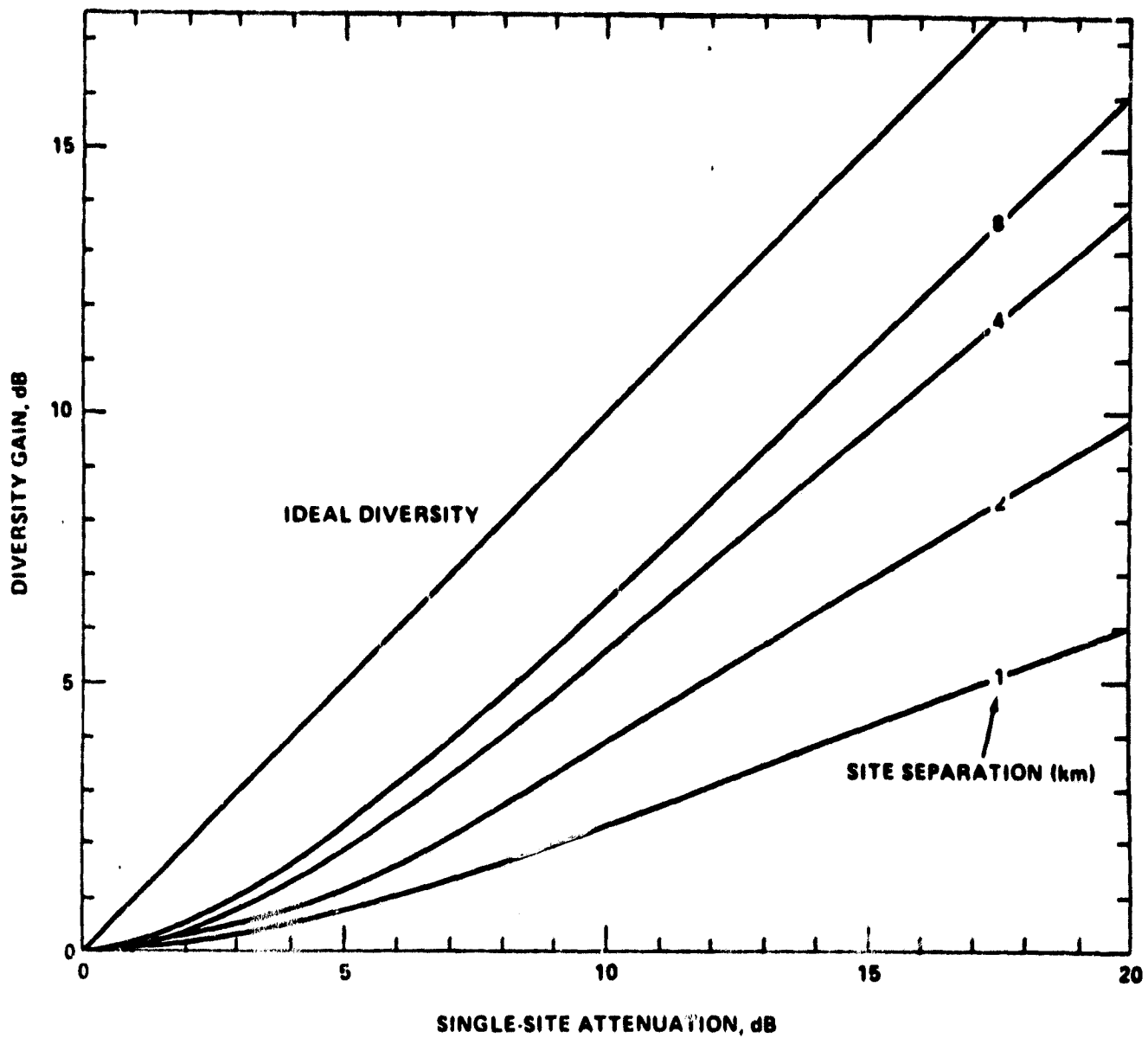
D = The site separation distance in km

a =  $A - 3.6(1 - \exp(-0.24A))$

A = The single site attenuation in dB

b =  $0.46(1 - \exp(-2.26A))$

Data taken using ATS-6 indicated that the diversity gain was not strongly dependent on frequency. A satisfactory separation for the diversity sites seems to be about 8 to 10 km. Diversity gain as a function of separation is shown in Figure IV-14.



DIVERSITY GAIN FOR VARIOUS SEPARATIONS  
(Hodge, 1976)

FIGURE IV - 14



TRANSMISSION SYSTEM CONSIDERATIONS

1.0 GENERAL CONSIDERATIONS

In Section II an analysis of the net accessible Ka-band market was made to estimate the portion of that market that might actually be captured by Ka band communications systems and the share of the estimated traffic volume that might be captured by the individual satellite carriers in their respective market areas. The transmission requirements of the carrier community may be divided into three separately identifiable systems in accordance with the services provided. The three system categories are: trunking, CPS, and combined trunking/CPS. A trunking system being appropriate for Bell, combined trunking/CPS for carriers such as Western Union and RCA, and all CPS for carriers addressing those market areas of interest to SBS, XTEN, SPC, etc. Each of these system categories requires a different satellite system design. From the work in Section II the Western Union market areas require both Trunking and CPS satellite system capabilities. The projected Western Union market share is estimated to grow to 7.5 GBPS in each category by the year 2000. An estimate of the size of an initial satellite in terms of capacity was identified previously as 4 GBPS of trunking capacity and 2 GBPS of CPS capacity. In the Phase I - Task 9 effort the

marginal utility of adding one more earth station in the trunking network was that the traffic capacity of that earth station be at least .11% of the total projected trunking traffic. For a two carrier split of the total traffic the minimum capacity required is .22% or 33 MBPS. The maximum network size for Ka services priced 20% below Ku band service is 89 earth stations. On the assumption that the objective of the two dominant private-carriers is to implement at least the most efficient network size (34 earth stations each), the minimum traffic capacity at any earth station is at least 30 MBPS. On this basis a SS-TDMA trunking system operating at a 500 MBPS burst rate is a reasonable choice. Ultimately 15 transponders at 500 MBPS each will be required to accommodate the projected traffic.

In the CPS case the traffic volume is the aggregate of a large number of small networks that include corporate, institutional, government, and low capacity trunking networks. Assuming that ultimately CPS services will be carried through some 1000 earth stations the average transmission capacity per station is 7.5 MBPS. Some will be as low as 64 KBPS, others may be in the 20-30 MBPS range or possibly higher. The nominal 32/128 MBPS uplink and 250 MBPS downlink transmission rates are reasonable choices for CPS, however, it will probably be more desirable to customize at least the

uplink transmission--and in the case of the southeastern region the downlink transmission--to provide adequate system margins (normal operating margin plus margin obtained by adaptive measures) to meet availability requirements. This is discussed further in Subsection 4.2.

In the following subsections some specific systems consideration are discussed in some detail.

## 2.0 PERFORMANCE

The two key measures of performance are BER and availability. The required BER performance,  $1 \times 10^{-7}$ , is driven by data transmission requirements. (Typically in PCM encoded voice and video systems BER performance levels of  $1 \times 10^{-6}$  and  $1 \times 10^{-5}$  respectively will provide high quality service.) The transmission link analysis is based on the  $1 \times 10^{-7}$  BER.

Availability requirements have been discussed in Section II. In the trunking transmission network a link availability objective of .9999 has been established. To meet the availability objective both adaptive compensation and diversity earth stations are generally necessary. However, as discussed in Section II, this availability could be obtained by considering use of terrestrial and other satellite bands.

The availability objective for the CPS services is .9990 although .9950 would be an acceptable level for some types of traffic. The availability criteria for

each user network would be considered individually to avoid an overdesign, although the basic system (satellite/earth station) design requirements are specified to meet the .9990 availability objective.

### 3.0 RAIN ATTENUATION COMPENSATION

The severity of rain attenuation in the 30/20 GHz band, particularly where high system availability is required, mandates that the system designer consider multiple techniques for improving system availability. These would include adaptive power control, adaptive FEC, space diversity earth station complexes, and location of the satellite within the domestic orbital arc. Any or all of these techniques would be appropriate in a given system.

### 3.1 ADAPTIVE POWER CONTROL

To meet availability objectives both the trunking and CPS systems require use of adaptive power control. In the trunking case adaptive power control is required for both the uplink and downlink. In the CPS case the satellite transmitter is operated normally at maximum output power and adaptive power control is limited to the uplink. Subsection 4.0 provides link summaries giving normal operating and adaptive power levels necessary for the trunking and CPS systems.

### 3.2 FORWARD ERROR CONTROL

The use of FEC is necessary in the CPS systems but need not be included in the trunking system. FEC has

the advantage of providing large increases in bit error performance and margin to offset the effects of rain attenuation. Rate 1/2 encoding with soft decision decoding, which will provide an 8.8dB coding gain at a constant transmission rate, has been assumed as a standard. However, the use of that rate does not imply that the total information data rate of the CPS system will be reduced to half of the uncoded transmission data rate. FEC is specified to be applied to individual sites that are under the influence of rain attenuation at the port rate within the Terrestrial Interface Modules and not at the transmission burst rate. The probability that more than 10% of the network stations are experiencing such conditions simultaneously is quite low. Thus for a station network with uniform distribution of traffic, (i.e. each has a peak hour traffic of 2.5 MBPS), one station out of ten experiencing rain conditions will reduce total throughput capacity from 250 MBPS to 225 MBPS. The impact on system throughput and blocking probability in the case of voice circuits even at peak hours will be relatively low as long as capacity can be reassigned among the stations. In off-peak hours there is not likely to be any noticeable effect on network transmission.

There are a number of interesting control scenarios by which required bandwidth can be allocated to stations

experiencing fades. These should be investigated to devise an optimum algorithm for resource control.

### 3.3 SPACE DIVERSITY EARTH STATIONS

To meet a postulated .9999 availability requirement for a trunking system, implementation of space diversity earth stations is required at all trunking nodes. A description of the diversity gain/spacing characteristics was given in Section IV. Diversity experiments are essential, since empirical data to substantiate the belief that there is a dB for dB diversity gain improvement for cases where single site attenuation exceeds the 15-18 dB range is not available. The importance of space diversity gain improvements is paramount to meeting trunking network availability objectives, since if the expected diversity gain improvements cannot be obtained, Ka band systems would not be an acceptable medium for trunking transmission under the .9999 availability assumption. However, as noted above, many trunking networks could tolerate poorer availability with appropriate network design and "fail-soft" operating procedures, so that this assumption requires further study.

### 3.4 SATELLITE POSITION IN THE DOMESTIC ORBITAL ARC

Rain attenuation increases appreciably as earth station elevation angles decrease. In Section IV the variation of rain attenuation as a function of elevation angle was given together with a plot of elevation

angle contours in CONUS. By selection of the satellite location in the orbital arc the best weighted CONUS coverage with the lowest rain margins can be obtained. From the plots in Section IV the optimum satellite position is  $97^{\circ}$  W longitude, providing a minimum elevation angle in CONUS of  $30^{\circ}$ . For orbital arc locations below  $90^{\circ}$ W and above  $104^{\circ}$  W the increased attenuation due to lower elevation angles in major population centers becomes a critical factor. The useful orbital arc can be extended through use of intersatellite links (to be discussed separately).

### 3.5 ADDITIONAL CONSIDERATIONS

Additional system margin can be obtained by adaptive reduction of the transmission data rate, providing an increased level of energy per bit for given available transmitter power conditions. The approach should be examined but is not considered a preferred choice because of its impact on throughput capacity and channel blocking. In subsection 4.0 reduced transmission data rates are considered to meet availability requirements for CPS stations in CONUS rain zone E, but in that case the peak transmission requirements would be considered in the design and the necessary total capacity provided through use of an appropriate number of FDM channels.

To minimize reduction in throughput data rates an adaptive reduction in the number of quantization bits

for digital voice channels can be employed. For example if the eight bit code normally used for voice channel quantization is reduced to six bits the per channel data rate is reduced from 64KBPS to 48KBPS. This approach should be explored as part of system design trade-off consideration.

#### 4.0 EARTH STATION ANTENNA SIZE AND SYSTEM MARGIN CONSIDERATIONS

##### 4.1 TRUNKING STATIONS

Both Hughes and TRW, in the baseline and alternative designs submitted to date, advocate use of large (12 meter) antennas for trunking systems. Western Union expects that a 5 meter antenna will be adequate for the trunking system, and in any event would not consider an antenna larger than 7 meters as being cost-effective. To substantiate the position that a 5 meter antenna will satisfy trunking network requirements comparative data is presented below using 5, 7, and 12 meter antennas.

There are a number of reasons why a 12 meter antenna is not a desirable choice. A 12 meter antenna is large, and with the surface tolerance requirements (.01 inch RMS or better) for the Ka band it is unlikely that a vendor would quote on providing the antenna on other than a developmental basis. The antenna cost will be very high. The beamwidth of the 12 meter



antenna is very narrow (.058°) and the foundation and structural rigidity required to meet operational performance requirements at wind velocities up to 60 MPH, (and slightly reduced performance in gusts up to 80 MPH) is severe and costly. (The degradation or tracking error at an average wind velocity of 35 MPH was not specified by Hughes or TRW.) There is no reason why the environmental requirements for the Ka-band antenna should be relaxed relative to "C" or "Ku" band systems. Environmental performance requirements normally specified by WU are given in Appendix A. The 12 meter antenna will also require a tracking subsystem somewhat more sophisticated and expensive than a step-track system. Further, since diversity systems will in any case be required at trunking nodes (see below), system cost is substantially increased because two 12 meter antennas per site are required.

The beamwidth of a 5.0M antenna is .14°, simplifying tracking requirements to that which may be accommodated with a step-track system. Surface tolerances are more easily obtained because of the smaller size, and foundation/structural rigidity requirements can be met at a lower cost because of the smaller surface area.

Tables V-1 through V-3 give uncoded link budgets for 12, 7, and 5 meter trunking systems, respectively. Using the earth station and satellite transmitter power levels shown the available margins for rain loss

CASE 1 - 12.0 ES Antenna  
Trunking TDMA 500 Mbps Link Budget  
 (Clear Weather)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	21.6 (150 W)	10 (10w)	dBW
TX. ANTENNA GAIN	69.0 (12 M)	51.2	dB
POINTING LOSS	2.0	1.0	dB
EIRP (WITH 2 JB LINE LOSS)	86.6	58.2	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	50.4	65.0	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	1.4	1.5	dB
NOISE TEMPERATURE @ LNA INPUT	29.0	28.7	dB . K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT (NOT INCLUDING RAIN FADE)	120.6	110.6	dB . Hz
INFO. BIT RATE	87.0	87.0	dB . Hz
CHANNEL $E_b/N_0$ (EFFECTIVE SYSTEM)	33.6	23.2	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
RAIN LOSS MARGIN	20.0	5.6	dB

TABLE V - 1

Case 2 - 7.0 ES Antenna  
Trunking TDMA 500 Mbps Link Budget:  
 (Clear Weather)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	21.6 (150 W)	10 (10W)	dBW
TX. ANTENNA GAIN	64.2	51.2	dB
POINTING LOSS	1.5	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	82.3	58.2	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.5	0.8	dB
RX. ANTENNA GAIN	50.4	60.3	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	1.4	1.5	dB
NOISE TEMPERATURE @ LNA INPUT	29.0	28.7	dB . K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT (NOT INCLUDING RAIN FADE)	116.3	105.9	dB . Hz
INFO. BIT RATE	87.0	87.0	dB . Hz
CHANNEL $E_b/N_0$ (EFFECTIVE SYSTEM)	29.3	18.9	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
RAIN LOSS MARGIN	15.7	5.3	dB

TABLE V -- 2

**Case 3 - 5.0 ES Antenna**  
**Trunking TDMA 500 Mbps Link Budget**  
**(Clear Weather)**

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	21.6 (150 W)	10	dBW
TX. ANTENNA GAIN	61.2	51.2	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	79.8	58.2	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	50.4	57.4	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	1.4	1.5	dB
NOISE TEMPERATURE @ LNA INPUT	29.0	28.7	dB . K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT (NOT INCLUDING RAIN FADE)	113.8	103.0	dB . Hz
INFO. BIT RATE	87.0	87.0	dB . Hz
CHANNEL $E_b/N_0$ (EFFECTIVE SYSTEM)	26.8	16.0	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
RAIN LOSS MARGIN	13.2	2.4	dB

are as shown. In Table V-4, and the similar tables, the required margins that can be accommodated by a 5 meter system are identified by diagonal lines. The additional cases that can be accommodated by 7 meter and 12 meter systems are indicated by the circles and triangles, respectively. The 12 meter case includes all 7 and 5 meter cases and the 7 meter case includes all 5 meter cases. The results indicate that the 7 and 12 meter systems have somewhat better clear weather margin than the 5 meter system. If we now add adaptive power control in the uplinks and downlinks the following total margins are obtained.

NORMAL OPERATING PLUS ADAPTIVE POWER MARGIN

Antenna size (M)	Up-link pwr. inc.	Down-link pwr. inc.	Total Margin (dB)	
			U.L.	D.L.
12.0	4.9	8.75	24.9	18.35
7.0	4.9	8.75	20.2	13.65
5.0	4.9	8.75	17.3	10.75

Table V-5 shows the availability levels in each rain zone that can be attained using combined normal operating plus adaptive power margins. Consider now the effects of adding rate 1/2 FEC margin (8.8dB) to the previous margins. Table V-6 shows the availability levels in each rain zone that can be attained with a combination of normal operation, adaptive power, and/-

**Table V-4**  
**Trunking System Availability**  
**Normal Operating Margin Only**  
**Rain Attenuation in dB for Satellite at 90° W**  
**(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	△	④	X	X
C	30	20	△	△	X	X
D <sub>1</sub>	40	23	△	△	X	X
D <sub>2</sub>	45	28	12	△	③	X
D <sub>3</sub>	50	36	17	12	③	X
E	55	55	29	29	④	X
F	40	17	△	④	X	X

**Rain Attenuation in dB for Satellite at 90° W**  
**(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	⑬	X	X	X
C	30	45	△	X	X	X
D <sub>1</sub>	40	50	△	⑭	X	X
D <sub>2</sub>	45	63	28	△	X	X
D <sub>3</sub>	50	80	39	27	X	X
E	55	120	64	43	18	X
F	40	37	⑬	X	X	X

KEY: / 5.0 M system    0 7.0 M system    △ 12.0 M system

**Table V-5**  
**Trunking System Availability with**  
**Normal Operating & Adaptive PWR Margin**  
**Rain Attenuation in dB for Satellite at 90° W**  
**(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	/	/	/	/
C	30	20	/	/	/	/
D <sub>1</sub>	40	23	/	/	/	/
D <sub>2</sub>	45	28	13	/	/	/
D <sub>3</sub>	50	36	17	12	/	/
E	55	55	29	20	/	/
F	40	17	/	/	/	/

**Rain Attenuation in dB for Satellite at 90° W**  
**(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	18	/	/	/
C	30	45	17	/	/	/
D <sub>1</sub>	40	50	21	14	/	/
D <sub>2</sub>	45	63	28	18	/	/
D <sub>3</sub>	50	80	39	27	/	/
E	55	120	64	43	20	/
F	40	37	15	/	/	/

KEY: / 5.0 M system

0 7.0 M system  
 △ 12.0 M system

Adaptive Power Level Increase  
 UL 4.9 dB  
 DL 8.75 dB

**Table V-6**  
**Trunking System availability with**  
**Normal Operating, Adaptive PMR & FEC Margins**  
**Rain Attenuation in dB for Satellite at 90°W**  
**(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	18	8	8	8	8
C	30	20	8	8	8	8
D <sub>1</sub>	40	13	8	8	8	8
D <sub>2</sub>	45	28	18	8	8	8
D <sub>3</sub>	50	36	18	18	8	8
E	55	55	29	20	8	8
F	40	18	8	8	8	8

**Rain Attenuation in dB for Satellite at 90°W**  
**(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	18	8	8	8
C	30	45	27	18	8	8
D <sub>1</sub>	40	50	28	18	8	8
D <sub>2</sub>	45	63	28	18	8	8
D <sub>3</sub>	50	80	39	27	8	8
E	55	120	64	43	18	8
F	40	37	18	8	8	8

KEY: / 5.0 M system

FEC Gain 0.8 dB

0 7.0 M system  
 △ 12.0 M system



or adaptive FEC margins for the three antenna sizes. From Table V-6 it is seen that an availability of .9999 is not realized by any of the three antenna sizes.

If instead of FEC we consider the use of space diversity earth stations at the trunking nodes, a diversity gain of 12 dB can be realized for the case where the single site attenuation is 18.0 dB. The combined margin available, i.e., operating margin plus adaptive power plus diversity gain is:

COMBINED MARGIN

Antenna size (M)	UL (dB)	DL (dB)
12.0	36.9	30.35
7.0	32.2	25.65
5.0	29.3	22.75

Table V-7 shows the availability levels that can be attained in each rain zone with a combined margin made up of normal operating margin, adaptive power margin, and diversity gain at a fade depth to 18 dB.

From Table V-7 the 12 meter system will provide an availability of .9995 in one additional rain zone and an availability of .9999 in two additional rain zones over the 5 meter system on the downlink. There is no advantage to the 12 meter system over the 5 meter systems for the uplink.

In both cases a .9999 availability requirement for CONUS has not been met.

Table V-7  
**Trunking System Availability with**  
**Normal Operating Margin, Adaptive PWR & Diversity**  
**Gain Margins**  
**Rain Attenuation in dB for Satellite at 90° W**  
**(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	15	8	8	8	8
C	30	20	8	8	8	8
D <sub>1</sub>	40	23	8	8	8	8
D <sub>2</sub>	45	28	15	8	8	8
D <sub>3</sub>	50	36	17	15	8	8
E	55	55	48	20	8	8
F	40	17	8	8	8	8

**Rain Attenuation in dB for Satellite at 90° W**  
**(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	25	15	8	8	8
C	30	45	17	17	8	8
D <sub>1</sub>	40	50	28	15	8	8
D <sub>2</sub>	45	63	26	18	8	8
D <sub>3</sub>	50	60	39	27	8	8
E	55	120	64	43	10	8
F	40	37	18	8	8	8

KEY: / 5.0 M system  
 0 7.0 M system  
 △ 12.0 M system

Diversity Gain 12 db for 18 dB  
 Single Site Atten.  
 dB/dB above 18 dB

If the diversity gain increases dB for dB for single site attenuations greater than 18dB then a .9999 availability requirement will be met by all three antenna sizes.

The conclusion is that a 5 meter earth station with use of normal operating margins plus adaptive power control and space diversity will satisfy trunking system performance requirements, and larger antennas are not warranted.

#### 4.2 CPS STATIONS

Table V-8 gives a link budget for a CPS TDMA system at 32 MBPS uplink and 256 MBPS downlink burst rates. The available clear weather margin for the uplink is 10.7 dB, and for the downlink, 5.3 dB. The crossed out cases in Table V-9 show that on the downlink the clear-weather margin provides an availability of .995 in all rain zones and .999 in rain zones B, C, and F. An uplink availability of .995 is provided in all but rain zones E and D<sub>3</sub>.

With the margin increase due to adaptive FEC (8.8dB), the total uplink and downlink margins are 19.5 and 14.1 dB, respectively. The availability on the downlink is then .999 in all rain zones except rain zone E and on the uplink is then .999 in all rain zones zone except D<sub>3</sub> and E (circled cases).

The use of uplink adaptive power control to increase the ES power amplifier output from 11.7 to 19.2 dBw

**Table V-8**  
**CPS TDMA 32 Mbps Link Budget**  
**(Clear Weather, No Coding)**

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W)	16.7 (75W)	dBW
TX. ANTENNA GAIN	58.1	48.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	66.8	64.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	52.6	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.0	dB
NOISE TEMPERATURE AT RCVR INPUT	32.2	29.6	dB · K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT	99.3	102.9	dB · Hz
INFO. BIT RATE	75.6	94.0	dB · Hz
CHANNEL $E_b/N_0$	24.3	18.9	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	10.7	5.3	dB

**Table V-9**

**CPS System Availability with normal  
Operating Margin, Adaptive UL PWR, Adaptive FEC  
Rain Attenuation in dB for Satellite at 90°W  
(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	6	/	/	/
C	30	20	8	/	/	/
D <sub>1</sub>	40	23	9	⑧	/	/
D <sub>2</sub>	45	28	12	⑨	/	/
D <sub>3</sub>	50	36	17	⑫	/	/
E	55	55	29	20	/	/
F	40	17	6	/	/	/

**Rain Attenuation in dB for Satellite at 90°W  
(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	13	⑨	/	/
C	30	45	17	⑪	/	/
D <sub>1</sub>	40	50	31	⑭	/	/
D <sub>2</sub>	45	63	28	⑰	/	/
D <sub>3</sub>	50	80	39	△27	⑧	/
E	55	120	64	43	⑩	/
F	40	37	13	⑨	/	/

KEY: / Normal Operating Margin

⑧ Adaptive FEC-UL & DL  
△ Adaptive UL PWR

Margins  
PWR 14.5 dB  
FEC 8.8 dB

**Table V-10**  
**CPS TDMA 128 Mbps Link Budget**  
**(Clear Weather, No Coding)**

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W)	18.7 (75W)	dBW
TX. ANTENNA GAIN	58.1	48.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	66.8	54.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	52.6	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.0	dB
NOISE TEMPERATURE AT RCVR INPUT	32.2	29.6	dB - K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT	99.3	102.9	dB - Hz
INFO. BIT RATE	31.0	34.0	dB - Hz
CHANNEL $E_b/N_0$	18.3	18.9	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	4.7	5.3	dB

:U-43  
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**Table V--11**  
**CPS System Availability with Normal**  
**Operating Margin, Adaptive FEC, Adaptive UL PWR**  
**Rain Attenuation in dB for Satellite at 90°W**  
**(20 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	6	/	/	/
C	30	20	8	/	/	/
D <sub>1</sub>	40	23	9	⑥	/	/
D <sub>2</sub>	45	28	12	⑧	/	/
D <sub>3</sub>	50	36	17	⑫	/	/
E	55	55	29	20	/	/
F	40	17	6	/	/	/

**Rain Attenuation in dB for Satellite at 90°W**  
**(30 GHz)**

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	13	⑨	/	/
C	30	45	17	⑪	/	/
D <sub>1</sub>	40	50	21	△	/	/
D <sub>2</sub>	45	63	28	△	⑥	/
D <sub>3</sub>	50	80	39	△	⑧	/
E	55	120	64	43	⑩	/
F	40	37	13	⑨	/	/

KEY: / Normal Operating Margin  
 0 Adaptive FEC, UL & DL  
 △ Adaptive Power, UL

**Margins**  
 PWR 13.3 dB  
 FEC 8.8 dB

(83 watts) provides an uplink availability of .999 in all rain zones except rain zone E (triangle case).

Thus, the combination of clear weather operating margin, adaptive FEC margin, and adaptive uplink power control will provide an availability of .999 in all rain zones except E. In rain zone E an additional margin of 5.9 dB is required on the downlink and 16 dB on the uplink. Table V-10 gives the link budget for a TDMA CPS system with 128 MBPS uplink and 250 MBPS downlink burst rates. Table V-11 shows the availability achievable in the various rain zones using normal clear weather margin, adaptive FEC, and adaptive UL power control as in the previous examples. In this case the CPS up-link transmitter power must be increased to 25 dBw (316W). Again with the combined margin an availability of .999 is provided in all rain zones except rain zone E.

The additional margin required on the down-link and uplink to achieve a CPS system availability of .999 in rain zone E is 5.9 db and 16 db, respectively. An approach to resolve the problem is:

<u>Downlink:</u>	<u>Margin Gain</u>
decrease burst rate to 128 MBPS:	2.9 dB.
Increase zone E CPS antenna size to 5.0 meters	<u>3.0 dB</u>
TOTAL	5.9 dB



<u>Uplink:</u>	<u>Margin Gain</u>
- Increase zone E CPS ES antenna size to 5.0 meters	3.0 dB
- Customize UL transmission rate (FDM), for example 6.3 MBPS.	
Normal operation gain increase (vs. 128 MBPS)	7.0 dB
- Additional Adaptive UL Power Margin	<u>6.0 dB</u>
	16.0 dB

The adaptive up link transmitter power required in Zone E is then 26.2 dBw (330W).

The lower CPS DL and UL transmission rates would require on board switching to 128 MBPS TDMA downlinks and the ability to receive demodulate, and decode FDM uplinks. Connectivity between zone E CPS stations and CPS stations in the other rain zones would be accomplished in the on-board base band processor.

Additional study is necessary to identify other alternative design approaches to adequately service high rain rate areas with low cost earth stations.

## 5.0 NETWORK SYNCHRONIZATION

### 5.1 GENERAL CONSIDERATIONS

#### 5.1.1 TIMING (FRAME "PHASE" ACQUISITION)

Network synchronization, in any TDMA system requires that stations sharing a transmission channel time their burst(s) per frame so as not to interfere (overlap) with the other channel users. It also implies that the stations have some prior knowledge of when in the frame to receive bursts destined for them; this second aspect (receive timing) is not as critical and is usually solved by placing a "window" of a few bits on either side of the framing location at which the unique word designating start of a burst destined for that station is expected. Transmit timing, on the other hand, especially when utilizing a satellite relay, requires computing of the distance, and thus propagation delay, from each station to the satellite so that burst overlap can be avoided with minimum guard times between allocated burst assignments.

#### 5.1.2 FREQUENCY (FRAME "FREQUENCY" ACQUISITION)

The transmitter data clock at any TDMA station determines the local frame rate (e.g. 128,000 bits per frame for a 128 Mbps channel using a 1 msec frame duration). This clock is usually locked to the station's master oscillator which also determines the RF transmit frequency and the receiver's local oscillator

frequency at the downconverter. The accurate frequency locking of all network oscillators (including the MO in the satellite) can improve demodulator performance both at the satellite (in the case of a CPS BPU technique) and at the ground station (for both the CPS and trunking networks). This enables the use of narrower filters in the demodulator's carrier and bit timing recovery circuits which in turn enables shorter preambles, for a given  $E_b/N_0$ , at the beginning of each burst. This is desirable in that it increases TDMA throughput since such preambles act as overhead, much the same as guard time. The following paragraphs, however, do not address the required or achievable network frequency accuracies for an operational system. It is felt that accurate frequency locking which includes tracking the satellite doppler frequency shifts will impact the cost of both the MCS and the earth station hardware and will require further analysis and perhaps demonstration during the experimental flight programs.

## 5.2 TIMING SYNCHRONIZATION - TRUNKING TDMA

### 5.2.1 CLOSED LOOP SYNCHRONIZATION

A closed loop system for acquiring trunking TDMA transmit burst synchronization can be implemented by having each trunking station transmit a local unique word (LUW) during a satellite switch (SS), "loopback" mode, once per frame. It also requires the MCS which

has acquired the SS to transmit a reference unique word (RUW) to each of the downlink beams at a known position, e.g. at the beginning of each of the modes which connect the MCS uplink beam with each of the downlink beams. Transmit timing is then continuously advanced or retarded to maintain steady state synchronization (a fixed number of bits or symbols between the reception of the RUW and the reception of the LUW. Accuracies of  $\pm 20$ nsec (a few symbols) can probably be achieved.

#### 5.2.2 OPEN LOOP SYNCHRONIZATION

Open loop synchronization of transmit burst timing is accomplished by calculating the slant range from each trunking station to the satellite periodically, and interpolating, via a simple range rate calculation, timing adjustments between range fixes (if needed). This requires fairly accurate ranging from two to four trunking stations to the satellite, and can be accomplished with turnaround ranging tones or via looped back unique words at each ranging station. From these (2 to 4) slant range measurements the range from any other trunking station can be simply calculated utilizing a "linearized" approximation to the quadratic range equations requiring only  $i^2$  multiplications plus 8 additions per range update. The accuracy of the original range measurements is degraded by at most a factor of two using this technique.

### 5.2.3 TRUNKING TDMA SYNCHRONIZATION RECOMMENDATION

The open-loop method of Paragraph 5.2.2 is recommended for the following reasons:

1. Ranging will be required in any event for satellite Station Keeping (and perhaps to obtain parameters for computing CPS station open-loop antenna pointing instructions).
2. The need for the (m) mode RUW and the (n) loopback LUW transmissions and associated burst synchronization circuitry is eliminated (where m = number of beams and n = total number of trunking earth stations).
3. The initial accuracy and frequency of update of the slant range measurements can be relaxed (guard time for 100-200 stations does not greatly impact overall frame efficiency) resulting in less expensive MCS processor capability.

### 5.3 TIMING SYNCHRONIZATION - CPS

#### 5.3.1 CLOSED LOOP SYNCHRONIZATION

The RUW/LUW technique described in Paragraph 6.2.1 is not practical for the CPS network since the uplinks are separated, in time, from the downlink due to BPU processing. A closed loop approach is possible in which the satellite assists by monitoring each uplink channel and counting the number of symbols between start-of-frame to reception of a CPS transmitted UW. This information is then transmitted back to the CPS on its downlink channel. The CPS then simply compares

the satellite measured count with its preassigned burst position count and advances or retards its transmit bursts accordingly.

### 5.3.2 OPEN LOOP SYNCHRONIZATION

Open loop synchronization can be accomplished for the CPS network exactly as in the trunking network of paragraph 5.2.2. The required range measurements (or calculated ranges for each station) are transmitted from the MCS to the CPS user via the OW.

### 5.3.3 CPS - SYNCHRONIZATION TIME RECOMMENDATION

Since the closed-loop technique requires increased BPU logic and complexity, and since there appears to be no "common" trunking/CPS closed loop approach, it is recommended that the open-loop method as described in Paragraph 6.2.2 be employed for the CPS scanning-beam network.

### 6.0 ASSESSMENT OF DUAL POLARIZATION AT 30/20 GHz

Some experience has been gained in dual polarization operation at the lower frequencies; however, extension of these results to the 30/20 GHz frequencies has not been validated. The experimental data on 30/20 GHz polarization isolation is also quite skimpy. We have based the following assessment on three sources: the NASA Propagation Effects Handbook, data collected with the RCA SATCOM system, and some reference articles that treat the subject.

## 6.1 PROPAGATION EFFECTS

### 6.1.1 NASA PROPAGATION EFFECTS HANDBOOK RESULTS

Table V-12 is extracted from the Handbook and shows a number of recommended formulas for computing the cross-polarization isolation at high frequencies. In these formulas, "A" is the attenuation in dB. Using the tables of attenuation calculated previously, we have computed the expected cross-polarization isolation; this is shown in Tables V-13 and -14.

### 6.1.2 RCA SATCOM RESULTS

Data for the predicted performance of the RCA SATCOM system are shown in Table V-15 for a number of CONUS locations. While these data are for 4/6 GHz, it is possible to scale them upward in frequency.

One researcher (T.S. Chu) has found a relationship to scale polarization isolation by frequency. The formula is valid between 3 and 30 GHz and is as follows:

$$XPI(f_2) = XPI(f_1) - 20 \log(f_2/f_1)$$

for the case of a given value of rain rate. This also corresponds to a given value of percentage of time. Hence, the RCA SATCOM data can be scaled in this way. The results of such scaling for the composite average values shown in Table V-15 are given in Table V-16

**Cross-Polarization Discrimination Versus Attenuation**  
(Least-Mean-Square Fits)

Blacksburg, VA		Elevation Angle = $\theta$
Period	Frequency/Polarization	$XPD = \tilde{a} - \tilde{b} \log_{10}(A)$
Aug 1977	11 GHz, RHCP (CTS, $\theta = 33^\circ$ )	$XPD = 44.7 - 22.6 \log_{10}(A)$
CY 1978	11 GHz, RHCP (CTS)	$XPD = 36.3 - 16.2 \log_{10}(A)$
Aug 1977	19 GHz, vertical (COMSTAR, $\theta = 44^\circ$ )	$XPD = 47 - 24.5 \log_{10}(A)$
Sept 1977	19 GHz, horizontal (COMSTAR)	$XPD = 37.1 - 20.0 \log_{10}(A)$
CY 1978	19 GHz, vertical (COMSTAR)	$XPD = 43.9 - 16.6 \log_{10}(A)$
Aug 1977	28 GHz, vertical (COMSTAR)	$XPD = 36.4 - 15.4 \log_{10}(A)$
CY 1978	28 GHz, vertical (COMSTAR)	$XPD = 31.2 - 7 \log_{10}(A)$

**Estimated Cross-Polarization Isolation for Various U.S. Sites Due to Rain**  
(Distribution of Rain Drop Canting Angles Assumed)

Category	Site	$\beta$	4 GHz			6 GHz		
			0.01%	0.1% (dB)	1%	0.01%	0.1% (dB)	1%
2	Boston	21.58	21.5	31.1	40.5	21.2	30.5	37.2
2	New York	21.50	25.5	35.1	41.4	22.1	31.1	38.2
2	Houston	16.72	30.6	39.9	46.3	26.5	36.1	42.6
2	Chicago	32.16	27.8	37.3	43.0	21.1	33.5	40.3
2	Denver	11.79	29.6	39.0	45.4	25.7	35.2	41.8
4	San Diego	51.87	31.9	41.7	47.1	30.8	37.8	43.4
4	Los Angeles	50.47	31.6	41.4	47.1	30.5	37.5	43.1
3	San Francisco	46.10	32.9	40.6	46.2	28.8	36.8	42.5
3	Seattle	35.22	30.8	38.6	44.0	26.9	34.9	40.8
1	Tampa	38.37	26.7	36.9	44.7	22.8	33.2	41.3
Average (Canting Angle Distribution)			29.7	38.5	44.6	25.9	34.7	41.1
Average (Constant Canting Angle)			23.7	32.5	38.6	19.9	28.7	35.1



**Table V-13**  
**Cross-Polarization Isolation at 20 GHz**  
**(dB)**  
**(40° elevation angle)**

Climate Zone	Percent of Time XPI is Exceeded				
	0.01	0.05	0.1	0.5	1.0
B	25	31	34	44	44
C	23	30	34	44	44
D <sub>1</sub>	21	27	30	39	44
D <sub>2</sub>	19	25	28	36	44
D <sub>3</sub>	18	23	26	34	39
E	15	20	23	34	39
F	24	32	36	44	44

**Table V - 14**  
**Cross-Polarization Isolation at 30 GHz**  
**(dB)**  
**(40° elevation angle)**

Climate Zone	Percent of Time XPI is Exceeded				
	0.01	0.05	0.1	0.5	1.0
B	21	23	25	28	29
C	20	23	24	28	29
D <sub>1</sub>	19	22	23	26	29
D <sub>2</sub>	18	21	22	26	28
D <sub>3</sub>	18	20	21	25	27
E	17	19	20	24	27
F	20	24	25	28	29

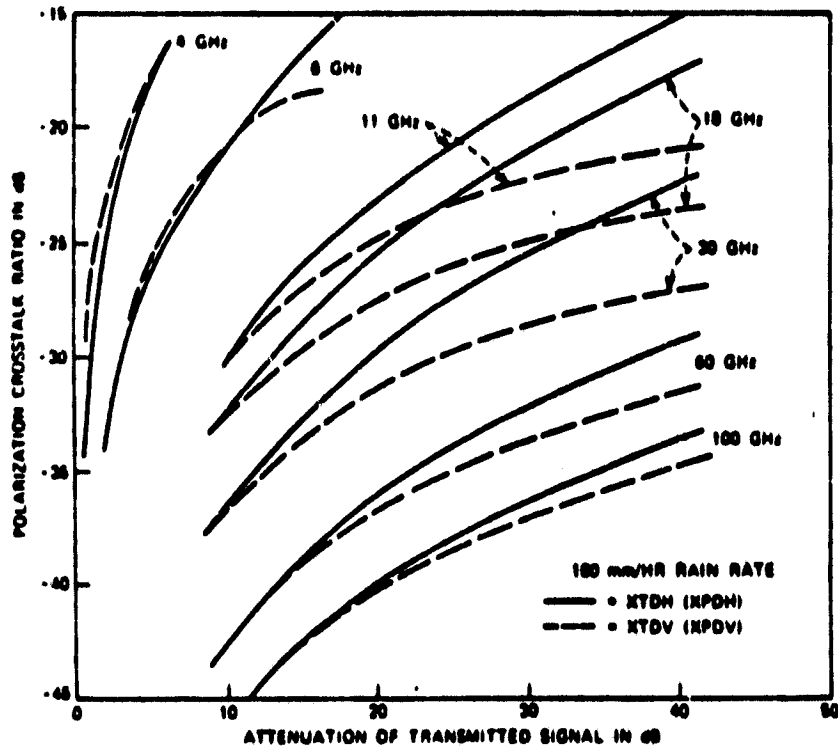
**Table V-16**  
**RCA SATCOM Data**  
**(Scaled to 20/30 GHz)**

	Percent of Time XPI Is Exceeded		
	0.01	0.1	1.0
20 GHz	16	25	31
30 GHz	12	21	27

These values compare favorably with those presented in Tables V-13 and -14. It should be noted that data on frequency scaling of such values is even skimpier than that for the direct calculation of cross-polarization. Earlier calculations by Chu, which are shown in Figures V-1 through V-3, demonstrate the general variation of cross-polarization with attenuation. The independence of the isolation from rain rate (for a constant attenuation) is also shown.

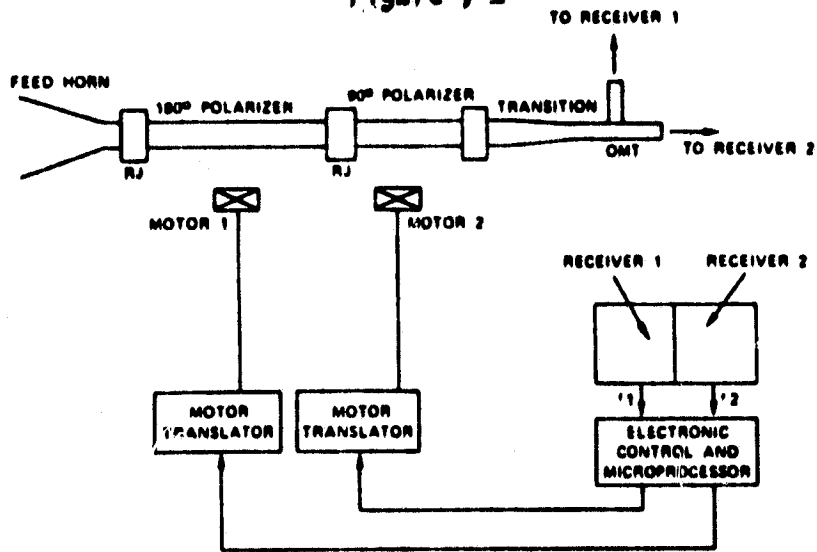
### 6.1.3 CONCLUSIONS

Rain caused depolarization should not prove to be a problem at 30/20 GHz. The main reason for this is that the attenuation caused by rain becomes severe at much lower rain rates than does the depolarization. The digital systems which are contemplated for the 30/20 GHz bands, particularly those employing coding,



**CALCULATED RAIN-INDUCED CROSS-POLARIZATION OF HORIZONTALLY AND VERTICALLY POLARIZED WAVES**

**Figure Y-1**



**Figure V - 4**

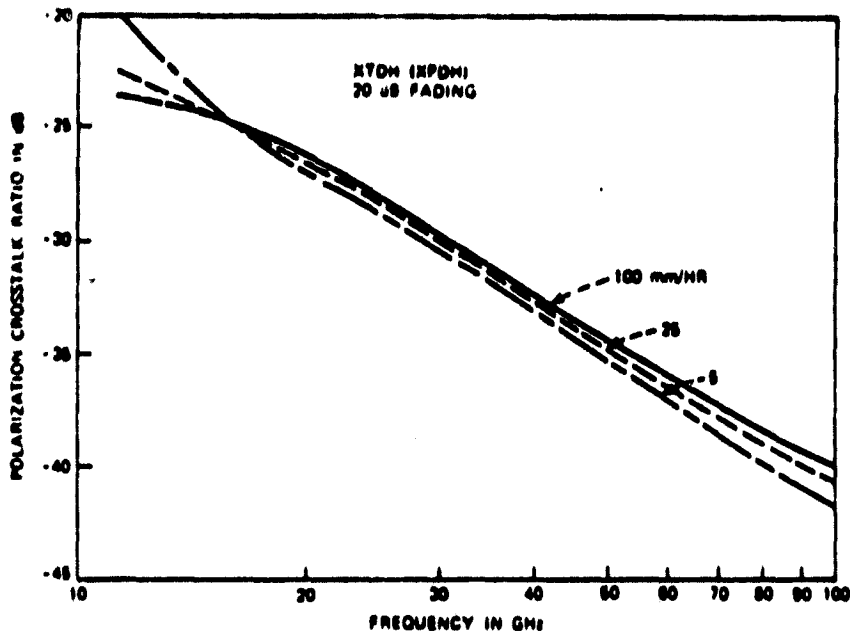


Figure V - 2

CROSS-POLARIZATION AT 20-dB FADING  
FOR VARIOUS RAIN RATES

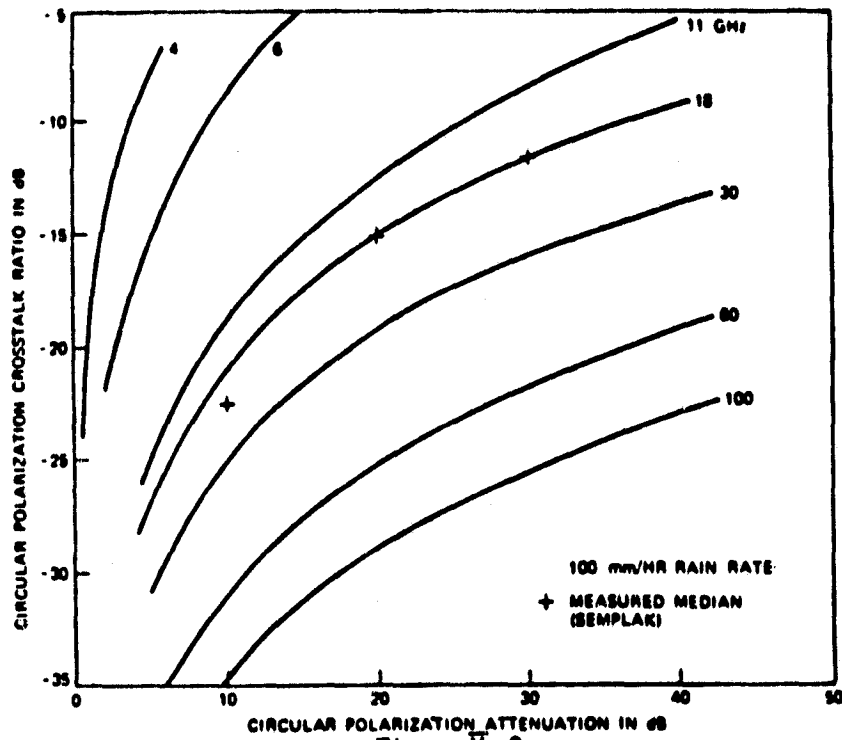


Figure V-3

CALCULATED RAIN-INDUCED CROSS-POLARIZATION  
OF CIRCULARLY POLARIZED WAVES

should be able to withstand cross-polarization interference at a -20 dB level without significant degradation. This provides an availability of about 99.95 percent.

## 6.2 CROSS-POLARIZATION PERFORMANCE OF ANTENNAS

Generally, the cross-polarization isolation of antennas is greatest at beam-center, and degrades as the scan angle increases. In actual antennas, the maximum of the cross-polarization isolation will not occur exactly on-beam, due to imperfections in the antenna and feed structure. This angular error is generally small in well-designed antennas.

For the earth station antenna, the above is of relatively little importance, since the tracking system can keep the pointing within tolerable bounds. For the spacecraft antenna, this degradation of polarization isolation is significant due to the multibeam or scanning beam system employed. Both systems need (relatively) larger scanning angles than would otherwise be encountered. While it is apparent that the antenna design will be complicated by this consideration, it is impossible to say (at this time) if the required levels of isolation can be achieved in practice.

### 6.2.1 POLARIZATION TRACKERS

Two polarization tracking mechanisms have been developed for satellite earth station use: one at COMSAT Labs, and another at NASA/Langley Research Center.

Both systems are motor-driven. The COMSAT system has been built and tested at 4 GHz; the NASA system is patented, and therefore must have involved a working prototype. No information concerning the frequency of operation is given.

The COMSAT adaptive polarization connection network is simpler of the two. It corrects for differential phase but not for differential attenuation; this is consistent with the C-band design. At C-band, differential attenuation is negligible because the fundamental attenuation is so low. At higher frequencies this would not be true, and a more complex correction system would be needed.

A block diagram is shown in Figure V-4. The system requires two CW beacons, one at each polarization, to be transmitted from the satellite. It is necessary to incorporate a microprocessor in the system because the relationship between the polarization errors and the position of the two rotatable polarizers is not a simple one, ruling out the use of direct feedback control. The microprocessor is capable of resolving the complex functions involved.

For the linear polarizations, and in systems where cost is a significant consideration, we expect that a simplified version of such a network may be developed. This would provide a reduction in cross-polarization with a reduced cost.

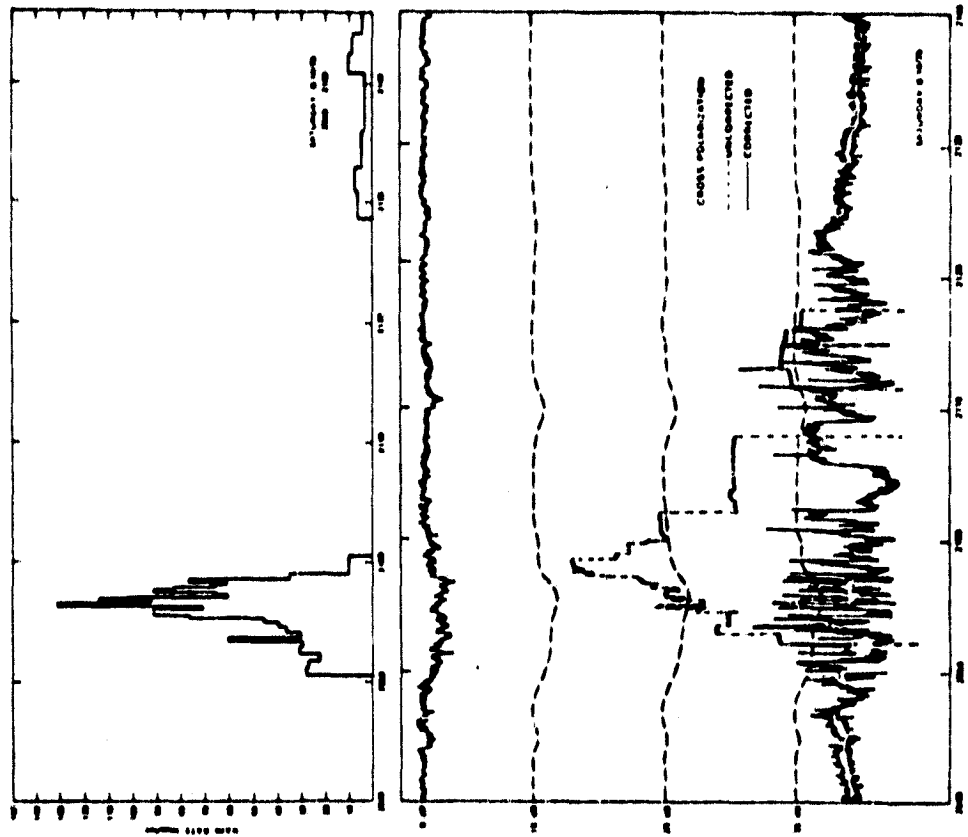


Figure V-5

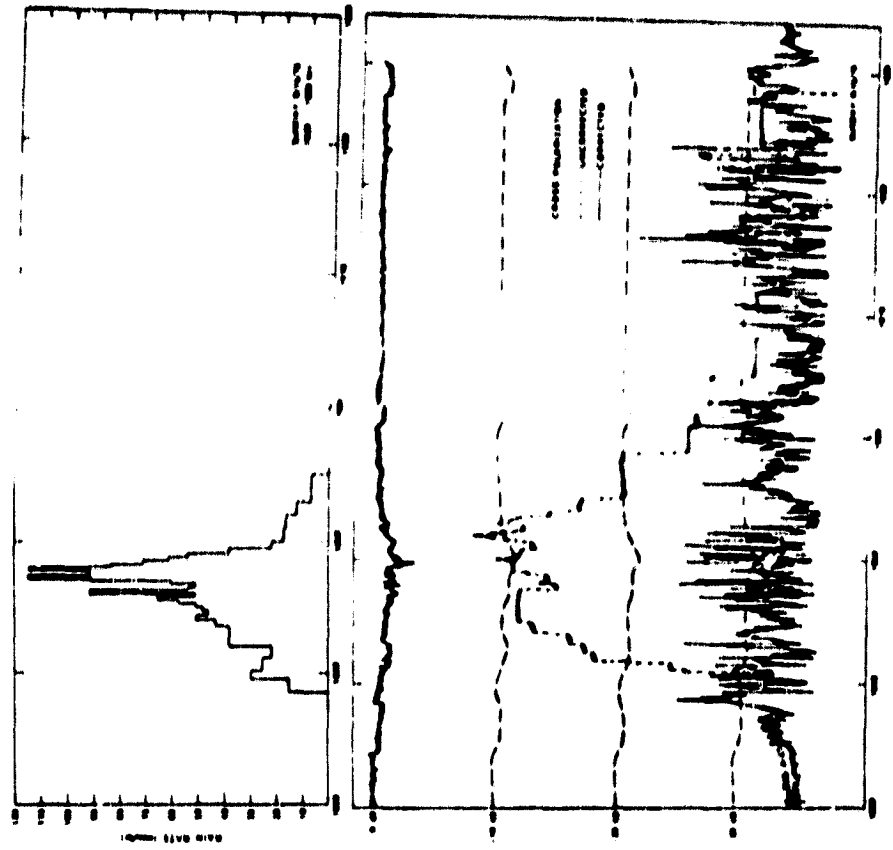


Figure V-6

Some of the experimental results for this polarization correction network are shown in Figures V-5 and V-6. Long-term statistical figures for the system have not been published. However, if the correction network proves to be reliable, the degree of correction shown in the figures, about 15 dB maximum, should be approached on a long-term basis.

The NASA/Langley polarization correction network is more complex. It is also adaptive, and involves motor-drive. This system features active cancellation of the cross-polarized component. The implementation also requires two CW pilots for operation. A block diagram is shown in Figures V-7 and V-8.



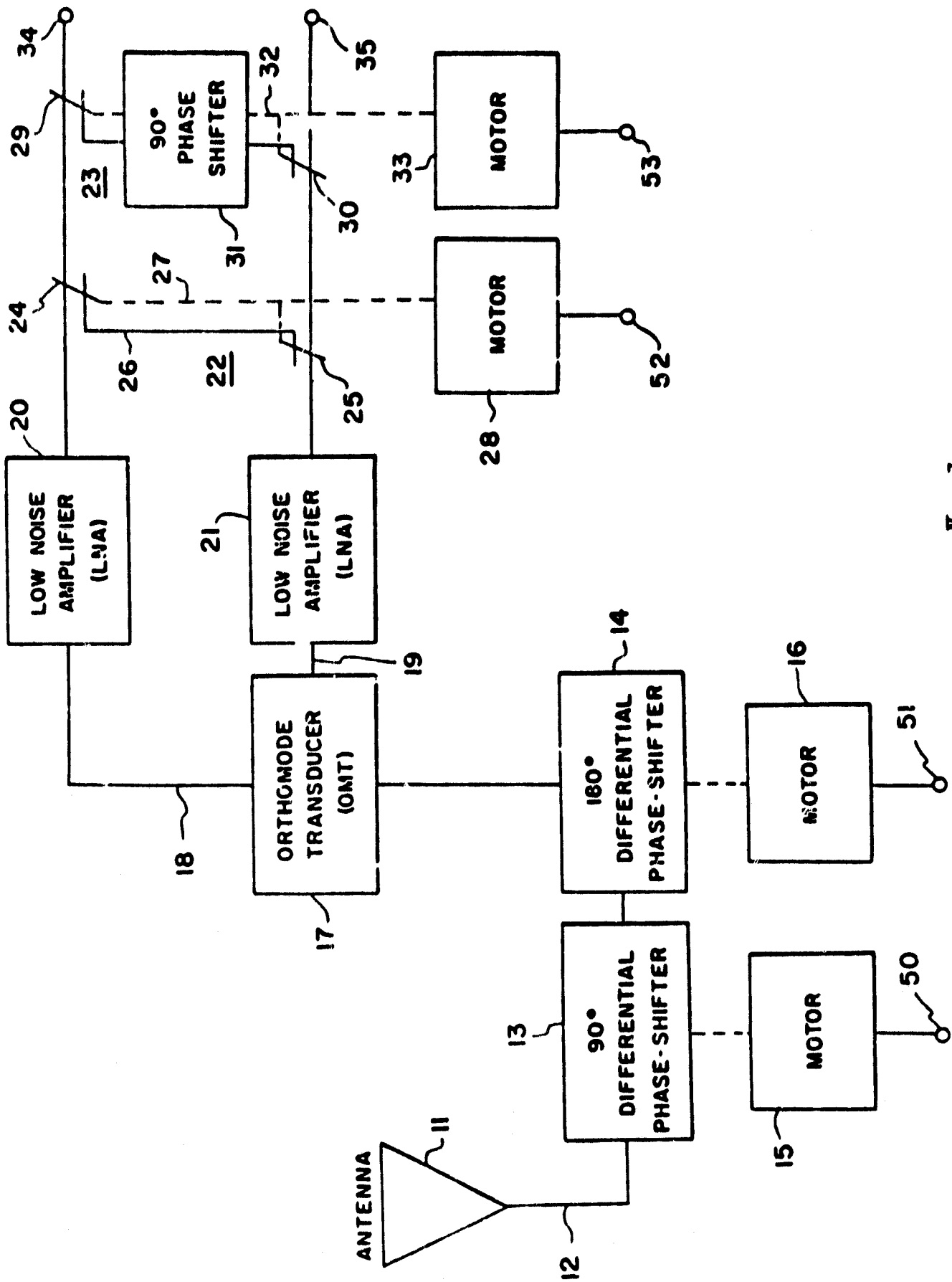


Figure V - 7

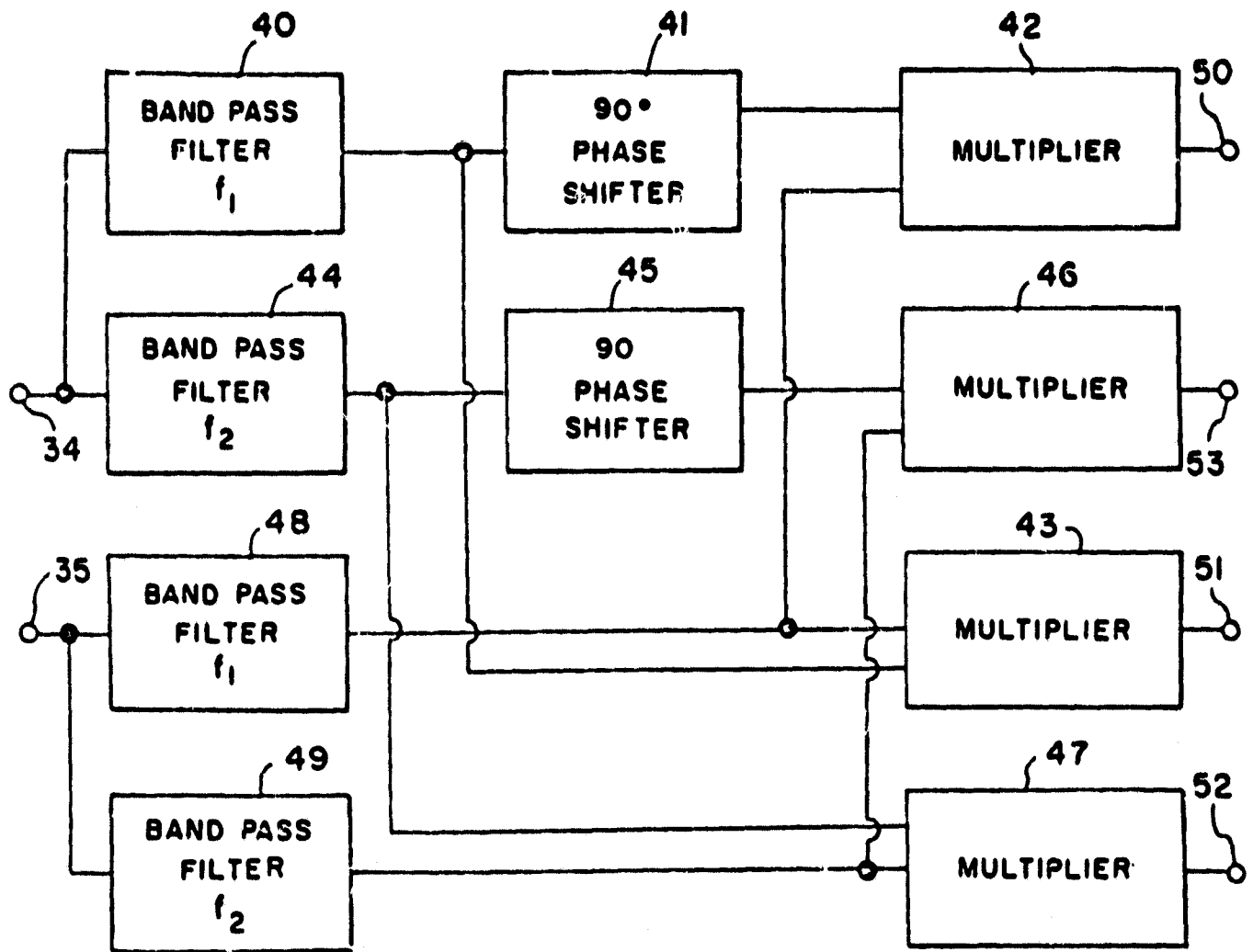
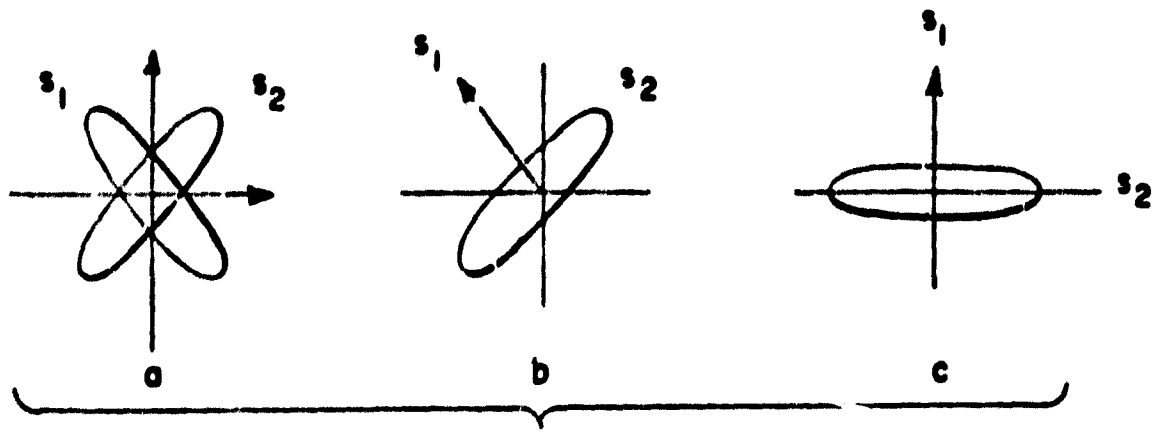


Figure V - 8

OPERATIONAL SYSTEM FUNCTIONAL REQUIREMENTS1.0 STATEMENT OF THE PROBLEM

The purpose of this section is to derive a consistent set of functional requirements for the space, ground, and control segments of a Western Union class carrier operational 30/20 GHz system. These should meet the primary objectives of capacity, availability, interconnectivity, and cost for a selected baseline system based upon a projected share of the accessible market in the 1990-2000 period.

2.0 INTRODUCTION

The baseline system chosen, as a result of the analyses of traffic, availability, and general technical considerations in Sections I through V, provides a combined Trunking and CPS service with an expected throughput capacity of about 4 GBPS trunking and 2 GBPS CPS.

The functional requirements for the two services are derived separately, although the technical solution for the combined system will be optimized by the development of elements common to both services. For example, in the space segment, the CPS users located in the fixed trunking beam areas can access the same beams (possibly on a separate frequency); similarly, smaller trunking terminals, not covered by a fixed beam, can access one of the CPS scanning beams. Also many control station functions such as network synch-

ronization, antenna pointing and satellite switch programming will have commonality between the trunking and CPS services.

### 3.0 METHODOLOGY

The achievable satellite characteristics of the TRW and Hughes Baseline System Concepts (number and size of antenna beams, available RF power at 20 GHz, weight limitations, etc.) were combined with the Earth Station characteristics (reasonable antenna size, HPA power, LNA noise temperatures, etc.) to derive the uplink and downlink budgets shown in Sections IV and V. Network control functions, including architectures, derived in the Ku-band Advanced Westar program, where applicable, were then added to develop a coherent set of functional requirements.

Frequency re-use through spatially separated spot beams will provide more than enough total bandwidth to meet the total 6 GBPS throughput capacity for the combined Trunking and CPS services. Thus, from the point of view of a single user (carrier), frequency re-use through polarization, that is the use of two orthogonal polarizations at the same frequencies in the same or overlapping beams, is not required.

However, the prime portion of the orbital arc, resulting in elevation angles of about 30°, is limited to about 15°. Several carriers, each with 2 or more satellites, will all want to be located in this prime

portion. Thus orthogonal polarization was considered for the operational system, and the corresponding requirements listed where applicable. Whether or not the operational system can utilize some degree of polarization re-use of course will ultimately depend on the test results from the Demonstration System, but it is certainly a most desirable goal and therefore should be included at this time for an operational system.

The need for an intersatellite link, although useful for extending the Ka-Band orbital arc as well as providing interconnectivity with other networks, will not be considered as part of this Trunking/CPS baseline operational system. However it can remain a viable candidate for the Demonstration System.

#### 4.0 GENERAL OPERATIONAL SYSTEM DESCRIPTION

The baseline operational system that can meet Western Union's requirements for capacity, connectivity, availability and minimum overall system costs is summarized here.

#### 4.1 TRUNKING SERVICE

The basic trunking service is provided by 18 fixed, .3° beams each connected to a 500 MHz, dual output power (75W/10W) transponder. Even if orthogonal polarization proves to be unfeasible, three separate carrier frequencies (each with 500 MHz bandwidth), each reused on 6 of the fixed beams, should provide the

required C/I through adequate sidelobe isolation, as specified below. Thus a frequency re-use factor of six is achieved. Complete trunking interconnectivity is provided using 500 Mbps, Satellite Switched TDMA channels which requires a 20 x 20 IF switch matrix in the satellite, programmable from a Master Control Station to satisfy changing traffic patterns. Although the maximum throughput is 9 Gbps, this will only be achievable for a completely balanced traffic pattern, i.e. the sum of all the traffic demands at each station would have to be 500 Mbps.

A more realistic achievable throughput, including secondary trunking stations serviced by scanning beams as described below, should be about 4 GBPS.

#### 4.2 CPS SERVICE

The basic CPS service can be provided by the additional satellite payload of six 500 MHz transponders, each with two 75 watt TWTAs connected to one .3° scanning beam. To reduce off-axis scanning losses 3 beams will scan Eastern CONUS and 3 beams will scan Western CONUS for a frequency re-use factor of three. Uplinks will use FDM to provide subchannel combinations of 32 Mbps and 128 Mbps burst rates (eg. three 128 Mbps and four 32 Mbps uplinks per beam). Each uplink subchannel in turn can utilize TDMA to accommodate sub-groups of CPS users, within a common scanning beam position, whose aggregate throughput is

less than or equal to 128 Mbps or 32 Mbps. The downlinks will use two 256 Mbps TDMA carriers per beam. The uplinks are routed through down converters to a Baseband Processor which demodulates and performs FEC decoding (if required by uplink rain attenuation). The baseband processor then routes each burst to the assigned downlink via an FEC encoder (if required by downlink rain attenuation), a 256 MBPS modulator, an upconverter, and a 75 watt TWTA that feeds the scanning beam downlink. Although the 6 transponders represent a maximum CPS throughput of 3 GBPS, because of the multiple uplinks (up to seven per scan position) and downlinks (two per scan position), it will be very unlikely that the CPS geographical traffic demand will utilize the full throughput. The realizable throughput will be about 2 GBPS.

#### 4.3 TRUNKING/CPS CROSS-CONNECT CONSIDERATIONS

Secondary trunking stations (not located in the 18 fixed-beam areas) can be added to the trunking Network and serviced by the scanning beam. One of the three East scanning beams will "visit" each of these smaller trunking stations once per TDMA frame, and similarly one of the West scanning beams is assigned to service those smaller trunking stations which are in the Western area. In the satellite these uplink/downlink signals are coupled to the receiver input/TWT output of one or two of the least-used 18 fixed-beam

transponders; it is only necessary to program the receive/transmit TDMA bursts of these additional trunking stations and that of the fixed-beam transponder(s) so that they do not overlap at the satellite. No on-board CPS-trunking cross-connect, with its attendant drain on the Baseband Processor Unit (BPU) throughput capacity, should be necessary to serve presently identified requirements. Instead, any required CPS-trunking cross-connections will be established on the ground at one or more trunking stations having co-located CPS terminals (see below). While this does introduce extra delay for the affected circuits, the overall system effects will not be significant and the reduction in satellite complexity an important consideration.

CPS users located within fixed-beam areas, but not colocated at trunking stations should be serviced by the scanning beam in the same manner as the CPS users not in fixed-beam areas. This alleviates the coordination between the two services which would be required if the fixed-beam CPS users shared the trunking frequency channel on a TDMA basis; it also alleviates the linearity requirement if the satellite trunking transponders had to accommodate multiple FDM uplinks (e.g. three 128 MBPS and four 32 MBPS simultaneous uplinks). Also many of these "fixed-beam" CPS users can be expected to be located within the coverage area



of high-capacity trunking terminals (e.g. New York, Chicago, Los Angeles) which could be filled to their 500 MBPS throughput capacities.

For CPS users co-located (or connected by terrestrial local loop) to a trunking terminal, two approaches can be considered. The first approach is to add CPS ground equipment (HPA, LNA, up/down converters, modems and codecs) to one of the pair of space-diversity trunking stations, in which case these CPS users are serviced like all other CPS users. Thus no additional antenna is required. The second approach would be to share the trunking up/down links on a TDMA basis which would cause increased cross-connect complexity in the spacecraft payload. For the reasons stated in the preceding paragraph, the first approach is recommended at this time. At the most, it would require equipping only 18 main trunking terminals with CPS transceivers, which would have a negligible impact on total system costs.

#### 4.4 SUMMARY OF PERFORMANCE OBJECTIVES

##### 4.4.1 THROUGHPUT CAPACITY

The maximum realistic throughput capacity for the first Western Union class system to serve the accessible 30/20 GHz market has been estimated in Section II at 4 Gbps Trunking and 2 Gbps CPS.

##### 4.4.2 LINK AVAILABILITY

The uplink and downlink rain margins are sized to

achieve an availability of .9999 for Trunking and .9950 to .9990 for CPS service at a user BER of  $10^{-7}$ .

#### 4.4.3 TDMA SYNCHRONIZATION

Open loop synchronization, utilizing slant range measurements from (up to) 4 trunking stations sent to all Earth Stations via Order Wire from the Master Control Station (MCS) will provide TDMA burst synchronization. In addition the Master Frequency Generator (MFG) in the spacecraft will be frequency controlled (using a disciplined PLL) by uplink command from the MCS, so that the only significant frame-to-frame timing and frequency error contributions will be due to satellite motion. These will be tracked out utilizing computed range rate at each station. The combined guard-time plus preamble (required for carrier and bit-timing recovery of the demodulators) should be less than 500 nanoseconds for the initial operating system. For a 1,000 station CPS network accessing the 6 CPS scanning beams, each with two 256 MBPS downlinks, there will be an average of 83 CPS users per TDMA downlink. Since each CPS users needs to burst once per frame there will be  $83 \times 500 \text{ nsec} = 41.5 \text{ usec}$  lost for guard-time/preamble per 1,000 usec frame (1 KHz frame rate). This represents an average TDMA frame efficiency of over 95%. The allocation of the 500 nanoseconds between guard-time and preamble depends upon the accuracy and frequency of the range measurements and will

also be influenced by the settling time of the scanning beam at each spot position. If many more than 1,000 CPS users per satellite are deployed at a later date, the ranging and frequency accuracy can then be increased to maintain TDMA frame efficiency.

#### 4.4.4 CONNECTIVITY

Full interconnectivity will be possible between all pairs of Trunking stations via a 20 x 20 Satellite Switch. Full interconnectivity is required for the CPS service and is provided by the Baseband Processor, with reprogrammable routing under control of the MCS. No absolute requirement for Trunking/CPS interconnectivity in the Satellite Baseband Processor has been identified at this time; the interconnectivity can be provided at the Trunking Stations.

Similarly, although DAMA 64 Kbps channel reassignments can be made by the MCS via the satellite Baseband Processor, this capability does not have to be implemented at full speed and maximum throughput efficiency in the initial system.

#### 4.4.5 THIN-ROUTE CONSIDERATIONS

Until CPS station costs come down to under \$50,000, it is unlikely that stations with less than 24 voice-channel capability (1.5 MBPS) can be justified; this implies that the first few hundred CPS stations will employ some degree of concentration of low capacity users within a local area. Thus the initial system will not have "tailored" low bandwidth up/down links.

#### 4.4.6 FREQUENCY PLAN

As described in Paragraphs 4.1 and 4.2, there will be 3 trunking channels and 2 CPS channels each approximately 500 MHz wide. If orthogonal polarization is used, the total spectrum occupancy can be reduced by half to 1.25 GHz. This may require dual feeds at some of the Earth Stations depending upon the outcome of the polarization re-use experiment. In addition a ranging/command and a Telemetry link of approximately 1 MHz bandwidth each will be required. Step-track at all of the Trunking stations and at some of the CPS stations may require a beacon other than the telemetry carrier, that is at a lower frequency (S or C Band), so that these stations may continue to track properly during rain conditions.

### 5.0 OPERATIONAL SYSTEM FUNCTIONAL REQUIREMENTS

#### 5.1 TRUNKING SERVICE

##### 5.1.1 TRUNKING - SATELLITE COMMUNICATIONS SUBSYSTEM

###### 5.1.1.1 NUMBER & SIZE OF BEAMS

The satellite will provide 18 fixed-beams of  $.3^\circ$  beamwidth pointed towards the 18 largest trunking station cities plus two scanning-beams of  $.3^\circ$  beamwidth of which at least one can be pointed to any one of a set of contiguous positions covering the CONUS area. One scanning-beam can service half of CONUS, and the other service the remaining half, to reduce off-axis scanning losses. Scanning beam positioning will occur at

a repetitive frame rate (1 KHz) programmable by ground command. See Section 5.2.1 for other scanning beam parameters.

#### 5.1.1.2 CONNECTIVITY

The satellite will provide a 20 x 20 matrix switch at the IF frequency which will allow 500 Mbps QPSK Trunking interconnectivity of any uplink beam to any downlink beam. The switch will repeat each connectivity state (mode) at the frame rate (1 KHz) with a maximum of 100 modes per frame.

#### 5.1.1.3 TRANSPONDERS

One transponder of 500 MHz nominal bandwidth will be provided for each beam. This will have dual output power at 20 GHz of 75w or 10w switchable by ground command to provide downlink rain response. A common IF frequency, selected to minimize spurious inband modulation products, will be used to allow the TDMA switch to connect the receive half of each transponder to the transmit half of any transponder. The trunking TWTA's will operate near saturation, since intermodulation is not a problem with a single carrier per transponder.

The frequency response and linearity of each transponder will be controlled over the central 315 MHz so that for any of the  $20 \times 20 = 400$  paths, and for a received flux density input range of 20 dB, there will be an acceptable BER degradation for TDMA 500 Mbps

QPSK modulation. These specifications cannot be determined until the ground segment's frequency response and linearity are also budgeted, but critical parameters which must be controlled are:

- Amplitude Flatness
- Group Delay
- AM-to-PM Conversion
- Phase Noise
- Out-of-Band Response

#### 5.1.1.4 SATELLITE EIRP

The EIRP for each trunking beam will be  $\geq 66.95$  dBW for the High Power Mode and  $\geq 58.2$  dBW for the low Power Mode. The satellite power supply will be sized to enable continuous operation of an average of one transponder in the high power mode. That is, for 20 beams, the worst-month 20 GHz rain margin will require downlink high-power for an average of about 1 hour per day per beam.

#### 5.1.1.5 SATELLITE G/T

The Satellite G/T for each trunking beam will be  $\geq 21.4$  dB/ $^{\circ}$ K.

#### 5.1.1.6 FIXED-BEAM ANTENNA PATTERNS

The fixed-beam antenna patterns will provide sidelobe isolation  $\geq 30$  dB between co-channel beams within their 3 dB contours on the same polarization and (if polarization frequency re-use is employed)  $\geq 35$  dB clear-sky isolation between orthogonal polarizations within the same beam.

The fixed-beam pointing will be maintained to within one-fourth beamwidth (one-half beamwidth during station keeping maneuvers) on all beams by automatic control of the spacecraft's attitude via monopulse tracking feeds on at least three beams. The nominal pitch, roll, and yaw offsets from an earth-centered coordinate system will be changeable by ground command.

#### 5.1.1.7 SATELLITE MASTER OSCILLATOR

The satellite master oscillator (MO) provides all up and down converter local oscillator frequencies and the frame and mode timing for the 20 x 20 TDMA switch. The MO will be frequency controlled by ground command from the MCS using a "disciplined PLL" technique. The short term frequency stability of the MO will be  $\leq 1 \times 10^{-11}$  per second.

#### 5.1.1.8 TELEMETRY AND COMMAND

Critical parameters will be continuously telemetered to the MCS on a separate Telemetry downlink channel, possibly including uplink received power levels for each beam.

A separate uplink command channel will be provided to enable MCS control of TWTA High/Low Power Modes, Satellite Switch Mode Sequence, Scanning Beam pointing for the Secondary Trunking stations, MO frequency control, attitude control bias offsets and other "housekeeping" functions including switching in redundant units.

#### 5.1.1.9 REDUNDANT UNITS

The fixed beam transponders should have common units enabling a 1-for-N redundancy for failed units. N is to be determined based on payload weight constraints and unit reliability. Units in critical paths such as the  $n \times n$  Satellite Switch and the MO should have at least 1 for 1 redundancy. All redundant units are switchable by ground command.

#### 5.1.2 TRUNKING - GROUND TERMINALS

##### 5.1.2.1 SPACE DIVERSITY

Space diversity earth-station pairs, spaced by 8 to 10 km are required at each Trunking node. A terrestrial diversity interconnect link and diversity switch will be implemented between the station pairs.

##### 5.1.2.2 TRANSMISSION MODE

The trunking stations will operate at 500 Mbps QPSK TDMA on both uplink and downlink. TDMA burst synchronization will be achieved "open-loop" via MCS slant range measurements and "linearized" range calculation for each station. The TDMA MUX will provide elastic storage so that the low-speed user interfaces can be assembled into high-speed TDMA transmit burst. The inverse operation will be provided for TDMA Receive bursts. A station will be able to transmit and receive up to 40 bursts per frame.

##### 5.1.2.3 EARTH STATION ANTENNA

The maximum antenna diameter will be 7.0 meters.



Dual, orthogonal linear polarization feeds and/or polarization tracking may be required at some trunking stations, if polarization frequency re-use is employed. Antennas will employ step-tracking to maintain a pointing accuracy of one-fourth the half-power beamwidth for steady-state winds at 30 mph with gusts up to 45 mph. The results of diversity-pair site experiments will determine whether the wind-loading may be relaxed (over that normally required at a single site).

#### 5.1.2.4 STATION EIRP

The station EIRP will be  $\geq 79$  dBW in the Low Power Mode and  $\geq 83.8$  dBW in the High Power Mode. The High Power Mode may be switched in or out for uplink rain response at each station as a result of downlink power monitoring or by command override by the MCS via the network Order Wire.

#### 5.1.2.5 STATION G/T

The station G/T will be  $\geq 28.6$  dB/°K.

#### 5.1.2.6 EQUIPMENT RELIABILITY

The trunking terminal equipment shall have an availability consistent with the rain margin availability of .9999. This would normally require completely, redundant units (except for the antenna) at each trunking station. However it may be possible to utilize the diversity link itself to provide some of the required redundancy, depending on the success of the diversity experiments.

## 5.2 CPS SERVICE

### 5.2.1 CPS - SATELLITE COMMUNICATIONS SUBSYSTEM

#### 5.2.1.1 NUMBER AND SIZE OF BEAMS

The satellite will provide 6 scanning-beams of .3° beamwidth which together can be pointed to any one of a set of contiguous positions covering the CONUS area. To reduce off-axis scanning losses, the three scanning beams will each have the capability to cover half of CONUS and the other set of three will each have the capability to cover the remaining half of CONUS. The scanning beams' pointing will occur at a repetitive frame rate (1 KHz) with dwell times at each position programmable by ground command from the MCS.

#### 5.2.1.2 CONNECTIVITY

Transmission channels will be Frequency Division Multiplexed (FDM) to provide up to seven channels per uplink beam (three at 128 MBPS and four at 32 MBPS) and two channels per downlink beam (each at 256 MBPS). Each uplink or downlink channel can in turn operate in a TDMA mode to accommodate multiple users per channel. Each uplink channel can be connected to any downlink channel through the Baseband Processor Unit (BPU). The BPU will provide the following functions:

- Demodulation of each uplink channel
- FEC Decoding (R=1/2, K=7, Soft Decision)-  
Switchable by Ground Command.
- Routing (including buffering and switching)-  
under control of instructions determined by  
ground command.

- FEC Encoding ( $R=1/2$ ,  $K=7$ )-Switchable by ground command.
- Modulation of each downlink channel.

There will be a maximum of eighteen 128 MBPS and twenty-four 32 MBPS uplink channels to be demodulated and twelve 256 MBPS downlink channels to be modulated by the BPU, due to the FDM subchannels formed by the 6 scanning beams. For rain response, a minimum of 8 decoders and 4 encoders should be available to be switched into any uplink or downlink channel respectively. Routing will be quantized in units of 64 KPS channels referred to the user rate, i.e. 64 bit blocks at the TDMA frame rate of 1 KHz. Thus any 64 KBPS sub-burst on an uplink channel can be routed to any downlink channel. The BPU will assemble all traffic destined for a particular downlink channel so as to require the minimum number of downlink bursts per frame per channel.

Connectivity to rain zone E requires further design study to develop an optimum approach. The increased margin can be obtained by tailoring uplinks and/or increased earth station antenna size.

#### 5.2.1.3 TRANSPONDERS

For each of the 6 scanning-beams there will be one equivalent transponder of 500 MHz nominal bandwidth and continuous output power at 20 GHz of two 75 watt power amplifiers. The input and output halves of the

transponders are connected via the BPU as described in Paragraph 5.2.1.2. The two CPS TWTAs are coupled at their outputs and routed to a single 20 GHz feed to form the two 256 Mbps downlink channels per beam; thus with only a single TDMA carrier per TWT operation near saturation will be possible.

The frequency response and linearity of each transponder will be controlled over the central 20 MHz, 80 MHz and 160 MHz for the 32 MBPS, 128 MBPS and 256 MBPS channels respectively to minimize overall BER vs Eb/No degradation. Critical parameters to be controlled include:

- Amplitude Flatness
- Group Delay
- AM-to-PM Conversion
- AM-to-AM Conversion (uplink channels)
- Phase Noise
- Out-of-Band Response
- Adjacent Channel Interference (Downlink Channels).

#### 5.2.1.4 SATELLITE EIRP

The EIRP for each of the two downlinks of each scanning beam will be  $\geq 64.3$  dBW at all scanned positions.

#### 5.2.1.5 SATELLITE G/T

The satellite G/T for each scanning-beam will be  $\geq 20.5$  dB/°K.

#### 5.2.1.6 SCANNING-BEAM ANTENNA PATTERNS

The scanning-beam antenna patterns will provide side-lobe isolation  $\geq 30$  dB between co-polarized, co-channel beams within their 3 dB contours, whenever the beam pointing positions are separated by at least  $.9^\circ$  (three beam widths) and, if polarization frequency reuse is employed,  $\geq 35$  dB clear sky isolation between orthogonally-polarized co-channels within the 3 dB contour of the same beam.

Scanning-beam pointing accuracy will be maintained to within one-fourth beamwidth (one-half beamwidth during station keeping maneuvers) by automatic control of the spacecraft's attitude via monopulse tracking feeds on at least three (fixed) beams and by control of the phase-shifters at each feed element if necessary. The total number of scanning-beam steerable positions will be such as to allow complete CONUS coverage with the minimum percentage of metropolitan areas located on the beam edges.

#### 5.2.1.7 SATELLITE MASTER OSCILLATOR

The satellite MO is described in 5.1.1.7. The MO may also be used to assist in the carrier and bit-timing recovery circuits of the uplink demodulators, depending upon the CPS stations' ability to (1) maintain their own frequency accuracy (with respect to the frequency standard of the MCS) and (2) track out Doppler due to satellite motion. For the initial net-

work, this CPS capability will probably not be implemented, and therefore the demodulators should not depend upon a long term relative stability between the MO and the CPS uplink frequencies of better than  $10^{-7}$ .

#### 5.2.1.8 TELEMETRY AND COMMAND

The Telemetry link will send status of critical parameters to the MCS, possibly including received uplink power for each channel and uplink BER indications for those channels which have the FEC decoders switched in.

The uplink command channel will enable MCS control of the FEC decoders and encoders, scanning-beam pointing commands for the 6 scanning beams, MO frequency control, routing instructions to the BPU, attitude-control bias offsets, and other "house-keeping" functions including switching-in redundant units.

#### 5.1.1.9 REDUNDANT UNITS

The scanning-beam transponders should have common units enabling a 1-for-N redundancy for failed units. Critical paths such as the BPU and the MO (plus related frequency synthesizers) should have at least a 1 for 1 redundancy. All redundant units are switchable by ground command.

#### 5.2.2 CPS - GROUND TERMINAL

##### 5.2.2.1 SPACE DIVERSITY

Space diversity normally will not be required at CPS

ground stations to meet the link availabilities of .995 to .999. However larger capacity stations located in Rain Zone E may be able to justify a diversity terminal pair.

#### 5.2.2.2 TRANSMISSION MODE(S)

The CPS station will operate its uplink at either 128 MBPS or 32 MBPS QPSK TDMA with or without an FEC encoder ( $R=1/2$ ,  $K=7$ ). Downlinks will operate at 256 MBPS QPSK TDMA. Scanning beam and TDMA burst synchronization will be achieved "open-loop" via MCS derived slant range measurements and "linearized" range calculation for each station. The TDMA Mux will provide user rate to burst rate data conversion and assembly on transmit and the inverse functions on receive. A station will be able to transmit and receive up to 4 bursts per frame.

#### 5.2.2.3 EARTH STATION ANTENNA

The normal maximum antenna diameter will be 3.5 meters. If polarization frequency re-use is used, dual orthogonal linear polarization feeds and/or polarization tracking may be required at some CPS stations. Antennas will employ either step-tracking or "commanded" tracking (open loop). Antennas will maintain a pointing accuracy of one-half the half power beamwidth for steady state winds of 60 mph with gusts up to 80 mph.

#### 5.2.2.4 STATION EIRP

The station EIRP will be  $\geq 66.8$  dBw in the Low Power Mode and  $\geq 80$  dBw in the High Power Mode. The High Power Mode may be switched in or out for uplink rain response by remote control of the MCS for unattended stations.

#### 5.2.2.5 STATION G/T

The station G/T will be  $\geq 23.0$  dB/°K.

#### 5.2.2.6 EQUIPMENT RELIABILITY

The CPS terminal equipment shall have an availability  $\geq .999$ . This may require redundancy of critical elements.

### 5.3 MASTER CONTROL STATION

#### 5.3.1 RANGING, TRACKING AND SYNCHRONIZATION

The MCS will track the 30/20 GHz satellite for the purposes of:

- (1) Planning and executing periodic station-keeping maneuvers (design goal is  $\pm .05^\circ$  North-South and  $\pm .05^\circ$  East-West)
- (2) Providing network synchronization for TDMA operation in both the trunking and CPS systems.

Slant range from each of four trunking stations to the satellite will be measured to an initial accuracy of  $\leq 200$  nanoseconds. Two-station turn-around ranging signals generated at the MCS (colocated with one of the trunking stations) may be used in cooperation with three other trunking stations; alternatively, the



transmission and reception of a TDMA Unique Word from each of the four stations may be used to measure the slant ranges.

The MCS will compute the satellite's ephemerides (State Vector) from the four slant ranges at least once per minute. It will then transmit this ephemeris, together with at least three of the four slant ranges to each network station via the network Order Wire (OW). Each station will then compute its own slant range to an initial accuracy of  $\leq 200$  nanoseconds; alternatively the MCS may make the individual station-to-satellite slant-range calculation, in which case the MCS would transmit these slant ranges to each network station via the OW.

At unattended CPS stations, employing commanded antenna pointing (open-loop), the MCS may also compute the local azimuth and elevation angle, for each station and transmit these as pointing commands to the station's antenna subsystem.

The MCS derived range measurement accuracies and computational speed should be capable of eventual growth, so that for a fully deployed network with 1,000 to 10,000 stations range and range rate accuracies can be improved by a factor of at least 100 to minimize inefficiencies due to guard times and/or preambles in a TDMA network with 100 to 1,000 accesses per beam per frame.

### 5.3.2 ROUTING CONTROL

#### 5.3.2.1 TRUNKING

The MCS will compute the trunking network's Satellite Switch TDMA beam interconnectivity modes and mode duration from the total traffic demand matrix. It will then reconfigure the satellite switch via the command link and send the appropriate burst assignments to each trunking station via the OW. Algorithms that minimize the number of bursts per station and/or maximize the trunking throughput efficiency of the satellite will be used.

#### 5.3.2.2 CPS

The MCS will compute the routing assignments and corresponding scanning-beam pointing frame sequence (phase shifter commands) and dwell-times for the total CPS traffic demand. These instructions will be transmitted from the MCS to the Satellite's BPU via the command link. At the the same time burst assignments will be sent by the MCS to the CPS stations via the OW. Algorithms will be used to reconfigure the routing for the most efficient use of the CPS throughput capacity. The algorithms will also take into account potential co-channel interference between pairs of the six scanning beams; that is, beams will be pointed to minimize interference due to sidelobes to the extent practicable.

### 5.3.3 ADAPTIVE RAIN RESPONSE

#### 5.3.3.1 TRUNKING

The MCS will monitor the received signal power levels and BERs at each Trunking station from signals uplinked from each of the other trunking uplink beams. It will then command the High Power Mode for the downlink transmitter(s) via the command link and for the uplink transmitter(s) via the OW. It may also grant requesting trunking stations permission to switch between Low Power and High Power modes for their uplinks based upon locally determined need. In any event the MCS will monitor the current status of the High Power Modes at both the satellite and the earth stations to determine potential interference to links not using High Power Mode(s) and to limit the number and duration of High-Power Modes in the satellite to remain within power supply constraints.

#### 5.3.3.2 CPS

The MCS will monitor the received signal power levels and BER's at each CPS station via the OW; it may also monitor received uplink signal power levels (and BER for channels using FEC decoders) at the satellite via the telemetry link. It will then instruct appropriate CPS stations to switch to the High/Low Power Mode and/or to switch in FEC uplink encoders and/or downlink decoders via the OW. It will also command the satellite BPU to switch in FEC uplink decoders and/or downlink encoders into the appropriate channels.

#### 5.3.4 FREQUENCY CONTROL OF THE SATELLITE MO

The MCS will control the frequency of the satellite MO to  $\leq 1 \times 10^{-7}$  (long term) using a "disciplined" Phase Locked Loop approach. It will transmit digital "error voltage" increments via the command link which are converted to analog corrections at the MO's PLL comparator.

#### 5.3.5 SATELLITE SWITCH TDMA SYNCHRONIZATION

The MCS will "acquire" the satellite switch, with the aid of the "disciplined" PLL MO procedure outlined in Section 5.3.4, and transmit Reference Unique Words every frame as appropriate so that both Trunking and CPS stations can establish receive synchronization with respect to the satellite's 1 KHz frame rate.

#### 5.3.6 SATELLITE "HOUSEKEEPING" FUNCTIONS

The following functions will be performed at the MCS:

- Maintain satellite attitude control and antenna pointing.
- Perform station-keeping maneuvers.
- Monitor the "health" of critical satellite subsystem parameters via the telemetry link. Command redundant configurations in the case of component failures.

## VII

### 30/20 GHz EXPERIMENTAL COMMUNICATION SYSTEM

#### FUNCTIONAL REQUIREMENTS

##### 1.0 STATEMENT OF THE PROBLEM:

The requirements of this subtask are to identify the minimum 30/20 GHz Experimental Communication System Functional requirements capable of demonstrating the applicability of 30/20 GHz satellite systems and their necessary supporting technology to commercial services.

##### 2.0 INTRODUCTION:

The primary purposes of the 30/20 GHz Experimental Communications Program are: A) to identify projected services that are viable candidates for 30/20 GHz communication systems; B) develop the critical technology required to facilitate use of that frequency band; and C) to design, construct, and operate an experimental satellite system that will demonstrate the technology developed and applicability of the system to commercial services, and provide the facilities to evaluate other technical and propagation factors that have an influence on system performance.

In summary, NASA's main thrust is to develop and demonstrate the technology necessary to design and implement operational 30/20 GHz systems at the time satellite service growth and market demands mandate expansion to that band. NASA's purpose is not considered to be oriented toward design and construction of

an operational system directed toward development of specific market areas.

The 30/20 GHz program objectives provided the guidelines for developing the experimental system functional requirements described in this section. Consideration is given to:

- NASA's new technology development programs
- Operational trunking/CPS system requirements
- The experiments proposed by the CWG and NASA that have been incorporated into the Experiment Planning Document.

### 3.0 METHODOLOGY

The 30/20 GHz experimental system functional requirements have been derived based on the following:

- Incorporation within the satellite communication subsystem of the new technology hardware being developed under the auspices of NASA.
- Incorporation of those operational system functional requirements (developed in Section VI) in the experimental system necessary to demonstrate applicability of the 30/20 GHz systems to commercial trunking and CPS services.
- Considering the Experiment Planning Document, incorporation of as many of the experiment technical features as is practical.

#### 4.0 GENERAL CONSIDERATIONS

##### 4.1 NEW TECHNOLOGY:

The new technology being developed by NASA includes:

- scanning antenna for CPS applications
- Low noise wideband receiver (30 GHz)
- Impatt Power Amplifiers
- GaAsFET Power Amplifiers
- Dual Mode TWTAs
- TDMA IF switches
- Baseband Processors

The new technology hardware is incorporated in the communications subsystem as shown on the experimental system block diagrams. The dual mode TWTAs is essential to demonstrating operational system capabilities since both low and high power (10W/75W) operation is required in the trunking system, and the CPS system requires a transmitter with a minimum output power of 75 watts. The output power levels expected from the Impatt and GaAsFET amplifiers (10W) are adequate for clear weather trunking operation only and cannot provide the higher power required to meet CPS requirements and the high power required in the trunking system to provide additional adaptively controlled margin to compensate for rain attenuation on the downlinks.

## 4.2 DEMONSTRATION SYSTEM CONSIDERATIONS

### 4.2.1 GENERAL SYSTEM CONSIDERATIONS

In Section VI operational system (trunking and CPS) functional requirements were identified based on estimated accessible Ka band market share and mix that may be captured by a Western Union type common carrier. The conclusion was that 500 MBPS SS-TDMA channels are a reasonable choice for trunking and that a mix of 32 MBPS and 128 MBPS uplink channels and 256 MBPS downlink channels is a reasonable choice for CPS systems except in the case of rain zone E. To meet CPS availability requirements in rain zone E one proposed design would customize uplink transmission rates to individual CPS earth station capacities using FDM channels as required and reduce the downlink TDMA transmission rate to 64/128 MBPS. (In addition the size of the proposed CPS earth station antennas in rain zone E would be increased to 5M.)

Another alternative for improving availability is the use of the Ku band for rain zone E. This would require a satellite with Ku-band receivers and transmitters interconnected to the Ka band channels operating in the other six CONUS rain zones. Interconnectivity could also be achieved by double hopping or via an intersatellite link.

### 4.2.2 PERFORMANCE OBJECTIVES

Experimental system quality performance objectives are



the same as those identified for the operational system in Section VI:

- Data BER  $\leq 1 \times 10^{-7}$
- Voice BER  $\leq 1 \times 10^{-6}$
- Video BER  $\leq 1 \times 10^{-5}$

The data BER requirement is the controlling system design criteria. Other major performance parameters (e.g. availability) will be measured as part of the experimental program with margins adjusted accordingly.

#### 4.2.3 TRANSMISSION LINK BUDGETS

Tables V-1 through V-3, V-8, V-10, VII-1, and VII-2 give the link budgets for the trunking and CPS systems. In the CPS case for rain zone E, Tables VII-1 and VII-2 give the link budgets using a 5 M antenna to provide uplink FDM transmission at 6.3 MBPS and TDMA transmission at 16 MBPS respectively with downlink TDMA transmission at 128 MBPS.

For the 16 MBS TDMA case a 5 M system is 2.9 dB shy on margin to meet a .9990 availability requirement in rain zone E. Required performance can be met with a 7 M system. A study of alternative approaches and cost trade-offs is required for the CPS system to develop optimum designs for rain zone E.

#### 4.2.4 SYSTEM MARGINS

Some normal operating margins to offset rain attenuation effects have been provided in the link budgets.

Table VII - 1  
 CPS System - Rain Zone E  
 6.3 MBPS FDM UL, 128. M3PS TDMA DL  
 (Clear Weather, Uncoded)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W)	18.7 (75W)	dBW
TX. ANTENNA GAIN	61.3 (5M)	49.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	70.0	64.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	57.4 (5M)	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.0	dB
NOISE TEMPERATURE AT RCVR INPUT	32.2	29.6	dB K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT	102.5	107.7	dB - Hz
INFO. BIT RATE	68.0	81.0	dB - Hz
CHANNEL $E_b/N_0$	34.5	26.7	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	20.9	13.1	dB

Table VII - 2  
 CPS System - Rain Zone F  
 16 MBPS TDMA UL, 128 MBPS DL  
 (Clear Weather, Uncoded)

ITEM	UPLINK * (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W)	18.7 (75W)	dBW
TX. ANTENNA GAIN	61.2 (5M)	48.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	69.9	64.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	57.4 (5M)	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.0	dB
NOISE TEMPERATURE AT RCVR INPUT	32.2	29.6	dB - K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/KT	102.4	107.7	dB - Hz
INFO. BIT RATE	72.0	81.0	dB - Hz
CHANNEL $E_b/N_0$	30.4	26.7	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
$E_b/N_0$ REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	16.8	13.1	dB

To meet trunking and CPS availability objectives of .9999 and .9990, respectively, additional system margins are required.

As discussed in Section V, in the case of the trunking system adaptive power control on the uplink and downlink, and space diversity earth stations at each trunking node, will provide the additional margins required. In the case of the CPS system (with the exception of Rain Zone E) adaptive uplink power control and adaptive uplink and downlink FEC will be adequate to provide the additional margins required. In the case of rain zone E, a larger earth station antenna and operation at reduced transmission data rates are required.

#### 4.2.5 TDMA SYNCHRONIZATION

In Section V-5 and 5-3, three TDMA synchronization approaches, two closed loop and one open loop, were identified. The open loop approach is similar to that proposed by TRW, but with less stringent accuracy and update frequency. Since the number of earth stations is limited in the demonstration system, a highly precise approach which maximizes TDMA frame efficiency, such as that recommended by TRW, is not necessary. The recommendation is to implement the demonstration TDMA system using the open loop approach identified in the operational systems functional requirements.

#### 4.2.6 TRUNKING - CPS CROSS CONNECTIVITY

An investigation of the technical and cost trade-offs of providing cross connectivity between CPS and trunk-

ing systems on-board the satellite or simply adding CPS capabilities in the trunking earth stations is recommended. Since there are a limited number of trunking earth stations the latter approach may be preferable. Switching can be incorporated at trunking earth stations to route CPS traffic through trunking channels where the terminating node is another trunking earth station or through a CPS channel where the terminating node is a CPS earth station.

#### 4.2.7 FREQUENCY PLAN

The frequency plan for the demonstration system should include orthogonal polarized transmission of a common channel to conduct frequency reuse and depolarization experiments. The experiments should be conducted in both the trunking and CPS cases.

### 4.3 DEMONSTRATION SYSTEM FUNCTIONAL REQUIREMENTS

#### 4.3.1 TRUNKING - SATELLITE COMMUNICATIONS SUBSYSTEM

##### 4.3.1.1 TRANSMISSION REQUIREMENTS

- . SS-TDMA            500 MBPS
- . FDM                274 MBPS (T-4)
- . NTSC color        video-analog 36 MHz BW

##### 4.3.1.2 NUMBER OF BEAMS

At least seven  $.3^\circ$  beams are required to demonstrate technology, system performance, and to conduct propagation related experiments in all CONUS rain zones. Candidate beam cities are:

<u>Rain Zone</u>	<u>City</u>
B	Denver
C	San Francisco or Seattle
D <sub>1</sub>	Cleveland
D <sub>2</sub>	New York
D <sub>3</sub>	Memphis
E	Tampa
F	Los Angeles

At least one beam should be steerable to conduct interbeam interference and frequency reuse experiments, preferable in heavy rain zone areas (e.g. Memphis beam steerable to Tampa). At least these two beams should be designed for orthogonally polarized transmission. System design should clearly demonstrate approach, requirements, and cost to provide full connectivity between twenty or more trunking nodes.

#### 4.3.1.3 CONNECTIVITY

TDMA - Full connectivity between all seven beams is not essential, but they should be capable of being interconnected in groups of at least four.

FDM - Connectivity between beam pairs, preferably beams directed to high rain zone areas.

Video - Connectivity between beam pairs.

#### 4.3.1.4 SWITCHING

TDMA SWITCH - An on-board TDMA switch is required to provide connectivity between beams. Switching modes and mode lengths should be reconfigurable on command

from the MCS. Mode changes should be synchronized to avoid loss of data in the experimental network.

FDM - Switch: FDM switching is required to connect selected beam pairs. FDM experiments need not be conducted simultaneously with TDMA or video experiments, therefore common transponder(s) can be used to conduct TDMA, FDM, and video experiments. The FDM switch should be capable of bypassing the TDMA switch.

Video - For video experiments the FDM switch can be used to bypass the TDMA switch and provide connectivity between selected beam pairs. Selection of the FDM or video transmission mode can be accomplished at the earth stations.

#### 4.3.1.5 TRANSPONDERS

At least six transponders are required, four on-line and two back-up. In addition at least one Impatt and one GaAsFET Amplifier should be incorporated in the design. The frequency plan should include adjacent frequency assignments to permit interchannel interference evaluation experiments.

##### 4.3.1.5.1 TRANSPONDER POWER

A Dual mode TWTA is required:

Low Power mode - nominally 10 watts

High Power mode - minimum 75 watts

##### 4.3.1.5.2 TRANSPONDER BANDWIDTH

TDMA - The bandwidth should be compatible with the burst rate, nominally 315 MHz for 500 MBPS burst rate

(1.25 x symbol rate for QPSK modulation).

FDM - Nominally 175 MHz for 274 MBPS transmission data rate (1.25 x symbol rate for QPSK modulation).

Video - The bandwidth should be 36 MHz for NTSC color video.

#### 4.3.1.6 SATELLITE EIRP

TDMA - Low Power Mode: 58.2 dBw min.

High Power Mode: 66.95 dBw min.

FDM - High Power Mode: 12.75 dBw/carrier

Video - High Power Mode: 12.75 dBw/carrier

Note: The Video EIRP is based on 53 dB SNR with a 4.75 dB margin. Since SNR can degrade to about 45 dB before noticeable impulse noise occurs, the effective margin is about 12.75 dB. Diversity gain can provide additional margin to maintain performance.

#### 4.3.1.7 SATELLITE G/T

Objective: 21.4 dB/°K

#### 4.3.1.8 ANTENNA POINTING

Station keeping pointing accuracy should be compatible with the beamwidths to maintain synchronization and the communication link's performance even during station keeping maneuvers. A monopulse tracking receiver will be needed to track pilot carrier frequency normally, and provide programmed tracking corrections to maintain pointing accuracy during station keeping maneuvers.



#### 4.3.1.9 ON-BOARD MONITOR

Monitors for uplink power control may be incorporated in satellite or at earth stations.

#### 4.3.1.10 SATELLITE COMMUNICATION SUBSYSTEM

Figure VII-1 shows a functional block diagram of the satellite trunking communication subsystem.

#### 4.3.2 TRUNKING - EARTH STATIONS

##### 4.3.2.1 SPACE DIVERSITY

Space diversity earth stations are required at each trunking node to meet availability objectives.

##### 4.3.2.2 TRANSMISSION MODES

TDMA - 500 MBPS TDMA using QPSK Modulation all earth stations.

FDM - Up to two 274 MBPS FDM channels using QPSK Modulation at selected earth stations.

Video - One 36 MHz analog video channel at selected earth stations.

##### 4.3.2.3 ANTENNA

###### 4.3.2.3.1 DIAMETER: 5.0 meter

###### 4.3.2.3.2 POLARIZATION

Dual linear polarization feeds at two trunking node systems. (Tampa being one of them). Single polarization elsewhere.

###### 4.3.2.3.3 TRACKING

Step tracked.

###### 4.3.2.4 HPA POWER

450 Watt minimum flange power.

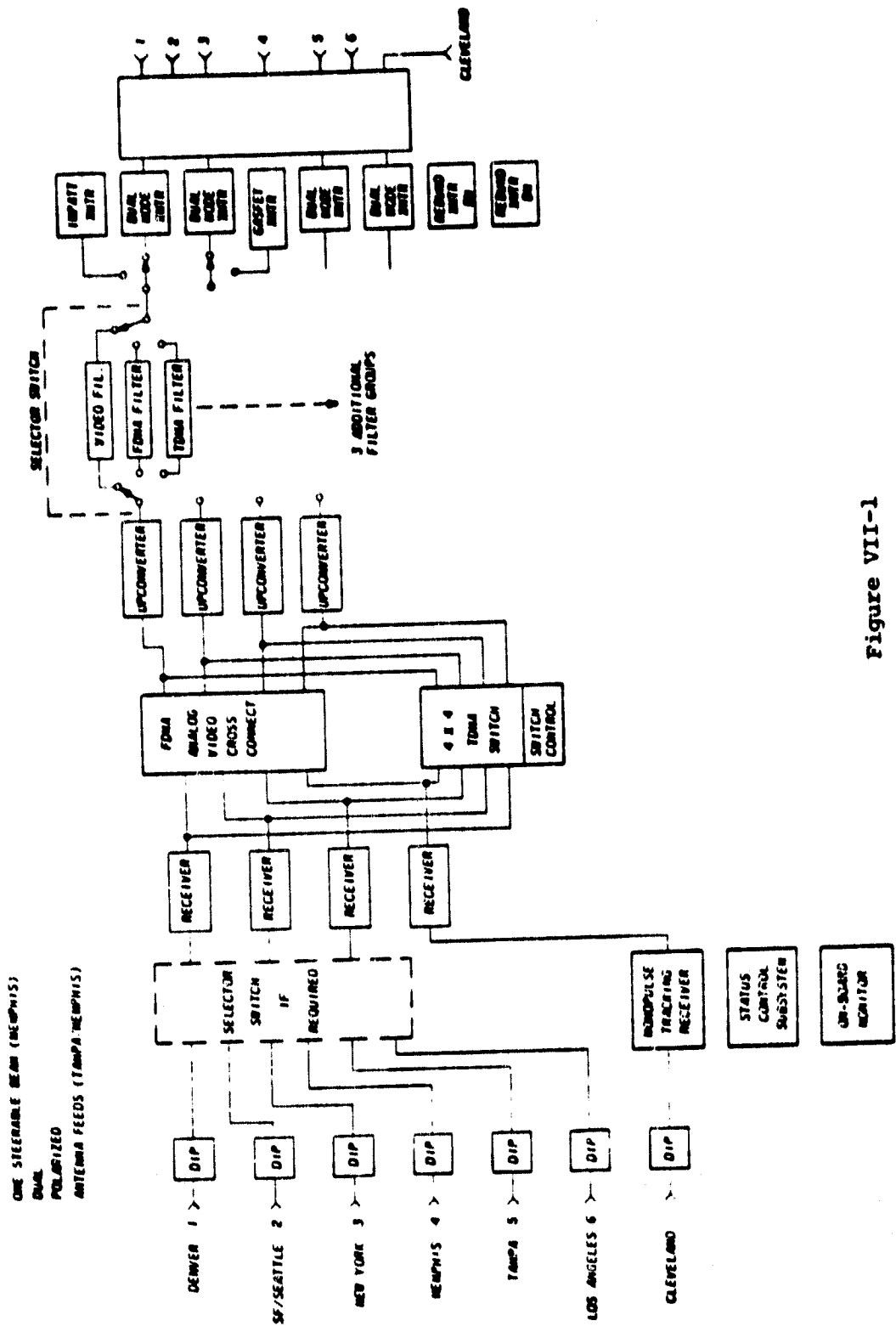


Figure VII-1  
 TRUNKING COMMUNICATIONS PAYLOAD  
 FUNCTIONAL BLOCK DIAGRAM  
 DEMONSTRATION SYSTEM

LEGEND  
 DIP - 2 Poles  
 CR - 24.032  
 MTR - TRANSMITTER

#### 4.3.2.5 HPA POWER CONTROL

15 watt to 450 watt

#### 4.3.2.6 DIVERSITY SWITCH

A diversity switch is required. Transmission between diversity earth stations should be at transmission data rates (500 MBPS TDMA, 274 MBPS FDM).

#### 4.3.2.7 DIVERSITY EARTH STATIONS INTERCONNECT LINK

Fiber Optic repeaters spaced approximately 2 KM apart. Mux/Demux at switch (one site) only.

Note: This assumes availability of hardware at the 500 Mbps rate. Alternatively, the signals can be broken down and assembled at each station and transmitted using parallel 44.7 MBPS links.

#### 4.3.2.8 FAULT MONITOR AND CONTROL

Status and alarm outputs interfaced to OW channel for transmission to MCS. Control inputs interfaced to OW channel from MCS.

#### 4.3.2.9 INSTRUMENTATION

In accordance with test and experiment requirements.

#### 4.3.2.10 INTERSTATION COMMUNICATION

Via an OW channel.

#### 4.3.2.11 ADAPTIVE CONTROL MONITORS

Monitors with appropriate logic to identify the need for adaptive uplink power control should be incorporated in the earth stations.

#### 4.3.2.12 TDMA SYNCHRONIZATION

Open loop approach using ranging data from master

ranging stations via OW channel.

#### 4.3.2.13 BASEBAND INTERFACES

TDMA/TDM - T-1 interface ports at Terrestrial Interface Modules.

Video - Picture Video 1.0 V p-p; Audio +8dBm/600 ohms

4.3.2.14 REDUNDANCY - Non-redundant equipment only for demonstration system. Consider diversity stations as back-up for each other for equipment failure as well as propagation problems.

#### 4.3.2.15 SATELLITE COMMUNICATION SUBSYSTEM

Figure VII-2 shows a functional block diagram of the satellite CPS communication subsystem.

#### 4.3.3 CPS - SATELLITE COMMUNICATION SUBSYSTEM

##### 4.3.3.1 TRANSMISSION REQUIREMENTS

- UPLINK: 32/128 MBPS QPSK TDMA - All rain zones except E  
6.3/12.6 MBPS QPSK-FDM Rain Zone E
- DOWNLINK: 256 MBPS QPSK TDMA - All rain zones except E  
128 MBPS TDMA - Rain Zone E

##### 4.3.3.2 COVERAGE

The demonstration system should have both scanning beam and contiguous fixed beam coverage to provide the capability to make comprehensive comparisons between the two approaches. Concerns with scanning beam systems include capacity limitations, scanning losses, synchronization complexity, gain contour slope

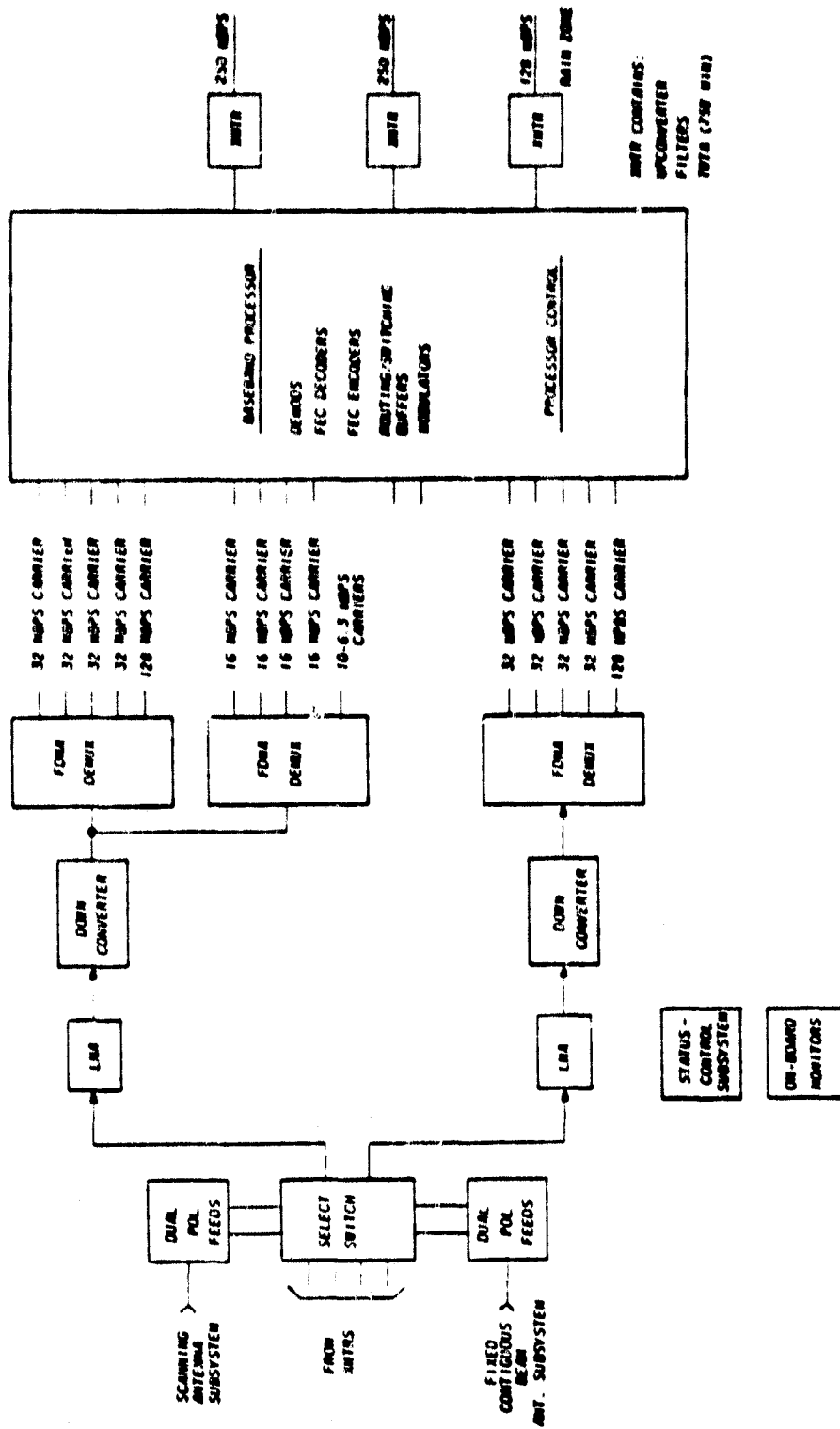


Figure VII-2  
CPS COMMUNICATIONS PAYLOAD  
FUNCTIONAL BLOCK DIAGRAM

effects, etc. Concerns with contiguous spot beams include switching and hardware complexity.

The CPS feed(s) should be designed to demonstrate and provide for analysis of frequency reuse and depolarization effects using orthogonally polarized transmission within each beam and adjacent beams. Frequency reuse via beam separation should also be demonstrated. Full CONUS coverage is desirable in the demonstration system.

If CONUS coverage cannot be implemented in the demonstration system the detailed design plan should clearly identify the design approach, performance, and cost to extend the coverage as well as the design approach for frequency reuse and implementation of at least ten CPS transponder on each satellite.

#### 4.3.3.3 CONNECTIVITY

The CPS System is expected to be comprised of a large number of individual networks (corporate, institutional, government, carrier, etc.), in which connectivity between user network nodes is provided via wired or permanently assigned channels. In addition there will also be a pool of Demand Assigned Multiple Access channels to provide service to customers on a call-by-call basis.

On board routing for the individual user networks can be essentially fixed in the baseband processor instructions and would normally require only occasion-

al reassignment as a customer expands his network, terminates services, or as a new customer enters the CPS System. A user may, however, have a need to cross connect to other user networks or may require access to DAMA channels to accommodate an overload condition on his network.

In the case of DAMA channels the requirement is to cross connect or route any input channel to any output channel.

Under the assumption that 70% of the CPS capacity will be utilized by user networks with fixed connectivity requiring occasional reassignments, and that 30% of the capacity will be utilized on a DAMA basis, the amount of real time processing is substantially reduced.

#### 4.3.3.4 BASEBAND PROCESSOR UNIT (BPU)

The Baseband Processor Unit (BPU) will provide the capability to route any uplink message channel to any downlink message channel, irrespective of RF channels.

The BPU includes:

- Demodulators
- FEC Decoders (R 1/2, K = 7) Soft Decision Decoding)
- FEC Encoders (R 1/2, K = 7)
- Routing/Switching Buffers
- Modulators
- Processor Control

- Uplink TDMA Expansion Buffers, Synchronization, and Control
- Downlink TDMA compression buffers, high speed mux, synchronization, framing, and control.

#### 4.3.3.5 CPS - RECEIVE SUBSYSTEM

UPLINK CARRIER SIZE (MBPS)	NO. OF CARRIERS	TRANSMISSION MODE	RECEIVE BANDWIDTH (MHz)
32	8	TDMA	20
128	2	TDMA	80
16	4	TDMA	10 (Rain Zone E)
6.3	10	FDM/TDM	4 (Rain Zone E)

Uplink Modulation - QPSK

Bandwidth = 1.25 X symbol rate

#### 4.3.3.6 CPS - TRANSMIT SUBSYSTEM

DOWNLINK CARRIER SIZE (MBPS)	NO. OF CARRIERS	TRANSMISSION MODE	TRANSMIT BANDWIDTH (MHz)
256	2	TDMA	160
128	1	TDMA	80 (Rain Zone E)



4.3.3.7 DOWNLINK TWTA POWER (FLANGE)

18.75 dBw (75W) minimum all carriers. Single mode.

4.3.3.8 SATELLITE EIRP

64.3 dBw per channel minimum - all carriers.

4.3.3.9 SATELLITE G/T

Objective 20.5 dB/°K

4.3.3.10 ON-BOARD ADAPTION MONITOR/CONTROL

Appropriate status outputs and summary alarms transmitted via the TT&C channel to the MCS are required. Communications subsystems switching and control received via command channel from MCS.

4.3.4 CPS - EARTH STATIONS

4.3.4.1 TRANSMISSION REQUIREMENTS:

- UPLINK

32/128 MBPS TDMA Carriers

16 MBPS TDMA Carriers (Rain Zone E)

6.3MBPS FDM/TDM Carriers (Rain Zone E)

- DOWNLINK

256MBPS TDMA Carriers

128MBPS TDMA Carriers (Rain Zone E)

4.3.4.2 ANTENNA:

4.3.9.2.1 DIAMETER:

3.5 Meter - Rain Zones B, C, D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>, F

5.0 Meter - Rain Zone E

4.3.4.2.2 POLARIZATION

Orthogonal linear polarization to provide for frequency reuse and depolarization experiments within a common beam and between adjacent beams.

#### 4.3.4.2.3 TRACKING

Step track.

#### 4.3.4.2.4 G/I

$\geq 23\text{dB}/^\circ\text{K}$ : 3.5M system  $\geq 27\text{dB}/^\circ\text{K}$ : 5.0M system

#### 4.3.4.3 HPA POWER

450 Watt minimum flange power

#### 4.3.4.4 HPA POWER CONTROL

Adaptive-15 watts to 450 watts

#### 4.3.4.5 FAULT MONITOR AND CONTROL

Status and alarm outputs interfaced to OW channel for transmission to MCS. Control inputs interfaced to OW channel from MCS.

#### 4.3.4.6 INSTRUMENTATION:

In accordance with test and experiment requirements.

#### 4.3.4.7 INTERSTATION COMMUNICATION

OW to MCS only. Individual network interstation communications via designated voice OW channel.

#### 4.3.4.8 ADAPTIVE MONITOR/CONTROL

Downlink BER/Carrier level monitors for control of adaptive downlink FEC via MCS.

Control to initiate adaptive uplink power and uplink FEC upon command from the MCS.

#### 4.3.4.9 TDMA SYNCHRONIZATION

Open loop as described for trunking system. A detailed investigation/analysis is required to establish synchronization requirements and system performance with scanning beam and fixed contiguous beam systems.

#### 4.3.4.10 INTERFACES

64 KBPS to 1.544 MBPS customer/terrestrial interfaces. A mixture of interface port rates selected for each CPS earth test for demonstration.

#### 4.3.4.11 REDUNDANCY

Redundancy only as required to meet CPS availability criteria. On shelf spares at depot locations.

#### 4.4 MASTER CONTROL STATION

All of the demonstration system spacecraft monitor/control functions and the communications network control functions are centralized at the Master Control Station (MCS).

#### 4.4.1 COMMUNICATIONS NETWORK CONTROL FUNCTIONS

##### 4.4.1.1 SYSTEM TDMA SYNCHRONIZATION

The open loop synchronization approach described in Section V and Section VI is recommended for the demonstration.

##### 4.4.1.2 CONTROL SPACECRAFT MASTER OSCILLATOR (MO)

Frequency lock spacecraft MO to MCS master oscillator via disciplined PLL control loop as discussed in Section VI.

##### 4.4.1.3 CHANNEL ASSIGNMENT/ROUTING CONTROL

The channel assignment/routing control unit is the central control center for channel assignments and message routing. It performs:

- Pre-programmed assignment of fixed channels, burst slots, and routing by manual entry.

- Determination of SS-TDMA switch interconnectivity mode lengths based on trunking earth station capacity requirements.
- Stored program control for CPS Baseband Processor.
- Reconfiguration of burst lengths or assignment of additional burst slots to accommodate FEC rain-response requirements.
- Computation of optimum scan pattern for the CPS scanning beam approach and generation of the required phase shift control commands.

#### 4.4.1.4 ADAPTIVE RAIN RESPONSE

Central command and control point for:

- Uplink and downlink power control for trunking network.
- Control of CPS UL and DL FEC separately for each earth station link.
- Uplink power control for CPS.

#### 4.4.1.5 EARTH STATION MONITOR/CONTROL

Remote monitoring of trunking/CPS earth station status. Remote control of critical earth station functions.

#### 4.4.1.6 SPACECRAFT MONITOR/CONTROL

- PCF for spacecraft antenna pointing control.
- Computation of spacecraft range, range rate (state vectors).

- SS-TDMA Switch Mode Control
- Orbit Control
- Attitude Control
- Power Control
- Thermal Control
- Solar Control
- Events Control
- Switching (redundancy, configuration, etc.)
- Maintenance

#### 4.5

#### SYSTEM INTERFACES

##### 4.5.1

#### TRUNKING NETWORK

- Voice orderwire channel between trunking earth stations.
- Customer baseband interfaces.
- OW channel between trunking earth stations and MCS for:
  - Voice communication
  - Earth stations - status/control
  - TDMA synchronization/burst assignments.
  - Adaptive rain response monitor/control

##### 4.5.2 CPS SYSTEM

- OW channel between CPS earth stations and MCS for:
  - Voice communication\*
  - Earth station status/control
  - Synchronization
  - Adaptive rain response monitor/control

- Channel/burst assignments.

\*For high capacity earth stations only. In other cases only a low speed alarm/control channel is required.

#### 4.5.3 MCS AND SPACECRAFT

- TT&C and wideband channels for:
  - Spacecraft status (Telemetry/Tracking)
  - Spacecraft command and control
  - Trunking SS-TDMA switch mode control and beam switching
  - Routing/switching control and status of CPS baseband switch.
  - CPS scanning beam control
  - Adaptive rain response monitor/control.

#### 4.6 DEMONSTRATION SYSTEM EXPERIMENT CAPABILITIES:

The functional requirements outlined in the preceding subsections will provide transmission system capabilities to conduct most of the service, technology, and combined service/technology experiments in the Experiments Planning Document.

Key experiments are those that are propagation related, particularly measurement of diversity gain in high rain climate regions where single site attenuation substantially exceeds 20 dB.

The proposed experiments that can be conducted with addition of appropriate instrumentation and terminal facilities are:

- Service Experiments

PS-1, PS-2, PS-3, PS-8, PS-9, PS-10, PS-11,  
PS-12, PS-13, PS-14, PS-15, PS-16, PS-24,  
PS-25, PS-26, PS-27, PS-28, PS-29, PS-30,  
PS-31, PS-32, PS-33, PS-34.

In the case of PS-16 the terrestrial interface must be designed to be compatible with the fiber optic link, T-3 interface probably. Experiments PS-28, PS-30, and PS-34 are experiments that require carrier participation.

- Technology Experiments

PT-1, PT-2, PT-3, PT-4, PT-5, PT-7, PT-9, PT-10, PT-15, PT-16, PT-18, PT-19, PT-20, PT-21, PT-23, PT-24, PT-25, PT-28.

- Service and Technology Experiments

PSAT-3, PSAT-4, PSAT-5, PSAT-6, PSAT-8, PSAT-9.

The proposed experiments that cannot be conducted with the demonstration system described are:

- PSAT-1, PSAT-2, PSAT-7, PSAT-11

The special capabilities required for these experiments are not incorporated in the functional requirements identified.

- PT-6, PT-14, PT-17, PT-22

These experiments require an intersatellite link that has not yet been identified as a 30/20 GHz program requirement.

- PT-12

FEC has not been incorporated in the functional requirements as identified pending more specific requirements.

PT-13

Recommendations via the proposed experiment pending NASA review.

PS-4

Beyond scope of 30/20 GHZ program. Additional hardware required.

PS-17

Trunking stations are diversity facilities. Diversity experiment as described can be implemented with a transportable earth station in conjunction with NYC facilities.

PS-18, PS-19, PS-20, PS-21, PS-22

Can be accomplished by simulations.

PS-23

"C" band capabilities not being considered because of the saturated status of available "C" band orbital slots.



## 5.0 30/20 GHZ DEMONSTRATION SYSTEM FUNCTIONAL PRIORITIES

5.1 GENERAL: The demonstration system functional requirements defined in the preceding sections are those considered necessary for demonstrating the applicability of a 30/20 GHZ satellite communication system to projected trunking and CPS carrier needs and services.

In the on-going Phase II study efforts the study contractors have developed baseline and alternate demonstration system design concepts. These identify the range of capabilities that might be developed and implemented in flight systems with various size launch vehicles (SUSS-D, SUSS-A, etc) and develop program cost projections for various required system capabilities. The demonstration system functional requirements and study contractor design concepts have been reviewed to rank the 30/20 GHZ technology and capabilities considered essential for demonstrating a 30/20 GHZ system for trunking and CPS carrier service applications in order of importance.

## 5.2 MODULATION TYPES

In Section II of this report three types of carriers were identified; trunking only carriers, CPS only carriers, and carriers providing both trunking and CPS services. To meet the needs of the three types of carriers the demonstration system must provide both trunking and CPS capabilities.

In the trunking case three types of transmission capabilities have been identified; TDMA, FDMA, and analog video. From a carrier point of view TDMA is the preferred transmission approach because it is more efficient and has greater flexibility than FDMA. The relative order of importance is, therefore, TDMA, FDMA, and analog video. The latter has been included in the functional requirements not as a trunking alternative, but to verify performance capabilities in the 30/20 GHz band for video service application.

In the case of CPS demonstration system capabilities the size of the potential aggregate of use networks and relatively large number of earth stations mandates that they be low cost, with only a level of redundancy adequate to meet CPS availability criteria. There are propagation (rain attenuation) problems associated with the CPS system concept that will probably result in customizing uplink/downlink channels and transmission rates to satisfy availability criteria. Consequently, both TDMA and FDMA transmission capabilities should be demonstrated.

### 5.3 SATELLITE ANTENNAS

The CPS system will be comprised of a large number of individual user networks with network nodes that can be located throughout the CONUS area. Demonstration of the CPS system's capability to provide CONUS coverage through the use of scanning beams and contiguous

beams is necessary, since there exists a fair level of concern relative to the performance capabilities of both approaches. In view of this performance uncertainty it is desirable to implement both types of antenna systems on the demonstration flight to evaluate their relative performance capabilities and to develop the necessary synchronization techniques required for system operation.

#### 5.4 SATELLITE SIGNAL PROCESSING CAPABILITIES

A demonstration of solutions to the availability problems require that the CPS communication subsystem be implemented with high power amplifiers and adaptive FEC decoders and encoders.

The baseband processor is the heart of the CPS system and must be demonstrated. The ability to support fixed assignment and demand assignment channels and routing under both average and peak hour loading conditions should be demonstrated. Demonstrations of CPS/Trunking cross connectivity can be provided for either in the satellite subsystems or on the ground.

#### 5.5 TECHNOLOGY DEVELOPMENT

The technology development efforts applicable to the trunking systems are:

1. 30 GHZ Low Noise Amplifier
2. IF Switch
3. Impatt Amplifier
4. GaASFET Amplifier
5. Dual Mode TWTA.

Items 3 and 4 are not likely to be available at required power levels to satisfy trunking system availability criteria in time for the demonstration system. The emphasis, therefore, should be on items 1, 2, and 5 for demonstration system implementation. Development programs for items 3 and 4 should be conducted on an on-going basis to develop amplifiers capable of operation at high power levels  $\geq 75W$ , a substantial extension beyond the present design objective. Because of the power limitations of the solid state amplifiers currently being developed, implementation of these devices in the demonstration system will not be useful. They will also not be essential to demonstrate trunking system capabilities for an initial operation Ka-band system since this can be done with the high power TWT's under development.

#### 5.6 PROPAGATION EXPERIMENT CAPABILITIES

Measurement of propagation characteristics in the 30/20 GHz band is necessary to develop propagation models for use in the design of operational systems, for example, available diversity gain during deep fades, and to analyze propagation effects on the performance of wideband data transmission system.

#### 5.7 SUMMARY

In summary, the demonstration system must as a minimum include those features defined for the TDMA trunking and CPS systems in preceding sections. In general

C-3

the demonstration system should provide the capability to conduct the systems operational/performance, propagation, beam characteristics, interbeam interference, synchronization, and frequency reuse experiments recommended by the carriers. Trunking FDMA and analog video capabilities are also of value but these may be assigned a lower priority.

## VIII

### ADDITIONAL STUDY RECOMMENDATIONS

There are several areas that can have considerable influence on the performance capabilities, technical design, and cost of both the demonstration and subsequent operational systems that require additional study efforts.

#### 1.0 Rain Zone E Alternate Design Approaches

Rain attenuation and the related margin required to meet the .9990 availability criteria for the CPS system has been shown to be a problem in the CONUS rain climate zone E. One alternative design approach to satisfy performance and availability requirements has been discussed. In that approach the CPS antenna size for earth stations in rain zone E was increased to at least 5.0M and transmission data rates were substantially reduced. A second approach using intersatellite links to a lower frequency band for rain zone E coverage was also identified. The basic premise of the CPS system is that it is intended to provide low cost direct to user services. Inefficient use of the space segment and increased ground segment costs lead to increased user service costs.

A study to identify alternate design approaches is required so that the system design implemented results in the minimum service cost of CPS users.

## 2.0 CPS Traffic Mix

The CPS system is planned to be implemented with an on-board Baseband Processor Unit to route traffic between assigned uplink and downlink channels. The central control of the BPU resides in a computer at the MCS. Machine size and processing requirements can vary considerably as a function of the number of circuit connections required on a message-by-message demand basis. At one extreme is the case where all channels are assigned on a DAMA basis and routing is required on a message-by-message basis. At the other extreme is the case where all channels and hence BPU connectivity is permanently or fixed assigned. The first case requires a computer with substantially more processing capabilities than the second. The real case is somewhere in-between.

A study is necessary to identify the probable CPS mix, i.e. ratio of fixed assigned to demand assigned channels, to appropriately size the machine and processing required.

## 3.0 TDMA Synchronization Approaches

A study is required to identify TDMA synchronization approaches and the performance/cost trade-offs between them. TDMA synchronization approaches vary widely in terms of their respective performance capabilities and cost, however, the ultimate design selected should be established on a total systems basis that considers:

- Cost and complexity of the synchronization approach.
  - The impact on cost and complexity in other areas of the system as a function of the synchronization approaches.
  - The impact on throughput efficiency and space segment cost.
  - Total system size (i.e. number of earth stations)
- it is desirable to select an approach that minimizes initial implementation cost, but one that can be gracefully expanded to improve system efficiency as the network size increases and additional capital costs can be more easily justified.

#### 4.0 SCANNING BEAM/FIXED CONTIGUOUS BEAM DESIGN AND PERFORMANCE:

There are enough concerns relative to capacity constraints, performance, complexity, synchronization, and cost of scanning beams that an in-depth design study is recommended to investigate both scanning beam and fixed contiguous beam approaches for the CPS system. The CPS system is only marginally capable of meeting established availability criteria and, as shown previously, cannot meet availability requirements in rain zone E without other system design changes. Additional losses will have further impact on system performance capabilities.



## IX INTERSATELLITE LINKS

### 1.0 INTRODUCTION

Rain attenuation varies appreciably as a function of earth station elevation look angle (as shown in Figure IV-3) and, therefore, high elevation look angles are desirable ( $30^\circ$  or greater). Elevation angle contours were shown in Figures IV-4 and IV-5 for satellites stationed at  $90^\circ\text{N}$  and  $97^\circ\text{W}$  Longitude. The elevation angle contour plots show that the preferred satellite location is  $97^\circ\text{W}$  and that the usable domestic arc for Ka band systems is between  $90^\circ\text{W}$  and  $104^\circ\text{W}$  Longitude.

Rain attenuation also imposes constraints on attainable transmission throughput rates in high rain zone areas, particularly in the case of the CPS system.

An intersatellite link has the potential to extend the usable orbital arc, improve transmission throughput rates and efficiency for Ka band systems, and offers other advantages when considered on an integrated system basis with other domestic and international satellites. Advantages, applications, and a cursory look at the basic intersatellite link functional requirements are given below. An intersatellite link implementation approach is identified. However, an in-depth effort is necessary to explore alternatives.

## 2.0 INTERSATELLITE LINK CONSIDERATIONS

Whenever the use of more than one satellite transmission hop is envisioned for a particular service category or class of user, which uses two or more different satellites, several factors should be assessed:

1. In most cases, the transmission delay is undesirable. This is particularly true for voice and interactive data applications. For other data applications such as facsimile, electronic mail, and remote batch computing, increased delay is not a fundamental problem, but increased storage is required at the sending location to permit operation with error correcting protocols.
2. The use of multiple hops requires that earth stations which do not have full connectivity via a single satellite have some means of accessing more than one satellite. This can be accomplished using multiple earth station antennas or by using a multi-beam torus antenna.
3. Multi-hop operation results in multiple use of a given bandwidth for the same channel, which results in inefficient use of frequency spectrum and orbital arc.
4. All of these effects of multi-hop transmission increase systems costs to some extent and, as such, should be minimized to the extent possible.

The use of an intersatellite link reduces these effects for some applications. The advantages and applications of intersatellite links are considered in the following sections.

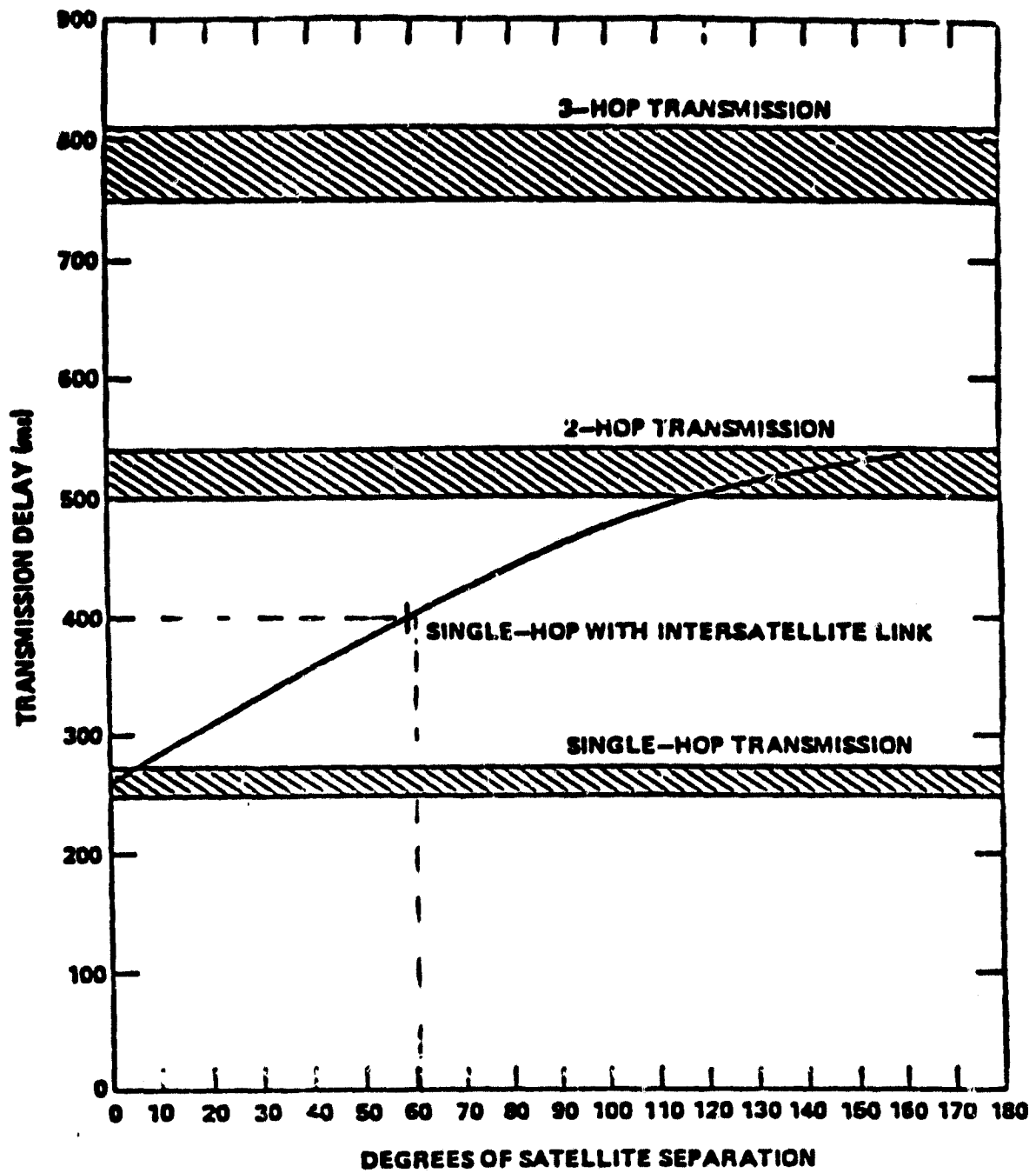
## 2.1 ADVANTAGES OF THE INTERSATELLITE TRANSMISSION LINK

### 2.1.1 DELAY

For all but the very largest longitudinal satellite separations, the satellite interconnection with intersatellite links result in much lower transmission delays than the multi-hop interconnection. This is illustrated in Figure IX-1.

The maximum distance between two satellites for which a single intersatellite link can be used corresponds to an angular satellite separation of about  $160^\circ$ . For a larger separation the earth would obstruct the direct transmission path between two satellites. However, already at an angular satellite separation of  $120^\circ$  the transmission delay time over the intersatellite link approaches that of the additional delay of a double-hop circuit.

It can be concluded that the direct link connecting two satellites through an intersatellite relay is always preferable to triple-hop connection which would result from the conventional interconnection of two domestic systems with the INTELSAT System. However, the intersatellite link also offers a substantial reduction in transmission delay relative to a double-



**MULTI-HOP INTERSATELLITE LINK TRANSMISSION DELAY**

FIGURE IX-1

hop connection when the angular spacing between two satellites is 60 degrees or less.

For full CONUS coverage, the maximum angular separation possible while still maintaining a minimum elevation angle of 10 degrees is about 73 degrees of longitude. Since in the 20/30 GHz fixed service satellite system the satellites are likely to be placed relatively close together and near the central portion of the possible orbital arc positions, the separation will be considerably less than 60°. Thus, use of intersatellite links in the 20/30 GHz satellite system will offer substantially decreased transmission delays relative to the use of multi-hop transmission.

#### 2.1.2 CONSERVATION OF FREQUENCY SPECTRUM

In addition, the intersatellite link uses higher frequency bands than those presently used for satellite communications. This is possible because of the absence of atmospheric absorption and precipitation attenuation for the intersatellite links, and it is desirable because very high directivities can be achieved with moderate size antennas. These frequencies do not interfere with earth-to-satellite transmissions, and therefore the use of the intersatellite link conserves the frequency spectrum.

#### 2.1.3 CONNECTIVITY

As the use of satellites for more and more communications needs expands, and there is overwhelming evi-

dence that this will indeed happen, the problems of connectivity will become increasingly important. It is easy to imagine a situation where a telephone call, for example, originating within a foreign domestic satellite system, is subsequently relayed to an INTEL-SAT satellite for transmission to the U.S, and relayed again via a domestic satellite before finally reaching its destination. In fact, even more satellite hops can be envisioned. The provision of intersatellite links on all types of communications satellites in the future can ensure that excessive delays are minimized, that valuable spectrum is used in an efficient manner, and that system costs are kept at a minimum.

### 3.0 POSSIBLE APPLICATIONS TO THE 20/30 GHz FIXED SATELLITE SYSTEM

Provision of full interconnectivity to all users of the 20/30 GHz system when multiple satellites are used can be accomplished through a combination of the techniques already discussed, i.e. use of multiple earth station antennas, multibeam torus antennas, and intersatellite links. In an operations system, a combination of these interconnection techniques can be expected to be used.

In the previous section dealing with elevation angle constraints, it was concluded that a minimum elevation angle of 30 degrees from an earth station to the satellite is desirable for a 30/20 GHz fixed satellite

system. The desirability of such a system geometry stems from the effect that elevation angle has on required rain attenuation margins. As elevation angles are decreased much below 30°, margins begin to become larger than can reasonably be provided by state-of-art earth station and satellite technologies. One of the solutions suggested was the use of a dual satellite system, one of which would serve the primary need of the eastern portion of the U.S. and the other of which would serve the primary need of the western portion of the U.S. The traffic which requires inter-connection between East and West Coast could conveniently be handled via an intersatellite link. In addition to providing more desirable elevation angles over a greater portion of the U.S., such an implementation may lead to simpler satellites designed specifically for East or West Coast use which in turn provide additional weight and power that can be used for more sophisticated on-board processing or increased EIRP coverage, for example. Such a configuration would require that traffic patterns in East and West Coast regions, as well as between the East and West Coast regions be known with sufficient precision to allow optimized satellites to be constructed. Hughes, in its final report, identified a case where the need for a maximum of three hops for connection of CPS traffic when any user within a fixed beam is

restricted to communicating with a master station in its own beam. The master station in turn would relay the traffic via a second satellite hop to another CPS station in the same beam. When the traffic is destined for a CPS station in another beam the traffic would first be relayed to the master station in that beam and finally, via another satellite hop, to the destination CPS station. In this latter case, the second relay of traffic could either be accomplished by terrestrial connection of master stations, in which case two hops would be involved, or via a satellite connection between master stations in which case a total of three satellite hops would be involved. The use of a two satellite configuration and intersatellite link as discussed could serve to relay traffic via intersatellite link to the second access community. The net effect of this approach would be a simpler CPS on-board processor (than one which must provide full interconnectivity to all CPS terminals on each satellite,) which would provide full connectivity between CPS terminals for a limited community of users without the need for multiple hops.

Another possible application of intersatellite links which could widen the attraction of the 20/30 GHz system would be as a relay of television signals to a CONUS coverage broadcast type satellite. This would be attractive to TV network operators who could



broadcast directly from any downtown location at Ka-band using a small, easily coordinated earth terminal. In this way, interconnect cost to remote earth stations would not be required, and an earth terminal could easily be placed on the rooftop of centrally located studios.

#### 4.0 FUNCTIONAL REQUIREMENTS

##### 4.1 GENERAL CONSIDERATIONS

An approach to implement a trunking system with an intersatellite link is to provide separate TDMA carriers for transmission between earth stations within the coverage area of each satellite and additional carriers for the intersatellite link.

The initial cursory functional design approach for the trunking network connectivity via an intersatellite link is similar to the previously described trunking functional requirements. A TDMA - IF switch provides the connectivity between the intersatellite link and the Ka-band trunking network. Switch mode configuration and mode length are controlled by the MCS.

In the CPS system uplink, Ka-band signals are processed and routed to the baseband processor unit and interfaced to an intersatellite channel. Conversely incoming intersatellite link traffic is processed and routed through the intersatellite link and interfaced to a Ka-band system downlink TDMA channel.

## 4.2 FUNCTIONAL REQUIREMENTS

### 4.2.1 Ka TRUNKING - INTERSATELLITE LINK CONNECTIVITY

Figure IX-2A shows a general block diagram of the Ka Trunking - Intersatellite Link satellite communications subsystem. The intersatellite link appears as an extra set of ports (input and output) on the TDMA - IF Switch. The basic additional functional requirements are:

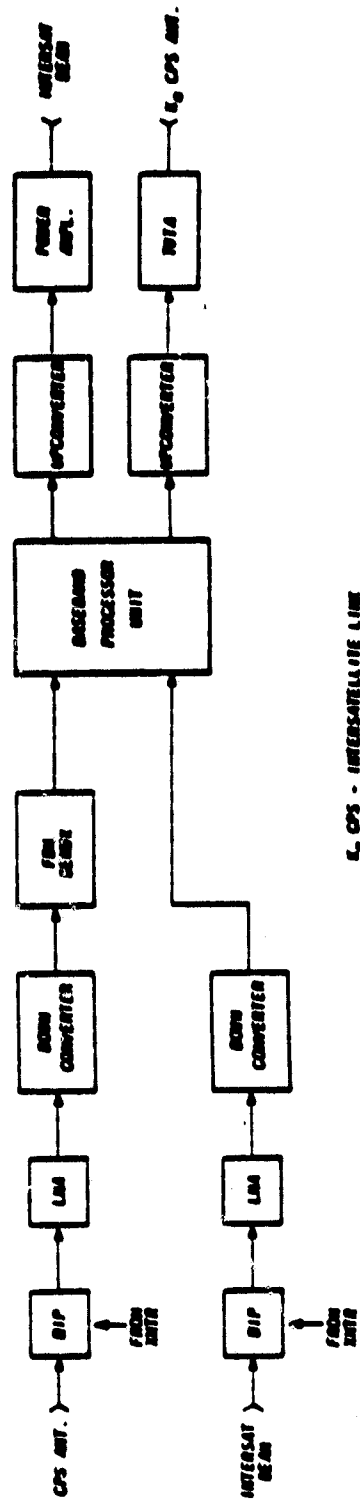
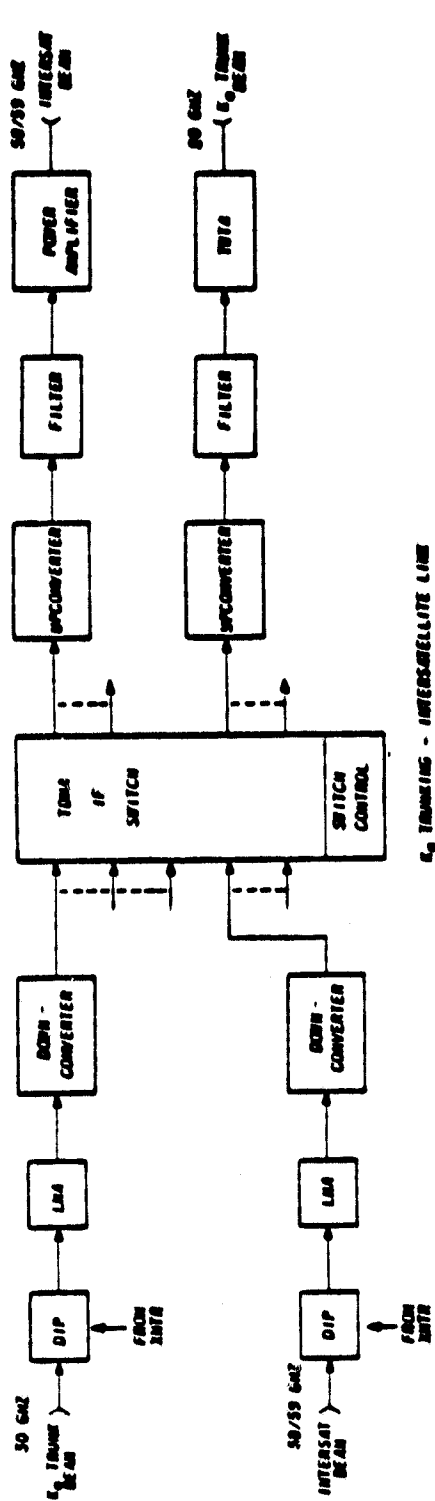
Intersatellite Link Receiver - An intersatellite link receiver is required to amplify (low noise) and down convert received 58/59 GHz carriers that are interfaced to the TDMA - If Switch for connection to Ka trunking downlink beams.

Intersatellite Link Transmitter - An intersatellite link transmitter is required to up convert and amplify trunking TDMA carriers for transmission via the intersatellite link.

Intersatellite Antenna Subsystem - An intersatellite link antenna(s) with an appropriate number of spot beams, compatible with the number of satellites to be interconnected, is required.

### 4.2.2 Ka CPS - INTERSATELLITE LINK CONNECTIVITY

Figure IX-2B shows a general block diagram of a Ka CPS-Intersatellite Link Communications subsystem. The intersatellite link appears as an extra set of ports on the baseband processor. The basic additional functional requirements are:



LEGEND:

DIP - DIPLEXER

Figure IX-2

K<sub>a</sub> TRUNKING & CPS INTERSATELLITE LINKS  
FUNCTIONAL BLOCK DIAGRAM

Intersatellite Link Transmit Subsystem - A transmit subsystem is required to upconvert and amplify TDMA carriers for transmission via a 58/59 GHz intersatellite link.

Intersatellite Link Receive Subsystem - An intersatellite link receive subsystem is required to amplify (low noise) and downconvert the received 58/59 GHz TDMA carrier for application to the BPU.

Intersatellite Antenna Subsystem - The intersatellite CPS and trunking traffic will share an antenna with an appropriate number of spot beams compatible with the number of satellites to be interconnected.

APPENDIX A  
ANTENNA SPECIFICATIONS

1.0 TYPICAL WESTERN UNION ANTENNA ENVIRONMENTAL SPECIFICATIONS

1.1 POINTING ACCURACY

a. The pointing accuracy shall be consistent with the following gain degradation limits in the direction of the satellite under Normal Weather Conditions and for 99% of the worst month of the year.

0.3 dB in the 3.7-4.2 GHz band

0.5 dB in the 5.925-6.425 GHz band

b. Additionally, the antenna pointing accuracy shall be not worse than 0.02 degrees rms under wind velocity conditions of 45 mph, gusting to 60 mph.

1.2 ENVIRONMENTAL CONDITIONS AND CAPABILITIES

The antenna shall be designed for continuous and reliable service over a minimum 15 year life. The above requirements shall be met under the following environmental conditions, applicable to the reflector/pedestal assembly:

a. Normal Weather Condition

Wind: 30 mph (any direction), gusting to 45 mph ( 3 sigma)

Temperature: 0 °F to +100 °F

Humidity: 20% to 100%, relative

Solar Radiation: 350 BTU/Ft<sup>2</sup>GR

b. Poor Weather Condition

Wind: 45 mph (any direction), gusting to  
60 mph (3 sigma)

Rain: a five-minute rate of 0.5 inches

Snow: 2 In/Hr

Ice: (a) 1" Thick radial over all antenna  
surfaces

(b) 1-1/2" over lower of half dish  
only

Temperature: -15 °F to +100 °F

Humidity: 0% to 100%, relative

Wind & Ice: All combinations of wind &  
ice

c. Extreme Conditions and Survivability

Wind (Survival): (a) 120 mph in stow  
position

(b) 70 mph with 1" ice in stow position.

Temperature: -30 °F to +100 °F

Drive to Stow: 70 mph wind load (worst  
direction)

Hold in Position: 80 mph wind load (worst  
direction)

d. Equipment Survival in Storage and Trans-  
portation

Temperature: -62 °F to +185 °F

Altitude: 40,000 Ft.

## 2.0 LARGE GROUND STATION ANTENNAS AT 20 - 30 GHZ

The TRW and Hughes trunking designs utilize 12 meter antennas. This is a comparatively a large antenna, even at 6 and 4 GHz, but for the 20/30 GHz range it presents many problems, the solutions to which are not all immediately obvious. Some of these problems are:

How to provide parabolic surfaces with sufficient accuracy.

How to design mounts and sub-reflector supports with adequate stiffness.

Automatic or programmed tracking.

Compensation for building sway.

Servo loop compensation.

All of the above problems are inter-related, but there is another problem not considered in lower frequency systems which may introduce perturbing inputs into the tracking system. This is the possible variation in phase across the aperture of the antenna of the arriving energy from the satellite, due to rain cells which can conceivably cause distortion of the arriving wave front, resulting in loss of signal over and above that caused by attenuation of the beam in passage.

### 2.1 SURFACES OF PARABOLIC DISHES

The operating efficiency of a parabolic dish, which relates actual gain to theoretical gain of an ideally

illuminated parabola, is determined by the deviation of the dish surface from the desired contour, and by the effectiveness of the feed in achieving the ideal illumination distribution.

At these frequencies, the dish shaping tolerance is the most difficult to achieve due to manufacturing and installation problems of the dish surface and back-up structure. In addition to still air conditions, the dish surface and feed geometry must be maintained under high and gusting wind conditions, depending on locality. Typical designs call for meeting performance specifications in the following environmental conditions:

Temperature range - 0°F to +100°F

Rainfall - a five minute rain rate of 0.5  
inches

Solar radiation - up to 1,000 kilo-cal/hr/M<sup>2</sup>

Wind - survival in winds up to 120 mph, move  
in winds up to 70 mph

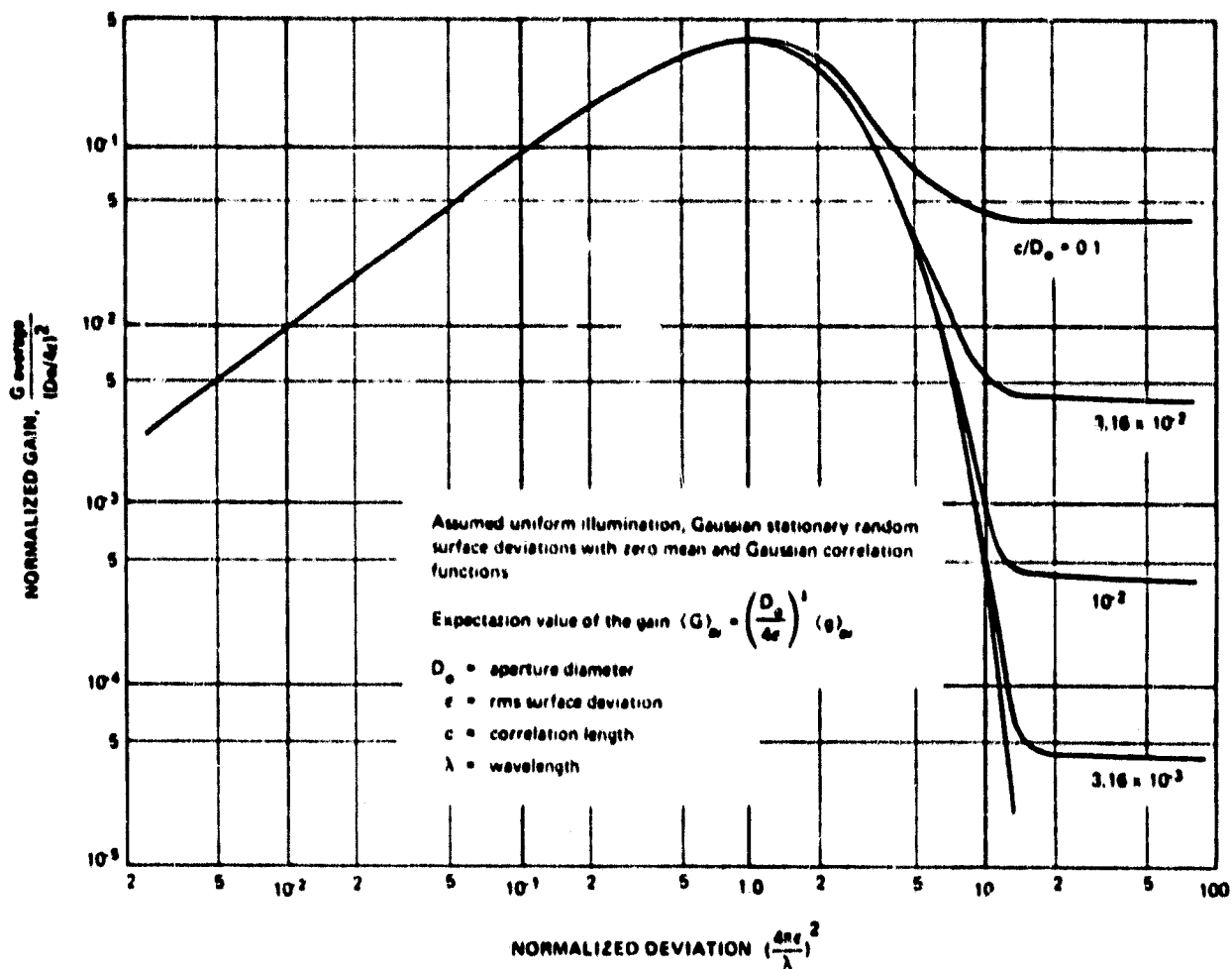
Tracking error - .0065° in winds 49 km/h  
gusting to 73 km/hr, 0.1° in winds of 75 km/hr  
gusting to 96 km/hr

Dish surface tolerance for any D/ is characterized by rms surface deviation and correlation interval. These factors are related to gain as illustrated in Figure A-1.

The gain loss illustrated in Figure A-1 does not in-



### Aperture Gain Loss Due to Random Errors



Reprinted from the Bell System Technical Journal, Vol. 47, No. 8, October, 1968, pg. 1643.

FIGURE A-1

clude gain loss due to high winds distorting the dish or affecting tracking accuracy. Extrapolation of costs from C or X band to arrive at a cost for a 20/30 GHz antenna is not considered a good approach.

## 2.2 MOUNTS AND SUB-REFLECTOR SUPPORT

The present dish structure designs are optimized for C-band and may not be suitable for 20/30 GHz, making extrapolation of costs questionable. It is likely that the dish and amount will both have to be redesigned, as well as the sub-reflector support. The closest known technologies are radio telescope antennas and solar tracking furnaces. These seem like logical places to start in predicting costs.

## 2.3 BUILDING SWAY

In the case of antennas mounted on the roofs of buildings more than a few stories in height, building sway can be a factor in determining the pointing angle. Monopulse tracking may not be affected in these cases, but step-track could experience a problem in certain wind conditions.

## 2.4 RADOME

Mention is made of the use of a radome, whose manufacturer claims that due to special surface-coating techniques, will yield a maximum alteration of 20/30 GHz of 1 dB. If this is true, it will greatly alleviate the above problems due to wind and rain loading.

## 2.5 POINTING

Antenna pointing will be a very large problem. If local pointing is used (monopulse or step-track) with great attention to design details, many of the perturbations can be minimized dynamically. This is particularly true with monopulse. With remote commanding of antenna pointing angle, the system operation depends on accurate prediction of losses due to environmental conditions and pointing command accuracy. One suggested solution is to provide a low-power beacon, operating at a lower frequency (4 GHz for example) to be used for pointing. This would ease the problem of loss of track in heavy weather at the cost of added complexity. This may not be necessary, since at least in the TRW system, there are phase-locked loops with 100 Hz bandwidth, which could possibly provide sufficient margin for step-track operation.

## 3.0 CURRENTLY AVAILABLE HARDWARE

Concern over the problems associated with the practicability of building both large and medium aperture antenna systems led us to look to a supplier of Radio Astronomy systems, which operate at frequencies up to 150 GHz. The problems associated with these antennas fall in the following areas:

1. Maintaining necessary surface accuracy during manufacture and assembly.

2. Maintaining surface accuracy under severe wind and rain conditions.
3. Pointing system accuracy.

We have located one viable source of suitable antennas. This is:

Electronic Space Systems Corporation  
 Old Power Mill Road  
 Concord, Massachusetts  
 Telephone: 617-369-7200  
 Contact - Samuel L. Hansel, Jr. ScD  
 Sales Manager/Systems Specialist

We have received a packet of very interesting information about these antennas, which is summarized below with comments.

### 3.1 SURFACE ACCURACY

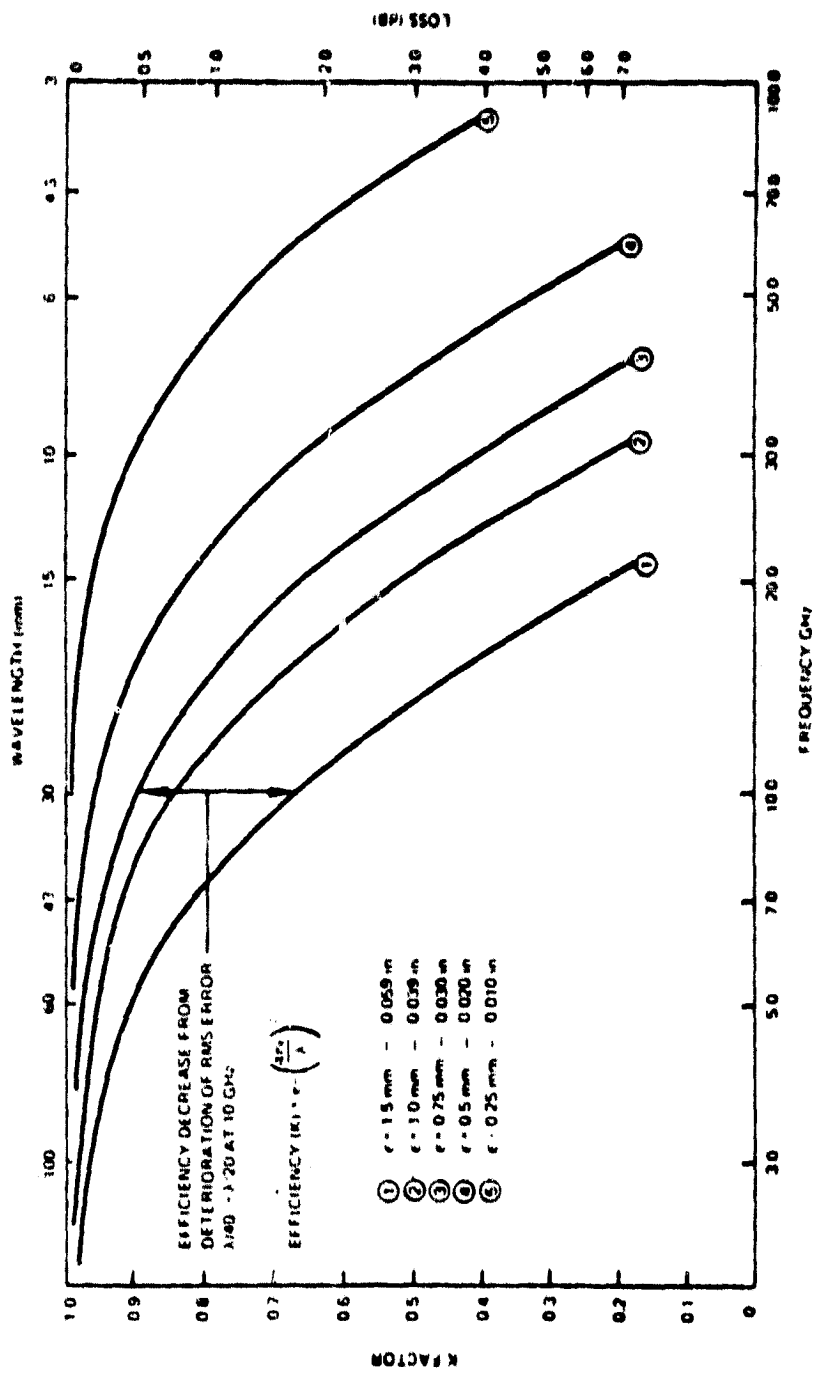
Surface rms error  $E$  is computed by means of the following expression:

$$E = \left[ \frac{1}{n} \sum_{i=1}^{i=n} X_i^2 \right]^{1/2}$$

if the distribution of surface errors  $X_i$  is Gaussian.

A curve relating  $E$  to  $k$  factor (efficiency) is shown in Figure A-2.  $k$  factor is computed according to the formula

$$k = e - \left[ \frac{4E}{\lambda} \right]^2$$



EFFICIENCY (K) FACTORS AND GAIN LOSS (dB) DUE TO REFLECTOR SURFACE RMS ERRORS

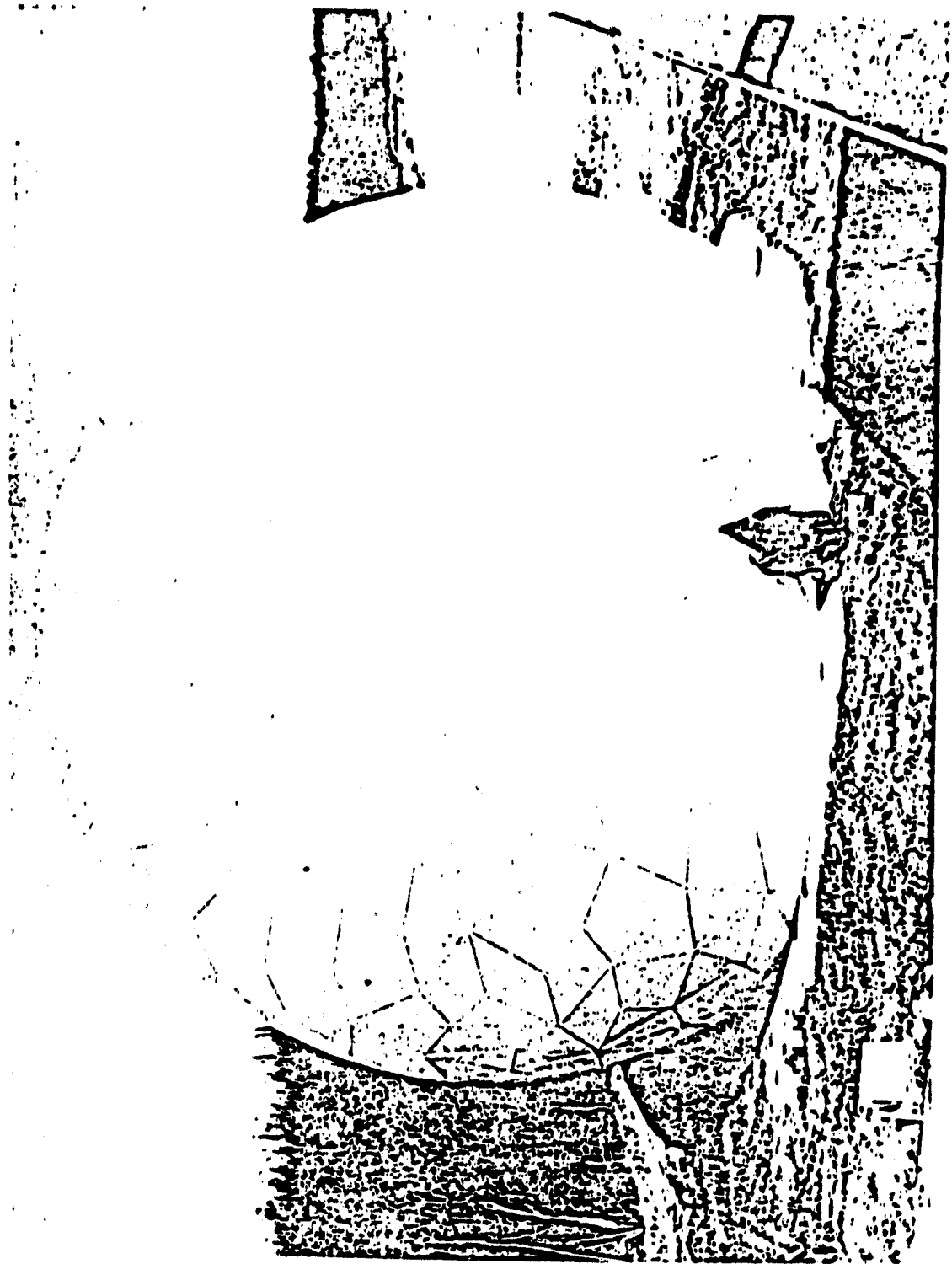
Figure A-2

These curves are completely theoretical. Some insight into actual performance expectations can be learned from an ESSCO pamphlet on a 45 foot dish built for the University of Massachusetts. The surface of this dish consists of 2 precision aluminum panels, manufactured to a surface accuracy of about 0.06 mm. The assembled dish has an overall accuracy of 0.1 mm across the entire aperture, better than required for 30 GHz operation by a factor of about 2.

### 3.2 EFFECTS OF WIND AND RAIN

ESSCO provides complete systems, including the antenna (with feed system), mount, and drive system. Their antenna design is based on operation inside a special radome of proprietary design. A typical radome is pictured in Figure A-3. It consists of an aluminum space-frame. The space-frame is composed of triangular panels bolted together to form the structure. The aluminum structural elements are encapsulated in a special low-loss dielectric, and the actual surface is made up of a special membrane.

The use of the radome effectively eliminates the effect of wind, with virtually no penalty on performance, which is very surprising. It simplifies both structure and drive systems and lowers costs in these areas. Rain accumulation on the radome is virtually nil, due to the membrane material which causes rapid runoff. The noise temperature increase due to rain



ESSCO Model M68-78 (68 ft. Diameter) Metal Space Frame Radome

Figure A-3

is quoted as less than  $10^{\circ}\text{K}$ . Another benefit is reduced maintenance, although the membrane surface does require some cleaning.

Performance of these systems is illustrated in Figures A-4 and A-5. There are theoretical curves for assumed  $k$  factors, but ESSCO asserts that actual systems attain values indicated in the curves or better.

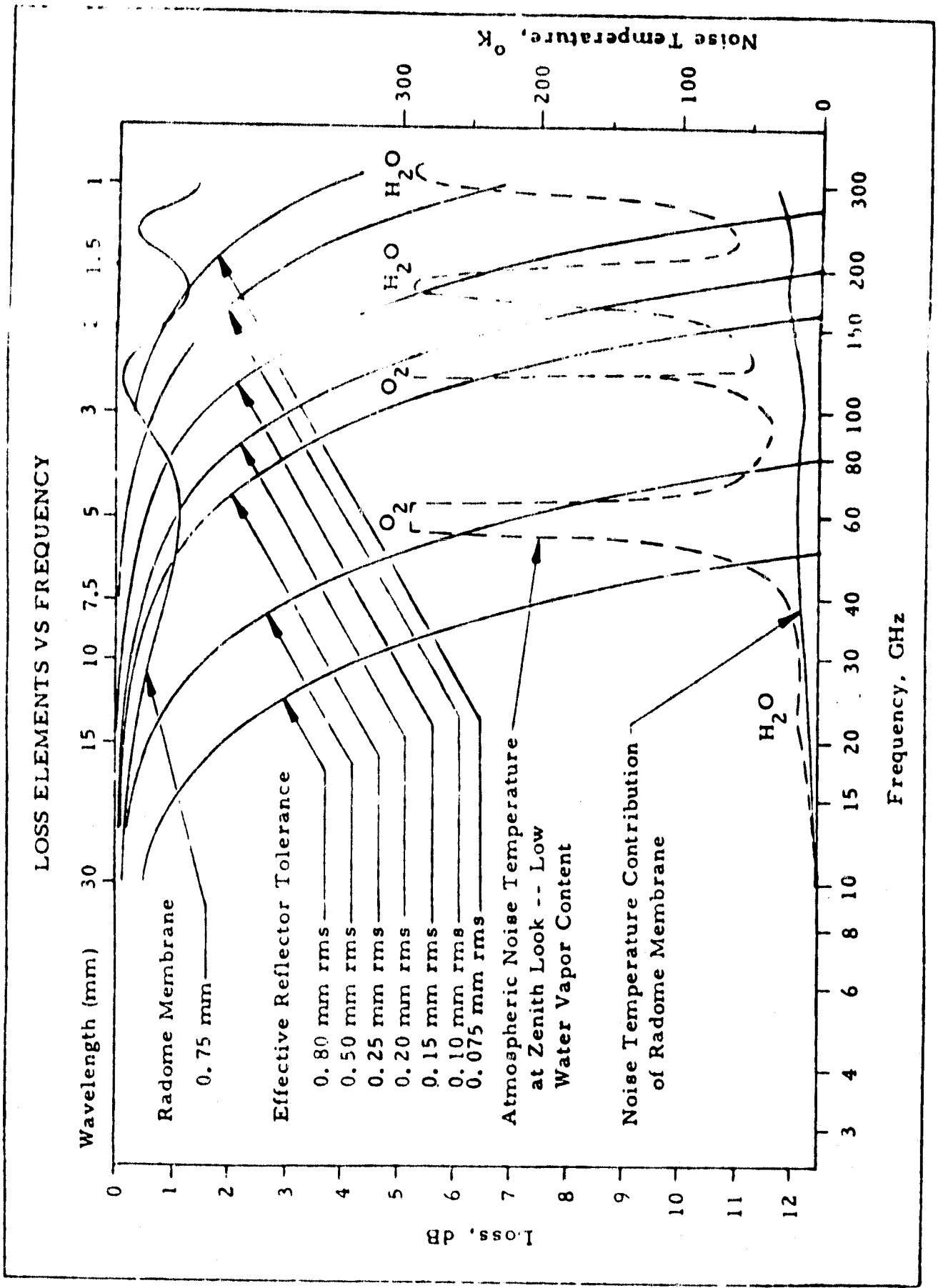
### 3.3 POINTING ACCURACY

Servo accuracy approaches 2 arc seconds.

### 3.4 COST

No costs were obtained, but they are undoubtedly very high. ESSCO is studying projected costs for quantity production (10 per month) in 2-3 years time, but no data is available at present. Some economies are obvious, particularly in the pointing systems, since full motion is not required for synchronous satellite application, nor is the extreme pointing accuracy.

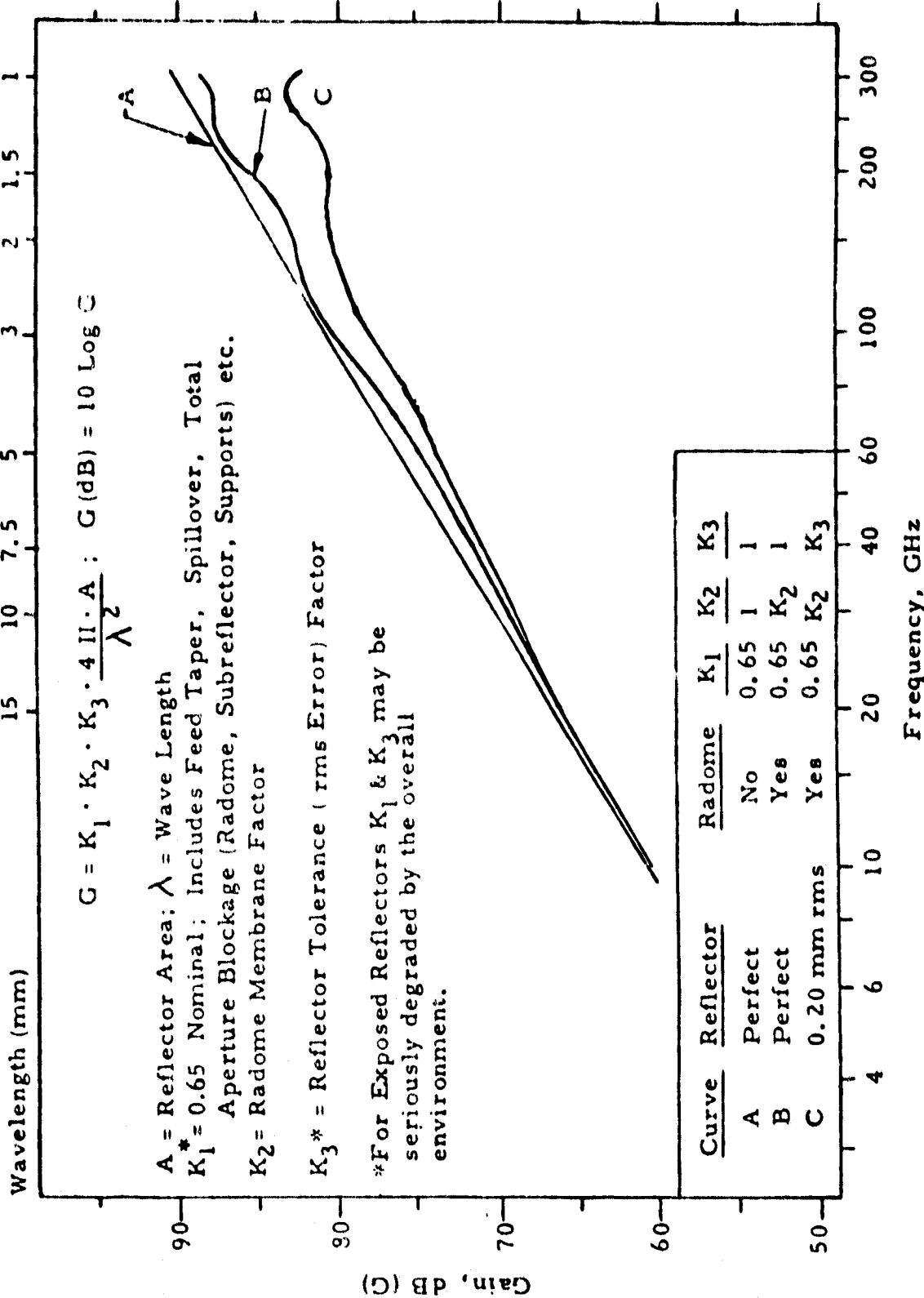




Loss Elements vs Frequency - ESSCO Synergised Antenna Subsystem

Figure A-4

TYPICAL GAIN VS. FREQUENCY



Typical Gain vs. Frequency - ESSCO 45 ft. (13.7m) Diameter Synergised Antenna Subsystem

Figure A-5