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UHF COMMUNICATIONS
SATELLITE SYSTEM

FINAL REPORT/VOLUME III

RCA **Space Systems**

RCA LIMITED
1001 Lenoir St., Montreal 207, Canada

UHF COMMUNICATIONS
SATELLITE SYSTEM

FINAL REPORT/VOLUME III

The work reported here was done under DDS Contract OPL1-0005 "Consulting Services for Cost Studied of UHF Satellite Communications Systems" and under the design authority of the Communications Research Center of the Department of Communications.

Prepared by:

Government and Commercial Systems Division,
RCA Limited, Ste. Anne de Bellevue, Quebec

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1.0 SYSTEM PERFORMANCE

1.1 Introduction

This volume discusses the detailed communications performance and the design and cost of the earth stations. A transistorized transponder is assumed and in order to relate the relatively well known "black box" characteristics of a travelling wave tube transmponder to the transistor version, a preliminary investigation into the intermodulation characteristics of a microwave transistor amplifier was carried out. The results indicated a 3 dB better two tone intermod. level as compared to a TWT and consequently it was judged relatively safe to assume that the transistor "black box" would be no worse that the TWT "black box".

The second major assumption is the use of analog companding techniques, and the improvement afforded by this technique (and emphasis) makes the system possible. The calculations are treated in detail in the following section.

The fading performance of a companded system, and the multicarrier transponder make some form of EIRP control mandatory and a number of alternatives were considered. One approach is a hard limiting transponder, and this was rejected because of the IM noise contribution and the requirement for different EIRP for different types of service. Another approach is to downconvert the received signals (in the satellite) to a frequency at which each carrier can be separately filtered and gain controlled. The levelled carriers are combined, upconverted to RF and amplified in the common transponder. This scheme has the very serious disadvantage of inflexible frequency assignment and again the problem of carriers which require different EIRP levels. The other alternative examined was an active EIRP control from each earth station. It has the disadvantage of increasing the cost and complexity of the earth station, but this is outweighed by the advantage of an "unconstrained" satellite transponder capable of carrying an arbitrary mix of carriers with varying bandwidths and power levels. Early in the study, it was judged very desirable to have as flexible a satellite transponder as possible, primarily to accomodate the different bandwidths and powers required by the system constraints, and equally important to allow the use of radically different future modes of operation such as TDMA.

The method of network control, and the network configuration, has been well defined by the work statement and no major derivations have been necessary. During the initial trade-off studies a slightly different operational concept was superficially examined in an attempt to minimize satellite EIRP. It was not pursued further when it became apparent that the EIRP could be easily met and its practicality depended on a knowledge of the traffic flow that could not be reliably predicted. The basic idea was to determine what portion of the traffic was directed into the Southern Canadian area served by the control stations and dedicate the edges of the transponder (which has the lowest IM) to that traffic. Because of the high G/T of the network stations (a by product of the satellite control requirement) satellite IM is the performance limiting consideration, and a first examination showed that these carriers could be about 5 dB lower than carriers working with small stations. This is still of importance in the case of remote telemetry stations, and is a worthwhile trade-off area if a closer examination of the traffic model shows a substantial North-South flow.

1.1.1 Systems Margins

To establish terminology, the following definitions will be used:

Implementation Margin:	This is defined as the difference between the calculated available clear weather C/N and the required C/N for circuit performance.
Fading Margin:	This is defined as the allowable C/N fading beyond that required for clear weather performance, such that the performance objectives are met for the specified percentages of time.
Threshold Margin:	This is defined as the margin above the demodulator threshold when the system has used up the fading margin.

Additionally there are other "margins" which may be called calculation or safety margins and which are not highlighted in this section. These "margins" typically involve choosing the more conservative of two apparently valid assumptions, when there is not enough data to make an unequivocal case for one.

Table 1-1 System Margins

	1.5GHz (2.5GHz)	300 MHz
Implementation Margin	1.5 dB	0 dB
Fading Margin 20%	0 dB	1 dB
Fading Margin .3%	2.5 dB	4.5 dB
Fading Margin .03%	4.5 dB	≃ 6 dB
Threshold Margin .3%	1.5 dB	1.5 dB

As will be seen later, the predicted fading at 300 MHz is less than the margins provided and thus approximately one dB of the fading margin could be "transferred" as an implementation margin.

1.2 Fading Environment

The selection of a link frequency around 2,000 MHz is desireable from fading considerations as it is virtually unaffected by ionospheric phenomena and tropospheric phenomena do not cause severe fades at such a low frequency. At 300 MHz ionospheric phenomena are the major aontributors to fading and tropospheric phenomena such as precipitation are negligible. The following fading mechanisms have been considered:

1. Precipitation

   Rain fading is not a consideration at 300 and 1,500 MHz. For a 2,500MHz system, the magnitude of rain attentuation is about one-third (in dBs) the attenuation which occurs at 4,000 MHz. Rain fading at 4,000 MHz has been measured by operational earth stations in the Intelsat network and it appears that a C/T degradation in excess of 0.5 dB has never been recorded. Considering that the Intelsat stations have a 70°K system temperature, only a few tenths of a dB can be expected at 2.5 GHz.

2. Solar Transit (Ref. 1, 2, 3, 4)

   Near the vernal and autumnal equinoxes, the declination of the sun equals the declination of the satellite and thus the sun passes behind the satellite. In the Intelsat system this causes communications utage, however, for the present study, the effects are less severe.

1.2.1 2500 MHz System

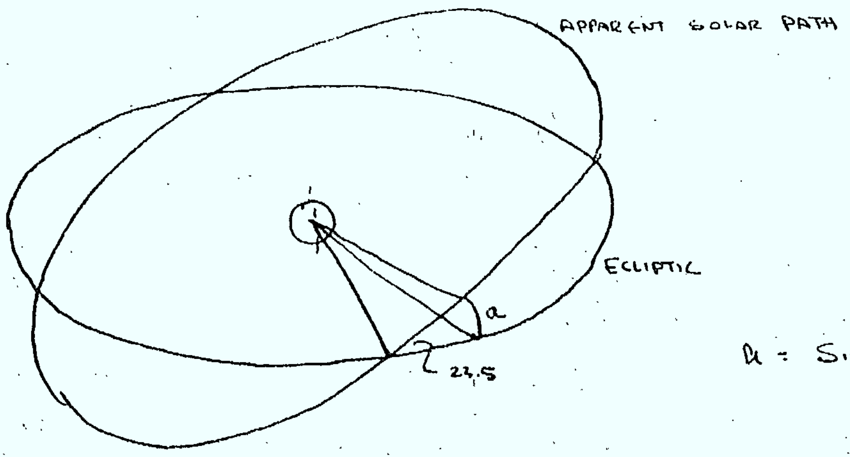
At 2500 MHz, the quiet sun has an apparent temperature of 80,000°K and the disturbed sun has an apparent temperature of 150,000°K. Occasional bursts can raise the

1.2.1 Cont'd......

temperature considerable higher, however, from a system's viewpoint, it seems reasonable to consider the quiet sun, which is the normal condition. Figure 1.1 shows the excess antenna temperature caused by the sun versus angle off boresight, assuming a 5' diameter antenna. The excess temperature for a 30' antenna such as the network control antennas is shown as Figure 1.2

To generate time statistics of the solar transit degradation, it is simplest to imagine the sun in declination and hour angle co-ordinates.

Geometry for Velocity in Declination



$$a = \sin^{-1}\left[\sin 23.5 \quad \sin \frac{2\pi d}{365}\right]$$

d is solar days measured from vernal equinox

a = SUNS DECLINATION

but for the case of interest d is small $\therefore \quad a \simeq \sin^{-1}\left[\sin 23.5 \cdot \frac{2\pi d}{365}\right]$

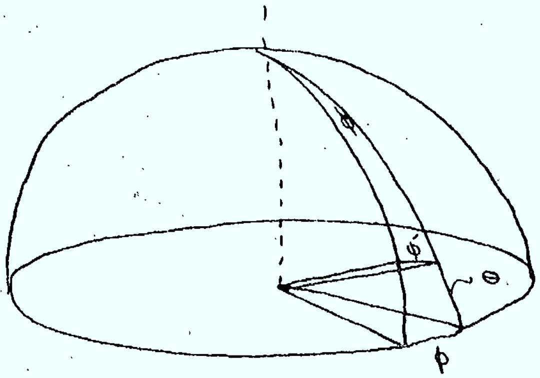
or $a \simeq \frac{2\pi d}{365} \cdot \sin 235$

$$\therefore \Delta o/\text{day} = \frac{2\pi}{365} \cdot \sin 235 \simeq 0.4 \text{ deg/day}$$

1.2.1 Cont'd......

Thus on each preceding and succeeding day of solar transit, the sun moves by 0.4 deg/day in declination. To separate the problem of axes, assume that we have an HA-DEC antenna, and we now have to find the velocity of the sun across the hour angle axis. This will vary with declination and has the same mechanism as that which causes the secant correction in an Ax-El mount.

Geometry for Velocity in Hour Angle



θ - declination
ϕ - hour angle

When ϕ' is the apparent angle for a declination of θ

$$\cos\phi' = \sin^2\theta + \cos^2\theta\cos\phi$$

or

$$\frac{\dot{\phi}'}{\dot{\phi}} = \frac{\cos^2\theta\sin\phi}{\sin\phi}$$

$$= \cos^2\theta \text{ for small angles.}$$

The ratio of velocty is $\cos^2\theta$.

As can be shown (REF 2), the greatest declination in Canada for a sun transit is about 8° thus the minimum velocity will be $\cos^2 8^\circ \cdot \frac{360}{24\times 60}$ deg/min $= 0.25$ deg/min

1.2.1 Cont'd......

From the foregoing calculations, the approach of the sun can be plotted vs. time and for each day preceding and succeeding the day of closest transit, and a cumulative distribution of angular distance versus time per month can be generated. Note that this is only applicable in April and October.

The increase in excess temperature causes a decrease in system G/T and thus the resulting fade in output subjective S/N can be calculated. Because of the "threshold" effect of the expandor, the peak fade is considerable and exceeds 300,000 pWp subjective noise. See figure 1.5. Note that this is still a useable channel and the system is still operational in contrast to systems at higher frequency.

For the 30' antenna, the solar transit will cause fading in excess of 20 dB, in effect reducing its G/T to about 5 dB, which is still adequate for traffic reception. A problem may arise in the reception of remote telemetry stations, where it is expected the transmit power will be consistant with reception by a 30' antenna (i.e. no downlink noise, only IM and uplink). Two alternatives are available:

1. accept the outage for the relatively short time it occurs. This may not be acceptable if some remote telemetry stations can signal independently.
2. ensure that the other network station is about 1,000 miles away and duplicate the remote telemetry control and receive equipment. By siting two stations 1,000 miles apart, both stations will not have a simultaneous outage.

1.2.2 300 MHz

At 300 MHz, the apparent temperature of the sun is approximately 10^6 °K, however,

1.2.2 Cont'd......

for a 5 foot nominal diameter antenna the on-axis temperature contribution is less than 100°K. Since the 300 MHz system has a system temperature close to 500°K, the fading is insignificant, and it can be said that the system is completely operational throughout the year. With a 30 foot antenna at 300 MHz, the fading is severe, but again normal traffic can be carried with some degradation and the same comments at 2500 MHz apply with respect to remote telemetry.

1.2.3 Ionospheric and Tropospheric Fading

General

Attempts have been made to calculate the fading due to these sources and the results are very sensitive to the assumptions made. Maynard and McCormick have measured statistics which can be scaled with some confidence to other frequencies and it was judged preferable to use the empirical data because of the sensitivity of system design to fading statistics. The assumed statistics are shown in Figure

While it has been demonstrated that depth of fade and frequency of occurrance are corelated, it is conjectured that there is also a good corelation between the depth and duration of fades and this is obviously the case for some fading mechanisms such as multipath. If this is the case, then the assumed degradations are conservative, since the CCIR performance objective defines noise powers up to 10^6pW as the one minute average. It is realized however, that this is the major constraint on system performance and for this reason the system is provided with a 2dB EIRP margin over the EIRP required to meet the CCIR objective assuming the foregoing fade statistics.

1.2.4 Refraction Variations

1500 MHz (and 2500 MHz)

The majority of total bending is contributed by the troposphere and temperature, pressure, and humidity changes cause a change in the refractive index, and hence variations in angle of arrival. For a fixed antenna at extrememly low elevation look this is a fading mechanism. To estimate the magnitude of this mechanism, the angle of arrivel variations has been calculated over a year, utilizing the twich daily radiosonde atmosphere profiles from Inuvik, NWT. The results indicate that 0.1 dB three sigma for a 5° elevation angle is an adequate allocation.

1.2.5 300 MHz

Tropospheric bending is virtually frequency insensitive (except for ducting which is not considered a problem at 5°) and thus the foregoing is applicable to 300 MHz. At 300 MHz there are additional variations due to ionospheric disturbances but this in not significant because of the very large beam width. Accordingly, no fading due to this mechanism is assumed for 300 MHz.

1.2.6 Satellite Induced Fading Mechanisms

1. Satellite pointing error:

   The specified beam edge coverage includes an allocation for the spacecraft antenna three sigma pointing error. As the pointing error is decreased the beam edge EIRP increases, the exact value depending on the antenna beam edge gain slope. This is thus a "reinforcing" fade and the value is approximately +0.3 dB three sigma. This is only applicable at 1.5 GHz.

1.2.6 Cont'd.....

2. Satellite Drift (1)

The EIRP coverage includes a component at beam edges due to the satellite's daily excursions of 1.6° max. This effect will increase the EIRP at beam edges by 0.3 dB max. when the satellite goes beyond the asending node. This is only applicable at 1.5 GHz.

3. Satellite Drift (2)

The motion of the satellite causes a pointing error in the earth station which, at 1.5 GHz, is a 0.25 dB loss. The loss at 300 MHz is insignificant.

1.2.7 Uplink Fading

Because ionospheric disturbances and hence fading can be large scale, it is not safe to assume that uplink and downlink fades (at two different stations) are independent and that the back to back fading statistics are the probability sum (convolution of the respective distributions) as in some cases it will be the arithmetic sum. Further, because of the nature of the system, two stations back to back may be geographically very close and hence be affected by similar tropospheric fading mechanisms, in which case the back to back fading distribution in the arithmetic sum of each fade.

These uncertainties, together with the sensitivity of communications performance to uplink fade, led to the assumption of earth station EIRP control. The system is described in more detail elsewhere, but basically it relies on the control station

1.2.7 Cont'd.....

closely maintaining the EIRP of the pilot at the satellite, and thus a measure of the pilot level (i.e. SAC level) at each earth station is a measure of the path loss. The AGC then used as an offset in the automatic level loop of the earth station power amplifier.

It is envisaged that the EIRP control loop will have a time constant on the order of 10 sec. and thus any uplink fades of that order of duration will not be removed by the AGC. As explained previously, this will have a much reduced effect on circuit performance (as measured against the CCIR objective) because of the one minute averaging.

A value of ± 0.5 dB three sigma has been assigned to the uplink EIRP control, and this is believed to be more than adequate. The only element outside the closed loop is the gain of the front end and the reference voltage for the AGC and ALC loops. Present day parametric amplifiers exhibit gain drifts of less than 0.1dB/week and it is felt that 0.25 dB is an adequate allocation for the envisaged paramp. The reference voltage can be a zener diode and this can be almost arbitrarily good.

1.2.8 EIRP Control at 300 MHz

It has been pointed out by Maynard in a private communication, subsequent to the completion of the bulk of the study, that fading rates shorter than the link delay time are not uncommon and thus a closed loop EIRP control through the satellite would not remove the effect of fast (and hence probably deep) fades. The EIRP control would be mechanized in a different way if this problem turned out to be significant. The satellite borne beacon would serve as a reference and thus the

1.2.8 Cont'd......

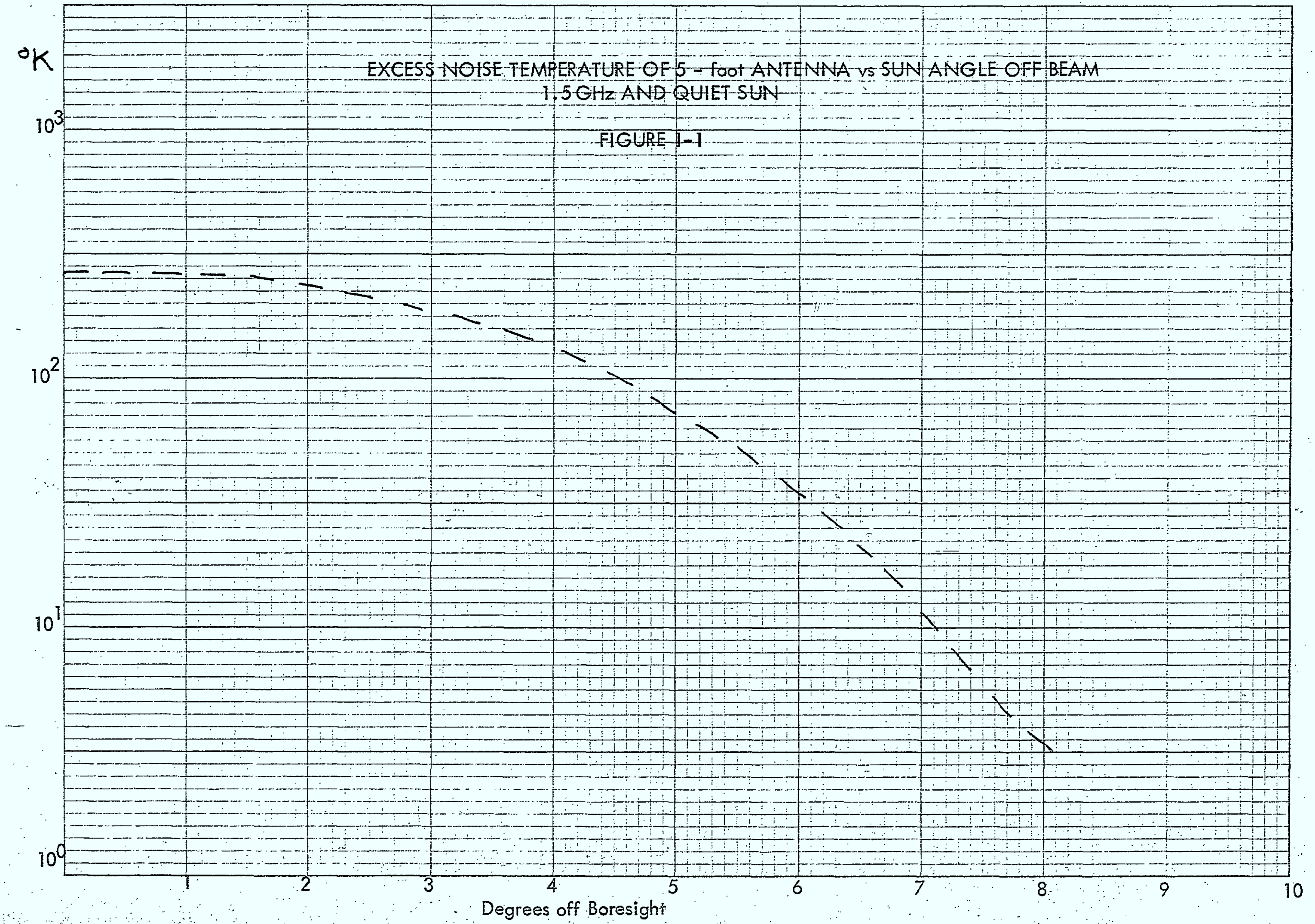
delay would consist of transit time from the ionsophere to ground and back to the ionosphere. To compensate for the affects of beacon ageing and to allow ground control of the system EIRP, the beacon should be adjustable by the Telemetry and Command Station.

It was also pointed out that the 6 dB margin assumed at 300 MHz is not applicable to high latitudes. To evaluate the situation would require a knowledge of the power spectral density of fading range, and if the conjecture that fading depth is related to duration is correct, then the 6 dB downlink margin may be adequate, since the circuit performance is measured as the one minute mean. Alternatively, larger G/T can be assumed for high latitude earth stations or more satellite EIRP can be provided at the expense of traffic capacity or spacecraft design margin.

1.3 Predicted Circuit Performance

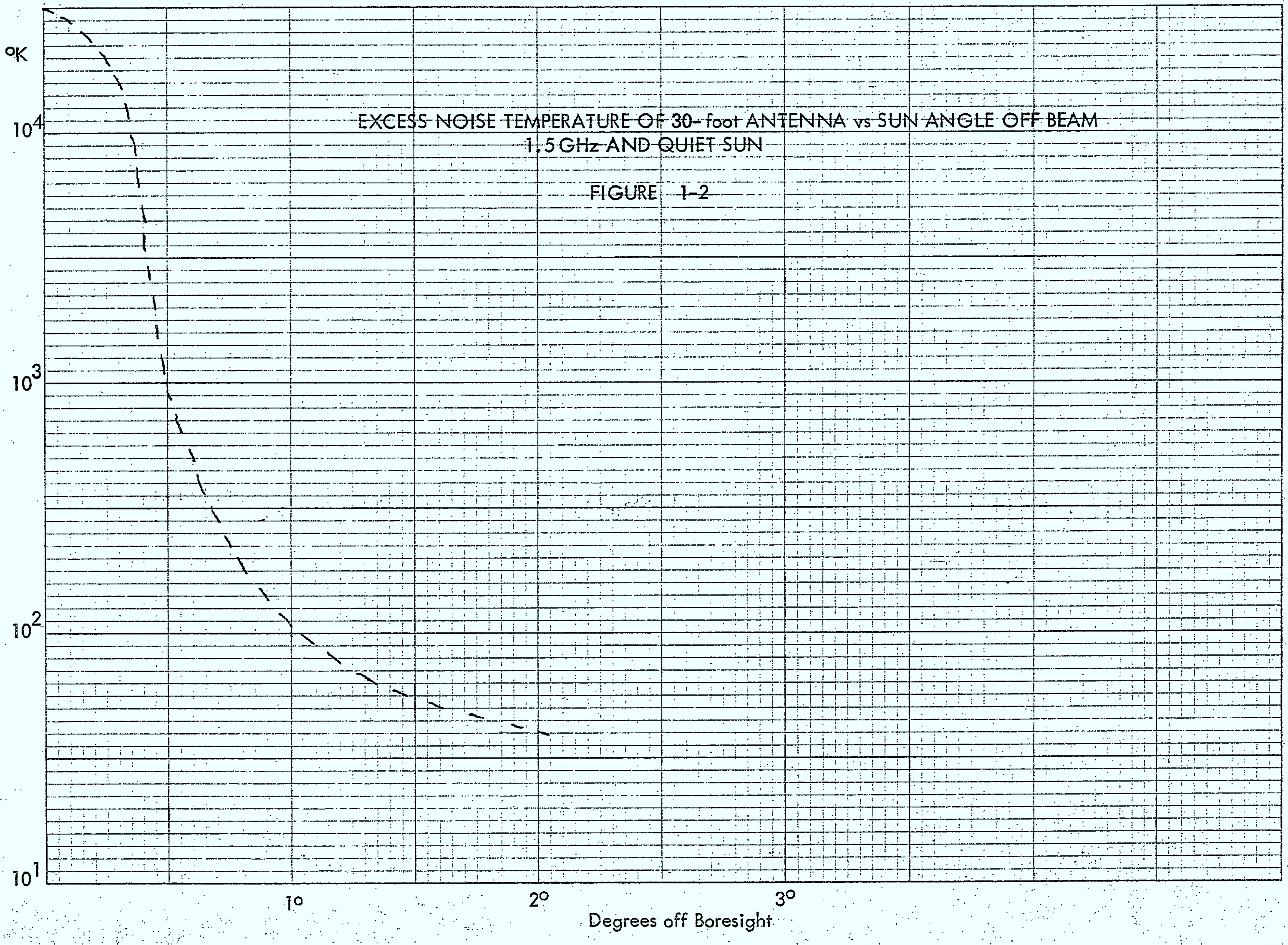
By removing uplink variations, the question of how to statistically add the back to back degradations disappears and performance can now be predicted from a knowledge of the one way fades (i.e. satellite to receiving station) with a 0.5 dB (assumed gaussian independant component). Note that this is not an exact solution because the uplink fades cause a greater (S/N)$_o$ fade than a fade of the same magnitude in the downlink. However, since uplink thermal is negligible and IM noise relatively small in comparison with downlink thermal the end result will not be materially different.

As can be seen from Figure the predicted performance exceeds the CCIR objective, for both system models. The only area of possible concern at 1.5 GHz is the assumption that 80% of the time correspondes to clear weather and if this is not the case some of the system margin should be allocated for any fading between clear weather and the 80% probability level. At 300 MHz, because of the more severe fading environment, it has been assumed that there is a 1 dB fade at all times.



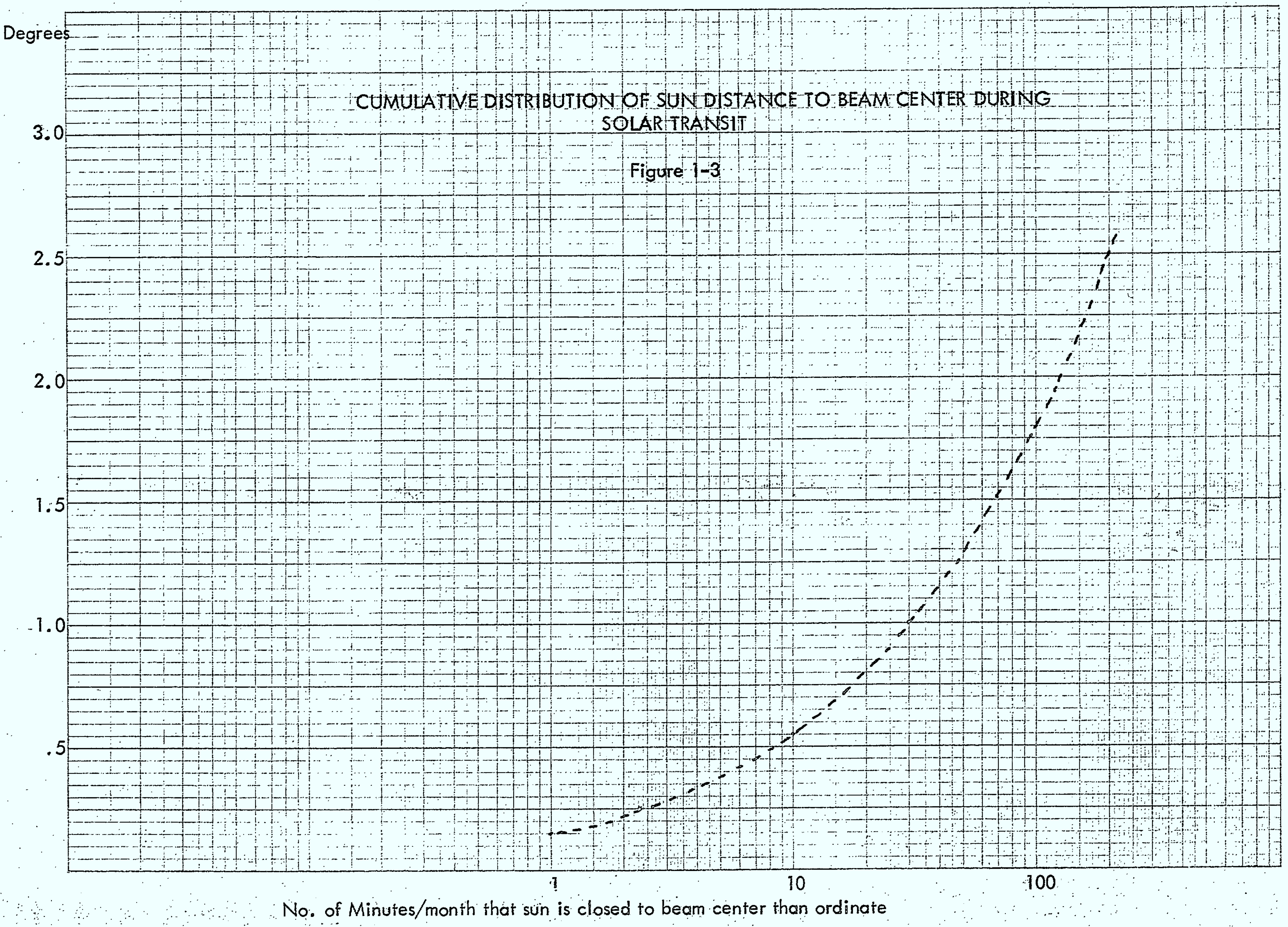
EXCESS NOISE TEMPERATURE OF 5 - foot ANTENNA vs SUN ANGLE OFF BEAM
1.5 GHz AND QUIET SUN

FIGURE 1-1



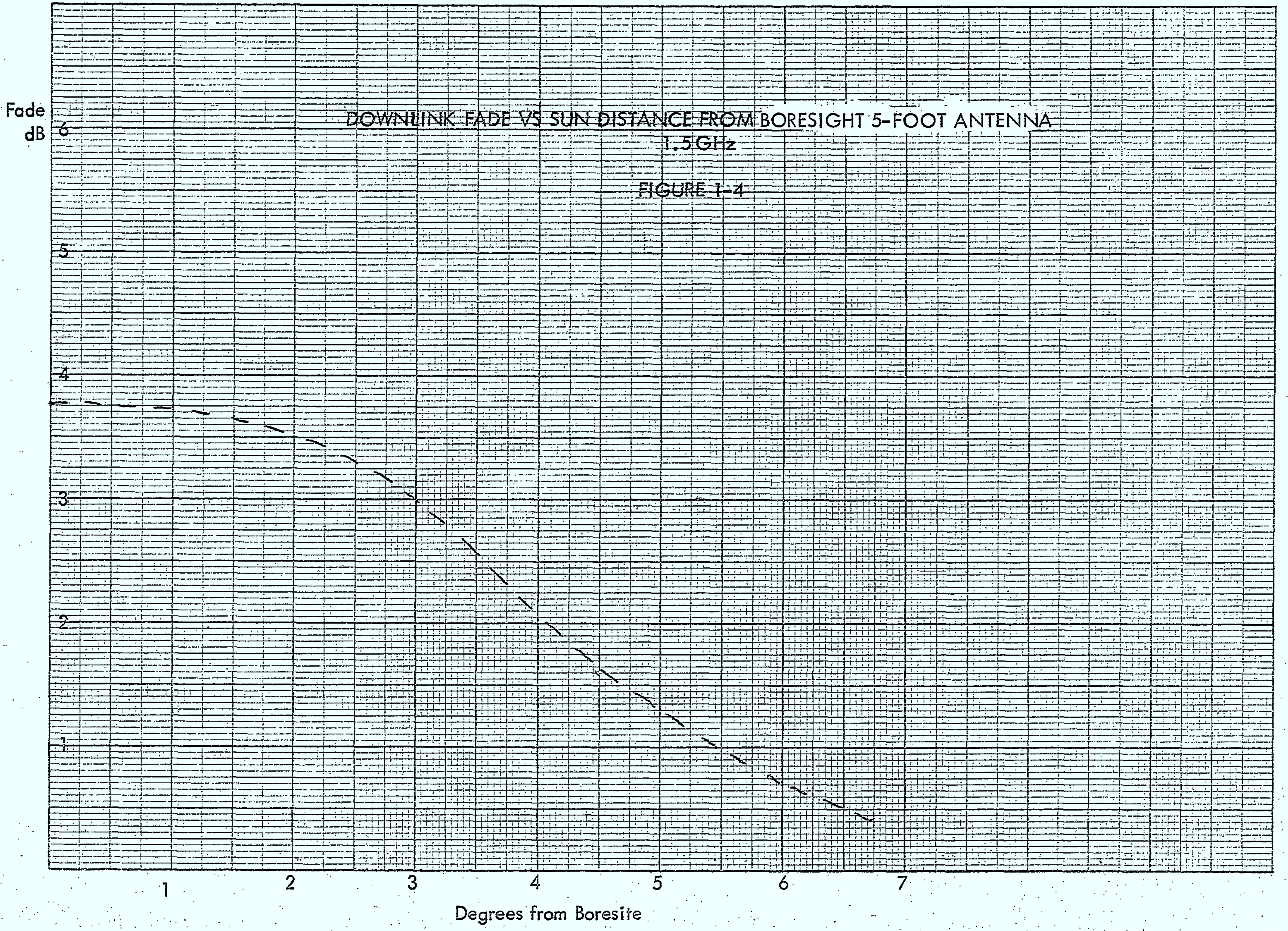
EXCESS NOISE TEMPERATURE OF 30-foot ANTENNA vs SUN ANGLE OFF BEAM
1.5 GHz AND QUIET SUN

FIGURE 1-2



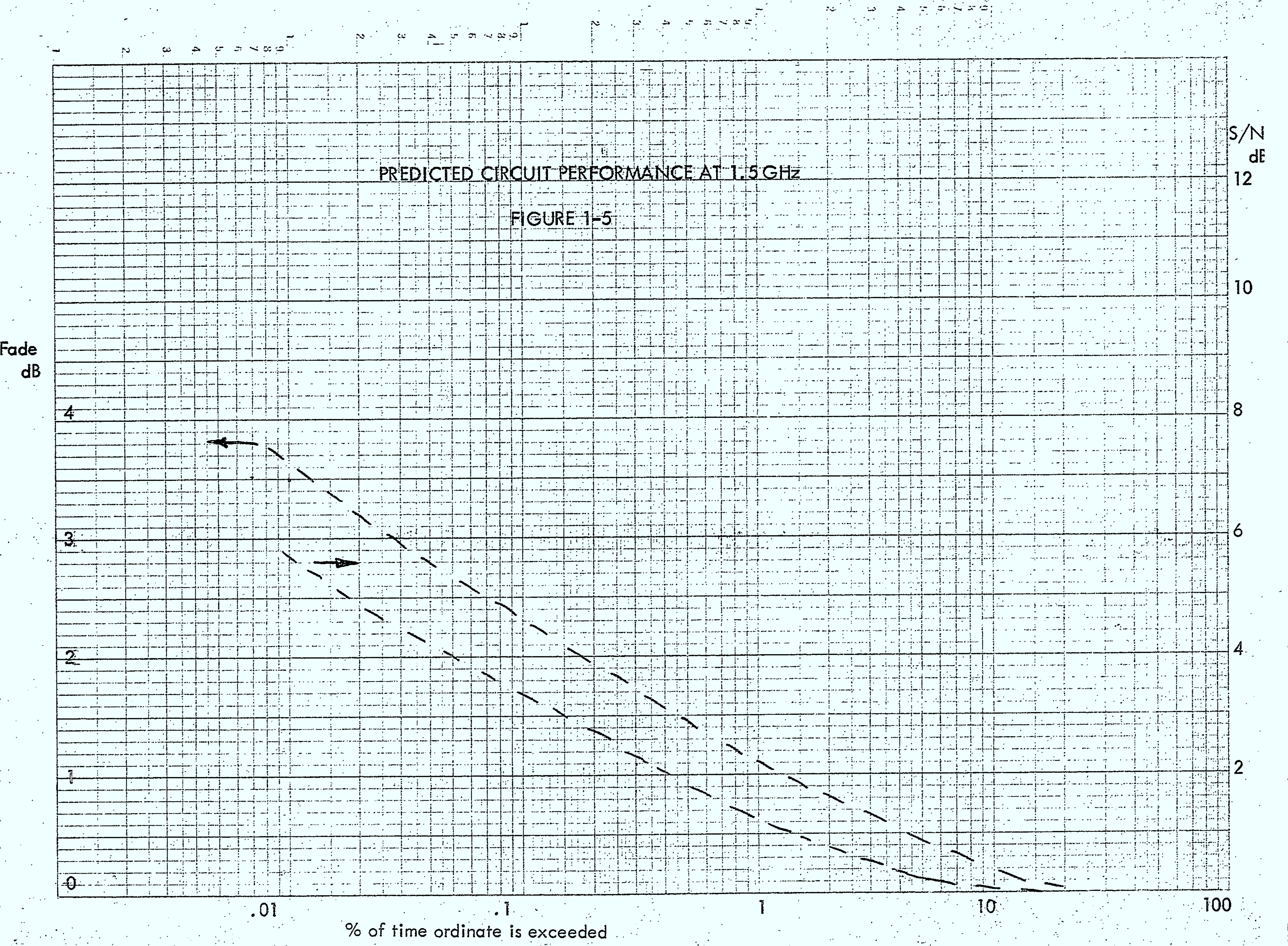
CUMULATIVE DISTRIBUTION OF SUN DISTANCE TO BEAM CENTER DURING SOLAR TRANSIT

Figure 1-3



DOWNLINK FADE VS SUN DISTANCE FROM BORESIGHT 5-FOOT ANTENNA
1.5 GHz

FIGURE 1-4



PREDICTED CIRCUIT PERFORMANCE AT 1.5 GHz

FIGURE 1-5

2.0 COMMUNICATIONS ANALYSIS

2.1 Introduction and Summary

The purpose of this chapter is to analyze whether or not the performance and traffic requirements given in Para. 2.1 can be satisfied within the constraints imposed upon the system by:

(a) available satellite EIRP and G/T, restricted by weight and size limitations and by availability of power amplifier devices.

(b) available Earth Stations EIRP and (G/T), controlled by cost considerations and by requirements for transportability.

From the numerous possible satellite transponder configurations, the single channel wideband transponder was selected for the baseline design of an operational system (Vol. II, Para. 3.1.2).

Therefore the present analysis places major emphasis on multicarrier intermodulation in wideband satellite power amplifiers. For the 1.5 and 2.5 GHz band, TWT and transistor power amplifiers were considered. It is shown that both of these devices would satisfy the communications performance requirements.

However, further studies are required to find the optimum operational conditions for a transistor power amplifier with a given power output with specified intermodulation performance.

In conventional satellite system calculations for FDM-FM-FDMA systems, the signal to noise is specified for the average talker level only and it is assumed that, once the signal to noise specifications are satisfied for the average talker, the corresponding test tone to noise ratio fully defines the carrier to noise and bandwidth requirements.

In this study, however, the method of Boudreau and Davies (Ref. 3) was employed. This method is specifically applicable to single channel per carrier systems and takes account of the noise performance improvement acheivable with syllabic compandors. Specified quality of performance is satisfied for 99% of the talkers.

The parameters calculated by this method were crosschecked with the conventional method, and good correlation was found between the results obtained in the two different ways.

It should be noted here that emphasis, and compandor improvement, and the performance of a threshold extender demodulator, are interdependent. Their expected performance was derived from theoretical calculations, with the exception of expandor improvement, which is the result of subjective tests. For an operational system, the combined performance must be cross checked with actual tests.

The results of the study are summarized in Table 2.1-1. at the end of this section.

The table shows that the maximum traffic capacity specified for the system can be transmitted in a 8.27 MHz bandwidth at 1.5 GHz and in a 6.11 MHz bandwidth at 300 MHz. The total radiated EIRP requirement is +37.6 dBW at 1.5 GHz and +41.25 dBW at 300 MHz. These EIRP values are realizable in the satellite. The available system margins are discussed in detail in Vol. III, para. 1.2. It is noted in the analysis that the performance calculations at 2.5 GHz are identical to those of the 1.5 GHz band.

The analysis is divided into three major parts. The first part (Para. 2.2 and 2.3) provides the input parameters, the traffic model, and describes the method of the analysis.

The second part (Para's 2.4.1 to 2.4.9) deals with the general FM performance considerations.

The practically achievable improvements due to emphasis and companding are discussed. The selection of threshold extender demodulators in the Earth Terminal receivers is justified. Satellite power amplifier intermodulation performance is analyzed assuming TWT and transistor power amplifiers operating within a given system noise budget.

In the third part of the study (Paras. 2.5 and 2.6), the detailed performance calculations are provided for operation in the 1.5 GHz and in the 300 MHz frequency band.

TABLE 2. 1-1 SUMMARY OF COMMUNICATION PERFORMANCE

	Commercial Quality		Military Quality		Program	
	1.5 GHz	300 MHz	1.5 GHz	300 MHz	1.5 GHz	300 MHz
Noise Specification for Nominal performance	10,000 pWpO	10,000pWpO	-28dBmOp	-28dBmOp	(S/N)rms= 53dB	(S/N) rms= 53 dB
Max. Number of simultaneously existing carriers	60	60	40	40	5	5
Number of available channels	150	150	100	100	5	5
Voice Activity factor	50%	50%	50%	50%	--	--
Threshold extender Demodulator	yes	yes	yes	yes	yes	yes
Active uplink EIRP Control	yes	yes	yes	yes	yes	yes
Fixed Energy Dispersal in Earth Station	yes	no	yes	no	no	no
Level Controlled Energy Dispersal	no	no	no	no	yes	yes
Satellite (G/T) dB/°K	-2.3	-11.0	-2.3	-11.0	-2.3	-11.0

Table 2.1-1 Cont'd....	Commercial Quality		Military Quality		Program	
	1.5 GHz	300 MHz	1.5 GHz	300 MHz	1.5 GHz	300 MHz
Earth Station (G/T) dB/°K	-1.0	-17.0	-5.0	-19.0	+1.0	-16.0
Emphasis improvement at nominal performance (dB)	8.0	8.0	8.0	8.0	--	--
Expandor improvement at nominal performance (dB)	8.5	8.5	8.5	8.5	--	--
Psophometric weighting (dB)	--	--	2.5	2.5	--	--
Program channel improvement (dB)	--	--	--	--	2.9	2.9
Carrier to noise ratio at nominal noise budget (dB)	10.0	11.0	9.5	10.0	10.0	11.0
Threshold Margin for at least 99.7% of time (dB)	1.5	1.5	1.5	1.5	1.5	1.5
Carrier to Intermodulation product ratio in the satellite P.A. (dB)	16.4	16.4	16.4	16.4	16.4	16.4
Travelling wave tube output b backoff (dB) at 1.5 GHz	2.5	--	2.5	--	2.5	--
Per Channel Carson's bandwidth (KHz)	19.8	18.6	12.8 with compandor 15.5 no compandor	12.6 with compandor	252.0	224.0

Table 2.1-1 Cont'd...

	Commercial Quality		Military Quality		Program	
	1.5 GHz	300 MHz	1.5 GHz	300 MHz	1.5 GHz	300 MHz
Carrier Spacing (KHz)	29.2	22.0	20.9	14.9	298.0	264.0
EIRP per carrier from Satellite (dBW)	+15.4	+19.6	+17.24	19.5	+24.98	+29.3
EIRP per Carrier from Earth Station (dBW)	25.4	+24.5	+22.64	+17.8	+36.1	--

	1.5 GHz	300 MHz
Total radiated EIRP from Satellite (dBW)	37.6	41.25
Total Satellite Transmitter Bandwidth (MHz)	8.27	6.11

2.2 Statement of the Problem and Input Parameters

2.2.1 Statement of the Problem

This is well summarized in Para. 1.0 of the Work Statement (Ref. 1)
"The UHF satellite communications system to be studied under this contract basically is intended for low capacity voice telephone service to remote areas of Canada. The system is envisaged to comprise a large number of terminals accessing a satellite transponder in a single channel per carrier frequency division multiple access mode. Terminals to be used in the system will range from two-way voice telephony fixed terminals to air and sea mobile terminals as well as radio program channel terminals and telemetry terminals for remote sensing platforms."

The Work Statement defines that the main emphasis in the study should be placed on the two-way voice channel service requirements to fixed and transportable stations. The other applications such as mobile, radio programs and telemetry services are to be considered only to the depth that the scale of the program permits.

Thus the detailed communications analysis is performed only for 2-way voice telephony and for radio program channels with fixed and portable terminals, required by military and civilian users operating via the satellite.

The signalling and control functions are considered only in that respect that they require bandwidth and EIRP from the satellite with corresponding equipment requirements in the Earth Segment. Detailed performance analysis was not performed for these modes of operation.

The Communications System calculations include the effect of the uplink, satellite transponder and the downlink, on the performance in a lightly or fully loaded system.

The hardware used in the Earth Stations and in the satellite, and the block diagrams were considered only when:

a) they had a direct effect on the communications performance.

b) it was a question of trade-off between cost and performance for the various systems or subsystems.

2.2.2 Specification (from the Work Statement)

Type of Transmission:	Single voice channel per carrier, voice activated, FM Modulated, in FDMA mode.	
Frequency Band A:	Uplink:	1500 - 1535 MHz
	Downlink:	1450 - 1485 MHz
	Max. Allowable Flux Density	$-144 \text{dBW/m}^2\text{/4KHz}$ in downlink
Frequency Band B:	Uplink and Downlink	225-400 MHz
Types of Services:	Two way telephony	commercial private
	Two way teleprinter	
	One way teleprinter	

Types of Services:	Radio Program One way Voice Low rate data Telemetry

Quality of Services:

Two way telephony, commercial quality to fixed stations Defined in CCIR Rec. 353-1	10,000 pWp0 for 80% of time, 50,000 pWp0 for 0.3% of time, 1,000,000 pWp0 for 0.03% of time.
Two way telephony, military quality to transportable stations	-28 dBm0p for 95% of time
Program Channel:	High Quality circuit defined by CCITT
Telemetry Channel:	Error rate 1p in 10^6

Number of duplex transponder channels:

Commercial quality voice	Min. 20	Max. 60	Minimum 41, maximum 105 simultaneously existing carriers
Military quality	Min. 20	Max. 40	
Program	Min. 1	Max. 5	

2.2.3 Traffic Model

The traffic capacity is given in Tables 8.1 and 8.2 of the Work Statement and is summarized below:

i) 740 Earth Stations for providing two way voice transmission in a voice activated demand assignment mode.

The total number of simultaneously existing carriers in the satellite, to carry this traffic is 100. This represents approximately a 14% utilization factor for the system.

ii) 500 telemetry stations transmit telemetry data in PSK format.

iii) 80 Earth Stations receive radio program via five program channels.

2.2.3 Cont'd.....

The Work Statement recommended to use PSK for telemetry, FSK-FM for signalling and for teleprinter services. However, the study recommends the use of PSK in all these modes. The detailed justification for this choice is provided in Chapter 5 of this volume.

2.3 Method of the Analysis

The scope of the study did not involve any testing, other than preliminary tests on the IM performance of a transistor power amplifier (Para. 3.3.2, Vol. II). Similarily new computer programs were not developed for system optimization. Such a program would be required, for example, to accurately calculate the expected intermodulation in the satellite power amplifier. Thus the study is based on information which was available at RCA as a result of previous programs and information available in the literature.

Specifically the improvement due to companding and emphasis was obtained from Ref. 3. The expected carrier to intermodulation noise ratio in the wide-band satellite power amplifier was obtained from Ref. 4. However, these values were crosschecked from alternative sources and wherever a difference was found, the more pessimistic value was chosen for a conservative design. Interference from sources external to the satellite system were not included in the noise budget. The main objective of the communications analysis is to calculate the available C/T ratio at the demodulator input to satisfy the signal to noise specification at normal conditions and in a fading environment.

2.3 Cont'd......

The analysis must consider the practical limitations imposed upon the system by:

a. economically available EIRP from the Earth Station and from the Satellite.

b. available RF bandwidth

c. threshold limitations in a practical demodulator.

Some of the other considerations are:

Signal to noise improvement due to speech processing,

Fading effects,

Noise budget, which includes the selection of optimum backoff in the satellite power amplifier,

Flux density limitations where applicable.

These factors are examined in the following sections.

2.4 FM Performance Considerations

2.4.1 Bandwidth Requirements

These considerations require the discussion of voice activity factor intermodulation in the satellite, and demand assignment. Para 8.0 of the Work Statement (Ref. 1) stated that the number of simultaneously existing duplex channels in a fully expanded system is as follows:

Commercial quality:	60 channels
Military quality:	40 channels

Thus with 5 simplex program channels, the total number of simultaneously existing carriers in the satellite is 105.

In further discussions with CRC it was established that these values were obtained assuming 50% voice activity factor for the duplex channels, i.e., the number of simplex channels is 2 x 100 = 200, plus 5 radio program channels

The 50% voice activity factor assumes that:

> only one person talks in a duplex circuit at any given time, therefore to optimize the system, the carriers are voice activated. In the absence of a preset minimum speech power, the carrier is turned off.

The effect of voice activation is two-fold:

1. reduces the required total EIRP from the satellite
2. improves the intermodulation caused by amplitude non-linearity in the power amplifier.

2.4.1 Cont'd.......

Thus for a system designed for minimum total bandwidth, the overall bandwidth is obtained from:

$$B_{total} = B_{ch} \times N_{simplex}$$

Where:

B_{ch} = the bandwidth per channel (MHz)

$N_{simplex}$ = 2 x No. of simultaneously existing channels.

However within the constraints of the total available bandwidth, the intermodulation generated in the satellite can be further decreased by increasing the total number of available channels i.e. the available total bandwidth. In this larger bandwidth, the carriers can be spaced unequally which results in intermodulation improvement.

A demand assignment system is in fact equivalent to an unequally spaced carrier spectrum when the number of available channels is more than the number of simultaneously existing carriers. This is due to the fact that as in such a system, the probability that the carriers selected from the pool of available frequencies will be equally spaced becomes less and less when the number of available channels increase.

The expected intermodulation improvement is the function of the following ratio:

$$\frac{\text{Number of Available Channels}}{\text{Number of Simultaneously existing Channels}}$$

2.4.1 Cont'd.......

The value of intermodulation in the worst channel at different values of power amplifier output backoff vs. this ratio, is normally calculated by a computer. The scope of the present study did not allow the development of such a computor program. Therefore the study used the results of a similar analysis performed for an Intelsat IV satellite operating in the SPADE mode (Para. 3.1 of Ref. 4). That reference provides carrier to intermodulation ratios vs. input backoff for the center carrier assuming that the number of equally spaced available channels is 800, with 320 simultaneously existing carriers resulting in ratio of $\frac{800}{320} = 2.5$.

To utilize this computed data the same bandwidth expansion factor is assumed for the present analysis with the following results.

No. of simultaneously existing carriers: 60 (duplex) + 40 (duplex) + + 5 (simplex) = 105

Total no. of available channels: (2.5 x 100) + 5 = 255

2.4.1 Cont'd.....

In a voice activated system, both required bandwidth and EIRP are affected by the percentage of time that the voice is present in each channel. This is voice activity factor.

The average talker speaks only 40% of the time (Ref. 4). For a large number of talkers therefore a 40% voice activity factor should be assumed. This is the case for the Intelsat IV when one RF channel amplifies 800 simplex voice activated SPADE carriers (Ref. 4).

For a smaller number of carriers, the voice activity factor would be somewhat larger. Reference 6 quotes a value of 0.57 for 60 simplex channels. These two values bracket the 200 simplex channesl specified in the present study.

Based on information from References (6) and (4) the voice activity factor in this case must fall between 57% and 40% and a value of 50% is considered reasonable. A further analysis was precluded by the scope of the present study. It is recommended, however, that in any extension of the study, this problem should be investigated, as it may result in EIRP and bandwidth reduction in the satellite.

2.4.2 Signal to Noise Improvement by Speech Processing

While in multichannel FDM-FM systems the 4 dB emphasis improvement in the top frequency slot is a well established value, this is not the case for a single voice channel loaded FM carrier.

For example Thomas (Ref. 7) states that: "Pre-emphasis provides negligible advantage when used in conjunction with a phase-lock demodulator". However, Thomas in a recent telephone conversation indicated that his statement should not have been taken dogmatically. His tests, performed on threshold extension demodulators, showed that emphasis improvement can be obtained by modifying the feedback loop according to the pre-emphasis characteristics. Hekimian-Mack, Ref. 8, also discuss the effect of pre-emphasis used in conjunction with threshold extension demodulators. The authors conclude that when the control loop filter in the feedback loop is altered to match the frequency characteristics of the pre-emphasis network, the demodulator will behave as a conventional demodulator operating above threshold and emphasis improvement is achievable. However, this should be experimentally verified and an accurate value of the pre-emphasis improvement should be established by actual tests performed on a threshold extension demodulator using single voice channel FM. The scope of the study did not include such tests. Therefore, the emphasis improvement calculated in Ref. (3) was used in the following analysis:

2.4.2 Cont'd.......

From that reference, the expected signal to noise improvement due to an emphasis network for flat speech is 8 dB, and 9.3 dB for telephone speech, with the speech signal contained within the band 300 to 3400 Hz. The 9.3 dB theoretical improvement assumes ideal conditions such as: the noise spectrum at the demod. output is triangular, the IF bandwidth is rectangular, the corner frequency of the emphasis network is 30 Hz, the effect of syllabic compressor negligible, the effect of spurious FM noise is negligible.

In a practical system the effective improvement is only 8 dB and this value is used in the present analysis, when operating 4 to 6 dB above threshold. The expected improvement due to a syllabic compandor for single channel per carrier mode was also obtained from Ref. (3). This paper provides a detailed calculation of compandor improvement. The improvement due to the expandor portion of a syllabic compandor is given as 5.8 dB to 11.0 dB, the actual value being a function of the signal to noise level at the expandor input in the receiver. This is a subjective improvement because of noise suppression by the expandor during speech pauses. The improvement vs. signal to noise at the expandor input is linear down to approx. 14 dB S/N ratio.

At lower S/N values the improvement is rapidly decreased reaching 0 dB at 9.6 dB S/N ratio. This threshold-like behaviour must be kept in mind when the voice channel performance is evaluated at degraded (C/N) conditions. The expandor improvement was obtained by practical tests using a group of 13 persons.

2.4.2 Cont'd.......

Ref. (3) provides a method to calculate the signal to noise at the expandor output for various speech power levels at the compressor input in the transmit side.

For a conservative design in the present report the signal to noise was calculated first using the method given in Ref. (3) then with the method used in the conventional FDM-FM-FDMA calculations. It was found that the latter method required 0.4 dB higher test tone to noise for a given signal to noise. This higher (more pessimistic) value was used in the system analysis.

2.4.3 Choice Between Conventional and Threshold Extension Demodulator

The system is not bandwidth but power limited i.e. the reduction of carrier to noise ratio can be compensated by increasing the bandwidth. Thus to minimize the required per carrier EIRP it is advantageous to use threshold extension demodulators. The threshold carrier to noise ratio for a narrow band threshold extension demodulator is taken as 6 dB. It will be shown later that the system design limits the carrier to noise ratio to 7.5 dB at maximum fading which corresponds to fading for not more than 0.3% of the time. This represents 1.5 dB threshold margin, so that for above threshold operation the conventional FM equation can be applied.

It was concluded in the previous section that with a properly designed threshold extension demodulator emphasis improvement is achievable,

2.4.3 Cont'd........

and the present analysis includes emphasis improvement.

Another feature of a threshold extension demodulator is the protection against interference from an adjacent carrier. Measurements were performed in the course of the study to observ these effects on a conventional and on a frequency feedback (FMFB) demodulator. A single voice channel demodulator was not available, therefore the test was made with two modulated carriers using Intelsat IV type voice channel loading and carrier spacing for 24 channel global beam carriers using a conventional and FMFB demodulator. The results of the test showed that at (C/T)'s which correspond to 12.7 dB carrier to total noise ratio, the performance of the two demodulators were nearly identical in the top slot which is the worst slot at this C over N. However at 2 dB lower (C/N) which corresponds to 10.7 dB, the conventional demodulator crashed resulting in an approx. 10 dB degradation of signal to noise in the bottom slot, while the threshold extension demodulator was still operating above its threshold. Similarly the presence of a disturbing carrier, located at minimum spacing for Intelsat IV system, did not affect the FMFB demodulator, while the performance of the conventional demodulator was degraded by approx. 2 dB. Even assuming a conventional demodulator developed specifically for a single voice channel mode, the performance of this demodulator would be inferior compared to a threshold extension demodulator.

2.4.3 Cont'd........

In conclusion, the use of threshold extension demodulators is considered justifiable for voice and radio program channels.

2.4.4 Carrier to Noise Requirements in a Fading Environment

It was discussed earlier that the system is designed to operate above threshold even when the carrier to noise is degraded due to fading at the demodulator input. Section 1.1.1, Table 1-1 of this volume shows the fading margins assumed for the 1.5 GHz and for the 300 MHz frequency bands. Based on those values, the required dry weather (C/N) for the various types of services is calculated in Tables 2.4-1 to 2.4-3.

Table 2.4-1 shows the calculation of (C/N) for commercial quality services for the 1.5 GHz band. For this service the noise allowance is 10,000 pWp for 80% of the time.

TABLE 2.4-1

Carrier to Noise Requirement at the Demodulator Input for Commercial Quality Voice Service (1.5 GHz Band)

(C/N) Dry Weather	10.0 dB (10,000 pWp)
Degradation from Dry Weather to 80% of time	0.0 dB
(C/N) 80% of Time	10.0 dB
Degradation for Not More than 0.3% of Time	2.5 dB
(C/N) for Not More than 0.3% of Time	7.5 dB (50,000 pWp)
Degradation from the 0.3% (C/N) value for not more than 0.03% of the time	2.0 dB
(C/N) for not more than 0.03% of time	5.5 dB
Demodulator Threshold	6.0 dB

2.4.4 Cont'd.......

Thus for 80% of the time which corresponds to 10,000 pWp noise limit, the demodulator operates 4 dB above the expected threshold. For 0.3% of the time corresponding to 50,000 pWp noise, the threshold margin is 1.5 dB, while for 0.03% of the time (1million pWp) the demodulator operates 0.5 dB below its threshold. It will be shown later that with these carrier to noise ratios, the noise specifications are satisfied.

(C/N) Requirements for Military Quality Channels (1.5 GHz)

The noise objective is to provide not more -28 dBm0p noise for 95% of the time. Table 2.4-2 shows the (C/N) requirements.

TABLE 2.4-2

(C/N) Requirements for Military Quality Channels (1.5 GHz Band)

(C/N) Dry Weather	10.0 dB
Degradation for 5% of the time	0.5 dB
(C/N) for not less than 95% of the time	9.5 dB (for -28 dBmOp)
(C/N) for not more than 0.3% of time	7.5 dB
Threshold Margin at 7.5 dB C/N	1.5 dB
Threshold	6.0 dB

2.4.4 Cont'd.......

It will be shown in the detailed calculations that with the assumed (C/N) the noise requirements are satisfied.

For the radio program channels operating in the 1.5 GHz band, the assumed carrier to noise ratios in the faded environment are identical to the values assumed for the commercial quality channels.

300 MHz Band

The carrier to noise requirements for the commercial quality channels are shown in Table 2.4-3.

TABLE 2.4-3

(C/N) Requirements for Commercial Quality Voice Service (300 MHz)

(C/N) Dry Weather	12.0 dB
Degradation from Dry Weather to 80% of time	1.0 dB
(C/N) for 80% of time	11.0 dB (10,000 pWp)
Degradation from 80% to 95% of time	1.0 dB
(C/N) for not more than 5% of the time	10.0 dB
(C/N) for not more than 0.3% of the time	7.5 dB (50,000 pWp)
Demodulator Threshold (C/N)	6.0 dB
(C/N) for not more than 0.03% of time	6.0 dB (1 M pWp)

2.4.4 Cont'd.......

(C/N) Requirements for Military Quality Channels

The noise specification is -28 dBmOp for 95% of the time. From Table 2.4-3 the corresponding carrier to noise ratio is 10.0 dB. The dry weather carrier to noise ratio from the same table is 12.0 dB.

(C/N) Requirements for the Program Channels

The requirement is identical to the values chosen for the commercial quality channels.

2.4.5 Noise Budget

The following noise sources were taken into consideration:

i) Up path thermal noise

ii) Satellite multicarrier intermodulation

iii) Down path thermal noise

The total received carrier to noise ratio (C/N), measured at the demodulator input in the noise bandwidth is given by:

$$(C/N)_{total} = (C/N)_{UL} + (C/N)_{DL} + (C/N)_{IM}$$

The $(C/N)_{IM}$ includes the intermodulation noise due to amplitude nonlinearity and due to AM-PM conversion. In order to reduce the effect of uplink noise contribution to the total system noise, it is assumed that the noise due to uplink is 10 dB below the noise generated by satellite IM and downlink thermal, as an initial examination showed that no problem existed in earth station transmit power.

With uplink EIRP control (described in Para. 1.1 Vol. III) the uplink noise is kept within 0.5 dB of its nominal value.

With this assumption then:

$$(C/N)_{UL} = (C/N)_{DL + IM} + 10 \text{ dB}$$

2.4.5 Cont'd.......

The noise calculations include the following steps:

STEP 1 Calculation of total carrier to noise ratio (C/N) total required at the nominal operating condition. This represents the required (C/N) for 80% of the time for commercial quality and program channels and 95% of the time for military quality channels.

STEP 2 By substituting:

$$(C/N)_{UL} = (C/N)_{DL + IM} + 10 \text{ dB}$$

Into:

$$(C/N)_{total} = (C/N)_{UL} + (C/N)_{DL + IM}$$

the value of $(C/N)_{UL}$ and $(C/N)_{DL + IM}$ is obtained.

STEP 3 The $(C/N)_{IM}$ vs. output backoff is available from Ref. (4), for a travelling wave tube, operating in the multicarrier mode.

STEP 4 The output backoff point is selected from a preliminary optimization process. This is discussed later in para. 2.4.7

STEP 5 For a selected output backoff the corresponding carrier to intermodulation noise ratio $(C/N)_{IM}$ is obtained from Ref. (4).

STEP 6 From the known values of $(C/N)_{DL + IM}$ and $(C/N)_{IM}$ the required $(C/N)_{DL}$ is calculated.

2.4.5 Cont'd.......

STEP 7 Then with:

$$(C/T)_{DL} = (C/N)_{DL} + 10 \log B_{RF} - 228.6$$

and with:

$$(C/T)_{DL} = EIRP_{satellite} - PL + (G/T)_{ES}$$

the required satellite EIRP per carrier is calculated. The calculation is performed for the commercial, private and program channels.

After all the system parameters are available, the initially selected satellite amplifier backoff point is rechecked and, if necessary, corrected.

2.4.6 Intermodulation Noise in the Satellite Power Amplifier

For the 1.5 GHz and 2.5 GHz band, travelling wave tubes and transistor power amplifiers are considered. In the 300 MHz band transistor amplifiers and beam power tubes are assumed. The main contributors of intermodulation noise in multi-carrier operation is noise due to amplitude nonlinearity and noise due to phase nonlinearity. The latter is commonly called amplitude to phase modulation conversion (AM-PM conversion). For a travelling wave tube type of amplifier these characteristics are well known. Typically the amplitude nonlinearity is the controlling factor up to -6 dB input backoff. Below -6 dB backoff the phase nonlinearity due to AM-PM conversion factor is dominant. For transistor power amplifiers operating in the Class C or in the Class B or AB modes the expected value of these nonlinearities is not so readily available. A brief investigation of IM in transistor amplifiers was

2.4.6 Cont'd........

performed in the RCA laboratory during the study and is described in Volume II of this report. The present system calculations refer to these results when analyzing the satellite intermodulation assuming transistor power amplifiers. In the case of a TWT the optimization process requires the knowledge of the intermodulation noise density distribution. The noise density is the function of the:

TWT amplitude and phase characteristics
TWT output backoff
Number of Carriers
RF Spectral density of carriers
RF Carrier Levels
Spacing between carriers

It was noted in Para. 2.4.5 that the carrier to intermodulation ratio for a given output backoff is available from Ref. (4). This particular reference provides the system capacity calculations for SPADE mode in the Intelsat IV system.

In conventional multicarrier intermodulation analysis for a given carrier level and carrier spacing in the amplifier, the expected intermodulation noise for the individual carriers is calculated from a computer program. The output of this program is the intermodulation noise density distribution as a function of output backoff. Such computer programs were developed at RCA for other projects. However, they were limited in the number of carriers which could be handled. In addition, the carriers were at preassigned frequencies. For the case under study the available programs were not satisfactory because;

the present study considers approximately 100 simultaneously existing carriers operating in a demand assignment mode.

2.4.6 Cont'd........

Thus the output of the computer program should have to provide the intermodulation noise density generated by 100 simultaneously existing carriers distributed randomly in the available bandwidth.

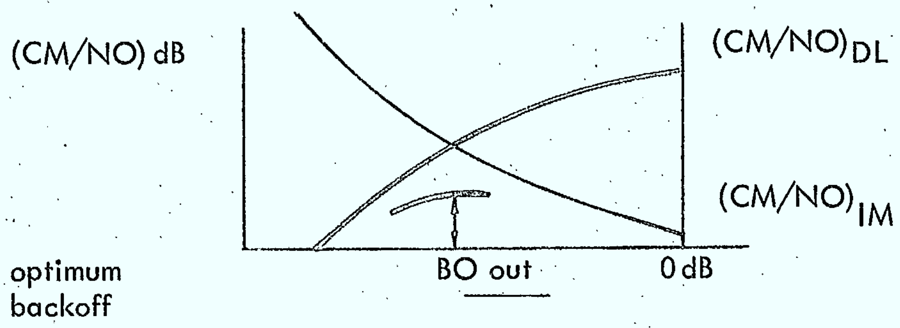
The scope of the present study was not adequate to carry out the required modifications in the program. Therefore an alternative approach was used, whereby the carrier to intermodulation noise ratios presented in Ref. (4), the SPADE study, were used. The (C/I) values of that reference were obtained by a computer program which calculated the carrier to intermodulation noise in a 36 MHz satellite RF channel operating with 320 simultaneously existing SPADE carriers randomly located in an 800 channel band. From the point of intermodulation in the satellite, the SPADE system and the traffic model of the present system are very similar. The SPADE system uses PCM-PSK-FDMA carriers, voice activated in a single voice channel per carrier mode. The carriers are spaced 45 KHz apart, all at equal levels. The only major difference between the FM modulated voice channel and PCM-PSK modulated SPADE channel is the IF spectral density distribution of the carriers For PSK it is "bell shaped", with most of the signal energy in approx. 2/3 rd of the noise bandwidth of the carrier. For single voice channel FM, with low rms modulation index, most of the energy is contained in a few KHz bandwidth centered on the carrier. However the overall IM noise density values will not be significantly changed due to this difference, as in both cases the IM noise is generated from 2A-B and A + B - C type of products of a large number of equally spaced carriers, resulting in nearly identical in-band IM noise densities. The SPADE study provides

2.4.6 Cont'd........

IM noise at the worst (center) carrier, caused by amplitude and phase nonlinearities in the TWT. Values are given from -6 dB to -18 dB input back-offs. The present study therefore will use the SPADE computed values for reference. It is recommended that the accurate IM noise density values should be calculated at a later date by modifying the existing computer program.

2.4.7. Optimum Backoff for the Satellite Travelling Wave Tube Amplifier

The optimum backoff is nomally chosen at a point where the sum of intermodulation noise and downlink thermal noise is minimum. This is shown in the sketch below:



The downlink thermal noise, assuming constant EIRP from the satellite, depends on the Earth Station (G/T) ratio. In the system under study 3 different (G/T)'s are assumed. (In the 300 MHz band only Class C transistor amplifiers were considered, where output backoff does not exist).

-1 dB/$^{\circ}$K for commercial service)
)
+1 dB/$^{\circ}$K for program and) 1.5 GHz Band
)
-5 dB/$^{\circ}$K for private service)

Thus the optimum is chosen as a compromise between the optimum output backoffs for the 3 types of (G/T)'s. The result of this optimization process is that the optimum input backoff is -8.5 dB for commercial quality and program channels, and

2.4.7 Cont'd........

approximately -5 dB for military quality channels, where the downlink thermal noise is dominant. However, the degradation of the military quality channels is only 0.5 dB at -8.5 dB input backoff. Thus this value was chosen for operation. -8.5 dB input backoff correspond to -2.5dB output backoff from single carrier saturation. The expected carrier to intermodulation noise in the satellite at this backoff is 16.4dB from Ref. (4), for a channel located at the center of the frequency band.

It will be shown in the detailed system calculations that in the 1.5 GHz band the per carrier EIRP's and the corresponding noise bandwidths are as follows:

	EIRP	Noise BW
Commercial quality voice carrier:	+15.4dBW	19.8KHz
Military quality voice carrier:	+17.24dBW	12.8KHz
Program carrier:	+24.48dBW	252 KHz

Thus the carrier levels in the Satellite power amplifiers are not equal.

This fact requires further consideration:

One consideration is that the present analysis assumes that for the worst carrier, the carrier to intermodulation product ratio is 16.4dB. This value was obtained assuming equal amplitude carriers.

In the present study, the EIRP levels are obviously not equal. The program carriers are 7dB larger than the military voice carriers, and 9 dB larger than the commercial quality voice carriers. The difference between the military and commercial voice carriers is only 1.8 dB. However, it is shown later in the analysis that the program carriers can be energy dispersal with a variable amplitude energy dispersal signal which disperses the

2.4.7 Cont'd......

program carriers to a fully loaded program channel bandwidth, even when the channel is not fully modulated with speech or with music.

With energy dispersal only and no modulating signal, the program channel carrier power is more than 10 dB below its CW value when measured in the noise bandwidth of a commercial carrier and more than 13 dB below its CW when measured in the bandwidth of a private channel. Therefore, assuming only energy dispersal on the program carriers, the 16.4 dB carrier to intermodulation product ratio in the worst channel will not be degraded.

When the program channels are fully modulated with speech or with music, the instantaneous RF carrier power density is not so easily predictable. However, due to the very large rms modulation index for these carriers ($\frac{Dfrms}{fmax} = 10.0$) most of the carrier power will be in the higher order sidebands. Thus with 252 KHz Carson's bandwidth for these carriers, it can be safely assumed that the program carrier power measured in a 19.8 KHz (commercial quality) or in a 12.8 KHz (Military) band, will be at least 7 to 9 dB below its CW value.

Thus with respect to intermodulation, the carrier levels of the program channels are equal or lower than the levels of the commercial quality and military quality voice carriers for both the modulated and unmodulated cases if energy dispersal is employed.

Another possible problem is the reduction of gain of a small carrier in the presence of a larger carrier. At -2.5dB output backoff, however, the TWT operates in its quasi-linear mode where the gain compression with unequal carriers is very low. Furthermore, it was shown in this section that the modulated carrier power densities are nearly constant,

2.4.7 Cont'd.....

they can be considered as nearly equal level carriers. Therefore, all carriers should be equally amplified in the TWT.

2.4.8 Transistor Power Amplifiers in the Transponder

While the intermodulation behaviour of a TWT is reasonably predictable, this is not the case with transistor amplifiers. Vol II Fig. 3-3 of this report presents test data on transistor power amplifier intermodulation. The tests were performed with two equal amplitude carriers, within a 6 dB input dynamic range, with the following results:

> The gain remained nearly constant within the dynamic range, while the level of the intermodulation products varied between 26 and 30 dB in a nearly parabolic manner.
>
> Outside the 6 dB input range the intermodulation increased rapidly.

The system analysis up to this point in the study assumed that the carrier to intermodulation noise ratio is 16.4 dB for a carrier located at the center of the RF band when all 105 carriers are present in a TWT amplifier. This value was achieved at -2.5 dB output backoff from single carrier saturation.

However, the 26 to 30 dB carrier to intermodulation ratio in the transistor amplifier was measured with two carriers only.

Therefore in order to compare the intermodulation performance of the two devices, it is necessary to find the carrier to intermodulation ratio for the TWT when measured with two carriers at -2.5 dB output backoff.

2.4.8 Cont'd......

The $(C/N_{IM}) = 16.4$ dB was calculated in Ref. (4) by a computer program where 32 carriers had access randomly to 80 available equally spaced channels. The 16.4 dB represented the intermodulation in the worst channel after the computer repeatedly randomly assigned the 32 carriers to the 80 channel slots. This method resulted in approximately 3 dB IM improvement over the equally spaced case.

Thus the equally spaced multicarrier (C/N_{IM}) is at least 3 dB worse than 16.4 dB, i.e. it is equal to 13.4 dB. The equivalent two tone intermodulation product at the same output backoff is then approximately 11 dB above 13.4 dB, i.e. equal to 24.4 dB. This is 1.6 dB worse that the 26 dB value measured with the transistor amplifier.

This would indicate that the intermodulation performance of a Class C transistor amplifier can be slightly better than the performance of a TWT which is operating at -2.5 dB output backoff.

It was shown in Vol. II that Class C transistor power amplifiers in fact can deliver the necessary total output power while limiting the intermodulation to 26 dB.

Accepting the assumptions given above, it follows that the present communications analysis is valid for either transistor amplifier or for TWT's.

It should be noted, however, that in the case of a TWT a clear trade-off exists between intermodulation and output power for a given tube efficiency. There is insufficient test data available at the moment for transistor power amplifiers to carry

2.4.8 Cont'd......

out such a trade-off.

2.4.9 Communications Performance in the 2.5 GHz Frequency Band

Margin requirements in this band are virtually identical to the 1.5 GHz band. Therefore, link calculations are identical for both bands and the analysis at 1.5 GHz in equally voted for 2.5 GHz.

2.5 Detailed Analysis in the 1.5 GHz Band

2.5.1 Summary of Input Parameters for Commercial Quality Voice Service

Noise:

Specified by CCIR Rec. 353-1 Vol. IV OSLO, page 205, which allows 10,000 pWpO for 80% of the time and 50,000 pWp0 for not more than 0.3% of the time; 1,000,000 pWp for not more than 0.03% of the time.

Power of medium talker = -13.9 dBmO)
)
Standard Deviation of talker power: = 5 dB) From
) Ref. 3
Emphasis Improvement: I_{emp} = 8 dB)
)
Expandor Improvement: Depends on (S/N) at expandor input)

Earth Station (G/T): = -1.0 dB/°K

Satellite G/T - -2.3 dB/°K

Path Loss = -188.4 dB for EIRP calculations at 1.5 GHz

Path Loss = -186 dB for flux density calculations in downlink

No. of simultaneously existing channels = 60

Required No. of channels for IM improvement for Section 2.5 = 150

Guardband between carriers in satellite = 18% of carrier bandwidth

2.5.2 Detailed Link Calculations for Commercial Quality Voice Service

Comparison of Test Tone to Noise Calculations using the Standard Method and the Method of Reference 3.

The signal to noise requirements were specified in terms of median talker level, standard deviation, and peak factor. The voice quality was specified in a similar way in Ref.(3), therefore, the present analysis uses the method given in that reference to calculate the required test tone to noise. The method was however,

2.5.2 Cont'd......

cross-checked with the standard method which is normally used in FM noise calculations. With the conventional method it is assumed, that for a noise specification of 10,000 pWp in the worst voice channel, the corresponding test tone to noise is 50 dB (emphasised and psophemetrically weighted) where:

Test tone = 0 dBm

Noise = -50 dBm

at 0 transmission level point. Once the rms test tone deviation is calculated, the multichannel rms deviation is obtained from the loading factor. The required Carson's bandwidth is then calculated by assuming a peak to rms factor which is 10 dB for Earth Station applications. With 2.5 dB psophometric weighting and 4.0 dB emphasis improvement, the required "flat" test tone to noise is:

$$\begin{array}{r} 50 \\ -\ 6.5 \\ \hline 43.5\,\mathrm{dB} \end{array}$$

This value will be checked with the method given in Reference (3).

In multichannel FM calculations the concept of average power talked is introduced. From Ref.(5) page 243, this is equal to:

$$P_{op} = V_o + 0.115\sigma^2 - 1.4\,\mathrm{dBm}$$

with $\sigma = 5$, and $V_o = -12.5$ VU

$$P_{op} = -11.0\,\mathrm{dBm}$$

The average power talker is a talker whose long term average power, multiplied

2.5.2 Cont'd,.....

by the number of talkers present gives the total long term average power of a multi-channel telephony system. Using this −11.0 dBmO for average power, with standard deviation $\sigma = 5$, the signal to noise and the test tone to noise is calculated with the method of Ref. (3).

Noise Spec. = 10,000 pWpO $\cong$ 40 dBrnCO,

or in dBm0: N(dBrnCO − 88) $\cong$ −48 dBmO at OTLP

then: $(S/N)_{av}$ = 37 dB after emphasis and weighting

This $(S/N)_{av}$ is related to TT/N as follows: (from Ref. 3)

$(S/N)_{av} = 37.0\,\text{dB} = TT/N + 3\,\text{dB peak factor} - 2.56\,\sigma + P + W$

With: peak factor = 10 dB

$\sigma = 5.0$ dB standard deviation

P = 4.0 dB emphasis improvement

W = 2.5 dB weighting

$(TT/N) = 37 - 3 + 10 + 12.8 - 6.5$

$TT/N = 50.3$ dB

But 10,000 pWp should correspond to 50 dB TT/N. By using −11.3 dBm for the average power talker, the resulting TT/N is 50 dB. This value includes 4 dB emphasis and 2.5 psophometric weighting improvement.

The calculation, presented above, showed that with the method of Ref. (3), 10,000 pWpO is equivalent to 50 dB test tone to noise for the average power talker which is normally used in FM calculations

The compandor improvement assumed by CCIR for the average talker is 17 dB. With

2.5.2 Cont'd.......

8 dB emphasis improvement the corresponding test tone to noise ratio is then:

$$50 - 17 - 8 = 25\,\text{dB} \quad \text{for the average power talker}$$

The test tone to noise ratio is calculated now with the method of Boudreau and Davies (Reference 3).

Calculation of TT/N with the Method of Reference 3 for Commercial Quality Service

The noise level at OTLP is equal to 10,000 pWpO which is equivalent to +40 dBrnCO, or converted to dBmO:

$$40\ \text{dBrnCO} - 88\ \text{dB} = -48\ \text{dBmO}$$

The speech power of the lowest talker from the specifications:

$S_{LT} = P_o - 2.56\,\sigma$ before companding, where P_o is the power of the median talker = −13.9 dBmO,

σ is the standard deviation = 5 dB

$2.56\,\sigma$ is the deviation for 99% of the talkers = 12.8 dB

Then:

$S_{LT} = -26.7$ dBmO and

$(S/N)_{LT} = 61.3 - 40 = 21.3$ dB

This is the signal to noise ratio for the lowest talker when the noise is 10,000 pWpO at OTLP. Thus the system is designed to provide 21.3 dB signal to noise r ratio for the lowest talker, knowing that the S/N ratio for 99.5% of the talkers will be higher.

In Section 2.4.4, it was stated that:

(C/N) for 10,000 pWpO = 10.0 dB (for 80% of time)

2.5.2 Cont'd.....

In section 2.4.4, it was shown that the commercial quality channels should be designed to provide 10,000 pWpO noise at 10.0 dB carrier to noise ratio.

From Ref. (3) the relationship between signal to noise and test tone to noise is given by:

$$(S/N) = TT/N + 3\,\text{dB} - \text{peak factor} - \Delta P$$

$$+ I\ \text{de-emphasis} + I\ \text{expandor} \text{---------} \quad \text{Eq. 2-1}$$

Where:

(S/N) = signal to noise ratio in dB

(TT/N) = test tone to noise ratio in dB

3 dB = peak to rms ratio of the sinusoidal test tone

Peak Factor = 10 dB

ΔP = difference between the loudest talker and the lowest talker after compression = 2.56 x = 12.8 dB

I de-emphasis = 8 dB

I expandor = 8.5 dB at $(S/N) = 21.3$ dB

Substituting these into Eq. (2-1) and solving the equation for test tone to noise:

$$TT/N = (S/N)_{LT} + 3.3\,\text{dB} = 24.6\,\text{dB}$$

This is very close to the 25 dB TT/N calculated by the conventional method at a - 11.3 dBm average speech level. For a conservative design, the 25 dB TT/N value will be used for commercial quality channels.

2.5.2 Cont'd.....

To complete the analysis, the loudest talker should be considered, the signal level for the loudest talker is:

$$S_{loud} = P_M + 2.56\sigma = -13.9 + 12.8 = -1.1\,\text{dBmO}$$

The corresponding signal to noise ratio:

$$(S_{loud}/N) = -1.1 - 40 + 88 = 46.9\,\text{dB}$$

i.e. 25.6 dB better than for the lowest talker.

The System is designed for 10,000 pWpO noise at OTLP, which results in 21.3 dB S/N for the lowest talker at the expandor output

Therefore if the test to noise ratio in conjunction with the FM equation satisfies the 21.3 dB S/N requirement for the lowest talker, the signal to noise ratio is better than 21.3 dB for 99.5% of the talkers which include the loudest talker. The level of the loudest lowest talker is -1.1 dB below test tone, thus the Carson's bandwidth calculated for test tone level satisfies the bandwidth requirements of the loudest talker. At voice levels greater than the loudest talker, the voice is clipped by the compressor.

Bandwidth Requirement

The test tone to noise ratio from the FM equation:

$$TT/N = 3(C/No)\frac{\Delta f\ rms^2}{f\ max^3} \qquad \text{Eq.(2.2)}$$

Where:

(C/No) = carrier to noise density

2.5.2 Cont'd.......

$$\Delta f\ \text{rms} = \frac{\Delta f\ \text{peak}}{\sqrt{2}}$$

$$\Delta f\ \text{rms}^{2} = \frac{\Delta f\ \text{peak}^{2}}{2}$$

But:

$$B = 2\,(\Delta f\ \text{peak} + f\ \text{max})$$

or:

$$\Delta f\ \text{peak} = (B/2 - f\ \text{max})$$

Substituting these into Eq. 2.2 with $f\ \text{max} = 3.4\text{KHz}$ and $(C/N)_T = 10.0$ dB:

$$TT/N = 25.0 = 10\log 3 + 10\log 10 + 10\log B + 20\log(B/2 - 3.4) -$$

$$- 10\log 2 \times 3.4^{3}$$

Solving the equation:

$$10\log(B(B/2 - 3.4)^{2}) = 29.14$$

$$B\left[(B/2 - 3.4)^{2}\right] = 829$$

Then:

$$B = 19.8\text{KHz}$$

and from:

$$B = 19.8 = 2(\Delta\ \text{fpk} + 3.4)$$

$$\Delta\ \text{fpk} = 19.8 / 2 - 3.4 = 6.5\ \text{KHz}$$

and $\Delta\ \text{frms} = 4.6\text{KHz}$

Noise Budget and EIRP

The total carrier to noise ratio at the demodulator input is:

$$(C/N)_{\text{total}} = (C/N)_{UL} + (C/N)_{DL} + (C/N)_{IM}$$

(not arithmetic sum)

2.5.2 Cont'd........

Where:

$(C/N)_{UL}$ = carrier to noise due to uplink effects

$(C/N)_{DL}$ = carrier to noise due to downlink effects

$(C/N)_{IM}$ = carrier to noise caused by intermodulation in the satellite.

For the present study, it is assumed that the interference from other systems is negligible. The uplink and downlink noises are thermal. The intermodulation noise, generated by the large number of RF carriers is also treated as thermal. The $(C/N)_{IM}$ is then proportional to noise.

It was shown in Para. 2.4.5 that the noise allocated for uplink should be 10 dB lower than for downlink and IM noise together.

Thus:

$$(C/N)_{total} = 10\,dB = 10.4\,dB + 20.4\,dB$$

Where:

$$(C/N)_{DL + IM} = 10.4\,dB$$

and:

$$(C/N)_{UL} = 20.4\,dB$$

The corresponding noise budget is then:

Total noise : 10,000 pWp

Uplink Noise : 900 pWp

Sum of downlink and intermodulation noise: 9,100 pWp

Then with:

$$(C/N)_{UL} = 20.4\,dB$$

2.5.2 Cont'd.......

Satellite antenna gain = 23.5 dB

Satellite receiver noise temperature = 380 °K ≅ 25.8 dB

Satellite (G/T) is = -2.3 dB/°K

Then if:

B = 19.8 KHz

$(C/T)_{UL} = 20.4 - 228.6 + 42.9 = -165.3$ dBW/°K

$EIRP_{UL} = -165.3 + 188.4 + 2.3 = +25.4$ dBW/CH

The gain of the Earth Station antenna referred to the output flange of the power amplifier is 20 dB. Thus the corresponding power at the amplifier output flange is +5.4 dBW or 3.5 watts. The transmit EIRP is kept constant (within 0.5 dB) by active EIRP control. For equipment design purposes, therefore, 3 dB more power is provided resulting in 7W output power.

Downlink and Satellite IM

$(C/N)_{DL + IM} = 10.4$ dB

From Para. 2.4.7 the carrier to intermodulation noise in the worst channel is 16.4 dB

Then:

$(C/N)_{DL} = 11.68$ dB

and:

$(C/T)_{DL} = 11.68 - 228.6 + 42.96$

$(C/T)_{DL} = -173.96$ dBW/°K

2.5.2 Cont'd........

if:

$(G/T) = -1\,dB / {}^{o}K$ for the Earth Station

$EIRP = -173.96 + 188.4 + 1$

EIRP = 15.44 dBW/carrier

For 60 channels:

$$\text{Total EIRP} = \begin{array}{r} 15.44 \\ \underline{+17.80} \\ +33.24 \end{array} \text{dBW total}$$

Flux Density and Energy Dispersal

Flus density on the earth may be calculated as follows:

15.44 dBW EIRP

-186.00 path loss

-170.56 dBW isotropic

+ 25.0 dBW for $1m^2$ antenna gain at 1.5 GHz

-145.56 dBW total power CW $<$ - 144 dBW/m^2/ 4 KHz

i.e. E.D. should not be required.

However Energy Dispersal is recommended based on the following considerations: For a satellite operating with a TWT power amplifier at -2.5 dB output backoff for full loading, the expected increase of gain for light loading is 2 to 3 dB. With this gain increase the flux density would go above the permissible limit. It should be noted that the automatic EIRP control described elsewhere does not compensate for gain variations in the satellite power amplifier, as the EIRP control carrier is not transmitted through that unit. Therefore a fixed energy dispersal signal is applied to each commercial carrier at its earth station transmitter modulator. Additional advantage of the E.D. signal is that by widening the carrier spectrum, the $(C/N)_{IM}$ for the unequally spaced carriers will be somewhat decreased. This E.D. signal

2.5.2 Cont'd.......

also helps to improve the intermodulation noise in the satellite. The E.D. signal is removed in the receiving Earth Station at the final demodulator input. This is discussed in more detail in the section showing the Earth Station Equipment.

For 3 dB expected gain increase in the satellite the required p - p energy dispersal is 5 KHz, i.e. : E. D. peak = 2.5 KHz.

Then:'

BW = 2 (6.5 + 2.5 + 3.4) = 24.8 KHz

Assume : 18% guardband

i.e. : 1.18 x 24.8 = 29.2 KHz in the satellite

For 150 channels (for IM improvement)

150 x 29.2 = 4.36 MHz Total BW is required in the satellite.

With a transistor power amplifier in class C operation in the satellite, the gain is nearly constant (within 1 dB) when the amplifier is operating within a 6 dB input dynamic range.

Therefore, as long as the amplifier input is kept within the 6 dB dynamic range the gain is fixed and energy dispersal could be omitted. However, depending on the more detailed characteristics of an operational transistor amplifier E.D. is retained.

It is discussed in the Earth Station description, that in case of a transistor amplifier, the input level is in fact kept constant by substituting the missing carriers by "dummy" carriers, radiated from the network control stations.

2.5.3 Military Quality Voice Service in the 1.5 GHz Band

Input Parameters

The input parameters are as follows:

(	Noise at OTLP	-28 dBmO	for 95% of the time
(	Power of median talker	-7.4 dBmO	
From Ref. 2 (	Standard Deviation σ	3.5 dB	
(	Peak Factor	6.0 dB	
(	Bandwidth of voice channel	300 - 3400 Hz	
	$(G/T)_{E.ST}$	-5 dB/°K	

Signal to Noise and Test Tone to Noise

The system is designed for - 28 dBmOp noise at OTLP, which is 22 dB worse than the commercial quality voice service performance.

-28 dBmOp is equal to 1.6 million pWpO which is 62 dBrnCO.

The speech power of the lowest talker:

$$P_{LT} = -7.4\,\text{dBmO} - 2.56 \times 3.5\ (\text{dBmO})$$

$$P_{LT} = -16.4\,\text{dBmO}$$

and:

$$(S/N)_{LT} = -16.4 - \left[62\ (\text{dBrnCO}) - 88\right]$$

$$(S/N)_{LT} = 9{,}55\ \text{dB at output of expandor}$$

This 9.55 dB S/N level assumes some kind of speech and noise processing for improvement. Two ways are available:

a) Emphasis and psophometric weighting

b) Emphasis and companding

2.5.3 Cont'd......

The required EIRP is calculated in both ways in the following paragraphs.

Emphasis and Companding

To utilize companding, an output signal to noise of 20.0 dB minimum must be assured as below this level the expandor improvement rapidly decreases. Assume that at the expandor output, $(S/N)_{LT} = 20.0$ dB. From Ref.(3) at this output S/N, the expandor improvement is 8 dB and the S/N at the expandor input is 12.0 dB.

Then if:

$P_{LT} = -16.4$ dBmO, the resulting noise is:

$$20 = -16.4 - \left[X(\text{dBrnCO} - 88) \right]$$

and

$$X\text{dBrnCO} = -16.4 - 20 + 88$$

$$X\text{dBrnCO} = 51.6 \text{ dBrnCO.}$$

If 40 dBrnCO is 10,000 pWpO, then 51.6 dBrnCO is equal to 14.5 x 10,000 = 145,000 pWpO

Thus the system is designed to provide 145,000 pWp instead of the specified 1.6 million pWpO for 95% of the time to which it may be degraded.

Test Tone to Noise

With:

6 dB peak factor

8 dB de-emphasis improvement

8.0 dB expandor improvement

σ = 3.5 dB (standard deviation)

2.5.3 Cont'd.......

$(S/N)_{LT} = 20\,dB = TT/N + 3\,dB - 6\,dB - 2.56 \times 3.5\,dB +$

$+ 8dB + 8\,dB$

Soloving:

$\underline{\underline{TT/N = 16\,dB}}$

i.e.:

$TT/N = (S/N)_{LT} - 4\,dB$

Where:

TT = 0 dBmO

$S_{LT} = -16.4\,dBmO$ before compressor

$S_{LT} = -7.4\,dBmO$ after compressor

(C/N) Requirement

The noise objective is to provide not more than 145,000 pWp noise for not less than 95% of the time. Assuming that the degradation of the total (C/N) is as follows:

-0.5 dB from dry weather to 95% of the time,

additional -2.0 dB for periods not more than 0.3% of time,

Then the required (C/N) values are:

(C/N) in dry weather	= 10.0 dB
(C/N) for 95% of the time	= 9.5 dB
(C/N) for not more than 0.3% of time	= 7.5 dB
Threshold margin provided	= 1.5 dB
(C/N) for threshold	= 6.0 dB

2.5.3 Cont'd........

Bandwidth Requirement

Substituting the following values into the FM equation:

$(C/N) = 9.5\,\text{dB}$

$TT/N = 16\,\text{dB}$

$f\ \text{max.} = 3.4\,\text{KHz}$

$TT/N = 16.0 = 10\log 3 + 9.5 + 10\log B + 20\log(B/2 - 3.4)$

$- 10\log 2 \times 3.4^3$

Where:

$B = 2(\Delta f\ \text{peak} + f\ \text{max})$

Then:

$10\log \quad B(B/2 - 3.4)^2 \qquad = 20.7$

$B(B/2 - 3.4)^2 = 117$

Solving, $B = 12.8\,\text{KHz}$ (Carson's Bandwidth)

and from:

$12.7 = 2(\Delta\,\text{fpk} + 3.4)$

$\Delta\,\text{fpk} = 12.8/2 - 3.4$

$\Delta\ \text{fpk} = 3.00\,\text{KHz}$

$\Delta\ \text{frms} = 3.00/1.41 = 2.12\,\text{KHz}$ rms is the test tone deviation

Noise Budget

For the noise budget:

if $(C/N)_{TOTAL} = 9.5\,\text{dB}$ for 145,000 pWp

and $(C/N)_{UL} = (C/N)_{T} + 10\,\text{dB}$

2.5.3 Cont'd.......

Then:

$(C/N)_{UL} = 19.5\,dB$

and:

$(C/N)_{DL+IM} = 9.9\,dB$

Then:

$9.9 = 16.4 + (C/N)_{DL}$

i.e. : $(C/N)_{DL} = 10.9\,dB$

Converting $(C/N)_{DL}$ into $(C/T)_{DL}$

$(C/T)_{DL} = 10.9 - 228.6 + 41.04 = -176.66\ dBW/^{\circ}K$

The required satellite EIRP per carrier:

EIRP = -176.66 + 188.4 + 5.0

EIRP = + 16.74 dBW/carrier for 95% of time.

Add 0.5 dB for fading degradation, the EIRP = 17.24 dBW/carrier

For 40 carriers:

+17.24

+16.00

+33.24 dBW is the total EIRP with companding

2.5.3 Cont'd.......

Energy Dispersal

With 17.24 dBW EIRP per carrier, the flux density is:

+ 17.24	EIRP
-186.00 dB	Path Loss
-168.76 dBW	isotropic power
+ 25.00 dB	$1m^2$ antenna gain
$-143.76\ dBW/m^2$	

This is only 0.24 dB more than allowed. However, the Energy Dispersal is provided for the periods when the satellite gain increases and for flux density reduction to reduce the IM modulation density in the satellite, when a TWT amplifier is used. With a transistor power amplifier the energy dispersal could be omitted if the 0.24 dB was acceptable and the transistor power amplifier permitted it from IM considerations.

Assuming 5 KHz p - p energy dispersal, which provides sufficient energy spread, the required per carrier bandwidth in the satellite:

$$B = 2\,(2.95 + 2.5 + 3.4) = 17.7\,KHz$$

add 18% bandwidth for guardband,

$B = 17.7 \times 1.18 = 20.9$ KHz is the per carrier bandwidth.

The available number of military quality channels in the satellite is 2.5 times the number of simultaneously existing military channels. This is necessary to enable the utilization of the intermodulation ratio values given in Ref. (4). Then the bandwidth in the satellite:

$$B = 2.5 \times 40 \times 20.9 = 2.09\,MHz$$

2.5.3 Cont'd........

EIRP Requirement for the Military Quality Channels without Compandor

It was shown earlier in this paragraph that for -28 dBmOp noise for the lowest talker, the corresponding signal to noise is 1.6 million pWpO.

Assuming pre-emphasis improvement of 8 dB, psophometric weighting of 2.5 dB and 6 dB clipping factor, the corresponding test tone to noise is expressed as:

$$(S/N)_{LT} = 9.55\,dB = TT/N + 3\,dB - 6\,dB - 9\,dB - 9.0\,dB + {}$$

$$+ 8.0\,dB + 2.5\,dB$$

$$\text{i.e. :}\quad (S/N)_{LT} = 9.55\,dB = TT/N - 10.5\,dB$$

or:

$$TT/N = 20.05\,dB$$

The test tone to noise requirement, when syllabic compandor was assumed, was 16.0 dB.

Bandwidth Requirement (no compandor)

Assuming 9.5 dB carrier to noise for 95% of the time, then from the FM equation:

$$20.05\,dB = 4.76 + 9.5 + 10 \log B + 20 \log (B/2 - fm)$$

$$- 10 \log 2fm^3$$

if fm = 3.4 KHz then:

$$B \times (B/2 - 3.4)^2 = 304$$

and B = 15.5 KHz

The bandwidth requirement with compandor was calculated as:

$$B = 12.8\,KHz$$

i.e. The EIRP requirement in dry weather is increased by 0.84 dB with respect to the compandored case.

2.5.3 Cont'd......

The new EIRP in dry weather is:

$$\begin{array}{l} +17.24 \\ \underline{+\ 0.84} \\ +18.08\ \text{dBW/ carrier} \end{array}$$

or for 40 carriers

$$\begin{array}{l} 18.08 \\ \underline{+16.00} \\ +34.08\ \text{dBW is the total EIRP in dry weather} \end{array}$$

The corresponding flux density in a 4KHz bandwidth is 142.92 dBW/m^2. To reduce this to -144 dBW/m^2/4KHz. 5KHz p - p energy dispersal is required. Then the per carrier bandwidth becomes

$B = 20.5$ KHz

With 18% guardband:

$B = 1.18 \times 20.5 = 24.2$ KHz

and for 100 channels (for IM improvement)

$B = 100 \times 24.2 = 2.42$ MHz is the required BW in the satellite.

Uplink Parameters

With $(C/N)_{UL} = 19.5$ dB

$(C/T)_{UL} = 19.5 - 228.6 + 41.04$

$(C/T)_{UL} = -168.06$ dBW/°K

The required Earth Station EIRP:

$EIRP_{UL} = -168.06 + 188.4 + 2.3$

$EIRP_{UL} = +22.64$ dBW/ carrier

2.5.3 Cont'd .....

From Para. 3.2 of Vol. III, the Earth Station transmit antenna gain for the military quality channel service is 19.0 dB, referred to the power amplifier output flange.

Thus the required power level at that point is equal to :

$$+22.64\,\text{dBW} - 19.0\,\text{dB} = 3.64\,\text{dBW}$$

or 2.3 watts.

It is assumed that with active EIRP control the uplink EIRP is kept within 0.5 dB peak of its nominal value. Therefore it is assumed that for equipment design purposes to available output power is increased by 3 dB to 4.6 Watts.

2.5.4 Program Channels in the 1.5 GHz band.

Input Parameters and Bandwidth:

It is assumed that for a satisfactory performance the requirement is to provide

$(S/N)_{rms} = 53$ dB for 80% of the time.

Then with 2.5 dB fading for 99.7% of the time, and with 1.5 dB threshold margin (at 99.7%) the required (C/N) for 80% of the time is equal to:

$$6 + 1.5 + 2.5 = 10\,\text{dB}$$

If :

f min = 100 Hz

f max = 8 KHz

Then:

from the FM equation:

$$53 = 4.76 + 10 + 10 \log B + 20 \log (B/2 - 8) + 2.9$$

where 2.9 dB is the net improvement of the program channel using standard CCITT

2.5.4 Cont'd.......

emphasis and CBC program weighting.

Solving the equation for B

$B = 252\,KHz$ is the Carson's bandwidth

and $B = 252 = 2\,(\Delta fpk + 8\,)$

$\Delta\ fpk = 118\ KHz$

$\Delta\ frms = 84\,KHz$

Noise Budget and EIRP

With $(C/N)_{total} = 10.0\,dB$

$(C/N)_{UL} = 20.0\,dB$

and $(C/N)_{DL + IM} = 10.4\ dB$

The carrier to intermodulation noise is assumed to be the same as for the other channels.

i.e. $(C/N)_{IM} = 16.4\,dB$

Then:

$(C/N)_{DL} + 16.4 = 10.4\ dB$ (not arithmetic sum)

and:

$(C/N)_{DL} = 11.68\,dB$

The corresponding $(C/T)_{DL}$:

$(C/T)_{DL} = 11.68 - 228.6 + 54.0$

$(C/T)_{DL} = -\ 162.92\ dBW/^{o}K$

The required per carrier EIRP from the satellite:

if $(G/T)_{EST} = +\,1\ dB/^{o}K$

$EIRP = -\ 162.92 + 188.4 - 1.0$

2.5.4 Cont'd........

EIRP = +24.48 dBW for 1 carrier

With 0.5 dB degradation due to the 0.5 dB tolerance of EIRP control, the

$$\text{required dry weather EIRP} = \begin{array}{r} 24.48 \\ \underline{+0.5} \\ +24.98 \text{ dBW per carrier} \end{array}$$

For 5 carriers:

EIRP = 24.98 + 7 = +31.98 dBW is the total EIRP in dry weather in the downlink. In the uplink the per carrier power is approximately 1W.

Energy Dispersal and Total Bandwidth Requirement

It was discussed in Para. 2.4.7 that to satisfy the intermodulation requirements in the satellite power amplifier, the program carriers are provided with level controlled energy dispersal signal, which disperses the program channels at all times to a fully loaded program channel bandwidth. The energy dispersal removal at the input of the program channel demodulator is therefore not required. With this assumption, the five program carriers can be equally spaced.

The per carrier Carson's bandwidth for the program channels is 252 KHz.

With 18% guardband, the spacing between program carriers is equal to:

$$1.18 \times 252 = 298 \text{ KHz}$$

For 5 carriers the total required bandwidth is:

$$\underline{\underline{B_{TOTAL}}} = 298 \times 5 = \underline{\underline{1.49 \text{ MHz}}}$$

2.5.5 Total EIRP and Total Bandwidth Requirements with 50% Voice Activity Factor (1.5 GHz)

It is assumed that all 100 telephone carriers are "on" at all times, ie. 200 simplex telephone calls are transmitted with 50% activity factor due to voice activated carriers.

2.5.5 Cont'd........

The total EIRP is shown in two different ways:

A. Military Quality Voice Channel with Emphasis and Compandor

60 commercial quality carriers = 33.24 dBW

40 military quality carriers = 33.24 dBW

5 program carriers = 31.98 dBW

Total number of duplex channels = 100

Total number of simplex channels = 5

Total radiated EIRP = +37.6 dBW

The 16.4 dB carrier to intermodulation noise ratio in the satellite assumed -2.5 dB output backoff from saturation for a travelling wave tube amplifier and Class C mode for a transistor amplifier.

Thus the total saturated EIRP is equal to (37.6 + 2.5) = 40.1 dBW when TWT is assumed. For a Class C transistor amplifier output backoff cannot be assumed, therefore in that case only the total radiated EIRP (+37.6 dBW) must be considered

B. Emphasis and Psophometric Weighting for the Military Quality Channels

Total EIRP:

60 commercial quality channels = 33.24dBW

40 military quality channels = 34.00

5 program channels = 31.98 dBW

Total number of channels = 105 (100 duplex and 5 simplex)

Total radiated EIRP = 38 dBW

With -2.5 dB output backoff the total saturated EIRP is equal to: 40.5 dBW when TWT is assumed.

2.5.5 Cont'd........

Total Satellite Bandwidth

For 150 commercial quality channels: 4.36 MHz

For 100 military quality channels without companding: 2.42 MHz

For 5 program channels: 1.49 MHz

Total Satellite BW: 8.27 MHz when Energy Dispersal is assumed on all carriers.

2.6 Satellite System Performance in the 300 MHz Frequency Range

Major differences between the 300 MHz and 1.5 GHz system are:

1. Fading
2. Achievable (G/T) in the satellite and in the Earth Stations.

Input Parameters from Para 3.4 of Vol.111

Earth Station (G/T):

Commercial stations: -17dB/oK

Private Stations: -19dB/oK

Program Stations: -16dB/oK

2.6.1 Commercial Quality Voice Service

Choice of (C/N) at the Demodulator Input for Commercial Quality Voice Service

The calculation of the required (C/N) in dry weather is shown in Para. 2.4.4. This is reproduced here for convenience.

Threshold (C/N) = 6.0dB

Threshold Margin = 1.5dB

(C/N) for 99.7% of time = 7.5dB

Degradation from 99.7% to 95% of time = 2.5dB

(C/N) for 95% of the time =10.0dB

Degradation from 80% to 95% of the time = 1.0dB

(C/N) for 80% of the time =11.0dB(10.000 pWp)

2.6.1 Cont'd........

Degradation from dry weather to 80% of the time = 1.0 dB

(C/N) in dry weather = 12.0 dB

The fading margins were obtained from Para. 1.4 Vol. III

Bandwidth and EIRP Requirements

Substituting the following values into the FM equation:

Test tone to noise = 25 dB from Para. 2.5

$(C/N)_{TOTAL} = 11.0$ dB

$$25 = (TT/N) = 4.76 + 11.0 + 10 \log B + 20 \log (B/2 - 3.4) - 10 \log \left((2 \times 3.4^3) \right)$$

Solving the equation for B

B = 18.6 KHz (Carson's bandwidth)

and

Δ frms = 4.22 KHz

Assuming the same noise budget as for commercial quality channels in the 1.5 GHz band, then:

$(C/N)_{TOTAL} = 11.0$ dB

$(C/N)_{UL} = 21.0$ dB

and $(C/N)_{DL + IM} = 11.4$ dB

The carrier to intermodulation noise in the satellite is the same as in the 1.5 GHz range i.e. 16.4 dB then:

$(C/N)_{DL} = 13.1$ dB

2.6.1 Cont'd

and $(C/T)_{DL} = 13.1 - 228.6 + 42.7$

$(C/T)_{DL} = -172.8\text{dBW/oK}$

and the required per carrier EIRP from the satellite with

$(G/T)_{ES} = -17\text{dB/oK}$

$EIRP = -172.8 + 174.4 + 17.0$

$EIRP = +18.6$dBW for 80% of time.

Adding 1dB for degradation from dry weather to 80% of time, the required per carrier EIRP is +19.6dBW.

Total EIRP for 60 Channels:

+19.6

+17.8

+37.4dBW

There is no flux density specification in the 300 MHz frequency band.

Thus energy dispersal is not provided in the 300 MHz band for commercial quality services. With 18% guardband, the carrier spacing is 1.18 x 18.6 KHz = 22 KHz. For 150 available channels the total satellite bandwidth required is: 150 x 22 KHz = 3.3 MHz

Uplink Parameters:

With:

$(C/N)_{UL} = 21.0$dB for at least 80% of the time

$(C/T)_{UL} = 21 - 228.6 + 42.7$

$(C/T)_{UL} = -164.9\text{dBW/oK}$

2.6.1 Cont'd

With:

(G/T) Satellite = -11.0dB/oK

EIRP = -164.9 +174.4 + 11.0

EIRP = 20.5dBW/carrier

This EIRP must be available for at least 80% of the time from the Earth Station. The degradation due to fading is 4dB from dry weather to 99.7% of the time.

Assuming active EIRP control in the Earth Stations, the required available EIRP must be: (at maximum fading)

EIRP in dry weather = 20.5 +4 = 24.5dBW/carrier

The Antenna gain of the Earth Station is 12dB. Then the required power at the output port of the power amplifier:

+ 24.5dBW	EIRP
-12.0dB	gain
+ 12.5dBW	
+ 3.2dB	Hybrid combiner loss
15.7dBW	
+ 1.5dB	Output loss
+ 17.2dBW or 52.5 Watts/carrier	

Uplink Parameters for the Network Control Station

The station transmits and receives 25 commercial quality voice channels, plus the required network control channels.

2.6.1 Cont'd

Total Earth Station EIRP Requirement

24.5dBW/carrier

+ 14.0dB for 25 commercial quality voice carriers

+ 38.5dBW

Assuming 6 additional control channels with approx. the same per carrier EIRP as the commercial quality channels.

i.e. +38.5 dBW

+ 7.8 dB

+46.3dBW is the total required EIRP.

With 26dB antenna gain at 300MHz, the power at the diplexer is:

+ 46.3 dBW

-26.0 dB

+ 20.3dBW Total Power

Assuming that the carriers are amplified in a common wideband power amplifier, the allowable maximum carrier to intermodulation ratio in the Earth Station transmitter is 34 dB for the worst carrier, if allowable earth station uplink noise is to be limited to 0.2 dB of the overall C/N.

Class A operation must be then assumed for the power amplifier.

With approx. 2dB O/P loss, the power is 22.3dBW or 170 Watts.

For intermodulation performance, the following is the requirement:

With 2 equal amplitude CW signals each +19.3dBW at the output port, the level of one IM product must be 42 to 44dB down.

2.6.2 Military Quality Channels

The analysis is performed assuming compandor improvement.

The specification is -28 dBm OP which corresponds to 1.6 million picowatts of noise for 95% of the time. It was shown in Para. 2.4.4, that for a minimum EIRP design the required carrier to noise is 10.0 dB for 95% of the time.

Bandwidth and EIRP Requirement with Compandor

From Para. 2.5.3 the test tone to noise for the lowest talker is 16.0 dB with compandor, when the signal to noise is 145,000 pWp0 for at least 95% of the time.

With these values:

$$(TT/N) - 16.0 \text{ dB} - 4.76 \text{ dB} + 10.0 \log B + 20 \log (B/2 - 3.4) - 10 \log 2 \times 3.4^3$$

i.e. $10 \log B(B/2 - 3.4)^2 = 20.2$

$B(B/2 - 3.4)^2 = 105$

$B = 12.6$ KHz

Δ frms $= 2.90$ KHz

With:

$(C/N)_{TOTAL} = 10$ dB

$(C/N)_{UL} = 20$ dB

$(C/N)_{DL + IM} = 10.4$ dB

Assuming again that the $(C/N)_{IM} = 16.4$ dB in the satellite then:

$(C/N)_{DL} = 11.7$ dB

and

$(C/T)_{DL} = 11.7 - 228.6 + 41$ dB

$(C/T)_{DL} = -175.9$ dBW/^{o}K

2.6.2 Cont'd........

The required EIRP if (G/T) E.S.t. = -19 dB/°K

EIRP = -175.9 + 174.4 + 19

EIRP = +17.5 dBW/carrier for 95% of the time.

For 40 carriers:

+17.5
+16.0

+33.5 dBW for 95% of the time

For dry weather EIRP, + 2.0 dB must be added to this value.

i.e. Total dry weather EIRP is +35.5 dBW

Uplink Parameters

With $(C/N)_{UL}$ = 20 dB:

$(C/T)_{UL}$ = 20 - 228.6 + 41

$(C/T)_{UL}$ = -167.6 dBW/°K

With:

Earth Station antenna gain = 12 dB
Satellite (G/T) = -11 dB/°K
The Earth Station EIRP is:

EIRP = -167.6 + 174.4 + 11

EIRP = +17.8 dBW per carrier. With 3 dB margin for uplink EIRP control

the EIRP is:

EIRP = +17.8 + 3 = +20.8 dBW

Then the Power Output at the output port of the power amplifier:

EIRP	+20.8 dBW
Antenna Gain	-12.0 dB
Diplexer O/P	+8.8 dBW
Loss in Output Hybrid	+3.2 dB
O/P Loss	+15. dB
TOTAL	+13.5 dBW

2.6.2 Cont'd........

i.e. The required maximum power output of the power amplifier is:

+13.5 dBW or 22.4 W

With 12.6 KHz Carson,s bandwidth per carrier and with 18% guardband the required total satellite bandwidth for 100 available channels is:

$$12.6 \times 1.18 \times 100 = 1.49 \text{ MHz}$$

2.6.3 Program Channels

The carrier to noise requirements and the relative allocations of the noise budget are assumed to be identical to those of the commercial quality channels. Then:

$(C/N)_{total} = 11.0$ dB for 80% of the time and

if:

$f_{max} = 8$ KHz,

$f_{min} = 100$ Hz

$$(S/N)_{rms} = 53.0\text{ dB} = 4.76 + 11.0 + 10 \log B + 20 \log (B/2 - 8.0) - 10 \log(2 \times 8^3) + 2.9$$

Solving the equation for B :

$B = 224$ KHz

and $\Delta f_{pk} = 104$ KHz

$\Delta f_{rms} = 73.8$ KHz

With:

$(C/N)_{IM} = 16.4$ dB

$(C/N)_{UL} = 21.0$ dB

2.6.3 Cont'd.......

then:

$(C/N)_{DL} = 13.0$ dB

$(C/T)_{DL} = -162.1$ dBW/°K

With (G/T) E. St = -16 dB/°K

EIRP = 28.3 dBW/carrier for 80% of the time

With 1 dB fading degradation from 80% of time to dry weather

EIRP = 29.3 dBW/carrier in dry weather

For 5 program carriers:

$$\begin{array}{rr} \text{Total EIRP} = & +29.3 \\ & \underline{+\ 7.0} \\ & +36.3\ \text{dBW} \end{array}$$

The program carriers must be energy dispersal to prevent the degradation of intermodulation noise in the satellite power amplifier. The level of the Energy dispersal is automatically controlled to provide full loading even in the absence of speech modulation. Assuming 18% guardband and 5 equally spaced program carriers, the total required bandwidth in the satellite is: 224 KHz x 1.18 x 5 = 1.32 MHz

2.6.4 Total EIRP and Bandwidth Requirements with 50% Voice Activity Factor in the 300 MHz Band

Assuming compandors for the military channels :

60 commercial quality voice channels: 37.4 dBW

40 military quality voice channels: 35.5 dBW

5 program channels: 36.3 dBW

Total EIRP = 41.25 dBW when $(C/N)_{IM} = 16.4$ dB in the satellite

2.6.4 Cont'd.......

Total Bandwidth

150 Commercial quality channels: 3.3 MHz

100 Military quality Channels: 1.49 MHz

5 Program Channels: 1.32 MHz

Total Bandwidth: 6.11 MHz

2.7 References

Reference 1: Baseline Definition of UHF Satellite Communications Systems Issued by CRC 17 May 1971.

Reference 2: Minutes of the First Progress Review Meeting Para. 1

Reference 3: Modulation and Speech Processing for Single Channel per Carrier Satellite Communications (P.M. Boudreau and N. G. Davies, ICC June 1971.)

Reference 4: Determination of the Capacity of an Intelsat IV Transponder for the SPADE System. (ICSC/T Temp. 31-129E 7 June 1969.)

Reference 5: Transmission Systems for Communications (Bell Telephone Labs. 1964.)

Reference 6: ICSC-45-13E W/1/70. Performance Characteristics of Earth Stations in the Intelsat IV System.

Reference 7: C. Melvil Thomas; Optimization of Phase Lock Demodulator for Single Channel Voice (The Microwave Journal June 1967).

Reference 8: Hekimian-Mack; A New Threshold Extension Demodulator for FM Multiplex. (Eascon '69 Record.)

3.0 EARTH STATION DESIGN

After initial selection of the G/T requirements, two main antenna concepts were pursued and estimated. These were:

1. Single reflector with orthocoupler and filters to achieve required TX into RX isolation.
2. Dual reflectors with simple feeds and spacial discrimination to acheive required TX into RX isolation.

Alternative 2) turned out to be more costly and had severe disadvatages for transportable users because of the larger overall assembly.

ANTENNA SYSTEM DESIGN

Figure 1) shows the achievable gain of focal fed parabolas (referred to the orthocoupler output) assuming an aperture efficiency of 50% and a surface tolerance on the dish of 0.25 inch peak to peak. Because of the losses associated with the orthocoupler and filters and connecting waveguide the antenna gain referred to the input of the LNR or power amplifier is 0.5 dB less. This loss is negligible from transmit considerations, but increases the system noise temperature by 32°K.

Noise Temperature at 1.5 GHz

Paramp and following stages	80°K
Sky and galactic	20°K
Earth Contribution	100°K
Loss in System	32°K
Total	232°K (24 dB°K)

Cont'd.....

	Commercial Quality Fixed station	Program Receive Fixed Station	Military Quality Transportable Station
Gain required for:			
G/T =	-1 dB	+1 dB	-5 dB
=	24 dB	26 dB	22 dB (2 dB for reflectior
(assume 1 dB margin)	4.5 ' dia.	5.5' dia.	3.5' dia.

Noise Temperature at 300 MHz

2 dB Receiver and following stages	170°K
Sky and Galactic	400°K
Earth Contribution	150°K
Misc. Loss	50°K
Total	770°K (29 dB°K)

and diameter required for G/T =

-17 dB	-16 dB	-19 dB
5.5 ' dia.	6.5 ' dia.	5.5 ' dia.

While a 2 dB noise figure receiver is possible at the present time some very low noise figure transistors are being developed and it may be possible to build a receiver with a 1.5 dB noise figure. In that case the antenna diameter could be reduced by 0.5 feet.

The 5.5 feet requirement for the private use is probably the largest acceptable size and it would seem valuable to tradeoff some system margin in this direction, if avoidable, or if the size is unacceptable reduce the system channel capacity.

Cont'd.....

A more practical solution in the VHF band would be a helical antenna. A single helix on the order of 6 feet for fixed stations and 7 feet for mobile stations would provide the necessary gain. A duplexer is now required, however, because both transmit and receive are co-polarized. The duplexer is not an expensive design, since it need handle less than 100 watts.

3.3 Communications System

3.3.1 Introduction

Functionally, the following types of stations are required:

a. Voice telephony with "commercial" quality

b. Voice telephony with "military" quality

c. Radio program receive

d. Two-way teleprinter

e. One-way teleprinter

f. Low data rate telemetry

The following is the electrical description of an Earth Station providing two-way telephony which was the main subject of the study. The other types of stations are either identical or are less complex than this station and can be implemented by using selected modules of the two way telephony station.

3.3.2 Subsystems

a. Transmit subsystem

b. Receive subsystem

c. Synthesizer subsystem

d. Power generation

e. Logic, monitor, control, alarm subsystem

f. Antenna subsystem

The simplified block diagram is shown in Figure 1.

3.3.2 Cont'd

After the initial installation and tests are completed, the station is operationally unattended in a fully automatic mode. It is controlled by a combination of local (in station) and remote (from Network Control Stations) control signals.

3.3.3 Transmit Path

Two independent transmitters are required. They provide the following functions:

a. Transmit one voice channel on carrier f1 while the second transmitter is auto-standby.

b. Transmit two voice channels on two RF carriers.

c. Transmit a 2 phase PSK modulated RF carrier on transmitter 1, with transmitter two in auto-standby.

d. Transmit mixed traffic i.e. one transmitter for voice traffic, while the other is operating in the PSK mode.

The only major difference between FM and PSK mode is the use of an FM modulator for FM analog input and PSK modulator for digital input. The wanted transmission mode is selected by a switch at the first upconverter input which selects either the FM or the PSK modulator.

Speech enters into the compressor and the signal is amplified, left unchanged or clipped depending on its input power level. After the compressor the signal in the "main" path is delayed for 50 milliseconds, while the voice level is being measured in the "secondary" path by a voice detector. The voice detector turns on or turns off the local oscillator of the first upconverter, depending on the presence or absence of voice power.

3.3.3 Cont'd

The 50 msec. delay in the main path is necessary to ensure that the leading edge of the voice is transmitted without distortion.

The pre-emphasized voice signal then FM modulates carrier and fixed level energy dispersal signal (the same as presently used in the Intelsat 1V system) is added to the baseband.

The first IF frequency is chosen in the 5 to 10 MHz frequency range with a required bandwidth of approximately 25 KHz.

The modulator output frequency is controlled by automatic frequency control in a phase-lock loop to meet the frequency stability requirements. The reference signal to the AFC is provided by the frequency synthesizer.

The first IF carrier is upconverted to the second IF frequency in the first upconverter.

The local oscillator to this upconverter is obtained from the synthesizer. The synthesizer frequency is selected by command from the Network Control.

A second upconverter with a voltage controlled oscillator translates the IF frequency to the final transmit frequency band centered at 1525 MHz from Earth to Satellite.

The RF output frequency band then becomes 1525 ± 6 MHz. The control voltage to this VCO is derived from the AFC reference carrier, transmitted from the Network Control Station.

3.3.3 Cont'd

After the second upconverter, the signal is amplified in a transistor power amplifier, operating at some output backoff. The backoff is necessary to enable the automatic EIRP control function by a pin diode leveller loop located at the input to the final power amplifier.

The control signal to the leveler is a composite signal, one of the inputs provides the voltage for levelling and is derived from the beacon carrier received from the satellite. The other input to the control signal is a local reference voltage which prevents the increase of the output power over a maximum permissible level, if the automatic level control fails. The power amplifier output is combined to a 3dB hybrid which feeds the antenna orthocoupler.

To minimize required satellite EIRP, the carrier is voice activated. A voice detector monitors the speech power level at the compressor output. With no voice input, the voice detector activates a switch which turns off the carrier by removing the synthesizer from the first upconverter, and turns on the carrier when the voice power is above a present minimum level. To prevent the distortion at the leading edge of the voice a 50 msec. delay is introduced in the main voice channel path which ensures that the carrier is already turned on when the voice power arrives to the FM modulator input.

Energy Dispersal

To reduce the flux density in the satellite to Earth link and to reduce intermodulation in the satellite, energy dispersal is applied at the modulator input.

Energy Dispersal

The energy dispersal signal is a saw tooth at a fixed amplitude. and is added to the speech at the modulator input.

Frequency Synthesizer

This unit generates a frequency from a pool of approximately 260 available frequencies. The frequency selection is done by command from the Control Station.

For a given duplex voice transmission there is a constant frequency difference between transmit and receive frequency as seen by the same station.

The same synthesizer frequency can be thus used in the first upconverter and the second downconverter.

The synthesizer provides additional fixed frequencies required in the Station.

3.4 Earth Station Receiver

3.4.1

The receiver consists of a redundant wideband receiver and individual receivers to provide the required outputs.

3.4.2 Common Wideband Receiver

Assuming a frequency translation in the satellite from 1525 ± 6 MHz to 1460 ± 6 MHz the full receive band in the 1460 ± 6 MHz band is received through an orthocoupler, then a bandpass filter, to provide the necessary isolation from the transmit band. A wideband downconverter converts the received carrier band to the first IF frequency which will

3.4.2 Cont'd

be chosen around 110 MHz.

The local oscillator for this mixer is a VCO, which performs AFC control. This is done using a reference carrier, transmitted from the Control Station in the center of the frequency band. At each Station this carrier is selected and compared with a local reference frequency generated by the station's own synthesizer. An error voltage is developed and this is used to control the VCO frequency and provide spectrum centering after the first wideband downconverter which also provides gain at the IF frequency. The output is split four ways to individual receivers.

Voice and PSK Receivers

Ports one and two of the IF divider are connected to two idential receivers. They can be used to receive a voice channel with the second receiver in standby, or they both receive voice traffic simultaneously.

One receiver consists of a second downconverter which receives its local oscillator secquence from the synthesizer. This way the wanted carrier, which in case of FM consists of energy dispersal plus voice modulation, is separated from all other carriers.

Following this module a splitter which routes the selected carrier to an FM receiver and PSK receiver to allow the Network control station control over a station at all times.

Voice and PSK Receivers Cont'd

With an FM commercial quality carrier, the carrier enters into the third downconverter with a VCO as a local oscillator. The function of the VCO is to remove the energy dispersal signal before it enters into the final demodulator. With energy dispersal superimposed on the voice modulation, the required pre-detection (C/N) ratio at the demodulator input is approximately 1.0 dB less than without energy dispersal.
In an actual system a 1 dB EIRP margin may be available in which case, predetection energy dispersal removal is not required. In this study, however, this was not assumed, and E.D. removal is provided.

One possible way is to split the IF carrier into two paths. In one path, only the ED signal is demodulated in an FNFB demodulator. In the second IF path the carrier enters into the third mixer mentioned previously in this paragraph, which has a VCO local oscillator. The ED signal in the proper phase then drives this VCO and the output of the third downconverter will not contain ED signal. The final predetection filter will thus require Carson's bandwidth for the test tone deviation only. The final demodulator is a threshold extender type, which is specifically designed for single voice channel. It is expected that 6 dB (C/N) threshold can be achieved for a single channel demodulator. The demodulated output is de-emphasized and after the final expandor is available to the telephony baseband interface.

Voice and PSK Receivers Cont'd

In PSK Mode after the second downconverter the PSK modulated carrier is routed directly to a PSK demodulator. It is assumed that ED removal is not necessary for this mode. The output of the 2 phase PSK demodulator which is a regenerative type of demodulator is in serial digital form.

3.4.3. AFC Reference Receiver

This consists of a second downconverter with a fixed frequency local oscillator which selects the AFC reference carrier.

The downconverter output is amplified and compared in frequency with a locally generated reference frequency. The error voltage of the comparator is then connected to the VCO of the wideband receiver downconverter.

A second AFC receiver is provided for standby.

EIRP Control Receiver

This receiver consists of a second downconverter with a fixed local oscillator which selects the EIRP control carrier. This carrier is amplified and its power level is compared with a reference power. From this an error voltage is derived which corresponds to uplink degradation only. It is used to control the EIRP of the transmitter.

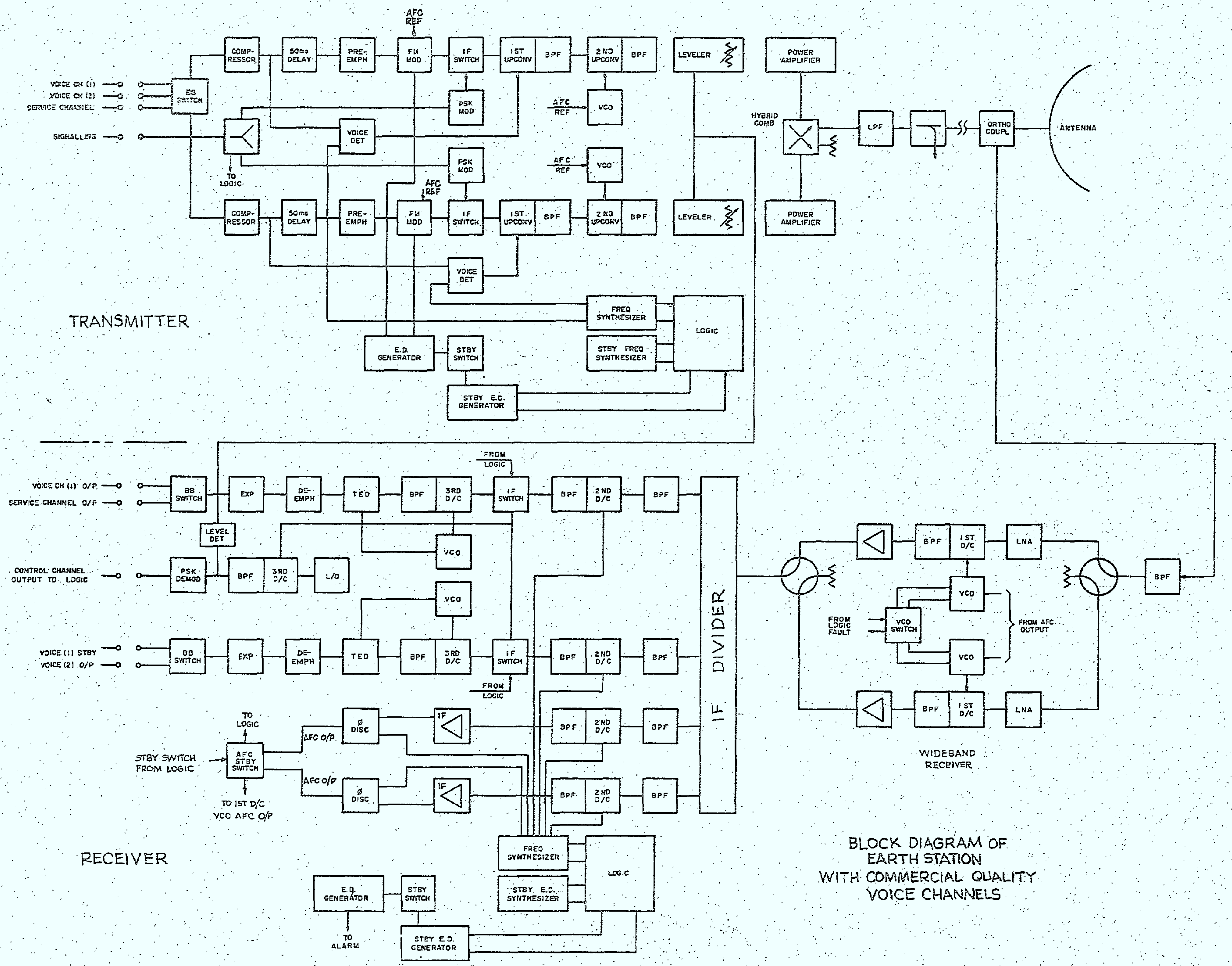
A second EIRP control receiver is provided for standby.

3.4.3 Cont'd

Logic, Control, Alarm

Beside the signalling, interrogation, and frequency selection functions, these units provide all secondary functions such as station status monitor, standby switching, alarm, periodic checks, etc..

All these functions are performed in conjunction with the Network Control Station.



BLOCK DIAGRAM OF
EARTH STATION
WITH COMMERCIAL QUALITY
VOICE CHANNELS

DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING. DO NOT SCALE DRAWING. ALL EXTERNAL THREADS TO BE CLASS 2A BEFORE PLATING AND CLASS 3A AFTER PLATING; ALL INTERNAL THREADS TO BE CLASS 2B, UNLESS OTHERWISE SPECIFIED.

WORKMANSHIP TO BE IN ACCORDANCE WITH RCA LIMITED WORKMANSHIP STANDARDS

VARIATIONS OF FINISHED DIMENSIONS UNLESS OTHERWISE MARKED

BASIC DIMENSIONS	2 PLACE DECIMALS	3 PLACE DECIMALS
UP TO 6	± .02	± .005
ABOVE 6 TO 24	± .03	± .010
ABOVE 24	± .05	± .015

ANGULAR DIMENSIONS ± ½ DEG.

SEE PENCIL SPEC. FOR STOCK TOLERANCE

NEXT

FIRST MADE FOR

USED ON

DRAWN BY

CHECKED BY

DESIGNED BY

COMMODITY CODE

RCA LIMITED
STE ANNE DE BELLEVUE, QUEBEC

D
SIZE

CODE IDENT NO. CS311

SHEET

CONT'D

TRANSTEX 23

8 7 6 5 4 3 2 1

4.0 AVAILABILITY

4.1 Introduction

The proposed system is designed for continuous operation with a minimum of downtime. This is achieved through the use of conservatively designed long-life components with extensive employment of redundancy.

Quantitative availability and reliability data are presented on each subsystem and major item of equipment. Station availability and mean-time-between-failure values are given is respect of a single antenna system operating on a continuous duty basis to a geo-stationary satellite.

Associated with each unit mean-time-between-failures (MTBF) value, is a mean time to repair (MTTR). With respect to individual units, MTBF, and MTTR values and unit availabilities are presented in Table 1.

The MTBF values quoted for all subsystems and major items of equipment have either been derived from figures for similar types of equipment, used in larger earth stations. The figures result from actual field use or calculations in accordance with MIL - 217A. The failure rate values quoted are derived from these MTBF values. It is generally agreed that calculation of MTBF,s by the method described in MIL-217A results in conservative values. These values are normally well exceeded with good commercial equipment operation.

4.2 Design Life

Special consideration has been given to non-redundant equipments in the earth station to assure that the overall station availability objective will be achieved. The availability block diagram is shown in Figure 1 and it can be seen that the major non-redundant components are the antenna and feed.

4.2 Cont'd........

For the mode of operation with a geo-stationary satellite the antenna is a fixed mechanical structure with no moving parts. The MTBF of this structure is predicted to be at least double the value for a large antenna which has bearings, gear boxes and rotating assemblies to consider. Calculations for these large (98 ft) antennas indicate an MTBF of 2.5×10^6 hours so it should be reasonable to assume 5×10^6 hours for the fixed smaller antenna. The antenna has been designed to withstand the extreme environmental conditions which will exist at the sites.

The antenna feed is composed entirely of passive components and consequently has a very high availability also.

Special emphasis has been given throughout the design of the proposed station to achieving a conservatively rated design life of 15 years and all operating electronic equipment is solid-state for maximum reliability and life. This includes a solid-state pump for the parametric amplifier.

4.3 Derivation of Availability and Reliability Functions

4.3.1 Definition of Availability

In the present application, the "average" availability is required. This may be defined as the proportion of time the system is available over a relatively long period of time.

Thus:

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

Where A is the availability

MTBF is the meantime between failures

MTTR is the meantime to repair or restore.

4.3 Cont'd........

4.3.2 Group Availabilities

a) Units in series - the availability of the group is the product of the availabilities of the units.

b) Units in parallel - for a group of n identical units in parallel, of which m are necessary for system survival, the group availability is given by:

$$A' = \sum_{i=m}^{n} \binom{n}{i} A^{i} (1 - A)^{n-i}$$

If the units are not identical, and there are two in parallel, having availabilities A_1 and A_2 respectively, the group availability is given by:

$$A' = A_1 + A_2 = A_1 A_2$$

4.3.3 Definition of Reliability

Station reliability may be defined as the probability that the station will perform its function satisfactorily for a stated time.

For a given unit of the system, the failures may be assumed to be exponentially distributed, and the reliability of the unit may be expressed:

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

Where is the unit failure rate (reciprocal of MTBF)

t is the time period.

4.3.4 Group Reliabilities

a) Units in series - the reliability of the group is the product of the reliabilities of the units.

4.3.4 Cont'd........

b) Units in parallel - for a group of n identical units in parallel, of which m are required for system survival, the group reliability is given by:

$$R' = \sum_{i=m}^{n} \binom{n}{i} R^{i} (1 - R)^{n-i}$$

If the units are not identical, and there are two in parallel having reliabilities R_1 and R_2 respectively, the group reliability is given by:

$$R' = R_1 + R_2 - R_1 R_2$$

4.3.5 System Mean-Time-Between-Failures (MTBF)

Although it is assumed that individual units have exponential failure distribution the systems under consideration, in which some of the units are redundant, will not have an exponential failure distribution and the statement

$$R_S (t) = \exp (- \lambda S^{t})$$

will not be true. This expression solved for $1/ \lambda S$ gives a fair approximation of the system MTBF only when the contribution of the redundant units to the system failure rate is unimportant compared with the contribution of the non-redundant units. To derive the MTBF of this station it is necessary to integrate the station or system reliability function from zero to infinity. That is:

$$MTBF_S = \int_0^{\infty} R_S (t) \, dt$$

4.4 Calculation of Station Availability

The earth station availability diagram for operation with a geo-stationary satellite is shown in Figure 1. A redundant receive chain is required to meet the specified availability and also to provide a two channel capability.

4.5 Availability Without Redundancy (I. E. Single Channel Capability)

From the entries in Table I, the availability can be calculated by taking the product of the availability of each subsystem. The result is 99.8% and this is considered inadequate

4.6 Availability With Redundancy

a)	Antenna	A = .999997
b)	Paramp Pair	$A = 2A - A^2$ = .99999999
c)	Downconverter & Demod Pair	A = .9999999
d)	Synthesizer pair	A = .9999999
e)	Cabling and Logic	A = .9997
f)	Exciter & Power Amp Pair	A = .9999999
g)	PSK Modem pair	A = .9999999
h)	Energy Dispersal, etc.	A = .9999

TOTAL AVAILABILITY A_{system} = 99.96%

The availability with redundancy compares favourably with a telephony network and is thus considered adequate. To increase the availability beyond the calculated value will require special techniques, as equipment design has definite limitations. All items that can be made redundant have to have a fairly simple fault indication - i.e. loss of signal or out of band noise for the receive chain and loss of signal on the transmit chain. To detect failure in the station logic or ED system is much more difficult and the traditional approach to provide automatic redundancy when failure is not easily detectable, is the majority vote system - three online systems with logic to select the majority vote. This was judged impractical in the present system.

4.5 Cont'd........

The mean time to repair (replace) assumes that spare modules are available for the non-redundant modules and that manual intervention to replace them is possible at each site. The failed redundant modules are replaced during routine maintenance and the assumption (compared to replacing a module whenever it fails) does not change the availability calculation if maintenance periods are shorter than the MTBF.

Without routine maintenance the station MTBF is 10,000 hours. With routine maintenance and replacement of modules which appear marginal on test the MTBF will be greater. Assuming routine maintenance (and the fact that very conservative MTBF figures are used in the calculation) an MTBF of greater than 15,000 hours would seem an achievable figure for the actual hardware.

TABLE 1

AVAILABILITY BUDGET

Reliability and Availability Budget	MTBF Hours	MTTR Hours	AVAIL.
Antenna	5.0×10^6	10	.999997
Feed	1.7×10^6	2	.999996
Paramp	20,000	2	.99990
Downconverter	21,800	2	.99991
Demodulator	16,000	2	.99987
Commercial Power			1.00000
Synthesizer	15,000	2	.99987
Cabling and Logic	15,000	4	.9997
Exciter Chain	10,000	2	.99980
Power Amplifier	20,000	2	.99990
PSK Modem	15,000	2	.99987
Energy Dispersal & Spectrum Centering	20,000	4	.9999

5.0 OPERATIONAL CONSIDERATIONS

A major yearly cost element will be incurred in operating the system on a routine basis, and to provide anything other than broad cost indications requires a knowledge of the operating entity. The concept of an unattended earth station is new, and to date only Telesat Canada has decided to implement a largely unattended system, with an availability requirement virtually the same as the present study. The Network and Northern Stations which in terms of mission are the closest in comparison to the present study, are nominally unattended but an elaborate status and alarm relaying system was considered necessary and remote manual intervention is possible. In any event, the maintenance agent is only a few hours away. Of the 8 NTV, NTC stations, four have automatic de-icing (and de-snowing) equipment, one is in a location where snow is infrequent and the others are in areas where icing isnot common and only dry snow is anticipated.

The effects of snow and ice on a very low noise receiving system ($\simeq 70^\circ$ system, $\simeq 130^\circ$ overall) is disasterous - a few inches of wet snow on the bottom half of a large antenna was recorded as causing 8 dB C/T fades. The fading mechanism is threefold:

1. The noise temperature is increased by the snow.
2. Signal attenuation due to phase errors.
3. Beam tilt (which was not applicable in the previously mentioned case which was a tracking antenna).

It is virtually impossible to separate the relative contribution of the above sources as this is of some importance to the present study, since:

1. will have no effect at 300 MHz and little effect at 1.5 GHz, assuming the RF feed window is kept clear.

Cont'd.......

2. will probably have no effect at 300 MHz and an unknown but small effect at 1.5 and a somewhat greater effect at 2.5.

3. will have virtually no effect at 300 MHz and an unknown effect at 1.5 and 2.5 GHz.

For these reasons, it must be assumed that the antenna is kept clear of ice and wet snow until some measured data are available. One possibility is to employ a membrane across the dish as is done in line of sight systems.

The foregoing serves to point out some of the uncertainities involved in system operation and it appears that unless a deicing system is installed (≃ 5 KW power required) some attention other than routine maintenance will be required. Another question is tolling the calls - it seems simple enough for the computor to keep track of usage on a per station basis, but since there will be usage of each station by multiple callers the question of tolling the calls is not simple, and no costs have been included for local exchanges and associated tolling equipment. Although not germane to the scope of the study an interesting question arises about how to toll the call - charge per access or a charge dependent on the distance between the two stations?

The Network control stations will be daytime manned (in particular the satellite control station) and employ an elaborate backhoul supervisory system to the operating entity where a technician employed on other tasks can provide a certain level of manual intervention when the station is unmanned.

5.1 Maintenance

On site maintenance would be prohibitively expensive, not primarily because of travel costs, but because of the implied requirement for workshop space, spares and test equipment. Accordingly it has been assumed that when one of the two channels fails, the station operates as a one channel station until the failed module can be replaced. At some sites, it may be possible to have an adequately trained part-time employee replace the failed module, and this would require a detailed trade-off of spares cost vs. labour cost. For the present study, it is assumed that a stock of 5% spare modules is available. It is envisaged that failed modules will be replaced by routine maintenance. A local person will be required in any event to be responsible for the welfare of the station and possibily to toll the calls.

Because of the diverse systems fed by the earth station, the interface has been assumed to be baseband voice with appropriate signalling, and it is further assumed that the station is installed in an existing structure such as a post office, schoolhouse, or the local exchange. Conceptually, in very remote and sparsely populated areas the station could be installed in a private individual's house, in much the same way as a rural post-office. Again without a detailed knowledge of the implementation plan, annual operating costs cannot be estimated with any confidence.

Network Control

It is assumed that the system operates with one Network Control Station, the other Network Control Station acting as a backup or being dedicated to the service to transportable stations. The functions of this station are:

a) Demand assignment
b) National Network Interface
c) Auto-check
d) Operational control of each station

The voice communication in the system including radio program is transmitted via FM modulated carriers. It is assumed in the baseline definition that Telemetry Stations, are transmitted via 2 phase, PSK modulated RF carriers. For economic reasons it is assumed that all stations will use the same type of 2 phase PSK modems, and this has the advantage of a foster signalling rate as compared to FSK.

The most stringent requirements are defined by signalling a minimum of 10 bits are required to address 1000 ground stations ($2^{10} = 1024$) and an error rate objective of better than 10^{-6} is assumed. To reduce the effective signalling error rate, below 10^{-6}, error correction is applied in the signalling bit stream. One probable method is the "longitudinal parity method" (CCITT Volume VIII Data Transmission Supplement No. 6 ISO/TC97/SC6).

Within one second 1000 earth stations are interrogated, i.e. the time allocated in each sequence is 1 ms per station. Presently it is assumed that each station transmite 20 bits; minimum 10 addressing bits + error correction bits + system control

Cont'd.......

bits.

Twenty (20) serial bits have an available time of 1 ms, i.e., 1 bit duration is 50 u.s. (As pointed out before 50 u.s. are assumed for one signalling bit), i.e. then the required bit rate is 20 kbits/s. A C/N minimum of 10 dB is required at the input of the demodulator. A 3 dB bandwidth of 40 KHz is required.

For telemetry 2400 bit/s are assumed; this rate could be increased without any modification of the modem.

For teleprinter a slow transmission rate is assumed (compared to the above bit rates). It is assumed that at the transmit point (input to the modulator) telemetry, signalling, and teleprinter information is available in digital form.

For all the above three services one modem is proposed, a coherent 2 PSK modulator-demodulator. The proposed modem will give an error rate less than 10^{-6} with a C/N (40 KHz) = 10 dB. For telemetry, signalling, and teleprinter, with appropriate coding, it will be assumed that the energy dispersal problem is solved, even when the transmit information is all ones or all zeros.

The demodulator is actually a data regenerator. Regeneration is required, because the demodulator output feeds the logic circuits.

The demodulator timing Phase Locked Loop is originally tuned to the bit rate of the signalling rate. The signalling information contains bits to control the tuned

Cont'd.......

frequency in the Phase Locked Loop.

The following is the channel assignment in the system starting from the lower edge of the band.

Ch. 1 Interrogation and acquisition control channel (ACC)

Ch. 2 Confirmation channel (CC)

Channel 2 is followed by 150 commercial quality telephony channels, 100 military quality telephony, and 5 radio program channels.

Assuming 2400 bit/second for the telemetry channels with 2 phase PSK the telemetry channels will fit inside the available channel bandwidth of the voice channels. For teleprinter a lower bit rate is assumed and no bandwidth constraint exists for that service. In the center of the frequency band one or two voice channel bandwidth is provided for an carrier transmitted from the Network Control Station. This carrier transmits a pilot for automatic frequency control and spectrum centering in the system. This is discussed in the section which describes the individual Earth Stations.

In the upper edge of the Earth to Satellite frequency range two additional control channels are provided.

Channel N-1: ACC prime. This is the acquisition control channel used exclusively by the Network Control Station.

Channel N: CC prime. This is a confirmation channel also used exclusively by the Network Control Channel. The following is a step by step description of a

Cont'd.......

call for a duplex voice transmission:

Abreviations:

" OT "	Station which originates the call
" RT "	Station which receives the call
NCT	Network Control Station
Rx	Satellite to Earth receiver
Tx	Earth to Satellite transmitter
LOS	line of sight microwave link

Step 1: Initially the PSK receiver of each station is tuned to channel ACC prime.

Step 2: Signalling arrives to " OT " from LOS

Step 3: At " OT " the local logic control auto-switches its PSK Tx to " ACC " and transmits the signalling information

Step 4: " OT " auto-switches its Rx to " ACC " and observes its own transmission. If correct the " OT " Rx is auto-switched ACC Prime and waits there.

Step 5: NCT station which continuously interrogates all stations receives the signalling from " OT " viz th " A C C " channel.

Step 6: The NCT station retransmits the signalling information to RT station via channel ACC prime, and simultaneously provides to RT station its frequency assignments.

Cont'd.....

Step 7: RT station after receiving the instructions confirms it via channel CC to the NCT station.

Step 8: The NCT station transmits the frequency assignment to OT station, and inhibits the selected frequency pair for the duration of the talk.

The system described above is one of many possible systems, and the optimum system depends on the operational concept. The details of the system is beyond the present scope. Demand assignment schemes can be divided into two broad classes which depend on the method of control - either central control where all functions of the network are controlled by a central controller or varying amounts of automonous control where a user can sieze a channel. The proposed scheme and SPADE are two extremes. Central control is assumed here to obviate the problem of lockouts if two stations signal independently and more importantly to reduce the chance of an equipment failure in one ground station resulting in the control channel being seized.

Other Functions of the Network Control Station

It was discussed in the communications system analysis, that both the TWT and the transistor amplifier in the satellite transponder exhibit gain variation as function of the total input power. To keep this gain variation to an acceptable level, during very light loading conditions, the Network Control Station instructs a number of non-operating stations to turn on their transmitter to provide loading carriers to the satellite transponder.

Cont'd......

All other functions such as auto-check of remote station status, operational control of the Earth Stations can be performed by the 2 phase PSK transmission via the acquisition control and confirmation channels.

7.0 COSTS

7.1 Introduction

The Earth Station was designed so that the different types of stations could utilize common modules and a baseline production run of 1000 seems reasonable, since the telephony stations have redundant modules. The manufacturing cost of the various modules can be estimated with an accuracy of approximately 10%.

This cost is increased by 20% which was judged to be a representative mark-up for this type of industry and this figure now represents the breakeven costs.

7.2 Development Costs

	cost in thousands
General Communications Equipment	$1,090
Antenna System	50
System Engineering and Integration	75
	$1,215

7.3 Network Control Stations

Two network control stations are required, one of which has a Tracking, Telemetry, and Control (TT & C) capability. The other station has a limited motion antenna system, suitable for tracking ges-stationary satellites with 2 degrees orbital inclination. These two stations can be compared to the tracking station and a Network Television Station of the Telesat Canada system.

The assumed costs are:

	costs in thousands
Fully tracking with TT & C equipment	1,500
Limited Motion	850

7.4 Integration Assembly and Test

The estimated cost of integration material such as PC board connectors etc., and assembly time is $600 for the electronics package. It is envisaged that the electronics will be tested on a GO - NOGO basis on the production line and $150 is an adequate allocation for test setups prorated over the large quantity.

7.5 Total Cost

The cost of each desired type of station can be determined from the following tables which give module costs. The total cost for a two way telephony station is shown below.

	COSTS IN DOLLARS	
Module Manufacturing Cost (Module A1 to C11)	13,430	13,430
Material Handling Applied at 10%	1,340	14,770
Assembly and Test	750	15,520
Markup applied at 20%	3,100	18,620
Development Prorated over 500 units (includes markup)	2,430	21,054
TOTAL	21,054	

7.6 Cost Differences at 300MHz

The majority of the modules are identical and the difference is in the antenna and feed, low noise receiver, and the power amplifier to a lesser extent. The costs which can be assumed for these modules at 300 MHz are as follows:

Power amplifier A 11	$ 250 each
LNA B3	$ 400 each
Antenna Hardware Total C1 to C6	$ 800 total
ED generator B 15	Delete for telephony, include for program

The development costs and all other costs can be considered as unchanged. On the same basis, the cost for a two way voice station, 500 of becomes as below.

	COSTS IN DOLLARS	
Module Manufacturing Cost (Module A1 to C11)	9,050	9,050
Material Handling Applied at 10%	905	9,955
Assembly and Test	750	10,705
Markup applied at 20%	2,150	12,855
Development Prorated over 500 units (includes markup)	2,430	15,285
TOTAL	15,285	

7.7 Other Types of Stations

Theccosts of a transportable station at both frequencies will be somewhat higher as there will be additional costs associated with a deployable antenna. These costs however have been assumed to be approximately equal to the installation costs of fixed station, and thus the top numbers as shown in Volume I of this report are applicable.

A ppssibility exists that the communications system parameters could be modified to allow the reception of program material by a commercial FM receiver and a low noise 300 MHz front end and antenna. The present design does not allow this because of the selected deviations and the operating carrier to noise ratio. Considering the type of user of such a direct broadcast service, the costly requirements of reliability, redundancy,remote control, and environmental temperature range can be deleted. For large quantities (500 of) a converter and Yagi antenna can be assumed to cost $500, providing the FM receiver AFC can provide adequate spectrum centering without requiring significantly larger than optimum pre-detection bandwidths.

TWO WAY TELEPHONY STATION

UNIT	QTY PER STATION	COST EACH (produced in quantity)	COST PER STATION
A1	1	10.00	10.00
A2	2	300.00	600.00
A3	2	50.00	100.00
A4	2	5.00	10.00
A5	2	5.00	10.00
A6	2	30.00	60.00
A7	1	295.00	295.00
A8	2	150.00	300.00
A9	2	305.00	610.00
A10	2	50.00	100.00
A12	1	15.00	15.00
A13	1	20.00	20.00
A15	1	20.00	20.00
A11	2	450.00	900.00
B1	1	20.00	20.00
B2	1	20.00	20.00
B3	2	1900.00	3800.00
B4	2	50.00	100.00
B6	1	20.00	20.00
B7	1	70.00	70.00
B8	4	35.00	140.00
B9	4	10.00	40.00
B10	4	150.00	600.00
B12	4	5.00	20.00
B13	2	300.00	600.00
B14	4	10.00	40.00
B15	2	100.00	200.00
B11	2	340.00	680.00
C1	1	400.00	400.00
C2	1	200.00	200.00
C3	1	140.00	140.00
C4	1	400.00	400.00
C5	1	280.00	280.00
C6	2	80.00	160.00
C7	1	1280.00	1280.00
C8	2	200.00	400.00
C9	3	75.00	225.00
C10	1	185.00	185.00
C11	1	360.00	360.00

UHF Satellite System Study

Transmit Subsystem

Unit Breakdown		Cost
A1	Baseband Switch	See detail sheets
A2	Compressor	
A3	50m's Delay Line	
A4	Pre-emphasis	
A5	Auto Switch	
A6	First Upconverter 50 MHz Filter	
A7	PSK Modem	
A8	Second Upconverter	
A9	Voice Modulator	
A10	Leveller	
A11	Power Amplifier	
A12	Combiner	
A13	Low Pass Filter	
A15	Voice Detector	

UHF Satellite System Study

Receive Subsystem

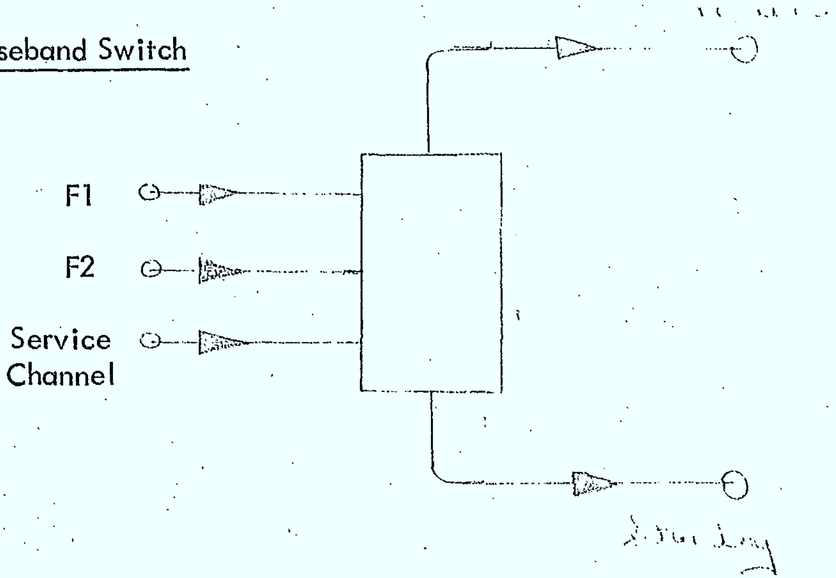
Unit Breakdown		Cost
B1	Input Filter	See detail sheets
B2	LNR Input Switch	
B3	LNR	
B4	First Downconverter	
B6	LNR Output Switch	
B7	Divider	
B8	Second Downconverter	
B9	Auto Switch	
B10	Third Downconverter	
B11	Demodulator	
B12	De-Emphasis	
B13	Expandor	
B14	Baseband Switch	
B15	ED Generator	

UHF Satellite System Study

Antenna and Integration

Unit Breakdown		Cost Each
C1	Antenna - assume 5' dia.	400
C2	Mount	200
C3	Feed and Phase Shifter	140
C4	Orthocoupler	400
C5	W.G.Runs and Transitions	280
C6	Interdigital Tx Filter	80
C7	Synthesizer and Lo Source	1280
C8	Power Supply	300
C9	Electronics Housing	75
C10	Station Logic	185
C11	Antenna Assembly and Lining	360

Unit A1 Baseband Switch



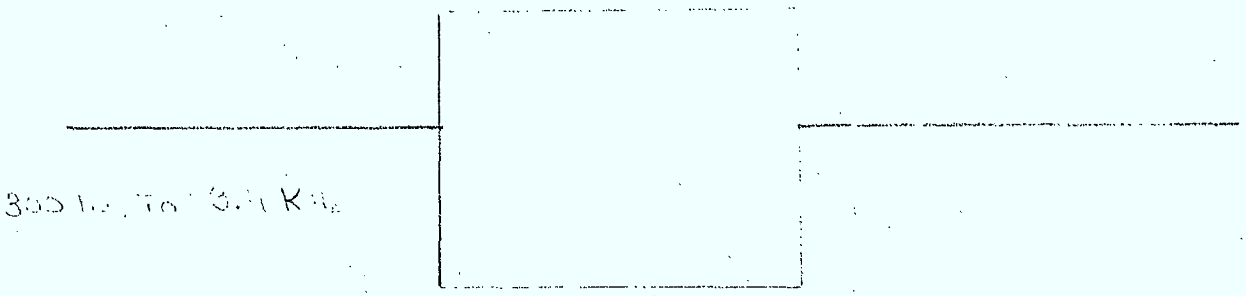
Speed not critical

Estimated Manufacturing Cost:	$10.00

Unit A 2 Compressor

Budgetory quotes from suppliers(lenkurt, RCA ,Camden)	$300.00

Unit A 3 Delay Line



50 MS Delay

Distortion not critical

Estimated Manufacturing Cost: $80.00

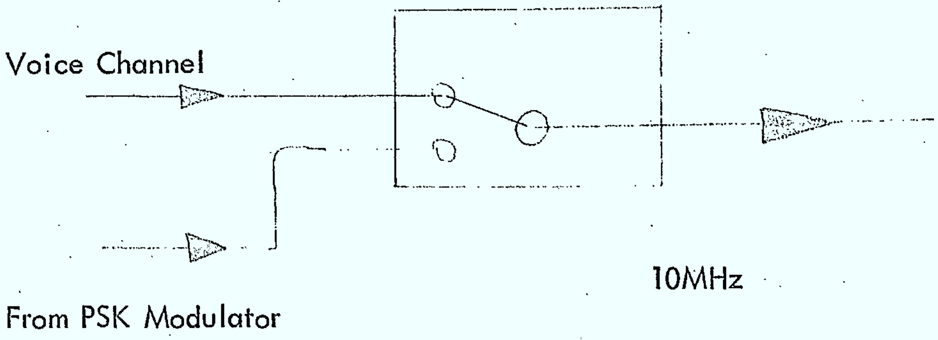
Unit A4 Pre-Emphasis

Cost as telephony emphasis network

Consists of about 10 R, L, and C components.

Estimated Manufacturing Cost:	$15.00

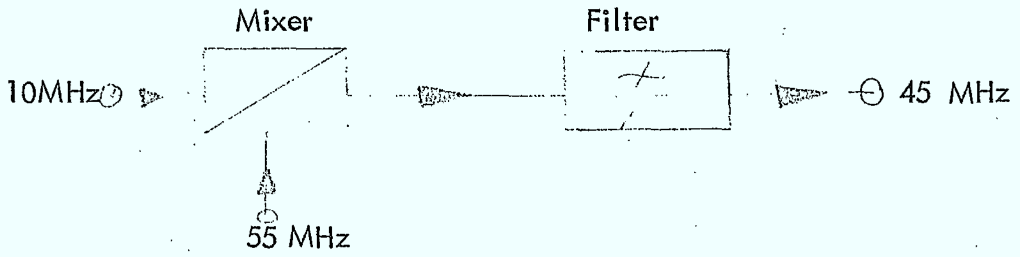
Unit A 5 Auto Switch



Diode on Relay Switch

Estimated Manufacturing Cost:	$15.00

Unit A 6 Tx 1st Upconverter



Mixer:

Double Balanced or Single Balanced

Relum, Anzac, Lovach printed circuit board mounting type. Will mount on the filter board

Filter:

Stripline

Estimated Manufacturing Cost:	$30.00

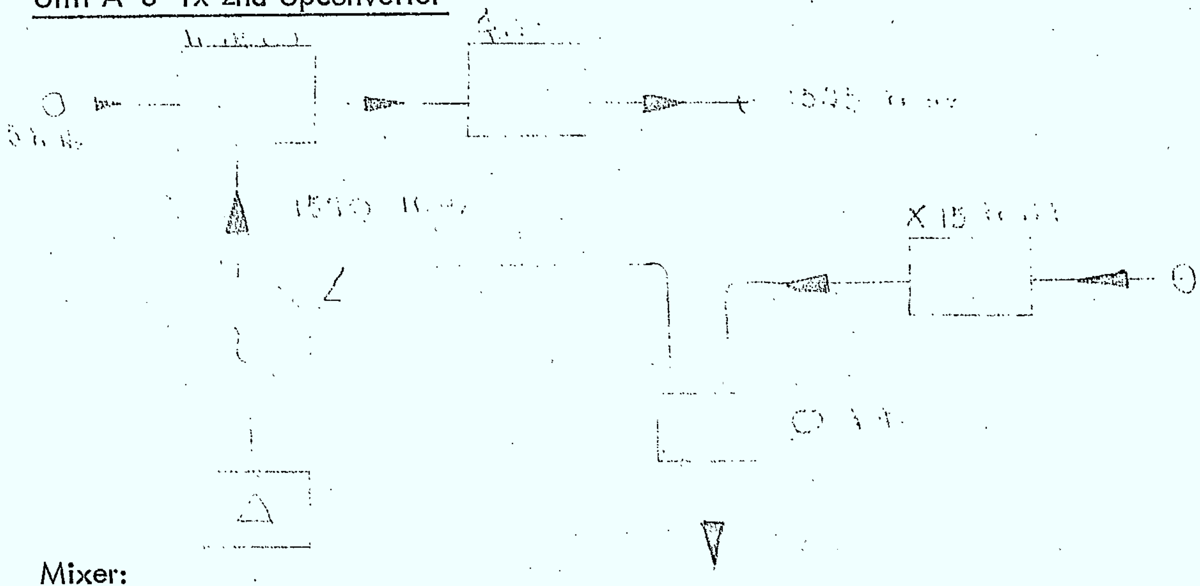
Unit A 7 PSK Modem

2 phase PSK Coherent Demodulator - Regenerator

10 MHz IF   Baseband data in serial stream.

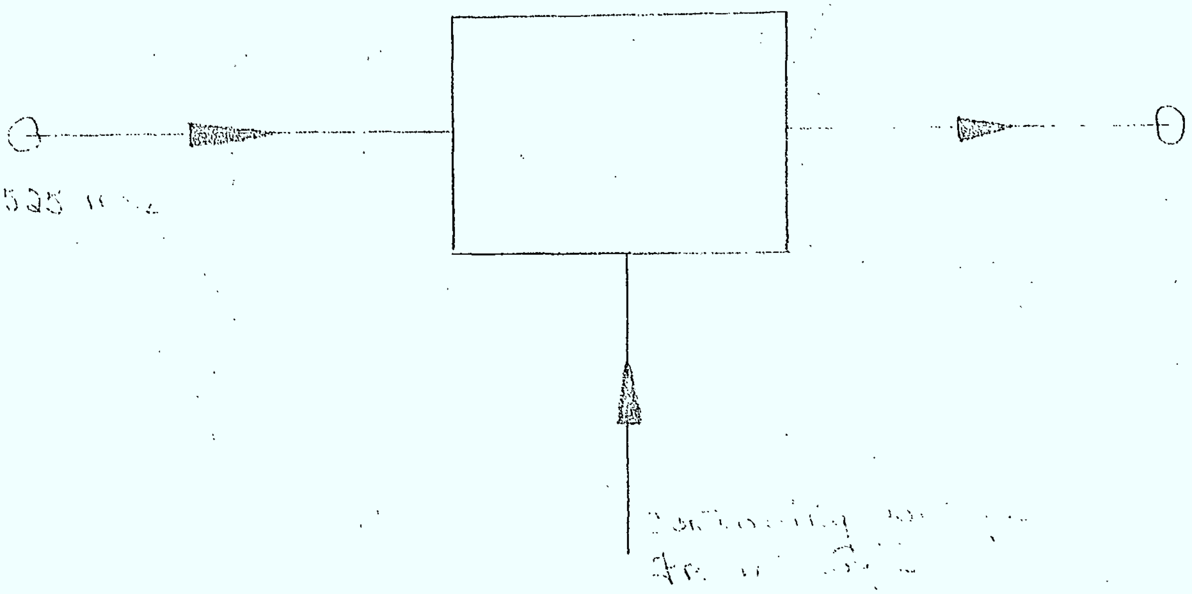
Estimated Manufacturing Cost:	$295.00

Unit A 8 Tx 2nd Upconverter



Mixer:	
Double or Single balanced	$25.00
Relcom, Anzac, Lorch, Aentech	
Filter:	5.00
Stripline	
Phase Locked Source:	
Package made by Fairchild, Engelmann.	
May be homemade - consists of a single transistor (BFY-90) oscillator in tuned cavity	35.00
DC Amplifier -- IC	15.00
Phase Detector -- Balanced Mixer	15.00
Multiplier	20.00
Case and Connection	15.00
Testing	20.00
Estimated Manufacturing Cost	$150.00

Unit A 10 Leveller



Norsal Industries: $125.00

Manufacturing Cost:

Diodes	5.00
Driver Circuit	15.00
Care and connectors	15.00
Testing	15.00
Estimated Manufacturing Cost:	$50.00

Unit A 11 Power Amplifier

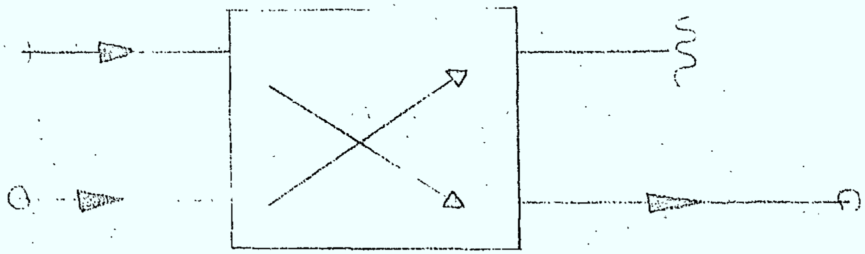
33dB gain, 10 watt o/p

1.5 GHz ± 10 MHz

-60° ± + 100°F

Budgetory quotes from suppliers(Avantek, Fairchild) $450.00

Unit A 12 Combiner



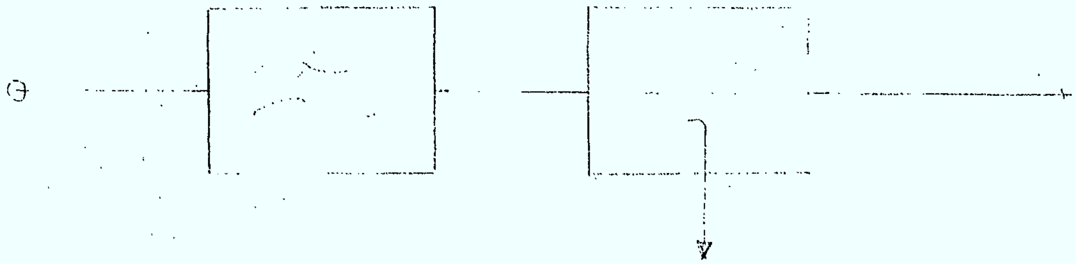
3dB Hybrid

Merriman Type

Catalog price for small quantity:	
in large quantity:	$10.00
case and connectors:	5.00

Estimated Manufacturing Cost:	$15.00

Unit A 13 Low Pan Filter



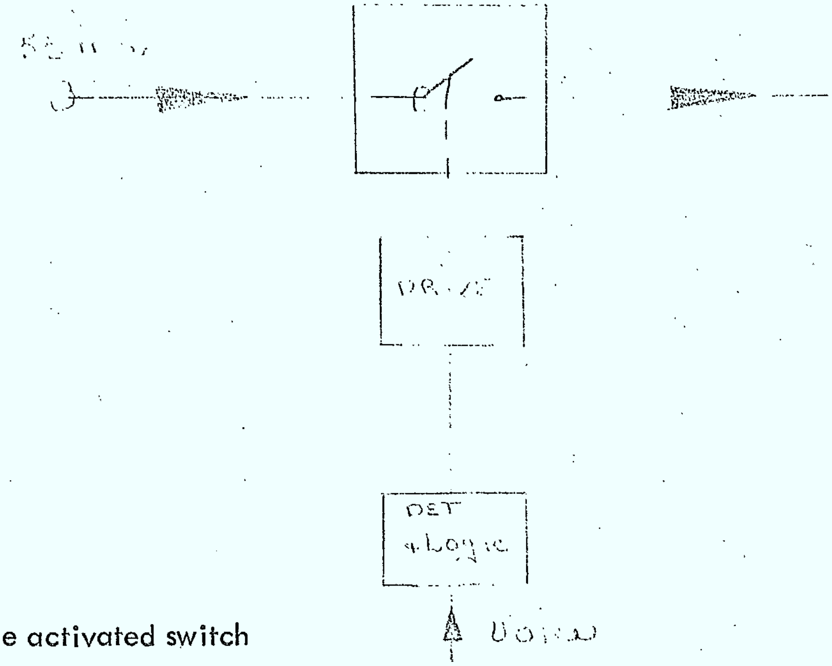
Filter: Stripline

Coupler: Stripline also may be combined in the same board.

Coupler purchased price:

Estimated Manufacturing Cost: $20.00

Unit A 15 Voice Detector

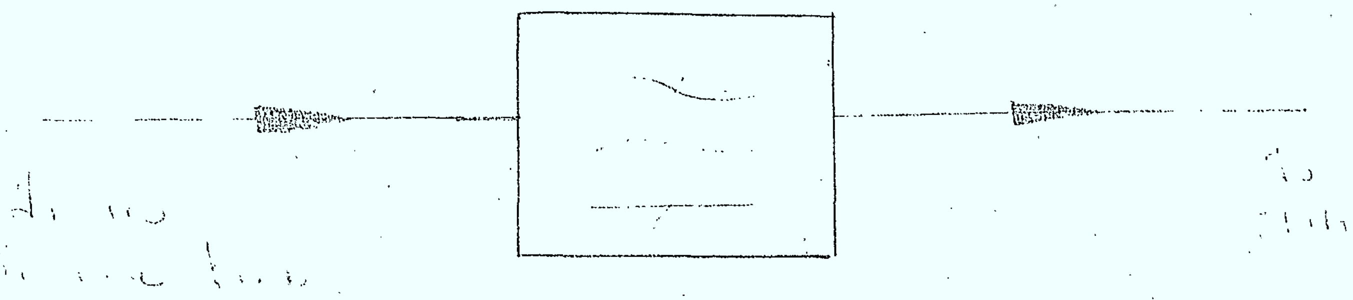


Voice activated switch

Logic includes tricks to differentiate voice from noise peaks.

Estimated Manufacturing Cost :		$20.00
Switch	$5.00	
Driver Circuit	$5.00	
Detector and Logic	$10.00	

Unit B 1 Input Filter



Filter:

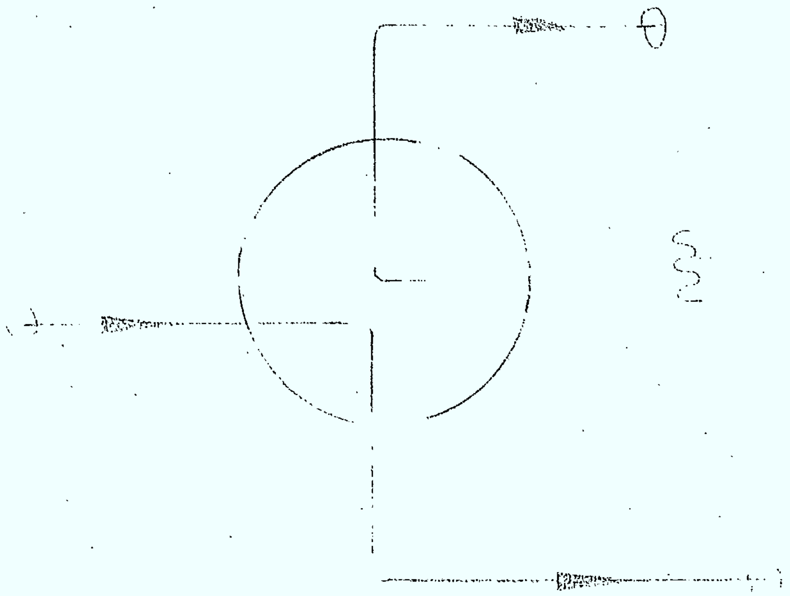
Function, to protect the LNA from the Power Amplifier output;

Also must be low loss

Cost as interdigital type.

Estimated Manufacturing Cost:	$20.00

Unit B 2 LNR Input Switch



Coaxial Transfer Switch

This is at low noise front and performance should be good.

Estimated Manufacturing Cost: $20.00

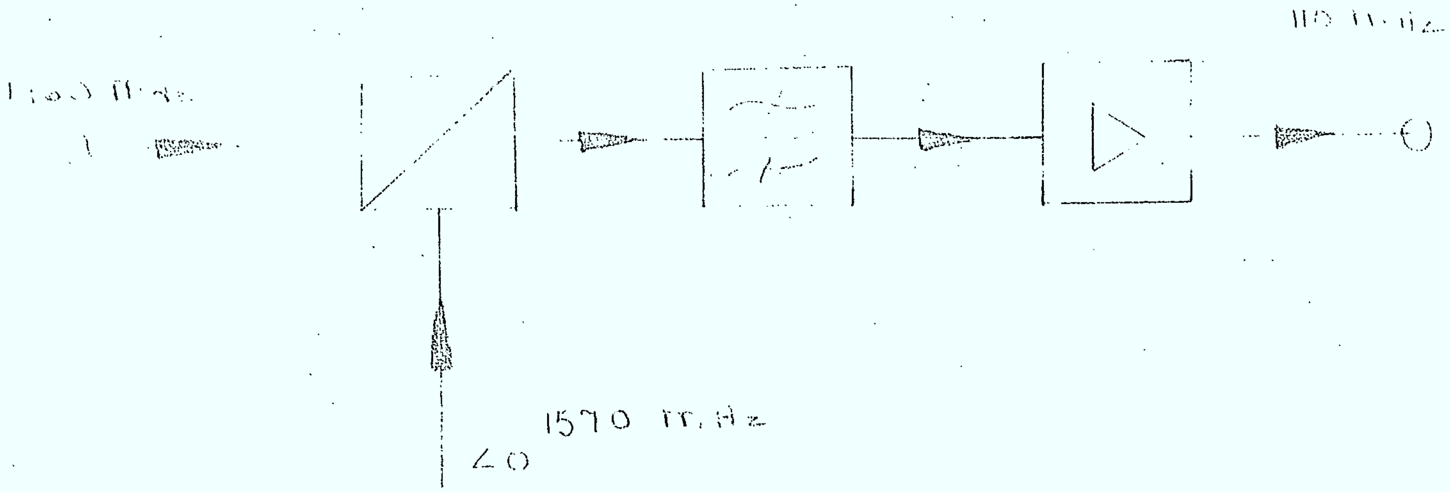
Unit B 3 Paramp

Noise temperature	75°K
Gail	20dB
Bandwidth	not limiting

Includes, Gunn Pump, Oscillator, Temperature Controlled Housing.

Assume RCA Princeton thin film design. $1900.00

Unit B 4 First Downconverter



Mixer:

Relcom, Lorch, Aentech, Etc.

Amplifier:

Avantek type 30dB

Filter:

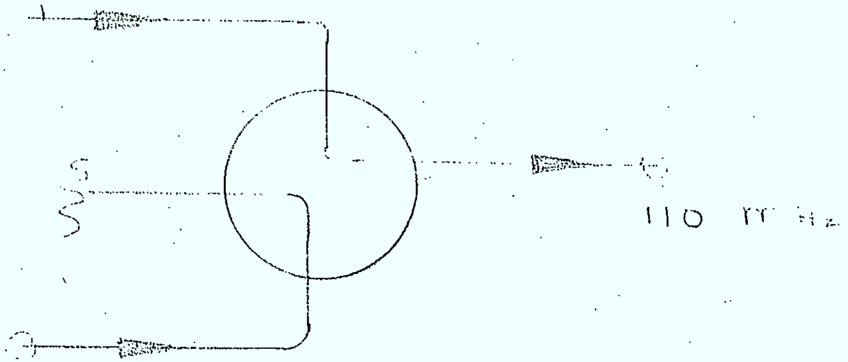
Conventional coil and capacitor type

The filter requirements may be covered by timed characteristics of the amplifier.

Costed as a single printed board:

Components costs:	
Diodes	7.50
Transistors	10.00
R, L, C,	7.50
Board and Connectors	10.00
Testing	15.00
Estimated Manufacturing Cost:	$50.00

Unit B 6 LNR Output - Switch

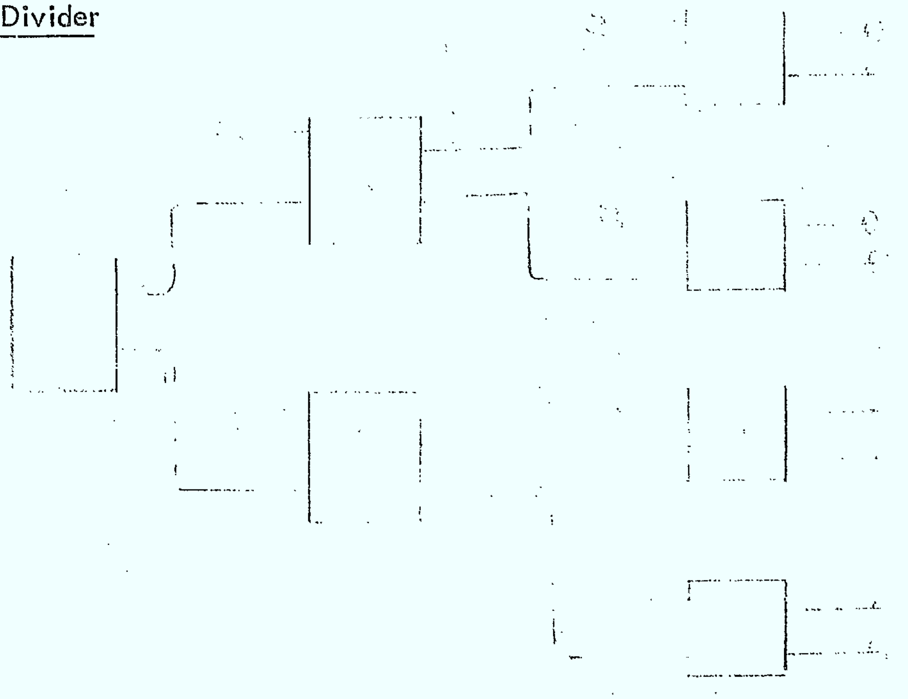


Coaxial Transfer Switch

Sage Teledyne

Cheap ones listed in Cesco catalog:	$10.00
Estimated Manufacturing Cost:	$20.00

Unit B 7 Divider



Quantity 7 3dB Hybrids

Merrimac Type

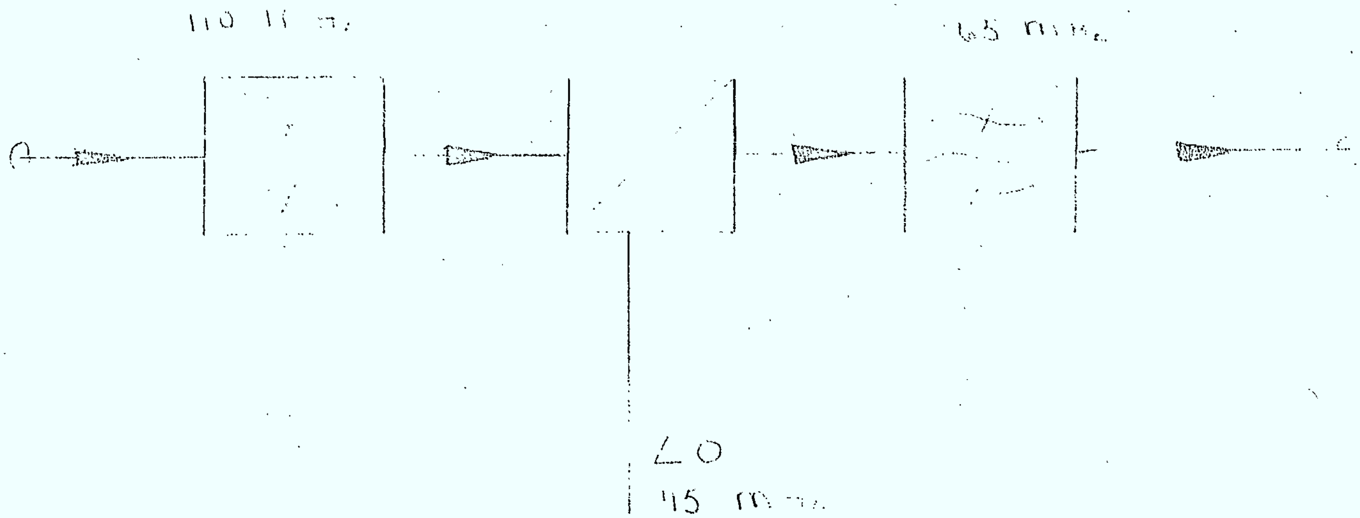
Catalog price for a small quantity:

Assume a large quantity:

Price:

Estimated Manufacturing Cost: $70.00

Unit B 8 Second Downconverter



Both filters convential or printed type. May be mounted on the same board together with the mixer.

Filter requirements:

1st filter: 30dB isolation at 155 MHz

2nd filter: 30dB isolation at 45 MHz

Mixer:
Relcom, Lorch, Aertech type

Costed as one printed board

Estimated Manufacturing Cost:	$35.00

Unit B 9 Auto Switch

Estimated Manufacturing Cost: $10.00

Unit B 10 Third Downconverter

Mixer:
Relcom, Lorch, Aentech type

Phase lock oscillator:
Fairchild Type

Filter:
Conventional type for suppression of local oscillator and input signal only. Main selectivity is given by the demod.

Costed as Unit A 8:	$150.00

Unit B 12 De-Emphasis

Cost as radio program de-emphasis network

Consists of about 10 R, L, and C components

Estimated Manufacturing Cost:	$5.00

Unit B 13 Expandor

Budgetory quotes from suppliers (Lenkurst, RCA Camden)	$300.00

Unit B 14 Baseband Switch

a couple of relays

Estimated Manufacturing Cost:	$ 10.00

Unit B 15 E.D. Waveform Generator

Function: Generator phase Locked to reference input

Output level is fixed

Estimated Manufacturing Cost: $100.00

UHF COMMUNICATIONS SATELLITE SYSTEM:
FINAL REPORT

RCA