MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

TO: Distribution 29 October 1970

FROM: R. L. Nickelson

SUBJECT: Indian Satellite (INSAT) Transponder Specifications

Please read the attached drafts with a critical eye and leave a copy of your comments with Darlene, C-324. I will return on 16 November--which will leave about a week to incorporate any revisions into the final study report prior to deadline. (We will present the study report in a briefing at NASA Headquarters during the first week in December.)

Keep a record of the time you spend and note the total with your comments--we have Ford Foundation money to reimburse the Laboratory for your efforts!

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R. L. Nickelson
29 October 1970

Communications Transponder Realization

The following specifications are presented as a guideline to assist in the development of final detailed transponder specifications. Because of the limited time available, it has not been possible to verify the accuracy and completeness of these specifications. In addition, sufficient analytical and experimental data are not available in all areas to completely specify some parameters. For instance, intermodulation limitations are not known for operating a video signal simultaneously with more than four audio subcarriers in the same channel. However, sufficient detail has been presented to enable initiation of transponder development. Those areas which were considered particularly difficult were examined in considerable detail. The resulting analyses, and in some cases, designs, are presented in subsequent sections.

The most important and most difficult-to-write portions of any useful specification document are the proof-of-performance items. For this specification, such items have been included initially only in some areas in which the specification itself was best expressed as a ~~total~~ test result. Most other proof-of-performance specifications and test procedures can be developed concurrently with the transponder development. All such requirements must be thoroughly defined and carefully stated prior to the initiation of prototype construction.

1.1 Transponder Performance Specifications

1.1.1 General

The transponder shall be of the form shown in the INSAT Transponder Diagram (Figure 1). Specific deviations from the block diagram will be allowed provided all performance requirements of this specification can be met when such deviations are included. Full justification, including experimental data, must be provided for all deviations.

1.1.2 Function

Functionally, the transponder consists of the following sections:

- Front end
- Command receiver
- Communications transponders
- TV transponders
- Frequency standard and local oscillators
- Beacon and telemetry transmitters (C-Band)

1.1.3 Front End

1.1.3.1 First mixer noise figure: The noise figure of the first mixer shall not exceed 8 dB. Design goal: 6 dB.

1.1.3.2 Losses: Total losses from all elements between the antenna and the first amplifier (exclusive of the mixer) shall not exceed 2 dB. Design goal: 1 dB.

1.1.3.3 Noise bandwidth: The noise bandwidth of the uplink shall be 500 MHz as determined by a band-pass filter. (See Filter 1, Table 1, "INSAT Filter Design Summary".)

1.1.3.4 Intermodulation distortion: This is not specified individually for all section of the transponder. Total allowable intermodulation distortion is stated in paragraph 1.1.4.1.4 for the command receivers.

1.1.3.5 Group delay: Total allowable group delay distortion is stated in paragraphs 1.1.5.7 and for the communication and TV links, respectively.

1.1.3.6 Amplification

1.1.3.6.1 Intermodulation and phase distortion: Front-end amplifiers shall introduce negligible amplitude and intermodulation distortion and group delay in each of the 40-MHz downlink channels.

1.1.3.6.2 Amplifier noise figure: The noise figure and gain of the first amplifier shall be adequate to assure that the receiver noise figure shall be degraded no more than 0.5 dB. Amplifier noise figure design goal: 7 dB.

1.1.3.6.3 Failure modes: The failure of a single component shall not render the amplifiers non-operational. At worst, single-component failures shall cause a degradation in amplifier noise figure and power gain not in excess of 6 dB in either case. If this requirement cannot be easily met, then provision for redundant amplifiers should be made.

1.1.4 Command Receiver (RF)

1.1.4.1 Main channel command receiver: The main channel command receiver shall be of the form shown in Figure 2, "INSAT Command Channels-Block Diagram." Deviation limitations as stated for the transponder in paragraph 1.1.1 also apply to the command receiver.

1.1.4.1.1 Co-existence with communications channels: The main command channel shall be derived by power-splitting and bandpass filtering at a convenient point in the front-end amplification chain.

1.1.4.1.2 Filters: All filter characteristics are shown in Table 1.

1.1.4.1.2.1 C-Band Filter: In order to minimize intermodulation products, a narrow-band C-Band filter is provided immediately ahead of the down-conversion mixer.

1.1.4.1.2.2 IF Filter: Immediately following down conversion to the 2.5-MHz IF frequency, the signal channel is passed through a crystal filter of sufficient bandwidth to pass the primary command channel FSK tones.

1.1.4.1.2.3 Signal filters: Following amplification and limiting, the primary command channel FSK tones are separated by means of narrow-band crystal filters.

1.1.4.1.3 Amplification

1.1.4.1.3.1 RF amplification: A minimum of 64 dB of RF amplification shall be provided between the antenna and the 2.5-MHz down-conversion mixer.

1.1.4.1.3.2 IF amplification: The 2.5-MHz IF amplifier will provide a limiting output which varies no more than ±0.5 dB for signal amplitudes at the IF amplifier input between -83 and -43 dBm (either tone). The magnitude of this limiting output will be determined by the envelope detector design.

1.1.4.1.4 Implementation degradation: Total performance degradation due to intermodulation products, spurious, IF amplifier self-noise, local oscillator phase noise, and other implementation effects is specified in terms of a standard CW test tone in the presence of broadband noise at the input to the diplexer.

1.1.4.1.4.1 Signal and noise test conditions:

Frequencies: 3707.5000 MHz and 3707.5010 MHz
Signal Level: -131 dBm (each signal) applied to diplexer input
Noise power density: -174 dBm/Hz (diplexer input)
Noise bandwidth (minimum): 5 MHz

1.1.4.1.4.2 Other test conditions: The transponder will be operated at full capacity and full power using simulated traffic signals on all four TV and eight telecommunications channels. Initial evaluation may use dummy loads for the TV and telecommunication power amplifiers, however, this test must be successfully completed with the power amplifiers driving all possible combinations of antennas. The test will be performed with both beacon/telemetry channels operational. The test will be repeated with the UHF-TV downlinks deactivated but all twelve C-band downlinks operating.

1.1.4.1.4.3 Test procedure: Measure signal-to-noise ratio at the envelope detector outputs using a true-RMS voltmeter. Optimum implementation for the receiver noise figure and losses specified would yield a signal-to-noise ratio of 3 dB for the specified signal and noise test conditions. The measured SNR shall be at least 1 dB. Design goal: 2 dB. Perform with both tones present.

1.1.4.2 Redundant command channel receiver: The redundant command channel receiver shall be of the form shown in Figures 1 and 2.

1.1.4.2.1 Relationship to primary command channel: The redundant command channel shall be completely independent of the primary command channel, as shown in the block diagrams. The redundant command channel will operate full-time using the earth-viewing horn.

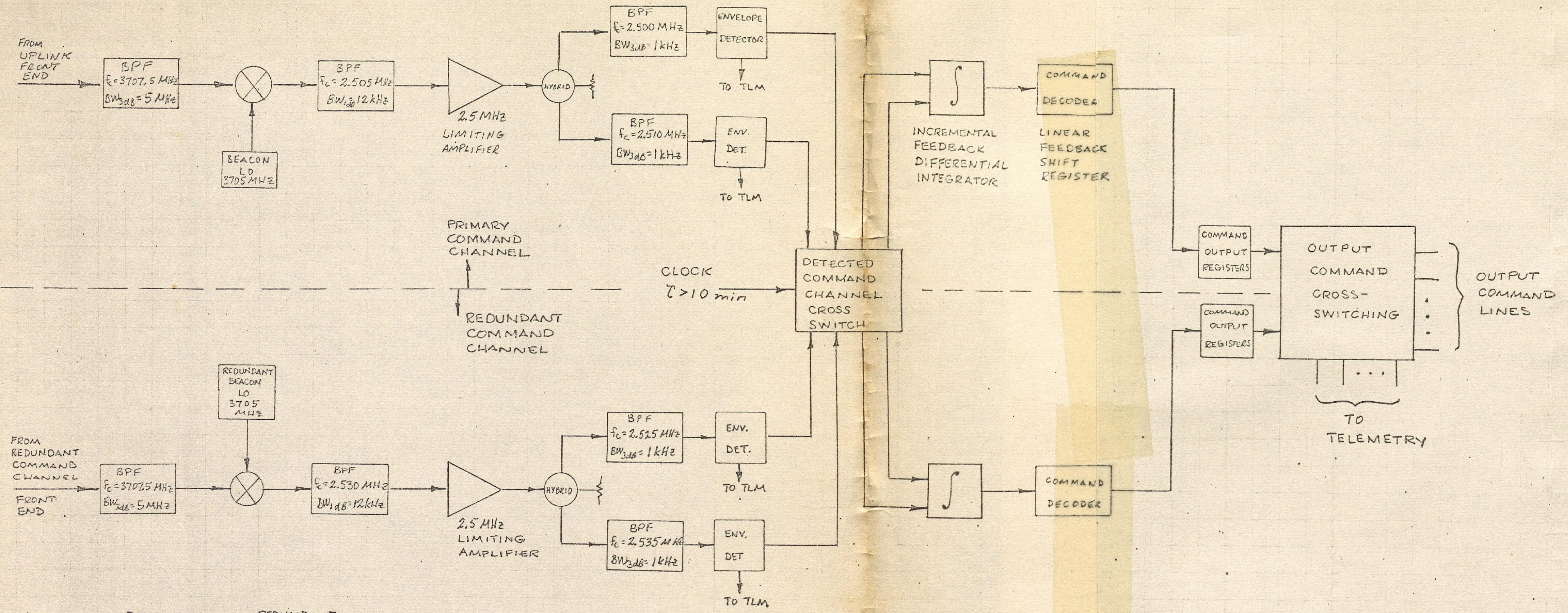
1.1.4.2.2 Filters: All filter characteristics are shown in Table 1.

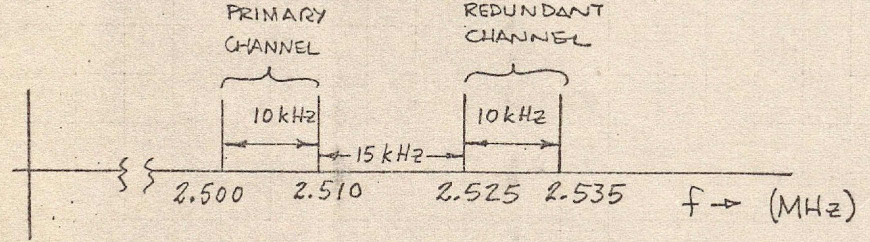
1.1.4.2.2.1 Input Filter: The front end noise bandwidth for the redundant command channel will be determined by a 5-MHz bandwidth filter ahead of the first mixer. This filter also provides additional protection to the mixer in case the telecommunications channels are operated downlink using the earth-viewing horn. (See Table 1.)

1.1.4.2.2.2 C-Band, IF, and Signal filters: These are identical to those used in the primary command channel.

1.1.4.2.3 Amplification

1.1.4.2.3.1 RF amplification: Same as main command channel.





RELATIONSHIP OF COMMAND CHANNEL FSK FREQUENCIES AT IF

Figure 2. INSAT COMMAND CHANNELS-BLOCK DIAGRAM

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1. 1. 4. 2. 3. 2 IF amplification: Same as paragraph 1. 1. 4. 1. 3. 2 except the signal level extremes are -77 and -40 dBm.

1. 1. 4. 2. 4 Implementation degration: Same as paragraphs 1. 1. 4. 1. 4, 1. 1. 4. 1. 4. 1, 1. 1. 4. 1. 4. 2, and 1. 1. 4. 1. 4. 3 except the signal level applied to the diplexer input shall be -128 dBm.

1. 1. 5 Communications Transponders

1. 1. 5. 1 General: The communications transponders will be implemented as twelve essentially-identical 36-MHz channels. The center frequency and TWT power output for each channel is shown in Table 2.

Table 2. Communications Transponders

Designation	Center Frequency (MHz)	P_{out}	Comments
Beacon/Telmetry	3705	100 mW	(Included on CD1)
CD1	3730	12 W	
CD2	3770	12 W	
CD3	3810	12 W	
CD4	3850	12 W	Telecommunications
CD5	3890	12 W	Downlinks
CD6	3930	12 W	
MAD1	3970	20 W	Multiple-access
MAD2	4010	20 W	Downlinks
CTVD1	4050	12 W	
CTVD2	4090	12 W	TV-distribution
CTVD3	4130	12 W	Downlinks
CTVD4	4170	12 W	

The twelve channels share a common uplink and front-end linear amplifiers. It is necessary to split the channels into groups of two, three, four, or six ahead of the driver amplifier because of power limitations in available drivers. The exact configuration will depend upon the driver chosen. Four groups of three are shown for the recommended solid-state drivers. Separation on a channel-by-channel basis will be done at the outputs of the drivers. For multiple-carrier operation, it is necessary to back off on TWT drive in order to avoid excessive intermodulation. A command-controlled step attenuator will be provided immediately ahead of each TWT power amplifier for this purpose.

Channelization is accomplished with steep-skirt directional filter demultiplexers immediately ahead of each TWT power amplifier. The characteristics of these input demultiplexers are shown in Table 1. The 40-MHz noise bandwidth for each channel is determined by these filters. In order to prevent significant amplification of the signal from an adjacent channel, the specified skirt slope must be attained. Such amplification would result in severe multipath effects on the signal involved when the direct channel and adjacent channel outputs were recombined in the output multiplexer. In-band ripple and phase delay specifications have significant impact upon group delay, crosstalk, and other intermodulation effects.

Output power combining (multiplexing) is required to recombine the channels with minimum loss and signal degradation. Since channelization has been accomplished in the input demultiplexers, the only adjacent-channel requirements on the output multiplexers are:

1. No significant power from one TWT output should be fed back into any other, and

2. No significant power from any channel should be lost in isolators or other protective devices.

In order to meet these requirements, some channel filtering will be required in each output.

1.1.5.2 Linear amplification: Each communications transponder will be designed for linear amplification up to the TWT power amplifier input for a nominal isotropic received signal power of -133 dBW/channel. Sufficient gain will be provided to deliver -58 dBW/channel to the driver amplifiers for the nominal signal input. All linear amplifiers will have bandwidths adequate to handle the number of channels involved without introducing significant delay or amplitude distortion in any individual channel.

1.1.5.3 Driver amplifiers

1.1.5.3.1 Gain: Sufficient linear gain and output power will be provided to overdrive the TWT by at least 3 dB and not more than 7 dB for a nominal isotropic received signal of -133 dBW/channel.

1.1.5.3.2 Intermodulation distortion: The 3^d-order intermodulation intercept will be at -16 dBW/channel, minimum.

1. 1. 5. 3. 3 Failure modes: The failure of a single component shall not render the driver amplifiers non-operational. At worst, single-component failures shall cause a degradation in power gain not in excess of 6 dB. If this requirement cannot be easily met, then provision for redundant amplifiers should be made.

1. 1. 5. 4 Command controlled attenuators: Each communication channel will have in series between the driver and TWT a command-controlled step attenuator which may be commanded in 3. 5 db steps from zero to 24. 5 dB. This allows for TWT back-off for more linear operation and improved intermodulation performance in the presence of multi-carrier signals.[1,2]

1. 1. 5. 5 Filters: Multiplexer filter specifications for the recommended configuration are shown in Table 1.

1. 1. 5. 6 Gain slope: Gain slope is determined by the amplitude/frequency characteristics of the multiplexers in the chain. Total gain slope per channel shall not exceed the values of Table 3.

Table 3. Maximum Allowable Gain Slope

% Channel Bandwidth	Maximum Gain Slope
< 70	< 0. 025 dB/MHz
70	0. 025
80	0. 05
90	0. 10
100	0. 20

1. 1. 5. 7 Group delay: Group delay is determined primarily by the phase non-linearities of the multiplexers in the chain. Total relative group delay for each channel shall not exceed 0. 20 n sec/MHz for linear group delay

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[1] J. Benton, et al, "Latest Advances in Space TWT's," Hughes Aircraft Company, paper presented at AIAA 3d Communications Satellite System Conference, April, 1970.

[2] A. L. Berman and C. E. Mahle, "Nonlinear Phase Shift in Traveling-Wave Tubes as Applied to Multiple Access Communications Satellites," IEEE Trans. on Communications Technology.

variations and 0.04 n sec/MHz^2 for parabolic group delay variations[3,4,5], or the envelope of Figure 3, whichever is greater.

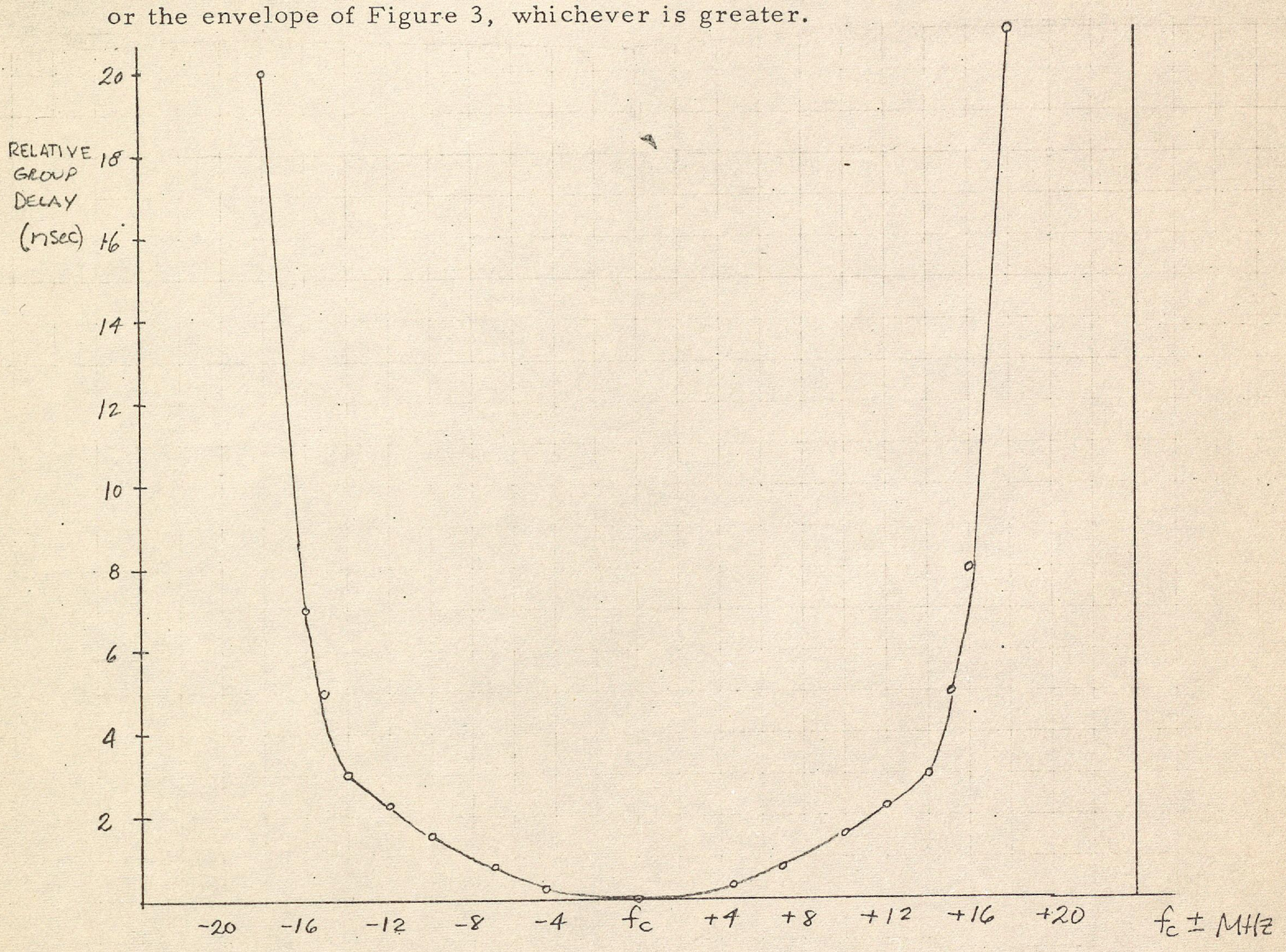

Figure 3. Relative Group Delay

1. 1. 5. 8 Group delay ripple: Total group delay ripple measured from receiver input to TWT output within the central 36-MHz portion of any channel shall not exceed 1. 5 ns peak-to-peak.

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[3] Simon B. Bennett, "Design of Commercial Satellite Communications Systems," Communications Satellite Corporation, 1970.

[4] Lucio S. Cossetto and Ronald F. Cuthbert, "Video to Audio Intermodulation Distortion in Broadband Systems," Cooby Creek Applications Technology Satellite Station, Quensland, Australia, October 1969.

[5] J. Jansen, et al, "Television Broadcast Satellite Study," NASA CR-72510, October 1969.

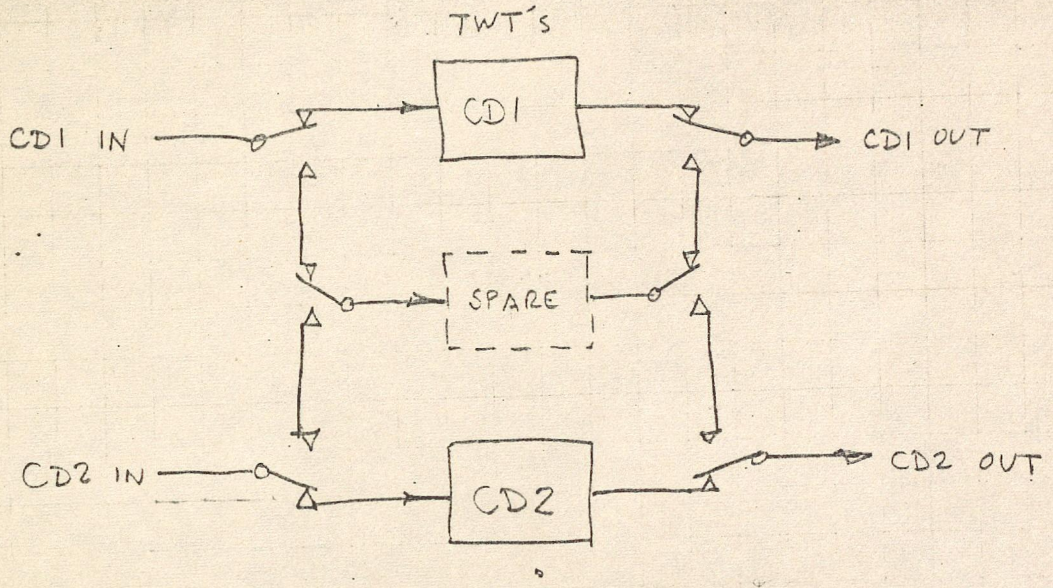
1. 1. 5. 8 Power Amplifiers

1. 1. 5. 8. 1 Gain and power output: Sufficient gain shall be provided to operate the power amplifiers at the power levels specified in Table 2.

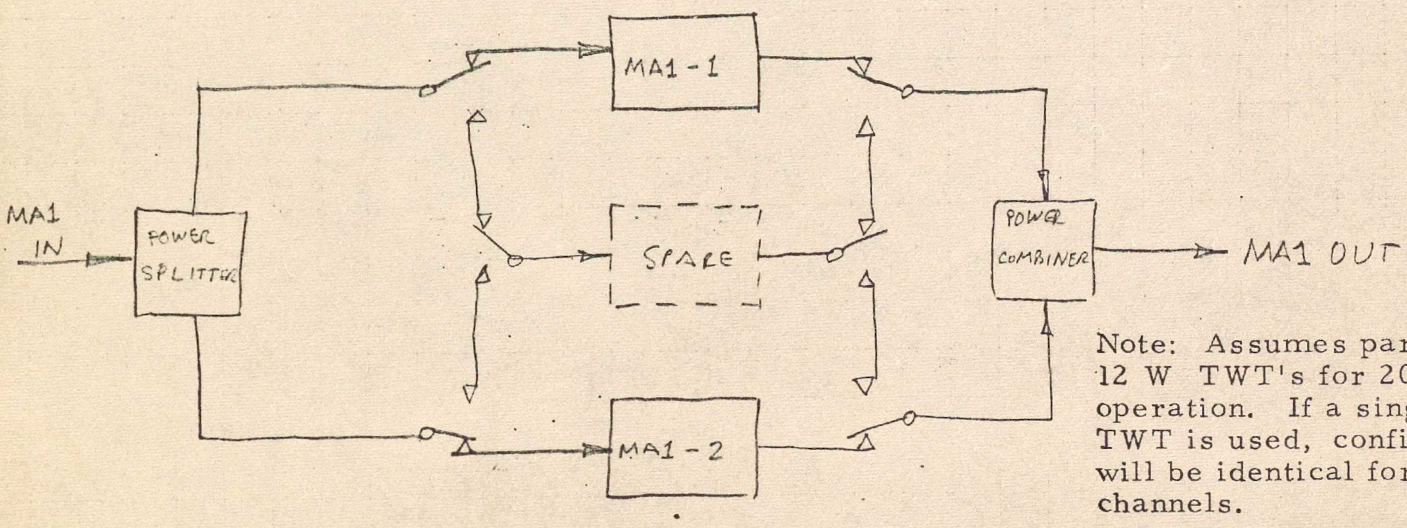
1. 1. 5. 8. 2 AM-PM conversion: AM-PM conversion occurs primarily in the power amplifier TWT's. The AM-PM transfer coefficient measured at the downlink power combiner output with two carriers applied at the receiver input shall not exceed 8^{o}/dB. Total phase shift will be determined by measuring the maximum shift of carrier phase when a single unmodulated carrier is varied from the specified drive level to zero and will not exceed 55^{o}. Both measurements will be made with total input signal levels sufficient to operate the TWT at the single carrier saturation point, with two carriers having an amplitude-modulation difference up to 20 dB. The larger carrier shall be amplitude-modulated 1 dB. This requirement shall be met for the following conditions:

1. For any separation between in-band carriers greater than 300 kHz.
2. At any frequency within a given channel.
3. For any modulating frequency up to 10 MHz, but not in excess of one-third of the frequency separation between the carriers used for the measurement.

1. 1. 5. 8. 3 Redundancy: Stand-by back-up spares will be provided for each TWT as shown in Figure 4.



IDENTICAL FOR CD3 & CD4, CD5 & CD6
CTVD1 & CTVD2, and CTVD3 & CTVD4



Note: Assumes parallel 12 W TWT's for 20 W operation. If a single 20 W TWT is used, configuration will be identical for all channels.

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Figure 4. TWT Redundancy Configuration

Power and RF interconnections for any spare will be activated by ground command.

1.1.5.8.4 TWT power supplies: Specifications for the TWT power supplies are presented elsewhere. Each TWT will be individually provided with command-initiated d-c power shut-off capability.

1.1.5.9 Spurious outputs: The total power in the frequency range 3700-4200 MHz resulting from the sum of all spurious signals (measured at the output of the downlink power combiner) shall not exceed:

1. -60 dBW in any 4 kHz band
2. -55 dBW in any 1 MHz band

} Exclusive of the 4 kHz band centered on the carriers

This requirement shall be met with the transponders operating in the configuration specified in paragraph 1.1.4.1.4.2 with a CW carrier at the center frequency of each transponder. These CW carriers shall be -100 dBW each and shall be inserted at the input to the diplexer.

1.1.5.10 Antenna switch: An RF switch shall be provided as shown in Figure 1 to transfer the combined 4-GHz output signals from the India-coverage spotbeam antenna to the earth-coverage horn on command. At least 30 dB isolation shall be provided between the active and inactive output ports of the switch.

1. 1. 6 TV and All-India Radio (AIR) Transponders

1. 1. 6. 1 General: The TV transponders will be implemented as four essentially-identical 36-MHz channels. In addition, a separate 2-MHz transponder will be provided for the All-India Radio network. The center frequency bandwidth, and final amplifier power output of each channel are shown in Table 4.

Table 4. TV and AIR Transponders

Designation	Center Frequency	Bandwidth	P_{out}
TVD1	810 MHz	36 MHz	150 W
TVD2	850	.	.
TVD3	890	.	.
TVD4	930	36	150
AIR	952. 5	2	2

The TV and AIR channels share the uplink and front end with the communications channels. Following front-end amplification at 4 GHz, the TV and AIR channels are down-converted to the 750-955 MHz band for additional amplification, channelization, power amplification, and recombination. Unlike the communications channels, the TV and AIR channels are operated as hard-limiting repeaters. Linear amplification is maintained to the point at which the individual channels are demultiplexed. Hard limiting is done in the first stages of the power amplifier block which follows channelization. These stages will be designed such that nearly-maximum output power will be maintained on front-end noise alone. The comments of paragraph 1. 1. 5. 1 on the importance of steep skirts on the demultiplexer filters and inband ripple specifications apply.

1. 1. 6. 2 Linear amplification: The TV and AIR channels will be designed for linear amplification up to the output of the channelization filters for isotropic received signal powers between -113 and -133 dBW/channel. All linear amplifiers will have adequate bandwidth to handle the number of channels involved without introducing significant delay or amplitude distortion in any individual channel. A minimum of 44 dB of linear gain will be provided immediately following the TV mixer.

1.1.6.3 Power amplifier block: Each power amplifier block will contain the following functional sections:

1. Hard-limiting preamplifier,
2. Driver amplifiers,
3. Power amplifiers,
4. Any single-channel power-combining circuitry required.

1.1.6.3.1 Gain: The saturated gain of the power amplifier chain will be 40 dB, minimum.

1.1.6.3.2 Power output and efficiency: Each power amplifier will deliver a minimum of 150 watts of RF power to the isolator at the input to the downlink power combiner for an isotropic received signal power of -133 dBW/channel. Net conversion efficiency (unregulated d-c to RF output) will be 58% minimum. Design goals: 200 W at 68%.

1.1.6.3.3 Failure mode: Failure of a single active device in the power amplifier chain shall not decrease output power by more than 25%.

1.1.6.4 Filters and multiplexers: See Table 1.

1.1.6.5 Signal degradation: There are several primary contributors to signal degradation in any communications repeater. These are summarized in Table 5.

For multicarrier operations with a transponder, all of these effects can contribute significant degradations to signal performance. The TV and AIR transponders are intended to be operated as single-carrier FM repeaters, however. For this case, the primary degradation is due to group delay distortion.[1] Hence, the transponder realization must concentrate on minimizing this parameter.

1.1.6.5.1 Group delay and group delay ripple: The specification of paragraph 1.1.5.7 applies.

1.1.6.6 Power: D-c power to each power amplifier block will be removable on command from the ground.

1.1.6.7 Spurious outputs: The total power resulting from the sum of all spurious signals (measured at the output of the downlink power combiner)

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[1] L. S. Cossetto and Ronald F. Cuthbert, "Video to Audio Intermodulation Distortion in Broadband Systems," Cooby Creek Applied Technology Satellite Station, Australia, October 1969

Table 5. Contributors to Signal Degradation (1)

Identification	Description	Effects on Signal	Sources
1. Group Delay	Derivative of phase non-linearity vs. frequency	a. Intermodulation distortion b. Intelligible crosstalk (when followed by AM/PM conversion--see below)	a. Bandwidth-limited circuits (i. e. , filters) b. Mismatches (cause group delay ripple)
2. Gain Slope	Derivative of amplitude vs. frequency response	a. Intermodulation distortion b. Converts FM to AM at the information rate (i. e. , coherently)	a. Filter band-endge slope b. Adjacent or co-channel interferenc (multipath). c. Mismatches, etc.
3. AM/PM Conversion	Related to slope of the differential phase shift curve.	a. Intermodulation distortion b. Intelligible crosstalk (when preceded by gain slope--see above)	Non-linear power amplifiers

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(1) Simon B. Bennett, "Design of Commercial Communications Satellite Systems," COMSAT Corporation, September 1970.

shall not exceed the values shown in Table 6, exclusive of the 1 kHz band centered on each carrier.

Table 6. Spurious Output

Frequency Range	Bandwidth	Maximum Total Spurious Power in Bandwidth
790-955 MHz	1 kHz	- 60 dBW
790-955 MHz	1 MHz	- 55 dBW
5900-6500 MHz	10 MHz	-150 dBW
5900-6500 MHz	40 MHz	-135 dBW

This requirement shall be met with the transponders operating in the configuration specified in paragraph 1. 1. 4. 1. 4. 2 with a CW carrier at the center frequency of each transponder. These CW carriers shall be -100 dBW each and shall be inserted at the input to the diplexer.

1. 1. 7 Frequency Standard and Local Oscillators

1. 1. 7. 1 Design Philosophy: All local oscillator frequencies (except for the VHF telemetry and command system, which is self-contained) will be derived from the satellite''s primary reference oscillator using X2 and X3 active multipliers, notch filters, and a minimum of mixing operations. Discrete spurious tones will be at least 60 dB below the desired outputs.

1. 1. 7. 2 Frequency Standard: The primary reference oscillator will be a 5-MHz crystal in an oven. Long-term frequency stability will be better than 4 parts in 10^8 per year. In event of an oven failure, long term stability will degrade no more than two orders of magnitude. Table 7 shows the maximum offsets to be expected as a result of primary standard long-term instability. (Assumes transponder and L. O. chains implemented as shown in the appropriate block digrams.)

TABLE 7. MAXIMUM FREQUENCY OFFSETS DUE TO PRIMARY STANDARD LONG-TERM DRIFT

	4 Parts in 10^8 1 YR	4 in 10^8 5 YRS	4 in 10^6 1 YR (oven failure)
6 and 4 GHz (includes command channels)	90 Hz	450 Hz	9 kHz
3. 7 GHz Beacon	150 Hz	750 Hz	15 kHz
900 MHz TV	40 Hz	200 Hz	4 kHz

1.1.7.3 Local oscillators: There are four local-oscillator frequencies required in the INSAT transponder (exclusive of VHF T & C) as shown in Figure 5. Special care must be taken in construction of the frequency standard and L. O. chains to assure that no spurious signals from the intermediate multiplying and mixing operations are allowed to leak out of the modules in which the L. O.'s are derived.

1.1.7.4 Redundancy: 100% redundancy will be provided in the frequency standard and local-oscillator circuits. Either frequency standard can be switched on command to drive either or both of the L. O. chains. Each of the L. O. outputs can be switched on command to drive either or both of the relevant mixers. (The 3240-MHz TV L. O. drives only one mixer.) See Figure 6.

1.1.7.5 Telemetry points: The offsets shown in Table 7 will have no detrimental effects on any ground operations, with the possible exception of the C-band command channels. A slight adjustment in uplink ground frequency may be used to compensate for any such drift. The amount of net oscillator drift at any time may be determined by tuning an accurately-calibrated CW ground transmitter operating near one of the command-channel center frequencies until satellite telemetry indicates maximum power from the envelope detector associated with that channel. Telemetry points will be provided in the command channels IF's for this purpose.

1.1.8 C-Band beacon and telemetry transmitters

1.1.8.1 General: Binary telemetry data will be used to directly biphase modulate the beacon at 3705 MHz by applying the bit stream to one input port of a balanced mixer and injecting the beacon signal at the other. The resultant signal will be injected at the edge of the lowest-frequency downlink communications power amplifier at a level appropriate to produce a minimum of 10 mW and a maximum of 20 mW at the output of the TWT when shared with a communications signal of sufficient drive power to saturate the TWT.

1.1.8.2 Redundant Beacon/Telemetry Channel: An identical, independent beacon L.O. and modulator will drive a low-power TWT to provide backup in event of a failure in the main beacon/telemetry channel. The backup channel TWT will supply a minimum of 100 mW of output power with a minimum saturated gain of 50 dB at the beacon frequency. The TWT itself will be provided an identical spare, which may be switched (RF and d-c power) on command from the ground.. The output of the backup-channel TWT will be power-divided in the proper ratios to produce equal EIRP signals at the outputs of the main channel 3.5' antenna and the rear-mounted earth-coverage horn.

Transponder Implementation Details

Several areas of the transponder were identified as being particularly difficult to implement and were subsequently examined in some detail in order to identify reasonable implementation techniques. These areas are:

1. C-band front-end and amplification
2. Channelization techniques
3. Output power combiners
4. VHF power amplifiers.

A detailed discussion of each of these follows. Not completeD

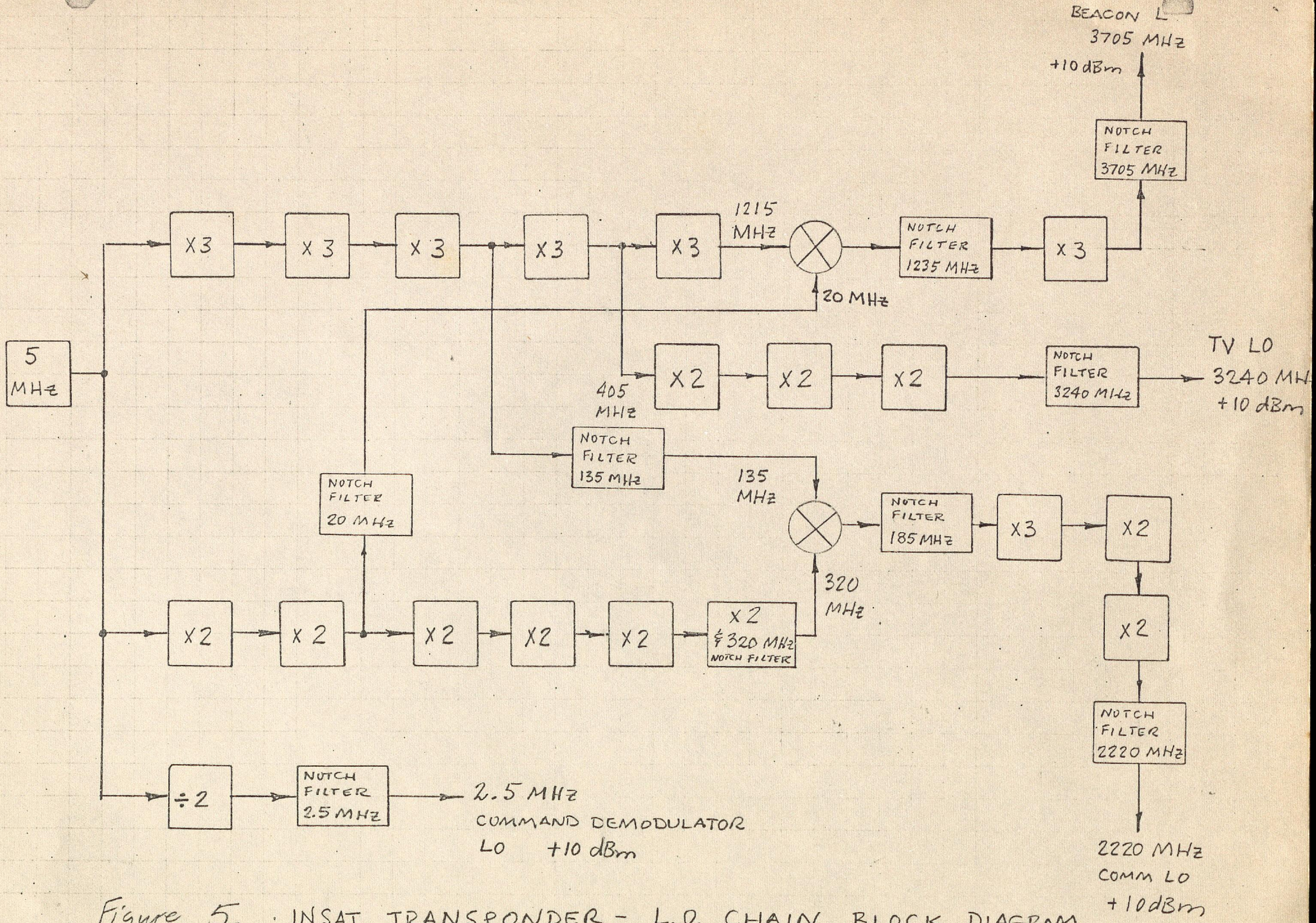

Figure 5. INSAT TRANSPONDER - L.O. CHAIN, BLOCK DIAGRAM

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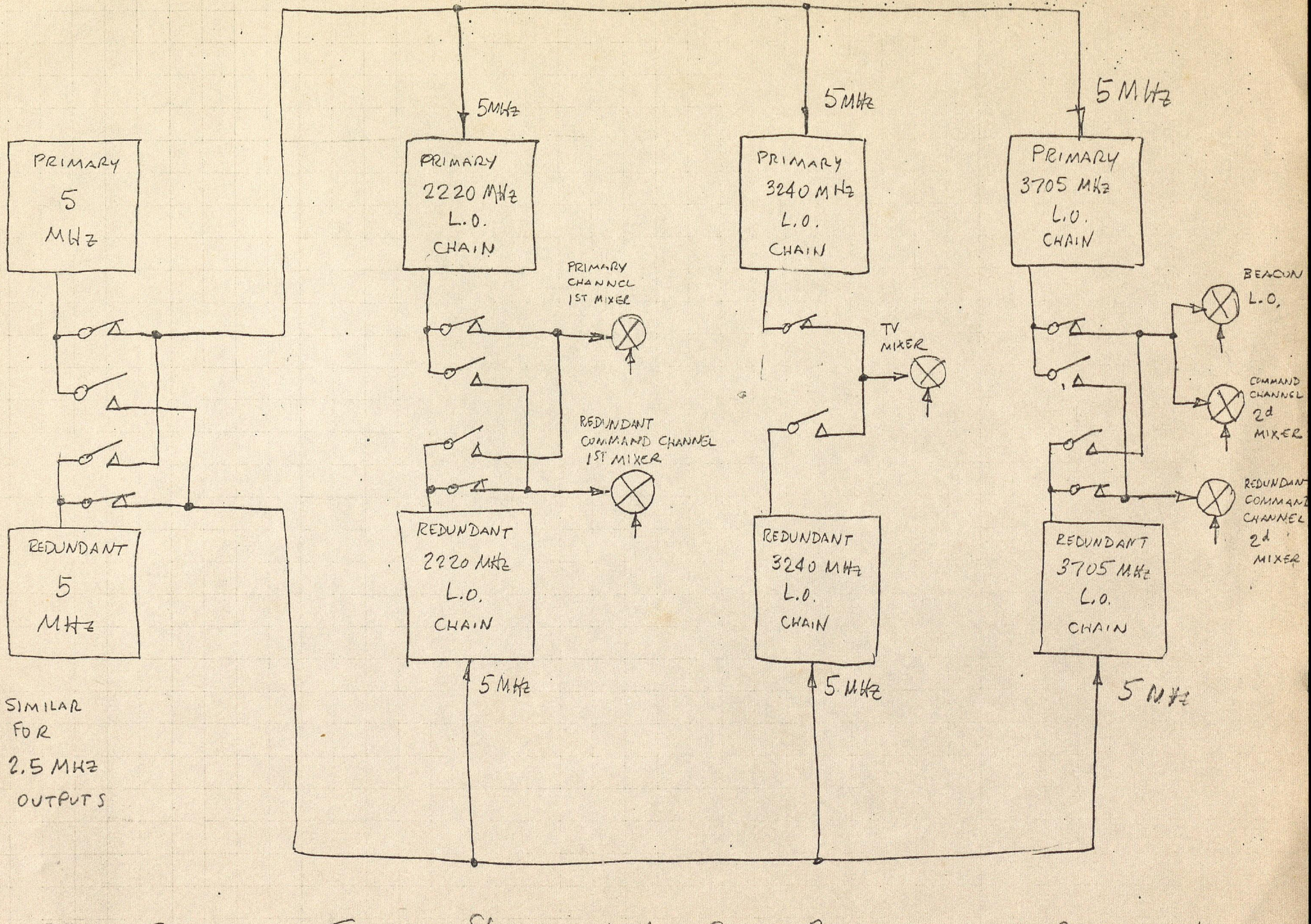

SIMILAR FOR 2.5 MHz OUTPUTS

Figure 6. Frequency Standard & L.O. Chain Redundancy by Cross-switching

Rev 19 OCT 70

Journal Of The British Interplanetary Society Vol. 23, pp. 125-136, 1970.

Rajan

The Advantages of Demand Assignment for International Satellite Communication Systems

W. L. PRITCHARD and J. G. PUENTE
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Demand assignment multiple access (DAMA) systems in satellite communications have strong technical and economic advantages over preassigned or time-assigned circuits. An earth station with a DAMA terminal can access any similarly equipped station in the system through a common frequency band without leasing a preassigned circuit. DAMA thus provides more efficient use of the available RF spectrum and increases the effective capacity of communications satellites.

1. INTRODUCTION

COMMERCIAL COMMUNICATIONS VIA satellite is in its fourth year of operation. In 1965 there were four earth stations in existence; today, there are twenty-two earth stations (Fig. 1) operating, with twenty more under construction and approximately a like number in planning. The INTELSAT III satellites* (1200-circuit satellites) will provide global coverage during 1969 when satellites are placed over the Pacific, Atlantic and Indian Oceans. Thus, in the short period of four years satellites will be able to provide direct point-to-point communications anywhere on the globe except for the northern and southern polar regions. Voice, data, television and facsimile can be transmitted in a matter of milliseconds between remote points on earth economically, provided that satellite channels are effectively used and techniques of access into satellites by earth terminals are efficient and practical.

This brings us to the subject of this paper, which is to discuss methods of accessing a satellite and assigning satellite channels between earth terminals. In particular we wish to discuss the techniques of demand assignment along with its technical and economic advantages.

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* INTELSAT is an acronym for the International Telecommunication Satellite Consortium.

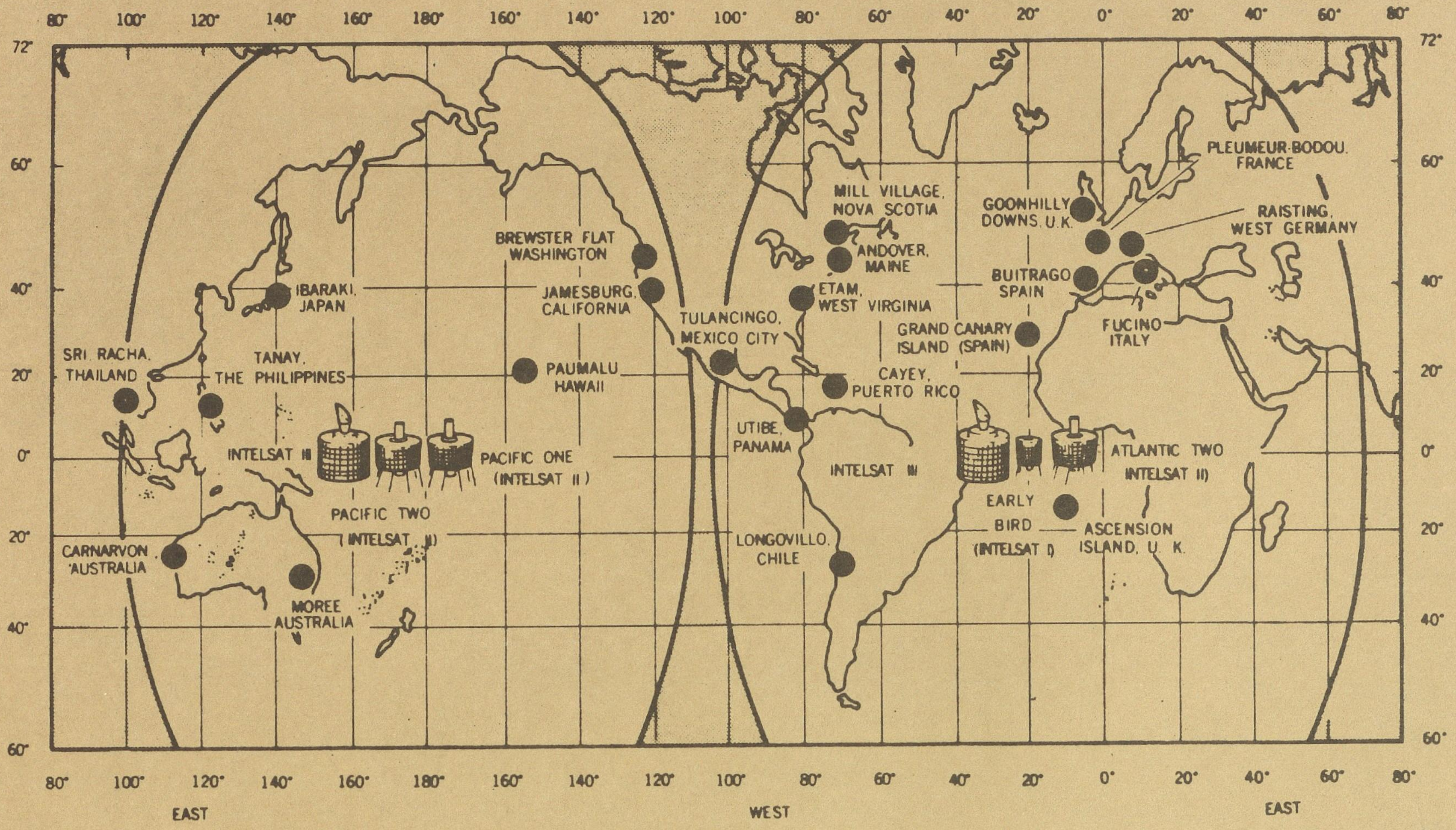

Figure 1. Twenty-two earth stations in operation.

2. MULTIPLE ACCESS

The term multiple access refers to the ability of three or more earth stations to conduct two-way communication with each other through the same satellite. The INTELSAT system in operation today employs Frequency Division Multiple Access, FDMA [1]. Each carrier entering the satellite is FM modulated and assigned a specified frequency. In order to reduce the complexity of frequency planning, i.e., assigning the frequencies of carriers accessing the satellite, the number of different carriers in capacity, power and bandwidth, respectively, is limited by INTELSAT to a few standards. To illustrate, assume an INTELSAT IV transponder with an RF bandwidth of 40 MHz.* Then using the standards of INTELSAT III (columns I and II of Table 1), the maximum number of accesses and maximum transponder capacity can be obtained.

TABLE 1. FDMA/FM transmission characteristics.

RF bandwidth (MHz)	Capacity per carrier (channels)	Number of accesses per transponder	Total capacity per transponder (channels)
2.5	24	16	384
5	60	8	480
10	132	4	528
36	900	1	900

In practice, combinations of 24, 60, and 132 channel carriers will pass through a single transponder. If a single carrier per transponder is used, upwards of 900 channels can be obtained. Table 1 shows the severe multiple access penalty resulting from the use of FDMA/FM, e.g., when 24-channel carriers are used, only 384 channels can be obtained per transponder.

In addition to the multiple access penalty, i.e., loss of total transponder capacity as the number of accesses increases, a rigid frequency plan must be

TABLE 2. FDMA/FM frequency planning.

Transmitting earth station	Assigned carrier frequency	Assigned capacity channels	Stations receiving carrier
A	F_1	132	STA B–60 channels STA C–60 channels
B	F_2	60	STA A–60 channels
	F_3	24	STA C–24 channels
C	F_4	60	STA A–60 channels
	F_5	24	STA B–24 channels

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* Actually INTELSAT IV is planned to have a 36 MHz bandwidth at the 1 dB points.

formulated by agreement among all users. It is rigid in the sense that once it is agreed upon any change effects every user of a particular transponder. For example, assume that three earth stations using a satellite transponder agree on the preassigned traffic distribution shown on Table 2. In this example five carriers are transmitted. The frequencies assigned to these carriers must be such that the intermodulation products of the larger carrier (132 channels) do not fall on the small carriers. The frequency plan must be carefully chosen since the five carriers occupy 25 MHz of the available 40 MHz with a total capacity of 300 channels. Station A will receive two 60-channel carriers and will purchase the necessary demodulation and demultiplexing equipment. Stations B and C will receive a 132 and 24-channel carrier, and will purchase corresponding equipment. With the frequency plan agreed to, equipment is purchased and operation begins. If, after a few months of operation, traffic between stations B and C increases and many calls are 'lost' because the 24-channel carrier is always 'busy', how does the system accommodate? First B and C would probably want a 60-channel carrier. If the traffic has only increased to 35 or 40 channels, then 20 to 25 channels are idle all the time. New modems and multiplexing equipment would be needed. The frequency plans would require change and would be agreed to only after negotiation with all parties and the usual expense and delay. A simple case of three earth stations has been chosen; one can imagine the difficulty of a change if 10 or 12 stations were considered instead. The point to note is that in the present mode of operation the satellite network is inflexible and therefore possibly inefficient in the allocation of satellite channels. Idle capacity assigned between points A and B above cannot be used between B and C causing a loss of traffic between B and C during busy hours.

Therefore, satellite multiple access systems should be designed to be flexible in the assignment of traffic between any two points. It should have a low multiple access penalty. It should be designed to match satellite capacity to network demands.

3. DEMAND ASSIGNMENT

Multiple access refers to the problem of techniques which allow a number of earth stations (greater than two) to enter a single satellite transponder with a modulated carrier, providing real time communications among all the accessing stations. The channels carried by these accessing modulated carriers can be assigned between earth stations in several ways, e.g., preassigned, time assigned or demand assigned. Fig. 2 illustrates preassigned and demand assignment of satellite channels. In preassigned operation, satellite circuits are permanently assigned between two earth stations. In time assignment, satellite circuits are preassigned between two points based on predicted variations in traffic load and independent of the instantaneous traffic demands. In demand assignment, satellite circuits are instantaneously assigned between two earth stations on demand. When the demand for a circuit ends, the satellite circuit becomes available for connection between any two other earth stations. In demand

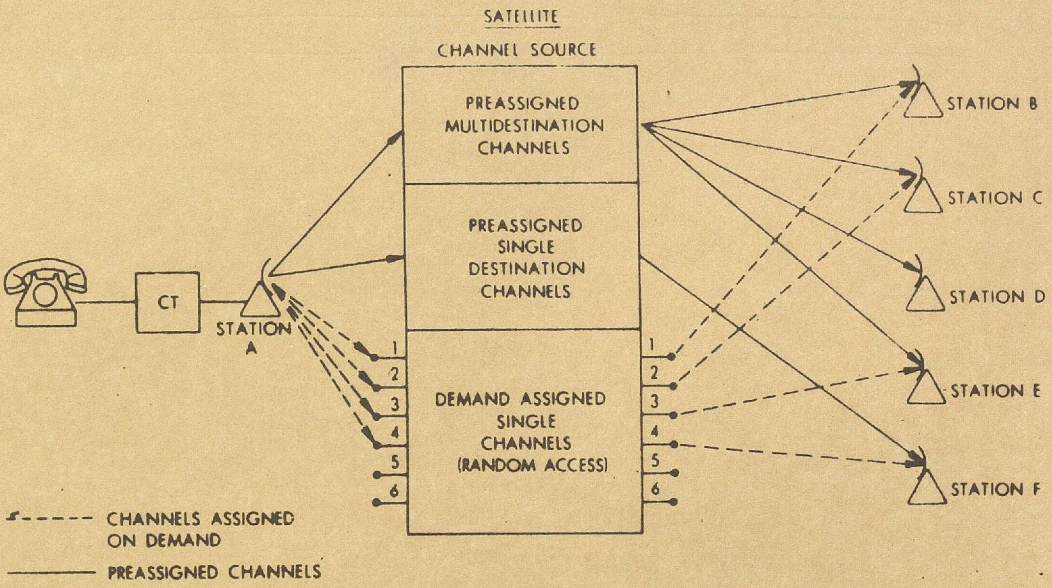

Figure 2. Methods of assigning satellite channels.

assignment, satellite circuits are not permanently associated with any pair of earth stations but are shared by all earth stations in the pool.

The concept of assigning telephone circuits on demand is not new. In fact, all major terrestrial facilities operate on exactly the same principle. The ordinary home/office telephone set is not preconnnected to all the numbers that can be found in a telephone book. Providing lines for a home phone point-to-point preassigned to every telephone is physically and economically impractical. Therefore, the terrestrial facilities assign a channel between two home phones on demand, and this is accomplished by dialing, normally at a local switching exchange. In Fig. 3 a simplified example is given. The local exchange can be connected to a hundred home telephones in City A. The number of lines to City B is less than 100 lines to accommodate the normal traffic between the two cities. Since the number of lines between the cities (long distance) is smaller than 100, the system cost is also smaller. Since there is a high probability that all 100 home phones will not be calling between the two cities simultaneously, the few long distance lines are shared, resulting in a more efficient utilization of the long distance lines. 'Grade of service' refers to how often a home customer will get a 'busy' when trying to make a call. Telephone systems are generally designed to

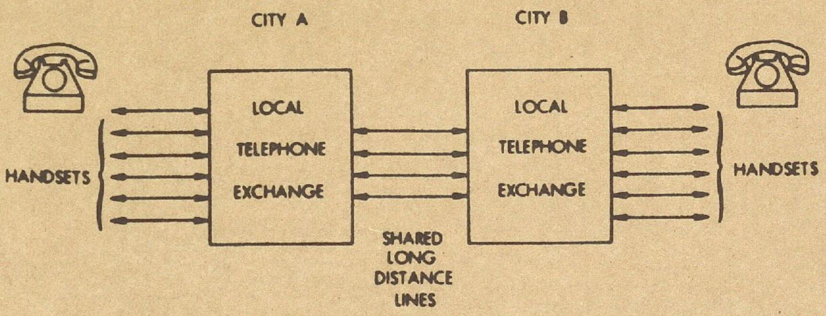

Figure 3. Demand assignment of long distance lines.

give a 'busy' on the average of one out of every one hundred times a call is attempted during the peak busy hour in the day. Satellite systems can use the same philosophy that terrestrial systems are now practicing to provide efficient, low cost communications. Demand assignment as applied to satellites results in optimal use of satellite power and bandwidth, improved network flexibility and efficiency, especially for low traffic links.

4. TECHNIQUES OF IMPLEMENTATION

INTELSAT has under development two techniques which can provide to an earth station a Demand Assigned Multiple Access, DAMA, system [2, 3]. The demand assignment notion is independent of whether the ultimate implementation is digitial or analog. A few reasons why the DAMA systems being developed for INTELSAT use digital techniques are:

(a) Pulse Code Modulation, PCM, and Phase Shift Keying, PSK, offer efficient utilization of the RF spectrum and available satellite power;
(b) Signals which are in a PCM format can be easily switched and routed;
(c) Digital systems are less sensitive to interference;
(d) Intelligible crosstalk, caused by non-linearities in the satellite transponder, does not occur with digital systems;
(e) It is expected that in the future, signals received at an earth station from terrestrial facilities will be digital;
(f) The cost of implementation and maintenance of digital systems is less than comparable analog systems;
(g) It is also possible, if desired, to provide secure satellite communications with little additional circuitry.

The two types of DAMA terminals under development each have their particular advantages and disadvantages. One is based on Frequency Division

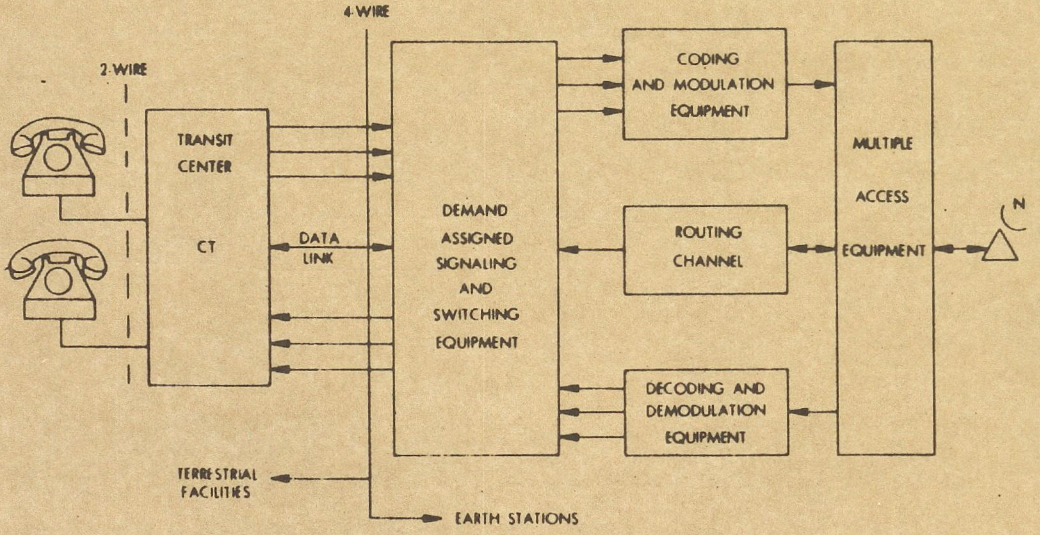

Figure 4. Basic functions in demand assigned systems.

Multiple Access and the other is a Time Division Multiple Access System. Fig. 4 shows the functional requirements for any type of demand assignment. There are three key functions:

1. *Multiple Access Equipment.* The equipment necessary to provide access to the satellite, e.g., FDMA or TDMA.
2. *Coding and Modulation Equipment.* The equipment necessary to modulate/encode and demodulate/decode the incoming and outgoing analog signals respectively.
3. *Demand Assigned Signaling and Switching, DASS.* The equipment necessary to connect with existing terrestrial equipment and the other users in the demand assignment pool through the Routing Channel. All channel requests, busy signals, terminating functions, system status reports, etc., are received and transmitted via the Routing Channel under the control of the DASS.

The Transit Center, CT, is not part of the DAMA system. It is normally located at major metropolitan areas and is connected to the earth station via cable or microwave links. Demand assigned systems, through the flexibility of a stored programmed DASS, can be designed to interface with all of the standard CCITT Signaling Systems such as CT1, CT4, CT5, CT5bis and the forthcoming CT6.

	TDMA	FDMA
INTERMODULATION	NON-EXISTENT	REQUIRES TWT OUTPUT BACKOFF
UP LINK CARRIER CONTROL	CAN HANDLE WIDE VARIATION	REQUIRES UP LINK CARRIER CONTROL
CHANNELS PER LINK	REQUIRES A MINIMUM NUMBER OF CHANNELS PER LINK FOR POWER EFFICIENT OPERATION	POWER EFFICIENCY INDEPENDENT OF CHANNELS PER LINK
NON STANDARD EARTH STATIONS	REQUIRES A MINIMUM G/T FOR ALL EARTH STATIONS	CAN HANDLE ALL SIZE EARTH STATIONS
TERMINAL COST	[✓ LOW COST FOR LARGE NUMBER OF CHANNELS PER LINK]	[✓ LOW COST FOR SMALL NUMBER OF CHANNELS PER LINK]
SYNCHRONIZATION	REQUIRES TIME SYNCHRONIZATION	REQUIRES FREQUENCY SYNCHRONIZATION
NETWORK FLEXIBILITY	LARGE NUMBER OF ACCESSES DECREASES EFFICIENCY	REMAINS AT HIGH EFFICIENCY FOR LARGE NUMBER OF ACCESSES

Figure 5. Comparison of TDMA/FDMA demand access.

Demand assigned multiple access systems developed by INTELSAT are described in References [2] and [3]; a comparison of features is shown on Fig. 5. An important difference between the two systems, TDMA versus FDMA, is the terminal cost effectiveness based on the capacity per link. In an application where there is a large number of low traffic sources desiring interconnectivity, a single channel per carrier FDMA system is extremely efficient. In an application where there is a relatively lower number of accesses with medium to heavy traffic (12-60 circuits) per link, TDMA offers the most efficient solution. As the numbers of channels per link increase, the effectiveness of the application of demand assigned channels decreases. Therefore, TDMA systems tend to be applicable to a combination of demand assigned and preassigned operations.

5. SOME ECONOMIC ADVANTAGES AND CONSIDERATIONS

If demand assignment equipment were readily available, an INTELSAT earth station owner entering the system would have two choices: (1) obtain a preassigned multidestination carrier, or (2) enter into a demand assigned pool. His choice would be determined to a large extent by the cost of the equipment and what the equipment would allow him to do. In Fig. 6* there is shown a partial listing of a typical traffic matrix for countries containing those links which have 12 circuits or less. We note, for example, that the prediction for South Africa is that it would have traffic to 14 countries and a total traffic of 21 circuits. It would therefore be given a 24-channel multidestination FDMA/FM carrier in the preassigned system. In a fully variable demand assigned system only 12 circuits are necessary to supply the same grade of service because of the effect of

	RUSSIA	SWEDEN	YUGOSLAVIA	BELGIUM	ITALY	GERMANY	SWITZERLAND	SPAIN	FRANCE	U. K.	U. S. A.	ALGERIA	ETHIOPIA	U. A. R.	KENYA	S. AFRICA	CONGO	NIGERIA	SENEGAL
SENEGAL							1	1		1	2	1		1		1		1	
NIGERIA						1	2		8	8	6	1	2	1	1	1	1		
CONGO	1	1	1		1	1	1	1	11		8	1	1	1	1	1			
S. AFRICA	1	1	1	1	1	1	1	1	1		7	1	1	1	2				
KENYA									2	7	4	1	1	1					
U. A. R.	2	1		1	2	1	3	1	1	10	8	2	2						
ETHIOPIA			1	1	2	2			1	2	3	1							
ALGERIA	1	3	8	4		4		1			8								

{ 21 PA CHANNELS   12 DA CHANNELS

☐ MORE THAN 12 CHANNELS REQUIRED

Figure 6. Demand access application to low traffic links partial 1972 circuit requirements–Atlantic region.

* Based on traffic predictions of the World Plan Committee of the CCITT.

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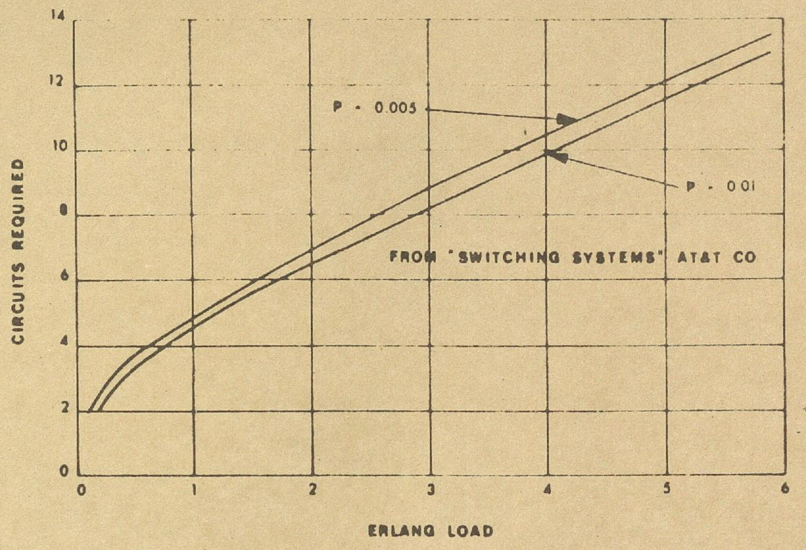

Figure 7. Erlang load vs circuits required.

channel sharing. This result is obtained by using the curves shown on Fig. 7, where the channel load is expressed in Erlangs* [4, 5]. The sum Erlang Load for all links is used to enter into the graph of Fig. 7. In the South Africa example the sum Erlang Load is approximately five Erlangs, which corresponds to a need of twelve channel modems to satisfy the grade of service.

In the preassigned system, South Africa would have to receive 14 FM carriers, demodulate the carriers, and demultiplex in order to strip off the channels preassigned to them. The cost of a receive chain is approximately $23,000. Thus, the cost to recover the 14 carriers is 14 x $23,000 = $322,000, not including the transmit chain costs. The cost to do the same function by an FDMA demand assignment system is $183,000. Typical comparisons are tabulated in Table 3.

Note that in the preassigned FDMA/FM approach every time an additional new link is wanted an additional $23,000 is needed, whether receiving one or more channels.

A more important aspect is symbolized by the blanks in the traffic matrix on Fig. 6. They indicate the traffic is so low between these points that a single channel is not justified. In the preassigned FDMA/FM system an earth station owner would not purchase an additional $23,000 receive chain for this traffic, but if he is in the demand assigned pool, there is absolutely no extra cost to assign channels point-to-point to any of the users of the DAMA pool independent of the traffic volume. This feature of DAMA yields additional traffic to an earth station owner at no additional cost. There is practically no question that with the introduction of DAMA terminals there will be an 'impulse' of new traffic from the now existing 'blanks' in the traffic matrix. DAMA terminals

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*** An Erlang is defined as that traffic load whose calls, if placed end to end, will keep one path continuously occupied. One Erlang is therefore equivalent to 3600 channel seconds per hour.**

provide low cost direct point-to-point communications to as many points as desired, requiring less total satellite channels. Preassigned FDMA/FM systems require additional cost for each new access; require more satellite channels for the same service; and are inflexible to change as total traffic varies from month to month.

TABLE 3. Capital costs comparison of pertinent earth station equipment (thousands of dollars).

	Multiplex equipment	Transmit chain	Receive chain	Total station
Pre-assigned system (FDM/FM/FDMA)				
4 circuits to each of 6 stations	$25	$20	$120	$165
2 circuits to each of 12 stations	40	20	240	300
2 circuits to each of 24 stations	60	20	480	560
Demand assignment system		*PCM-FDMA equipment*		
4 circuits to each of 6 stations*	$150	$20	$15	$185
2 circuits to each of 12 stations*	150	20	15	185
2 circuits to each of 24 stations*	150	20	15	185

* Note that the cost per station to equip for demand assignment is independent of the number of available (or required) destinations.

The economic factors listed above show the advantage to an earth station owner, but what happens to the INTELSAT revenue picture? The advantage of DAMA is to that earth station which requires a large number of low traffic links, e.g., South Africa. In an analysis of links of 12 circuits or less the number of satellite channels saved using DAMA systems in comparison with preassigned systems is 67%. The results are shown on Table 4.

But for the overall satellite system there are also links with high traffic which will remain preassigned. Studies [6] have shown that approximately 10-15% fewer channels will be required on a global basis. This faces INTELSAT with the problem of recovering its revenue requirement from a smaller number of circuits sold. If the 'impulse' of new traffic is great because of the introduction of DAMA systems, then there is no problem. But if this does not occur immediately, the price per circuit would need to be increased. Whether this increase should be spread over the preassigned and demand assigned circuits or whether it should be confined to demand assignment circuits, is a matter of charging policy which is currently under study by INTELSAT.

TABLE 4. Traffic comparison 1972 traffic Atlantic area–29 countries, grade of service, $P = 0.01$.

	Preassigned systems	Fully variable demand assigned systems
Number of satellite circuits required to provide same grade of service $P = 0.01$ for traffic requirements	728	240
Corresponding number of satellite channels	1456	480

It is worth bearing in mind that, if traffic were transferred from preassigned to demand assigned circuits, and if the price of demand assignment circuits were raised correspondingly to secure the INTELSAT revenue requirements, the DA users collectively would still be paying no more in aggregate than they were paying previously. The rate per circuit would be higher, but the number of circuits would be less. The opportunity provided by DAMA to gain additional traffic should enable the earth station owner to earn more traffic revenue for a lower outlay in INTELSAT charges than under preassignment conditons and thus imrpove the economics of his station.

6. SOME TECHNICAL ADVANTAGES

We note in Table 4 that for the low capacity links a large savings in the required satellite capacity is obtained. In technical terms this translates into effective use of the natural resource, frequency spectrum. Therefore, bandwidth is conserved on the ratio of 3:1 over preassigned systems, which extends the useful life of the 500 MHz bandwidth allocated to satellite communications in the 6 and 4 GHz bands. Also, by using the satellite channel capacity more efficiently the time is extended before additional satellites need to be launched, allowing capital investment to be carried over a longer period of time and reducing the per year revenue requirement. Thus, DAMA systems provide more effective use of RF spectrum and may extend the time before a new satellite is required.

7. CONCLUSIONS

DAMA systems offer advantages to earth station owners who desire to communicate directly point-to-point with a large number of other stations. If preassigned techniques are used, the earth station owner may only be able to afford a few receive links and still be profitable. For other traffic he would have to transmit through a 'middle man'; pay transit charges; go through longer terrestrial links with a corresponding increase in degradation in quality; and be dependent on the transit station operation for communications. In the future, when double hop satellite communications are a reality, a DAMA terminal will allow any earth station to have direct communications to any point on earth.

INTELSAT is now considering the introduction of DAMA systems and it is quite possible that the systems will be in operation in the early 70's.

ACKNOWLEDGEMENT

This paper contains information based upon work performed in COMSAT Laboratories under INTELSAT sponsorship. INTELSAT is presently considering the implementation of demand assignment within the INTELSAT system. However, the views presented in this paper do not necessarily reflect those of INTELSAT.

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9/3/70
A. Marble

BLOCKAGE EFFECTS

The blockage effects of a disk around the focal point are shown in Figure 1. The effect of the blockage on the sidelobes depends on the illumination provided by the feed. The figure shows that the required 20 db sidelobe level could be meet with a simple feed only if the blockage disk was smaller than about 2.8 ft. It is unlikely that the Earth Viewing Module (EVM) can be that small. Also, no allowance has been made for strut blockage effects. It can also be seen from the figure that even for an antenna with no sidelobes in the unblocked case, 20 db sidelobes would result due to disk blockage of about 5.5 ft. This size is therefore a firm upper bound to EVM size.

From the above discussion it is clear that achieving the 20 db sidelobe level will be quite difficult. One method of easing the problem is to apply the specification only in the direction of land masses, in this case the area north and somewhat west of India. Low side lobe levels can be easily provided in this region by translating the feed to the south so that the antenna beam squints to the north. Unblocked sidelobe levels of about 30 db can be achieved by squinting the beam about 2.5 degrees. The southerly sidelobe, which points into the Indian Ocean, will be raised to about 18 db. Squinted patterns without blockage are shown in Figure 2 and a 1.5 degree squinted beam with 4.6 ft. blockage is shown in Figure 3. None of the above patterns include strut blockage.

Another effect of disk blockage is to reduce the width of the main beam. This is a fairly small effect; a 4.6 ft. diameter disk would narrow the beam about 7%; but would reduce the power level at the beam edge by about .5 db so it is an effect which should be included in the design.

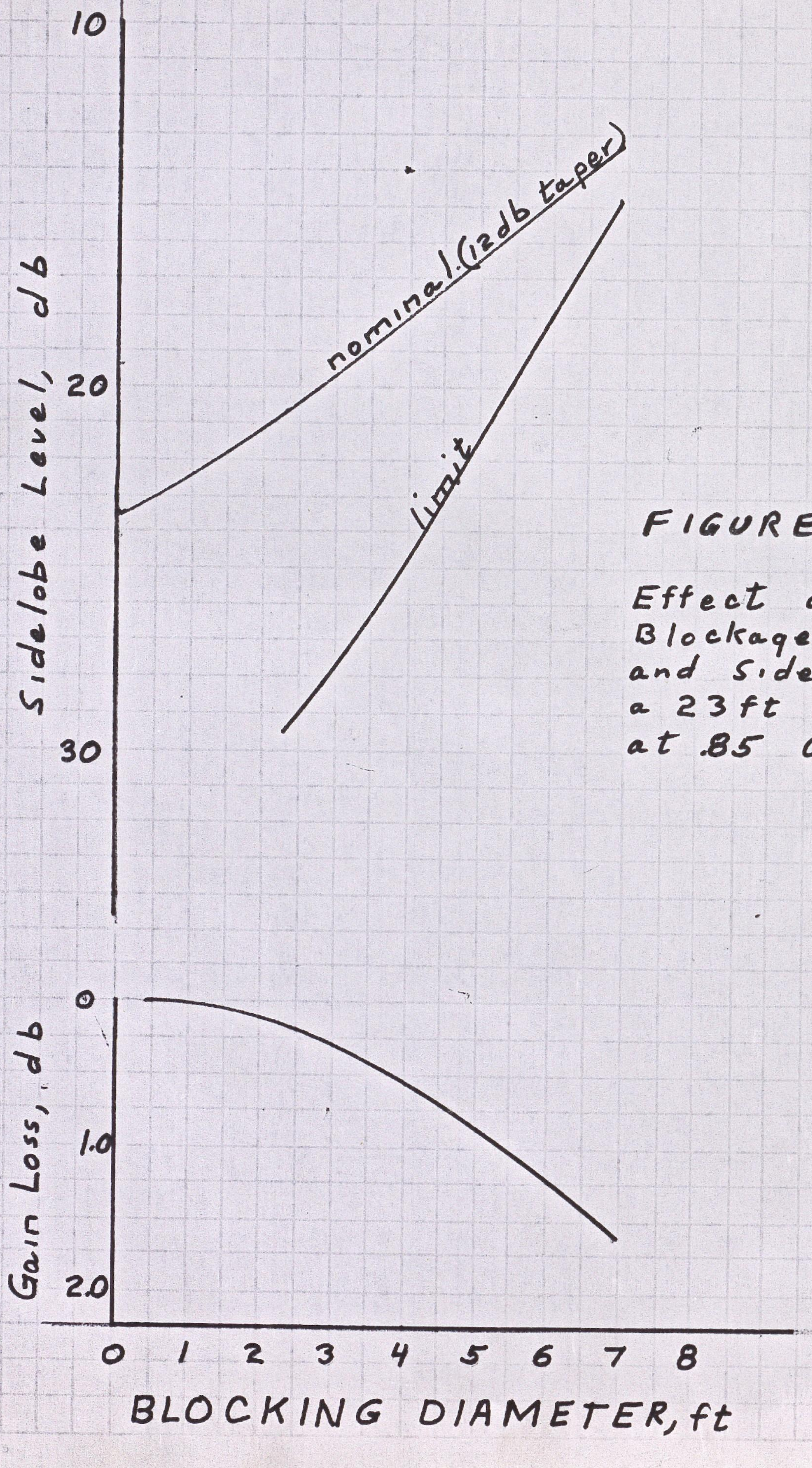

FIGURE 1

Effect of Disk Blockage on Gain and Sidelobes of a 23ft reflector at .85 GHz

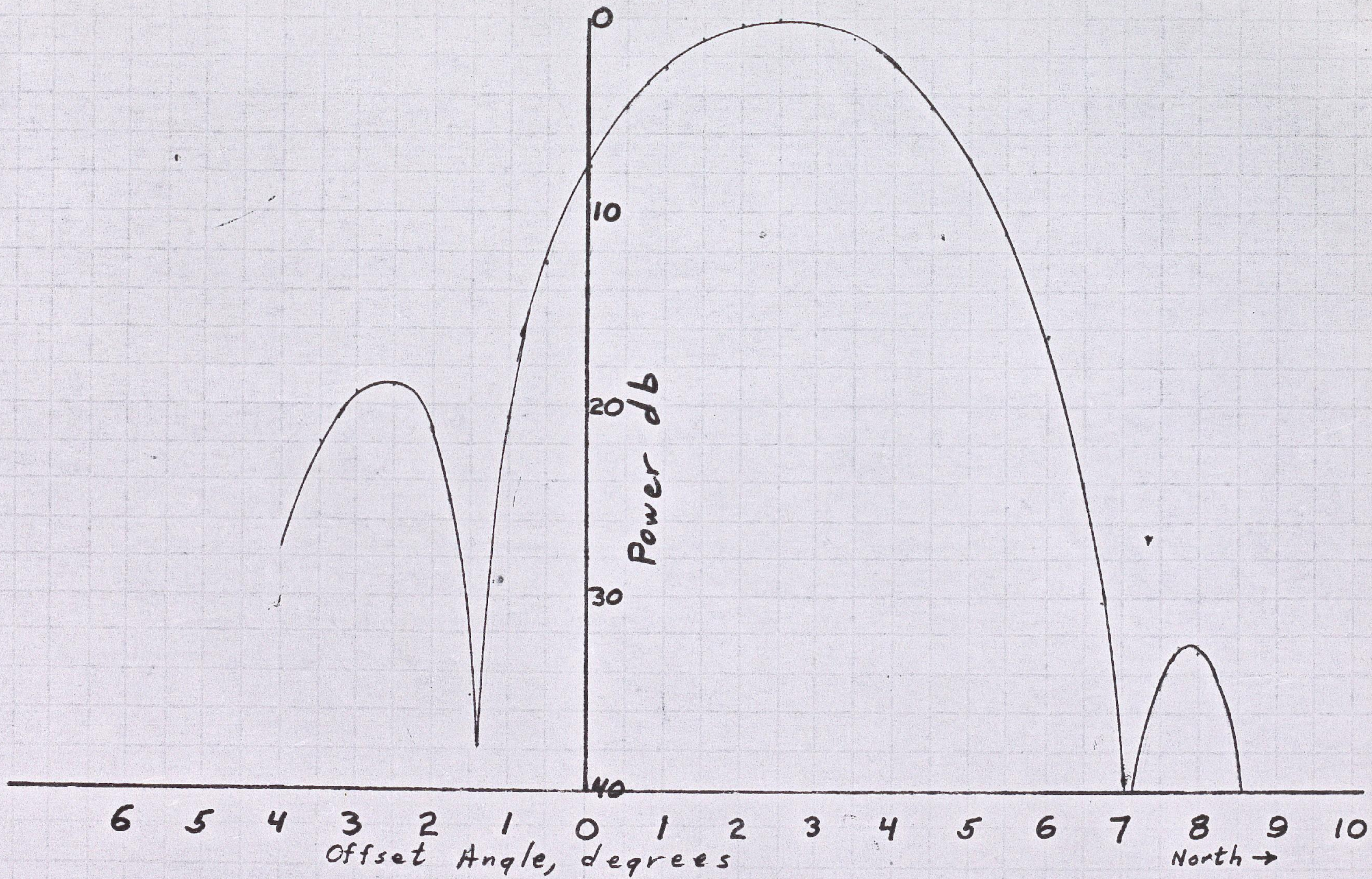

FIGURE z Squinted Beam, 23 ft reflector, .85 GHz
No blockage, 12 db taper

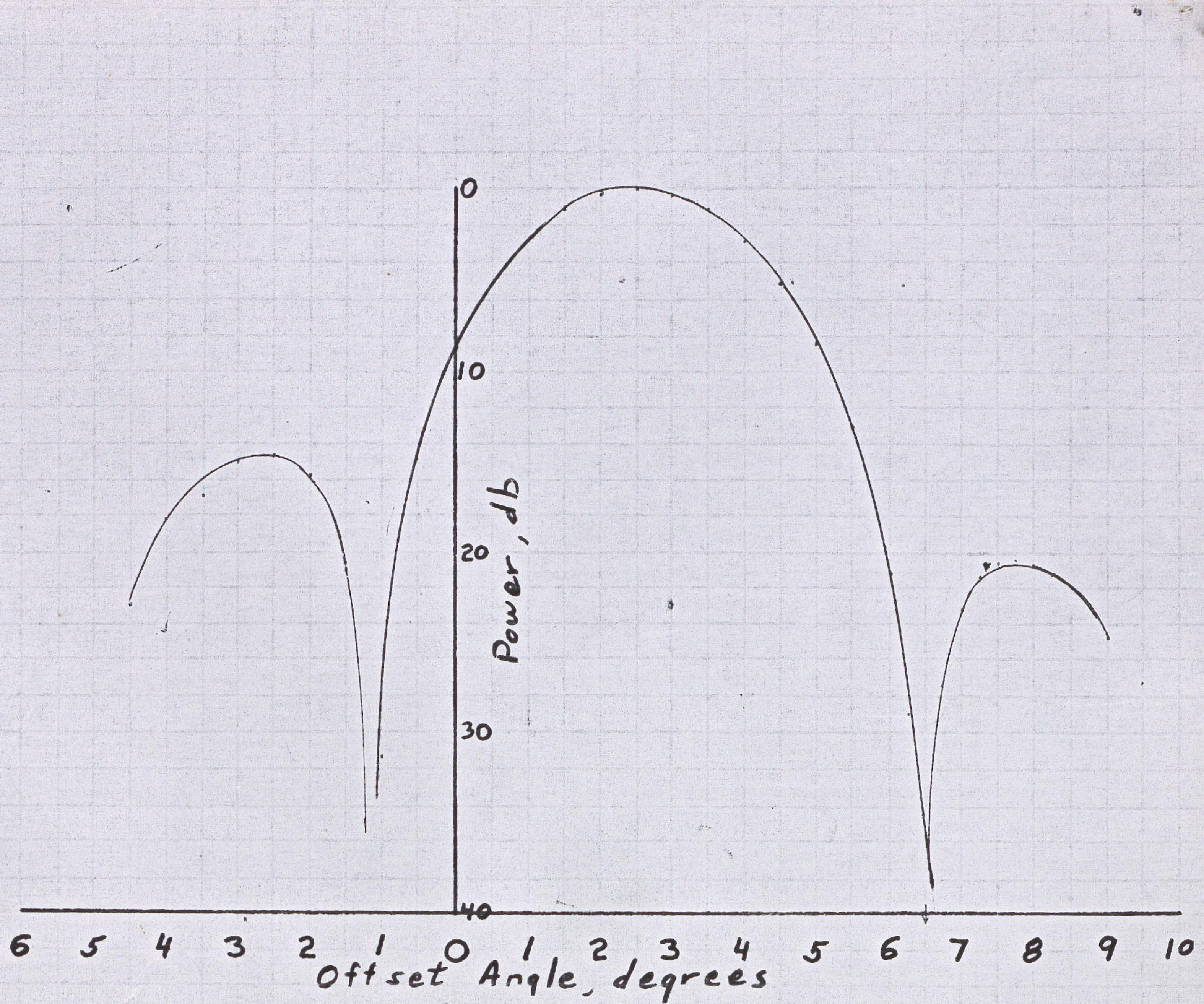

FIGURE 3 Squinted Beam, 23 ft Reflector, .85 GHz

4.6 ft diam Blockage 12 db taper

The ATS-F&G strut configuration would cause a 23.6 db sidelobe or raise a 30 db sidelobe to about 20 db. It is therefore important to choose a configuration which minimizes strut blockage. The RF optimum support structure is one that is completely transparent. This can be accomplished by using a plastic shell and conventional airborne radome techniques. The resulting ogive shaped plastic sandwich was investigated on ATS-F&G (design, fab and breadboard tested) but was not selected because it is heavier than a metal composite truss. For this application it should be reconsidered due to the tighter antenna performance requirements. An ogive would yield about .75 db higher gain and 3-5 db lower sidelobes than a metal truss. [redacted]

9/3/70
A. Marble

ELLIPTICITY

It is recommended that the ellipticity of the UHF antenna beam be estimated at 3 db (within the 3 db beamwidth) for link analysis.

The recommendation is based on the full scale tests on the ATS-F&G antenna. These tests were conducted on a 30 ft. reflector with support trusses similar to the candidates for the Indian satellite. The ellipticity was less than 3 db within the 3 db beamwidth.

9/3/70
A. Marble

USE OF ATS-F&G ANTENNA

The ATS-F&G antennna is a deployable 30 ft. parabola suitable for use at C-band in synchronous orbit. The ATS-F flight is scheduled for ________. This section discusses the impact of using this antenna on the Indian television satellite.

The conclusion is that the use of the 30 ft. reflector will substantially raise the cost, weight and risk of the spacecraft and will result in lower antenna performance. It is therefore recommended that a new reflector be developed for this application.

The ATS-F antenna will have a 2.6 degree beamwidth at .85 GHz compared to the 3.5 degree required to cover India. The beamwidth can be broadened by defocussing the feed to cause a phase error or by under-illuminating the reflector by using multiple feeds.

The effect of defocussing the feed is shown in Figure 4. The solid curves are patterns of the 30 ft. antenna with various amounts of defocus. The dashed curve is the pattern of a 23 ft. reflector. The gain of the 23 ft. antenna at the edge of the field of view, 1.75 degrees, is higher than any of the 30 ft. patterns. Defocussing the feed of the ATS-F antenna will therefore result in lower performance than using a 23 ft. antenna.

Amplitude taper can be provided by increasing the size of the feed or by using multiple feeds. The multiple feed will be discussed here because this approach could feasibly provide some beam shaping to more closely approximate the shape of the coverage area. India is shaped somewhat like a diamond which suggests using 4 feeds in a symmetrical diamond configuration. It was found, however, that four symetrically disposed feeds

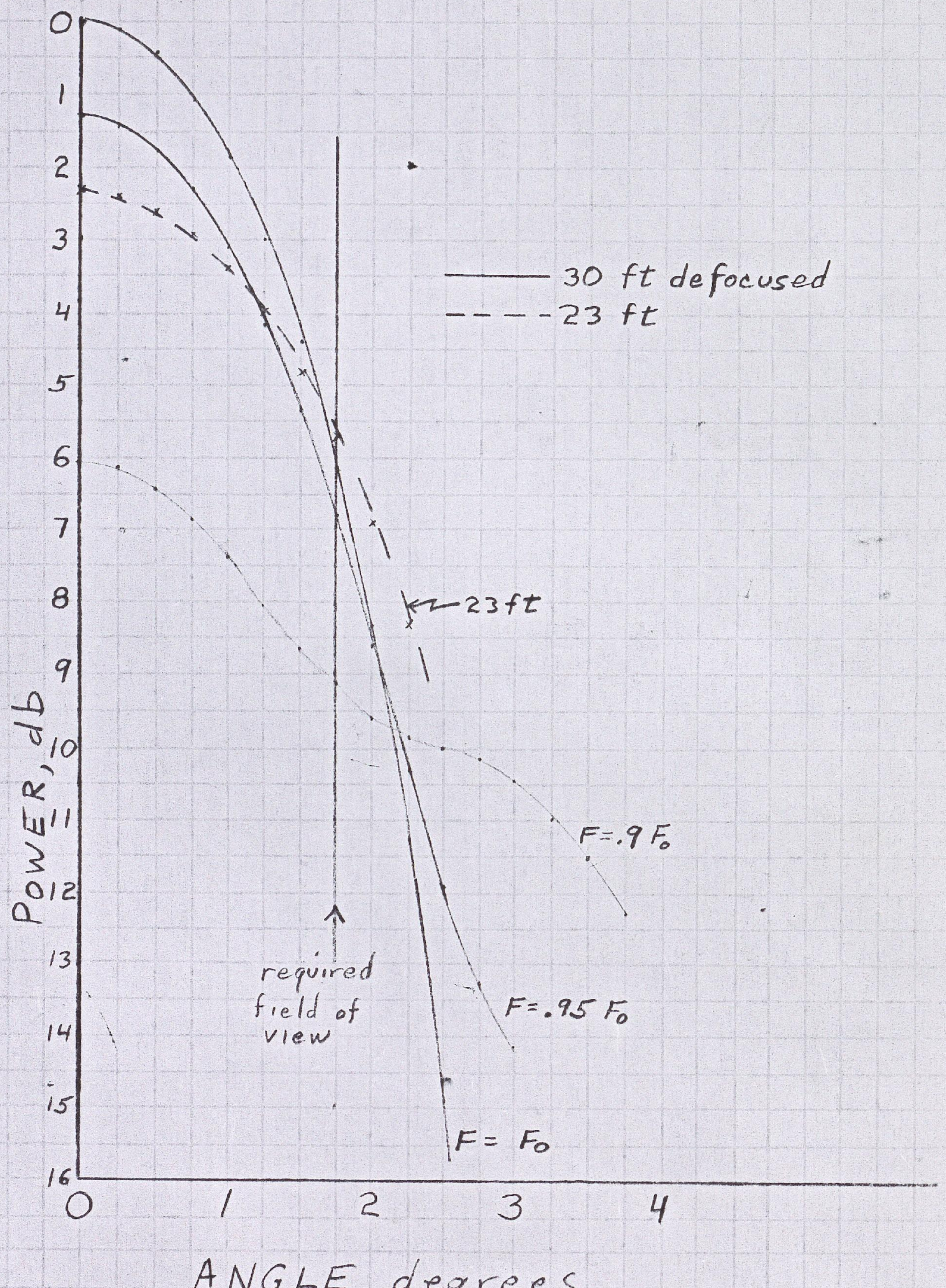

Figure 4 Patterns of Defocused ATS-F Antenna

result in a circularly symetric beam. The patterns of the 4 element feed are shown in Figure 5 along with the pattern of a 23 ft. antenna. It can be seen from the figure that the 23 ft. antenna provides higher gain over the field of view than any of the four-element feeds. Although many other combinations could be tried, it appears that the 23 ft. reflector will provide the best coverage over the field of view.

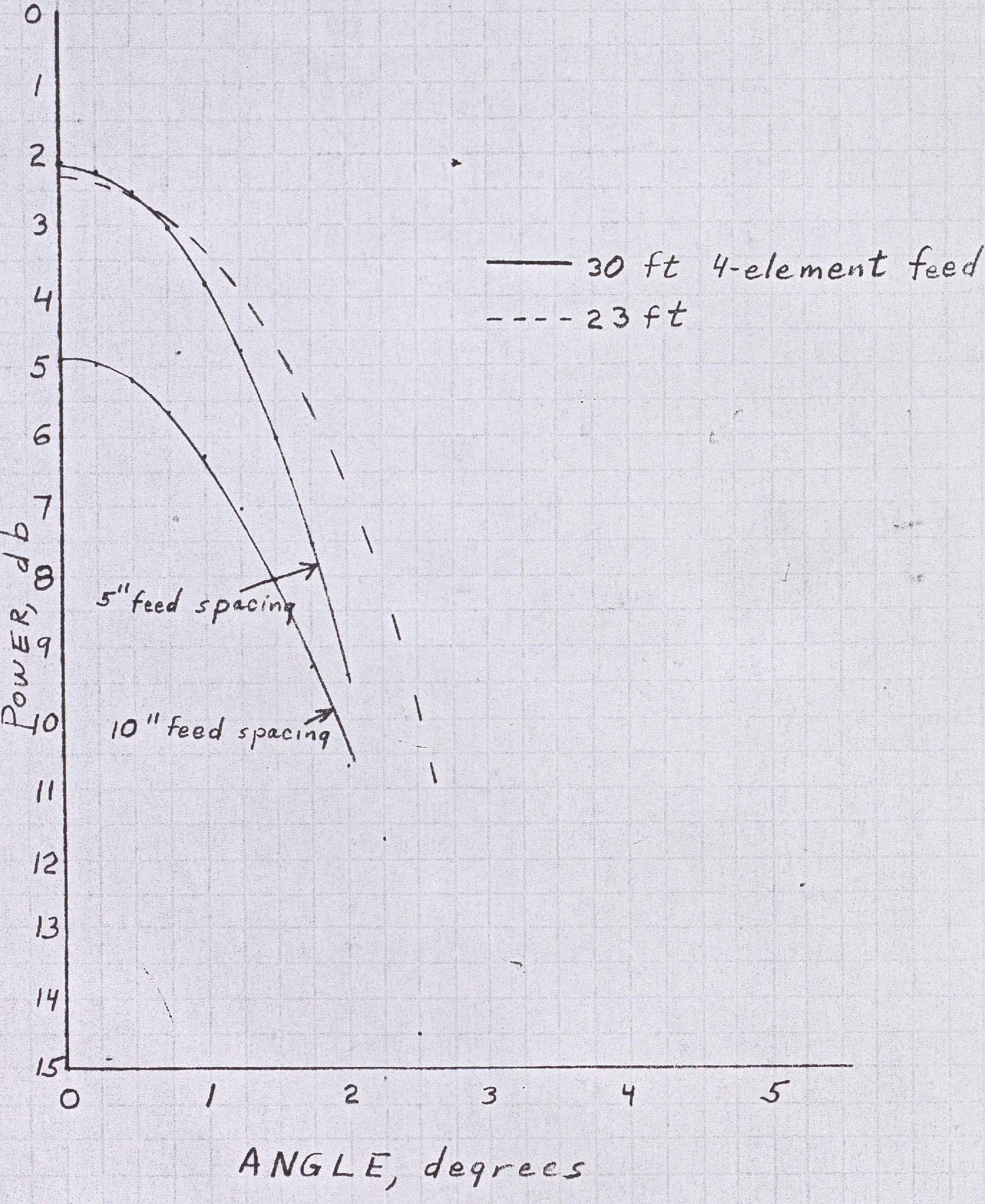

FIGURE 5 Patterns of ATS-F Antenna With 4 Feeds

9/1/70
A. Marble

GROUND ANTENNA

The initial link requirement for the telephony ground antenna can be met with a 30 ft. diameter parabola. The planned addition of channels would require a 60 ft. ground antenna. It has been suggested that the 30 ft. antennas could be designed so that they could be expanded to 60 ft. by adding panels. This concept is discussed below.

A paraboloidal surface is characterized by a focal length, which remains unchanged if the diameter is changed. Therefore, a 30 ft. antenna would have half the F/D ratio of the same antenna with the diameter increased to 60 ft. Simple feeds can provide good antenna efficiency for F/D ratios from about .35 to about .45. The 2:1 diameter (hence F/D) change would result in considerable compromise in performance at both the 30 and 60 ft. sizes.

The cost of the extendabable 30 ft. system will also be quite a bit higher than an ordinary 30 ft. antenna. The feed support structure would be longer, stiffer and have larger attach radius due to the eventual 60 ft. usage. This added cost and weight is accompanied by a probable reduction in 30 ft. performance due to RF blockage of larger support members. The pedestal will have to be sized to carry the 60 ft. loads and pointing capability built in to accomodate the narrower beamwidth of the 60 ft. reflector.

By making several simplifying assumptions a comparison of the cost of the extendable system can be estimated. Assume:

(1) The cost of a ground antenna is proportional to the cube of the diameter.

(2) The feed system is .1 the total cost.

(3) The feed support structure is .1 the total cost.

(4) The reflector is .4 the total cost.

(5) The pedestal is .4 the total cost.

(6) The added reflector panels will cost 20% more if purchased at a later time.

The relative cost of the extendable antenna is given in the table.

	30 ft.	30 ft. Extendable	Extending to 60 ft.	60 ft.
FEED	.1	.8		.8
FEED SUPPORT	.1	.8		.8
REFLECTOR	.4	.4	3.4	3.2
PEDESTAL	.4	3.2		3.2
COST	1.0	5.2	8.6	8.0

Although the total cost of an 60 ft. extended system is slightly less (8.6 vs 9.0) than separate 30 ft. and 60 ft. systems the initial investment of 5.2 is an extreme risk if extension is not certain.

It is therefore recommended that the 30 ft. and 60 ft. systems be procured as separate items.