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FINAL REPORT

TT&C Subsystem Study UHF Spacecraft

Prepared for:
Department of Communications
Ottawa, Ontario

DSS Contract Reference PL36100-4-0969

RCA

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

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RCA

1.0 INTRODUCTION

COMMAND, RANGING & TELEMETRY SUBSYSTEM CONSIDERATIONS FOR AN OPERATIONAL UHF-SHF COMMUNICATIONS SATELLITE

1.0 INTRODUCTION

The Command, Ranging and Telemetry Subsystem (CR & T) for any spacecraft is required to perform the following critical functions:

- o Receive command transmission from ground, and demodulate the command message.
- o Retransmit the receiver command message to ground via the telemetry link, to provide command verification prior to execution.
- o Issue commands, upon receipt of "Execute" signals to the various spacecraft subsystems to select desired operational states.
- o Issue commands upon receipt of "Execute" signals to various thrusters used for satellite manoeuvering and station keeping.
- o Provide ranging information for precise orbit determination, both transfer and synchronous.
- o Sample and process telemetry data from various subsystems and sensors in the spacecraft.
- o Transmit the telemetry data and/or ranging signals to ground via the telemetry transmitter.
- o Generate and distribute clock signals, as required.

These functions must be performed accurately and reliably during the entire mission, including the critical launch and transfer orbit phases.

In order to establish the requirements and desirable features for a Command, Ranging and Telemetry Subsystem, it is in order to first briefly review the launch and positioning operations, and the existing ground station facilities and systems.

1.1 Review of Mission Events, Launch to "On-Station"

The launch of a communications satellite is usually from the NASA range at Cape Canaveral, Florida.

A three stage launch vehicle, typically a Thor-Delta, uses the first two stages to put the spacecraft into a "parking" orbit, which is inclined 23° - 27° to the equator, and whose first perigee is within ± 1° of Longitude.

The third stage then spins up the spacecraft, and launches it into an inclined, highly elliptical "transfer" orbit, with perigee at about 100 miles and apogee at approximately synchronous range of 21,000 miles.

Up to this point, all control is from the launch range operation, using the rocket's Command and Telemetry System, and NASA tracking facilities. The next step is to determine the transfer orbit parameters as quickly as possible in preparation for the move to synchronous orbit, and subsequent positioning.

This is done using the spacecraft's Telemetry and Ranging System, and tracking station facilities at various locations. Thus, the Telemetry and Ranging antenna(s) must provide a sufficiently omnidirectional pattern to ensure adequate coverage despite 'look angles' which differ with tracking location and throughout the transfer orbit.

The NASA network includes stations at Tananarive (Malagasy), Carnarvon (Western Australia), Santiago (Chile), Rosman (North Carolina), and is equipped for VHF/UHF and 2 GHz operation.

The INTELSAT/COMSAT System uses facilities at Carnarvon, and is equipped for 4/6 GHz operation.

1.1 Review of Mission Events, Launch to "On-Station" (Continued)

TELESAT Canada uses facilities at Guam, rented from the Hughes Aircraft Company, and operates at 4/6 GHz. RCA GLOBCOM uses INTELSAT facilities for tracking, and its own East and West coast U.S.A. ground stations for station acquisition and control.

Having established the orbital parameters, acquisition information is available for the main TT/C Station antennas for the second transfer orbit.

Attitude data and spin information from earth and sun sensors is now processed, and the spacecraft must be reoriented to the correct attitudal position for firing the apogee motor at the apogee of the transfer orbit. For a North American Satellite, the apogee motor would normally be fired at the second or the fourth apogee, to avoid battery run-down and spacecraft temperature problems, etc.

Spacecraft re-orientation and apogee motor firing are performed, in the various systems, by the following control stations:

NASA	Rosman, North Carolina
INTELSAT/COMSAT	probably Fucino, Italy
TELESAT, Canada	Allan Park, Toronto
GLOBCOM	Possibly Fucino, Italy
CTS (CRC)	Shirley Bay, Ottawa

This firing removes the inclination of the transfer orbit, and establishes the spacecraft in the drift orbit at synchronous altitude. The next step is to drift the spacecraft to the desired final position, at approximately 115°W, and re-orientate so that the spin-axis is perpendicular to the plane of the orbit, and the Antenna is up (i.e., North).

1.1 Review of Mission Events, Launch to "On-Station" (Continued)

In the case of a spin-stabilized satellite, the antenna must now be de-spun, and "station acquisition" is complete. Earth lock of the antenna is maintained using the data from the same earth sensors used during the transfer orbit operations.

For a three-axis stabilized spacecraft, the next step is to de-spin the satellite to a low rate (degrees/minute), and deploy the solar sails, slowing the craft further. Final de-spin and orientation then take place.

To provide earth data on-station, the fixed earth sensors used during the spinning phase can not be used, and a mechanical scanning system using a mirror provides two-axis attitude information.

1.2 LAUNCH SUPPORT FACILITIES

The satellite will almost certainly be launched from Cape Canaveral by NASA. NASA supports a launch with its Spaceflight Tracking and Data Network (STDN). This is a world wide complex of stations used to provide communications with both manned and unmanned spacecraft.

The network is operated primarily in direct support of earth orbital scientific and appli cations Satellites, and the United States Manned Space Flight program, but also may be used to support other programs. Operational frequencies of the network are VHF-UHF and S-band (2 GHz) but not all stations are equipped to handle both frequencies.

Present NASA plans are to phase out use of the VHF/UHF network by 1978. It is therefore very doubtful that any presently planned spacecraft would use VHF/UHF command and telemetry frequencies.

The S-band network will have an operational life into the '80's and has ground stations at Tenerife and Carnaervon which, together with a Canadian ground station, are capable of putting a spacecraft into synchronous orbit. However, it is highly unlikely than an S-band frequency assignment would be available for an operational Communications Satellite. Therefore, the chances of using NASA's STDN network for command and telemetry of the spacecraft are slim.

TELESAT Facilities

Telesat's main TT & C facility is located at Allan Park. Three antennas are used to control two spacecraft.

TELESAT Facilities (Continued)

For normal operations, all TT & C functions for the ANIK I Satellite are connected to the Heavy Route (HR) antennas, and all telemetry and command functions for the ANIK II Satellite are connected to the TAC-2 antenna, with tracking performed by the TTAC antenna.

The TTAC antenna is used during the transfer orbit and prior to arrival of a satellite on station. In addition, it serves as a backup to both the HR and TAC-2 antennas for all TT & C functions during commercial service, as well as for engineering tests and is also available for subsequent launches.

During the transfer orbit, the Allan Park complex is further backed-up for vital telemetry and command (T & C) functions, such as apogee motor firing, by the T & C facilities on the HR antenna at Lake Cowichan. This HR antenna is also used for range information for orbit control of ANIK I, during commercial service. In addition, for the transfer orbit phase of a mission, a transportable Tracking, Telemetry and Command Station (TTS), located in the Eastern Hemisphere on the island of Guam, forms an integral part of the TT & C system. Appendix I gives parameters for the Telesat ground stations.

Telesat is therefore fully equipped to handle all phases of a spacecraft launch from Cape Canaveral. However, with the launch of Anik III, all of Telesat's TT & C antennas will be used to control an operational spacecraft and they will not have a spare antenna for use on the "UHF Satellite". An additional antenna would therefore have to be built for the "UHF Satellite" together with all the TT & C R.F. equipment.

(NOTE:- These are the launch facilities available prior to the launch of of Anik III)

INTELSAT Facilities

The INTELSAT TT & C ground station network includes stations at Carnarvon and Fucino, Italy. This system also operates in the 4 GHz/6 GHz region, qith typical ground station parameters as listed in Appendix I.

GLOBCOM Facilities

RCA GLOBCOM uses INTELSAT facilities for tracking, and has East and West Coast U.S.A. ground stations for station acquisition and control. Parameters for these stations are listed in Appendix I.

2.0 T.T. & C. REQUIREMENTS

2.0 TELEMETRY, COMMAND AND RANGING REQUIREMENTS

2.1 Telemetry

2.1.1 General

The Telemetry Subsystem is required to provide the ground station with information concerning the general state of the satellite, and its operational status, together with ranging return signals.

This information is of diverse characteriatics, and can be characterized as follows:

Table 1 shows the basic telemetered data.

2.1.2 Basic Telemetered Signals

a) Housekeeping Signals

The operating conditions of the spacecraft are assessed from sample measurements of the major electrical and thermal parameters. Since most of the parameters to be sampled do not vary rapidly (e.g., battery voltage) the sample rate need not be very high. Under special circumstances, a parameter may be continuously monitored if a "dwell mode" is available on command. Obviously, the number of parameters sampled must be sufficient to permit a full diagnosis of the spacecraft state.

b) Flags

The flexibility of a modern dual band communications transponder permits selection of many operating configurations, and it is therefore important to provide a 'quick-look' facility via telemetry, to give the ground station operators an immediate appreciation of the configuration. Status information, indicating on/off or connected/disconnected status by means of a single binary digit is therefore required. These indicators are called, appropriately, flags.

2.1.2 Basic Telemetered Signals (Continued)

c) Spacecraft Signature

In a multi-satellite system, the requirement for identification of each spacecraft is obvious. A unique 'signature' consisting of a binary number or other coded format can be assigned to each spacecraft, and transmitted periodically via telemetry (typically once per sub-frame)

d) Command Verification

A frequently used command concept is that a command instruction received by the spacecraft is not immediately executed, but stored in the command decoder. This received command is then telemetered back to ground to allow operator verification that the command has been correctly received. After such verification, the operator then instructs the spacecraft to execute the stored command.

Command verification is thus an important part of the telemetry system.

e) Earth Sensor (Pulses)

During the transfer orbit and station acquisition operations, a knowledge of the spin rate and spacecraft spin axis orientation is required. This is provided by the optical earth sensor units, which provide pulse outputs whenever the field-of-view of the sensor moves from deep space to the earth's disc, or vice versa. A positive pulse followed shortly after by a negative pulse is produced as the sensor's field of view crosses the earth.

f) Sun Sensor (pulses)

Before the satellite is placed 'on-station', the attitude of the spacecraft relative to the earth must be determined and monitored during the subsequent manoeuvering in order that it can be correctly oriented in space for firing of the apogee motor. The earth sensor's fields of view are too restricted to permit them to be used for this function. A sun sensor, having a much wider field of view, is used to provide information as to the direction of the sun relative to the spacecraft.

2.1.2 Basic Telemetered Signals (Continued)

g) Ranging tones

These are the recovered signal tones transmitted to the spacecraft via the command system, and are to be transponded back to ground to provide range information.

2.1.3 Multiplexing of Telemetry Signals

2.1.3.1 Real Time Signals

The ranging tones, differing in frequency, can be directly combined since simple filtering will provide separation of the tones. However, the sensor pulses (earth and sun) are not so easily handled since they occupy essentially the same frequency bands. The most often used method of multiplexing the sensor signals is to directly modulate sub-carriers of different frequencies with each of the signals.

Separation of the sub-carriers after transmission can then be simply achieved, again by direct filtering. N such signals obviously require N sub-carriers if complete separation is required.

An alternative to the transmission of the sensor data in real time is to process the sensor data 'on board' into a coded format which fits in with the sampled data. Using this approach, a very considerable reduction in required signal bandwidth from that needed for direct real time transmission can be achieved, albeit at the expense of equipment complexity. In the interests of simplicity most present systems appear to favour the real time transmission of sensor data.

2.1.3.2 Sampled Signals

The most common time division multiplex methods are PAM and PCM. PAM is ordinarily favoured for low capacity systems, whilst PCM is favoured for higher capacity systems. Telesat's ANIK satellite and the RCA Globcom U.S. domestic satellite both use PAM.

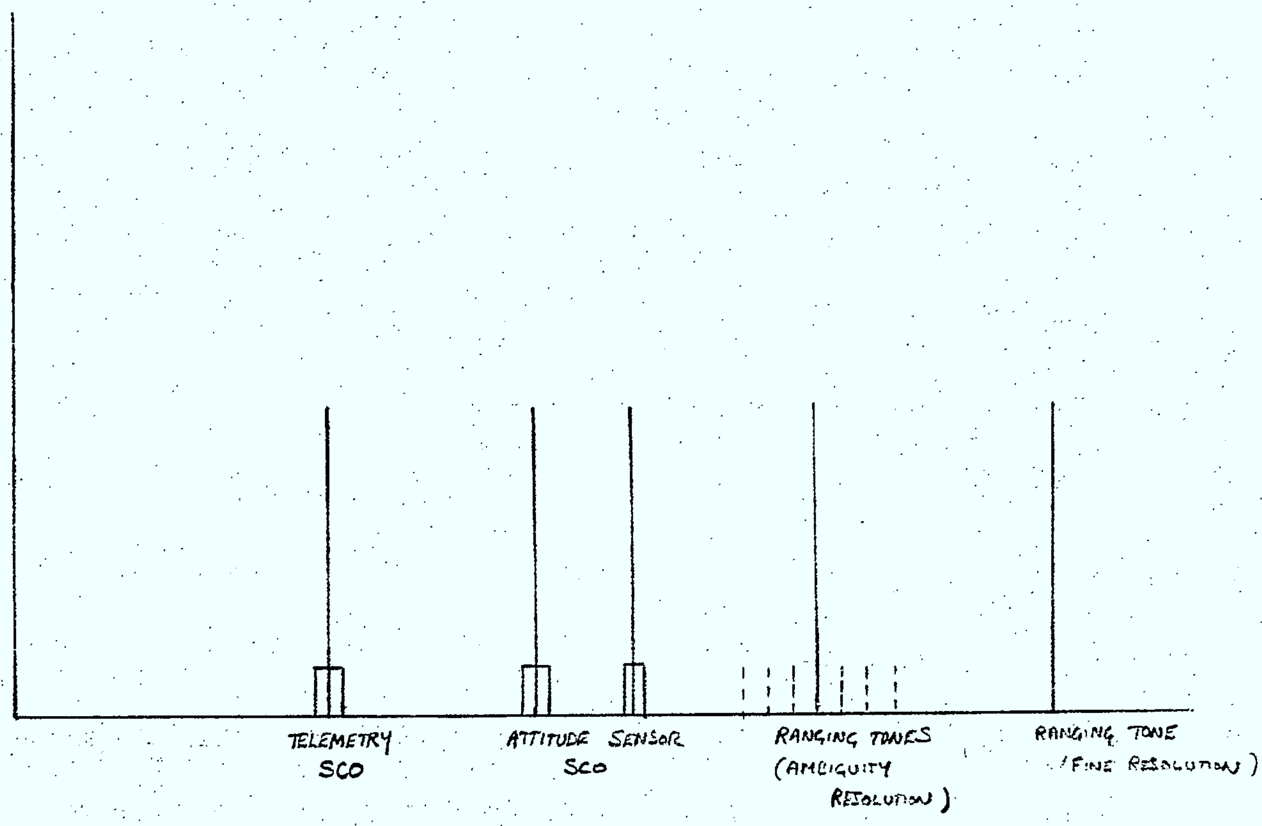
Since a proposed Canadian UHF/SHF communications satellite would require a medium capacity telemetry system either PAM or PCM would be practicable. The fact that existing Canadian ground stations which would probably be used are equipped for PAM operation, would favour the choice of PAM.

The PAM telemetry signal is modulated on to a sub-carrier for combination with the real time signals, and the resulting composite baseband spectrum then modulates the telemetry link RF carrier. The typical baseband spectrum is shown in Figure 2.1.

SIGNAL	TYPE	DATA	USE	COMMENTS
Housekeeping	Analogue	Sampled	Monitoring & Diagnostic	Sampling rate relatively low
Flags	Digital Bit	Sampled	Operational monitoring	
Spacecraft Signature	Coded	Sampled	Identification	Not essential for single spacecraft
Command Verification	Coded	Sampled	Operational monitoring	Sample rate relatively high
Earth Sensor Data	Analogue	Real Time	Station acquisition and keeping)	Sensors for acquisition and keeping are different
Sun Sensor Data	Analogue	Real Time	Station acquisition and keeping)	
Ranging Tones	Analogue	Real Time	Operation	

TABLE 1

BASIC TELEMETERED SIGNALS



TELEMETRY BASEBAND SPECTRUM FIG 2.1

2.2 Command

2.2.1 General

The command system is required to permit operational changes to the spacecraft's subsystems, as desired, and must be capable of achieving this in a flexible and secure manner.

Critical requirements are:

a) the ability to set up the spacecraft into any or all of its possible operational configurations.

b) the ability to correctly position (and re-position) the spacecraft as required by station-keeping considerations.

c) the provision of sufficient redundancy to allow at least restricted performance if certain key circuits should fail.

The command system should also provide, as far as possible, protection against the following:

d) incorrectly transmitted commands
e) commands corrupted by noise
f) interfering carriers
g) equipment failures
h) gross operator errors.

2.2.2 Command Formats

Three basic command methods are listed in NASA's Aerospace Data Systems Standards. These are:

a) the Tone Command System

The commands are transmitted as an assembly of audio tones in serial time sequence. The frequency and the order of the tones identify the particular command. A second set of tones, differing from the above, constitutes a unique address, and this address precedes the actual command message.

The possible number of commands is given by M^N where M is the number of tones in a given command, and N is the overall number of different tones. Some degree of protection is given by requiring that no tone be sounded more than once in a given command. In this case the possible number of commands is given by $M!/N!$.

b) the Tone Digital System

In this system, a digital code constitutes the command, the code 100% modulating a carrier tone to produce tone bursts. The coding uses Pulse Duration Modulation, a digital "1" being represented by a tone burst lasting $\frac{1}{2}$ bit period, and a digital "0" represented by a tone burst lasting $\frac{1}{4}$ bit period.

A complete tone digital command comprises a sync tone burst followed by the command text (consisting of an address and the command), and then a blank interval.

c) the PCM Command System

This system is used where high command capacity is required, and is probably the most widely used command system.

2.2.2 Command Formats (Continued)

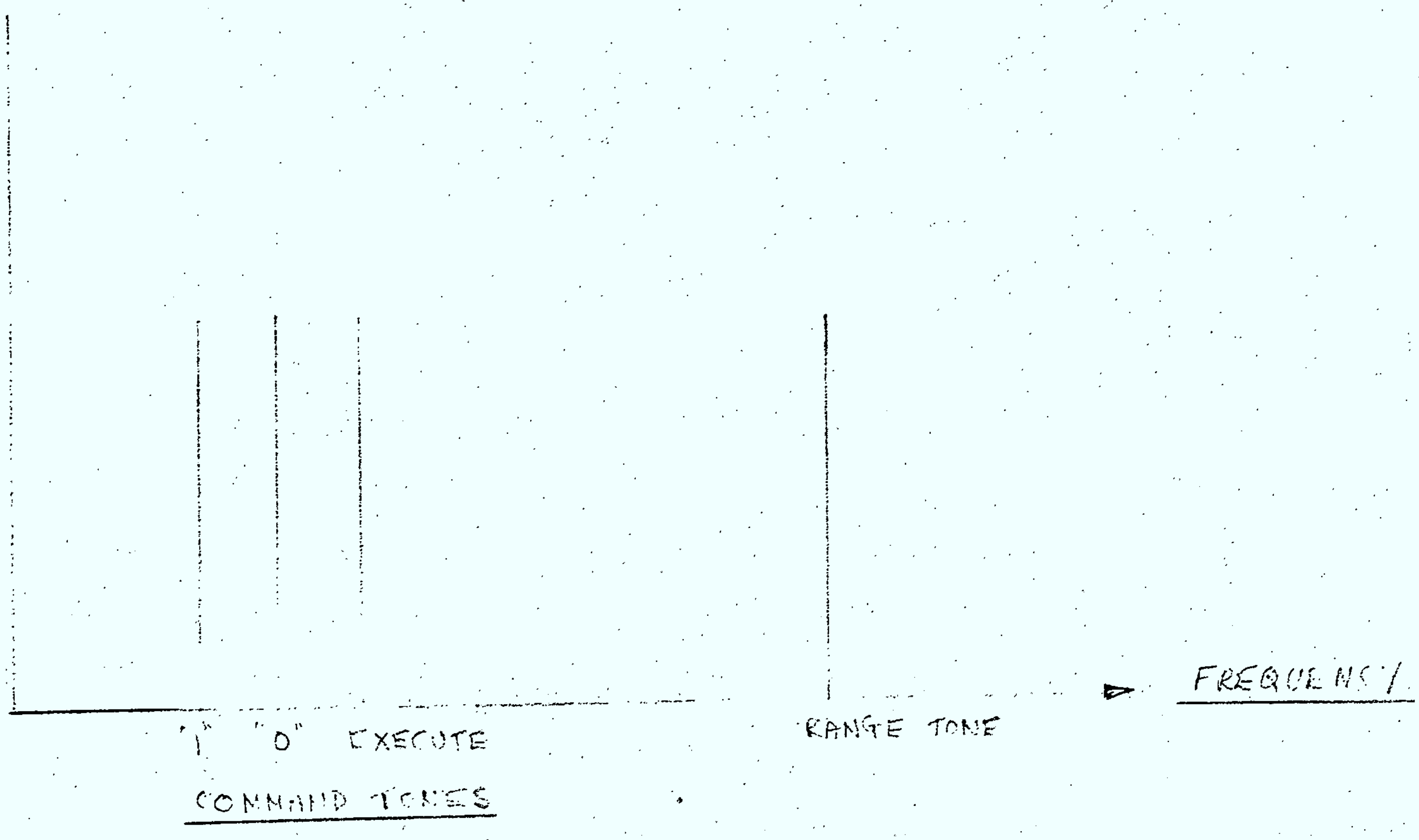
c) the PCM Command System (Continued)

Commands are coded in a PCM format, and the resulting binary signal 'frequency shift keys' a sub-carrier oscillator between two frequencies so that a "1" is represented by one frequency and a "0" by the other. The clock is transmitted as an amplitude modulation on the sub-carrier.

The tone command system has the obvious disadvantage that each tone requires a filter; thus for a medium capacity system, probably seven or eight tones, requiring seven or eight filters in the command decoder, would be required to provide sufficient address and command capability.

Using only one tone, the tone digital system has the merit of simplicity, but it can be shown that the use of Pulse Duration Modulation to transmit "1" and "0"s entails a signal to noise ratio penalty of nearly 3 dB when compared with a FSK system.

The PCM/FSK system is the most flexible, and is the recommended command format for the proposed UHF satellite. Thus, the command link baseband would be as shown in Figure 2.2.



COMMAND BASE BAND SPECTRUM FIG 2.2.

2.3 Command Link Security

Military usage of a communications satellite system demands the highest possible degree of command link security, in the sense of maximum protection against deliberate interference by an adversary. Many sophisticated schemes or combinations of schemes can be devised to provide such immunity - spread spectrum transmission, frequency agile systems, command encryption techniques, and etc. Much of the hardware in such schemes is often government furnished equipment, with both the hardware and the detailed system techniques subject to the strictest military security.

A high degree of command link protection can be provided by a combination of spacecraft antenna directivity (spot-beam) and the signal 'capture effect' exhibited by an FM receiver. This topic is discussed in some detail in Appendix 3, which concludes that a protection of approximately 10 dB can be obtained in this manner (i.e., an interfering ground station located outside the land boundaries of Canada would have to provide an up-link E.I.R.P. 10 dB higher than that provided by a suitably located Canadian military ground control station).

Further command protection techniques remain to be studied, as the UHF satellite and its Tracking, Telemetry and Command Sub-system concepts progress.

2.4 Ranging

Determination of spacecraft range is normally achieved by transmitting ranging tones from a ground station to the spacecraft, which retransmits the tones back to ground via a transponder.

Due to the finite velocity of the electromagnetic radiation, the received tones undergo a phase delay with respect to the transmitted tones. This phase shift is a measure of the spacecraft range.

2.4 Ranging (Continued)

Digital ranging techniques can also be used to determine range. A pseudo-random binary code modulates the up-link carrier, and is transponded by the spacecraft back to the ground station, where the received ranging code is compared with a time shifted code provided by the ranging system, and thus round trip time for the code is determined.

It is usual practice to use the Command System receiver and the Telemetry System transmitter as the ranging transponder. The NASA Goddard Range and Range Rate (GRRR) System requires a phase-coherent transponder, i.e., coherence of the up-link frequencies must be maintained through the transponder and back to the ground receiver, where frequency comparison against a sample of the up-link frequency extracts Duppler information, thus giving range rate (spacecraft velocity).

Operation of the GRRR system is at frequencies in the VHF band, and also at 2 GHz.

In the Tone ranging system, range rate information can be extracted if required by a process of differentiation of the continuous 'range' output. Commercial spacecraft operation favours the use of tone ranging, and suitable facilities exist at Canadian ground stations.

A derivation of the Ranging System link requirements is presented in Appendix 2.

3.0 T.T. & C. ANTENNAS

3.0 TT&C Antenna

There are four basic approaches to the problem depending on the choice of frequency. The condition that the on station TT&C signal will be carried by the main communication antenna is for the time being not considered, since it will only reduce the complexity of the TT&C antenna design.

The function of the TT&C antenna is to provide satellite to ground communication during the transfer orbit phase, the on station maneuvers and station keeping. For this reason, the antenna pattern for the TT&C antenna should have a "donut" shaped pattern around the apogee motor axis for the transfer orbit phase and a hemispherical pattern pointing towards earth for the rest of the mission. The following discussions shall elaborate on the types of antennas which will satisfy these needs and a solution for each of the four approaches is analyzed.

The four approaches are based on the four prefixed frequencies of i) VHF 130 MHz, ii) UHF 400 MHz, iii) 4 & 6 GHz, and iv) 12 & 14 GHz.

The selected TTC Antenna is identical to the SATCOM Satellite. This antenna is the combination of a resonant biconical helix for the spinning mode operation and an endfire resonant helix for the on station cardioid pattern operation.

This antenna is quite small for the 4/6 GHz band operation and can be mounted on top of the feed supporting tower. It remains unobstructed during the spinning mode since the folded reflector ribs do not reach that height. After the satellite is in station, the endfire mode of the antenna is used, which remains independent of other antenna functions.

Specification 2278136 attached, defines the detailed performance requirements of the SATCOM antenna.

REVISIONS		Rev	
Ltr	Description	Date	Approved
A	For description of changes see ECN CCB #SC045	4/16/74	H.A. Riebe
B	For description of change see ECN CCB #SC 793		

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For Continuation of Revisions, See Sheet ____

First Made For RCA Satcom	Contract No. B 70000-N1	**RCA**	RCA Corporation Astro-Electronics Division Princeton, New Jersey
Used On	Written H.A. Riebe Date 12/17/73	PERFORMANCE SPECIFICATION CR&T Omni Antenna	
	Sys Eng K.L. Date 12/18/73		
	PMO Date 1-21-74	Size A	Code Ident. No. 49671	PS- 2278136
Prod A Date 1-16-74	1/16/74	Sheet 1 of 9	

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1.0 SCOPE

This specification establishes the requirements for the performance, design, test and qualification of the Command, Ranging and Telemetry (CR&T) Omni Antenna. Two identical antennas are employed on the RCASatcom spacecraft, one mounted coincident with the launch spin axis and the other mounted parallel to the rotational axis of the solar array (N-S).

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect form a part of this specification to the text specified herein. In the event of a conflict between this specification and any referenced specification, this specification shall take precedence.

RCA

2272349	Subcontractor Product Assurance Requirements Specification
2272351	Subsystem Environmental Test Specification
2272680	RCA Satcom Interface Specification

3.0 REQUIREMENTS

3.1 Performance

3.1.1 Functional

The CR&T Omni Antenna Subassembly comprises separate colinearly-mounted antennas which transmit Telemetry signals at 3.700.5 or 4,199.5 MHz and receive Command and Ranging signals at 6,423.5 MHz. The radiation patterns of these antennas are toroidal about the colinear axis of the antennas with 3 db beamwidths of about 40 degrees. One of the antennas, identified as the Launch Omni, is mounted coincident with the launch spin axis above the Communications Antenna System feed-horn assembly. Another antenna, identified as the Orbit Omni, is mounted parallel to the solar array rotational axis (N-S) on a support between the N-E and N-W communications reflectors. Both antennas are connected by coaxial transmission lines to the internally mounted CR&T equipment located on the North Panel.

3.1.1.1 Electrical

The electrical requirements for the CR&T Antennas are summarized in Table 1.

Table I

Parameter	Frequency (±2 MHz) Terminal 1	Terminal 2
	3,700.5 MHz and 4,199.5 MHz	6,423.5 MHz
3.1.1.1.1 Polarization	Vertical (Parallel to Central Axis)	Horizontal (Orthogonal to Central axis)
3.1.1.1.2 Axial Ratio between 81° and 99°	30 db Min	30 db Min
3.1.1.1.3 Nominal 3 db Beamwidth	40° (= 70° to 110°)	40° (= 70° to 110°
3.1.1.1.4 Minimum Gain all Ø		
= 90°	3.5 dbi	3.5 dbi
= 81° to 99°	3.0 dbi	3.0 dbi
= 70° to 110°	0.5 dbi	0.5 dbi
3.1.1.1.5 Isolation between Terminal 1 and Terminal 2	30 db	20 db
3.1.1.1.6 VSWR	1.5/1 Max	1.5/1 Max
3.1.1.1.7 Power Sea Level to Vacuum	5 watts min	N.A.

3.1.2 Operability

3.1.2.1 Reliability

Each CR&T Omni Antenna shall have a probability of survival of 0.990 for 8 years of orbital operation in the environment specified in Paragraph 3.3.2.

3.1.2.2 Useful Life

The useful life shall be the sum of the mission life and shelf life. All performance requirements shall be met over the life of the equipment.

3.1.2.2.1 Shelf Life

The unit shall be capable of meeting the storage requirements of Para. 3.3.3 without service or parts replacement (except age sensitive items). In addition the unit will be subjected to a maximum of two months of orbital mode operation (except radiation) during ground testing.

3.1.2.2.2 Mission Life

The in-orbit mission life of the unit shall be a minimum of eight years. The unit shall be capable of continuous operation in orbit.

3.2 Interfaces

3.2.1 Mounting

The unit shall be mounted by means of four screws as shown in Fig. 1.

3.2.2 Connectors

Terminal 1 - SMA Male
Terminal 2 - SMA Female

3.3 Design and Construction

3.3.1 General Design Features

The unit shall comply with materials, parts, process and workmanship requirements of RCA2272349.

3.3.1.1 Envelope

The unit shall comply with the envelope drawing shown in Fig. 1.

3.3.1.2 Weight

The maximum weight of the unit shall be less than 1.0 pounds.

3.3.1.3 Material

The material interfacing with the spacecraft support structures shall be aluminum.

3.3.2. Environmental Requirements

3.3.2.1 General

The unit shall be capable of withstanding launch and orbital environment as specified herein without failure, malfunction, or degradation in performance.

3.3.2.2 Pressure

The unit shall be capable of performing within specification requirements at all ambient pressures from sea level to deep space (10^{-10} Torr).

3.3.2.3 Thermal

a) Orbit Thermal Environment - The unit shall operate within specification from - 80°C to 50°C.

b) Thermal Vacuum - The unit shall be capable of meeting the specified performance after exposure to the thermal vacuum profile delineated in RCA 2272351.

3.3.2.4 Vibration

The unit shall be capable of meeting all specification performance requirements after exposure to the vibration environment specified in RCA 2272351 for the protoflight and flight units.

3.3.2.5 Radiation

The unit shall meet all specification performance requirements while exposed to the space radiation environment. The design requirements for the radiation environment will be satisfied by worst case performance analysis based upon the exposure levels specified in RCA 2272680, RCA Satcom Interface Specification.

3.3.3 Storage

The unit shall be capable of being stored for a maximim of 5 years in a suitable protective container under controlled conditions of humidity and temperature (30 to 50% R.H. and 72 $\pm$5°F). Age sensitive parts, materials, and components shall be subject to special identification and controls (these are to be treated in the Quality Assurance Plan). During the storage period, the assembly may be subjected to intermittent or continuous tests of a non-destructive character.

3.4 Identification and Marking

3.4.1 Identification

The unit shall be identified with the part number and serial number in accordance with RCA2272349.

3.4.2 Terminals

The terminals shall be identified as indicated in Table 1 and Fig. 1.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Testing

The units shall be tested for compliance with the performance requirements as shown in Table II.

Table II

Paragraph	Parameter	Proto	Flight	Post Environmental
3.1.1.1.2	Axial Ratio	X	X	X
3.1.1.1.3	Beamwidth	X	-	-
3.1.1.1.4	Minimum Gain	X	X	-
3.1.1.1.5	Isolation	X	X	-
3.1.1.1.6	VSWR	X	X	X
3.1.1.1.7	Power	X	-	-
3.3.2.1	Temperature*	X	X	-
3.3.2.2	Vibration**	X	X	-

* The unit shall be cycled 4 times from - 80°C to +50°C while monitoring VSWR.

** The VSWR shall be monitored during vibration testing.

5.0 PREPARATION FOR DELIVERY

Preparation for delivery shall be in accordance with RCA 2272349.

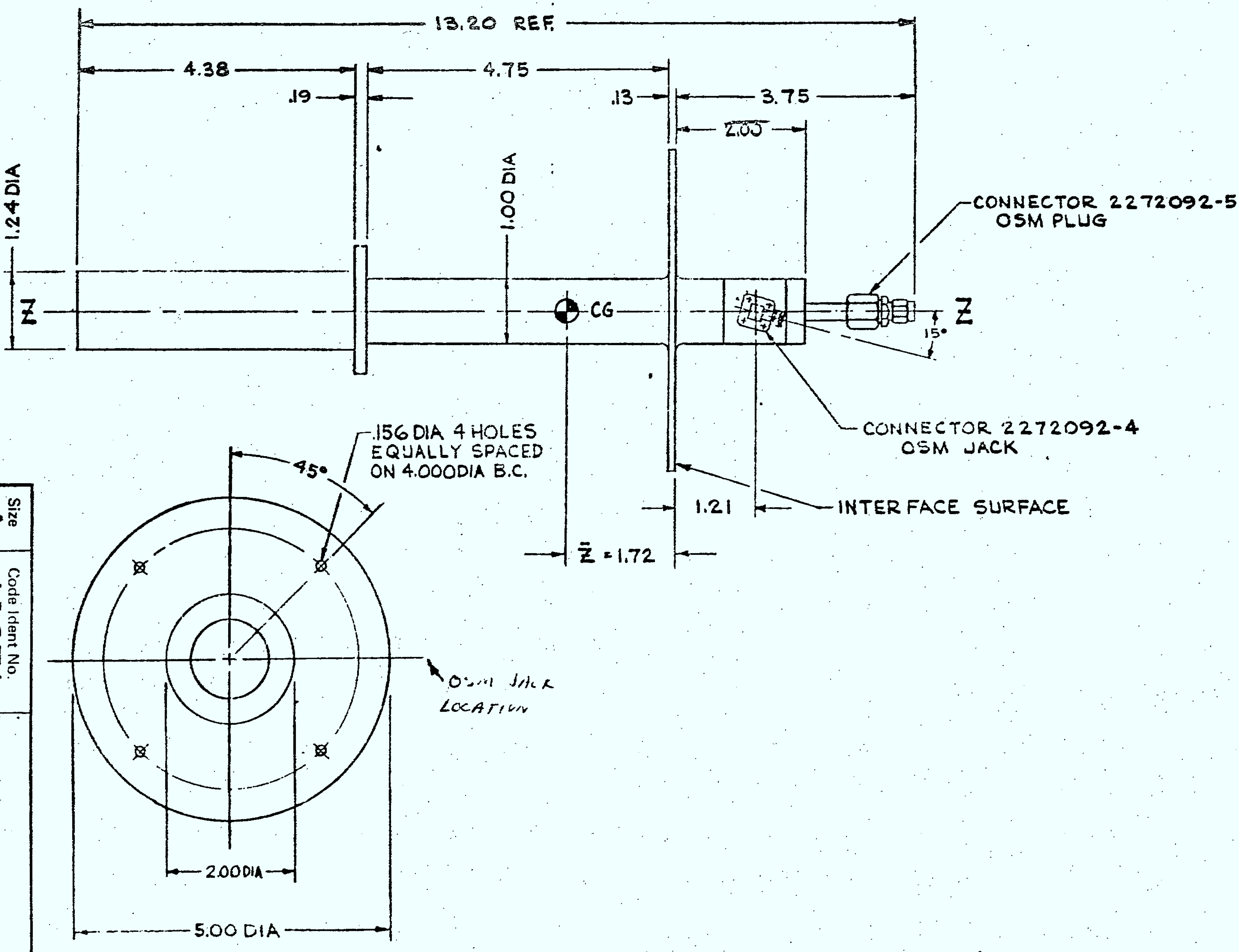


FIGURE 1 OUTLINE DRAWING (2283425)

Size A | Code Ident No. 49671 | 25-2278136

4.0 PROPOSED CR&T SUBSYSTEM

4.0 Suggested Command, Ranging and Telemetry Subsystem

Operating frequency

The optimum choice of operating frequency for the CR & T subsystem of the UHF/SHF Satellite would appear to be 4/6 GHz, from the following considerations:

1. VHF/UHF operation is considered impractical because NASA's launch support operations at these frequencies are being phased out by the late '70's. In addition, band occupancy is very high at these frequencies, generating interference problems. Little protection against interfering signals (either deliberate or unintentional) can be provided by antenna directivity.

   European launch support facilities at VHF are available, but the station locations are intended primarily for polar orbits, and are thus not really suited to control equatorial orbit operations.

2. S-band (2 GHz) is also not suitable, as frequency assignments (North America) in this band are normally for scientific or experimental spacecraft. It is unlikely that an assignment would be available for an 8 year lifetime operational satellite, except possibly for launch (and subsequent back-up) use only. This would require two different RF systems, and the "dead-weight" penalty eliminates this from further considerations.

3. 12/14 GHz may be considered to be reasonably practical, especially for the case where the communications sub-system operates at the same frequency. Use may then be made, for example, of the communications antenna gain and directivity.

3. (Continued)

However, there are some negative aspects:-

- Availability of space-qualified RF units
- High path loss
- Lack of comprehensive world wide facilities to support launch
- Probably more expensive ground station equipment
- The spacecraft TT & C would probably require a significant hardware interface with the Communications subsystem (use of spare TWT, antenna, multiplexers, etc.) This sub-system inter-dependence is a definite disadvantage in the design, implementation and testing phases, and possibly also in operation during an 8 year mission.

One advantage of a 12/14 GHz system is that the ability to provide command link protection by antenna directivity is enhanced, for the same spacecraft antenna dish size, as compared with a 4/6 GHz system.

From the above considerations, it is therefore concluded that the operating frequency of the CR & T subsystem should be 4/6 GHz, for both the UHF 4/6 and UHF /12/14 versions of the Communications package.

Adequate telemetry and command margin can be obtained using small, uncomplicated omni-antennasfor both launch and on-station operation.

Block Diagram

The proposed block diagram for a 6/4 GHz CR & T subsystem is shown in Figure 4.1.

Uplink

Two omni-directional antennas provide uplink command capability for all angles of spacecraft attitude. The launch antenna provides the coverage required during the transfer orbit whilst the orbit antenna provides coverage when the spacecraft is on station. These omni-directional antennas are coupled to the receivers via two 4-port quadrature hybrids. The spot beam antenna is coupled to the receiver via a port of one of the quadrature hybrids as shown in the block diagram.

Each of the omni-directional antennas consists of two separate antennas, one at the uplink frequency of 6 GHz, the other at the down link frequency of 4 GHz. This configuration gives approximately 40 dB of isolation between the transmit frequency and the receive frequency.

The uplink frequency is vertically polarised and the nominal flux density at the spacecraft is $-80\ \mathrm{dBw/m^2}$. This translates to a signal power at the antenna port of -117.7 dBw, as shown below:

The receiving area of an isotropic antenna is given by

$$A_R = \frac{\lambda^2}{4\pi}$$

At a receive frequency of 6.4 GHz

$$\lambda = \frac{3 \times 10^8}{6.4 \times 10^9} = 0.0469$$

$$A_R = \frac{(0.0469)^2}{4\pi} = 1.7 \times 10^{-4}$$

$$= -37.69 \text{ dB below } 1\mathrm{m}^2$$

$$\text{Antenna power} = -80 \ -37.69$$

$$= \underline{\underline{117.69 \text{ dBw}}}$$

The losses between the antenna and the receiver would be made up as follows:-

Cable loss	2.5
3 dB Hybrid	3.5 dB
	6.0 dB

the power at the receiver terminals is −117 + 6 = −123.7 dBw

The command receivers operate in active redundancy with power applied at all times.

FM has been chosen for the uplink modulation because it provides the greatest protection from interfering signals. An analysis showing the expected protection provided by a typical F-M receiver coupled to the receive antenna system is shown in Appendix 3 .

The signal interface between the receiver and decoder is the demodulated FSK tones.

The recommended interface between the uplink and the spacecraft is the command output of the decoder. The command output consists of the required number of command channels. Each command channel provides a command output pulse on receipt of an execute pulse.

The uplink will almost certainly be encrypted, in which case a decryption unit will follow the decoder.

Downlink

The encoder monitors spacecraft data in the form of analog channels and flags and encodes these onto a sub-carrier oscillator. PAM has been chosen over PCM because it provides:

adequate accuracy

is simpler than PCM

and is compatible with present ground stations

Real time data is also encoded onto a sub-carrier oscillator.

The encoder output consists of two sub-carrier oscillators, either of which may be selected to phase modulate either transmitter. The deviation chosen ensures that there is always an adequate residual carrier for tracking. The transmitters operate in standby redundancy and may be coupled to either antenna via a transfer switch.

Two downlink frequencies have been chosen, one at 3.7 GHz, the other at 4.2 GHz. This gives the advantage of being able to transmit simultaneously using both transmitters. With both transmitters on simultaneously at the same nominal frequency, the ground station receiver is unable to discriminate between the two frequencies which would have a small finite frequency separation. An alternative is to phase-lock both transmitters to the same drive source. This would, however, remove the redundancy between transmitters.

Powering both transmitters, one at 3.7 GHz and the other at 4.2 GHz during the transfer orbit gives almost complete ground coverage regardless of the spacecraft attitude.

The power output of each transmitter is 1 watt. Assuming a 2 dB coaxial switch and cable loss, this provides an EIRP of -2 dBw from the omni-antennas.

The power output of the transmitter can be reduced to 0.1 watts on station if the communications antenna is used.

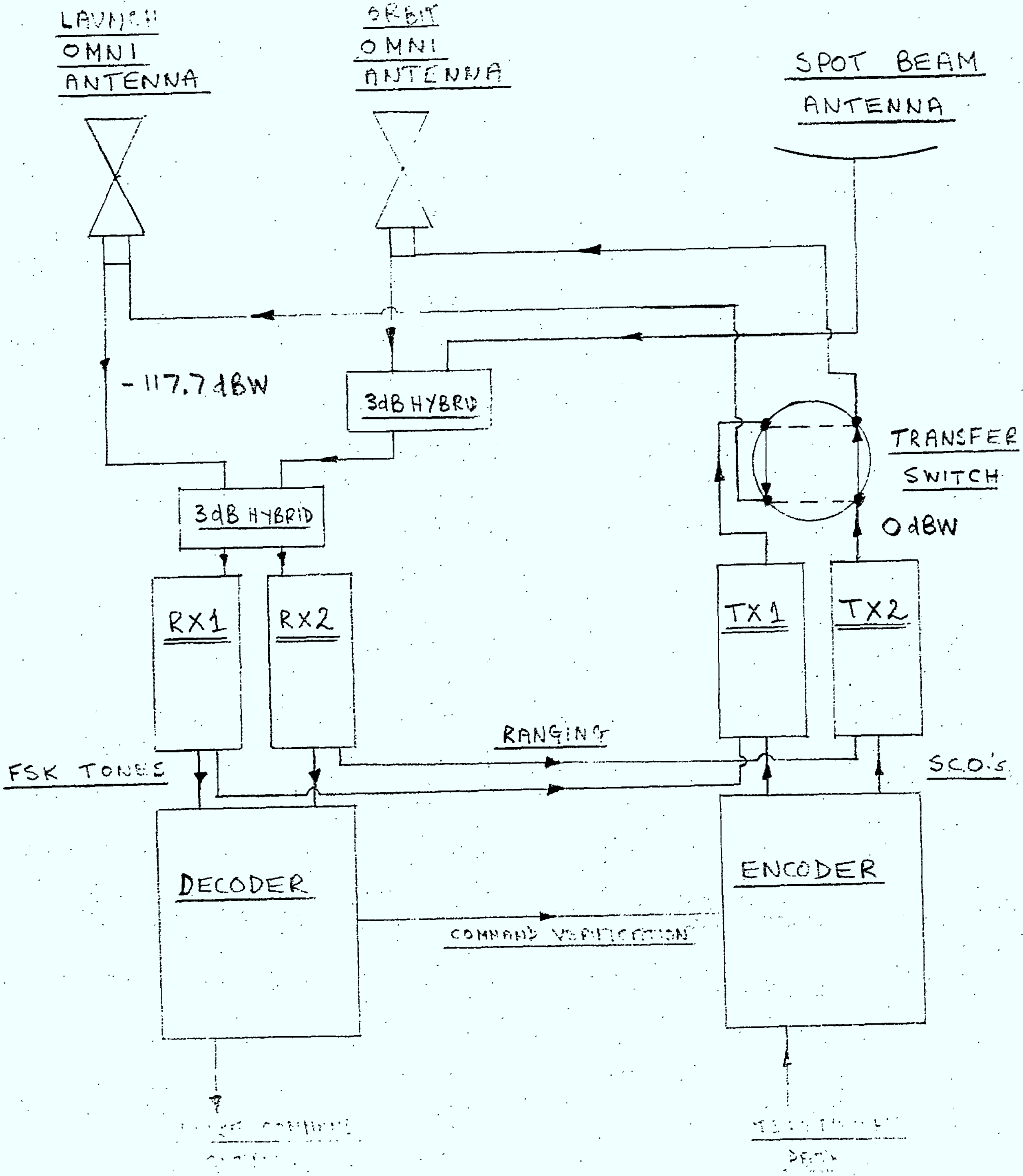

LAUNCH
OMNI
ANTENNA
ORBIT
OMNI
ANTENNA
SPOT BEAM
ANTENNA
-117.7 dBW
3dB HYBRID
3dB HYBRID
TRANSFER
SWITCH
0 dBW
RX1
RX2
TX1
TX2
RANGING
FSK TONES
SCO's
DECODER
ENCODER
COMMAND VERIFICATION

FIG 4.1

5.0 SYSTEM PARAMETERS

5.0 SYSTEM PARAMETERS

5.1 RF Link Requirements

5.1.1 Telemetry/Beacon Link

The signal-noise ratio requirements for the various baseband signals modulated on to the down link carrier are derived as shown in Appendices 2, 4 and 5, and summarized as below:

SIGNAL		S/N dB	Bandwidth Hz	S/No dB/Hz
Telemetry		23	2600 Hz	50.7
Sensor Data		16.3	4800 Hz	46.8
Range Tone	1	35		35
	2	35		35
	3	35		35
	4	35		35

The above tabulation is based on the following assumptions:-

1. Telemetry accuracy required is ± 2.5% of full scale
2. Angle accuracy (sensor data) is 0.025° R.M.S.
3. Ranging accuracy better than ± 50 metres for the 27 kHz tone.

We will assume that only one of the range tones is present at any given time (the fine resolution tone or one of the three ambiguity resolution tones).
Further, to limit spacecraft transmitter power, we will allow the down-link to contribute 90% of the total noise.

Thus,	S/No (total)	=	35 dB
	S/No (up)	=	45 dB
and	S/No (down)	=	35.5 dB

To simplify the apportionment of the total downlink deviation to the baseband signals, we will round off to 51 dB, the S/No requirement for the two SCO signals. Also, since we are proposing a dual frequency down link, we can propose that only one SCO frequency be used - Transmitter A carrying Telemetry data on its SCO, and Transmitter B carrying Sensor data on its SCO.

Thus, modulating a transmitter, we have one signal at S/No 51 dB and one at S/No 35.5 dB.

The recoverable power in the 1st order sidebands of the nth sinewave subcarrier is

$$P = \frac{2 J_1^2 (x_n)}{J_o^2 (x_n)} \prod_{i=1}^{n} J_o^2 (x_i) . \; Po \qquad \ldots\ldots\ldots \quad (1)$$

where $J_o(x)$ = zero order Bessel function

$J_1(x)$ = first order Bessel function

x_n = phase deviation of the nth sinusoidal sub-carrier

x_i = phase deviation of the i th sinusoidal sub-carrier

The power remaining in the carrier after modulation by n sinusoidal sub-carrier is

$$P_c = P_o \prod_{i=1}^{n} J_o^2 (xi)$$

Let us now define 'modulation loss' as the ratio of the unmodulated carrier power to the recoverable power in the 1st order sidebands of the nth subcarrier.

i.e., $ML = \frac{Po}{P_n}$

$$M_L{}^{-1}{}_{(n)} = \frac{2 J_1^2 (xn)}{J_o^2 (xn)} \prod_{i=1}^{n} Jo^2 (xi) \qquad \ldots\ldots\ldots$$

We have one sub-carrier requiring an S/No of 51 dB and one requiring an S/No of 35.5 dB. Let the required deviation for the first signal be x_a and that for the second be x_b.

Thus, from equation 1,

$$\frac{\text{1st order sideband power for tone at } x_a \text{ deviation}}{\text{1st} \quad " \quad " \quad " \quad " \quad x_b \text{ deviation}} = \frac{\frac{2J_1^2(xa)}{Jo^2(xa)} \; Jo^2(xa) \quad Jo^2(xb) \; Po}{\frac{2J_1^2(xb)}{Jo^2(xb)} \; Jo^2(xb) \quad Jo^2(xa) \; Po}$$

$$= 51 - 35.5 \text{ dB}$$

$$\frac{J_1^2(xa)}{J_0^2(xa)} - \frac{J_1^2(xb)}{J_0^2(xb)} = 15.5 \text{ dB} \qquad \ldots\ldots\ldots\ldots(\ \ )$$

Thus, for any value of x_a, there is a corresponding value for x_b which sets the power ratios as required. We can now tabulate values for x_a, and the corresponding values for x_b, M_La and M_Lb, and choose the optimum values, for minimum modulation loss consistent with the limit imposed on the maximum down link deviation, by the requirements of the ground receiver.

From Table 1, the minimum modulation loss occurs for values x_a and x_b which produce a peak phase deviation of about 2.2 radians. To simplify the ground receiver, we shall use a maximum down link deviation of, say, 1.4 radians,

thus, we choose $x_a = 1.12 \rightarrow M_{La} = -3.55$ dB

$x_b = 0.23 \rightarrow M_{Lb} = -18.87$ dB

TABLE 1

x_a	$2J_1^2(xa)$	$Jo^2(xb)$	M_{La}	x_b	$2J_1^2(xb)$	$Jo^2(xa)$	M_{LB}
0.8	-5.65	-0.05	-5.7	0.15	-19.5	-1.45	-20.95
0.88	-4.98	-0.065	-5.045	0.165	-18.7	-1.77	-20.47
0.96	-4.39	-0.075	-4.465	0.185	-17.8	-2.13	-19.93
1.04	-3.87	-0.09	-3.96	0.2	-17.0	-2.53	-19.53
1.12	-3.43	-0.12	-3.55	0.23	-15.9	-2.97	-18.87
1.22	-2.95	-0.14	-3.09	0.25	-15	-3.59	-18.59
1.30	-2.64	-0.17	-2.81	0.28	-14.15	-4.15	-18.3
1.50	-2.06	-0.2	-2.26	0.36	-12.03	-5.82	-17.85
1.70	-1.75	-0.5	-2.25	0.47	-9.8	-8.00	-17.8
2.0	-1.77	-1.4	-3.17	0.79	-5.7	-13.0	-18.7

Transmitter Power Calculation

We require $\frac{S}{No}$ = 51 dB at the ground receiver output.

But S = received carrier, C - modulation loss ML_a

= C - 3.55

& No = kT where

M_La = 3.55 dB for Ø = 1.12 rads

k = Boltzmann's constant

= 1.38 10^{-23}

T = ground station receiving noise temperature

Hence C = 51 + 10 log kT + 3.55

But received carrier C = E.I.R.P. from spacecraft - path loss L_p + ground antenna gain G

= E.I.R.P. - L_p + G

Typical parameters, for say an Intelsat type station

L_p = 196.7

G = 50.4 dB

T = 100°K

kT = -208.6 dBw/Hz

E.I.R.P. required = 51 - 208.6 + 3.55 + 196.7 - 50.4

= -7.75 dBw

It is reasonable to assume a gain of 0 dB from the omnidirectional TT/C antenna (see Section 3).

Diplexing and cable losses between the transmitter and antenna will be typically 2 dB, say. Thus, to produce an EIRP of -7.75 dBw, the transmitter power must be

P_T = -7.75 - 0 + 2 dBw

= -5.75 dBw

= 266 mW

Transmitter Power Calculation

Power output in the 500 mW - 3W range are practical, and obtainable in existing versions.

Thus, with say a 1 watt transmitter, the telemetry downlink would have a margin of 6 dB.

Tracking Carrier Level

The power remaining in the carrier after modulation by the two signals at 1.12 rads and 0.23 rads is given by

$$Pa = Po \; Jo^2 \; (1.12) \; Jo^2 \; (0.23)$$

$$\text{i.e.,} \quad \frac{Pa}{Po} = -2.97 + 0.12$$

$$= -3.09 \text{ dB}$$

- received carrier level = -7.25 - 196.7 + 50.4 - 3.09 = -156.64 dBw

If the tracking station noise temperature is 100°K, the system noise density

$$No = -208.6 \text{ dBw/Hz}$$

Noise power in	3 kHz bW	300 Hz
	-173.8 dBw	-183.82
Received carrier power	-156.64 dBw	-156.64
C/N ratio for tracking	20.16 dB	27.17

Since the ground receiver loop requires a minimum of 6 dB C/N for acquisition, there is adequate margin for tracking.

5.1.2 Command Link

The deviations required for the command tones and the ranging tone are derived in Appendix 4, on the assumption that an error rate of 1 in 10^6 or more should be provided down to a carrier to noise ratio of 5 dB at the receiver input.

Receiver Carrier Power at the Receiver

$$P_R = P_T + G_T + G_R - L_p - L_a \qquad \ldots\ldots\ldots \quad (1)$$

where

P_r = ground transmitter power

G_r = transmit antenna gain

G_R = receive antenna gain

L_p = path loss

L_a = atmospheric loss

Equivalent noise power at the receiver input

P_r = kTBF

= -137.8 dBw

where k = Boltzmann's constant = 1.38 10^{-23}

T = Absolute temperature = 300^ok

B = Receiver noise bandwidth = 400 kHz

F = noise figure = 10 dB typical

We can now determine the ground station E.I.R.P. which is required to produce a C/N of 5 dB at the receiver

We require $P_R = P_N + 5$

$= -132.8$ dBw

and from (1) $= P_T + G_T + G_R - L_p - L_a$

But $P_T + G_T$ = E.I.R.P. required

required E.I.R.P. $= P_R - G_R + L_p + L_a$

5.1.2 <u>Command Link</u> (Cont.)

We shall assume, to be realistic, that $G_R = 0$ dB, and a cabling and hybrid loss of 6 dB between the antenna and receiver

Path and atmospheric losses are as derived in Appendix 4.

Thus, E.I.R.P. = $-132.8 - 0 + 6 + 200.7 + 1$ dBw

$= +74.9$ dBw

If we now add an operating margin of 5 dB (producing a C/N of 10 dB at the receiver), the ground station E.I.R.P. requirement becomes +80.9 dBw.

PROPOSED SUB-SYSTEM PERFORMANCE PARAMETERS

GENERAL

Operating Frequency,	Command	6 GHz
	Telemetry/Beacon	4 GHz
Carrier Modulation,	Command	FM
	Telemetry/Beacon	PM
Ranging	4 Tone CW	
Range Tone Frequencies	27 kHz, 4 kHz, 280 Hz, 35 Hz	
Redundancy	All Units Redundant	

COMMAND

PCM/FSK/FM (35 kHz Deviation of 6 GHz)

FSK Tones	2 groups of 3 frequencies (1, 0 & Execute), 5 - 12 kHz
Command Capacity	256

RANGING

FDM/FM Uplink (8.3 kHz Deviation of 6 GHz)

FDM/PM Downlink (0.25 Rads Deviation of 4 GHz)

The Three Low Frequency Ambiguity Resolution tones are transmitted as sidebands of a 19 kHz Subcarrier Tone.

TELEMETRY

PAM/FM/PM (1.12 Rads Deviation of 4 GHz)

256 Point Capacity, 2.5% accuracy

IRIG Sub-Carrier Carries either Telemetry or Attitude Sensor Data

6.0 INTERFACES

6.0 INTERFACES

6.1 Power Sub-system

The principle of having a 'raw' common supply rail within the spacecraft, with each unit containing its own converter/regulator, is proposed as the optimum approach. This method minimizes the interaction between the Power and the TT & C Subsystems during the specification and development phases of the project, and also minimizes the unit EMC problems. It also precludes a major single point failure.

Typically, therefore, each powered unit of the TT & C subsystem would be designed to operate from a supply rail of, say, 24 - 35 volts, and would contain internal regulation and EMC provisions as required by that particular unit.

6.2 Command Interfaces

All command instructions to the spacecraft are in the form of logic level pulses at the command decoder output lines. Pulse width is approximately 35 mS, and amplitude 5V.

6.3 Telemetry Interfaces

Each analog channel provides an input impedance $> 1\ M\Omega$, and accommodates an input range of 0 - 5V. Flags are accommodated by encoding 3 Flags (at a time) into an 8-level voltage, and treating this as an analog point.

6.4 Command and Telemetry Requirements of the TT & C Subsystem

For monitoring and control of the TT & C Subsystem, the following Command and Telemetry points will be typically required.

6.3.1 Command

1) Select Tx – Antenna combination 1
2) Select Tx – Antenna combination 2
3) Telemetry, dwell, Encoder A
4) Step command, commutator, Encoder A
5) Telemetry, dwell, Encoder B
6) Step command, commutator, Encoder B
7) Telemetry, commutated, Encoder A
8) Telemetry, commutated, Encoder B

6.3.2 Telemetry

Sync	5 analog points
Amp. calibration	2 analog points
Command verification	6 analog points
Monitor received signal (AGC)	2 analog points
Temperature Tx 1	1 analog point
Temperature Tx 2	1 analog point
Position monitor, RF switch	1 Flag

6.5 Communications Subsystem

A single RF interface is proposed, via the output multiplexer, to enable the reception of command transmissions via the communications spot beam antenna.

7.0 GROUND STATION REQUIREMENTS

7.0 GROUND STATION REQUIREMENTS

For operational use, the TT & C ground station for the UHF Satellite will be required to provide the up and down link RF parameters as derived elsewhere in this report, and summarized below.

RF Parameters

Uplink

Frequency	6 GHz band
E.I.R.P.	+ 81 dBw, at single frequency
Carrier Modulation	FM

Down-link

Frequency	4 GHz band		
Receiving System	$\frac{G}{T}$	30	dB/°K

Carrier Demodulation PM

Since dedicated facilities are obviously required, the use of existing Canadian ground stations, e.g., Allan Park, Ontario, Lake Cowichan, B.C., and Communications Research Centre, requires the provision of new antennas and ground equipment at those sites.

As shown elsewhere, the use of a spot beam antenna for command reception at the spacecraft gives a very worthwhile degree of command link immunity to interfering signals, and it is therefore desirable to consider a geographical location for the TT & C control station which takes maximum advantage of this feature. This location may also fortuitously fit in with the requirements of any proposed military or commercial communications ground station network.

For launch and positioning operations, use may be made of suitably located 4/6 GHz ground station facilities of Intelsat to provide initial tracking and orbit determination. Firing of the apogee and station acquisition could be controlled from the UHF Satellite main TT & C Station.

APPENDIX I GROUND STATION PARAMETERS

NASA STDN

VHF Station typical parameters.

Command

Frequency	147 - 155 MHz
Antenna gain	17 dB
Beamwidth	13°
Tx power output	200W
	2500W
	5000W

Telemetry

Frequency	136 - 138	
Antenna gain	20 dB	21 dB
Beamwidth	15°	13°
Receiving noise figure 3.5 dB		

Telesat Ground Station parameters 4/6 GHz

Tracking Telemetry & Command Antenna (TTAC)

Used during transfer orbit, and prior to the arrival of a Satellite on Station.

Reflector diameter			36 feet (11 m)
Antenna gain			51 dB at 4 GHz
			54.5 dB at 6 GHz
G/T	28 dB/^oC	at	4 GHz
EIRP			85 dBW at 6 GHz

Telemetry & Command Antenna (for ANIK 2) (Anik 1 uses HR on station) (TAC^2)

Reflector diameter			26.5 ft.	
Antenna gain			48 dB at 4 GHz	
			51 dB at 6 GHz	
G/T	20.5^odB/^oK	at	4 GHz	EIRP 76 dBW

Transportable Tracking Station (Guam)

Reflector diameter		24 ft.
G/T	28 dB/^oK	(with cooled parametric amplifier)
EIRP		85 dBW at 6 GHz.

INTELSAT

The INTELSAT TT & C ground station network includes stations at Carnarvon and Fucino, Italy. This system also operates in the 4 GHz/6 GHz region, with typical ground station parameters as listed below.

Telemetry 4 GHz		Command 6 GHz	
Antenna gain	51.4 dB	Antenna gain	54.8 dB
feeder loss	2 dB	feeder loss	2 dB
Noise Temperature	100°K	Transmit power	+40 dBW
$\frac{G}{T}$	30.4 dB/°K	E.I.R.P.	92.8 dBW

Globecom (Satcom) parameters 4/6 GHz.

Uses Intelsat Station (s) for tracking, 1st transfer orbit

Down link	Up-link
G 51.4 dB loss 2 dB	Tx +40 dBW loss 2 dB
T 100°K	Ant. gain 54.8 dB
- 150.3 dBW received signal	EIRP 92.8 dBW
$\frac{G}{T}$ 30.4 dB	

Globecom East / West Coast USA Command Stations

G 50.4 dB 2 dB loss	Tx +34.8 dBW 2 dB loss
Rx Signal - 151.3 dBW	Ant. gain 54.1 dB
T 80°K	EIRP +86.9 dBW
$\frac{G}{T}$ 30.4	

Spacecraft EIRP -1dBW

APPENDIX II RANGING

RANGING

Determination of spacecraft range is normally achieved by transmitting ranging tones from a ground station to the spacecraft, which retransmits the tones back to ground via a transponder.

Due to the finite velocity of the electromagnetic radiation, the received tones undergo a phase delay with respect to the transmitted tones. This phase shift is a measure of the spacecraft range.

Digital ranging techniques can also be used to determine range. A pseudo-random binary code modulates the up-link carrier, and is transponded by the spacecraft back to the ground station, where the received ranging code is compared with a time shifted code provided by the ranging system, and thus round trip time for the code is determined.

It is usual practice to use the Command System receiver and the Telemetry System transmitter as the ranging transponder. The NASA Goddard Range and Range Rate (GRRR) System requires a phase-coherent transponder, i.e., coherence of the up-link frequencies must be maintained through the transponder and back to the ground receiver, where frequency comparison against a sample of the up-link frequency extracts Doppler information, thus giving range rate (spacecraft velocity).

Operation of the GRRR system is at frequencies in the VHF band, and also at 2 GHz.

In the Tone ranging system, range rate information can be extracted if required by a process of differentiation of the continuous 'range' output. Commercial spacecraft operation favours the use of tone ranging, and suitable facilities exist at Canadian ground stations.

RANGING (Continued)

The accuracy of the range measurement obviously depends on the accuracy with which the phase shift can be determined. If the phase measurement accuracy is independent of frequency, then the ranging accuracy is better at higher frequencies, since a given phase uncertainty corresponds to a shorter time uncertainty, i.e., a smaller range uncertainty.

Let us assume we wish to measure the spacecraft range with an accuracy of say, ± 100 metres.

The following factors establish the limits of accuracy:

1) uncertainty in the measurement of phase
2) uncertainty of delay time in the ground equipment
3) uncertainty in the turn-round' time through the spacecraft transponder.
4) noise introduced in the up and down links.

The first two of these factors are contributed by the ground equipment, and in any case, the second can probably be eliminated by calibration.

Let us assign 75% of the total permissible uncertainty to the spacecraft portion of the system (i.e., factors 3) and 4) are allowed to contribute ± 75 metres of uncertainty), and the remaining 25% to the phase measurement accuracy. Thus, we can perform sample calculations as to the contribution of the various factors.

1) If we assume that phase measurement accuracy is 2°, then the lowest range tone frequency that will provide the required $\pm$ 25 metres accuracy can be determined.

We have $\Delta_R = \frac{\Delta t}{2} \times C$ (the factor 2 allows for the fact that the range tone travels the same path twice - up-link and down-link)

where Δ_R = range uncertainty

Δt = time uncertainty

C = velocity of electromagnetic radiation

= 3×10^8 metres/second

$$\Delta_R = \frac{\Delta \phi}{360} \cdot \frac{1}{2f} \times C \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where $\Delta \phi$ = phase uncertainty

f = range tone frequency

$$f = \frac{\Delta \phi}{360} \quad \frac{1}{2\Delta_R} \cdot C$$

$$= \frac{2}{360} \quad \frac{1}{25} \quad \frac{3}{2} \quad 10^8$$

$$= \underline{\underline{33.3 \text{ kHz}}}$$

A plot of equation 1, with range tone frequency as the variable parameter, is shown in Figure 3 .

2) As previously stated, this contribution is assumed to be subject to calibration.

3) The turn-around time through the ranging transponder can be calibrated before launch. However, during the life of the spacecraft, there will be slight variations due to temperature, equipment, aging, etc. If the variation is Δt, in seconds, then the resulting range uncertainty is $\frac{\Delta t \times C}{2}$, i.e., 0.15 metres/nS.

A reasonable allowance for delay variation over the mission lifetime is possibly $\pm$ 100 nS.
This would correspond to a range uncertainty of $\pm$ 15 metres.

4) This leaves $\pm$ 60 metres as the permissible uncertainty contributed by noise, and we may determine the required signal-to-noise ratio as follows:

Let $\Delta \phi$ be the total RMS noise deviation in radians (up and down link).
Then the signal-to-noise power ratio

$$\frac{S}{N} = \frac{1}{2(\Delta \phi)^2}$$

If the peak noise deviation is $K \Delta \phi$, the range error introduced is

$$\Delta_R = \frac{K \Delta \phi}{2\pi} \times \frac{C}{f} \times \frac{1}{2}$$

$$= \frac{KC}{4\pi} \frac{1}{f} \sqrt{\frac{1}{2} \frac{1}{S/N}} \quad \ldots\ldots\ldots\ldots (2)$$

For noise of Gaussian distribution, we may take the 3σ value for K, i.e., 99.75% probability that the peak noise is less than or equal to $3 \Delta \phi$. Thus, for a range tone at 33.3 kHz, the required S/N from eq^n 2 is:

$$\frac{S}{N} = \frac{9 \times C^2}{16 \times \pi^2} \frac{1}{f^2} \frac{1}{2} \frac{1}{\Delta R^2}$$

4) (Continued)

$$= \frac{9 \times 10^{16}}{\pi^2 \; 33.33^2 \; 10^6 \; 2 \; 3600} \qquad \frac{9}{16}$$

$$= 28 \text{ dB}$$

Equation 2 is plotted with f as a parameter, in Figure 2 .

Ambiguity Resolution

For a tone of frequency f, a phase difference of $\Delta \phi$ radians between sent and received tones corresponds to a range of

$$\frac{\Delta \phi}{2\pi} \quad \frac{1}{f} \quad \frac{C}{2}$$

If the range is such that $\Delta \phi > 2\pi$, then there is range ambiguity at intervals of $\lambda/2$. Obviously, to ensure complete freedom from ambiguity, the frequency must be such that the maximum range is

$$\frac{2\pi}{2\pi} \cdot \frac{1}{f} \quad \frac{C}{2} \qquad \text{i.e.,} \qquad f = \frac{C}{2R}$$

For an orbit having an apogee of approximately 22,300 nautical miles, this frequency is about 3.6 Hz.

However, much is known about the orbit quite early in the orbital manoeuvers, and much of the ambiguity is effectively eliminated. If the range is known to within, say, 10,000 km, then the lowest frequency which is required to resolve this ambiguity is

$$f = 3 \times 10^8 / 10 \times 10^6 \times 2$$

$$= 15 \text{ Hz}$$

Since the phase measurement accuracy is essentially independent of range tone frequency, the range uncertainty from the low frequency measurement can exceed the ambiguity interval of the high frequency measurement, and it is necessary to introduce a third and fourth tone to overcome this.

The frequency ratio between the tones must be chosen such that the total error due to noise and phase measurement accuracy at one tone frequency, is less than the ambiguity interval at the next frequency. Let us set the limit as half of the interval. Thus, from equations 1) and 2), we have

$$\text{Range-error at } f_1 \text{ is } \frac{\Delta \phi}{2\pi} \quad \frac{1}{2 f_1} \quad C + \frac{3C}{2\pi} \quad \frac{1}{2 f_1} \left(\frac{1}{2} \quad \frac{1}{S/N} \right)^{1/2} < \frac{1}{2} \quad \frac{C}{2 f_2}$$

from which

$$\frac{f_2}{f_1} \left[\Delta \phi + 3 \left(\frac{1}{2} \quad \frac{1}{S/N} \right)^{1/2} \right] < \pi \quad \ldots\ldots\ldots (3)$$

This equation is plotted in Figure 1, which assumes that $\Delta \phi$, the phase measurement accuracy is 2°.

If the frequency ratio is r, then we have

$$r^N = \frac{f_{max}}{f_{min}}$$

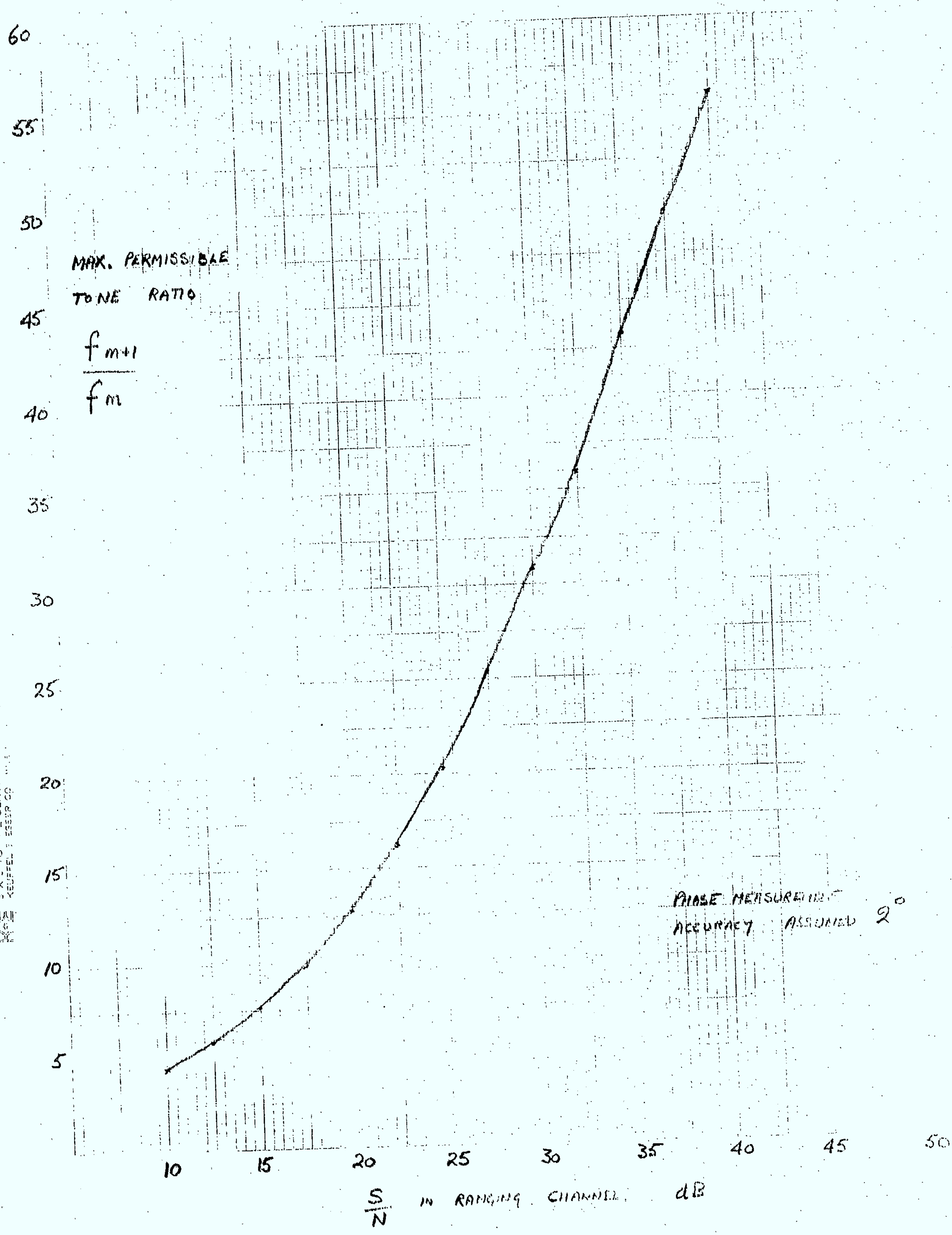
f_{max}	=	range tone frequency giving required range accuracy
f_{min}	=	lowest tone frequency providing desired ambiguity resolution
N	=	number of tone intervals at ratio r.

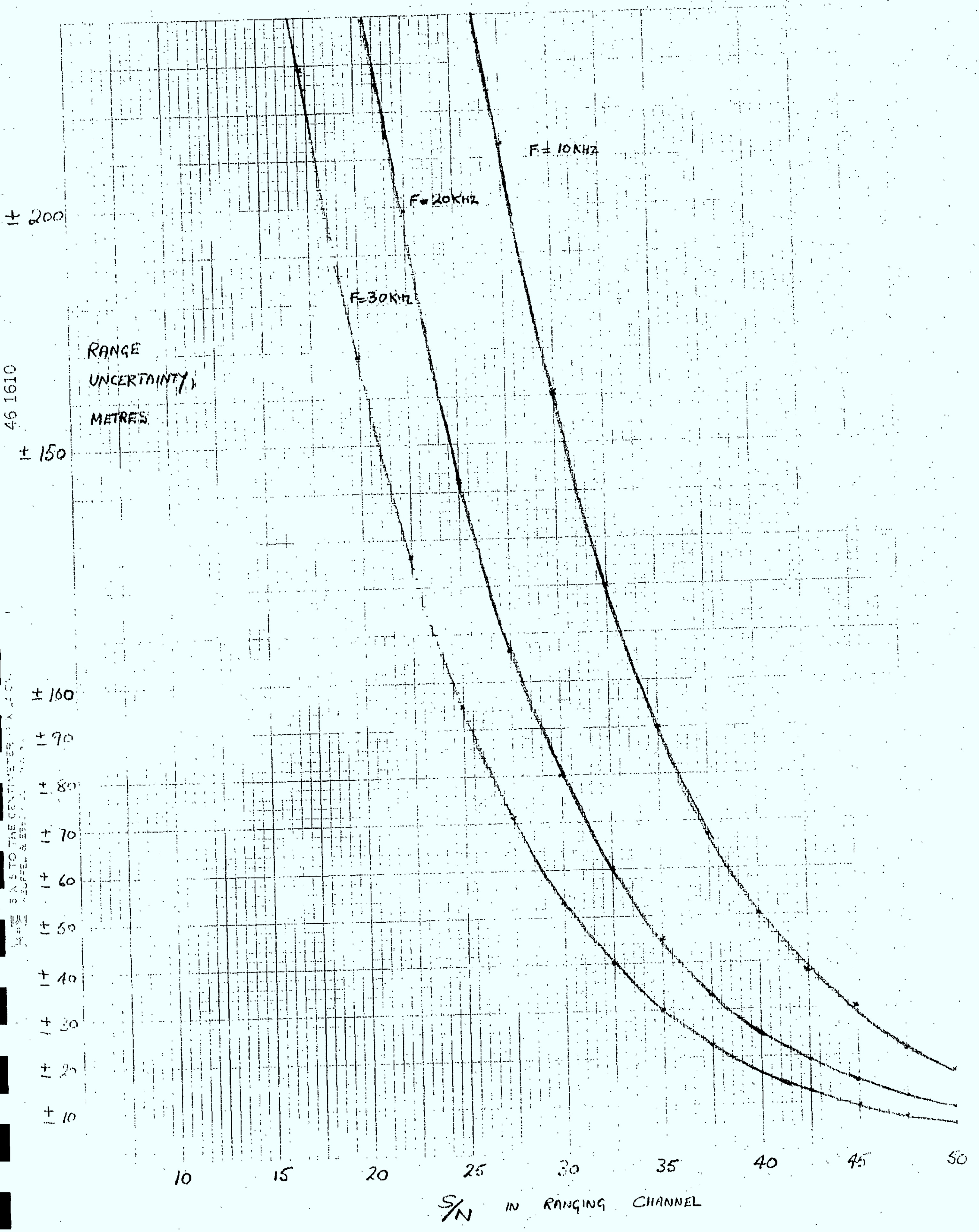
Ranging

The low frequency tones required for ambiguity resolution are normally not transmitted at their actual frequency, since they would be so close to the carrier as to cause possible problems at the ground receiver. Normal practice is to translate them to a higher frequency for transmission, as for example by mixing the low frequency tone with one of higher frequency, and transmitting the low frequency tone as the upper sideband from the mixing action.

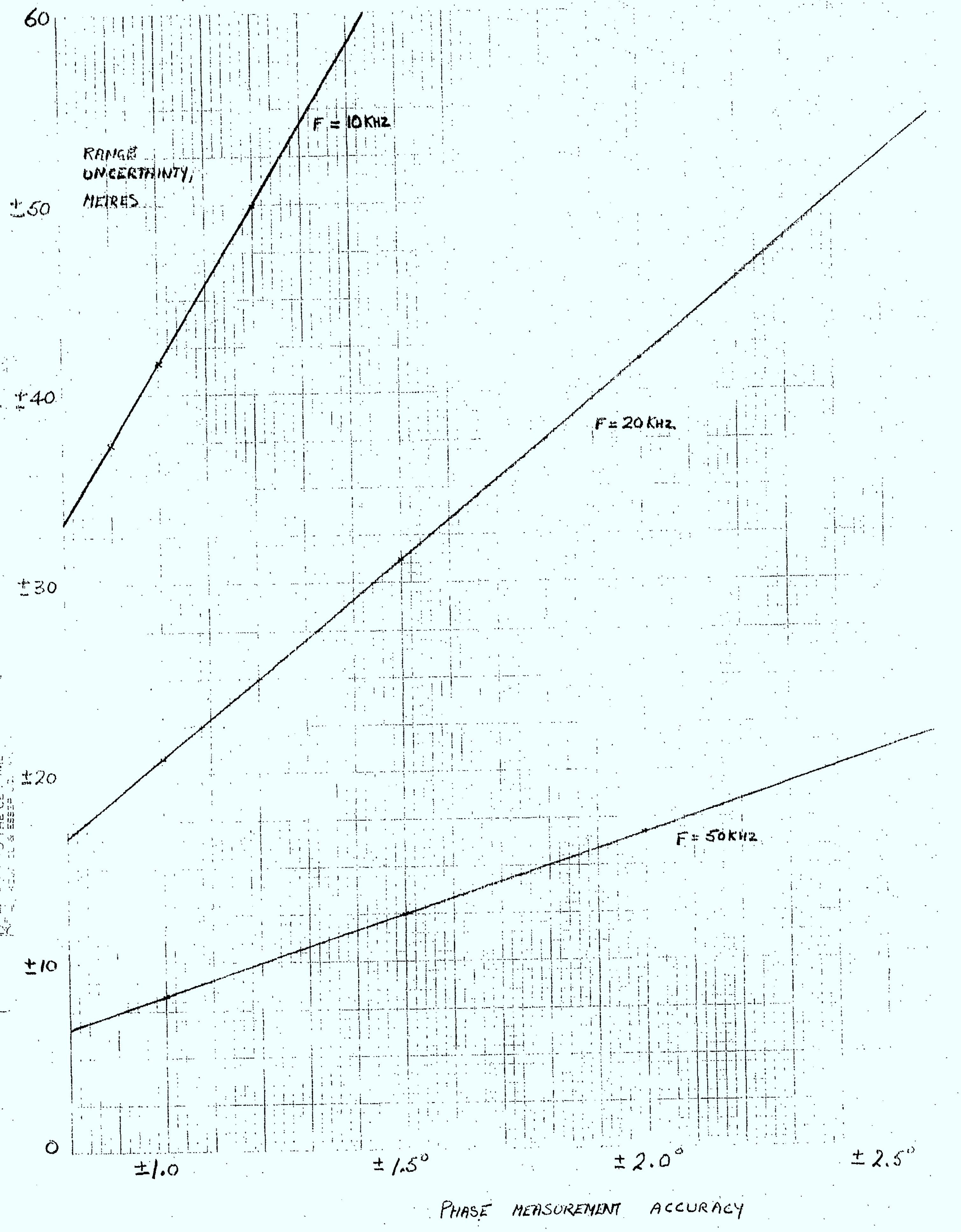
If it is required to transmit the tones at their actual frequency, then the baseband circuitry in both the command receiver and the telemetry transmitter must be capable of handling the low frequency without excessive phase shift.

Depending on the lowest frequency, this consideration may impose some penalty on the equipment design.


MAX. PERMISSIBLE TONE RATIO
f m+1 / f m
60
55
50
45
40
35
30
25
20
15
10
5
10
15
20
25
30
35
40
45
50
S/N IN RANGING CHANNEL dB
PHASE MEASUREMENT ACCURACY ASSUMED 2°



F = 10 KHZ
F = 20 KHZ
F = 30 KHZ
RANGE UNCERTAINTY, METRES
± 200
± 150
± 100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
10
15
20
25
30
35
40
45
50
S/N IN RANGING CHANNEL
46 1610


60
RANGE UNCERTAINTY, METRES
±50
±40
±30
±20
±10
0
F = 10KHZ
F = 20 KHZ
F = 50KHZ
±1.0
±1.5°
±2.0°
±2.5°
PHASE MEASUREMENT ACCURACY

APPENDIX III FM COMMAND LINK INTERFACE

Interference level handling capability of the Command Link

The elements forming the command link are:-

Antenna
Receiver

Receiver

The receiver is most sensitive to interference that falls inside the intermediate frequency (I.F.) bandwidth. The typical characteristics of an F.M. receiver which uses a limiter ahead of a frequency demodulator is shown in Figure 1. This graph shows the "capture effect" of an F-M demodulator. When the amplitude of the desired signal exceeds the interfering signal, then the interfering signal is suppressed. However, when the amplitude of the interfering signal exceeds the desired signal then the desired signal is suppressed.

Typical interference suppression characteristics when the signal exceeds the interference is shown in Figure 2. This shows that an F-M receiver gives very good protection against interference provided that the desired signal exceeds the interference by 3 dB or more.

The sensitivity of the receiver to image signals and spurious responses will typically be 60 dB below the desired signal. Assuming a desired signal strength of -90 dBm, this gives a required receiver input of -30 dBm. Also a typical input required to produce 1 dB of receiver desensitisation due to out of band signals will be -20 dBm.

Therefore, providing that inband interfering signals are always at least 3 dB below the desired signal, an interference free command link will be maintained.

Antennas

During transfer orbit the omni directional antenna is used and clearly there is no protection against signals from outside continental North America.

It is possible to use the communications antenna when the spacecraft is on station. However, the protection afforded to signals outside of North America is practically zero, as shown in Figure 3.

A separate high gain directional antenna could be used. The beam width for parabolic antennas from 1' to 10' is shown in Figure 4. A normalised graph showing the typical antenna pattern of a parabolic antenna is shown in Figure 5.

Antennas (Continued)

Combining Figures 4 and 5 we obtain Figure 6 , which shows the relative response of parabolic antennas versus degrees from beam centre.

The projection of Figure 6 onto a map of Canada as seen from the spacecraft at 114°W longitude shows the response of antenna from 3 to 6' diameter at various points across Canada. (FIG 7)

TYPICAL F-M RECEIVER CHARACTERISTICS

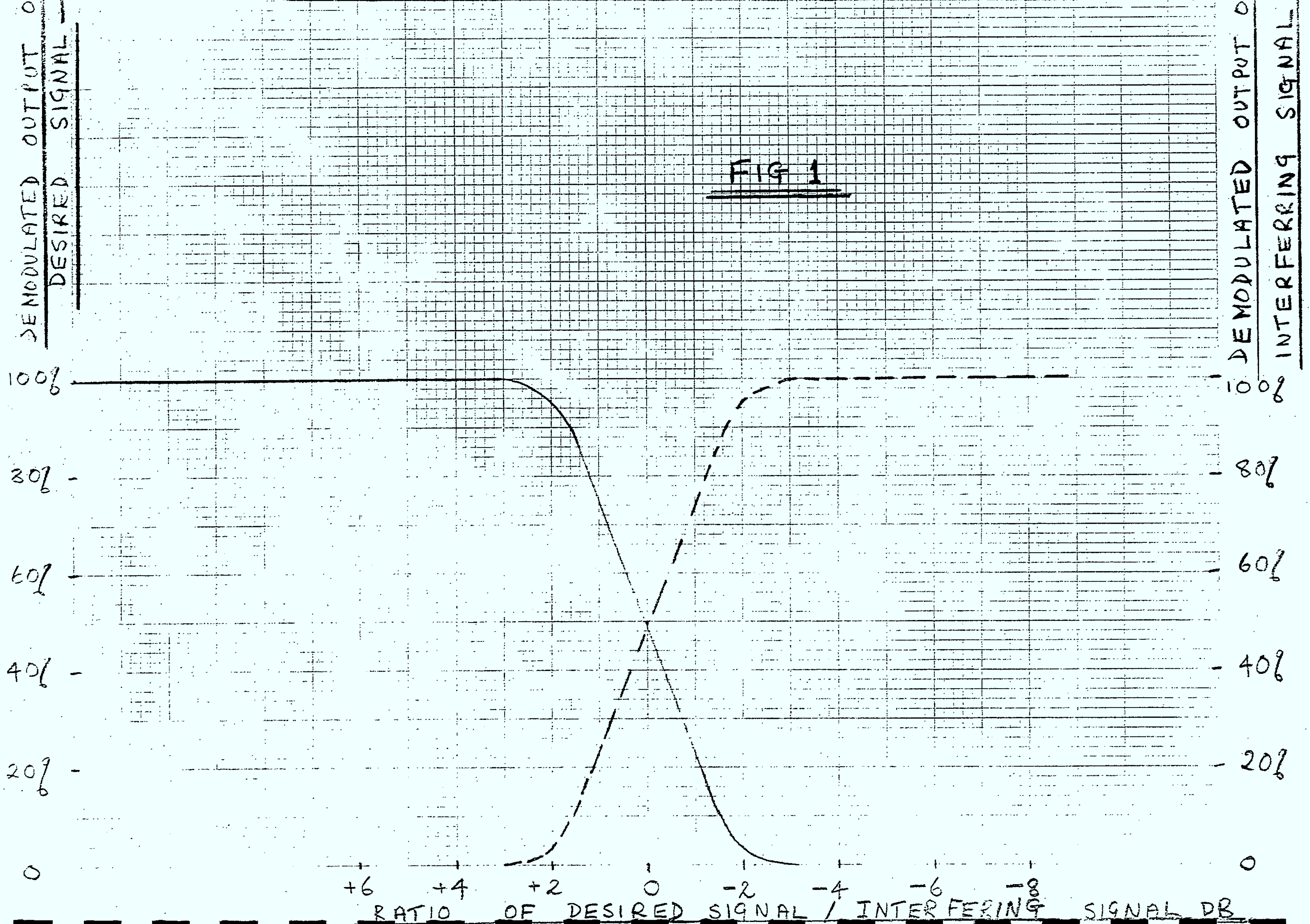


FIG 1

TYPICAL F-M RECEIVER CHARACTERISTICS

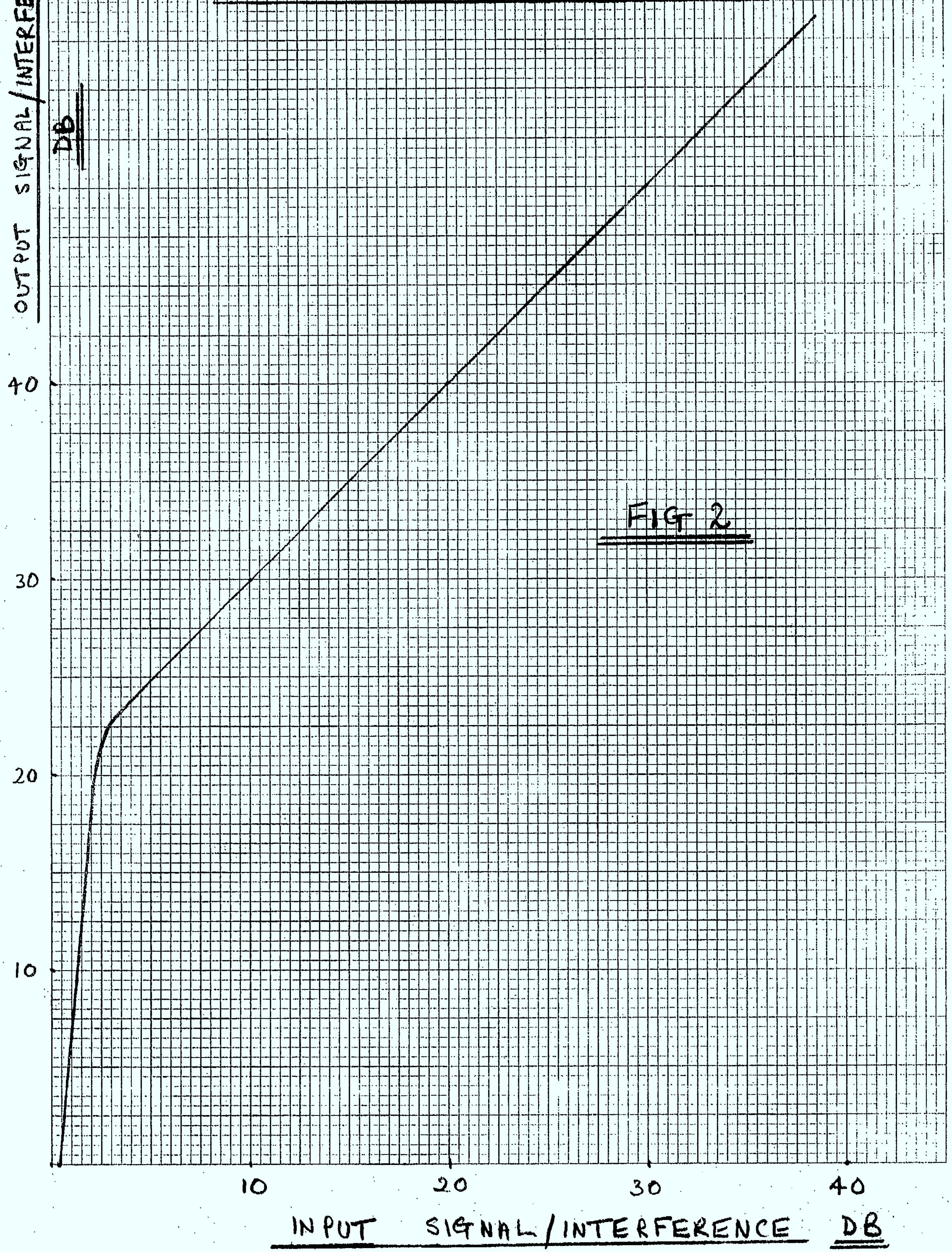


FIG 2

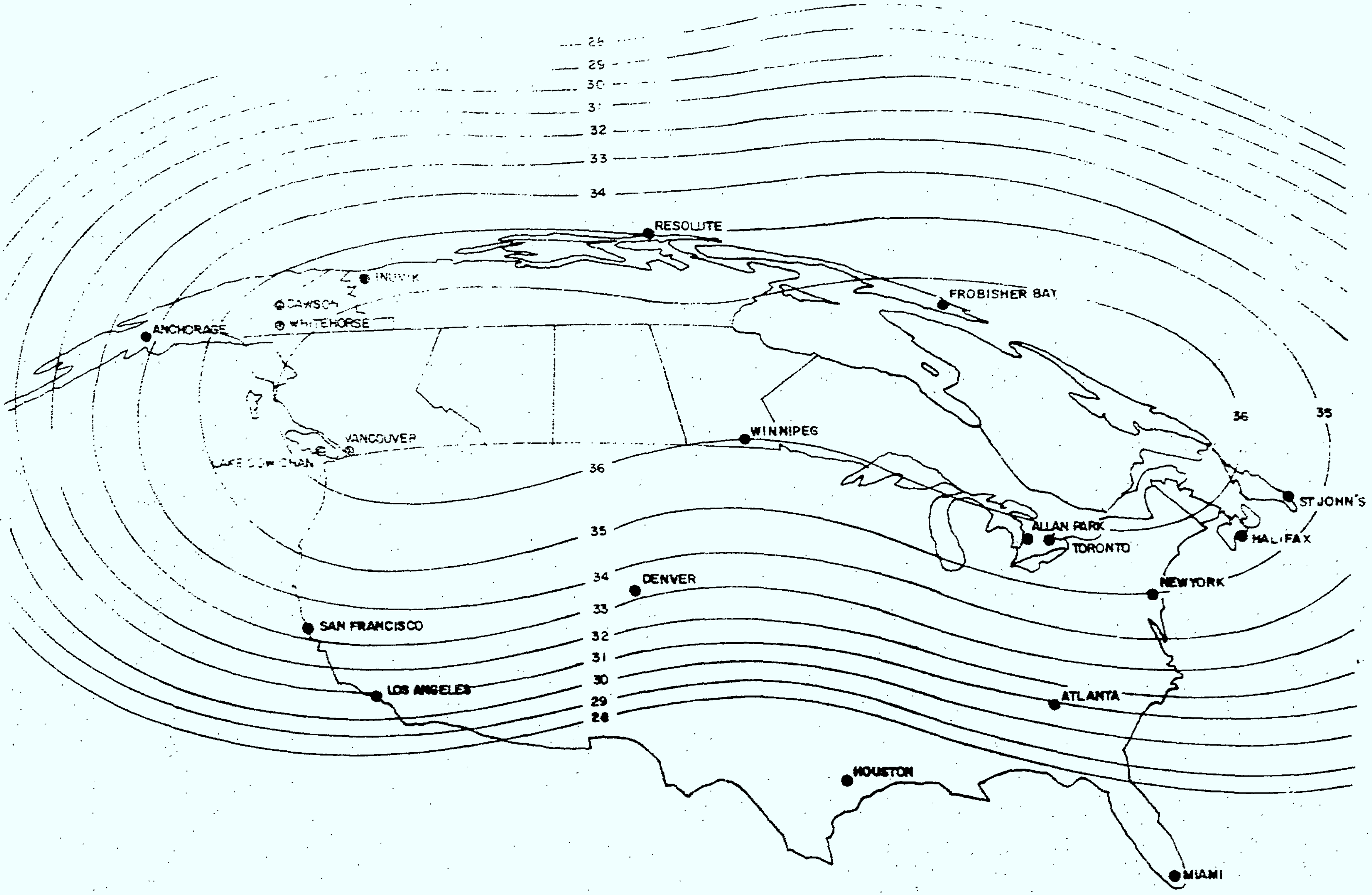
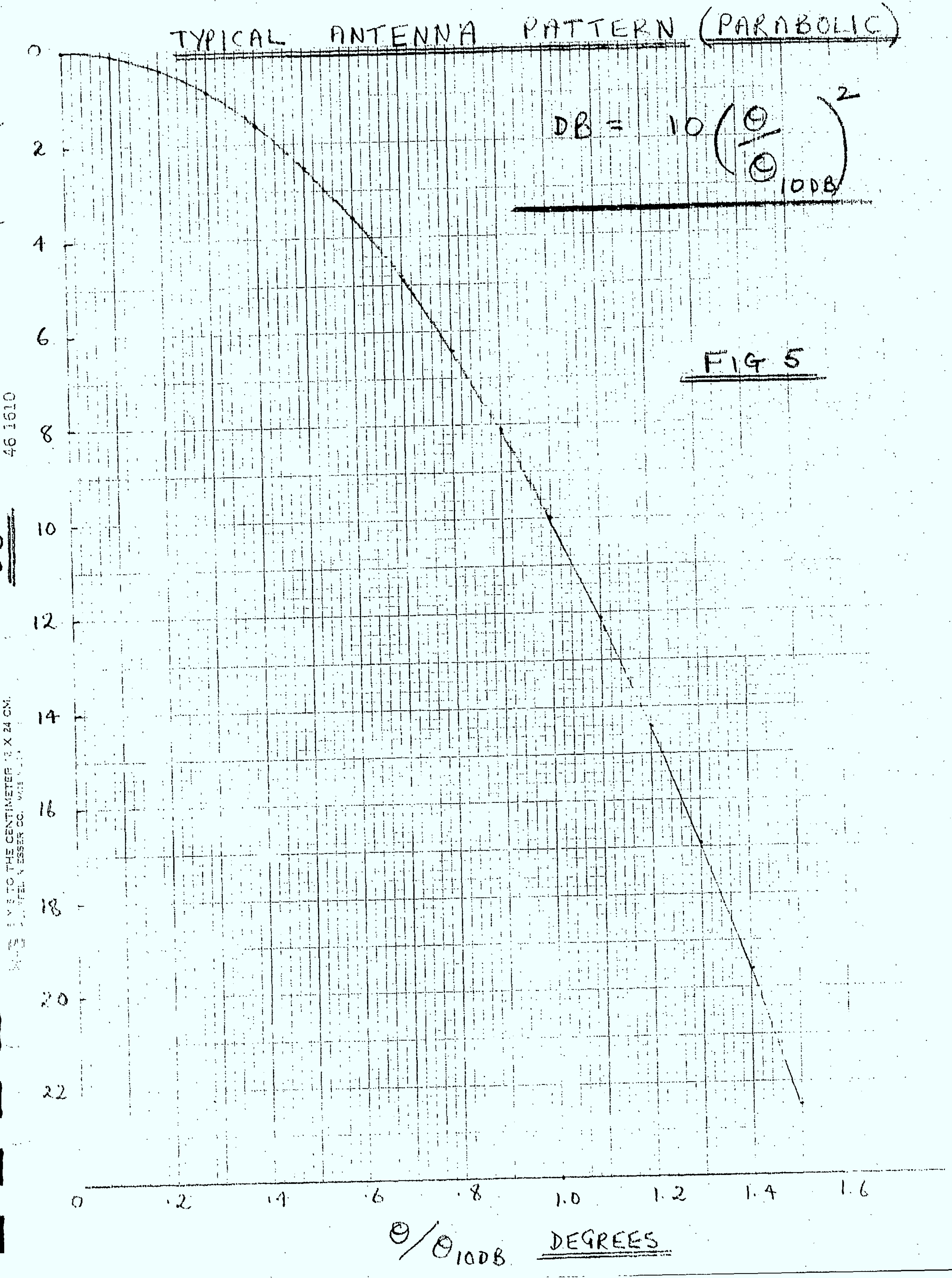
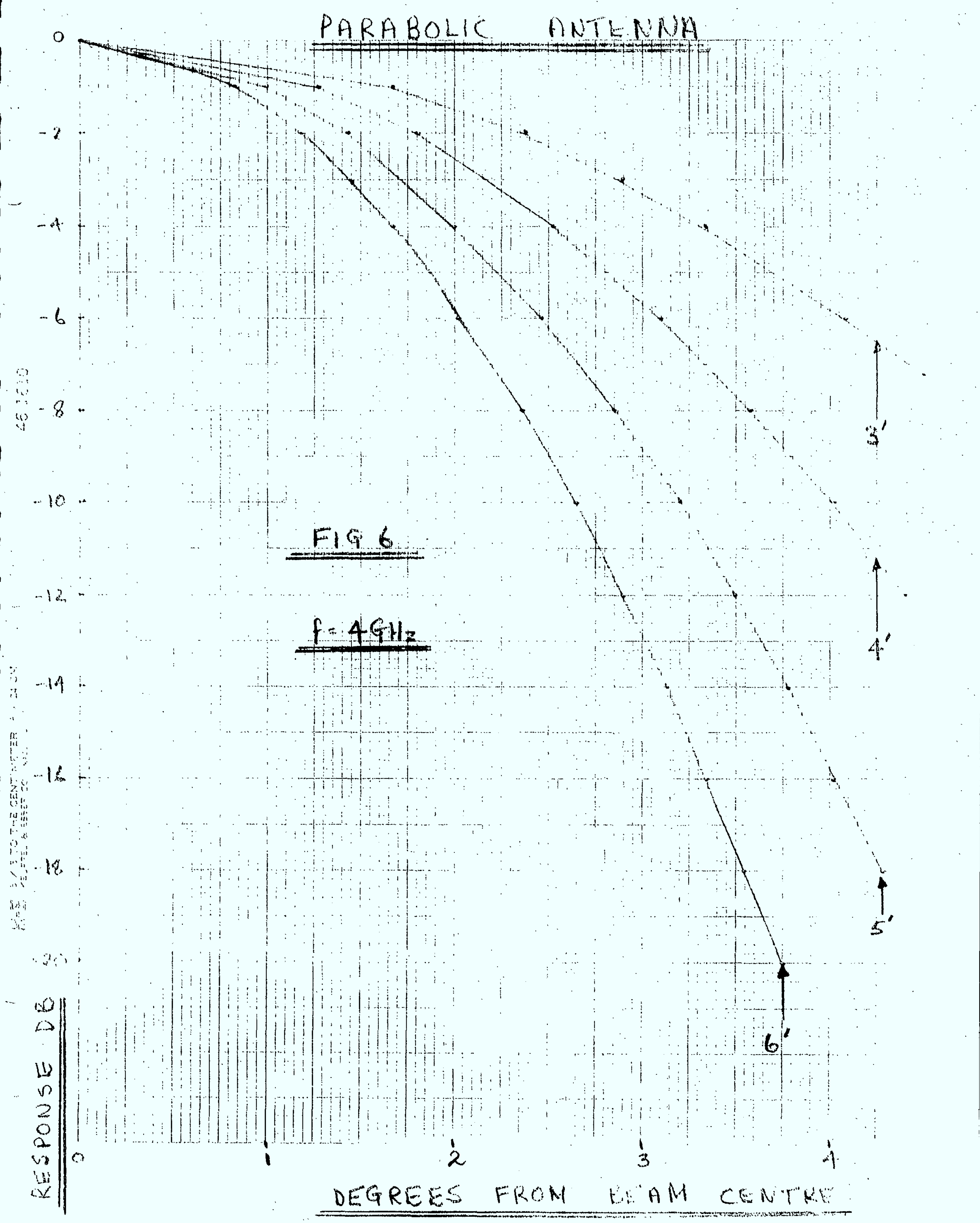


FIG 3 *Typical ANIK EIRP Contours in dBW*



TYPICAL ANTENNA PATTERN (PARABOLIC)
$DB = 10\left(\frac{\Theta}{\Theta_{10DB}}\right)^2$
FIG 5
DB
0
2
4
6
8
10
12
14
16
18
20
22
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
Θ/Θ_{10DB} DEGREES
46 1610
10 X 10 TO THE CENTIMETER 18 X 24 CM.


PARABOLIC ANTENNA
FIG 6
f = 4GHz
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
RESPONSE DB
0
1
2
3
4
DEGREES FROM BEAM CENTRE
3'
4'
5'
6'

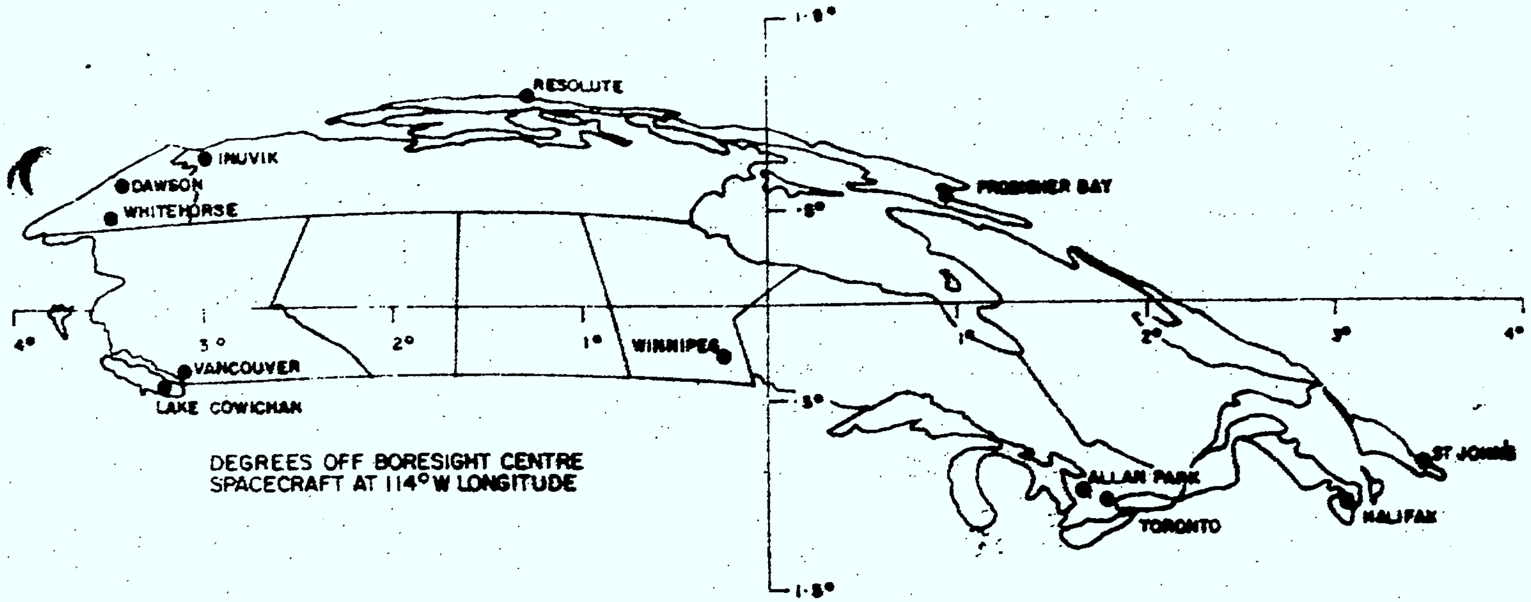
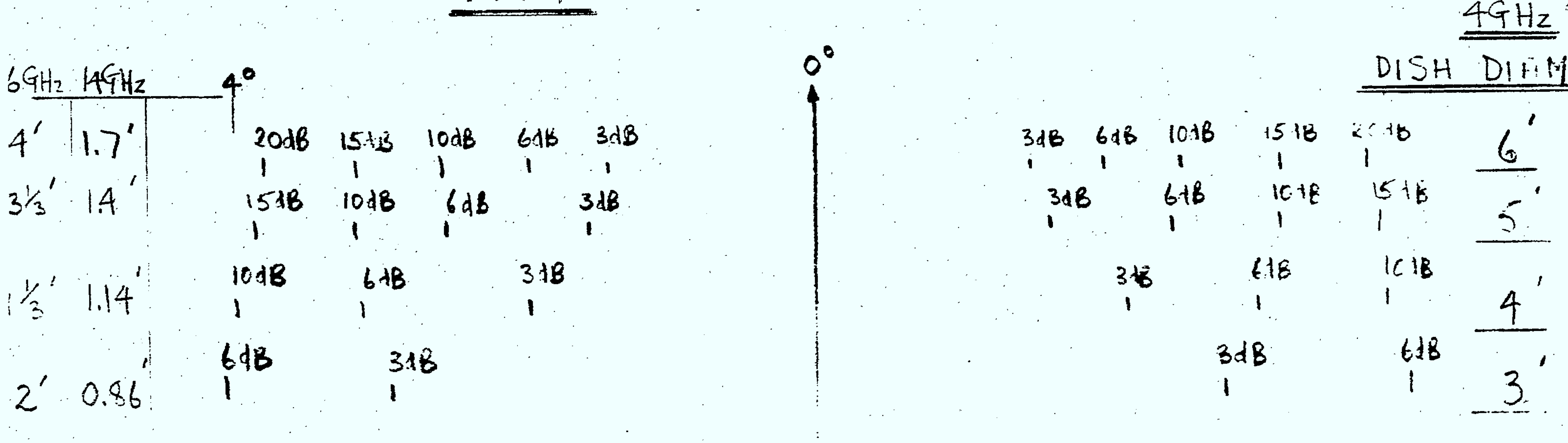


FIG 7 *Projection of Canada From Synchronous Altitude*



RELATIVE RESPONSE OF PARABOLIC ANTENNAS

APPENDIX IV COMMAND LINK DEVIATION

PCM/FSK SYSTEM

In this system, "1"s and "0"s are distinguished by using two separate tone frequencies. Further, the tone burst representing the 'Mark' is only present for half of the bitwidth. A simplified block diagram of this system is given in Figure 1 .

If the two tone frequencies are 'f_1' and 'f_2' and the bit rate is 'F' then the filter bandwidths required are $f_1 \pm 3F$ and $f_2 \pm 3F$ in order to pass both the fundamental and the third harmonic of the tones.

We will consider a return to zero signal with a 50% mark to space ratio and with equal probability of "1"s and "0"s. Then a bit error probability of 1×10^{-6} at the decoder is realized with a signal/noise ratio of 13.8 dB. (see Fig. 2)

This is the theoretical limit and assumes perfectly matched filters. In practice, it is possible to build a filter which is 6 dB from theoretical; therefore, the signal/noise ratio required is

19.8 dB

If we assume that commands shall be accepted at 5 dB below the receiver threshold then the required signal/noise = 19.8 + 5 X 3 = 34.8 dB.

The required command tone bandwidth is 6 X bit rate. If we assume a bit rate of 150 bits/sec. then the command bandwidth = 950 Hz, let us assume 1 kHz.
The required range tone signal/noise ratio is 45 dB/Hz (see telemetry assumptions)

Command tone	64.8	dB/Hz
Range tone	45.0	"

Thus, $\frac{S}{No}_c = \frac{C}{N} \; M^2_c \; \frac{B}{2} = 64.8 \text{ dB}$ .... (1)

and $\frac{S}{No}_R = \frac{C}{N} \; M^2_R \; \frac{B}{2} = 45 \text{ dB}$ .... (2)

From which $\frac{M^2_C}{M_R^2} = 64.8 - 48 = 19.8 \text{ dB}$

$$f_c = 4.23 \; \Delta f_R$$

where Δf_c = command tone deviation

Δf_R = range tone deviation

Uplink peak deviation $= \Delta f_c + \Delta f_R$

$= 5.23 \; \Delta f_R$

Now from (2)

$$\frac{S}{No}_R = \frac{C}{N} \; M^2_R \; \frac{B}{2}$$

B = total RF bandwidth

= required signal bandwidth + L.O. drift allowance + Doppler + aging

$= 2 \; (5.23 \; \Delta f_R + f_R + 150)$ kHz

$$\frac{S}{No}_R = 10 \times M_R^2 \; (144.87 \, M_R + 177.7) = 45\text{dB}$$

$\longrightarrow M_R = 0.127$

$\rightarrow \Delta f_R = 27.7 \times 0.127 \text{ kHz} = 3.5 \text{ kHz}$

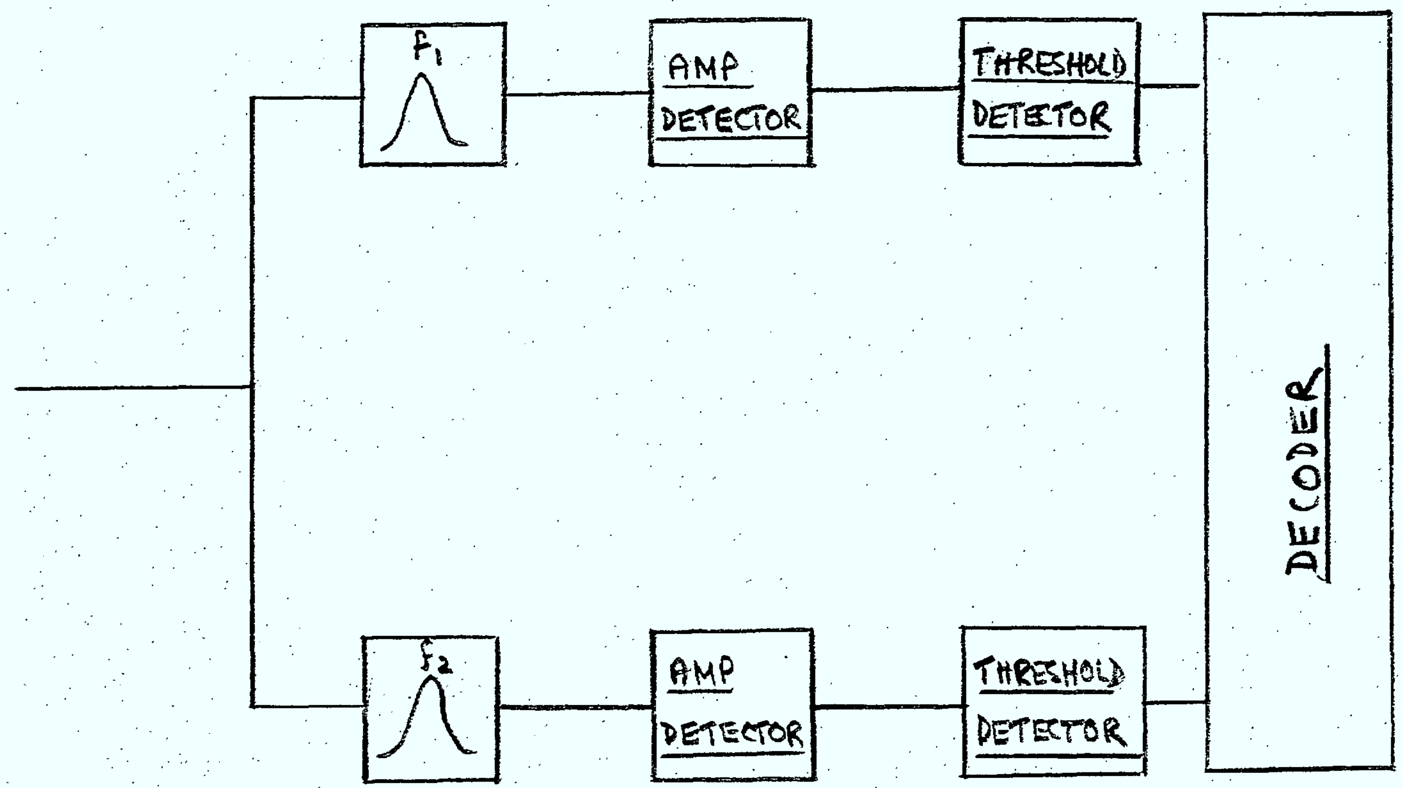
$\rightarrow \Delta f_c = 4.23 \times f_R = 14.89 \text{ kHz}$

These are the minimum deviations required, at a C/N of 10 dB. To allow a margin, let us choose $\Delta f_R = 6$ kHz

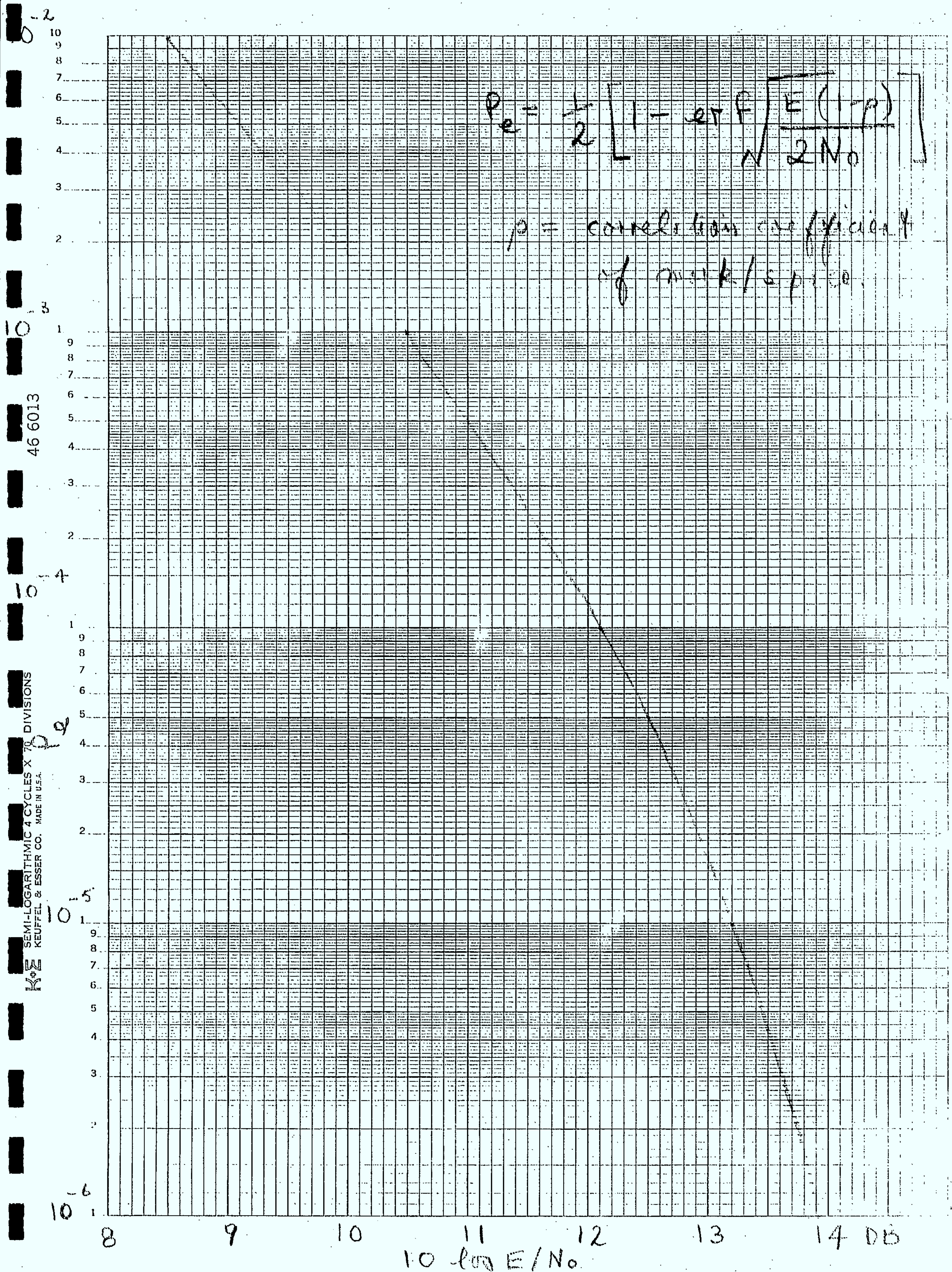
$\Delta f_c = 25$ kHz

from which $B = 2 \; (5.23 \; \Delta f_R + 177.7)$

$= 418$ kHz



F.S.K. DETECTOR FIG 1



$P_e = \frac{1}{2}\left[1 - \mathrm{erf}\sqrt{\frac{E(1-\rho)}{2N_0}}\right]$
ρ = correlation coefficient of mark/space
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
P_e
8
9
10
11
12
13
14 DB
10 log E/No
46 6013
SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

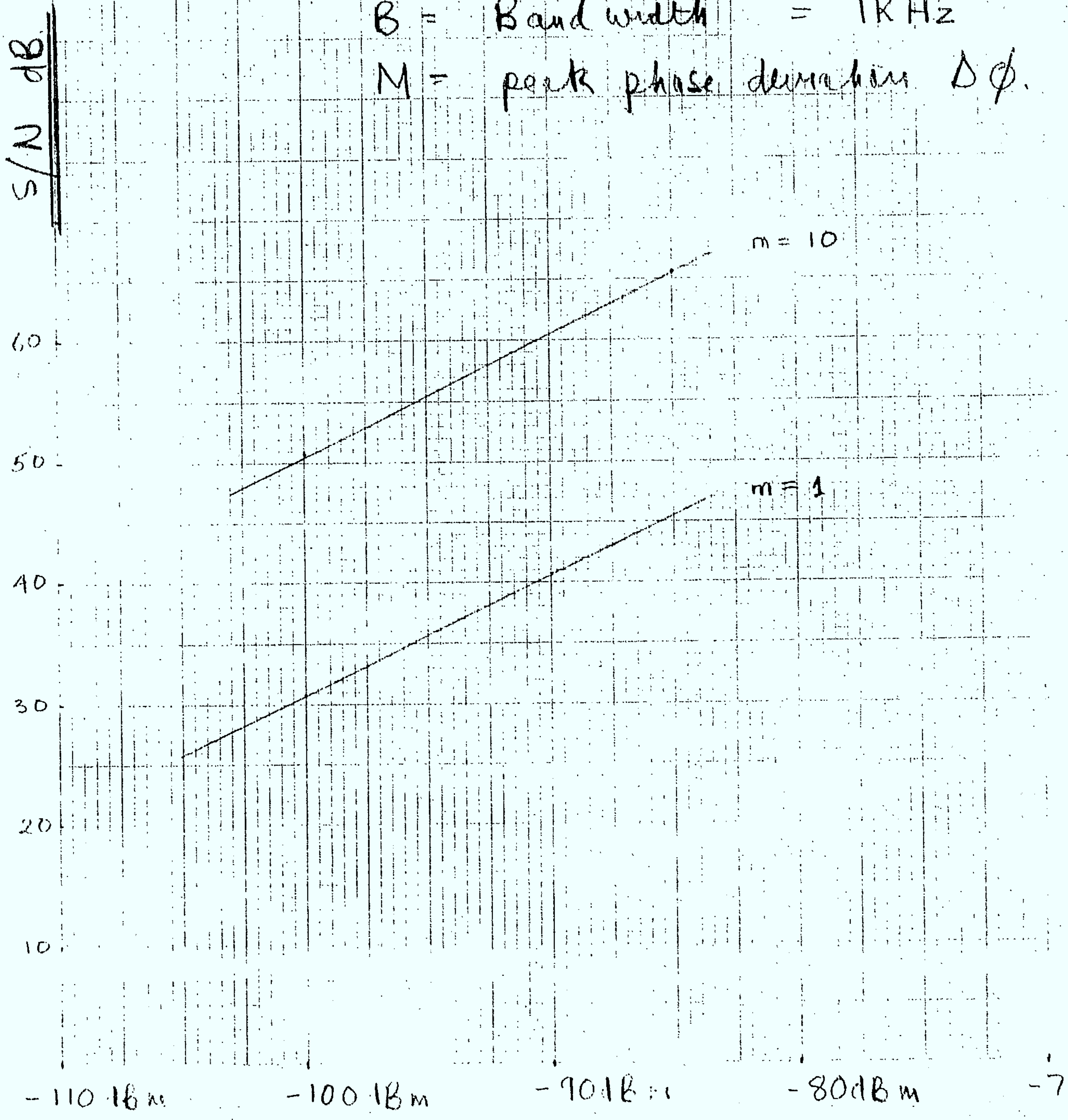
$$S/N = 10 \log C - 10 \log 2 - 10 \log N - 10 \log KT - 10 \log B + 20 \log M$$

C = carrier power

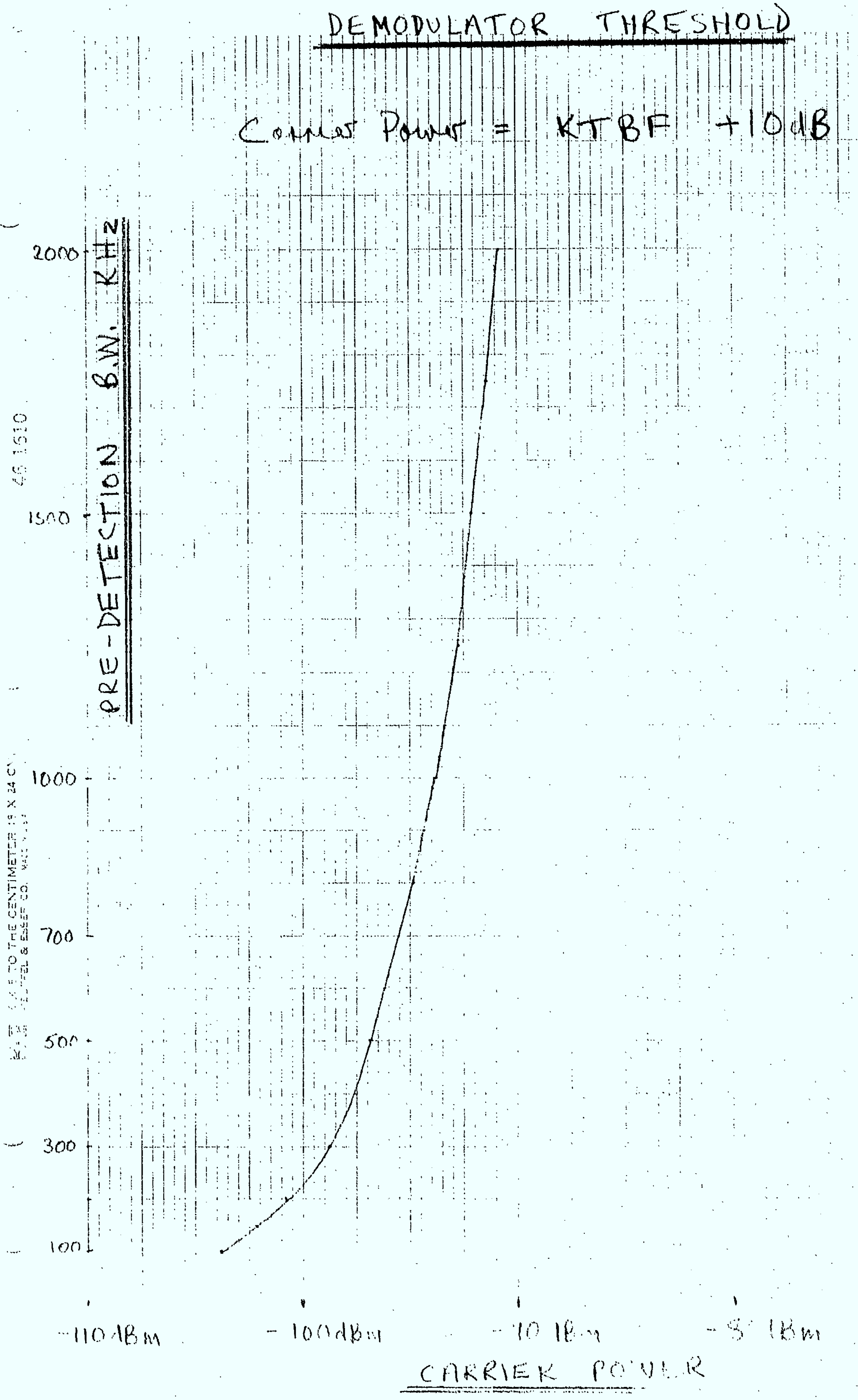
N = Noise Figure = 10 dB

B = Band width = 1 KHz

M = peak phase deviation $\Delta\phi$.



CARRIER POWER



DEMODULATOR THRESHOLD
Carrier Power = KTBF +10dB
PRE-DETECTION B.W. KHz
2000
1500
1000
700
500
300
100
-110dBm
-100dBm
-90dBm
-85dBm
CARRIER POWER

APPENDIX V TELEMETRY SIGNAL/NOISE CALCULATION

The telemetry channel capacity and rate requirement for the UHF satellite are unlikely to exceed those for the Globcom spacecraft – 256 point frame, 1 frame/sec, transmitted via an IRIG channel 13 subcarrier link. The SCO C/N requirement can thus be derived.

We have, $B = 2(\Delta f + f_{mod})$ by Carson's rule

Thus, IRIG channel 13 bandwidth is nominally

$$B = 2\,(1.088 + 0.220)\ \text{kHz}$$
$$= 2.6\ \text{kHz}$$

We shall provide a channel bandwidth (i.e., f_{mod} max.) of 2.7 X sample rate, to maintain crosstalk between channels to 40 dB or better (Nichols and Rauch, Ref.)

$$\text{Thus we have } f_{mod}\ \text{max} = 2.7 \times 256$$
$$= 690\ \text{Hz}$$

Thus, for a sub-carrier link B = 2.6 kHz, we can use

$$f = \frac{B}{2} - f_{mod}\ \text{max}$$
$$= (1.3 - 0.69)\ \text{kHz}$$
$$= 0.61\ \text{kHz}$$

With $f = 0.61$ kHz and $f_{mod} = 0.69 \rightarrow m = \dfrac{0.61}{0.69} = 0.88$

From the FM equation, we have

$$\left(\frac{C}{N}\right)_{in} = \frac{\left(\frac{S}{N}\right)_{out}}{3\,m^2} \cdot \frac{2b}{B}$$

$B = 2.6$ kHz

$b = 690$ Hz

$m = 0.88$

& $S/N = 23$ dB required

$$\rightarrow \frac{C}{N} = 23 + 3.01 - 1.61 - 4.77 + 1.11 - 4.149$$

$$= 16.6 \text{ dB}$$

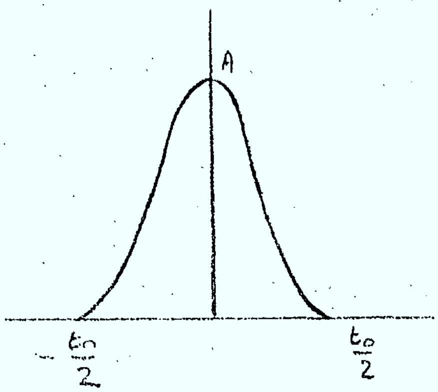
Now $B = 2.6$ kHz

$$\frac{C}{N_o} = 16.6 + 10 \log (2.6 \cdot 10^3)$$

$$= \underline{50.7 \text{ dB}}$$

Signal-noise Ratio Requirement for the Sensor Data Sub-Carrier Oscillators

The output signal from the earth and sun sensors may be closely approximated by a cosine squared pulse



$$g(t) = A \cos^2 \pi \frac{t}{t_0}$$

$$= \frac{A}{2}\left[1 + \cos 2\pi \frac{t}{t_0}\right]$$

If we equate g(t) to A/2, and solve for t, we can obtain the expression

$$g(t) = \frac{A}{2}\left[1 + \cos \pi \frac{t}{T}\right],$$ where T is the half-amplitude pulse width

Let the slicing level for time-of-occurrence be at half-amplitude.

Then, a noise voltage of peak amplitude U_n will shift the time of occurrence by τ,

Where $\frac{U_n}{\tau}$ = slope of pulse at time $t = -\frac{T}{2}$

i.e., $$\frac{U_n}{\tau} = \frac{d}{dt} g\left(-\frac{T}{2}\right)$$
$$= \frac{A\pi}{2T}$$

i.e., $$\tau = \frac{2T}{A\pi} U_n$$

The mean-square error in time of occurrence is thus

$$[\tau^2]_{mean} = \frac{4T^2}{A^2 \pi^2} [v_n^2]_{mean}$$

If the spacecraft spin rate is R revolutions per minute, then the corresponding angle error is

$$\varepsilon_{RMS} = \frac{\tau_{RMS}}{60/R} \times 360^{\circ}$$

$$\rightarrow [\varepsilon^2]_{mean} = \frac{36R^2 \; 4T^2}{A^2 \pi^2} [v_n^2]_{mean} \quad \dots\dots\dots\dots\dots (1)$$

The cosine squared pulse has an average power equivalent to a sinewave of peak to peak amplitude A, and period 1/2T.

Thus, the average signal-noise power ratio is

$$\frac{\left[\frac{A}{2\sqrt{2}}\right]^2}{[v_n^2]_{mean}} = \frac{A^2}{8\,[v_n^2]_{mean}}$$

Substituting for $\frac{A^2}{[v_n^2]_{mean}}$ from equation (1).

$$\frac{S}{N} = \frac{18 \; R^2 \; T^2}{\pi^2 [\varepsilon^2]_{mean}}$$

Typical figures for R and T are 60 RPM and 2 mS. Figure I shows the required S/N ratios vs desired angle error, using these values.

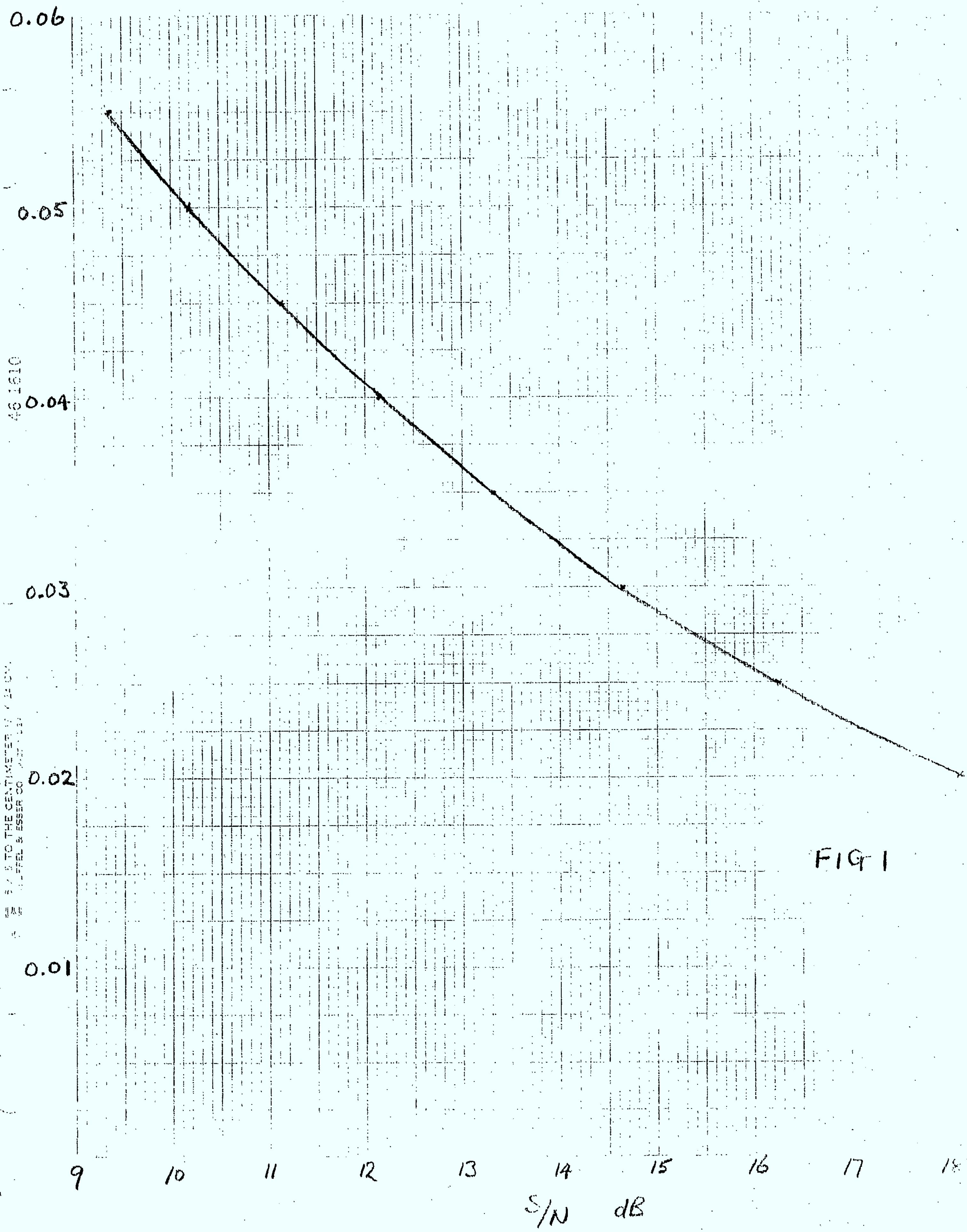


FIG 1

This calculation derives the S/N ratio required at the sub-carrier demodulator output. We can now derive the requirement for C/N ratio at the input to the SCO demodulator.

Using the FM equation

$$\frac{S}{N}_{out} = 3\,m^2 \,\frac{B}{2b}\,\frac{C}{N}_{in}$$

where m = mod. index $= \frac{\Delta f}{b}$

B = RF bandwidth

b = baseband width $\equiv$ maximum modulating frequency

By Carson's rule,

$$B = 2\left(\Delta f + f_{mod}\right)$$

$$= 2\left(mb + b\right)$$

$$= 2b\ (m + 1)$$

$$\frac{S}{N}_{out} = 3\ m^2\ (m + 1)\ \frac{C}{N}_{in}$$

If we assume a desired accuracy of, say, 0.025 degrees R.M.S., then from the graph $\frac{S}{N}_{out}$ = 16.3 dB.

We can further assume that the highest frequency to be transmitted is 1000 Hz (i.e., $2 \times \frac{1}{T}$, where T is the half amplitude width, typically 2 mS)

If we use an IRIG constant bandwidth A channel, say, 40 kHz, this channel (for the 2 kHz max deviation) would have a Carson's rule bandwidth of 2 (2 + 0.4) = 4.8 kHz.

We could thus use a deviation of 1200 Hz, with a maximum modulating frequency of 1200 Hz.

This gives $m = 1$,

$$\text{from which} \quad \frac{S}{N}_{out} = 3 \times 2 \times \frac{C}{N}_{in}$$

$$\frac{C}{N} = 10 \log \frac{S/N}{6}$$

$$= 16.3 - 7.78$$

$$= 8.5 \text{ dB}$$

This is actually below the FM threshold of the sub-carrier demodulator. We therefore set the $\frac{C}{N}$ requirement up to 10 dB.

Since $B = 4.8 \times 10^3$, the sub-carrier signal to noise density,

$$\text{i.e.,} \quad C/N_o = 10 + 10 \log (4.8 \ 10^3) = 46.8 \text{ db/Hz}$$

Telemetry Signal-Noise Requirement

We will assume that a telemetry accuracy of 2.5% of full-scale value is required.

With a PAM system, the error is simply expressed

$$\frac{N_{RMS}}{S_p} \quad \%$$

Thus,

$$\frac{N_{RMS}}{S_p} = 0.25\%$$

S_p is the full-scale value, i.e., max. pulse height.

The equivalent signal power is that of a sine wave of peak-to-peak amplitude equal to the maximum pulse height.

i.e.,

$$S_{RMS} = \frac{S_p}{2\sqrt{2}}$$

$$\frac{N_{RMS}}{2\sqrt{2}\, S_{RMS}} = \frac{2.5}{100}$$

$$\frac{S}{N} \text{ (power ratio)} = \left[\frac{2\sqrt{2} \quad 2.5}{100}\right]^2$$

$$= \underline{\underline{23 \text{ dB}}}$$

APPENDIX VI SURVEY OF EXISTING EQUIPMENT

a) Availability of Equipment (C-Band TT & C)

Equipment is available that would satisfy the requirements of a spacecraft as outlined in this study. Typical power, weight and dimensions are tabulated below.

UNIT	SIZE	Weight	Power Consumption
Receiver (Two)	6.75" X 4.0" X 1.5" Total	2.6 lbs total	1.5 watts each
Transmitter (Two)	3.5" X 4.5" X 4.0" Total	2.4 lbs total	Lo. 5 watts Hi. 20 watts Total
Telemetry Module	7.1" X 8.7" X 5.5"	5.5 lbs	2.0 watts
Command Demodulator	7.0" X 7.6" X 8.7"	6.9 lbs	5.5 watts (4 watts standby)
Logic Processor	7.7" X 10.0" X 8.0"	10.9 lbs	4 watts

AVAILABILITY OF EQUIPMENT

b) The CTS S-band TT & C Subsystem

This equipment was designed for use on the Communications Technology Satellite, with a mission life of two years operational in geo synchronous orbit.

The subsystem operates in the 2 GHz band, and is compatible with NASA's STDN network and the Goddard Range and Range Rate System.

Major characteristics of the RF equipment are shown in Table 1, and a detailed description of the overall subsystem follows:

The PCM encoder unit contains a TRANSFER ORBIT ELECTRONICS section, which processes attitude data during the transfer orbit and handles 15 bit commands to despin and orient the spacecraft until final orbit position is reached.

TABLE 1

Component Characteristics Summary for the CTS TT & C Subsystem

Component	Key Features	Performance Summary	Physical Data	Source
Command Receiver Assembly	o Active redundancy o Passive coupling of two antennas to both receiver units o Isolated outputs for command and ranging	o Frequency: 2197.192 MHz o Carrier Tracking Phase Lock Loop o Tracking Range: ± 150 kHz o Noise Figure 7.5 dB at Receiver Input o PM Receivers, with FM sub-carrier demodulator o Ranging Bandwidth 1 MHz o Frequency Stability 20 ppm	o Weight 5.35 lbs o Size 9.85" X 4.82" Footprint 5.5" max. ht. o Power 4.86W	RCA Ltd.
Telemetry Transmitter Assembly	o Standby Redundancy, Isolated outputs	o Frequency 2277.5 MHz o PM Transmitters o Internal Isolators on RF outputs o 2W output power o Modulation Bandwidth 1 MHz o Modulation Index to 1.4 Rads o Choice of Internal or External Drive o Frequency Stability 25 ppm	o Weight 4.71 lbs o Size 8.12" X 4.62" footprint 3.28" max. ht. o Power 12.5W	RCA Ltd.
Dual Bandpass Filter	o Isolated Receive & Transmit Filters	o Insertion Loss 0.5 dB o 50 ohm impedance, VSWR 1.2 o Receive Filter 60 dB rejection at image freq. o Transmit Filter 60 dB rejection at receive freq.	o Weight 1.09 lbs o Size 6.0" X 2.1" footprint 2.0" max. ht.	Com Dev Ltd.
Coaxial Transfer Switch	o Magnetic Latching 4-port transfer	o Insertion Loss 0.1 dB max o 50 ohm impedance VSWR 1.2	o Weight 0.33 lbs o Size 2.16" X 2.0" footprint 1.37" max. ht.	Transco

T.T.&C. TRANSPONDER

1.0 GENERAL

The T.T.&C. transponder provides a coherent S-Band phase-locked communication link between STDN tracking stations and the spacecraft. The link provides the following functions:-

a) command system to the spacecraft
b) ranging and range rate
c) telemetry data from the spacecraft

Units forming part of the transponder are:-

1) two dual band pass filters
2) coaxial transfer switch
3) 3 dB hybrid
4) dual command receivers
5) dual telemetry transmitters

Table 1 shows the power consumption, size, weight and footprint of each of the above units.

Figs. 1thru 4 show the outline drawings of the transmitter, receiver, dual bandpass filter and coaxial switch. The 3 dB hybrid is approximately 1" x 1" x 3/8".

2.0 UNIT SPECIFICATIONS

2.1 Dual Bandpass Filter

This consists of two separate filters, one at the receive frequency, the other at the transmit frequency.

2.1.1 Receive Filter

Centre frequency 2097.198 MHz
Impedance 50 ohms
V.S.W.R. 1.2:1 max
Insertion loss 0.5 dB max. c.f. ± 10 MHz
Attenuation $>$ 60 dB at 2002 MHz.

2.0 UNIT SPECIFICATIONS (continued)

2.1.2 Transmit Filter

Center frequency 2277.5 MHz
Impedance 50 ohms
V.S.W.R. 1.2:1 max
Insertion loss 0.5 dB max c.f. ± 10 MHz
Attenuation > 60 dB at 2097.198 ± 10 MHz
> 60 dB at 14.0 GHz to 14.5 GHz

2.2 Coaxial Transfer Switch

This is a four port device which accepts the outputs from both telemetry transmitters and connects them to two dual bandpass filters. Changing the state of the switch reverses the connection between transmitter and dual bandpass filter.

Center Frequency 2277.5 MHz
Impedance 50 ohms
V.S.W.R. 1.2:1
Insertion loss 0.1 dB max
Switch type - magnetic latching, coil power 0.8 A at 28 V for 50 m sec. max.

2.3 3 dB Hybrid

This unit combines the output from the antennas and splits the resultant power equally between the two receivers.

Centre frequency 2097.198 MHz
Impedance 50 ohms
V.S.W.R 1.2.:1 max
Insertion loss 0.5 dB max
Power division. not greater than 0.5 dB

2.4 Receiver

This unit is a phase-locked loop receiver capable of tracking carrier frequency shifts of greater than ± 60 KHz. It employs a wideband phase detector and coherent AGC. In operation, receiver phase lock is achieved by sweeping an un-modulated carrier over a ± 90 KHz segment of the assigned centre frequency.

...3

2.4 <u>Receiver</u> (continued)

When the receiver is locked it provides a coherent drive for the telemetry transmitters as well as wideband ranging tone demodulation and command sub-carrier demodulation.

Centre frequency 2097.198 MHz	
Input dynamic range,	- 134 dBm to - 73 dBm
Max input level	-53 dBm no damage
Impedance	50 ohms
Input V.S.W.R.	1.5:1
Noise figure	8 dB max
Frequency stability	2 in 10^{-5} from 5° C to 45° C
Lock loss threshold	- 134 dBm
Loop Bandwidth	800 Hz at - 134 dBm 3200 Hz max at - 100 dBm
Carrier Acquisition,	90% probability at - 109 dBm when carrier swept ± 90 KHz at 35 KHz/sec. 90% probability at -100 dBm to - 77 dBm when carrier swept ± 90KHz at 100 KHz/ sec.
Phase tracking	$<$ 15 degrees at 6 dB above threshold for carrier shift of ± 150 KHz. $<$ 5 degrees at - 100 dBm for carrier shift of ± 150 KHz
Phase Detector	Coherent 90°
Command Sub-carrier demod.	70 KHz
A.M. Rejection	30 Hz at 30% A.M. to give an equivalent output from phase detector $<$ 0.1 rad peak to peak.
Squelch	Squelch - 112 dBm ± 1 dB Unsquelch -110 dBm ± 1 dB
Input Level Monitoring	-Within O - 5 V
Phase error Monitor	Within O - 5 V
Lock Status	'O' and '5V'

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2.5 Transmitter

When the receiver is locked the transmitter accepts the coherent drive from the receiver and multiplies it up to the output frequency. When the receiver is out of lock the transmitter uses a standby oscillator as its drive source.

Centre Frequency -	in lock 240/221 times the receive frequency
Centre Frequency -	out of lock 2277.5 MHz ± 45.55 KHz
Phase Stability -	$\leq$ 3.5 degrees r.m.s. measured in a loop noise bandwidth of 50 Hz (includes receiver).
R.F.Power O/P	2.0 watts min into 50Ω load 1.5:1 V.S.W.R. any phase angle. Stable into load of 3:1 V.S.W.R. any phase angle and capable of surviving O/C and S/C.
Power amplifier BW	20 MHz min for 1 dB BW.

DISCRETE

Spurious Outputs:

- 70 dBm max 2025 - 2120 MHz

- 70 dBm max 2002 ± 20 MHz

- 60 dBm max 14.0 to 14.5 GHz

- 25 dBm at any other frequency

NOISE

- 70 dBm / Hz max 2025 - 2120 MHz

- 70 dBm / Hz max 2002 ± 20 MHz

- 30 dBm in a 10 KHz BW max 14.0 to 14.5 GHz

- 25 dBm at any other frequency in a 3 KHz bandwidth

Modulation: Ranging - uplink / downlink deviation ratio to be 0.5 up 0.7 rads deviation, B.W. 1 dB to 1 MHz.

Telemetry - deviation 1.0 radians ± 10% for a 30 KHz S.C.O.

Ranging Switch Ranging on/off switch to be provided.

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3.0 OVERALL REQUIREMENTS

3.1 Delay

The total delay through the transponder shall not exceed 1000 n secs with a stability of ± 50 n secs for input frequency changes of ± 40 KHz and level changes of -100 dBm to - 73 dBm.

3.2 Command Subcarrier

The command modulation signal will be a 1 ~~70 KHz~~ sine wave clock and a coherent 2 KHz PSK sinusoidal data signal. The characteristics of the command subcarrier are summarized in Figure 7 and as follows:

a) Command Signal: 1 KHz and 2 KHz composite signal (equal amplitudes).

b) Subcarrier Freq: 70 KHz (IRIG) Channel 18

c) Subcarrier Modulator:

Type FM

Deviation: ± 5 KHz (Composite total)

d) Carrier Modulation:

Type: PM

Modulation Index: 0.4 to 1.8 radians peak (sine wave)

3.3 Ranging Signal Characteristics

For the STDN stations the ranging signal will be either: a) a wideband pseudo-noise digital code, or b) a single sinusoidal tone or a composite of two sinusoidal tones. The characteristics of these ranging signals are summarized below:

a) PRN Ranging Characteristics

i) Signal:

<u>During Ranging Acquisition</u> - Modulo 2 sum of pseudo-random noise digital code with repetitive binary 10 clock waveform (496 KHz square wave)

<u>After Range Acquisition</u> - Repetitive binary 10 clock waveform (496 KHz square wave).

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a) PRN Ranging Characteristics (continued)

ii) Signal Waveform: NRZ-L

iii) Bit Rate: 991.666 kb/s

iv) Spectrum:

During Range Acquisitions - sin x/x, with full null at 1 MHz
After Range Acquisition - 496 KHz square wave.

v) Significant Modulation Spectrum: 3.2 KHz to 1.5 MHz

vi) Carrier Modulation:

Type: PM

Modulation Index: 0.4 to 0.8 radians peak (square wave)

b) Tone Ranging Characteristics

i) Signal:

<u>During Range Acquisition</u> - Linear sum of two sinusoidal tones, one from each of these groups.

Major Tone	Minor Tone	
500 KHz	100 KHz *	* The 100 KHz may also be chosen as the major tone.
100 KHz *	4800 Hz **	** The minor tone may also be modulated by the ambiguity resolving code as described in Item (iii) of this section.
	4160 Hz	
	4032 Hz	
	4008 Hz	
	4000 Hz **	

<u>After Range Acquisition</u> - Single sinusoidal tone (major tone)

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3.3 Ranging Signal Characteristics (continued)

ii) Carrier Modulation:

Type PM

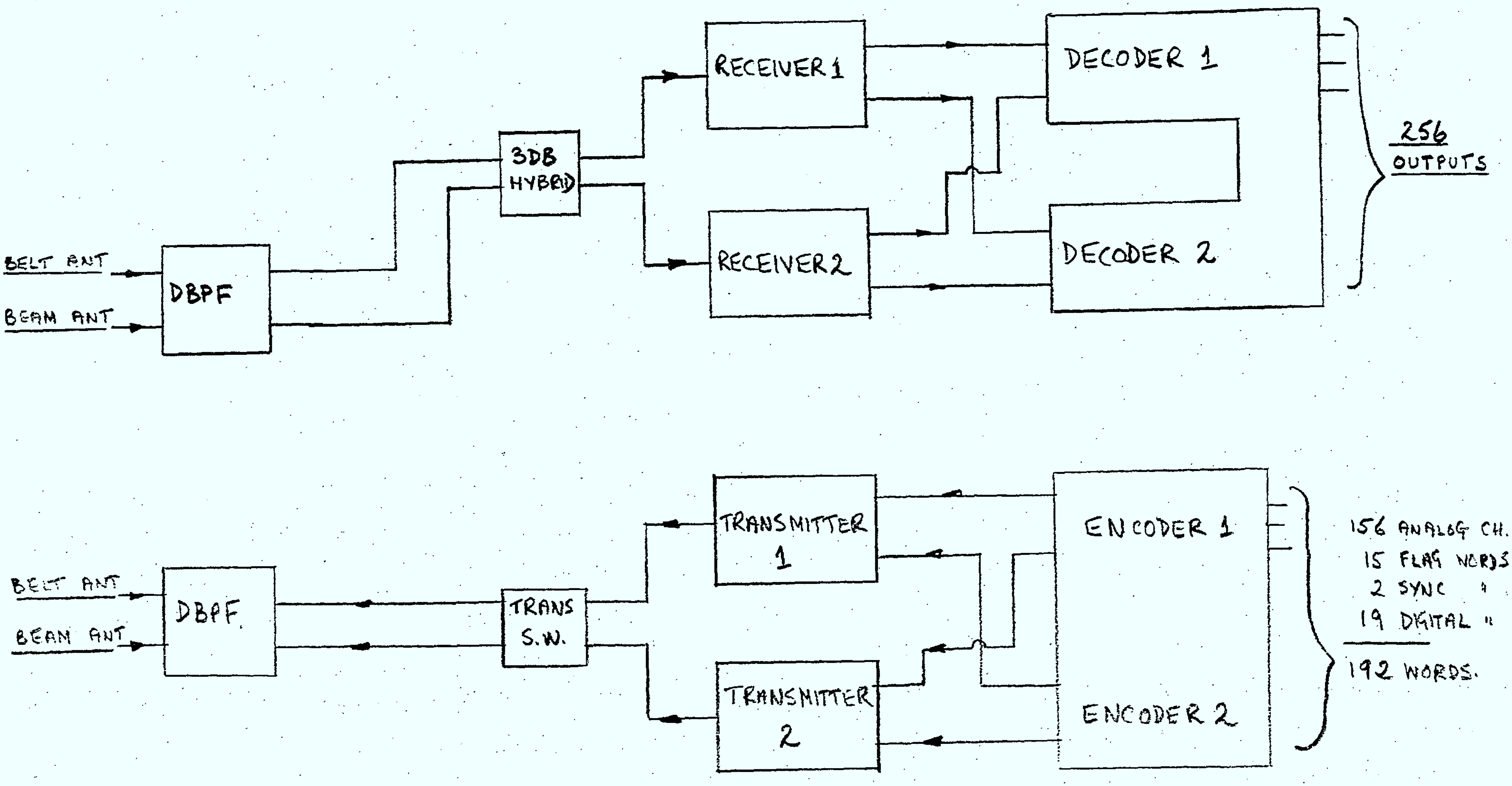
Modulation Index:

Major Tone: 0.5 to 1.06 radians peak (sine wave)

Minor Tone (if present): 0.2 to 0.7 radians Peak (sine wave)

iii) Anbiguity Resolving Code:

Modulo 2 sequence of PRN code and 4 KHz clock on 4 KHz sub-carrier.



TT & C SUBSYSTEM

Telemetry Encoder

One main frame	=	192 words
Bits/word	=	8
Bit rate	=	1536 Bits/sec.

Inputs

a) 156 Analog channels (8 bits)

b) 15 Flag words

c) 2 Sync words

d) 19 Digital words (ACS)

192 words

Command Decoder

No. of commands - 256

Commands	Bits
a) Set command without ground verification	48
b) Set command with ground verification	65
c) Set value without ground verification	65
d) Set value with ground verification	82

Bit rate - 1000 Bits/sec.

TT & C SUBSYSTEM STUDY - UHF SPACECRAFT: FINAL REPORT.

DATE DUE
DATE DE RETOUR
