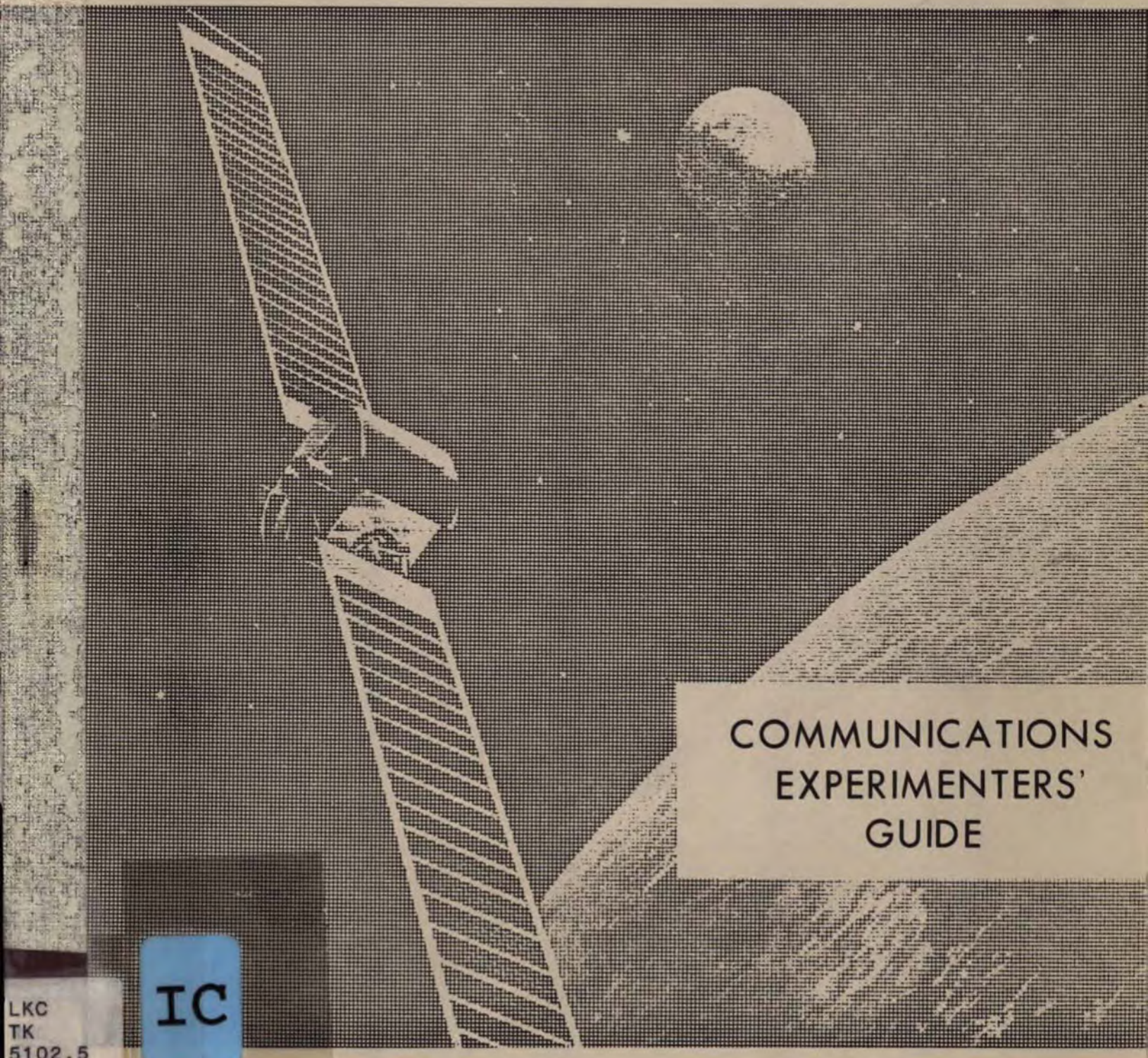
Library File Copy
REFERENCE COPY
MUST REMAIN IN LIBRARY

Communications Technology Satellite



COMMUNICATIONS EXPERIMENTERS' GUIDE

IC

LKC
TK
5102.5
.R48e
#652
c.2

Communications Canada

Communications Research Centre

Centre de recherches sur les communications

CRC TECHNICAL NOTE NO. 652

Issue 1

October 1972

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

Industry Canada
Library - Queen

MAR 2 0 2013

Industrie Canada
Bibliothèque - Queen

COMMUNICATIONS EXPERIMENTERS' GUIDE

COMMUNICATIONS TECHNOLOGY SATELLITE

Communications Systems Directorate
Space Systems

ISSUE 1

COMMUNICATIONS CANADA
CRC
DEC 1 1986
LIBRARY – BIBLIOTHÈQUE

CRC TECHNICAL NOTE NO. 652

December 1972
OTTAWA

CAUTION
This information is furnished with the express understanding that:
Proprietary and patent rights will be protected.

COMMUNICATIONS EXPERIMENTERS' GUIDE

COMMUNICATIONS TECHNOLOGY SATELLITE

Table of Contents

1. Introduction 1

2. Spacecraft 2

3. Transponder 4

4. Spacecraft Antenna Coverage 8

5. Spacecraft Motion 8

6. CRC Ground Terminals 13

7. Communications Applications 16

7.1 TV Broadcast 17
7.2 TV Remote Transmission 21
7.3 Sound Broadcast 21
7.4 Two-Way Voice Transmission 21
7.5 Digital Transmission 31

COMMUNICATIONS CANADA
CRC
DEC 1 1986
LIBRARY – BIBLIOTHÈQUE

COMMUNICATIONS EXPERIMENTERS' GUIDE
COMMUNICATIONS TECHNOLOGY SATELLITE

1.0 INTRODUCTION

The Communications Technology Satellite (CTS) is a joint experimental program of the Canadian Department of Communications and the United States National Aeronautics and Space Administration to explore the application to satellite communications of advanced technology. It is planned to launch the experimental satellite in August 1975. In addition to the development and flight testing of advanced spacecraft sub-systems, both countries will carry out an experimental program in communications using the satellite. The U.S. and Canada have agreed to share the use of the satellite for communications experiments on a 50-50 basis.

One of the main technology experiments on CTS will be the testing of a 200 watt, high-efficiency, travelling-wave tube operating at a frequency of 12 GHz. The RF output power will be significantly greater than that provided by any existing spacecraft.

Prior to 1971, the only frequency bands allocated for satellite communications were below 9 GHz. Bands at 4 and 6 GHz are being used extensively in international systems such as INTELSAT, and will also be used by Telesat Canada for the first Canadian domestic satellite system scheduled to begin operations early in 1973. These bands are allocated on a primary basis, but shared with equality by the Fixed-Satellite (communications satellite) and the Fixed (terrestrial) Services, and are subject to sharing constraints and power flux density limits by international agreement.

In July of 1971, the I.T.U. World Administrative Radio Conference on Space Telecommunications allocated a number of new frequency bands to the space services. CTS will transmit in the new band at 11.7-12.2 GHz and receive in the band 14.0-14.5 GHz.

There is no power flux density limit imposed on satellite transmissions at 12 GHz and, therefore, the development of high e.i.r.p. satellites is appropriate.

Although the 12 GHz band is not allocated exclusively to space services, terrestrial services, by international agreement, may be introduced only after the elaboration and approval of plans for space services to ensure compatibility of the use of the band within each country. In fact, the ability to locate ground stations close to the user, by avoiding co-ordination problems often encountered in the lower frequency shared bands, may be one of the more important features of the use of the band by domestic systems with large numbers of terminals. In Region 2, which comprises North and South America, use of the 12 GHz band by space services is limited to domestic systems. It is allocated to the Broadcasting-Satellite Service as well as the Fixed-Satellite Service.

Communications experiments using CTS will be aimed primarily at exploring those applications that particularly take advantage of the use of the 12 GHz band and the high satellite e.i.r.p. Ground station development within the CTS program will tend to concentrate on low cost terminals having small diameter antennas which can be located close to the user. The satellite and ground terminals will be particularly suitable for technological and socio-economic experiments in the areas of:

- TV broadcasting to remote communities
- Educational or instructional television to remote communities with a telephone quality return channel
- TV relay from remote communities
- Sound broadcasting
- Two-way telephony
- Data links
- Wideband distribution

2.0 SPACECRAFT

The Communications Technology Satellite will be launched from the NASA Test Range on an advanced three-stage Thor-Delta launch vehicle and placed in the geostationary satellite orbit at 114° west longitude. The design lifetime in orbit is two years. When on station, a momentum wheel and reaction control jets, operated in conjunction with earth and sun sensors, will stabilize the spacecraft in three axes so that the communications antennas always face the earth. The spacecraft orientation accuracy will be $\pm 0.1°$ in pitch and roll, $\pm 1.0°$ in yaw and the stationkeeping jets will maintain the longitudinal position to within $\pm 0.2°$. Beam pointing with respect to any selected point on the earth will be maintained to an accuracy of $\pm 0.2°$. A mercury bombardment ion engine for north-south stationkeeping will be carried on board as an experiment but a north-south drift of up to $\pm 1.3°$ could occur during the lifetime of the spacecraft. Power will be supplied to the spacecraft by two solar sails measuring approximately 54 feet tip-to-tip which will be unfurled in orbit. Figure 1 is a sketch of the spacecraft.

The satellite will be controlled from a telemetry, tracking and command station located near Ottawa. The configuration of the spacecraft communications system can be varied (select operational modes, adjust transponder gains and point spacecraft antennas) in accordance with user experiment requirements. Monitoring of spacecraft systems' operation will be continuous.

A major technology experiment on the spacecraft is the use of a 200 watt high efficiency (> 50%) TWT which, in combination with a transponder package and antenna system, will be capable of relaying communications signals between suitably located ground terminals. The antenna system

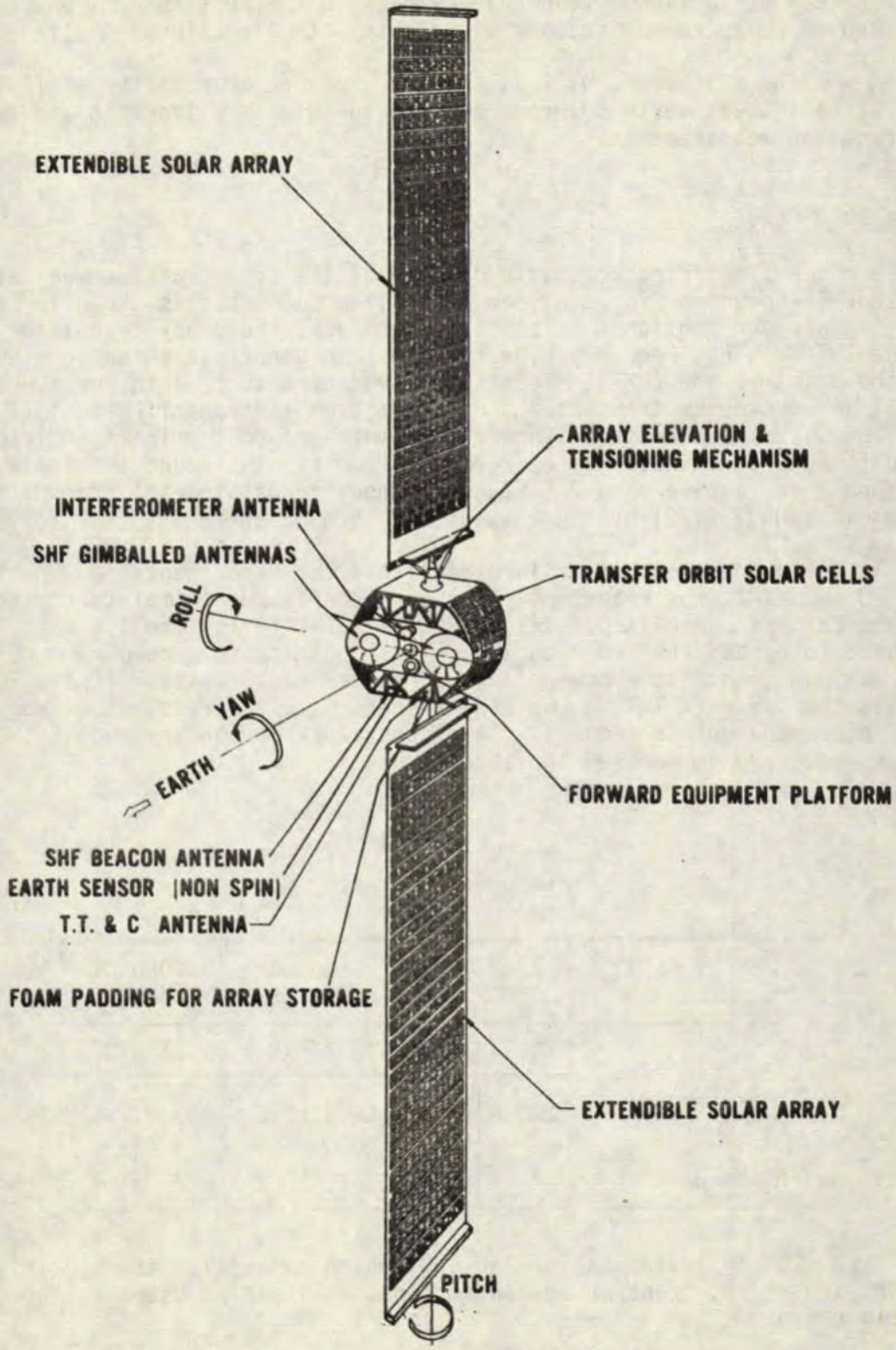


Fig. 1. Communications Technology Satellite.

consists of two fully gimballed antennas with a beamwidth of 2.5°. Either antenna can be commanded to point anywhere in the Western Hemisphere and can be used to relay communications signals in both directions simultaneously.

The spacecraft will also carry a beacon transmitter at 11.7 GHz operating into an earth coverage antenna for use as a tracking aid and for propagation measurements.

3.0 TRANSPONDER

A simplified schematic diagram of the spacecraft communications package is shown in Fig. 2(a) and a detailed schematic is shown in Fig. 2(b). The transponder portion consists of a receiver, frequency translator and three TWT's. The frequency plan for the transponder is shown in Fig. 3. In the primary mode (PM1), signals received by antenna 1 in receive band 1 (RB1) are frequency translated and transmitted in transmit band 1 (TB1) by the 200 watt TWT through antenna 2 to remote ground terminals (RB1 to TB1). Simultaneously, signals may be received from remote ground terminals by antenna 2 in receive band 2 (RB2), frequency translated and transmitted in transmit band 2 (TB2) by the 20 watt TWT through antenna 1 (RB2 to TB2).

In the event of failure of either the experimental 200 watt TWT or the 20 watt TWT, the transponder can be reconfigured to maintain a reduced communications capability. If the 200 watt TWT fails, the 1.5 watt TWT can be used to bypass the 200 watt TWT. This constitutes secondary mode 1 (SM1). The maximum transmitter power is thus reduced to 20 watts. If the 20 watt TWT fails, the 1.5 watt TWT can be used instead with the result that power in the return channel is reduced. This constitutes secondary mode 2 (SM2). These modes are summarized in Table 1.

TABLE 1

Transponder Operating Modes

	PRIMARY MODE		SECONDARY MODE		SECONDARY MODE	
	TB 1	TB 2	TB 1	TB 2	TB 1	TB 2
Max Transmit Power	200 W	20 W	20 W	1.5 W	200 W	1.5 W
Antenna	2	1	1	2	2	1

The following table (Table 2) which summarizes the specifications of the spacecraft transponder and antenna, will assist users in the design of experiments.

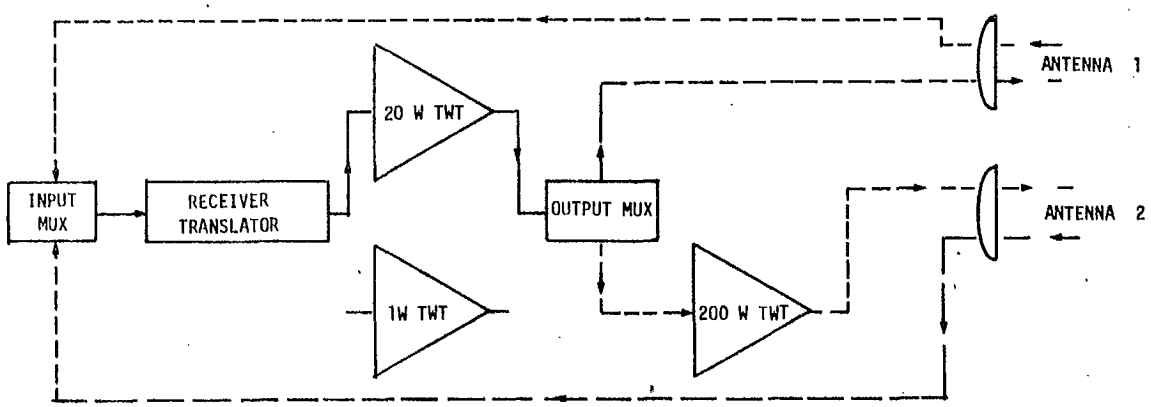


Figure 2(a)

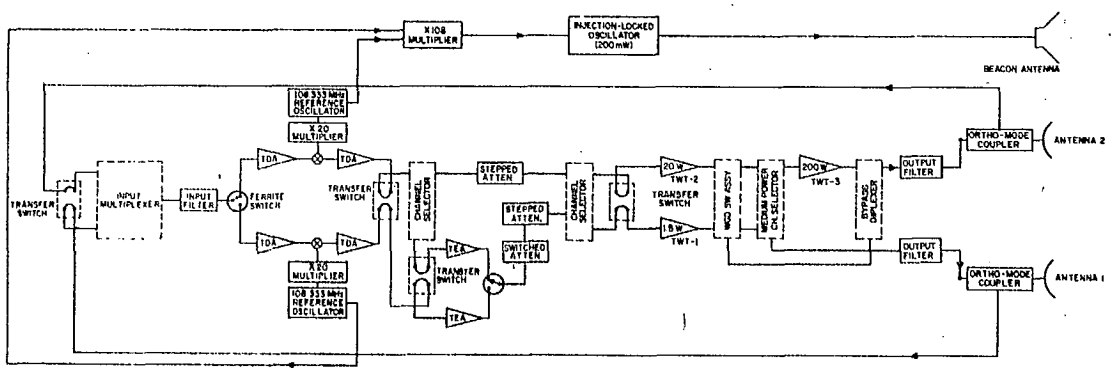


Figure 2(b)

Fig. 2. CTS Transponder.

S.H.F. FREQUENCY PLAN

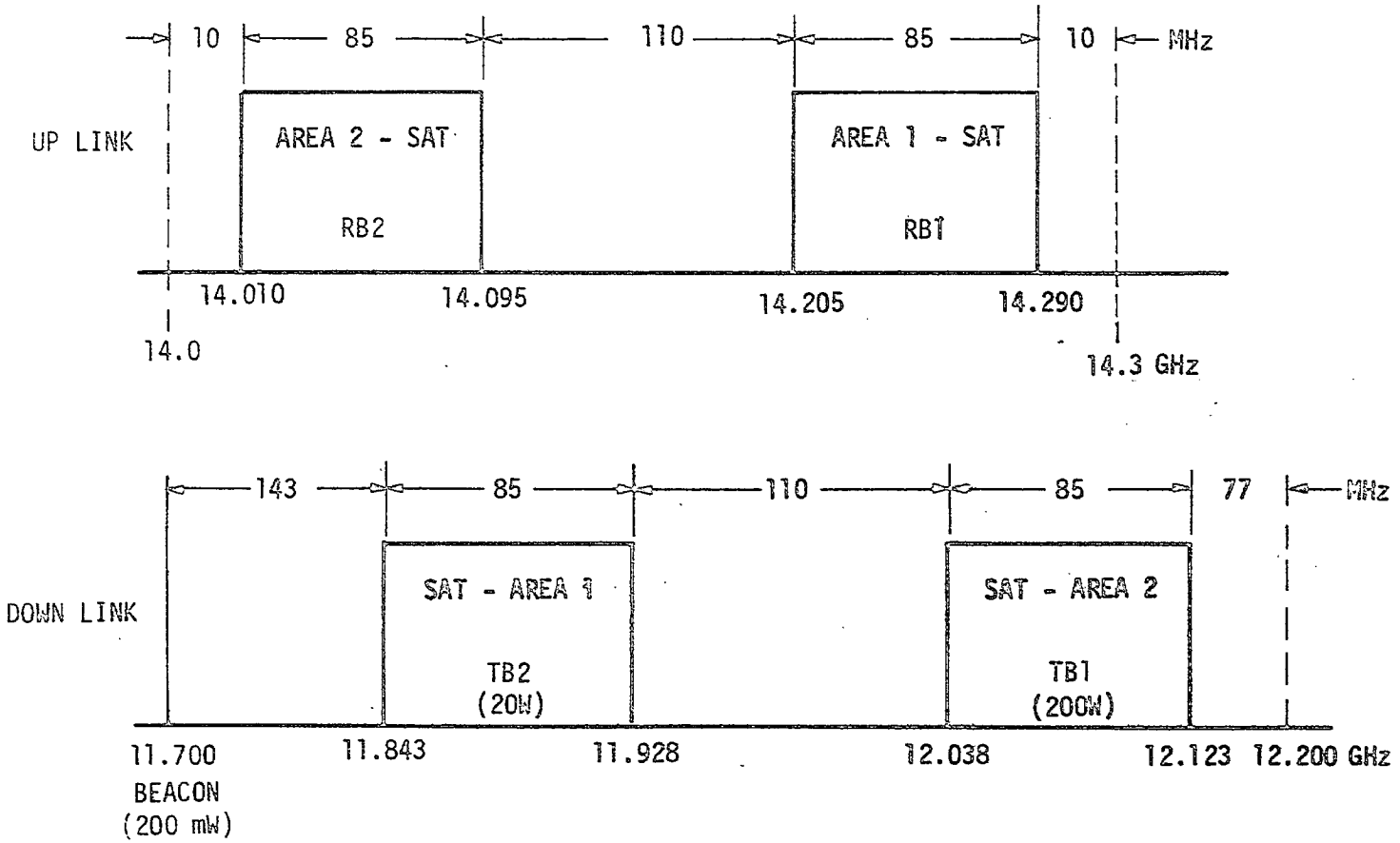


Fig. 3. S.H.F. Frequency Plan.

TABLE 2

Transponder and Antenna Specifications

Receive Band 1 (RB1)	14.205 - 14.290 GHz
Receive Band 2 (RB2)	14.010 - 14.095 GHz
Transmit Band 1 (TB1)	12.038 - 12.123 GHz
Transmit Band 2(TB2)	11.843 - 11.928 GHz
Polarization (Transmit & Receive)	Linear, Orthogonal
Transmit Antenna Gain (Boresight)	36.3 dB
Reduction in Transmit Gain ($\pm$1.25° off boresight)	2.6 dB
Filter Loss TB1 (200W)	0.5 dB
Filter Loss TB2 (20W and 1.5W)	1.0 dB
Filter Loss TB1 (20W)	1.0 dB
Filter Loss TB2 (1.5W and in SM1)	1.3 dB
Receive Antenna Gain (Boresight)	36.2 dB
Reduction in Receive Gain ($\pm$1.25° off boresight)	3.0 dB
Gain RB1 to TB1	116, 114, 112, 110 (saturated gain)
Gain RB2 to TB2	108, 106, 104, 102 (small signal gain)
High Gain Mode RB1 to TB1	126, 124, 122, 120 (saturated gain)
Gain Selection	By ground command
Gain Flatness (not including 200W TWT)	$\pm$0.75 dB over centre 68 MHz
	$\pm$1 dB over 85 MHz (RB1 to TB1)
	$\pm$1.25 dB over 85 MHz (RB2 to TB2)
Receiver Noise Temperature	2000°K

4.0 SPACECRAFT ANTENNA COVERAGE

The spacecraft antennas are gimballed so that they can be aimed at any point on the earth's surface that is visible from the satellite. Figures 4,5 and 6 show the coverage obtained for a typical set of boresight aiming points. The contours represent the areas within which at least half of the peak incident satellite power will be received, taking into account satellite motion. In all cases, coverage area 2 is associated with the 200 watt spacecraft transmitter, and coverage area 1 is associated with the 20 watt transmitter.

Figure 4 shows how the spacecraft antennas might be aimed to permit the Ottawa terminal to transmit signals to ground terminals in Central Canada, using the 200 watt tube. The return link to Ottawa would use the 20 watt tube.

Since the spacecraft antennas are independently gimballed, their coverage patterns may be superimposed. This is illustrated in Figure 5. Here, a terminal in, say, Quebec, could transmit via the 200 watt tube to ground terminals in most of the Province of Quebec, with a return link via the 20 watt tube. Note that a terminal in the region that is common to both beams could receive its own transmission if it were capable of receiving in both of the down-link bands. This is the only example illustrated where "loop" testing of this kind is possible.

The situation of Figure 6 is similar to that of Figure 4, except that the appropriate ground terminals are assumed to be in, say, Newfoundland and British Columbia.

5.0 SPACECRAFT MOTION

The CTS is nominally geostationary, but all geostationary satellites require some form of station-keeping system to maintain their positions to some specified accuracy. CTS will use reaction jets to maintain its position at 114° W longitude within $\pm$ 0.2° in the east-west direction. Although an ion engine will be carried on CTS as an experiment, it is unlikely that north-south station-keeping will be possible. Current plans call for orbit injection with a nominal bias in orbit inclination of one degree. In this case, the spacecraft will have an initial daily north-south motion of $\pm$ 1 degree. The orbit inclination should decrease during the first year of operation and, depending on the launch node, may become nearly zero resulting in correspondingly small daily north-south excursions. The advantage of using a satellite with limited motion is, of course, that it permits the use of fixed, non-tracking ground antennas.

Figure 7 gives an example of a possible path described by the satellite during a 24 hour period as seen by a ground station at Ottawa. The crosses give the satellite position at hourly intervals. The exact path described by the satellite will be a complex one dependent on many factors

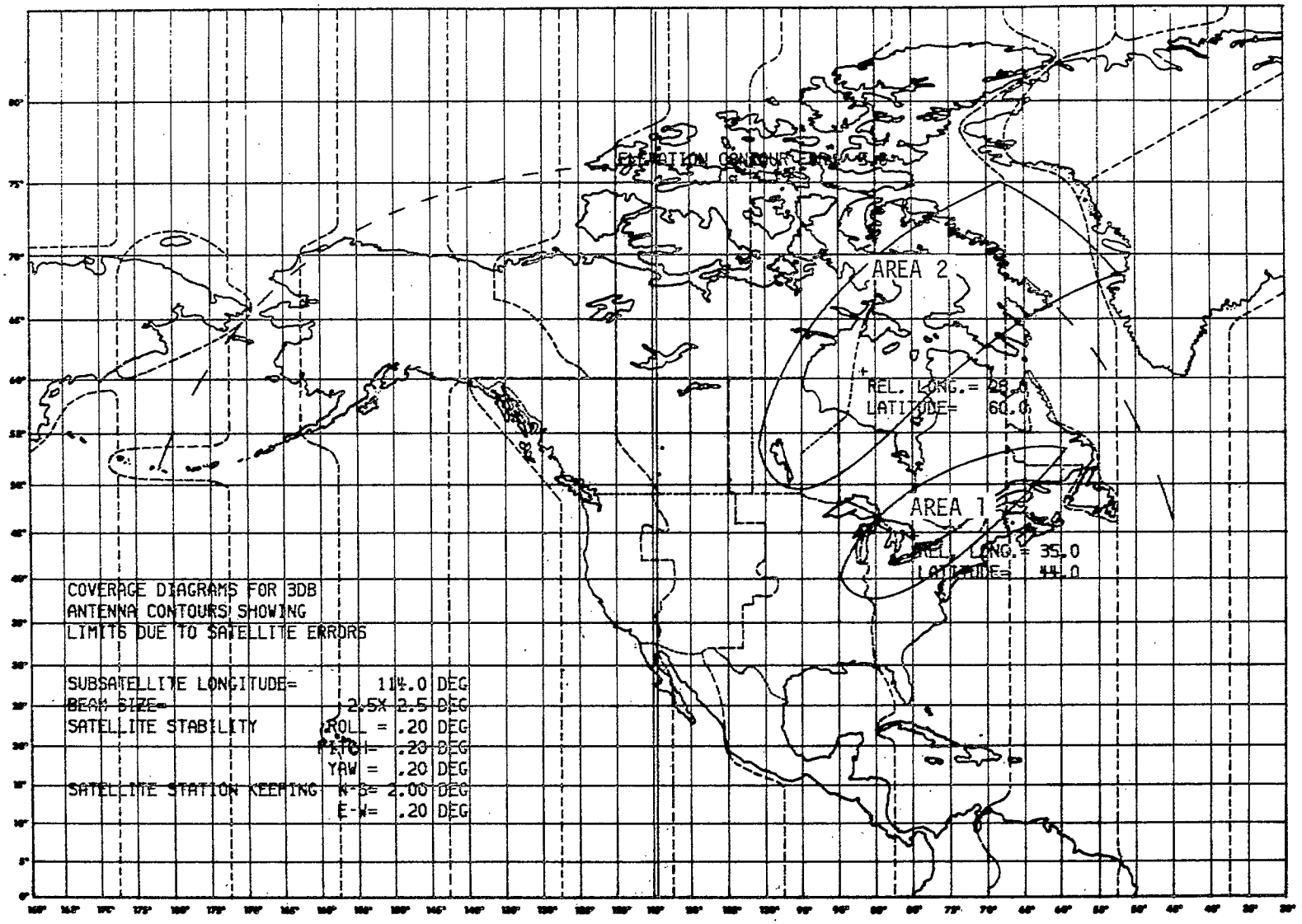


Fig. 4. Area coverage diagram.

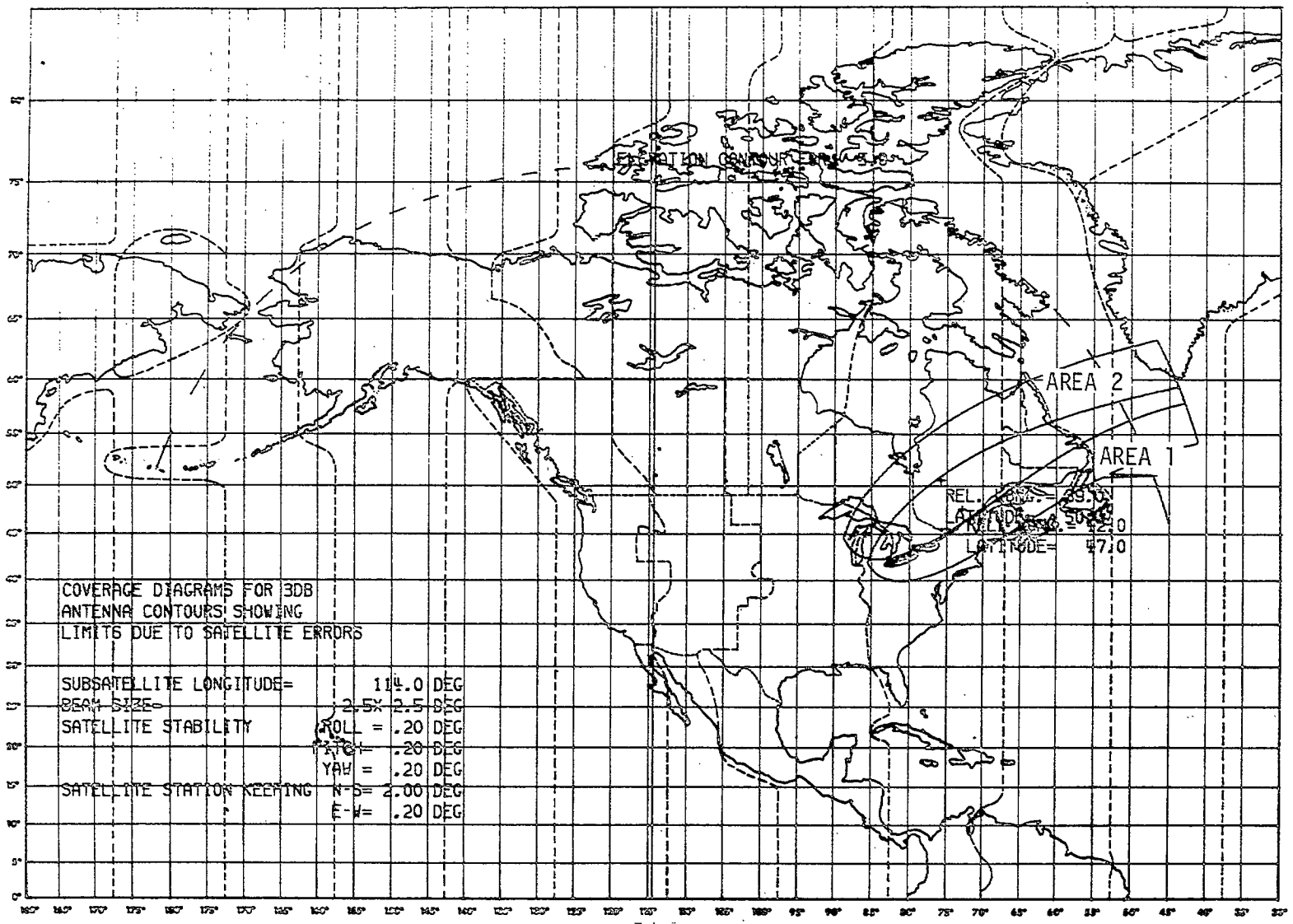


Fig. 5. Area coverage diagram.

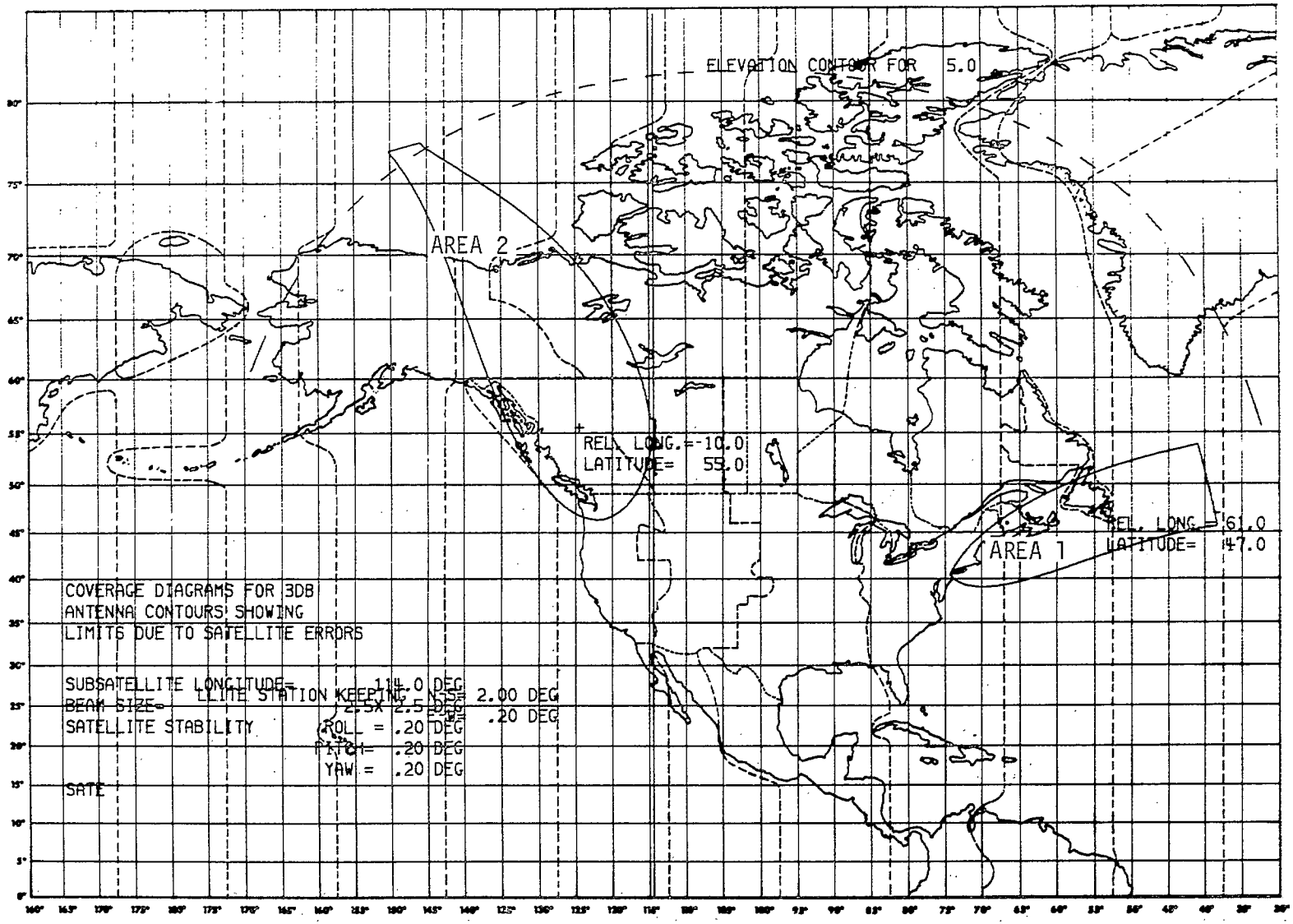


Fig. 6. Area coverage diagram.

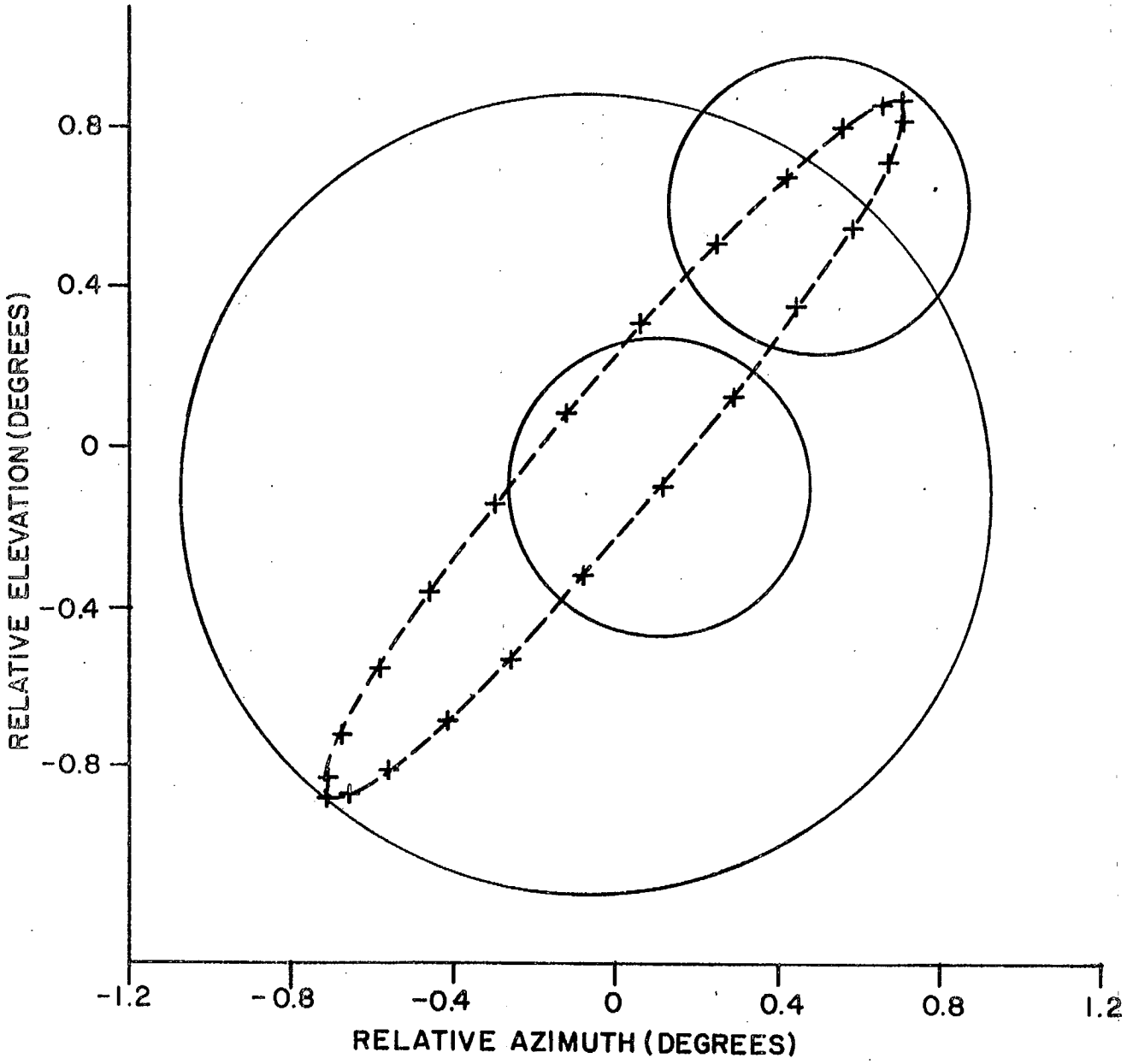


Fig. 7. Daily satellite motion.

and it will change with time. At present, one can only predict that the satellite will lie within an inclined rectangular box having a width of about 0.47° and a length of about 2.36° as seen from a point on the earth's surface, assuming an inclination of one degree. Considering launch dispersions, this length could be slightly larger at beginning of life. The angle of the major axis of this rectangle with respect to the local vertical will depend on the geographical position of the ground station and the exact parameters of the satellite orbit.

In order to examine tracking requirements for ground antennas, 3 dB contours for an eight foot and three foot antenna at 12 GHz are shown as solid lines on Figure 7. The small circles are for an eight foot antenna and the large circle is for a three foot antenna.

Based on the assumptions used in deriving Figure 7, a non-tracking eight foot antenna will provide between 2 and 8 hours of operation during a day, depending on the desired operating times. A non-tracking three foot antenna provides nearly full 24 hour coverage. In fact, if sufficient satellite power is available, it may be reasonable to consider using the ground station antenna as much as 4 dB off-axis, in which case the 3 foot antenna provides full 24 hour operation for the conditions postulated in Figure 7. There is little point in considering operation much beyond this point because the decrease of gain with increasing off-axis angle becomes very great. In this case it would be preferable to use a smaller ground antenna with a lower on-axis gain but greater beamwidth.

The conclusion to be drawn from the above is that for typical satellite motions expected, antennas having diameters of about eight feet or more will probably require some form of tracking or frequent manual re-positioning. Antennas with diameters about three feet or less should provide a substantial number of hours of operation per day throughout most of the mission lifetime without a requirement for tracking.

6.0 CRC GROUND TERMINALS

The following constitutes a brief description of the types of ground terminal that are presently planned by CRC. It is expected that an experiment plan will be evolved from the proposals submitted, and within the constraints of this plan and to the extent possible within the resources which may be made available to CRC, the terminals described will be made available to experimenters. Their characteristics are summarized in Table 16.

The largest is the existing 30-foot terminal at CRC, Ottawa. This has a fully steerable auto-tracking antenna, and will be modified from its present configuration to operate in the CTS frequency bands. The R.F. electronics are housed on the antenna pedestal, with the remaining electronics, control circuits and associated computer in a nearby building. It is expected that this terminal will act as a focal point in the control and the conduct of many of the CTS experiments. The terminal will be capable of

transmitting all types of signals envisaged for the CTS experimental program.

The major field transmitting terminal will be the TV Remote Transmission Terminal (TVRTT). This will comprise an air and ground transportable trailer with an attached ten-foot antenna and a high-power transmitter. The terminal should take no more than a few hours to set up or to dismantle, using two people. The antenna will be stowed for transportation.

The TVRTT will normally be accompanied by skilled operators. It will be capable of transmitting and receiving all of the types of signals envisaged for the CTS experimental program, although in some cases (e.g. TDMA) appropriate specialized demodulation and baseband equipment will have to be supplied. This terminal will also provide a back-up to the Ottawa Communications Control Terminal in the event of a major failure.

The medium sized terminal envisaged for this program will have an 8-foot antenna mounted on a pedestal designed to be installed on the ground or on the top of a flat roofed building. It will be capable of receiving a TV signal with one audio channel and/or receiving and transmitting a duplex telephone quality voice channel (for order wire or experimental telephony purposes) and/or receiving sound broadcast signals.

Both the TVRTT antenna and the 8-foot antenna have sufficiently narrow beamwidths that they will be equipped with some form of tracking mechanism to follow the motion of the satellite.

The smallest terminal type envisaged will have a broad enough beamwidth to obviate the necessity for tracking while still providing almost 24-hour operation. It will have a 3-foot antenna, and is intended to be portable. Its primary applications are the operation of a duplex voice channel and sound broadcast reception. However, it may, alternately, be fitted to receive a moderate quality TV signal in clear weather

TABLE 16

SUMMARY OF PROPOSED CTS SHF GROUND TERMINALS

TERMINAL TYPE	ANTENNA		RECEIVER		Transmitter Power (W)	ANTENNA CONTROL
	Dia. (ft)	Approx. Gain (dB)	Type	System Noise Temp (K)		
Communications Control (Ottawa)	30	59	Uncooled Paramp.	425	350	Auto Track
TVRTT	10	50	TDA(1)	1150	350	Programmed Track
Medium	8	47	TDA(1)	1150	1(2)	Programmed Track
Small	3	39	Mixer	2660(3)	1(2)	None

NOTES:

(1) TUNNEL DIODE AMPLIFIER

(2) WHEN TRANSMITTER IS INCLUDED

(3) A TDA WOULD BE NEEDED FOR TV RECEPTION (SYSTEM NOISE TEMP 1150°K)

7.0 COMMUNICATIONS APPLICATIONS

In this section, some typical applications appropriate to the CTS are described and sample link calculations are given illustrating communications system performance to be expected.

Possible applications for CTS in its primary mode (PM1) include the following:

1. TV Broadcast
   - TV broadcast to small communities in remote areas
   - Educational TV broadcast with a voice/data return channel for interactive ETV
2. TV Remote Transmission
   - TV transmission of special events in isolated areas from a transportable terminal to a central area for network distribution or retransmission to a remote region.
   - Two-way video transmission for teleconferencing between a remote transportable terminal and a large central terminal.
3. Radio Broadcast
   - Broadcast of radio program material to a small ground terminal.
4. Two-way voice
   - Telephony service to and between small, transportable ground terminals
5. Digital Communications
   - Digital data transmission and exchange
   - Investigation of high speed data transmission by satellite
   - Investigation of time division multiple access techniques.

One factor to be considered at 12 and 14 GHz is attenuation of the signal due to rainfall. Of importance to the communications systems designer is the establishment of system margins, the attenuation exceeded for given small percentages of the time. Considerable work has been done, including work at CRC, on measurements of rainfall attenuation. CRC is now implementing a program to gather attenuation statistics at various points across Canada using 13 GHz radiometers.

For CTS experimental applications, margins adequate to ensure operation for at least 99.9% of the time have been assumed. In many cases, sufficient transmitter power will be available to permit greater margins if desired. In addition to signal attenuation due to rainfall, fading due to tropospheric scintillation will be significant at low elevation angles. However, in Northern Canada, where operation at low elevation angles will be required, rainfall should be less of a problem.

Values used in determining minimum margins for propagation fading are given in Table 3. These numbers have been obtained from CRC published data, CCIR documents and extrapolation of data obtained by CRC.

In arriving at a total margin, these numbers should not be added arithmetically since the fading due to different effects should be statistically independent. In the calculations given below, the margins have been combined in a statistical way to give a typical total margin on the order of 4 dB. In all link calculations that follow the total link carrier-to-noise ratio (clear weather) is sufficient to provide this operating margin.

7.1 TV Broadcast

As an example of TV broadcast we consider transmission of a color video signal with one audio sub-carrier from the Ottawa 30 foot terminal to an eight foot receive terminal located in Northern Canada with an elevation angle to the satellite of five degrees. The spacecraft receive antenna is boresighted on Ottawa, coverage area 1, as shown on Figure 4. The eight foot receive terminals are located anywhere within coverage area 2. The 200 watt spacecraft channel is used and frequency modulation is assumed.

The minimum transmit powers necessary to achieve a picture quality suitable for community receivers are shown in the summary of link calculations given in Tables 4 and 5. It can be seen that up to 3-1/2 dB additional spacecraft transmit power is available, depending on the back-off required if multiple signals are being transmitted through the transponder. An increase in ground transmit power would be required. This additional power can be used to improve the performance, with increased fading margin, or to provide the possibility of operating for additional hours per day using a non-tracking eight foot antenna (at some time during the mission).

The transmit power required for ground stations having antennas smaller than the 30 foot used in this example can be obtained by doing a similar calculation. For example, the minimum transmit powers required for a 10 foot or 8 foot antenna replacing the 30 foot antenna would be 158 watts and 327 watts respectively.

A second example of TV broadcast using the 10 foot transportable terminal as a transmit station might be TV broadcast from Newfoundland to British Columbia. For this situation, the 10 foot terminal would be located in Newfoundland and the spacecraft antenna 1 would be boresighted on this terminal. Eight foot receive terminals could be located anywhere within coverage area 2 as illustrated in Fig. 6. Performance would be essentially the same as that given in Table 5 except that minimum ground transmit power for the 10 foot terminal would be nominally 158 watts.

TABLE 3

Elevation Angle of Antenna	Rain Attenuation (dB)	
	12 GHz	14 GHz
5°	1.2	2
26°	1.4	2.8

Elevation Angle of Antenna	Tropospheric Fading (dB)	
	12 GHz	14 GHz
5°	3.0	3.5
26°	1.0	1.0

TABLE 4

TV BROADCAST UPLINK Frequency 14 GHz	
Transmit ground station:	
Location	Ottawa
Transmit power video only (21.8 watts)	13.4 dBW
Transmit power video + audio (23.4 watts)	13.7 dBW
RF bandwidth video only	20.9 MHz
RF bandwidth video + audio	22.4 MHz
Line loss	1.0 dB
Antenna:	
Diameter	30 feet
Efficiency	50%
Gain	59.5 dB
Tracking error loss	0.0 dB
Losses:	
Path loss (26°)	207.2 dB
Atmospheric attenuation	0.17 dB
Spacecraft:	
Antenna:	
Gain	36.2 dB
Pointing error loss	0.08 dB
Up-path system temperature	2315°K
Up-path carrier-to-noise ratio (clear weather)	22.4 dB
Transponder gain	118 dB

TABLE 5

TV BROADCAST DOWNLINK Frequency 12 GHz	
Spacecraft:	
Transmit power video (82.1 watts)	19.1 dBW
Transmit power video + audio (88.2 watts)	19.4 dBW
Output filter loss	0.5 dB
Antenna:	
Gain	36.3 dB
Beam edge allowance	2.6 dB
Losses:	
Path loss (5°)	206.3 dB
Atmospheric Attenuation	0.66 dB
Receive ground station:	
Antenna:	
Diameter	8 feet
Efficiency	50%
Gain	46.7 dB
Tracking error loss	1.2 dB
Down-path system temperature (TDA)	1151°K
Down-path carrier-to-noise ratio (clear weather)	22.4 dB
Total link carrier-to-noise ratio (clear weather)	14.8 dB
Video performance:	
Baseband	4.2 MHz
Mod. index (M)	1.48
FM improvement $3M^2$ (M+1)	12.2 dB
Noise weighting	10.2 dB
Pre-emphasis advantage	2.8 dB
RMS to peak-to-peak (excluding sync) conversion	6.0 dB
Peak-to-peak signal to rms weighted (clear weather)	46 dB
Audio performance:	
Sub-carrier frequency	4.5 MHz
Baseband	15 kHz
Mod. Index	1.67
Test Tone-to-noise ratio	50.0 dB

7.2 TV Remote Transmission

The example to be considered is transmission of a TV signal from a 10 foot transportable terminal located in Northern Canada anywhere within coverage area 2 shown on Figure 4 to the Ottawa 30 foot station in coverage area 1. The signal would be network quality colour video with up to four simultaneous audio channels. Transmission in this direction would be through the low power, 20 watt, channel on the transponder.

The signal received at the Ottawa station could be distributed to a national TV network for live coverage of a special event, or could be re-transmitted by the Ottawa station through the 200 watt satellite channel to eight foot receive terminals located within coverage area 2. Simultaneous two-way television transmission between the 10 foot and 30 foot terminals is possible.

A typical link calculation for this case is given in Table 6 and 7.

7.3 Sound Broadcast

This example considers broadcast of an FM sound signal from the 30 foot Ottawa station to a small sound broadcast receive terminal located in a remote region. The spacecraft antenna 1 is boresighted at Ottawa in coverage area 1 as shown on Figure 4. Receiver terminals may be located anywhere within coverage area 2 on Figure 4. Transmission is through the high power, 200 watt, satellite channel and, for the purposes of this example, a receive terminal with a three foot antenna and a simple mixer front end has been assumed. It is further assumed that the receive terminal is non-tracking and the performance obtained is equal to or better than that given in Table 8 for satellite positions within the 3 dB beamwidth of the 3 foot antenna, which would be about two degrees at 12 GHz.

The minimum transmit powers given in Table 8 are modest and it should be possible to increase these to provide better output performance and/or greater fade margin above receiver FM threshold if desired. It is also possible to consider use of a smaller receive antenna size.

To transmit from an eight foot antenna rather than the 30 foot antenna used in the example, the minimum ground transmitter power would be increased from 3.2 watts to 65.3 watts (with a 1.7 dB tracking error loss assumed for the eight foot antenna).

7.4 Two-way Voice Transmission

It is expected that a capability will exist within the CTS communications experimental program for a two-way voice channel amongst any of the communications ground terminals. This capability will provide an order wire service between terminals and a two-way voice channel for those

TABLE 6

TV REMOTE TRANSMISSION UPLINK Frequency 14 GHz	
Transmit ground station:	
Transmit power video only (238 watts)	23.8 dBW
Transmit power video + audio (286 watts)	24.6 dBW
RF bandwidth video only	32.1 MHz
RF bandwidth video + audio	38.6 MHz
Line loss	1.0 dB
Antenna:	
Diameter	10 feet
Efficiency	50%
Gain	50.0 dB
Tracking error loss	0.44 dB
Losses:	
Path loss (5°)	207.6 dB
Atmospheric attenuation	0.82 dB
Spacecraft:	
Antenna:	
Gain	36.2 dB
Beam edge allowance	3.0 dB
Up-path system temperature	2315°K
Up-path carrier-to-noise ratio (clear weather)	16.9 dB
Transponder gain	108 dB

TABLE 7

TV REMOTE TRANSMISSION DOWNLINK Frequency 12 GHz	
Spacecraft:	
Transmit power video only (4.0 watts)	6.0 dBW
Transmit power video + audio (4.8 watts)	6.8 dBW
Output filter loss	1.0 dB
Antenna:	
Gain	36.3 dB
Pointing error loss	0.07 dB
Losses:	
Path loss (26°)	205.9 dB
Atmospheric attenuation	0.14 dB
Receive ground station:	
Location	Ottawa
Antenna:	
Diameter	30 feet
Efficiency	50%
Gain	58.2 dB
Tracking error loss	0.0 dB
Down-path system temperature (Paramp)	425°K
Down-path carrier-to-noise ratio (clear weather)	20.7 dB
Total link carrier-to-noise ratio (clear weather)	15.4 dB
Video performance:	
Baseband	4.2 MHz
Mod. index (M)	2.82
FM improvement $3M^2$ (M+1)	19.6 dB
Noise weighting	10.2 dB
Pre-emphasis advantage	2.8 dB
RMS to peak-to-peak (excluding sync) conversion	6.0 dB
Peak-to-peak signal to rms weighted noise (clear weather)	54 dB
Audio performance:	
Sub-carrier frequency (Top channel)	8.24 MHz
Baseband	15 kHz
Mod. index	10.0
Test Tone-to-noise ratio	57.0 dB

TABLE 8

SOUND BROADCAST UPLINK Frequency 14 GHz	
Transmit ground station:	
Location	Ottawa
Transmit power (3.2 watts)	5.0 dBW
RF bandwidth	177 kHz
Line loss	1.0 dB
Antenna:	
Diameter	30 feet
Efficiency	50%
Gain	59.4 dB
Tracking error loss	0.0 dB
Losses:	
Path loss (26°)	207.2 dB
Atmospheric attenuation	0.17 dB
Spacecraft:	
Antenna:	
Gain	36.2 dB
Pointing error loss	0.08 dB
Up-path system temperature	2315°K
Up-path carrier-to-noise ratio (clear weather)	34.8 dB
Transponder gain	118 dB

TABLE 9

SOUND BROADCAST DOWNLINK Frequency 12 GHz	
Spacecraft:	
Transmit power (12.2 watts)	10.9 dBW
Output filter loss	0.5 dB
Antenna:	
Gain	36.3 dB
Beam edge allowance	2.6 dB
Losses:	
Path loss (5°)	206.3 dB
Atmospheric attenuation	0.66 dB
Receive ground station:	
Antenna:	
Diameter	3 feet
Efficiency	50%
Gain	38.2 dB
Off axis allowance	3.0 dB
Down-path system temperature (Mixer)	2660°K
Down-path carrier-to-noise ratio (clear weather)	14.2 dB
Total link carrier-to-noise ratio (clear weather)	14.1 dB
Audio performance:	
Baseband	15 kHz
Mod. index (M)	4.89
FM improvement $3M^2$ (M+1)	26.2 dB
Noise weighting and pre-emphasis advantage	9.6 dB
Test tone-to-rms weighted noise ratio (clear weather)	50 dB

user experiments that require them. Present plans suggest that the implementation of such a capability will be done in the simplest way possible that will meet the specific needs of the experimental program. The resultant system configuration may not necessarily be representative of an operational telephone service using satellites.

At present, it is assumed that a two-way telephone channel will be available between remote terminals and the Ottawa 30 foot terminal. Each remote terminal will have a unique transmit and receive frequency assigned to it. Frequency division multiple access will be used with provision for the requisite number of separate, voice carriers within the transponder 85 MHz passband. The main Ottawa station will have a capability to transmit and receive all voice channels. A 10 foot transportable terminal may also have this capability to avoid the necessity to loop signals through Ottawa. Communication between two small terminals located remotely will require a double hop through the satellite with channel switching at the Ottawa station.

In the example to follow, transmission is between remote terminals having three foot antennas located anywhere within coverage area 2 as shown in Figure 4 and the Ottawa station in coverage area 1. It is assumed that spacecraft antenna 2 is boresighted on Ottawa and that the three foot remote antennas are non-tracking so that a 3 dB off-axis allowance is included. Transmission from Ottawa to the remote stations is by way of the 200 watt channel in the transponder and that from the remote area to Ottawa uses the 20 watt channel. Single-channel-per-carrier frequency modulation with companding is assumed in the example. Digital modulation techniques are also being considered. Typical link calculations are given in Tables 10 through 13.

TABLE 10

TELEPHONY UPLINK OTTAWA TO REMOTE Frequency 14 GHz	
Transmit ground station:	
Location	Ottawa
Transmit power per channel (0.18 watts)	-7.3 dBW
RF bandwidth per channel	14 kHz
Line loss	1.0 dB
Antenna:	
Diameter	30 feet
Efficiency	50%
Gain	59.5 dB
Tracking error loss	0.0 dB
Losses:	
Path loss (26°)	207.2 dB
Atmospheric attenuation	0.17 dB
Spacecraft:	
Antenna:	
Gain	36.2 dB
Pointing error loss	0.08 dB
Up-path system temperature	2315°K
Up-path carrier-to-noise ratio (clear weather)	33.5 dB
Transponder gain	118 dB

TABLE 11

TELEPHONY DOWNLINK OTTAWA TO REMOTE Frequency 12 GHz	
Spacecraft:	
Transmit power per channel (0.7 watts)	-1.6 dBW
Output filter loss	0.5 dB
Antenna:	
Gain	36.3 dB
Beam edge allowance	2.6 dB
Losses:	
Path loss (5°)	206.3 dB
Atmospheric attenuation	0.66 dB
Receive ground station:	
Antenna:	
Diameter	3 feet
Efficiency	50%
Gain	38.2 dB
Off axis allowance	3.0 dB
Down-path system temperature (Mixer)	2660°K
Down-path carrier-to-noise ratio (clear weather)	12.8 dB
Total link carrier-to-noise ratio (clear weather)	12.8 dB
Audio performance:	
Baseband	3.4 kHz
Mod. index (M)	1.02
FM improvement $3M^2$ (M+1)	8.0 dB
Noise weighting, de-emphasis, and companding improvement	29.2 dB
Test tone-to-rms weighted noise ratio (clear weather)	50 dB

TABLE 12

TELEPHONY UPLINK REMOTE TO OTTAWA Frequency 14 GHz	
Transmit ground station:	
Transmit power (1.1 watts)	0.3 dBW
RF bandwidth	14 kHz
Line loss	1.0 dB
Antenna:	
Diameter	3 feet
Efficiency	50%
Gain	39.5 dB
Off axis allowance	3.0 dB
Losses:	
Path loss (5°)	207.6 dB
Atmospheric attenuation	0.82 dB
Spacecraft:	
Antenna:	
Gain	36.2 dB
Beam edge allowance	3.0 dB
Up-path system temperature	2315°K
Up-path carrier-to-noise ratio (clear weather)	14.1 dB
Transponder gain	108 dB

TABLE 13

TELEPHONY DOWNLINK REMOTE TO OTTAWA Frequency 12 GHz	
Spacecraft:	
Transmit power per channel (1 milliwatt)	-30 dBW
Output filter loss	1.0 dB
Antenna:	
Gain	36.3 dB
Pointing error allowance	0.07 dB
Losses:	
Path Loss (26°)	205.9 dB
Atmospheric attenuation	0.14 dB
Receive ground station:	
Location	Ottawa
Antenna:	
Diameter	30 feet
Efficiency	50%
Gain	58.2 dB
Tracking error loss	0.0 dB
Down-path system temperature (Paramp)	425°K
Down-path carrier-to-noise ratio (clear weather)	17.9 dB
Total link-carrier-to-noise ratio (clear weather)	12.6 dB
Audio performance:	
Baseband	3.4 kHz
Mod. index (M)	1.04
FM improvement $3M^2$ (M+1)	8.2 dB
Noise weighting, de-emphasis, and companding improvement	29.2 dB
Test tone-to-rms weighted noise ratio (clear weather)	50 dB

7.5 Digital Transmissions

The extent of the capability of the CRC ground terminals to support digital transmission experiments has not yet been determined. If voice signals are transmitted using frequency modulation, the system will support transmission of digital data at a rate up to 2.4 kb/s with appropriate voice frequency modems. If voice signals are transmitted digitally, the system will support transmission of digital data at rates up to 50 kb/s. Alternatively, users may interface with CRC terminals at an intermediate carrier frequency with user supplied modems. As for the two-way voice transmissions, all transmissions must be routed through the 30 foot Ottawa terminal or an appropriately located 10 foot terminal. Direct terminal-to-terminal links can only be accommodated if arrangements are made to change the transmission and reception frequency bands of the terminals.

Two sample link calculations are given illustrating digital transmission between the 30 foot Ottawa station and an eight foot terminal or a three foot terminal at bit rates of 1 Mb/s or 50 kb/s respectively. Transmission from Ottawa to the remote terminal uses the transponder 200 watt channel and that in the reverse direction the 20 watt channel.

The calculations are summarized in Tables 14 and 15. The three foot antenna is assumed to be non-tracking and, hence, has an allowance of a 3 dB for off-axis operation.

TABLE 14

DIGITAL UPLINK Frequency 14 GHz		Ottawa to 8 Foot	8 Foot to Ottawa	Ottawa to 3 Foot	3 Foot to Ottawa
E/No for ideal DPSK moden ($PE=10^{-5}$)	dB	10.3	10.3	10.3	10.3
Data rate	Kb/s	1000	1000	50	50
Implementation loss	dB	1.5	1.5	1.5	1.5
Fade Margin	dB	4.2	4.1	4.4	4.1
Required carrier-to-noise ratio (clear weather)	dB	16.0	15.9	16.2	15.9
Transmit ground station:					
Transmit power	watts	1.4	17.1	1.5	8.3
RF bandwidth	MHz	1.0	1.0	0.05	0.05
Line Loss	dB	1.0	1.0	1.0	1.0
Antenna:					
Diameter	feet	30	8	30	3
Efficiency	%	50	50	50	50
Gain	dB	59.5	48.0	59.5	39.0
Pointing Loss	dB	0.0	1.7	0.0	3.0
Losses:					
Path loss	dB	207.2	207.6	207.2	207.6
Atmospheric attenuation	dB	0.17	0.82	0.17	0.82
Spacecraft:					
Antenna:					
Gain	dB	36.2	36.2	36.2	36.2
Pointing loss	dB	0.08	3.0	0.08	3.0
Up-path system temperature	°K	2315	2315	2315	2315
Up-path carrier-to-noise ratio (clear weather)	dB	23.7	17.4	36.9	17.4
Transponder gain		118	108	118	108

TABLE 15

DIGITAL DOWNLINK Frequency 12 GHz		Ottawa to 8 Foot	8 Foot to Ottawa	Ottawa to 3 Foot	3 Foot to Ottawa
Spacecraft:					
Transmit power	watts	5.3	0.14	5.5	0.007
Output filter loss	dB	0.5	1.0	0.5	1.0
Antenna:					
Gain	dB	36.3	36.3	36.3	36.3
Beam edge allowance	dB	2.6	0.07	2.6	0.07
Losses:					
Path loss	dB	206.3	205.9	206.3	205.9
Atmospheric attenuation	dB	0.66	0.14	0.66	0.14
Receive ground station					
Antenna:					
Diameter	feet	8	30	3	30
Efficiency	%	50	50	50	50
Gain	dB	46.7	58.2	30.2	58.2
Pointing error allowance	dB	1.2	0.0	3.0	0.0
Down-path system temperature	°K	1214	425	2660	425
Down-path carrier-to-noise ratio (clear weather)	dB	16.7	21.2	16.2	21.2
Total link carrier-to-noise ratio (clear weather)	dB	16.0	15.9	16.2	15.9