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THE COMMUNICATIONS TECHNOLOGY SATELLITE AND THE ASSOCIATED GROUND TERMINALS FOR EXPERIMENTS

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ABSTRACT

The CTS project is a joint effort between the Communications Research Centre in Canada and National Aeronautics and Space Administration in the United States with both nations equally sharing available spacecraft communication time. The CTS spacecraft will be placed in synchronous orbit at 116° west longitude. General spacecraft operational characteristics are discussed with particular emphasis on communication system parameters. The associated Canadian and United States user ground terminals are reviewed with particular emphasis on wideband communications. In Canada the experimenter (user) ground terminal communication equipment is government owned whereas in the United States the user terminal equipment is the responsibility of each user.

INTRODUCTION

The Communications Technology Satellite (CTS) is a joint experimental program of Canada's Department of Communications (DOC) and the United States National Aeronautics and Space Administration (NASA) to explore the application of advanced technology to satellite communications.[1] The satellite launch is planned for December 1975. Once the satellite is on station it will be controlled from Ottawa by DOC.

There are three main technology experiments associated with the spacecraft (s/c). These include:

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(a) The development and flight testing of a traveling wave tube (TWT) with a power output of 200 watts and an efficiency of 50%.

(b) Flight evaluation of lightweight, flexible, extendable solar arrays with an initial total output power greater than 1.2 kilowatts.

(c) Flight evaluation of a 3-axis stabilization system on a s/c with flexible appendages.

During the two year design lifetime of the satellite, the bulk of the time available (excepting that required for spacecraft technology experiments) will be divided equally between the United States and Canada for user communication experiments.

In Canada DOC will provide ground terminals to experimenters; this includes Federal and provincial government agencies, universities, and other groups. A variety of ground terminals to be used in Canada are now being built.

In the United States each experimenter (user) is responsible for providing the necessary communication ground terminals. Several United States experimenters have installed ground terminal hardware or have it ordered.

This paper presents information on the general s/c operational characteristics with particular emphasis on the communication system parameters. Also, the associated Canadian and United States user ground terminals are discussed with particular emphasis on wideband communications.

TEXT

CTS Spacecraft Characteristics

A drawing of CTS as it will appear in orbit is shown in Fig. 1. The overall length of the s/c is greater than 17 meters with the solar arrays extended as shown; however, these long flexible arrays complicate the attitude control problems. The two communication antennas marked SHF (super high frequency) gimballed antennas in Fig. 1 point towards the earth. Each antenna boresight is aimed at the desired location by slewing the parabolic antenna reflector about the roll and pitch axes. Both communication antennas have only one feed horn each which is used to transmit and receive linearly polarized orthogonal signals. Each feed horn is fixed to the main body of the s/c and does not move as the antenna reflectors are slewed. The beacon antenna is also mounted to the main s/c body. It is a circular waveguide horn that transmits a right-hand circularly polarized signal to the entire area of the earth that is in view from the s/c.

A summary of the most important characteristics of CTS is given in Table I. The s/c will be launched on a Thor Delta model 2914 vehicle from the Eastern Test Range and the s/c will be placed in a stationary satellite orbit at 116^{o} west longitude. When on orbit the power available from the deployable solar arrays is greater than 1.2 kilowatts at the beginning of the mission and should be just less than 1.0 kilowatts after two years.

The s/c attitude control pointing accuracy is $\pm 0.1^{o}$ in pitch and roll which is one of the limiting factors on the communication antenna pointing accuracy. The s/c will be east-west station kept within $\pm 0.2^{o}$; however, there is no north-south station keeping and this requires that all ground terminals with narrow antenna beams (such as video receive stations) have antennas that can move both in azimuth and elevation. This significantly increases the cost of the wideband user terminals.

The communication frequencies are 12 and 14 gigahertz for the downlink and uplink respectively. All communication signals are received and transmitted by the two parabolic antennas indicated in Fig. 2 which are 0.7 meter (28 in.) in diameter and have a nominal gain of 37 db. The total pointing error for either antenna is $\leq \pm 0.25^{o}$. It should be pointed out that either antenna can receive and transmit signals; however, the communication transponder which has two channels(2) is so configured that a signal received on one antenna must be transmitted by the other antenna. Both transponder channels have a bandwidth of 85 megahertz with one transponder channel having a nominal output power of 200 watts and the second one 20 watts.

The frequency plan for the two transponder channels is given in Fig. 3. The higher frequency bands (RBI and TBI) are associated with the uplink and downlink respectively of the 200 watt channel. The lower frequency bands (RB2) and TB2) are associated with the 20 watt channel. Also, a 200 milliwatt beacon signal is provided at a frequency of 11.7 gigahertz. However, this signal is not easily received by low cost terminals because of the low beacon power and low beacon horn gain.

The CTS communication antennas have a nominal 3 db beamwidth of 2.5°. Typical CTS ground contours (coverage areas) for Canada are shown in Fig. 4. The upper left contour is associated with the 12 gigahertz downlink and the lower right contour is associated with the 14 gigahertz uplink. Hudson Bay is shown near the center and Greenland near the upper right hand corner of the figure. A typical 3 db contour for a 2.5° beamwidth is shown for Alaska in Fig. 5(a). The contour for a 2.0° beamwidth is also shown. The upper left edge of the contour is determined by the 5° elevation angle line which is the location on the ground where the angle between the incoming s/c signal and the horizon is 5°. In general for elevation angles less than 5° the communication reliability may be less than desirable due to multipath affects and intervening obstacles. Three typical 3 db downlink contours for the lower 48 states are shown in Fig. 5(b) where each contour basically covers one time zone. However, at any given time only one downlink contour can be associated with the 200 watt channel and one with the 20 watt channel. It can be seen from Figs. 4 and 5 that the ground contours encompass a sizeable area.

Canadian Experimenter Terminals

A summary of the important characteristics of the Canadian communication ground terminals is given in Table II. DOC will make available the following number of these terminals to be shared among experimenters:

(1) Three large terminals consisting of: Two - 3 meter transportable ground terminals and One - 9 meter Ottawa ground terminal.

(2) Sixteen small terminals consisting of: Eight - 2 meter ground terminals and Eight - 1 meter ground terminals.

The 9-meter Ottawa terminal is the largest of the terminals and is the only one which cannot be moved. The terminal has a 9.14 meter (30 ft) diameter antenna mounted on a pedestal. Some of the communications equipment is located in an antenna cabin mounted on the pedestal directly behind the main reflector. Near the antenna is an operations building which contains the remainder of the communications equipment and a control console for the antenna. From this building, control of the entire terminal is provided. The terminal will be capable of providing transmission and reception of television, sound program and digital data of various rates, as well as serving as the network control for the telephony system.

The two 3-meter terminals are transportable terminals in the form of trailers. They each have a 3.05 meter (10 ft) diameter antenna and contain essentially identical communications equipment to that of the 9-meter terminal. Since they are quite readily transportable, they make available from different locations within Canada the same communications capabilities as the 9-meter Ottawa ground terminal.

The 2-meter terminals are transportable terminals primarily designed for reception of television signals relayed from any of the 3-meter or 9-meter terminals through the high power channel of the spacecraft. They consist of a 2.13 meter (7 ft) diameter antenna with associated communications equipment. In addition to receiving television, they are equipped to provide one telephony channel and to transmit and receive one sound program channel. A drawing of the 2-meter terminal is shown in Fig. 6.

The 1-meter terminals are small transportable terminals primarily designed for telephony applications. They consist of a 0.81 meter (32 in.) diameter antenna and associated communications equipment. Each will be equipped for telephony and, in addition, provide a capability of transmitting or receiving a sound program signal.

United States User Terminals

In the United States each user is responsible for providing all terminal equipment associated with his experiment. A summary of several existing and planned U.S. terminal characteristics are given in Table III[3]. One important kind of U.S. user experiment involves the reception of single channel video by several ground stations and may include the transmission of return audio. These ground stations could have similar characteristics to the third terminal listed in Table III.

A typical FM video receiver which could be used in such an experiment is shown in Fig. 7(a); it consists of an outdoor mixer down converter and an indoor intermediate frequency (IF) receiver. This receiver could provide either baseband, VHF-AM output, or both and could accommodate one or more audio sub-channels. Also, in conjunction with the outside unit a tunnel diode amplifier (TDA) would be included to improve the receiver sensitivity. Another possible type of receiver, which uses an image enhanced mixer, is also available and it would not require a TDA preamplifier.

A 3-meter (10 ft) parabolic antenna which could be used with this video experiment is shown without the leed assembly in Fig. 7(b). The antenna system, which has two-axis limited motion pointing capability, can accommodate the anticipated N-S and E-W movement of the CTS s/c. The antenna pointing system is motor driven and remotely controlled from indoors. The antenna and outdoor receiver unit can be located up to 30 meters from the indoor equipment. A block diagram of a typical FM video receive ground terminal is shown in Fig. 8.

A video uplink or transmitting station is much more expensive than a receive only station because of the dominating cost of the high power amplifier. A block diagram of a typical video transmitting station is shown in Fig. 9. The video baseband signal is modulated, up converted, amplified to a high power level and radiated from the antenna. If the uplink station is located in the downlink coverage region, the uplink station can receive its own signal from the s/c with the transmitting antenna, orthomode coupler, TDA, and receiver as shown. However, it should be noted that for some experiments the uplink is not located in or near the downlink coverage area and thus the uplink station can not monitor its own signals as transmitted by the s/c. For example this would occur with an uplink station in the eastern U.S. transmitting to a downlink coverage area in the Western U.S.

In addition, a beacon receiver as indicated at the bottom of Fig. 9 is recommended for all transmitting stations; however, for transmitting stations that cannot receive their own signals from the s/c it is a virtual necessity.

REFERENCES

1. Franklin, C. A. and Davison, E. H.: A High-Power Communications Technology Satellite for the 12 and 14 GHZ Bands. AIAA Paper No. 72-580. (The ion engine and liquid metal slip ring experiments listed in this report have since been deleted from the CTS program.)

2. Braun, L. D. and O'Donovan, M. V., December 1974: Characteristics of a Communications Satellite Transponder. Microwave Journal.

3. Lumb, D. R. and Sites, M. J., December 1974: CTS Digital Video College Curriculum-Sharing Experiment. Paper presented at the National Telecommunications Conference, San Diego, California.

TABLE I. - SPACECRAFT CHARACTERISTICS.

GENERAL	
LAUNCH VEHICLE	THOR DELTA MODEL 2914
ORBIT	SYNCHRONOUS (22 235 STATUTE MILES) & EQUATORIAL AT 116^{0} W LONGITUDE)
OPERATIONAL LIFE	2 YR
SPACECRAFT WT, LB:	
APOGEE MOTOR	739
STRUCTURE	126
SUBSYSTEMS	332
EXPERIMENTS	289
STRUCTURE	
MAX DIMENSIONS (SOLAR ARRAY STOWED FOR LAUNCH)	71 x 66 IN.
LENGTH (EXCLUSIVE OF APOGEE MOTOR NOZZLE)	68 IN.
TOTAL SPAN (SOLAR ARRAY EXTENDED)	52 FT 9 IN.

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TABLE I. - CONTINUED.

POWER	
DEPLOYABLE SOLAR ARRAY:	
TWO RECTANGULAR PANELS	97.7 SQ FT
12 636 N-ON P SOLAR CELLS (2 x 2 CM)	1260 W
ARRAY ORIENTATION	AUTOTRACK BY SUN SENSOR, 1 REV/DAY IN 0.025^{0} STEPS FAST SLEW FOR SUN ACQUISITION 30^{0}/MIN
BODY ARRAY (HOUSEKEEPING POWER UNTIL MAIN ARRAY DEPLOYMENT)	30 SQ FT (TWO PANELS PLUS TWO JETTISONABLE PANELS)
3460 N-ON P SOLAR CELLS (2 x 2 CM)	90 W
BATTERIES	TWO 5 A-HR Ni-Cd WITH 24 CELLS EACH
POWER AVAILABLE AT END OF 2 YR	918 W

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TABLE I. - CONTINUED.

CONTROL	
ATTITUDE POINTING ACCURACY:	
PITCH & ROLL	$\pm 0.1^{0}$
YAW	$\pm 1.1^{0}$
PITCH & ROLL REF	EARTH HORIZON SENSORS
ATTITUDE CONTROL ACTUATORS:	
PITCH AXIS	MOMENTUM WHEEL
PRINCIPAL & OFFSET AXIS	HYDRAZINE THRUSTERS
STATION KEEPING ORBIT CONTROL	HYDRAZINE THRUSTERS EAST-WEST ONLY
VELOCITY INCREMENT TOTAL CAPACITY	6.7 FT/SEC
DEAD BAND	$\pm 0.2^{0}$
THERMAL	
THERMAL CONTROL	VARIABLE-CONDUCTIVE HEAT PIPES, SECOND SURFACE MIRRORS, SUPER INSULATION BLANKETS, & THERMAL CONTROL HEATERS
OPERATING CHARACTERISTICS:	
SPACECRAFT TEMP LIMIT	GENERALLY 0^{0} TO 40^{0} C
HIGH POWER DISSIPATION	TO 660 W

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TABLE I. - CONTINUED.

EXPERIMENTS	
COMMUNICATION	DEMONSTRATE TELEVISION TRANSMISSION AT 12 & 14 GHz USING LOW-COST GROUND TERMINALS; DEMONSTRATE A TRAVELING WAVE TUBE HAVING 50% EFF & POWER OUTPUT OF 200 W
SPACECRAFT	DEMONSTRATE THREE-AXIS STABILIZATION WITH ANTENNA BORESIGHT ACCURACY OF $\pm 0.2^{0}$; DEMONSTRATE A LIGHTWEIGHT EXTENDABLE SOLAR ARRAY, WITH MORE THAN 1 KW OUTPUT
COMMUNICATIONS	
PARABOLIC ANTENNAS	TWO - 28 IN. IN DIAM, F/d = 0.445
FREQUENCY BANDS	12 GHz (DOWNLINK) & 14 GHz (UPLINK)
POWER AMPLIFIERS	ONE 200 W
(TRAVELING WAVE TUBES)	TWO 20 W
TRANSPONDER BANDWIDTH . . .	85 MHz

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TABLE I. - CONTINUED.

TELEMETRY	
TELEMETRY TRANSMITTER	2 W TO 17 dB HORN OR TO OMNI-DIRECTIONAL ANTENNA
SPECIAL FEATURES	PCM/FM/PM
TELEMETRY:	
BIT RATE	1 536 BITS/SEC
WORD LENGTH	8 BITS
TOTAL CAPACITY	120 BILEVEL MEASUREMENTS 156 ANALOG MEASUREMENTS
EXPERIMENT ASSIGNED	81 ANALOG MEASUREMENTS
SPACECRAFT ASSIGNED	129 ANALOG MEASUREMENTS
SPACECRAFT STATUS	145 BITS

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TABLE I. - CONCLUDED.

COMMAND	
COMMAND RECEIVE MODES	STDN COMPATIBLE PCM/PSK/FM/PM
COMMAND ANTENNA	17 dB HORN
COMMANDS:	
TOTAL NO.	225
RATE	1000 BITS/SEC
FORMAT:	
SYNCHRONIZATION WORD	14 BITS
ADDRESS WORD	7 BITS PLUS 1 DECODER BIT
COMMAND WORD	8 BITS PLUS 1 PARITY BIT
VALUE COMMAND WORD	16 BITS PLUS 1 PARITY BIT
EXECUTE WORD	8 BITS PLUS 1 PARITY BIT
COMMAND PSK FREQUENCY	2.0 KHz
COMMAND ASSIGNMENTS:	
EXPERIMENT ASSIGNED	58
SPACECRAFT ASSIGNED	162

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TABLE II. - SUMMARY OF PLANNED CANADIAN SHF TERMINAL CHARACTERISTICS (12-14 GHz).

TERMINAL	PROPERTIES							
	ANTENNA			RECEIVER		SYSTEM G/T, dB/K	TRANSMITTER POWER, W	ANTENNA CONTROL
	DIAM, M	PEAK GAIN, dB 12 GHz	3 dB BEAMWIDTH, DEG	PREAMP	NOISE TEMP, K			
OTTAWA	9	58	0.2	UNCOOLED PARAMP	200	32.8	200	AUTO-TRACK
TRANSPORTABLE	3	49	.5	UNCOOLED PARAMP	200	22.8	1200	STEP-TRACK
TV RECEIVE ONLY & TWO-WAY VOICE	2	47	.7	TDA	670	16.6	20	MANUAL ADJUSTMENT
TWO-WAY VOICE	.8	37	1.8	TDA	670	8.2	20	NONTRACKING

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TABLE II. - SUMMARY OF SEVERAL EXISTING AND PLANNED U.S. SHF TERMINAL CHARACTERISTICS (12-14 GHz)

TERMINAL	PROPERTIES							
	ANTENNA			RECEIVER		SYSTEM G/T, dB/K	XMITTER POWER, W	ANTENNA CONTROL
	DIAM, M	PEAK GAIN, dB 12 GHz	3 dB BEAMWIDTH, DEG	PREAMP	TOTAL SYSTEM NOISE TEMP, K			
CLEVELAND	5	52	0.4	TDA	800	24	1250	STEP-TRACK
ROSMAN	5	53	.4	UNCOOLED PARAMP	450	26	1250	AUTO-TRACK
TV RECEIVE ONLY TWO-WAY VOICE	3	48	.6	TDA	900	18	500	REMOTE MOTOR DRIVE
TWO-WAY VOICE	1.2	40	1.5	TDA	900	10	20	MANUAL ADJUSTMENT
TWO-WAY VOICE	.6	34	3.0	TDA	900	4	20	FIXED

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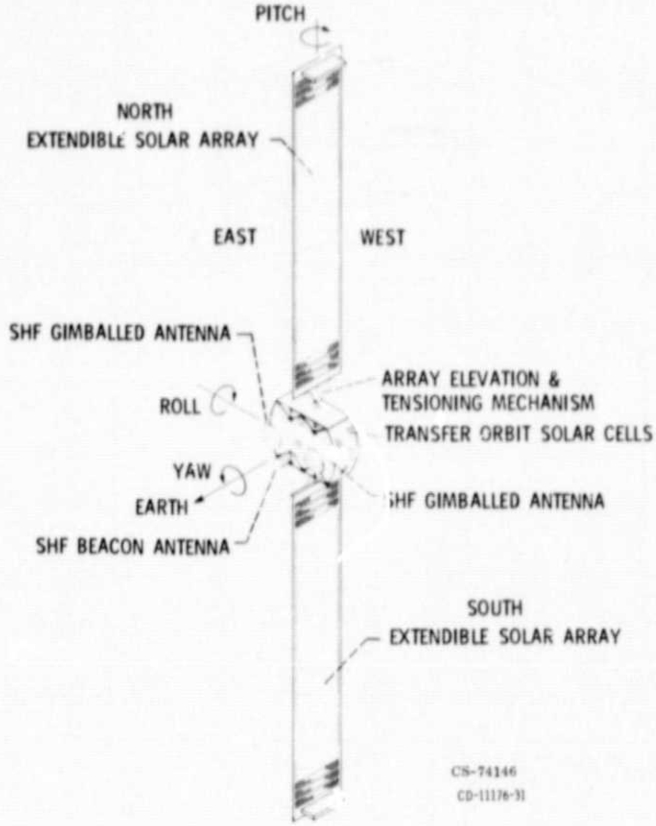

Figure 1. - CTS - on station.

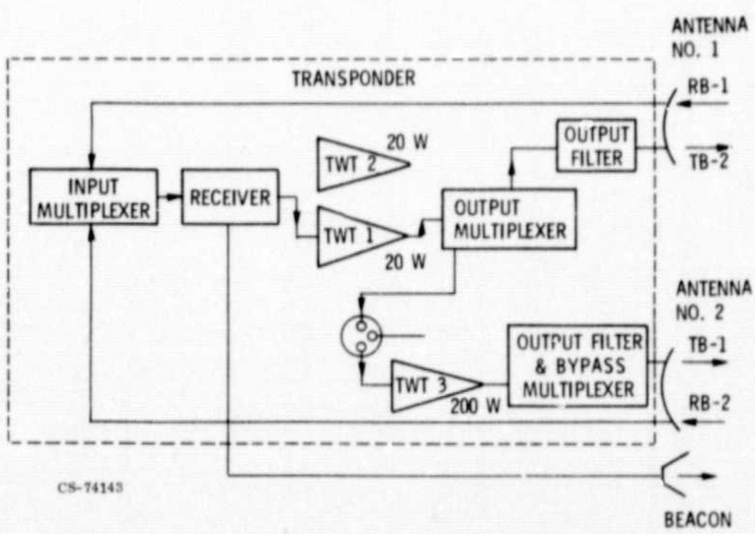

Figure 2. - SHF system configuration for primary operational mode (PM).

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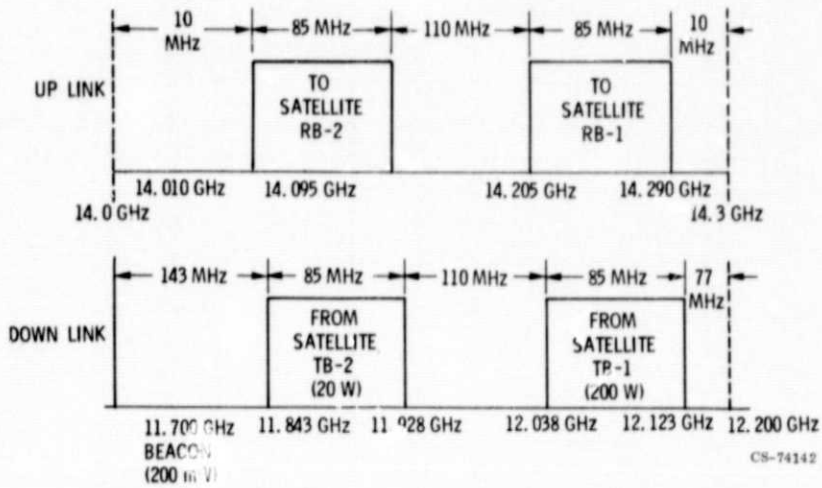

Figure 3. - SHF frequency plan, primary mode (PM).

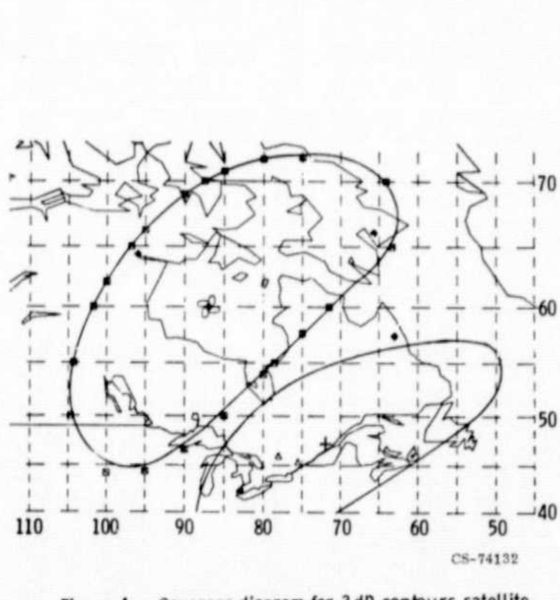

Figure 4. - Coverage diagram for 3 dB contours satellite longitude = 116.0° W.

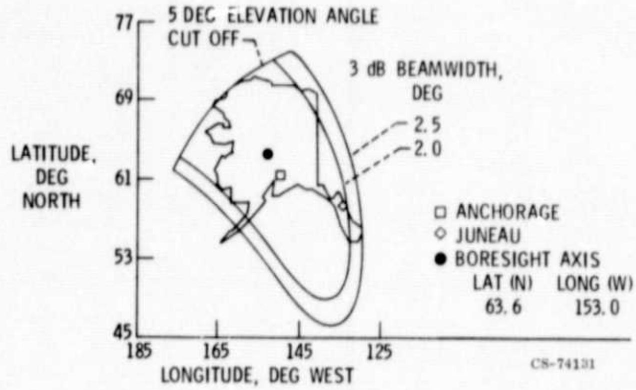

Figure 5(a). - Typical CTS antenna coverage for given boresight axis in Alaska.

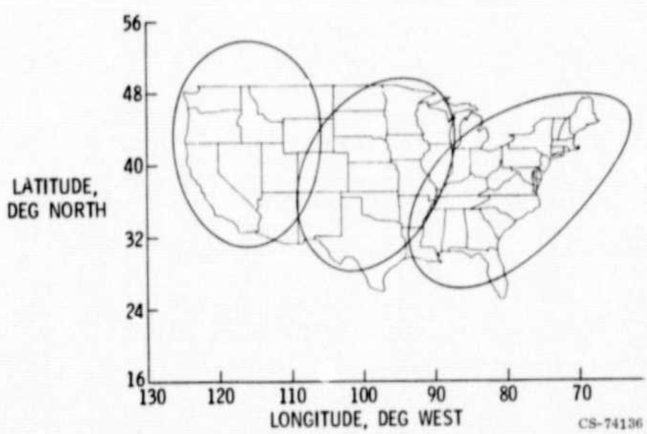

Figure 5(b). - Three typical CTS antenna coverage areas for United States (lower 48 states).

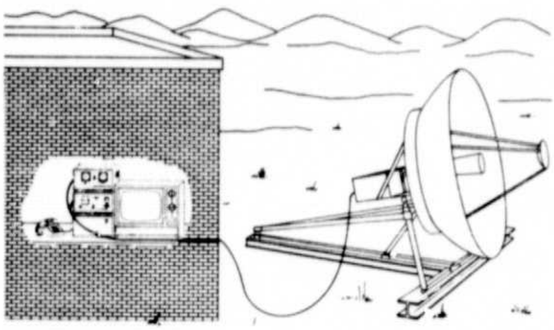
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Figure 6. - Canadian 2 meter video ground terminal.

Figure 7(a). - Typical U.S. user FM-video receiver.

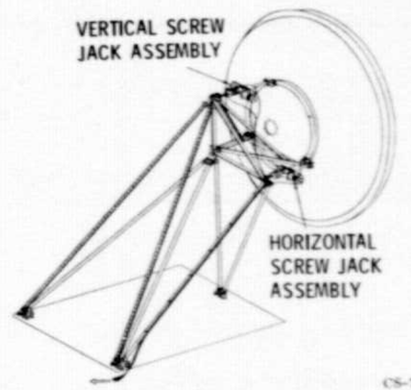

Figure 7(b). - Typical U.S. user 10-ft diameter two axis antenna system. (Shown without feed horn.)

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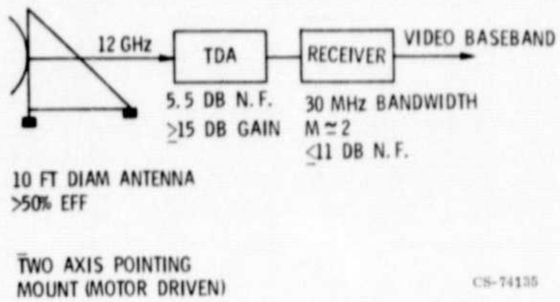

Figure 8(a). - Typical U.S. user video receive ground terminal.

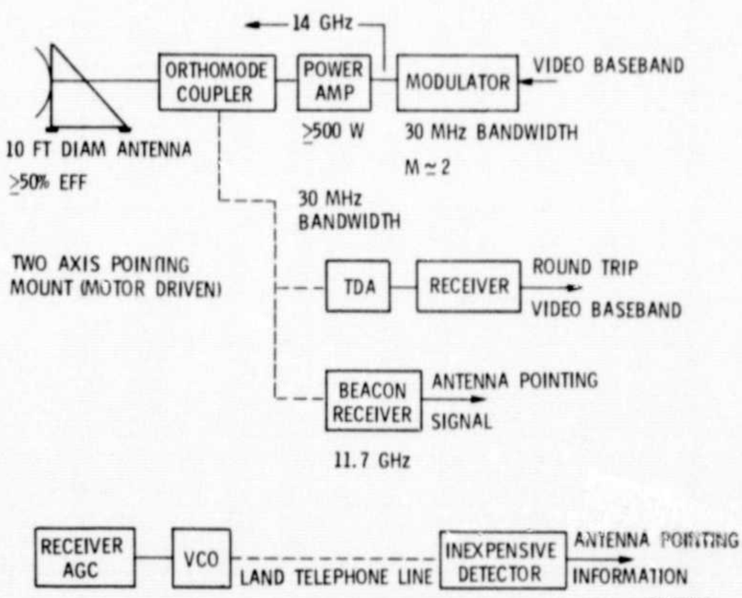

Figure 8(b). - Typical U.S. user video transmit ground terminal.