The Space Congress® Proceedings | 1976 (13th) Technology For The New Horizon

Apr 1st, 8:00 AM

The Development Of The Telesat Domestic Communication Satellite System

John Almond

Assistant Vice President, Engineering, Telesat Canada, Ottawa, Ontario

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Mr. John Almond
Assistant Vice President
Engineering
Telesat Canada
Ottawa, Ontario

ABSTRACT

A review of the development of the Telesat Communication Satellite System is given including a brief discription of the earth and space segments of the initial system. The growth and development of the earth stations and services since the start of operation in January 1973 are outlined with emphasis on services provided to remote northern communities. The most likely areas for future system expansion are reviewed and an indication of the possible space segment improvements for future satellites in the system given.

INTRODUCTION

Following the successful use of geostationary satellites for international long distance communications in the Intelsat System active consideration was given to the use of such a system to provide domestic communications within Canada as early as 1966. The large land mass of Canada, with its relatively widely scattered population and rugged terrain, seemed to provide an ideal situation in which to use this new communication technology.

Several studies were carried out in both government and industry and proposals made to the Canadian Government regarding the establishment of a domestic communication satellite system. The Canadian Government established its policy with respect to the use of satellites for communications in Canada by a Government white paper pubblished in March 1968(1). This document outlined the kind of system which should be established and also the kind of corporation that should own and operate it. The main features of this policy were that the new corporation would essentially have a monopoly for the use of satellites to provide communications within Canada and would own and operate both the earth space segment of the system on a commercial basis. In addition the ownership would be a partnership between government, existing communication carrier companies and the public. The legislation establishing this new organization, the Telesat Canada Act, was passed by the Canadian Parliament in June 1969 and Telesat Canada, the name of the new corporation, came into existance in September of that year. Telesat then took over the responsibility of providing domestic communication service by satellites in Canada and the first satellite was launched in November 1972 and commercial service commenced in January 1973.

The system is a multi-purpose telecommunications facility capable of providing television, radio, voice, data and facsimile transmission services throughout Canada. It is capable of handling analog and digital signals, providing a high level of over-all performance. It augments and is interlinked with the existing terrestrial systems.

The space segment presently consists of three spin-stabilized satellites in geostationary orbit, one launched in November 1972, the second in April 1973 and the third in May 1975. The initial three space positions are at 114°, 109° and 104° west longitude.

The satellites are produced by the Hughes Aircraft Company of California, in conjunction with two Canadian sub-contractors, Northern Electric and Spar Aerospace, who manufacture the on-board electronics and communications equipment, and the main structure, respectively. The launch vehicles and launch facilities are provided through the National Aeronautics and Space Administration (NASA) of the United States.

The earth segment of the system consists of six types of permanent earth stations with service provided at 58 locations at the end of 1975 and more under construction.

SPACE SEGMENT

The satellites are active spin-stabilized multi-channel repeater communications satellites. Each satellite has twelve high capacity microwave channels and each channel is capable of relaying one colour television program or up to 960 multiplexed voice signals using a single carrier. Multicarrier voice modulated signals can also be accommodated within a microwave channel with some reduction in total capacity. Each channel has a bandwidth of 36 MHz and was specified to provide not less than 33 dBW effective isotropic radiated power (EIRP) throughout Canada. The communications antenna beam pattern is shaped and aimed to provide optimum coverage of Canada and the system in fact provides better than 35 dBW EIRP per channel throughout most of Canada. Typical EIRP contours are shown in Figure 1.

The satellite communication subsystem is a channelized microwave repeater operating in the 6 GHz and 4 GHz bands allocated for satellite service. The repeater is an all microwave, fixed gain, single conversion, 12 channel design in which each channel is essentially an independent transponder with a bandwidth of 36 MHz. Channels are separated by a 4 MHz guard band. Each channel can be operated with one or more carriers in either a saturated (maximum output power) or linear mode. The only active equipment common to all channels is a redundant (switched) wideband receiver which establishes the system noise temperature, translates the 6 GHz carriers to 4 GHz, and amplifies the 4 GHz carriers to an intermediate power level prior to channelization.

The spaceframe of the satellites consists of a 30-inch diameter thin wall cylinder coaxial with the satellite, and a 73-inch diameter honeycomb sandwich platform. The cylinder surrounds the apogee motor & supports the spin platform, on which is mounted the communications repeater, telemetry and command electronics, and the batteries. The platform supports the cylindrical solar panel at its periphery and the despin motor by a pedestal-type support at its center. The solar panel substrate is a honeycomb sandwich with fiberglass laminates, on the interior of which are mounted three dynamic balance mechanisms 120° apart. A photograph of the satellite mounted on top of the launch vehicle is shown in Figure 2.

The major satellite charateristics are listed below:

Coverage	all of Canada
Number of transmission channels	12
Channel bandwidth	36 MHz
Receive frequency band	5927 - 6403 MHz
Transmit frequency band	3702 - 4178 MHz
EIRP per channel	33 dBW minimum
Receive G/T	-7 dB/$^{\circ}$K
TWT output power	7 dBW (5W)

SATELLITE CONTROL

The Telesat satellites, launched from Cape Kennedy, are injected by the launch vehicle into a highly elliptical transfer orbit with an inclination of 27° to the equator, the perigee and apogee heights of which are 110 and 19,565 nautical miles, respectively.

Each satellite is normally retained in transfer orbit for seven revolutions and is then injected into a drift orbit by firing the apogee motor. Thereafter the satellite is guided to its designated position in geostationary orbit through a series of orbit synchronization maneuvers. The longitudinal positions of the first three satellites are 114°W, 109°W and 114°W.

The satellites are kept on station by precise stationkeeping maneuvers, with orbit control in latitude and longitude to within $\pm 0.05^{\circ}$ for Anik II and Anik III and $\pm 0.1^{\circ}$ for Anik I. Spin axis attitude control is maintained within a constraint of a maximum deviation from the orbit normal of $\pm 0.15^{\circ}$ for all satellites.

The Tracking, Telemetry and Command (TTAC) facilities required for Telesat missions are at three locations, namely the Allan Park Station in Ontario, the Lake Cowichan Station on Vancouver Island, and on the island of Guam in the Pacific. The latter is a tracking station which is used only during the transfer orbit phase of a mission. All TTAC activities are controlled from the Telesat Satellite Control Centre in Ottawa.

The hardware and software systems were developed by Telesat to control its satellites through the various orbital phases and subsequent commercial service.

EARTH SEGMENT

The major characteristics of earth stations in operation or under implementation are summarized in Figure 3. The system includes approximately 89 antennas with service provided at 69 permanent locations. The locations of the earth stations are shown on the map in Figure 4.

In Figure 3 the stations are listed by type indicated the purpose for which the original installation was made. The additional types of service added to the stations is also shown in the Figure. The gain over noise temperature ratio (G/T), which is an essential figure of merrit of the earth station receiving capability is also shown in the Figure. The permanent station types are listed below:

- Heavy Route Stations (HR)
- Tracking, Telemetry and Command (TTAC)
- Northern Telecommunications (NTC)
- Network Television (NTV)
- Remote Television (RTV)
- Thin Route Message (TR)

There are two heavy route stations designed for large volume traffic. One station is located north-west of Toronto at Allan Park and the other at Lake Cowichan on Vancouver Island. These stations are used for the transmission and reception of television signals and the transmission and reception of message traffic. They use 98-foot antennas with uncooled parametric amplifiers to give a minimum G/T of 37.5 dB. Both stations are fully manned and capable of considerable expansion.

In addition to the communications antenna located at Allan Park there are three additional antennas used to provide tracking, telemetry and command (TTAC). One of these antennas is a fully tracking facility used to provide the TTAC functions during the transfer and drift orbit phases of the mission. The other two manually steerable antennas are dedicated to providing the telemetry and command functions on F2 and F3. The communications antenna is used to provide these functions on F1 and the fully tracking TTAC antenna is free to provide auxiliary functions and tests on all satellites, provide system redundancy and participate in later launches. Figure 5 is a photograph of the Allan Park earth station site showing the four antennas. The Lake Cowichan station is equipped with ranging facilities in order to improve orbit determination for stationkeeping.

The NTC earth stations are used to provide two-way communications between northern communities as well as between northern communities and southern Canada. This type of station is used where from 6 to 60 two-way voice circuits are required. The stations are also capable of receiving TV signals from the satellite. The stations have been designed for unmanned operation and are suitable for operation in severe Arctic conditions. The first two stations of this type are located at Frobisher Bay and Resolute, with additional locations under consideration.

TV signals are transmitted to the satellite both from heavy route stations at Allan Park and Lake Cowichan and from the six NTV stations located near the major cities in southern Canada. Network TV stations are used to receive CBC (Canadian Broadcasting Corporation) programs for further distribution by terrestrial means. The NTV stations are the same size as the NTC stations. One of the NTV stations located near Halifax is also used for trunk message service between it and the Allan Park earth station servicing Toronto.

In the more remote areas a smaller station is used to provide network television service to communities not served at present by terrestrial microwave facilities. The antenna is smaller than the network stations with 2 dB less antenna gain and, in order to reduce costs, the station contains less redundant equipment. These stations, termed "remote TV earth stations" (RTV), are located as close as practicable to the TV re-broadcasting stations in the communities they serve. Twenty-five earth stations were planned for the start of operation and 9 additional stations are under implementation. These stations were initially equipped to provide TV reception only but Figure 3 shows where addition service of radio program distribution and message service have been added. Because of increased satellite EIRP over that specified it has been possible to reduce the G/T of the newer stations of this type and still maintain the required quality of service.

Telephone message service and radio programming is provided to small communities in the north by means of the thin route earth stations (TR). These stations are designed to receive and transmit up to six voice circuits using a single-voice-channel-per-carrier technique. The antenna system in the initial stations of this type was the same as the remote television stations but a less expensive low noise amplifier was used. These stations use a 300^{o}K parametric amplifier for the prime system with a 600^{o}K transistor amplifier as a standby unit. In later stations smaller 15 foot antennas have been used. There are several instances, and we anticipate many more, where the thin route message capability, television and radio programme reception are combined at the one station.

In addition to the stations at permanent locations Telesat has transportable stations for service at temporary locations for both television and message traffic. The TV transportable station consist of redundant up and down links which is housed in a trailer, available for use with this electronic equipment is either a 32 foot antenna or a 15 foot antenna which can be transported on a special design truck trailer. This station is used to provide TV pick-up and distribution by the satellite system of special events such as sports or election coverage. A photograph of this station with the two antennas is shown in Figure 6.

Telesat presently has six transportable earth stations available for thin route message service and is expecting delivery of 15 additional transportable station in early 1976. These stations uses a 12 foot diameter antenna and have been designed so that the complete station can be transported in a Twin Otter aircraft which is a light plan used extensively in the Canadian Artic. The station can be assembled by two technicians and placed into operation within eight hours of arrival on site. The station is designed to provide up to four voice circuits on a single voice circuit per carrier system. The system uses a 40 kbps delta PSK modulation technique and each channel is capable of handling simultaneously, a voice grade circuit plus 4 teletype circuits or voice plus 2400 band data service. A photograph of the station is shown in Figure 7.

COMMUNICATION TECHNIQUES AND SERVICES

A wide variety of communication techniques are used in the system to provide the different services. The RF channels used for television distribution carry, in addition to the video signal, two audio channels, a cue and control channel and a radio program channel. The two audio channels and the cue and control channel are frequency division multiplexed on a subcarrier which together with the video signal frequency modulates the main carrier. The radio program channel is provided on a separate carrier near the band edge of the RF channel to provide the most ecconomical means of radio program distribution to remote northern communities.

A unique feature of the television distribution system is the cue and control network which allows remote switching of all television transmit and receive chains in the system. The system permits the complete control of program distribution by either manually or by computer from either of two identical control centres at the customer premises in Toronto and Montreal. The customer for this service is the Canadian Broadcasting Corporation who presently uses three full period RF channels on the satellite and two channels for occassional use for either special events or news gathering.

The message service provided by the system ranges from the provision of 960 voice circuits at a location to just one voice circuit. The 960 voice channel capacity is provided between the two heavy route stations which serve Toronto and Vancouver and the system operates in the single carrier FM mode using two RF channels in the system.

For medium route message requirements, where between 12 and 250 circuits are required a frequency division multiple access (FDMA) mode is used. To avoid intermodulation problems in this multicarrier mode of operation in a satellite RF channel the channel must be operated at reduced RF output power which limits the capacity of the channel. To avoid this problem a 60Mb/s time division multiple access (TDMA) system has been developed and will be in commercial service between Toronto and Halifax early this year. The system will provide 400 very high quality voice circuits between these two locations. For smaller communications requirements to remote communities, where between one and six voice circuits are required, the same mode of operation is used as is used with the transportable message terminals. This service is termed the Thin Route service and makes use of a single-voice-channel-percarrier PSK-FDMA technique. In addition to voice, facsimile, teletype, and data services are available and the analogue-to-digital convertor chosen in this case was a delta modulation codex operating at a clock rate of 40 kbs.

FUTURE DEVELOPMENTS

In December of 1975 Telesat initiated procurement of its fourth spacecraft with delivery scheduled for February 1978. While this new spacecraft was principally required as a replacement satellite for F1 or F2 it will carry two distinct and seperate microwave communications facilities. A 12 RF channel transponder will operate in the 6/4 GHz bands providing Canadian coverage comparable to our present satellites and essential will be a replacement for one of them. The second transponder operates in the 14/12 GHz bands using four 20 watt TWTA's and will provide Canadian coverage with four spot beams. A coverage diagram for the two bands is shown in Figure 8. There are two separate antennas and feed systems for the two bands as shown in Figure 9. The spacecraft will be 3-Axis stabilized and will have a design life of 7 years. It will be launched from ETR on a Delta 3914 vehicle with a payload capability of 2000 pounds into transfer orbit.

While Telesat will operate the total satellite on a commercial basis the initial use of the 14/12 GHz service is for communication experiments in this new band. Telesat's present spacecraft replacement policy calls for initiation of further spacecraft procurement activity by the end of 1976. Economic and technical studies are underway in order to determine the optimum configuration for these new spacecrafts. Active consideration is being given to both large capacity dual band satellites similar to the F4 concept and smaller single band satellites similar to our original satellite concept.

Telesat forsees the major expansion in its system occurring in the next decade in the areas of TV destribution and message service to remote areas. A significant expansion of message services in Southern Canada is not anticipated until the mid 1980's unless significant cost reductions can be achieved. One factor which may achieve some cost reduction is the use of the 14/12 GHz. Because this band is an exclusive satellite band, earth stations may be located in urban areas as no coordination with terrestrial systems is required. The use of higher frequency bands such as the 30/18 GHz is not presently forecast for use in the Canadian system until after the mid 1980's.

REFERENCE

(1) White Paper on "A Domestic Satellite Communications System for Canada", Honourable C.M. Drury, Ministry of Industry, 28 March 1968.

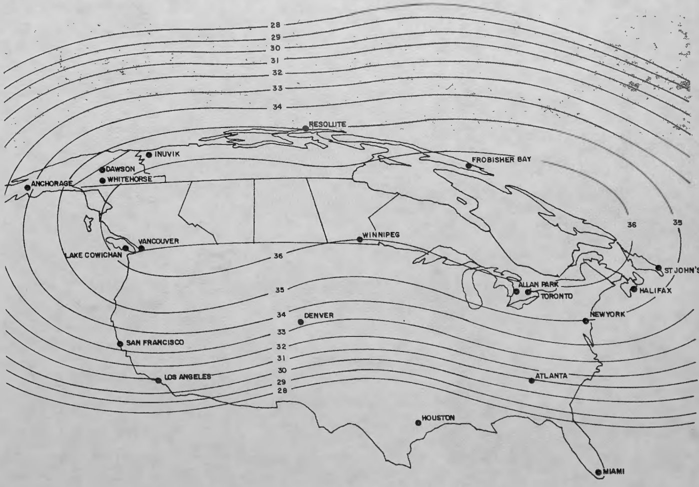

Figure 1. Typical EIRP Contours in dBW

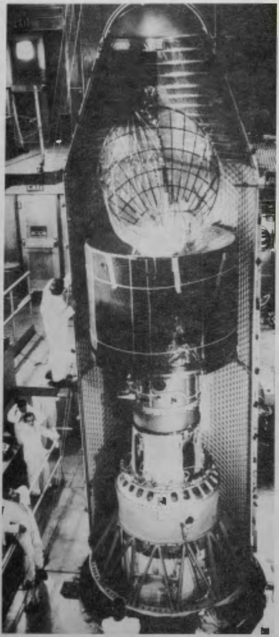

Figure 2. Telesat's F1 Spacecraft Being Prepared for Launch

EARTH STATION CHARACTERISTICS

EARTH STATION TYPE	MINIMUM G/T	ANTENNA STEERING	TYPE OF COMMUNICATIONS	NO. OF STATIONS
Heavy Route (HR)	37.5 dB	Simplified Tracking	Tx & Rx Message Tx & Rx TV	2
Tracking, Telemetry & Command (TTAC)	28 dB	Fully Tracking	Telemetry Command Ranging	1
Telemetry & Command (TAC)	20.5 dB	Manually Steerable	Telemetry Command	2
Northern Telecommunications (NTC)	28 dB	Manually Steerable	Tx & Rx Message Rx TV Rx & Tx Radio Program	2
Network TV (NTV)	28 dB	Manually Steerable	Tx & Rx TV	5
Network TV (NTV)	31 dB	Fully Tracking	Tx & Rx Message Tx & Rx TV	1
Remote TV (RTV)	26 dB	Manually Steerable	Rx TV	22
Remote TV (RTV)	26 dB	Manually Steerable	Rx TV Rx & Tx Radio Program	3
Remote TV (RTV)	26 dB	Manually Steerable	Rx TV Rx Radio Program	2
Remote TV (RTV)	26 dB	Manually Steerable	Rx TV Rx & Tx Message Rx Radio Program	1
Remote TV (RTV)	21.7 dB	Manually Steerable	Rx TV Rx Radio Program	4
Remote TV (RTV)	21.7 dB	Manually Steerable	Rx TV	2
Thin Route	22 dB	Manually Steerable	Rx & Tx Message	11
Thin Route	22 dB	Manually Steerable	Rx & Tx Message Rx TV Rx Radio Program	6
Thin Route	19 dB	Manually Steerable	Rx & Tx Message	6
Thin Route	22.5 dB	Manually Steerable	Rx & Tx Message	3
Thin Route (Transportable)	13 dB	Manually Steerable	Rx & Tx Message	16
TV Transportable	28 dB	Manually Steerable	Rx & Tx TV	1
TOTAL ANTENNAS				89

Figure 3. Earth Station Characteristics

Figure 4. Telesat Earth Station Locations

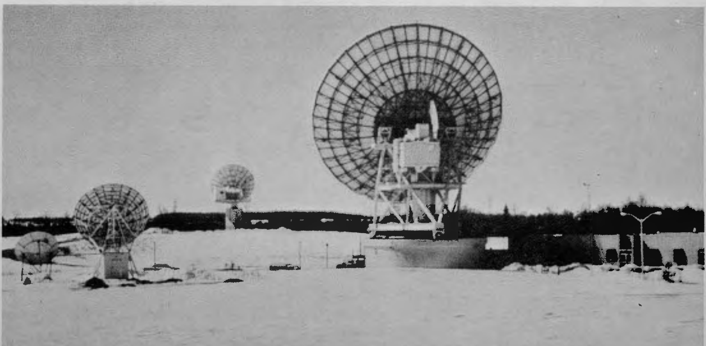

Figure 5. Telesat's Allan Park Earth Station Site

Figure 6. TV Transportable Earth Station

Figure 7. Thin Route Transportable Earth Station

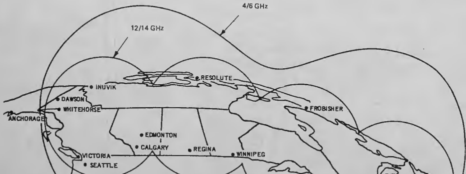

Figure 8. Dual Band Antenna Coverage for F4

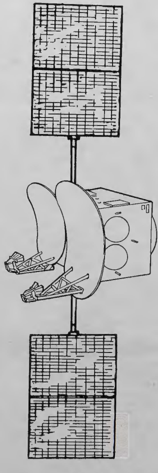

Figure 9.
F4 Spacecraft Concept