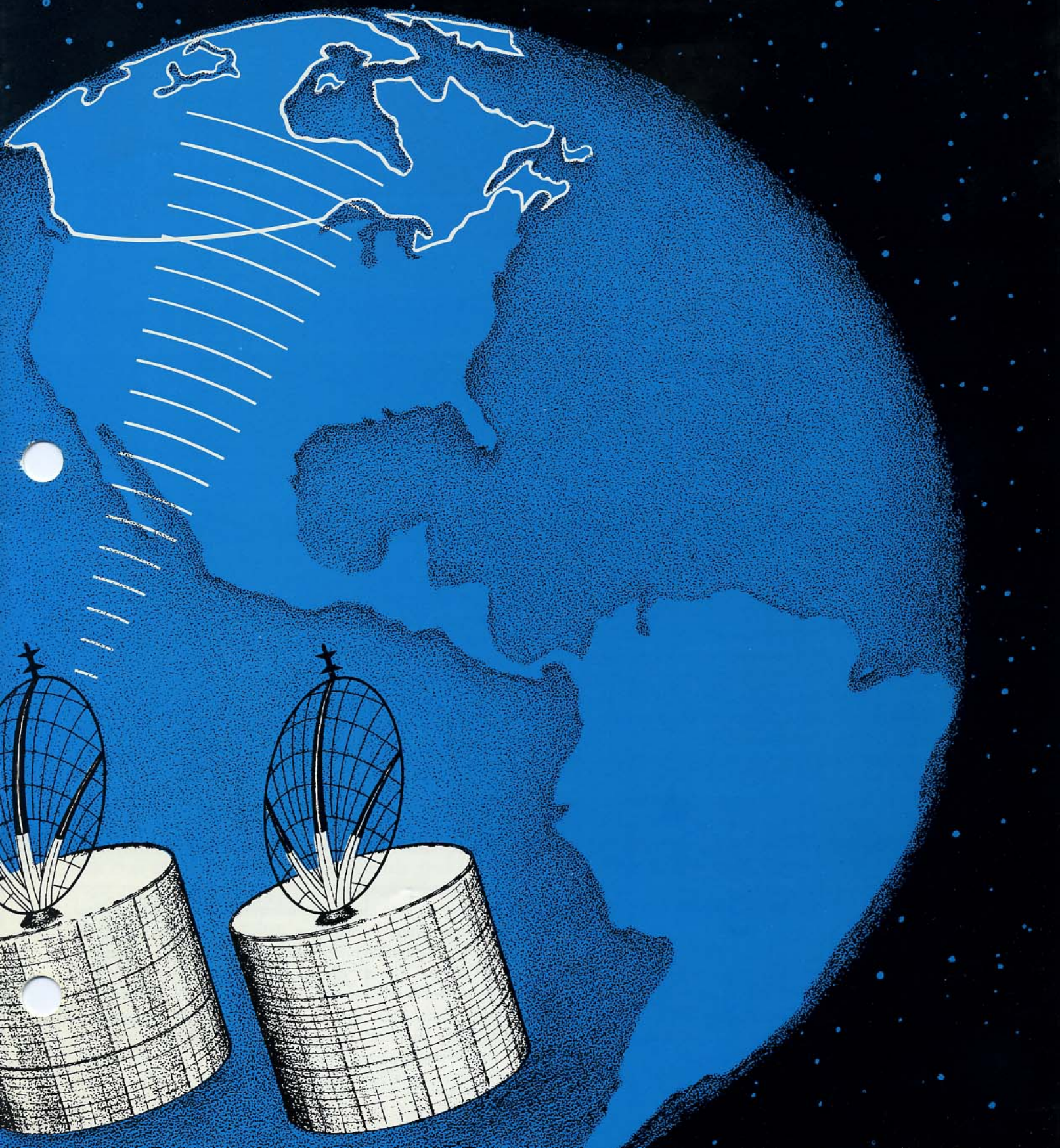
A solution to a measurement problem for TELESAT CANADA, OTTAWA, ONTARIO

Domestic Communications Satellites

A World's First



Domestic Communications Satellites – A World's First

SYNOPSIS: TELESAT CANADA'S ANIK I AND ANIK II

On November 9, 1972, Telesat Canada successfully launched Anik I, the world's first domestic communications satellite, into an earth-synchronous orbit. Two months later, domestic communications via satellite became a reality in Canada. Anik I's antenna beamwidth covers all of Canada from coast to coast and parts of the U.S. as well. On April 20, 1973 Anik II, the world's second domestic communications satellite, was launched and subsequently placed into an earth-synchronous orbit.

Anik II is an "identical twin" of Anik I (anik means brother in the Eskimo language), offering the same kind of communications services and containing the same number of communications channels. As its primary function, Anik II provides in-space redundancy (full-channel backup), for Anik I, guaranteeing service to Telesat's original Canadian customers. In addition, Anik II will also provide service to U.S. customers, until such time as U.S. domestic communications satellites begin operations, during the next 12 to 24 months. Telesat has made it very clear that Anik I customers have first priority, and that Anik II will immediately take over Anik I functions in the event Anik I is out of service. Technically, this involves changing the attitude of Anik II so that its antenna beamwidth covers Canada instead of the United States.

Present plans call for a third spacecraft to remain on the ground as further protection for the satellite communications system.

Launching the Satellites

Initial phases of the launches from Cape Kennedy, Florida, were supervised by the U.S. National Aeronautics and Space Administration (NASA). After the satellites achieved transfer orbit, Telesat mission control in Ottawa took over from NASA. Telesat's engineers and technicians placed its own computer system on-line and monitored information from the satellites through tracking stations at Lake Cowichan, B.C., Allan Park, Ontario, and Guam in the Pacific ocean. Data received were evaluated to determine precisely when each satellite would be in position for injection into synchronous orbit. When the satellites were in position, the apogee motors were fired on command from Ottawa, changing the elliptical transfer orbits into circular ones, 19,308 nautical miles from the surface of the earth at the equator. At this altitude, the orbital velocity coincides with the speed of rotation of the earth. Ongoing orbital corrections (effected by firing short bursts on the satellite's reaction control thrusters) will make the satellites appear to be stationary from any given point on the earth's surface. Both satellites have a usable life expectancy of a minimum of seven years.

Variety of Telecommunications Services

Telesat Canada is essentially a bulk supplier of telecommunications services for individuals or organizations who need this service. Customers include large organizations such as Canadian Broadcasting Corporation (CBC), which leases three channels full time. Another category of customers is the telecommunications common carriers, such as the telephone companies. These companies incorporate leased satellite channels into their own systems and retail the services to their subscribers whose requirements are not such as to justify the leasing of dedicated channels of their own. Telesat Canada's policy is to provide, on a contract basis, equipment and services as required by the customer. In short, Telesat's customers determine the nature, quantity, and location of the telecommunications services available from Telesat Canada. Telesat's first customers are using the system to distribute telephone, data, Telex, TWX, and network television to locations throughout Canada. There are twelve radio frequency channels on each satellite. Ten channels are available for commercial use, while the other two provide backup capacity. Each channel is capable of transmitting one color television channel and its associated audio, or its equivalent in message traffic. This can be as high as 400 two-way voice or data circuits per channel.

Earth Station Systems

Telesat Canada began commercial operations with a system of 37 earth stations of six different classes. The earth stations receive signals from the satellite and, in turn, feed these signals into local communications distribution systems such as telephone, television, data, and radio networks for further distribution into homes and offices of the communities served. The six classes of earth stations include: (1) Heavy-Route (HR) stations. Located at Lake Cowichan and Allan Park, these are the largest stations in the system, handling all forms of telecommunications. They are the only manned stations in the system, (2) Network Television (NTV) stations. The initial system includes six NTV stations

which are equipped to send and receive TV signals for regional distribution of network programming, (3) Remote Television (RTV) stations. Crossing Canada from east to west are 24 RTV stations, providing live CBC network television for broadcast in northern communities not served by microwave systems, (4) Northern Telecommunications (NTC) stations. Two NTC stations provide medium density telephone service between the far north and the mainstream of telephone communications in the south, (5) Thin-Route (TR) stations. A smaller and simpler class of stations, the TR provides light telephone service and radio programming for small, isolated communities, and (6) Telemetry, Tracking, and Command (TT&C) stations. In addition to the broad telecommunications capabilities at Allan Park, this station also performs TT&C functions in conjunction with the Guam and Lake Cowichan stations during transfer orbits. The Guam functions are terminated after the spacecraft achieves geostationary orbit. Functionally, the TT&C facilities at Guam are the same as at Allan Park, except that additional redundancy, spares, and displays are at Allan Park, as it is the permanent TT&C facility during commercial service.

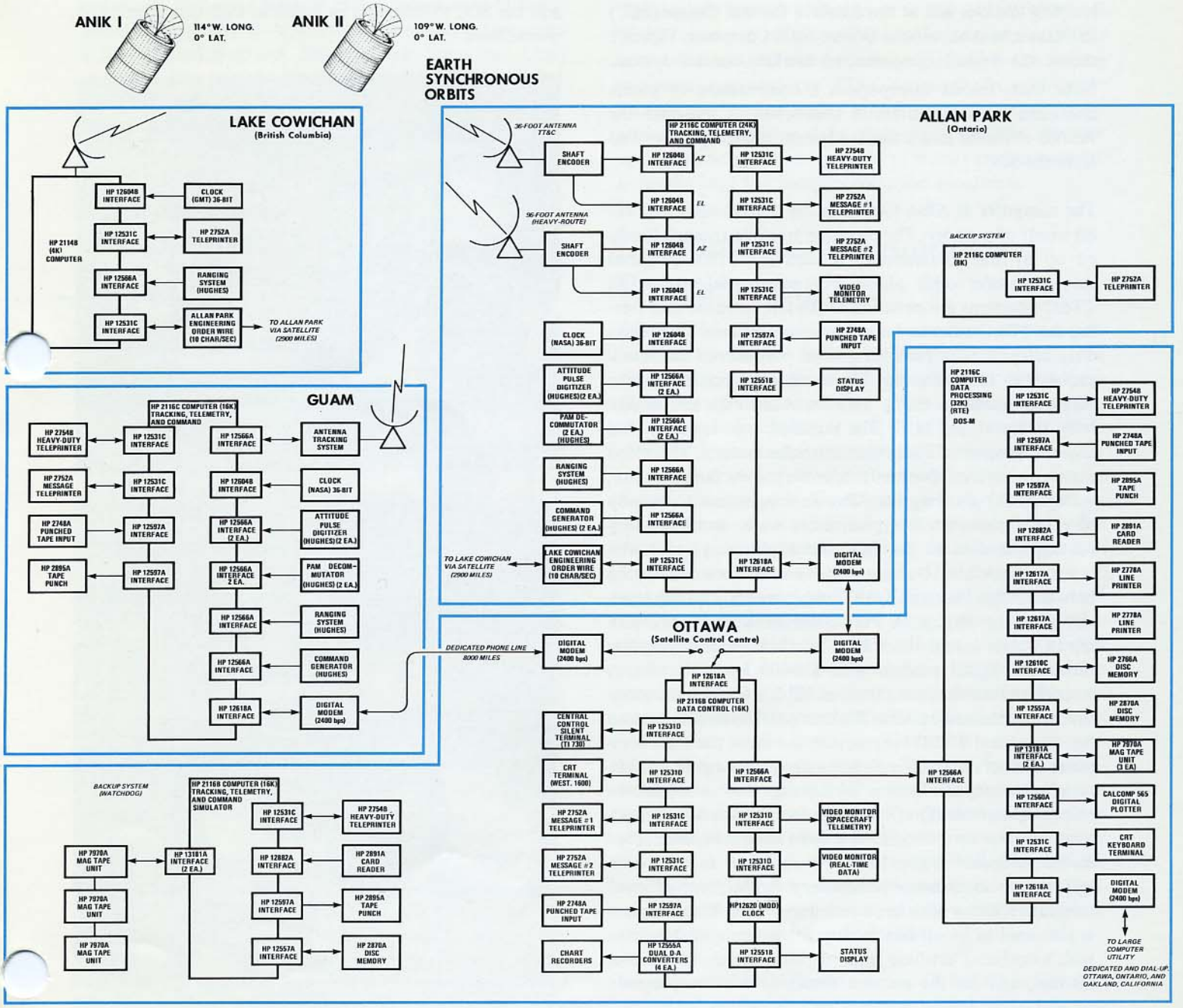


Figure 1. Satellite control system showing all tracking stations and the Satellite Control Centre.

More than two years of intensive computer system design and software development have been devoted to Telesat's satellite computer system. Telesat was well aware of the need for a computer-based system to handle the very complex and crucial calculations associated with the launch phase. Initial investigations revealed that it would be feasible and most advantageous to configure a dedicated system which would handle the launch phase as well as the broad spectrum of telemetry, tracking, and command functions on a routine day-to-day basis throughout the satellite's lifetime. The computer system configuration, determined by Telesat as best suited to handle its needs, consists of a series of Hewlett-Packard minicomputers located at each of the tracking stations and at the Satellite Control Centre (SCC) in Ottawa, and an off-site Univac 1108 Computer. Figure 1 shows the overall computerized satellite control system. Note that Telesat incorporates a combination of phone lines and even the satellites themselves to integrate the various elements into a unified system, centrally controlled from the SCC.

The computer at Allan Park is an HP 2116C with 24K 16-bit words of memory. The precision tracking antenna (backed up by the HR antenna) is used for TT&C purposes during transfer orbit phase. For commercial service, all TT&C functions are switched to the HR antenna, thus freeing the TT&C antenna for a subsequent launch. The heavy-duty teleprinter is used for general purposes of communication with the computer. The message teleprinters handle hard-copy message traffic between Allan Park and similar teleprinters at the SCC. The punched tape input is used to read programs, data, etc. into the system. The video monitor displays spacecraft telemetry data (temperature, voltage, etc.) allowing the Allan Park operators to visually observe certain satellite parameters while simultaneously routing the data to the SCC. An engineering order wire interface provides 10-character-per-second communications between Allan Park and Lake Cowichan over a service channel in the satellite. Allan Park communicates directly with the SCC over leased phone lines interfaced to the computer through a digital modem with a 2400 bps data rate. A second, and smaller, computer, an HP 2116C with 8K memory, is maintained at Allan Park to provide on-line backup for the critical TT&C functions in the event the main computer is out of service. *Herein lies a significant aspect of Telesat's "minicomputer system" philosophy – an out-of-service minicomputer usually affects only certain elements of a system, whereas an out-of-service large-scale computer often means complete system shutdown. Also, it is more cost-effective to incorporate redundancy in the form of minicomputers, rather than large-scale computers.* The computer is also used as an off-line facility for antenna tracking control, calculating attitude pulse digitizer threshold detector settings, and for the antenna despin acquisition program.

At Lake Cowichan, an HP 2114B Computer with 4K 16-bit words of memory is dedicated to ranging data acquisition functions. During early launch phases, TT&C functions are also performed in conjunction with the Guam and Allan Park stations. During commercial operations, the ranging system is controlled remotely from the SCC.

The computer at Guam is an HP 2116B with 16K 16-bit words of memory. The Guam station performs TT&C functions in the eastern hemisphere for the purpose of precisely determining the satellite location and attitude following launch, during the elliptical orbit phase. During geostationary orbit, the Guam station is shut off and all TT&C functions are handled by the Allan Park and Lake Cowichan stations. The Guam station is not part of the satellite communications system. Direct communication between Guam and the SCC in Ottawa is by means of high-speed dedicated phone lines.

Figure 2. Inside the Computer Centre at the Satellite Control Centre. Top: the data processing computer, Bottom, from left: backup (simulator) computer, and the data control computer.

At the Satellite Control Centre in Ottawa, two on-line minicomputers and appropriate peripherals in conjunction with a remotely-located large-scale computer, handle the centralized data acquisition and control activities for the entire satellite system. An off-line backup minicomputer system is also on site. Figure 2 is two different views of the computer room, showing the three computers and peripherals.

A data control computer, an HP 2116B with 16K 16-bit words of memory, controls and displays the entire data flow from the tracking stations. The Silent Terminal (TI730) is used for central control and general purposes of communication with the overall system. The message teleprinters handle hard-copy message traffic between the SCC and similar teleprinters at Allan Park. The punched tape input is used to read programs, data, etc., into the system. Chart recorders, interfaced to the computer through dual digital-to-analog converters, provide continuous strip chart recordings of satellite telemetry data. Figure 3 shows the recorders and an overhead video camera installed about midway in the row of equipment. The camera transmits the recordings to conveniently located monitors in the SCC. Other displays controlled by the computer include spacecraft telemetry and real-time display of positional information. Communication line switching between the SCC and tracking stations is through switching equipment in the computer room.

Figure 3. Analog and communications equipment inside the Data Room. The overhead video camera transmits strip chart recordings to monitors in the Satellite Control Centre.

The data processing computer, an HP 2116C with 32K 16-bit words of memory, controls the major data storage and input/output peripherals of the overall system and also serves as a remote job entry (RJE) terminal for a large computer which is owned and operated by a computer utility. Many of the large RJE programs are prepared on punched cards and entered into the system through the card reader. The two line printers provide hard-copy printout of any data requested by the operator. The disc memories and magnetic tape units provide virtually unlimited storage capacity for both raw data, while awaiting reduction on the large computer, and for reduced data held in storage and printer out as requested. The digital plotter provides fast and accurate X-Y plots of selected satellite parameters as another means of adding to the knowledge of satellite performance. The CRT keyboard terminal is used for program/data entry by the data analysis group and also provides a visual display of parameters as requested. The digital modem interfaces the computer to dedicated and dial-up telephone lines for communication with the large computer utility in Ottawa and also to an identical backup utility in Oakland, California.

The backup system computer is an HP 2116B with 16K 16-bit words of memory. Prior to launch, two complete mission simulations were conducted in which the backup computer simulated the TT&C functions. In addition to backup, the system is also used for program development purposes and off-line data processing. The disc memory and magnetic tape units provide sufficient storage capacity to handle large and complex computer programs.

Comprehensive Computer Programming

Telesat Canada has developed comprehensive computer software, for the Univac 1108 Utility Computer, to control the satellite during transfer orbit, drift orbit, and station-keeping phases of the mission. Each program is written in FORTRAN IV and consists of a main calling program plus a group of mathematical subroutines. The programs require only a minimal derived input, consisting, in most cases, of a given satellite orbit and attitude, velocity or time increments, and some spacecraft parameters. The programs reside in storage on the Univac 1108 at the computer utility. Telesat analysts access these programs, off-line, through the data processing computer in the RJE mode. Mission control software consists of four major categories: (1) prediction programs. These include launch window analysis, shadow prediction, and acquisition prediction, (2) determination programs. These programs accept unprocessed tracking and sensor data, and determine statistically the state of the orbit and attitude of the satellite, (3) satellite maneuver programs. These are the reorientation program, hydrazine control system calibration program, axial and canted hydrazine thruster programs, and maneuver evaluation programs, and (4) station-keeping programs. These programs accurately predict the future motion of the satellite, compute the optimum cycle and magnitude of orbit, and computer attitude corrections required to maintain the satellite on station and pointing it in the right direction.

In addition to the RJE tasks run in off-line mode, the data processing computer also operates on-line collecting and storing data. Both are run in the foreground area of computer memory under control of the HP real-time executive (RTE) software operating system.

Satellite Control Centre

Control of the satellite for the transfer and drift orbit phases and for commercial operations in synchronous orbit originates from the Satellite Control Centre in Ottawa. The SCC consists of several equipment and work areas, designated as the: (1) Operations Room, (2) Data Room, (3) Analysis Room, and (4) Computer Centre.

The Operations Room, shown in Figure 4, contains the consoles and status display facilities used by mission personnel during launch and transfer orbit activities, and by operations personnel during commercial service. All relevant satellite data are displayed within this room, providing on-line information for making decisions affecting the operation and control of satellites and ground stations. The control consoles house the master control panels for the intercom system, telephone links to the TT&C stations and other outside facilities, arrays of switches for the updating of satellite status displays, and video monitors for display of satellite analog data and satellite telemetry in engineering units in semi-real time. The status boards (on the wall) display the condition of all switchable functions in the satellites, the display of satellite attitude and orbital information, and other system parameters as required. The digital clocks display elapsed time and GMT.

The Data Room (shown earlier in Figure 3) includes analog modems and patch panels, analog telemetry reduction equipment, analog display equipment, an analog tape recorder, telecommunications equipment, and a time-code reader and generator. Analog data received directly from the tracking stations are recorded for historical records, and simultaneously converted into a form suitable for display on the video monitor system. Digital data are forwarded directly to the data control computer in the computer room.

Figure 4. The Operations Room at the Satellite Control Centre. Here, all satellite measurement parameters are displayed and operations personnel initiate control and command signals to the satellite.

In the Analysis Room, shown in Figure 5, systems analysts are primarily concerned with maintaining the satellite in an accurate orbit and attitude. From parameters observed on the video displays, orbit and attitude determination calculations are made. Since a certain amount of fuel is expended in firing the satellite positioning rockets, accurate records are maintained to account for the amount of fuel remaining onboard. A CRT terminal (not shown) gives access to the computer system for display of specific data as requested by the analysts. Also available are HP35 Pocket Calculators which have proven to be popular and virtually indispensable tools for many of the rough calculations and checks performed by the analysts.

The Computer Centre houses that portion of the Telesat computer system which is located at the SCC. All major elements in the Telesat computer system network have been described earlier.

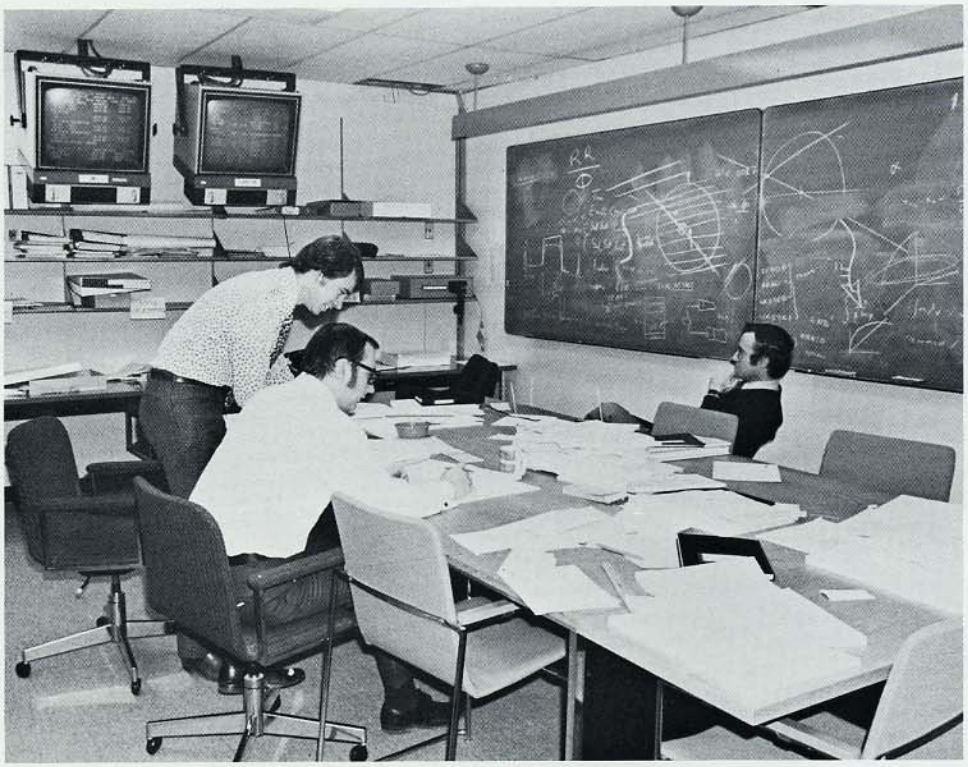


Figure 5. The Analysis Room at the Satellite Control Centre. Here, analysts closely observe all satellite parameters for the ultimate purpose of maintaining the satellites in proper orbital position.

A Successful First

From early checkout and launch through final day-to-day operations, computers are used to control the myriad tests, measurements, verifications, and many other activities in operating a successful communications satellite. Telesat Canada considers its computerized satellite control network as a pioneering contribution, and perhaps as an example to follow for other nations contemplating their own comparable satellite communications system.

HEWLETT hp PACKARD

For more information, call your local HP Sales Office or East (201) 265-5000 • Midwest (312) 677-0400 • South (404) 436-6181 • West (213) 877-1281. Or write: Hewlett-Packard, 1501 Page Mill Road, Palo Alto, CA 94304. In Canada: 275 Hymus Blvd., Point Claire, Quebec. In Europe: Hewlett-Packard, P.O. Box 85, CH-1217 Meyrin 2, Geneva, Switzerland. In Japan: Yokogawa-Hewlett-Packard, 1-59-1, Yoyogi, Shibuya-ku, Tokyo, 151.

APPLICATION NOTE 135-13 9/73

Printed in U.S.A. (06)
5952-1693