THE LES-8/9 TELEMETRY SYSTEM: PT II, GROUND TERMINAL DESIGN AND PERFORMANCE*

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ABSTRACT

The LES-8/9 telemetry ground terminal is a distributed system providing simultaneous reception of digitally encoded telemetry from both LES-8 and LES-9 satellites via S-band, K-band, and UHF downlinks at ground commendable rates of 100-bps and 10-Kbps. Antenna control and demodulation as well as frame synchronization and error detection are provided at a centralized facility, and resultant baseband telemetry is distributed in processed digital format over serial-data lines through a coaxial-cable distribution network. Comprehensive, realtime telemetry processing is provided by separately located minicomputers which provide alphanumeric data displays to a distributed network of standard TV-type video monitors. Telemetry is recorded directly in IBM compatible form under minicomputer control and selection, with post-processing performed at the IBM-370 Lincoln Computation Center. Additional real-time processing is also provided by dedicated panels portraying subsystem operations. Extensive operational software has been developed for evolving needs from initial satellite integration and test through post-launch operation and monitoring. These programs as well as the related hardware equipment and organization are described and traced through the course of the LES-8/9 project.

INTRODUCTION

Development of the LES-8/9 telemetry ground terminal began shortly after the launch of LES-6 in 1968. LES-6 had been supported by a relatively small hardwired telemetry terminal which provided numerical printout on paper tape and magnetic tape telemetry recordings for later computer post-processing. Shortly before launch, direct linking to the laboratory time-shared computer augmented the minimal capability by providing telemetry monitoring at time-share terminals. While this link significantly increased real-time

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processing, it was continually hampered by the constraints and limitations of the general-purpose time-share system.

As a consequence, a fundamental concept was advanced for the LES-8/9 terminal. System development would be centered around a minicomputer dedicated to real-time telemetry processing. The facility would be provided with magnetic tape drives for telemetry recording plus computer storage CRT terminals for telemetry display.

Initial development began in 1969 with the acquisition of an HP 2116B minicomputer with 8K of core memory and a paper-tape operating system. In the ensuing years, the spacecraft designs became increasingly complex, making increasing demands on the ground terminal facility, not only for monitoring but for test purposes as well. The rapid advance of minicomputer technology facilitated change and growth into a system of three computers. The onset of microprocessors led to realization of relatively complex display panels. This evolutionary process, initiated with a relatively small computer, culminated in the complex facility which now exists at Lincoln Laboratory.

TELEMETRY GROUND SYSTEM

Major features of the LES-8/9 telemetry ground terminal facilities at Lincoln Laboratory are shown in Fig. 1. Spacecraft telemetry at S-band and UHF, received via several antennas located on the roof of one of the Laboratory buildings, can be fed to appropriate receivers in the rf control room by the telemetry antenna selector. Baseband telemetry, subsequently derived from BPSK demodulators, is fed to format synchronizers for synchronization, error detection, and initial processing. Baseband telemetry demultiplexed from K-band and UHF communication channels is similarly fed to data synchronizers via the telemetry baseband selector. The three data synchronizers are identical to the three format synchronizers except for carrier acquisition control and mag-tape recording capability. Comparable outputs from both are routed through the telemetry output selector to computer and display panel facilities in nearby LESOC (Lincoln Experimental Satellite Operations Center). The telemetry computer system is generally identified as the TOP (Telemetry Output Processor).

Telemetry Antennas

The two high-gain parabolic antennas are required for reception of 10-Kbps telemetry. The 30' dish has an S-band Cassegrain feed with a dichroic reflector (43 dB gain) behind which is mounted a focal-point UHF feed system (23 dB gain). The 10' dish operates at S-band with 33 dB gain, which is just adequate for high-rate telemetry. Both dishes are mounted on steerable elevation over azimuth mounts.

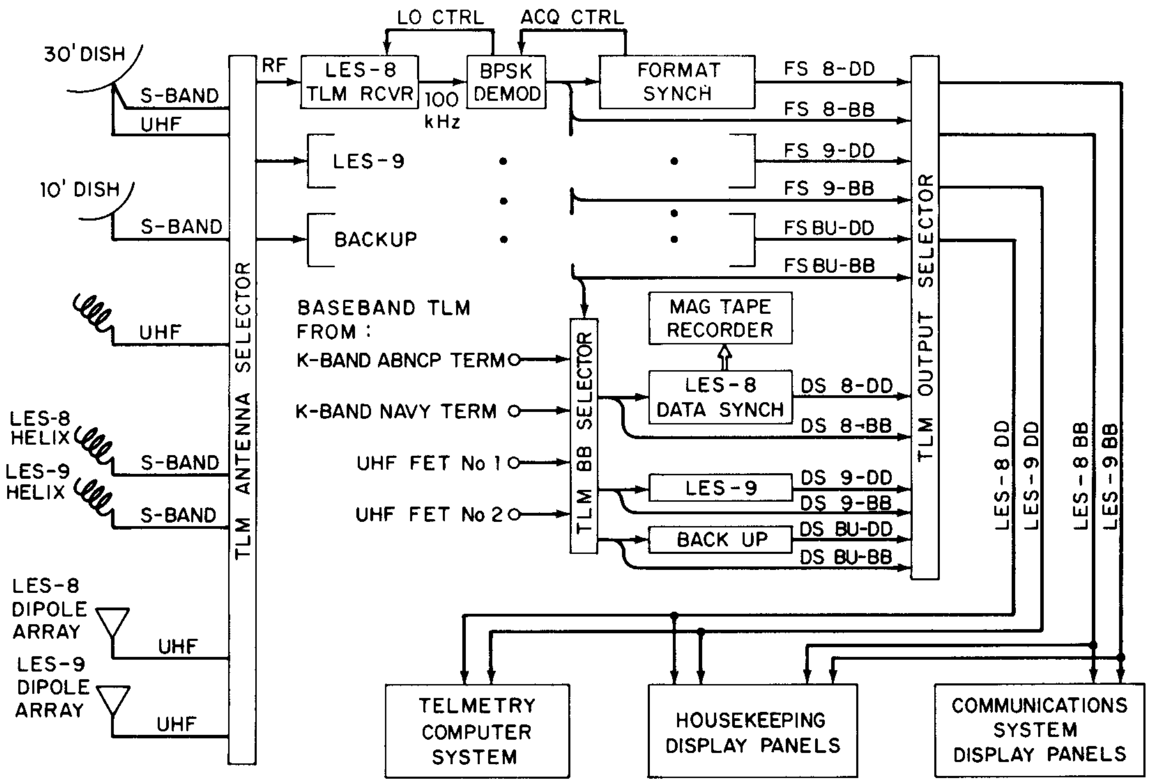

Fig. 1. LES-8/9 Telemetry Ground Terminal System

Low-rate telemetry for routine monitoring is provided by two helix arrays mounted on nodders, which are necessary to maintain adequate antenna gain over the 50° elevation excursion of the satellites. The UHF antennas shown, primarily used for commands and communications, can also be used for telemetry when a satellite UHF transmitter is set to its transponder mode.

Antenna Selection and Telemetry Receivers

The telemetry antenna selector provides a convenient means for controlling antenna connections to the telemetry receivers. Selection is done with latching type transfer switches, control being arranged so that a simple push-button operation throws all switches required to set up a desired path. Three identical telemetry receiver channels permit reception from LES-8 and LES-9 plus active back-up for either satellite. Each channel contains a commercial S-band/UHF receiver driving a Lincoln BPSK demodulator and a format synchronizer.

The receiver downconverts the BPSK modulated rf signal to a 100kHz IF. RF plug-in tuning heads enable reception at S-band and UHF. Both heads are configured for external first LO (local oscillator); four external oscillators establish S-band or UHF frequencies from the two spacecraft.

Carrier Acquisition and Demodulation

The BPSK demodulator compares the phase of the 100 kHz input signal to a 100 kHz reference and provides an error signal that controls the receiver first LO frequency in a closed carrier-phase-tracking loop. Other control voltages summed to the phase error voltage allow initial phase locking either manually from demodulator front panel controls or automatically under format synchronizer control.

The matched filter output in the demodulator in-phase channel is digitized and fed directly to the format synchronizer for bit synchronization and higher order synchronization of words, frames, and format count.

The demodulator also contains a frequency discriminator, an energy detector, a phase lock detector and a sweep generator to facilitate automatic telemetry carrier acquisition. Acquisition control from format synchronizers provides a very positive check on whether or not the carrier tracking loop should stay locked by utilizing available sync status information. It completely eliminates false locks such as locking onto a sideband. If no sync confirmation appears during a set number of formats, the frequency discriminator will turn on and attempt to pull the loop back to lock. If no lock or sync signal appears in the next two formats, the local oscillator is then swept to cover the full doppler range. This is done alternately for both high- and low-rate telemetry. When energy is detected, sweeping halts, and the frequency discriminator provides fine pull-in. Phase-lock indication or the appearance of a sync signal turns off the frequency discriminator.

Data Synchronization

Synchronizer operation is illustrated by the block diagram of Fig. 2. Selected baseband telemetry together with the input from a cesium-beam controlled 1 MHz standard is utilized by the clock synchronizer to produce sampling and counter clocks properly phased for the received bit rate. High accuracy of the satellite master oscillators and the 1 MHz standard allow the synchronizer to free run through appreciable telemetry breaks without loss of original sync upon recovery.

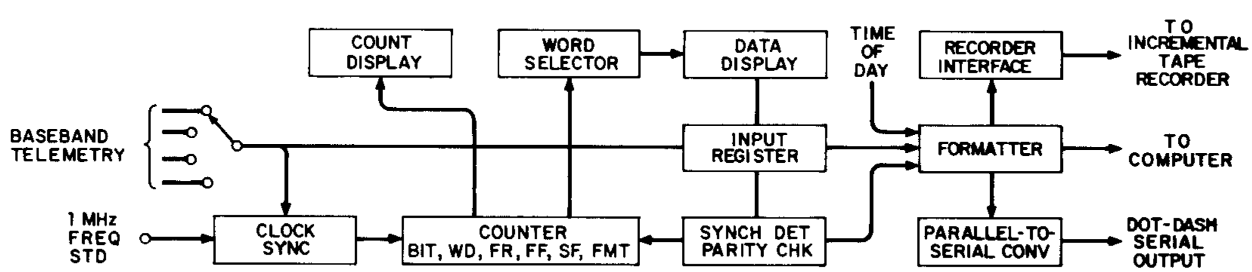

Fig. 2. Data Synchronizer Block Diagram

Frame sync is the basis for word identification in the format, and minimization of false frame sync is therefore of utmost importance. Sync information is provided at the beginning of every frame in the telemetry format; even frames include a unique 16-bit sequence (S), while odd frames include the complement of S ($\bar{S}$) plus an additional 16 bit sequence (S1). Frame identification is contained in word 1 of even frames. The normal sync sequence is to look for S and when detected check if $\bar{S}$ and S1 were detected the correct number of bits earlier. If so, the next word is word 1, and the frame counter may be set after that word has passed parity checks and frame identification has been extracted. The length of the sync pattern sequence (48 bits) and the check for proper check-sum on adjacent words make the possibility for erroneous sync negligible and thereby eliminates the need for sequential techniques. With the attainment of frame sync, format sync readily follows by a check of format count indicated by word 1 of frames 0 and 2.

Frame and format sync indications have been included in the synchronizers to indicate that valid frame and format synchronization has been achieved. However, the checking for complete sync sequences is continuous, and each one detected updates a sync confirmation indicator. Lack of sync confirmation thereby indicates loss of sync.

Normally the telemetry links are very good, sync is confirmed every other frame, and very rarely is a data word tagged with a bad parity check. However, during severe weather conditions the links may become marginal, sometimes to the point of almost no confirmation of synchronization, but as long as sync has been established at some point, all the good data words can be extracted. Initial sync to a marginal link might present a problem because of the stringent sync sequence. To alleviate this difficulty, a “short sync” mode has been provided to allow word sync at the beginning of every frame on the basis of either S or $\bar{S}$ and S1 only, followed by a valid frame count word. When sync has been established, normal sync mode must be entered to avoid false re-synchronization which is much more likely in the “short sync” mode.

Data Synchronizer Parallel Output

The formatter section of the data synchronizer provides a computer output in parallel form. Originally used for direct computer drive, this output provides the basis for serial data output and distribution in the present configuration. Timing of this output is slaved to incoming telemetry so that every serial input word received produces a corresponding parallel output word.

Throughout this process, the 12-bit telemetry data words remain unaltered, while the remainder of the format is overlaid as shown in Fig. 3. Since sync and parity content are expendable after reception and error checking, the four-bit check sums can be overlaid with four new bits. One of these is a parity check flag indicating reception errors; a second

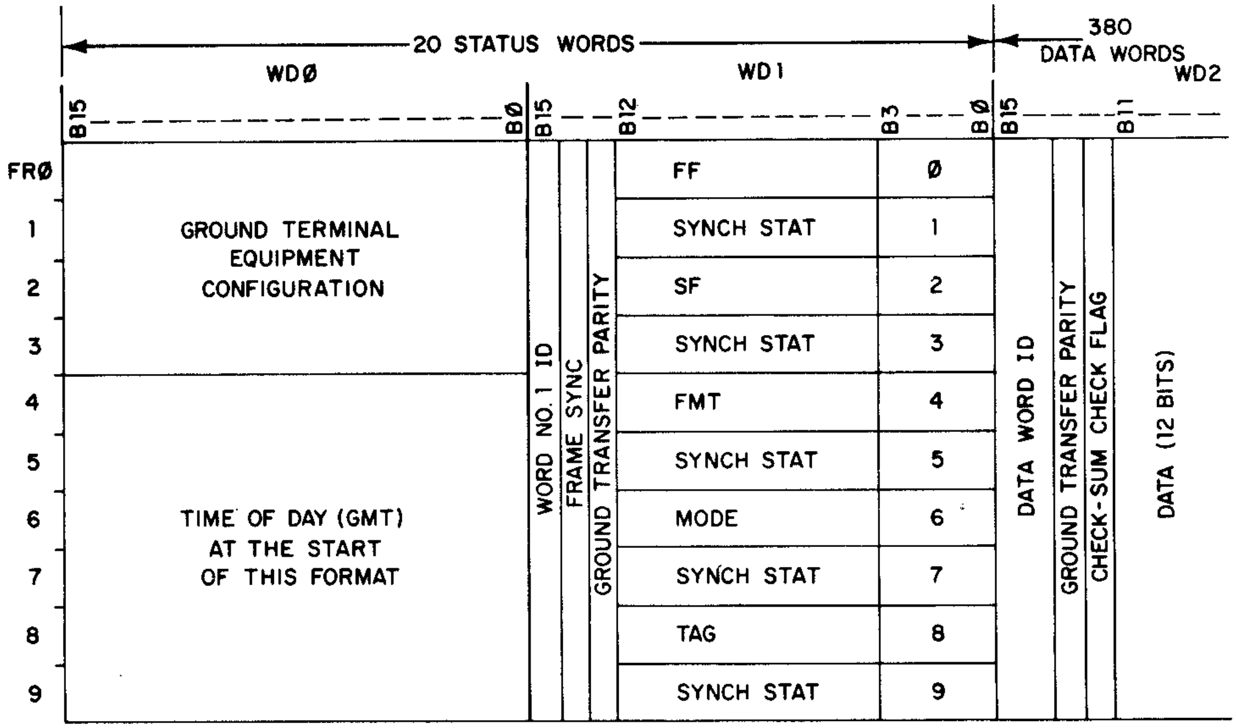

Fig. 3. Data Synchronizer Parallel Outpur

is a parity added by the synchronizer for subsequent ground transfer checks. The remaining two bits provide auxiliary word identification.

Sync words in the WDO position are overlaid with ground terminal equipment configuration information and TOD (time-of-day) information, which includes date. This overlay provides a record of all ground equipment through which the format is routed. Successive equipments modify this content accordingly.

Data Synchronizer Serial Output

For general distribution of telemetry, the overlaid parallel-output format is converted to serial form, expanded to include added word tags, and finally fed to the system in "dot-dash" (DD) form in accordance with Fig. 4.

Dot-dash signalling is a versatile format which is generally employed for most information distribution. It utilizes short pulses to denote logic ZEROs and long pulses to denote logic ONEs. For telemetry, ZEROs are two microseconds long, ONEs are eight microseconds. For reception, the leading edge is used as a time reference and the line state is strobed 2-6 microseconds later to distinguish between ZEROs and ONEs. With a distribution bit rate of 100-Kbps, each 32-bit burst occupies 320 microseconds.

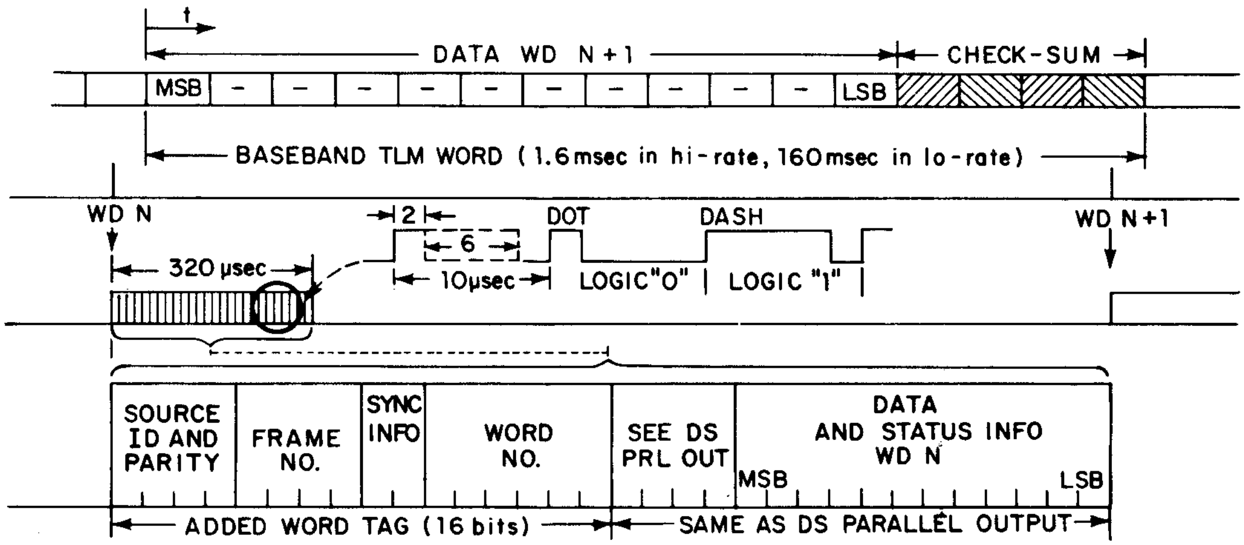

Fig. 4. Data Synchronizer Serial Output

Coax Interconnection Network

The large and continually varying requirements for signal communication in ground terminal operations necessitated a flexible interconnection network. For this, a standardized interconnection system using RG-58/U coaxial cable was developed and sets of 10 to 20 cables installed between locations needing video or digital communication. Dot-dash signalling facilitated simple single line hookups, one line for one link. This principle has greatly simplified interconnection and related patching, avoiding the encumbrance of multiconductor lines and introducing valuable flexibility in system arrangements. Duplex communication, when required, has been provided by timed multiplexing. For video lines, channel selection has been provided by reverse signalling through a selector button connected directly in the coaxial line.

Three standard types of signal transmissions have been generally employed: 1) TTL-level, ground true matched TTL source, normal TTL load; 2) TTL-level, positive true, fully matched line with 8T23 drivers and 8T24 receivers; 3) video levels per RS-170 with matched lines. For each type, standard 3 1/2" patchboard distribution panels have been developed to provide banks of identical buffers with LED annunciators. Simple pc buffer stages have been readily fabricated in large quantities for this purpose.

Coaxial patchboard facilities have been installed in a variety of Lincoln locations. The largest of these is a multi-rack unit in LESOC for the central distribution of all telemetry related signals as well as others generally related to satellite ground support.

Telemetry Computer System

The TOP (telemetry computer system) as it existed at launch is depicted in Fig. 5. It consisted of three similar computer systems, denoted A, B and C, one being the originally acquired HP2116B with memory expanded to 32K, the others being HP2108 computers, also with 32K of memory. All three were fed from a common bus system carrying LES-8 and LES-9 telemetry in dot-dash format as well as TOD information. Dot-dash telemetry interface units provided the necessary serial-to-parallel conversions for computer input as well as panel monitoring of input operations. TOD interface units provided similar conversions for TOD inputs as well as associated monitoring.

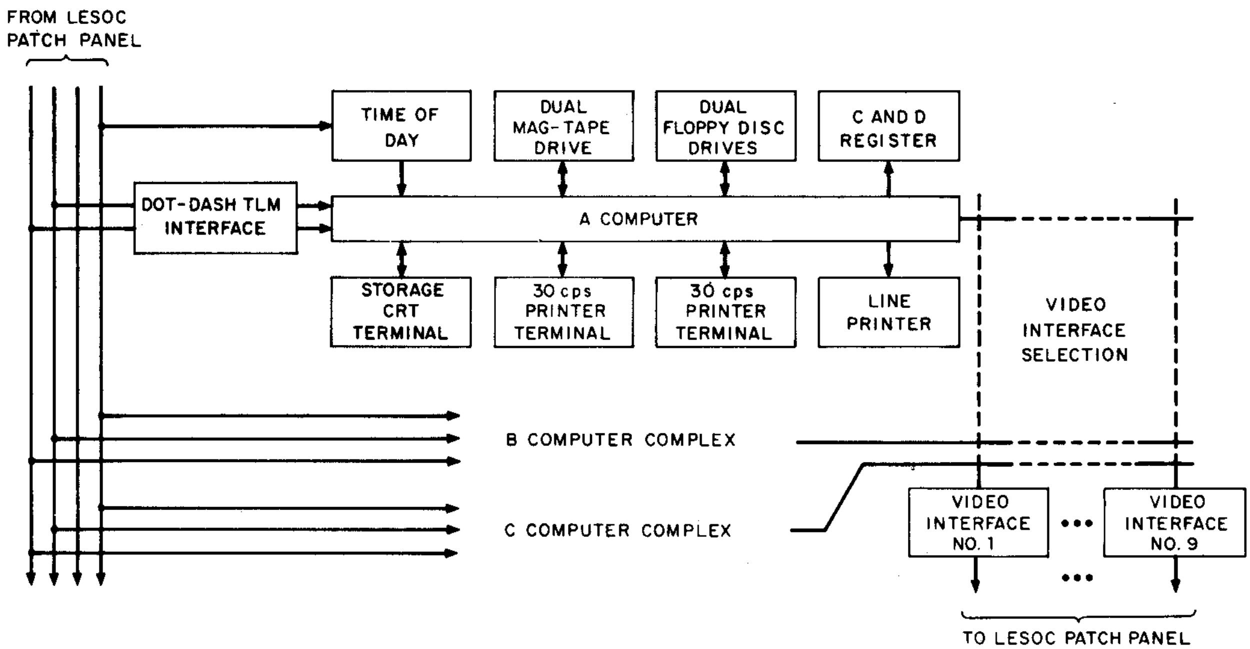

Fig. 5. Telemetry Computer System

All three computers provided multiple outputs for alphanumeric display on TV-type crt monitors. These outputs, in parallel ASCII code, were fed through a video interface selection arrangement to a set of nine video interface units manually switched to either of two computers. These units generate standard RS-170 video to create alphanumeric displays of twenty-four 80-character rows. The resultant video outputs were fed to the LESOC patch panel for distribution to the TV-type crt monitors. Distribution was further made through sequential channel selection switches at the patch panel. Series push-buttons at the monitors controlled these switches for sequencing through computer output channels as well as remote TV camera pickups. Multi-push-button selectors at the computers provided direct and rapid switching from these locations.

The video interface units incorporated basic video display units manufactured by Ann Arbor Corp. These were modified for computer readback of stored information and for other needed features.

A disc operating system for each computer was provided through dual floppy-disc drives. Dual mag-tape drives on two of the three computers provided for mag-tape recording of telemetry in IBM compatible format. Keyboard terminal control was provided by high-speed storage crt terminals and 30 character-per-second thermal printer terminals, with thermal line printers for additional printout capability. The built-in A and B register displays in the computers were augmented by adding external C and D register displays for simple and continuous monitoring of performance and status with appropriately labeled LED indicators. The C and D register units also included outputs for remote alarm and monitoring.

Telemetry Display Facilities

The various forms of telemetry display facilities currently in use are shown in Fig. 6. TV monitors above the racks present computer output displays as well as pictorial output from remote cameras. Panels below include microprocessor controlled units with digital LED readouts as well as meter panels developed earlier for continuous monitoring of power distribution aboard the satellites. Panels for LES-8 and -9 are arranged to the left and right respectively. In the central operating position a thermal line printer is located atop a thermal keyboard terminal.

The first (and most general) panel displays developed were the “mini-data synchronizers”, located directly below the meter panels in Fig. 6. These units, which predate microprocessor availability, operate directly from baseband telemetry to generate digital LED display of 16 selectable data words. They also include synchronizing functions and telemetry housekeeping displays embodied in the data and format synchronizers as well as additional facility for display of accumulated telemetry errors. Selected data words can be displayed in binary, octal, and hexadecimal or converted to single-or dual-range voltage readings. Because of the early availability, versatility, and self-sufficiency, the mini-data synchronizers were particularly valuable during system development.

TOP SOFTWARE

Similarity of the three TOP computers and their arrangement in the system has allowed comparable similarity in the TOP software. Although the computers run independently, each utilizes common software. Basic to this is TEP (Telemetry Executive Program), a real-time operating system resident in each computer. TEP was developed as a core-resident, multiprogram executive for controlling all computer resources. Under TEP,

Fig. 6. Telemetry Display Facilities

appropriate combinations of interchangeable programs can be loaded and run on any of the three computers. Major provisions of TEP are:

1. Operator communication support -- allowing control of programs and devices.

2. I/O request processing -- providing common interface into device drivers and allowing automatic buffering of output messages.

3. Central interrupt processing -- providing a common interface for interrupt services.

4. Program scheduling -- allowing programs to operate on request and at priority levels.

5. Program communication interface -- allowing programs to use the facilities of the executive.

6. Privileged library -- allowing programs to use common code thereby reducing core requirements.

7. I-O drivers -- for the various devices included in the system.

8. Built-in utility programs -- for general system operation and control.

Operationally TEP divides the machine into four partitions and the hardware prevents the programs in high-memory partitions from destroying those in lower-memory partitions. From high to low the partitions are:

1. Background/Application

2. Real time/Acquisition and Recording

3. Utility and Library

4. System modules and drivers

While many features of the TEP system are standard parts of a real-time or multi-programmed supervisor, a few features deserve special comment.

1. Scheduling of programs is not restricted to the occurrence of external stimuli, but is extended to include internal events, such as the completion of format processing. Programs can “defer” execution and allow programs of equal priority to run.

2. Each program is assigned a logical switch register which can be manipulated under operation control to alter flow within the program. (This simulates the physical switch register located on the computer.)

3. Each program has a “private” device reference table that can be easily manipulated by the operator. Using this table, a given program output can be re-directed without stopping that program or affecting other program outputs.

4. Any program is allowed to break itself into separately executing sub-tasks which can operate at independent priority levels. Thus a common data checking (collection) module can monitor telemetry and queue messages with no loss due to device peculiarities.

Utility Programs

Among the utility programs for operation and control of TEP, one of the simplest and most useful is WHO, which can be readily interrogated at a terminal to list all operational programs resident in memory plus the operational status of each at any time. The most complex utility program is LOADR, a relocating loader providing links so that programs cannot only be added but also removed and replaced without interruption of telemetry processing.

Acquisition and Recording Programs

Of the actual operational telemetry processing programs, those for telemetry acquisition (TLM) and recording (LSRCD) are the most basic and have been partitioned separately from application programs. TLM acquires both LES-8 and LES-9 telemetry from a dot-dash telemetry interface unit. It includes a check of status as overlayed onto the telemetry format by the preceeding format or data synchronizer. It also adds to this status overlay in accordance with processing by TLM. In response to a resync following telemetry breaks, TLM reorganizes incoming buffer storage in an orderly manner to minimize disruption of application programs. For monitoring, it drives the D-register LED display associated with each computer to indicate receipt of telemetry formats and related status. To confirm telemetry transfer by TLM, the program feeds telemetry words back to the dot-dash telemetry interface panel for comparative display with originating telemetry.

LSCRD records LES-8/9 telemetry formats on mag-tape in a selectable manner according to operating needs. In the process it adds to the equipment configuration overlay in the telemetry format to identify both the computer and tape drive involved. If necessary, it can provide full recording of all telemetry from both satellites on a single tape. To eliminate unnecessary recording in fast rate (where both satellites could fill a 2400-ft reel in 90 minutes), LSRCD includes a nominal “medium” rate for general recording which records pairs of successive formats at intervals of 19 skipped formats. Paired formats provide for A and B sub-multiplexing. To avoid loss of any important data in this mode, LSRCD also monitors telemetry data for indication of command reception at either satellite and initiates additional recording of a format pair accordingly. LSRCD can also be switched to full fast-rate recording in response to data signalling a test in progress. To supplement “medium” rate recording, an additional program called SQISH has also been written to accumulate selected telemetry at fast rate for subsequent recording in single blocks. With SQISH, high-rate samples over extended time periods can be collected and analyzed without requiring high-rate recording of all data and consequent tape handling.

Application Programs

In support of the many and varying needs for telemetry processing and display, a large number of application program modules were written for operation in the background partition of TEP. Among the most widely used were those organized under the HPAGE program for “half-page” displays fed through the video interface units onto TV-type crt monitors depicted at the top of Fig. 6.

Under HPAGE, telemetry displays are organized to occupy the upper or lower half of 24-row 80-column alphanumeric displays in selectable combination with 12 rows of 80 characters thereby allotted to each half page. A maximum of eight different half pages can be displayed simultaneously. The desired set of half pages is selected by the operator from an available library of over 40 different half pages. For half-page composition, a special program was developed for the IBM 370 and used for efficient transformation of engineers' layout specifications into tables of display commands for interpretation and real-time display by HPAGE. An important adjunct to HPAGE is COPY, which provides printout of half-page displays by reading back the internal shift-register memory content of selected video interface units and transferring this content to any hard copy output device. COPY can also be controlled by the operating system to produce periodic printout from selected displays automatically.

Another general program for video display is REQST for line request from a number of canned, system-related outputs that are simple and short and use only a single line of text. A sequential set of such lines can be selected for scrolling display so that the last 24 such lines can be viewed continuously. Conceived for emergency situations in which satellite systems might misbehave and affect one another in an unanticipated way, REQST can provide a readily composed and coordinated display useful in the diagnosis and monitoring of such events.

A predecessor to both HPAGE and REQST was SHOW, a program like REQST for single line scrolling display or printout but with considerably more flexibility. SHOW provides single-line displays individually composed by the operator to include up to nine telemetry points selectable by TIC number, TIC word number, and conversion rule (output in volts, temperature, decimal integer, octal integer, binary, etc.). SHOW is useful for composition and display of telemetry not available from other programs and was used mainly in early development and in the checkout of other programs.

The generalized approaches of HPAGE, REQST, and SHOW have supported most display requirements. In addition, displays requiring complicated mathematical operations and data gathering over extended time periods have been provided by a number of special-purpose programs such as PWRST, SAZ8 and SAZ9.

PWRST is an important full-page display providing comprehensive power management information based on the status of satellite systems. It displays the primary power bus voltage and current plus all separate power converter currents and power loads. For each major satellite subsystem it displays total bus power in use, power radiated from the satellite, and transient power which could be automatically demanded. Total spare power and overboard power are also displayed. The program alternates in updating LES-8 and LES-9 displays unless requested to handle one satellite only.

SAZ8 and SAZ9 interpret sun-sensor telemetry to provide information about attitude and pitch rate. Their main importance was in the launch period from separation until earth acquisition by the automatic attitude control systems during which time the sun-sensors provided the only on-board attitude information.

Other special display programs included TGGMW for monitoring the satellite gyro and gimballed momentum wheel systems and TMPMP, which provided comprehensive temperature maps of each satellite.

A significant but little used display program is TPLOT, a telemetry plotting program for use specifically with the Computek storage crt. This provides a real-time plot of selected telemetry over selectable time periods and allows immediate hardcopy from such plots. Alternate plotting capability more generally used is provided by post-processing of recorded telemetry.

LIMITS is an important and unique program which monitors telemetry for out-of-limit conditions such as high or low temperatures, voltages, currents, or illegal switch states. Boundary or limit conditions have been specified for all telemetry points of interest. Both alarms and violation messages are generated for points found out of range. Violation messages are also stored on disk or mag-tape for further analysis. Alarms have been divided into two classes: yellow for points out of bounds but not in need of urgent remedy, and red for catastrophic conditions. Limit boundaries have been modified as necessary to reflect ongoing changes in the operational configuration of satellite subsystems.

Auxiliary Programs

Three auxiliary programs of significance are STATE, VUCMD, and RELIV. To monitor overall TOP performance, STATE was created as a watch dog program. This program, run on all of the TOP computers, produces a simple one-line display of telemetry rate, mag-tape recording rate, and the format count for both satellites. An indication of large numbers of errors in telemetry or the failure of telemetry recording is also given. Thus operators can obtain at a glance, information on the general state of telemetry and recording. VUCMD is a similar program which presents a list of recent satellite commands.

RELIV was designed for “reliving” past telemetry during telemetry breaks encountered in testing and launch. An A and B format pair is stored for each satellite and continually updated during reception of valid telemetry. This stored telemetry can be used to drive the telemetry distribution network through an associated dot-dash simulator unit which provides the necessary format structure and timing. Both programs and panels can therefore be kept running smoothly in the face of telemetry loss, such as was experienced during launch.

Programming

Support for generating the above programs was provided separately from the TEP operating system by the Hewlett-Package Magnetic Tape Standard Input Output (MTSIO) system and by a cross assembler installed on the laboratory IBM-370 time-share system. The MTSIO was used for all of the early programming effort. Because it required shutdown of the computer for telemetry processing, its use caused increasing conflict between programmers and telemetry processing needs. This led to purchase and installation of the cross assembler, which not only alleviated conflicting demands on the TOP computers but facilitated more efficient and rapid programming.

SYSTEM OPERATIONS

Initial Development and Test

The initial HP2116B computer with its paper-tape operating system included an ASR-35 teletypewriter for operational control and telemetry printout and a single 200 bit-per-inch mag-tape drive for telemetry recording under programmed control. A Computek storage-type crt terminal was subsequently acquired for development of line-at-a-time and page displays of telemetry in real time. Graphic capability of the Computek offered potential for pictorial and graphic telemetry presentation; an associated Tektronix hardcopy unit allowed direct reproduction of any display stored on the face of the terminal storage tube.

Telemetry was to be acquired through a data synchronizer which would derive 16-bit telemetry words from the serial telemetry stream and also provide for direct telemetry recording on an incremental mag-tape recorder.

Therefore, initial concerns were develoment of software for this computer system and design and construction of associated data synchronizer units. This required early establishment of a standard telemetry format mutually consistent with satellite and ground terminal needs. Early applications included support for attitude-control subsystem experiments on an air-bearing table facility and support for test runs in conjunction with a computer-controlled automatic test system used for rf subsystem development. Comprehensive checkout of an autonomous stationkeeping system under simulated operating conditions was also provided.

During this initial period, the original single mag-tape drive was replaced with a dual 800 bit-per-inch unit and software adapted to a mag-tape operating system.

Satellite Integration

Shortly before commencement of satellite integration in the Lincoln clean room, the telemetry ground terminal facility was relocated to a “telemetry” room adjacent to the satellite integration and test areas. A supporting network of coaxial cables was installed at this time, providing connections back to a central patch panel in the telemetry room from all satellite test locations.

For initial assembly and integration, telemetry data was required at the satellite location in the clean room. Operation began with portions of the setup shown in Fig. 7. All telemetry was taken directly from the TOC through a test connector on the side of the satellite. Limited drive from the TOC was buffered at the satellite to provide low impedance drive to RG-58/U coax cables at TTL levels. These drove a mini-data synchronizer for local monitoring as well as a remote data synchronizer for coupling into the HP2116B TOP computer in the telemetry room. Independence from the TOP made the mini-data synchronizer a particularly valuable tool during this period since the TOP was heavily dedicated to program development for subsequent needs and there was strong contention between telemetry users and programmers for TOP availability. Throughout testing, heavy emphasis was placed upon mag-tape recording of telemetry as an essential procedure. Both the data synchronizer and TOP were equipped for this function.

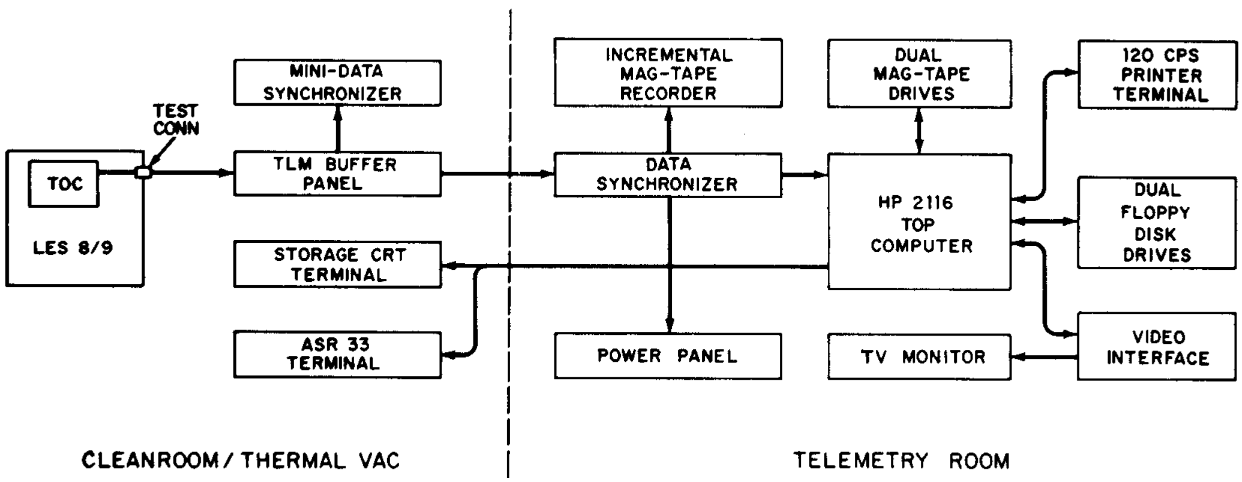

Fig. 7. Integration and Test Configuration

Initial use of the TOP for data display at the satellite was accomplished via the remotely driven Computek storage-type terminal and an ASR-33 teletype terminal in the clean room, both being driven through interconnecting coaxial lines. Since the Computek had been designed for parallel interface operation adjacent to the TOP, special parallel-to-serial-to-parallel interface circuits had to be developed for remote operation. This general setup was quite limited, being required to serve both satellites plus programming needs with a minimal set of peripheral equipment.

As operations proceeded towards thermal vacuum tests, increasing emphasis was placed upon telemetry monitoring from the telemetry room, an arrangement greatly facilitated by the introduction of closed-circuit TV as well as intercom and direct telephone lines. To augment output independent of the heavily used TOP, dot-dash telemetry was also introduced at this time as an additional data synchronizer output, permitting introduction of a dot-dash driven power panel to fill an urgent need for continuous satellite power monitoring. In addition, TOP capability was further enhanced by the addition of video monitor equipment, a 120-cps printer and a floppy-disc subsystem. All of this led to the full complement arrangement of Fig. 7 in which power panel and alphanumeric video displays were used alternately in clean room and telemetry room locations. A second computer was subsequently added and the number of video displays gradually increased to four. A bank of 23" TV monitors was also installed in the telemetry room for telemetry monitoring and closed-circuit TV observation of satellite activity.

Prelaunch Operations

Upon completion of satellite testing at Lincoln, telemetry ground terminal operations were relocated to LESOC in preparation for launch. The third TOP computer was added at this time. With the subsequent shipment of LES-8 and LES-9 to Cape Canaveral, one of the computers was then shipped to support prelaunch checkout of the satellites in the Satellite Assembling Building (SAB). This computer was returned to LESOC following the checkout.

For remote fast-rate telemetry support from LESOC, a pair of 9.6-Kbps leased-line data links were installed between the SAB and LESOC as illustrated in Fig. 8. Telemetry was transmitted from the SAB to LESOC, and processed output was transmitted back. Telco Interface units were developed for this specific task.

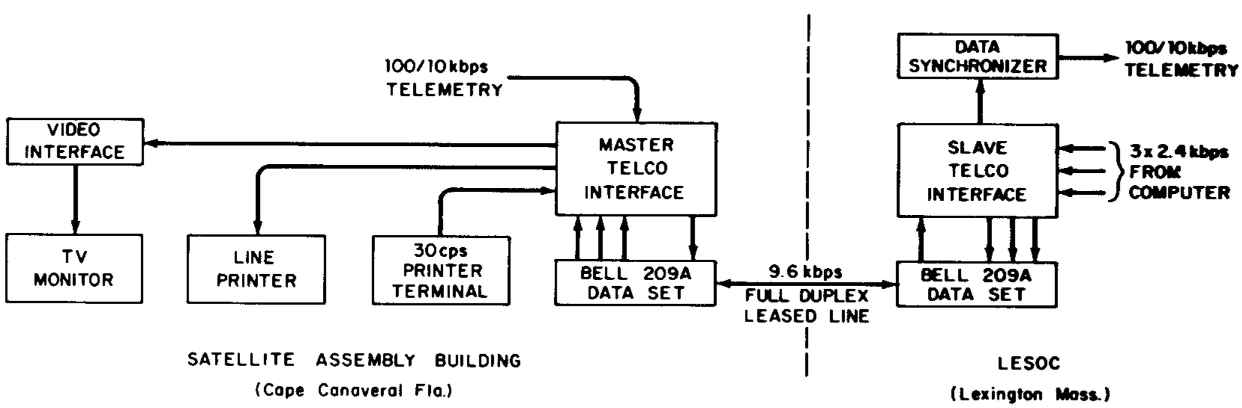

Fig. 8. Cape Canaveral/LESOC Configuration

For fast-rate transmission through the 9.6-Kbps data links, telemetry rate was reduced from 10-Kbps to 9.6-Kbps by stripping a fixed set of 256 check sum bits from each format and smoothing the resultant bit rate through an elastic shift register. Upon reception at LESOC, the missing check-sum bits were rederived and inserted to recreate the originating telemetry. In this operation, the Master Telco Interface established data-link clock to which the Slave locked.

For return transmission to the Cape, the 9.6-Kbps channel was available as four separate 2.4-Kbps channels through the Bell 209A Data Sets. These channels were used for driving a TV-monitor display plus a line printer and a 30-cps printer terminal in the SAB slaved to identical units in LESOC.

Fast rate monitoring of SAB operations continued until the satellites were transported to the Titan launch pad. For this trip, special telemetry panels were installed aboard the transportation vehicle and connected to monitor the radio-isotope generator (RTG) temperatures. These RTGs power both satellites and were mounted aboard them in the SAB. Temperatures of the RTG units were a prime concern warranting careful monitoring throughout the slow trip to the pad and the hoist to the top of the Titan launch vehicle. Fast-rate telemetry was utilized throughout this operation with the TOC set to time out automatically to slow-rate telemetry shortly after installation at the pad.

Following installation aboard the Titan, telemetry monitoring was continued at slow rate by hardwire connection through the umbilical and site cabling to the Vertical Integration Building (VIB), where telemetry equipment had been installed for retransmission through several miles of landline back to the SAB. From this location the 9.6-Kbps synchronous links to LESOC were used simply as asynchronous sampling channels for the relatively slow 100-bps telemetry.

Launch Operations

With the advent of launch, the physical arrangement of equipment in LESOC was modified significantly to reflect specific requirements for personnel, systems, and operations. This was greatly facilitated by the standardized single-line coax distribution system.

Shortly before launch, the hardwired telemetry link from the Titan pad was replaced by the Titan transtage rf link through which all telemetry was subsequently obtained until separation. The slow-rate 100-bps LES-8/9 telemetry was asynchronously sampled by 300-bps Titan telemetry channels. Transtage telemetry was received at the Titan telemetry reception center in the VIB, where the 300-bps LES-8/9 dedicated channels were decommutated and sent to the Lincoln retransmission facility in the VIB. Here the 100-bps

LES-8/9 data streams were reconstructed from the Titan telemetry data streams and then transmitted to the SAB via the landlines described previously.

During the period before launch, the TOP computers in LESOC were loaded with a carefully organized set of programs as follows:

	Computer A	Computer B	Computer C
Running:	LSRCD PWRST TMPMP	LIMTS HPAGE	LSRCD STATE PRT8, PRT9 RELIV
Available in core:	REQST TGGMW VUCMD STATE COPY	COPY	TMPMP

The organization of these programs satisfied launch requirements and defended against computer failure by redundant program assignments and allowance for possible reconfiguration.

On the pad, a principal concern was the temperatures aboard the satellite, especially RTG temperatures. This concern continued during launch, when air conditioning was discontinued and the satellites were being carried into vacuum. Prior to launch the RTGs were filled with xenon to equalize external atmospheric pressure and avoid internal oxidation. The xenon also acted as a thermal shunt, limiting available power from the RTGs. During lift off, the RTGs were allowed to vent and reach their operating temperature for maximum power generation. At this time, therefore, key programs were PWRST (for power monitoring) TMPMP (for temperature mapping) and PRT8 and PRT9 (for RTC temperature monitoring).

At liftoff, telemetry remained available through the transtage rf link for several minutes but was lost as the Titan proceeded downrange from Cape Canaveral. Reception was stored thereafter only during prespecified “windows” of roughly five to ten minutes each hour during the ascent phase. During the breaks in telemetry, RELIV allowed continued observation and review of valid telemetry last received. Following the last ascent “window” for telemetry reception, software on the C computer was reconfigured by removing PRT8 and PRT9 and loading SAZ8 and SAZ9 for interpretation of sun sensor telemetry in determining satellite attitude upon separation. Backup copies of SHOW and

REQST were also loaded into the C Computer at this time for backup support.

Just before separation, Titan telemetry provided a brief final link which was then lost upon separation, after which direct links from LES-8 and LES-9 were established through slow-rate UHF transmission directly to Lincoln Laboratory. Following orientation of the satellites into proper attitude and corresponding lock to earth direction, the S-band transmitters were activated. After establishment of 100-bps slow-rate reception through the S-band channels, telemetry was commanded to the 10-Kbps fast rate which was then maintained for both satellites during the first weeks with round-the-clock operations in LESOC. For the first few days, temperature maps were made for each satellite roughly every half hour. Every half-page was put on a screen at least once an hour and hard-copies made. Individual systems, such as the K-band systems, the third generation gyro, the stationkeeping system, etc. were checked out using both half-pages and specific programs devoted to the system under checkout. For rf systems checkout, telemetry was routed to the automatic test facility, which had been used extensively for developmental testing of rf systems and components used later relocated to LESOC prior to launch. This automated test facility also utilized a Hewlett-Packard computer but was programmed mainly in BASIC and operable with only one program at a time. Many of the tests used to characterize systems before satellite integration were modified for use after launch using this automatic test system.

After about a week, the intense observation of the two satellites was lessened. At this point, it became feasible to support observation needs with only two of the three computers. Computer C was taken off-line and used for further software development, review of recorded telemetry and diagnostic checkout.

Telemetry during launch not available at the Cape but recorded on mag-tape at field sites was subsequently processed at Lincoln Laboratory.

CONCLUSION

Following the launch of LES-8/9, the telemetry ground system supported a succession of satellite performance and evaluation tests. It has since served as an ongoing operations facility. The original HP2116B computer has now been retired and replaced. The floppy disc drives have been eliminated and replaced by a centralized hard-disc system and computer. Software has been modified and refined accordingly.

The ground system has served a succession of varying functions during LES-8/9 development and following launch. That it has not only withstood repeated expansion reorganization, and relocation but undergone these changes with relative ease attests to the versatility imparted to this system by standardization, distributed organization, and flexible interconnection capability.

Contributory to the success of the ground system was its development in close conjunction with that of the satellite system. To a very large extent, the ground and satellite terminals were developed as a single system with design tradeoffs readily made between both to the ultimate benefit of the overall LES-8/9 program.

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