SMALL INTERCONTINENTAL BALLISTIC MISSILE

TELEMETRY PROCESSING SYSTEM

Mr. Milt Woodham
Martin Marietta Corporation
and
Mr. A.L. Kelley
Fairchild Weston Data Systems

ABSTRACT

Development of the Small Intercontinental Ballistic Missile (SICBM) requires a versatile Telemetry Processing System to support the various tests throughout the development. These test requirements created a need for high-speed data processing and display for real time decisions. These requirements were driven by the need to reduce development time and cost of the small ICBM.

Martin Marietta was also interested in an off-the-shelf system (hardware and software). The system had to be menu-driven and user-friendly. Martin Marietta entered into a contract with Fairchild Weston Systems Inc. to supply five (5) of these systems, known as Telemetry Processing Systems (TPS).

This paper defines the TPS System hardware and software capabilities and how it is being used to support the small ICBM testing.

INTRODUCTION

The TPS System hardware and software design were dictated by the test requirements of the SICBM. The TPS System supports Wafer Testing Post Boost Vehicle Testing and Support Testing at Vandenberg Air Force Base (VAFB).

Martin Marietta is responsible for assembly and test of the SICBM. The TPS is used in conjunction with other items of support equipment during the following phases of missile build-up and test:

1. IRSS (Instrumentation and Range Safety System) Wafer Production (Denver)

2. Stage IV Production and Acceptance Test (Denver)

3. Stages I, II, III, and IV Checkout (VAFB)

4. Integrated Missile Checkout (VAFB)

5. Pre-launch Operations (VAFB)

The SICBM is a 4-stage missile. Stage IV is manufactured by Martin Marietta while Stages I, II and III are manufactured by other contractors. An IRSS wafer is installed in Stage IV. The wafer contains an instrumentation system CU (Central Unit) which collects vehicle measurement data and provides these data to the TPS via umbilical and RF data links for decommutation, processing, analysis, display, and recording. Stage IV is manufactured by Martin Marietta while Stages I, II and III are manufactured by other contractors.

This paper discusses the TPS configuration and how the TPS is used to support SICBM testing during each of the phases listed above. Figure 1 depicts the missile instrumentation system configuration and the connections to the ground equipment.

The system operates in three modes: Pre-Mission, Real Time, and Post-Mission. It has the capability to acquire, demodulate, synchronize, decommutate, display and record data from one FM multiplex, one PCM data stream, and a group of discretes. The TPS System was designed utilizing standard products manufactured by Fairchild Weston and Digital Equipment Corporation, and has proven to be very reliable.

In the pre-mission mode, calibration tapes for the PCM and FM are generated. PCM calibration tapes are generated by the operator at a CRT terminal. Calibration Values stored in the parameter data base (previously obtained from data entry or automatically using the calibrator) are written to a digital mag tape. A calibration table is also written to the digital mag tape.

In real time the system records analog, PCM and time signals which are supplied via hard line in real time. The TPS synchronizes on the incoming PCM signal, limit checks 150 channels, outputs 16 channels to strip charts, and displays 32 parameters on the CRT’s. An additional display that automatically monitors the 150 parameters that are limit-checked, and notifies the user of any limit violations.

In the post processing mode, the system plays back the analog tapes, synchronizes on the PCM data, recombines data bytes into data words, and formats onto digital tape. It also processes the missile PCM data and formats to digital tape. The FM data is digitized, blocked and stored on digital tape, too.

GENERAL SYSTEM DISCUSSION

The TPS system consists of six major subsystems as shown in the high-level system overview, Figure 2. These subsystems are:

- Time and Analog Tape Recording Subsystem
- Calibration and Simulation Subsystem
- Telemetry Front-End
- Pre-processing Subsystem
- Host Computer
- Data Outputs, including strip charts, color displays and alarm print-outs

Inputs

The system has the capability of handling one PCM data stream, one FM multiplex (14 channels) and IRIG time. The inputs are brought into a patch panel for proper distribution for the test being run. Raw NRZ-S, NRZ-L, Bi-Phase and quadrature clock outputs of the bit sync, PCM simulator outputs, time code generator output, and the FM calibrator output are also routed to the patch panel for distribution to the system.

The two Analog Tape Recorders record all PCM, FM and time data supplied to the system. They operate in the ping-pong mode to prevent loss of any data. This operation starts the second tape recording prior to the first tape reaching the end, thus preventing any loss of data.

Real Time Operation

The FM multiplexer is patched to the tape recorder for recording and also to the FM discriminators for FM demodulation. After demodulation, an output patch panel is provided which allows flexibility of recording the FM discriminator outputs on the 16 channel strip chart recorder.

IRIG time is patched to the tape recorder for recording and also to the time code translator. The translator demodulates IRIG time and multiplexes it with PCM and digitized FM data in the Telemetry Preprocessor.

PCM data is patched to the tape recorder for recording and also to the bit synchronizer. The bit synchronizer accepts PCM data in real time, filters the noise, synchronizes on the incoming signal, and outputs a reconstructed PCM NRZ-L signal along with clocks to the frame/subframe synchronizer. The bit synchronizer also outputs a reconstructed signal to the patch panel for tape recording if desired. The frame/subframe synchronizer synchronizes on the frame and subframe sync patterns, does a serial-to-parallel conversion, and outputs the data (bit parallel, word serial) along with appropriate timing signals to the Telemetry Preprocessor. The Telemetry Preprocessor has a merger-tagger, high-speed arithmetic processor, 16 DACs and an output card. The merger-tagger merges PCM data with time and assigns a unique tag with each word. The high-speed arithmetic processor performs several functions on the data. First, it limit checks the 150 channels that have been selected by the operator and flags the parameters that are out-of-limits. The Telemetry Preprocessor distributes the operator selected 16 channels to Digital-to-Analog Converters. The analog outputs of the DACs to the strip chart patch panel for patching to the strip chart. The high-speed Arithmetic Processor outputs major time, minor time and tagged data to the parallel data output card. If a channel has exceeded limits, it will be identified. The TPS Processor displays the data on a 600 LPM printer for display alarm logging.

Post Processing Mode

In the post-processing mode, there are three basic processes performed. The Guidance and Control data is re-assembled and formatted onto digital tape; the missile data is processed and formatted onto digital tape, and the FM data is digitized and formatted onto digital tape. The speed at which these processes are performed is controlled by the rate at which the data is formatted to digital tape. The digital tapes operate between 210 and 220 Kilobytes/second continuously. Therefore, our thru-put rate is limited to 210 kilobytes/ second (this includes data, tag and time).

On the first pass of the analog tape, the system synchronizes on PCM the same as in real time. The Guidance and Control data is separated out in the Frame Synchronizer (by the AFS if it is an imbedded format), and output over a separate port, reassembled by the high-speed arithmetic processor in the Telemetry Preprocessor, ID tagged, and input to the processor for formatting onto digital tape. Since the data rate of the combined PCM and G & C data are greater than 210KB, the analog tape must be slowed down, data compressed, or two passes of the analog tape made.

On the second pass from the Analog Tape, FM data is demodulated in the FM discriminators, multiplexed and digitized in the Multiplexer/Encoder. The digital output of the encoder is input to the Telemetry Preprocessor where the data is tagged and formatted on digital tape by the processor. The 14-channels of FM data are sampled at 10 kilosamples per second per channel for a total sample rate of 140 kilosamples per second of 12 bit data. This is equivalent to 280 Kbytes/second. Therefore, the analog tape playback is slowed by a rate of 4:1 during FM data playback.

Time Merging and Tagging

The Time Code Translator accepts serial IRIG-A time in, demodulates the input and outputs time in parallel, 38 binary bits. Major time is input on port 4 of the preprocessor every millisecond, and merged with data as a unique time tag.

Discrete Inputs

Up to 48 discrete status signals are input into the PCM data stream and merged during the frame sync pattern time. These words are input to the preprocessor as status words in the PCM format.

OPERATION

The TPS System is a turn-key system, ready to support testing. The system is under control of the system operator from the terminal with the exception of the FM discriminators, the two patch panels, and the strip chart recorder.

The system is checked out and ready prior to the start of a selected missile test/evaluation. The PCM telemetry front end is checked out by programming the PCM simulator to simulate the incoming format for verification of PCM system operation. The FM is checked out by using the FM calibrator. The analog tape recorders are controlled by the Tape Search Unit and a time segment on either tape recorder is searched for and played back through the system from the operator’s console. IRIG “B” time can also be generated by the time code generator and output on the tape recorders, when needed.

MISSILE SUPPORT TESTING

IRSS Wafer Production

The IRSS Wafer contains a CU. In the full missile configuration it collects Stage IV transducer data and collects Stage I, II, and III data from Remote Units (RUs) in those stages via instruction/reply busses. For checkout during IRSS Wafer production, the Stage IV transducers and Stages I, II, and III are not present.

CU channelization, channel gain, and cross-talk tests utilize the TPS in conjunction with another item of support equipment called the Transducer Output Simulator (TOS). The

TOS simulates Stage IV transducer outputs to the CU, and can select either 10%, 50% or 90% FS output for any channel. The TPS Alarm Logging function is used for this test, and monitors all Stage IV channels. The TOS initially sets all channels to 90% FS, which the TPS Alarm logger is programmed to accept as the “in limits” value. The TOS steps each channel from 90% to 10%, then back to 90% while the TPS Alarm Logger reports channel breaks, times for breaks/recoveries, and data values. After the TOS has stepped through all channels, the TPS Alarm Logger printout is analyzed. If the reported channel sequence is the same as the TOS program sequence, the CU channelization is correct. If the 10% and 90% data values are correct, then the channel gains are correct. If only one channel at a time breaks limits and recovers, then there is no unacceptable cross-talk between channels.

The TPS Alarm Logger function is implemented in this rather unique manner:

> When a parameter breaks the programmed alarm limits, the parameter value displayed on the CRTs is highlighted by reverse video. A message to the line printer identifies the alarmed parameter, parameter value, which alarm limit (high or low) was broken, and the time of the alarm.
>
> If the parameter stays in alarm condition, the CRT display remains highlighted, but only one message is output to the line printer.
>
> If/when the parameter returns to “in limits” condition, the reverse video highlight is extinguished and one message is output to the line printer which identifies the parameter, parameter value, time, and that the parameter is returning to “in limits”. Again, only one message is output to the printer.
>
> The TPS Alarm Logger system can accommodate up to 150 parameters and can resolve alarm times to approximately one second resolution. Exact event times are extracted from the processed (digital) data tapes by post test processing.
>
> This technique for alarm logging avoids a shortcoming of other similar systems which continually report “out of limits” parameters to the line printer as long as the parameter is out of limits. This swamps the printer and generates reams of useless redundant data.

The TPS Alarm Logger function is used in conjunction with another item of support equipment called the Transducer Output Simulator (TOS) to perform CU channelization, channel gain, and crosstalk tests.

Similar channelization, channel gain, and channel cross-talk tests are performed on the RU channels by connecting an RU to each instruction/reply data bus and using the TOS to simulate RU transducer channels.

Stage IV Production and Acceptance Tests

The TPS End-to-End Accuracy Test capability is used to verify the Stage IV instrumentation System accuracy after the IRSS wafer is assembled into Stage IV. The Transducer Test Set (TTS) induces three known offsets into each data channel and the TPS collects 16 data samples per channel at each offset point. The TPS then performs linear regression calculations on the collected data and outputs a summary report which lists the following information for each measurement channel:

- The collected data samples (readings)
- The corrected coefficients, up to 5th order polynomial
- Worst case FS error between expected and actual values
- Standard distribution
- “R” Statistic

The TPS data playback and analysis capability is used to provide a 10 second plot of each measurement channel at ambient conditions. These plots characterize the noise signatures of all channels for future data correlation.

Stages I, II, III, and IV Checkout (VAFB)

The TPS and TTS repeat the End-to-End Accuracy Tests which were performed on Stage IV in Denver to confirm the channel accuracy, and also to define the ambient conditions.

After RUs are installed on Stages I, II, and III, the stages are connected to the TPS and TTS to perform the End-to-End Accuracy Test in a similar manner to what was done for Stage IV. However, for Stages I, II and III tests the RUs interface to a ground CU located in the TTS which then provides the PCM data to the TPS for processing. The TPS does the same type of linear regression calculations and issues the same type of summary report as was done by the Stage TV channels.

The TPS has the capability to execute operator programmable FORTRAN algorithms (called Derived parameters). This capability is used to process one measurement per stage (I, II, III) which cannot be processed by the standard algorithms. The algorithm essentially extracts 2 samples of a parameter value from the PCM stream, separated by a known time, and does a rate of change calculation. This data is then presented to the operator via CRT and to the digital tape for storage.

Integrated Missile Checkout (VAFB)

For integrated missile checkout the TPS is programmed to limit check and alarm log critical parameters. Alarm conditions are highlighted by reverse video on the CRTs and are output to the line printer in near real time. Discrete parameters are alarm logged on both ON and OFF transitions. All compressed data except the FM vibration measurements data are recorded on digital tape.

The End-to-End Accuracy Test is repeated on each stage to confirm that channel responses have not changed.

After missile insertion into the cannister the TPS continues to monitor critical missile and ground equipment functions as a health check.

Prelaunch Operations

The TPS continues to monitor the cannisterized missile at the launch pad. Critical missile and ground equipment measurements are limit checked, alarm logged, and displayed in real time on the TPS CRTs.

Post Test Data Reduction

The TPS provides the capability to play back in either raw analog form or processed digital form and to output various types of data plots and printouts. This capability is widely used at both Denver and VAFB to support troubleshooting and anomaly reviews/resolution.

Software

The TPS Workstation combines Fairchild Weston’s standard Parameter Database, Data Acquisition, Data Display and Analysis software with Digital Equipment Corporation’s VMS to provide a standalone Telemetry Workstation capable of acquiring and displaying telemetry data to one or more users in both real-time and post real-time environments.

The TPS offers, in one packaged system, all hardware and software required to setup and control the telemetry front end acquire data during real-time and display that data to four totally independent users, and optionally, acquire data to 9 track magnetic tape and make that data available post mission for evaluation and analysis. Data may be displayed in both tabular and graphic formats.

The TPS has been designed to allow the user to specify the configuration of the telemetry front end equipment. Once specified, the workstation software will automatically support setup and control programmable front end units.

The software has four primary areas of support (see Figure 3).

1. Setup and control of the telemetry front end equipment (TFE)

2. Real time data acquisition

3. Real time quick look displays

4. Playback displays

Setup information is defined to the workstation through a series of menus which may be subdivided into unit-oriented menus and parameter-oriented menus. The unit-oriented menus define generic information required to setup each individual unit. The parameter-oriented menus define information that may vary on a parameter-by-parameter basis (i.e., word length).

An important feature offered by the Telemetry Workstation is the ability to retain multiple setup definitions on-line. Thus, in an application where one workstation may be shared between several projects or where one project must support multiple mission formats, all formats may be retained on-line in the TPS.

Real Time Data Acquisition

The Telemetry Workstation acquires data from the preprocessor via one input port to support the realtime display functions, and optionally acquires data via a second input port to support the recording of data to tape. In either case data is acquired by the Telemetry Workstation directly into MicroVAX memory.

Real Time Data Processing and Quick Look

Once present in MicroVAX memory, data intended to support real-time displays is processed and written into a current value table where it may be accessed asynchronously by the display software. The processing performed on data includes input number conversion to reformat the data into the 2's complement notation used internally in the Telemetry Workstation, and engineering unit conversion to permit the display of acquired data in terms of the physical parameter actually being measured. The user always has the option of not performing any calculations on data for any parameter or set of parameters and displaying the raw data sample if he so desires. Data processing is done on a parameter-by-parameter basis, thus permitting different number conversion and engineering unit conversion techniques to be used for each parameter.

Limit-checking is performed on each selected data sample. If requested, each sample is compared against an upper and/or lower limit specified by the operator in engineering units. Limit violations are flagged to the operator by highlighting the offending data field(s) in a contrasting color on any displays being viewed.

The processing performed on data used to support real-time displays occurs at a maximum rate of ten updates per second, or as fast as the available processing power permits. The Telemetry Workstation operator has control of how many of the acquired parameters are to be processed, and thus can always insure that the ten per second rate will be met by limiting the number of processed parameters to only those which are intended to be actually displayed.

Real Time Displays

The Telemetry Workstation provides each user with a selection of four different displays that may be viewed during a data collection run. The four displays are:

- Four Parameter Scrolling Alphanumeric Display
- Sixteen Parameter Barchart Display
- Thirty-Two Parameter Alphanumeric Display
- Four Parameter Graphic Display

Post Real-Time Data Processing

Data acquired by the Telemetry Workstation for the purpose of recording to 9-track digital magnetic tape is input through a second channel in parallel with data being acquired to support real-time displays. Typically, the same data has been acquired through both input channels. The acquired data is not processed in any fashion prior to recording to tape. Each physical record written to tape is approximately 8K 16-bit words long and includes a 12 word header followed by n frames of data, where n is chosen to fit within the 8K word record size. The data tape written by the Telemetry Workstation is fully compatible with the DEC VMS file system, permitting the use of standard VMS utilities such as COPY, BACKUP, and DUMP to inspect or copy the contents of the tape.

Once data has been acquired to digital tape it may subsequently be played back and displayed through the post real-time displays. These displays operate on segments of data that have been restored from the digital tape to the 71 MB data disk via a utility provided as part of the Telemetry Workstation package. Multiple segments of data from the same or different tapes may be resident on the disk at one time, limited only by the amount of disk space available. Multiple users may therefore simultaneously display data from a single data segment, multiple data segments from the same data run, or multiple data segments from multiple data runs.

Number conversion processing, engineering unit processing, limit checking, and derived parameter processing analogous to that performed in real-time are performed on data displayed in the post-real-time environment. The only difference in the post real-time environment is that the user(s) may inspect every data sample, whereas in the real-time environment, the user(s) probably will not see every data sample for each selected parameter due to the fact that the data will typically be acquired at a higher rate than may realistically be displayed.

Most of the post-real-time displays offer the operator a capability to search the data segment being processed for up to four distinct events. These events are defined as a particular parameter exceeding a defined value, equaling a defined value, or passing below a defined value, or the delta between two consecutive samples of the parameter exceeding a defined value, equaling a defined value, or passing below a defined value. If any of the conditions specified by the operator are found in the data segment, the time of first occurrence is displayed. The operator uses this time to select a window of data around the event to inspect in more detail.

Each real-time display program asynchronously accesses data samples from a Current Value Table (CVT) which is written by the data acquisition software. Data is read from the CVT on a periodic basis at a rate specified by the user.

Each real-time display has two menus or pages associated with it. The first is a setup page into which the user may enter a title, the list of parameters to be displayed, and other information required by each individual display program. Once all of this data has been entered it may be saved to a disk file, such that on subsequent entries to the display program a previously defined setup may be recalled. Any number of display setups may be saved for each display. The second page associated with each display is the actual display.

Post Real-Time Displays

The Telemetry Workstation provides the user with three displays which may be used in the post real-time environment to inspect data previously recorded to tape or disk. The three displays are:

- Four Parameter Scrolling Alphanumeric Display
- Thirty-Two Parameter Alphanumeric Display
- Four Parameter Graphic Display

SUMMARY

These Telemetry Processing Systems for the Small ICBM Program provide a turn-key solution to the problems of setup, data acquisition, real-time data display, and post-test data analysis at the production facility in Denver as well as at the Vandenberg launch site. Each system is easy to operate, and provides a variety of displays. Growth potential is built into the systems to allow for higher data rates, more complex formats, or different display requirements.

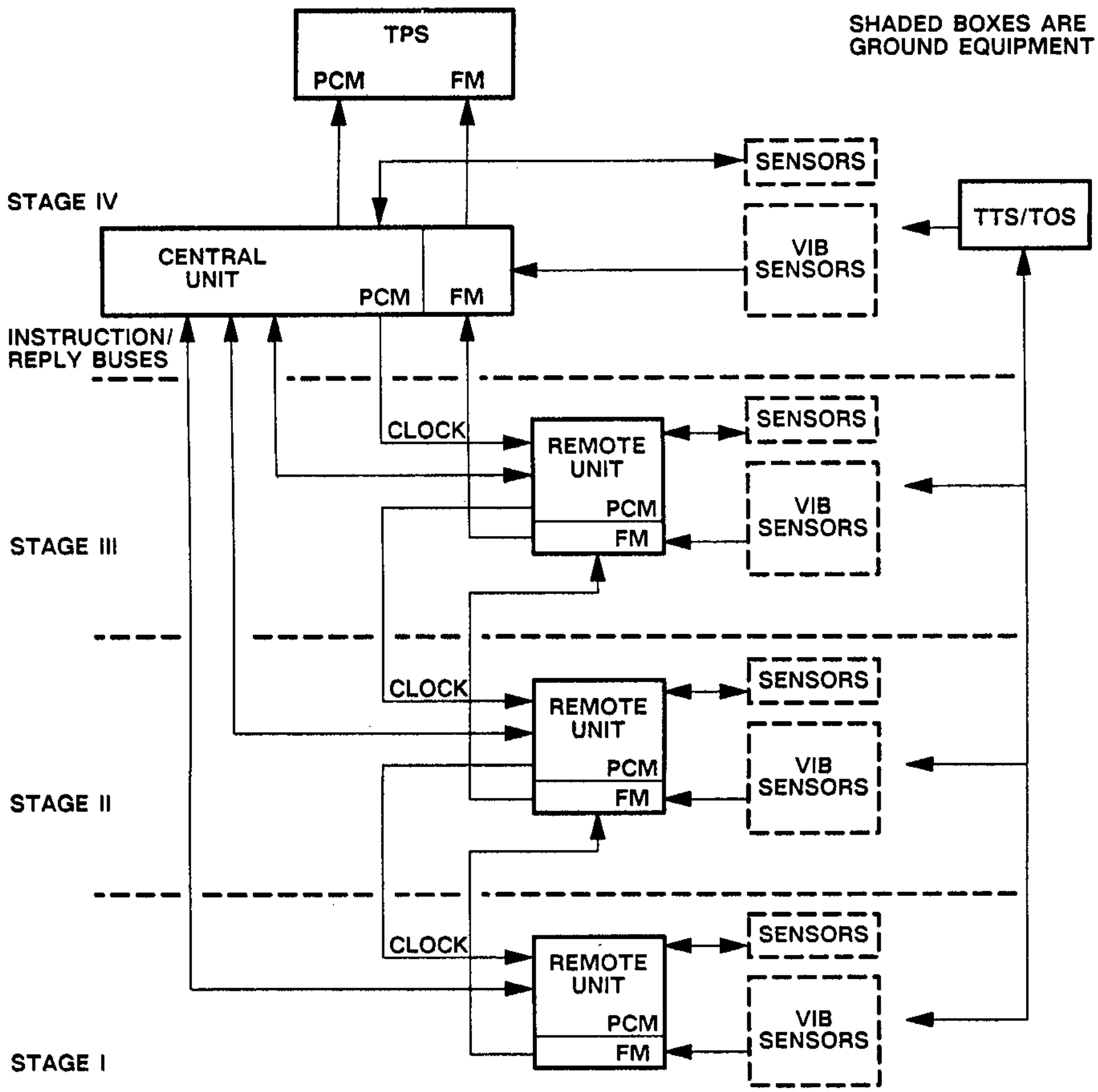

Figure 1. Missile Instrumentation System Configuration and Ground Equipment Connections

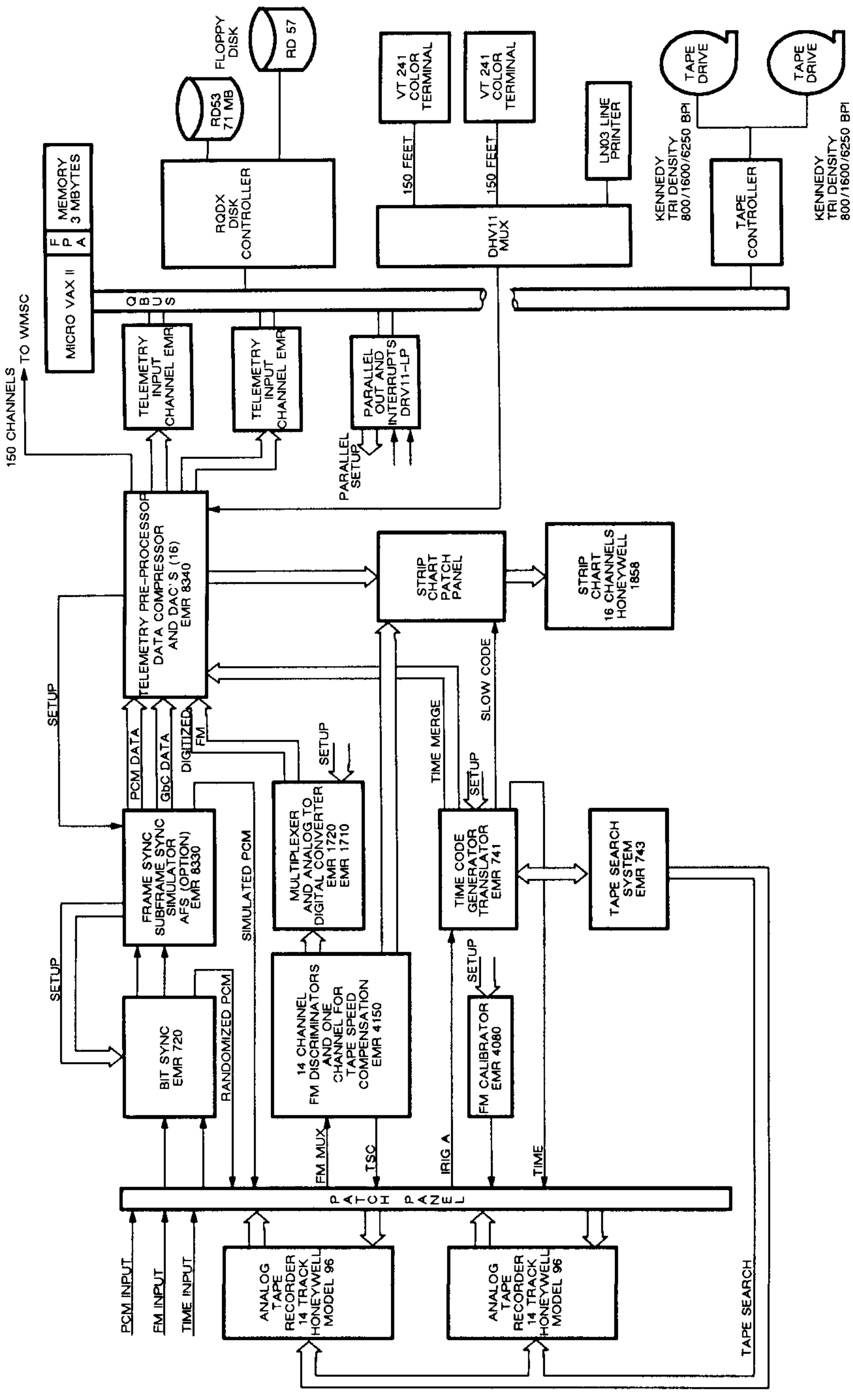

Figure 2. System Overview

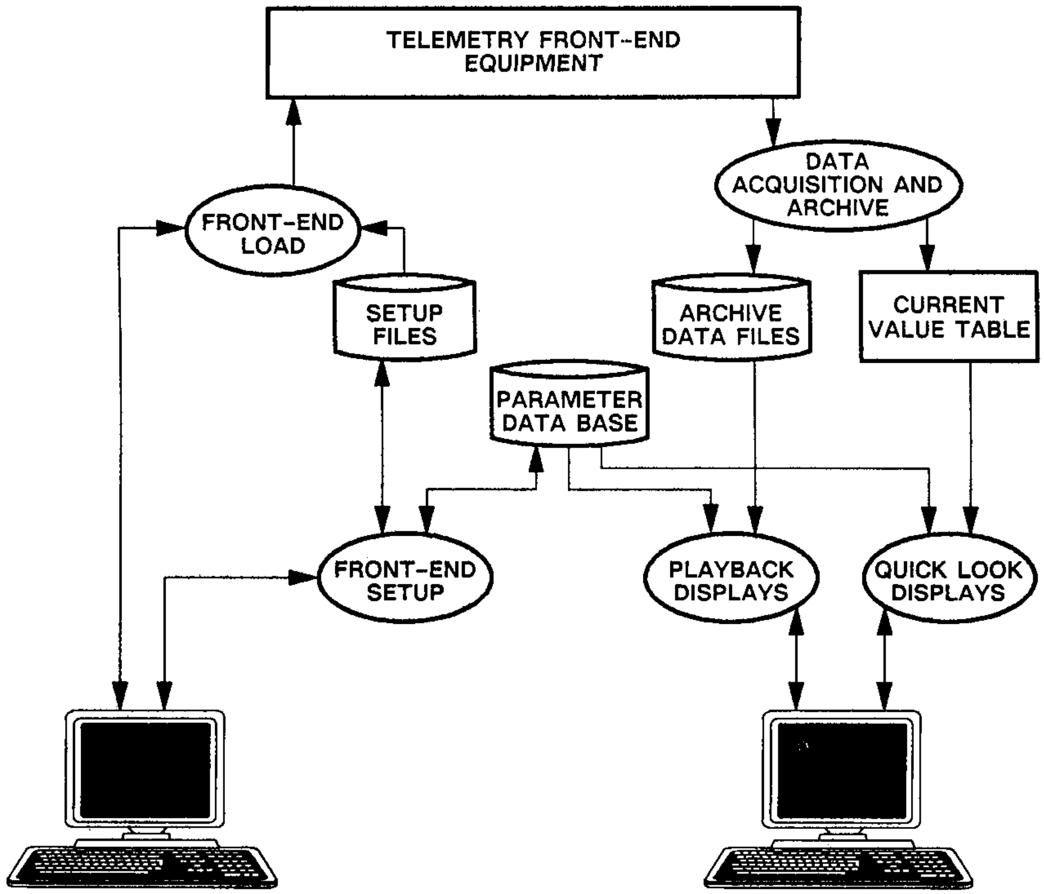

Figure 3. Telemetry Software Overview