A Flexible Telemetry Processor for Spacecraft Testing

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ABSTRACT

In the past, telemetry data systems in support of JPL flight projects -- such as Voyager and Galileo -- were designed specifically for each mission. Third-generation computers and minicomputers were combined into a distributed system, and many man-hours of software development were invested to meet each project's unique processing requirements. These systems were used to support the Spacecraft testing on the ground and -- later -- for mission operations after launch.

The Magellan System Test Data Processing Subsystem (STDPS) marks a departure from these past designs. For the first time, a re-usable telemetry-processing subsystem has been designed that is flexible enough to meet the spacecraft-testing requirements of the present project -- and can be easily changed for future projects as well. These changes are all accomplished through a user-friendly, menu-oriented interface. Extensive software re-programming is no longer required. The Magellan spacecraft is being constructed for JPL by Martin Marietta Astronautics Group, Denver, Colorado. The STDPS is currently in Denver, supporting the spacecraft testing.

Keywords: Telemetry processing, Magellan Project

INTRODUCTION

This paper describes the hardware design and application of a commercially available telemetry processor in the testing of the Magellan spacecraft. The requirements, established in 1985, dictated a compact, transportable subsystem for processing the spacecraft telemetry data. A survey of available hardware was conducted and a procurement initiated. With the choice of a vendor, the final design was completed.

Because of the requirement for simple remote workstations, certain assemblies were designed and fabricated by JPL.

At Martin Marietta Astronautics Group, the STDPS was put to work in developing the parameter database. Several man-months were expended in developing this database. Towards the end of the development, an IBM-PC with a Bernoulli disk was enlisted to contain all six of the parameter databases. Upon completion of this database, the STDPS was ready to support the spacecraft testing program.

TELEMETRY PROCESSORS

The STDPS utilizes a commercially available telemetry processor manufactured by Loral Instrumentation, of San Diego, California. The Loral ADS-100 (telemetry processor) is a distributed microprocessor-based instrument containing over 220K bytes of firmware. The telemetry processor provides bit synchronization, frame/subframe synchronization, dccommutation and display of the incoming telemetry stream. A technique known as data-flow processing is used to decommutate the data. In addition to decommutating the prime telemetry stream, the STDPS is capable of handling Embedded Asynchronous Data Streams. Algorithms for processing this form of data are “built-in” to the firmware. The resulting parameter values are then distributed to remote workstation displays and printers for analysis by the subsystem engineers.

In addition to its real-time capabilities, the STDPS is capable of recording on 9 track magnetic tape the decommutated data for subsequent play-back and analysis. In the case of Magellan, both the low rate engineering data and high rate radar science data are recorded.

The man-machine interface of the telemetry processor is a fourth generation product which has been optimized a great deal. A combination of system commands, display menu pages and audio/visual feedback allows the operator to customize the machine’s functions to the spacecraft telemetry data format. Once this format has been specified to the machine, it may be saved on one of the integral floppy disk drives or the 9 track magnetic tape. Thus many different inputs may be handled merely by re-loading it with the proper setup information.

Another feature which is useful for the novice user is it’s self-prompting commands. All system commands and acceptable menu parameters are available by “wheeling” through them using the NEXT key.

The front panel also contains up to 14 programmable function keys. Each function key can be programmed to retain up to 128 keystrokes. This sequence of keystrokes can be executed by depressing the function key or processing the EXECUTE command.

Telemetry data is displayed on the integral CRT or remotely on 15" monochrome monitors. Three types of displays are provided to view the prime, processed or derived parameters. These displays are Data Page, Bar Chart and Graph Page. Up to ten pages of each type may be pre-defined for display. Any parameter may be immediately displayed by selecting it by name.

Operator entered conversion equations are used to convert the parameter values into the desired units. These equations are defined on the Parameter Page when the machine is programmed for the proper setup. The resulting values may be displayed in scientific, floating point, integer, binary, hex, octal or symbolic notation.

MAGELLAN STDPS HARDWARE DESIGN

Figure 1 shows a block diagram of the Magellan STDPS configuration. There are six telemetry processors and one expansion chassis. These units are used to monitor the spacecraft subsystems. The low and high rate data inputs are applied to the TC/LPM and expansion machines through an Input Interface Assembly which provides signal-level conversion. The prime telemetry stream is decommutated in these two machines, tagged, and sent to the remaining processors over a daisy-chained bus called the Muxbus. There, additional processing may be performed as desired.

At the same time, the data may be recorded on 9 track magnetic tape drives attached to the expansion chassis. These tapes can later be re-played into the STDPS for further analysis or different algorithm processing. A 300 lpm printer is provided on the TC/LPM machine for spooling of selected parameters. Finally, the data is time tagged from a NASA 36-bit time code input.

Six remote (up to 500 feet) workstations are attached to the main STDPS racks. This distance requirement was a constraint imposed on the design as the original operational plans called for the support equipment to be located in trailers outside the spacecraft test chamber. Each workstation consists of a 15" Monochrome Video Monitor, a keyboard and a 300 lpm line printer. A JPL designed and fabricated “Remote Interface Assembly (RIA) and Remote Driver/Receiver Assemblies” provide the video and data conversion circuitry to drive the long cable lengths. The RIA contains a Z80 microprocessor and Dual Asynchronous Receiver Transmitters (DART) for conversion of the parallel printer data to serial data. Commercial video amplifiers are used to drive the video differentially over the long distance. These remote workstations are used by the spacecraft subsystem engineers for monitoring, analysis, and manipulation of the telemetry data.

APPLICATION OF STDPS TOWARDS MAGELLAN SYSTEM VERIFICATION

THE MAGELLAN TELEMETRY STREAMS

The Magellan (MGN) Spacecraft (S/C) transmits two separate telemetry streams to ground based systems. The low rate stream is downlinkcd at a data rate of either 1200 or 40 bps and the high rate stream is downlinked at either 268.8 or 115.2 kbps. The low rate stream contains the Spacecraft Engineering Data (SED), which consists of all data corresponding to the health and status of the S/C. Once the spacecraft is inserted into orbit around Venus, the non-emergency modes of operation utilize MGN's single High Gain Antenna (HGA) for both mapping (using Synthetic Aperture Radar) and the subsequent playback of data. The HGA must be pointed at Venus for mapping operations and at Earth for data playback.

All data comprising the high rate stream is recorded on the S/C on-board Data Memory Subsystem (DMS) in one of two different formats: the Radar Composite Data (RCD- contains all the scientific data gathered by the S/C in the mapping of Venus with interleaved SED) or Recorded Engineering Data (RED - commutated in the same format as the SED, but with additional filler), before it is downlinked to Earth.

The STDPS is being used for display of all data within the SED during system integration, and testing on the S/C. The STDPS is co-located with the S/C at Martin Marietta Astronautics Group (MMAG) in Denver and will eventually be moved to the Kennedy Space Center (KSC) in support of launch activities up to and including the acquisition by the Deep Space Network (DSN - approximately 48 hours after launch). During the test phase in Denver, the display of the data within the SED is the primary objective of the STDPS. The SED is available through hardline or RF links and is available at any time the S/C is powered up. The two high rate streams, RCD and RED, are not fully dccommutated for real-time analysis, but are stored to one set of the 9 track tape drives.

The data path for the MGN telemetry streams during subsystem integration and testing (reference Figure 1) is from the S/C Command and Data Subsystem (CDS) to the associated ground support equipment via direct access or RF link. The low rate telemetry is then routed through a modified Panasonic AG-1900 Video Cassette Recorder (VCR) where the data and corresponding bit synchronization clock is encoded onto the stereo hi-fidclity audio channels using frequency shift keying (FSK). The VCR concurrently records voice, video and GMT during all test activities yielding a compact compilation of all output data. The high rate data by-passes the VCR and is routed directly to the STDPS.

DECOMMUTATION STRATEGY

The decommutation of both telemetry streams is accomplished within the master TC/LPM telemetry processor and it's expansion chassis. The low rate data stream is dccommutated within the master unit and the high rate telemetry is decommutatcd within the expansion chassis. Menu driven display pages, resident in the system's firmware, are used to select data formats, data rates, frame sizes and synchronization techniques.

The SED is commutatcd into 91 minor frames per major frame with parameter sample frequencies of 1, 7, 13, or 91 times per major frame (60.67 sees). In addition, there are 15 bytes per minor frame of embedded asynchronous data with a modulo count of 24. The algorithms used for processing this data reside within the telemetry processor compressors. Using a similar algorithm, the interleaved SED within the RCD can be recovered.

DATA PROCESSING

The expansion chassis for the TC/LPM telemetry processor contains three compressors to process incoming data into the displayable measurements. It is necessary for all measurements within the telemetry stream to be displayable at all workstations in their measurement dependent formats. The MGN telemetry commutation map contains measurements of 8, 16, 24 and 32 bits. The standard decommutation set requires all parameters decommutated at a fixed bit distance from the frame sync code have identical bit lengths. Therefore, two of three expansion chassis compressors are dedicated to splitting pulse code modulated (PCM) prime parameters of 16 bits into two separate 8 bit measurements or combining two 8 bit PCM prime parameters into 16 bit measurements. The third compressor is dedicated to the processing of the embedded asynchronous data.

After the SED is decommutated, it is passed to the other subsystem workstations utilizing the system Muxbus in a Tag and Data format (16 bits each). All data in the MGN telemetry streams are passed along the bus and are available at each of the different subsystem workstations (RFS, EPS, AACS, RS and CDS) for display of Engineering Unit (EU) conversion, status and software configuration measurements. Additional processing on a particular measurement is accomplished within the "downstream" units by reading the tag associated with the required measurement and then processing this data further using the data compressor installed within each of the downstream units.

All telemetry which has been defined as critical to the operation of the S/C is limit-checked as it is initially decommutatcd or after processing within one of the compressors. Out-of-tolerance measurements are spooled to both the system printer and the printer of the subsystem whose measurement is in an alarm state. Alarms are prioritized from 1 to

255 with the highest priority alarm being displayed on the upper-most line on the display. All alarms can be quickly viewed on the special alarm display page.

Located within the expansion chassis are two Digital Tape Interface (DTI) cards for interfacing to four Kennedy 9300 tape drives. The only parameters that are recorded on the set of tape drives are those decommutated from one of the telemetry streams or those input to the system for the time tagging of data. The low rate data PCM prime parameters are saved on one set of tape drives in a “Tag and Data” format. The high rate stream’s PCM prime parameters are saved on the other set of tape drives in a “Data Only” format and are processed later on the Hughes Aircraft Company (HAC - the radar subcontractor for Magellan) ground support computer. As the low rate stream’s subframe ID is passed across the system bus, a Parallel Input Module (PIM) allows for the addition of GMT time from the time code translator (TCT) to the system bus thus time tagging the digital tape data with days, hours, minutes and seconds.

By saving the low rate stream prime parameters only, the digital tapes can be played back post-test without duplication of the processed parameters. The DTI does not support the recording of 24 or 32 bit parameters for subsequent playback and therefore all of these measurements were broken down into 8 and 16 bit parameters or two separate 16 bit parameters respectively.

In addition to utilizing the digital tapes for post test data analysis, the low rate telemetry was also recorded on video cassettes. This enables recovery of all voice, time video and telemetered data corresponding to a particular test. Digital tapes are played back through the STDPS, after the addition of “Bit Change” or other algorithms to the standard databases, to aid the recovery of event times. The video tape can then be played back, using the modified VCR at the time in question and the data routed to and processed by the STDPS.

The preferred method of viewing the data output by the subsystem analysts is via the 15" monitors located at the workstations. The telemetry processors have ten data pages with the capacity of 13 measurements per page. Each subsystem group has defined their data pages which are stored in their default database. To display measurements currently not displayed, the subsystem analyst need only select any data page and enter the names of the measurements he wishes to view. The data will be processed and displayed on the next occurrence of that measurement within the telemetry stream.

At anytime an analyst desires, a “Print CRT” command from his workstation keyboard sends the data on the display to the printer for a hardcopy. Other methods used for obtaining a hardcopy of telemetry include the use of the data spoolcr, “Print Data Pages” and printing “Sort Data” - a Loral Instrumentation, firmware implemented, method to take a snapshot of the frame. Generally, the only data which is sent to the spooler (during real-time processing) is that which has passed through some type of data compression algorithm. This yields the GMT and new data value. By limiting data which is allowed to go to the printer in this manner, spooler buffer overruns and the possible deletion of critical telemetry from the printouts can be prevented. "Print Data Pages" are utilized to print data at specified time intervals (generally every 60 seconds). The last method used by the subsystem analysts is the printing of "Sort Data". By setting up the machine with "Sort Parameters", a "snapshot" may be taken of any part or parts of the frame and then dumped to the printer. This enables the analyst to view many more parameters than he is limited to on the standard 10 data pages (as only 55 of these parameters are being updated at any one time).

STDPS DATABASES

The STDPS databases consist mainly of three types of parameters: parameters for display at all workstations, subsystem peculiar parameters and system parameters. The only processing required by the "downstream" telemetry processors is to apply display equations to the data for analog measurements or for display in the proper raw format (hex, octal, binary or integer). Subsystem peculiar parameters are defined to be those which pick up raw data from the system Muxbus and further process the data for subsystem use.

Examples of subsystem parameters are Delta ZFN parameters for trend data analysis, "Bit Change" for time duration recording and "Bit Match" for event time recording. The system parameters are mainly used within the TC/LPM processor and are used in the building of displayable measurements. Although the tags for system parameters and corresponding data are passed down the Muxbus, they generally are not used by the subsystem workstations.

An IBM-PC with a National Instruments GPIB to PC interface card is used to aid in database management. Each one of the telemetry processor's GPIB port is bussed with each of the other processors. This allowed for all six workstation databases to be stored on a single IOMEGA Bernoulli disk. On power up of the system, databases could be loaded and subsequent system initialization was accomplished autonomously through the use of the GPIB interface. Additionally, the databases could be printed out and controlled more usefully than the telemetry processors support. Using other support programs written on the IBM-PC, large database changes could be handled efficiently through the manipulation of files saved in the format consistent with the telemetry processor database files.

LIMITATIONS

As with all things, the STDPS has its limitations. The maximum input data rate is limited to 4 Mbps NRZ-L. The maximum number of parameters (prime, processed and derived) is limited to 4096. Individual recorded time periods cannot be readily accessed without replaying the entire tape from the beginning.

CONCLUSION

The Magellan STDPS has met the requirements established for it. This compact subsystem (4 racks) is easily transported and will be used at the Cape for Magellan launch support. Future projects -- such as Comet Rendezvous/Asteroid Flyby (CRAF) -- will be able to use this same subsystem in their testing program without the expense of new hardware or a new programming effort.

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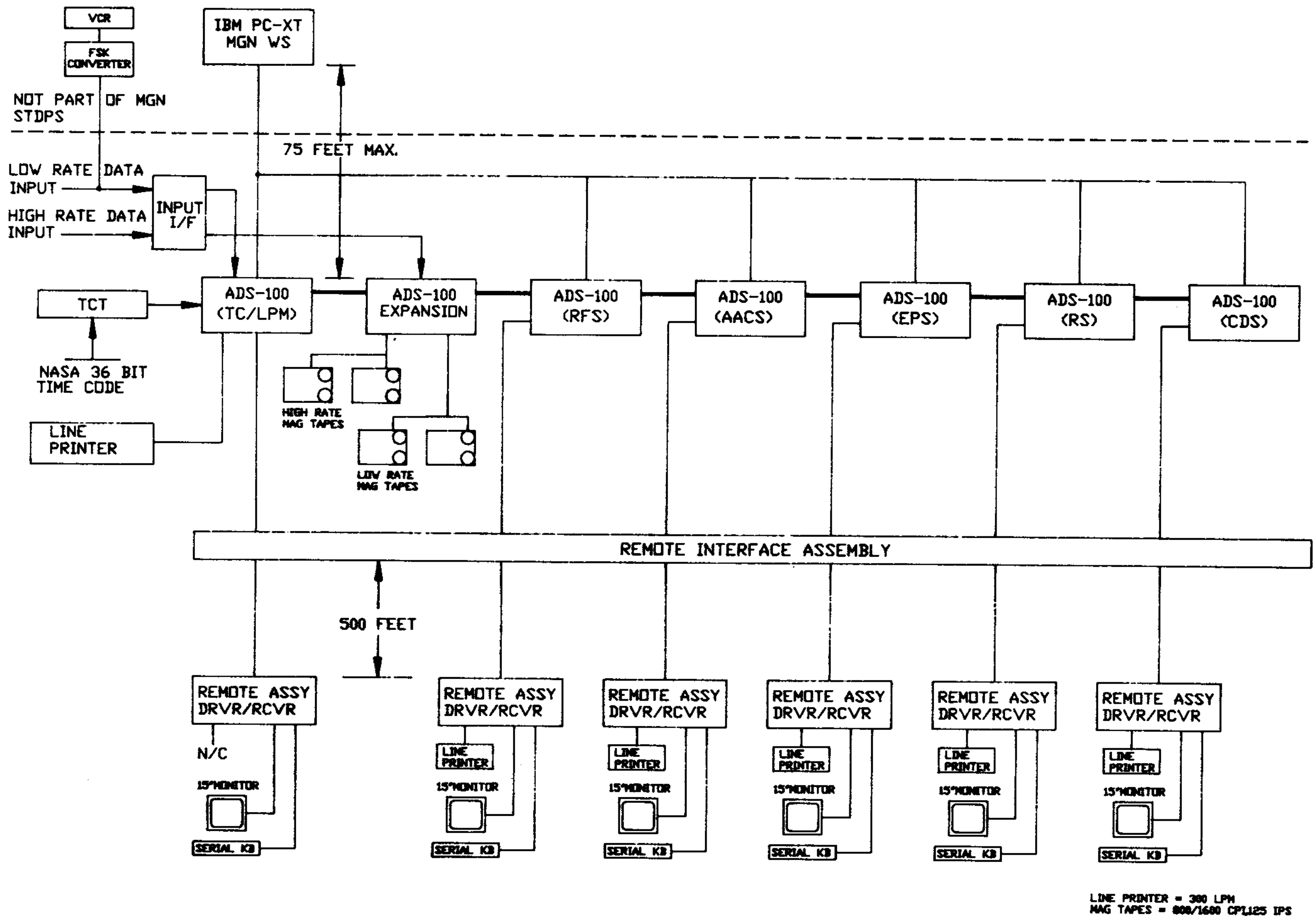

Figure 1- Magellan System Test Data Processing Subsystem Block Diagram