A Low Cost, Open-Architecture-Based System Provides Portable Satellite Telemetry & Control

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ABSTRACT

A comprehensive examination of the market demands for cost reduced satellite telemetry & control stations will be presented. These systems are implemented using flexible, open architecture-based high performance real-time systems. The trend for combining telemetry monitoring of satellite data with closed-loop satellite command and control functions will be presented. This combined functionality opens up the possibilities for completely integrated, reduced cost satellite control systems. The market forces driving the demand for this integrated functionality include the broadening of non-military satellite applications, the widening international deployment of commercial satellites and the accompanying drive toward decentralized satellite control.

The major requirements for the telemetry processing and command & control functionality of the integrated, reduced cost satellite control system will be presented. These requirements include: full real-time performance for processing telemetry data; flexible architecture for the incorporation of a wide range of I/O devices; capability of performing real-time, closed-loop control based on conditions in the telemetry data; user friendly development environments for application-specific customization of the system; and low system costs with the capability of indigenous support. The divergent requirements of performance, flexibility and price of these integrated, reduced cost satellite control systems is made possible via the use of open architecture building blocks that include standard VME boards combined with specialized real-time software drivers and user oriented, flexible Graphical User Interface (GUI) software.

INTRODUCTION

The concept of a, "*Low Cost*" satellite telemetry & control station has historically been a contradiction in terms. Such a system, by the very nature of its components (large autotracking dish antenna, wideband receivers, diversity combiners, microwave power amplifiers, telemetry processing subsystems) will probably remain very expensive for the foreseeable future. However, because of the proliferation of non-military satellite applications in the United States and the widening international deployment of commercial communications satellites, the requirement for *lower cost* telemetry and control equipment for satellite applications continues to grow. Traditional ground station equipment, with its custom components and proprietary architectures are no longer cost effective in today's highly competitive, cost and schedule sensitive international market place.

In today's environment, satellite programs are undergoing ever shortening development and deployment cycles. These facts mandate that the command, control and telemetry ground equipment used to support these missions must be highly flexible, easily reconfigureable, supportable on an international level and above all, be based around a totally open system architecture whose hardware and software components adhere to published international standards. The use of equipment and components that are available from only one vendor, or that are specific and limited in their focused application are becoming unacceptable to the majority of users.

COMBINING TELEMETRY MONITORING WITH COMMANDING

Ground systems that integrate the functions of telemetry processing with command & control are becoming more and more popular because the combination reduces program costs and development time for the end user. An example of a system that combines telemetry processing and monitoring with satellite command, control & ranging capabilities is the AP Labs VMEstation Telemetry System (VTS). Figure 1 presents a block diagram of the system. This system utilizes a real-time telemetry acquisition and analysis front end that is tightly coupled with a SPARC 20 Unix workstation. The workstation acts as the display server for other X-Windows displays on the network. For support of a satellite that employs SGLS (Space Ground Link System) communications, the real-time subsystem consists of a control CPU, an IF receiver and subcarrier demodulator, a telemetry bit synchronizer (with Viterbi decoder), a PCM decommutator and PCM simulator, an IRIG time code generator/reader and a high performance SCSI-2 controller with real-time archival disk. Satellite uplink command and ranging functions are supported by a SGLS modulator, linear phase modulator and range/range rate card set.

The circuit cards in this system are housed in a 20 slot 6U VME chassis and are totally open architecture from a hardware standpoint. The decommutator board for example uses the standard VME and VSB interfaces for the movement of information. Data is decommutated into a double buffered, dual ported memory that is accessible across the VSBbus, rather than a private/proprietary bus. The approach used by this decommutator, where a large buffer of data is acquired before passing it into the system, has several advantages over the conventional tag and data bus architecture historical to telemetry processing. First and foremost, a "true" open architecture is achieved that gives the end user much more flexibility in configuring CPU and I/O capabilities. This means that any board that has a VME/VSB interface, and there are many, may be used to interface with the telemetry data stream. The user of this system is not tied to any one vendor for system components and support. To upgrade capability, the addition of newer, faster CPUs and other interface and processing boards is straightforward. Standard VME boards from a multitude of vendors are available for most required I/O interfaces. By utilizing strictly VMEbus-compliant boards, the flexibility and growth potential for the system is significantly increased with minimal cost impact.

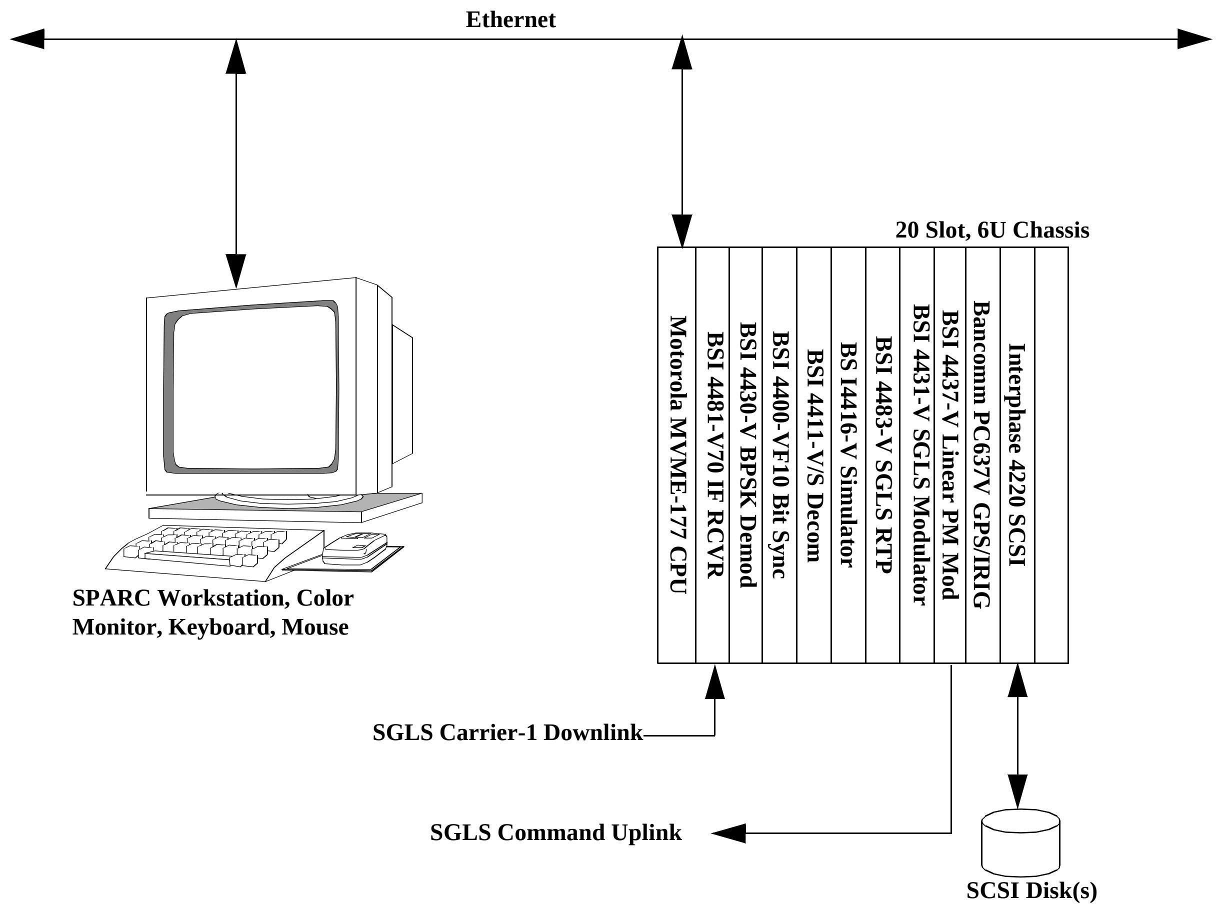


Figure 1 - Satellite Telemetry & Control System

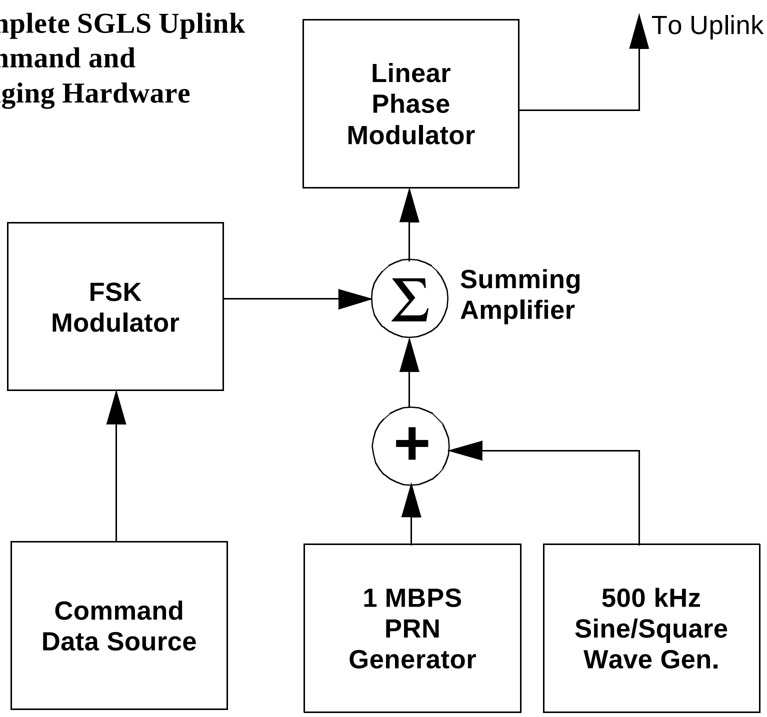
SATELLITE RANGING FUNCTIONS

Historically, with the possible exception of the telemetry processing subsystem, the functional elements that make up a typical satellite ground station (wideband receivers, diversity combiners, ranging equipment, antenna controllers, etc.) have all been box level, rack-and-stack devices with their own respective power supplies, card cages, front panel controls, etc. This trend has begun to change over the last several years however with the advent of VME-based receivers, diversity combiners and satellite ranging board sets that perform the same functions as their larger, bulkier rack-and-stack counterparts. Of specific interest with regards to this paper are the satellite range and range rate board sets being developed to support SGLS and STDN satellite programs.

The Space Ground Link System, or SGLS as it is referred to provides full duplex communications for commanding, tracking, telemetry, and ranging between a spacecraft and ground stations around the world. Command uplink services are provided via an L-Band (1750 to 1850 MHz) microwave link, and telemetry, tracking, and ranging services are provided on an S-Band (2200 to 2300 MHz) downlink. The SGLS downlink system provides two downlink carriers that can be received simultaneously. These two carriers are called Carrier-1 and Carrier-2. The function of Carrier-1 is to provide for antenna autotracking, range, and range-rate tracking, and for low speed PCM or analog telemetry. The Carrier-1 downlink may also contain multiple subcarriers. When command uplink and ranging functions are being performed, one, or two subcarriers at frequencies of 1.024 MHz and 1.7 MHz respectively are often used. The second downlink carrier, (Carrier-2) is always at a fixed frequency offset that is 5 MHz below the frequency of Carrier-1 and is used for PCM bit streams employing Phase Shift Key (PSK) modulation. The example system presented in this paper only uses the Carrier-1 downlink.

In the SGLS system, the commanding and ranging functions are combined in the uplink as shown in the figure below. Commands sent to the satellite are first FSK (Frequency Shift Key) modulated and are then combined with a 1.0 Mbps PRN (Pseudo Random Noise) ranging code, and 500 KHz square wave to form the composite uplink. This composite signal is then linear phase modulated to provide the uplink. The receiver on the satellite detects the ranging code, multiplexes it with vehicle data (telemetry), and re-transmits it on the Carrier-1 downlink. The Carrier-1 signal is received by the groundstation where the ranging and telemetry information are extracted from the carrier. Satellite range is then determined by a Range Processor (RP). The RP determines the slant range of the satellite by processing the range-tone echo recovered from the Carrier-1 signal. The RP accepts this echo, and reference signals and makes the necessary measurements of the slant range. Coarse range is determined by a correlation reception of the 1.0 Mbps PRN sequence. Fine range is determined by measuring the coherent phase angle difference a 500 KHz square wave reference signal, and the same square wave signal recovered from the Carrier-1 echo.

Figure 2
Complete SGLS Uplink Command and Ranging Hardware



INTEGRATING RADIO RECEIVERS WITH TELEMETRY & COMMANDING SYSTEMS

The combination of telemetry processing and monitoring with command & control capabilities within the *same* VME chassis opens up the possibilities for completely integrated, reduced cost satellite control systems. A further step towards this goal is migrating the radio reception of the satellite downlink channels into the VME chassis where the digital baseband processing takes place. This step allows truly portable, small footprint systems capable of receiving and processing telemetry data to be fielded. These systems are principally used in the ground testing of satellites, both during assembly and later during pre-launch testing where the radio range between satellite and test system is limited. This is a factor because the nature and size of high power microwave transmitters used in the command uplink, do not lend themselves well to integration with other components in a small footprint VMEbus package.

The reception of the microwave downlink channel from a satellite (both in orbit or on the ground) has been successfully implemented within the VMEbus environment by several vendors of telemetry equipment. The IF receiver used in this system for example is a single, 6U VME card that provides on-board FM, Linear PM and BPSK demodulation for data rates up to 5 Mbps. The receiver's superheterodyne based design with programmable (tunable) input pre-selector and multiple IF bandwidths can support a wide range of telemetry and satellite applications. All receiver functions are set up from the VME bus and include input frequency, IF bandwidth, filter bandwidths with readbacks of the actual bit rate, synthesizer lock, demodulator lock, and signal and loop stress. To process the subcarrier present in SGLS Carrier-1, a separate subcarrier demodulator is used. Like the IF receiver, the subcarrier demodulator used in this system is a single, 6U VME card that provides on-board BPSK or QPSK demodulation with programmable (tunable) input carrier frequency, bit rate, loop bandwidth and filtering.

Further refinements in receiver design and packaging have resulted in receivers that not only employ traditional analog designs, but DSP implementations as well. These new receivers offer true wide-band reception at data rates up to 40 Mbps, with PM, BPSK and QPSK demodulation implemented via high speed digital signal processing (DSP). In addition to these new receivers, there are a series of companion diversity combiners that have been developed that provide true AM/AGC weighted optimal ratio combining for both post-detection only, and pre-detection/post-detection scenarios. These efforts have resulted in VMEbus-based telemetry receiver/diversity combiner products that are currently being used to control autotracking antennas and receive and process telemetry data from satellites that have been placed into orbit.

SYSTEM REQUIREMENT AND IMPLEMENTATION

The major requirement involving a system that combines telemetry processing with satellite command & control is that the system hardware and software must support in real-time, the generation of commands that are derived in whole or in part from conditions that are revealed in the satellites telemetry data. This implies that the processing of the satellite's telemetry downlink and the transmission of the command uplink is tightly coupled in a closed-loop system where real-time performance is critical (the example system presented in this paper is such a system).

The system in this example is implemented using a totally open hardware and software architecture. This ensures a flexible system that can incorporate a wide range of processor and I/O devices that are available from a large number of sources. With an open architecture, the user can grow and adapt the system to a variety of different mission requirements. By adhering to industry standards for software and network technology, the user can change, add or enhance the systems functionality by creating additional software programs to support new satellite launches.

For the example system presented in this paper, the AP Labs VTS software consists of low level drivers that control the boards in the system and higher level application software which allow setup and control of the telemetry, commanding and I/O boards. AP Labs' Asynchronous I/O (AIO) utilities are utilized in the example system to provide low overhead access to the telemetry and I/O hardware. The VTS application software consists of real-time VME-based software running under the VxWorks operating system. This software controls the acquisition and processing of the PCM telemetry stream, generation of uplink commands and the Unix workstation-based setup and control graphical displays. The setup and control software running on the Unix host communicates with the real-time processor over an industry standard Ethernet link.

AP Labs’ VTS software provides the high level control required to operate the system as a fully integrated product. The graphical setup and display portion of the software allows the user to configure and control each real-time task graphically and intuitively from the host workstation, using a series of icons, setup menus and display devices (referred to as “widgets”). The software architecture for the VTS system is seen in figure 3.

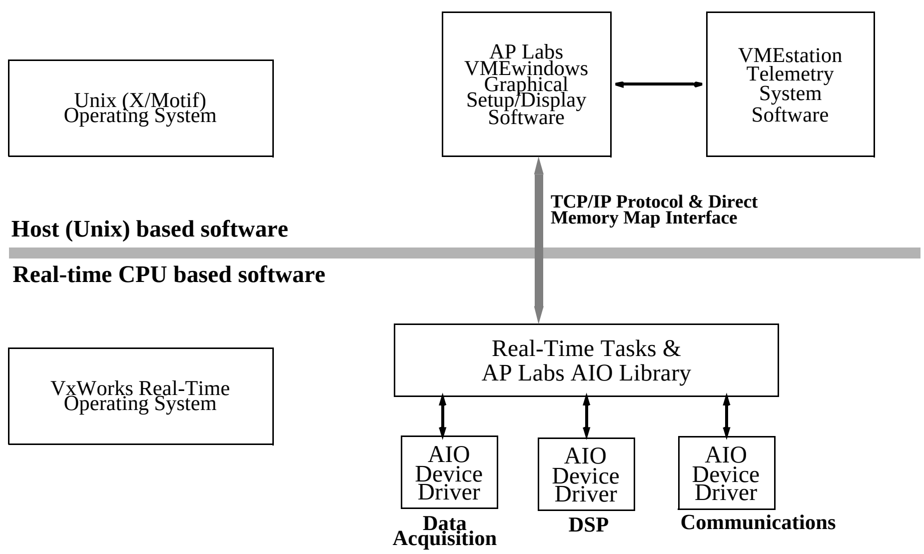


Figure 3 - VMEwindow Software Architecture

The industry standard X-Windows/Motif-based graphical user interface software provides system setup, telemetry and command parameter definition, display definition and real-time display capabilities. It performs error checking on user-input parameters and signals the user when an invalid parameter is entered. Hard copy output of the systems configuration is supported. System configuration allows the user to graphically set up each of the telemetry I/O interfaces, the other I/O interfaces and the network. The parameter definition allows the user to enter/edit parameter processing definitions. The parameter ID and input information as well as the various algorithms to be applied to it are defined here. The display definition allows the user to select from a number of widgets (numeric display, gauge, bar graph, strip chart, X-Y plot, scrolling tabular display) and define the colors, ranges, positioning, size and format of each output window. Parameters (with their respective out-of-limit values) are associated with the widget to define a display. Displays are grouped to windows and windows are grouped to a configuration. Save, restore and edit capabilities are available for each user-configuration item.

The goal of the VTS graphical user interface in the example system is to show the current state of the real-time side of the system using a block diagram format and to allow the user to easily modify the operation of the real-time system through the manipulation of this diagram. The top level VTS screen contains the data flow diagram shown in figure 4. This diagram is a graphical representation of the flow of data between various processes on the real-time system. This diagram consists of a group of icons that are interconnected to show the desired routing of data. The top level VTS screen also contains the main menu, which contains all of the commands necessary to configure and run the system.

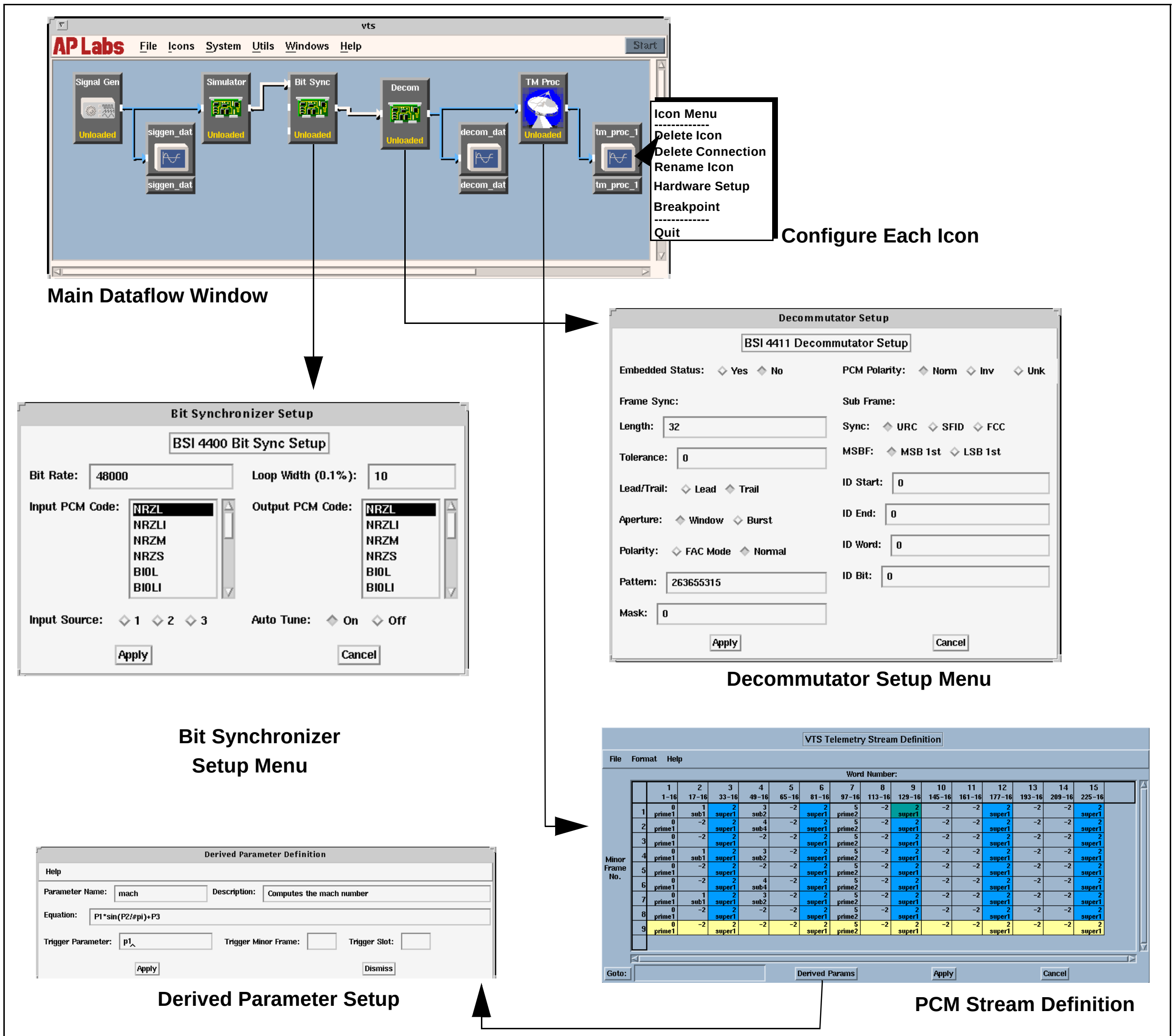


Figure 4 - VTS Graphical User Interface

As shown in figure 4, the PCM bit synchronizer in the example system is configured via the BIT SYNC icon and the PCM decommutator (frame synchronizer) is configured via the DECOM icon. All PCM stream definition and processing is defined and configured using the telemetry processing (TM PROC) icon. Double clicking the mouse on any of these icons will bring up the appropriate setup menu(s) for the function selected. When selected, the PCM stream definition setup menu provides an easy-to-use interface for defining major/minor frames, raw PCM measurands, derived parameters, parameter processing.

CONCLUSION

As the design and deployment time lines for military and non-military satellite programs continues to shrink, the need for open architecture, lower cost telemetry and control systems will continue to grow. The development and procurement of proprietary telemetry equipment and components that are available from only one vendor can no longer be justified in today's market place.

The trend for the 21st century and beyond is for less expensive, simpler satellites that can be mass produced and quickly deployed into low earth orbits. This capability will require low cost, flexible, easily reconfigurable telemetry & commanding equipment that can be used and reused to accommodate the fast pace and rapidly changing satellite development environment.

ACKNOWLEDGEMENTS

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REFERENCES

1. Advanced Processing Laboratories, VMEstation Telemetry System User's Guide, San Diego, California, October 1993.

2. The Aerospace Corporation, Air Force Satellite Control Network Space/Ground Interface (TOR-0059(6110-01)-3 Reissue-I, El Segundo, California, March 1992.