THE INFLUENCE OF MICROPROCESSORS ON SPACE (AIR/GROUND) SYSTEMS

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ABSTRACT

This paper discusses current and future trends in technology for on-board processing and the impact of these trends upon the architecture and processing capabilities of the ground receiving stations. Both the advantages and disadvantages of increased digital processing and software controlled multiplexing are addressed from the ground station processing viewpoint. Increased on-board processing should lead to a decrease in telemetry data rates as well as a diminished role for the ground support stations. This is shown by the paper to be a false assumption. Indeed, the reverse of this supposition is explored in detail and shown to be correct.

INTRODUCTION

Within the last few years as microprocessors came into widespread use and increased in sophistication and capability, much speculation was generated that on-board processing would most certainly lead to a reduced role for ground support stations. The rationale which led to this conclusion viewed such tasks as the processing of satellite imagery, space vehicle data and ballistic missile information being accomplished primarily by on-board microprocessors with only the refined and processed data being telemetered to the ground station for final processing, analysis and display. Many other factors regarding the widespread utilization of greater numbers of more powerful microprocessors were overlooked. Some of these factors include increased time and processing capability required to test sophisticated satellites after they have been placed in orbit. This testing insures that the more complex on-board systems are functioning properly. Other factors include the processing of additional telemetry information from ballistic missiles and space vehicles to insure that on-board navigation and control systems as well as computers are functioning correctly. It was not previously envisioned that in the event of the loss of an ultra-expensive spacecraft or space booster on-board processed data is insufficient for analysis, hence raw unprocessed data must also be transmitted to the ground station. The reduction in size and increase in capability of on-board telemetry equipment provides increased capability for the transmission of more complex telemetry streams containing greater volumes of data. Improvements in transmission equipment also allow for increased data rates.

PROGRAMMABLE MULTIPLEXERS

The increased use of software controlled multiplexers on-board ballistic missiles, space boosters and spacecraft have recently led to much more complex telemetry data streams. The use of microprocessors on-board the vehicle provides for the collection of large amounts of data in buffers prior to transmission. The software controlled multiplexer then fragments the data and distributes it evenly over the available time period for transmission in order to maximize utilization of the on-board telemetry multiplexing and transmitting equipment. For example, consider a software controlled multiplexer which assembles a 2048 byte frame of telemetry information for transmission. The multiplexer microprocessor can capture a 48 bit measurement from the on-board inertial navigation computer and then hold this measurement until the software controlled multiplexer divides the 48 bit measurement into six bytes of information containing 8 bits each. The 8 bit bytes are then inserted into the 2048 byte frame of information at locations 1, 350, 700, 1050, 1400 and 1700. This technique will maximize data throughput but the ground processing station must capture each of the bytes from the pre-determined location and correctly concatenate the information to produce a 48 bit measurement for further processing. Thus, modern software controlled multiplexers are not only used to process samples and time multiplex these measurements but to fragment measurements to increase throughput capability. It is readily apparent that when many measurements are fragmented the workload of capturing and concatenating this data back into meaningful information significantly increases the workload of the ground station.

A second capability of software controlled multiplexers is their ability to change formats. This means that at a point in time, usually identified by on-board events processed by the microprocessors, all or part of the telemetry stream is changed to a different set of information with an accompanying different set of demultiplexing requirements. Consider the example of a three stage space booster with a 1024 byte frame of information being transmitted to the ground station for processing. A significant portion of the 1024 bytes may be used for the transmission of information relating to navigation, control of the engines and engine performance. When Stage I of the booster is discarded and Stage II takes over there will be many reserved spaces in the 1024 frame which are no longer being used. However, if a format change occurs coincident with the staging event then the unused previously reserved spaces in the 1024 frame may be utilized for second stage information. The same process may be repeated when Stage II falls away and Stage III ignition occurs. This provides for maximum utilization of the telemetry equipment in transferring information to the ground station. However, the ground station must either recognize the event or more often a change indicator or format identifier transmitted in the telemetry stream in order to know when to change to a new demultiplexing scheme and alternative data processing software. Accomplishing this in real-time dictates that multiple demultiplexing schemes be loaded into the telemetry demultiplexers simultaneously and constant checks performed to determine which demultiplexing scheme is to be used on the next frame of information. The format change sequence has profound implications since failing to change formats at the correct time would obviously lead to erroneous information.

A third advantage of software controlled multiplexers is their adaptability to change. This allows the same on-board multiplexers to be used for many different applications as well as allowing for the easy correction of errors and last minute changes to include data previously overlooked for transmission to the ground station. However, the ground station must be kept in synchronization with the multiplexer load changes or correct processing of information cannot be accomplished. When this capability is combined with the data fragmentation and format change capabilities in a multi-contractor environment for research and development testing of a space booster, ballistic missile or spacecraft, then management of the project can raise many serious questions such as:

1. Who has the authority to change the on-board multiplexer load format?
2. How late in the sequence of events leading to a successful launch effort can the multiplexer load be changed?
3. How can the changes be inserted into the ground station to insure correctness?

It has been determined that the most reasonable way to deal with multiplexer load format changes in a multi-contractor complex environment is to appoint a single point of contact who is responsible for insuring all changes are implemented on the vehicle and that the same changes are provided to the ground station. A single integrating focal point for this activity also prevents different contractors from interfering with each other in making changes to the multiplexer load information. The single point of contact can also serve as arbitrator should the capacity of the on-board telemetry system be exceeded by the number of measurements available for transmission to the ground station.

The next section provides answers to the remaining questions as dealt with at the Western Space and Missile Center where a general purpose telemetry system is used to process telemetry information.

TELEMETRY INTEGRATED PROCESSING SYSTEM (TIPS)

The TIPS is a general purpose telemetry data processing center located in the operations control facility at Vandenberg Air Force Base. The final segment of this system was commissioned on 16 March 1983. It consists of three user systems and a range safety system as depicted in Figure 1. Inertial guidance and other telemetry data are processed in pre-launch, launch and post launch operations. The real-time TIPS is comprised of five functional subsystems:

a. Telemetry Front End equipment consisting of Analog Processing and Decommutation (ADP) and PCM Synchronization and Decommutation (PSD) hardware including data compressors.
b. Telemetry Pre-Processors (TPPS) which provide for limit checking and coordinate transformation.
c. Mass Storage Controllers (MSCs) for recording data on disk.
d. Configuration Interface Controllers (CICs) for software distribution to the system and system control.
e. Quick-Look Display Areas (QLDAs) for users to view the inertial guidance and other telemetry data on plasma displays and printer/digital stripchart recorders. Eighteen plasma displays and thirty digital stripchart recorders with a capacity of sixteen channels on each recorder are available for the users.

Items b,c,d, and e above each have a Gould-Systems Equipment Laboratory (SEL) Series 32 computer to support the function described (e.g. there is a total of 21 real-time computers).

Besides the real-time processors a Near Real-Time Batch Processor (NBP) consisting of a CDC Cyber computer with 1.25 megawords of memory and 4.6 billion bytes of on-line storage is available to support post launch operations and the TIPS telemetry compiler. This compiler is the “glue” that holds the system together as it provides a menu which telemetry analysts communicate with to define processing requirements. The compiler then outputs source code which is received, assembled and distributed to the real-time computers by the Configuration Interface Controllers.

System A, B and C shown in Figure 1 process telemetry data according to requirements determined in advance by the user who is usually the manufacturer of the equipment to be tested. The most recent significant capability added to the TIPS is the ability to accept and process digital strapping tapes from a user. These are the tapes containing the information used to load the on-board vehicle multiplexers. This same information is processed by the Cyber computer to generate demultiplexing information for loading the ground station telemetry front end equipment. This provides a rapid turnaround and update capability as

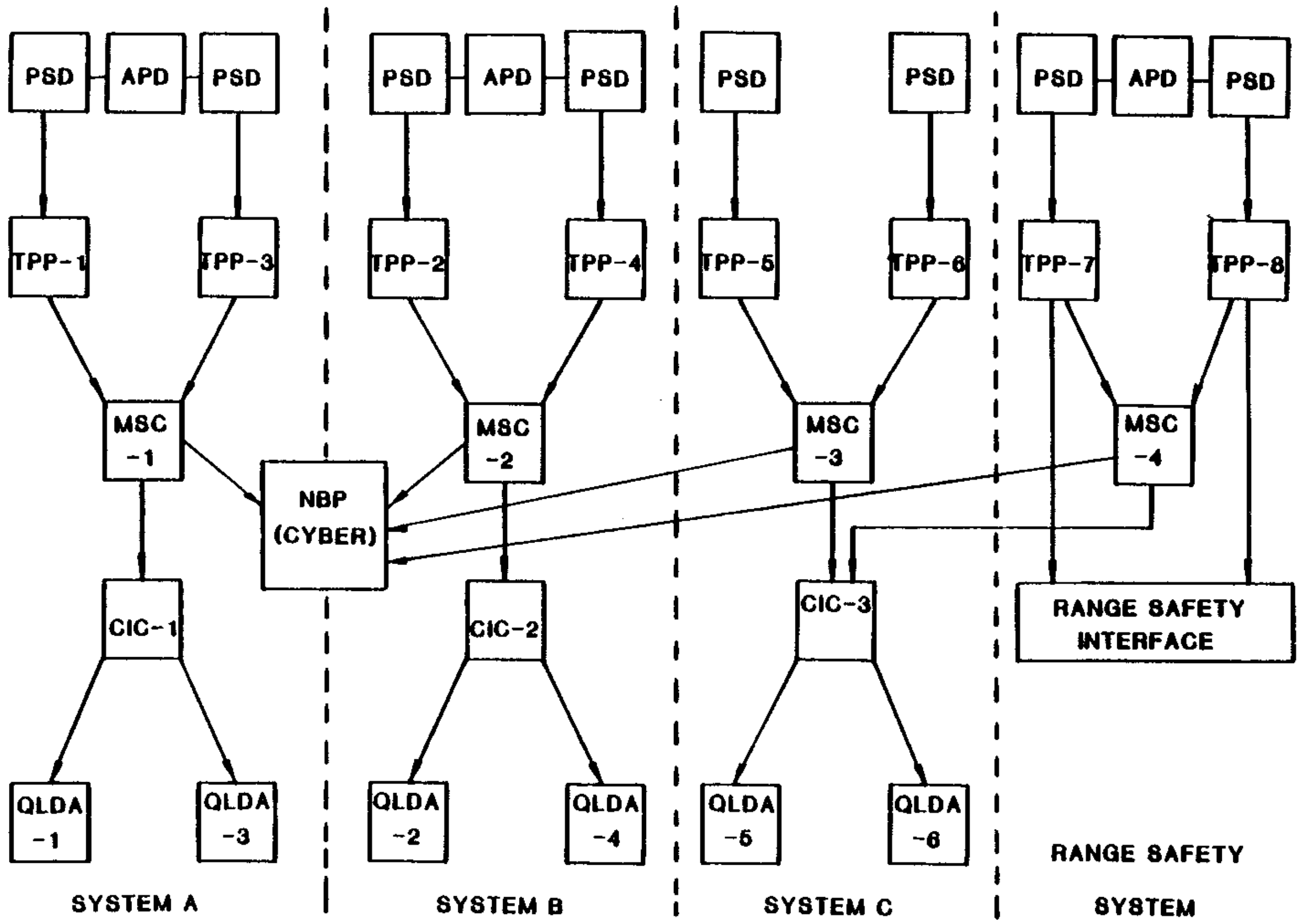

Figure 1 TIPS System Block Diagram

well as additional assurance that the new multiplexer load information is entered correctly since the possibility of human error in manually entering the information is eliminated. Thus, late changes can be inserted into the ground station system with a reasonable guarantee of success.

The question of how late in the sequence of events changes can be accommodated is complex and at this time dealt with on a case by case basis. The Western Test Range as a user oriented facility attempts to provide assurances for timely and accurate processing of information. Thus, last minute changes must in general be made in a manner that allows sufficient time for checkout. Since the degree of testing in this case is contingent upon the size and complexity of changes as well as the criticality of the data impacted each late change must be evaluated on an individual basis.

INCREASES IN COMPLEXITY OF SATELLITES

Orbiting satellites are used increasingly for data transmission relay stations, weather surveillance, land, crop and geological analysis, mineral exploration, environmental analysis and navigation. Increases in on-board processing have decreased ground station processing requirements in the area of instrumentation control. In the past the location of a satellite in darkness, twilight or sunlight and variations in the earth's albedo could cause imagery data to be digitized in a narrow dynamic range by wide range instrumentation. However, a microprocessor controlled scanner can prevent information from being digitized in a narrow dynamic range and thus obviate the necessity for histogram equalization processing of satellite imagery to correct this type of deficiency. However, new satellites are becoming so complex and automated that before relinquishing control to all of the automated systems in an orbiting satellite it is necessary to perform extended testing and analysis of telemetry data to ascertain that the satellite will perform as anticipated for several years. Recent tests have been so extensive as to require recording over 1,400 reels of analog telemetry tape information for test and analysis.

CURRENT AND FUTURE TRENDS

Presently microprocessor assist the on-board capabilities for automated control of systems and the production and transmission of increasingly larger volumes of more complex data to the ground stations. Microprocessors do not seem to have the capability to provide much assistance to the ground station for data production and analysis which currently requires large powerful computers to produce the desired results. Microprocessors have the capability to assist in the demultiplexing and concatenation processing of the telemetry information. This appears to be an emerging trend, however, much more capability including large buffer memories to store incoming telemetry and very large memories for storing many demultiplexing schemes simultaneously are required. Because of lack of capabilities in the telemetry front end hardware many processes which can be more efficiently accomplished by this hardware are being pushed back into the general purpose computers where software accomplishes these tasks as desired but with severe timing penalties since this slows up the entire process. Microprocessors are being increasingly employed at ground receiving stations for activities such as space diversity combiners which permit many received signals to be combined into a single reliable best source of information. Thus, microprocessors can provide assistance to the ground stations in areas of signal processing.

Future trends seem to be toward more complex telemetry data streams containing more complex information which will be transmitted at increasing data rates. Data rates of 400 thousand bits per second have given way to 800 thousand, 1.6 million and 3.2 million bits per second today. Advanced systems are available which can transmit 40 to 50 million bits per second and these are expected to be common place in 4 to 5 years. On-board multiplexers capable of dynamically changing the transmitted telemetry stream in response to automated control system malfunctions may be common place in the next few years.

Post test data can be satisfactorily processed by recording the very high speed data and playing it back at reduced rates for computers to capture and analyze. However, real-time processing requires more powerful, faster computers but even more important in the future real-time processing will require more intelligent combining of test results for display and more selective methods of discarding information not essential to the real-time processing and display effort. This will become increasingly important to prevent saturation of the real-time computers as well as the analysts who interpret this information.

CONCLUSION

With the proliferation of on-board microprocessors, software controlled multiplexers and systems capable of transmitting higher data rates the workload for the ground processing station is increasing rapidly. The reasons for this appear to be:

a. Potential loss of a vehicle dictates that all raw data be transmitted to the ground station.
b. Solutions calculated by on-board microprocessors are also transmitted to the ground station.
c. Increased sophistication in inertial guidance and microprocessors controlled operations dictate that many more health and status items be transmitted to the ground stations.

In the future more powerful sophisticated hardware will be required at the ground processing stations. Even more important than advanced hardware will be better means of selective identification and intelligent combining and discarding of information for the processing and display of real-time data. It is of paramount interest that these goals be pursued to prevent future saturation of even the most powerful computers as well as the human observers.

GLOSSARY OF TERMS, ACRONYMS AND ABBREVIATIONS

Albedo	Reflectivity of a planetary body
APD	Analog Processing and Decommutation
Batch Processing	Computer job processing in a sequential stream without operator intervention

Commutation	Sequential sampling, on a repetitive time-sharing basis of multiple data source for transmitting and/or recording on a single channel
Data Compression	The elimination of redundant data samples by digital filtering with predefined algorithms
Decommutation	Recognition and separation of a continuous bit stream into meaningful telemetry data
Diversity Reception	That method of radio reception whereby, in order to minimize the effects of fading, a resultant signal is obtained by combination and/or selection of two or more sources of received-signal energy which carry the same modulation or intelligence, but which may differ in strength or signal-to-noise ratio at any given instant. Diversity reception may employ frequency, polarization, or space diversity
Frame	The set of telemetric measurements occurring between the appearance of two successive frame sync patterns. (Sometimes known as main frame or minor frame)
Frame Rate	The frequency derived from the period of one frame
Limit Checks	Comparison of data with a fixed standard for out of tolerance conditions. Standard limits cover the normal expected range of data values. Critical limits are normally wider and when exceed, signal an alarm condition. The fixed limit corridor may float up or down with varying conditions
Link	A radio frequency or carrier used as a transmitting medium
MSC	Mass Storage Controller
Multiplexing	The simultaneous transmission of two or more signals within a single channel. The three basic methods of multiplexing involve the separation of signals by time division, frequency division and phase division
NBP	Near-real-time and Batch Processing

PAM	Pulse Amplitude Modulation, time division multiplexed analog pulses with the amplitude of the information channel pulse being the analog variable parameter
PCM	Pulse Code Modulation, information transmission by a code representing a finite number of possible values of the information at the time of sampling
PDM	Pulse Duration Modulation, the time duration of the received pulses, which are measured to obtain a representation of the original data
Plasma Display	A display panel using a dense grid of individual points sealed within a plasma gas for the display of information. The panel need not be continually refreshed, and is transparent so that microfiche data can be projected from the rear
PSD	PCM Synchronization and Decommutation
QLDA	Quick-Look Display Area, the range user station for monitoring and interacting with telemetric processing during real-time, playback or simulated operations
Telemetry Compiler	A specialized language processor capable of accepting inputs such as equipment designations, telemetry format identifications, processing selections (limits, EUC, event detection algorithms, data compression algorithms) and output formats for plasma terminals and printer/plotters; and capable of combining these inputs with a selected library of programmed routines to produce executable code or data for all hardware elements in subsystems to support a telemetry mission
TIPS	Telemetry Integrated Processing System
TPP	Telemetry Preprocessor
TTC	TIPS Telemetry Compiler
WSMC	Western Space and Missile Center