A State-of-the-Art Data Acquisition System

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Abstract

Recent developments in manufacturing technology have afforded a new capability in miniaturized instrumentation systems. The advent of ASIC (Application Specific Integrated Circuit) technology has provided the tools to implement very sophisticated signal conditioning circuits in micro-miniature instrumentation. This paper discusses the development of the Automatic Gain Ranging Amplifier (AGRA) and its implementation in the Aydin Vector MMSC-800 instrumentation package. Also discussed is the miniaturization of a 1553 Bus monitor, IRIG-B Time Code reader/accumulator and the development of a helical scan miniature tape recording system capable of recording 2^+ hours of 3.4 Mbps data. The paper concludes by giving applications for and benefits of using this new state-of-the-art instrumentation.

Background

The Flight Dynamics Laboratory (FDL) developed the first general purpose Automatic Gain Ranging Amplifiers (AGRAs) in 1967. These AGRAs were used as the primary signal conditioning for all transducers. These early AGRAs were built on a 4x5 inch card and used discrete components. Anti-alias filtering was accomplished by using a second 4x5 inch card that contained the programmable filters. The performance of these amplifiers was reasonably good, and for the first time, during flight testing, no prior knowledge of the transducer output was required to establish the appropriate amplifier gain setting for a given test condition. This yielded quality data in one flight instead of having to repeat test flights.

About mid 1978 we began to look at the future requirements of flight testing. We decided that in order to meet future needs the data acquisition systems would have to be smaller and also capable of acquiring significantly larger quantities of more accurate data. A circuit design was developed and queries were sent out for contractors to build this new AGRA.

It wasn't until 1982 that FDL was able to find a contractor, namely Aydin Vector, who was willing to develop a hybrid form of the AGRA (Ref. 1).

The design goals were to provide a module that would meet the Mil- Spec temperature range and significantly improve the performance of the previous device. This program was completed in 1985 and delivered a hybrid which is 2x2.3x0.25 inches and has a total error band of approximately • 0.5 dB over a temperature range of -25 C to +85 C.

In 1986 a contract was let to Aydin Vector (the developer of the hybrid AGRA) to design and build a 16-channel multiplexer using the new AGRA hybrid as the signal conditioner. The multiplexer provides both NRZ-L and randomized NRZ-L PCM output streams. A few of the design goals of this system were: (1) programmability (2) 20,000 Hertz bandwidth per channel, (3) 12 bit A/D, (4) parallel output for future expansion, (5) computer control and (6) the ability to synchronize multiple units in order to provide simultaneous sampling across the system. The system was designed to preserve the accuracy of the AGRA. A decision was made during the design phase to reduce the last filter in the AGRA to 10 kHz to allow 8 channels of data to be acquired at 4.25 Mbps. Techniques were developed to enable recording this PCM rate on a standard two megaHertz direct record tape transport (Ref. 2). The first of these units were delivered in March of 1987 in time to support the A-10 Gun Bay Test at McClellan AFB in Sacramento, CA.

Advanced System

OVERVIEW

The original Aydin Vector SCU-700 multiplexers were approximately 7.5x5x15.5 inches. This was large, and imposed significant restrictions on their placement in aircraft. A second iteration of the design was implemented in 1988 that reduced the cross-section to 5x4.9 inches and increased the length to 16.25 inches. This change helped, but it was clear that in order to meet future requirements additional changes were needed.

The down-sizing of the multiplexers was necessary to meet the long range goals of a support effort that FDL had with the AMRAAM (Advanced Medium Range Air-to-Air Missile) JSPO (Joint Systems Program Office). This requirement is to fit two 16-channel AGRA multiplexers, a 20-channel low frequency multiplexer, time code generator, 1553 bus data selector, and a tape recorder in the rocket motor case, which is approximately 7 inches in diameter and somewhat less than four feet long. Also, it is desired to make this system totally self-contained by providing battery power within the case that would allow a minimum of two hours stand-alone operation. See Figure 1.

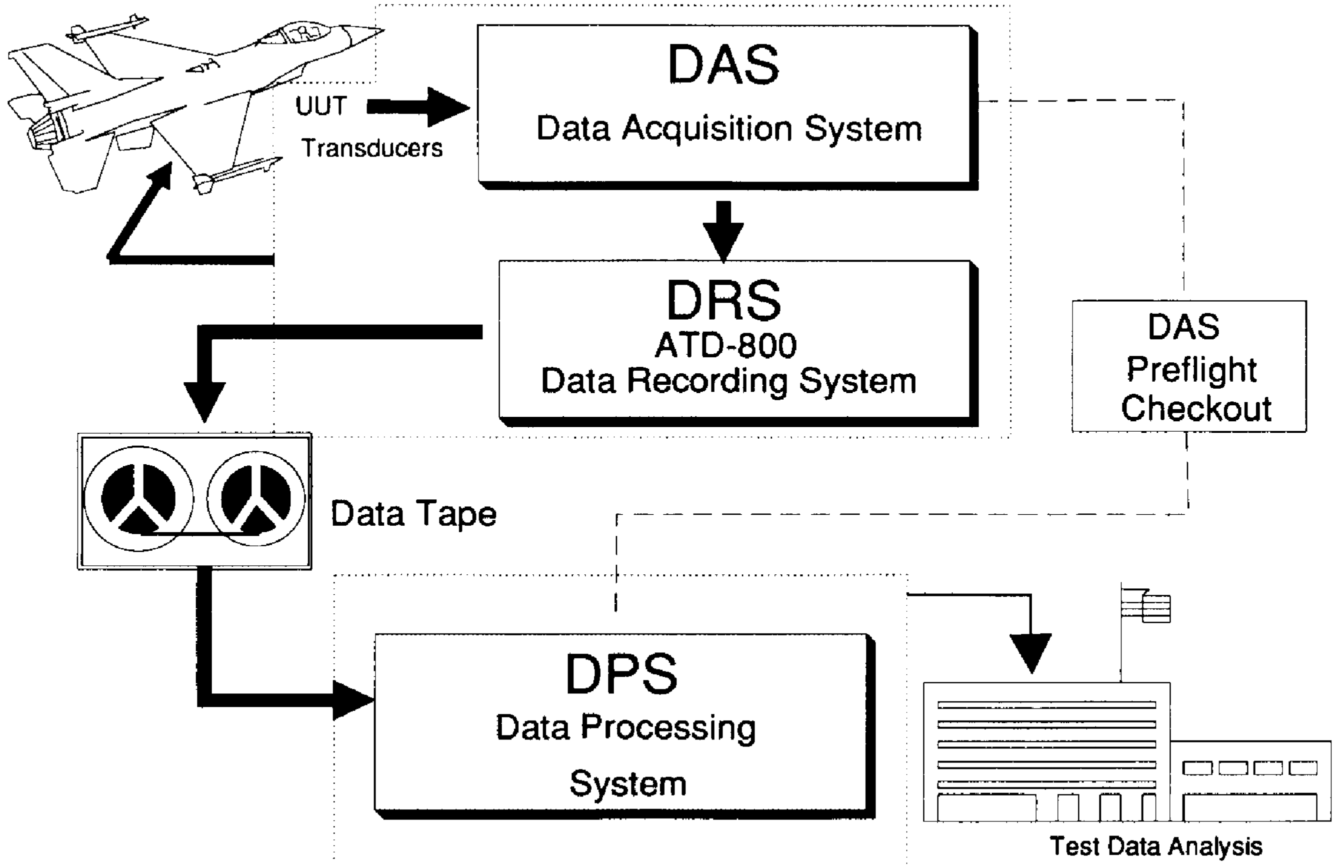

Figure 1. Digital Data Acquisition and Processing System

SYSTEM DESIGN

When designing an advanced system one must consider all aspects of the requirements. One area that must be treated is the requirement for correlating the vibration, acoustic, temperature and structural response data to aircraft performance. In order to accomplish this, avionics bus data must be selected and recorded with the response data. Additionally, IRIG time must be recorded with this data as a reference for individual aircraft flight test conditions.

Another area to be considered is the method of recording all of the data accumulated during flight tests. The current available methods are either to use direct recording techniques or one of the newer High Density Digital Recording (HDDR) techniques. The problem with all of these approaches is the size of the existing recorders precludes mounting them in a test vehicle as small as a missile. In order to fit the advance instrumentation system in a missile or within similar size constraints, the recorder must have a cross section on the order of 4x5 inches or less.

The approach taken in this effort was to redesign the SCU-700 multiplexers using ASIC (Application Specific Integrated Circuit) technology which would provide significant size, power and weight reductions. The platform chosen for the new AGRA multiplexer was the Aydin Vector MMSC-800 system. The use of the MMSC-800 platform reduces the size of the SCU-700 chassis from in excess of 600 cubic inches to approximately 27 cubic inches. This micro miniature package is based on proven technology. The housing and the interconnects were developed and patented in 1973. To date, three thousand systems have been produced and flown in missiles, aircraft and spacecraft.

The design of the packaging is such that when modules are plugged into each other it extends the bus signals and therefore eliminates the need for a motherboard. Each module contains an I/O connector to provide a minimum path between the transducer and the input circuitry. Refer to Figure 2. Features of this unit are modular construction capable of mixing a wide range of analog and digital signal conditioning modules to achieve any measurement ranging from RTDs, strain gages, and accelerometers to discretes (bi-level digital signals), frequency counters and synchros or resolvers. The range of channels that can be addressed in a single system is from two to 496; however, by use of asynchronous subframes this can be expanded infinitely.

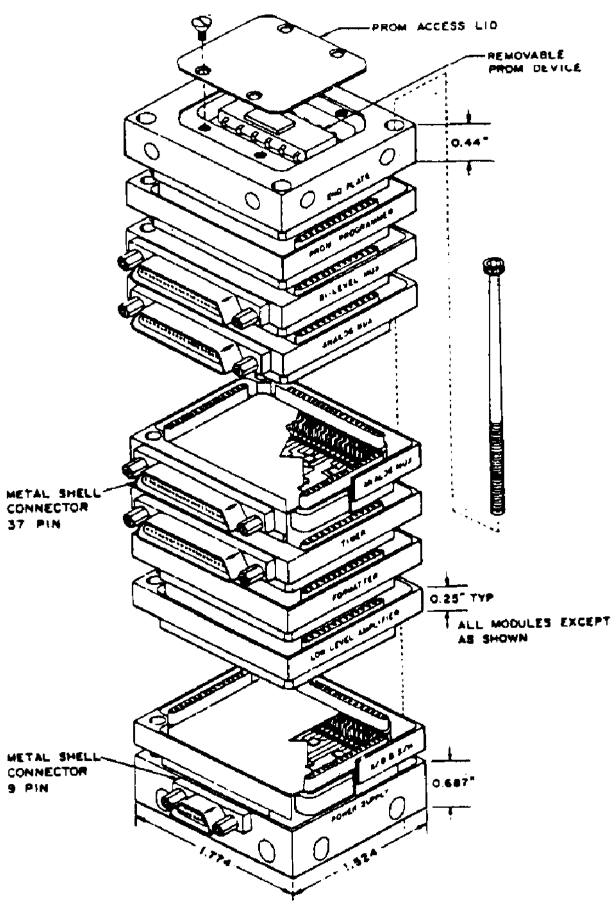

Figure 2. Micro PCM System

A new module was designed to produce IRIG time for the system. This is a double height MMSC slice capable of synchronizing to IRIG-B time as long as the modulated time is present and then running in an accumulator mode when the IRIG-B code is removed.

The 1553 bus data is handled by redesigning existing circuits using ASIC technology into a comparably sized package as the MMSC-800 system. This bus monitor may be used as a stand-alone device producing PCM output or as a remote multiplexer to other systems. The size was reduced from greater then 400 cubic inches to approximately 24 cubic inches.

ARCHITECTURE

The system design must provide for the most efficient method of packing the data onto the recorder. The design should also consider the computer processing of the data. The following system architecture is a result of considering all of these requirements and blending them into what we perceive to be the best overall combination.

The structure of the stream is a super commutated format. This increases the efficiency by inserting a frame sync pattern only once every 64 data words. Each of the wideband multiplexers contains up to 32 channels of AGRA signal conditioners. Since the wideband data channels are the driver of the PCM bit rate, these data are recorded in the top level format of the data stream. To increase the number of wideband channels beyond 32 in the system one adds more multiplexers. These multiplexers are then synchronized to provide simultaneous sampling across the system. Each multiplexer runs a flat or single layer format. This is done to decrease the memory requirements in the multiplexer and to allow any multiplexer to be a "master" in the system. Each multiplexer generates its own unique PCM stream and the tape recorder interface is used as the combiner.

To add temperature or other low frequency data to the stream one AGRA channel is replaced with an interface to a remote multiplexer. This multiplexer then runs its own single layer format including a frame sync word. The result is a lower sampling rate for these channels (the rate is equal to the sampling rate of the wideband channel divided by the number of channels in the remote or sub multiplexer plus one). This procedure in repeated in the remote multiplexer to add avionics bus data.

MMSC-800-AGRA

The AGRA contains a two-stage amplifier that has programmable gains from 1 to 1024. The gain changes occur in steps of four and are set in one of three ways. The amplifier can be programmed to function in "full automatic" where the gain tracks the input signal up and down as it changes, "down only" where the data is tracked from a preset gain in the down or decreasing gain direction, or be manually programmed. The AGRA utilizes a "quasi-peak" detector for gain control. This detector monitors the output of the AGRA and sets the gain to maintain it within the range of the A/D. A 6 pole Butterworth pre-sample filter follows the amplifier which may be programmed to a low pass bandwidth of 500, or 2, 5, or 10 kHz. Optionally, the last filter may be changed to 20 kHz. The AGRA input coupling can be programmed to be either AC and DC. Refer to Figure 3.

Figure 4 illustrates the AGRA word format. This shows the data word is in a quasi 16 bit floating point format. The status bit should always be '0' except when there is a gain change, which produces a '1' for 1 millisecond. All other occurrences of a one indicates an error condition in the amplifier or data stream itself.

As an example of how this frame structure would work, the following description is offered (See Figure 4).

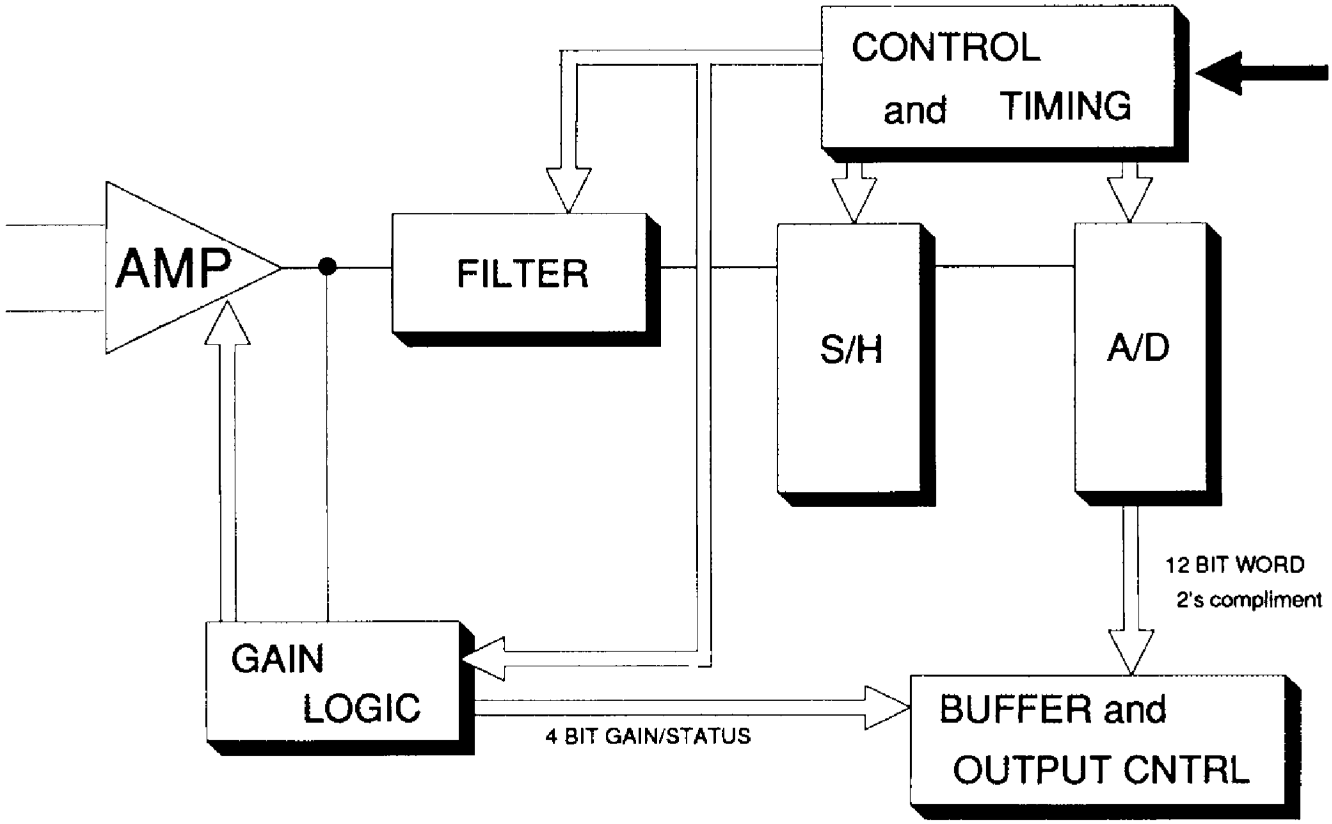

Figure 3. Automatic Gain Ranging Amplifier (AGRA)

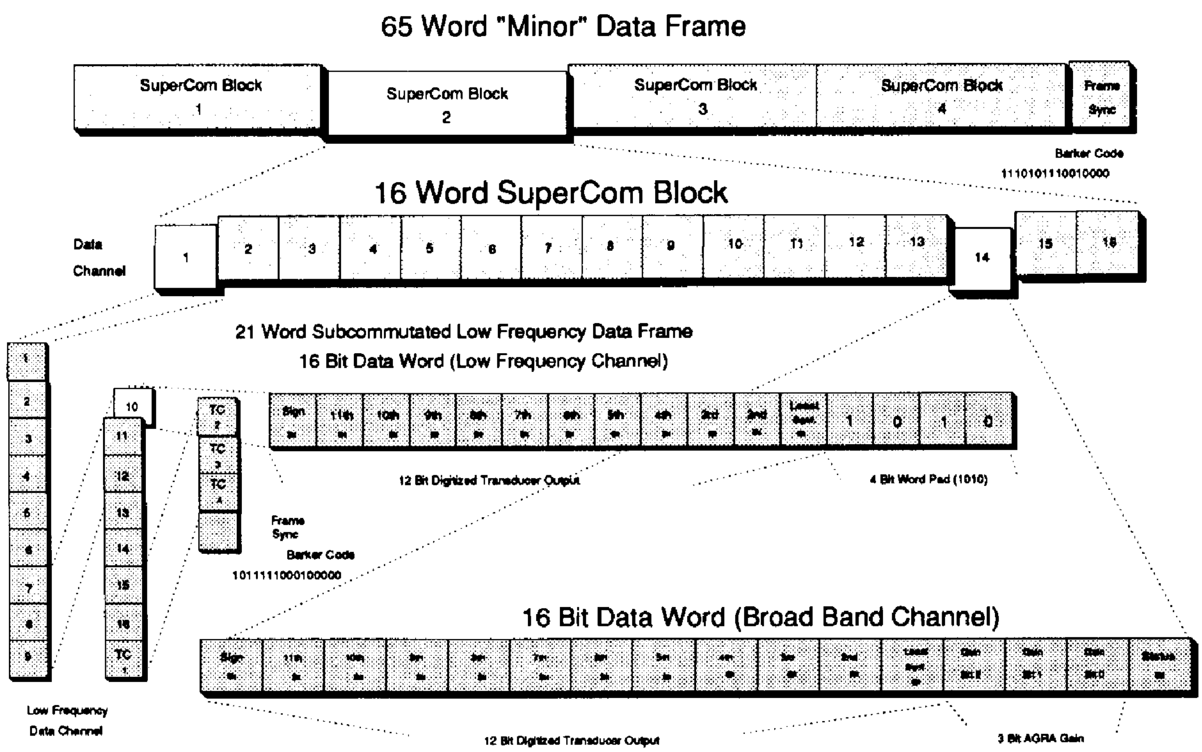

Figure 4. PCM Frame Structure

Each top layer PCM frame consists of 65 words in a format of N scans of M channels, where M can take on one of the following values: 1, 2, 4, 8, 16 or 32. Thus, if there are 16 channels in the scan, there would be four scans (super commutation) in the frame. The 65th word is a 16 bit frame sync code. Channel one of the super commutated sequence is an asynchronous subcommutated channel which contains up to 33 words, including a sub-frame sync word. This technique allows the insertion of many lower frequency channels in place of one wideband channel.

The MMSC-800-AGRA series overhead modules scan the channels in the stack and produce PCM output. Multiple formats may be programmed via an RS-232 link to a laptop computer.

Remote multiplexer

The remote or sub multiplexer is a standard MMSC-800 series signal conditioner with an overhead module that interfaces to the AGRA MMSC. It is used to acquire data such as strains (loads), time code, temperatures, discretes, etc. These data generally do not require as high a sampling rate.

In the AMRAAM system the AGRA channel is set for 2 kHz, this sets the sampling rate of the wideband channel at approximately 6.5 kilo-samples per second. The sub multiplexer contains 20 channels which are each sampled at 300^+ times per second. Figure 4 depicts the format of the sub commutated data words. Multiple formats may be programmed via an RS-232 link to a laptop computer.

Time Code Reader/Accumulator

The IRIG-B time code module is connected to a time code head to synchronize the module to standard time. After this sync is accomplished the generator can be removed and the module will continue to keep time in an accumulator mode. The module contains a IRIG-B DC level port that can be connected to external systems, such as the 1553 data bus monitor, to provide time tagging of its acquired data. Internally, the time module has addressable registers that contain time in varying resolution from day of year to milliseconds. These registers can be inserted into the PCM stream.

MPBM-1553 Dual Redundant Bus Monitor

The MPBM-1553 can acquire data from one dual redundant 1553 bus and conforms to the MIL-STD-1553A or B standard. It can select up to 240 messages types from the bus, time tag and store them for inclusion in the PCM format. Refer to Figure 5. The 1553 Bus monitor contains Electrically Erasable Programmable Read Only Memory (EEPROM) for storage of the trigger list and formats. It is programmable via an RS-232 adapter using a laptop computer.

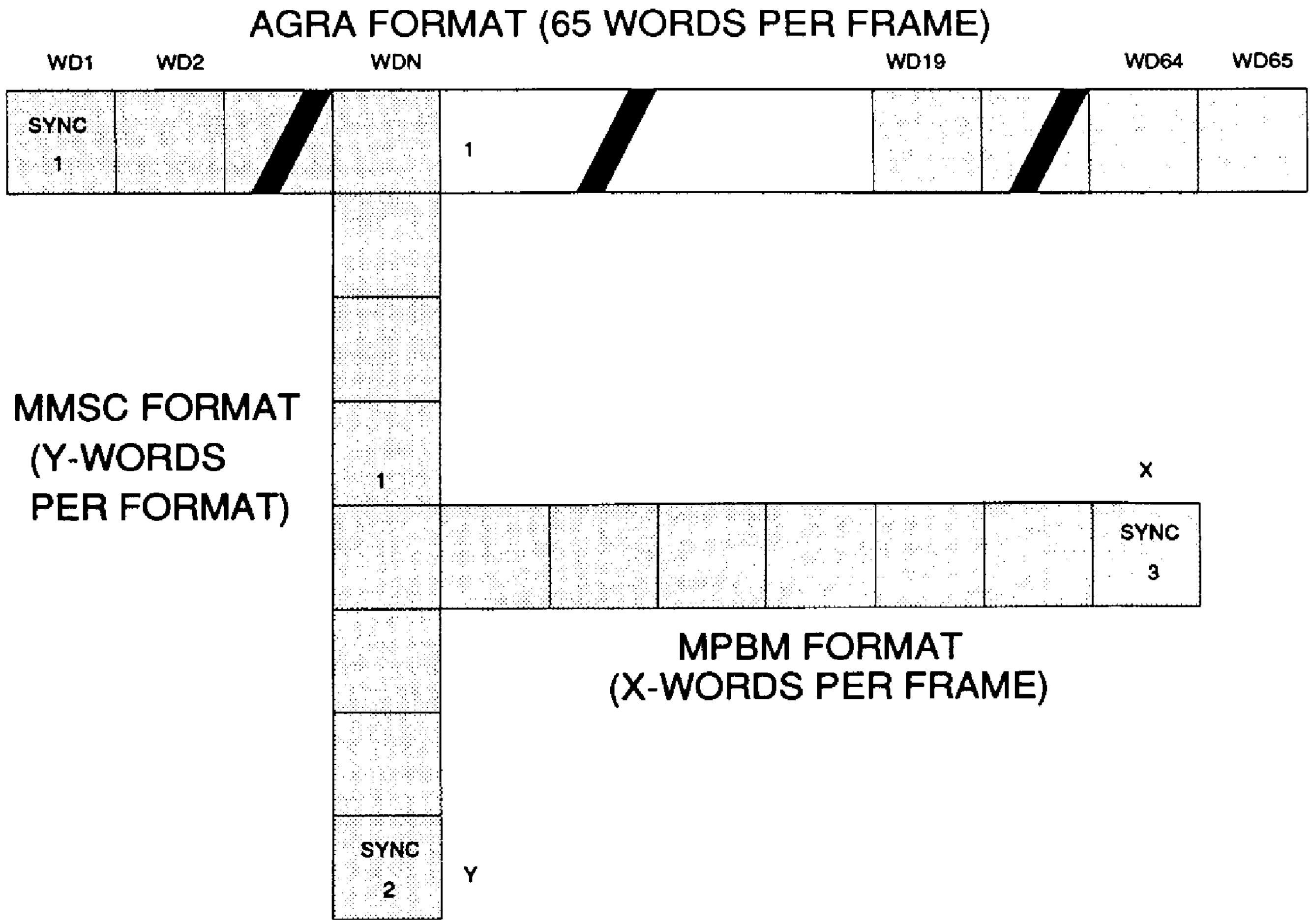

Figure 5. Composite Output Format

ATD-800 Tape Sub-System

A Digital Recorder System (DRS) is under development for use with the MMSC Data Acquisition System (DAS). The prototype DRS is a derivative of the Exabyte model EXB-8200. The 8200 is capable of recording approximately 1.9 Mbps of PCM data; however, the second generation of this recorder will be capable of recording 4 Mbps of PCM for 2^+ hours. The recorder is being modified to include a PCM interface that will accept one to four PCM streams and to be vibration hardened to accommodate flight environments. It will utilize the NRZ-L and clock outputs from the DAS and record in a block format that is directly readable by the Data Processing System (DPS). The PCM interface requires that the PCM streams be synchronized and it will then interleave them onto the tape.

The system being designed to support the AMRAAM flight tests requires the DRS to operate at a composite rate of 3.4 megabits per second from two AGRA multiplexers for two hours or more. This provides 31 channels of 2 kHz data and 20 channels of low frequency (under 100 Hz) data. A recorder “ON” indicator line is provided. See Figure 6.

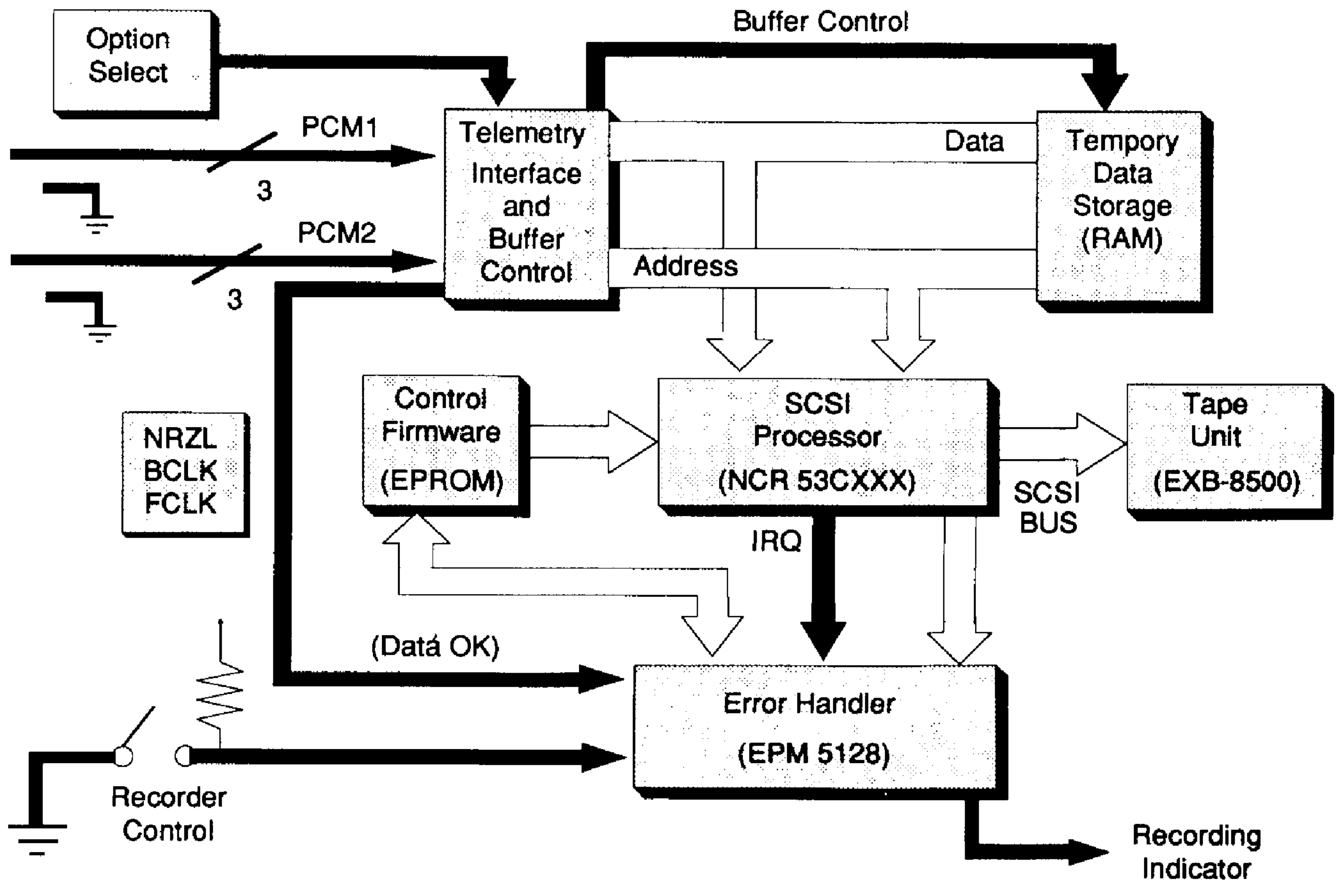

Figure 6. Tape Interface

A ground true recorder start logic level is provided, but it is anticipated that normal missions will be accomplished by automatically starting the DRS when missile power is applied and recording data throughout the flight. Recording in this mode provides all data and eliminates the problems of missing important data.

There are two versions of the Exabyte that will be used in the AMRAAM DDAPS (Digital Data Acquisition and Processing System). The first is a standard off-the-shelf model used in the Data Processing System (DPS), and the second is a modified version that contains the PCM interface and is vibration hardened for flight environments.

The DPS version of Exabyte serves as a mass storage system which may be used for system backups, a mountable file system, and the source of PCM data for the analysis and display operation. PCM data tapes will be generated on the airborne version of the recorder. This modified recorder will produce tapes with an identical format to the commercially available units (i.e. 1024 byte records etc).

The current EXB-8200 tape system has a maximum transfer rate of 246 kBps with a maximum storage capacity of 2.3 gigabytes; however, the soon-to-be-released EXB-8500 will have a transfer rate of 500 kBps and maximum storage of 5.6 gigabytes. The EXB-8500 is the recorder that we plan to use to satisfy the requirements of the AMRAAM program. We are using the EXB-8200 for development, since these recorders are upwardly compatible. There is a third generation that will have a transfer rate of at least 1 MBps and a storage capacity of 11^{+} gigabytes.

DATA PROCESSING SYSTEM

Overview

The Data Processing System (DPS) is a stand-alone portable system packaged in shipping containers. The CPU, graphics display terminal and keyboard/mouse are mounted in a container that has removable front and rear covers. When removed these covers form tables for the system. A PostScript-capable laser printer is provided for general output of plots and tabular data. This printer has a separate shipping container. Setup will consist of opening the shipping containers, connecting the printer to the computer system, plugging in the power, and then turning on the system. See Figure 7.

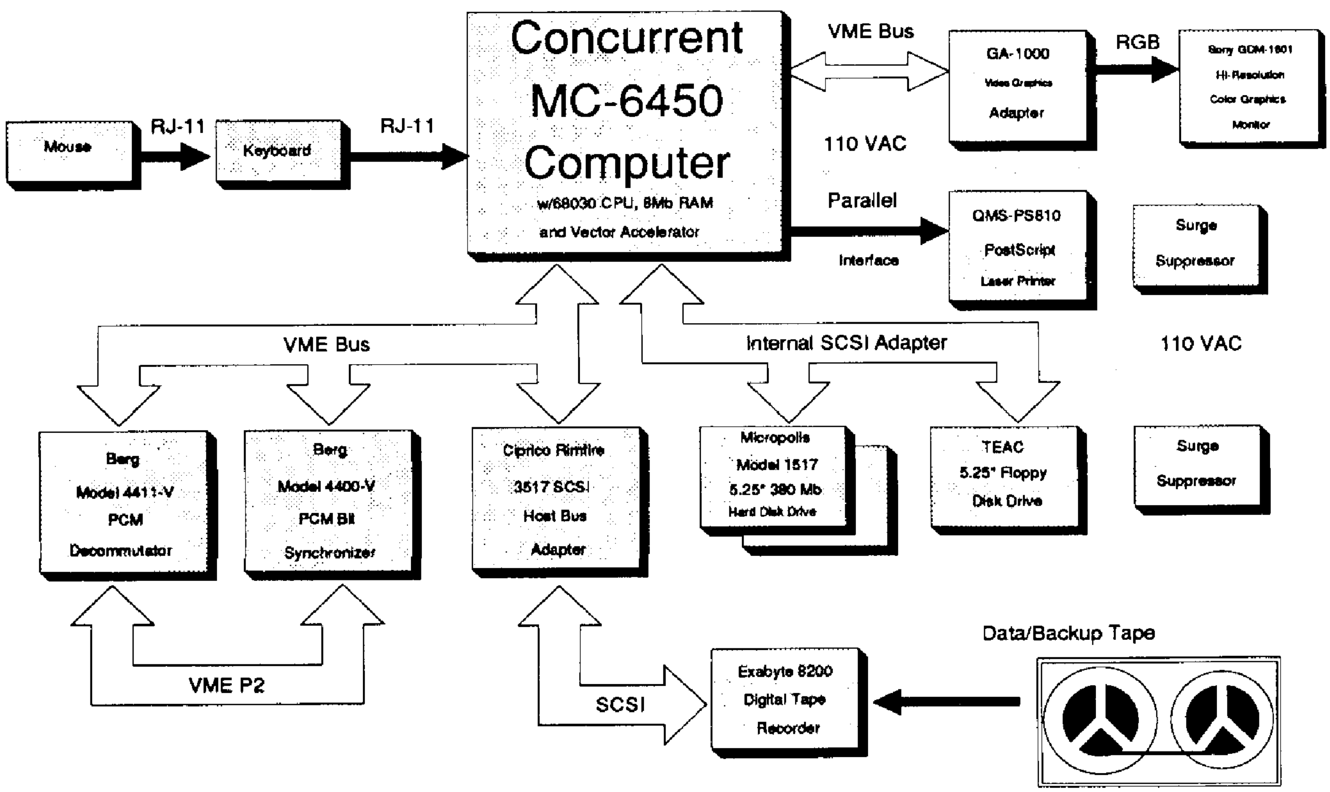

Figure 7. Data Processing System

The DPS uses a UNIX operating system with real time extensions. It is compatible with both AT&T SVID and 4.2BSD. Power requirement for the DPS is less than 20 amps at 115 VAC/60 Hz.

The application software includes the capability to perform pre-flight checkout of the Data Acquisition System (DAS) instrumentation. The system is capable of performing standard statistical processing such as PSDs, cross PSDs, histograms, amplitude spectra, and instantaneous and RMS time histories, on the data acquired during flight tests and pre-flight checks of the instrumentation. It will have a real-time oscilloscope display mode for monitoring the data in both the frequency and time domains.

The software uses pull-down/pop-up menus for setting up and controlling the system. A point and click method is used to select the desired functions. When the menu items have been selected a window appears on-screen with required information listed in a fill-in-the-blank format. Once the questions have been answered the information may be saved or downloaded as setup information to the rest of the system.

Operation Scheme

Data are acquired from three sources: a Pulse Code Modulation (PCM) interface to the processing system, the Exabyte tape sub-system, and the system disks.

The data from the PCM interface has a maximum rate of 600 kBps and the system is capable of transferring data to disk without the loss of any words (real time). This requirement is met for the time that it takes to fill a disk drive (300 MB). Simultaneously, the raw data are displayed for the purpose of coarse editing. These displays may be in the time or frequency domain. Data compression techniques are used to accomplish the real time displays. When instantaneous data words are dropped from the display, the data is displayed as a bar with the maximum and minimum values being the max and min of all data between the time samples. Currently, one or two channels of the incoming data may be displayed in this mode; however, the system will be upgraded to include a second 68030 processor and more memory to increase the real time performance.

When data are extracted from the Exabyte tape sub-system or the disk and passed to the scope display for editing, it is processed as fast as the respective interfaces allow. The output of the editing session is then used as the source for post processing of the data. The results of the post processing operation are stored in the form of meta files and/or plot files and passed to the UNIX spooler for plotting on a laser printer. The standard RS-232 printer interface has been replaced by a Centronics parallel interface to improve the performance.

The application software includes the capability to perform pre-flight check-out of the Data Acquisition System (DAS) instrumentation as well as post-processing of flight data. The system is capable of performing standard statistical processing such as PSDs, cross PSDs, transfer functions, coherence functions, amplitude histograms, amplitude versus frequency, instantaneous and RMS time histories, RMS and crest factor meters on the data acquired during flight tests and pre-flight checks of the instrumentation. These analyses are performed as non-real time processes and may be performed as background processes.

Coarse editing is performed as a parallel process where the data being acquired is forked to the mass storage device and display. In this mode attempts are made to display all incoming data; but this is not always possible, so a scheme of decimation is used which presents the data as a series of vertical bars that represent the maximum and minimum of the missing data. Storage of the incoming data must be accomplished without any corruption of the time domain (i.e. absolutely no losses of bits, bytes or words).

The engineering conversion units are provided in a table form for each channel (i.e. the offset (if any) and the sensitivity in engineering units/volt). These conversions are stored in a file keyed to a specific setup so they may be recalled with an “instrument” (An instrument is a collection function blocks that make up a process; such as a Power Spectral Density [PSD] measurement). Normally these setups only change with the acquisition system configuration. Also, there is a conversion for the volts per count of the A/D in the acquisition system. The AGRA words have a • 10 volt full scale while the low frequency analog words have a • 5 volt full scale with programmable gain. Both use an A/D that is 12 bits wide (11 plus sign).

The scaling of the data into engineering units requires conversion by an mX + B calculation. Once the data are gain corrected, the final scaling can be done at the tail end of the processing, since it translates to a scaler operation. Some data (typically thermocouples) requires special linearization that is generally accomplished by table lookup. These data may also involve gain correction. Nth order Polynomial conversions are also provided.

In order to accomplish the post processing of the sub commutated data the frame sync pattern must first be detected. Since any given block of data always starts with channel one but doesn’t necessarily start with the sub frame sync word of that channel, sub frame synchronization is required. This is accomplished by scanning the sub frame until the pattern is detected and then storing the appropriate set of pointers. Since the main frame is 64 words in length and the blocks are always an integer multiple of this, the sub frame will always be in word one of the block. This is true for the AMRAAM development program but, may not hold true for other uses.

Application

The data acquisition system described in this paper was developed for the AMRAAM Captive Carry Reliability program. The primary objective of this effort was to develop a system that would replace the FM/FM technology that was being used to acquire data during the program. The FM/FM technique imposes a very limited dynamic range on the user. It also is man-power intensive during calibration and testing. The AGRA with its 60^+ dB dynamic range in a single gain step and its overall 120^+ dB range provides a much greater resolution and accuracy to the user. The built-in accuracy of this system is such that it may be ignored in most calibration procedures. It is important to note that the MMSC-800-AGRA requires no adjustments to achieve the stated accuracies.

With the tools that have been developed during the AMRAAM program new potentials have been opened up in the data acquisition arena. The acquisition system is very small and should fit in most every current and known future flight systems. There are many flight test requirements today that do not allow the data acquisition systems to be mounted in or near the test article due to the size constraints.

To date WRDC/FIBG has conducted nine flight tests consisting of 39 flights using the AGRA technology.

The instrumentation systems consisted of one to three SCU-700 type multiplexers. One test used three multiplexers with reed switches in front of each channel to double the channel capacity. Data were then recorded in two blocks of 48 channels taking a time record of one block and then switching to the second block.

The SCU-700-AGRA has a built-in constant current source to provide power for transducers with on-board electronics. This current source may also be used for medium accuracy strain gage and bridge type transducer applications. The advanced system will provide the same current source.

Summary

One minor problem that arises from the miniaturization of this instrumentation is the signal conditioner interface connectors. These connectors are, by the very nature of the system, extremely small. The connectors chosen for the MMSC-800 were micro miniature “D” type. These connectors have not been well received in the flight test community because they are delicate and require extreme care during installation. We feel that this is an educational problem and is more than offset by the gains in accuracy and the decrease in power, size and cost of the equipment.

The system under development is tailored to meet the AMRAAM requirements but, the design is flexible and can be used to fill the needs of many other flight tests. It has enormous capabilities, being able to generate single PCM streams up to 10 Mbps and to condition literally thousands of channels. Currently the Data Recording System (DRS), which has a significant size advantage, will support up to 4 Mbps data rates; other recorders will handle much higher rates. The primary emphasis during this development was to find a recorder that would meet the size requirements and handle the bit rate of the AMRAAM program. We feel that this objective was met and the recorder offers a significant advancement in flight test recording technology. A new formatting scheme was developed to improve efficiency by not requiring the total format memory map to reside in the system controller or master; this is viable and does allow essentially an unlimited number of channels to be included in one PCM stream. The AGRA, now available in the micro miniature signal conditioner, brings a new dimension to flight testing. The total size of the AMRAAM data acquisition system (50 channels) is approximately 250 cubic inches instead of well in excess of one cubic foot. And the introduction of the MMSC AGRA with its 120 dB dynamic range will have a significant impact of the cost of future flight testing by providing the capability to automatically adapt the gain of the system to the transducer output regardless of the test condition. The estimated flight time savings is on the order of 80% over the current test methods.

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