A NEW GENERATION OF RECORDING TECHNOLOGY THE SOLID STATE RECORDER

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ABSTRACT

The Test & Evaluation community is starting to migrate toward solid state recording. This paper outlines some of the important areas that are new to solid state recording as well as examining some of the issues involved in moving to a direct recording methodology. Some of the parameters used to choose a solid state memory architecture are included. A matrix to compare various methods of data recording, such as solid state and magnetic tape recording, will be discussed. These various methods will be evaluated using the following parameters: Ruggedness (Shock, Vibration, Temperature), Capacity, and Reliability (Error Correction). A short discussion of data formats with an emphasis on efficiency and usability is included.

KEYWORDS

Solid State Recorder, Tape, FLASH memory, FlashDisk, Mil-Std-1553, PCM, File Formats

INTRODUCTION

Merlin Engineering Works recently evaluated several different approaches for data recording before deciding on producing a Solid State Recorder for the test and evaluation community. This paper will attempt to quantify some of the areas of interest when looking at a new way to record data. Some old assumptions of the way data is recorded will be examined so that data is recorded in the most efficient way possible. Aspects of a solid state recorder design will be discussed so as to compare and contrast with other recording technologies. File formats and PC compatibility are important issues to a solid state recorder approach. Also, the construction of the solid state recorder will be discussed and important aspects of this design considered. Finally, one approach to designing a solid state recorder will be shown as an example of this new generation of recording technologies.

SOLID STATE TECHNOLOGY VERSUS TAPE

The advantages and disadvantages of various recording methods need to be considered when designing a new data recorder. Factors like Ruggedness (Shock, Vibration, and Temperature), Capacity, and Reliability (Error Correction) need to be considered. All of the preceding factors are important in the design of a recording system. They can lead to different choices in the recording media, error correction scheme and recorder characteristics. In telemetry, data reliability is put at a premium, lost data can be very costly. A recorder must be able to withstand the shock, vibration, and temperature associated with recording onboard telemetry data while preserving data integrity.

Environmental stresses are often of major concern in the telemetry data acquisition market. The affect of vibration, shock, temperature, and humidity should be minimized. Humidity is an important factor in recording and reproducing data on a tape recorder. As the humidity changes tape stretches or shrinks causing tracking problems for the tape recorder. Extremes in temperature can also cause similar tape problems. Shrinkage from aging and dropouts from media flaws are two other well-known tape environmental problems.

A tape-based system inherently suffers from the limitations of a mechanical system and the environmental limitations of the tape. Mechanical systems suffer from wear and are subject to the affects of vibration, shock, and temperature. Great care must be taken in the design of mechanical systems and any required isolation from the environment. Additionally, mechanical systems require routine maintenance schedules and this cost is usually not considered when purchasing a recorder. In a perfect world, a recorder would work forever and never need repair. However, this is not a perfect world.

Because of the environmental and mechanical limitations of tape based systems, Error correction coding (ECC) is used to compensate for errors in the recording media. ECC has come far in the last few years in compensating for these errors, but even the best ECC cannot correct for all media errors. ECC adds overhead to data recording that lowers the data rate or recording capacity to some degree.

But for all the problems with tape it has one huge advantage. It provides a cost effective archival media for storing data. In a laboratory environment, the cost of tape recording systems is unbeatable. Magnetic tape is still a very cost-effective recording media.

A solid state approach to data recording is much less affected by environmental factors than a mechanical tape system. A solid state recorder uses only electronic parts for data storage; there are no mechanical and vibration isolation systems. Solid state memory has, until recently, been either technologically or cost prohibitive. In the past the power requirements of a solid state approach could be quite high. Until recently the most viable options for a solid state recorder were to use either DRAM (Dynamic Random Access Memory) or SRAM (Static Random Access Memory). DRAM and SRAM are volatile devices and require a battery backup to provide a continuous power source, as well as, requiring significant amounts of power during operation. The new FLASH memory technology is providing a viable solution to these past problems. FLASH memories are nonvolatile devices. The power used to "remember" data is now non-existent. When power is removed from the device, the data stored in the FLASH memory remains; no battery backup system is required.

	ME-981 With HI-8 VCR	DAT	DLT	VHS (IRIG)	SSR (ME-1000)
Size/Weight (cu. Inches) (lbs.)	2 Boxes 334 14.6	½ ATR 355 13	¾ATR/2modules 712/1400 24/50	15.2 x 15 x 6.5 1482 38	11.1 x 5.5 x 6.35 388 17.5
Capacity (Gigabytes)	2	8	20	13.8	3.1 (9x350 Mbytes)
Humidity	5-95%	20-80 %	20-90%	80%	95%
Temperature (°C)	-40 to +60	-30 to +50	-20 to +50	-40 to +55	-30 to +60
Shock (g)	20	15	10/15	20	40
Vibration (g)	7.5	5	5	Unknown	10.5
Data Error Rate	10^7	10^{12}	10^{10}	10^{11}	10^{14}
Future Expansion	N/A	N/A	Possible	Unknown	9 Gbytes expected in 1999
Data Rate (Mbits/sec)	2.2	4	12	32	16
Disadvantages	2 units, Capacity	Packaging, Capacity	2 units, Size/Weight	Size/Weight	No archival media, Capacity
Advantages	Uses Existing Equipment, Archival Media	Archival Media	Archival Media	Data Rate, Archival Media	Rugged, Ultra-Reliable, Upgradeable

FLASH memory density is continuing to increase, driven by the technological advancement of the commercial market. As memory die sizes drop, the cost of memory has decreased rapidly while the amount of data that can be stored on the memory has increased. PCMCIA modules made by companies such as SanDisk, Hitachi, Fujitsu, and AMD for the portable PC market are now becoming widely available. These PCMCIA modules allow us to utilize the economies of scale of the commercial personal computer industry. The one problem that solid state recorders have not overcome is the cost of the archival media. Using solid state memory as the archival media is still cost prohibitive, and likely to remain that way for some time.

The obvious solution for recording telemetry data is to use a dual system. The advantages of both tape systems and solid state systems can be used to create a near ideal recording system. A solid state recording system can be used to gather onboard data in severe environmental conditions. The data can be downloaded to a PC and then backed up on a commercial tape backup system. This gives the advantage of the robustness of the solid state data acquisition with the archival advantages of tape systems.

FLASH MEMORY ARCHITECTURE

Once we have decided to design a solid state recording system, we must first chose a memory architecture for the system. The memory architecture is an important factor to consider, because many other design considerations are dependent on this basic system building block. We must decide if the design will incorporate discrete IC's (Integrated Circuits) or use off-the-shelf memory modules. Merlin Engineering examined this issue in some detail before choosing their system architecture.

Use of discrete devices allows a great deal of design flexibility. Storage word size can be adjusted to optimize for data rate and data block size. Memory can be configured in many different ways, and circuit card size can be greatly varied. However, additional design features like error detection and correction have to be built into the assembly so that bad memory devices can be identified and replaced or repaired should they fail during operation. Also, the choice of a discrete device ties the design closely to the characteristics of the device and also sometimes to a specific manufacturer.

Memory modules have a fixed mechanical size, capacity, and architecture, but they often have other features that make them very desirable. One of the more interesting memory modules is the PCMCIA FlashDisk card. These PCMCIA cards are available from many manufacturers, but interest can be focused immediately on SanDisk, due to the size of the modules they offer, and their position as a market leader. SanDisk offers modules in capacities of 2 Megabytes to 350 Megabytes. Larger modules are expected in the near future from SanDisk and other manufacturers.

These FlashDisk modules contain error correction, redundant memory for replacement of bad memory locations, and additional features for managing the Flash memory. The FlashDisk does a read after write to confirm that data has been written correctly. In the rare case that there is an error, the FlashDisk can replace this bad cell or even an entire sector and put the missing data into a good cell or sector. In addition to these very impressive defect management capabilities the FlashDisk contains ECC coding to correct for any remaining errors that could normally take place. All of these features are transparent to the user and are performed internally in the module, without any user intervention.

The SanDisk FlashDisk cards are designed to work in portable computer PCMCIA slots and emulate disk drives for storing data. The FlashDisk's use an industry standard ATA command set for communicating with the PC operating system software. As FLASH memory sizes increase, the ATA command set will support the increased size and allow the communication protocol to remain the same among modules. This avoids the problem of constantly having to redesign the recorder to upgrade for larger memory device sizes. In addition the ATA command set removes the recorder from dependence on the details of erasing and programming flash memory depending on the specific architecture of the FLASH memory devices. Unlike a tape recorder, when denser recording media becomes available an ATA-based solid state recorder can be upgraded by the user in the field in minutes. Also, the ATA-base solid state recorder retains backward compatibility to old media as well as the forward compatibility to the new media.

The FlashDisk's features of defect and error management, ATA command set, endurance, dynamic power minimization, and ruggedness make it a very good selection for use in a Solid State Recorder.

RECORD TIME AND CAPACITY

The simple question "How long does it record for?" seems like it should have a very straight simple answer, but it does not when it comes to a fixed capacity recorder, the answer is, "It depends". The obvious capacity divided by data rate is not enough to typically answer this question, we must determine the actual recorded data rate. The actual recorded data rate is sometimes very different from the input data rate.

Recorders with a fixed capacity or data rate, buffer the input data to accommodate their recording rate on the media. These recorders have a fixed capacity. The capacity does not change dependent on the data rate. In order to find out what an approximate record length for your recorder is, you must divide the capacity by the input data rate.

$$\text{Record Time} = \text{Capacity} / \text{Data Rate}$$

However, if a more exact number is needed then you most correct for the overhead in the system. The overhead is the additional non-data information added to a recording for various reasons.

$$\text{Record Time} = \text{Capacity} / \text{Data Rate}\ (1+\text{overhead})$$

Unfortunately the overhead is often not a fixed number but depends on the user's data format. For example, with PCM data, the word size can have a strong impact on the overhead rate. Words are often recorded in 8 bit bytes, so that a word size of 9 bits might be recorded as 2 bytes or 16 bits. This would give an overhead of (16 – 9)/16 = 43.5 %. With PCM data of 15 bits per word the overhead due to the word size would become (16-15)/16 = 6%. If recording Mil-Std-1553 data, words with up to 20 bits per word we use a 3 byte or 24 bit recording word size. In this case there would be (24-20)/24 = 16.7% overhead due to the word size. From the formula above, it can be seen that these different overheads cause a very different recording time.

There would also be some additional overhead for data identification, time tagging, and error correction. Typically, an overall overhead runs from 5% to 60 %. Obviously, there is then a real need to keep the overhead of the recorder as low as possible to maximize the record length.

DATA SOURCES

A solid state recorder should be able to record several different types of data onboard a typical aircraft or vehicle under test. Standard data formats like PCM, Mil-Std-1553, Analog Voice, RS-232/422 asynchronous data, and IRIG serial time should be supported. In addition, it would be desirable to support an event mark scheme. Each of the data sources should be recorded in a format that is compatible with a computer analysis system. These formats should be similar enough to each other that once an end user is familiar with one format he can use any of the formats with only some small modifications.

Data collected from a Mil-Std-1553 data bus should be selectable by the particular RT (Remote Terminal) and SA (sub-address) or to record all of the bus traffic on the data bus. Selectively recording RT's and SA's allows some filtering of the data to preserve bandwidth and recording time. The PCM interface should allow multiple channels to be recorded and be flexible in the format of the data input to the interface. RS-232/422 interfaces should be provided to allow the ability to record GPS information or any other informational asynchronous serial data stream. The recording of GPS position information combined with the recording of the inertial guidance information from the Mil-Std-1553 data bus provides a unique opportunity for recreating the position data of a flight with great accuracy. An analog voice channel should be provided to record relevant audio sources. This allows for the finding of the occasional "Oh-Oh" event and correlating it easily with the telemetry data sources. All of these different data sources must be time-tagged so that the data can be compared between channels and sources.

DOWNLOADING DATA

Once data has been stored in a solid state recorder, it must be retrieved from the recorder for analysis and dissemination. Data can be downloaded into a computer in a number of different ways from a tape recorder. By replaying the original data streams, they can be captured using a bit synchronizer and a demultiplexer to sample the data at a fixed rate. This process converts the data to a format that can be read by a computer system. This is an effective way to process data, but it has the unfortunate capability of hiding data or producing data that is not always present in the original system. Gaps in data are often "hidden" from the user during this process. An alternative method is transfer the raw data directly into a computer, bypassing the pre-processing, for analysis. However, this alternative requires some thought as to how the data will be transferred to the computer.

Several obvious methods of transferring data into a computer are though Parallel, RS-232, GPIB, or SCSI ports. Parallel ports are sometimes used because they are very common, but their transfer rate is limited. Serial RS-232 ports cannot be used because they have an extremely limited transfer rate. GPIB ports are commonly used in laboratory environments for test, but they are not used very commonly in the telemetry community. However, SCSI ports have the highest data transfer rates of these choices and they are fairly common. SCSI ports have become the preferable selection for transferring moderate amounts of data to computer systems for processing. They are commonly used to connect to external storage devices, scanners, and printers. In this case, the SCSI port appears to be a good choice to transfer the data from a solid state recorder to a computer for analysis. However, the data in the recorder must now be in a format that is readable by a computer analysis system.

FILE FORMATS AND PC COMPATIBILITY

Typically the file formats that are used for data analysis are far removed from the actual data collection format. This is usually the results of the low overhead, simple to implement requirements of the data collection format versus the need for a computer compatible format for analysis. Standards, like IRIG 106, are not really computer friendly. Their bit-oriented structure is not directly usable by computers for plotting or analyzing data. Data analysis software use a word oriented data format with words spread over integer values of bytes. For example, Mil-Std-1553 words are typically organized over three bytes; PCM words are typically organized over 1 or 2 bytes. Each word is organized into a data structure so that it can be identified. In PCM data this structure is usually the frame format. In Mil-Std-1553 data, the structure is the message format. Each word position in the structure is significant, indicating which variable's value is being reported. Ideally a file format should be efficient (low overhead), computer compatible, simple to implement, have the ability to be expanded in the future, and of course reliable. Unfortunately, there is no such file format. Each requirement causes compromises with the others.

Data analysis software is usually used to plot values or print out the data values of each different variable in the telemetry data. The variable value can usually be printed as an instantaneous value or plotted as a value over time. Most software packages allow the plotting of data on a scaled axis. That is, the raw data value can be scaled and offset to translate the raw data to engineering units. It is also normal to be able to view the data in an unprocessed format so that any problems with the data can be examined before processing. A modern data recorder must provide utilities for easily viewing the data on at least a PC.

Also, once data is in a computer compatible format it can be translated into other compatible formats to allow export of the data to other systems. Emphasis should be placed on the conservation of information. Ideally, any format should contain all the information that is present in the original data and this should be preserved throughout the translation process.

One side affect of the computer compatible data format is that some processing must occur in the recorder to store the data in a compatible format. It is possible to generate data in such a way as to make it hard to recover from a glitch like a power interruption. The recovery time from a power interruption should be minimal. The recording system should not have to go back over the entire recording to a header to know were the end of the recording is or to know where to continue the recording. Long fast forward and rewind sequences must be avoided. Systems that require up to 10 minutes recovering from a power glitch are unacceptable. The recorder in an onboard data acquisition system should recover quickly on reconnection of the power. The possibility of power glitches should be considered carefully when designing or choosing a modern recording system.

CONSTRUCTION

The construction and packaging of a new data recorder is often an overlooked item. Of course a recorder should be rugged and it should minimize the affects of temperature, humidity, vibration, shock and EMI (Electro-Magnetic-Interference), while providing a compact lightweight package for the recorder. Temperature is of particular concern in a solid state recorder. The excess heat generated by the electronics must be carefully considered and a method for the transfer of this energy to the outside of the electronic enclosure must be integral to the design of any electronic enclosure. As semiconductor devices are getting smaller and faster, the transfer of heat from these devices to the enclosure is growing more important.

One interesting way to transfer excess heat to the outside of an enclosure is through the use of heat transfer plates. The plate sits on the top of an IC (Integrated Circuit) and has a mechanism (heat conductive foam or silicone) to transfer the heat from the IC to the plate. The plate is then used to conduct the heat to the enclosure wall. The enclosure may be mounted on another “cold” surface to conduct the heat away from the enclosure. Or air conduction of the heat through convection may be relied on in the outside environment. An additional feature of the heat plate is that it can provide structural support to a PCB (printed circuit board). The heat transfer plate avoids the use of mechanical fans to move air and heat out of a particular assembly and allows the unit to be a sealed unit.

Printed circuit boards should be designed to minimize EMI and allow for thermal expansion and contraction of the PCB and its components. Components on the PCB should be mounted in such a way as to minimize the affects of vibration. EMI can be further minimized by using appropriate EMI filtering on signals going in or out of the recorder. The use of direct PCB mounted connectors allows EMI filtering on the PCB to be very repeatable and reduces the assembly cost associated with wire harnesses. All of these factors must be considered when designing an enclosure and electronics.

ONE SOLUTION

A new generation of solid state recorders is on the horizon. Features to make the new recorders as robust and rugged as possible should be stressed. This new generation of recorders will be used to acquire data onboard vehicles for later direct entry into computer systems. The ability to handle multiple data sources and to correlate them to a time source will be an inherent capability of solid state recorders. Error correction and device error management will be important to the quality of these recorders. One such implementation of a solid state recorder is the ME-1000 Solid State Recorder from Merlin Engineering. It contains nine (9) PCMCIA FlashDisks and accepts a variety of data sources, including PCM, Mil-Std-1553 data busses, RS-232/422, IRIG Time, Event Marks and Voice. The ME-1000 is designed using the latest construction techniques to minimize the affects of EMI and to transfer heat out of the electronic package as efficiently as possible. The data formats used to store data are consistent and written in such a way as to be easily transferred to a computer system. Software for quick look data processing is included with the recorder. The Merlin ME-1000 is among the first of the next generation of Solid State Recorders.