ABSTRACT

A Digital Output Recorder (DOR) system was developed by JAYCOR under contract to Defense Nuclear Agency (DNA) for the recording of high-speed digital data from test hardware exposed to radiation during an Underground Nuclear Test conducted at the Nevada Test Site (NTS) in 1991. Electronics hardware for the system is based on the well-supported Versa Module Europe (VME) bus which has become an industry standard for digital process and control systems. The system collects, identifies, and telemeters the data from several interfaces using the VME bus to a common data collection point above ground. The system was designed with built-in flexibility and expandability to meet digital data recording requirements on future underground tests (UGTs).

INTRODUCTION

The UGT community has been engaged in the gathering of digitized analog data for a period of several years. Typically these recording systems have very high bandwidth associated with EMP and other radiation effects with short duration requiring sample rates in the hundreds of megasamples per second. The transient resulting from these impulses can last for several seconds, or even minutes, requiring relatively long recording times. Most previous measurements have been analog in nature or have not generated a significant amount of raw digital data.

With the development of high technology weapons systems and their possible exposure to battlefield and space-borne nuclear situations, more emphasis has been placed on the hardness of the electronics in these systems. To determine their hardness and resulting survivability, measurements must be made on systems when exposed to nuclear event
radiation levels in UGTs. Common radiation induced problems of interest include latch up in solid state electronics, upset levels, recovery times for circumvention circuitry and memory loss threshold. The system designed for this purpose and discussed in this paper was fielded on a UGT at NTS. Several types of military hardware using sophisticated electronic control technology were tested at system specification radiation levels. The purpose of the DOR system was to record enough data from the digital interfaces, buses and memories to establish the nature of potential system upset using state of the art recording techniques. In order to perform this function, the DOR system had to be rugged, possess large amounts of storage capability, and record data through the transient EMP events expected during this test.

The following sections discuss this application more specifically and outlines what happens to solid state electronics hardware being subjected to large radiation doses. Also presented is the development of the final DOR, and the individual recording elements of the system. The final section presents some enhancements which will be designed into future tests. While the application of this system is somewhat removed from traditional telemetry systems utilized on above ground testing ranges, its use of existing telemetry technology was more than accidental. The choice was made as telemetry technology provided the best solution for the system design.

DOR TEST ENVIRONMENT

Large-scale military systems containing digital instrumentation packages subjected to previous UGT events have provided their own unique data recording instrumentation. Some systems have used their Command and Control (C²) support electronics system and down-link telemetry for digital communications and data recording. A departure from this technique of digital recording was used on more recent tests by recording digital data generated by computer memory using memory modules from transient digitizers (128 kilobytes of data). Using this technique successfully demonstrated the capability to record digital data directly from digital experiment hardware. This was a relatively small amount of data compared to that which was to be required on future UGTs and a better recording system had to be developed.

Electronic systems used to record data during UGTs are subjected to a severe operating environment. The data recording system must be operated in an underground test bed which is made up of many experimenters; there are manifold construction activities and electrical noise generated by support equipment and operating environments are dirty (dust, moisture) compared to a laboratory or computer facility. It is essential that electronics systems for use on UGTs must be designed to function reliably as there is only one opportunity to collect data from the experiment.
Systems exposed (Figure 1) to the first level included experimental C² Processors (System A) and a single-channel radio system. These systems were also exposed at a second level along with an ensemble of subsystems. Total approximate data to be recorded from the second set of electronics was 51 megabytes and 6 megabytes from the first set of systems.

As presented in Figure 1, there was a wide variation in the types of data to be recorded. The System A Processor had two data outputs: a 48-bit wide parallel data bus operating at 3 MHZ/sec and a MIL-STD-1553 serial data communications link between two processors. Data from the radios was also recorded from both levels. These radios were capable of providing voice and digital communications while using complex operating modes involving frequency hopping. Data recorded included receive and transmit data produced within the radio as well as health, status and bit error information from an IEEE-488 bus. Data generated in System B was transmitted to the DOR on a 32-bit wide parallel data bus running at approximately 160 kilo samples per second. An EIA RS-232 serial communications link was monitored to record health and status information. Electronics hardware being monitored for System C included a MIL-STD-1553 and in EIA-STD RS485 multipoint serial communications bit stream at approximately 1.3 megabits per second. Data from System D was transmitted over an IEEE-488 bus at approximately 200 Kbytes per second.
Initial system engineering involved establishing the design parameters which the customer considered essential for a successful data collection system. These requirements included robustness, capabilities to interface to a variety of systems under test (SUT), and future expansion capabilities. The government agency for which this system was being provided had a long and extensive history in preparing and performing UGTs but lacked the expertise necessary to field new data collection equipment which met the aforementioned requirements. This was further complicated by the paucity of specifications determining the type of measurements required by the experimenters and how much information was to be collected.

A prerequisite in the project was to develop interface specifications on the amount of information to be manipulated, the data rates and duration of the collection process, and key environmental parameters the data collection equipment had to meet in order to survive the experiment. This involved meeting with individual experimenters and continually refining the interfaces to their equipment, a process that continued for the entire system development cycle. To establish an initial scope of the amount and content of the data, experimenters were required to develop interface specifications stating their requirements such as:

1) Data Format: MIL-STD-1553, RS-232, RS-422, bus, etc.
2) Data Rates
3) Electrical Specifications
4) Duration of Data Collection

Circumstances involving experiment system hardware design and the late delivery of detailed interface information dictated that initial system level designs require significant broadening of the scope in terms of data collection rates and actual amounts (e.g., some system interfaces were, in effect, over designed to be certain of meeting requirements that were not fully specified until late in the DOR development cycle).

The collection of large amounts of data requires some rather complicated equipment, therefore, understanding environmental conditions were as important during the initial design phase. The UGT environment is not kind to systems performing measurements, and severe stress due to higher than normal radiation levels, fluctuating power, dust, high humidity, and mechanical shock are often encountered. Additional constraints were imposed on the ability to reliably retrieve data after the event due to potential tunnel collapse and the possibility of power failure. Concerns about the survivability of the data
collection equipment generated an initial requirement that all data be sent above ground between the blast EMP and ground shock, a period of approximately 50 ms. Considering the amount of data collected, this would generate a requirement for incredibly high data rates or large numbers of optical fiber cable for the transmission of the data.

The above requirements and the scheduled time frame required the use of existing off-the-shelf equipment. It was decided early in the project to rely on a well-known architecture that had a variety of off-the-shelf interface boards available. An obvious choice was the VME bus supported by several hundred vendors supplying many types of boards and a mature bus structure which offered reasonably high throughput rates. The decision to use an existing standard allowed us to concentrate on the system fundamentals of how information should be stored and routed to the above ground portal data recovery area.

FINAL SYSTEM DESIGN
Overview

The evolution of system components was partially determined by the bandwidth of the various signals and the proximity of the equipment to the source. Of significant importance was that the data collection equipment be non-invasive and not affect the SUT. In addition, the data collected was in no way to be altered by the data collection equipment. To accomplish this purpose, a junction box consisting mainly of passive and radiation hardened line termination and transmission devices was placed in a semi-protected side drift. The system element served to condition the signals for transmission over twin-axial cable to the data recording alcove. Once the signals arrived at the data collection units in the recording alcove, they could be recorded on more sophisticated VME equipment. These units provided the interface between the asynchronous SUT and the synchronous fiber optic links to the decommutation equipment above ground at the Portal Recording Station (PRS).

As stated previously, the decommutation equipment located at the PRS was off-the-shelf equipment which allowed the user to select data based on a tag ID assigned as a function of a particular source parameter in the input stream. This required a slight modification to the decommutation equipment but still allowed the use of an off-the-shelf system. This element of the system will not be discussed in this paper. It is sufficient to say classical techniques for tagging, identification and processing of data with telemetry decommutation systems were used in the design.

Junction Collection Box (J-Box)

Experiment hardware was located within test cells which allowed for connection to the J-Box located in a cross-cut (a small tunnel at oblique angles to the main tunnel [main
Each SUT had its own J-Box consisting of redundant power supplies, line drivers and receivers and miscellaneous interface circuits. The System A Processors J-Box contained interface circuits to the 48-bit parallel data bus and the MIL-TD-1553 data used in communications between two System A Processors. The data from the interfaces was converted into EIA RS-422 format and transmitted to the digital alcove on RF-21 twin-axial cable where it was converted back to the original format. Of critical importance was the timing skew associated with signal delays in the cables. All transmission cables between the recording alcove and the J-Boxes had to be measured and trimmed to within 10 ns of each other to maintain interpulse timing. Table 1 outlines the interfaces within the J-Boxes and their relative data rates.

Table 1. Test Data Summary.

<table>
<thead>
<tr>
<th>Equipment Under Test</th>
<th>Interface Type</th>
<th>Data Rate</th>
<th>Data Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>System A 2nd Level</td>
<td>MIL-STD-1553 2 48-bit bus</td>
<td>1 Mbits/sec 2 x 3 Mwords/sec</td>
<td>&lt; 8 Mbytes (per pair)</td>
</tr>
<tr>
<td>System B</td>
<td>32 bit Parallel EIA RS-232</td>
<td>160 Kwords/sec 19.2 Kbits/sec</td>
<td>1.62 Mbytes</td>
</tr>
<tr>
<td>Radio System</td>
<td>IEEE-488 F/O Serial F/O Serial</td>
<td>50 Kbytes/sec 3 x 4.8 Kbits/sec 2 x 320 Kbits/sec</td>
<td>16 Mbytes x2</td>
</tr>
<tr>
<td>System C</td>
<td>MIL-STD-1553 RS-485 IEEE-488</td>
<td>1 Mbits/sec 1.33 Mbyte/sec ~200 Kbytes/sec</td>
<td>&lt; 8 Mbytes</td>
</tr>
<tr>
<td>System D</td>
<td>IEEE-488</td>
<td>~200 Kbytes/sec</td>
<td>&lt; 5 Mbytes</td>
</tr>
<tr>
<td>System A 1st Level</td>
<td>MIL-STD-1553 2 48-bit bus</td>
<td>1 Mbits/sec 2 x 3 Mwords/sec</td>
<td>&lt; 8 Mbytes (per pair)</td>
</tr>
<tr>
<td>Radio System 1st Level</td>
<td>IEEE-488 F/O Serial F/O Serial</td>
<td>50 Kbytes/sec 3 x 4.8 Kbits/sec 2 x 320 Kbits/sec</td>
<td>1.62 Mbytes</td>
</tr>
</tbody>
</table>

Data Collection Units

The conceptual design of the DCU presented an interesting challenge to the team of engineers and programmers responsible for this instrumentation. The DCUs (Figure 2) had to interface to a variety of input data types which contained different data rates, signal
levels, word sizes and coding techniques. Some of the data rates (> 12 Mbytes/sec) were rather high for a microprocessor-based system and required careful selection of vendors whose boards could handle high data rates. Data was collected and stored locally on purchased interface VME boards (MIL-STD-1553, IEEE-488, RS-422) or boards designed specifically for project (parallel). Battery-backed CMOS RAM provided for temporary non-volatile storage of limited amounts of data.

With the data acquisition problem solved, the next design issue was the routing of data from each interface to a common transmission point using a 25 Mbit/sec fiber optic link to the PRS. In addition, redundancy was provided by requiring data to be recorded on local Digital Audio Tape (DAT) drives in case the fiber optic link should fail due to tunnel collapse. Using the VME bus to transfer the data was ideal because it is a multimaster bus which allows each board to operate independently of the others. Since the transfer took place after the time-critical data acquisition period, storage speed was not a factor. To provide a common point for the arrival of the data during the experiment, a 32-bit time stamp was provided on the bus which could be read by all the individual interface processing boards prior to the transfer of data to system memory.

At this point in the design, it became necessary to determine how data would be transferred to a common area for transmission to the PRS and for storage on the DAT tape units. Since the goal was to collate the information and transfer it over a common resource
Perhaps an existing technology could be utilized. The similarities to a modern telemetry system were striking in that individual experiments provided a number of data sources which were collated into a single data stream, transmitted to a remote site, and recovered into data files representing the original sources. If the data sent from the underground environment could be made to appear similar to telemetry data, then why not send it in standard telemetry formats as frame/sub-frame data and decommutate it at the receiving end. Initial considerations included sourcing the data in the telemetry stream according to word location with frames and sub-frames. Since the data sources were highly asynchronous, this proved to be a particularly difficult problem. Rather than use the sub-frame or frame location, a source ID was included and the information was sent as packets with the following information:

1) Source Identification
2) Number of Words
3) An Identification Code
4) Linked List for Concatenation
5) Time Stamp

This determined the data format once it left the individual interface boards for the bus master and system memory. The protocol for this transfer was as follows:

1) The individual interface requested control of the bus from the bus master.
2) After control was granted by the bus master, the interface would write a packet of data to system memory.
3) Control was relinquished to the bus master, at which time the bus master would store the data on DAT tape and begin transmission of the data over the fiber optic link.

At this point, the data was handed to the fiber optic electronics and stored on the DAT tape unit as backup.

Optical Fiber Interface

Early in the project the customer dictated the use of existing fiber optic plants which limited the bit rate to 25 Mbits/sec. This required dozens of optical links, so it was decided to begin the transmission of data through the cable after the subsidence of the initial EMP and maintain the data in battery-backed memory for later storage on the underground DAT.
media. The DOR fiber optic subsystem consisted of a transmission and receiving unit with the sending unit receiving data from the bus master through a FIFO interface (first in/first out).

The transmitter prefixed a 16-bit sync word to the packet and terminated it with a CRC16 (cyclic redundancy check). The data was then bi-phase encoded and sent to drive two redundant laser transmitters connected via multimode optical fibers to the PRS receivers. The receiving unit accepted the redundant optical signals from the multimode fiber, decoded each signal, and performed a level comparison to select the redundant signal having the highest amplitude. The selected data and clock were then passed to the decommutation equipment at the PRS. In order to maintain bit sync in the decommutators, a “Null” packet was transmitted when the FIFO buffer was empty.

Portal Data Recovery

The receivers located at the end of the fiber optic link in the PRS were designed to accept the bi-phase encoded information and provide clock and data to the decommutation equipment. Since the data arriving was not in the standard frame/sub-frame pattern, the decommutation equipment had to be adapted to look for certain ID patterns sent in the packet header. Their were eight bit synchronizers interfacing to the decommutation equipment, creating a total data stream of 240 Mbits/sec. As a temporary buffer each decommutation module contained 85 Megabytes of non-volatile memory between the system bus and the data input stream. Permanent storage consisting of a 760 Mbyte hard disk and backup optical drive provided the final repository for all of the experiment data. Data stored on the hard disk was also recorded onto floppy disks which were provided to each of the experimenters for data reduction. In addition, the decommutation equipment also proved valuable during pre-event system testing and signal dry runs.

SYSTEM SUMMARY

The relatively short development cycle of this system (15 months) dictated the borrowing of concepts from technologies heretofore not utilized in the underground test community. The adaptation of existing telemetry technology to this system proved that development cycles can be shortened significantly if other alternatives are considered.

SYSTEM ENHANCEMENTS

System improvements to support more complicated UGTs will be a continuous process at NTS. Efforts are underway to develop a 1.2 Gigabit/sec fiber optic link from the underground alcove to the PRS. Other system enhancements will include a more reliable storage system at the PRS, standardized interfaces to the SUTs and larger data storage
capability. These improvements will enable data to be transmitted at the rate it is gathered, thereby reducing the requirement for underground data storage and the attendant risk of tunnel collapse or system failure. The standardization of interfaces will be extremely important as the complexity of each SUT increases by allowing flexible strategies for data collection to be utilized by experiment designers. This allows DNA to maintain a field data collection systems that broader coverage over experiments than systems designed specifically for each UGT.

SUMMARY

Direct digital data acquisition for UGTs are being met by the DOR system which records a diversity of digital data generated by many types of digital electronic systems. The system was designed using the adaptable and versatile VME bus, utilizing existing off-the-shelf hardware, and designing custom interfaces where necessary. A modified commercial telemetry package was used at the PRS to recover and record data using a unique source address and tag ID. To transmit data from the tunnel area, custom fiber optic transmitters and receivers were also developed which interfaced directly to the portal decommutation equipment. System improvements are an ongoing process and will continue through a series of UGTs until a ‘standard’ direct digital data recording system is in place.