FIBER-OPTICALLY ISOLATED INSTRUMENTATION FOR PULSED POWER SYSTEM DIAGNOSTICS

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Abstract

Advances in analog fiber optic telemetry and high sample rate/wide bandwidth analog-to-digital converters have enabled the development of increasingly sophisticated instrumentation suited for the highly stressing electromagnetic environment associated with many pulsed power systems. We report the development of several new capabilities, one based on analog modulation of the fiber-transmitted light and one in which a high-bandwidth digitizer is packaged in a compact configuration and the light signals are transmitted digitally using standard network protocols. Both systems are battery powered and heavily shielded to allow measurements to be made in regions of extremely high field strengths. Connection with external instrumentation and control systems is accomplished by using only fiber-optic cabling, providing completely isolated measurements.

I. INTRODUCTION

Instrumentation of high voltage pulsed power experiments can be problematic because of the strong electromagnetic (EM) fields present around the measurement location, and the need to maintain isolation through the walls of shielded enclosures. Isolation is important to maintain measurement quality and to ensure personnel safety.

Traditional methods of instrumentation involve placement of an oscilloscope inside a shielded container in close proximity to the measurement point, or the use of analog fiber-optic telemetry systems to route the measurement signal to an external oscilloscope. The first method permits DC-coupled wideband measurements with input impedances of 50 or 1 M , while the second method does not.

Several approaches have been used to build specialized instrumentation to meet specific requirements. The ideal time-domain acquisition system would digitize the analog signal as close as possible to the measurement point. However, space, power consumption, and bandwidth constraints may limit the utility of these remote digitizing systems. For these reasons, several application specific systems have been developed, including a compact remote digitizer and an ultra-wideband analog fiber optic link.

II. COMPACT REMOTE DIGITIZER

Analog fiber-optic telemetry systems require regular calibration and careful treatment of fiber-optic cable and terminations. These restrictions can be significantly reduced by digitizing the analog signal at the source and transmitting digital data via fiber. The compact remote digitizer (CRDAQ) currently under development seeks to lift these restrictions. This system is a fiber-optically coupled, battery-operated device contained in an EM-hardened case with dimensions of 8.4” x 4.4” x 5.3”.

The instrument is based on the 3U CompactPCI (cPCI) standard using commercial-off-the-shelf (COTS) computers and digitizers. For this application the computer was chosen for low power consumption since the need for computing power is minimal. Two digitizers, a 250MHz and 1.5GHz model, have been tested in the system. The 250MHz digitizer or DC110, is a commercially available product from Acqiris while the 1.5GHz (DC152) system is a new product being developed through a cooperative effort between the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), and Acqiris USA. Table 1 presents a summary of the CRDAQ specifications and Figure 1 shows a system block diagram.

Table 1 - CRDAQ Specifications

Parameter	DC110	DC152
Battery	28.5V, 5.5 Ahour Lithium-ion	
Power Consumption Sampling Standby	 30Watts 3 Watts	 45.6 Watts 3 Watts
RF Bandwidth	DC-250MHz	DC-1.5GHz
Resolution	8 bits	10 bits
Sample Rate	100S/s - 1GS/s	200S/s - 4GS/s
Memory	128k	256k/channel
Full Scale Range	50mV to 70V (1 W Avg Power)	
Segments	200 max	1800 max
Input Impedance	1meg, 50 ohms	50 ohms

CRDAQ consist of the electronic subassembly containing all of the system components in a single package and an enclosure into which the subassembly is inserted for EM shielding. The electronic subassembly is designed to be removed from the enclosure and remain fully functional while allowing access to the system components for maintenance or repair. Figure 2 shows how the cPCI computer, digitizer, battery pack, and

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Advances in analog fiber optic telemetry and high sample rate/wide bandwidth analog-to-digital converters have enabled the development of increasingly sophisticated instrumentation suited for the highly stressing electromagnetic environment associated with many pulsed power systems. We report the development of several new capabilities, one based on analog modulation of the fiber-transmitted light and one in which a high-bandwidth digitizer is packaged in a compact configuration and the light signals are transmitted digitally using standard network protocols. Both systems are battery powered and heavily shielded to allow measurements to be made in regions of extremely high field strengths. Connection with external instrumentation and control systems is accomplished by using only fiberoptic cabling, providing completely isolated measurements.

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controller board (power conversion, communications, power control, and system health) make up a self contained assembly. The hardware to contain the electronic subassembly consists of a custom designed part (produced via Stereolithography or SLA techniques) that attaches to the cPCI backplane to make the self contained assembly. This complete assembly is then inserted into the shielded enclosure, which has ST connections for fiber Ethernet, a SMA connector for the input signal, EMI air filter for cooling, and a separate cover for easy removal of the battery (Figure 3).

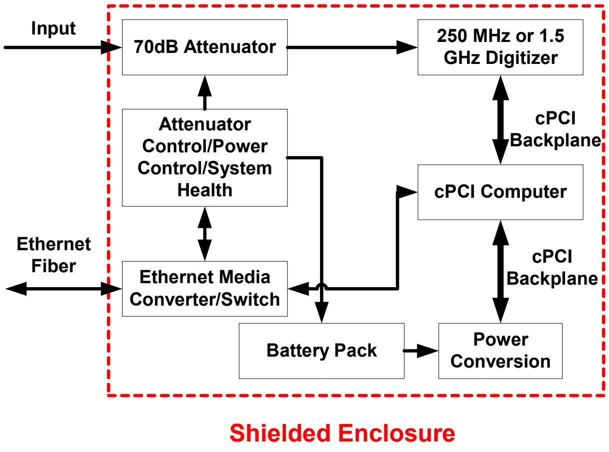

Figure 1 - CRDAQ system block diagram

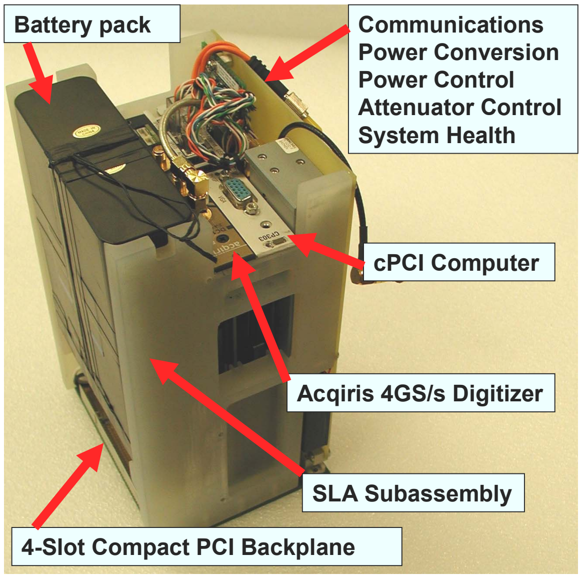

Figure 2 – Photograph of the CRDAQ electronic sub-assembly

In order to keep the CRDAQ as efficient and compact as possible the controller board is a simple two layer printed circuit board populated with COTS components. Using COTS components reduces the dependence on extremely specialized circuits, thus making maintenance and repair for the end user easier (Figure 4). The same is true for the battery pack since it is comprised of 4 Sony Lithium-Ion camcorder batteries connected in series to produce the 28.8V 5.5 amp hour pack.

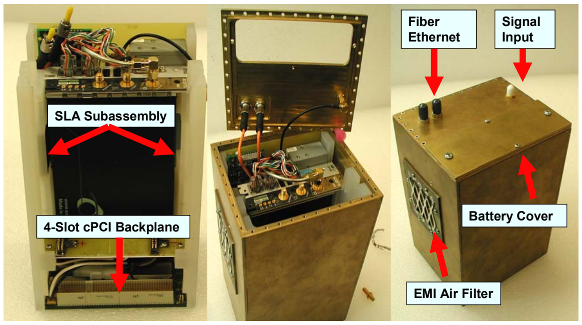

Figure 3 – Photo series showing the CRDAQ assembly process

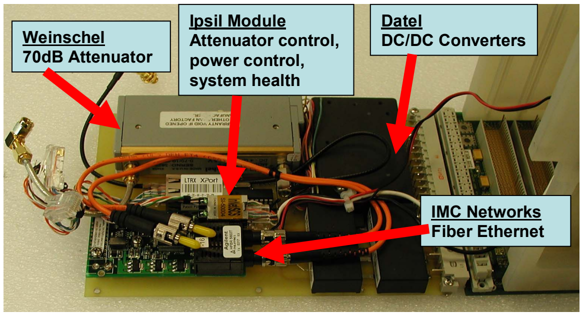

Figure 4 – Photograph of the CRDAQ controller board

Control of the CRDAQ is accomplished using any Windows XP operated computer with Ethernet communications by two programs; one to control the Ipsil module and one to control and obtain the data from the Acqiris digitizer. The Ipsil module program monitors battery voltage, internal temperature, controls the attenuator setting, and provides for remote startup and shutdown to conserver battery life. A program developed by Acqiris, AcqirisMAQS or Multichannel Acquisition Software, provides a virtual window into the digitizer for configuring the acquisition parameters, arming the unit, and displaying the digitized data which can be saved to a file for further analysis at a later date.

Testing of both the 250MHz and 1.5GHz CRDAQ models has been performed showing very good correlation with commercial measurement equipment. The DC110 or 250MHz model was used in a recent field test of a pulsed power source at MOATS, the NSWCDD open air test facility which supports testing of a variety of radio frequency and high-voltage sources. In this test an Eaton 91550-2 150MHz current clamp was used to measure the coupled current on a single power cable with both the DC110 CRDAQ and an EG&G ODT-E6 200MHz analog fiber transmitter. Figure 5 shows how well the CRDAQ signal is correlated with the EG&G signal. One significant observation is that the noise floor of the CRDAQ is less than that of the EG&G.

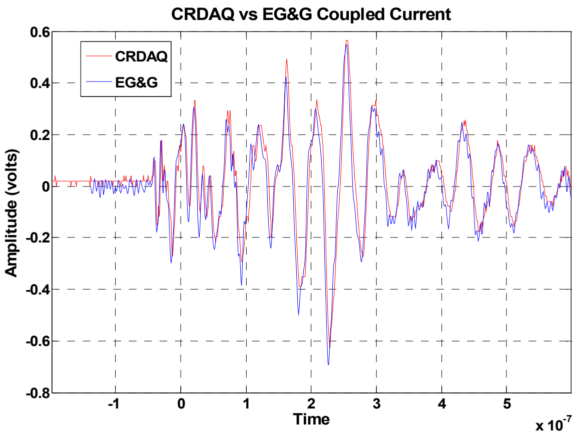

Figure 5 – Waveform comparison from signal measured with 250 MHz CRDAQ and EG&G analog system

The DC152 or 1.5GHz CRDAQ verification measurement was made in the laboratory, where it was compared with a Nanofast OP300 1GHz analog fiber link and a direct measurement into a Lecroy Wavemaster 8300A, using a Bournlea pulse generator as the stimulus. The signal from the Bournlea was sent through a 3-way power splitter to all three instruments where a single pulse was simultaneously sampled and used for comparison. In Figure 6 it can be seen that the CRDAQ measurement is in agreement with the Lecroy oscilloscope as well as exhibiting less noise than the Nanofast analog measurement.

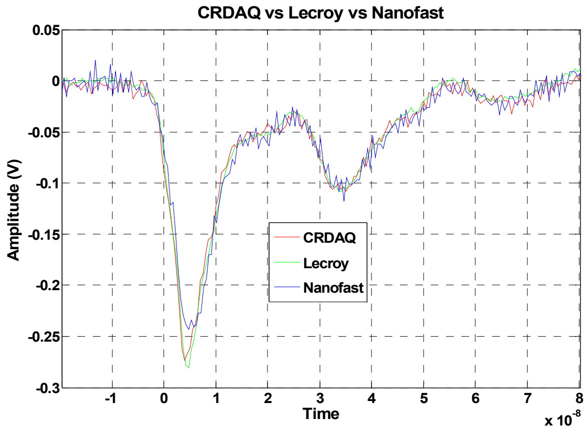

Figure 6 – Waveform comparison form signal measured with 250 MHz CRDAQ, Lecroy Wavemaster, and Nanofast OP300

III. ULTRA-WIDEBAND ANALOG FIBER OPTIC LINK

Direct acquisition of signals with frequency content above 1.5 GHz currently cannot be performed with reasonably sized remotely located digitizers. The remote instrumentation size is particularly important when sampling the EM field inside an object or building, as is commonly done in High Power Microwave (HPM) testing. As a result, an analog ultra-wideband (UWB) capability was developed. The overall size of the UWB transmitter is 5”x5”x5”, which is a comparable to other analog transmitters exhibiting an order of magnitude less band width.

The system, pictured in Figure 7, consists of up to eight EM-hardened, battery operated link transmitters (brass box), fiber optic cable up to 2 km in length (one single mode data fiber and two multi-mode Ethernet fibers), and an eight-channel link receiver (white box with blue front). The effect on system gain for different fiber optic cable length is relatively minor, as shown in Figure 8, and can be easily corrected for a measurement.

Figure 7 – Photograph of UWB analog link transmitter, fiber, and 8-channel receiver

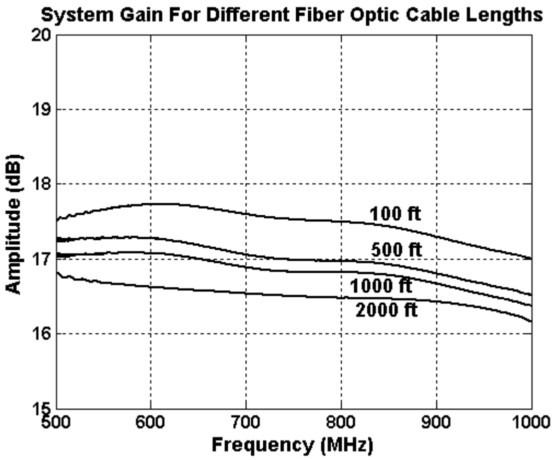

Figure 8 – Graph showing attenuation variation with fiber optic cable length

Each link transmitter has a default gain of +18 dB and contains a bank of six programmable attenuators, which are set to 6, 10, 12, 20, 24, and 40 dB, allowing the overall system gain to be varied from +18 dB to -94 dB. The frequency response for each attenuator is shown in Figure 9 for 50 MHz to 6.5 GHz. The attenuators are controlled by a C-programmable embedded controller, which is mated to a custom printed circuit board containing analog monitoring circuitry. This circuitry allows the transmit laser temperature and battery voltage to be monitored. Communication with the link transmitter is by 100 Mb/s fiber Ethernet. The complete system is functionally described in Figure 10.

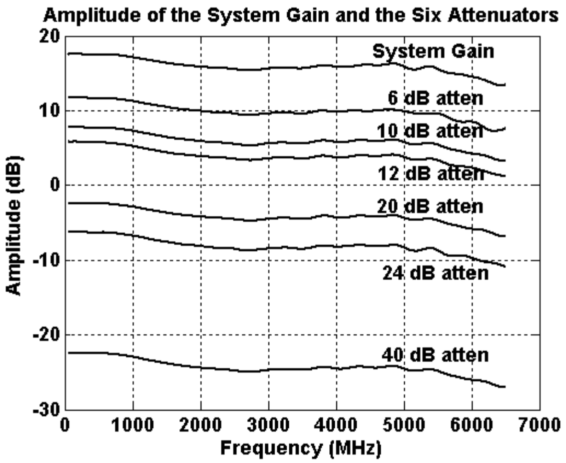

Figure 9 – Graph showing frequency response of the different attenuators (note the +18 dB offset because of the fixed internal gain)

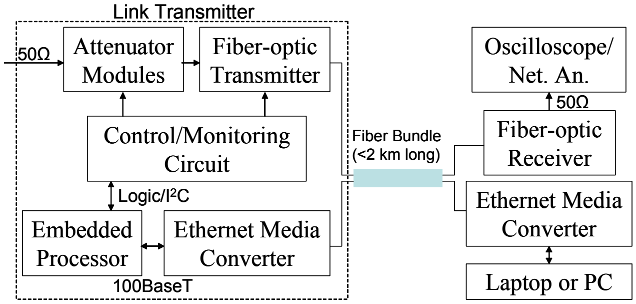

Figure 10 - UWB Analog Link Block Diagram

The link transmitter physical layout is shown in Figure 11. The fiber transmitter was mounted directly to the brass enclosure using thermally conductive grease to facilitate heat transfer.

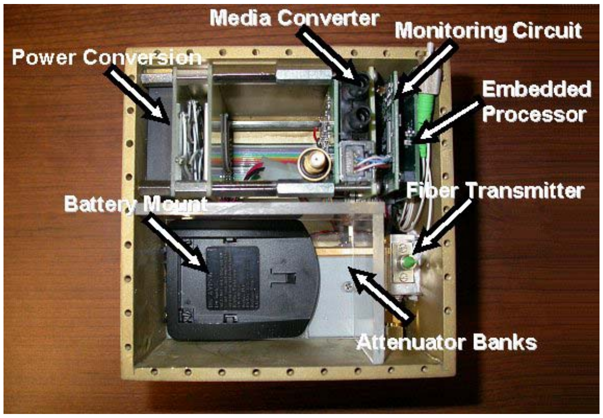

Figure 11 – Photograph showing the link transmitter physical layout

Laser-based fiber-optic transmitters and receivers are used to convey the RF signal (50 kHz to 6 GHz). The fiber-optic components were custom manufactured by MITEQ, Inc. The use of single mode fiber has significantly increased the bandwidth of these devices, but requires laser diode-based transmitters with a 1550 nm wavelength. This type of laser is susceptible to temperature dependent wavelength variation, which is mitigated by the use of thermal electric cooler (TEC) devices. Transmit laser wavelength variation as well as preamplifier gain variation results in decreased link gain with increases in temperature. The average link gain decreases by 1.4 dB from 25º to 50º C. The current supplied to the TEC increases from 172 mA to 688 mA for the same change in temperature. Therefore, the links remain stable over a greater temperature region but the TEC will draw more current. The UWB link performance specifications are shown in Table 2.

Table 2 - UWB Specifications

Parameter	Typical Value
Power Consumption$^{\Psi}$	13 Watts
Battery Pack	
Voltage	7.2 Volts
Capacity	5.5 Amp-Hours
Chemistry	Lithium-ion
Battery Life	
Standby	8 Hours
Active	3 Hours
Operating Temperature	0 to 50° C
Input Impedance	50
Spurious-Free Dynamic Range	40 dB (1 GHz BW)
Minimum Detectable Signal	-69 dBm/80 μV_{RMS} (1 GHz BW)

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V. REFERENCES

[1]“Technical Product Description, Models DC152 & DC122,” Acqiris SA, Geneva, Switzerland, Apr. 2004.
[2] Email Communication, Jan 2003, From D. Sundberg, MITEQ Corporation.

[Ψ] Power consumption specifications include a 70% conversion efficiency for the power conversion circuitry