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FIBER OPTIC TELEMETRY SYSTEM FOR LLL HIGH-VOLTAGE TEST STAND

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FIBER OPTIC TELEMETRY SYSTEM FOR LLL HIGH VOLTAGE TEST STAND*

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Summary

This paper describes the Fiber Optic Telemetry System designed to operate in the hostile particle and electromagnetic radiation environment of the High Voltage Test Stand. It discusses system criteria, components, packaging, and performance.

In all tests to date, the system exceeds its design goals with very comfortable margins. It is well advanced into the fabrication stages with all crucial components tested and only straightforward TTL (Transistor Transistor Logic) circuitry to be completed.

System Criteria

The basic system requirement was to provide for transmission of digital and/or analog signals over a distance of 20 to 30 metres while providing high voltage isolation of 200-kV. Digital signals were to have word lengths up to 32 bits for slow data. However, it was also desired that response capability of 1 μs be available for interrupts. Analog signals were to be dc to 50-kHz response, bipolar 10-V 12-bit resolution. A dc signal normally on was required for fail-safe control of the crowbar on the 200-kV power supply.

System Implementation

Type

A fiber optic system was chosen to provide the high voltage isolation and, in addition, eliminate noise interference and ground loops. Direct-amplitude, modulated-analog systems using solid state emitters suffer from nonlinearity, dc baseline drift, and loss of calibration due to emitter and link degradation. Our choice of a readily available analog to digital converter sidestepped these problems and saved design time. Of course, a compatible digital to analog unit is required at the receiver end of the system. The A/D converter chosen is an 8-bit successive-approximation type with fast conversion speed (2.8 μs) and low cost ($55 in unit quantity). Our 2-megabit clock rate drives the converter at a conservative 4.0 μs sample interval. Allowing five consecutive sampling intervals to define a cycle, the 250,000 samples per second should comfortably reproduce the 50-kHz required. We are programming the A/D over several unipolar and bipolar ranges up to and including ±10-V. In our application, we are using the serial data output option. The digital portion of the telemetry system is standard TTL logic which is readily available, low cost, and reliable. Most of it was available in LLL stock.

Format

A major constraint was the requirement for a continuous output signal to be turned off when crowbar was required. This places harsh requirements on the transmitter LED. However, once this condition was met, the duty cycle of the digital pulse train was no longer a consideration and the need for special formatting and its complexities disappeared. Our transmitted pulse train comes directly from the output of the multiplexers.

Design Goals

To provide maximum versatility in the types of data channels available, the circuitry was partitioned building-block fashion into several segments. In that way, the same blocks could be used in several different configurations. Rapidly changing experimental requirements can be accommodated by removing some blocks and replacing them with others. In addition, new blocks can be designed and added as the need arises. Thus, obsolescence is not one of our problems. Table 1 is a listing of circuit boards presently used in our system. As previously noted, these can be connected to provide the following types of data channels: digital direct; 2-, 4-, 8-, 16-, 32-bit multiplex analog direct; single analog plus 18-bit digital-bit hybrid and dual analog plus 2-digital-bit hybrid. In some cases, the boards are only partial, loaded with parts. The 2- and 4-bit digital channels are in reality an 8-bit channel with the inputs appropriately strapped together. A partial listing of channels

	Type No.
Fiber optic transmitter	1
Fiber optic receiver	2
Clock, buffer and sync generator	3
Digital data and control, 8 bit	4
Digital line driver	5
Digital line receiver	6
Analog line driver	7
Master sync and control II	8
Testpoint	9
Analog line driver, 12 bit	10
Digital multiplexer, 32 bit	11
Hybrid multiplexer, 8 bit	12
Transformer testing, 8 bit	13
Digital sequencer, 32 bit	14
Hybrid sequencer, 8 bit	15
A/D converter and signal conditioner	17
D/A converter	18
Transfer data, 8 bit	19
Power supply regulator - data, to ±5 V	20
Hybrid data, 8 bit	21
Power supply regulator - data, to ±15 V	22

Table 1. Circuit boards

*This work was performed under the auspices of the U.S. Department of Energy under contract No. W-7405-Eng-48.

Hybrid MPX w/dual A/D	TX	1-071	2-171	1-131	1-021		
	RX	1-031	1-161	1-211	1-141	1-191	2-181
		2-111	1-061				
Hybrid MPX - 18 bit	TX	5-071	1-131	1-171	1-021		
	RX	1-031	1-161	2-211	2-141	1-181	1-111
		2-191	5-061	1-KLU			
Digital Direct	TX	1-071	1-021				
	RX	1-031	1-061				
Digital MPX 8 bit	TX	2-071	1-121	1-021			
	RX	1-031	1-151	1-051	1-141	2-061	
Digital MPX 16 bit	TX	4-071	1-121	1-021			
	RX	1-031	1-151	1-051	1-151	4-061	
Digital MPX 32 bit	TX	8-071	1-121	1-021			
	RX	1-031	1-151	1-051	2-141	8-061	

Sta 1 needs Master Clock and sync - 091
2 ea clock buffer and sync detector - 041
3-021

Sta 2 needs	1-031	1-041		
Sta 3 needs	1-031	1-041	2-221	5-201
Sta 5 needs	1-031	1-041	1-221	1-201

Table 2. Multiple Channel PC-board Complement

and the boards needed to implement them appear in Table 2. Typical block diagrams of an 8-bit digital link transmitting and receiving end appear in Figs. 1 and 2.

Packaging

Each circuit board noted in Table 1 is in CASH card format with the PCD artwork on single-1-1/2- or double-width cards as required. The standard card is 2-1/2-in. wide by 5-in. high for the single-width unit. Interconnections, power, and I/O are made using 16-pin flat cable with appropriate connectors. Each card has one or more cables that go to a header card where the connections are made. All cards are mounted into a planar packaging chassis (Fig. 3) which can hold 36 single-width cards. The fiber optic transmitters and receivers mount to the back apron. Power supplies for ground potential units mount to the front panel. Dual fans are provided on the side aprons. Balanced digital I/O are on circular MS connectors. Analog signals are on BNC connectors. Provision is made at each connector to have cable shields either grounded or floating to avoid ground loops.

Components

Fiber Optic Cable

One of the first choices of a designer is to pick a suitable cable. The choice is not easy since there are so many types. The variables include step index, graded index, plastic, glass; glass type and index for core; glass type and index for clad; core diameter, clad diameter, numerical aperture, core-to-clad ratio, packing fraction, number of fibers, fiber attenuation, and reflections, etc. It is beyond the scope of this paper to discuss all of these. What is of interest is to find a cable that will do the job and is cost effective. As a rule of thumb, the lower loss-per-foot cables have far higher end losses and are not cost effective until long runs are involved. An excellent discussion of this characteristic is available in the literature.[1] On this basis, we chose a cable having 212 fibers of flint-glass core with borosilicate cladding in a step-index bundle of approximately 45-mil diam. We noted some brittleness which is thought to be caused by water absorption. Fortunately, the problem appears to be controlled by

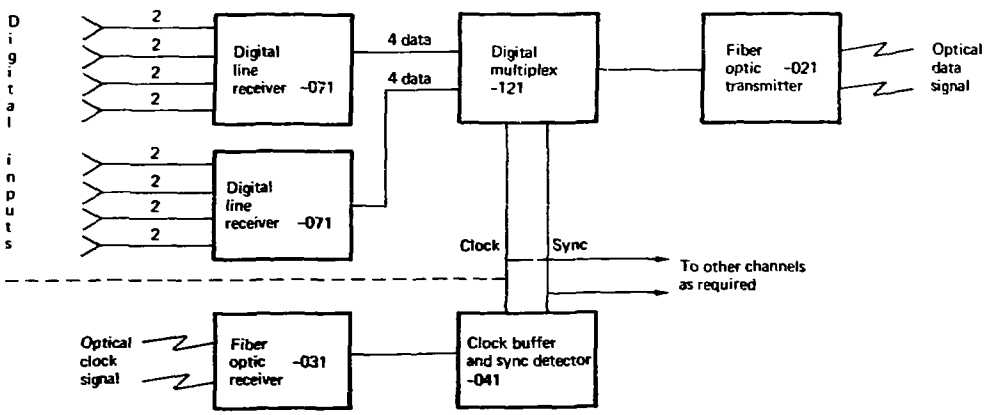

FIG. 1: Typical 8-Bit Digital Transmitter

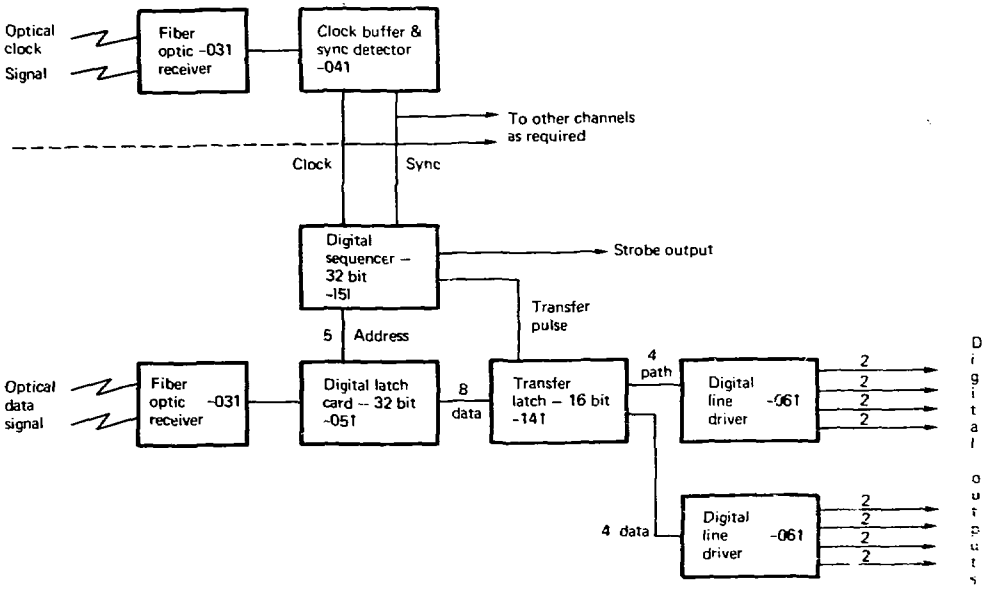

FIG. 2: Typical 8-Bit Digital Receiver

careful terminating procedures. First, the space between fibers must be filled with bonding agent to avoid capillaries, and second, ethylene glycol should be used as a carrier for the polishing grit in place of water. Tests results were poor in some of the first cables we prepared using 5-min epoxies and water for polishing. Current tests just completed using Loctite® No. 414 and ethylene glycol yield minimal damage, i.e., none to several broken fibers under the same conditions. The Loctite has low initial viscosity to thoroughly wet the fibers, yet bonds rapidly when required. The present connector interface withstands better than 3 days of water immersion.

Fiber Optic Connector

Once a suitable fiber optic bundle is chosen, the only way a user can optimize and minimize insertion losses is to optimize packing fraction and end losses. The other parameters are vendor controlled. Thus, our choice should provide:

- The ability to optimize packing fraction.
- The ability to terminate and polish under field conditions using ordinary laboratory technicians with minimal training to produce repeatable results.
- A broad line that we can adapt to whatever cable, transmitter or receiver we happen to require in our system.
- Economical price for cost effectiveness.

A thermoplastic connector is available that meets all these criteria. The thermoplastic material is radially compressed about the fibers at assembly by a polishing bushing, and is the means of optimizing packing fraction. At least one source has determined there is no advantage beyond a 600-grit finish [1] which is easily producible in the field. There are some potential problems using plastic connectors:

- Inadequate bonding of the fibers to the body of the connector.
- Variation in the plane of the polished bundle if a "soft" polishing bushing is used and insufficient attention is paid.
- Larger tolerances in axial alignment than found in metal connectors.
- Lack of metal heat-sink properties.

Bonding-We noted a problem using both fast epoxy and a slower overnight-cure type stocked at LLL. In some cases the entire bundle slipped. In other cases,

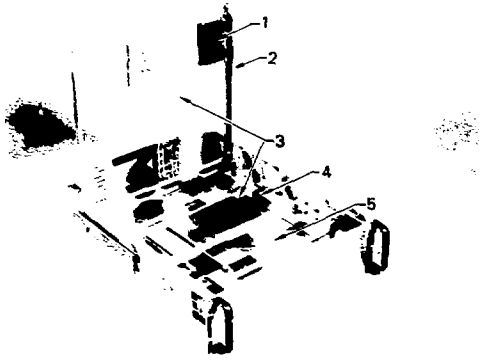

FIG. 3: Planar Packaging Concept:
1) top plant--18 PC card locations;
2) top layer tilts up for easy maintenance;
3) PC card mounting rails;
4) PC cards mount flat;
5) bottom plane--18 PC card locations.
One or more chassis constitute a system.

individual fibers throughout the bundle shifted with respect to the body, indicating poor wetting by the epoxy. The problem is apparently solved using the Loctite mentioned earlier.

Polishing–A polishing bushing made of plastic is soft compared to polishing grit. There is only one distance from the seated bushing that is ideal for the face of the finished bundle. Terminations longer than that will produce interference on assembly, and fortunately are unlikely. Terminations shorter than ideal produce setback and loss of coupling. There are two solutions to the problem. One possibility is to use coupling gel to fill the setback. A second is to fabricate a polishing bushing using a hard metal at exactly the proper distance. This is the sure-fire method if you are doing enough cables to make it worthwhile; it is our choice.

Axial Tolerances–There are possible axial misalignments of around a mil or so with plastic connectors. In our case, since we have a 20-mil source centered on a 45-mil diam bundle, this error in itself is not serious. There are far greater errors elsewhere in the system, to be discussed later.

Heat Sinking–There is no combining heat sink and connector, since to make a connector of metal would preclude its use in radially compressing the bundle to optimize packing fraction. The solution to this problem is to make an independent heat sink for the few LED's that require it. The advantages of this type of connector outweigh the small extra cost, at least for our bundle geometry.

Fiber Optic Receiver

The fiber optic receiver board consists of a hybrid IC optical receiver, a comparator and dual Schmitt trigger inverters. These components are mated on a small PC board with a fiber optic connector. Their purpose is to detect the optical signal and regenerate the original digital waveform, restoring it to TTL levels for use by the rest of the demultiplexing logic. The hybrid consists of a PIN photodiode coupled to a high-gain bandwidth transimpedance amplifier in a TO-5 package with a window top. This type of device, available from several manufacturers, offers noise and bandwidth advantages over the equivalent discrete-components circuitry. Our choice is specified to give 50-mV/μW output at 900-nm with a 3-dB bandwidth of 4.5-MHz and an rms noise output of 500-V. The only problem with this unit has been getting enough of them. The comparator has an adjustable threshold to set the slicing level of the incoming waveform and restore the 50% duty cycle to the clock waveform. The output drives Schmitt triggers to sharpen the leading and falling edges of the regenerated waveform.

Fiber Optic Transmitter

The fiber-optic transmitter board consists of an LED, driving IC, pulse control circuit, and heat sink. These components are mated with a fiber-optic connector and a hold down ring designed to keep the fiber bundle face centered and parallel to the LED emitter.

LED Choice–The choice of a suitable LED for a high-performance system becomes a tedious process. From the start we knew that 100% "on" duty cycle would pose some problems. Naturally, we took care to minimize losses elsewhere, thereby minimizing the radiant energy we would need to launch into the cable from the LED. Initially, some LED's can be ruled out. Silicon-doped GaAs are high output diodes, but have slow rise and fall time limiting them to systems under 1-MHz. Straight GaAs is faster, but output at 905-nm is close to absorption band in glass. Gallium-Aluminum-Arsenide is available radiating at 885-nm with rise and fall times under 100-ns, and is our material of choice. In our first efforts we used a device designed for very high power having a massive stud mount to draw heat away, and a large dome epoxy lens to focus the output into a smaller beam angle. We had to discard this unit when we discovered tolerances on the epoxy part too loose to accommodate our connector, but not before we discovered that grinding the epoxy lens to within a few mil of the chip resulted in an increase of 2.5 times the amount of power through our test cable, with all other conditions the same. We found an LED with desirable characteristics in a TO-5 header. It is rated at 2-mW at 100-Ma forward current, 885-nm, under 100-ns rise and fall time, 20-by-20-mil, die very close to the face of the header, embedded in epoxy. We have experienced a number of problems with this LED; the most severe is that some chips are not on the centerline of the header. Despite our problems with this unit, it is the best one available for its cost at the present time.

Circuit Choice–Our circuit configuration was influenced by a number of references in the literature. First, references indicate that LED risetime can be speeded up by a spike on the driving waveform leading edge. Second, other references indicate that part of the problem of slow falltime is caused by stored charges in the junction after turnoff, and recommend back biasing to sweep them out. At least two vendors, Develco and Texas Instruments, apply this principle in published circuitry. Our driver IC is an SN75024 dual-clock driver in totem-pole configuration designed to provide 1.5-A current pulses to highly capacitive loads. It is unlike ordinary TTL, however, in that source and sink transistors, which carry most of the chip, cannot be on at the same time. Current glitches in the power supply are thus prevented. Both sides are driven in parallel. The outputs feed the LED cathode through current-limiting resistors. The LED anode returns to a +5-V buss. Small capacitors shunting the resistors provide the leading edge spike. They charge to about 2-V, and provide reverse bias when the IC switches from sink to source. Sometime after the initial circuit was tested, we discovered inrush current glitches in the supply, and RFI radiating into the TTL logic. Ferrite beads at several points in the circuit, including each capacitor lead, solved the problem. We have measured risetime at 35-ns or considerably better than the specification sheet, which seems to affirm that theory. We have not had such good luck with falltime; it is around 90-ns.

Heat Sink–The heat sink assembly (Fig. 4) is designed to conduct heat from the base of the TO-5 through a

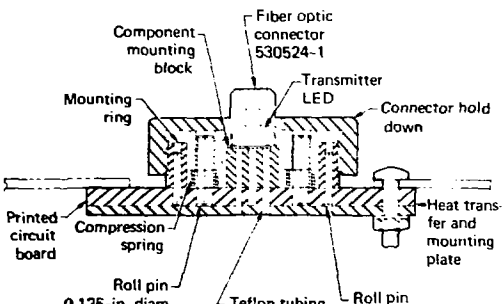

FIG. 4: Heat Sink Assembly

copper slug to a copper plate, and then to the chassis apron. Also attached to the copper plate are a threaded ring which holds a threaded hold-down cap in contact with a spring-loaded connector. These other parts are also made of copper to add thermal mass in contact with convective air. They also provide additional shielding. This arrangement is designed to keep the polished fiber end in contact with and parallel to the face of the TO-5 header. Tests were run to determine the method of attaching the LED to the copper slug. We tried standard heat sink grease, thermal conductive epoxy, and indium solder. The temperature required to apply the latter caused the LED epoxy to become opaque making it unacceptable in service, though we did test its conductivity. The conductive epoxy Delta Bond No.152[7] appears to be every bit as good as the indium and far superior to heat sink grease. The heat sink probably represents overkill. Bench tests indicate an LED seating plane temperature of approximately 80° F at 100 mA drive current, 100% duty cycle. This was 7° F over ambient. With the sink connected to a chassis plate drawing heat out, and a fan blowing air at it, it will probably run even cooler. In fact, the IC tends to run hotter than the LED, and benefits also from a heat sink glued to its top surface. We ran as much as 250-mA continuous through both units, with the temperature stabilizing well below limits of either unit (85° F). We expect no problems in service.

Performance

The signal at the output of the receiver amplifier after traversing a cable of 55-ft., including all interfaces, is a healthy 200-mV. Since comparators can and do easily recover digital waveforms from as little as 10-to-20-mV signal, one can see we have an enormous margin. The input to the LED to produce this signal was a 2-MHz, 50%-duty-cycle clock signal driving the LED at an average current of 50-mA. An extra 9-dB loss would reduce the signal by a factor of 8 to an acceptable 25-mV. Doubling the fiber optic length to 110 ft. would only use up an additional 4.25-dB, so we could easily double the length. Alternatively, we could reduce the transmitter power. Keeping the system as is, we have very comfortable margins against emitter and fiber degradation, worst case misalignments, etc. All components are performing above minimum requirements.

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