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SHIELDING INTEGRITY ON A CONTROLLED FUSION EXPERIMENT**

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USE OF FIBER OPTICS TO ELIMINATE GROUND LOOPS AND MAINTAIN
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Abstract

Fiber optic technology is being used to solve electromagnetic compatibility problems on ZT-40. Design and performance parameters of four different types of optical links are discussed.

Introduction

The CTR Division of Los Alamos Scientific Laboratory is engaged in research directed at developing a power source utilizing magnetically-confined fusion plasma. The most recent experiment being constructed is the ZT-40 Reversed Field Pinch. A significant feature of this type of device, from a systems designer's point of view, is the potential for a large amount of electromagnetic interference with control and data signals. The primary noise source is in the form of a pulsed dipolar magnetic field. It is necessary to interconnect the various electrical subsystems in such a way that ground loops are eliminated or minimized. It is also necessary to house the data acquisition equipment in a shielded enclosure, which should be protected from penetration by conductors exposed to the field. Since the control system and data acquisition system are connected to the same computer, a conflict arises because the control system must necessarily extend outside the shield.

Design work on ZT-40 began in 1977, when the use of fiber optics to break ground loops and penetrate shields was just beginning to be practical, and the new technology was adopted for these purposes. Figure 1 is a sketch of the ZT-40 system showing the major subsystems and interconnections, and indicating the problem loops and connections and the points at which these are broken by some isolation device. The points marked with asterisks are broken with the optical coupling hardware which will be discussed in this

Fig. 1. Sketch of interconnections among ZT-40 sub-systems.

paper. The target date for initial operation of the 2T-48 system, including the optical links described here, is June 1979.

I. Optically Coupled CAMAC Serial Highway

The computer interface to the control, data acquisition and trigger subsystems is accomplished via the CAMAC¹ standards. Several CAMAC crates are located in the screen room, the control center, and an auxiliary screen room used for routine capacitor bank diagnostics. A byte-serial CAMAC highway is carried on optical links to the externally located crates.

The byte-serial highway consists of 8 data lines and one clock line carried in a loop connecting the CAMAC driver in the computer and all the CAMAC crates. Thus 18 optical channels are required, 9 in each direction. The CAMAC standard requires differential current-driven pairs which operate at rates from DC to 5 Mbaud. To establish the reliability required in the 2T-48 operation, these data communications channels should have an overall bit error rate of less than 10^{-10} . A survey of the market in 1977 turned up several reasonably priced candidate links, some of which were bought and tested. All showed problems and were rejected. The decision was then made to develop the necessary hardware in-house.

The circuit resulting from this effort is a standard configuration, shown in Fig. 2. The design procedure was somewhat as follows: bit error rate, noise level, and provisions for signal degradation, component and power supply variations determine the signal level required at the comparator input. This and the gain bandwidth product of available amplifiers and the bit rate requirement determine the optical power which must be incident on the photo diode. That power, cable and connector losses and bit rate then provide criteria for selecting the LED, fiber, and connectors. The LED selected injects a minimum of 150 μ w at 825 nm into the fiber. At least 40 μ w is detected by the photodiode. The signal-noise ratio at the comparator input is about 30.

Some relaxation of signal level requirement would be possible if provision were made at the comparator stage of some sort of automatic threshold control to compensate for signal amplitude variations. This feature is difficult to implement in a system which operates down to d.c., and so was foregone. A bi-phase modulation scheme would make implementation easier but at a cost of doubling the system bandwidth requirements.

The splice indicated in the figure deserves comment. We wanted to use AMP plastic connectors but a splice with these has losses of 3-4 dB. We developed a technique of making splices by leaving the polishing bushing on the AMP connector and aligning the fibers in an x-y positioner, then gluing the bushings together. This produces splices with 1-2 dB loss.

* Manufactured by RCA, model #C38133.

Fig. 2. Block diagram of 5 Mbaud optical link for byte-serial CAMAC highway.

Nine copies of each circuit are produced on printed circuit boards and mounted in a card file with necessary power supplies and wiring. In tests, the completed byte serial highway transmitted over 10^{10} bits without error. The ZT-40 control system is connected with this highway; a second is under construction to communicate with an auxiliary screen room used for bank diagnostics.

II. Optically Coupled Fast Trigger Generators

The electrical energy to operate the experiment is stored in several large capacitor banks. Each bank consists of capacitor-spark gap combinations all connected in parallel to a load. All the gaps in a bank must be triggered simultaneously within a few nanoseconds and timed with respect to other banks within a few tens of nanoseconds. Such a system requires low jitter, short risetime, high voltage trigger pulses, and is susceptible to noise induced in intra- and inter-system ground loops. Decoupling the timing system has been a goal of experimenters at LASL for many years.

A block diagram of one channel of the trigger generator is shown in Fig. 3. (There are 24 channels available.) A computer generated trigger starts a digital time delay. The delayed output drives a laser diode with a 40 amp pulse rising in about 5 nsec. The diode output is about 12 watts peak at 904 nm. It is mounted in a modified AMP bulkhead connector and coupled into a length of up to 100 m of Du Pont PFX-S120R PCS fiber. The detector is an RCA C30808A photodiode also mounted in an AMP bulkhead connector. The photo current is amplified and triggers a KN6-B krytron which produces the 5 kV output pulse. Another circuit, not shown, detects the output pulse and produces an "output confirm" indication at another chassis located in the screen room. This signal is also optically coupled.

The optical receiver electronics is mounted in a shielded module which also contains all necessary power supplies and an air turbine-driven alternator. This unique feature eliminates troublesome ground loops which often otherwise occur as a result of connections to the AC power line. Even isolation transformers have enough capacitance (typically 300 pf) to complete the loops for the high frequency components of some waveforms.

III. Slow Analog Links

To break a ground loop in the vacuum and fill pressure monitoring section of the vacuum control subsystem, a slow, precise analog optical link was required. The link design was based on the Burr-Brown VFC 32 voltage-to-frequency converter. Figure 4 is a block diagram. The input level of 0-10 volts DC is converted to light pulses varying in frequency from 12 kHz to 21 kHz. The LED is a Fairchild FLV 104, a low cost panel mountable display type with a plastic lens emitting at 660 nm. For this application and others we mount the LED in an AMP bulkhead connector by first grinding off the plastic lens

Fig. 3. Block diagram of timing system optical link.

Fig. 4. Block diagram of slow analog optical link utilizing voltage-to-frequency converters.

and body to within a millimeter of the die, then polish the surface and glue it in place with epoxy cement. The fiber used is DuPont Crofon 1100, a low cost, high loss plastic fiber suitable in this application for runs less than 10 meters.

The detector is a C30808A photodiode mounted in the AMP bulkhead connector and driving a National LM302CH in the transimpedance amplifier mode. The comparator and VFC32 comprise the remainder of the circuit needed to produce the output voltage. Additional circuitry adjusts for offset voltage and calibrates the overall system gain. The circuit has a natural bandwidth of 300 Hz. We have rolled it off at 20 Hz to reduce interference problems. The linearity is close to 0.1%.

IV. Slow Digital Optical Link

The vacuum system also requires optical isolation in the on-off control line for valves and pumps, and the lines which monitor the positions of these valves. The link developed for this purpose is shown in Fig. 5. Input signals, either contact closures or open collector TTL outputs operate an FLV-104 LED mounted as described previously. Crofon 1100 fiber is used again here. The detector is a Fairchild FPT 100A photo transistor and a current amplifier. The output device can be either a low-current relay solenoid, a Monsanto MCA 255 photo-darlington isolator, or a Hewlett Packard HCPL 2601 optically isolated TTL gate, as required by the application. Delay time is about 1 msec. About 160 channels of these links are installed on ZT-40.

V. Availability of Commercial Links

The availability, price and quality of some types of commercial links have changed

Fig. 5. Block diagram of optical link for slow control and monitor functions.

considerably in the two years since design work began, and if it were begun today commercial links would be used in some areas. There are still blank spots in the market place, particularly in the areas covered by the links described in sections III and IV.

There are two isolation functions on ZT-40 which will be implemented by commercial links: remote terminals will be connected to the computer on RS-232C links, the Burr-Brown model 3712, and voice communications are planned to be done on commercial links which have not yet been selected.

VI. Conclusions

The engineering staff responsible for the design of ZT-40 has invested heavily in optical data communications. Most of the links installed have been designed and built locally, often with home-made components such as the connector mounted LEDS described in Section II.

The availability of fiber optics technology has made it possible for the designers of ZT-40 to eliminate problems which have plagued experimenters in this field for many years. We are optimistic that continued developments, particularly in the area of high speed analog links, will make it possible that more problems will be solved in the near future.

References

1. IEEE Standards 595 and 596.