Fiber Optic Communications Links for the Main Ring Control System Upgrade

Robert J. Ducar
Fermi National Accelerator Laboratory *
P.O. Box 500
Batavia, IL 60510

Abstract

Fiber optic communication links have been implemented throughout the 6.5 km circumference of the Fermilab accelerator facility in support of the upgrade of the Main Ring Control System. The choice of optical fiber as a communication medium was based on cost and limited plant capacity for additional conventional copper based medium, rather than by the inherent advantages of high bandwidth and low loss. Details of component selection and performance of the custom designed repeater facilities will be discussed.

I. RATIONALE FOR FIBER OPTIC MEDIUM

As plans for replacement of the the Fermilab Main Accelerator control system began to materialize in early 1988, it was clear that additional links would be necessary to support the planned upgrade. The original coaxial cabling supporting Main Accelerator controls was routed through the accelerator enclosure and surfaced at each of the thirty service buildings of the 6.5 km ring. Periodic measurements had revealed a gradual degradation of the cable's characteristic impedance to the point where it was not reasonable to expect support of the new links which were to be an order of magnitude higher in bit rate. Five ring-wide cable paths were deemed necessary for the new control system. Some excess capacity remained on the installed nineteen conductor Heliax cable already in use for the Tevatron control system. However, these five circuits were available only in two-thirds of the ring circumference. Recapture of needed capacity from the nineteen conductor could have been made possible by installation of additional coaxial cable and by consolidation of several remote consoles.

A detailed analysis was performed to compare costs associated with implementation of conventional copper/coaxial links versus fiber optic links. The cost of a fiber optic installation was projected to be \$168K, which compared quite favorably to the \$187K cost of conventional links. A decision was made to install a twenty-four fiber trunk cable and to proceed with necessary engineering work to implement the desired 10 Mbit/sec links.

II. FIBER OPTIC CABLE INSTALLATION

A multimode graded index fiber (62.5/125 micron) was selected for the installation. Attenuation properties were not a significant issue since most runs were calculated to be approximately 300 meters in length. Bandwidth was also judged sufficient for anticipated applications. Multimode fiber was also considered to be easier to splice and better suited to the economical optical emitters and receivers available from component manufacturers.

Nearly nine kilometers of trunk cable was necessary for the installation. The installation involved thirty-one distinct pulls, ranging in length from 150 to almost 600 meters. Most of the pulls were routed in recently installed communication ducts buried below the Main Accelerator access road. This routing handily avoided exposure of the fiber optic cable to any radiation from the operation of the accelerator. Innerduct was utilized in these communication ducts. Innerduct was used sparingly once the cable was inside the accelerator service building, typically at only those points of high congestion or multiple bends. Cable ends were always routed directly to a rack mounted splice enclosure.

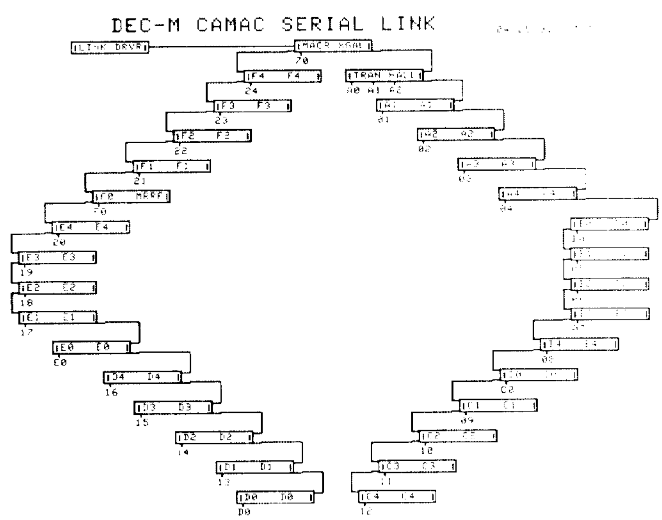

Figure 1. Diagram of Main Ring communications links for the installed CAMAC system. Boxes represent repeaters at service buildings. Numbers outside of the repeater boxes represent the addresses of connected CAMAC crates.

The selected cable contains four loose tube buffers, each holding six optical fibers. Connections to each of the five new links were required at each cable terminus. At the time of installation, no plans existed for use of the remaining nineteen fibers. Seven of these fibers were classed as building to building links and were fusion spliced to ST-connectorized pigtails at each terminus, as were the five necessary link fibers. Six of the remaining fibers were classed as longer sector to sector circuits. These were fusion spliced to pigtails at the sector zero buildings and series fusion spliced at numbered service buildings. The last six remaining fibers were left unspliced at each terminus. The splice enclosures housed six or seven splice trays, each tray accommodating six pigtail

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splices, or six series splices. Two splice trays were installed for the buffer tubes containing unterminated fibers. Pre-terminated and tested ten meter ST jumper cables were purchased and subsequently were cut and prepared as two separate pigtails.

Trunk cable installation and splicing was performed under contract with non-Fermilab personnel. Almost one thousand fusion splices were necessary to complete the installation. Nearly four hundred terminated fiber paths were certified with OPM and OTDR equipment at 850 and 1300 nm wavelengths.

III. FIBER OPTIC REPEATER DEVELOPMENT

The Main Ring Control System Upgrade [1] called for replacement of original (circa 1972) interface hardware with CAMAC crates and modules. Though some new designs were developed and implemented, much of the necessary hardware was already available. The Tevatron Serial Crate Controller [2] was re-engineered to a two-wide module. The Main Ring Power Supply Link was completely redesigned with new transmitter and receiver hardware. All necessary links for the Upgrade were based on the 10 MBit/sec serial protocol already in wide use in the Fermilab accelerator control system. Extant links are based on frequency detection of a 50 MHz carrier over coaxial cables, with the repeaters for this system being housed in 5 1/4" NIM bins [3].

Given the significant time of flight delays in the link cabling system, either coaxial or fiber, there was no significant motivation to develop faster links. There was, however, incentive to rework the nature of the repeater unit itself. The older "rf" repeaters were expensive and time consuming to build as well as difficult to adjust and troubleshoot in place. Local inputs or outputs of individual "rf" repeaters were limited to four. Branch points in implemented links required two slots of NIM space. These disadvantages were overcome with the new repeater design.

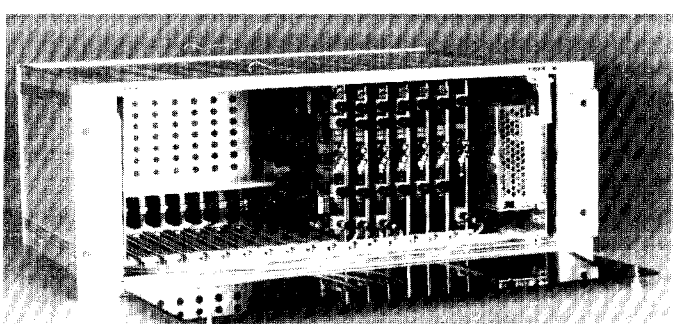

Figure 2. Fiber optic repeater chassis.

A repeater system was developed as a single chassis with individual printed circuit boards, rather than modules, serving as link repeaters. Fiber optic connections are made at the front of individual repeaters and are adequately protected behind a swing-down front panel. Local coaxial connections to the repeaters are accommodated at the back of the repeater chassis. Lemo style connectors are mounted directly at the rear of the repeater board and protrude through the repeater chassis back panel when the repeater is inserted. When inserted, the repeater board also connects to a small mother board that serves to distribute five volt dc power sourced from a power supply board assembly at the right end of the repeater chassis. Each repeater chassis can support up to sixteen individual repeater boards. Fiber optic pigtail cables from the adjacent splice center enclosure enter the chassis from the rear and are channeled at the left end of the repeater chassis to individual repeaters.

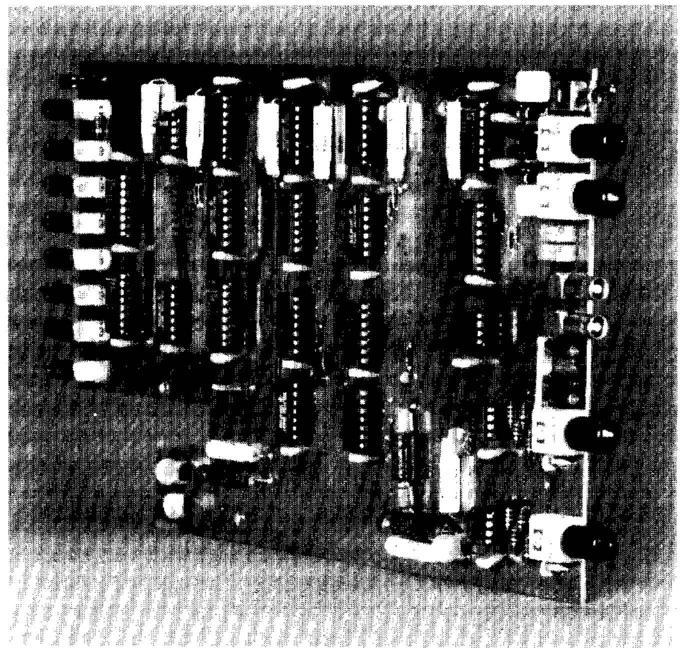

Figure 3. Typical fiber optic repeater. Pairs of optic transmitters and receivers are mounted at the front top and bottom of the repeater board. Local TTL 50 ohm connections are made at the rear of the repeater by means of Lemo style connectors.

The repeater board design is common to fan-in and fan-out configurations, determination made by selective component loading. Provision is made for two optic transmitters and for two optic receivers to facilitate link branch requirements at a single repeater station. Local coaxial connections at the rear of the module provide for six fan-in or fan-out connections as well as separate direct in and direct out connections. Separate LEDs at the back panel indicate the type of repeater as being fan-in or fan-out. Timing adjustments and diagnostic LEDs and signals are facilitated at the front of the repeater. A separate repeater board was designed to support the Main Ring abort link.

The design of the repeater circuit utilized low cost HP optic components (HFBR-1414/2414) connectored for ST. The LED transmitter was more than adequately driven by a single 74F3037 gate. The receiver circuit was developed from HP application notes [4] and employed the LT1016 comparator. The repeater processes 20 MBd data as 50 and 100 nanosecond light pulses that arrive in data frames of two to four microseconds in duration. The repeater's function is to pass leading edges of incoming signals with as little induced time skew as possible. Repeated pulse widths are adjusted locally at each repeater. This approach, also employed by the "rf" repeaters, avoids the necessity of reclocking data, but can present difficulties as minor time skews at an individual repeater accumulate after the signal is processed by multiple repeaters. Given the relatively short distances between service buildings, receiver sensitivity was really not an issue in the design.

Commissioning of the repeater system surfaced several problems with the repeater board design. Leading edges at certain positions in the data stream were being skewed by more than three nanoseconds per repeater. After four or five repeats, the transmissions were beyond the range of acceptance for local hardware. This problem was traced to a RC discharge problem at the input of the LT1016 comparator and was largely solved by reducing the coupling capacitor value from 39 pf to 12 pf. That action reduced sensitivity at the receiver. Because the skewing problem was aggravated at lower levels of input optical power, compensation was made at the transmitter by increasing driver current to near maximum. This lead to a second problem of overdriving the receiver. In analyzing this difficulty, measurements were taken of the output power of the transmitter at maximum drive. Output power of numerous individual transmitters was measured at -10 dBm, the maximum stated on the data sheet, rather than the expected -12 dBm typical specification. Reduction of transmitter drive current from 60 ma to 40 ma solved the overdrive problem. Subsequent measurements of the installed repeater system showed leading edge skew to be less than one nanosecond per repeater. Link signals repeated approximately fifteen times arrived at the far end of the repeater system with sufficient quality to operate error free.

IV. CONCLUSIONS

With more than eighteen months of operational experience, the new fiber optic link system has performed remarkably well. After the gross problems of leading edge skewing were solved, transmission errors are at such a low level that the links are considered error free. There have been no failures or problems with the installed plant cable, nor with any components of the installed repeater system.

Expenditures for the repeater system have been very reasonable. The cost of a powered repeater chassis is less than \$500. Individual repeater modules cost approximately \$170. Total repeater parts costs for 31 stations and some 150 individual repeater cards totalled less than \$40k.

Predictably, spare fibers have been used for other purposes. Two fiber circuits are currently supporting 802.5 Token Ring around the accelerator, using commercially available optic hardware. Other fibers support video and Ethernet facilities. Several fiber circuits were used to bypass coaxial "rf" repeater circuits that were temporarily disconnected during a construction period. The common transmission protocols made the bypass very easy to implement.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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[4] Hewlett-Packard Application Bulletin 73, "Low-Cost Fiber Optic Transmitter and Receiver Interface Circuits," 5954-8415(6/87), Figure 12.