# FIBER OPTICS IN THE BNL BOOSTER RADIATION ENVIRONMENT*

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## ABSTRACT

The Booster instrumentation uses analog and digital fiber optic links, designed to withstand at least 50 krads without performance degradation. The links use inexpensive and commercially available components that operate at a center wavelength of 820 nm. The analog link operates to 30 MHz over a 200 m fiber and can provide insertion gain. The digital link provides 60 ns timing pulses without the dispersive effects of coaxial cables. The optical fiber is a step-index hard clad silica type with a 200 micron core. This paper presents the component selection criteria, link design, installation, testing and performance for the optical links in the Booster instrumentation systems.

## INTRODUCTION

Fiber optic links used in the Booster Beam Position Monitor (BPM) System satisfy timing and analog signal transmission requirements as well as provide electrical isolation.[1] The signals are sent between a rack in an equipment bay outside the tunnel and electronics subracks located underneath the dipole magnet supports inside the Booster. Each subrack contains a pair of analog transmitters, including switchable gain pre-amps, and digital receiver circuitry for timing. The fibers are in an unshielded cable tray five feet above the beam pipe. Flexible conduit is used to protect the cables where they transition from the overhead tray to the electronics on the floor.

The radiation exposure on the Booster floor has been estimated using CASIM software.[2] The cumulative dose estimate per year for unshielded locations on the floor are 5-27 krad (Si) for ionizing radiation and 3.4-17 x $10^{12}$ n/cm$^2$ for neutrons. The ranges show the difference between typical and worst case points, but exclude the dump and septum locations. The objective was to design a link capable of operating for at least 5 years at a typical point in the Booster. It is expected the magnet supports will provide some shielding for the electronics. During commissioning, radiation detectors will be arrayed on all the devices to monitor absorbed dose.

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## FIBER SELECTION

The fiber selected for the links is the Ensign-Bickford (Avon, CT) HCR series fiber. The fiber is a 200 micron core step-index hard clad silica (HCS) type and was selected for its low induced loss, large numerical aperture (0.37), and low intrinsic attenuation (5 db/km maximum). The large numerical aperture and core size combine to reduce the mismatch loss at the transmitter. The HCS material is radiation resistant and recovers quickly from high dose rate exposures. The high attenuation, relative to telecom grade fibers, is because the dopants useful for reducing attenuation often cause an intolerable sensitivity to radiation. Typical dopants are germanium, boron, and fluorine.[3] Step-index fibers generally have a lower length bandwidth product than graded-index fibers however, using less than 0.3 Km over 50 MHz of bandwidth is achieved. This exceeds the bandwidth requirements of the transmit/receive pairs. Crimp and cleave style connectors are used because these connectors do not require polishing or epoxying as is typical of many optical connectors. Termination is simple and can be performed easily in the field within 30 minutes. SMA connectors are used because they are inexpensive, repeatable, and provide adequate alignment at this core size. Fiber lengths up to 100 m have been radiation tested in the AGS up to 50 krads without degradation.

## ANALOG LINK

Meret, Inc. (Santa Monica, California) MDL288TV components have been selected as the transmit/receive (T/R) pair for the analog fiber optic link. An LED with a center wavelength of 820 nm and dc output of 100 $\mu$W is used in the transmitter. A PIN photodiode with a responsivity of 2 mV/$\mu$W is used in the receiver. The T/R pair are separately packaged in 10.8 cm x 4.5 cm x 3.3 cm enclosures housing the conversion between electrical and optical signals. Each enclosure has a BNC and SMA 905 connector and dc power terminals. Also, there is a gain adjustment on both components.

The transmitter input is ac coupled with a lower 3 db point of 6 Hz. Up to a 1 V (p-p) signal can be transmitted by the link with better than 2% differential linearity. Larger signals do not damage the transmitter, but significant distortion in the received signal will result. The noise

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floor of the received output is 1 mV (rms) in a 30 MHz bandwidth. However, as the transmitter input signal level increases, the harmonic levels in the receiver output increase. A two-tone test over a peak envelope range of 200 $\mu$V to 1 V showed that the second order intermodulation products are at least -20 dbc. Also, < 4% THD exists for link outputs up to 0.5 V (pk).

The peak value of the transmitter input is expected to vary over a range of tens of millivolts to several volts; therefore, a preamplifier/attenuator is used prior to the optical transmitter. It is used to enhance the received SNR for low level signals or attenuate high level signals to lower the distortion. The gain selections are 1/10, 1, 5, and 50. The preamp uses an Analog Devices 9610 current feedback amplifier as the gain element (Figure 1), providing a selection of 1 or 50. The attenuator is a resistive divider and provides either 1 or 1/10 gain. The gain is selected via the computer controls system. Two preamp/attenuators and transmitters are packaged within one chassis in a 3 U x 14 HP x 220 mm eurocard format.

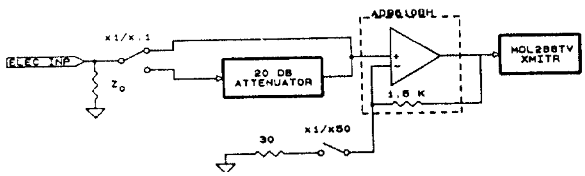


Fig. 1. Block diagram of pre-amplifier/attenuator.

It is expected that the 9610 will provide the required radiation tolerance because many opamps operate into the 0.1-1 Mrad range. Additional care has been exercised in designing the remainder of the circuit. To improve the circuits radiation resistance, low current relays driven by TTL peripheral drivers have been used to switch the gain. TTL components have demonstrated radiation tolerance into the megarad range.[4] Semiconductor switches are a potential source of analog and digital failures due to radiation. Diodes (1N4446) used to limit the relay coil EMF during switching should pose no threat to radiation induced failure and should provide reliable operation to at least $10^{14}$ n/cm$^2$ which is > 6 years of operation at a worst case point on the Booster floor.[5]

Radiation tests on the Meret components were performed in the AGS over a 2 month period. In that time, the link was exposed to 45-50 Krads (Si) as measured by an array of TLDs. This corresponds to a 10 year dose on the Booster floor. No degradation in either power output or bandwidth were noticed in the lot of transmitters tested. The receivers were also tested with no noticeable effects. Considering the dose rate for this test greatly exceeds the dose rate expected in the Booster, we expect to have a link lifetime exceeding 10 years.

The receiver circuitry consists of the Meret receiver and separate buffer/driver electronics. These circuits are located outside the radiation environment. The optical receiver outputs interface to the buffer electronics through a patch panel. The receiver units are packaged in a separate enclosure that allows access to all of the units for gain adjustment. The buffer (Figure 2) circuit provides unity gain and can drive 50 Ohm cables with a 2 V p-p signal at 40 MHz. If required, the circuit can provide either high frequency peaking or increased gain. The buffer circuits are packaged with four channels on a card in a 3 U x 14 HP x 220 mm eurocard package.

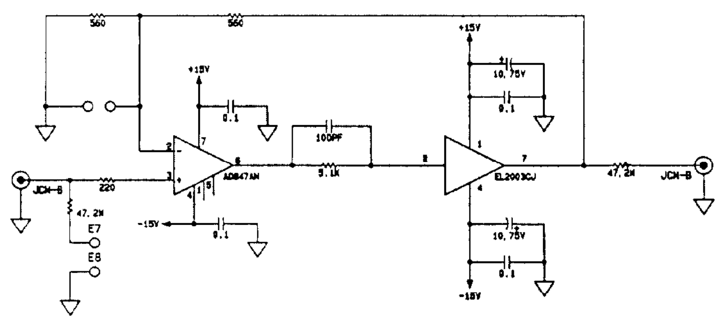


Fig. 2. Schematic diagram of a buffer/driver channel.

The system was installed in the Booster and used during commissioning. The transmission systems were calibrated for a gain of unity from the BPM front end electronics to the Main Control Room operator stations. To maximize the received SNR, the optical transmitter gain was adjusted to the maximum and the receiver gain set to compensate for link-to-link variations in received signal. The system bandwidth is > 25 MHz at a gain of 50. The primary limitation of the system bandwidth is in the optical T/R pair.

## DIGITAL TIMING LINK

The timing link is used to simultaneously place a 60 ns TTL level pulse at multiple locations radially distributed in the Booster. The signal is generated at a central location and transmitted in a star topology. The period of this signal tracks the rf frequency. The differential delay between the pulse edges and width of the pulse must be tightly controlled at each station. Additionally, electrical isolation of the receiving circuitry must be maintained. To solve the problem, a digital fiber optic link was constructed. The link uses Hewlett-Packard photodiodes (HFBR 1402/2404) operating at 820 nm for the transmit/receive pair and the same fiber as the analog link. The link accepts ECL level pulses, translates them to TTL, transmits over 300 m of fiber to the receivers located in the tunnel, and regenerates the pulse with a TTL pulse generator. The generator accepts the TTL pulse output from the receiver as a trigger and produces a 60 ± 1.5 ns pulse. To control the differential delay between stations, the fibers have been cut to a 3 ns tolerance, and in each channel is a digital delay line. The resolution is 2 ns with a ± 2 ns accuracy and compensates for delay variations in each channel. The HP diodes were selected because of the commercial availability, high speed (up to 30 Mbd with fast rise/fall times) and a low cost of $45 per pair. It is expected that because of the AlGaAs material, they would perform well in radiation environments.[6]

The transmitter diode forward current has been set at 20 mA, but can be increased up to 60 mA if necessary. At 20 mA, the link operates at full speed and with sufficient power margin, but some optical power has been reserved to compensate for radiation effects. The transmit and receive circuits were adapted from an HP application note.[7] The transmitter circuit (Figure 3) consists of a ECL/TTL converter, delay line, and a TTL driver to switch the LED on and off. The receiver (Figure 4), consists of HFBR-2404 analog amplifier followed by a differential video amplifier to drive a comparator. The comparator output pulses are regenerated by the pulse generator to precisely 60 ns. Tests on the link have shown it to operate to 20 MHz, although including the pulse generator, the maximum frequency required is below 15 MHz.

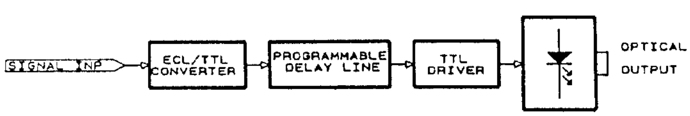


Fig. 3. Block diagram of the digital fiber optic transmitter.

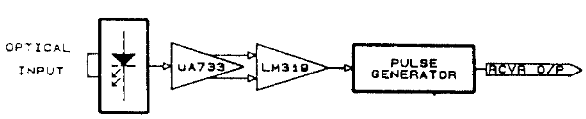


Fig. 4. Block diagram of the digital fiber optic receiver.

The transmit and receive diodes have been radiation tested in the AGS. Over a period of approximately 2 months they were exposed to 28 Krad. During the test, the transmitter and receiver characteristics were monitored and found to be unaffected by radiation at this level. The main thrust of this test was to confirm published data that commercial grade AlGaAs LEDs will perform well in radiation environments. This is significant because the link budget does not require additional margin for receiver/transmitter degradation. In addition, commercial grade components are less expensive than components specifically manufactured as rad-hard. The only concern with the radiation tolerance of the link is the tolerance of the video amplifier and TTL pulse generator. The video buffer amp should not cause a failure for several years because it is used to overdrive the comparator and degradation of the gain will not cause significant problems until it is greatly reduced. The TTL components are not expected to cause radiation induced failures.

## REFERENCES

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