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Abstract

During the operation of the Advanced Test Accelerator (ATA) large radiation induced noise signals have been observed on the cables coming from beam current monitors and photomultiplier tubes in those areas of the beamline where beam current is lost. These signals are caused by Compton and pair production electrons produced by x-rays striking the coaxial cables. The induced signal is negative and ranges up to 5 volts in magnitude. The suseptibility of several different cable types and dielectrics has been experimentally investigated. Measurements of induced signal versus cable type and dose rate are given. These noise signals have been successfully eliminated by differencing out the radiation pickup. This technique will be discussed, and recommendations for cable shielding and routing, as well a choice of cable types to be used in high intensity radiation environments will be given.

Introduction

In the presence of intense gamma ray, x-ray, and neutron radiation coaxial cables can produce large noise signals. These effects are well known [1,2] and have also been observed on the ATA in cables in the vicinity of beam spill. Typical parameters of the ATA electron beam are 50 Mev, 6 to 10 kA, with a 50 ns pulse length. The x-ray dose rate has been measured in excess of 10^{10} rad/sec, and neutron production of 10^{12} neutrons/pulse. These factors have complicated some of the lower current measurements. A typical example is shown in fig. 1, which shows a beam current signal degraded by a negative x-ray produced signal. Here and following I use the term "x-ray" to denote all electromagnetic radiation in the range of 1 keV to 50 MeV. The noise signal is eliminated by a differencing technique which is described later. The noise pulse is negative, is proportional to the beam current, and comes from x-rays produced by beam spill upstream of the diagnostic. For this particular device the cabling was routed upstream several meters before leaving the tunnel. Therefore, the x-ray induced signal appears ahead of the beam pulse.

Two types of effects are observed. The first is that shown in fig. 1, and seen as the first trace in fig. 2. It comes from free electrons produced near the surface of the conductors of the cable which are directed across the gap, forming a current. This effect, even though it is due to several mechanisms, is often called the Compton electron current. The second effect is seen in the third trace of fig. 2. It arises from electromagnetic interference (EMI) produced by x-ray ionization of air molecules around the beamline. Large currents are induced in the outer conductors of the cables, which act as antennas. If the cable has a braided outer conductor, such as RG-58, some of this EMI noise current can leak through into the cable and appear as the ringing noise signal that is seen. It is also possible for the signal to leak through any connections in the cable.

Two other radiation effects are also often observed but have not been a problem with the ATA. One is a neutron induced noise signal in the diagnostic cabling. The neutrons interact with the cables through nuclear collisions which create charged particles. The other effect is an x-ray induced conductivity change in the cable dielectric. This effect has not been studied on the ATA.

Compton Electron Current

The Compton electron current effect is shown schematically in fig. 3. X-rays illuminating the cable produce free electrons in the conductors and dielectric by the photoelectric effect, Compton scattering, and by electron-positron pair production. The photoelectric effect dominates below 800 keV, Compton scattering dominates between 800 keV and 5 MeV, and above that pair production dominates. Electrons produced within the conductors and dielectric by the various processes are generally isotropically directed. As a result there is no net current flow, except at the interfaces. A net current can result because the photo-emissivity of the conductor and the dielectric usually differ. For an air core or evacuated cable the net current is related to the difference in the surface areas of the inner and outer conductors. That is, more electrons are directed inwards from the outer conductor than vice versa. On the other hand, if the photoemission of the dielectric equals that of the conductor there are as many electrons going into the conductor as leaving. The result is no radiation induced current. In table 1 relative photoemission of several dielectrics and metals at 200 keV is given [3]. As seen from the table, the ideal cable, from the standpoint of minimizing the Compton current, would be an aluminum cable with a Kel-F dielectric. However, the high dispersion of Kel-F, mylar, and polyvinylchloride(PVC) rules out their use as dielectrics for high frequency signal cables. Teflon is also not useful with our machines because it is easily damaged by radiation.

Table 1. Relative photoemission of several metals and dielectrics with a photon energy of 200 keV.

Material	Relative Emission
copper	7.8
aluminum	1.0
polyvinylchloride	1.1
Kel-F	1.0
teflon	.26
mylar	.10
kapton	.075
polyethylene	.03

Techniques for Reducing X-ray Effects

Three techniques can be used to reduce the x-ray generated Compton current in cables. The first is to use cables in the high radiation fields that are less sensitive to these effects. Measurements of the suseptibility of several cable types are given in the next section. The second technique is to shield the cables where there is intense radiation. A tenth value-layer (TVL) in lead for MeV and greater energy x-rays is 5 cm. With the ATA the cabling extends from the diagnostic to the ceiling before it exits the tunnel. Supporting lead shielding above the beamline is not practical. The third technique is to subtract out the Compton current. This technique is accomplished by either adding a positive and inverted signal from the same diagnostic, or by adding the inverted signal of an unconnected, but terminated cable to that of the signal cable. For the ATA beam current monitor [4], which gives both positive and inverted signals, the differencing is done as shown in fig. 4. The critical factors in the technique are: (1) matching cable lengths to within 100 ps, (2) using an inverter and summer with a sufficiently fast risetime and long droop time (100 kHz to 2 GHz bandpass for ATA experiments), and (3) insuring that the summer is balanced to within the desired common mode rejection ratio.

To reduce the EMI effects one should use at least a double braided cable, or a solid outer conductor cable. Also, the number of cable connectors needs to be minimized, and the connectors used should be a screw type, such as SMA or type N. The goal should be to build a complete Faraday cage around the signal.

Cable Radiation Tests

Several cable types were exposed to the x-ray and neutron radiation of the ATA. The x-ray dose was determined by measuring the accumulated dose at 1 meter intervals along the path of the test cables with thermoluscent dosimeters. The total dose rate was determined by integrating the dose along the length of the cable and by dividing by the pulse length. The x-ray response of the various cables was then normalized to the total dose rate determined from the TLD's. The x-ray dose was not measured for all the cables in these tests. Rather, an FSJ4-50A 1/2 inch Heliax was calibrated to determine its response per dose rate and used to determine the dose rate for the other cables tested. The results of the Compton electron effects for the cables tested is given in table 2. The units Coul/rad-cm are equivalent to amp-sec/rad-cm. The second column in the table is the voltage response of a 50 Ohm cable per total dose rate. These same results, along with the EMI suseptibility of each cable is shown in fig. 5. The EMI results above 0.1 volts are valid. Below that level EMI pick up through poor connectors dominated the results.

Table 2. Measured Compton current in several cable types.

Cable Type	Coul/rad-cm	Volts/rad-cm/sec
FSJ4-50A	-2.5×10^{-13}	-1.3×10^{-11}
FSJ4-50B	-6.5×10^{-14}	-3.3×10^{-12}
HJ4-50	-1.3×10^{-13}	-6.5×10^{-12}
RG-214	-7.0×10^{-14}	-3.5×10^{-12}
LDF2-50	-5.8×10^{-14}	-2.9×10^{-12}
RG-223	-2.0×10^{-14}	-1.0×10^{-12}
RG-58	-3.8×10^{-14}	-1.9×10^{-12}
FSJ1-50	-3.8×10^{-14}	-1.9×10^{-12}
RF-23	-7.5×10^{-14}	-3.8×10^{-12}
RG-174	-1.3×10^{-14}	-6.5×10^{-13}

From these tests we learned several things about cable use in radiation environments. First is that there is both a Compton electron current and an EMI signal induced on the diagnostic cables by the x-ray radiation. Second is that the magnitude of the Compton electron current signal is proportional to the cable diameter. Third is that solid outer conductor cables are more immune to the x-ray induced EMI signals. Fourth that high density dielectric cables have a much lower radiation induced signal than low density or air core cables.

The best cable for minimizing both Compton electron current and EMI noise is a small diameter, solid outer conductor cable which a solid polyethylene dielectric. The cable diameter choice however needs to be balanced with how much attenuation that can be tolerated from the smaller diameter cables. For this reason we are using a staged cabling technique for future installation. Small diameter, radiation insensitive, but high attenuation cables will be used near the experiment. Further away larger diameter cables will be used to limit the attenuation.

Conclusions

It has been been experimentally determined that an EMI and a Compton electron current noise signal are produced by x-rays and gamma rays. Techniques have been given for reducing this effect; the best being to eliminate the effect by shielding, or proper choice of cable. It is also possible to difference out these noise signals, but that is less desireable. Several cable types were tested and their suspectibilities to radiation induced noise given. *The best cable has a small diameter, a* solid outer conductor, and a solid, high density dielectric.

Auspices

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References

[1] V. A. J. van Lint, IEEE Trans. Nucl. Sci. NS-17, 210(1970).

[2] J. K. Notthoff, "Coaxial Cable Responses to Ionizing Radiation from FX-100 and PR-1590 Flash X-ray Machines", McDonnell Douglas Astronautics Company-West Report No. G0436, 1970.

[3] Francis Hai, "Measurement Notes; Note 26. Summary of Cable Response Experiments", Aerospace Corp. Report, El Segundo, California, July 1977.

[4] T. J. Fessenden, et. al., Rev. Sci. Instrum. 43, 1090(1972).

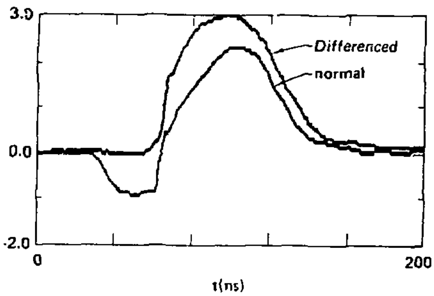

Fig. 1. X-ray induced noise signal on a beam current signal.

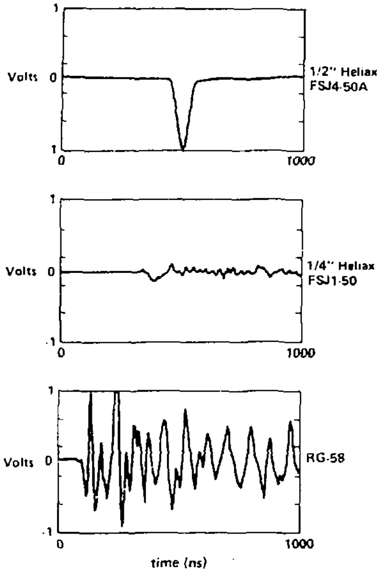

Fig. 2. Typical x-ray induced noise signals on three types of cables.

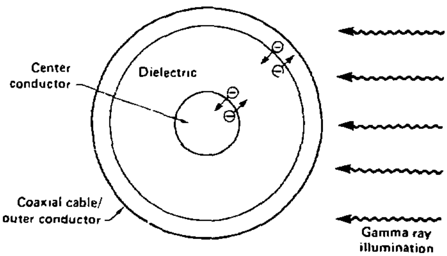

Fig. 3. Free electrons produced by the photoelectric effect, Compton scattering, and pair production induce currents in a coaxial cable.

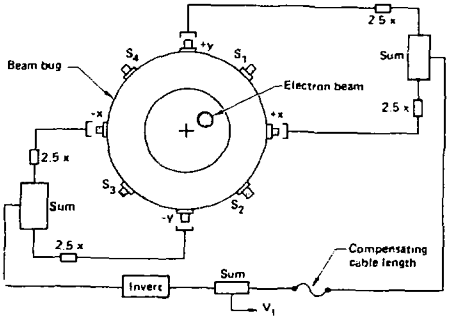

Fig. 4. Differencing technique for the resistive beam current monitor.

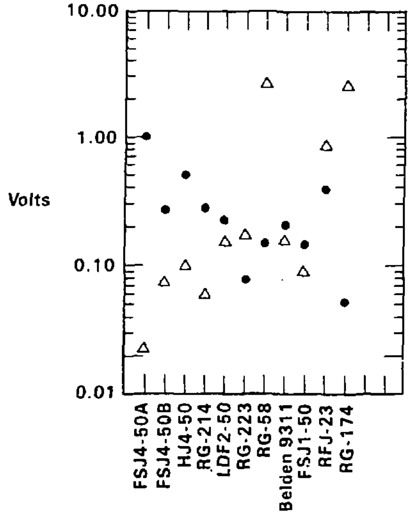

Fig. 5. Compton electron (dots) and EMI (triangles) noise signal levels in various cables for a 2000 rad-cm radiation dose in 30 ns.