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Electrical Grounding, Shielding, and Isolation for the MFTF-B Plasma Diagnostic System

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ELECTRICAL GROUNDING, SHIELDING, AND ISOLATION FOR THE MFTF-B PLASMA DIAGNOSTIC SYSTEM

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Abstract

The electrical grounding, shielding, and isolation of plasma diagnostics on the Mirror Fusion Test Facility (MFTF-B) is a key part of the overall design. The Electromagnetic Interference (EMI) environment in which the Plasma Diagnostics System (PDS) will be required to operate is very harsh. The electrical grounding and shielding design which is being implemented to cope with this environment follows one which has been used successfully on the Tandem Mirror Experiment (TMX) [1]. Details of the MFTF-B plasma diagnostics facility, equipment grounding, shielding and isolation, and the cabling system are described in this paper.

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Introduction

The MFTF-B, now under construction at the Lawrence Livermore National Laboratory (LLNL), is scheduled to begin initial operation in the latter part of 1986. When testing gets underway, the PDS [2] will be called upon to play a key role in determining the physical parameters of the plasma, and also to aid in assessing the overall performance of the machine. We are currently designing the diagnostic instruments and installing the facilities which will be used to house and support the plasma diagnostic system on MFTF-B.

The establishment of conditions which are suitable for fusion in a mirror machine such as MFTF-B requires the use of high power plasma heating techniques, which together cover a broad electromagnetic spectrum. The external electrical interference environment produced by these auxiliary heating systems can be substantial, particularly when viewed from the standpoint of one making low-level diagnostics measurements in this environment. The manner in which the plasma diagnostic signals are handled is crucial if valid data is to be obtained. This paper discusses the aspects of the MFTF-B plasma diagnostics system design which relate to EMI problems. We describe the procedures and policies which we are implementing in the design of the electrical grounding, shielding and isolation of the MFTF-B plasma diagnostic system to minimize the impact of the EMI environment on the diagnostic measurements.

The MFTF-B Facility

MFTF-B is physically a very large test facility. Figure 1 illustrates pictorially the configuration of MFTF-B. The fusion chamber is a long cylindrical structure approximately 58 meters in length and 11 meters in diameter. It is housed in a vault whose dimensions are approximately 73 m x 23 m x 20 m. The vault is constructed of borated concrete walls, 2.1 m thick, which are designed to provide necessary radiation shielding for personnel and equipment from the 2.5 MeV neutrons produced during machine operation. (Predicted neutron fluence inside the vault will be greater than 1×10^7 neutrons/cm^2/plasma-sec.

Three major plasma heating subsystems are considered to be the prime contributors to the total MFTF-B EMI environment which the plasma diagnostics system will have to contend with. The neutral beam heating system consists of 24 0.5-sec and 30-sec 80 kV at 80 A pulsed sources which are distributed about the machine. Total peak power delivered to the neutral beam system alone can be in excess of 150 megawatts. The EMI from the neutral beam sources and their associated power supplies is produced through a variety of mechanisms, which include the normal high voltage pulse turn-on and turn-off, rapid pulse turn-offs due to source spark-down and crowbar operations, corona discharges, and source filament and arc contactor operation. The spectrum of interference from the neutral beam system is very broad and extends from the sub-Hz region to the GHz regions.

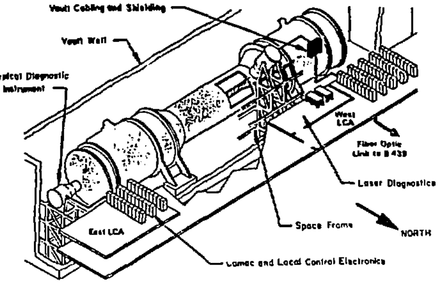

Figure 1. Pictorial view of the MFTF-B plasma diagnostics facilities which shows the location of the West and East Local Control Areas.

A second major source of EMI will be from the Electron Cyclotron Resonant Heating (ECRH) system. ECRH employs microwave RF heating at power levels of 800 KW @ 56 GHz, 400 KW @ 35 GHz, and 400 KW @ 28 GHz. While these frequencies are far beyond the active spectrum of most of the diagnostic instrumentation, the possibilities for the excitation of nonlinearities and component burnout and arcing will be present.

The third source of interference on MFTF-B will be from the Ion Cyclotron Resonant Heating (ICRH) system. Here, RF in the spectrum from 6 to 20 MHz will be utilized in the center cell region of the vessel to heat the plasma. Since these frequencies fall within the normal spectrum of some of the the diagnostic measurements [3], ICRH is considered to be a major factor to the EMI environment.

Due to the hostile radiation environment in the vault, the level of local front-end electronics which we can use to preamplify the plasma diagnostics signals to improve signal to noise is very limited without the use of extensive neutron shielding. This means that a majority of the data acquisition and control electronics will be remotely located outside of the vault at distances as great as 100 m away from the diagnostic detector. Two areas, called the West and East Local Control Areas (WLCA and ELCA) have been set up to house the PDS data acquisition and control electronics as shown in Figure 1. The manner in which we will use these two areas will be described more fully below.

The Plasma Diagnostics System

The design of the MFTF-B PDS electrical grounding, shielding and isolation system follows that which has been successfully used on the TMX-U experiment at LLNL [1]. It is also similar in concept to that described earlier by Norris of the Tokamak Fusion Test Reactor (TFTR)[5]. The design is driven by several constraints. Some of these constraints are technical, while others are purely operational. Personnel safety during machine operation is a key art of the plan. We felt it highly desirable to be able to occupy the diagnostics control rooms while the machine was running in order to locally operate, debug and maintain the diagnostic data acquisition equipment. Additionally, we chose to implement the signal conditioning and data acquisition tasks with commerically available CAMAC-based equipment wherever possible. Both of these implementations placed constraints, for example, on the grounding and isolation of signals and equipment, which in turn drove the overall design of the electrical system. We have followed a defensive EMI protection plan in the design of the PDS system where practical and economical.

As noted above from Figure 1, two diagnostics control areas will be used by PDS. A majority of the hardware will initially be housed in the WLCA for the start-up suite of plasma diagnostic measurements. However, both areas will be fully utilized as the PDS system expands to support a full set of diagnostic measurements.

Since access to the vault area is restricted during machine operation, all of the diagnostic instruments will be remotely controlled. Remote operation places heavy demands on the cabling system which interconnects the vault and the Local Control Area (LCA), and the cabling is an important part of the EMI minimization problem, since the conductors can easily act as antennae to pick-up unwanted interference if not handled properly.

Electrical isolation of the diagnostic signals is also an important part of the overall EMI minimization scheme. Obviously, on a system which is distributed over such a large area as the one on MFTF-B, grounding and ground loops are a major consideration. We require that all electrical signals be isolated from the vessel before they enter the LCA. A single point ground reference is established at the LCA, and other conflicting grounds are not allowed in the design without adequate isolation.

Finally, the diagnostic facilities, the LCAs, are an important part of the EMI plan. The racks, cable trays, power distribution, electrical isolation and grounding have all been designed to control the unwanted effects of EMI. Details on each of these designs are covered below.

The Plasma Diagnostics Local Control Areas

A majority of the instrumentation for the Start-Up Set (SUS) of plasma diagnostics will be housed in the WLCA which is located on the ground floor of the MFTF-B building. Figure 2 illustrates a plan layout of the WLCA. For the SUS of instrumentation, we will install 35 EMI hardened equipment racks in the WLCA. Each rack is equipped with EMI gaskets on the front and rear doors and honeycomb air vents at the top and bottom. (We evaluated the use of a fully hardened screen room to house the diagnostics, but concluded that the number of penetrations required to carry the many signal cables in and out of the room could easily violate the integrity of the screen room, and that the cost could not be justified at this point. We have, however, retained the space and access to install a large screen room at a later date if its need is established during the early testing periods.)

The racks are mounted on fiberglass rails to electrically isolate them from the raised floor and adjacent racks. Beneath the raised floor is a copper diagnostics ground plane which is electrically connected to building steel at a ground well junction point. This serves as the signal and safety ground reference point for the diagnostics system. The racks are individually grounded to the ground plane at one point. (It should also be noted that the pedestals for the raised floor are electrically connected to the ground plane and they in turn ground the metallic backing of the raised floor tiles to the ground plane. The tiles are otherwise isolated from the remainder of the building steel and other equipment. We felt this action would provide additional shielding for the cabling beneath the floor, but we are able to easily isolate the floor if this action causes additional interference.)

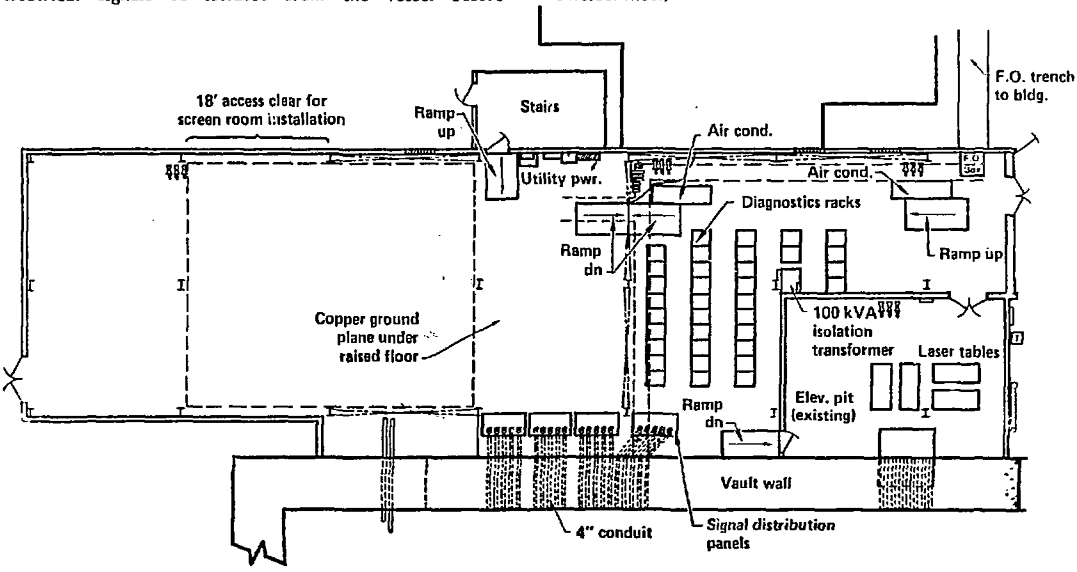

Figure 2. Plan view of the West LCA. A copper ground plan will be installed below the raised floor to provide diagnostics ground reference. Thirty-five racks will be installed for the start-up set of instruments.

Diagnostics of only one type (e.g., RF probes) are housed within a given rack. However, the sensors for a given diagnostic type may be located at several different locations on the vessel, and thus to prevent ground loops it is essential that the diagnostics be isolated from the vessel and other equipment. Each rack is bonded to the ground plane at only one point with a low inductance ground strap, and this point serves as the single point ground reference for all the equipment in that rack. For situations where the equipment for a given diagnostic occupies more than one rack, we are able to remove the adjoining rack side panels and join multiple racks with RF gaskets. Again, however, only one ground point will be used for the multiple racks. Other ground points are not allowed, and if one series of racks requires a signal from another series in a different area of the LCA, the interconnects will utilize either optical or transformer isolation. (Note that data transfer between the diagnostics computer system and the CAMAC system is via fiber optic cables.)

Signal and control cables from the instruments in the vault are routed through an array of 40-4" conduits in the WLCA and 20-4" conduits in the ELCA. The cables from the vault are terminated in six separate signal distribution panels in the LCA for distribution to the proper racks. We have chosen to distribute the signals to the racks by way of lay-in cable trays which are located below the raised floor. The trays are capable of being upgraded to shielded enclosures, but will not be fully hardened for the initial SUS of instrumentation. They will not be electrically isolated from the ground plane, but will be connected to the ground at several locations to minimize the cable tray currents at high frequency. The cable trays will, however, be isolated electrically from the racks at the point of rack connection to prevent ground loops between the rack and the trays.

Two distinct categories of cable trays will be used. One, classified to carry sensitive diagnostic data signals, will be reserved for low level information which may be susceptible to cable crosstalk and other interference. This cable tray will be routed along the front of the racks beneath the raised floor, with branches leading to the racks so that signals may be fed up to the front area of the racks. A second network of cable trays will be routed to the back-side of the racks to support high level data lines such as monitor and control signals and diagnostic DC power distribution.

Clean electrical power will also be distributed to the racks beneath the raised floor. Figure 3 illustrates how the equipment described in this section is configured. The next section discusses the electrical power distribution system for PDS.

Electrical Power Distribution

EMI can result from conducted interference which is directly coupled through the AC power mains. On MFTF-B, three measures have been taken to minimize this source of electrical interference. First, the AC power mains used for PDS will be serviced from a clean electrical source. Secondly, separate isolation transformers will be used to power each diagnostics rack, and finally, the isolated power in each rack will be further filtered with an EMI filter to eliminate any remaining noise.

Particular care was exercised in the selection of the electrical power mains used to operate the plasma diagnostics system. The "Clean AC" line used to supply power to the two LCAs is derived from a point on the LLNL power grid which is not subjected to large pulsed loads. Additionally, line voltage is regulated to a plus and minus 7 percent tolerance. Plasma diagnostics and the SCDS computer system are the only users of the 1000 kVA transformer used for the clean diagnostics power.

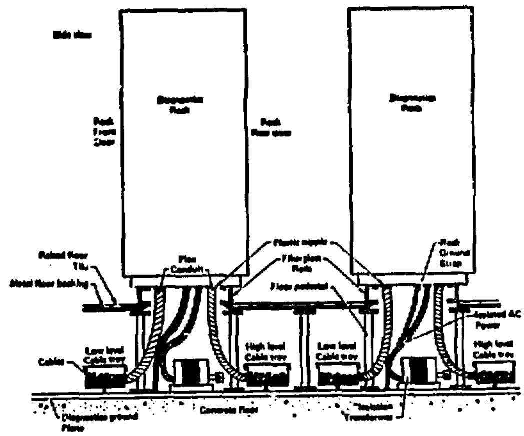

Figure 3. Cross-sectional view of rack installation which shows how signals and clean AC power are distributed.

From the main transformer, power is fed to each of the two local control areas through two triple-shielded 100 KVA isolation transformers, and from this point, the power is further distributed to each of the racks as shown in Figure 4. In order to provide electrical isolation between the racks, each rack receives its electrical power through an additional 2.5 KVA triple-shielded isolation transformer, which is grounded to the single point rack ground. The isolation transformers are mounted under the raised flooring beneath the racks as shown in the figure, and the isolated power is fed through a metallic conduit to the rack power distribution panel. The reason for placing the isolation transformer outside of the rack is twofold. First, it is useful to physically remove the power transformer from sensitive circuitry which may be subject to mutual inductive coupling of the 60 Hz power, and secondly, it is important to make the impedance of the grounding connection between the transformer Faraday shield and the ground reference as low as possible if good common mode interference rejection is to be realized.

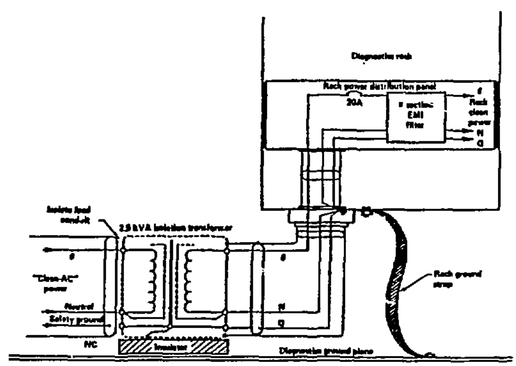

Figure 4. Isolation transformers feed "clean AC" power to each rack.

As a third measure followed to ensure clean AC power we utilized a Pi-section EMI filter on the supply line for the electrical power in each rack. The EMI filter is used in addition to the two outer differential mode shields of the isolation transformers, and it provides additional protection from interference which may be coupled through the isolation transformer.

Diagnostics Cabling System

As discussed earlier, the cabling system is an important element in the overall EMI protection plan since it is easy to pick up stray interference on the cables if they are not adequately protected. Basically, two types of cabling will be used for the plasma diagnostics system. Individually Shielded Twisted Pairs (STP) will be used for signals where the required bandwidth is less than 500 kHz. A large portion of the diagnostic signals used for the SUS of instrumentation fall below the 500 kHz limit [3]. We will make extensive use of STP cabling for both the data channels and also the majority of monitoring and control functions. To limit the variety of connectors and cables used on the system, we will use #20 AWG cabling in bundles of 15-pair, 6-pair and 1-pair. An additional 1-pair of #14 AWG will be provided to supply clean DC power to any instruments requiring power in the vault.

Triaxial cables will be used for the remainder of the cabling system needs where the frequency requirements are less than 150 MHz. Additionally, triax will be used for high-voltage bias supplies below 2 kV. Above this potential, standard high voltage coaxial cables will be utilized.

To limit the capacitive coupling of interference to the cabling system, all cables will be individually shielded, with the shields grounded at the LCA rack. All cabling in the vault areas will be routed through 4-inch rigid steel conduit. The conduits will be run from the vault penetrations serving the two LCA to an array of diagnostic junction boxes distributed near the diagnostic instruments in the vault. Separate conduits and junction boxes will be allocated for high-level and low-level signals, as we have done with the cable trays in the LCA, in order to minimize the problems of cable cross-talk. To dissipate coupled EMI currents which may be induced on the conduits themselves, we plan to multiply ground the conduits at several points in the vault to building steel. To prevent direct coupling of the vessel EMI directly into the LCA, we intend to provide dielectric breaks in the conduits as they enter the signal distribution panels.

Inductively coupled EMI will be controlled in two ways. First the steel conduits will be effective in providing magnetic shielding at frequencies above a few kilohertz, however, cable-to-cable crosstalk and low frequency EMI will still be present. To counter inductively coupled interference, we will use balanced circuitry with the STP cabling whereever feasible. Balanced designs are very effective in combating high noise environments. Similarly, by properly using the two separate shields on the triax cables, currents induced on the outer shield will not directly enter into the signal path. (There is, however, a transfer impedance between currents on the outer shields and the inner shields which must be considered.)

Diagnostic Shielding and Isolation

All shields which serve the cabling associated with a given diagnostic will be terminated at the appropriate rack in the LCA. To prevent ground loops, we will require that the diagnostic instruments must be either physically isolated from the fusion chamber or electrically isolated through the use of isolation transformers or optical couplers. For the majority of the diagnostic instruments being designed for the SUS this is not a problem. Figure 5 illustrates the grounding, shielding and isolation configuration for a typical diagnostic instrument. Here the outer shield of the triax and STP are connected to the electrostatic enclosure which surrounds the instrument to prevent capacitive coupling of EMI to the enclosed circuitry. Balanced circuits are used for the STP. The electrostatic shield is isolated from the vessel to prevent ground loop currents from flowing on the shields, and the shields are isolated from ground and other shields as they are routed to the conduit system to the LCA. A more detailed example of a specific instrument design for MFTF-B is given in the paper on the EMF diagnostic by House, et al [4].

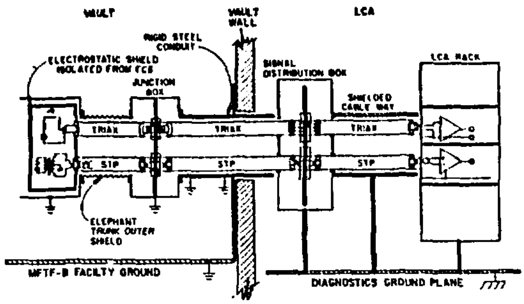

Figure 5. Shield termination and isolation is shown for a typical diagnostic.

Acknowledgements

The design of the grounding, shielding and isolation system for MFTF-B plasma diagnostics represents the work of many individuals. I am especially grateful for the many useful suggestions from my colleagues, David Goerz, Peter Jautaikis, Norman Lau and Gerald Coutts, under the project leadership of Alan Throop.

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