CMS EMU CSC policy on Grounding, Shielding and Power Distribution.

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Introduction

In the electronic devices of such scale and complexity as CMS Endcap Muon detector careful attention must be paid to the implementation of grounding, shielding and power distribution.

The purpose of this note is to outline the basic principles of the good grounding, shielding and power distribution practice, which must be followed system-wide. Any deviation from these rules can lead to the significant problems with EMI pickup and signal integrity.

Terminology

Documentation and implementation must clearly distinguish between three types of "grounds":

1. Safety ground (SG). Connection to earth.

Symbol:

2. Reference ground (RG). Zero volt reference for the system.



3. Signal return (SR). Path for returning a signal to its source. Connected to reference ground in a single point for each signal.

Symbol:

RG implementation.

- 1. The CMS EMU system from electronic point of view will consist of three main parts two End Caps, and the equipment located in Control room. The ground contact between two End Caps is unavoidable since the data coming from them must be processed in the same trigger and DAQ system, and not all of the data paths will be implemented as optical links. The place where this contact is likely to occur is Control room.
- 2. CMS EMU Chambers will sit on the surface of the huge metal disks (CMS return yoke). We suppose that these disks have very low resistance, and they will be

very well connected to each other in each of the two End Caps. Due to the good conductivity of these disks, they can be used as part of RG for all electronics sitting on chambers and disks.

- 3. The outer shell of the chambers is used as RG now (see [6]), so this shell should be connected to the disk surface very well.
- 4. This RG must be present in the Control room, so both End Caps' disks should have RG connection to the Control room RG. This connection must be very reliable.

Having all this in mind, the rough schematics of both End Caps and control room would look like this:



Figure 1. Reference Ground layout.

The alternative schematics of the Reference Ground is possible:



Figure 2. Alternative Reference Ground layout.

On both pictures, thick lines represent copper conductor carrying RG's zero potential. Both schematics do not contain ground loops. Other configurations are also possible. Please consult grounding committee before selecting one of them.

If possible, all the signal and power cables should be routed along these conductors, at least partially, to minimize accidental ground loops. The best case would be to have these conductors implemented as ducts and route all the signal and power cables inside them. This will create the Faraday cage for cables and significantly reduce the influence of the unavoidable accidental ground loops. This approach is used at D0 [8,9]. On the disks, the signal cables should also lay on disk's surface.

This approach requires both End Caps to be insulated from the support structures to exclude the unpredictable connections to SG and ground loops. This is a common approach for large detectors [4,5,8,9]. The exact places where the insulators and points of RG connection are located should be selected by the mechanical engineers designing the disks and support structure, and approved by grounding committee.

RG in the control room could be implemented as a plane made of copper grid. All crates must be grounded to this grid.

There are the following types of non-electric communications:

- 1. Gas.
- 2. Water for cooling system.

These communications also need to be insulated because for both of them the metal pipes are used on the chambers, and these pipes are connected to RG. Gas and water pipes should have the insulating inserts entering each End Cap. Distilled water should be used to reduce the conductivity, and the insulating insert in water pipe(s) should be done as long as possible. Routing of gas/water pipes on the disk surface should be done as close to the disk surface as possible, providing good electric contact between pipe and disk in multiple points.

SR implementation and its connection to RG.

The following guidelines should be used for signal transmission:

1. Analog signals.

They are divided into two subtypes:

- a. Particle data from the chambers. These signals are transformed into the digital form immediately on the chamber, passing via very short cables or no cables at all (see [6]). Their grounding and shielding is experimentally optimized.
- b. Service signals temperature sensors, ???. The best way is to digitize the analog signals immediately on the disk surface, and transmit them in digital form to the control room (see below the section for digital signals). If it appears to be impossible, the sensors should be electrically insulated from the disk surface, and the signal is transmitted to the control room using shielded twisted pair, with the shield connected to the RG in Control room. These signals are typically slow, and any parasitic pickup can be filtered out from them in control room.
- 2. Digital signals.

All the digital signals must be sent to/from detector via optical link or have optical insulators. This completely eliminates pickup, ground loops, etc. If the electrical transmission is absolutely necessary the signals should be sent to/from control room in differential form (LVDS – preferable, or ECL, PECL) via shielded and properly terminated twisted pairs; the individual twisted pair shields should be connected to RG on the transmitter's side.



Figure 3. Digital signal transmission.

The overall cable shield is used to form the continuous Faraday cage (see Fig. 3). This structure avoids the ground loop to the maximum extent possible, since the input impedance of the differential receiver inputs is very high. The individual shield cannot be grounded on both sides because this immediately leads to a ground loop. If the shield is grounded on the receiver side (and not grounded on transmitter side), the parasitic capacitance between shield and twisted pair wires creates the ground loop for AC current. The signals coming from one point of detector to another (not to control room) can be transmitted electrically as described above.

Power distribution.

This section is based mostly on the Marvin Johnson's document [8] and describes the approach used in Fermilab for several experiments.

The power for detector electronics load and everything else (cranes, pumps, etc.) should be converted by two separate transformers. The grounds of these two systems are connected to building ground at the power distribution panels for safety (see Fig. 4). In particular, the noise generated by, for example, motors should go through at least two transformers before getting into the electronics power.

The power for analog and digital electronics should be also converted into 220 or 110V by two separate transformers, if possible. This will reduce the possibility of the digital noise corrupting the analog signals.

All the secondary transformers for the detector electronics should be double Faraday shielded. This will separate the detector RG from the outside world.

Due to safety reasons the detector cannot be completely isolated, and the RG needs to be connected to SG, which is the building ground. One solution is to use the inductor between the two shields of the secondary transformer as shown on Fig. 5. The impedance of 50 μ H inductor at 60 Hz is 19 m Ω , and at 1 MHz it is 300 Ω . The inductor must be able to carry the maximum possible fault current without damage.



Figure 5. Secondary transformer.

Low Voltage power for on-chamber electronics.

Low voltage for on-chamber electronics will be supplied by DC-DC converters sitting near the disk surface. These converters are fed from the AC-DC converter located off-disk. AC-DC converter has transformer inside which is the secondary

power transformer shown on Fig. 5, and should be implemented this way. There is no need to insulate input and output of the DC-DC converter since AC-DC converter already provides such insulation, so the return wire of the AC-DC can be connected directly to RG.



Figure 6. DC-DC converter shield and case connection.

LV power for crates.

Typical VME crate has the internal ground connected to its case, and case is connected to the grounding wire in the power plug. So there is no other choice but to consider VME crate case as part of RG, and connect it to RG with thick copper conductor. The crates sitting on the disk should be connected to the disk surface, and in control room to the RG structure. The ground socket in the power outlets for crates should be connected also to the RG.

The crates located on the disk will be powered from DC-DC converters due to high ambient magnetic field that will not allow regular power supply to operate in this area. Please see section 3 above this text for DC-DC converter discussion.

High Voltage power.

The HV power supply will most probably consist of two stages: the mainframe situated in the control room, and distribution boards located on the disk surface. The mainframe's HV output is floating and its SR is connected to RG only in the HV destination point, which is chamber HV input connector.



Figure 7. HV power distribution.

For a complete set of HV system vendor recommendations on how to implement HV grounding see [7].

The Low voltage power for Distribution boards is supplied also by the mainframe, and the guidelines for LV power distribution are to be used here (see section for LV power distribution above). The control signals use optical links.

Sometimes the ground loops unavoidably have to be created. For example, in HV distribution schematics the coaxial cable from Mainframe to Distribution board should have its braid grounded for safety. If this braid is connected to RG in any point it will immediately create the ground loop, since it is the HV return conductor simultaneously. To reduce the effect of such loop, this connection to RG can be done via resistor in the order of KOhms or non-linear network having high impedance on low voltages (Zener diode).

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