

DETECTOR NOISE SUSCEPTIBILITY ISSUES FOR THE FUTURE GENERATION OF HIGH ENERGY PHYSICS EXPERIMENTS

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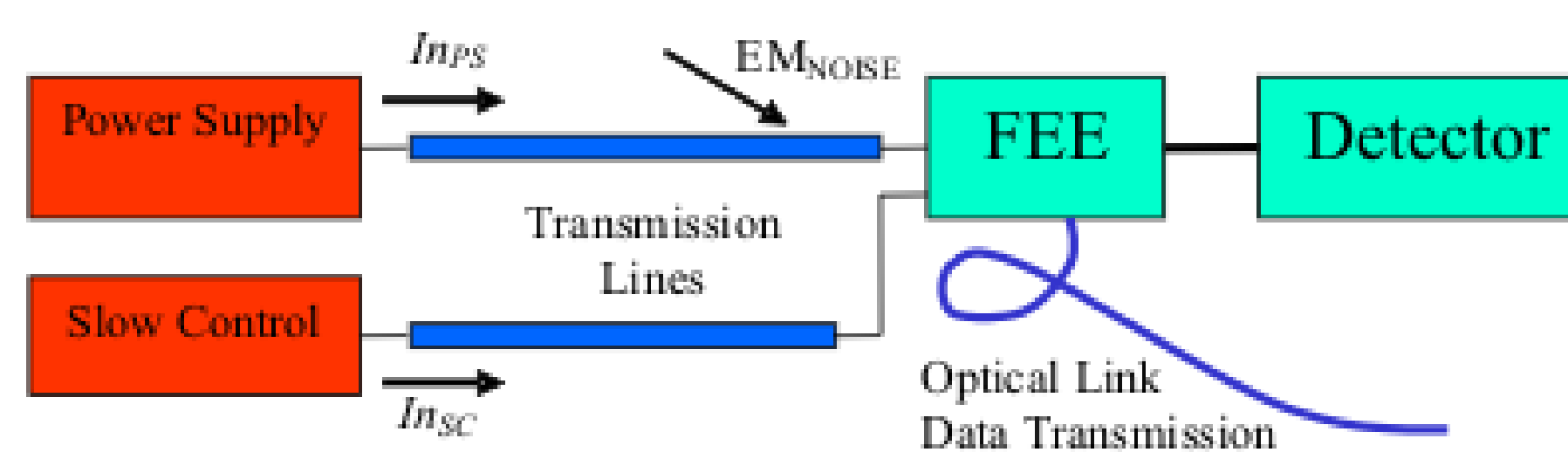
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Abstract-- The electromagnetic noise characterization of the FEE and the compatibility of the different systems are important topics to consider during the experiment upgrades. A new power distribution scheme based on switching power converters is under study and will define a noticeable noise source very close to the FEE detector electronics. Knowledge and experience with both FFE noise and electromagnetic compatibility issues from previous detectors are important conditions to guarantee the design goals and the good functionality of the upgraded LHC detectors. This paper shows an overview of FEE noise susceptibility studies performed in different CMS sub-detectors. The impact of different topologies in the final FEE sensitivity and design recommendations are presented to reduce the noise susceptibility of the system to be compatible with the future power distribution topologies.

ELECTROMAGNETIC NOISE COMPONENTS OF FEE

The minimum signal that the front-end electronics can process is determined by the level of the total noise coupled to the system. In addition to the intrinsic thermal noise perturbing the input stages of the FEE, electromagnetic interferences degrade the noise performance of the system. Because the bandwidth associated with the front-end electronics and the dimensions of the sensitive processing areas, the electromagnetic noise perturbing the FEE is coupled by conductive and near field mechanisms.



In this scheme, the total noise that degrades the performance of the FEE can be divided in four components:

1. Thermal noise
2. EMI picked up by Detector - FEE connection
3. EMI picked up by FEE - external connections
4. Additional sources, as ADC quantization error

$$n_a(t) = n_{th}(t) + n_{EMI-in}(t) + n_{EMI-ex}(t) + n_{ADC}(t)$$

EM NOISE CHARACTERIZATION OF FEE

The characterization of the FEE to electromagnetic interferences (EMI) can be achieved via [immunity tests on prototypes or via numerical simulation](#). The main goal is to define the susceptibility of the FEE to EMI.

- [Immunity tests](#) have been performed on several prototypes of the CMS sub-detectors. The idea of these test is to inject a perturbing signal $i_{pert}(t)$ to the FEE at different amplitudes and frequencies and measures the output signal $V_{out}(t)$ of the FEE by its own acquisition system to evaluate the performance of the FEE.

- Numerical simulations using mathematical models of the Detector-FEE have been carried out during the design stage of several subsystems. EMI coupling to critical parts of the FEE have been modelled using Multiconductor Transmission line Theory (MTL)

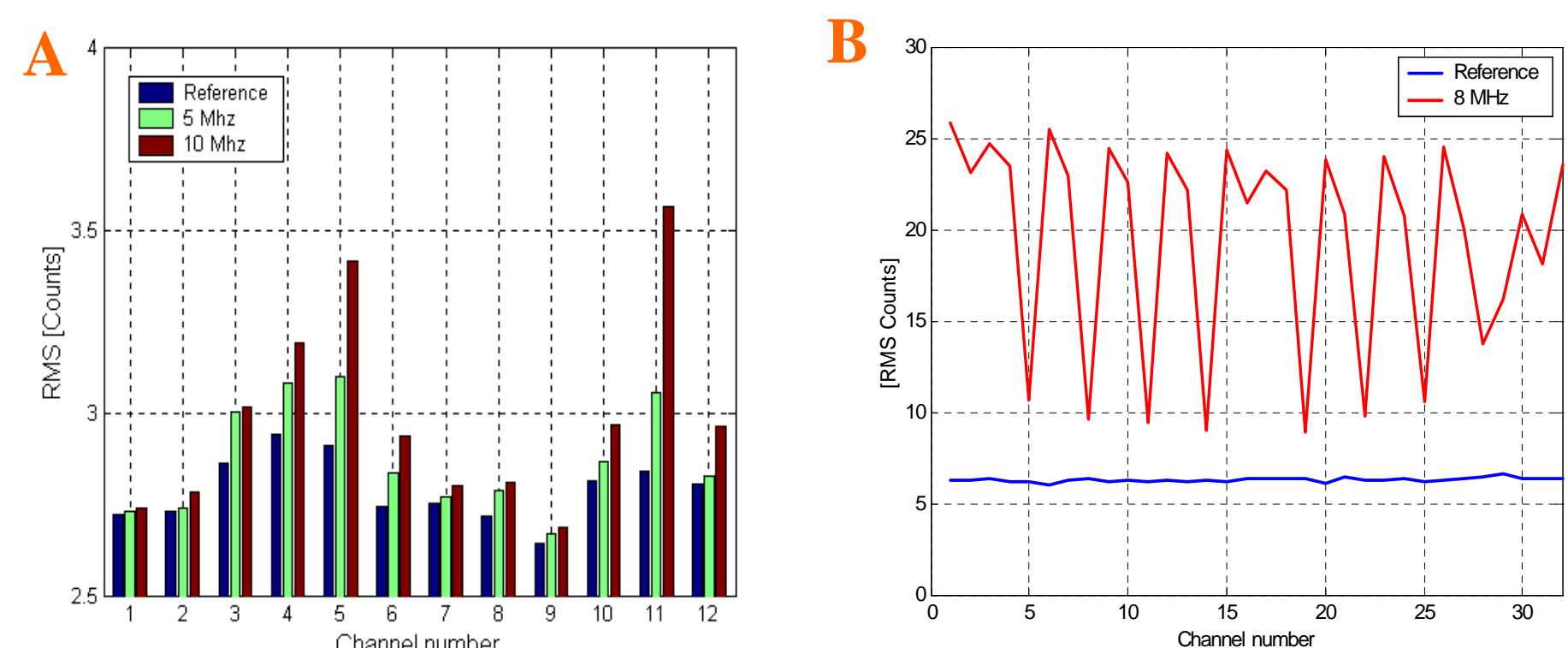
$$i_{pert}(t) \rightarrow \text{FEE} \rightarrow V_{out}(t)$$

The immunity tests and numerical models results may be used to characterize:

1. Noise distribution among channels in the FEE
2. Estimate the transfer function $TF(f)$ between the EM noise and the FEE output: $TF(f) = \frac{V_{out}(f)}{I_{pert}(f)}$
 - Frequency response of the FEE to EM noise
 - Define the coupling mechanism between EMI-FEE
 - Define the noise emission level of PS compatible with FEE.

These characterization tests allow identifying critical elements in prototypes that reduce the FEE performance. Characterization tests are used to understand the coupling mechanism of EM interference in the system. All these issues are very important in the up-grade and design of the future generation of HEP experiments

DETECTOR-FEE CONNECTION

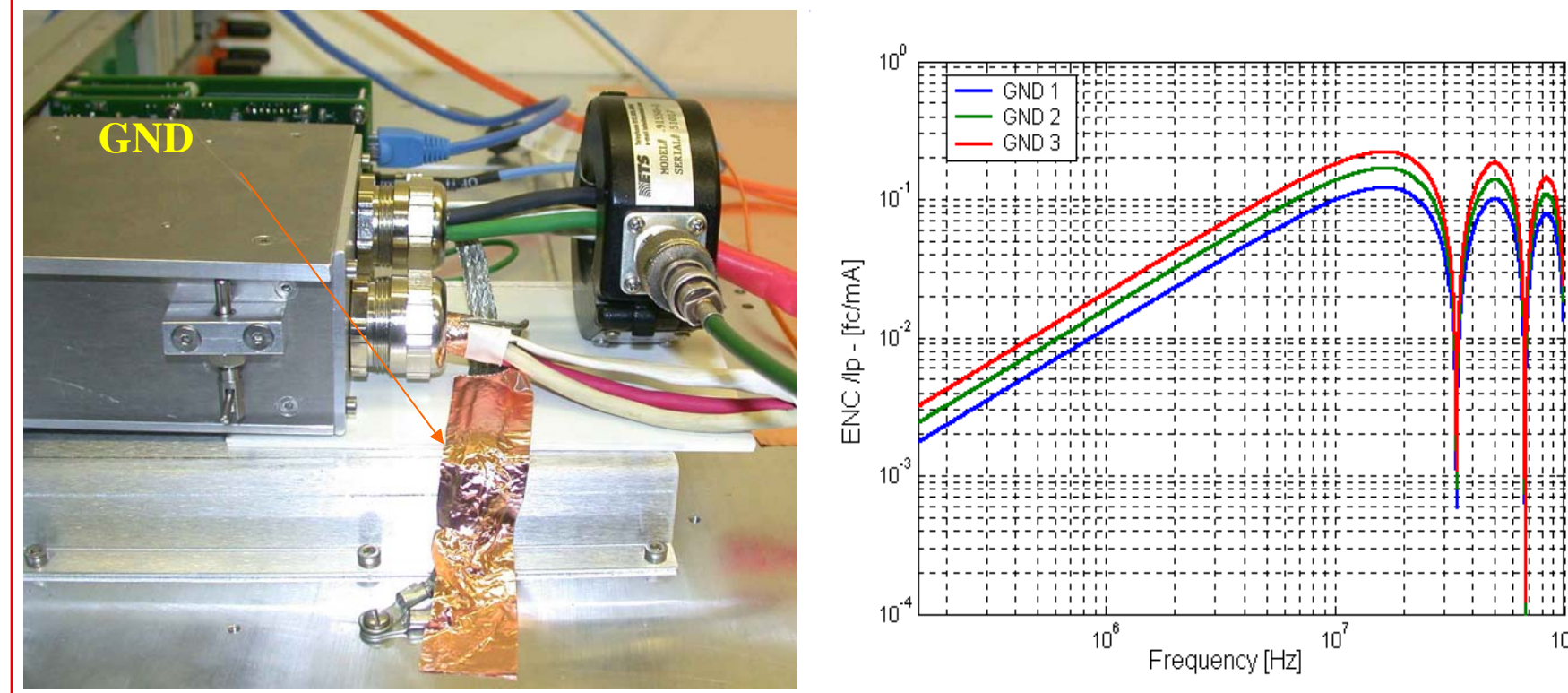


METHODOLOGY: Noise injection test - HCAL & Preshower

OBSERVED EFFECTS: Figures show the digitised RMS value of the amplifier output voltages for all channels of HCAL FEE (A) and Preshower FEE (B) when perturbing currents are injected through the power cables. Because slight differences in the Detector-FEE connections, the noise does not couple equally in all the FEE channels

LESSON LEARNED: For future designs, special attention should be paid in planning the Detector-FEE connection with similar common signal paths to equally distribute the noise current to all the FEE channels, avoiding 'critical paths' or 'sensitive channels'

GROUNDING CONNECTION

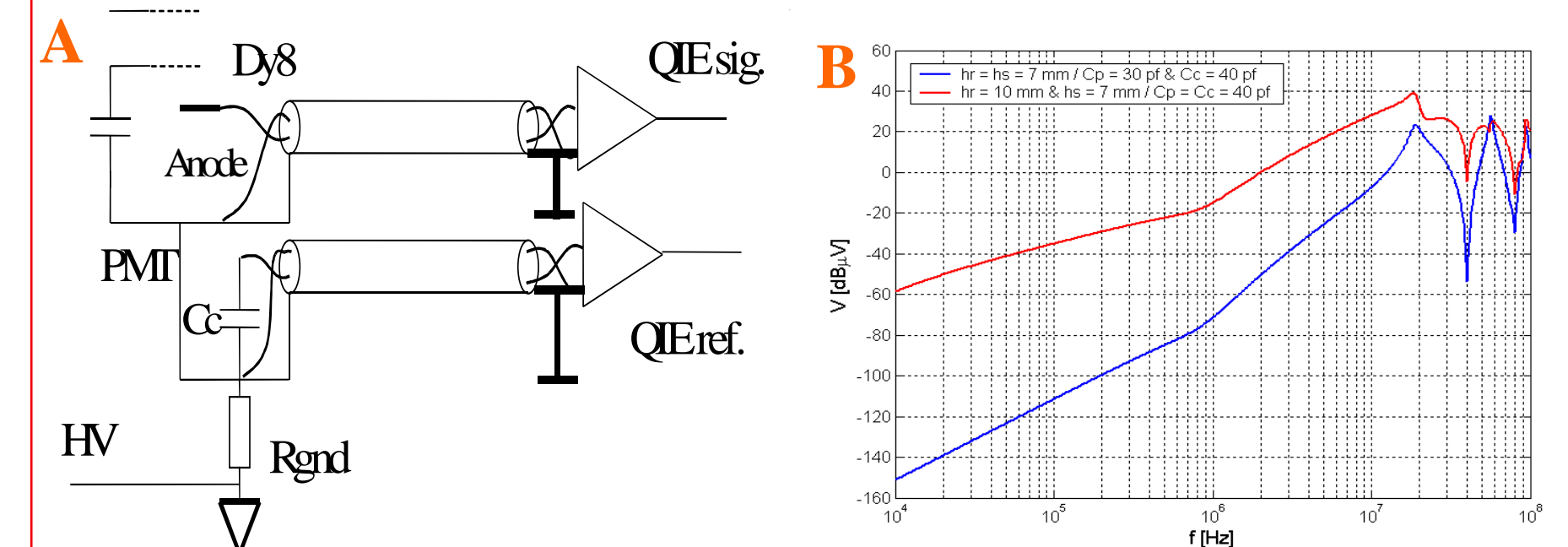


METHODOLOGY: Noise injection test— HCAL

OBSERVED EFFECTS: Results show the FEE susceptibility to CM currents for three different types of ground connections. The length and the routing of this connection has been changed. The photo depicts the connection under study.

LESSON LEARNED: The ground connections plays an important role in the FEE immunity. It defines the impedance between the FEE and the ground, setting the amount of noise that is capable to enter inside the FEE metallic box. These connections should be short, flat and the routing path should be as close as possible to the ground structure.

FEE TOPOLOGY—UNBALANCES

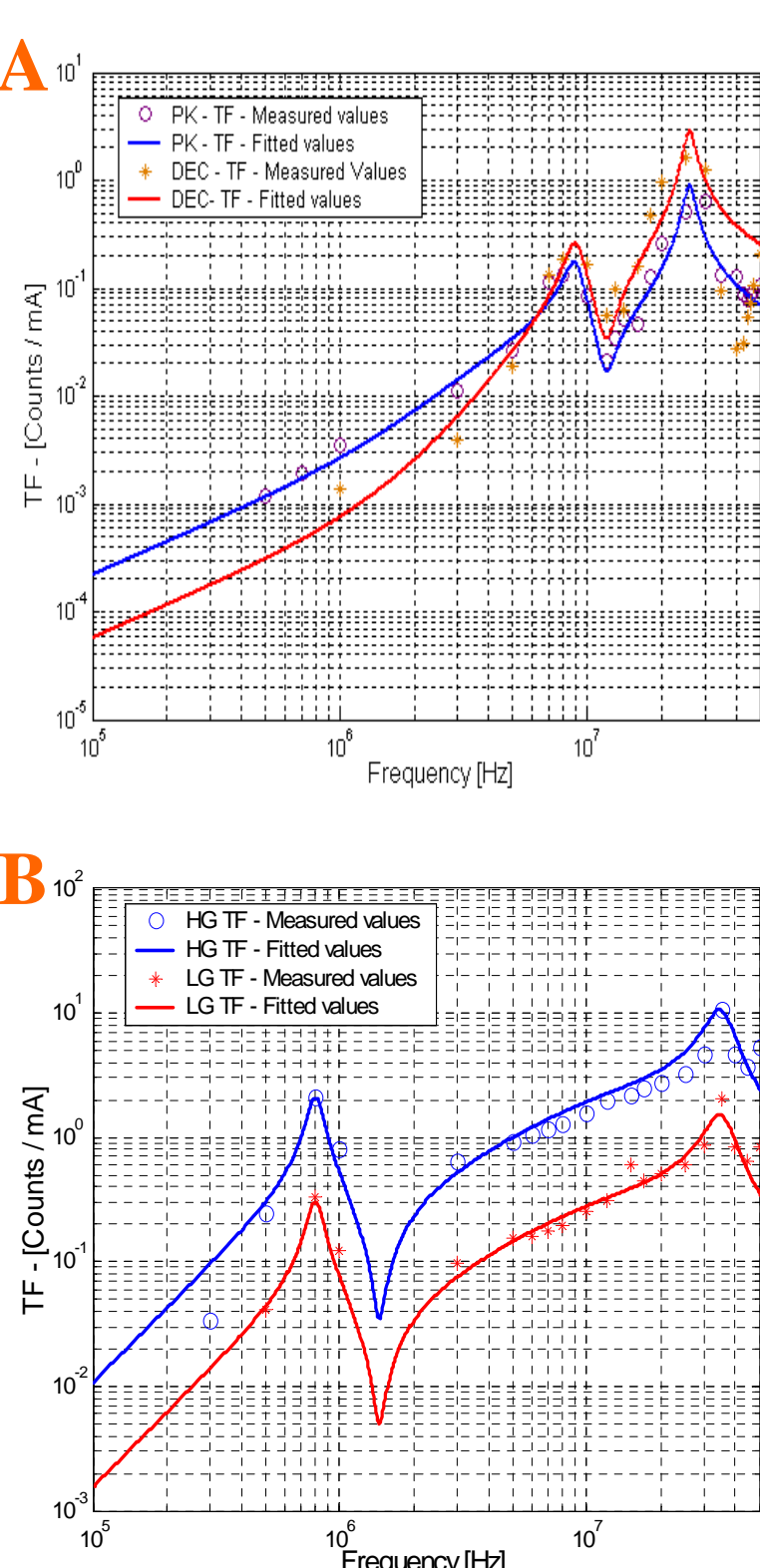


METHODOLOGY: Numerical simulation (MTL) - HCAL Fwd (HF)

OBSERVED EFFECTS: The influence of unbalances generated by the connection between the photodiodes and the FEE located 4 meters away is studied. The picture B shows the common mode rejection of the HF FEE topology depicted in figure A. The performance of the differential amplifier (QIE) is decreased more by the different position of the cables on the cable tray than the capacitance unbalance of the photodiodes.

LESSON LEARNED: Unbalances in the input signal circuit strongly increase the FEE noise susceptibility to EMI noise. The selection of specific components and the topology help to decrease unbalance effects. In this particular case, the HF immunity was improved by selecting a double twisted pair cable with a single braided shield.

FEE RESPONSE TO EM NOISE

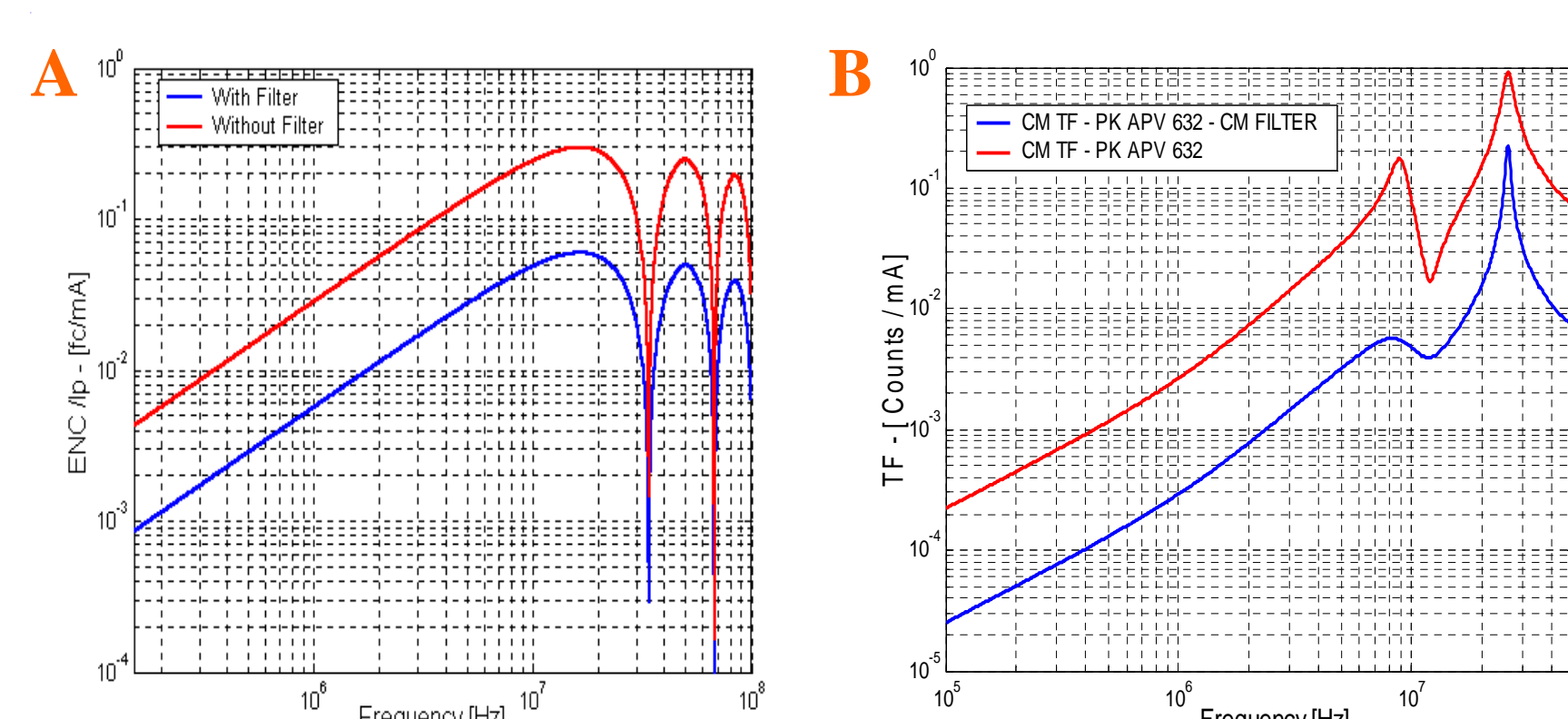


METHODOLOGY: Noise injection test - TEC & Preshower

OBSERVED EFFECTS: Plots show the measured and estimated Transfer Functions (TF) for Tracker (TEC) and preshower when CM noise is injected through the power cables. Fig. A shows TEC TF for the two operation modes of the APV (PK & DEC) and Fig. B the Preshower TF for two different gains of PACE chip (LG & HG). In both cases, the sensitivity of the FEE is different for the two operation modes of the chip. Also, the FEE is more sensitive to high frequency noise than a low frequencies due to coupling network.

LESSON LEARNED: The FEE operation mode have an strong influence in FEE immunity. The noise coupling network modifies the frequency response of the FEE, increasing the sensitivity of system to high frequency noise.

CM FILTER

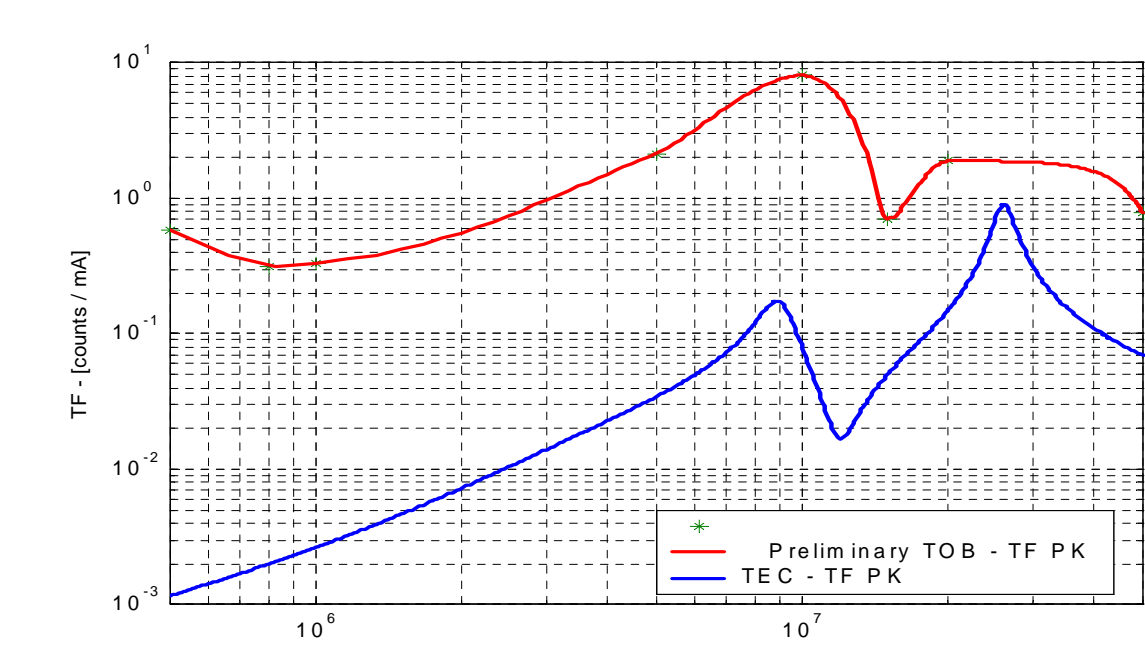


METHODOLOGY: Noise injection test - HCAL & TEC

OBSERVED EFFECTS: The plots depict the CM TF of HCAL (A) and TEC (B) FEE with and without CM filter. Both figures show a general improvement around 14 dB, for HCAL and 12-30 dB, for TEC of the FEE susceptibility

LESSON LEARNED: The implementation of CM filters at the input of the FEE increase the immunity of the systems against CM noise currents. This improvement will be in the range of 10-20dB, because the CM filter cannot be implemented with inductors based on magnetic materials. The high magnetic field in the central area of the detector excludes the use of magnetic materials.

Power Distribution Board Designs - ICB



METHODOLOGY: Noise injection test - Tracker TOB&TEC

OBSERVED EFFECTS: The figure shows the TF to CM noise currents of TEC and TOB FEE (APV peak mode). The immunity of TEC system is much higher than the TOB. Both sub-systems use the same silicon sensors and amplifiers (APV). The main difference between them, is the ground plane of the power distribution board (ICB). The TEC sub-detector ICB includes a ground plane that shields the EM fields generated by power currents.

LESSON LEARNED: The ICB design has an strong impact in the FEE susceptibility. A ground plane in the ICB design helps to decrease the length of ground connections and confine within the board the EM fields generated by the DC power distribution. These measures in the ICB design improve the immunity of the FEE.

SLHC IMPLICATIONS

Up-upgrades for the central detector in both the CMS and the Atlas experiments require defining new schemes for the DC power distribution. The power schemes proposed can be grouped into: Serial Power Distribution System and DC-DC switching power converters. Both schemes have advantages and disadvantages, but the viability of each of them will be closely associated to the FEE design.

- **DC-DC switching power converter based:** Aspects like CM noise and radiated noise are very important, being crucial to pay attention to power distribution boards, ground planes and CM filters to ensure the compatibility between FEE and power system.
- **Serial power Distribution System:** Aspects associated to the Detector-FEE connection will be crucial to guarantee good performance due to the lack of global ground.

In both cases, it will be crucial to conduct EMC studies on the future generation of detectors to be able to improve the noise immunity of the front-end electronics to be compatible with the noise emitted by the power converters. **The compatibility between PS and FEE can only be achieved minimizing both the radiated and conducted noise emitted by the power supplies and the sensitivity of the FEE to EM noise.**

CONCLUSIONS

EMC tests and studies based on numerical simulations have been conducted on prototypes of CMS sub-detectors to characterize the FEE against EM noise. A summary of these studies, including the impact in the FEE susceptibility of FEE topology, Detector-FEE connection, power distribution board design and CM filter, and FEE grounding connection is presented. These tests have been remarkable important to evaluate weak areas of the system and the impact of the design in the FEE noise immunity. Similar procedures will be valuable to assess the noise compatibility between the FEE and PS in critical sub-detector up-upgrades for the LHC calorimeters.