Assessment of EMC Parameters of LHC Front End Electronics

by Fritz Szoncsó CERN TIS

1) Introduction

EMC parameters are an issue for LHC detector electronics because package density and man made noise interfere strongly with the susceptibility that is a by-product of the dynamic range required by many detector systems.
The parameters include relevant noise emissions by switch mode power supplies, noise transfer by linear power supplies, noise behaviour and emission by the electronics itself. It will be shown that radiation of noise is generally small and, in case this turns out to be a problem, may easily be screened. However, conducted noise may affect electronics via all connections and stray capacitances. Conducted noise handling will depend on system grounding, powering, cabling, connector quality. Screening efforts may interfere with conducted noise when screens become major stray paths.
Knowledge about system immunity and the levels of conducted noise to be expected, all over the entire frequency range of the electronics, will enable designers to react early in the system design stage.
EMC parameters allow for sound system choices whilst avoiding over engineering of power systems. Common mode current load also determines the layout of the grounding scheme. The ground configuration may then be chosen such that inevitable common mode currents may enter and leave the system where they do no harm.

2) Measurement of common mode noise of switch mode power supplies

Switch mode power supplies (SMPS) generate differential mode noise that in general is called ripple. Ripple may easily be filtered to reach any value desired. However, SMPS also generate common mode noise. Pollution of the ground system becomes inevitable if this part of the noise is allowed to stray. Figure 1 shows how the SMPS couples to the mains and to the output lines.

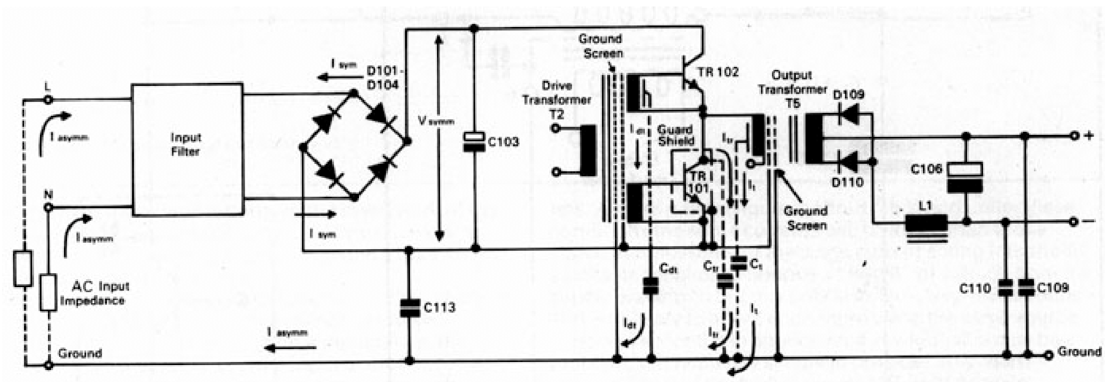

fig. 1 Interference paths of a switch mode power supply

Large voltage swings occur in the primary winding of the power transformer T5. Connections to the switching transistors share part of the problem. Power supply designers will try to have capacitive currents circulate as much as possible inside the power supply. It is, however, impossible to decouple the power stage entirely from the case. Output rectification adds on to the problem because of diode noise and imperfect screening of the cabling and the transformer. Thus, in addition to the ripple that remains after the smoothing filter L1/C106, plus C110 and C109, the radio frequency potential of the entire output section varies somewhat with respect to ground. Due to the inherent asymmetry of the output section the radio frequency potential will not be the same when comparing positive and negative line. If one output line is grounded the resulting ground current will not be equal for positive and negative polarity grounding.

Standardised EMC measurements are done using 150 Ω terminations (valid for the standardised conducted noise spectrum) which is supposed to simulate the mains impedance. The result is not particularly relevant for physics detectors. Firstly, mains impedances at CERN are one to two orders of magnitude smaller because of the abundant presence of other power circuits and the close vicinity of large power transformers. Secondly, there is a widely spread tendency to ground the connected loads, i.e. the detector electronics, at the detector side. Both boundary conditions require entirely different impedances for measuring the actual common mode current.

Measurements in this paper were done using the configuration drawn up in fig. 2.

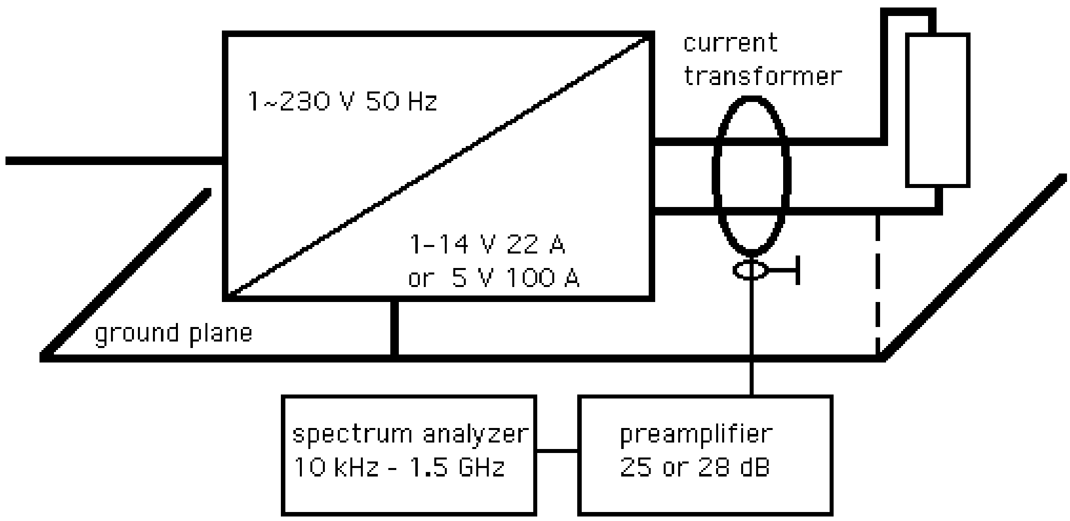

fig. 2 Measurement configuration for SMPS noise assessment

The mains impedance is simply neglected which reflects the conditions in the caverns to a large extent. One output polarity is grounded at the supply output, be it directly or via a resistor. This is, in terms of noise current, a worst case assumption. Low impedance grounding of the input circuitry will largely limit or even make impossible the development of any sizeable common mode voltage between mains input and ground. This effect "pushes" the common mode towards the load. For the common mode noise measurements a wide range current clamp is used to have access to the spectrum of the ground current under various conditions.

Measurements shown in fig. 3 show a slight common mode dependence on the polarity and some dependence on the load. The aim of the measurement is to determine whether or not a particular SMPS will be compatible with the immunity level of the electronics or system supplied. Measurements 4 and 5 (see fig. 3) detect the common mode noise when the SMPS is idling. The output asymmetry is visible but not dramatic. Bad quality SMPS would show much larger differences. Under load (measurement 8 and 9 in fig. 3) there is a broadening of the SMPS power pulses, a resulting different switching waveform and a more saturated operation of the magnetic elements. As a consequence the lower part of the spectrum, say, between 10 kHz and a few MHz, shows much higher noise generation. Whilst remaining within standards dictated by European Community decrees common mode noise now increases considerably. Common mode noise is conducted the better the lower the frequency becomes. It is this part of the spectrum that needs to be taken care of when treating the common mode problem. In particular, matching between the immunity spectrum (see section 4) and common mode generation would be advisable.

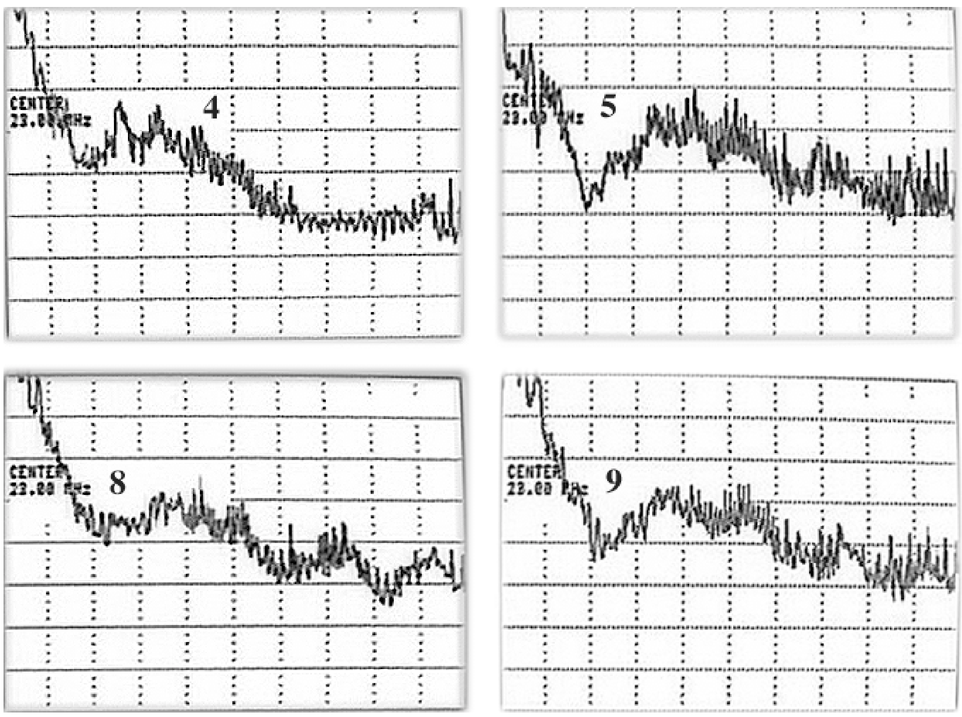

fig. 3 Conducted common mode noise of 5V 100 A SMPS grounded via a short lead. horizontal 5 MHz/div, vertical 10 dB/div a top line with reference level of –58 dBm (calibration: –60 dBm correspond to 0.45 mA)

The higher elements of the common mode noise spectrum do not show apparent differences between idling and loaded operation of the SMPS. A small difference for positive and negative grounding remains, however, visible even under load. This is the proof that, when this SMPS was designed, the output asymmetry has been thought of thoroughly.

SMPS of different manufacturers will have very distinct patterns of common mode generation. A second series of measurements, not shown in detail in this paper, indicated a strong polarity dependence of the noise spectrum. This second type of SMPS was evidently designed for negative grounding via short leads.

3) Measurement of common mode of switch mode power supplies followed by linear regulators

SMPS followed by linear regulators or long cables "see" a radio frequency impedance to ground that may be as high as a few kΩ. The resulting common mode currents now depend mainly on the impedance to ground seen by the non-regulated lead. This lead could have, for the radio frequency range, impedances in the kΩ-range. If used in an intelligent way the linear regulator following an SMPS may well be used for reducing common mode currents as much at it may reduce differential mode. Small common mode voltages may then develop without provoking currents above the immunity level of the front end to be supplied.

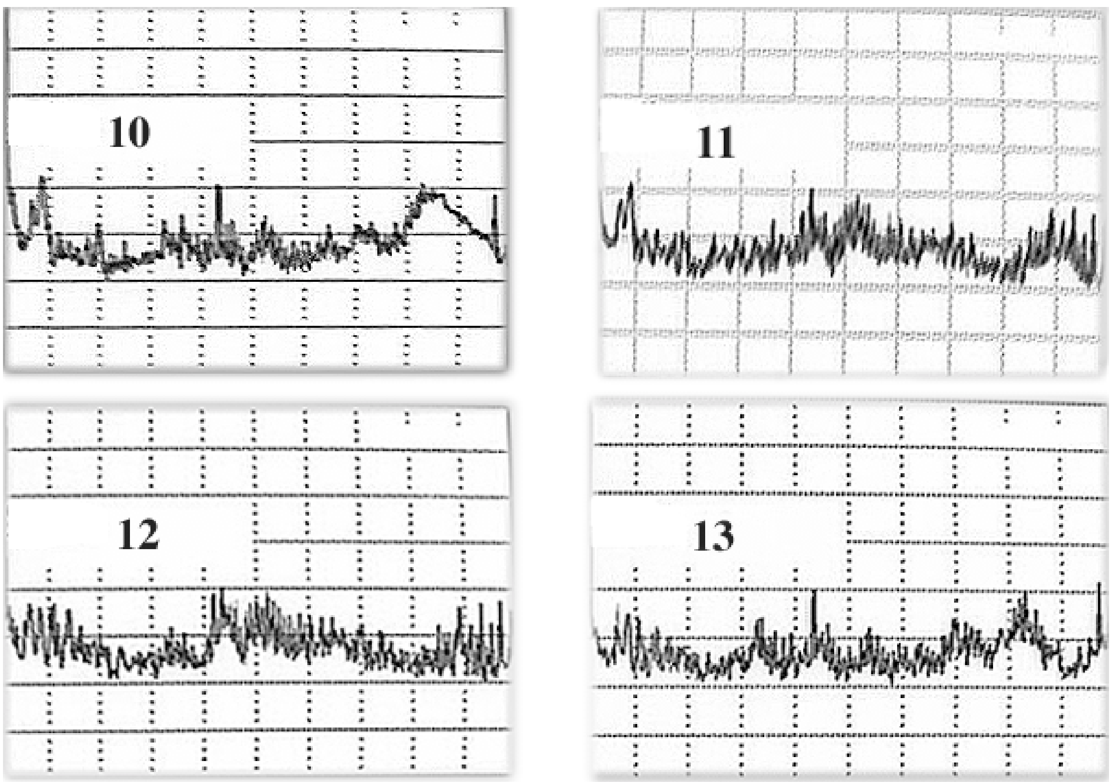

fig. 4 Conducted common mode noise of 5V 100 A SMPS grounded via 5 kΩ horizontal 5 MHz/div, vertical 10 dB/div with a top line reference of –58 dBm (calibration: –60 dBm correspond to 0.45 mA)

Again there are four measurements, 10 and 11 (fig. 4) when idling, 12 and 13 (fig. 4) for two thirds of the nominal load. Grounding is done by connecting a 5 kΩ resistor between the negative lead and ground (measurements 10 and 12 in fig. 4) or between the positive lead and ground (measurements 11 and 13 in fig. 4). Common mode generation is the same as in chapter 2 but no common mode currents are allowed to develop. Any load supplied by a long cable may easily be kept free of SMPS-generated common mode noise if the asymmetric impedance (impedance to ground) is kept high according to common mode requirements established by a system policy or by immunity measurements.

It is stressed again that noise voltages have little effect provided they are not allowed to drive any noise currents over large loops. Noise and stray currents are easily accessible for precise measurement.

4) Common mode immunity measurement of an electronics device

Front end boards are part of a system and need to reply to many boundary conditions. Grounding is necessary for many reasons. Grounding serves at the same time for safety equipotential, high level system reference, screen connection. It should, if ever possible, not be used for any power return.

The radio frequency potential difference between metallic enclosures and the board will be one of the ingredients for common mode. However, the largest "user" of the common mode budget, i.e. the ground connection(s), is the power supply system because of its inherent galvanic connection throughout the caverns and counting rooms. Some common mode on power supply lines inevitably strays everywhere, including on to the screens of signal input cables. Board analogue inputs and threshold lines are the most sensitive points.

Fig. 5 shows the sensitivity of a board's test pulse input to common mode noise. It does not matter where this common mode comes from. Measurements 1, 2, 3, 4 give the noise suppression capability of the board. The board's analogue output is connected directly to a spectrum analyser. Common mode is introduced on the test pulse line with a level of 0.1 V, 0.4 V, 2.5 V and 5 V respectively, over the frequency range of 0 - 100 MHz, on the current probe now used as a broad band signal transformer. A distinct pattern of noise sensitivity in the range of a few dozens of megahertz is clearly visible.

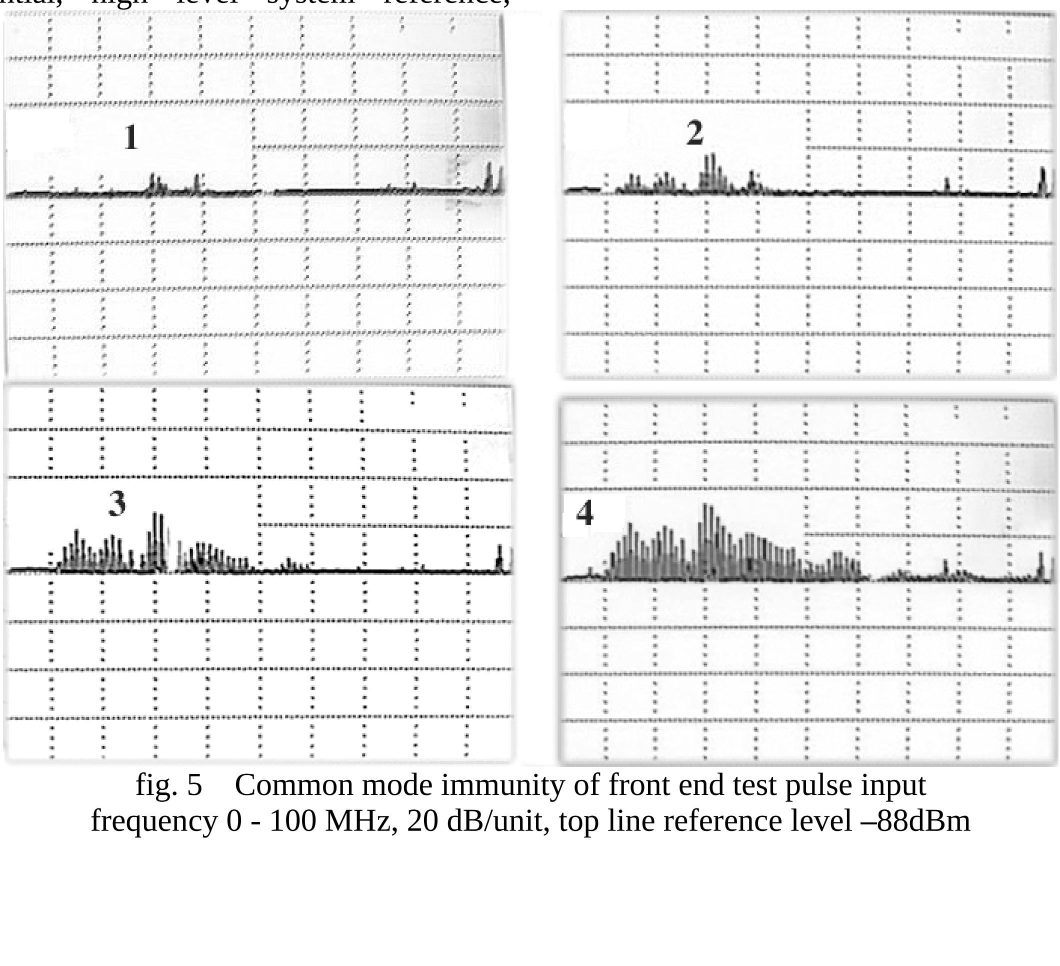

fig. 5 Common mode immunity of front end test pulse input
frequency 0 - 100 MHz, 20 dB/unit, top line reference level –88dBm

Using the same method the noise sensitivity of the board was tested on all other connections leading to or from the board, such as analogue power return, digital supply lines, threshold input line. All other lines were found to have higher immunity to common mode. The weakest point remains at the board input where common mode must be kept below a level that may be derived from the dynamic range and the measured board immunity. The level of common mode noise present after final installation inside a detector depends on the ground impedances present at the connections of the board. Ground impedances are often to be considered like parallel impedances, hence the large confusion once the grounding system needs to be modified in order to achieve better noise performance. Stray ground currents originating outside the system under test usually are quickly found.
A radio frequency radiation test showed very little board radiation of max. 78 µA/m in the lower MHz-range. As a consequence the board would be immune up to even higher field levels due to reciprocity. Radio frequency irradiation over large frequency ranges may only be tested in screened rooms. This test was not performed.

5) Conclusion

The paper intends to establish a direct relationship between the noise generation by power supplies and the noise immunity of front end systems.
Both noise generation and immunity parameters may easily be determined using slightly modified EMC-procedures that reflect the situation inside the physics experiments.
EMC parameters allow designers to use cost effective SMPS even in delicate environments. Matching of SMPS and delicate load must be done over the entire frequency range that falls into either bandwidth. In case common mode noise is allowed to drive currents some power line radiation will occur.
Linear power supplies also generate noise. The common mode part is generally small because linear power supplies actively generate very little common mode noise. However, quite close coupling to the mains is established by the capacitance of the windings of the mains transformer ($\approx$ 2 nF). Electrostatic screens reduce this coupling by a few orders of magnitude. Electrostatic screens therefore are mandatory for common mode and mains noise decoupling. It may also be shown that linear power supplies with long distance remote sensing show systematic limitations on the achievable noise performance.