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21 December 2006

On LHCb muon MWPC grounding

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Neither Maxwell equations nor Maxwell ® will be used to find the order in chaos of electromagnetic coupling in a big system

Abstract

My goal is to study how a big MWPC system, in particular the LHCb muon system, can be protected against unstable operation and multiple spurious hits, produced by incorrect or imperfect grounding in the severe EM environment of the LHCb experiment. A mechanism of penetration of parasitic current from the ground loop to the input of the front-end amplifier is discussed. A new model of the detector cell as the electrical bridge is considered. As shown, unbalance of the bridge makes detector to be sensitive to the noise in ground loop. Resonances in ground loop are specified. Tests of multiple-point and single-point grounding conceptions made on mock-up are presented.

Contents

Introduction

The problem considered here is related to the LHCb Muon system which consists of about 1300 multi-wire proportional chambers (MWPC), see ref. [1, 2]. The note has been based on a presentation made by author during LHCb week [3, 4] and further study. My goal is to study how a big MWPC system, in particular the LHCb muon system, can be protected against unstable operation and the multiple spurious hits, produced by incorrect or imperfect grounding in severe EM environment of the LHCb experiment.

There are 3 items to be considered: mechanism of penetration of parasitic current from the ground loop to the input of front-end amplifier in enclosed detector; how reduce current in ground loop; how move out of the front-end electronics (FEE) bandwidth the resonances which usually exist in the complex impedance of the ground loop.

Fig.1 shows 5 muon stations M1-M5 each of which is a 'wall' of many MWPCs. It is clear that all chambers will irradiate EM field and noise, and each individual channel can detect it. In addition, many other sources of EMI will contribute: other sub-detectors, LHC clock, etc.

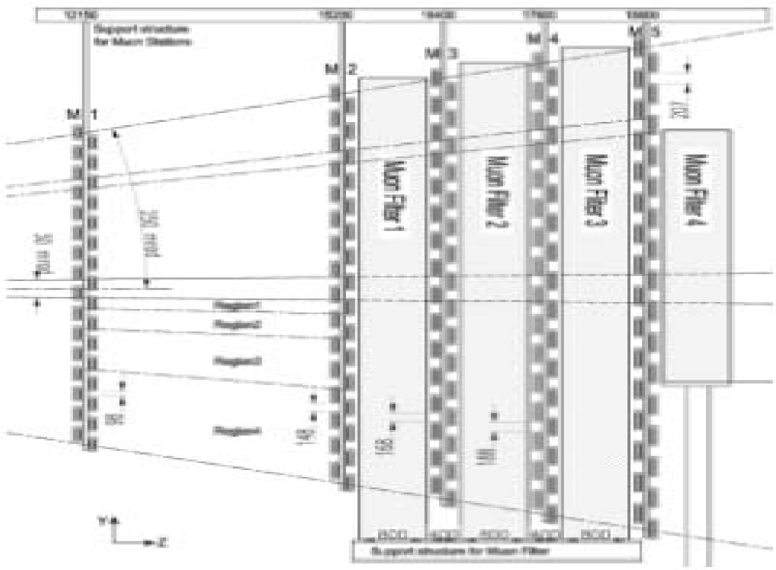

Fig.1. Schematic layout of the LHCb Muon system.

The LHCb muon system consists of 20 different design configurations of MWPC (4 regions by 5 stations). Four schemes are used: Wire Pad Chamber (WPC) in which the pad is a wire strip; Cathode Pad Chamber (CPC) where cathode is segmented into pads of various sizes depending on region and station. There are CPC in which one cathode has been segmented (Single Cathode Readout, SCRO) or both cathodes segmented (Double Cathode Readout, DCRO). In order to reduce the number of channels in the system in the inner regions R1 and R2 of stations 2 and 3 the chambers have combined readout of both cathode pads and wire strips (CWPC). These chambers have been made as DCRO in region 1, and as SCRO in region 2. Station 1 of region 1 (the closest to the beam line) has been equipped with Triple GEM chambers [2], while region 2 with DCRO, region 3 with SCRO and region 4 with WPC. Fig.2 shows example of multiple loops in ground through the screens of cables attached to the chamber M5R1 (CPC-SCRO) enclosed by Faraday Cage (FC). Different chambers have different number of cables and different number of loops.

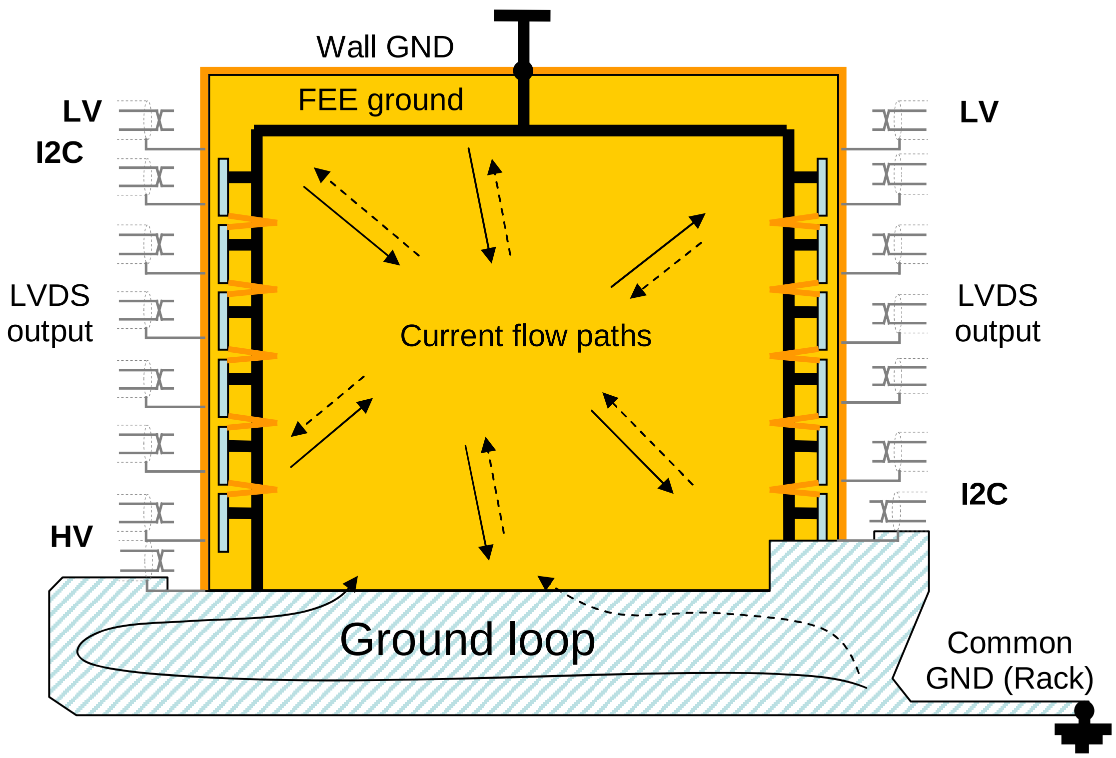

Fig.2. Multiple loops in ground through the screens of cables attached to the chamber.

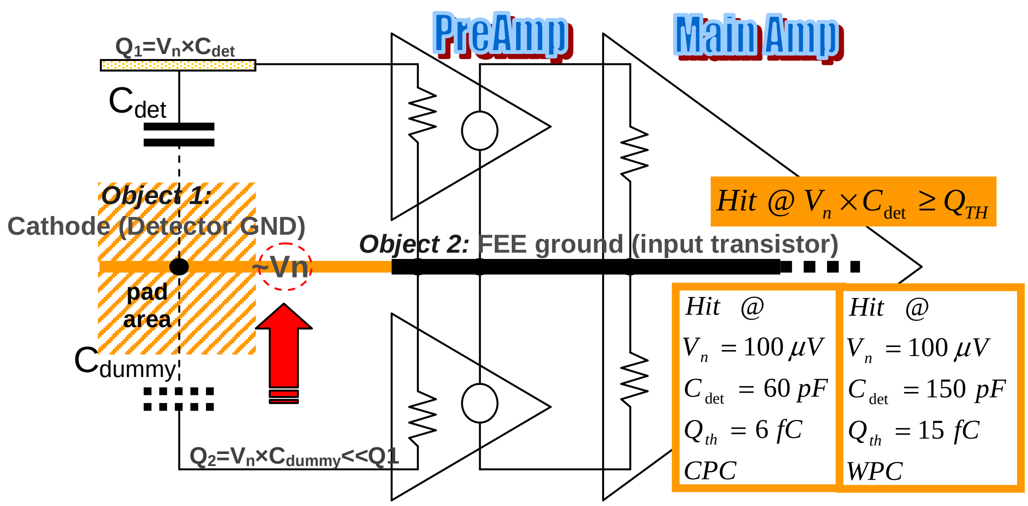

Fig.3. Simplified schematics of the frond-end amplifier connected to the cathode or wire pad.

Fig.3 shows simplified schematics of the front-end amplifier. One input of the preamplifier is connected to the detector cell, e.g. to the cathode pad with the detector capacitance C_{det}, while the second input is so called ‘dummy’ (floating) with capacitance C_{dummy} which is much less than C_{det}. The voltage V_n~100µV between 2 grounds, the detector and the FEE ground (input transistor), produces parasitic hit, if the charge $Q_1=V_n \times C_{det}$ exceeds the threshold, Q_{th}. To be immune to such voltage in ground the dummy input must have the same capacitance as C_{det}. But this solution increases noise and has been rejected.

1. Detector cell as an electrical bridge

Another protection against penetration of the parasitic voltage from the ground to the amplifier and a mechanism, how V_n shown in Fig.3 is created when both grounds are well connected together will be considered below.

The amplifier input connected to the cathode pad in CPC_SCRO is coupled via capacitor C_{det} to the solid cathode, i.e. to the detector ground. A connection of the solid cathode to the FEE ground is done in our particular case via the detector enclosing Faraday Cage (FC) in several points through the contact resistors which are not zero. The detector cell with its amplifier is represented in Fig.4 as an electrical bridge with the contact resistors (*R1-R4*) in arms. The amplifier is located in one diagonal and the external parasitic voltage source connected in series with its internal impedance is applied to another diagonal of the bridge. Fig.5 shows one cell of the WPC as a double electrical bridge.

In a balanced bridge, i.e. if R1/R2 and R3/R4 are equal (see Fig.4), any parasitic voltage V of any frequency can not penetrate to the input of amplifier. However, in an unbalanced bridge, i.e. if R1/R2 and R3/R4 are not equal, it can penetrate and produce a parasitic hit if the injected charge exceeds threshold. A polarity of injected into amplifier parasitic signal depends on unbalance factor, i.e. ratio R1R3/R2R4, which can be either more or less than 1.

A full detector is represented as a set of electrical bridges according to the number of amplifiers (channels). Careful design of the detector has to be done in order to get balanced bridge in each channel. In practice it is a hard task, and the various channels are usually unbalanced with different factors. As a result, one can see often that some channels are more and some channels are less sensitive to the noise in the ground. It is well known, that the electrical bridge has maximum sensitivity to the resistor variation in vicinity of balance condition. An unbalance by factor of 5 due to spread of contact resistors in practice, e.g. from *10 mΩ* to *50 mΩ*, provides a drastic penetration effect, the parasitic signal can exceed threshold by factor of 100.

Model

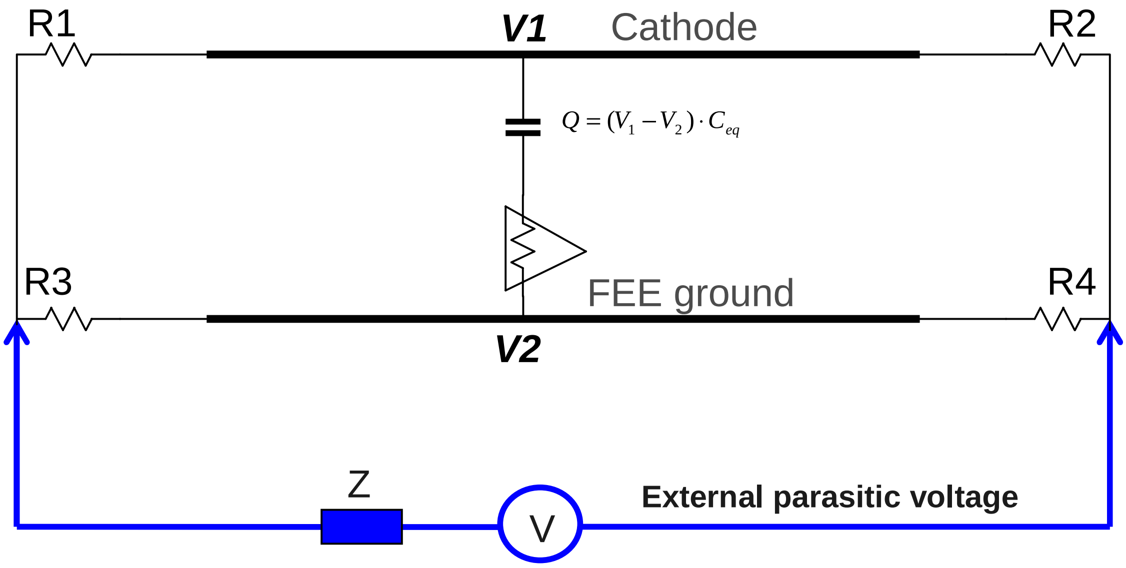

Fig.4. Detector cell of the CPC-SCRO as an electrical bridge with the front-end amplifier located in one diagonal of the bridge and the parasitic voltage applied to another diagonal.

Model

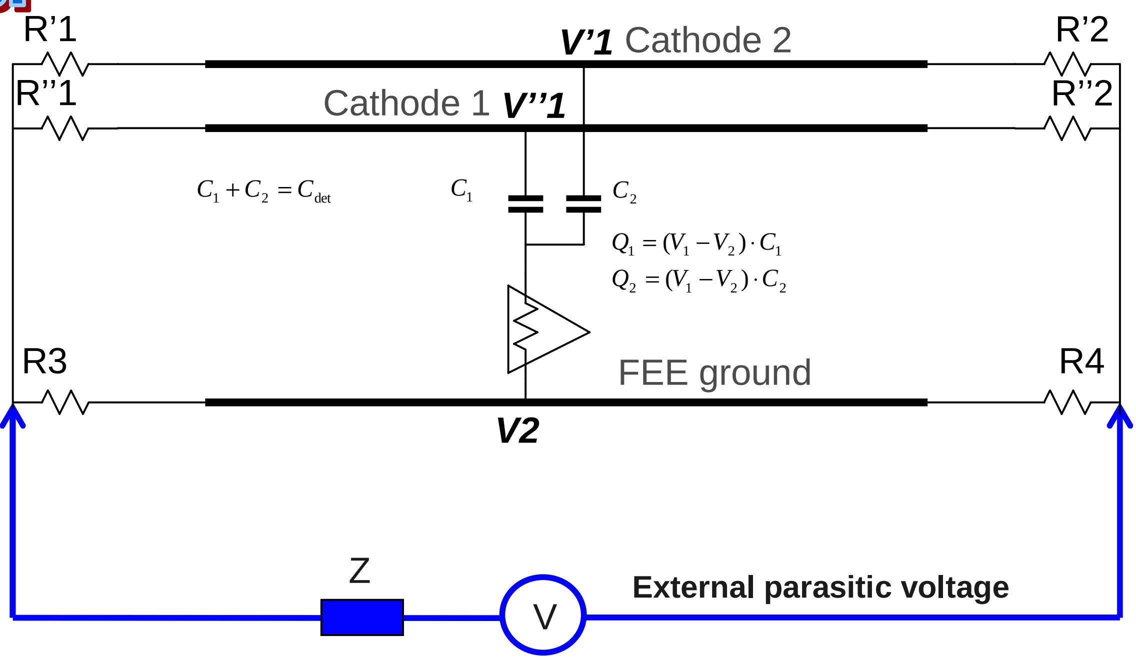

Fig.5. Detector cell of the WPC as a double electrical bridge with common arm.

2. Multiple-point and single-point grounding conceptions

The complex impedance with many inductances and capacitors connects the enclosed detector to the common ground, i.e. rack. This impedance has intrinsic resonances. Low frequency resonances due to decoupling capacitors used in series with screens of cables will be cut-off by FEE bandwidth. High frequency resonances located within FEE bandwidth will be considered below. For the inner chambers located near the beam the cables are routed along and near the grounded wall, such the transmission lines are created in the ground loop, see photo in Fig.6. In case of peripheral regions there is no such possibility and the screens of cables are considered as inductances.

The multiple-point grounding scheme for the lumped lines attached to the chamber is presented in Fig.7. The detector (one cell, as an electrical bridge, is shown for simplicity) is DC connected to the wall in order to have the voltage reference (V=0) and for safety requirement. The wall, in turn, for same reason is DC connected to the common ground (rack) by the Copper braid with low ohmic resistance and high enough inductance (reactance) called main inductance in Fig.7. The cable screens in a return branch can be considered either as inductances or transmission lines in series to inductances.

The single-point grounding scheme is presented in Fig.8. It has difference from the previous scheme in the capacitance which appears (see circle) after disconnection of all screens from the chamber side and connection to the wall.

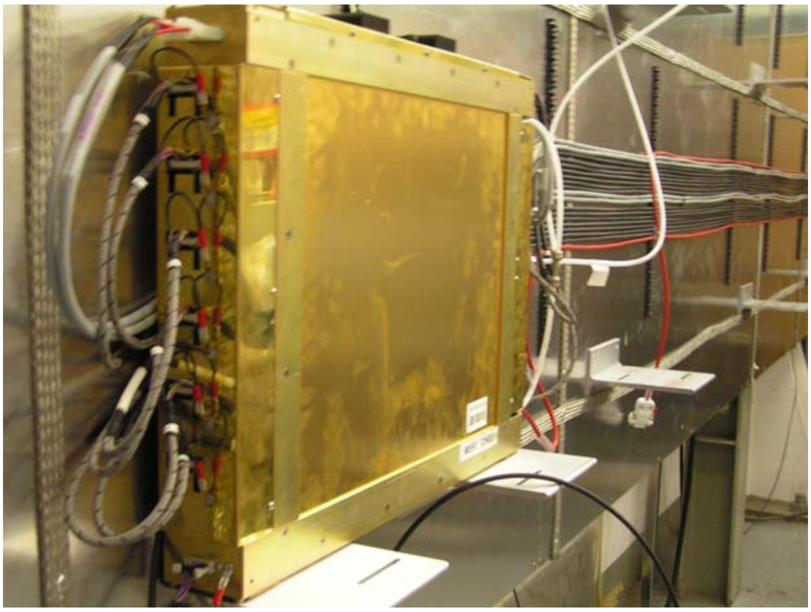

Fig.6. Cable routing from the inner-most chamber to the rack.

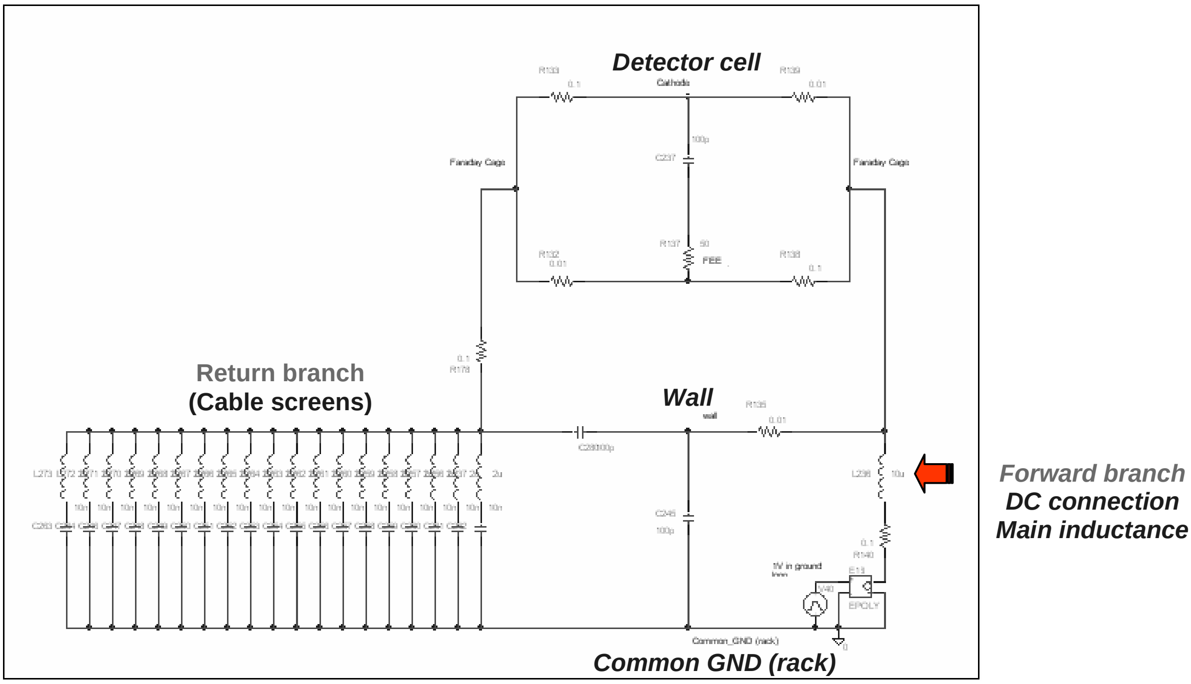

Fig.7. Multiple-point grounding scheme.

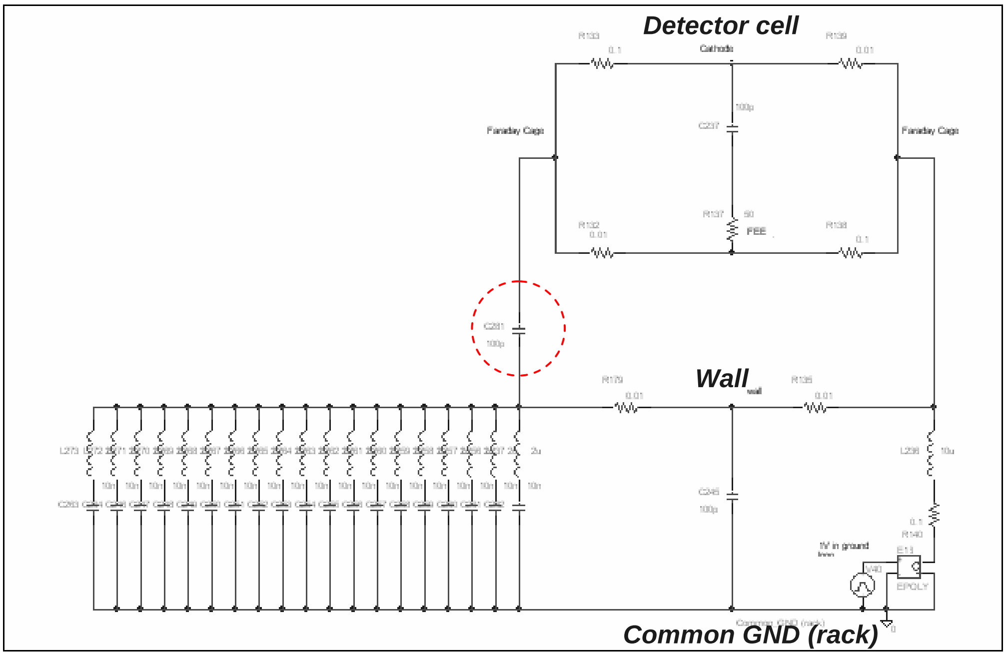

Fig.8. Single-point grounding scheme.

3. Resonances in the ground loop

The current in the ground loop is very high in case of series resonance. SPICE modeling will be used in this section to study resonances and to find methods of reduction of the current in the ground loop. Parameters used in simulations here are qualitative rather than quantitative. It has been considered already a mechanism how part of the current from the ground loop penetrates inside the enclosed detector and creates hit. The detector with so low resistors, as the contact resistors in arms of bridge, will be considered below as a short-circuit point and only current in the ground loop will be considered. The most dangerous case if the system is excited in resonance, it behaves similar to instability providing huge number of parasitic hits. In Fig.9 three schemes of the ground loops attached to the detector (Faraday Cage) are presented which interest for practice. In each case two models are considered: with short (lumped) or long (transmission) lines within the ground loop depending on routing of cables along the grounded wall. In the first scheme on top in Fig.9 the cable screens are DC connected to FC (multiple-point grounding), in the second one the cable screens are not connected on detector side (single-point grounding) and in the third one the screens are connected to the wall (also single-point grounding scheme).

SPICE shows unique, i.e. one per chamber, resonance in the lumped model. The resonance is specified in this case by the capacitance ‘wall-to-rack’ together with the equivalent inductance of cable screens attached to the chamber. The inductance and the resonance frequency depend on the number of cables attached to a certain chamber. Multiple resonances appear in case of long lines in the ground loop. This case is much complex: the resonances are specified by the parameters and length of transmission line, capacitance ‘wall-to-rack’ and the number of cables attached to a certain chamber.

So, one can conclude that the best is the single-point grounding scheme with connection of the cable screens on the detector side to the wall, see Fig.10. It has to be noted, that resonances have the same frequencies as in case of multiple-point grounding scheme. In case when the screens are not connected on the detector side the resonances are shift to higher frequencies.

Unfortunately, in the LHCb muon system the worst scheme (multiple-point grounding) has been implemented as the simplest one. In order to minimize the current in the ground loop in this scheme the main inductance has to be maximized. SPICE shows that this inductance must be above 20μH at parasitic voltage amplitude 1 Volt between rack and wall. For further reduction of the current in the ground loop especially in this scheme it can be proposed to add small resistors in series to cable screens on both sides, see damping effect in Fig.11 shown for the multiple-point grounding scheme. Similar effect will be in case of grounding screens to the wall.

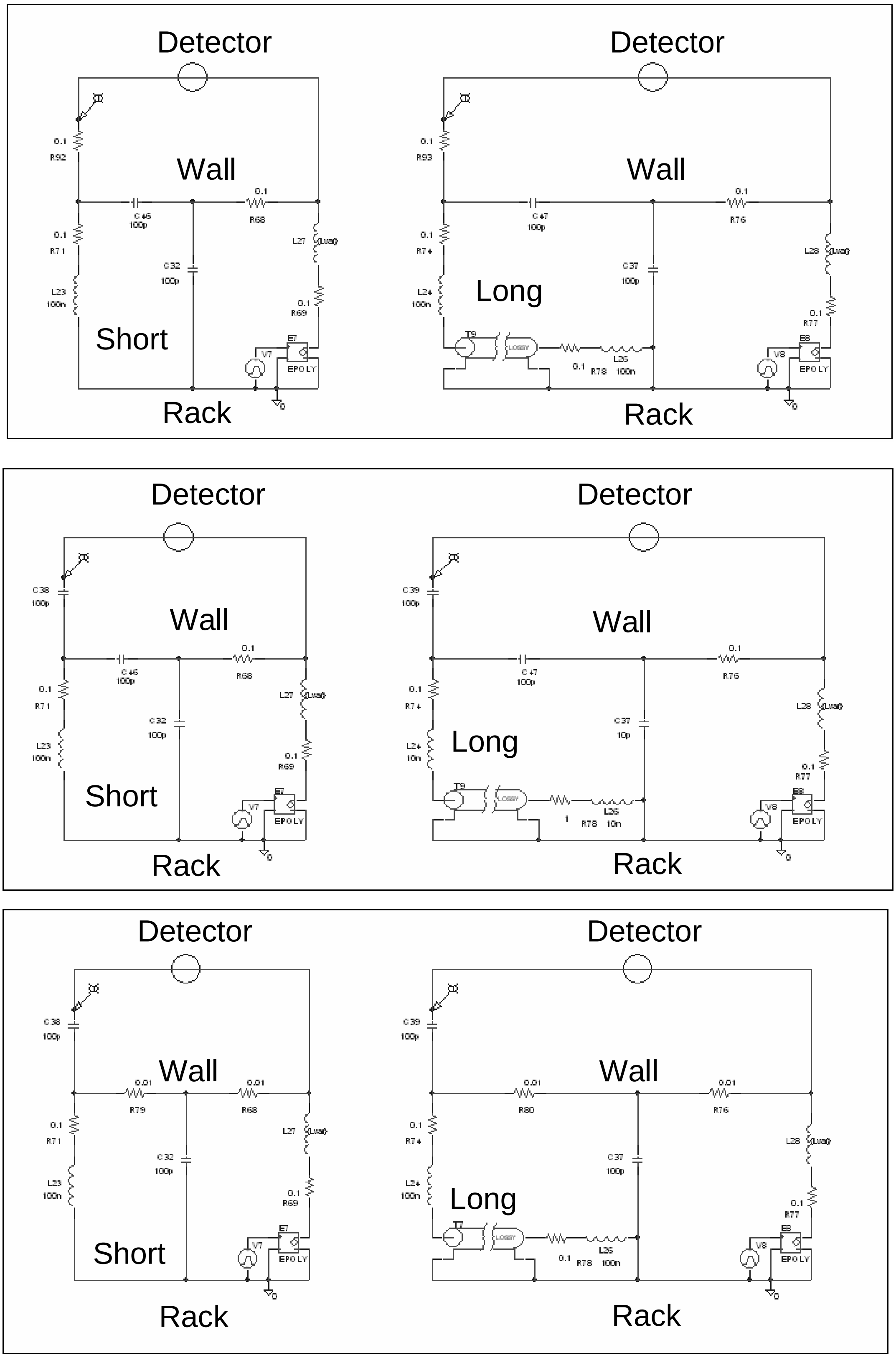

Fig.9. Ground loop models with short (left) and long lines (right).

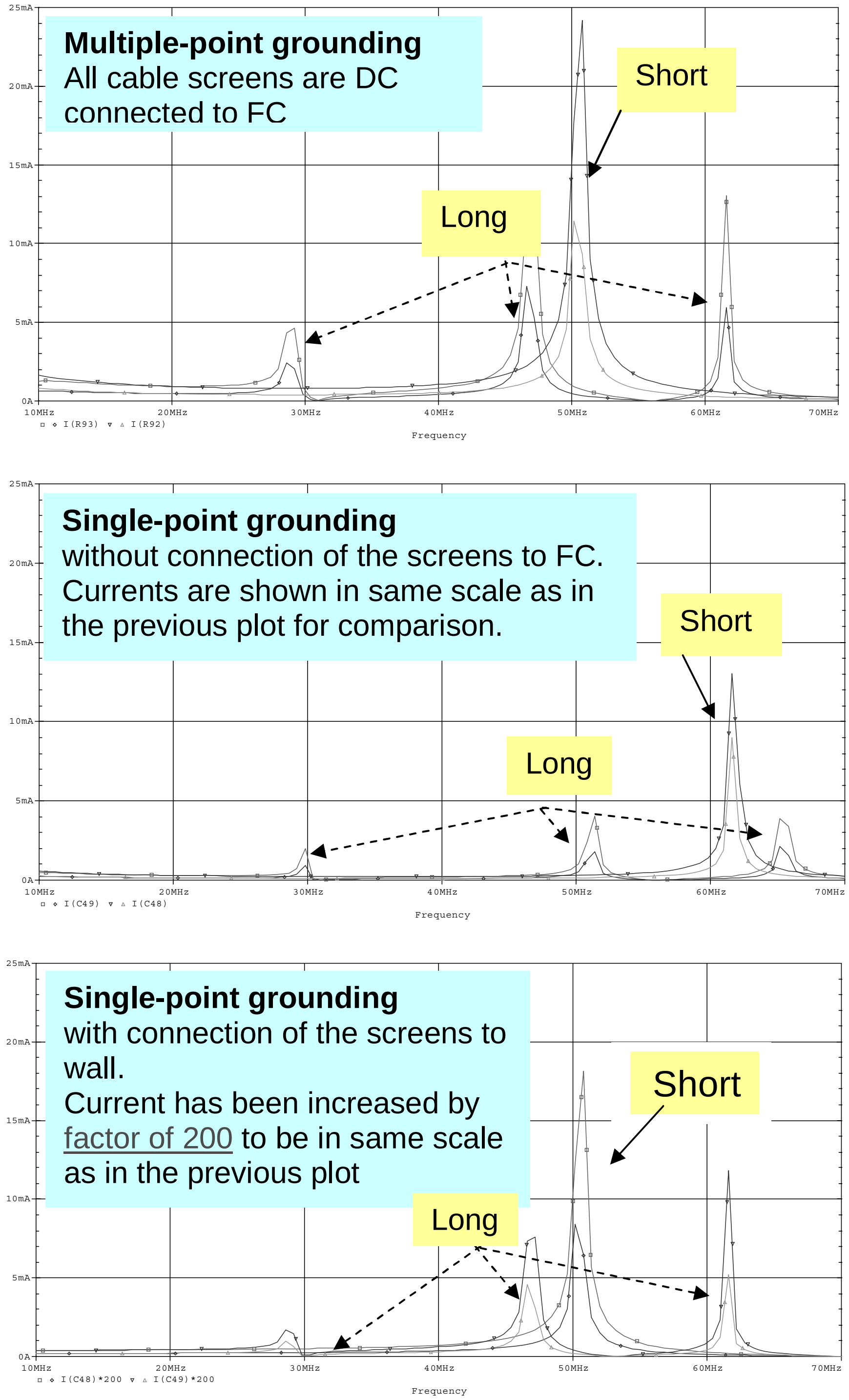

Fig.10. Resonances in frequency range of 10-70MHz in various cases.
Effect of main inductance 10µH and 20µH is illustrated (two peaks)

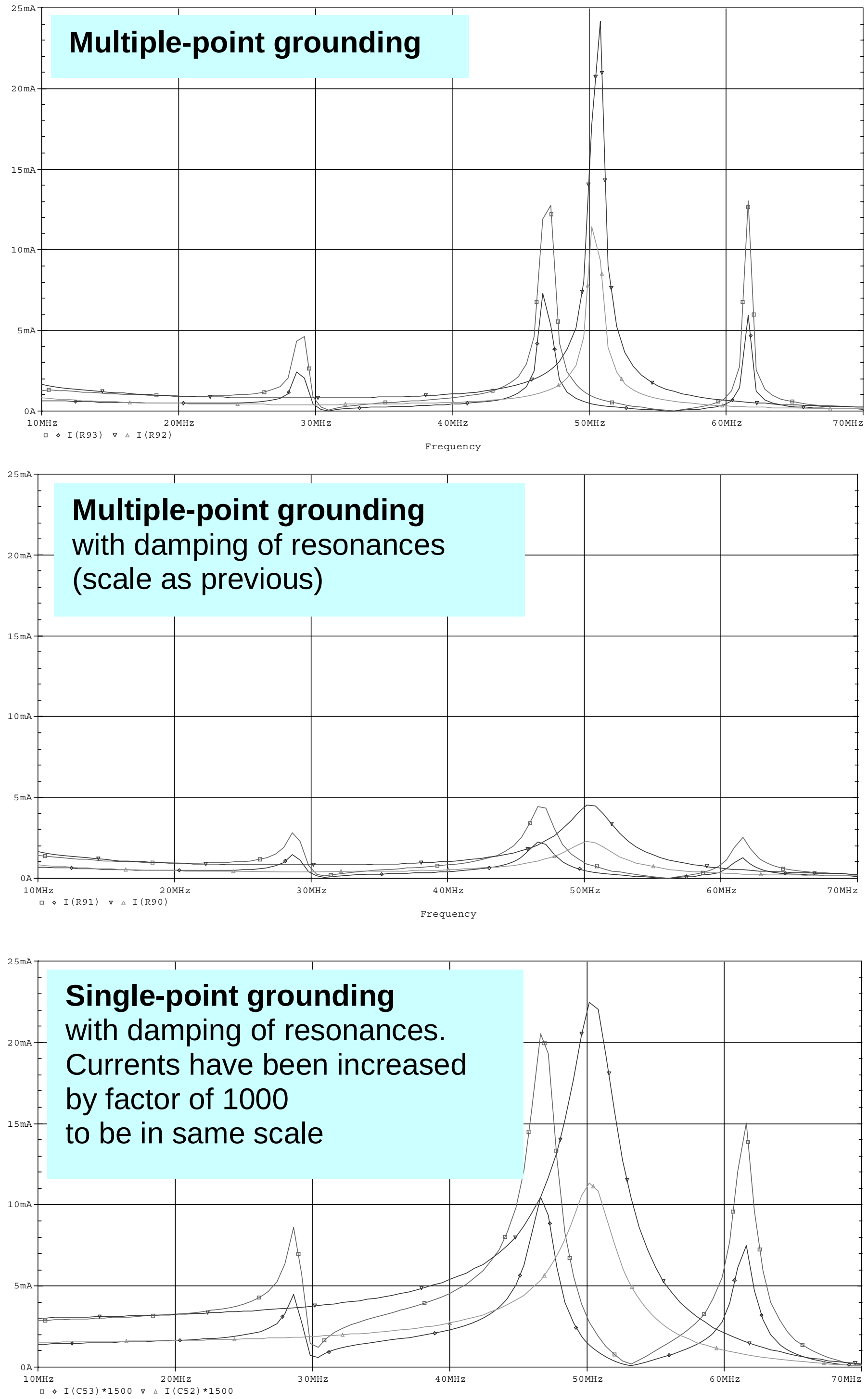

Fig.11. Damping effect by small resistors (few Ohms) in series to cable screens. Effect of main inductance 10µH and 20µH is also shown (two peaks).

4. Mock-up tests

Grounding problem of the LHCb muon system was studied on mock-up [5]. Mock-up is a part of the muon station with a size of 1.5m×5.5m (see Fig.12) on which various chambers were installed on supporting balconies and connected to the rack by all needed cables. How the real wall of chambers for the LHCb muon system will be implemented in detail one can find in ref. [5].

In Fig.13 the work station used on mock-up tests is shown. It is based on proposal presented in ref. [6]. MWPC in vertical position were tested on cosmic rays (CR) with this setup using self-triggering mode (2 bi-gaps operate in coincidence). To be able detect rather low rate of CR the noise count in each bi-gap must be below a few Hz.

The network which was tested is shown in Fig.14. One can see here how various parts of equipment were grounded. The main inductance (approx. 14 μH) used here is a Copper braid with a cross-section of 50mm×10mm, i.e. with very low ohmic resistance. Parasitic voltage, 2V pick-to-pick, with a rather wide spectrum in range of (8-16) MHz has been found in the ground loop during tests, see Fig.21. CAEN2527 HV system was responsible for this noise in our case. It is the reason why 1 Volt parasitic voltage source has been used in the SPICE models. As shown in section 3 the main inductance reduces current in the ground loop. The noise count in Hz as a criterion of system performance has been used. The noise level is accepted, if it is low and uniformly distributed from channel to channel at operational both threshold and HV. An example of not acceptable noise (high penetration of the noise from the ground loop) is illustrated in Fig. 16 and acceptable one in Fig.17. Such low noise, as shown in Fig.17, makes possible to count CR with rather low rate of about 0.06 *Hz* per pad in coincidence pad-to-pad between two bi-gaps, as in case of M5R1 (CPC-SCRO) in vertical position of the chamber on mock-up. Fig.18 shows another example of good performance of the system in case of M3R2W (wire readout). One can see profile of the wire strip width. CR count vs. HV scan presented in Fig.18, shows HV- plateau and cross-talks, as a slope of the plateau, i.e. two fundamental characteristics of the detector.

It would be impossible with the noisy system to get high performance in chamber operation as illustrated in Fig. 18 and Fig.19.

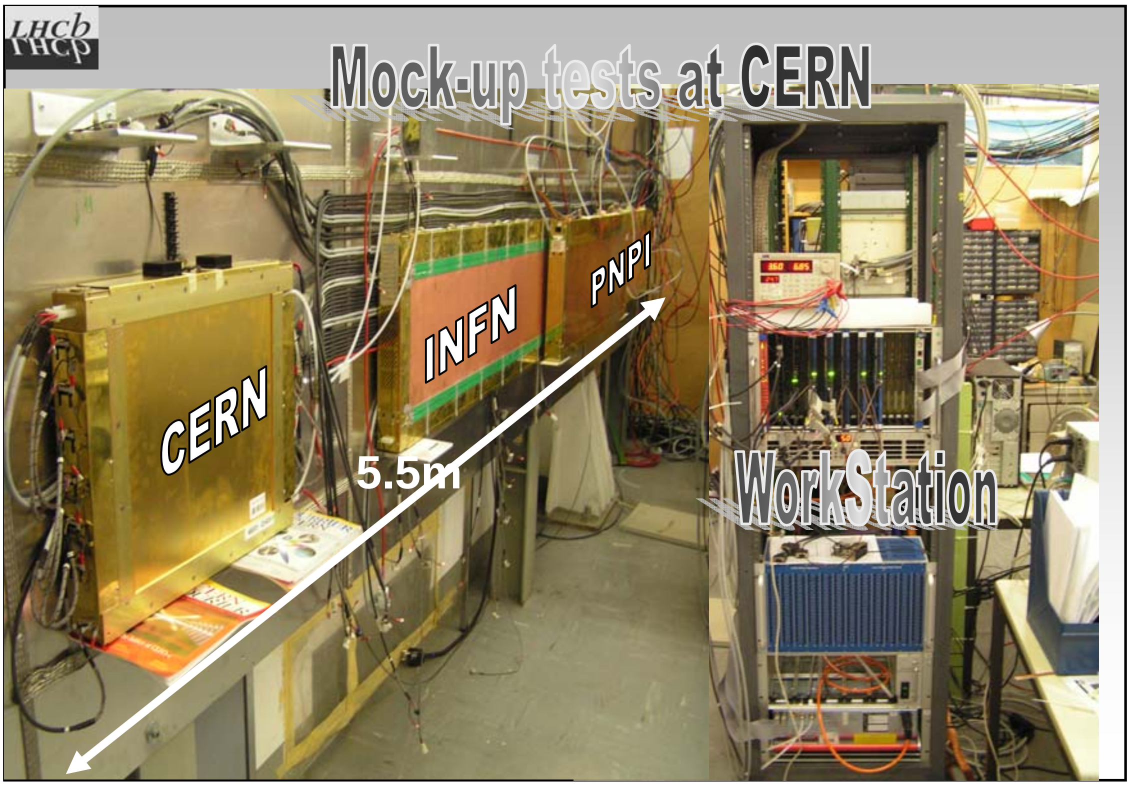

Fig.12. Mock-up with various chambers built at CERN, INFN and PNPI.

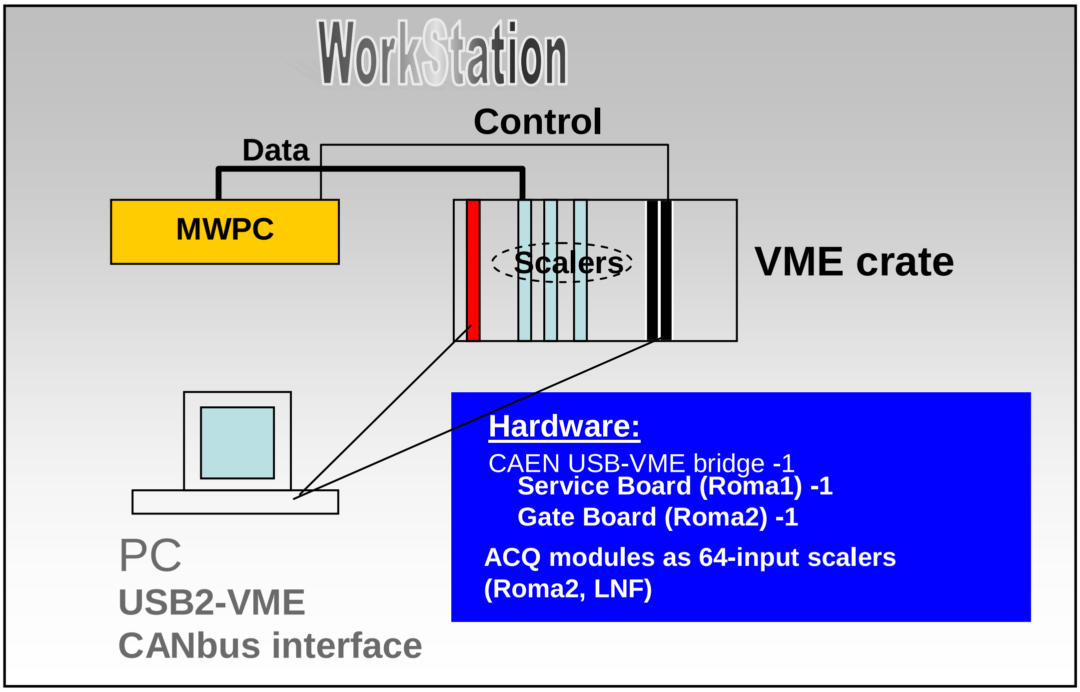

Fig.13. Work station used in the mock-up tests.

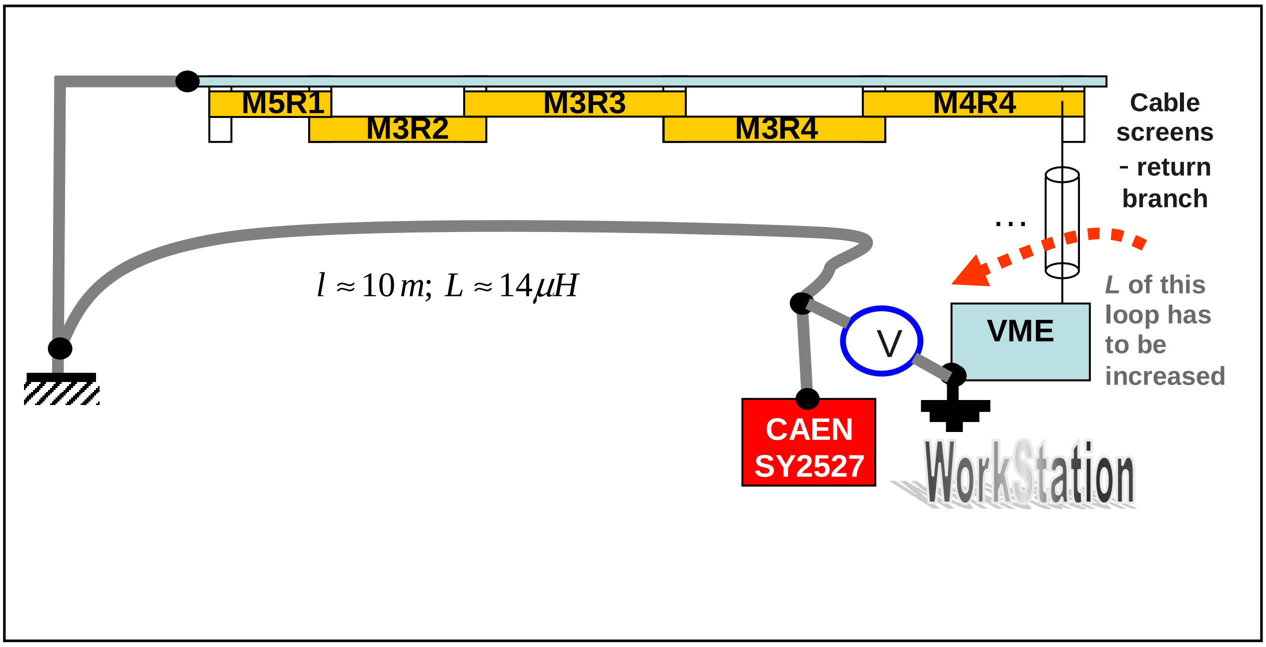

Fig.14. Network of grounding of the equipment used in mock-up tests.

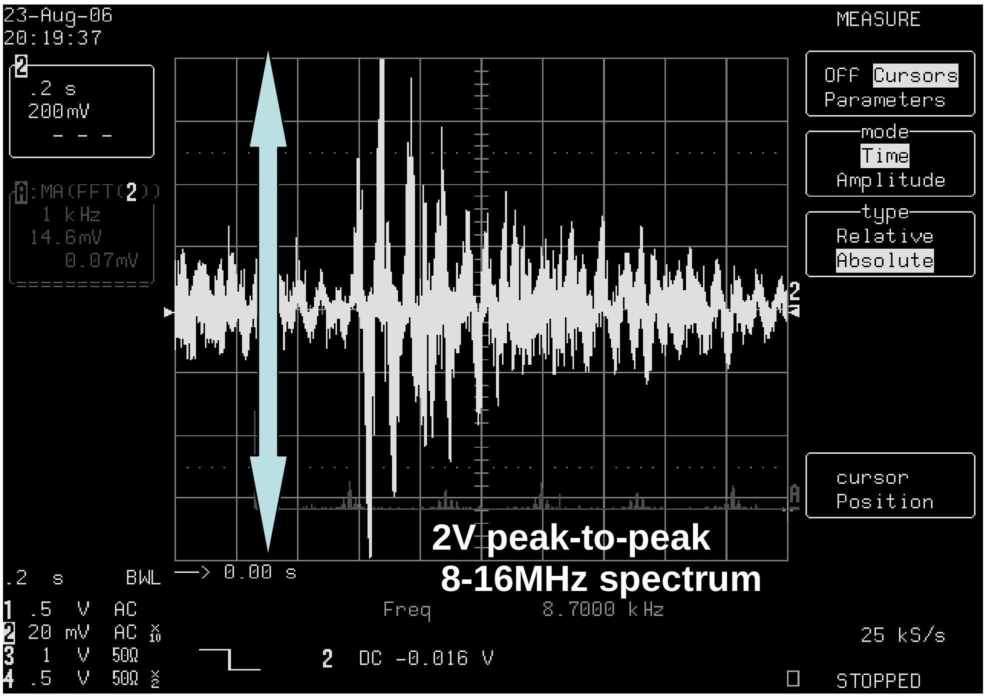

Fig.15. Pick-up in the ground loop produced by CAEN 2527.

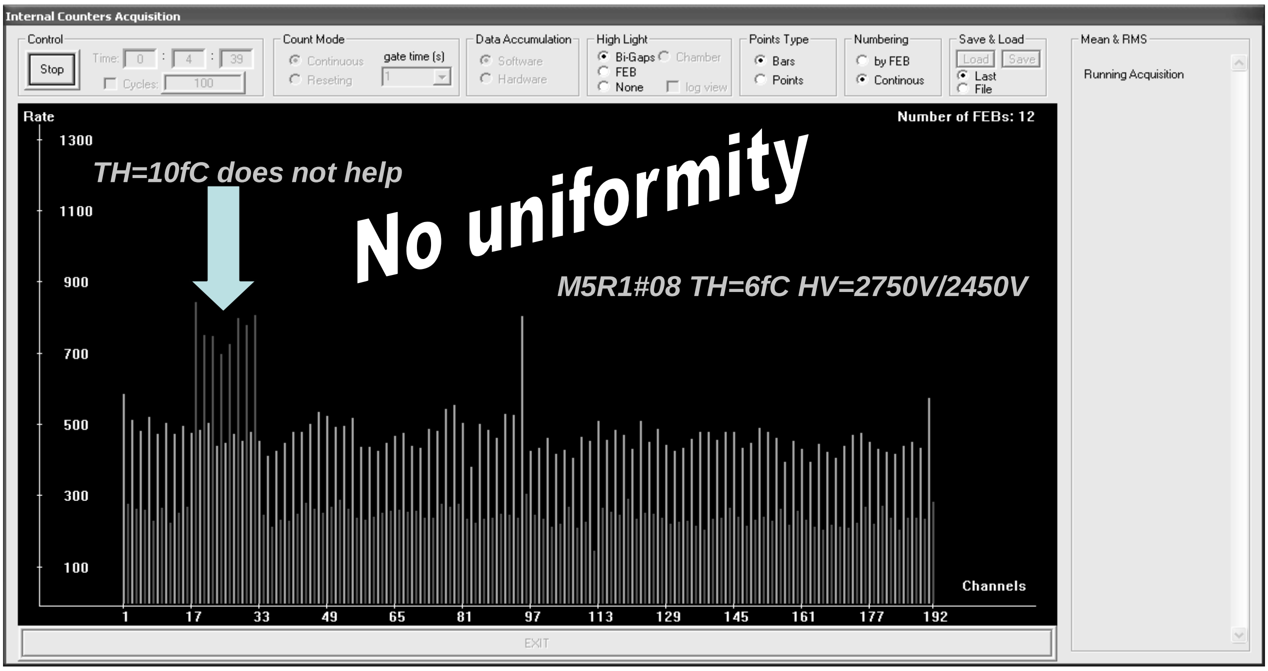

Fig.16. Example of high penetration of the noise from the ground loop.

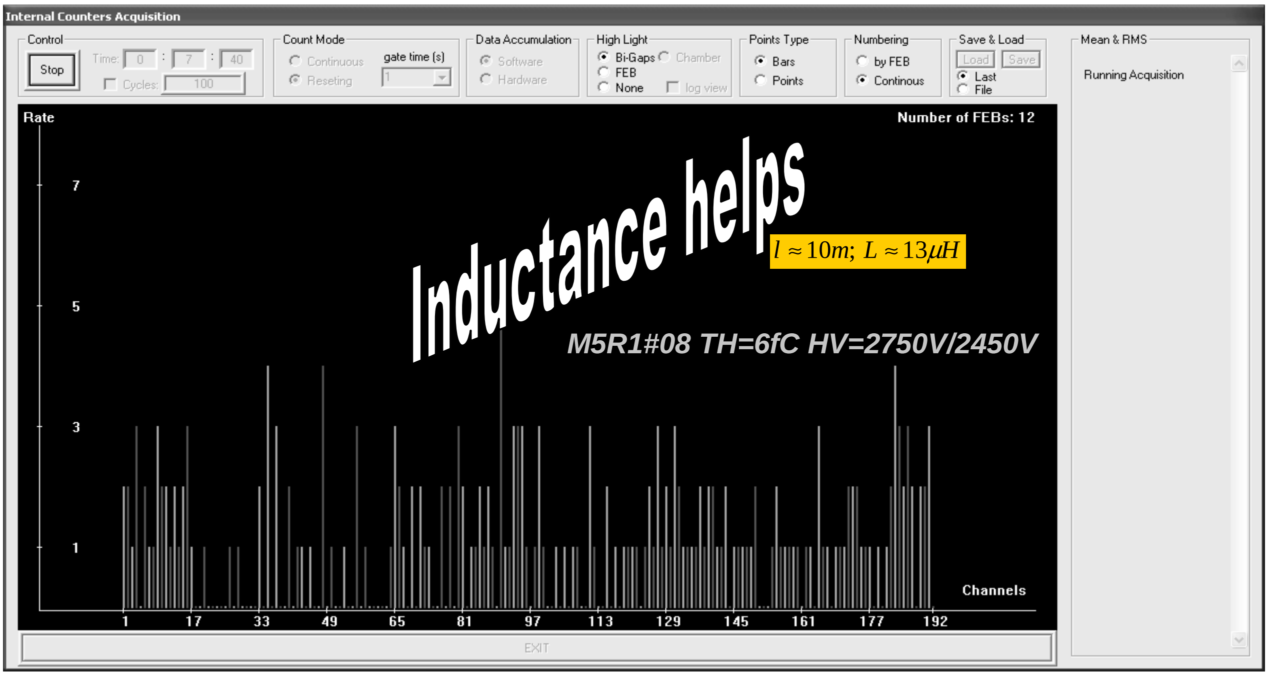

Fig.17. Correct noise count in Hz in each channel of M5R1: green line corresponds to one bi-gap, red – to another bi-gap.

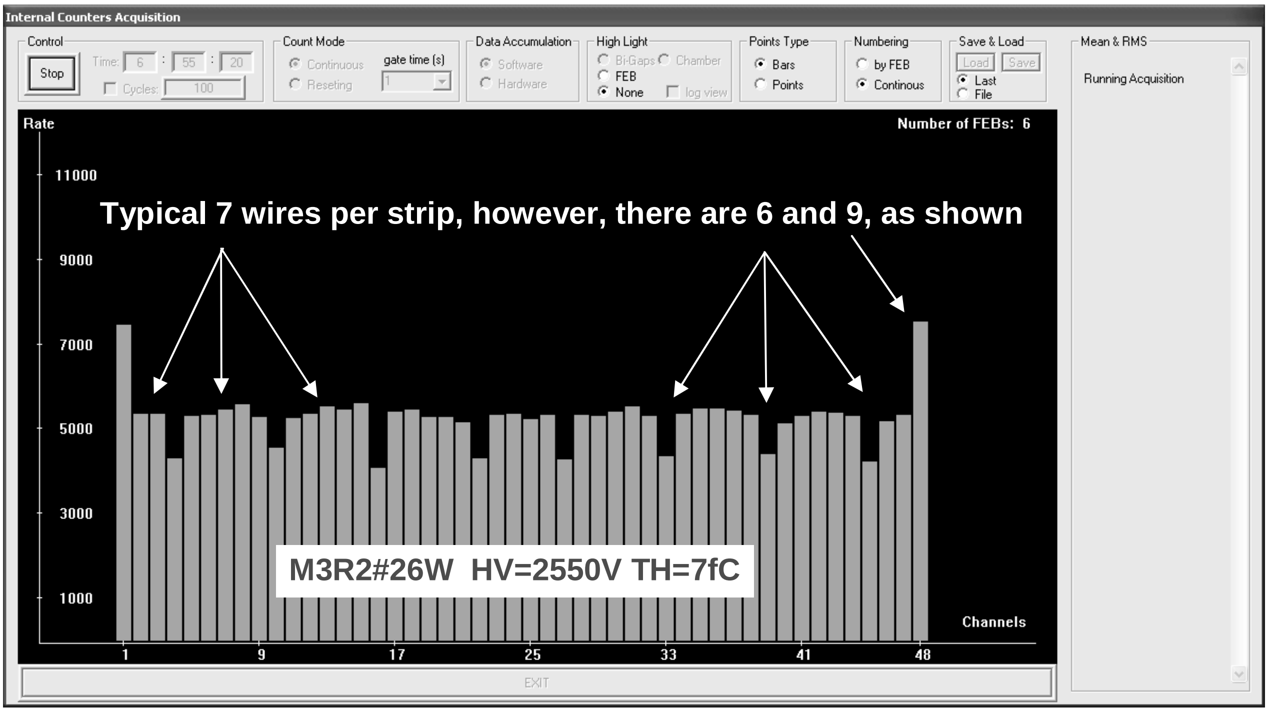

Fig.18. Cosmics counted by M3R2W (wire readout) at vertical position of the chamber on mock-up. One can see profile of the wire strip width.

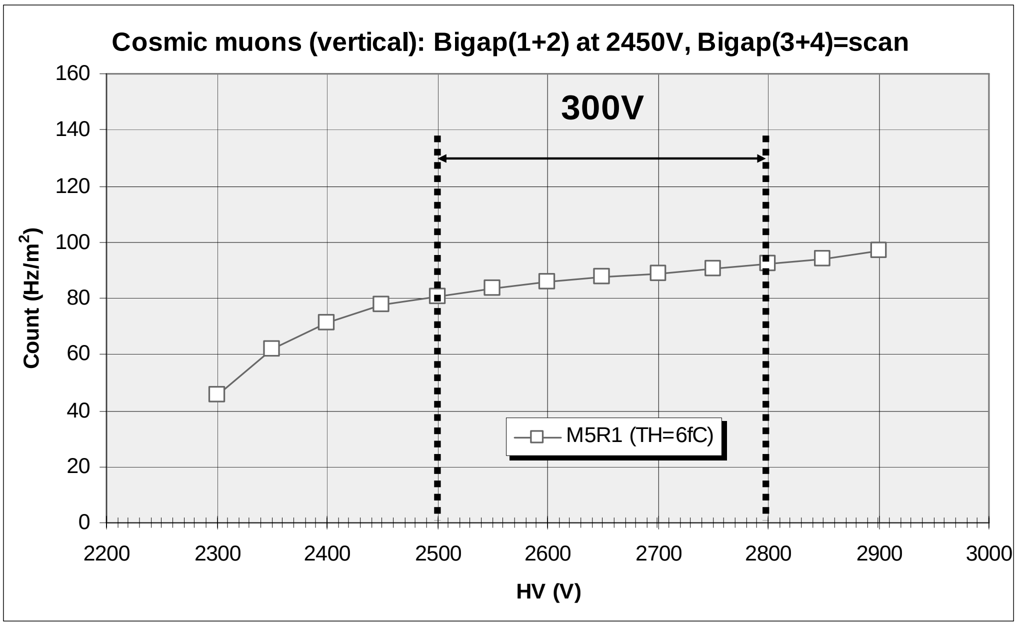

Fig.19. HV-plateau and cross-talks, as a slope of the plateau, measured on CR with M5R1.

4. Conclusion

A model of the detector cell as the electrical bridge has been proposed and used in considering the mechanism of penetration of parasitic current from the ground loop to the input of the front-end amplifier. Unbalance of the bridge makes detector to be sensitive to the noise in the ground loop. Results of grounding problem study in case of a big system, as the LHCb muon, are promising. Both multiple-point and single-point grounding conceptions are successful ones if the current in the ground loop is reduced to the accepted level.

The single-point grounding scheme has advantage: much less current flows along Faraday Cage (at least by order of magnitude), and it is recommended, especially for CPC-DCRO (M1R2, M2R1, M3R1), see Appendix.

Acknowledgments

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References

[1] LHCb Muon System. Technical Design Report, CERN LHCC 2001-010, 28 May 2001.

[2] http://lhcb-muon.web.cern.ch/lhcb-muon/documents/TDR-GEM/GEMaddendum.pdf

[3] http://indico.cern.ch/getFile.py/access?contribId=5&resId=1&materialId=slides&confId=3884

[4] http://indico.cern.ch/getFile.py/access?contribId=3&resId=3&materialId=slides&confId=5410

[5] http://indico.cern.ch/getFile.py/access?contribId=s1t22&resId=1&materialId=0&confId=a056444

[7] http://indico.cern.ch/getFile.py/access?contribId=5&resId=1&materialId=slides&confId=864

Appendix

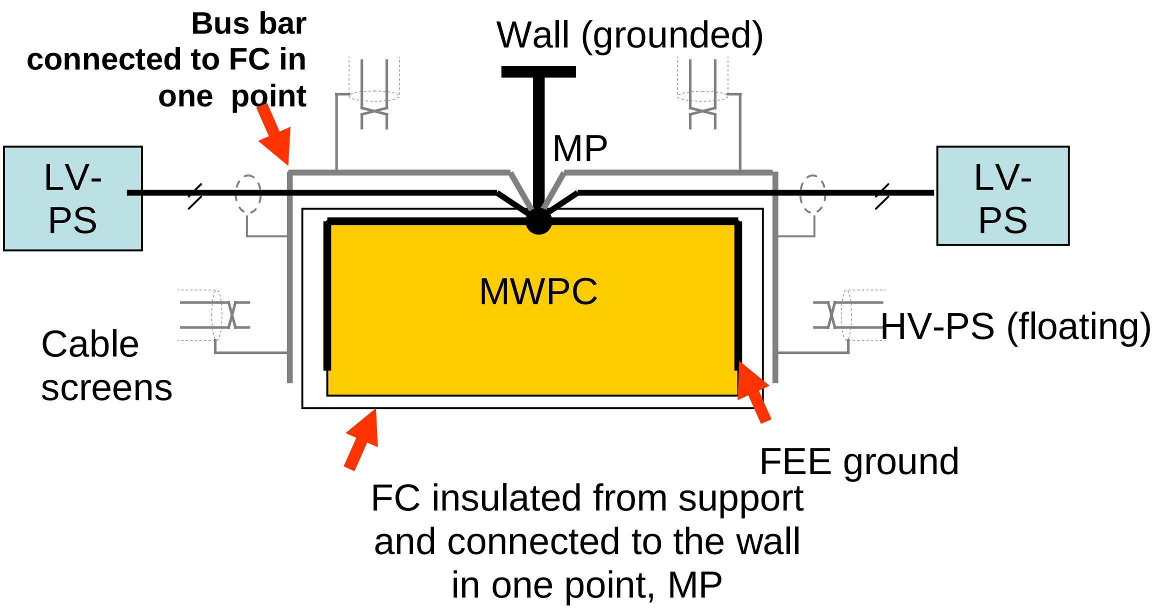

Fig.A1. Single-point grounding conception in MWPC design.