# A SAFETY SYSTEM FOR EXPERIMENTAL MAGNETS BASED ON COMPACTRIO

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## *Abstract*

This paper describes the development of a new safety system for experimental magnets using National Instruments CompactRIO devices. The design of the custom Magnet Safety System (MSS) for the large LHC experimental magnets began in 1998 and it was first installed and commissioned in 2002. Some of its components like the isolation amplifier or ALTERA Reconfigurable Field-Programmable Gate Array (FPGA) are not available on the market any longer.

A review of the system shows that it can be modernized and simplified by replacing the Hard-wired Logic Module (HLM) by a CompactRIO device. This industrial unit is a reconfigurable embedded system containing a processor running a real-time operating system (RTOS), FPGA, and interchangeable industrial I/O modules.

A prototype system, called MSS2, has been built and successfully tested using a test bench based on PXI crate. Two systems are currently being assembled for two experimental magnets at CERN, for the COMPASS solenoid and for the M1 magnet at the SPS beam line. This paper contains a detailed description of MSS2, the test bench and results from a first implementation and operation with real magnets.


## INTRODUCTION

The Magnet Safety System (MSS) is a part of the Magnet Control Project (MCP) at CERN, which was initiated in 1998 with the goal of producing an integrated system for controlling, protecting and analyzing data for the large magnets in the particle detectors at the Large Hadron Collider experiments. Common hardware and software are designed to this purpose, with manageable maintenance and operation in mind. The system can be adapted to both warm and cold magnets.

The first prototype of the safety system, custom-made to specifications, was used to protect the Central Solenoid at the first surface tests at KEK in Japan.

This system introduced two new protection types for cold magnets:

- Superconducting Quench Detector, or SQD,
- Differential voltage measurement, comparing voltages between various parts of the magnet system voltages.

The final version of MSS was installed in all large LHC experiments: ATLAS, ALICE, CMS and LHCb. It has been running continuously ever since, a time span of 6 years.

## MSS

MSS continuously measures safety parameters from magnet sensors and collects information from subsystems to control the magnet (Fig. 1).

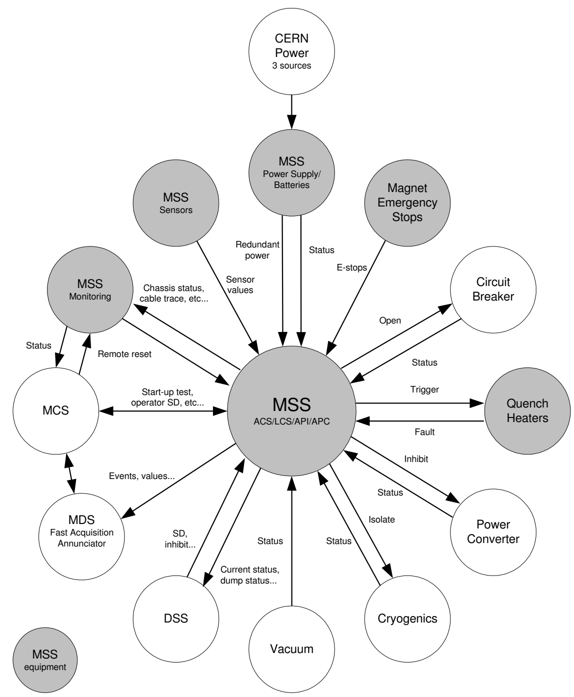


Figure 1: Information exchange in MSS.

### *Structure*

As shown in Fig.2, the safety system has 3 main components:

- An analog interface ACS containing the safety measurement channels, deciding whether a safety parameter has been exceeded, thus generating an alarm. Detections are made with 3 purpose-built signal condition modules:
  - A dual/differential voltage detection module - DVM
  - A dual bridge measurement module -DBQD
  - A dual resistive measurement module - DRM
- A logical decision unit LCS determining the current machine status based on received parameters and alarms. The main electronic card of this unit is the Hard-wired Logic Module based on ALTERA FPGA.
- An application interface API/APC between the logic unit and the actual machine which is the magnet with services. This interface controls main breakers, quench heaters, power converter, etc.



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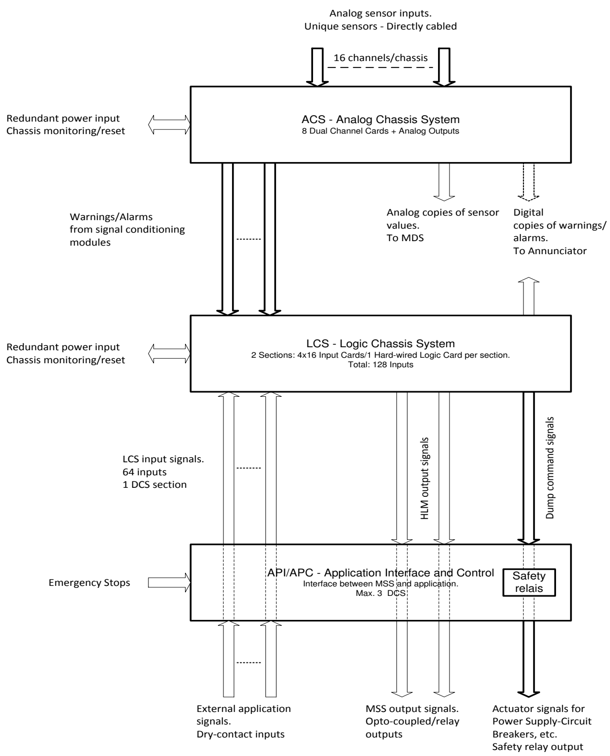


Figure 2 : MSS Block Diagram.

## *Diagnostic Tools*

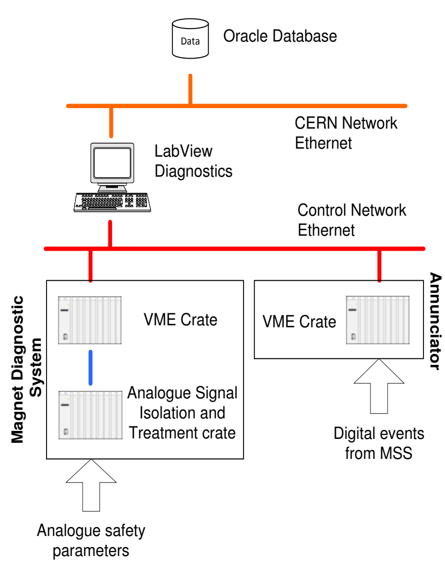


Figure 3: MDS and Annunciator Architecture.

For post analysis, there are two VME-based systems for data acquisition, as shown in Fig.3:

- The Annunciator is a fast digital data acquisition with a resolution of 1 ms, storing all logical events from MSS to be able to discriminate events clearly,
- The Magnet Diagnostic System (MDS) provides from the analog safety parameters a slow data acquisition at a rate of 1 Hz and a post-mortem file after a magnet quench (1mn before and 5 mn after at a rate of 100 Hz).

## MSS2 AN EVOLUTION OF MSS

Some components used by MSS have become obsolete such as the **ALTERA fpga** implanted in the HLM and the **isolation Amplifier** implanted in the 3 custom-made cards used in the ACS. The replacement of these components implies a full re-design process, and this opportunity was taken to review the MSS system overall and develop a new and state-of-the-art approach.

### *MSS2 Update*

The overall MSS2 philosophy and functionality remain the same as for MSS (Fig.2), in particular to stay consistent with the existing cabling and hardware being used in the experiments.

Two major modifications were done on the hardware:

- Design of a new analog card to replace the three analog modules used in the ACS.
- Replacement of LCS module by a crate containing a cRIO.

This changes result in two major improvements:

- XILINX fpga from the backplane of cRIO will replace the ALTERA fpga and do the analog treatment of the safety parameters
- The annunciator and MDS for small application is implemented in the real time embedded processor.

Figure 4 shows a typical MSS2 rack. It consists of:

- User interface unit with touch screen
- VAC module: Versatile Analogue Chassis, Analogue 3U chassis containing 8 analogue modules (2 or 4 channels), interfaces and redundant power supplies
- MAC module: Main Chassis, Principal 6U chassis of the MSS2 system; contains CRIO controller, interfaces and redundant power supplies
- APC module: Application Control, MSS Chassis with relays for application control



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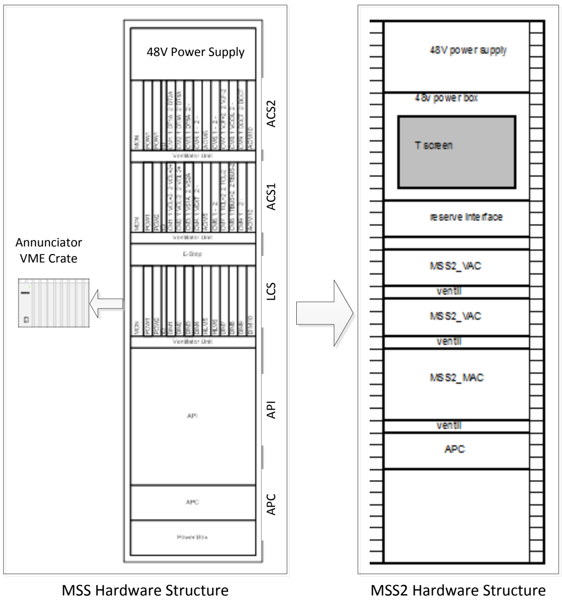


Figure 4 : Hardware evolution between MSS to MSS2.

### *Test Bench*

MSS2 racks are built and tested in-house. A test bench has been developed to test the hardware elements (internal cabling, crates) and the response of the system to digital or analogue stimulus (Fig.5).

This test system is based on PXI Crate with Analogue and Digital Cards and permits carrying out tests in manual or automated modes.

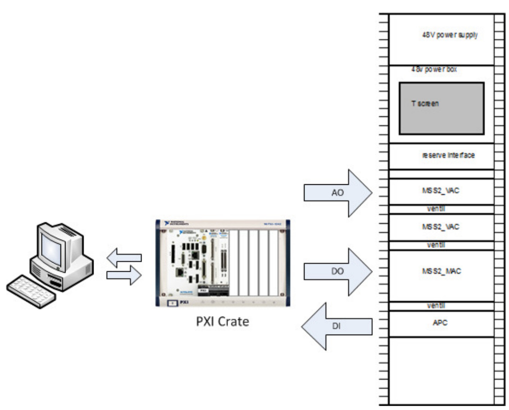


Figure 5: Test Bench structure consisting of a PXI Crate with analogue and digital cards connected to the MSS2 rack.

### *First Implantations*

MSS2 systems will be installed to protect one of the superconductive magnets of the COMPASS experiment and the M1 magnet in the SPS test beam area at CERN.

COMPASS is a high-energy physics experiment at the Super Proton Synchrotron (SPS) at CERN. The purpose of this experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams.

A set of magnets is used to polarize a target for physics. In the axis of the solenoid, it provides a 2.5 T magnetic field.

The COMPASS magnet system is composed of several units, all in the same cryostat.

- 1 solenoid (Inom = 660A, L = 12.65H)
- 1 dipole (Inom = 590A, L= 2.6H )
- 16 correctors magnets (Inom < 15A)

The quench detection system has been designed as follows:

- For the solenoid (Fig.6):
  - 4 bridges DUP1, DUP2, DUP3 and DUP4
  - 2 voltages of the current leads Vadi1 and Vadi2
  - 1 SQD for each Current Lead
- For the dipole (Fig.7):
  - 3 bridges DUP1, DUP2, DUP3
  - 2 voltages of the current leads Vadi1 and Vadi2
  - 1 SQD at the bottom of each CL

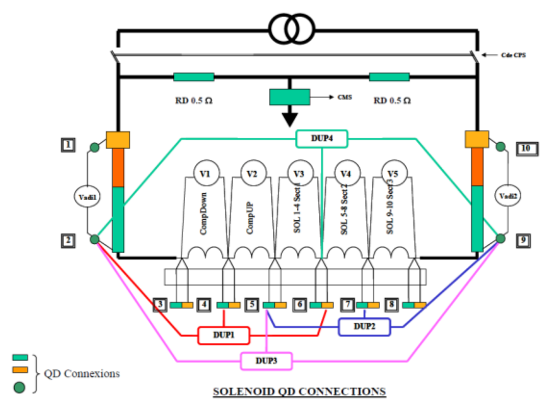


Figure 6: Solenoid electrical circuit.

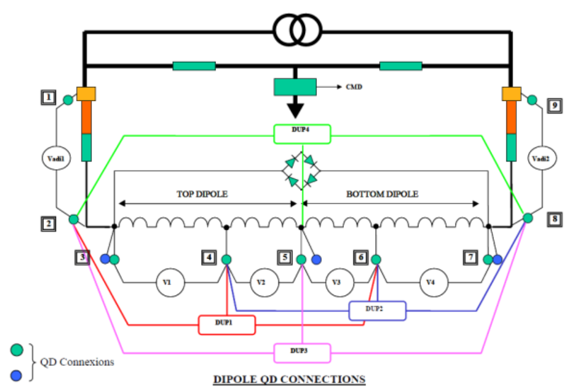


Figure 7: Dipole electrical circuit.



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The M1 magnet at the SPS beam area is a 40 years old magnet composed of two superconductive coils in different cryostats. It provides 3T on axis in the center.

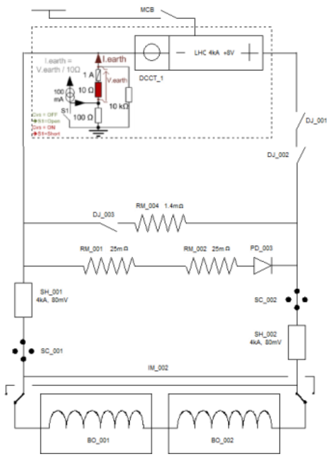


Figure 7: M1 electrical circuit.

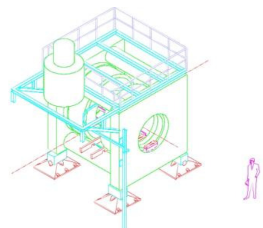

Figure 8: M1 Magnet.

The parameters included in MSS2 for magnet protection are:

- Foot current leads temperatures
- Helium level for each cryostat
- Voltage of each coils
- Bus bars temperatures

Two racks are now fully tested and ready to be installed on site.

Operational tests of MSS2 for both the COMPASS and M1 magnets are now starting.

Figure 9: M1 MSS2 Rack.

Figure 10: Compact RIO Crate.

## CONCLUSION

The evolution of MSS to MSS2 permits to:

- Reduce the system size by integrating the annunciator in the cRIO processor and a new design of the analogue card,
- Simplify and improve system maintenance by limiting the number of custom analogue cards to one and integrating industrial material like cRIO.
- Improve the interactivity of the system in situ by means of a touch screen that provides real-time states of inputs/outputs as well as a view of the annunciator.

## REFERENCES

[1] LHC Experiments "Magnets Control Project" MT-19 paper THA03PO0.



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