ENHANCING MEASUREMENT QUALITY IN HL-LHC MAGNETS TESTING USING SOFTWARE TECHNIQUES ON DIGITAL MULTIMETER CARDS-BASED SYSTEM

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ABSTRACT

The HL-LHC magnets play a critical role in the High-Luminosity Large Hadron Collider project, which aims to increase the luminosity of the LHC and enable more precise studies of fundamental physics. Ensuring the performance and reliability of these magnets requires high-precision measurements of their electrical properties during testing. To meet the needs of the new superconducting magnet technology R&D program, a new voltage measurement system was developed, built upon experience gathered during test and validation campaing of LHC magnets. The system was equiped with a set of digital multimeter (DMM) cards installed in a PXI modular chassis and controlled using CERN's in-house software development. It allowed for the measurement of the electrical properties of the magnet prototypes during their study phase.

However, during the renovation of the magnet test benches and in preparation for the production HL-LHC magnet measurements, some limitations and instabilities were discovered during long recordings. Consequently, it was decided, that measurement system renovation will be necessary to ensure top-notch data acquisition standards. The emergence and promises of the new PXIe platform, along with the requirement to build eight additional systems (to be operated in simillar manner to the existing four), led to complete redesign of the system architecture. This article describes the various software techniques employed to address platform compatibility issues and significantly improve measurement accuracy, thus ensuring the reliability and quality of the data obtained from the HL-LHC magnet tests.

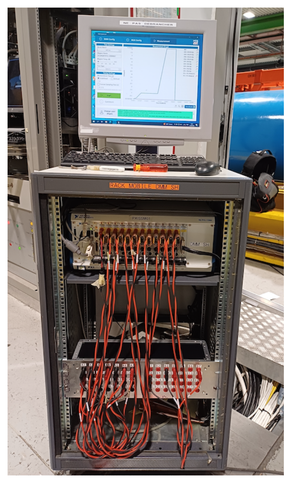
INTRODUCTION

The first generation of Digital Multimeter (DMM) based measurement system, used for the LHC magnet series tests

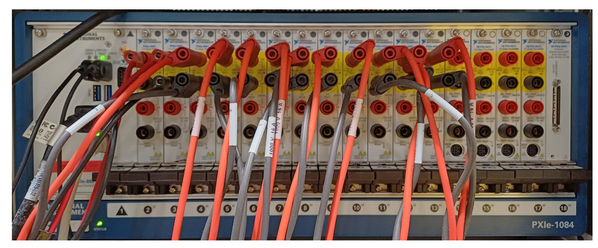
- Deployed in early 2000's
- 6 x KEITHLEY® 2001 DMM controlled from SUN workstation (via GPIB bus)
- Used in magnet acceptance tests:
  - RRR - Residual Resistivity Ratio
  - Loss - Energy losses in superconducting cable strands
  - Splice - Coil splices resistance measurement
- Tested 1232 dipoles and 480 quadrupoles magnets prior to their installation in the LHC tunnel

The second and third generation of Digital Multimeter (DMM) based measurement system, used for HL-LHC magnet prototypes and series tests

- First system deployed in 2011
- 16 x PXI-4071 DMM inside of PXI-1045 chassis with PXI-8108 CPU
- Embedded control of converters powering superconductive magnet under test
- Mainly used for tests of HiLumi-LHC and other magnet prototypes
- More than 13400 data files generated between 2011 and 2016

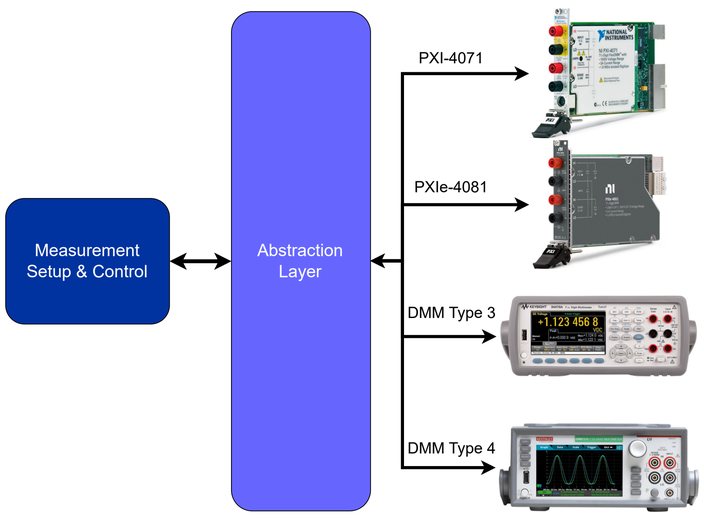


- Hardware in operation since 2018
- 16 x PXI-4081 DMM inside of PXIe-1075 (or PXIe-1085) chassis with PXIe-8821 CPU
- New common software deployed in 2020
  - Universal for all hardware revisions
  - Integrates multiplexer to increase # of channels
- Nine racks commited to date



DEVELOPMENTS

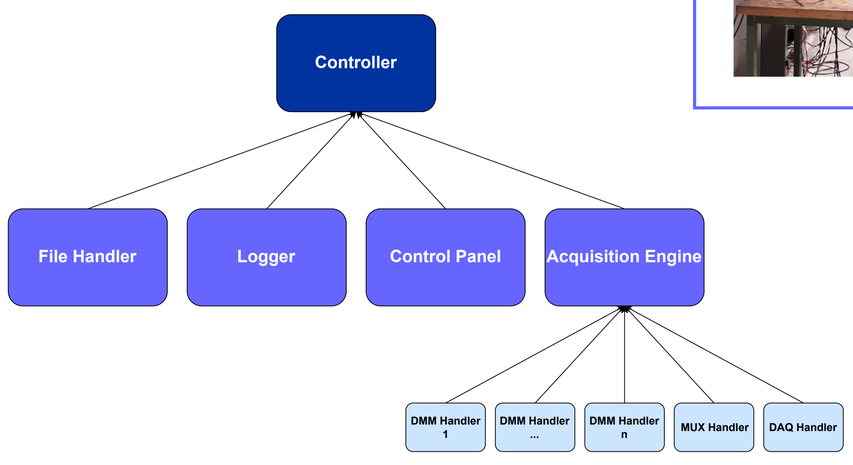
Unification of PXI and PXIe test platforms



Handling differences of PXI and PXIe based DMM card

	PXI-4071	PXIe-4081
Trigger Polarity	Falling Edge	Rising Edge
Latched Trigger	Yes	No
"Get Measurement Period" function	Available	Unavailable
Trigger and Sample Trigger	Shared source	Shared or Separate sources

Application developed with Actor Framework



Comparing *Effective # of Digits* depending on *# of Averages*

NI PXIe-4081 *With AutoZero On, ADC Calibration On, DC Noise Rejection High-Order

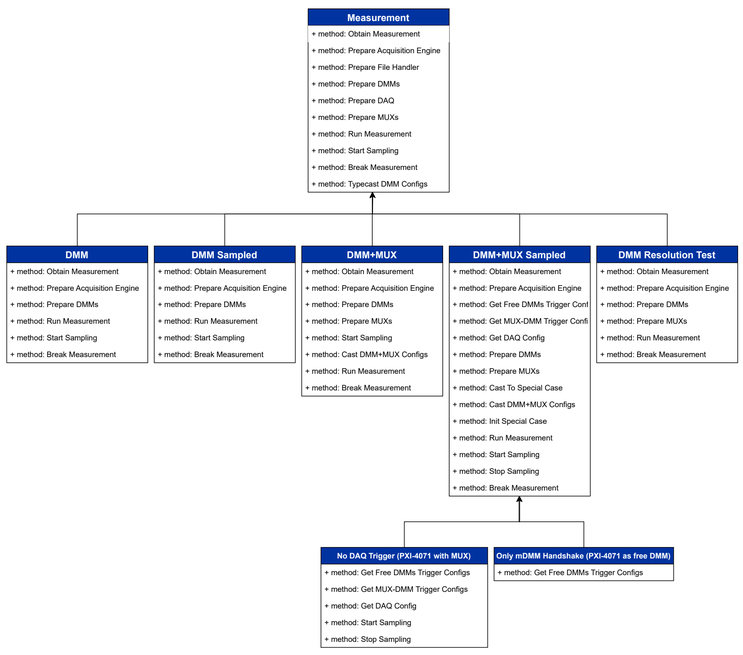
Range	Aperture Time	# of Averages	Theoretical Resolution	Noise P-P	Effective Resolution	Effective # of Digits
+/- 0.1V	100ms	1	10nV	600nV	312nV	5.80
+/- 1V	100ms	1	50nV	600nV	312nV	6.80
+/- 10V	100ms	1	500nV	3uV	1.56uV	7.10

NI PXIe-4081 *With AutoZero On, ADC Calibration On, DC Noise Rejection High-Order

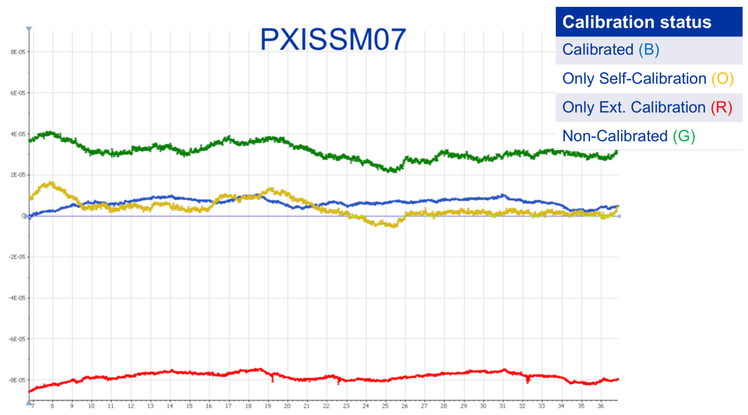
Range	Aperture Time	# of Averages	Theoretical Resolution	Noise P-P	Effective Resolution	Effective # of Digits
+/- 0.1V	100ms	4	10nV	320nV	166nV	6.08
+/- 1V	100ms	4	50nV	320nV	166nV	7.08
+/- 10V	100ms	4	500nV	1.6uV	832nV	7.38

Examples of DMM measurement systems being used in a wide range of magnets tests inside of SM18 facility

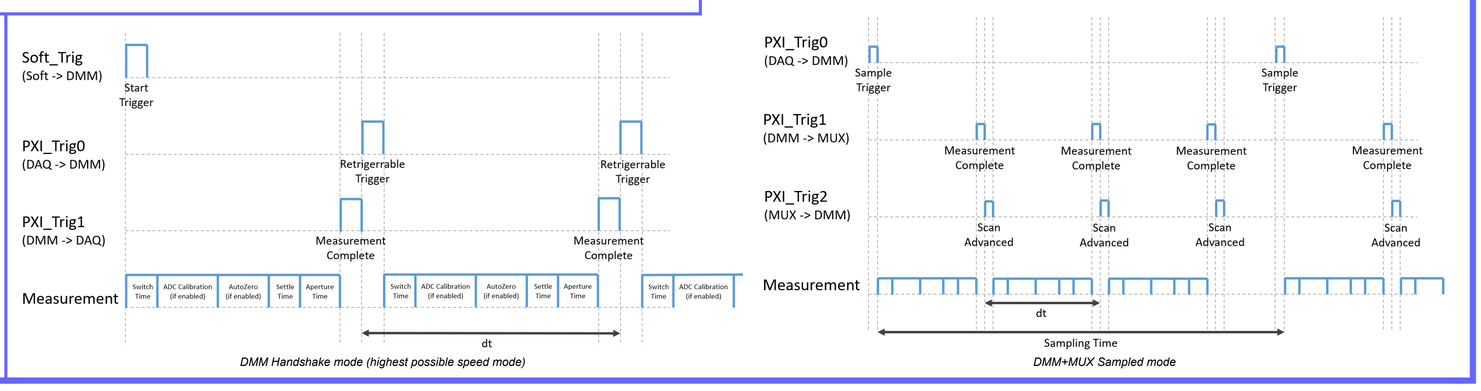
Measurement type abstraction



Impact of calibration on measurement quality



Triggering techniques embedded into application logic



CONCLUSIONS

After two years of operation, we can confirm that system reached its goals and demonstrates superiority in reliability and performance compared to previous generations. Final users acknowledged the flexibility and enhancement that new software brought to their daily routine as now the same application is reused on all measurement stations. Multiple graphical user interface improvements simplified the measurement configuration and control, at the same time enabling new features and monitoring options. This year, deployment of the application has been automated with use of CERN homemade cloud synchronization client (CERNBox).

The most compelling problem was related to high CPU consumption in certain measurement scenarios. Operators have noticed that in demanding scenarios, when operating multiple DMM devices simultaneously, application can utilize major part of system processing power and in consequence start losing data points. Extensive tests showed that this problem is unrelated to software architecture and comes directly from NI DMM internal drivers. Finally, it turned out that raising priority for the Windows application process solved the problem completely. Currently application has been running in production without any issues for more than a year and no new development is foreseen.

BEAMS DEPARTMENT

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TUPDP087