Time Domain Reflectometry: Practical Insights for ELQA

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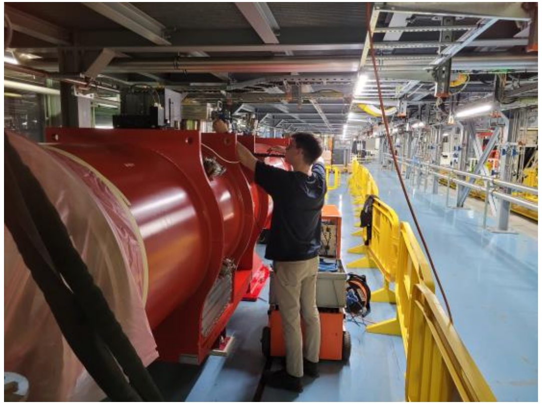
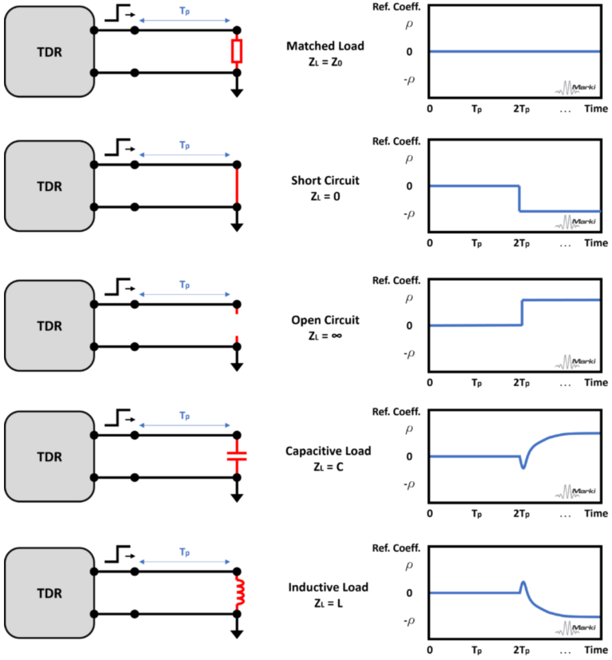
Introduction

- Time Domain Reflectometry (TDR) is a diagnostic technique used to analyse the characteristics of electrical paths, such as, cables, V-Taps and QH’s.
- TDR is being developed for use by the ELQA team as another tool to help identify nonconformities in the instrumentation of magnets.
- A dedicated multichannel device is being integrated into the TP4 system (in collaboration with IFJ PAN), ready for routine use on Hi-Lumi assets.



Basic Theory

- TDR works by sending an electrical pulse down a transmission path and observing the reflected signal.
- The key idea is that any changes in the cable's properties, such as breaks, faults, or impedance mismatches, will cause some of the pulse energy to be reflected.
- By analysing the time it takes for the reflection to return and the nature of the reflection, you can determine the location and type of fault
- TDR is not a new technique, but portable measurement systems have made it easier to deploy.



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LHC Project Note 181

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TIME DOMAIN REFLECTOMETRY FOR THE LOCALIZATION OF ELECTRICAL FAULTS IN THE INSTRUMENTATION OF THE LHC STRING MAGNETS

A Study Case of Voltage Tap, Temperature, and Pressure Transducer Circuits

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Keywords: diagnostics of superconducting magnets, instrumentation circuits, time domain reflectometry, pulse reflection, fault localization

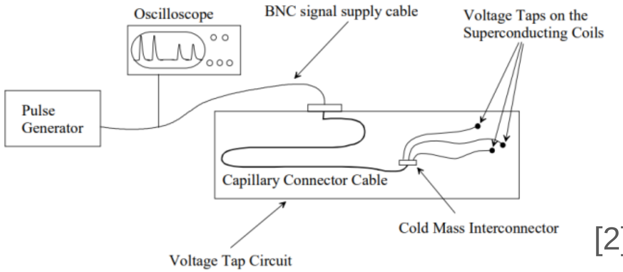
Abstract

Time Domain Reflectometry (TDR) is one of the most powerful methods used to analyze the integrity of the signal propagating in a transmission line. The method is based on the principle that the wave propagating in the line is reflected at the locations where the impedance of the line changes. The fault points, joints, branches, junctions, abrupt cross-section changes, etc., cause such reflections. The reflectometry technique involves the excitation of the circuit under test with either a fast edge step function or a well-defined impulse confined in time and frequency domains, and thereafter detection of the amplitude and time of the reflections. Both variants of the method were successfully applied to localize open circuit faults in the voltage tap connections, pressure transducers, and temperature sensing carbon gages circuits of the LHC String Dipole Magnet MB2 and Short Straight

[2]

Quick Overview of Setup

- A Picoscope 6426E is used as both the signal generator and oscilloscope.
- 5 V step (3.5 ns rise) and 5 GS/s sampling.
- The input/output of the system is connected via BNC cables to the DUT (via a multiplexer).
- Depending on the aim of the test, the grounding strategy is adjusted.
- In general, all instrumentation wires for a circuit are tested and compared. The tests for which can be multiplexed by hand or with our new multiplexer system (slide 7).



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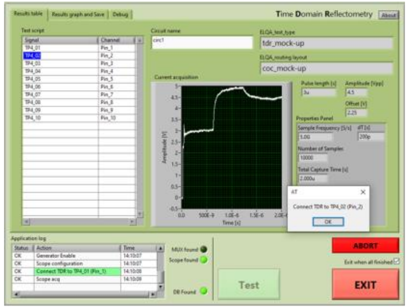
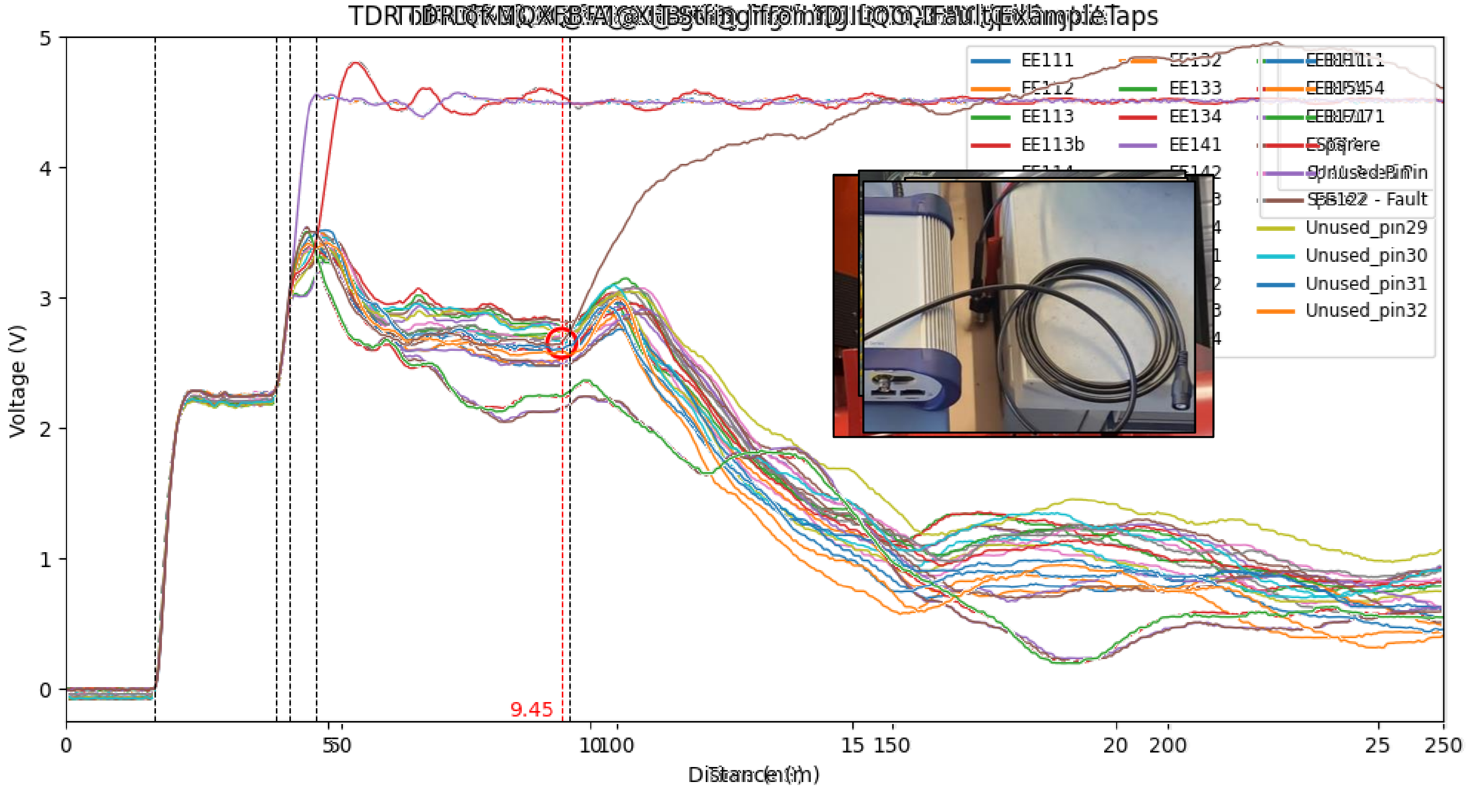


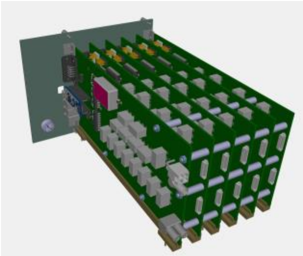
Simple TDR Example – IT-String Q2A



(Simulated Fault! The magnet is fine ☺)

Multiplexing Hardware

- In collaboration with the ELQA team, our colleagues at IFJ PAN (HNINP) have developed a multiplexer system to enable rapid routine measurements.
- The device allows control of the injected signal and the grounding strategy.
- It is completely integrated with the TP4 measurement system hardware and software
- Prototype in use, production confirmed.



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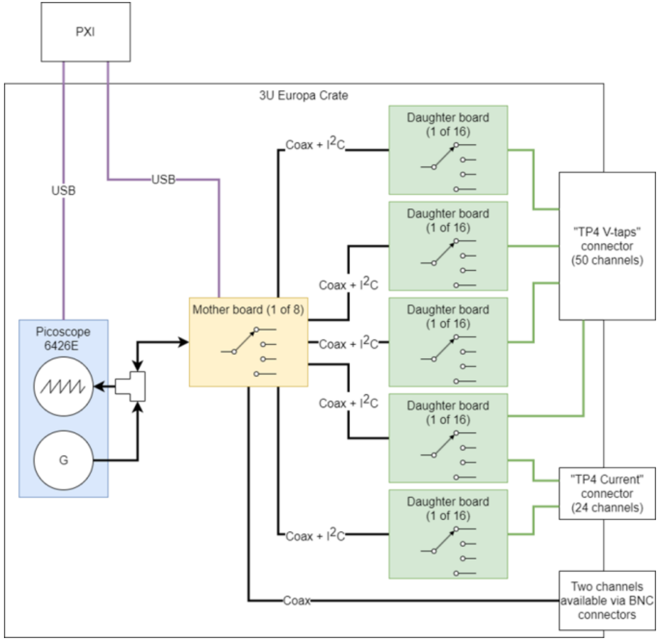

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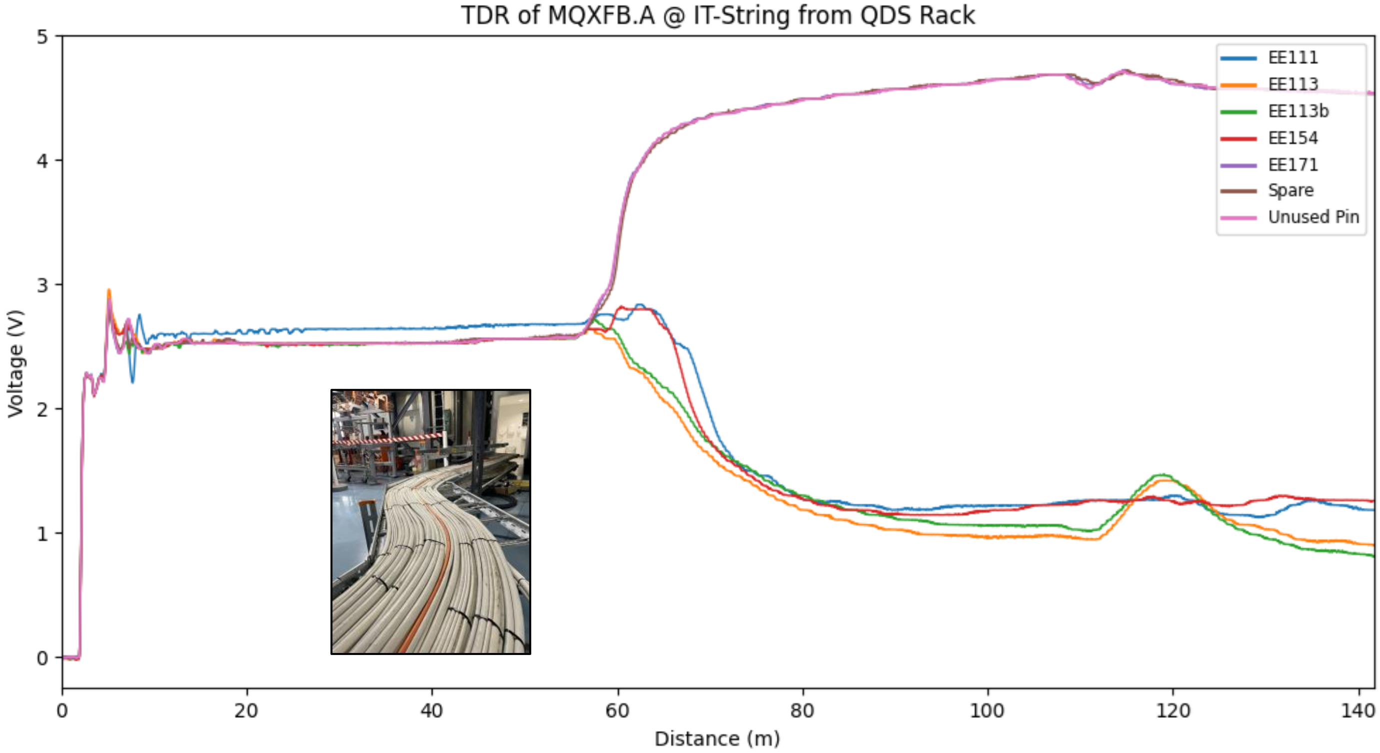
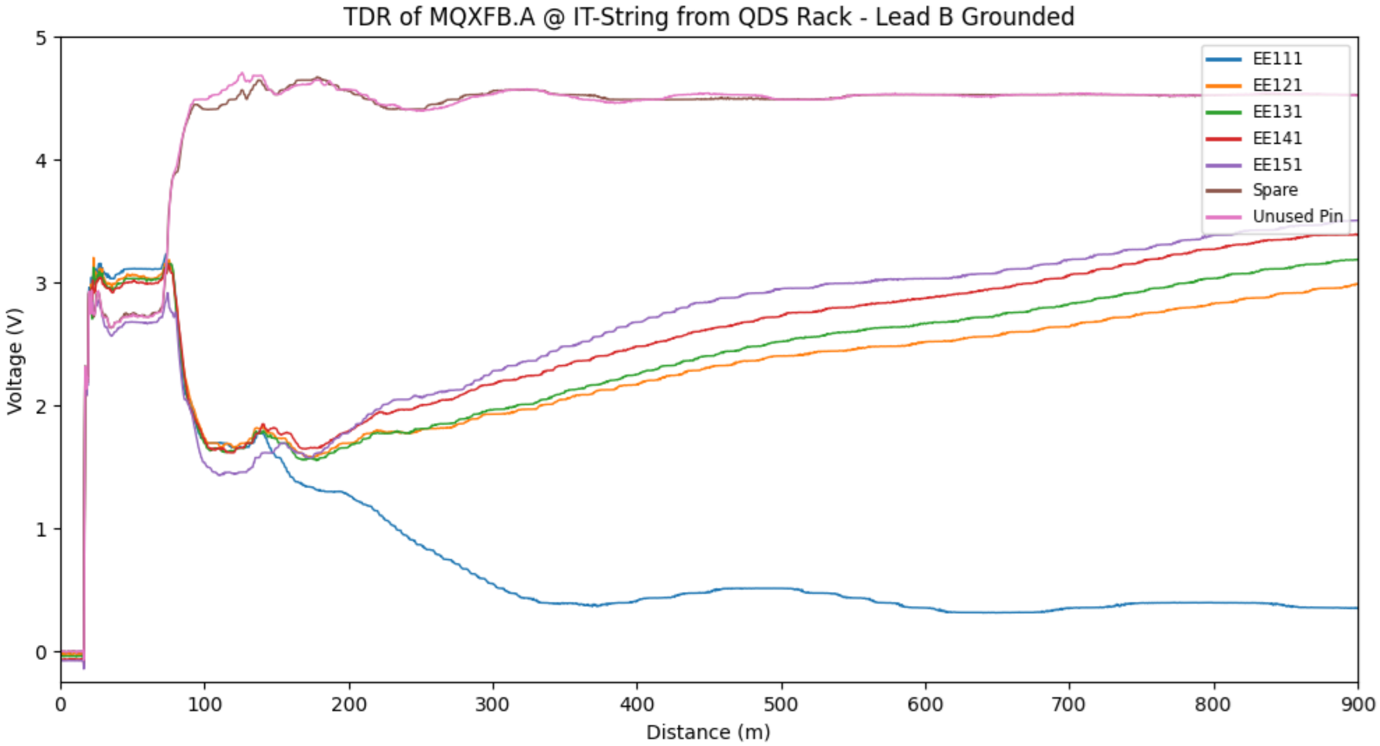
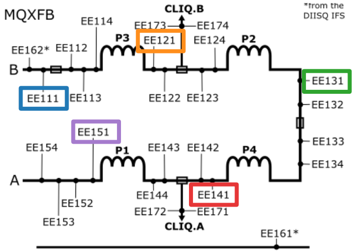
Thank-you to Jaromir Ludwin and Karol Marciniak for their hard work on the development!

Example – Measurement from QDS Racks



Example – Injection into the Magnet Coils





Strengths and Limitations of TDR

Strengths

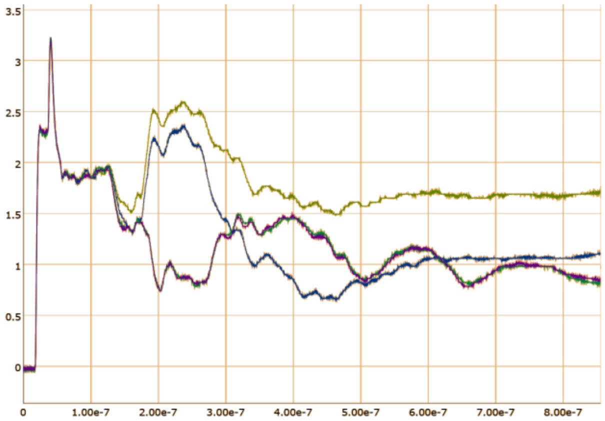
- The position of faults can be located intuitively and accurately.
- Can help determine not only the location but the type of fault
- Low energy and voltage and non-destructive
- Capable of rapid measurement of many wires/circuits (when using an integrated multiplexer).
- Can/has been integrated with existing ELQA measurement systems
- Measurements can be performed at a distance through long cables.
- Results stored in ELQA DB

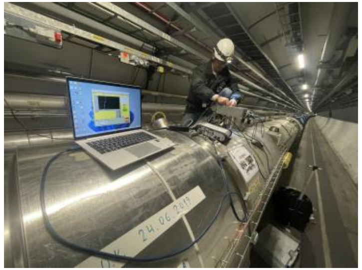
Limitations

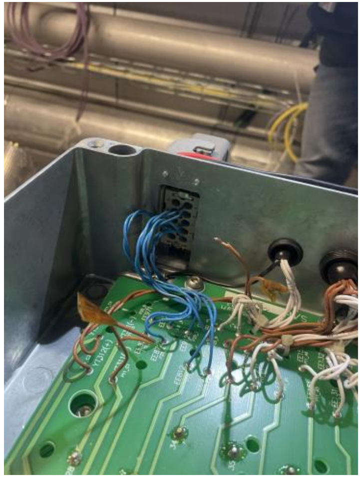
- With distance, the rising edge degrades, which reduces the clarity of the resulting waveform
- Complex circuits with many reflections and stubs can distort the signal and extremely difficult to interpret it
- Results look different depending on where in the circuit they are taken.
- Can’t currently be used on active circuits
- Most effective with a reference measurement or when a circuit is understood very well

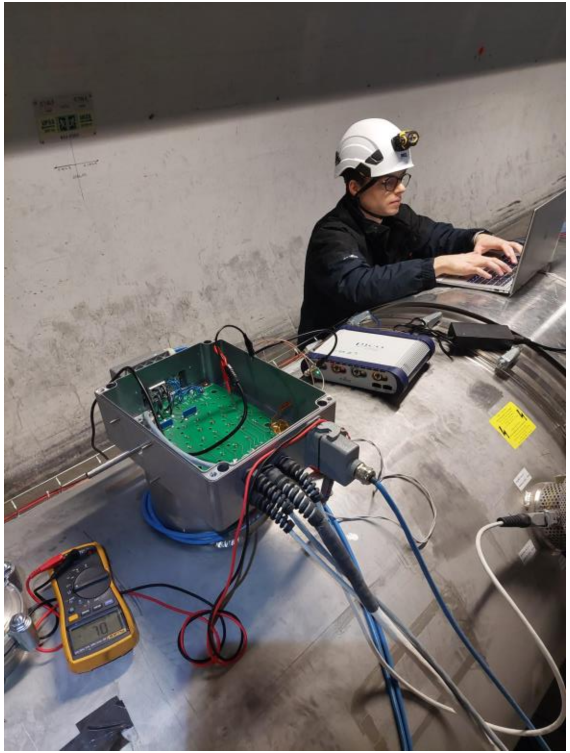
Today - TDR of QH in MQ14.L3

- Measurements performed today on MQ14.L3 in the LHC
- After a Quench during operation, the circuit was measuring ~ 30 Ω, approximately 3x nominal resistance
- TDR measurements performed in an attempt to understand more about the fault.



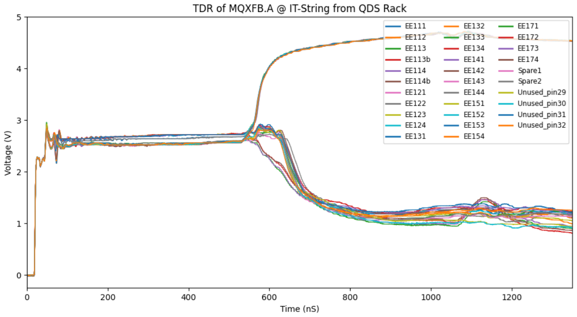






Conclusions

- The ELQA Team are able to localise faults with high precision using TDR.
- The development of the multichannel TDR device has been successful, and series production is ready to be launched.
- Routine measurements are already underway for Hi-Lumi assets, which are already providing valuable insights and helping us further understand how best to roll out the measurement.
- Development of analysis tools and models is required.



Future Strategy

- Continue to take as many references measurements as possible for Hi-Lumi.
- Develop more models and tools for analysis and signal reconstruction.
- Potentially roll-out in the LHC.
- Investigate the use of SSTDR, for live circuits or long duration measurements.


HiLumi
HL-LHC PROJECT
CERN
Electrical Quality Assurance
Thank you for
your attention!
Q2-07

References

- [1] https://markimicrowave.com/technical-resources/application-notes/debugging-surface-mount-footprints-with-time-domain-reflectometry/
- [2] http://cds.cern.ch/record/691791/files/project-note-181.pdf?version=1
- [3] https://edms.cern.ch/document/3016042/1
- [4] https://edms.cern.ch/document/3151033/1

Measurement from QDS Racks - Explained