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## Enabling Real-Time Impedance Measurements of Operational Superconducting Circuits of Accelerator Magnets

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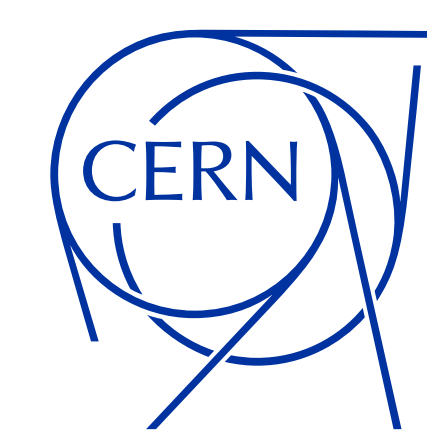
# Enabling Real-Time Impedance Measurements of Operational Superconducting Circuits of Accelerator Magnets

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M. Wozniak<sup>1</sup>, J. Østergaard<sup>2</sup>

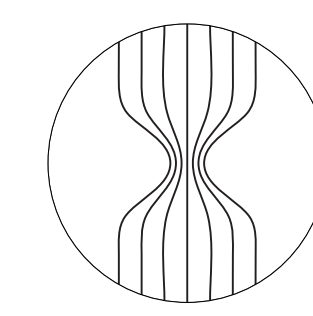
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High Field Magnets



## Motivation & Research Goals

The goal of this research is to develop a new platform to safely inject electrical stimuli into a powered superconducting magnet circuit, and subsequently measure the response. Specifically using it for impedance estimation of a magnet is demonstrated. This research paves the way for continuous electrical integrity measurements of live circuits. Additionally, if the platform can be further developed to demonstrate high quality results for narrow measurement windows, it can enable research into quench analysis and detection.

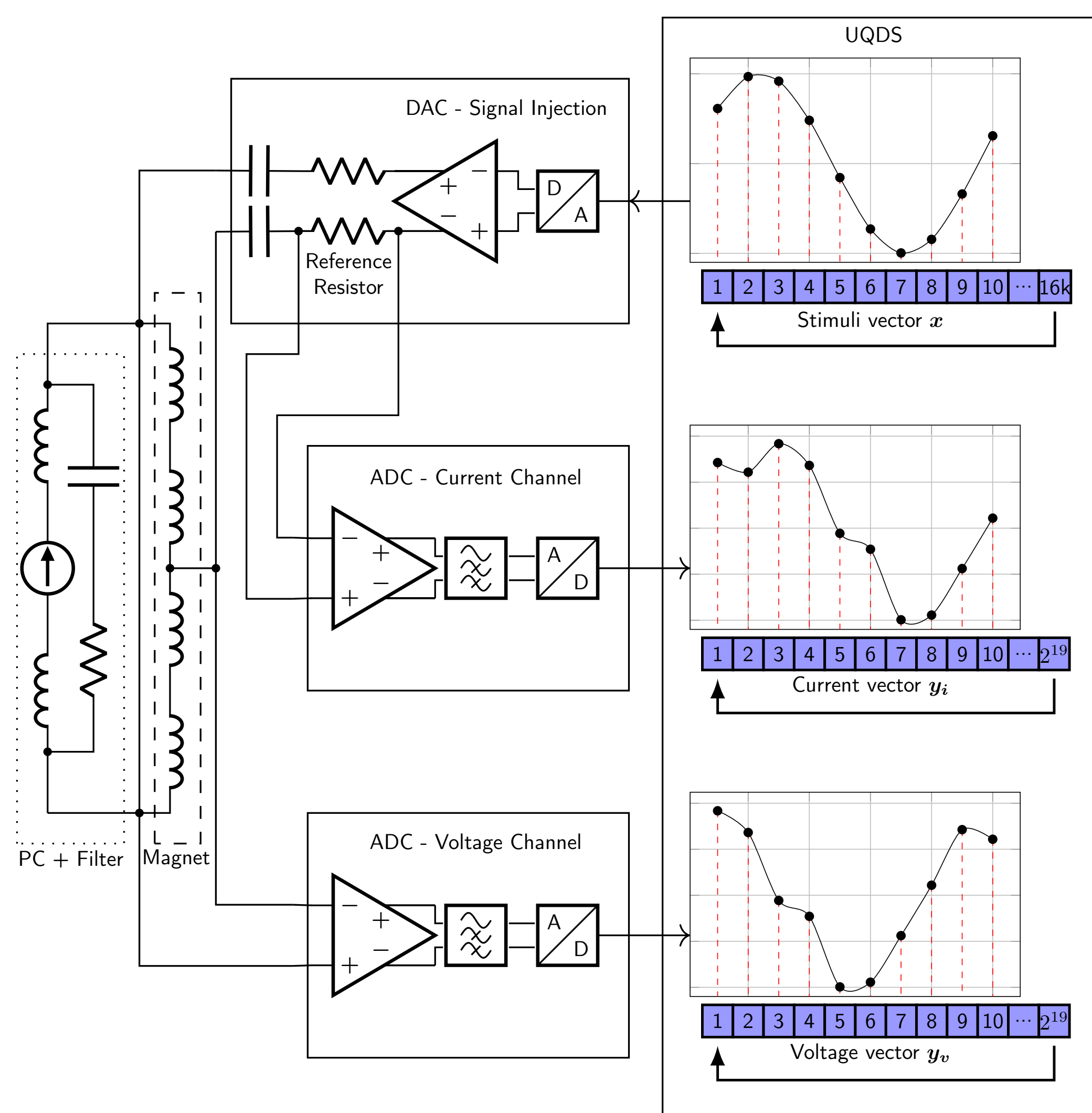
## Methods

We have designed a platform to safely inject stimuli into a magnet.

- **The hardware** is based on CERN's universal quench detection platform [1]. It has been extended with a DAC output stage.



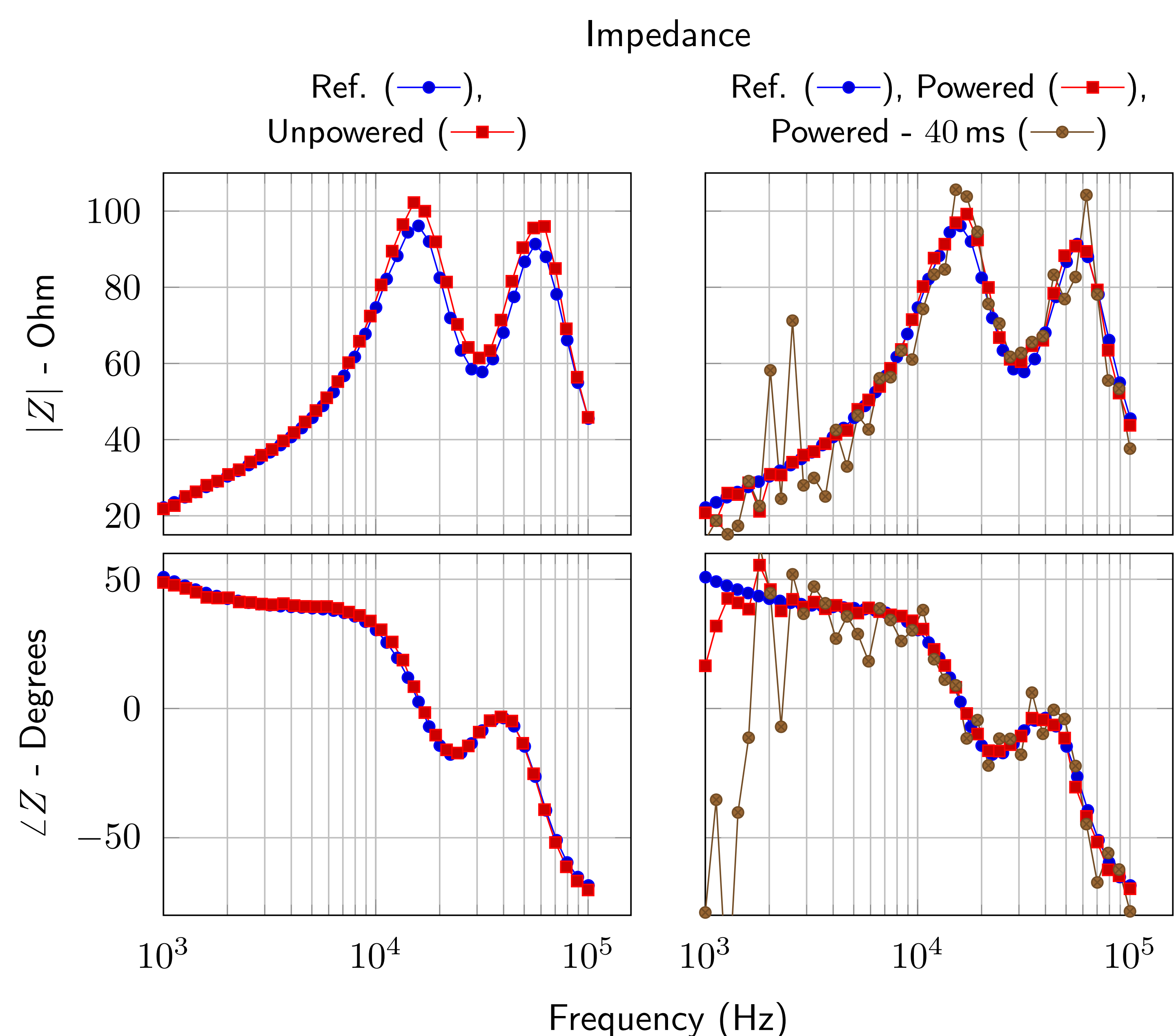
- **The stimuli signal** is composed of an arbitrary amount of sinusoids. This allows us to probe multiple frequencies simultaneously.
- **The response signals** represent the injected current and voltage across the magnet. These parameters are set by the magnet's impedance.
- **Estimating the complex amplitude** of the current and voltage amplitudes is done by solving a minimization problem that fits the input sinusoids to the observed responses [2].
- **Magnet impedance** is found by dividing the terms of the estimated voltage and current spectra.



## Selected Results

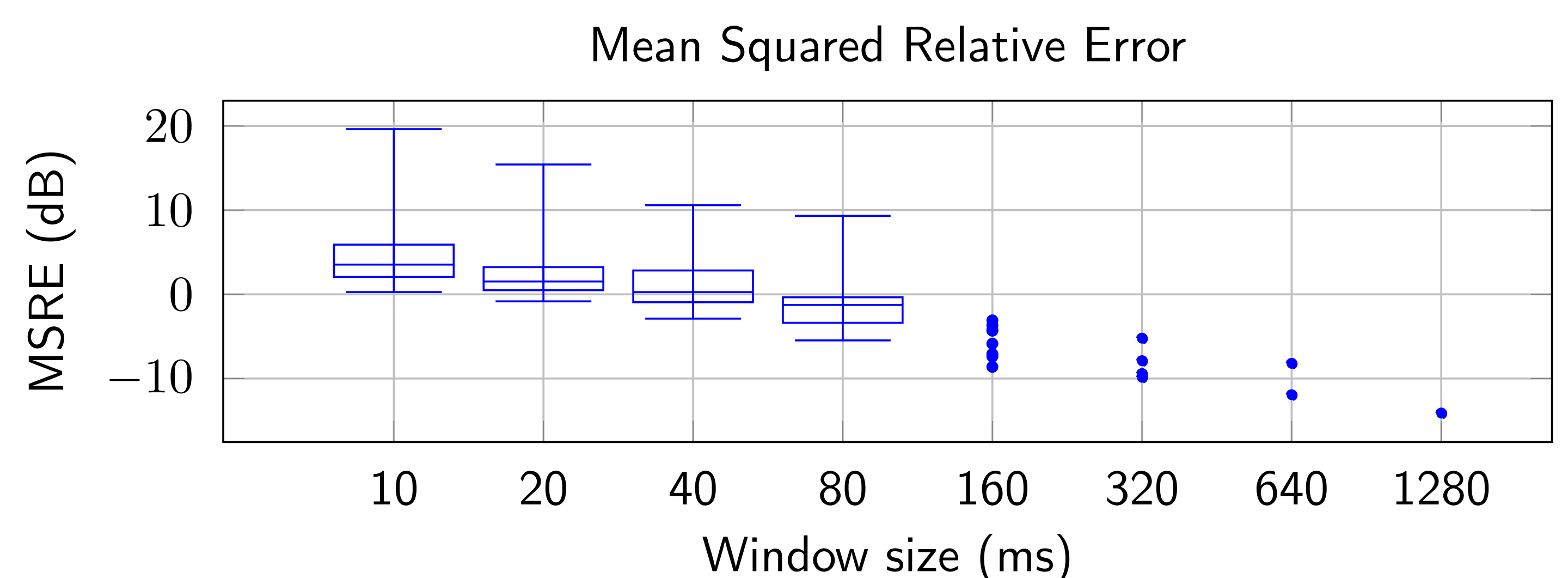
We tested the system on a D2 prototype magnet [3].

- The magnet was measured when unpowered and powered (50 A).
- We made reference measurements using an industrial impedance analyzer [4].
- Impedance estimate based on 1.28 s ( $2^{19}$  samples) of data acquisition.
- Results show good correspondence between the powered, unpowered, and reference measurements.



We analyse the methods merit for estimating impedance at short time scales.

- For this we split our acquisition into smaller windows and find the relative error with respect to our reference measurements.



## References and Acknowledgements

The authors would like to thank the staff at CERN's SM18 magnet test facility for their invaluable assistance and support in conducting the measurements presented in the MT28 conference. We also thank the High Field Magnet program for funding this research.

[1] Jens Steckert et al. "Application of the Universal Quench Detection System to the Protection of the High-Luminosity LHC Magnets at CERN".



[3] Barbara Caiffi et al. "The development of the superconducting dipoles D2 for the high luminosity upgrade of LHC".



[2] Petre Stoica, Hongbin Li, and Jian Li. "Amplitude estimation of sinusoidal signals: Survey, new results, and an application".



[4] Jaromir Ludwin and Piotr Jurkiewicz. "Upgrade of the Automatic Measurement System for the Electrical Verification of the LHC Superconducting Circuits".



## Conclusion

- We demonstrate that we can measure impedance of powered superconducting circuits accurately.
- More work is needed to obtain high quality short window impedance estimates.