SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Innovative Protection Systems for High-Pen PV Grids

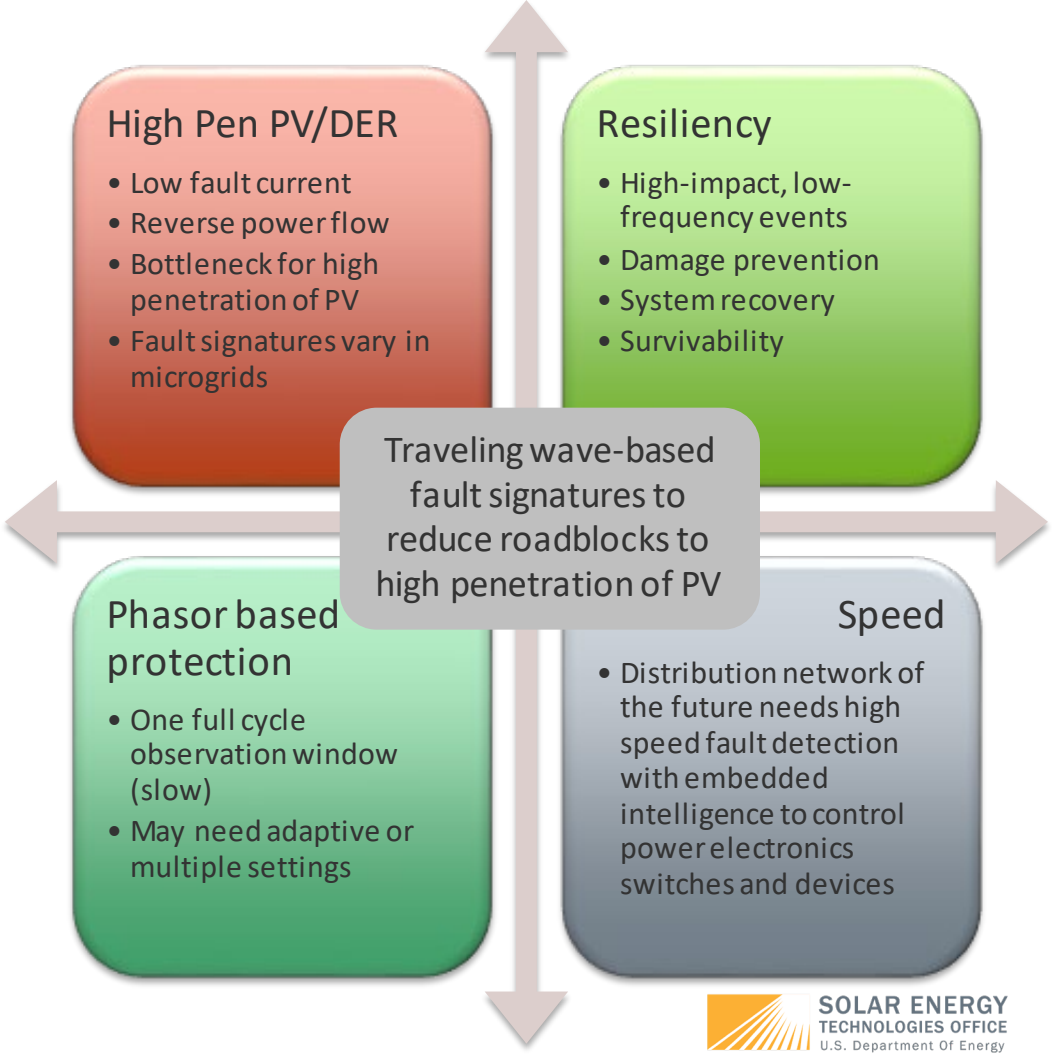
Kumaraguru Prabakar

Presentation Date – Nov. 16 2021

DOE Solar Webinars: Fast Time-Scale Modeling of Power Systems with Distributed Solar

Principal Investigator: Kumaraguru Prabakar
Other Contributors: Lucas Monzon (CU Boulder), Dhananjay Anand (NIST)

The Challenge

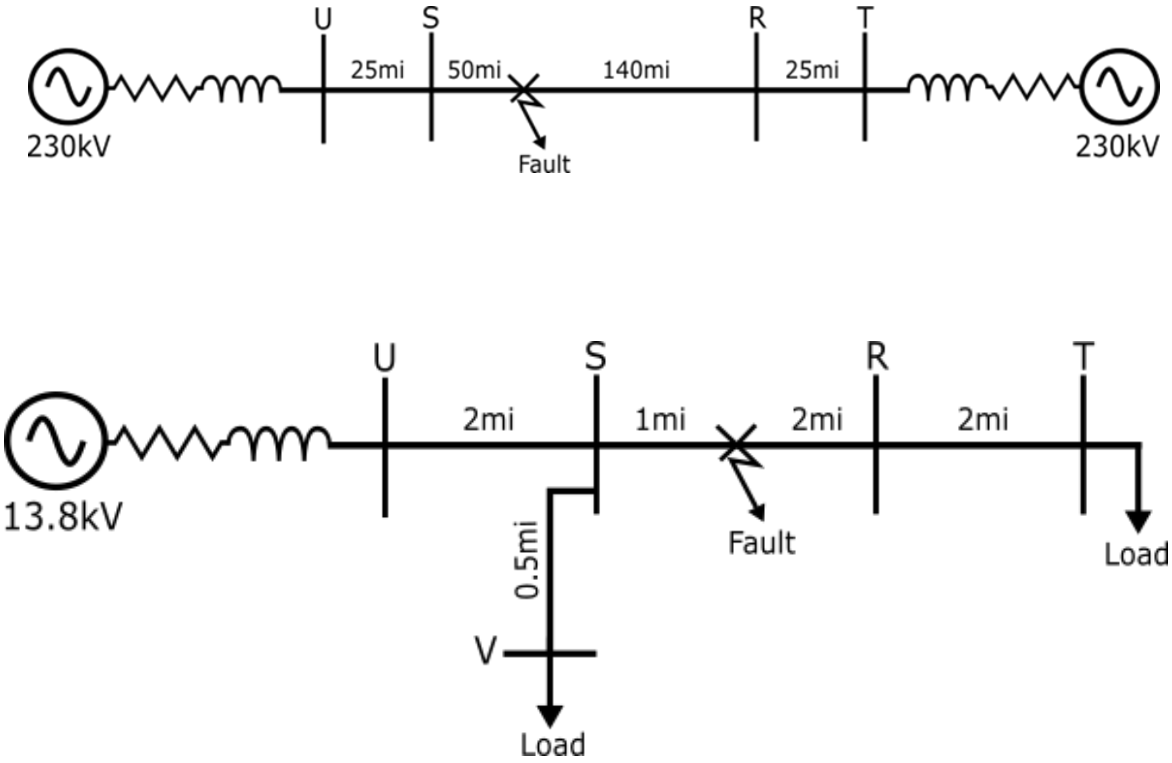


SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

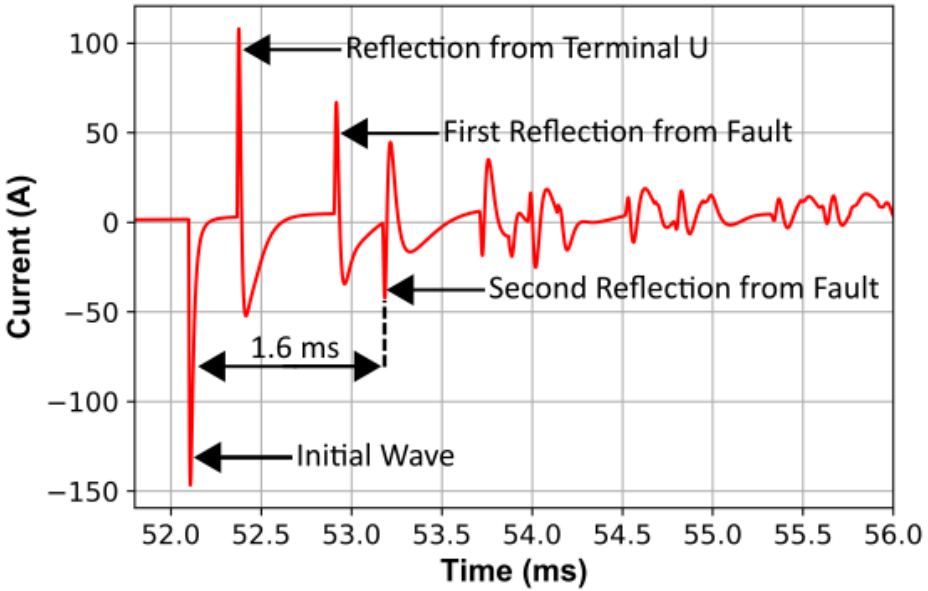
Software modeling of distribution lines and traveling wave recreation in software

Case#1: TW in Transmission and Distribution

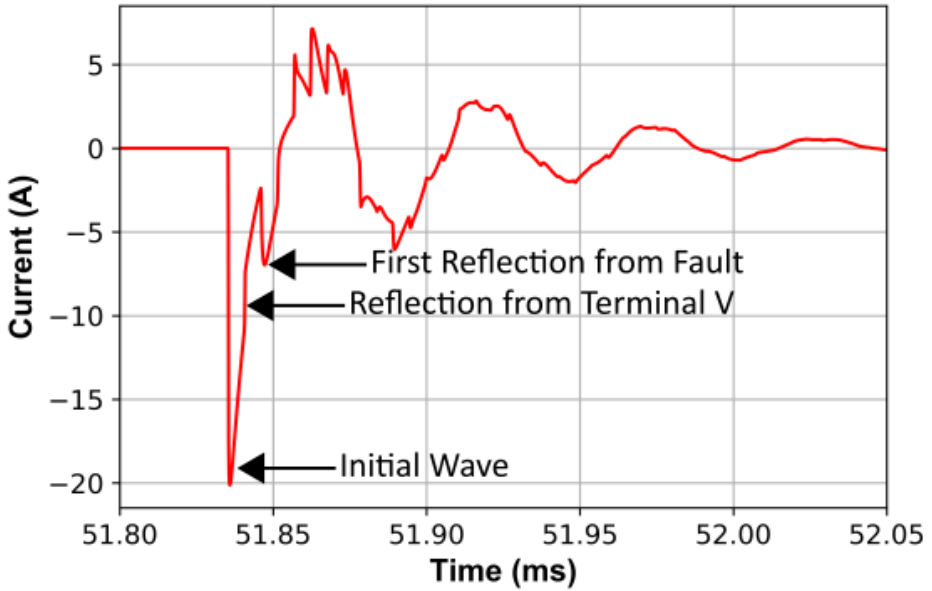
- Transmission & Distribution are modeled at 230kV & 13.8kV respectively with source impedance.
- Second order band pass filter from EMTP-RV is tuned at 20kHz in transmission.



Case#1: TW in Transmission and Distribution

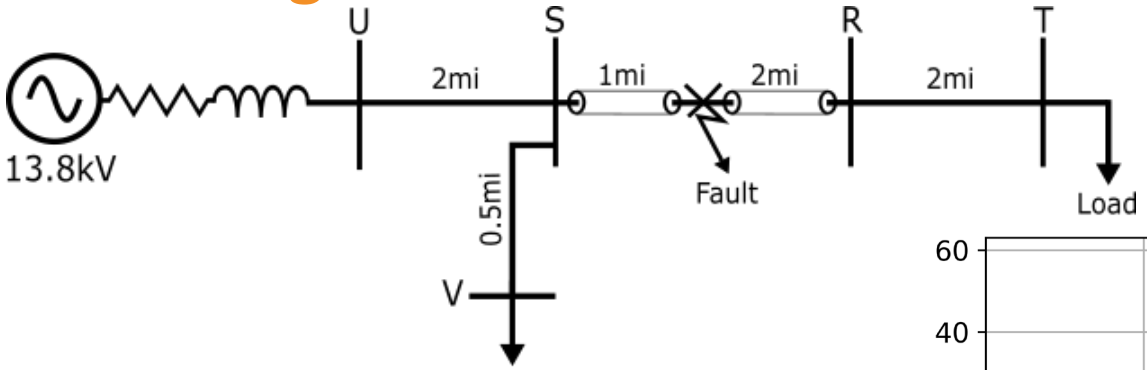


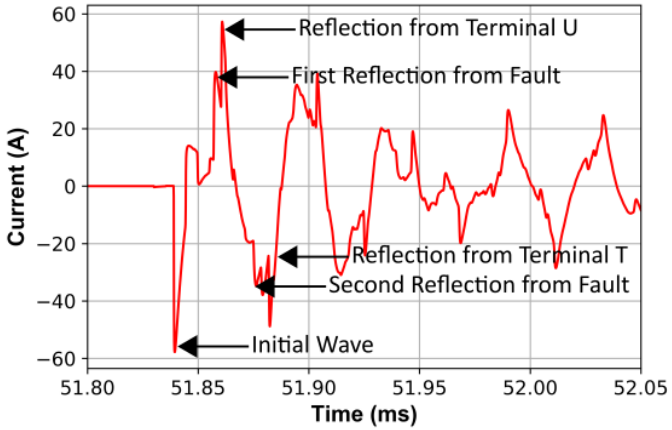
Filtered data at terminal S in transmission system

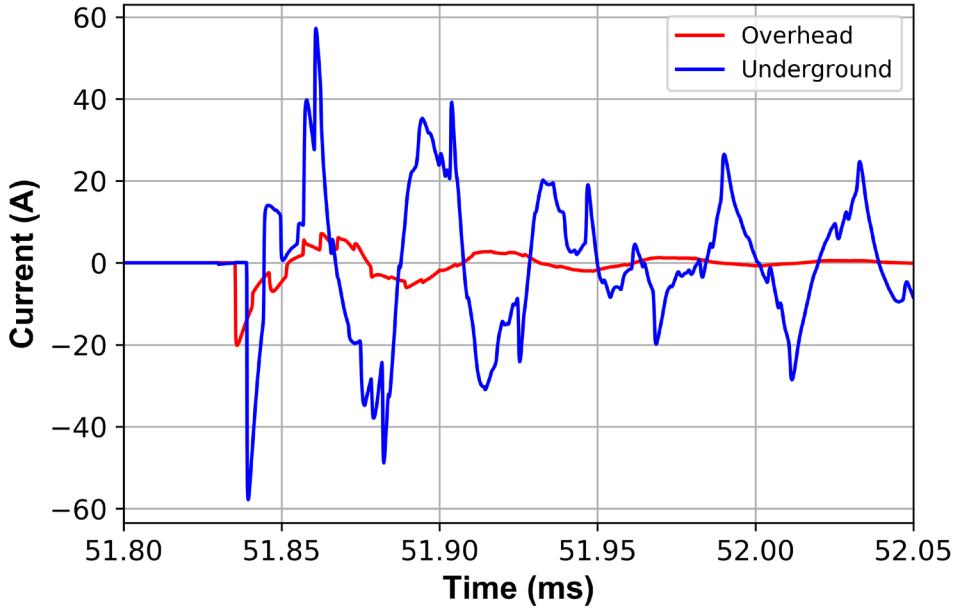


Filtered data at terminal S in distribution system

Case#2: TW Comparison with Overhead Lines and Underground Cables

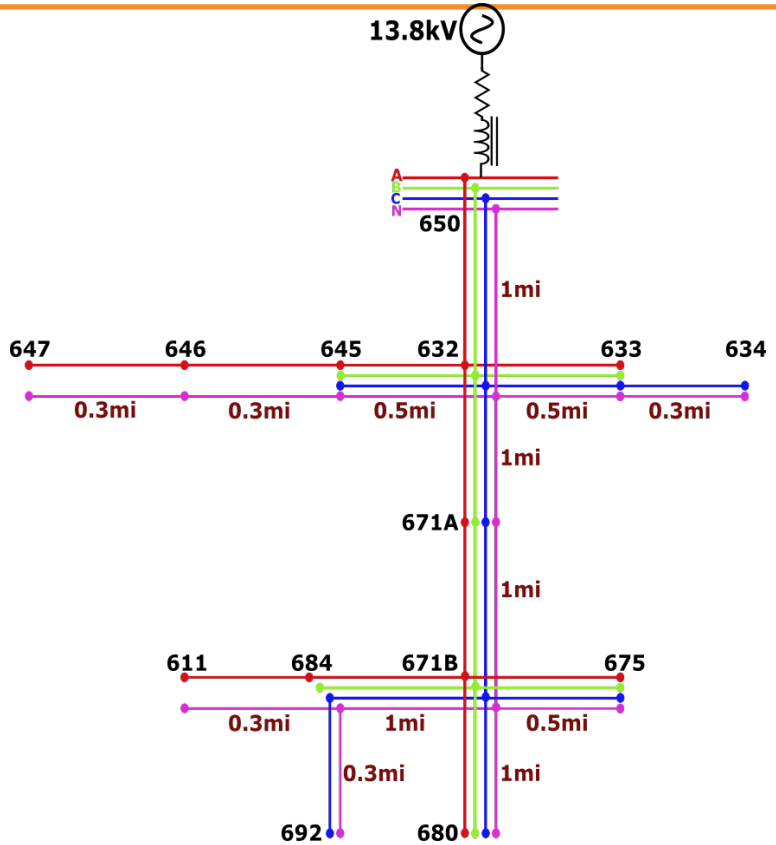


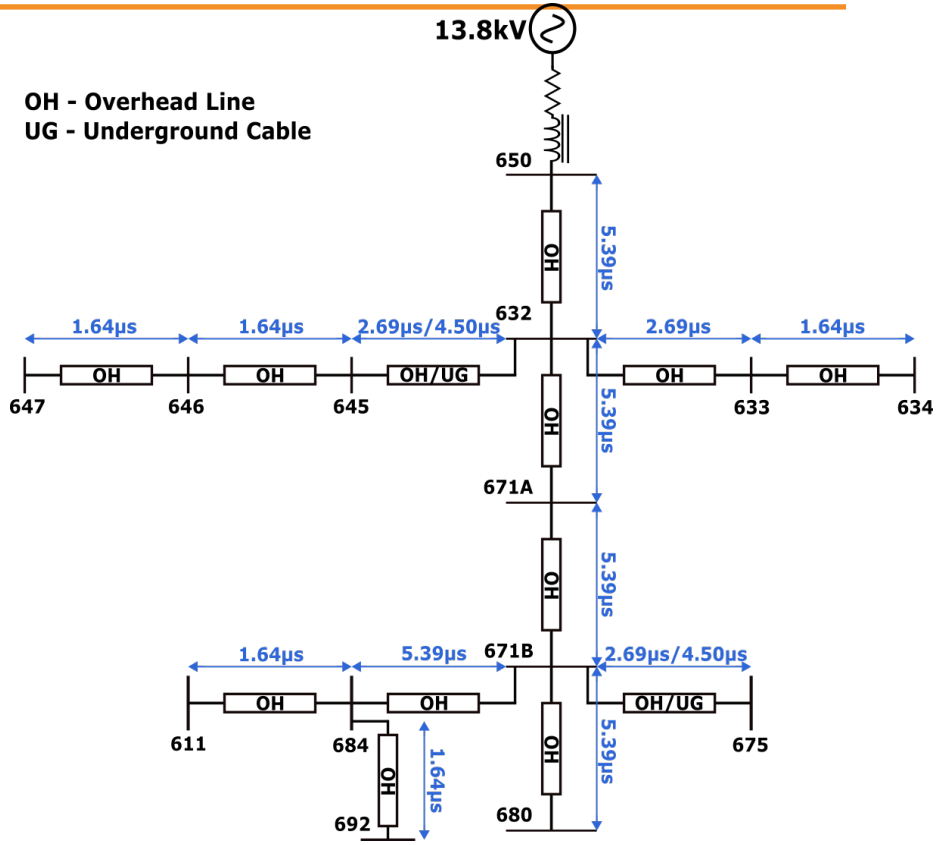




Filtered data at terminal S in distribution system with underground cable

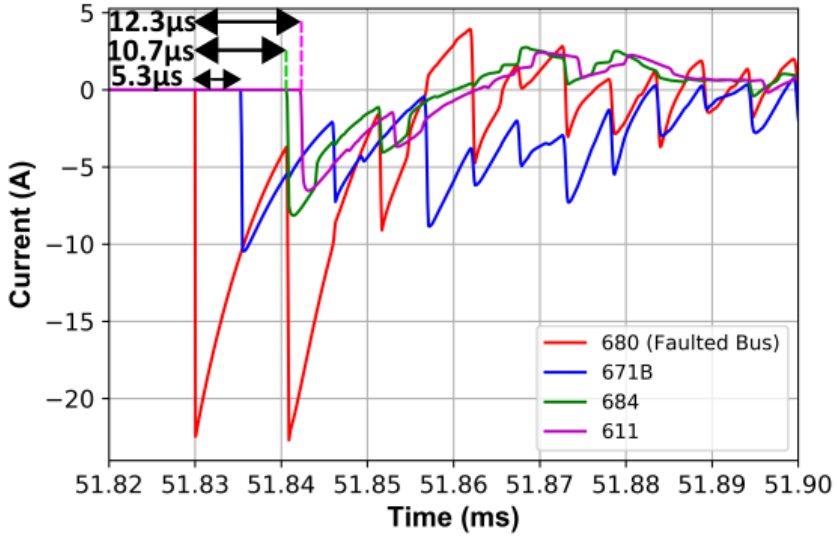
Modified IEEE 13 bus system

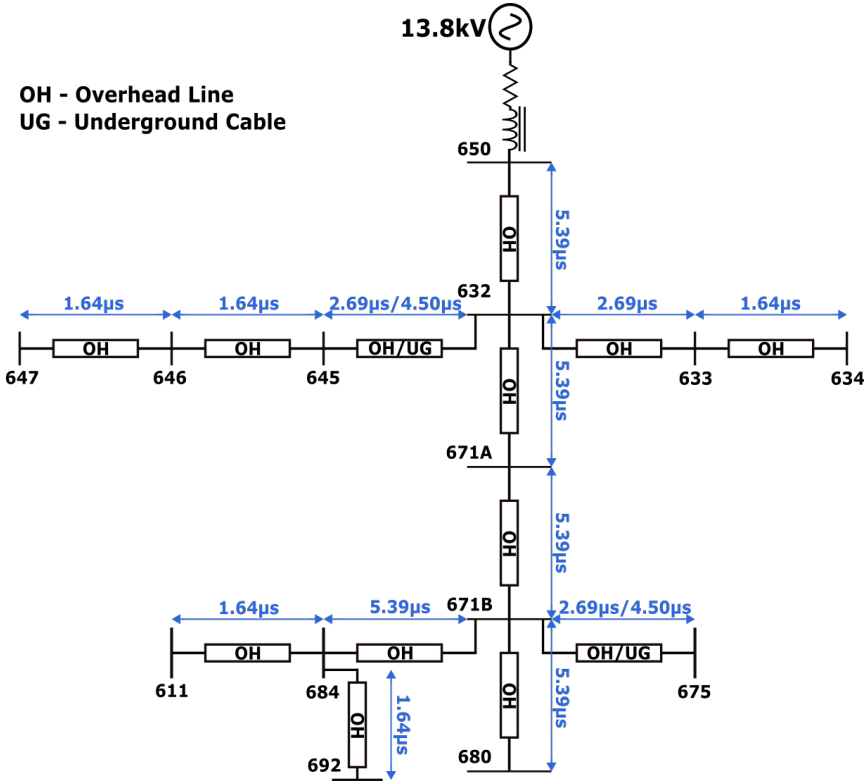




Case#4: Overhead Lines with Fault on Bus#680

- Initial wave times estimated at 671B, 684, 611 are 5.39µs, 10.78µs, 12.42µs respectively.
- In the simulations, they arrive at 5.3µs, 10.7µs, 12.3µs.





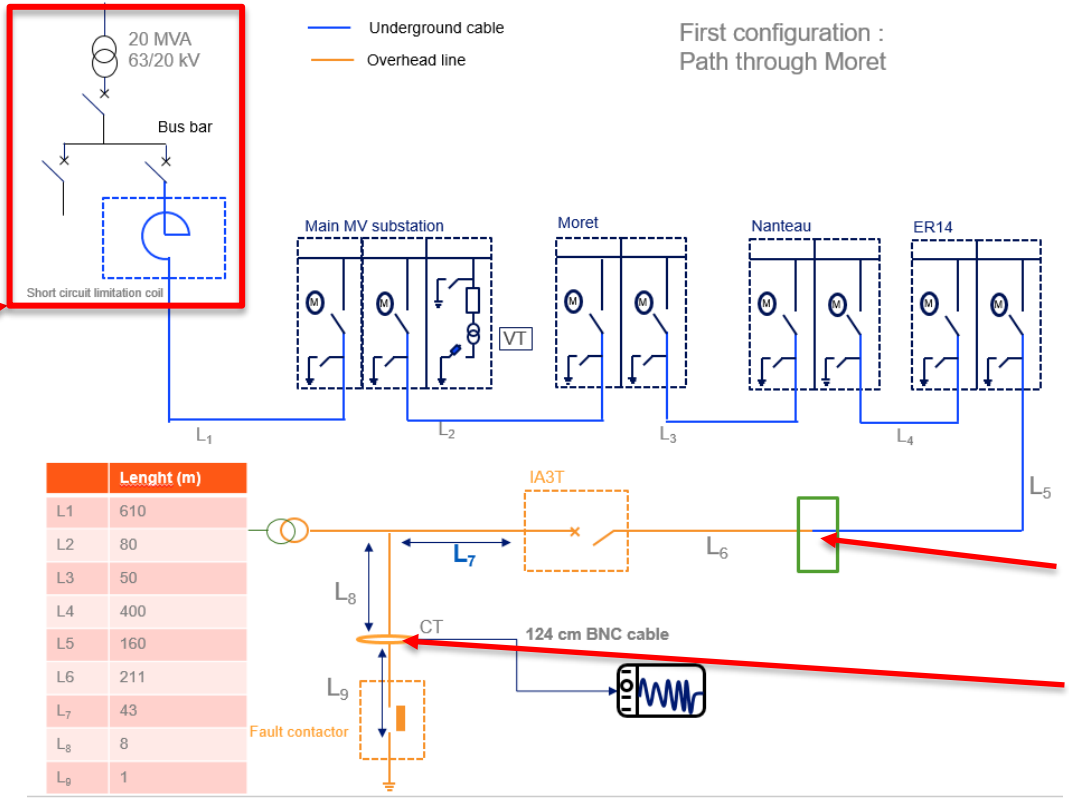
Hardware emulation of distribution line and recreate traveling wave in hardware

Goals of the experiments

- Use real-world overhead and underground lines (no digital or analog emulation)
- Use real faults
- Use off-the shelf available, inexpensive CT's
- Capture wide frequency data (up to ~100 MHz)
- Show traveling wave in a field experiment
- Show capability to differentiate between noise and high frequency waves in real time

Field experiment

Potential impedance mismatch

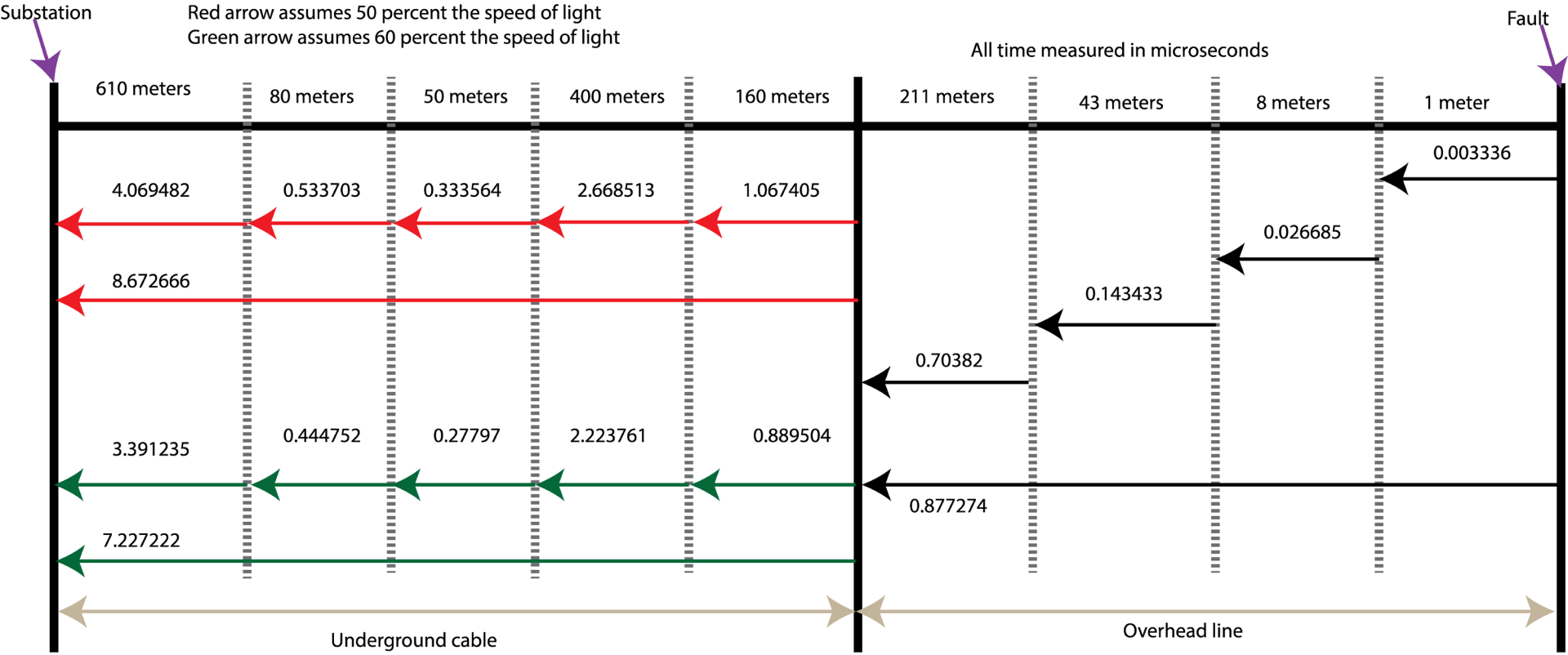


	Lenght (m)
L1	610
L2	80
L3	50
L4	400
L5	160
L6	211
L_7	43
L_8	8
L_9	1

Potential impedance mismatch

Measurement location

Length of the lines and theoretical traveling time

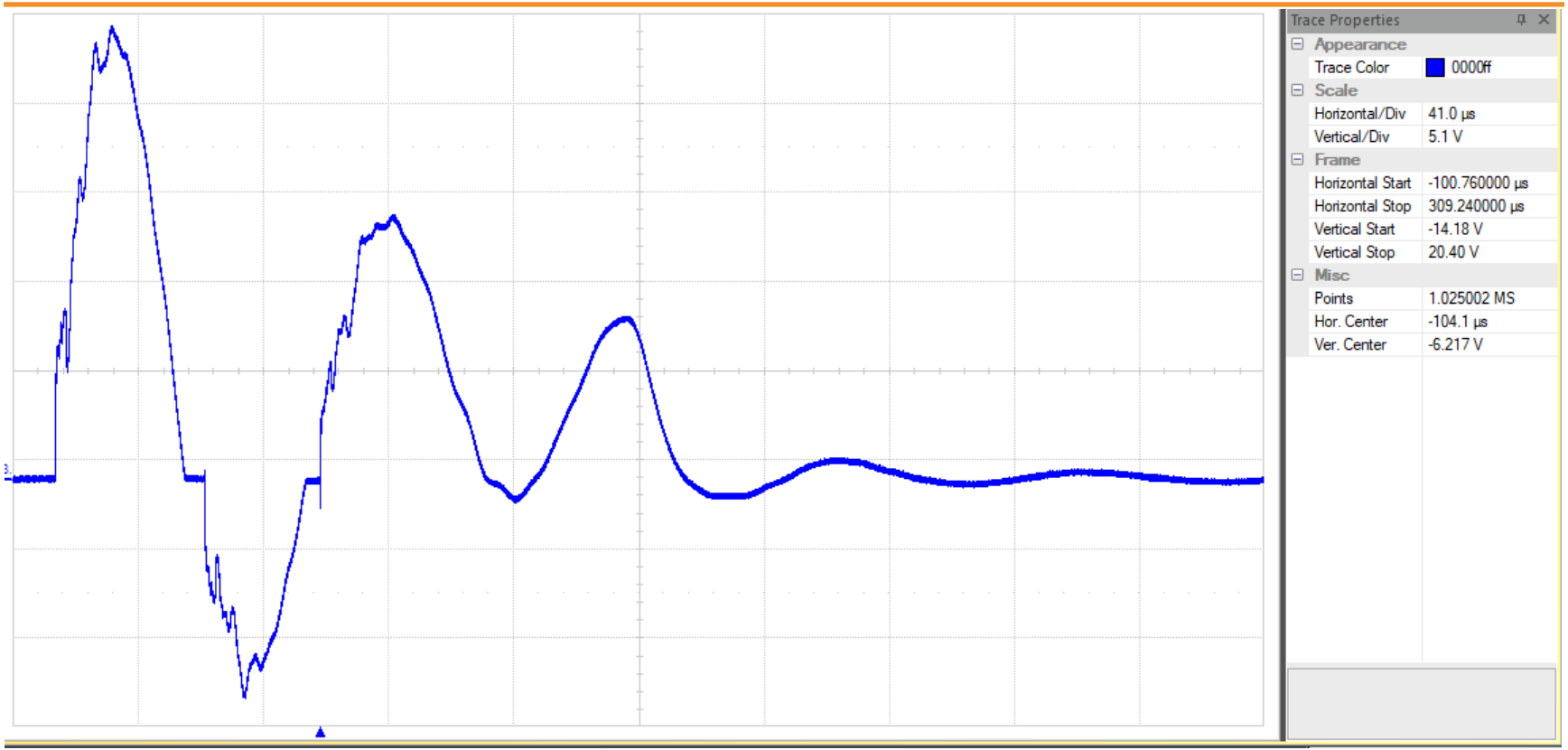


Field experiments

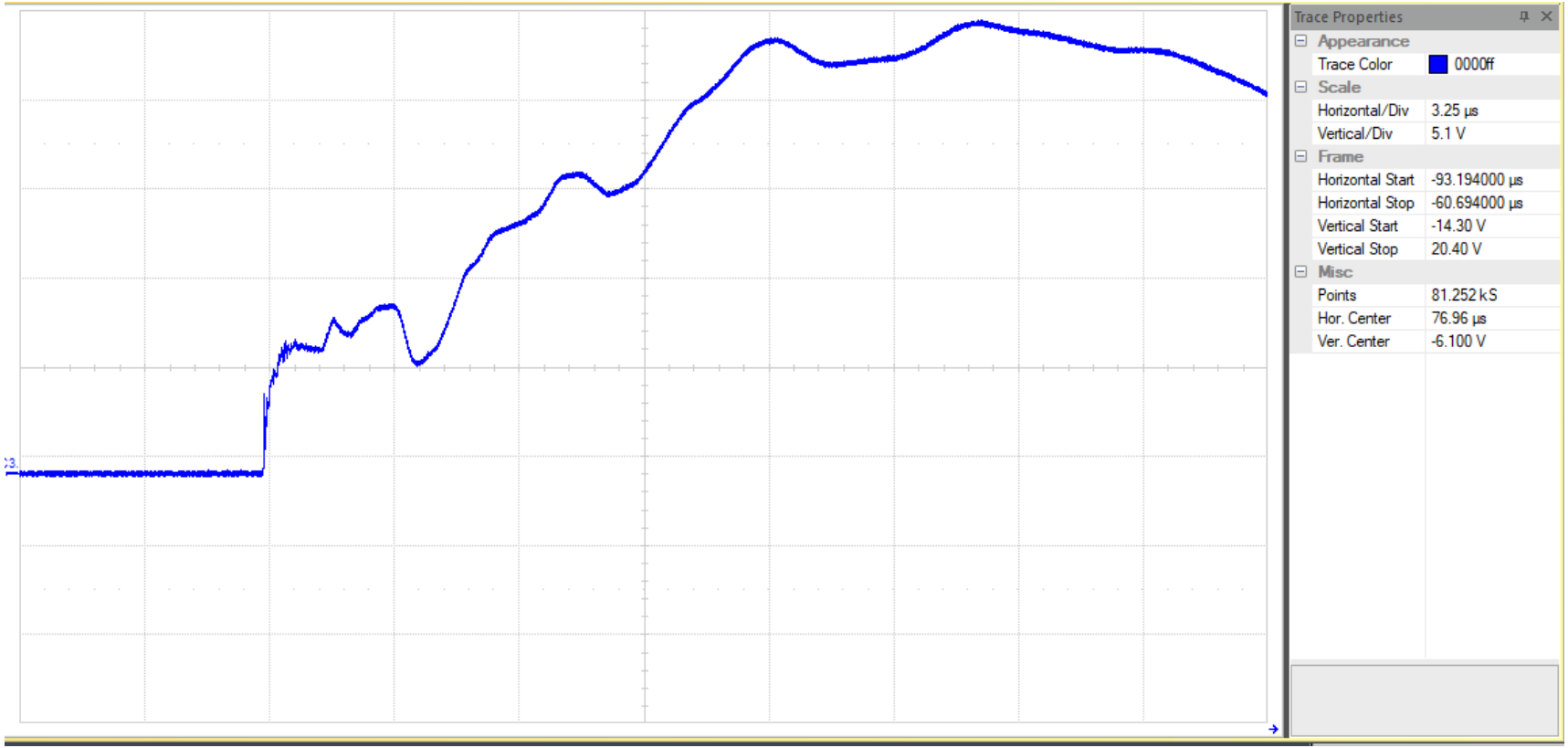
Setup for Single-Phase Faults

Experimental setup

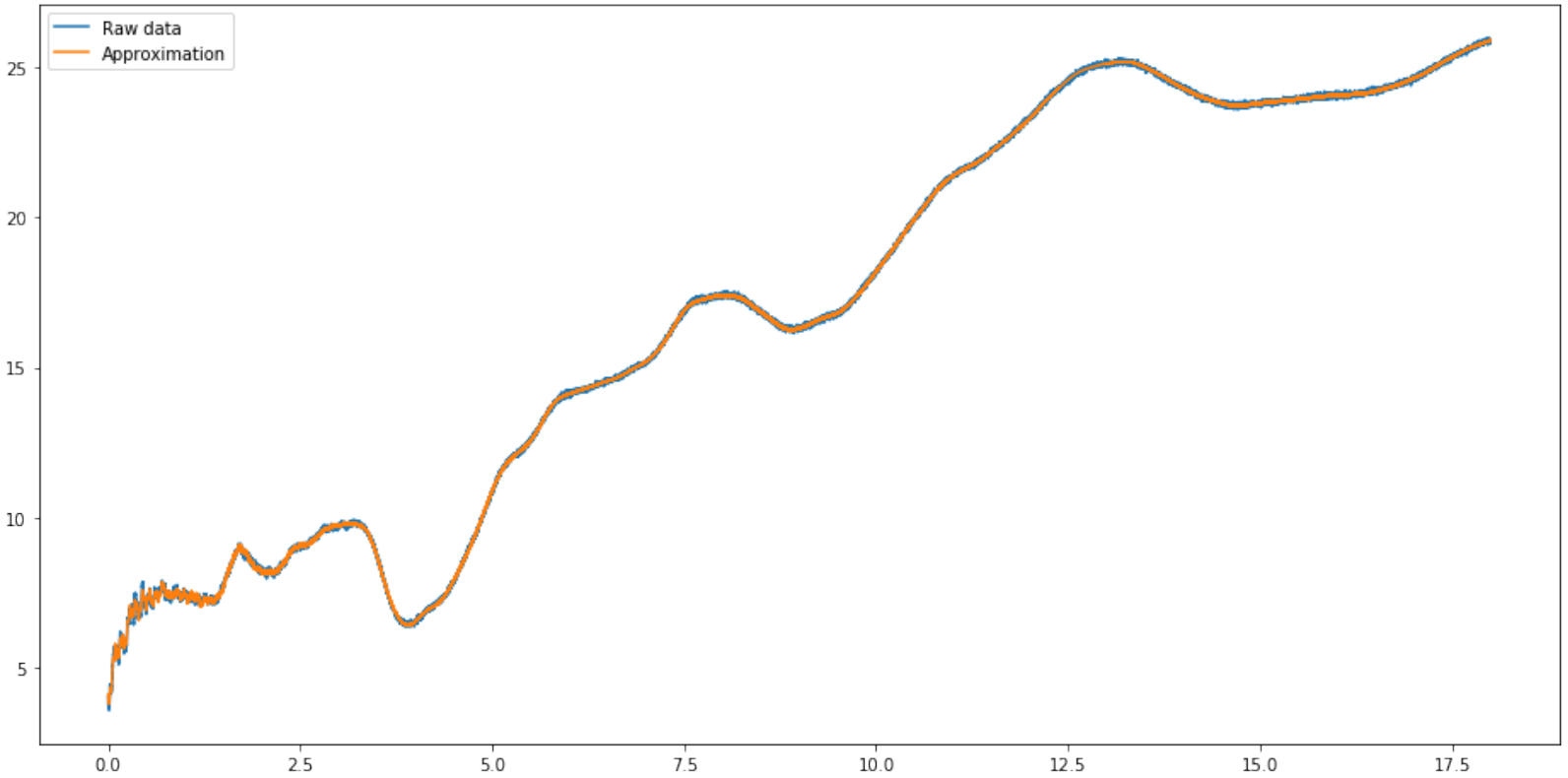
Raw (unfiltered) data collected in the oscilloscope



Zoomed in version (unfiltered)

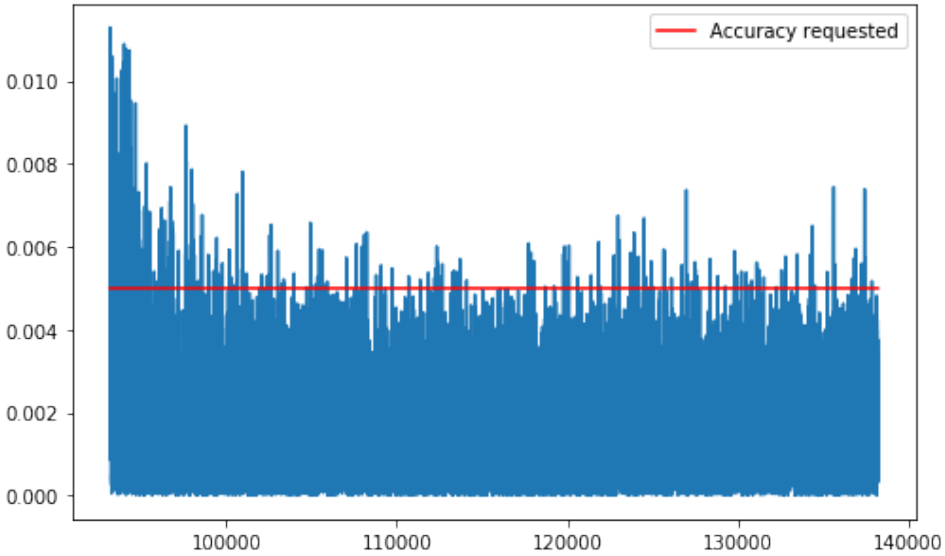


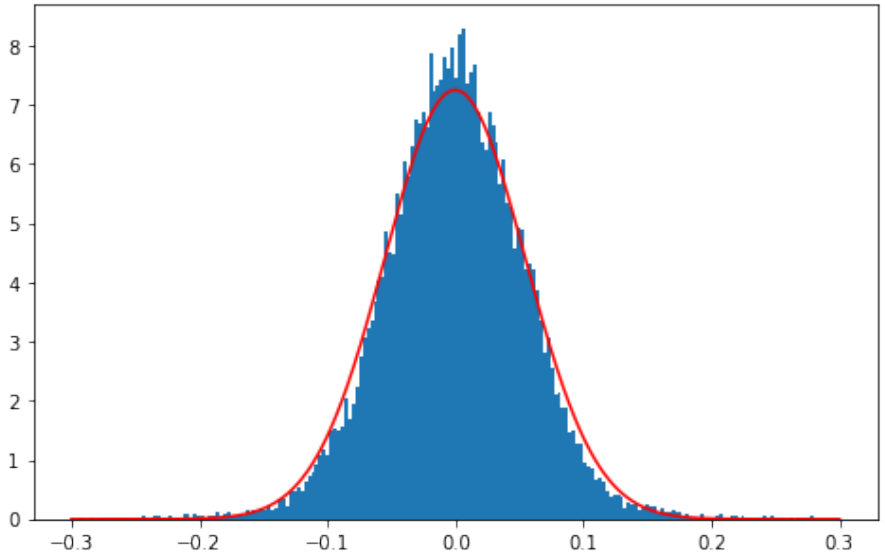
Advanced mathematics-based signal processing result



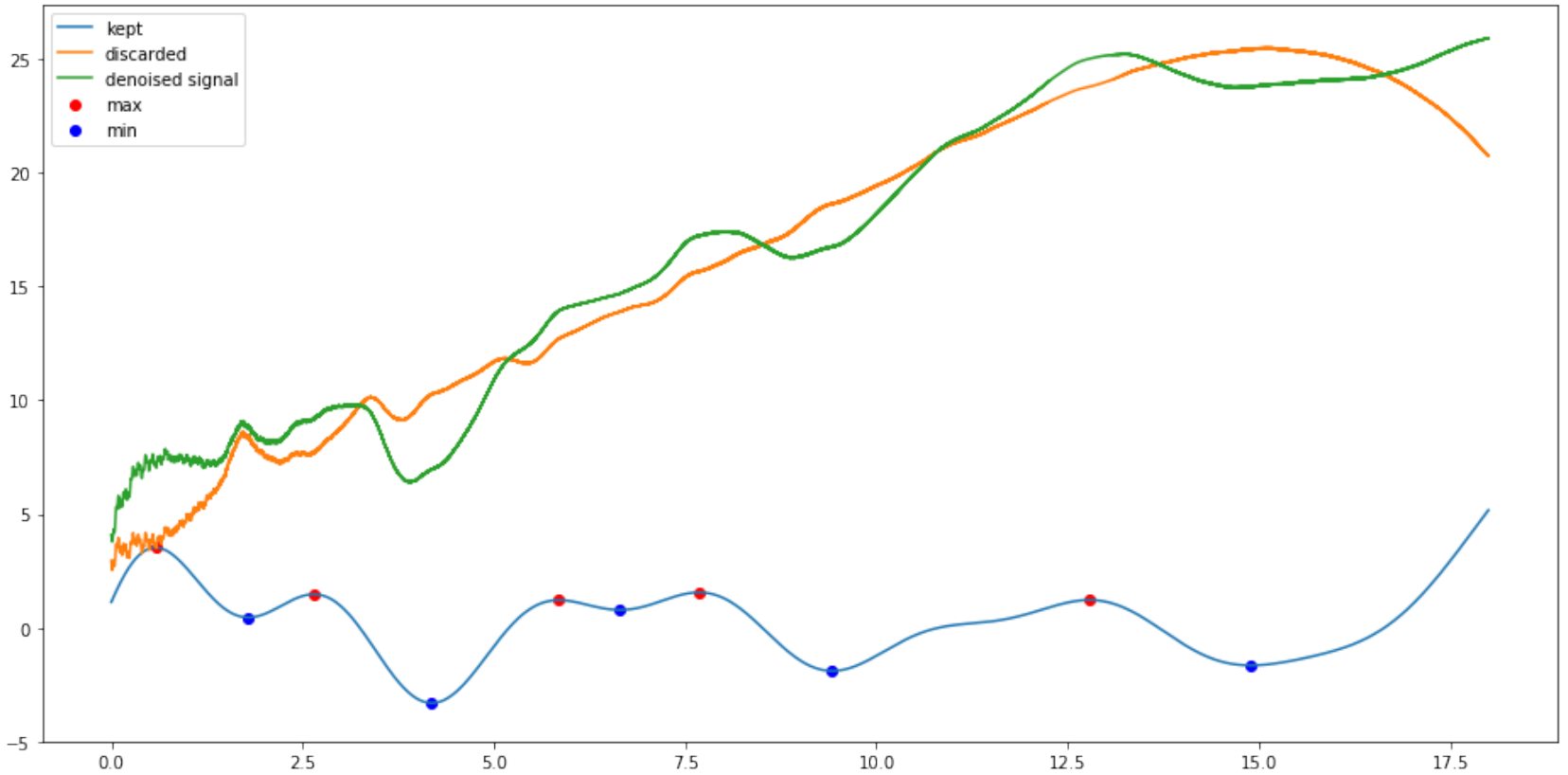
Time in microseconds

Advanced mathematics-based signal processing result



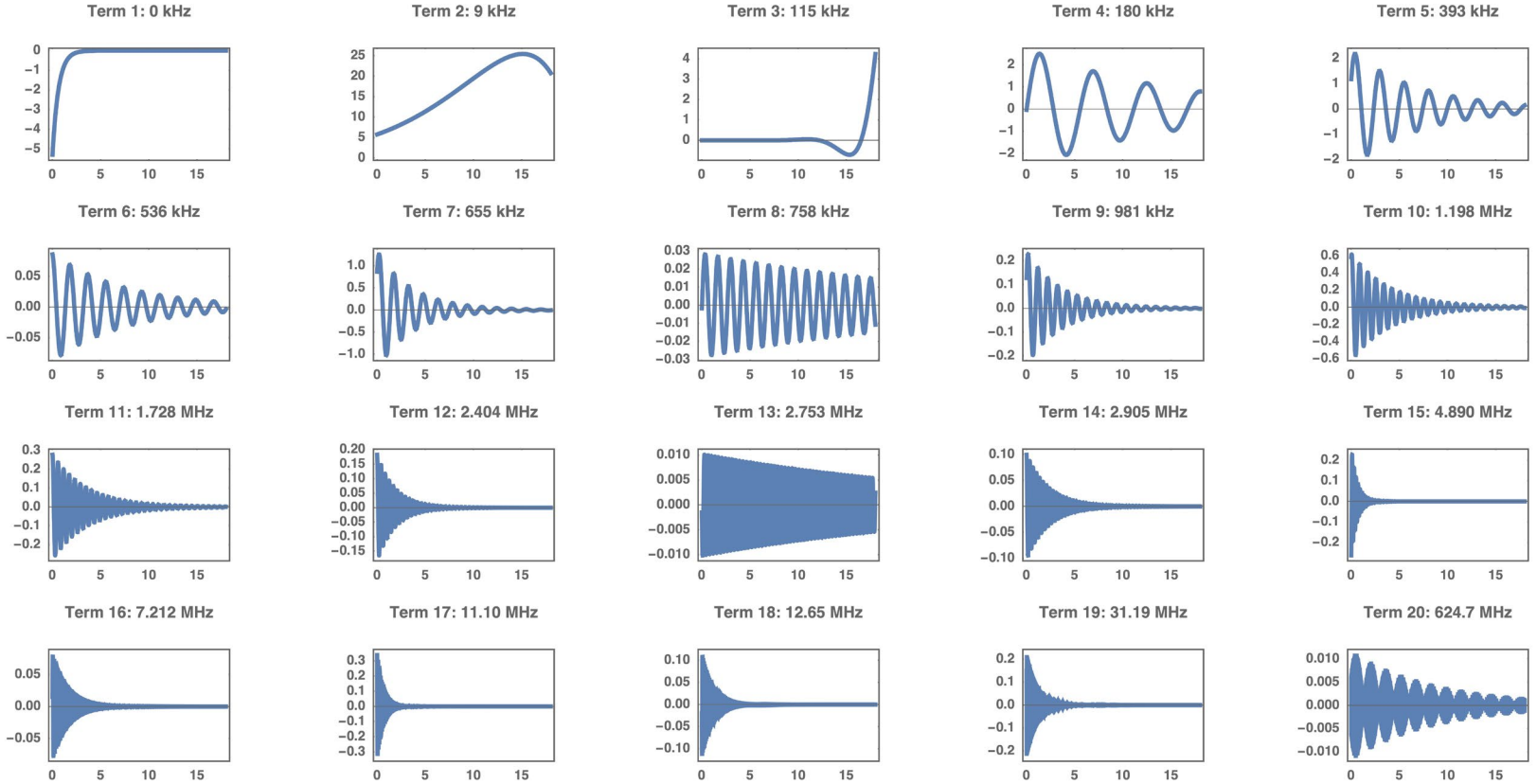


Advanced mathematics-based signal processing result

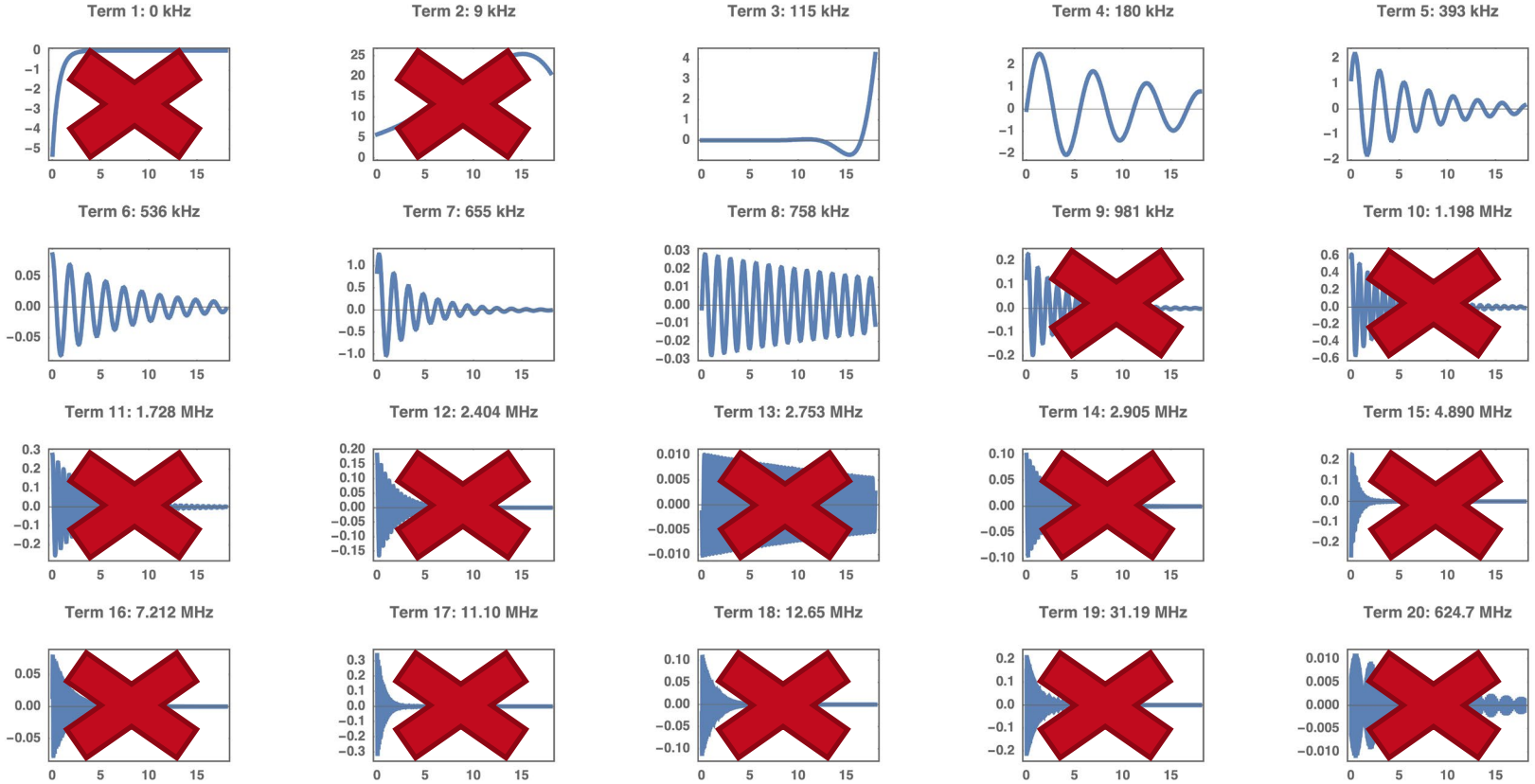


Time in microseconds

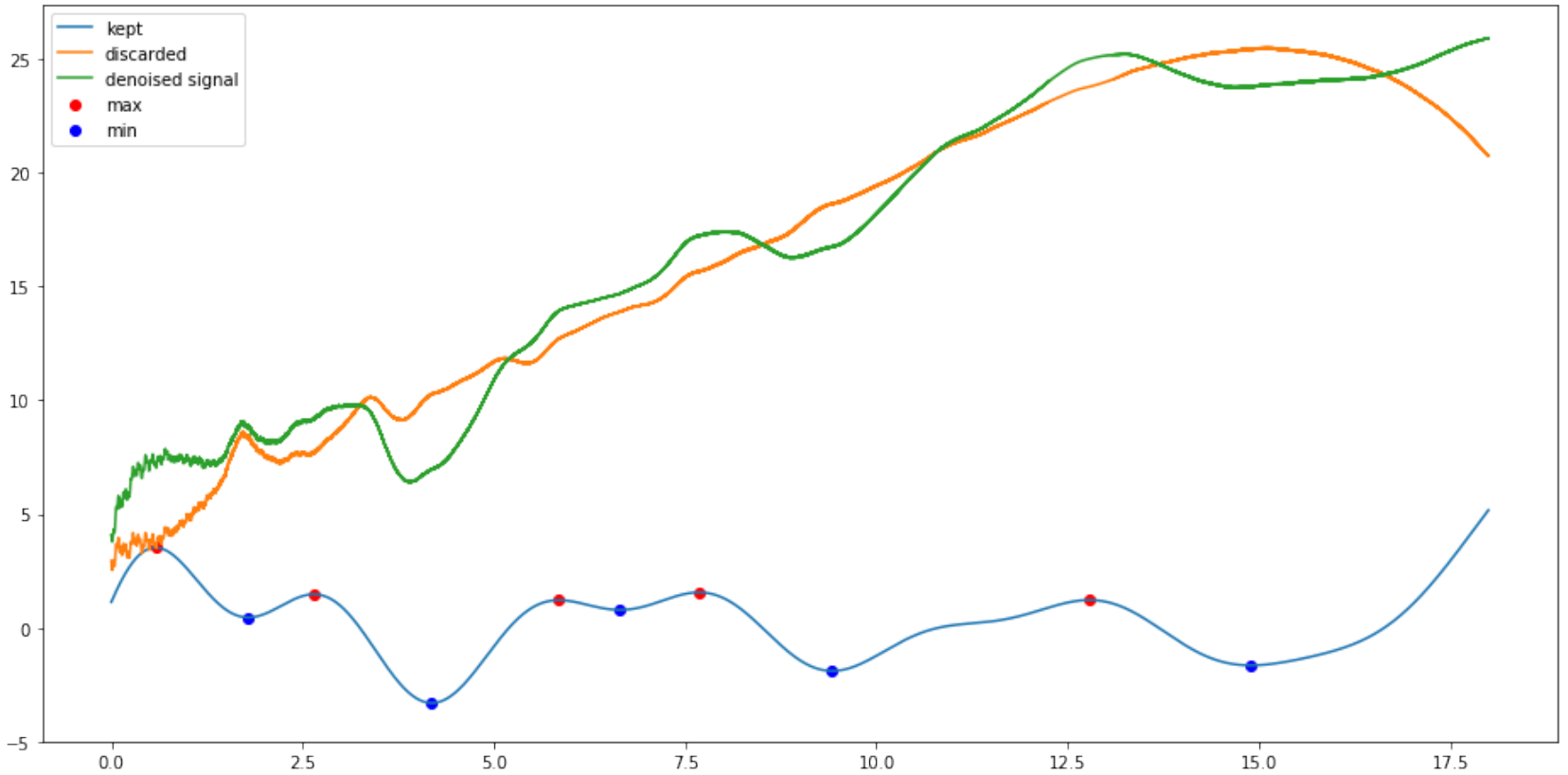
Advanced mathematics-based signal processing result



Advanced mathematics-based signal processing result

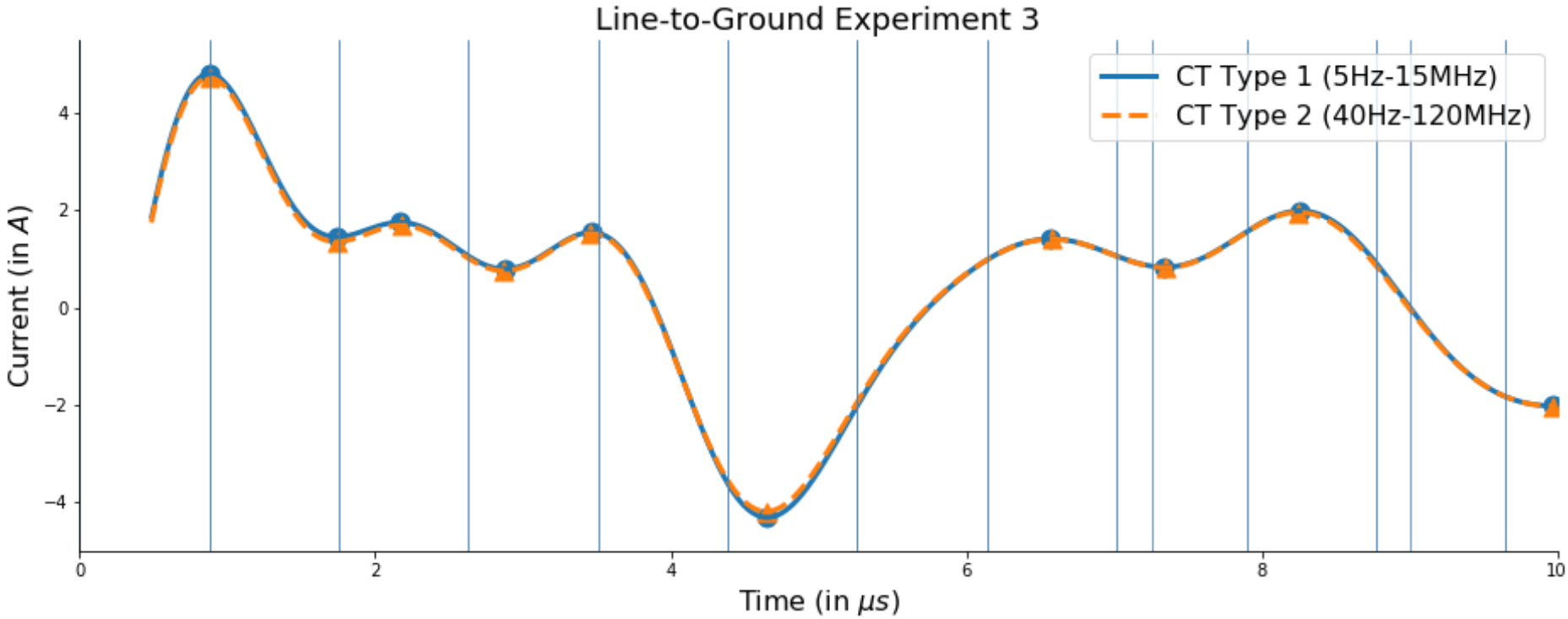


Advanced mathematics-based signal processing result

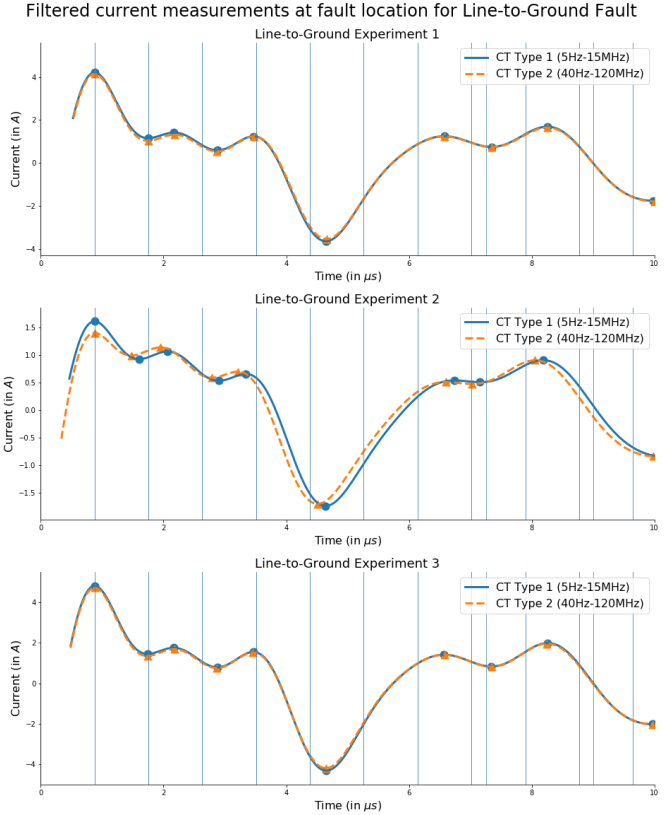


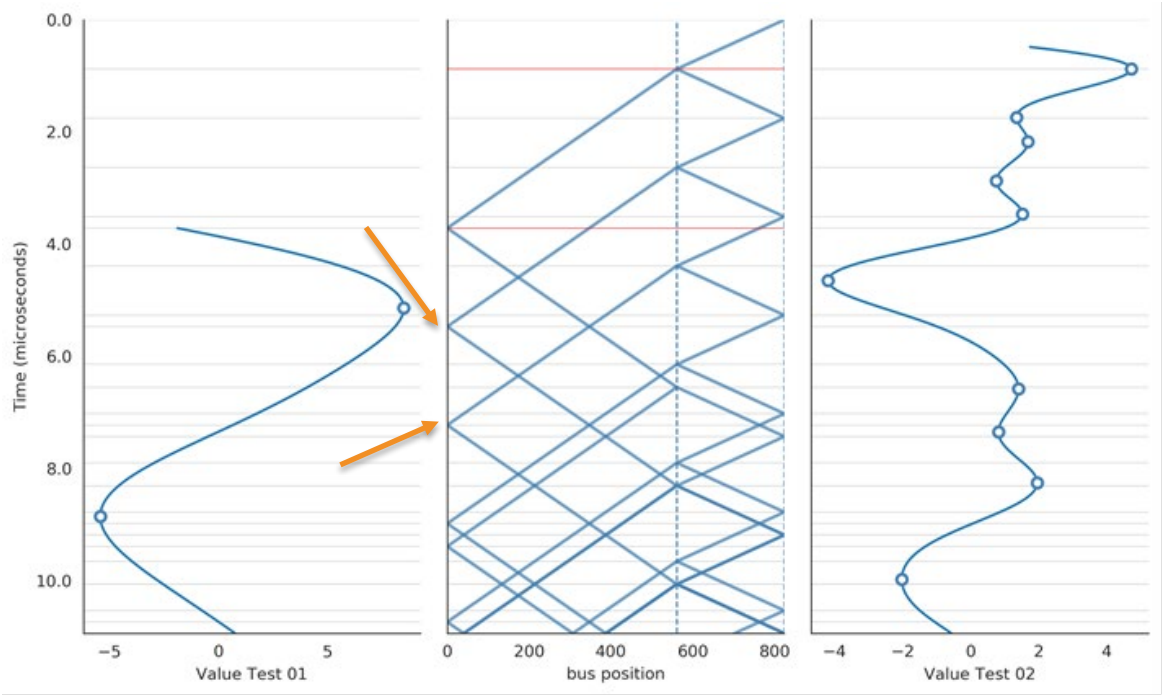
Time in microseconds

Advanced mathematics-based signal processing result



Advanced mathematics-based signal processing result





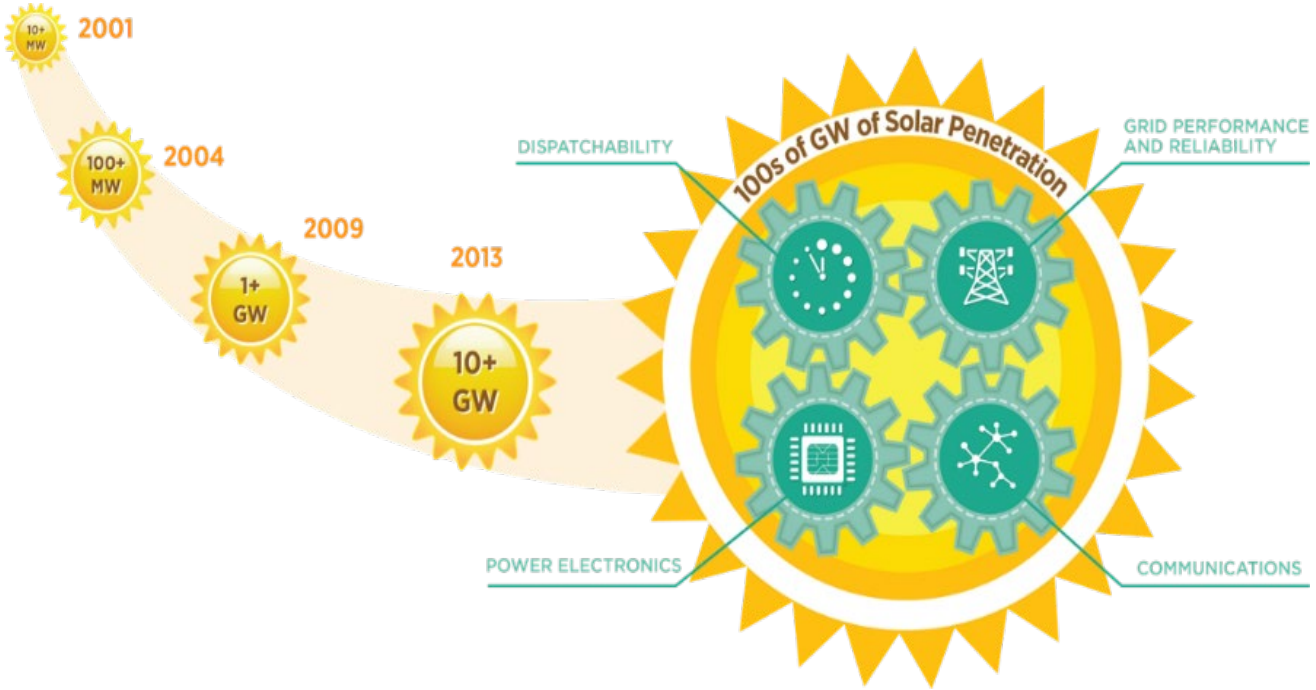
Summary

- Simulations need wide band models of system components to accurately simulate traveling wave events.
- Experimental results provided for line-to-ground fault
- Advanced filtering technique accurately fits raw data and then removes noise as well as frequency components outside the CT calibration range

Link to report

- Link to the OSTI entry:
- https://www.osti.gov/biblio/1814596
- Link to the technical report:
- https://www.nrel.gov/docs/fy21osti/78057.pdf

Questions?



This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34237. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.