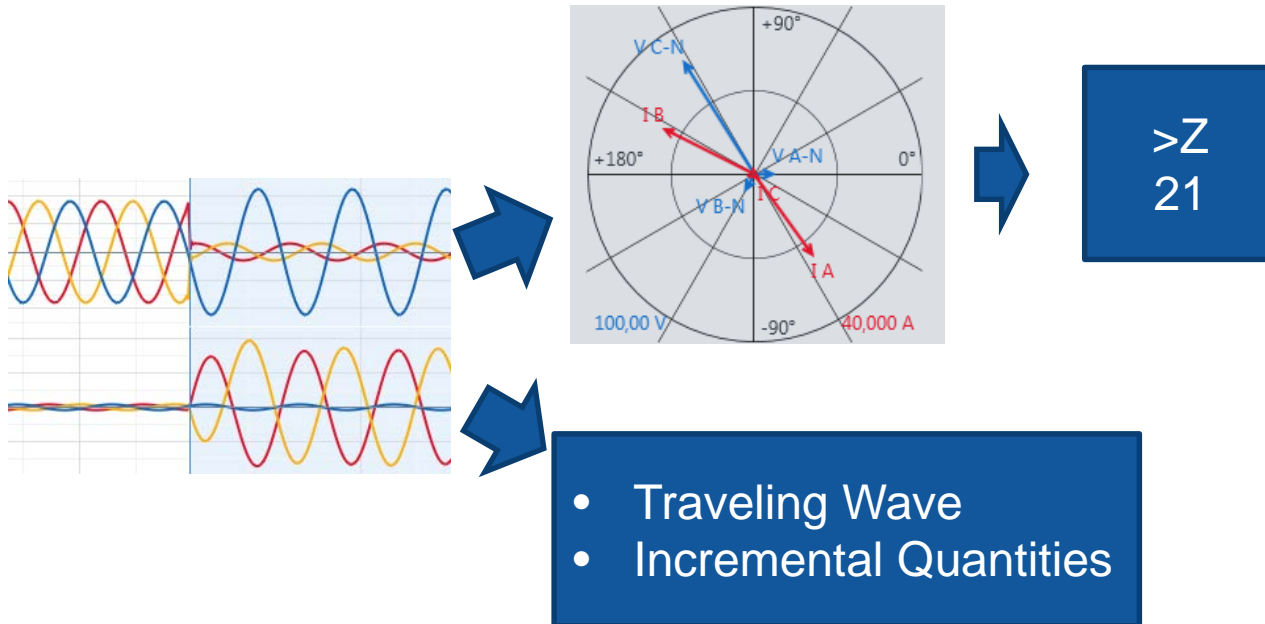




New Possibilities for Testing Traveling Wave Fault Location Functions in the Field

Phasor vs. Time Domain



Key technologies

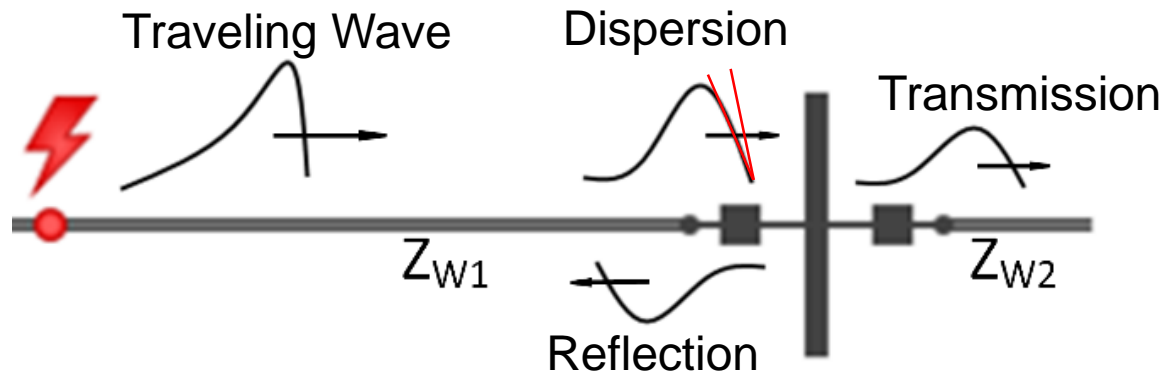
- > Accurate time
- > Processing speed (FPGAs)
- > High bandwidth communication

Traveling Wave

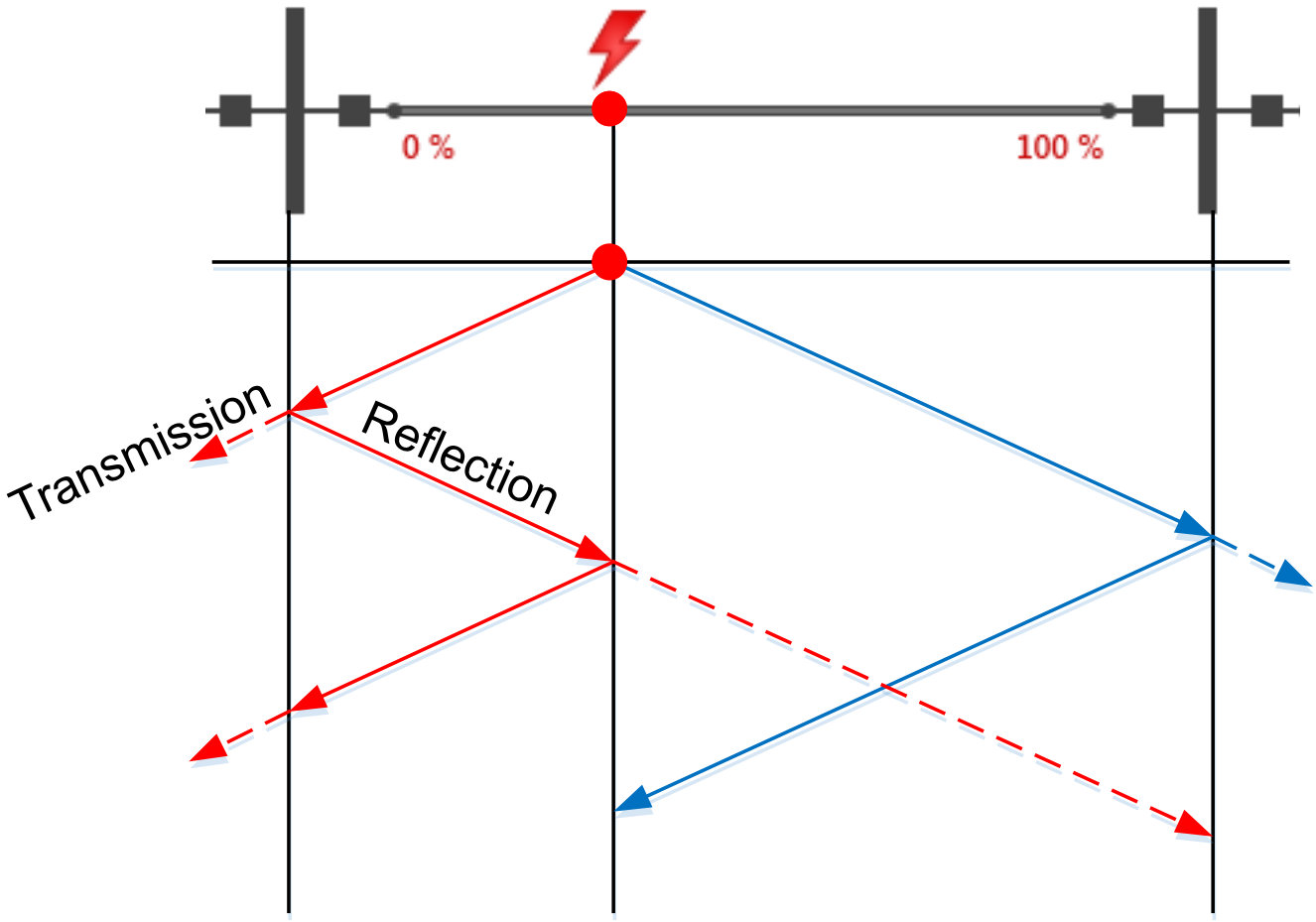
- > A fault on a line generates a traveling wave
 - > (inception angle $\neq 0^\circ$)
- > The wave propagates close to the speed of light



Wave Terminology

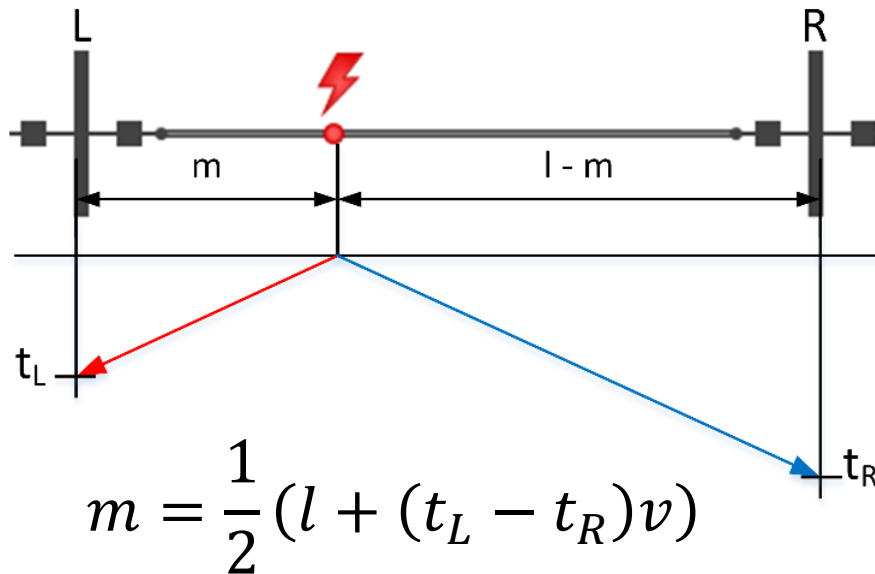


Bewely lattice diagram



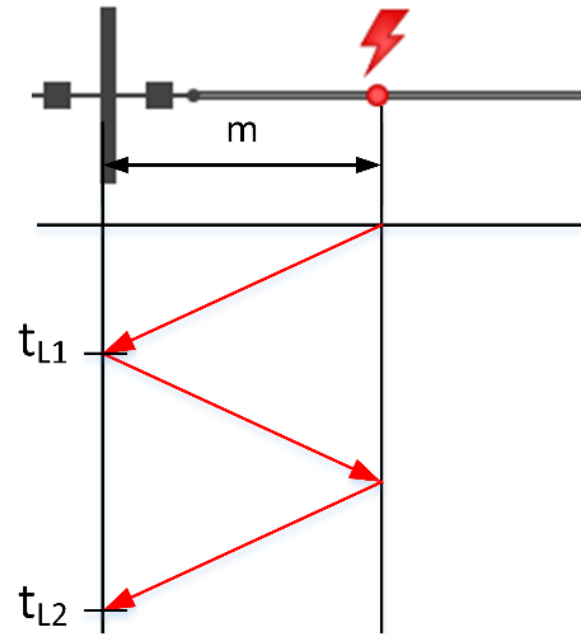
Two-Ended Fault Location

- > Only relying on first wave, thus immune to reflections. Robust!
- > Successfully used in fault locators for many years
- > Protection will requires high bandwidth communication
- > Requires highly accurate absolute time stamping



Single-Ended Fault Location

- > No communication required
- > Only relative timestamps
- > Susceptible to reflections
- > First principle that was used



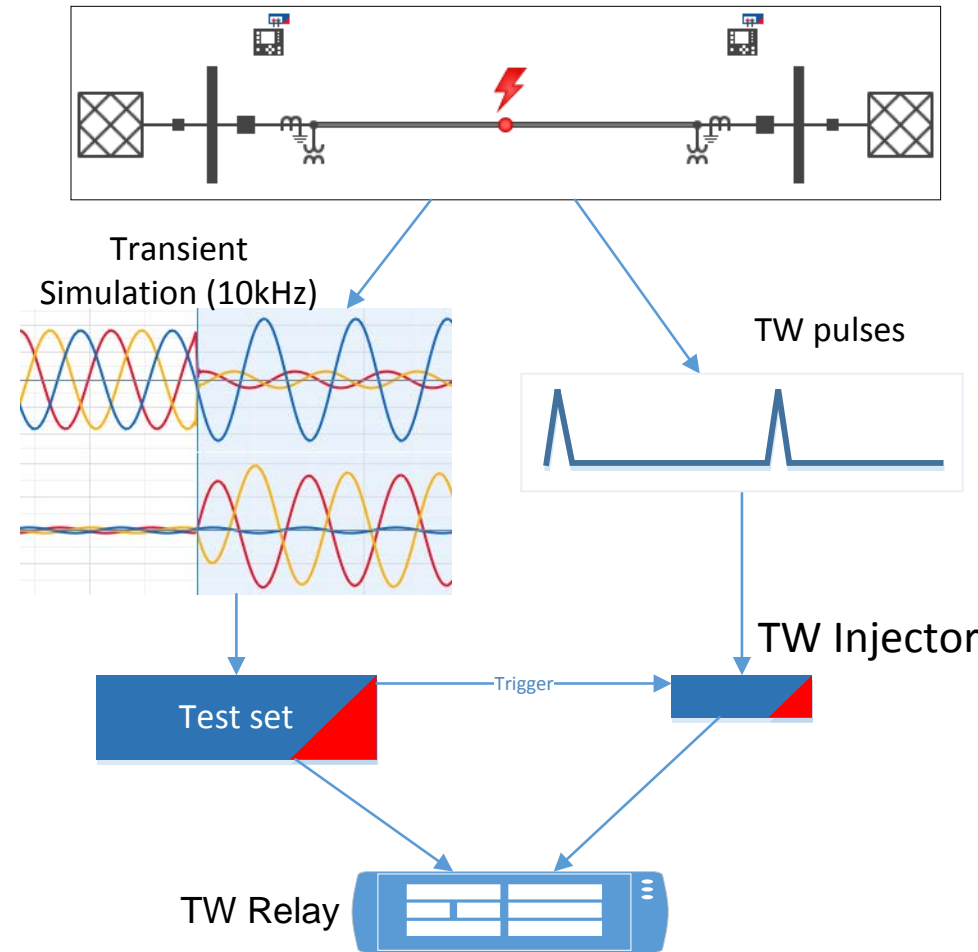
$$m = \frac{t_{L2} - t_{L1}}{2} v$$

Laboratory vs. Field Environment

- > EMTP simulation with 2MHz
 - > Required for wave steepness
 - > Several MB size
 - > Minutes to calculate a few 100ms
- > Real-time simulator
 - > with high-speed FPGA
- > Relays in one place
- > Injection to the low-level Inputs
 - > bypassing internal CTs
 - > Opening the housing
- > Test set with max. 10kHz
- > End-To-End setup
- > Injecting in 5A inputs
- > Driving inductive burden

Signal-Generation & Injection

- > Driven by single application
- > Simultaneous testing with fault current & TW pulses
 - > Required by relay logic
- > Test set is in a phase lock loop (PLL)
- > TW pulses timed exactly point on wave



Commissioning

- > Single ended execution possible
- > Highly accurate synchronization



Time Accuracy

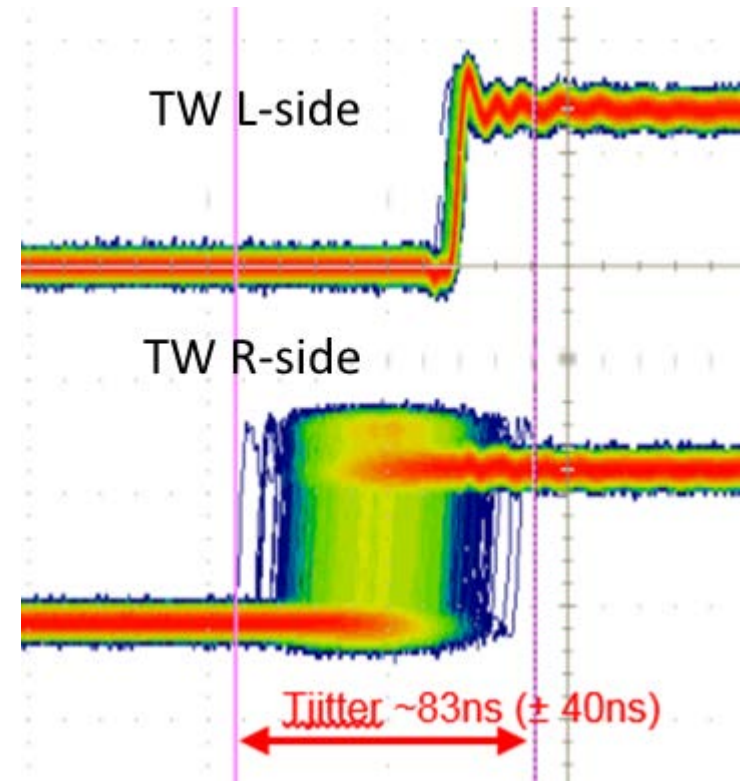
Time Accuracy is vital

> $1\mu\text{s}$ Jitter = 300m/900ft error

Achieved Accuracy in experiment
over End-To-End!

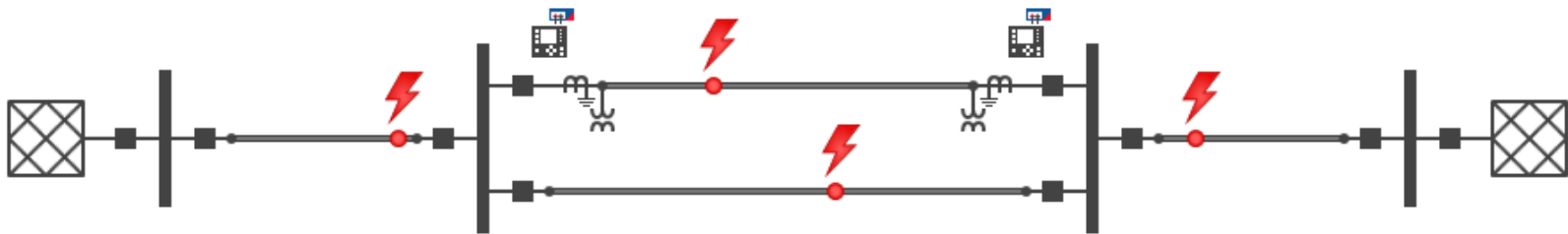
> Jitter of +/- 40ns achieved

> Relay fault locator compared
to simulated fault location
10-30m / 30-90ft



Future Outlook

- > Experiments only done with two ended Fault Locator
- > Time Domain Protection a new challenge:
 - > Multiple TW elements and incremental quantity elements combined
 - > Elements logic working together to achieve security
 - > Voltage and current waves
 - > Discriminates polarity
- > Challenging Test Cases



Conclusion

- > TW Fault locator was successfully tested!
 - > Without test modes, masking, disabling or any other manipulation of the relay
- > New Generation Protection requires new tools for commissioning
- > For compliance an End-To-End test will be required
- > Today test sets can be enabled for testing TW protection relay
- > Test sets must have a high time accuracy (<100ns)
- > The future stays exciting!