Locating Faults by the Traveling Waves They Launch

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Estimate Location From Current

“JM Drop” circa 1936

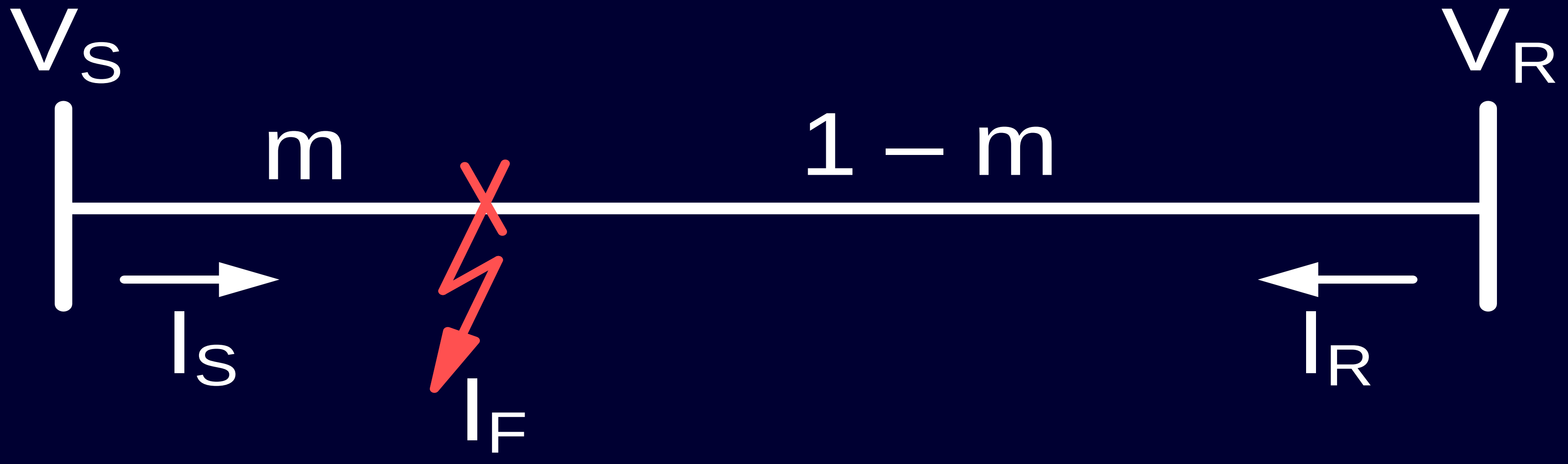
Adheres to Standard
SIS 12 AWG/10-32/5A

Quick Test, 2013

Set	1	3	5	10	15	20
Measured	0.97	3.00	4.7	10	14	20

Not bad for 77 years!!!

Estimate Location From Impedance

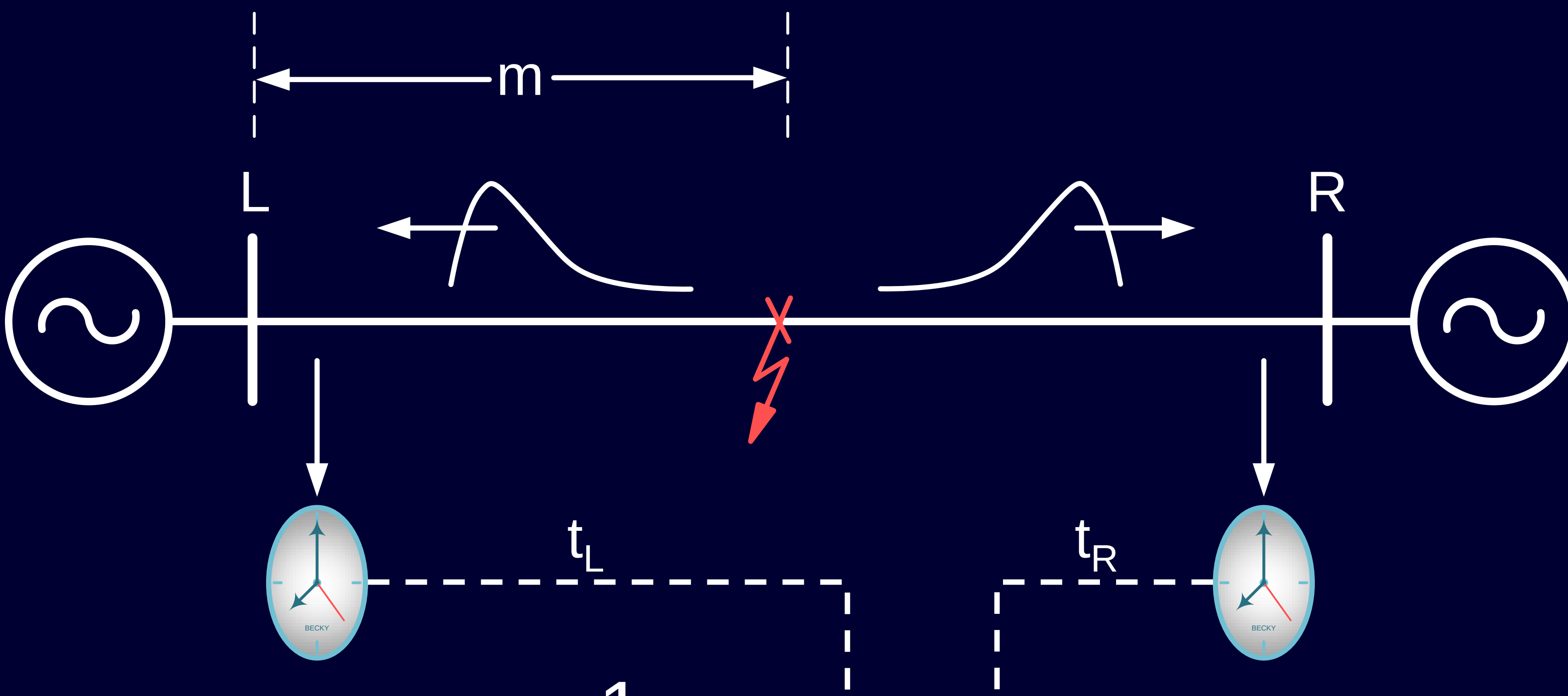


Line Impedance = Z_L

Character of Impedance-Based Methods

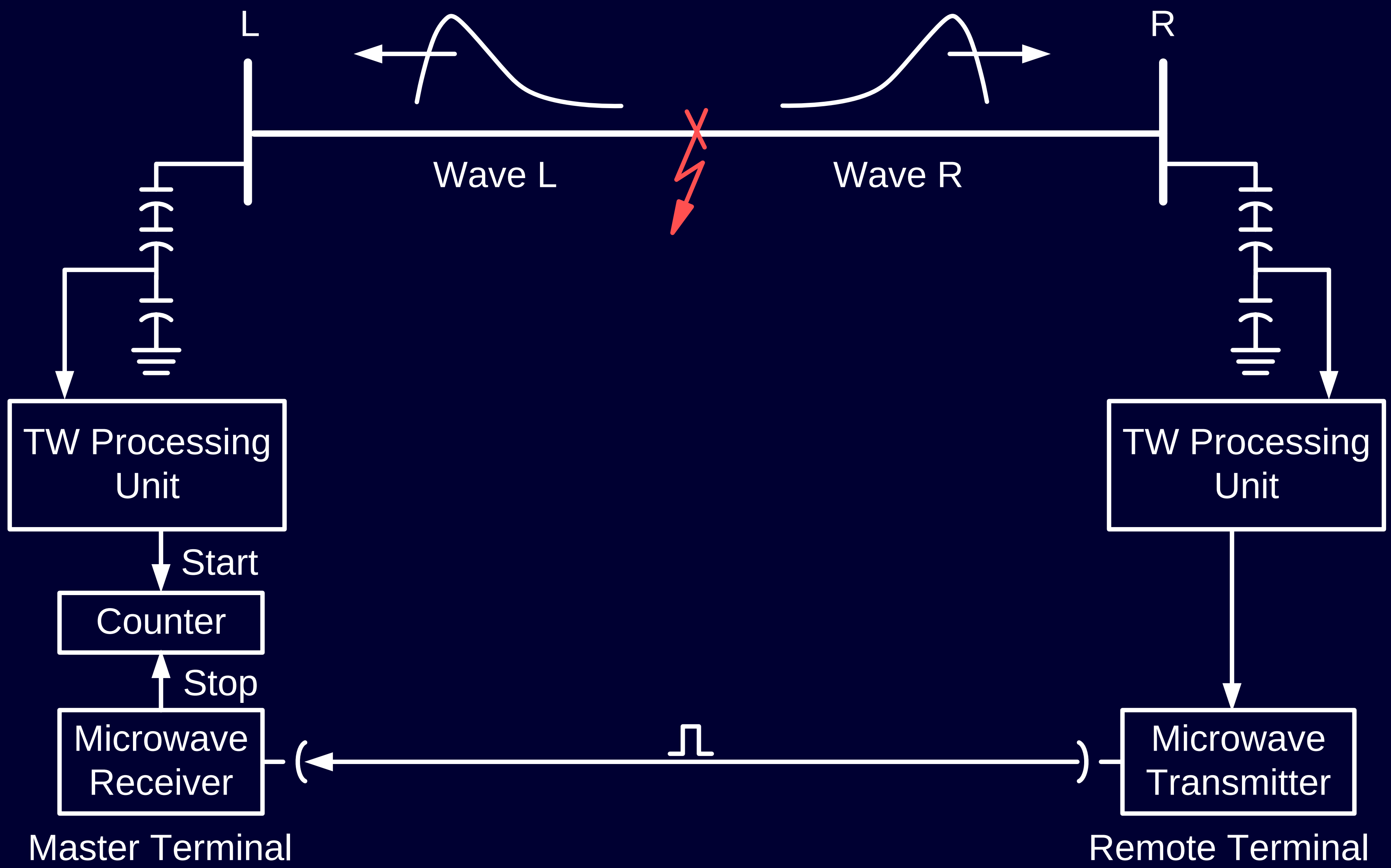
- “Free” and proven in distance relays today.
- No communications required.
- Helps find problems with line constants, connections, and grounding.
- Short faults: faster relays and breakers
- Series comp, mutual coupling, transposition
- CCVT accuracy and transient response
- Need voltages and currents

Lightning and Faults Launch Traveling Waves

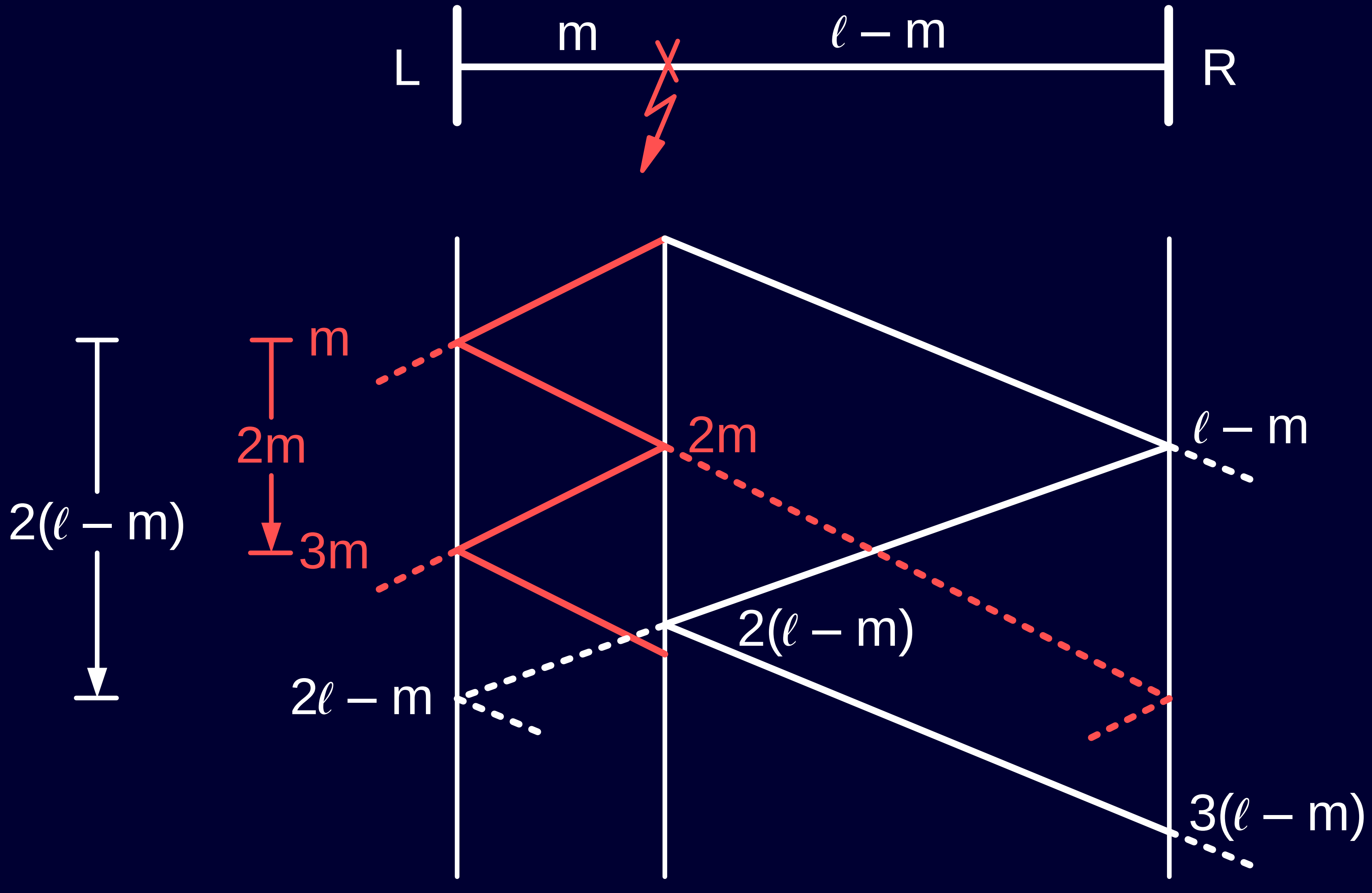


$$m = \frac{1}{2}\left[\ell + \left(t_L - t_R\right)v\right]$$

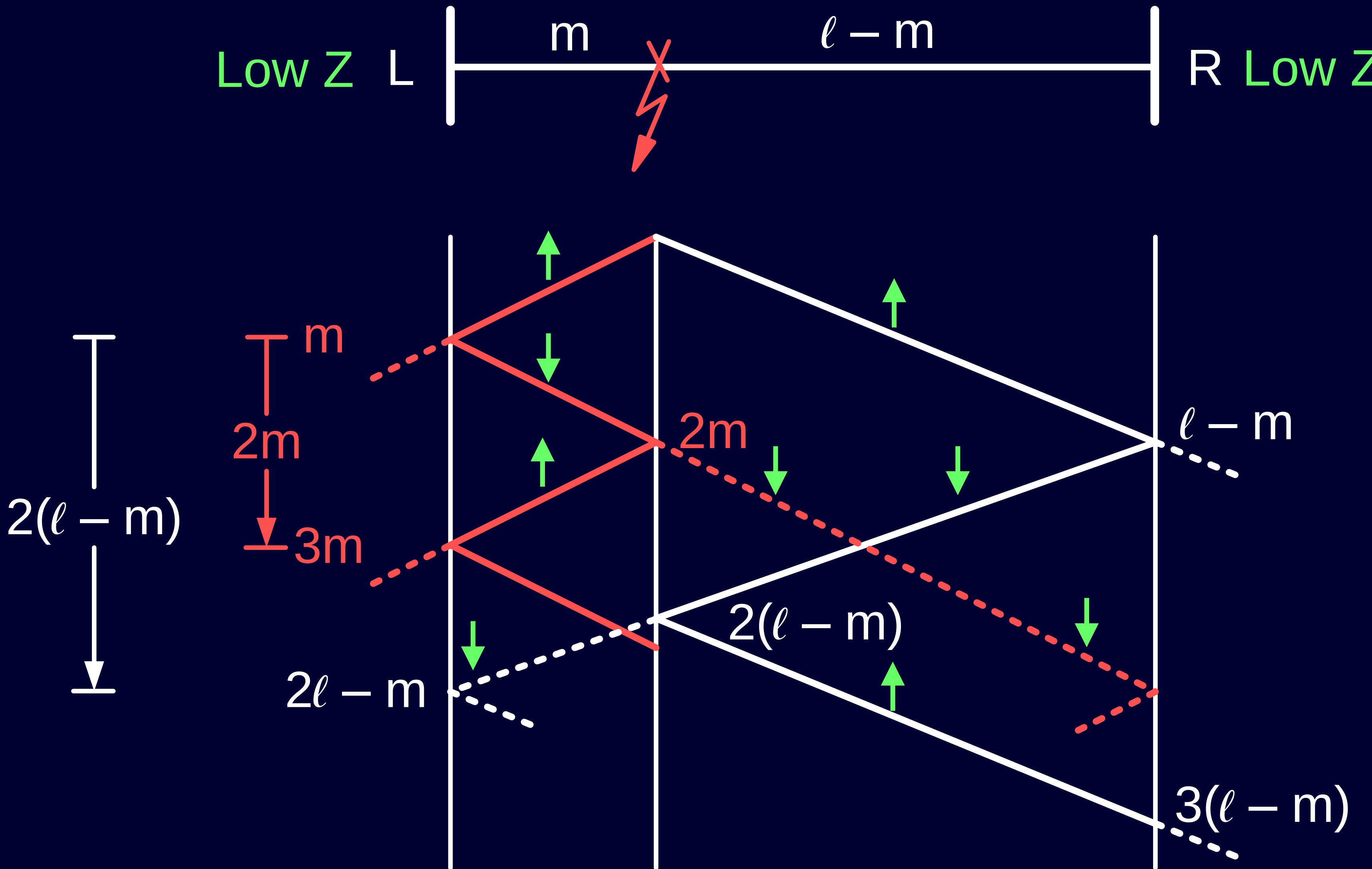
Automatic Fault Locator (BPA, 1972)



Single-End TW DC Fault Locator



Polarity of Voltage Waves



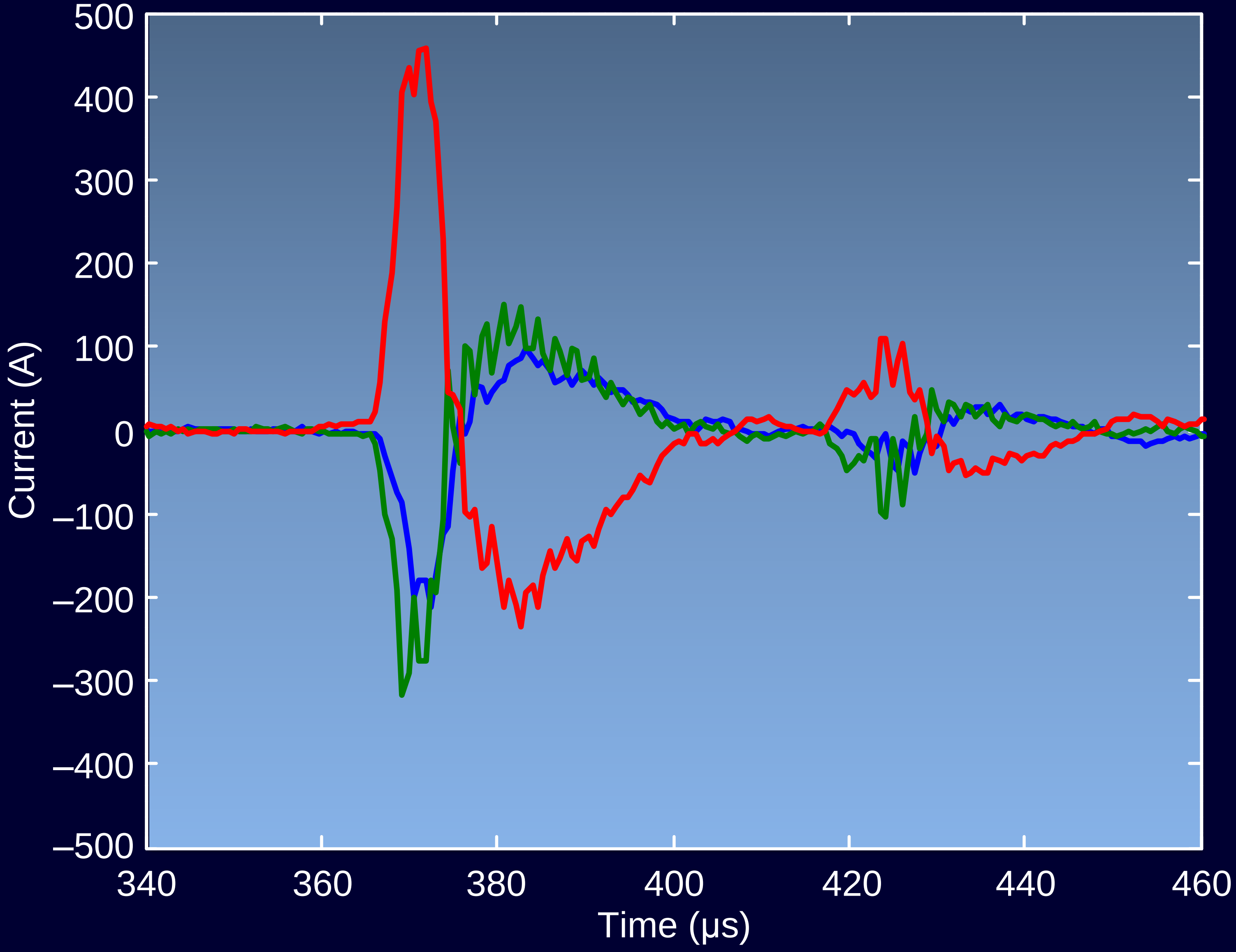
Practical Considerations

- Forming v_I, v_R uses all the information (v and i)
- That helps sort out reflected, transmitted waves
- CTs are pretty “hi-fi” for transients: over 100 kHz
- CCVTs are not, except at the capacitive voltage divider tap, but that means new cabling
- Use currents and two-end method
- Perfect in current differential relays
- Re-use same communications channel

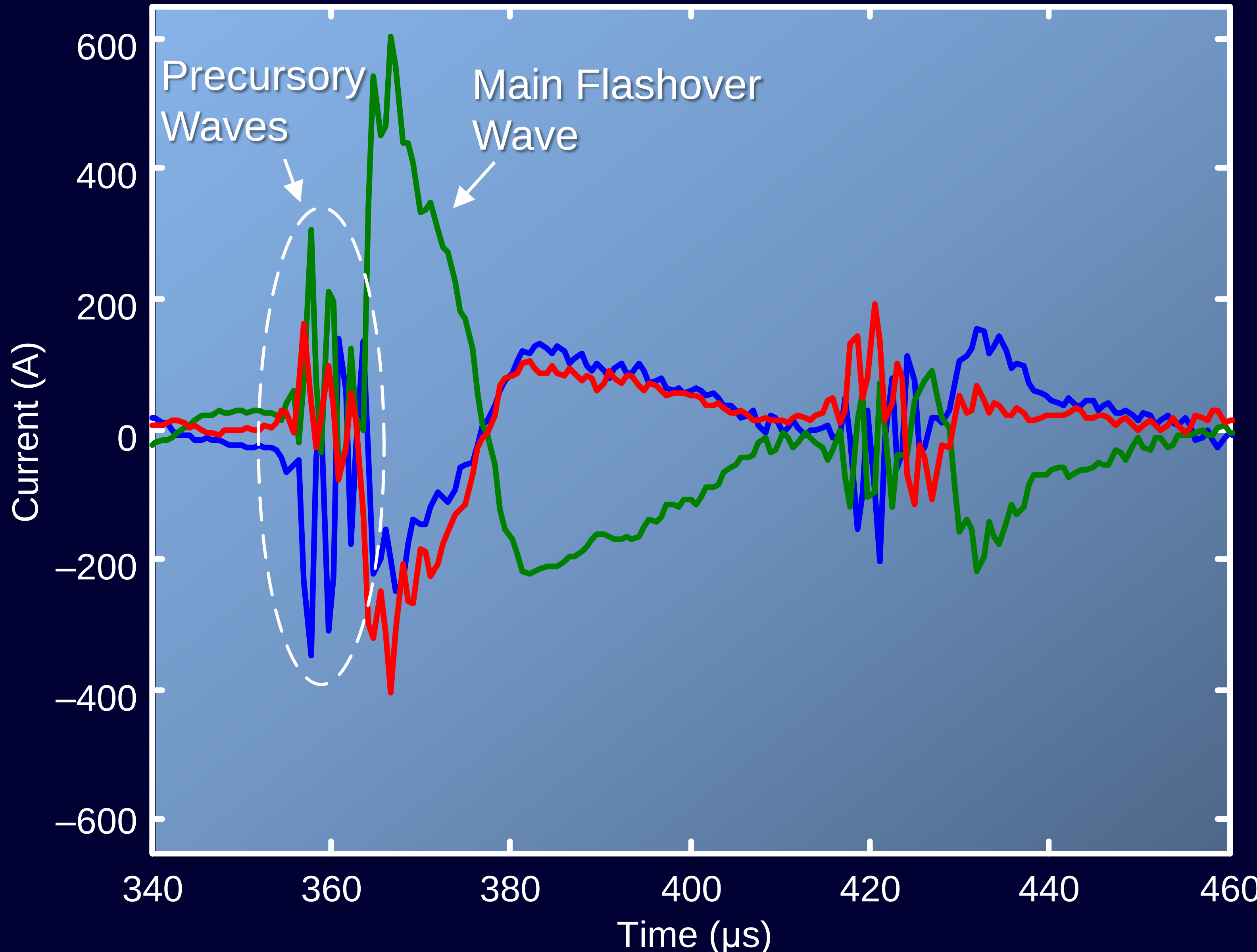
Nature of Traveling Waves

- Lightning surges coupling onto line
- Wave launched by fault
- Reflections from discontinuities
- “Messy” electrical breakdown
- Can’t expect “textbook” waveshapes

Clean Breakdown: CG Fault



Precursory Waves: Shield Coupling??



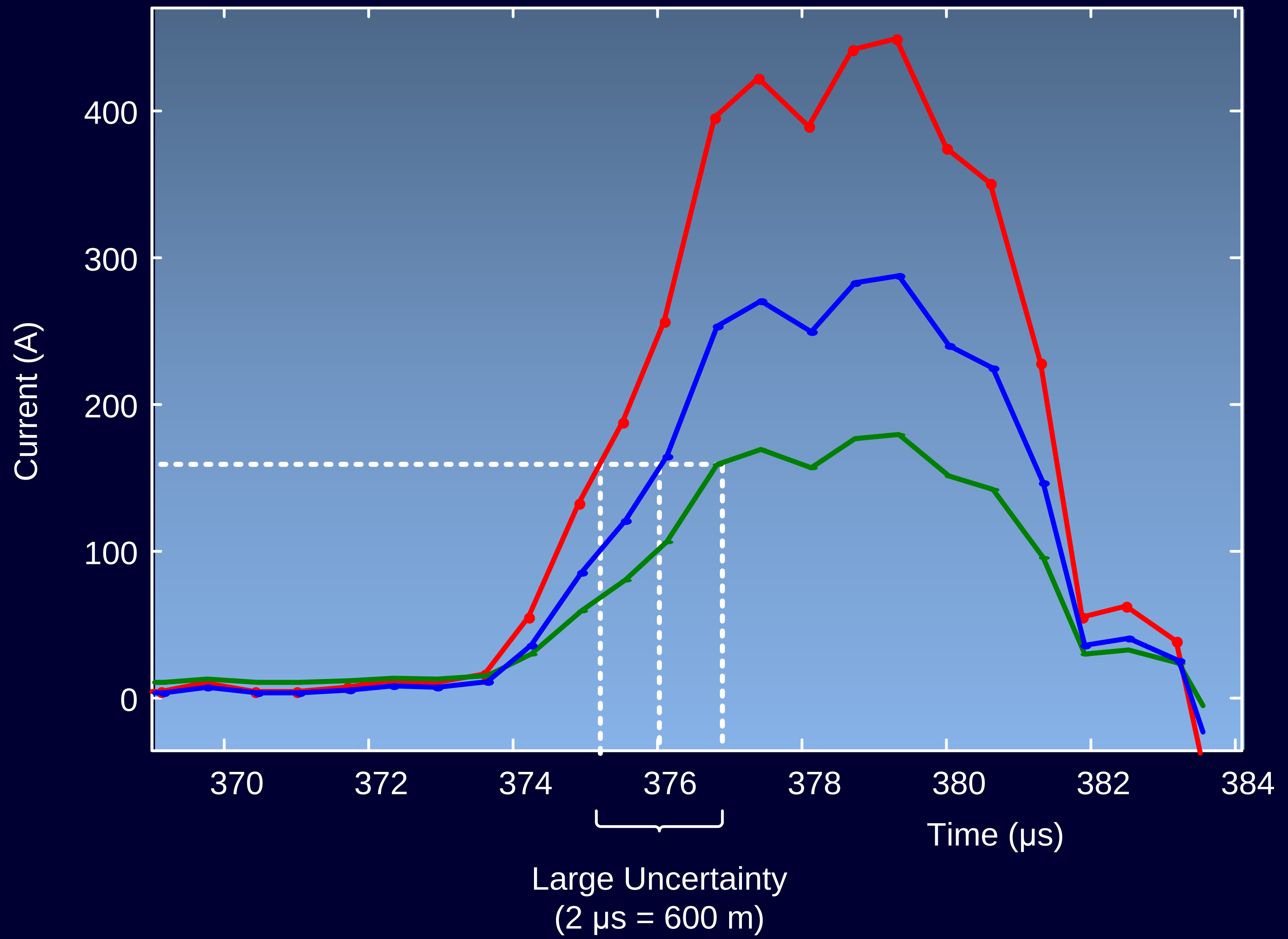
TW Fault Locator Design Concept

- Filter and sample currents
- Isolate desired mode
- Accurately measure time of arrival
- Exchange with other end, over same 87L channel
- Calculate location using two-end equation
- Save data

Accurately Measure Time of Arrival

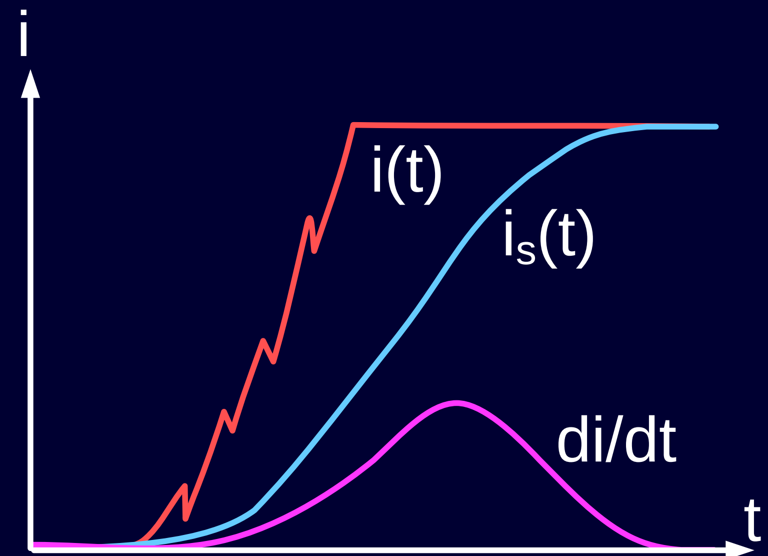
- Surges travel at “speed of light”
  11″/ns   6 μs/mile
- 50′ resolution => 100 ns
- Waveforms are irregular
- CT bandwidth ≈ 100 kHz
- Fortunately, the signals are BIG!
- Get absolute time from GPS or terrestrial network

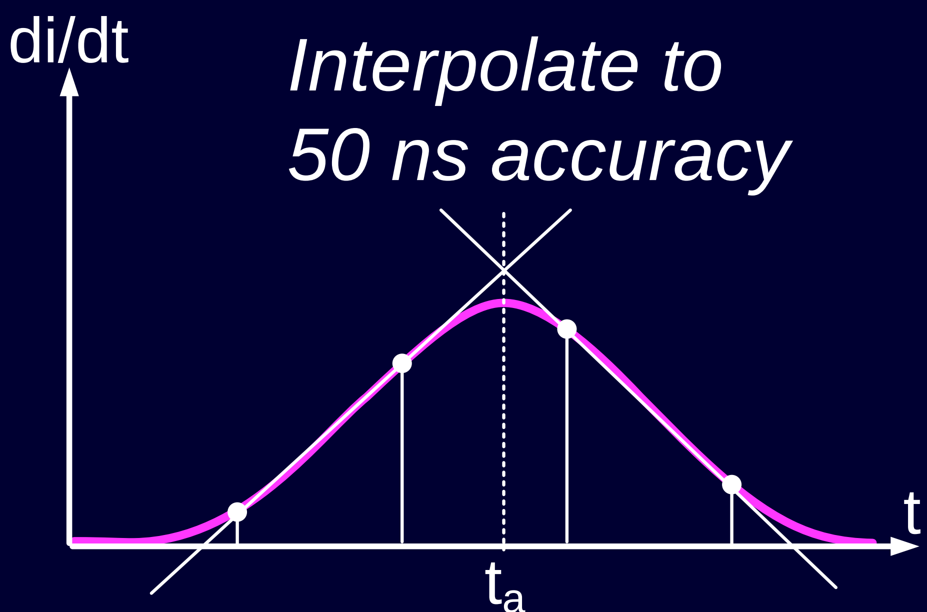
Simple Threshold Won't Work



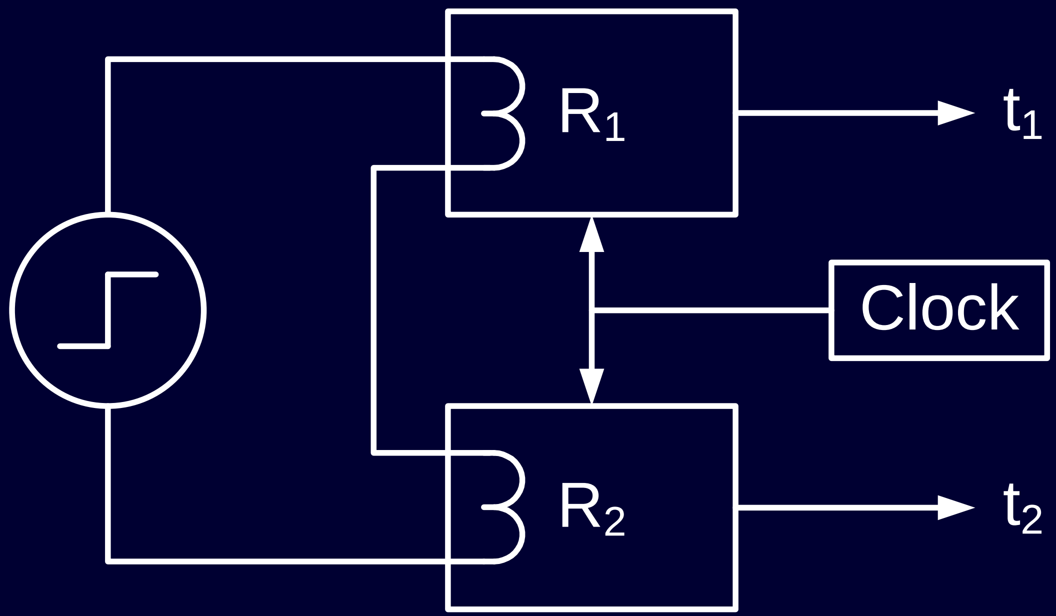
Differentiator-Smoother Works Great

Borrowed Idea From “Leading Edge Tracking”





Relative Accuracy ~ 50 ns

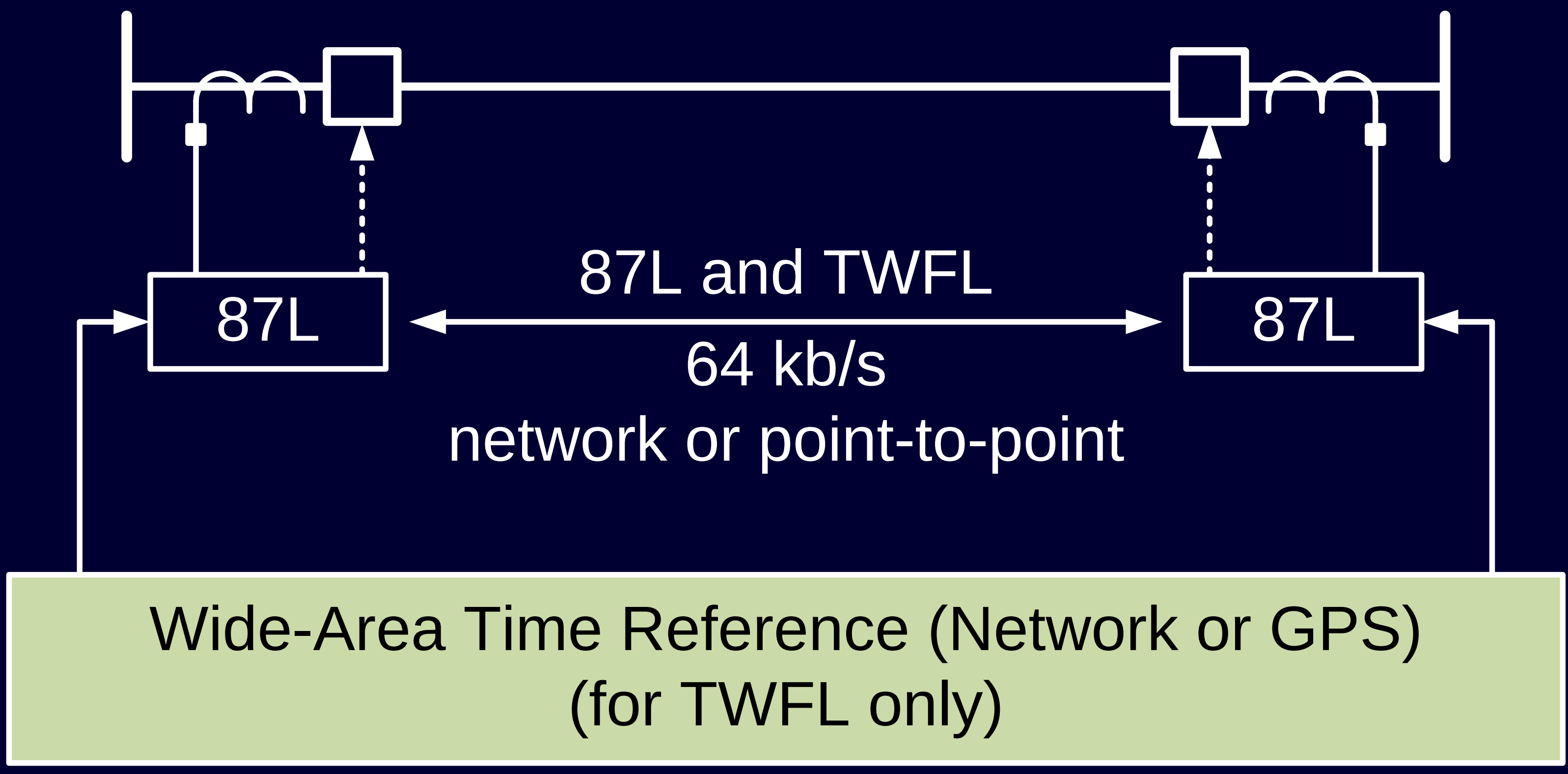


$\Delta t = t_1 - t_2$

Mean Error = 17 ns or 8′

Standard Deviation = 32 ns or 16′

87L and TWFL Share 64 kb/s Channel



BPA Experience on 117.11km 161kV Line

Line Energization (remote end open)

$$t = 790.605\ \mu\text{s} \quad \text{round trip}$$

$$\ell = 117.11\,\text{km}$$

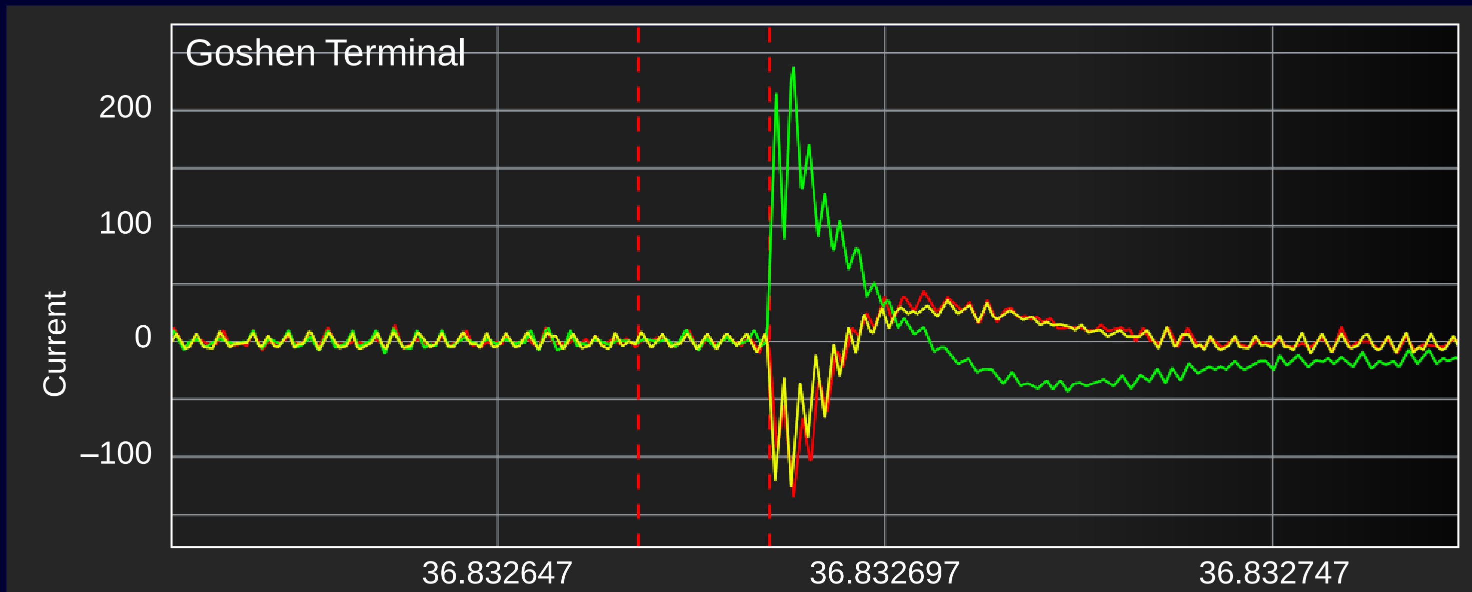
$$v = \frac{(2)117.11}{790.605} = 296259.1\,\text{km/s}$$

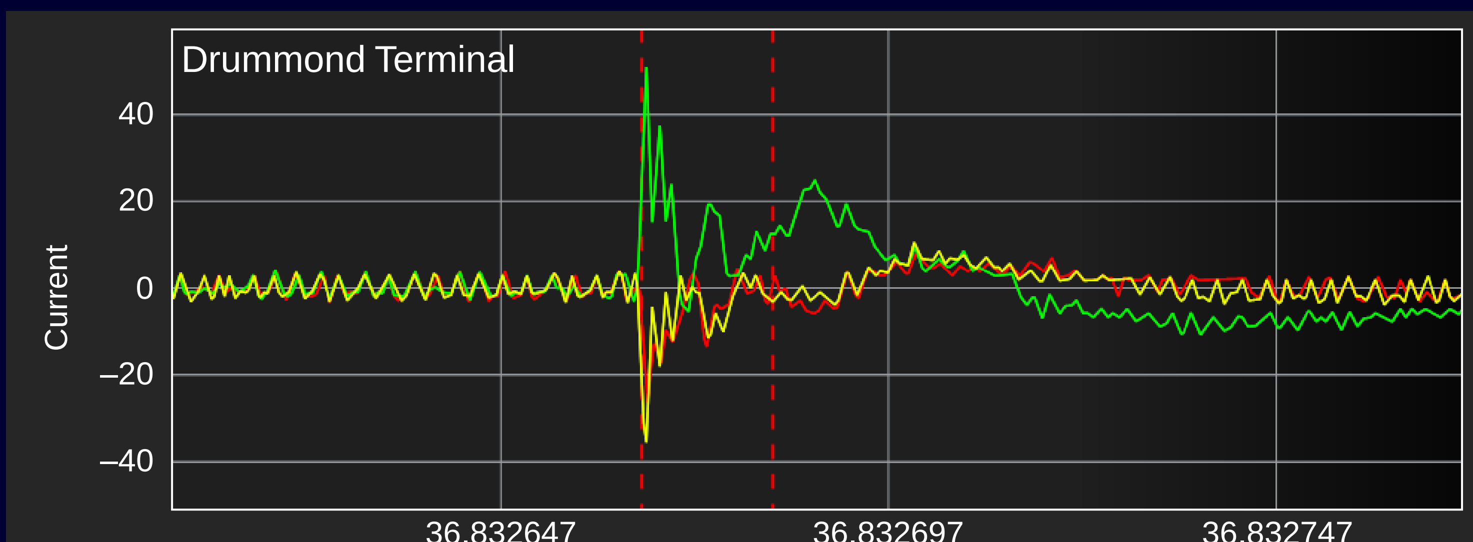
$$c = 299792\ \text{km/s}$$

$$v = 0.98821\,c$$

Gunshot

Phase Currents at Goshen and Drummond





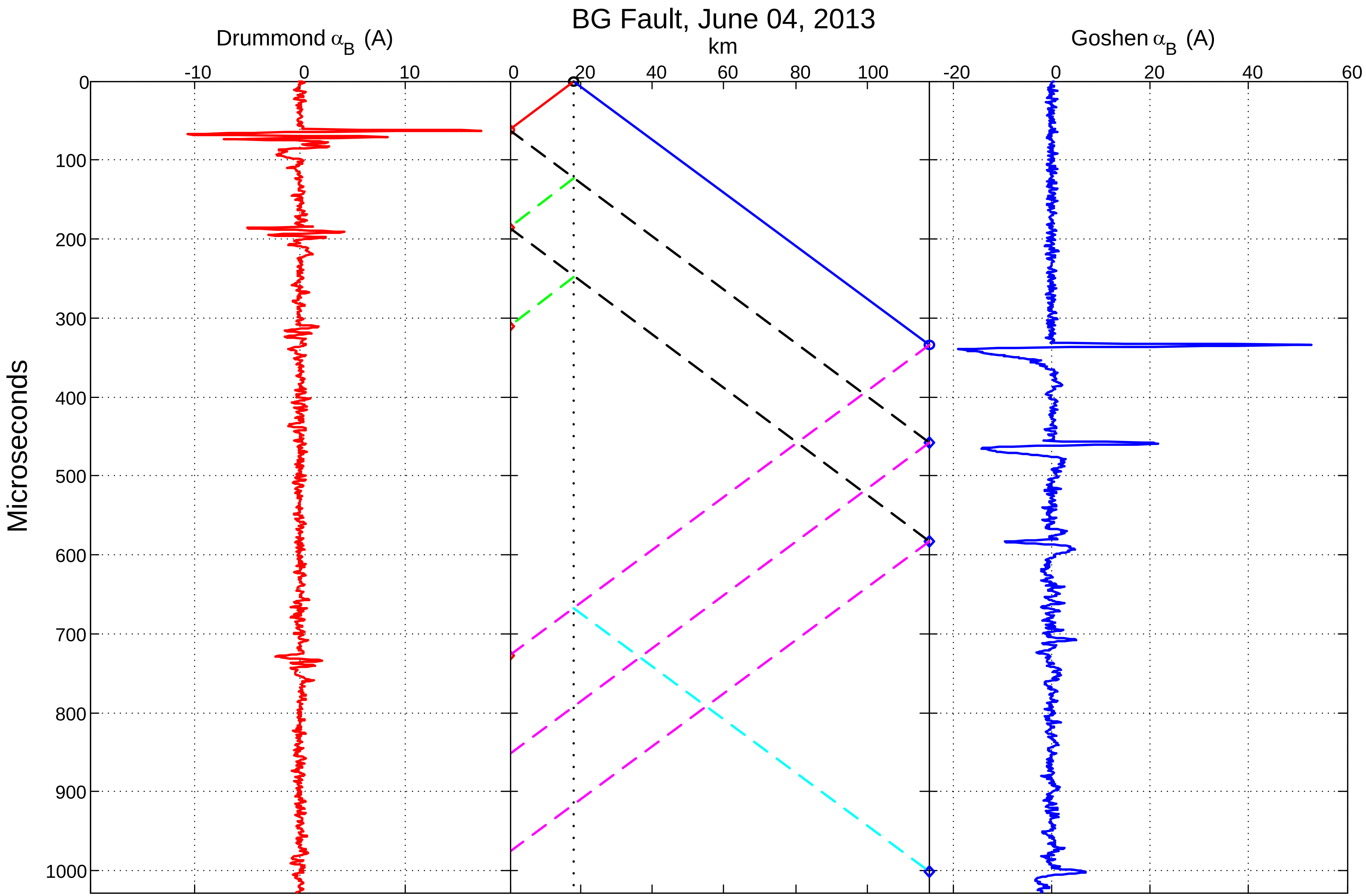
Traveling Wave vs Line Patrol

Goshen – Drummond Line

Fault	TW	Patrol	Difference
CG	109.74 km	109.29 km	0.45 km
BG	61.12	61.41	– 0.29
BG	108.23	107.60	0.63
BG	***98.85***	***98.98***	***– 0.13***
BG	95.02	95.02	0.00

BG Fault Located at 62/10…Irrigation

Currents and Bewley Lattice Diagram



How Do Timing, Speed, and Length Affect Fault Locating?

$$m = \frac{1}{2}\left[\ell + v\left(t_L - t_R\right)\right]$$

Introduce variances for time, speed, length

$$\sigma_m = \frac{1}{2}\left[\sigma_\ell + \sigma_V\left(t_L - t_R\right) + v\left(\sigma_{tL} + \sigma_{tR}\right)\right]$$

Length Velocity Timing

Summary of Typical Errors

Relay Error	50 ns	25′
Timing (clock)	50 ns	25′
Line Length	(0.1% of 100 mi)	500′
Speed	0.05%	250′
Allowance for other errors		250′

…on the order of one span

Excellent Accuracy

- Fits “hand-in-glove” into differential relay.
- Easy to set up and use.
- Not affected by series caps, mutual coupling, or very fast clearing.
- Complements impedance methods.
- Adds to our understanding of lines.