SCHWEITZER ENGINEERING LABORATORIES

MEPS 2010, keynote presentation

Advancements in Line Current Differential Protection

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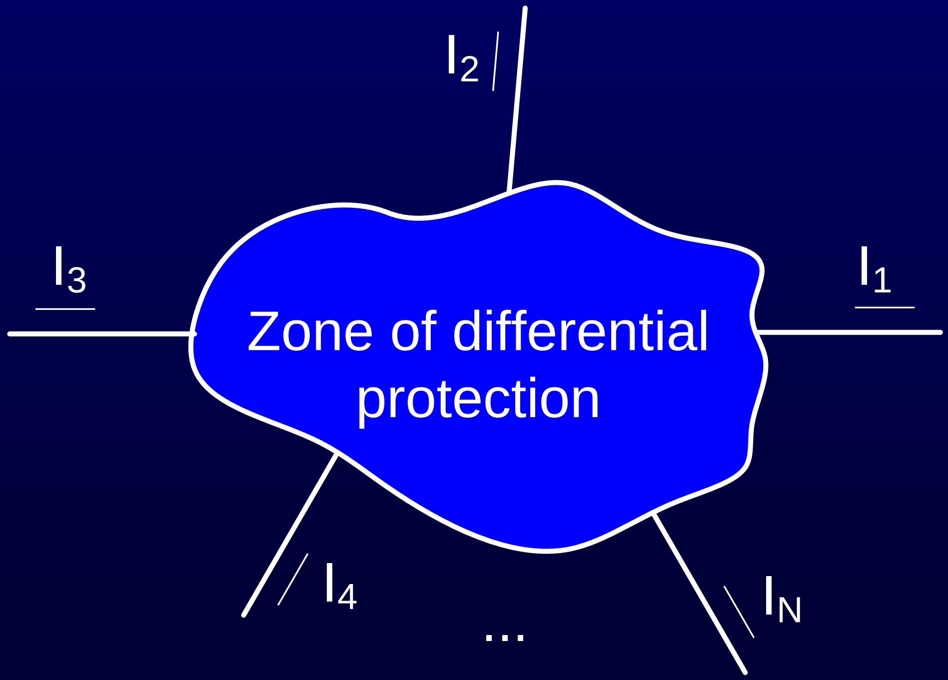
Schweitzer Engineering Laboratories, Inc.

Making Electric Power Safer, More Reliable, and More Economical®

Current Differential Protection



$I_1 + I_2 + I_3 + I_4 + \ldots + I_N \approx 0 \rightarrow$ no fault

$I_1 + I_2 + I_3 + I_4 + \ldots + I_N \neq 0 \rightarrow$ fault

Traditional issues:

- Speed
- CT saturation
- CT trouble

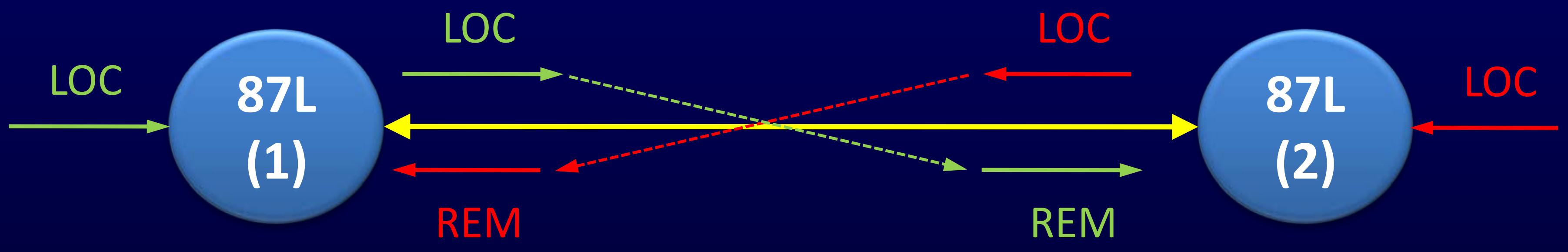
Line Current Differential Protection

New issues due to the physical dimension:

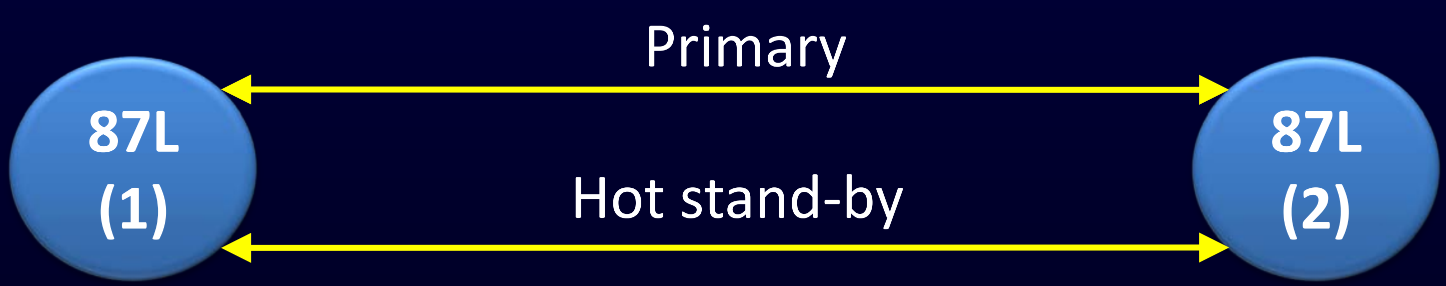
- Distributed scheme
- Need wide-area communications
- Need to align the currents
- Channel availability and misbehavior
- Time sources, if used
- Line charging current and reactors
- High resistive faults and sensitivity

Two-terminal applications

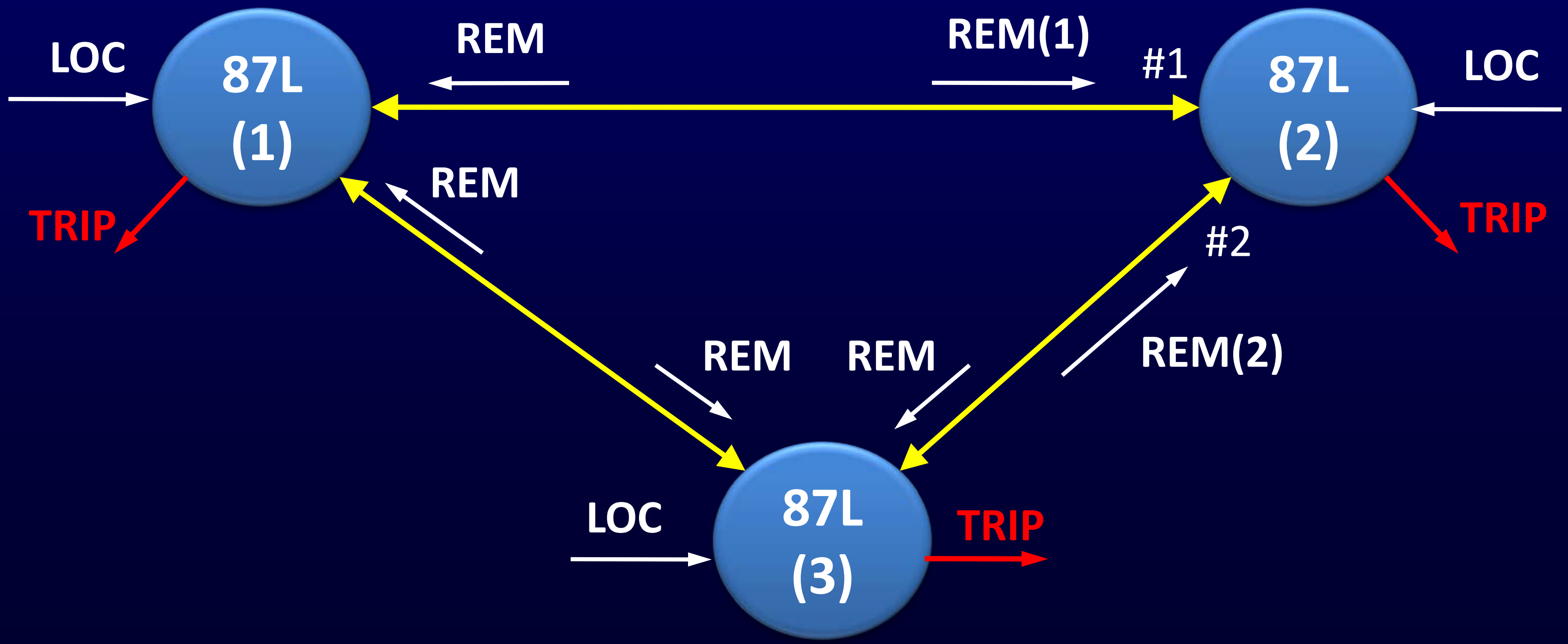
Single-channel application



Dual-channel application



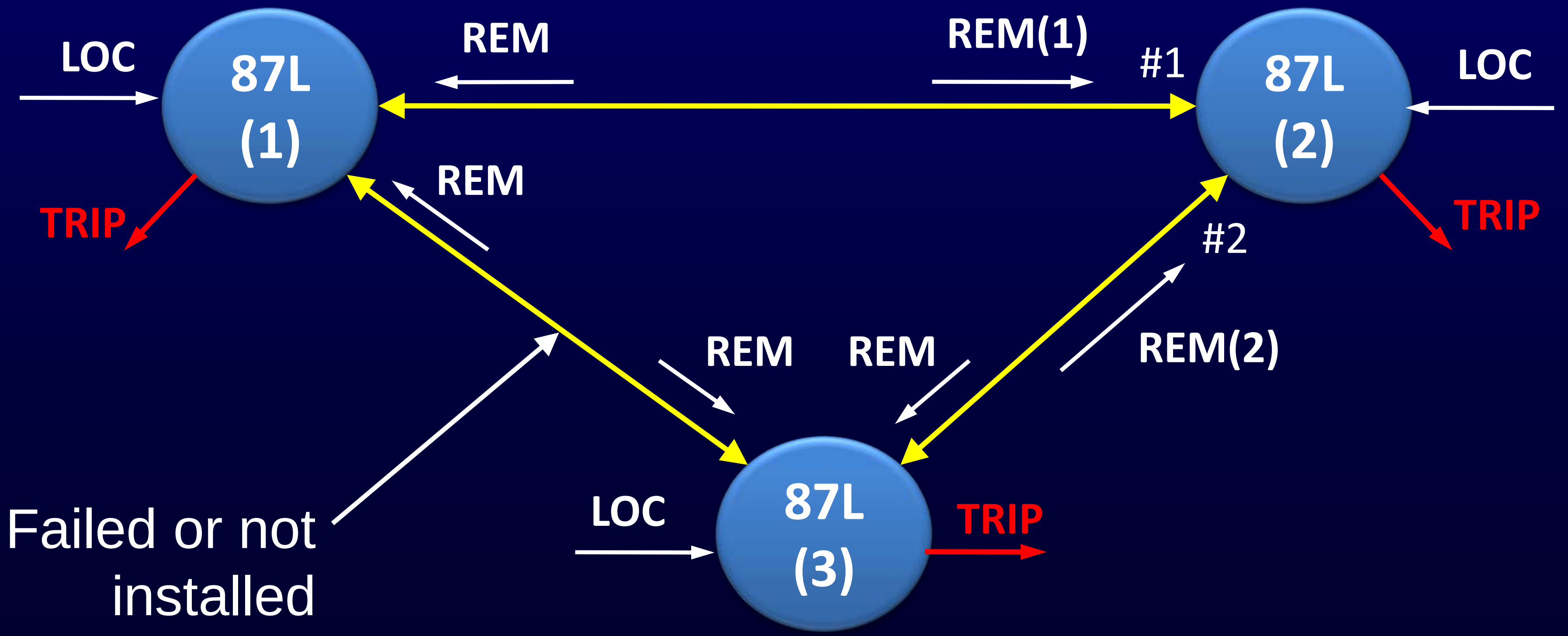
Three-terminal applications



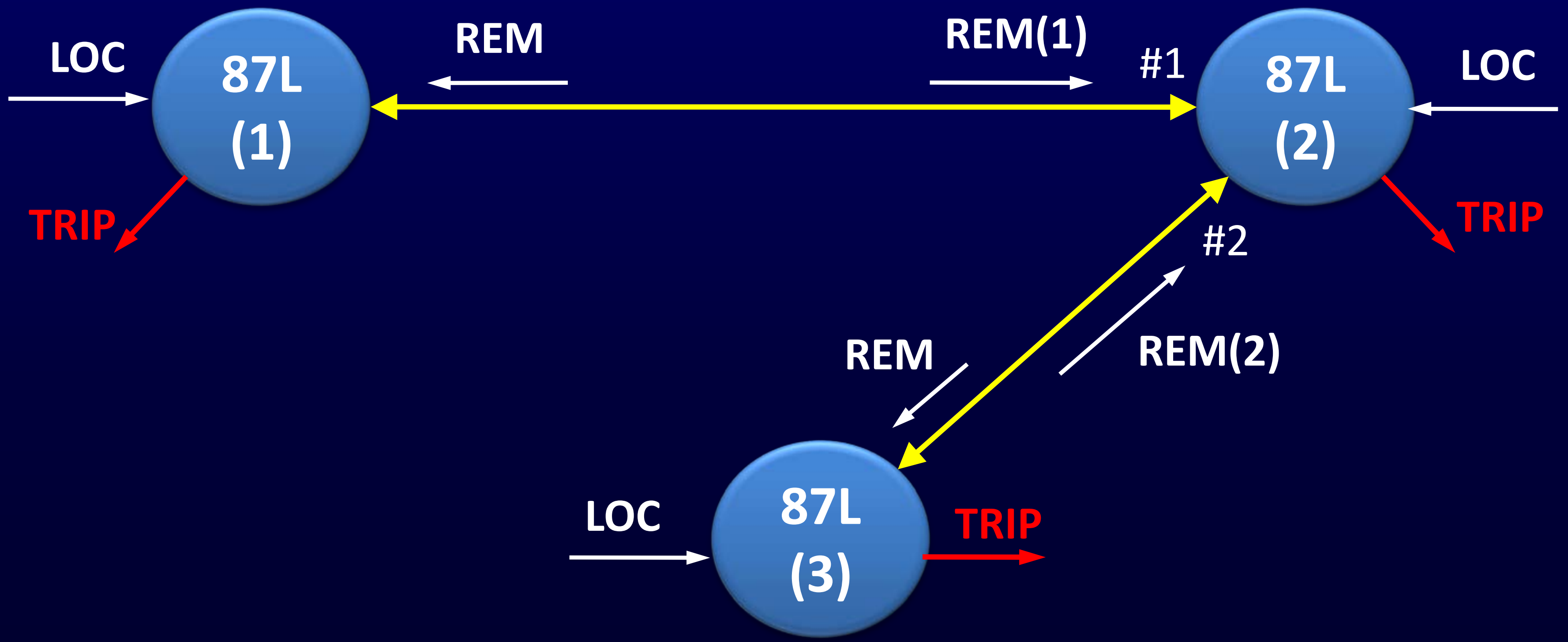
All relays are “masters”

- receive all remote currents
- run the 87L elements
- trip from the differential current

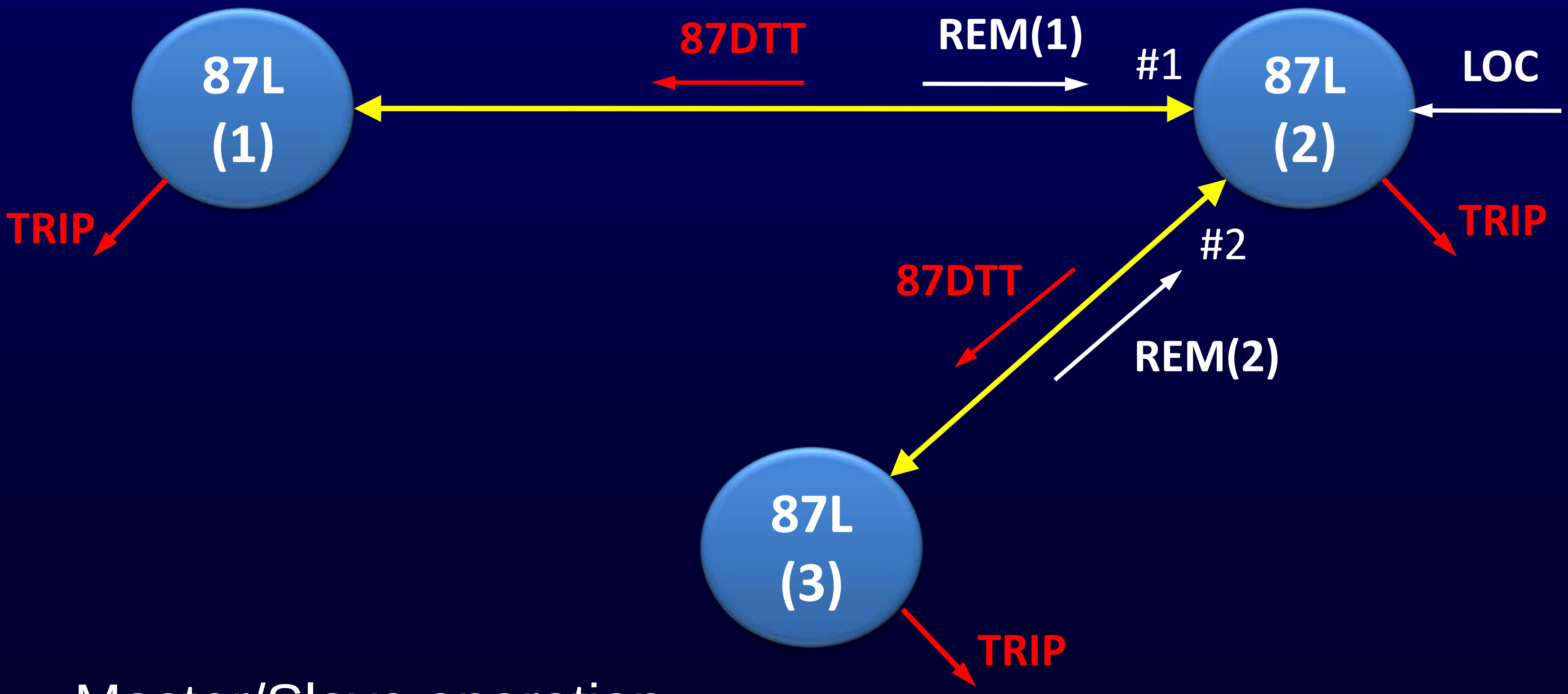
Master vs. Slave operation



Master vs. Slave operation



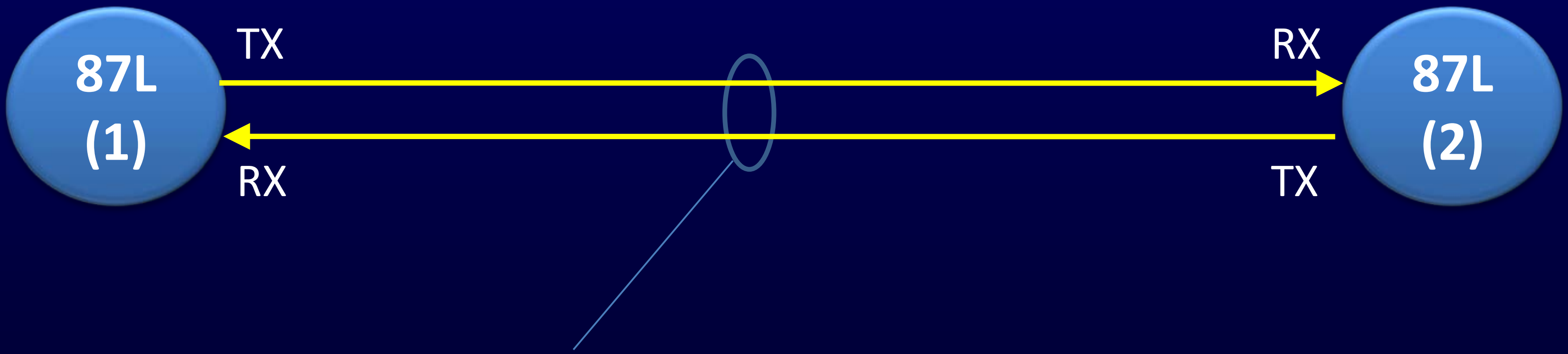
Master vs. Slave operation



Master/Slave operation

- 87L (2) is a “master”
- 87L (1) and (3) are “slaves”
- Slaves serve the currents and trip via 87DTT

Point-to-point channel



(+) Fiber-based due to distance requirements

(+) Dedicated and deterministic, only 87L data

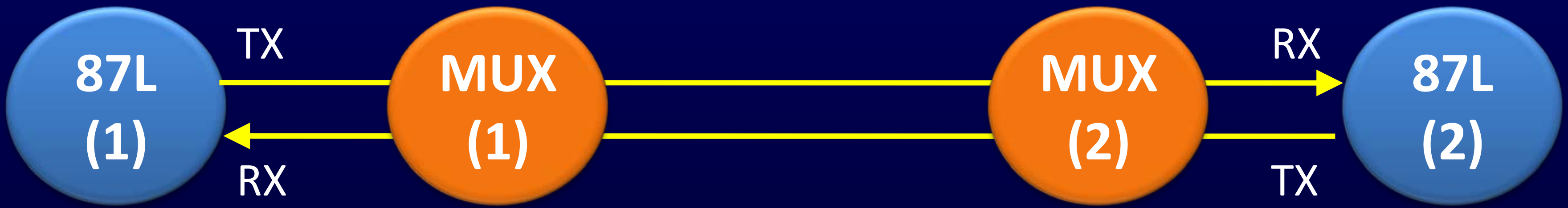
(+) Symmetrical, 1→2 and 2→1 delays equal

(+) Passive, no extra equipment involved

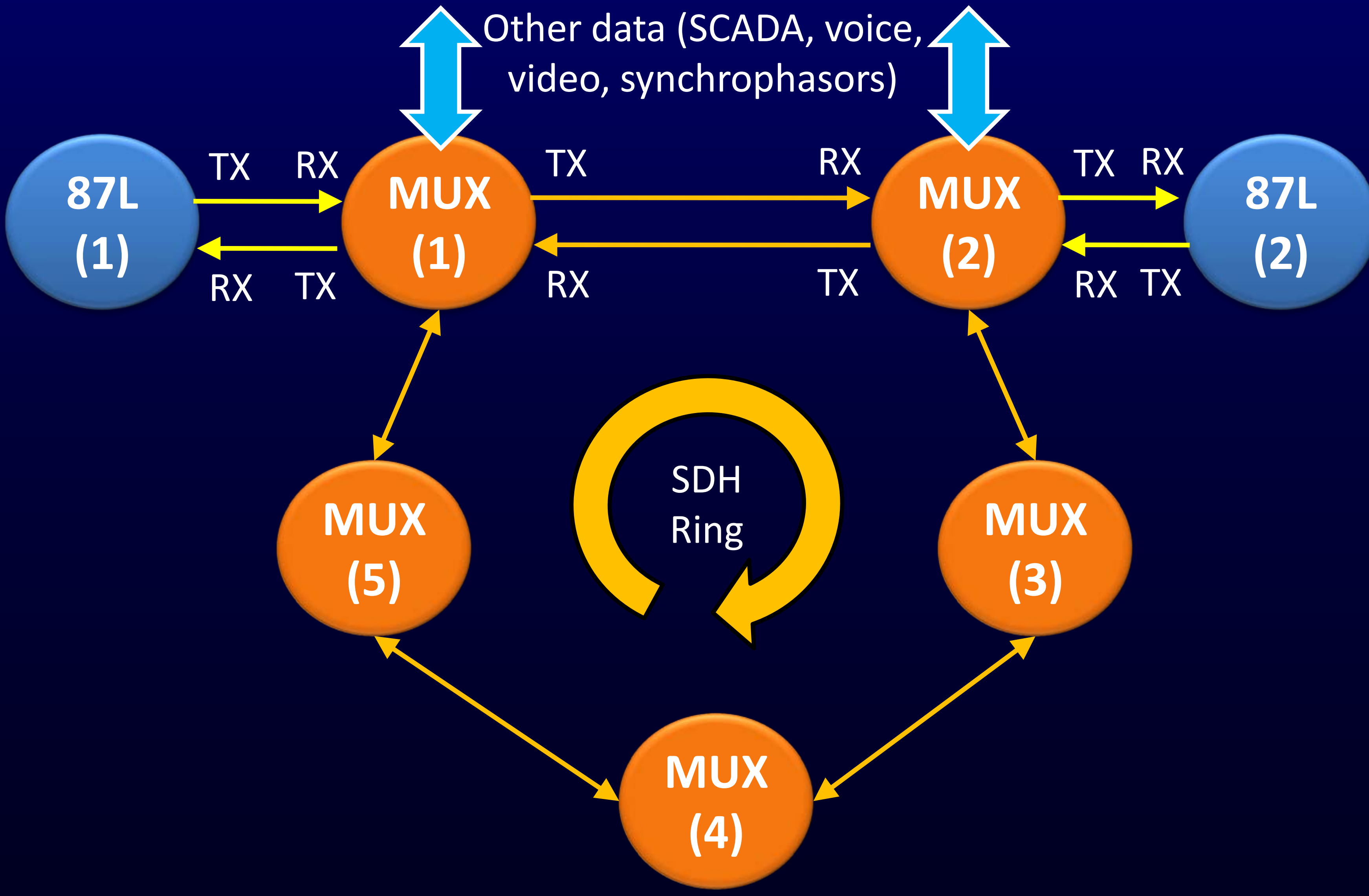
(–) No channel redundancy (re-routing)

(–) “Waste” of bandwidth, untapped opportunity

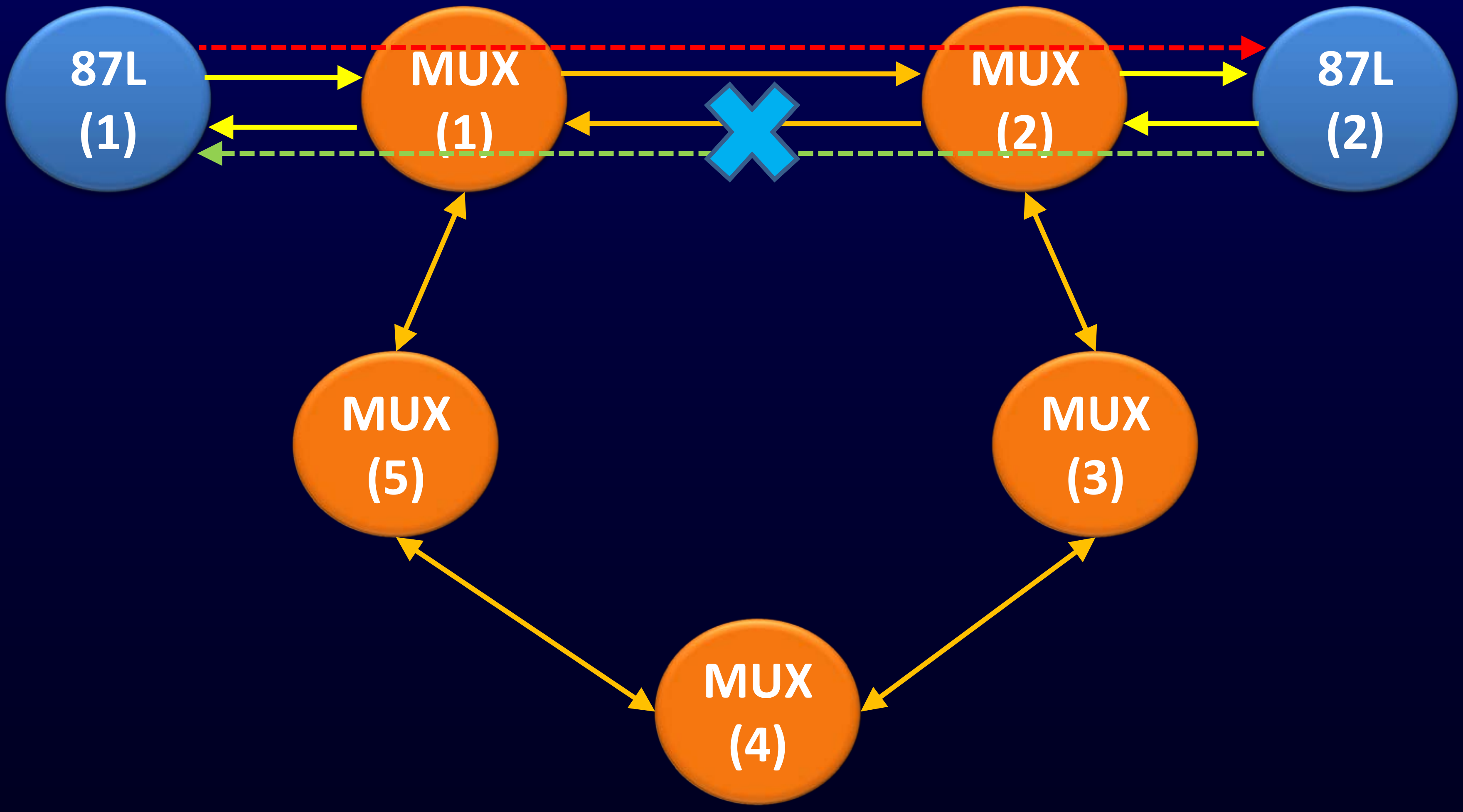
Multiplexed channel



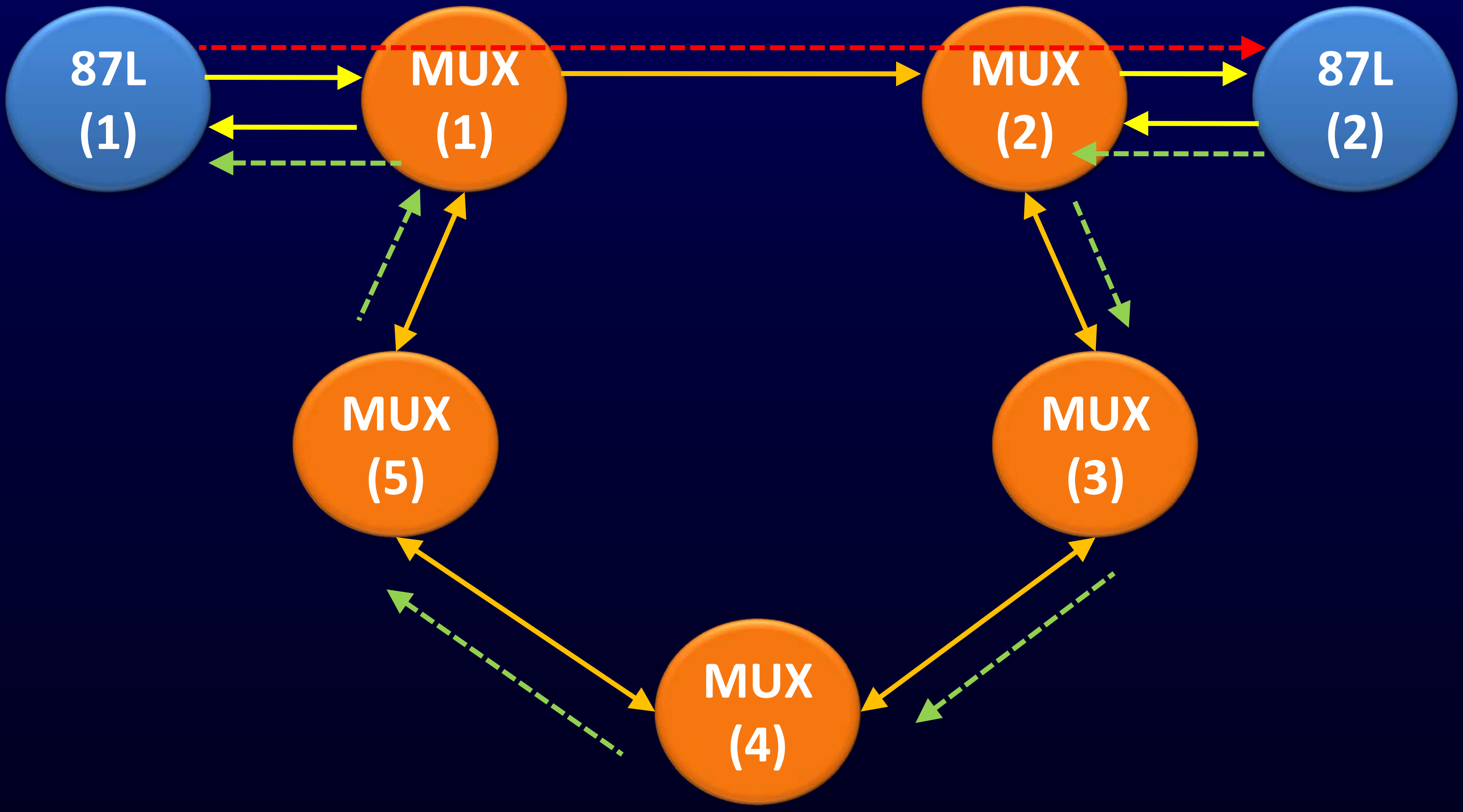
Multiplexed channel



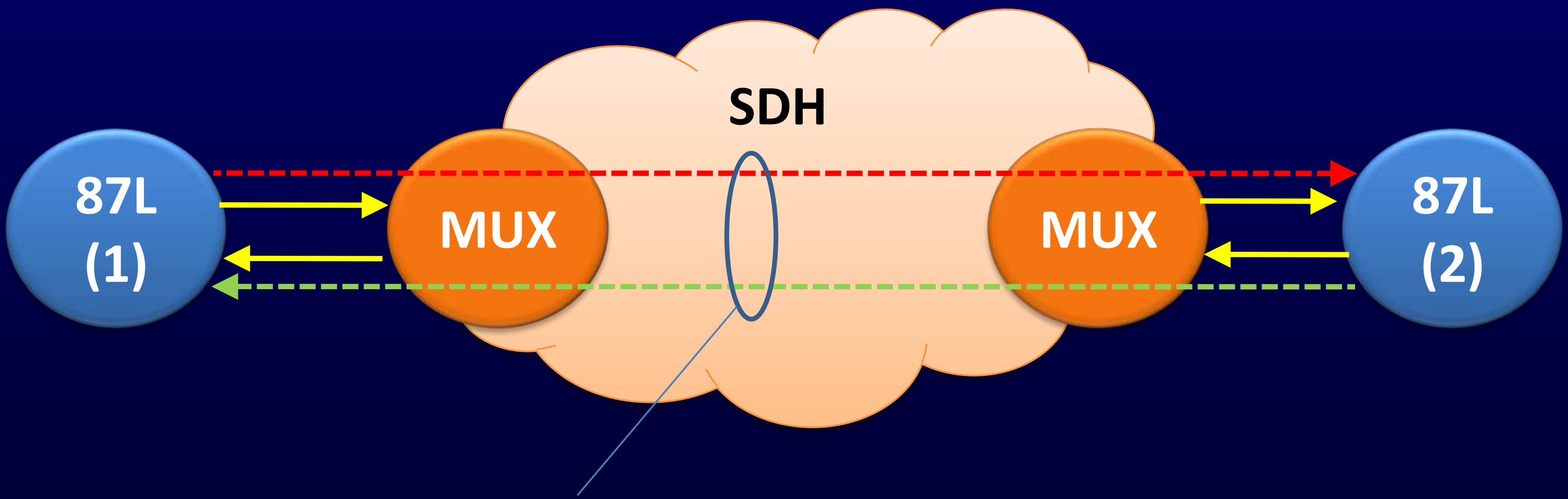
Path switching



Path switching



Multiplexed channel



(+) Channel redundancy (path switching)

(+) Shared data – no “waste” of bandwidth

(–) Active – extra equipment involved

(–) Can be asymmetrical, 1→2 and 2→1 delays may differ

(–) More complex

Challenges for data exchange

- **Power system security…**
  need to "see" all zone currents
- **Speed…**
  send packets often
- **Advanced applications…**
  instantaneous currents desired
- **64kbps channels…**
  allow only ~130bits at 8/packets cycle
  including ~50bits of overhead

Assume a 64kbps channel

- 64,000 bits per second =
- 1,067 bits in a 60Hz power cycle =
- 267 bits per quarter of a 60Hz cycle =
- 132 bits per 1/8th of a 60Hz cycle =
- 66 bits per 1/16th of a 60Hz cycle

Communications overhead

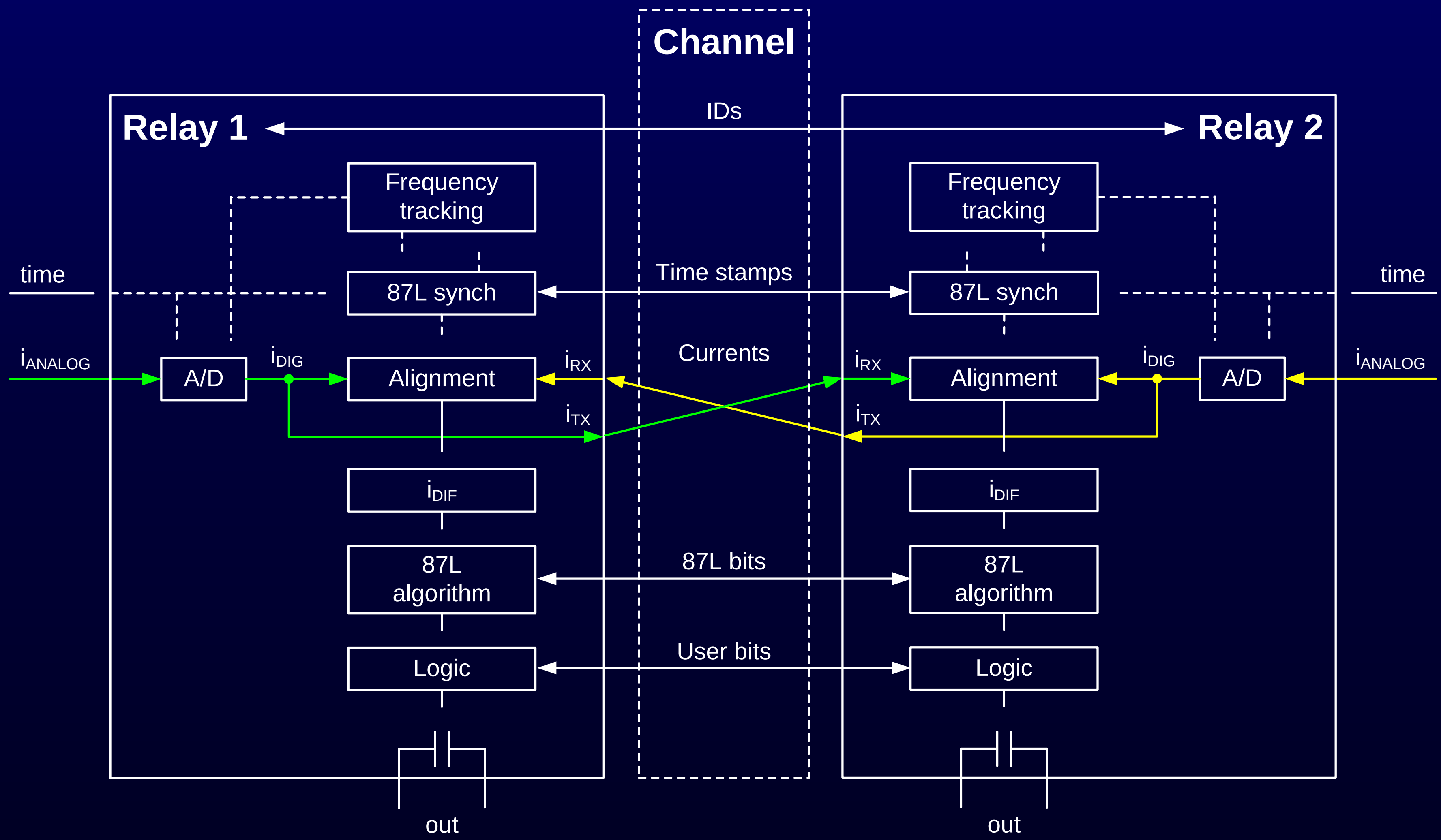
- A header to tell packets apart ~15 bits
- Data integrity check (BCH or CRC) ~32 bits
- Time stamps for synchronization ~16 bits
- Relay ID against cross-connection ~4 to 8 bits
- 87DTT, user bits and other flags ~4 to 8 bits

- TOTAL of overhead / packet ~50 - 80 bits
- Available at 8 packets a cycle 132 bits

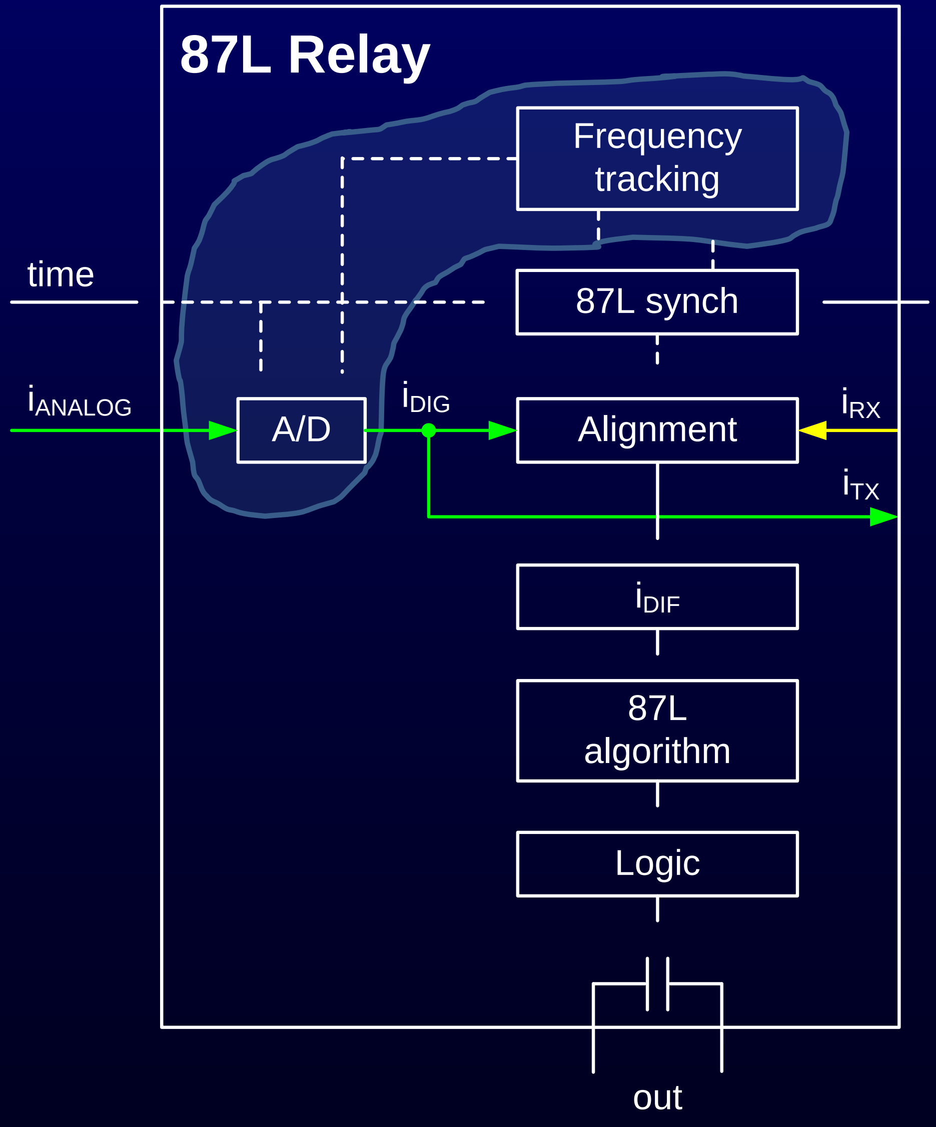
Solutions

- Send “smart” quantities
  - Do the protection job, and
  - Minimize the communication payload
- Improve payload-to-overhead ratio
- Optimum encoding
- Sending quantities at the right rates

Simplified 87L scheme diagram

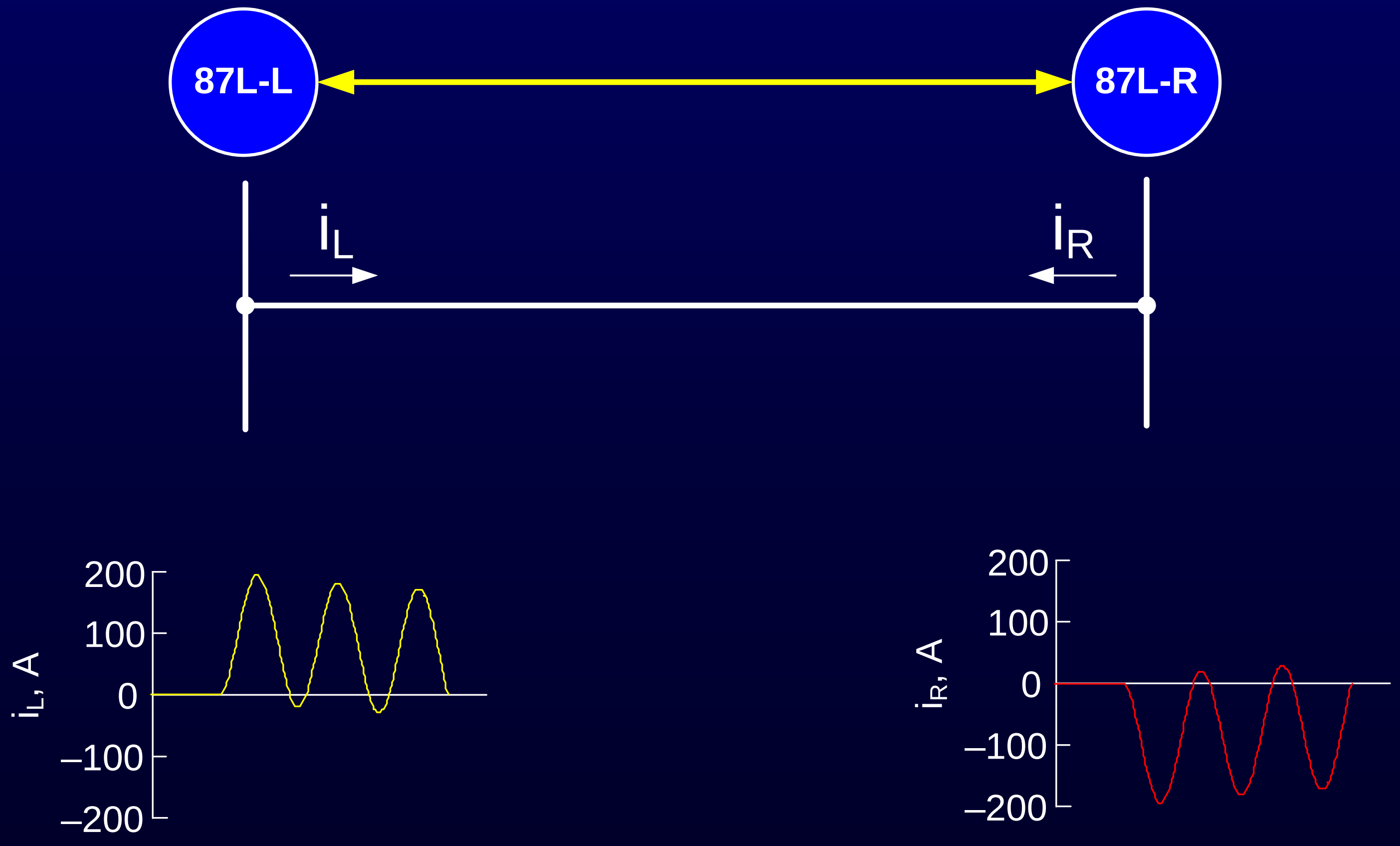


Sampling

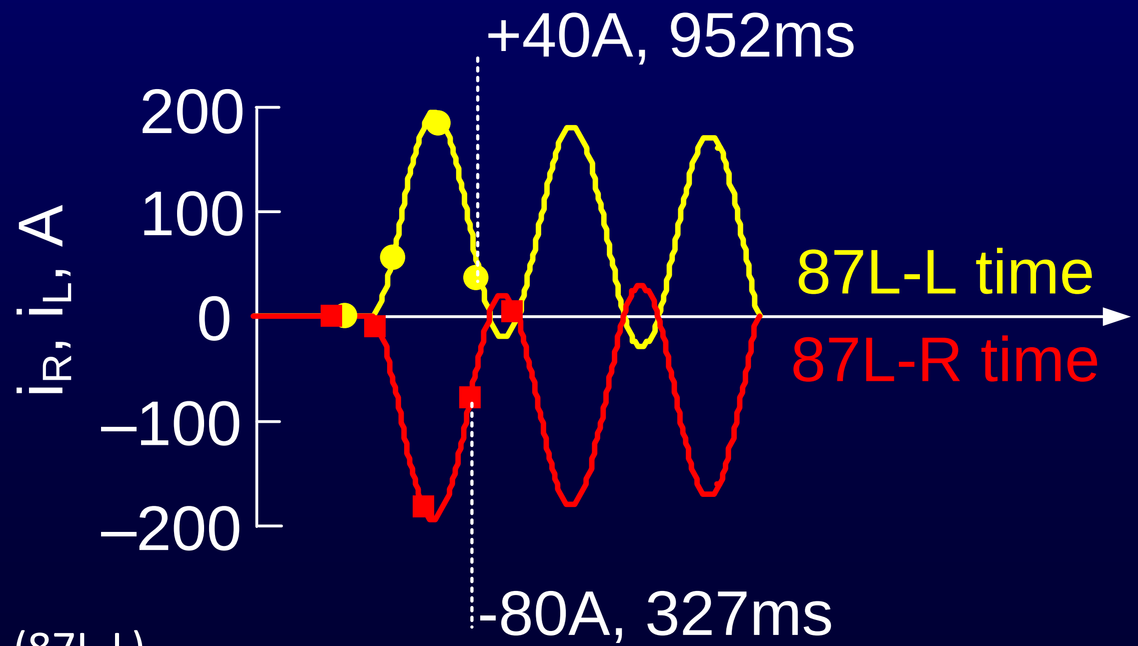


- Variable rate with frequency tracking
- Constant rate synchronous with time

Data synchronization and alignment



Data synchronization and alignment



Local samples (87L-L)

62A, 951ms
40A, 952ms
-20A, 953ms
-40A, 954ms
-80A, 955ms
-75A, 956ms

???

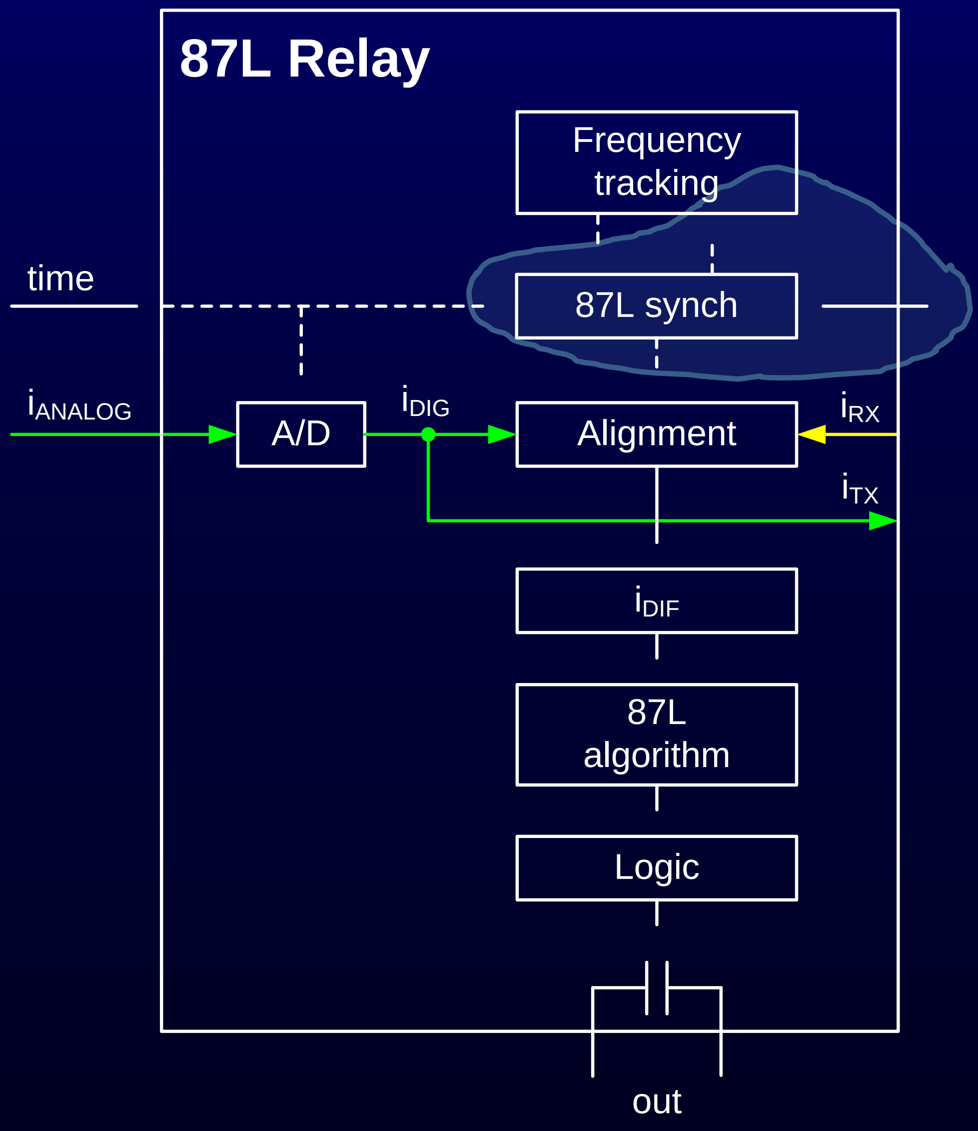
???

???

Received from 87L-R

-80A, 327ms

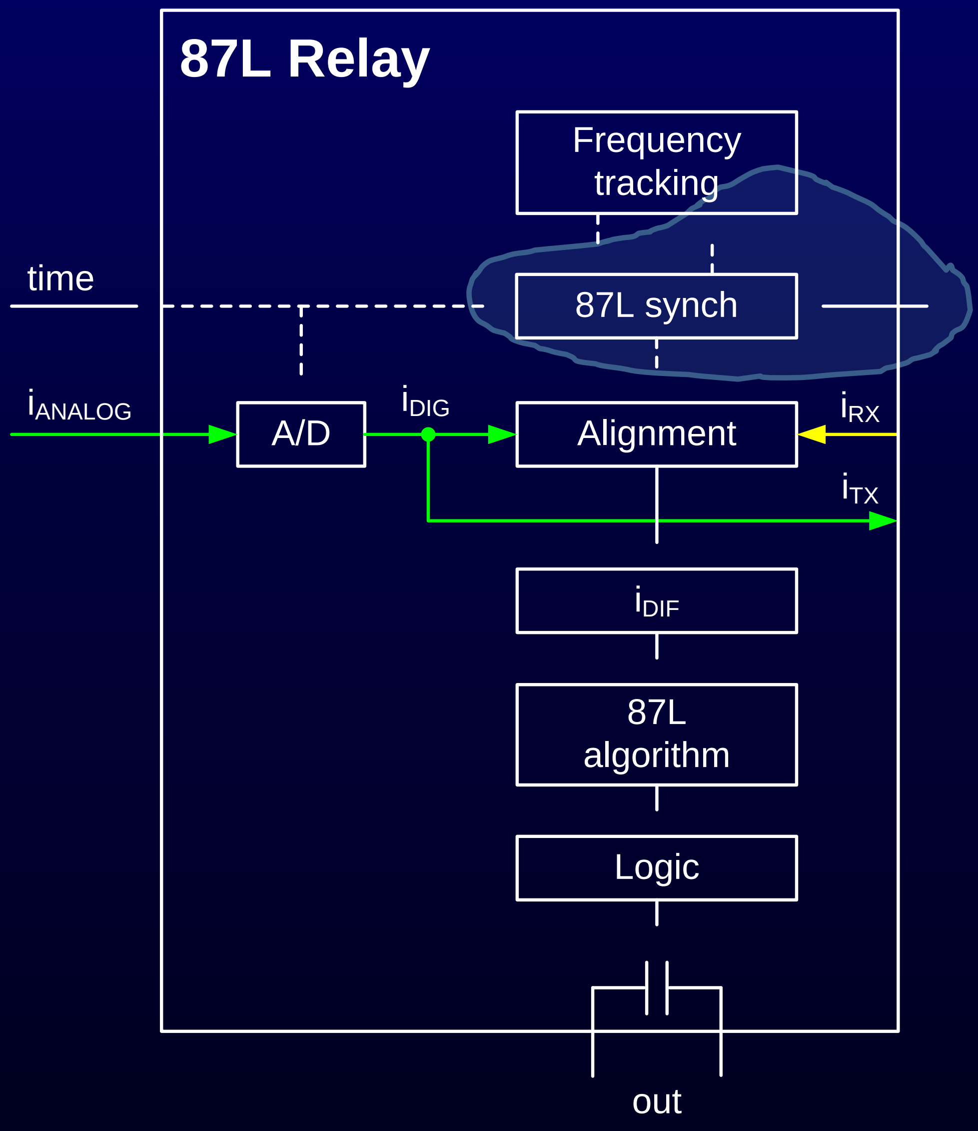
87L synchronization



Industry wide approach:

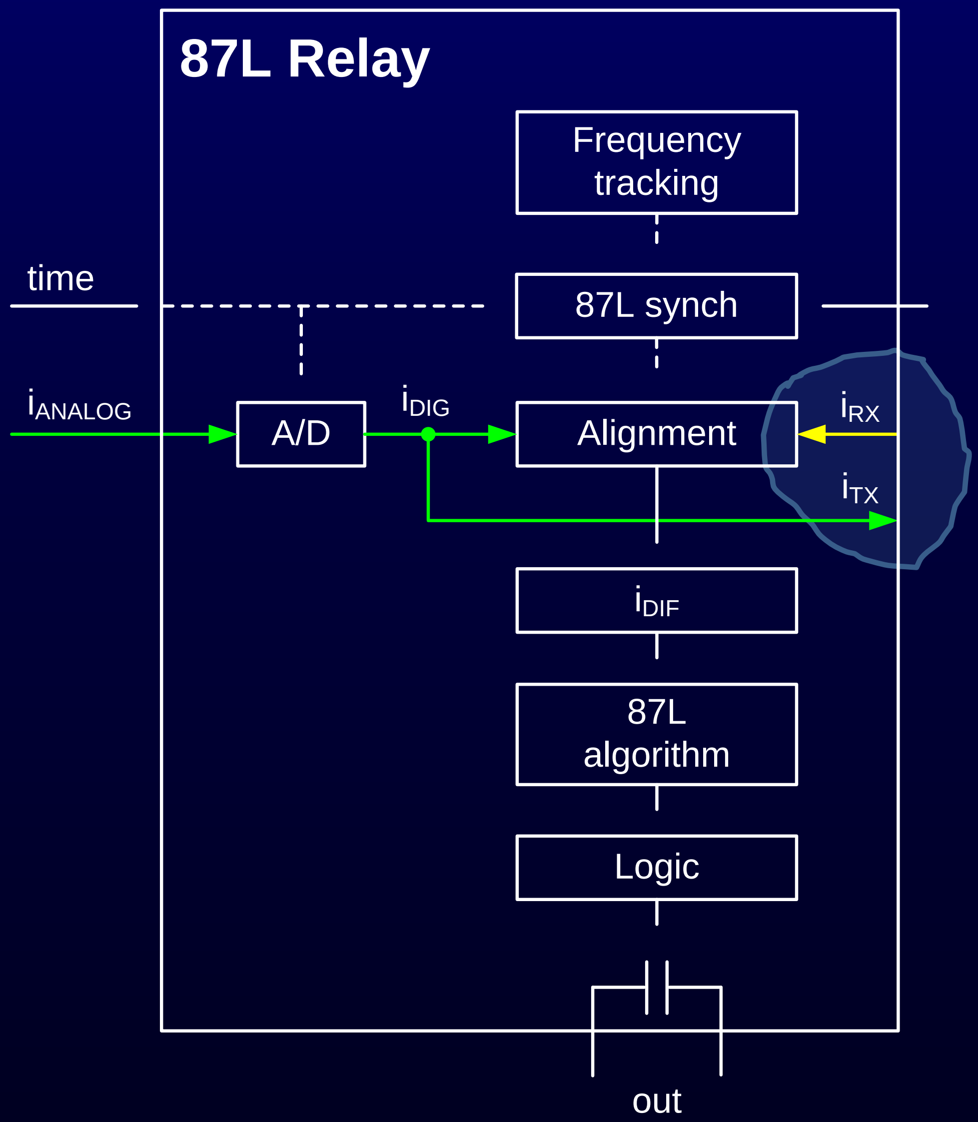
- Ping-pong algorithm (symmetrical channels)
- GPS clocks (asymmetrical channels)

87L synchronization



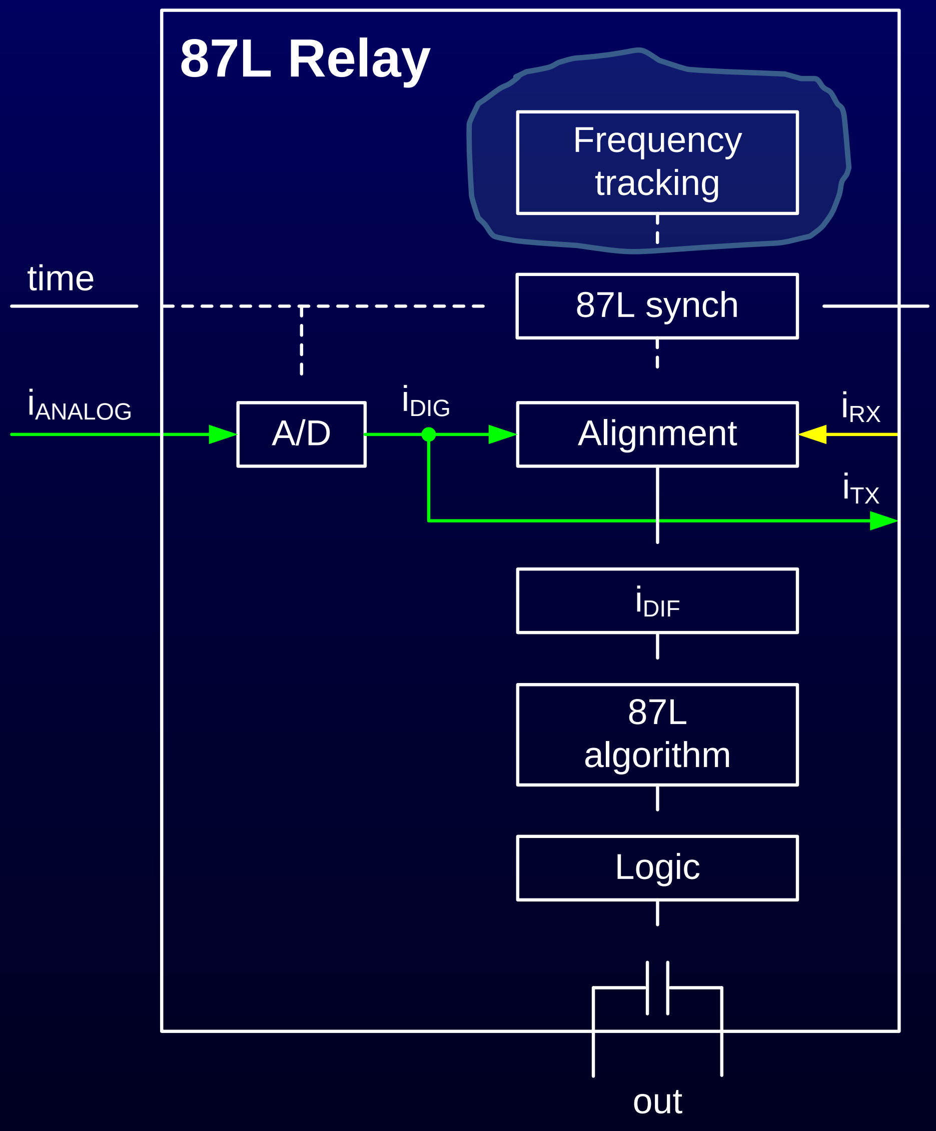
- Synch by forcing simultaneous sampling
- Synch by measuring the clock offset and aligning the data

Samples vs. phasors



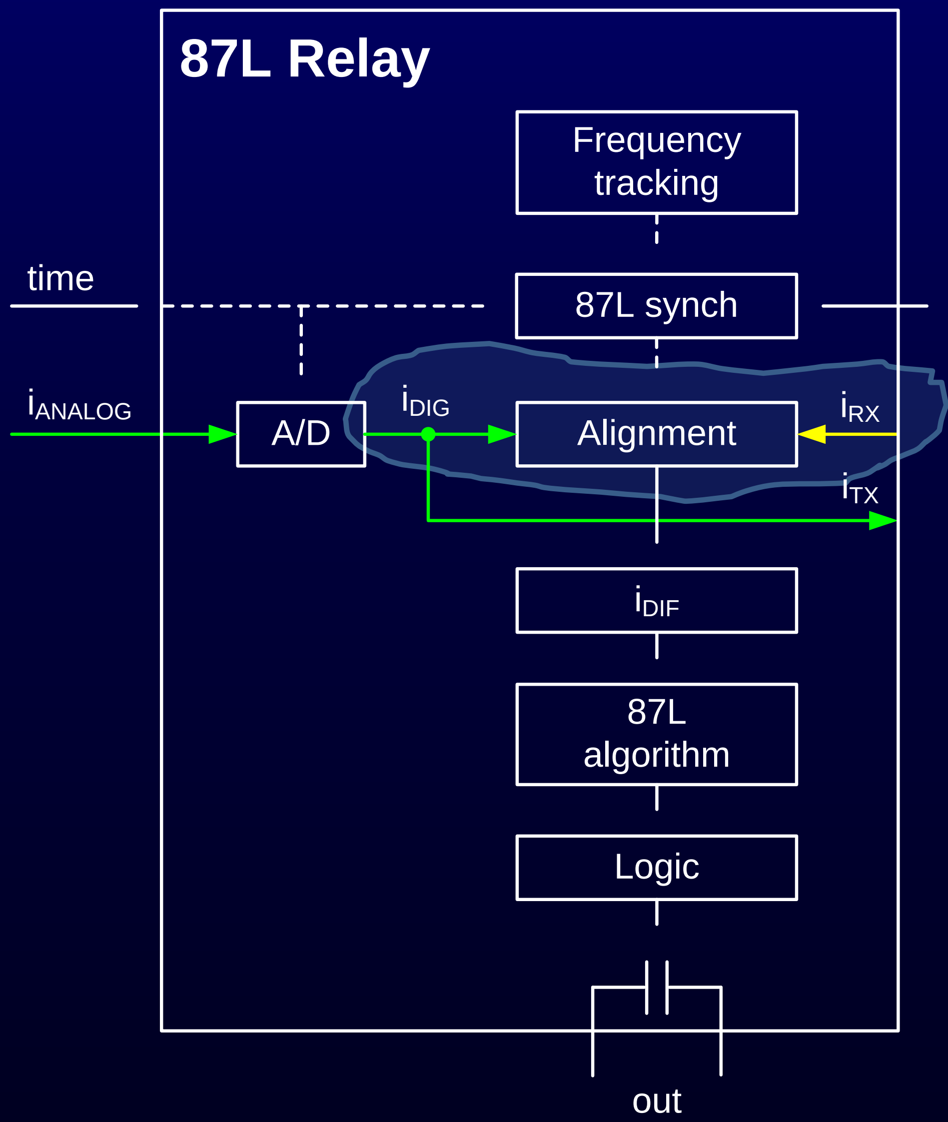
- Phasors
  - Sampling must be synchronized
  - Loss of fidelity due to filtering
- Samples
  - Good fidelity of data (harmonics, external fault detection)
  - Asynchronous sampling allowed

Frequency tracking



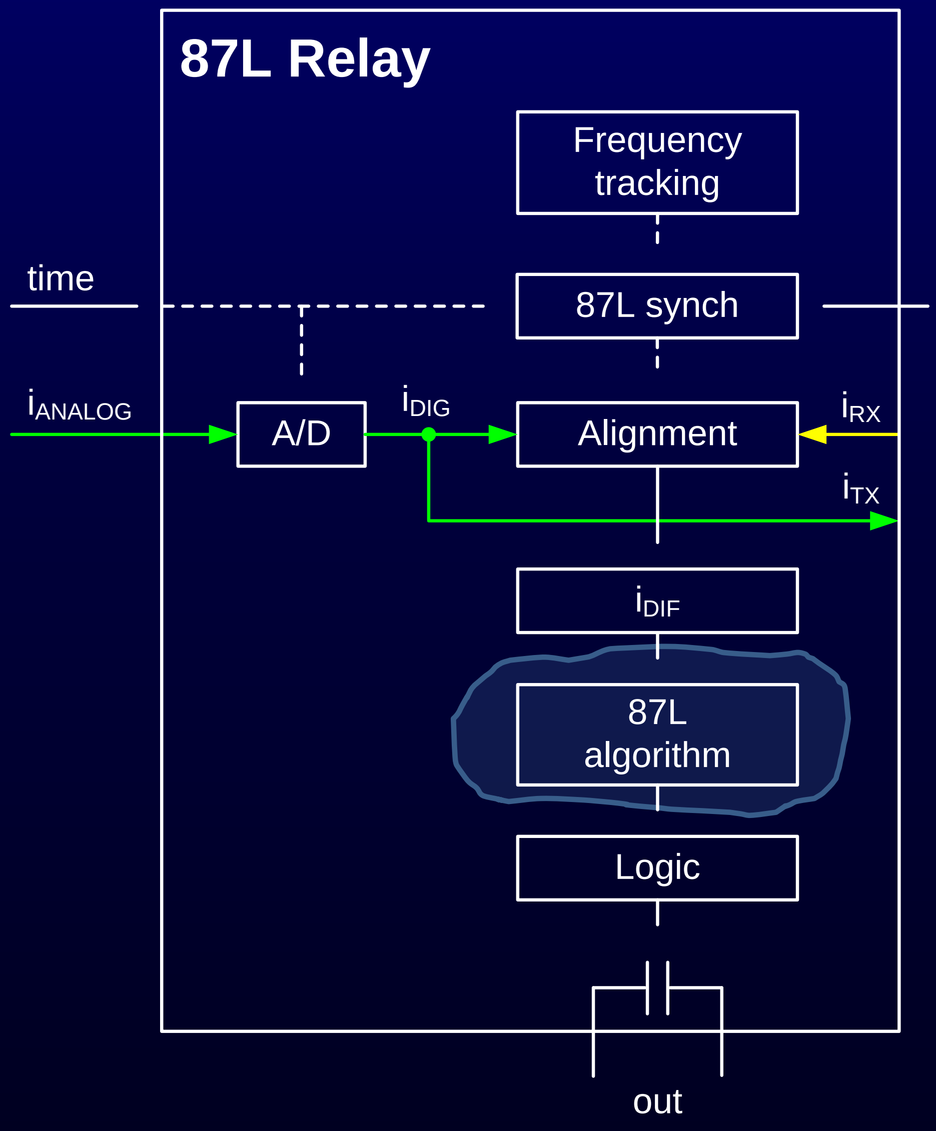
- Applied to transmitted data
  - A must when working on phasors
  - Need to ensure all relays track the same frequency
- Applied when aligning the data

Alignment



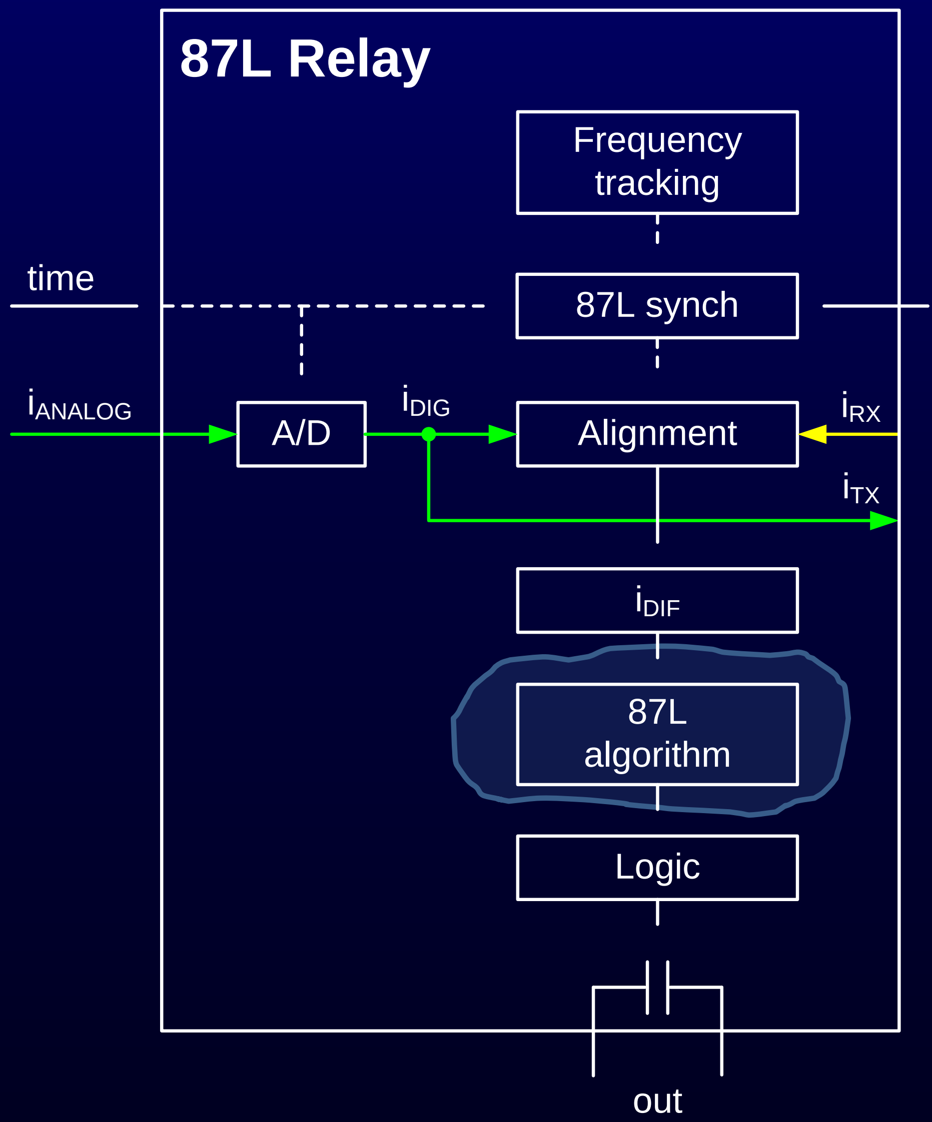
- Compensate for channel latency (wait for the slowest channel)
- Alignment of data provided by individual relays
- Frequency tracking by re-sampling

87L algorithm



- Percentage differential
- 87L-specific operating equations, e.g. Alpha-plane

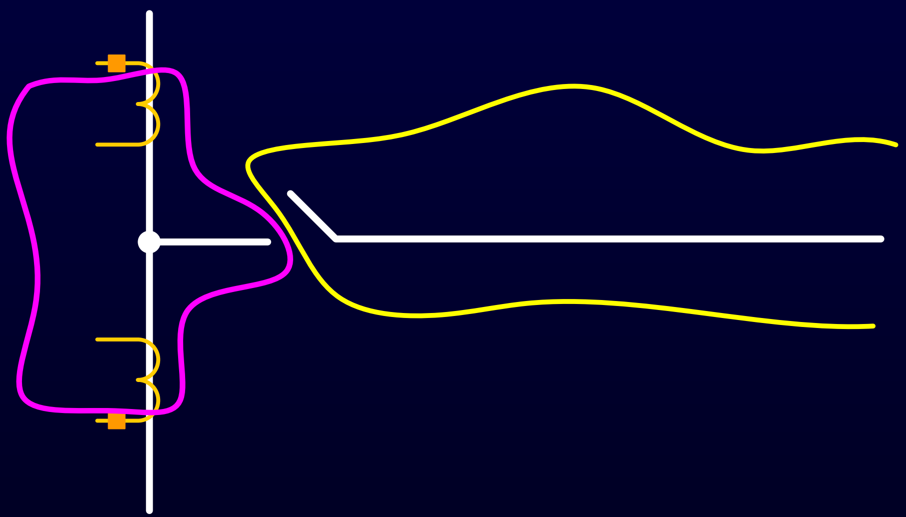
87L algorithm with samples



- In-line transformer applications
- External fault detection
- High-speed operation

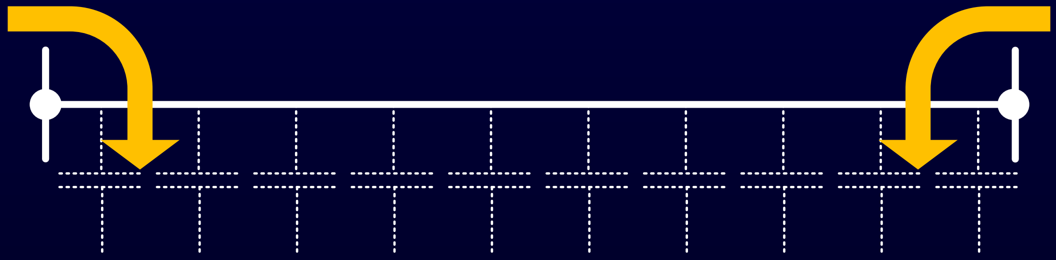
Application considerations

- Dual-breaker terminals – CT saturation, security and sensitivity
- Stub bus configuration



Application considerations

- Dual-breaker terminals – CT saturation, security and sensitivity
- Stub bus configuration
- Line charging current

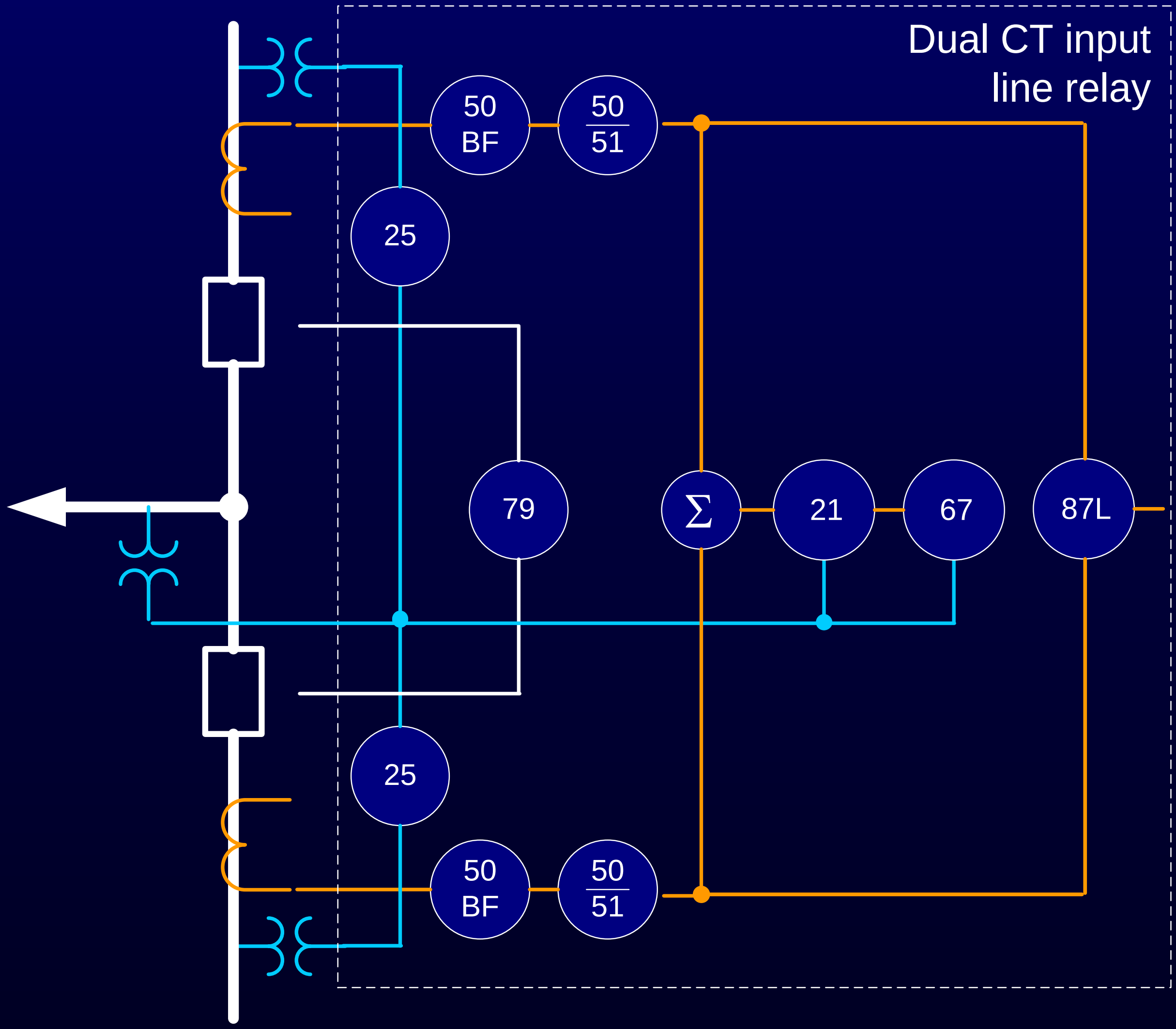


$I_{DIF} \neq 0 \rightarrow$ fault

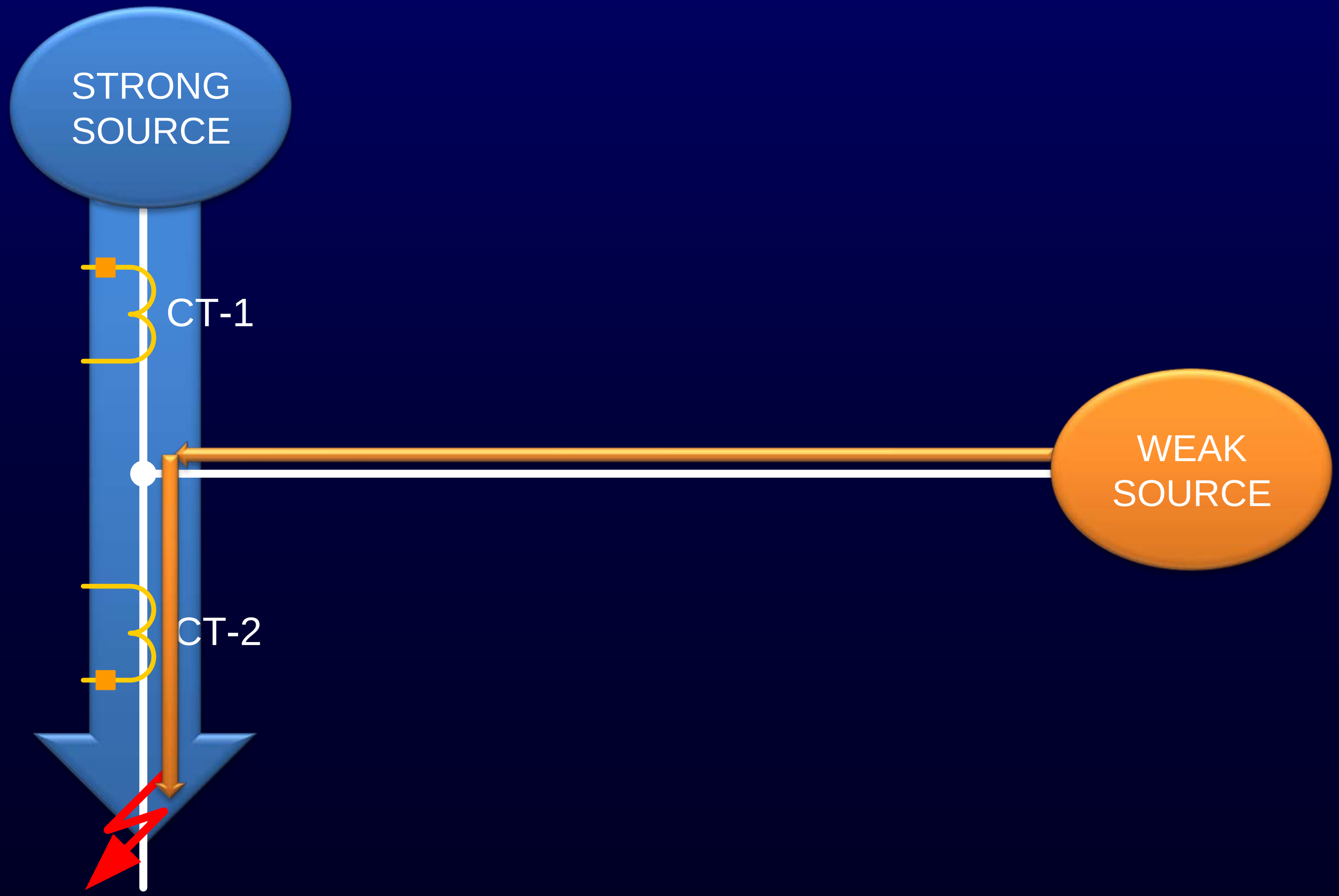
Application considerations

- Dual-breaker terminals – CT saturation, security and sensitivity
- Stub bus configuration
- Line charging current
- In-line transformers

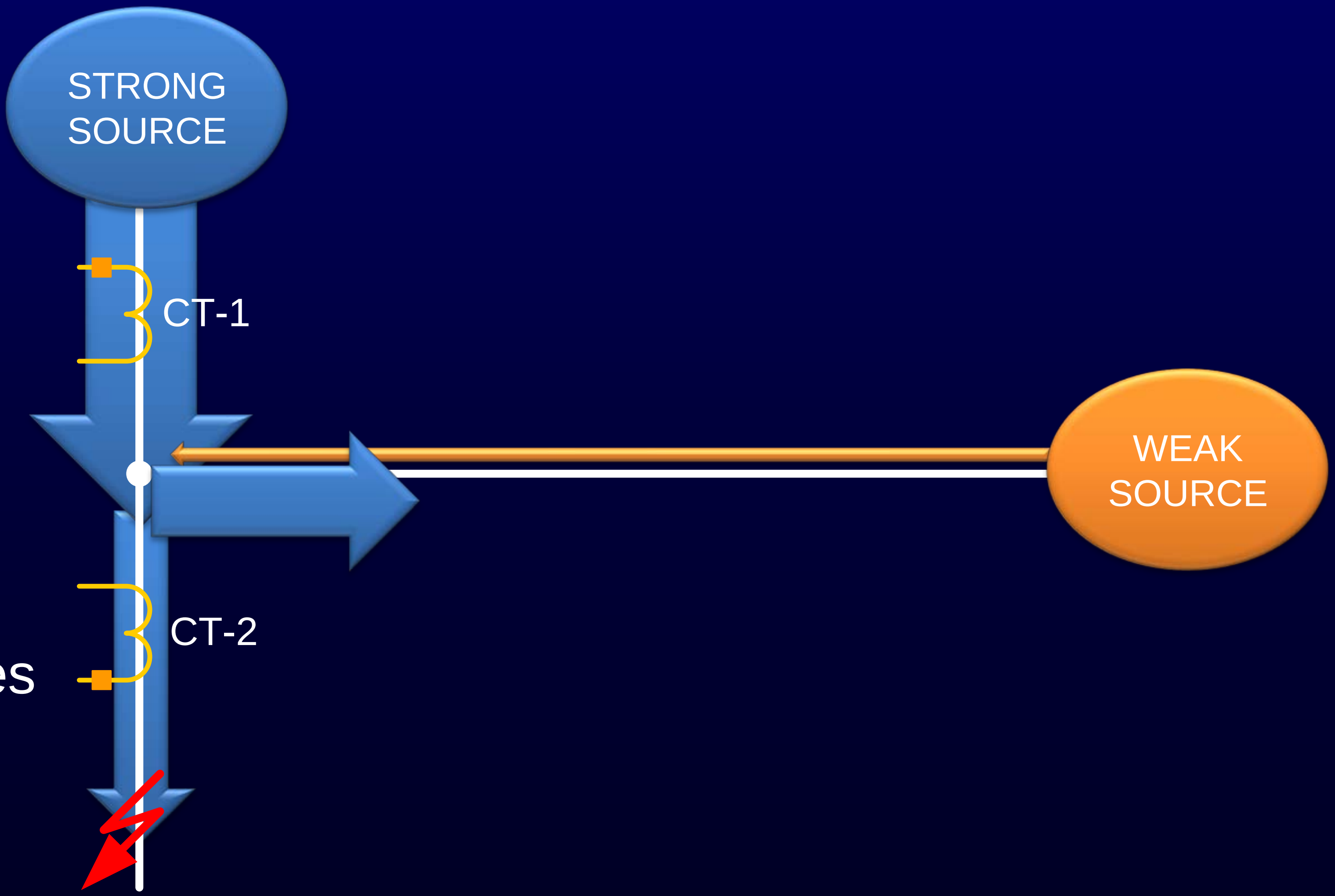
Dual-breaker line terminals



Security

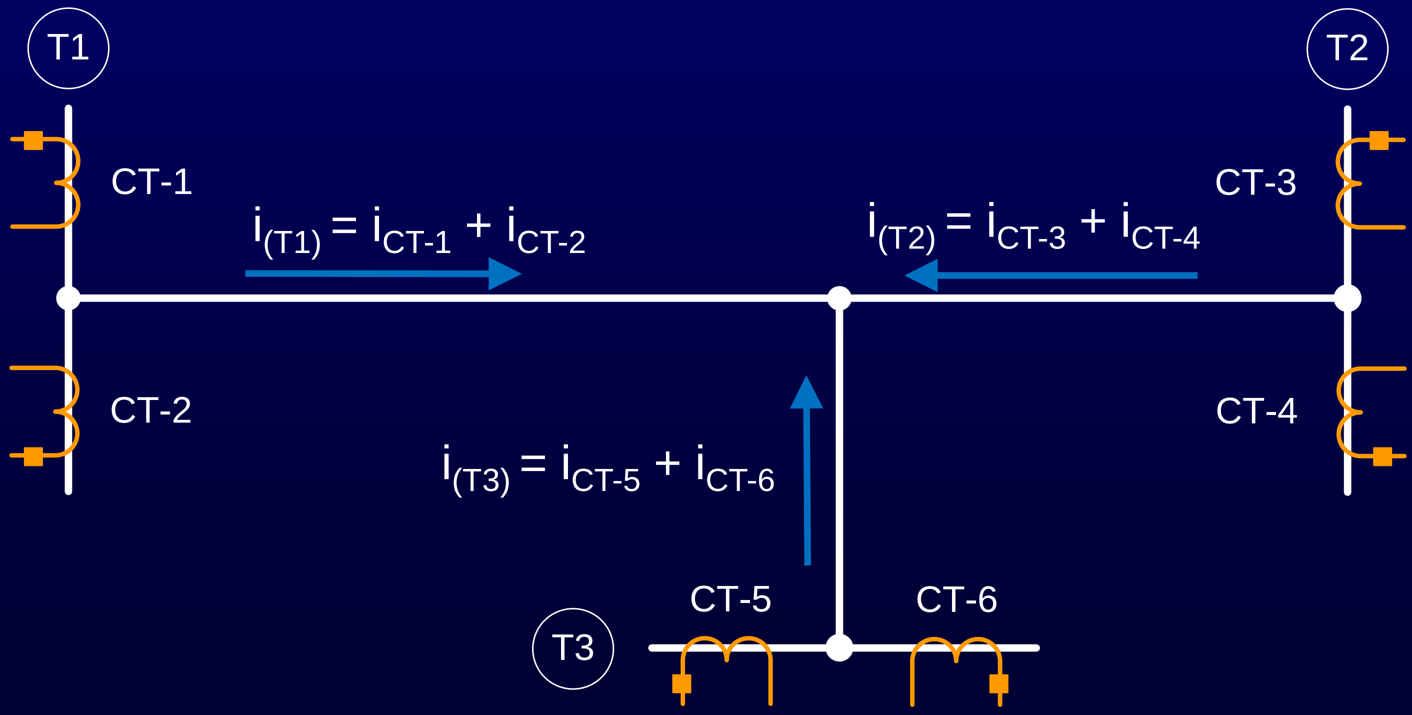


Security



CT-2 saturates

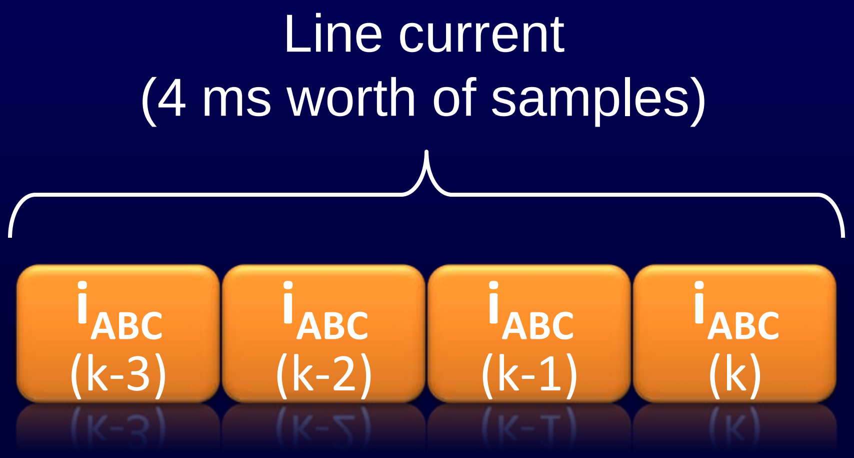
Consolidating terminal currents



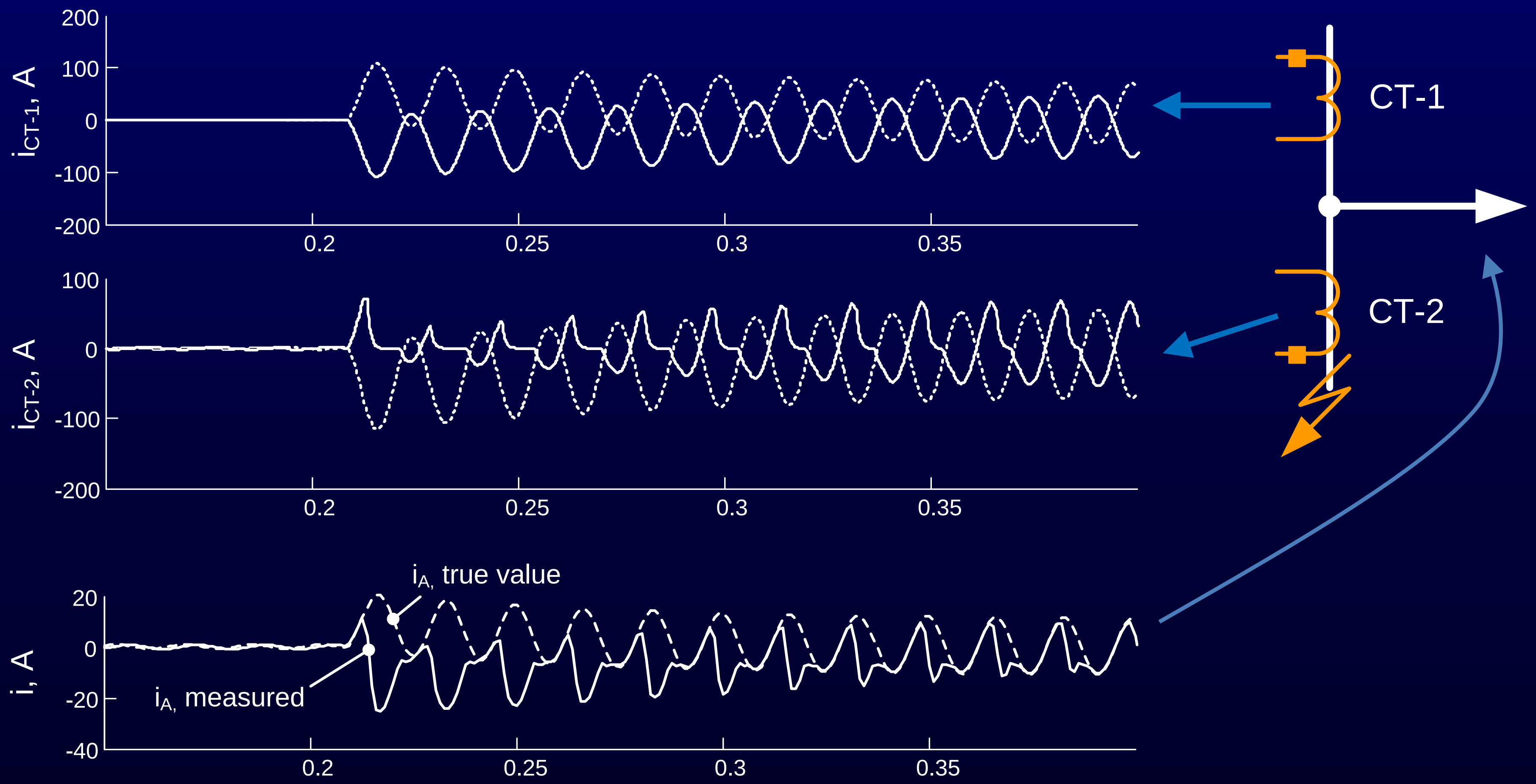
$$i_{DIF} = i_{(T1)} + i_{(T2)} + i_{(T3)}$$

$$i_{DIF} = i_{CT-1} + i_{CT-2} + i_{CT-3} + i_{CT-4} + i_{CT-5} + i_{CT-6}$$

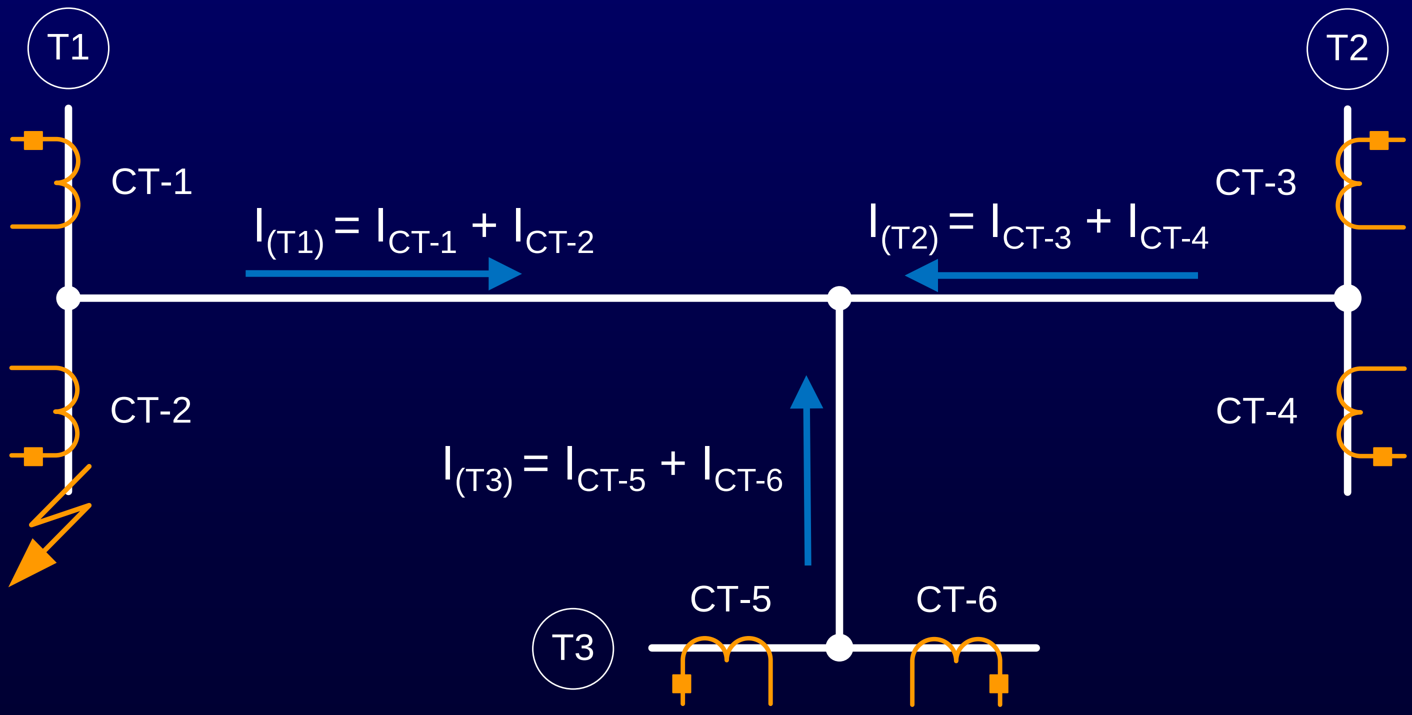
Sample 87L packet



CT saturation



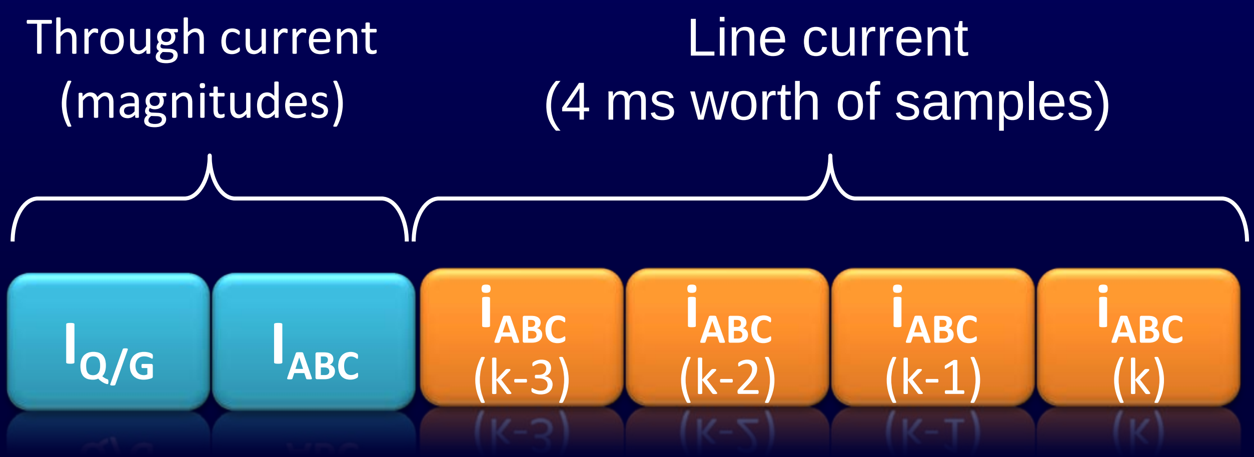
Consolidating through currents



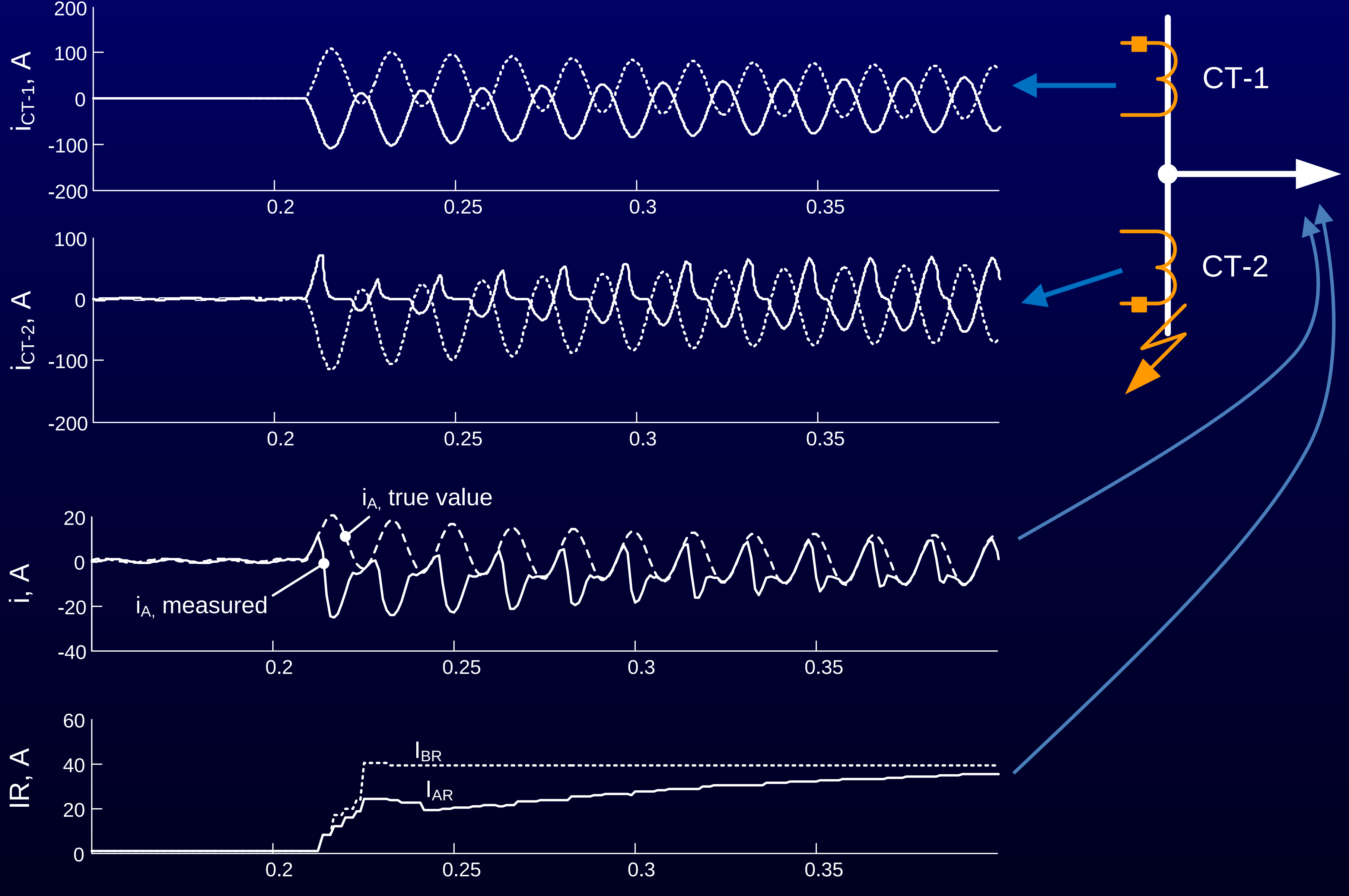
$$I_{RST} = I_{(T1)} + I_{(T2)} + I_{(T3)}$$

$$I_{RST} = I_{CT-1} + I_{CT-2} + I_{CT-3} + I_{CT-4} + I_{CT-5} + I_{CT-6}$$

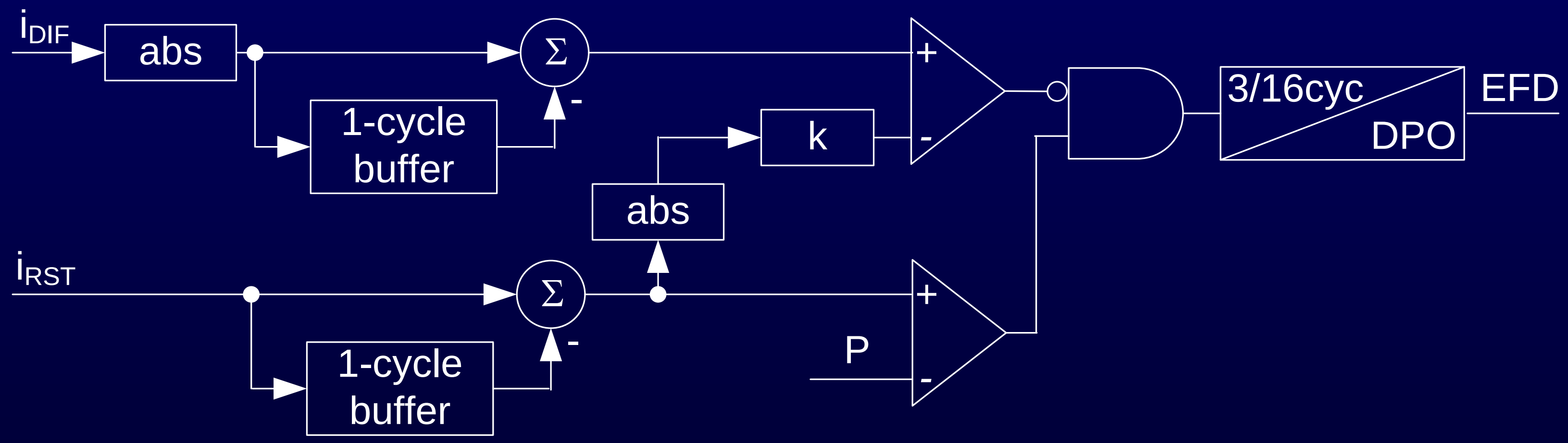
Sample 87L packet

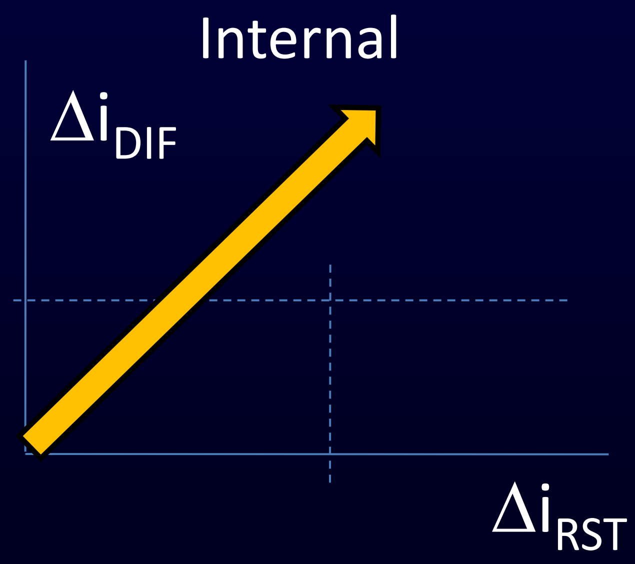


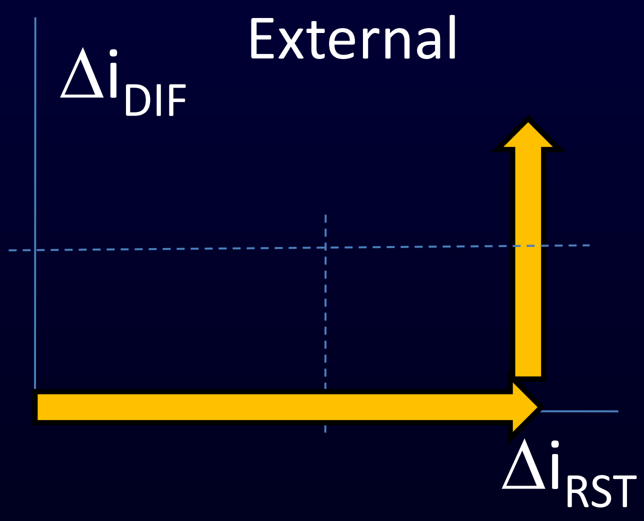
Through current



External Fault Detection, AC path







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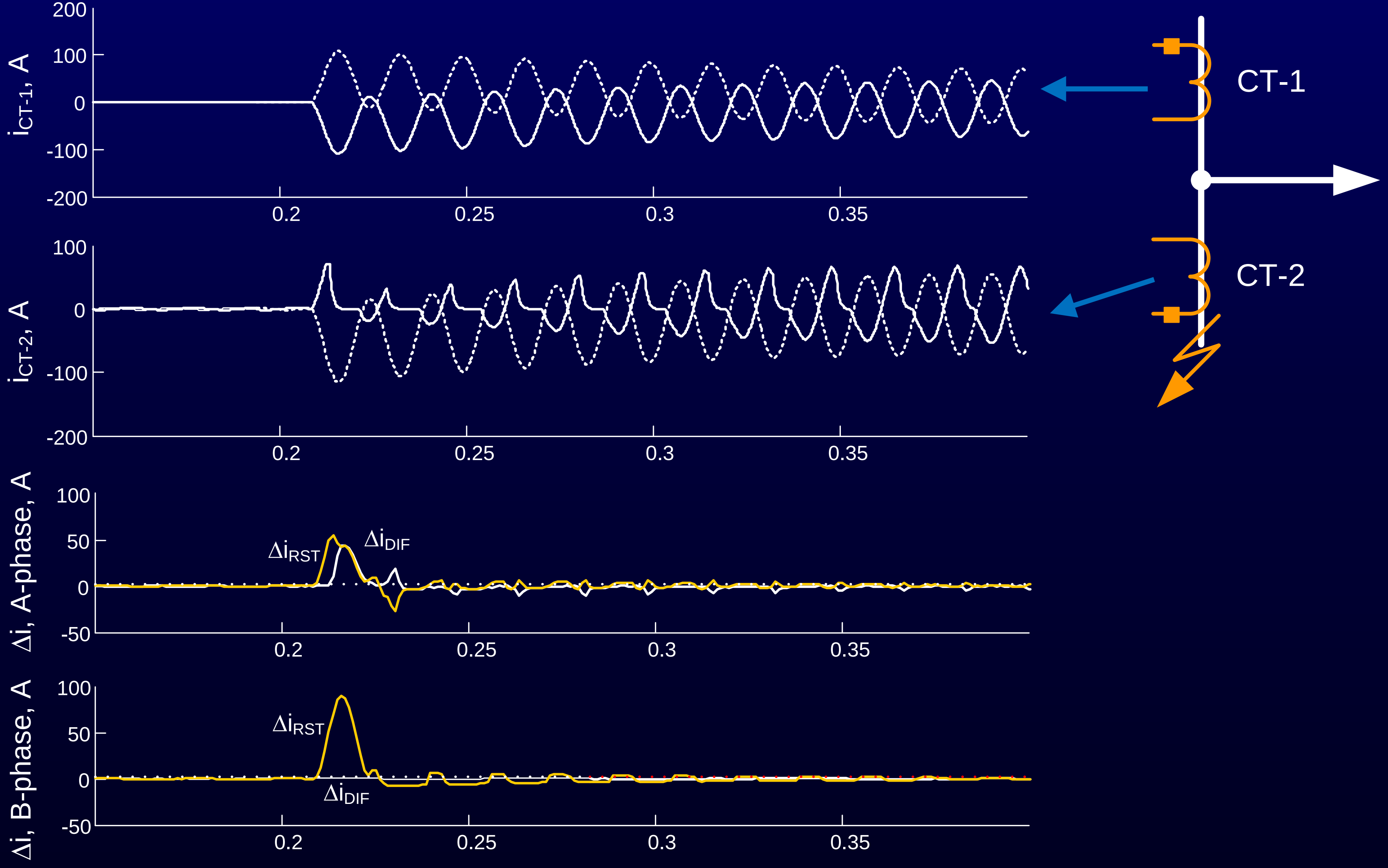
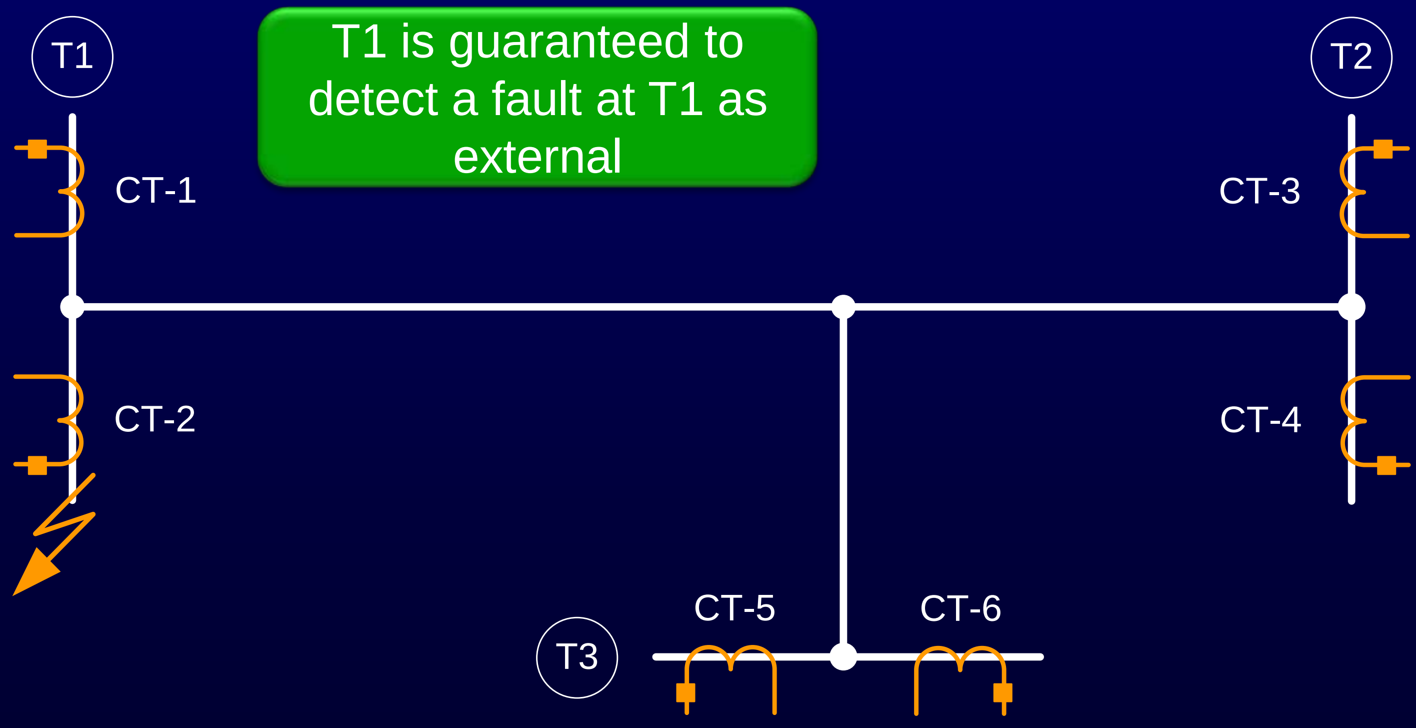
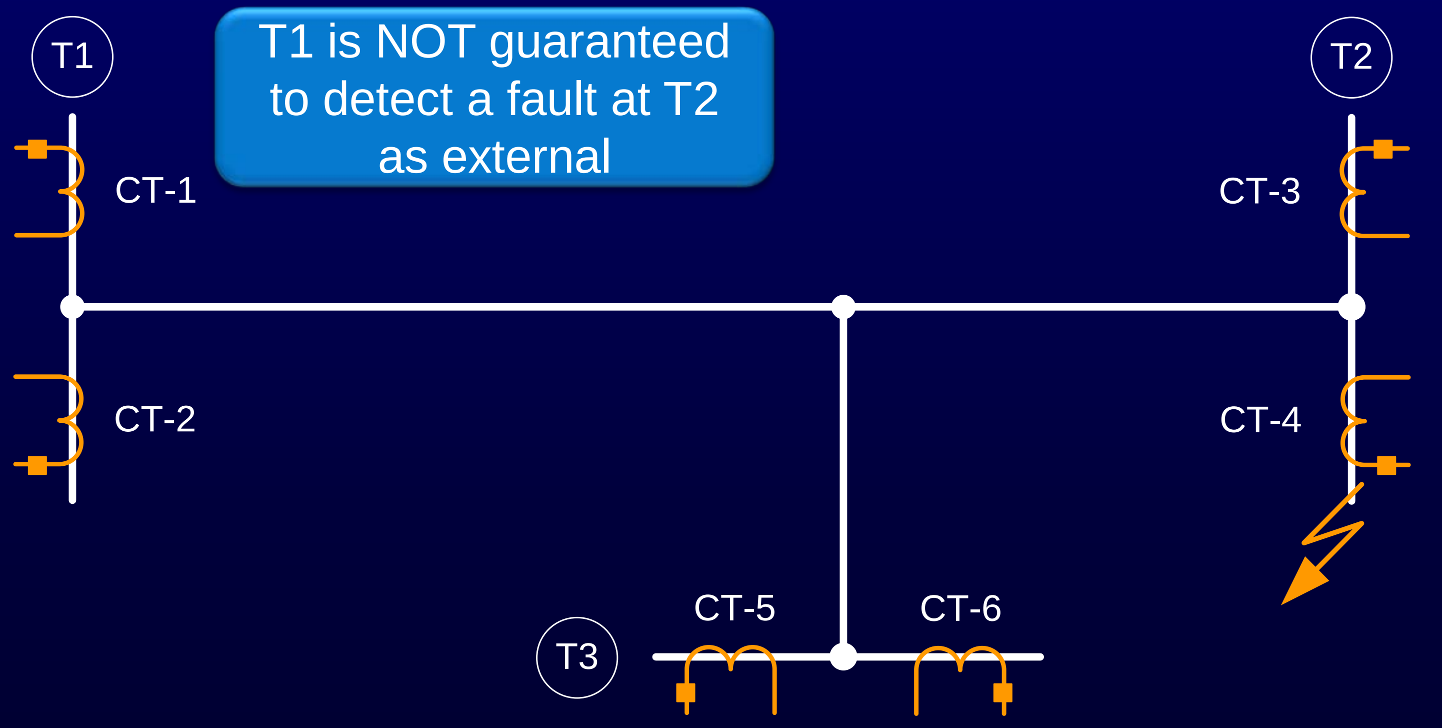


External Fault Detection



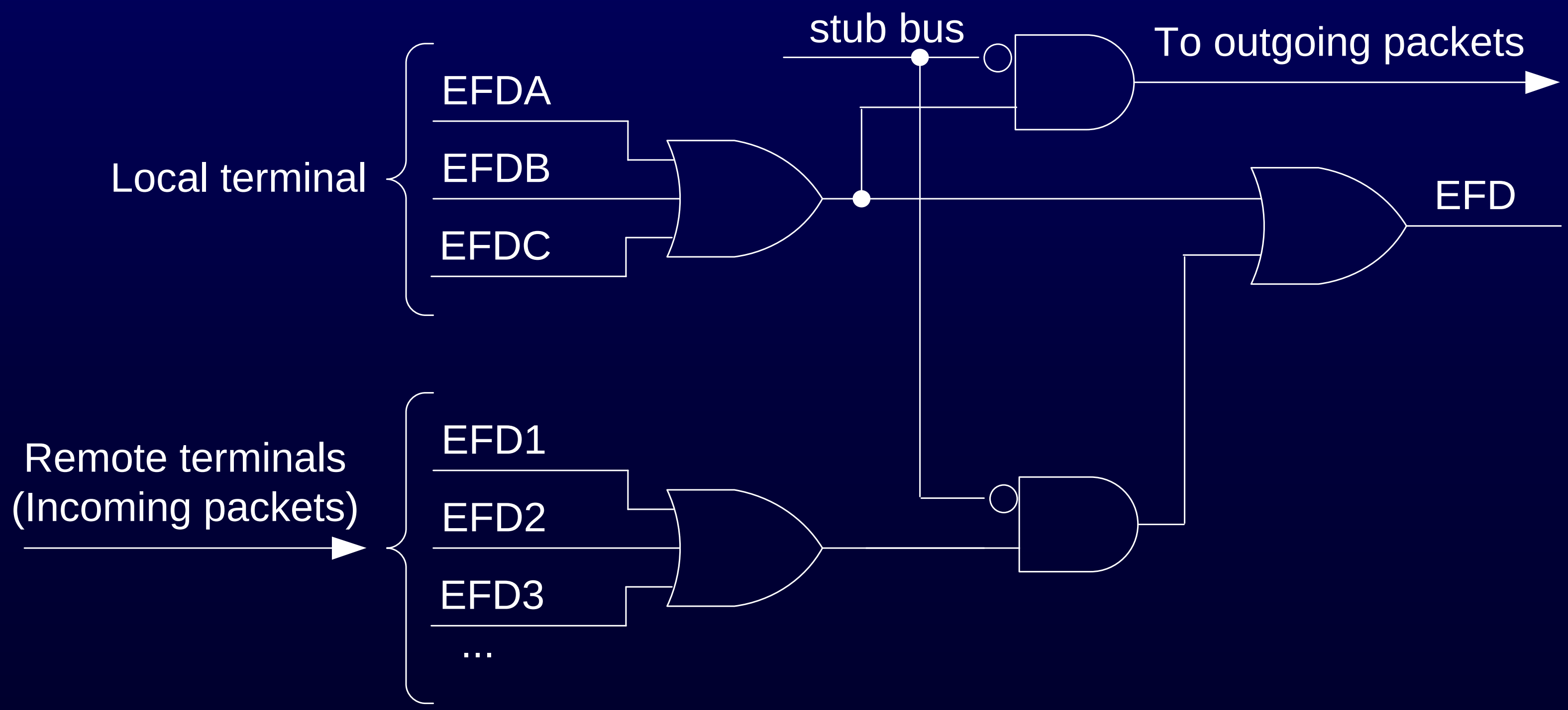
$$i_{RST(T1)} = |\, i_{CT-1} \,| + |\, i_{CT-2} \,| + |\, i_{CT-3} + i_{CT-4} \,| + |\, i_{CT-5} + i_{CT-6} \,|$$

External Fault Detection

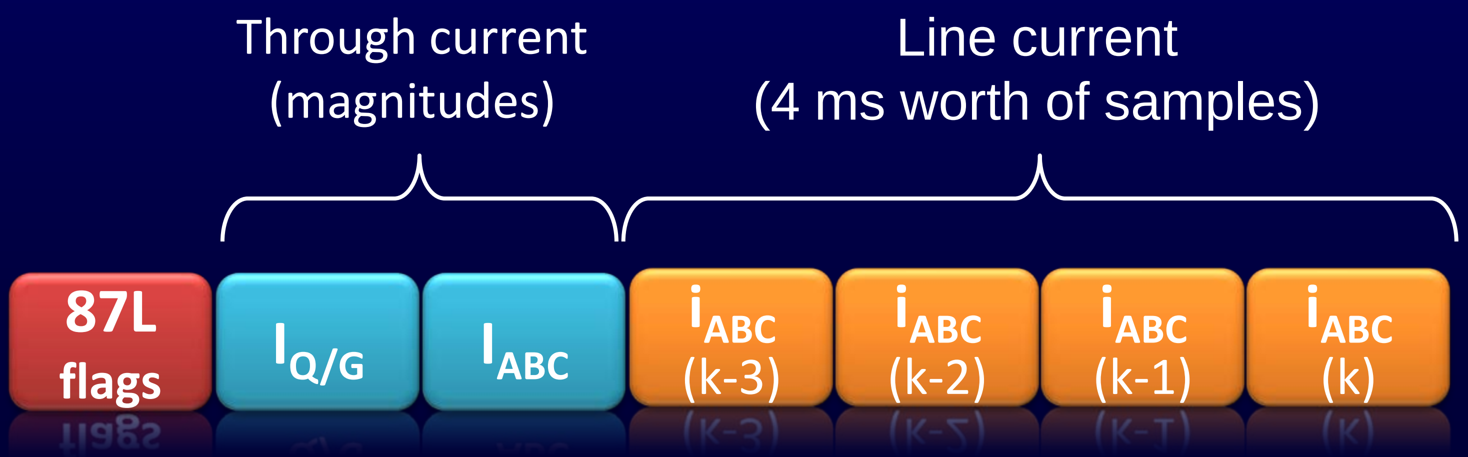


$$i_{RST(T1)} = |\, i_{CT-1} \,| + |\, i_{CT-2} \,| + |\, i_{CT-3} + i_{CT-4} \,| + |\, i_{CT-5} + i_{CT-6} \,|$$

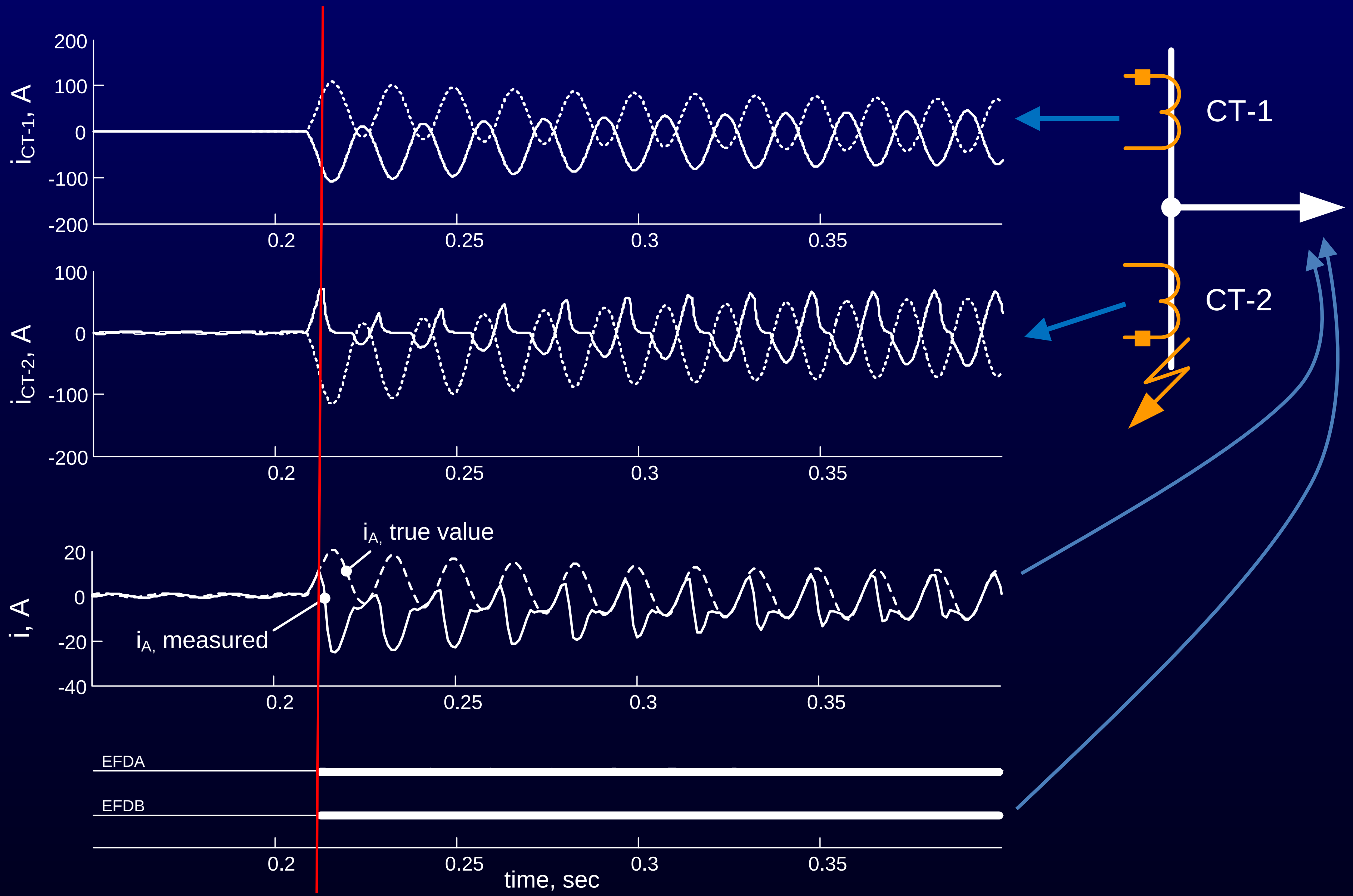
External Fault Detection



Sample 87L packet



External Fault Detection



Summary

- Differential protection is conceptually simple, but…
- 87L design and application call for multi-disciplinary knowledge
  - Protection
  - Communications
  - Signal processing
  - System engineering