The Synchronization Experts.

WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Initial Results of Testing Redundant Time Synchronization and Recovery Analysis of Protective Relays

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Agenda

- What Is The Purpose Of This Testing?
- Why Is It Important?
- Test Setup: How Did We Conduct Tests?
- Review of Test Cases
- What Did We Learn?
- What Should We Improve Next Time?

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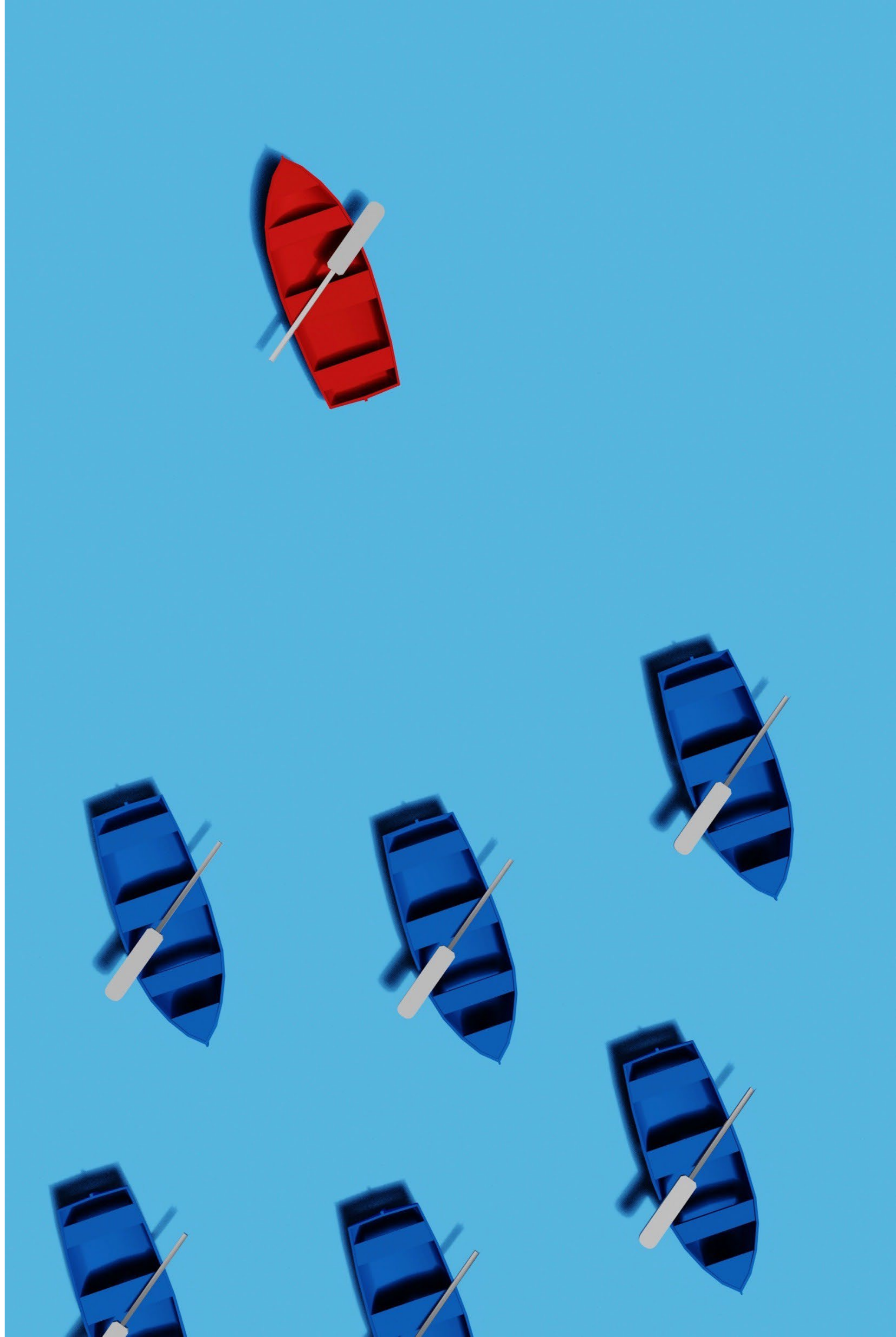
Acronyms Used In This Presentation

- GM: Grandmaster Clock
- TC: Transparent Clock
- OC: Ordinary Clock
- IED: Intelligent Electronic Device
- SV: Sampled Values – Digitized Measurements of Current/Voltage (Defined by IEC 61850-9-2)
- PRP: Parallel Redundancy Protocol (Defined by IEC 62439-3)

What Is The Purpose Of This Testing?

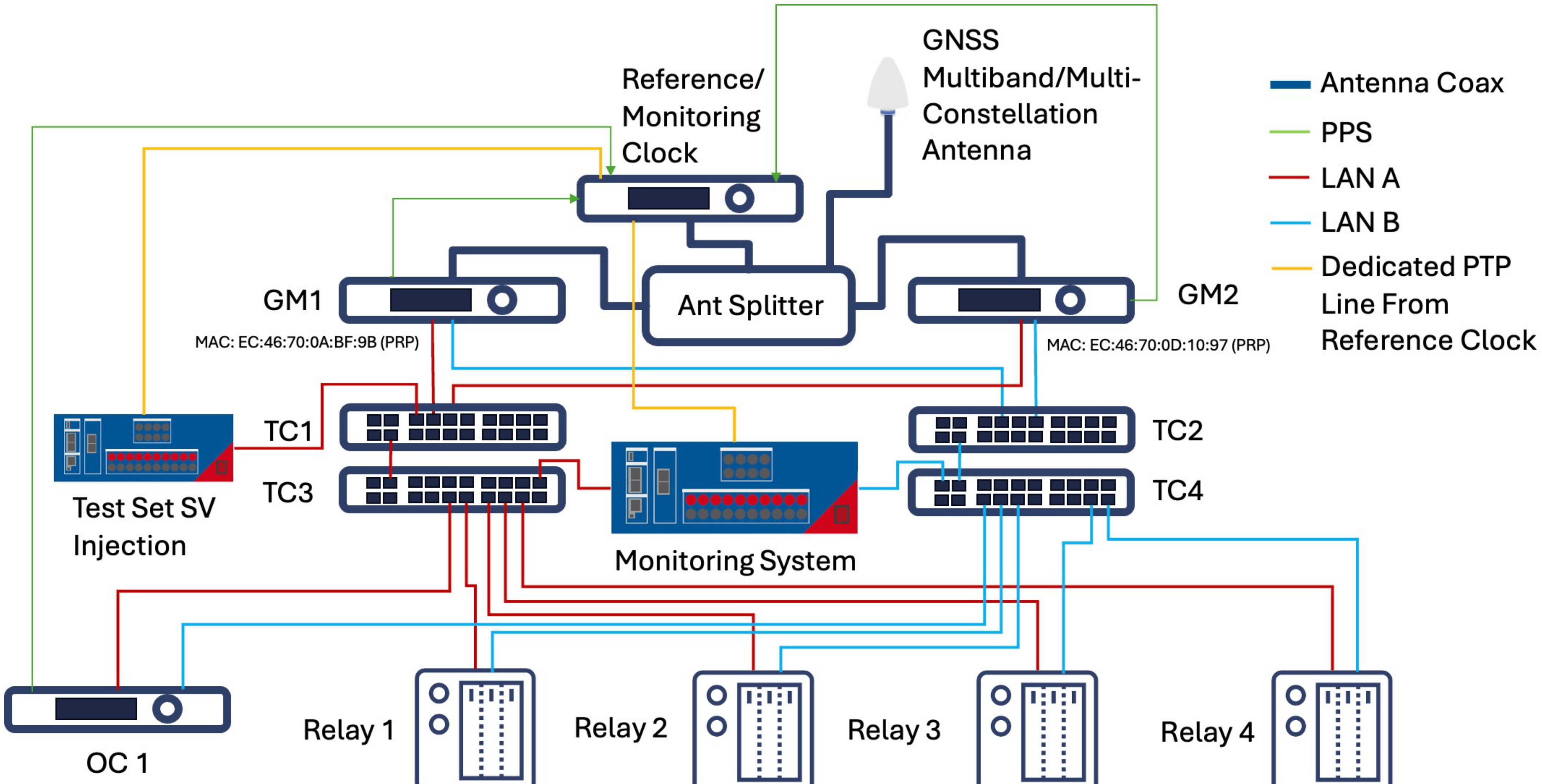
- Goal: Understand How Protection Relays React To Real World Time Synchronization Anomalies/Configurations
  - Transition From One Clock To Another (Grandmaster Clock Failover)
  - Multiple Singly Attached Grandmaster Clocks in PRP network
  - Time Jumps due to:
    - Loss of GNSS primary reference and resynchronization
    - Loss of GNSS primary reference and failover between two unsynchronized clocks
  - Loss of Synchronization Between Protection Relay and Clock (Free Running IED)



Why Is It Important?

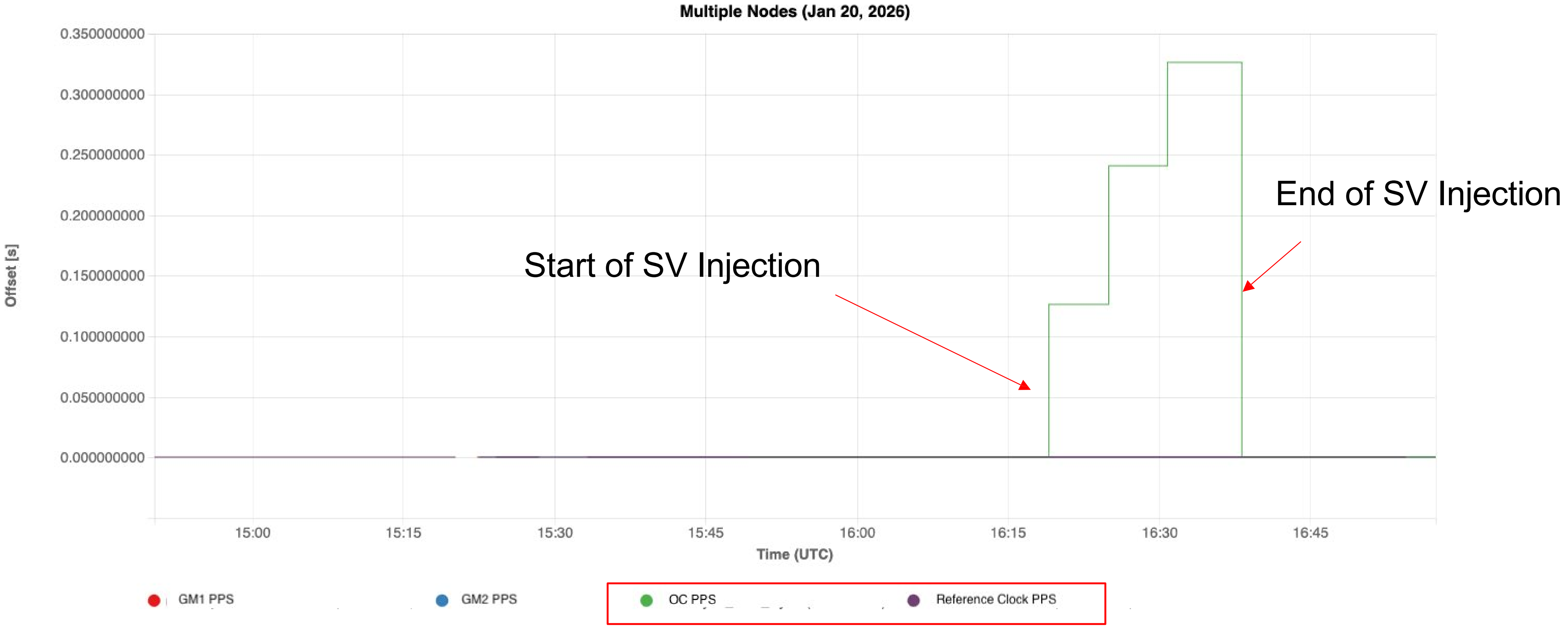
- Protection Issues Can Result From Synchronization Anomalies
  - WAMPAC
- If Issues Are Present, Industry Should Be Aware

Test Setup: How Were Tests Conducted



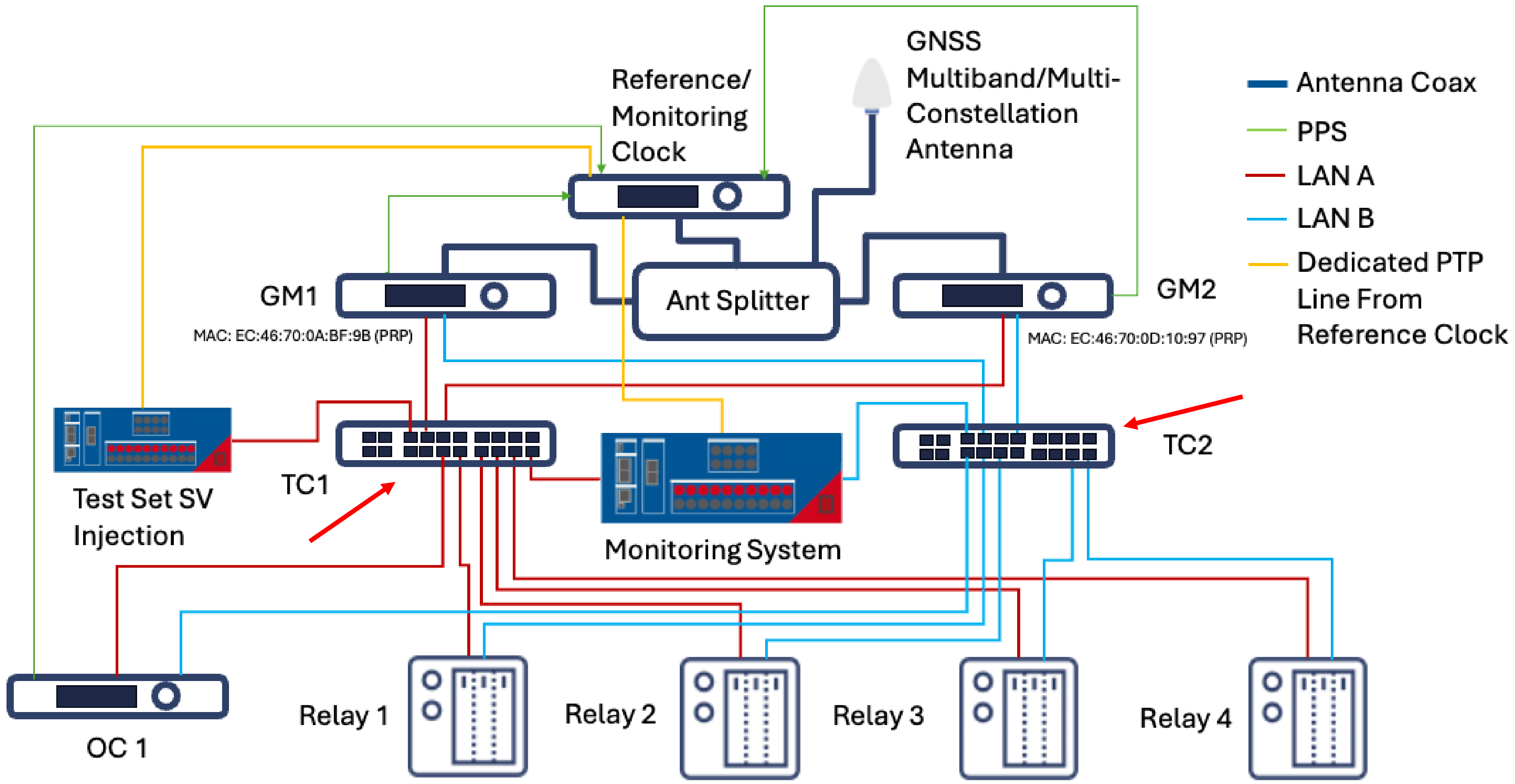
Test Setup: How Were Tests Conducted

One Pair of Transparent Clock Switches Did Not Accurately Correct For Time When SVs Were Injected



Monitored via OC/Reference Clock In Previous Diagram

Test Setup: How Were Tests Conducted

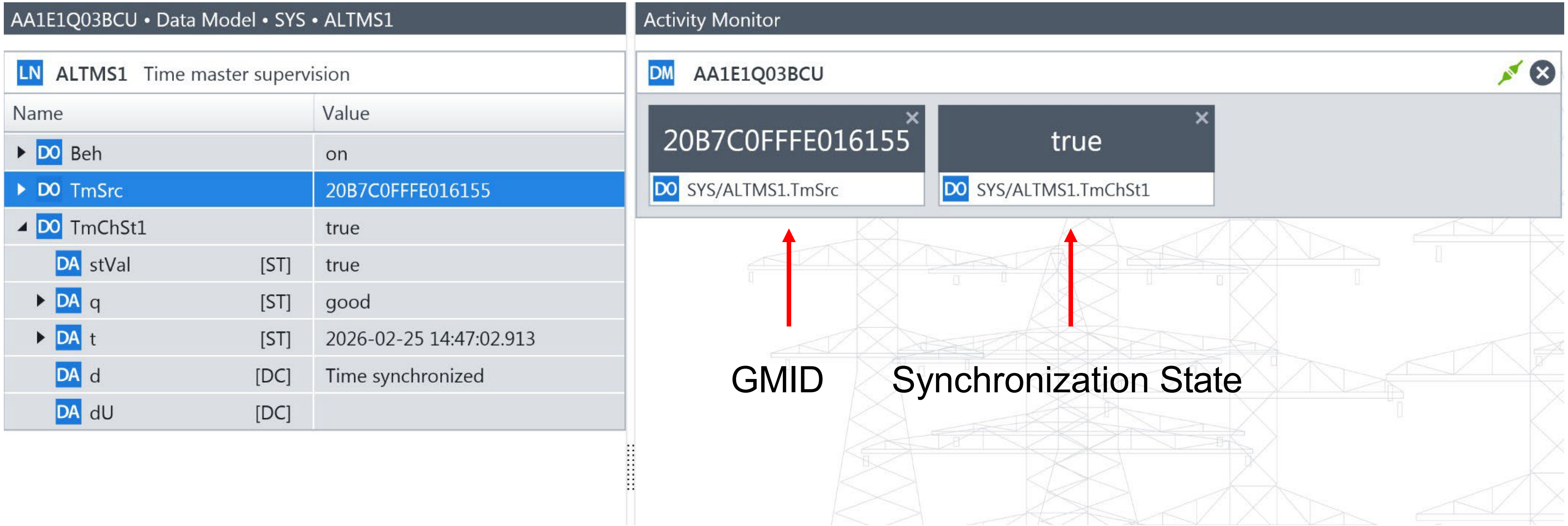


Network Simplified And With Switch Pair Removed After Isolation

Test Setup: How Were Tests Conducted

- Monitoring of LTMS

Note

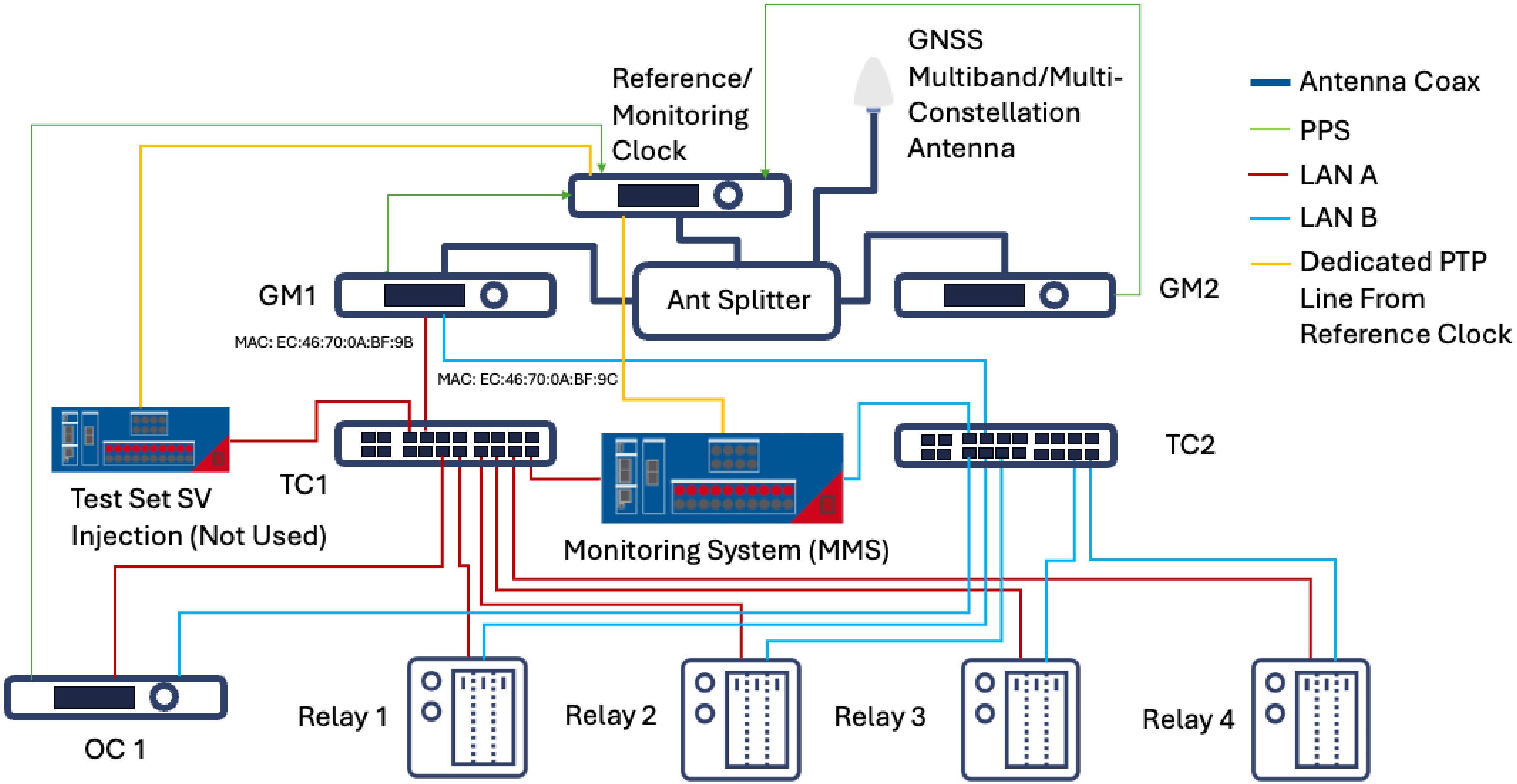


Note: Image Shown Is An Example To Show Monitoring. Devices Shown Did Not Participate In Testing

Test Setup: How Were Tests Conducted

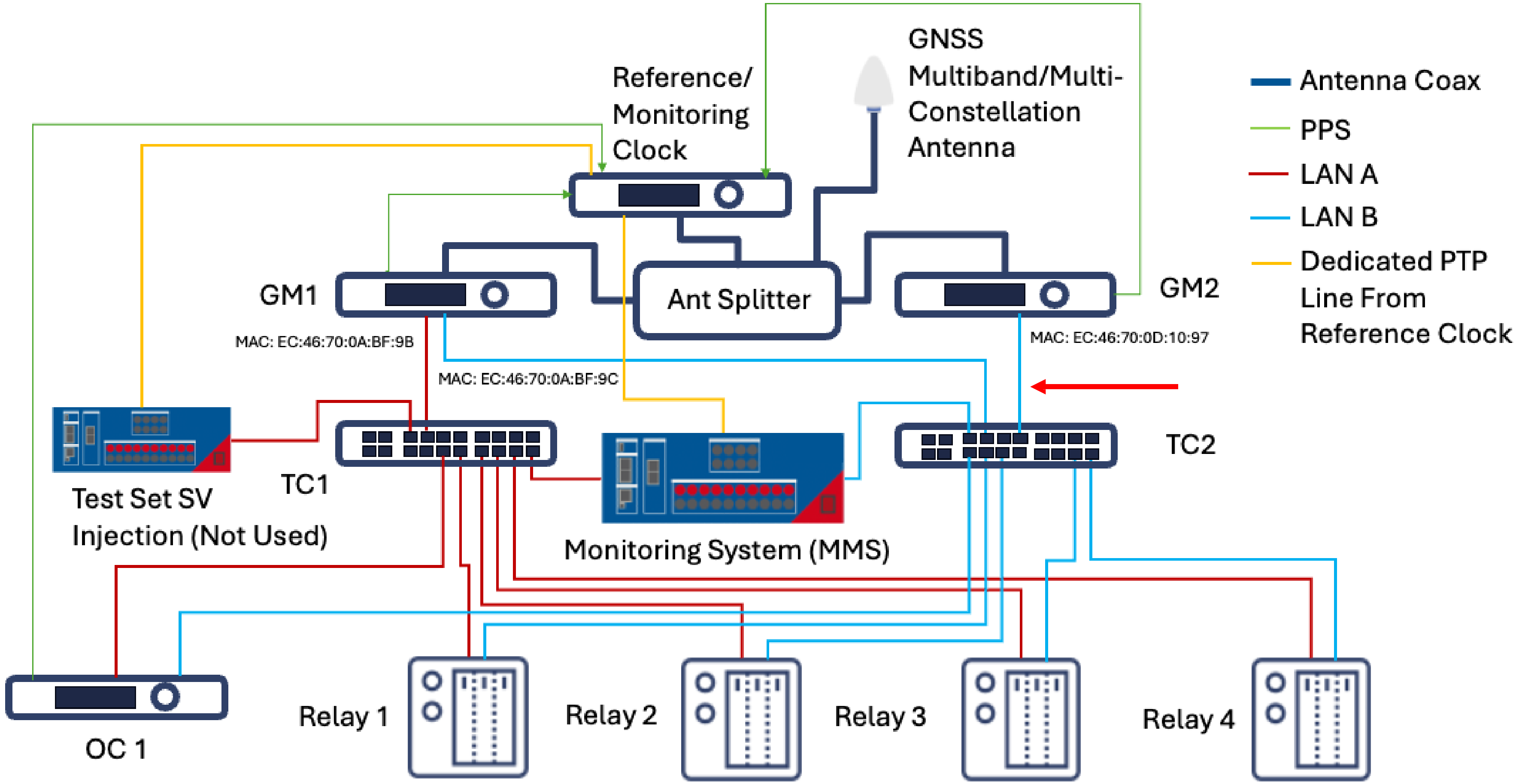
Review Of Test Cases

Case 1: Multiple Singly Attached Grandmaster Clocks



Review Of Test Cases

Case 1: Multiple Singly Attached Grandmaster Clocks (Adding Third Clock)



Review Of Test Cases

Case 1: Multiple Singly Attached Grandmaster Clocks (Table Shown For Reference)

	Relay 1		Relay 2		Relay 3		Relay 4	
	Initial State	Final State	Initial State	Final State	Initial State	Final State	Initial State	Final State
1 – MAC ending in 9B on LAN A	Unknown, but synced	N/A	9B on LAN A	N/A	N/A –cable disconnected from LAN A because it bridges networks		9B on LAN A	N/A
2 – swapped clocks on LAN A/LAN B, 9B on LAB B	Unknown, but synced	Unknown, but synced	9B LAN A	9B LAN B	N/A - Inconclusive		9B LAN A	9B LAN B
3 – Reverse swap and add second clock to LAN B – which had 9C to create new Best Master	Unknown, but synced	Unknown, but synced	9B LAN A	10:97 LAN B	N/A - Inconclusive		9B LAN A	10:97 LAN B

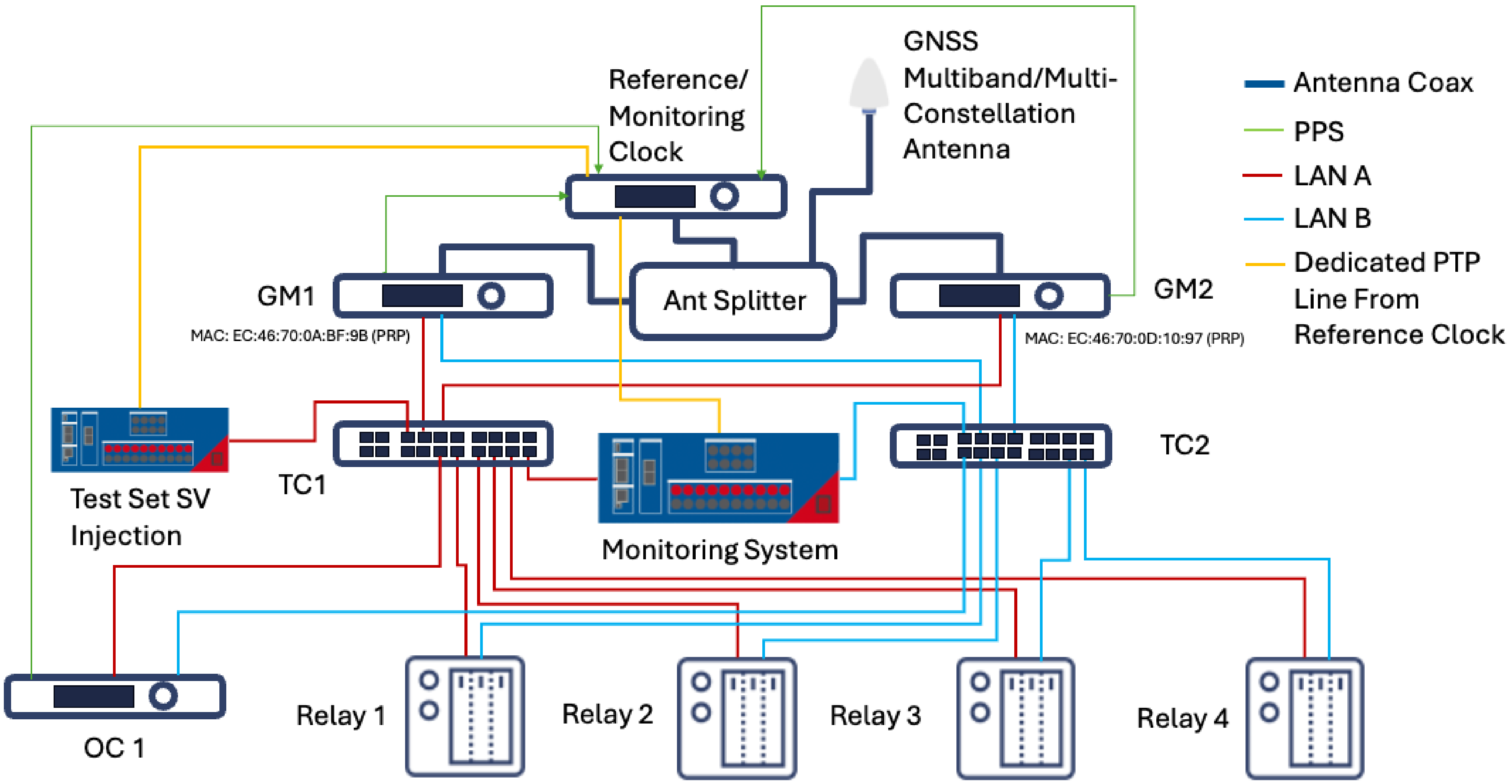
Review Of Test Cases

Case 1: Multiple Singly Attached Grandmaster Clocks

- At Step 2 where singly attached clocks were swapped to LAN B from LAN A, Relays 2 and 4 performed as expected and showed the same GMID on LAN B.
- At Step 3, where third clock (MAC: 10:97) with lower Priority 1 was introduced to LAN B, Relays 2 and 4 chose third clock as GM as expected.
- Relay 1 Does Not Provide Enough Information To Determine Results
- Relay 3 Had An Issue Where it Bridges LAN A/LAN B on PRP Network

Test Setup: How Were Tests Conducted

Case 2: PRP Resiliency Test. What Happens When One Leg of PRP Network Is Lost?



Review Of Test Cases

Case 2: PRP Resiliency Test. What Happens When One Leg of PRP Network Is Lost? (Reference Table)

	Relay 1		Relay 2		Relay 3		Relay 4	
	Initial State	Final State	Initial State	Final State	Initial State	Final State	Initial State	Final State
1 – Normal Configuration as per Figure 3	Unknown, but synced	N/A	9B on LAN A	N/A	N/A –cable disconnected from LAN A because it bridges networks		9B on LAN A	N/A
2 – GM with higher priority disconnected from LAN A	Unknown, but synced	Unknown, but synced	9B on LAN A	9B on LAN B	N/A - Inconclusive		9B on LAN A	9B on LAN B
3 – GM with higher priority is reconnected and disconnected from LAN B	Unknown, but synced	Unknown, but synced	9B on LAN B	9B on LAN A	N/A - Inconclusive		9B on LAN B	9B on LAN A

Review Of Test Cases

Case 2: PRP Resiliency Test. What Happens When One Leg of PRP Network Is Lost?

- Relay 2 and 4 Maintained Synchronization to GM Clock When LAN A/LAN B of PRP Network Were Disconnected
- Relay 1 Does Not Provide Enough Information To Determine Results
- Relay 3 Had An Issue Where it Bridges LAN A/LAN B on PRP Network

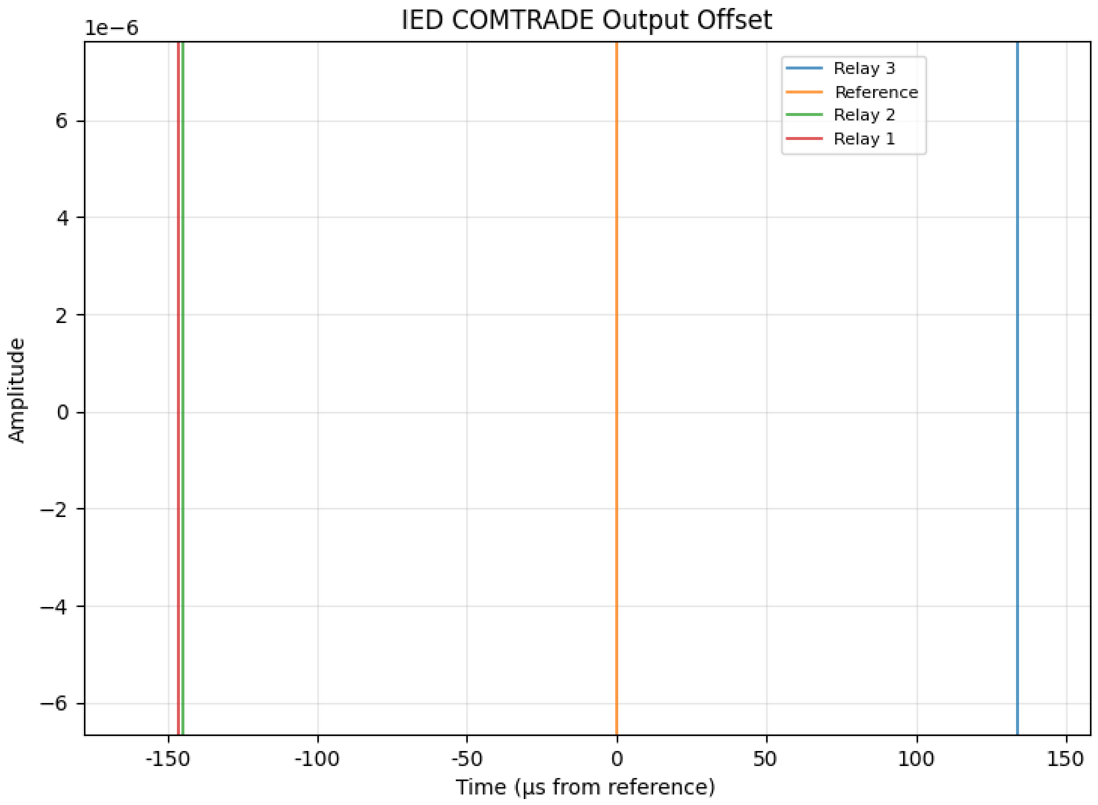
Review Of Test Cases

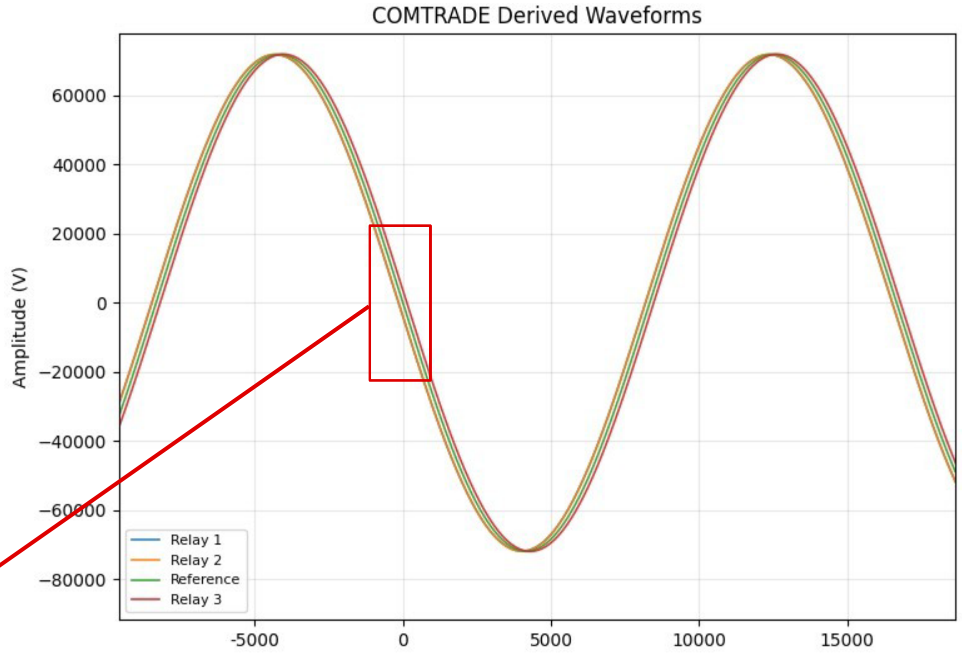
Case 3: Free-Running IED Test

- A known waveform was injected
  - 100kV 60Hz
- PTP synchronization signal was removed
- Fault current was applied, identically to each relay, triggering oscillography capture
- Oscillography saved as a COMTRADE file with UTC timestamping
- Oscillography was compared to evaluate oscillator offset
- Time offset was captured at each 0 crossing and averaged
- No industry tool was found to perform this calculation directly. AI was leveraged to create analysis tool and was validated against common industry software.
- Test was repeated while IEDs were unsynchronized for several time intervals
  - 10 s, 1 min, 3 min, 5 min, 10 min, 20 min, and 12 hours

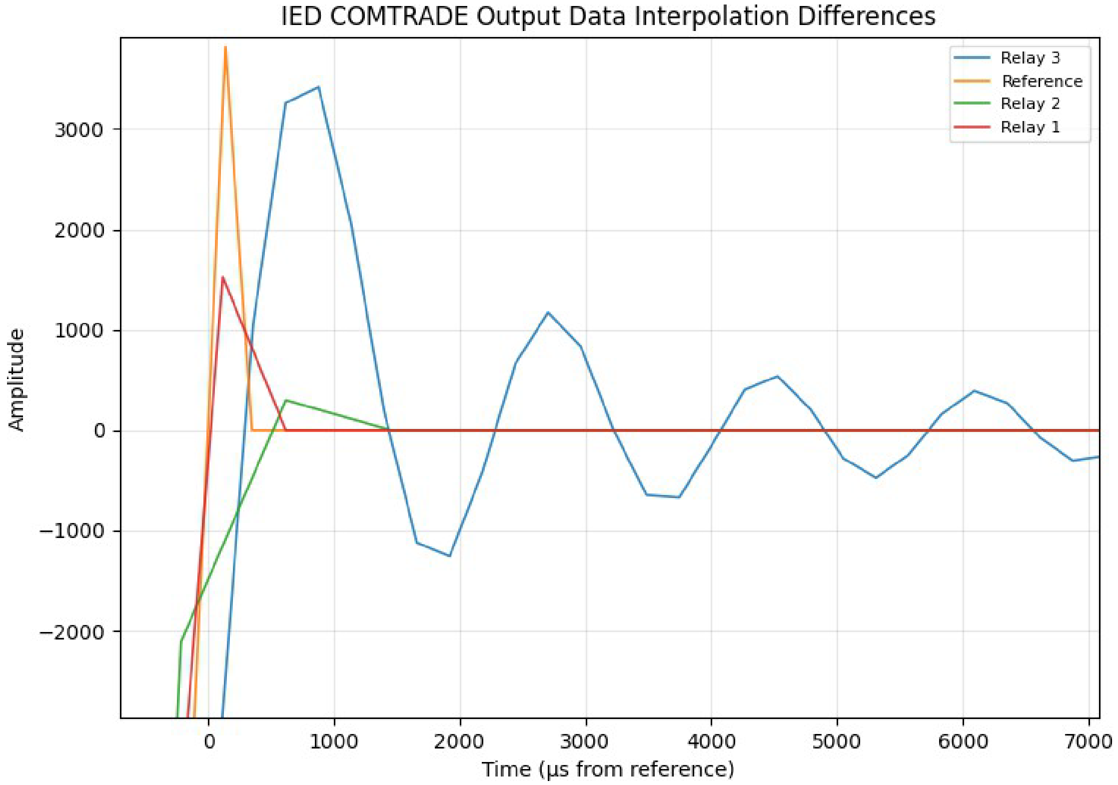
COMTRADE Zero Crossing Offset

- Zero crossings were used to calculate time offset
- Offset was found to be stable over most portions of waveform





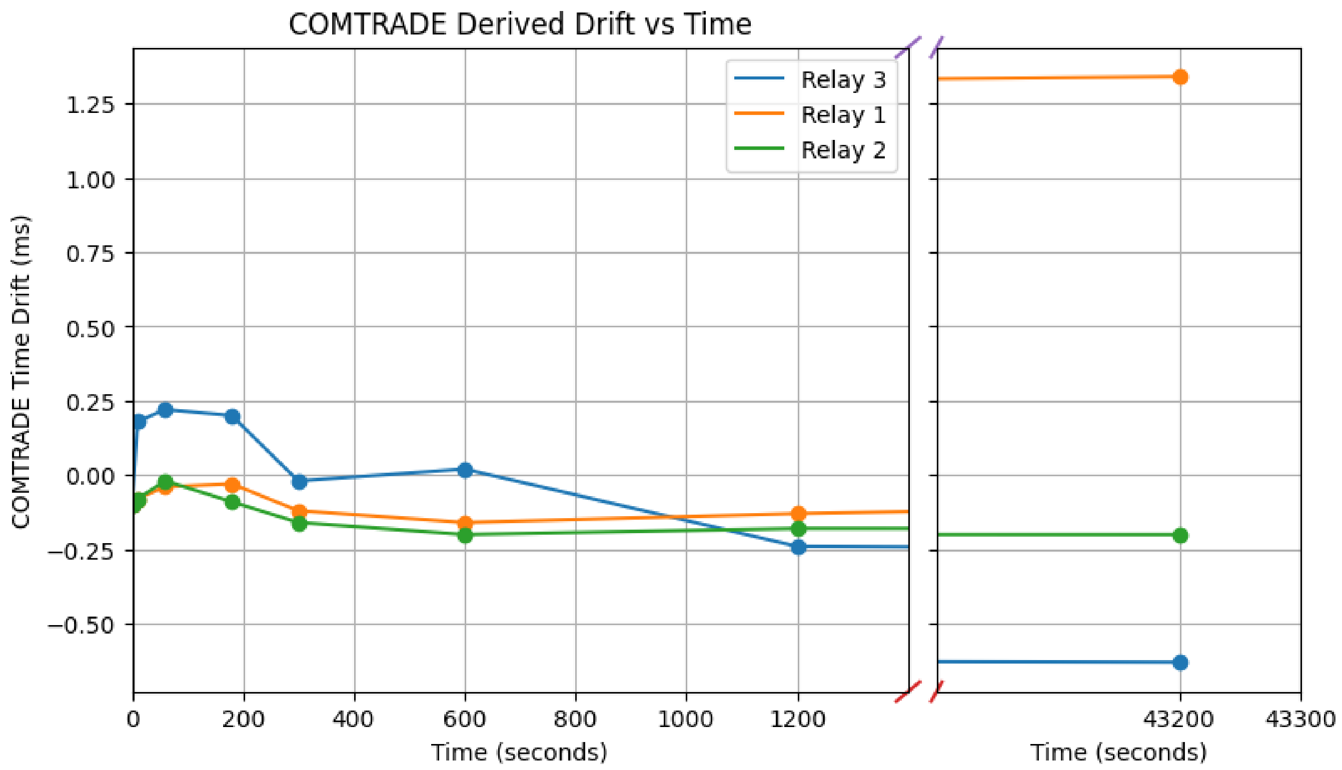
COMTRADE Interpolation Differences



- Differences in the waveforms (outside of time offset) can be seen at beginning and end of injection
- Differences are consistent with different interpolation methodologies from data points (linear, spline)
- Injected waveform does not vary frequency or amplitude, so within a cycle waveforms match outside of time offset
- Only zero crossings after waveform was settled were used for time offset calculations

COMTRADE Derived Drift vs Time

- Some vendors provided specifications for expected unsynchronized drift
- Worst drift tested was 1.34ms over 12 hours



Takeaways & Conclusions

Conclusions

- Specifications are not always available for IEDs that list synchronization accuracy or COMTRADE output accuracy
- All IEDs tested were significantly more accurate for drift than suggested by common relay specifications
- COMTRADE outputs in relays tested were not accurate enough to validate 1us timing accuracy by orders of magnitude.
- Testing of time synchronization accuracy and functionality is difficult with many IEDs due to lack of data output. This is not ideal in the power industry, due to rigorous testing standards.
- System level testing is important to validate that IEDs and network hardware interoperate with each other

Improvements

- Compare state of the art IEDs vs most commonly implemented
- Work with relay vendors to ensure full data output capabilities are being used for testing
- Add merging units into the testing
- Add additional vendors to the testing setup

Thank You For Your Time

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