# Evaluation of Precision Time Synchronisation Methods for Substation Applications

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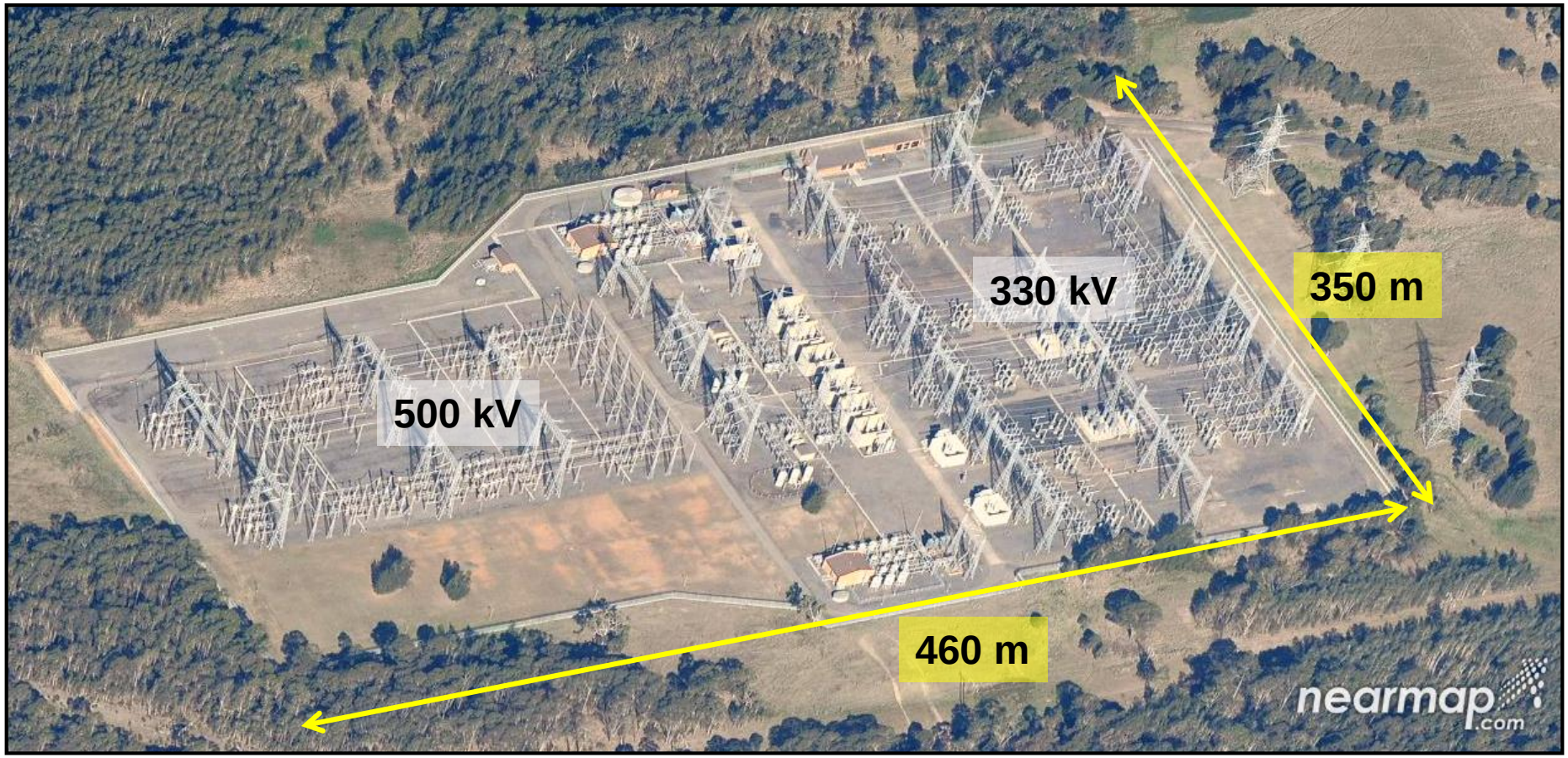
# Presentation Outline

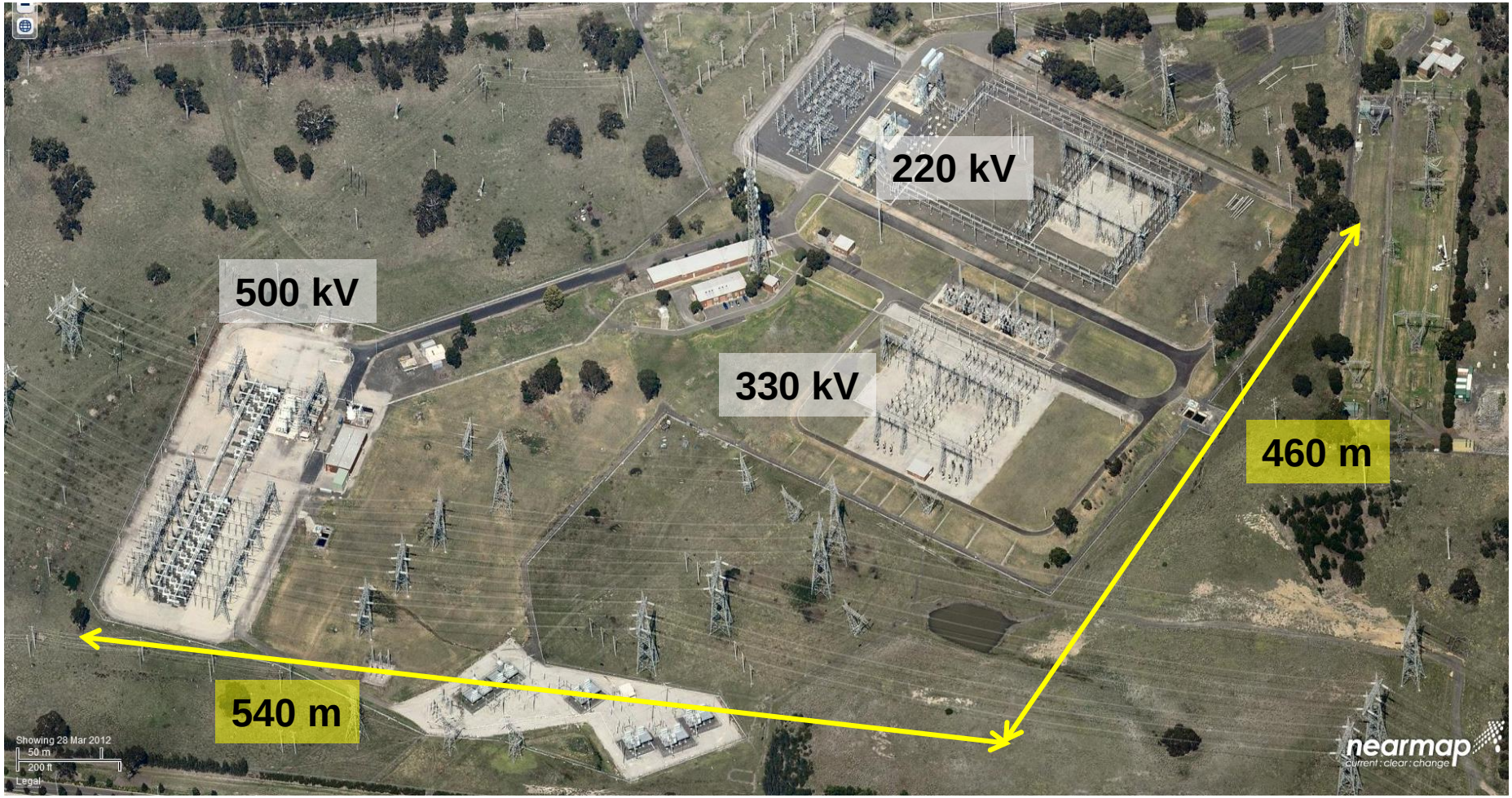
- High voltage substations
  - Substation applications
  - Synchronisation requirements
- Synchronisation methods
- Performance tests
- Discussion of results
- Conclusions

# Transmission Substations




*Aerial photograph from NearMap Pty Ltd (www.nearmap.com)*

# Transmission Substations

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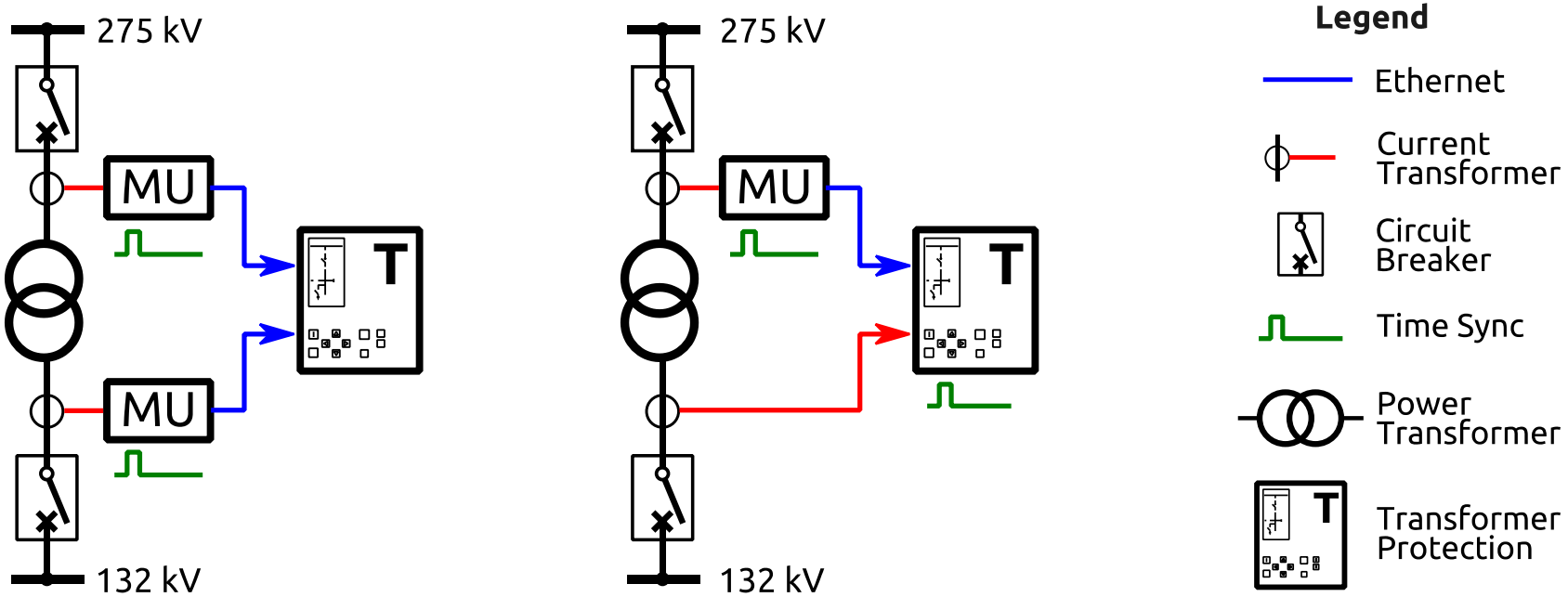
# The Need for Accurate Synchronisation

- Power system incident investigation
- Phasor monitoring (magnitude & angle)
- Process bus sample synchronisation



# Performance Requirements

## Process Bus

IEC 61850-5 timing classes

- UCA “9-2LE” requires ±1 µs to meet P2 (overall accuracy).

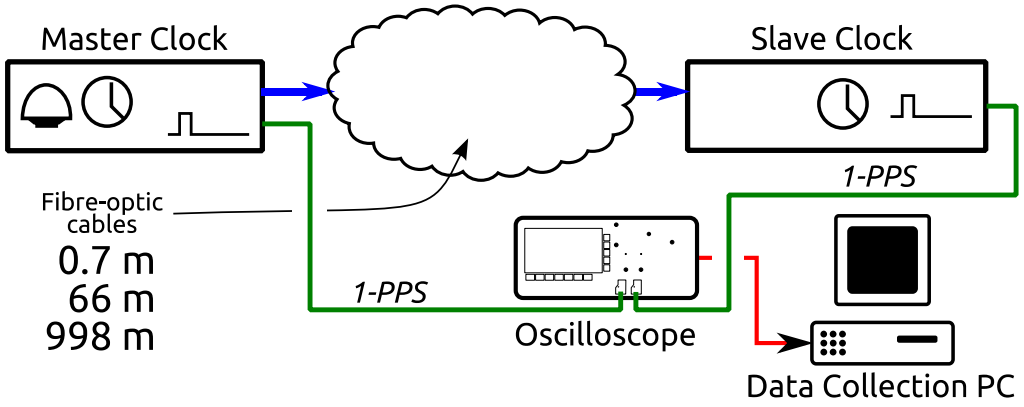
| Prot. Class | Required Accuracy | Timing Class (Ed .1 / 2) |
|---|---|---|
| P1 | ± 25 µs | T3 / TS3 |
| P2 | ± 4 µs | T4 / TS4 |
| P3 | ± 1 µs | T5 / TS5 |

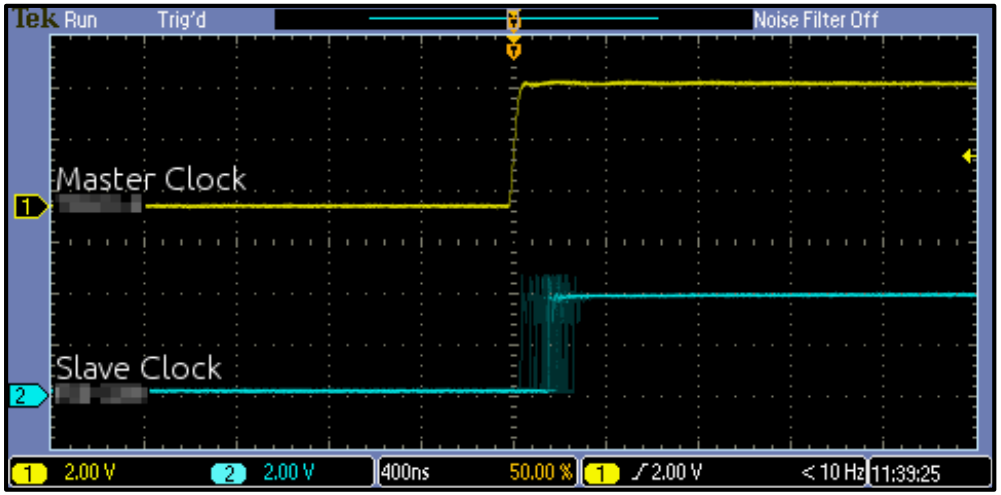
## Synchrophasors

IEEE Std C37.118.1 ‘Total Vector Error’ <1%.

- 26 µs (60 Hz) or 31 µs (50 Hz) if no magnitude error or CT/VT phase error.
- Suggested in several papers that ±1 µs be used as synchronisation accuracy.

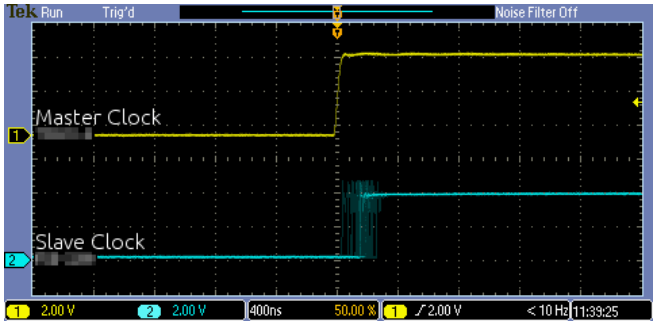
# Test Equipment

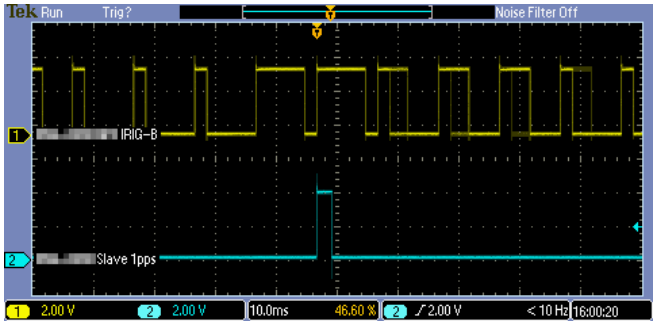



# Time Synchronisation Methods

- One pulse per second (1PPS)
  - The simplest method
- IRIG-B
  - Widely used substation timing
- IEEE 1588 Precision Time Protocol (PTP)
  - The “power profile” specified in IEEE Std C37.238 was used.



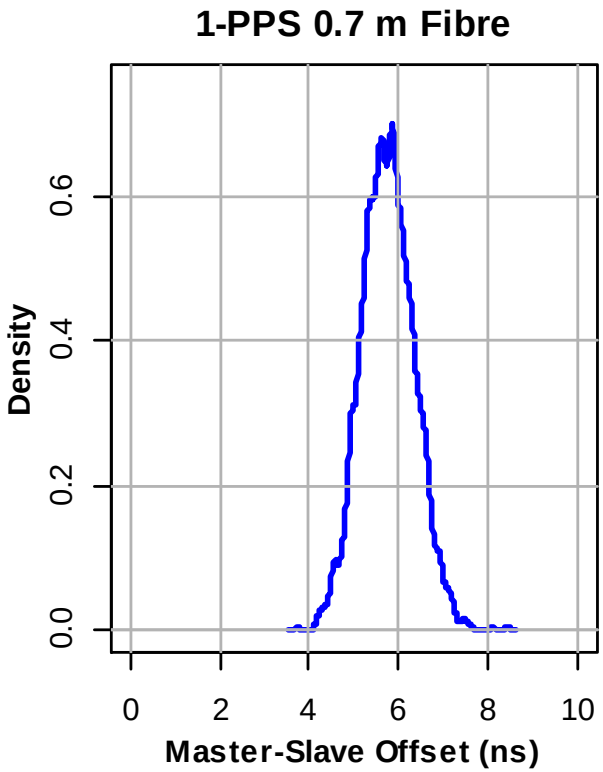



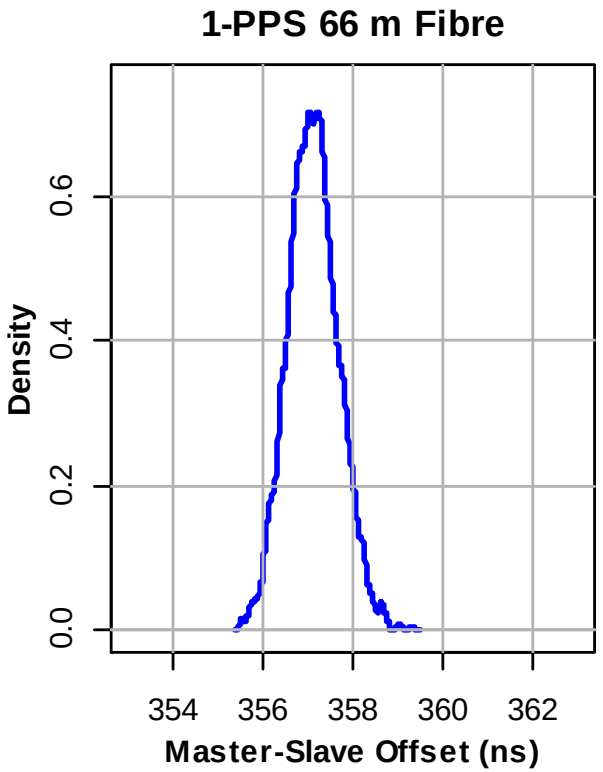

| Time | Length | 2-Step | Correction | Info |
|---|---|---|---|---|
| 0.7807 | 82 | False | 0 | Announce Message |
| 0.7815 | 64 | True | 0 | Sync Message |
| 1.0201 | 72 | True | 0 | Path_Delay_Resp Message |
| 1.023C | 72 | False | 0 | Path_Delay_Resp_Follow_Up Message |
| 1.036C | 64 | False | 3361370 | Follow_Up Message |
| 1.668S | 72 | False | 0 | Path_Delay_Req Message |
| 1.672З | 72 | False | 0 | Path_Delay_Req Message |
| 1.804C | 64 | True | 0 | Sync Message |
| 2.043S | 72 | True | 0 | Path_Delay_Resp Message |
| 2.047C | 72 | False | 0 | Path_Delay_Resp_Follow_Up Message |
| 2.059З | 82 | False | 0 | Announce Message |
| 2.0617 | 64 | False | 2101865 | Follow_Up Message |
| 2.677C | 72 | False | 0 | Path_Delay_Req Message |
| 2.6811 | 72 | False | 0 | Path_Delay_Req Message |
| 2.827S | 64 | True | 0 | Sync Message |

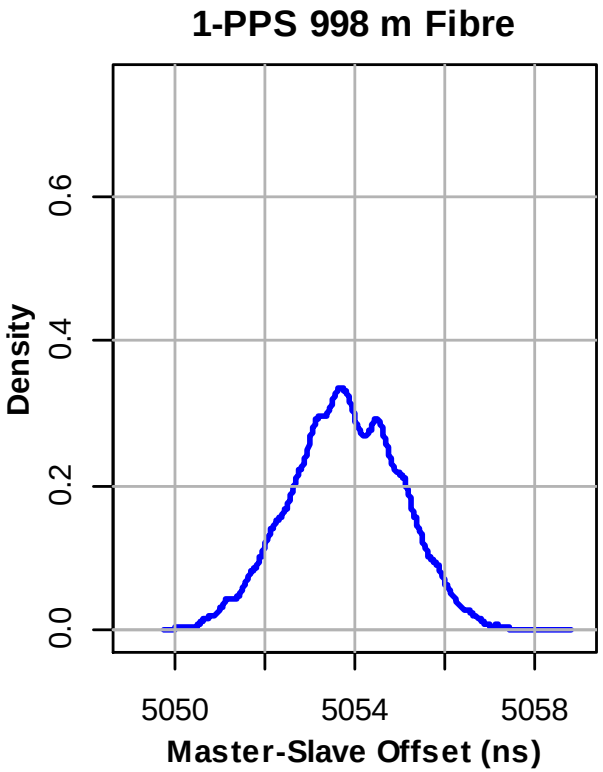
# PTP Message Parameters

| Parameter | Setting |
|---|---|
| Sync message rate | 1 s |
| Announce message rate | 1 s |
| Path delay mechanism | Peer to peer |
| Path delay message rate | 1 s |
| Line rate | 100 Mb/s |
| Message type | Layer 2 multicast |

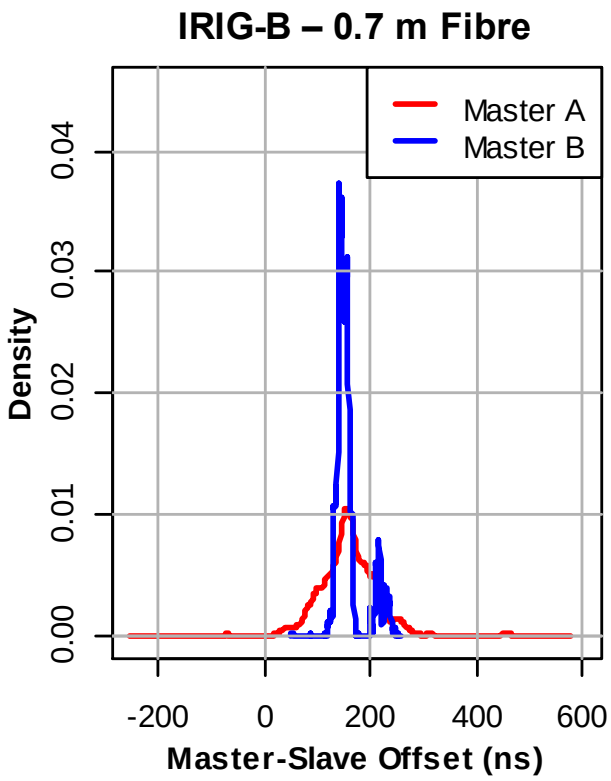
# One Pulse per Second

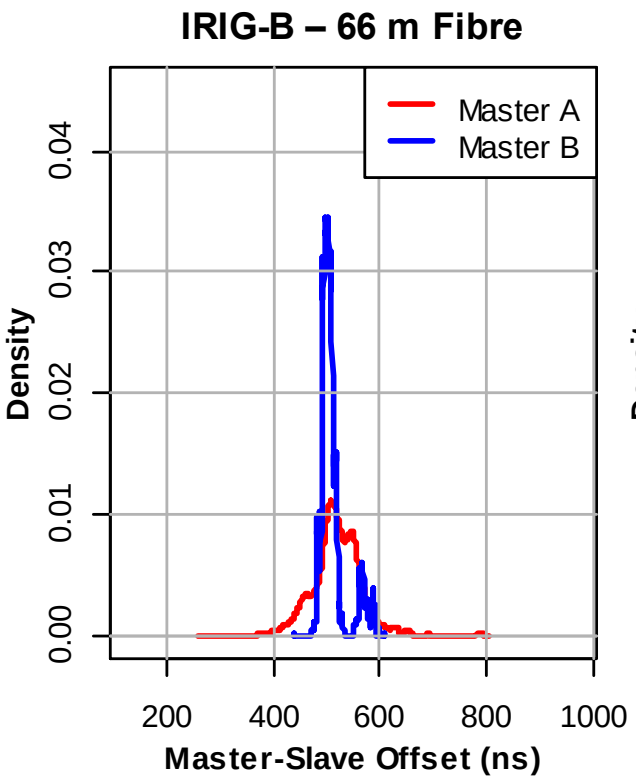


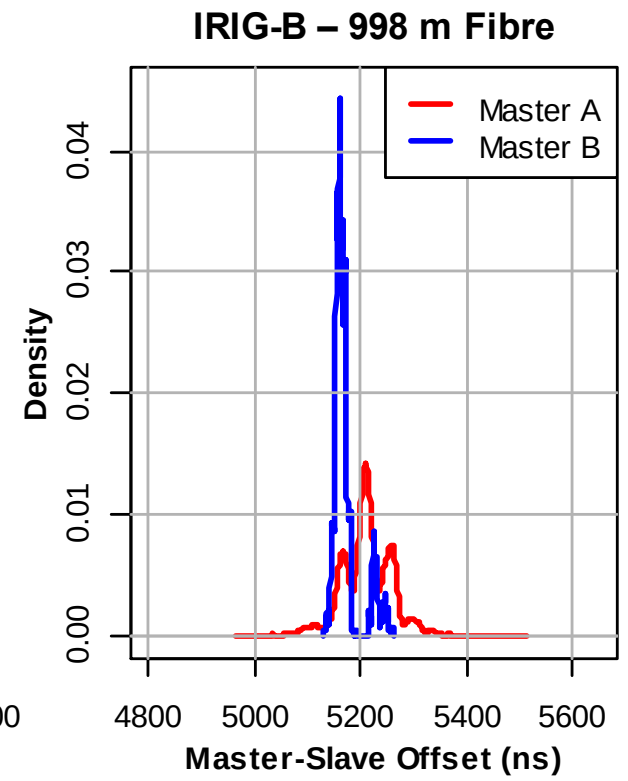



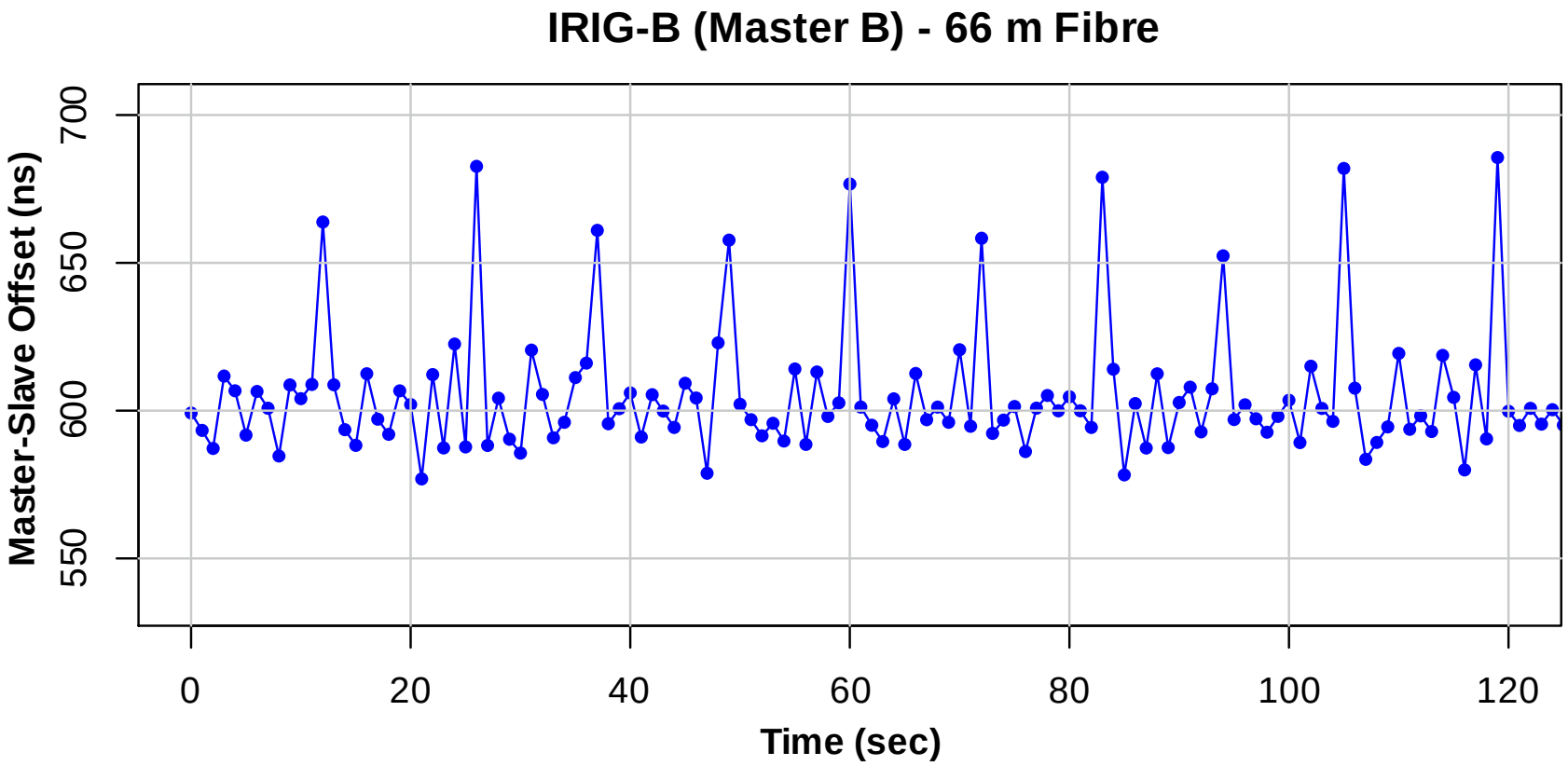
# IRIG-B



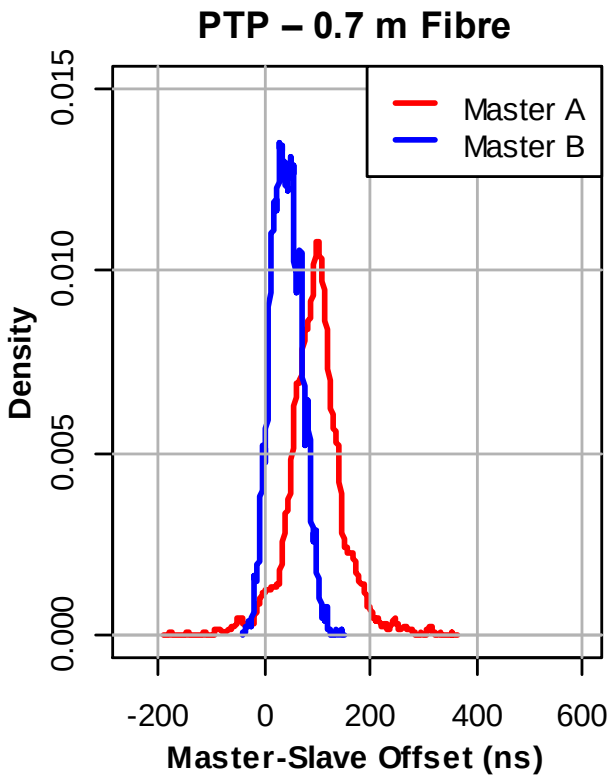



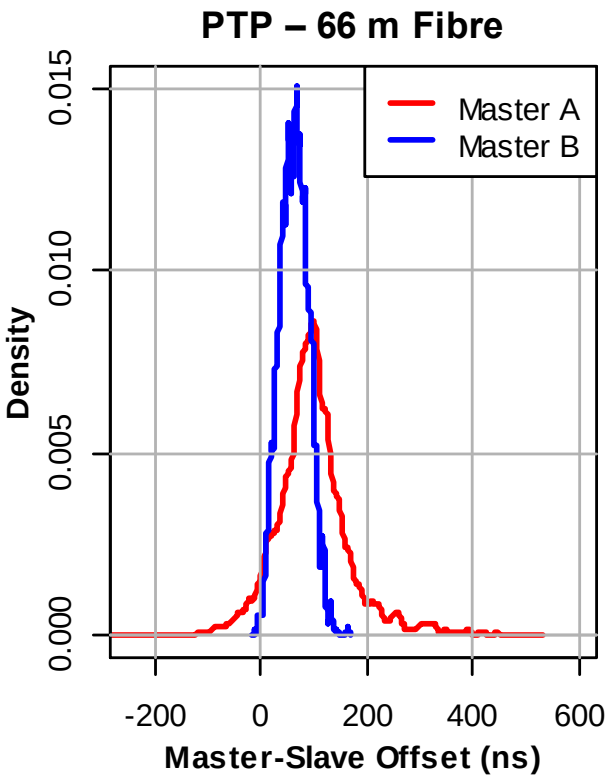



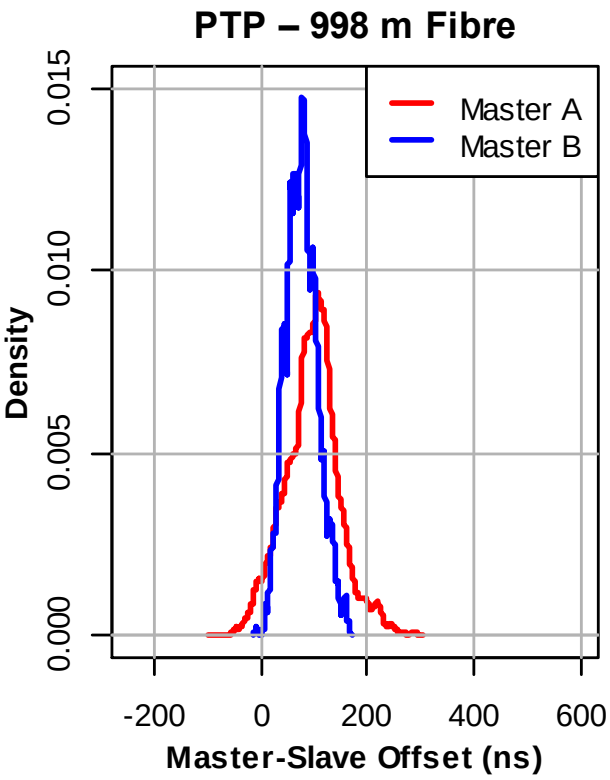
# Bimodal IRIG-B



# Precision Time Protocol



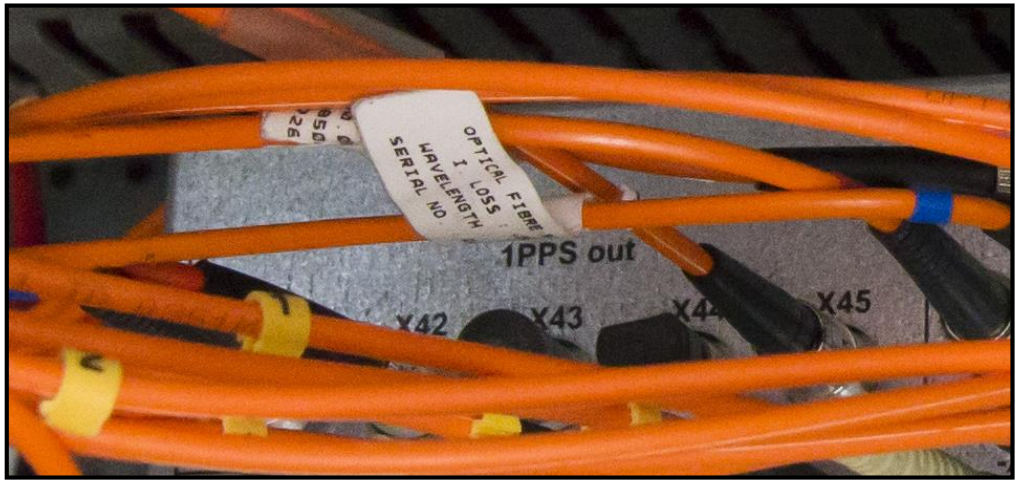



# Statistical Analysis

| Method | 66 m Fibre | 998 m Fibre |
|---|---|---|
| Predicted Delay | $t_d = 330\,ns$ | $t_d = 4493\,ns$ |
| 1-PPS | $\overline{\Delta t_d} = 351\,ns$<br>$s_{t_d} = 0.561\,ns$ | $\overline{\Delta t_d} = 5048\,ns$<br>$s_{t_d} = 1.23\,ns$ |
| IRIG-B Master A | $\overline{\Delta t_d} = 361\,ns$<br>$s_{t_d} = 52.3\,ns$ | $\overline{\Delta t_d} = 5054\,ns$<br>$s_{t_d} = 52.0\,ns$ |
| IRIG-B Master B | $\overline{\Delta t_d} = 352\,ns$<br>$s_{t_d} = 24.6\,ns$ | $\overline{\Delta t_d} = 5015\,ns$<br>$s_{t_d} = 25.6\,ns$ |
| PTP Master A | $\overline{\Delta t_d} = 0.904\,ns$<br>$s_{t_d} = 73.6\,ns$ | $\overline{\Delta t_d} = -1.62\,ns$<br>$s_{t_d} = 52.1\,ns$ |
| PTP Master B | $\overline{\Delta t_d} = 21.2\,ns$<br>$s_{t_d} = 26.8\,ns$ | $\overline{\Delta t_d} = 34.1\,ns$<br>$s_{t_d} = 30.0\,ns$ |

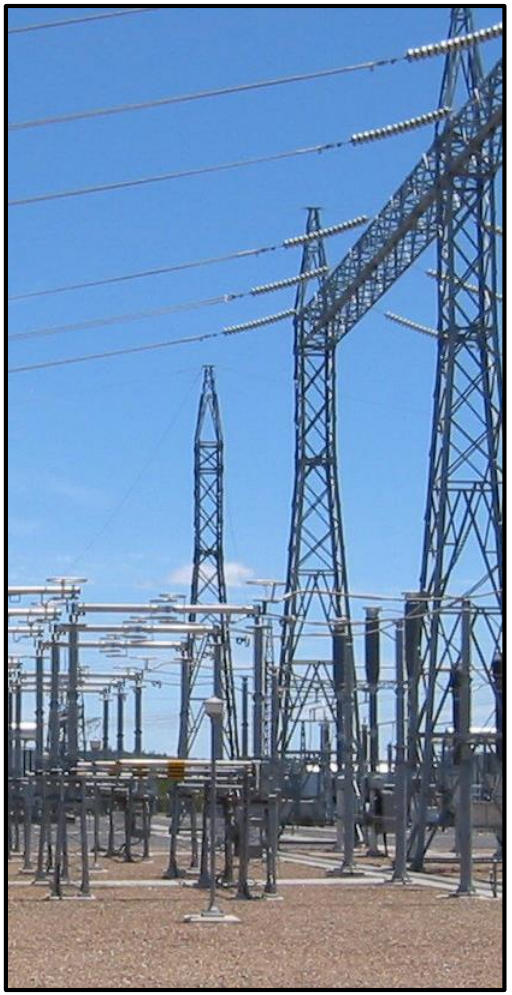
# Discussion – Performance

- 1-PPS provides the least jitter:
  - No ‘time of day’ information
- IRIG-B can meet ±1 µs requirements
  - No compensation for propagation delay
- PTP with C37.238 meets ±1 µs requirements
  - Compensates for propagation delay
  - Supports redundancy of grandmasters



# Discussion – Signal Distribution

- Optical cable used to take signals out to the switchyard.
- 1-PPS and IRIG-B require multiport repeaters
  - Introduces error
  - OTDR cannot see through repeater
- PTP with C37.238 requires transparent clocks
  - Can share Ethernet with process bus or PMU connection.



# Discussion – Compatibility

- 1-PPS is most compatible, but least information
- IRIG-B clients can have mutually incompatible requirements
  - Local time vs UTC
- PTP + C37.238 has limited options
  - Improves compatibility of grandmasters and slave clocks
  - Must use TAI as time reference

# Conclusions

- 1-PPS and IRIG-B can be used for small substations, or where merging units are in the control room.
- PTP overcomes shortcomings of 1-PPS and IRIG-B for large substations.
- PTP benefits are not at the expense of synchronising performance.
  - Similar performance between IRIG-B and PTP from the same clock hardware

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