GPS Timing In Substations at Dominion Energy

CIGRE USNC Grid of the Future

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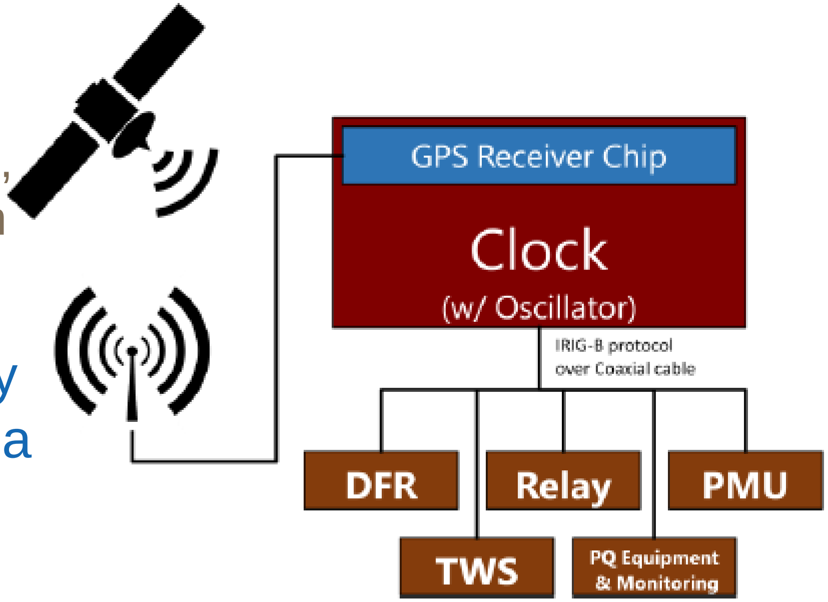
History of our substation timing

- Since the early to mid 90s, Dominion has been using substation clocks to synchronize monitoring equipment.
- The first clocks used were GOES satellite and WWVB receivers.
- Began the transition to GPS clocks in the late 90s as costs lowered.

Current substation timing architecture

- A single GPS satellite clock installed at all Dominion transmission substations (100kV and above) and many distribution substations.
  - Located inside substation control houses, these are stand-alone GPS clocks, which have an internal GPS receiver chip
- Time synchronization is provided to many substation devices from the GPS clock via IRIG-B over coaxial cable
  - Includes Digital Fault Recorders (DFRs), protective relays, Phasor Measurement Units (PMUs), Traveling Wave fault locators (TWS), meters, and more.

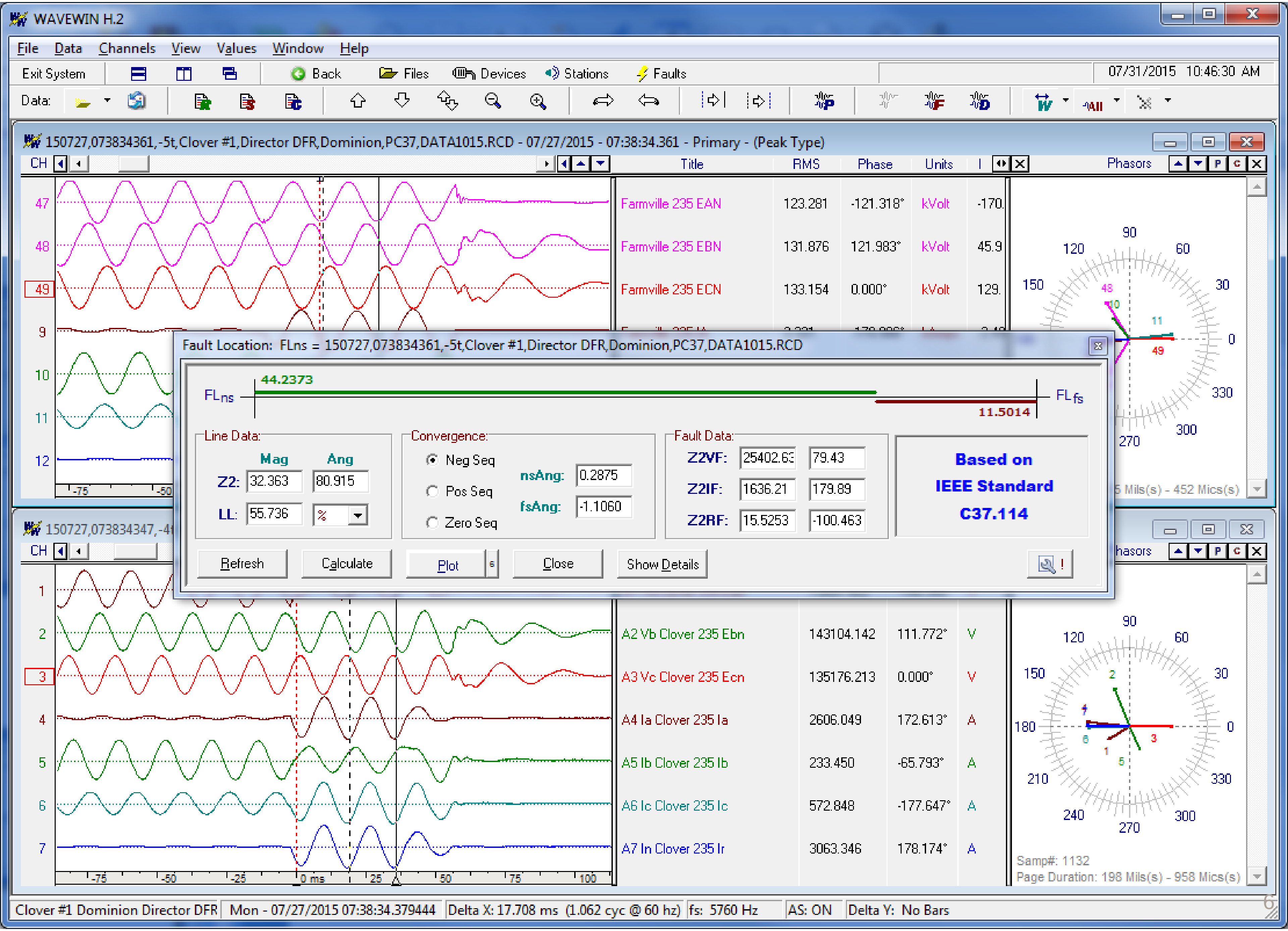


Current substation timing

- Until recently, substation timing has been taken for granted – it hasn't been as carefully scrutinized and tested as other equipment.
- Requirements & expectations are changing with the advent of new devices and expansion of substation digital devices that are able to make use of, or are dependent on, precise timing.
    - Starting to see more issues and alarms than previously

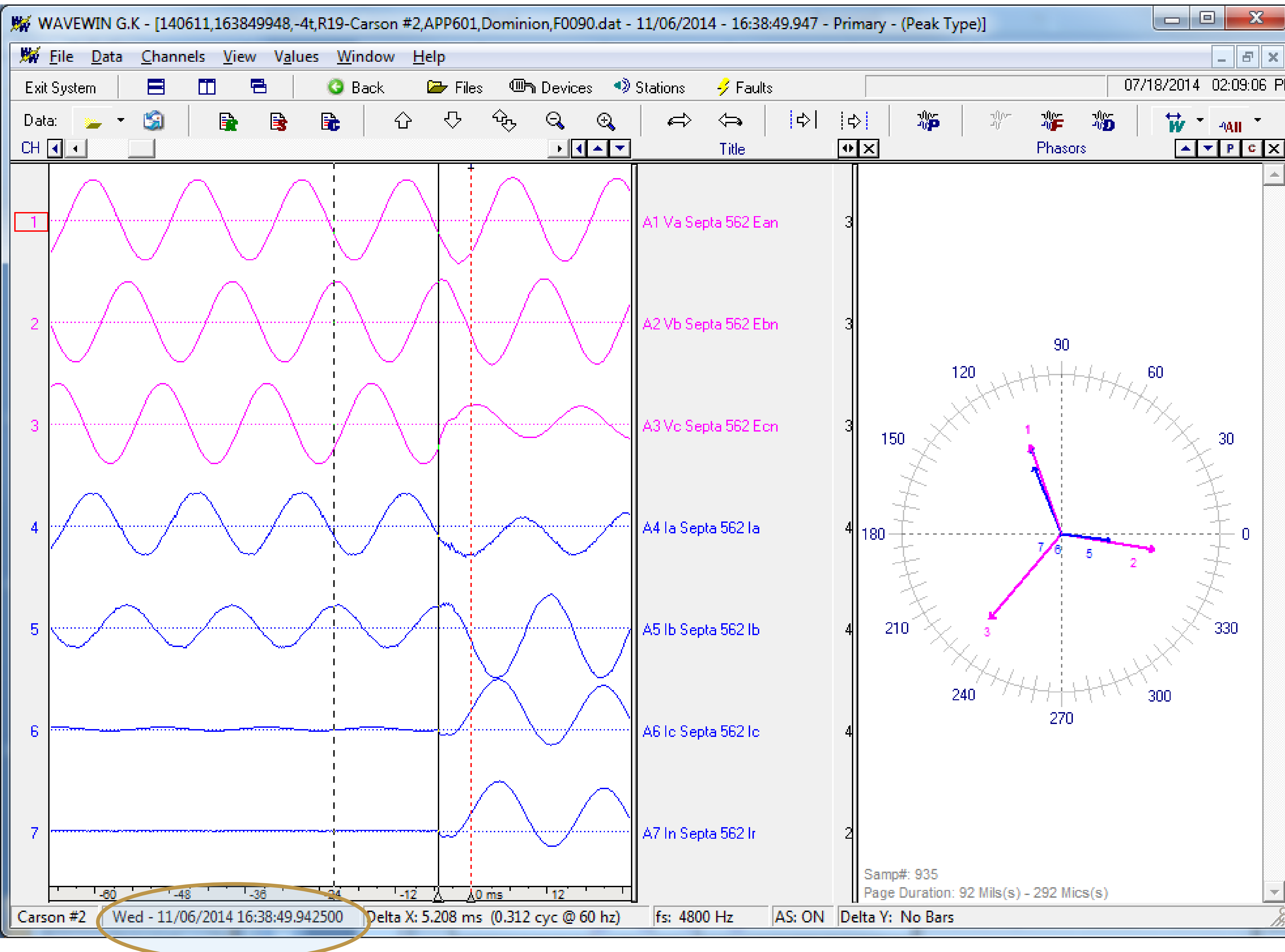
Timing Applications - DFRs

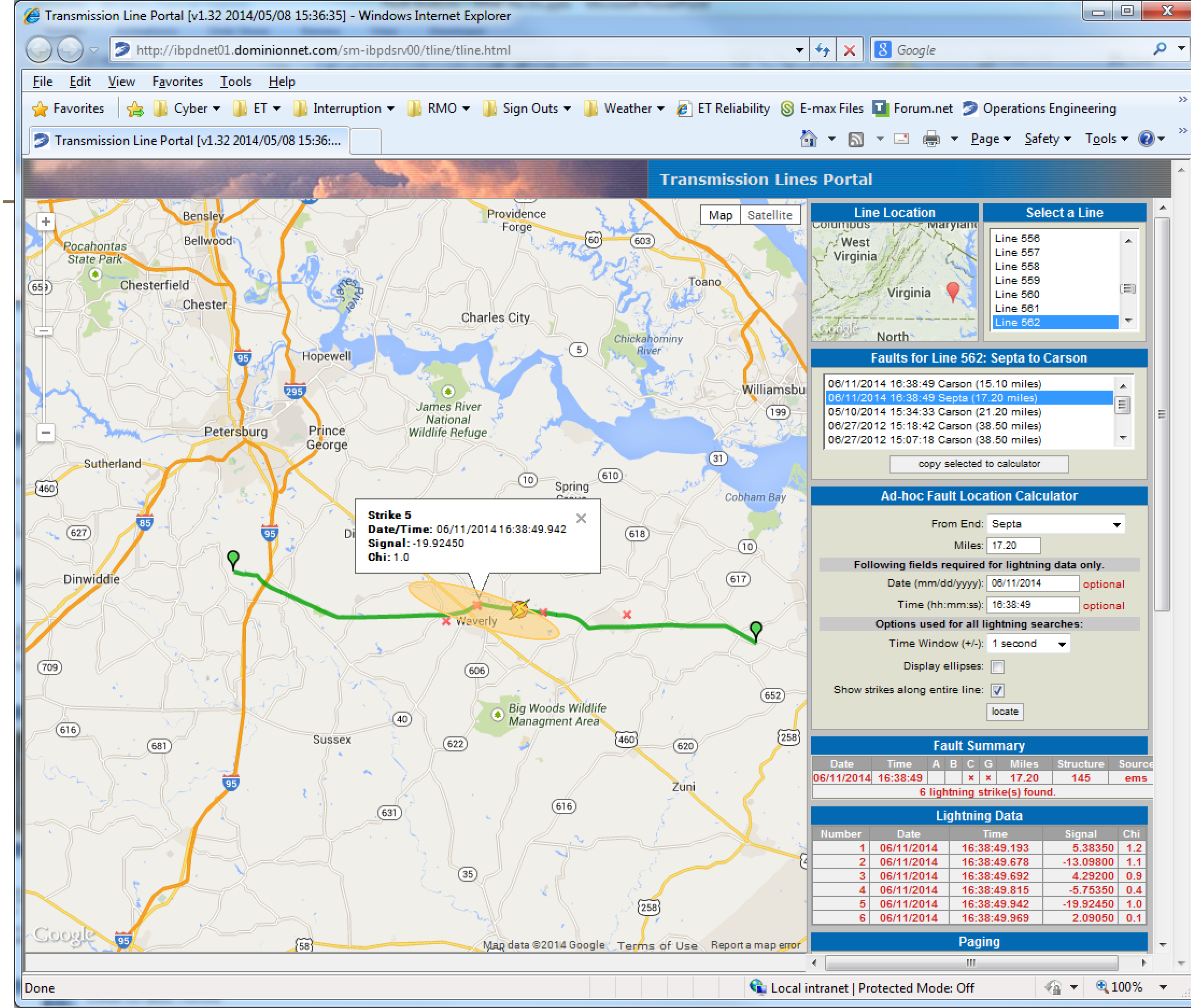
- Digital fault recorders (DFRs) (1 ms) - monitors the power flowing on the grid and take high sample rate snapshots of the currents and voltages. Time synchronized data can be matched with other recorders to analyze system events.


WAVEWIN H.2
File Data Channels View Values Window Help
Exit System Back Files Devices Stations Faults
07/31/2015 10:46:30 AM
Data:
150727,073834361,-5t,Clover #1,Director DFR,Dominion,PC37,DATA1015.RCD - 07/27/2015 - 07:38:34.361 - Primary - (Peak Type)
CH Title RMS Phase Units Phasors
Farmville 235 EAN 123.281 -121.318° kVolt
Farmville 235 EBN 131.876 121.983° kVolt
Farmville 235 ECN 133.154 0.000° kVolt
Fault Location: FLns = 150727,073834361,-5t,Clover #1,Director DFR,Dominion,PC37,DATA1015.RCD
FLns 44.2373 11.5014 FLfs
Line Data:
Mag Ang
Z2: 32.363 80.915
LL: 55.736 %
Convergence:
Neg Seq
Pos Seq
Zero Seq
nsAng: 0.2875
fsAng: -1.1060
Fault Data:
Z2VF: 25402.63 79.43
Z2IF: 1636.21 179.89
Z2RF: 15.5253 -100.463
Based on IEEE Standard C37.114
Refresh Calculate Plot Close Show Details
A2 Vb Clover 235 Ebn 143104.142 111.772° V
A3 Vc Clover 235 Ecn 135176.213 0.000° V
A4 Ia Clover 235 Ia 2606.049 172.613° A
A5 Ib Clover 235 Ib 233.450 -65.793° A
A6 Ic Clover 235 Ic 572.848 -177.647° A
A7 In Clover 235 Ir 3063.346 178.174° A
Samp#: 1132
Page Duration: 198 Mils(s) - 958 Mics(s)
Clover #1 Dominion Director DFR
Mon - 07/27/2015 07:38:34.379444
Delta X: 17.708 ms (1.062 cyc @ 60 hz)
fs: 5760 Hz
AS: ON
Delta Y: No Bars

Timing Applications - Lightning

- Lightning correlation (1 ms) – Oscillography data can be used to determine fault inception time, which can then be used to determine if lightning caused the event by comparing our recorded event time to lightning strike data from a lightning service, such as FALLS from Vaisala.

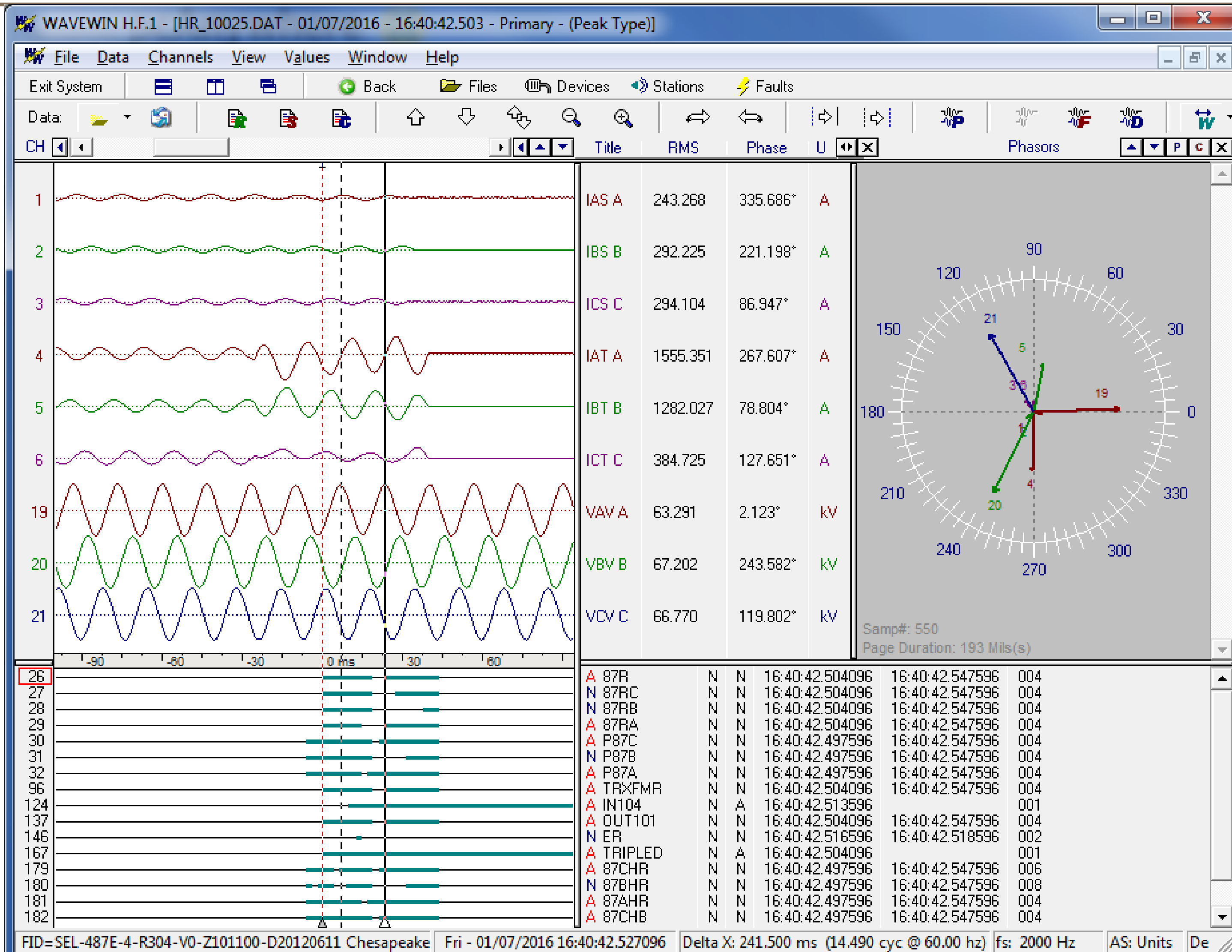

WAVEWIN G.K - [140611,163849948,-4t,R19-Carson #2,APP601,Dominion,F0090.dat - 11/06/2014 - 16:38:49.947 - Primary - (Peak Type)]
File Data Channels View Values Window Help
Exit System
Back
Files
Devices
Stations
Faults
07/18/2014 02:09:06 PI
Data:
CH
Title
Phasors
A1 Va Septa 562 Ean
A2 Vb Septa 562 Ebn
A3 Vc Septa 562 Ecn
A4 Ia Septa 562 Ia
A5 Ib Septa 562 Ib
A6 Ic Septa 562 Ic
A7 In Septa 562 Ir
-60
-48
-36
-24
-12
0 ms
12
90
120
60
150
30
180
0
210
330
240
300
270
Samp#: 935
Page Duration: 92 Mils(s) - 292 Mics(s)
Carson #2
Wed - 11/06/2014 16:38:49.942500
Delta X: 5.208 ms (0.312 cyc @ 60 hz)
fs: 4800 Hz
AS: ON
Delta Y: No Bars


Transmission Line Portal [v1.32 2014/05/08 15:36:35] - Windows Internet Explorer
http://ibpdnet01.dominionnet.com/sm-ibpdsrv00/tline/tline.html
File Edit View Favorites Tools Help
Favorites Cyber ET Interruption RMO Sign Outs Weather ET Reliability E-max Files Forum.net Operations Engineering
Transmission Lines Portal
Map Satellite
Strike 5
Date/Time: 06/11/2014 16:38:49.942
Signal: -19.92450
Chi: 1.0
Line Location
Select a Line
Line 556
Line 557
Line 558
Line 559
Line 560
Line 561
Line 562
Faults for Line 562: Septa to Carson
06/11/2014 16:38:49 Carson (15.10 miles)
06/11/2014 16:38:49 Septa (17.20 miles)
05/10/2014 15:34:33 Carson (21.20 miles)
06/27/2012 15:18:42 Carson (38.50 miles)
06/27/2012 15:07:18 Carson (38.50 miles)
copy selected to calculator
Ad-hoc Fault Location Calculator
From End: Septa
Miles: 17.20
Following fields required for lightning data only.
Date (mm/dd/yyyy): 06/11/2014 optional
Time (hh:mm:ss): 16:38:49 optional
Options used for all lightning searches:
Time Window (+/-): 1 second
Display ellipses:
Show strikes along entire line:
locate
Fault Summary
Date | Time | A | B | C | G | Miles | Structure | Source
06/11/2014 | 16:38:49 | | | × | × | 17.20 | 145 | ems
6 lightning strike(s) found.
Lightning Data
Number | Date | Time | Signal | Chi
1 | 06/11/2014 | 16:38:49.193 | 5.38350 | 1.2
2 | 06/11/2014 | 16:38:49.678 | -13.09800 | 1.1
3 | 06/11/2014 | 16:38:49.692 | 4.29200 | 0.9
4 | 06/11/2014 | 16:38:49.815 | -5.75350 | 1.0
5 | 06/11/2014 | 16:38:49.942 | -19.92450 | 1.0
6 | 06/11/2014 | 16:38:49.969 | 2.09050 | 0.1
Paging
Done
Local intranet | Protected Mode: Off
100%

Timing Applications – Protective relays

- Protective relays (1 ms) - similar to DFR in use of timing.
  - Provide time stamping of waveform data and internal logic events (SER records).

Timing Applications – Protective relays

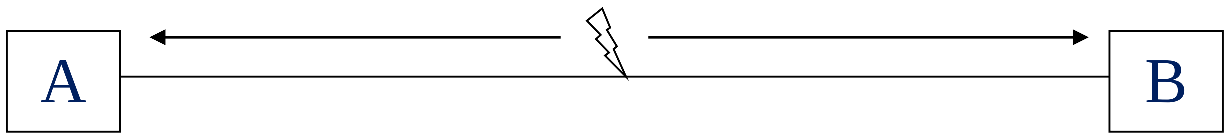


Timing Applications - TWS

- Traveling wave fault location (0.1 µs) - Uses precise time to measure high frequency waves generated by faults on transmission lines.
    - Wavefront arrival time is used to calculate fault location to within 500 feet or less.

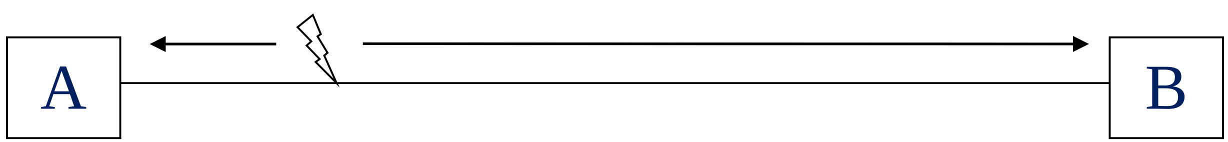
Travelling Wave Theory

Fault in middle
of the line



Travelling wave arrives at both
ends at the same time

Fault near
station “A”

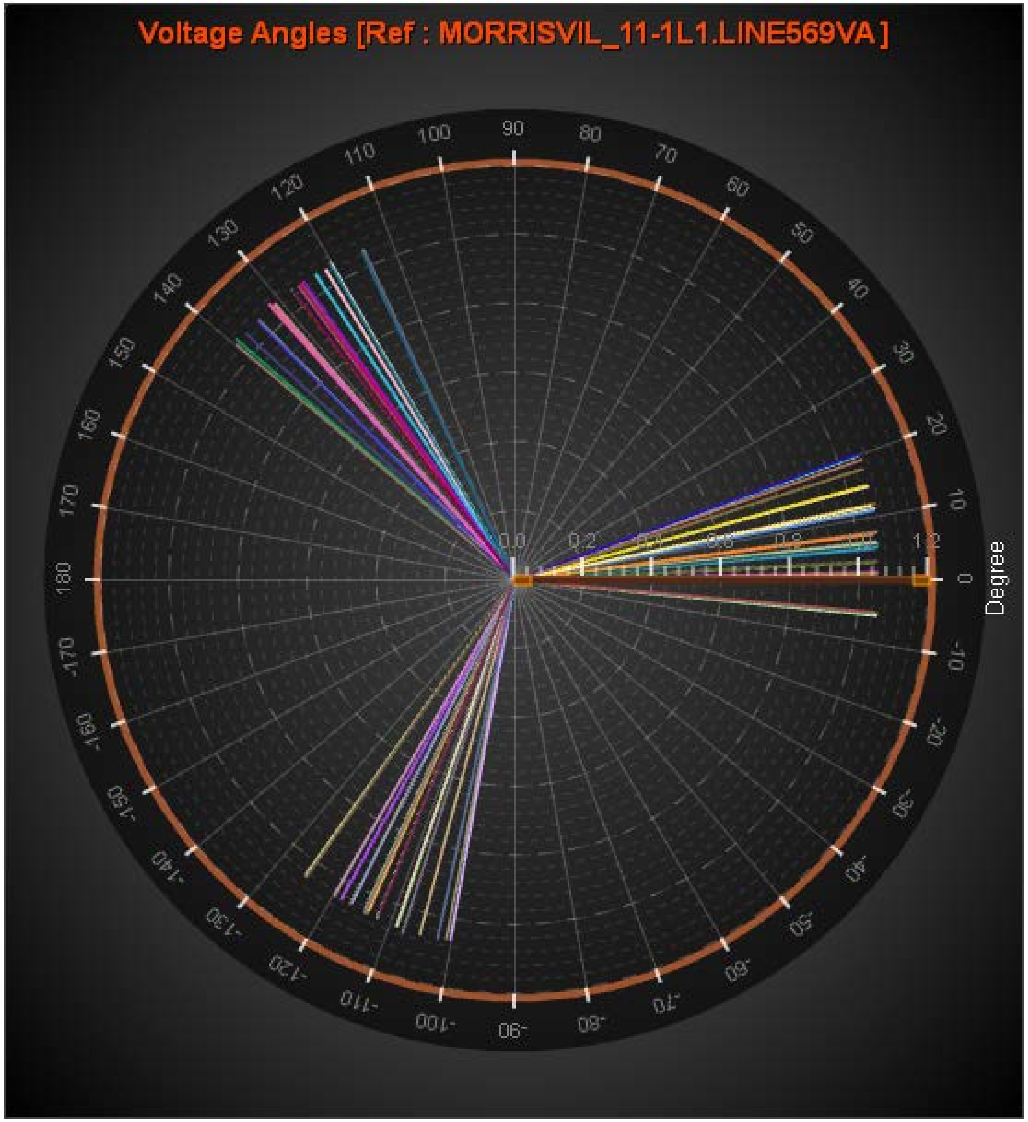


Travelling wave arrives at “A”
before “B”

Timing Applications - Synchrophasors

- Synchrophasors (1 µs)
- Synchrophasors are precisely time stamped voltage or current vectors.
- Measurements are taken simultaneously from across the grid.
- Operators can determine the health of the system from these measurements.

Synchrophasor angles



Timing Applications – PQ monitors

- Power quality monitors (1 ms) - mostly on distribution level voltages, 34.5kV and below. Timing is used to correlate events recorded at different locations.
    - Utility and customer recordings.
    - Distribution events caused by transmission events.

- <u>Future devices to receive time sync:</u> Power line Carrier sets
    - Recent event with PLC issues. No time sync on the PLC SER led to difficult and extended event analysis and RCA.

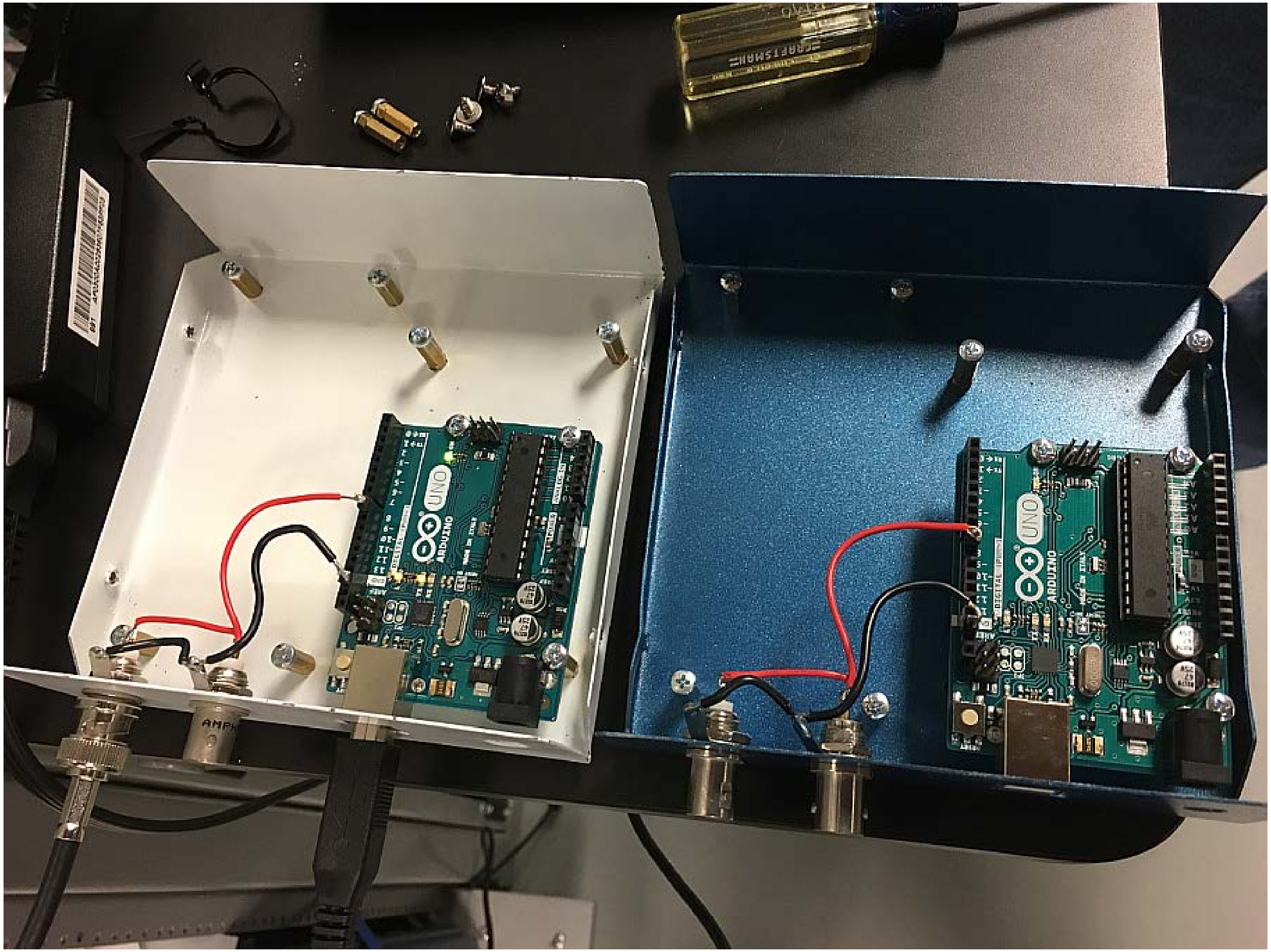
Timing Problems

- Timing events
  - Problems surrounding the changeover during Daylight Savings Time transitions
  - Leap second handling
  - Year rollover issues
- Loss of signal/hardware issues
  - Cabling
  - Antenna mounting
  - Installation practices

Timing Problems

- Most issues we have experienced have been in the clock firmware, not in the receiver firmware or end-device firmware
- Monitoring and logging of the IRIG-B timing output from the clock is very insightful.
  - Without monitoring IRIG-B output of clock, when time errors occur we do not know if the problem is the clock, receiver, or the end-device (PMU, DFR, etc.)
- By decoding the IRIG data stream we learned a lot. This data was previously unavailable to us due to a lack of tools.
- New IRIG monitoring tools are now on the market.

$50 IRIG monitor



$50 IRIG monitor

Year	Day	Time	LSP	LS	DSP	DST	TZS	TZ Offset	TZ30M	TFOM	Parity	CTQ	SBS
16	366	18:59:56	1	0	0	0	1	5	0	0	1	0	68396
16	366	18:59:57	1	0	0	0	1	5	0	0	0	0	68397
16	366	18:59:58	1	0	0	0	1	5	0	0	0	0	68398
16	366	18:59:59	1	0	0	0	1	5	0	0	1	0	68399
16	366	18:59:60	1	0	0	0	1	5	0	0	1	0	68400
16	366	19:00:00	0	0	0	0	1	5	0	0	1	0	68400
16	366	19:00:01	0	0	0	0	1	5	0	0	0	0	68401
16	366	19:00:02	0	0	0	0	1	5	0	0	0	0	68402

$50 IRIG monitor

Year	Day	Time	LSP	LS	DSP	DST	TZS	TZ Offset	TZ30M	TFOM	Parity	CTQ	SBS
16	366	18:59:56	1	0	0	0	1	5	0	0	1	0	68396
16	366	18:59:57	1	0	0	0	1	5	0	0	0	0	68397
16	366	18:59:58	1	0	0	0	1	5	0	0	0	0	68398
16	366	18:59:59	1	0	0	0	1	5	0	0	1	0	68399
16	366	18:59:60	1	0	0	0	1	5	0	0	1	0	68400
16	366	19:00:00	0	0	0	0	1	5	0	0	1	0	68400
16	366	19:00:01	0	0	0	0	1	5	0	0	0	0	68401
16	366	19:00:02	0	0	0	0	1	5	0	0	0	0	68402

Leap year, year rollover to 2017, leap second addition,

and local time zone

Impact of June 2015 Leap Second

- **First real event that we monitored was the June 2015 Leap Second**
  - Had no expectations of problems, monitored multiple clock firmware versions (including newest) that we have deployed in field
  - Monitored out of curiosity, and to test out the IRIG-B logger
- **First sign of problem – 30 seconds after Leap Second occurred**
  - Main synchrophasor PDC server went to 100% CPU and 100% RAM usage
  - Stopped all PMU data flow to downstream applications

Impact of June 2015 Leap Second

- **Discovered all our substation clocks had a firmware bug that performed the leap second late (5 seconds or longer)**
  - Caused all PMU data to be one second later compared to actual UTC time, for as long as it took clocks to eventually perform the leap second
  - Main Synchrophasor PDC setup with a “wait time” of one second to keep PMU latency low
  - All PMU data rejected as “late” data by the PDC (data was thrown
- **This did impact all substation devices that have time synchronization (DFRs, relays, etc.)**
  - No operational impact to protection functions
  - Data records did have inaccurate timestamps until clocks did the leap second

Time should have progressed as:

19:59:58
19:59:59
19:59:60
20:00:00
20:00:01
20:00:02
20:00:03
20:00:04
20:00:05

Time actually progressed as:

Year	Day	Time	LSP	LS
2015	181	19:59:58	1	0
2015	181	19:59:59	1	0
2015	181	20:00:00	0	0
2015	181	20:00:01	0	0
2015	181	20:00:02	0	0
2015	181	20:00:03	0	0
2015	181	20:00:04	0	0
2015	181	20:00:05	0	0
2015	181	20:00:05	0	0
2015	181	20:00:06	0	0

Impacts of Timing Problems

SCADA data transfer with Comm. Processor

- Due to year roll over bug in clocks, relays set with incorrect year.
- New Comm. Processor had time checks, began filtering out SCADA traffic from relays with wrong date/time

Timing issues can impact automation

- 6th man and other polling software looking for specific timestamps.
- If records incorrectly time stamped, polling can ignore these records

New Timing Initiative

- Evaluating new clocks and technologies. Our current clock model is well over 10 years old.
- Timing has been an afterthought. Not treated with the same importance as other substation equipment. (Training)
- More rigorous testing of timing equipment:
  - We have purchased a GPS simulator to test clocks and firmware updates. (It costs less than a relay test set)
- Fundamental shift in our timing architecture:
  - Move towards better devices and architecture that ensure high accuracy and high availability of precise timing sources

Future Timing Initiatives

- **New specifications:**
  - Backup timing source (offsite PTP, for example)
  - Appropriate holdover oscillator
  - Local distribution of timing – consider IRIG-B alternatives such as PTP, NTP, fiber
  - Remote firmware updates
  - CIP compliance
  - Anti-spoofing and jamming detection and handling.
  - Data logging of time signals and sources.
  - Firmware locks on clocks
  - Thorough new firmware evaluation and testing process

Future Timing Initiatives

- We are in the process of developing a training module for the Relay technicians that covers the following topics (subject to change, this is still a work in progress)
  - Basic GPS and satellite clock theory
  - Substation timing clock usage
  - IRIG-B timing signal composition
  - Satellite clocks associated hardware
  - Installing a satellite clock
  - Programming a satellite clock
  - Installing firmware upgrade to a satellite clock

Example of tests to perform

- **Daylight Saving Time On:** transition from DST off to DST on
- **Daylight Saving Time Off:** transition from DST on to DST off
- **Year Rollover UTC, no leap second:** year transition at UTC midnight with no leap second
- **Year Rollover UTC, leap second add:** year transition at UTC midnight adding leap second
- **Year Rollover UTC, leap second remove:** year transition at UTC midnight removing leap second
- **Year Rollover Local:** year transition at local time
- **June Leap Second Add:** midyear leap second addition
- **June Leap Second Remove:** midyear leap second removal
- **GPS Epoch Week Rollover:** transition from week 1023 to week 0
- **Holdover:** ability of clock to retain time during loss of signal

Conclusions

- Timing in electric substations is becoming more important as more technologies and control schemes become available that rely on accurate time.
  - Need to establish a highly accurate and highly redundant/available substation timing architecture
- Treat the timing system with the same thoroughness given to other substation systems.
- Need to keep up to date with industry developments in timing and the state of GNSS.