GPS Timing In Substations at Dominion

NIST Timing Challenges in the Smart Grid workshop

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Dominion Virginia Power

History of 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.

Current timing

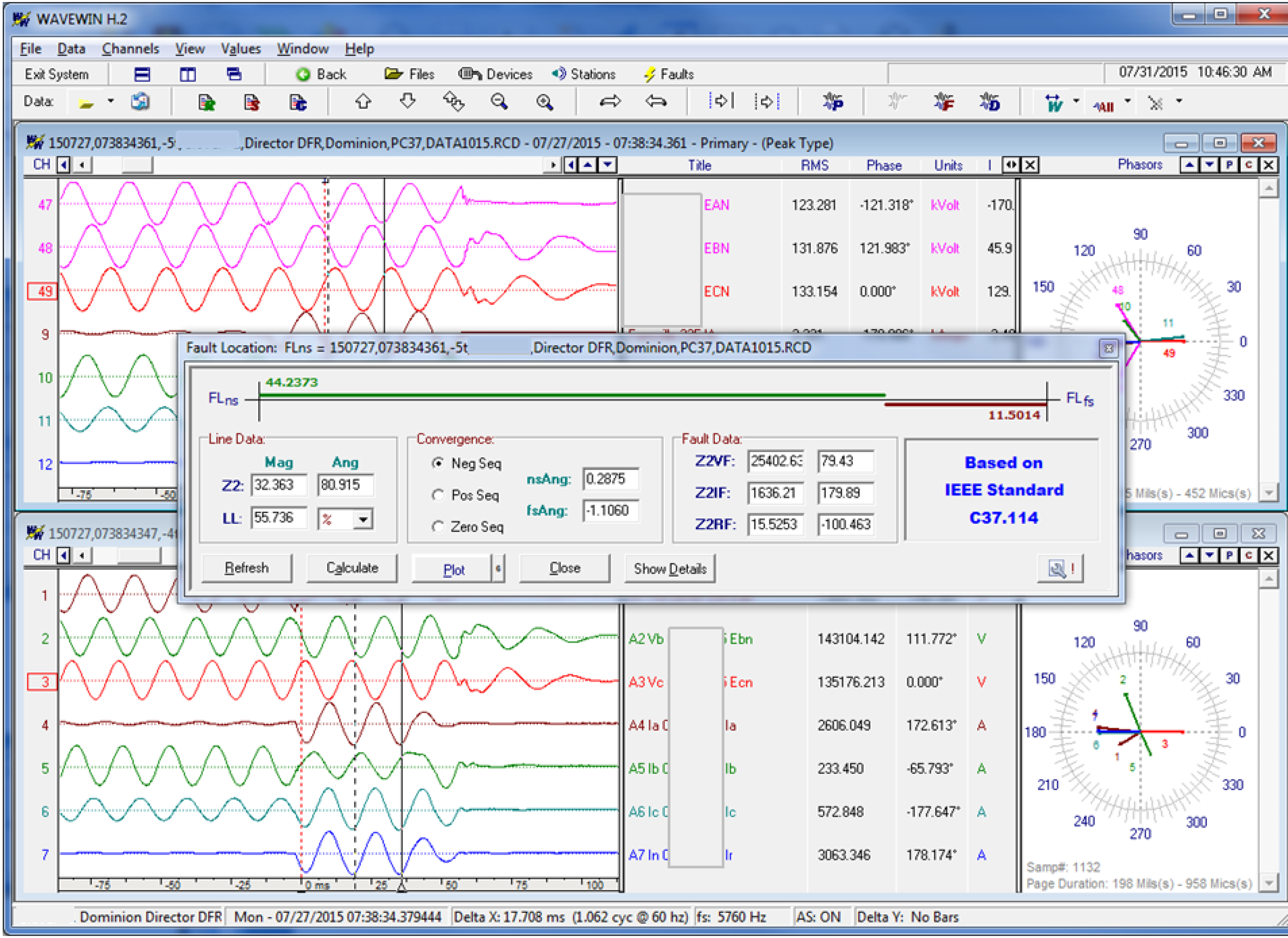
- GPS receivers installed at all transmission (100kV and above) and many distribution substations.
- Time sync signal is provided to many devices, including Digital Fault Recorders (DFRs), protective relays, and Phasor Measurement Units (PMUs).

Current timing

- Until recently, substation timing has been taken for granted – it hasn’t been as carefully scrutinized as other equipment.
- That is changing with the advent of new devices that are able to make use of precise timing.

Timing Applications

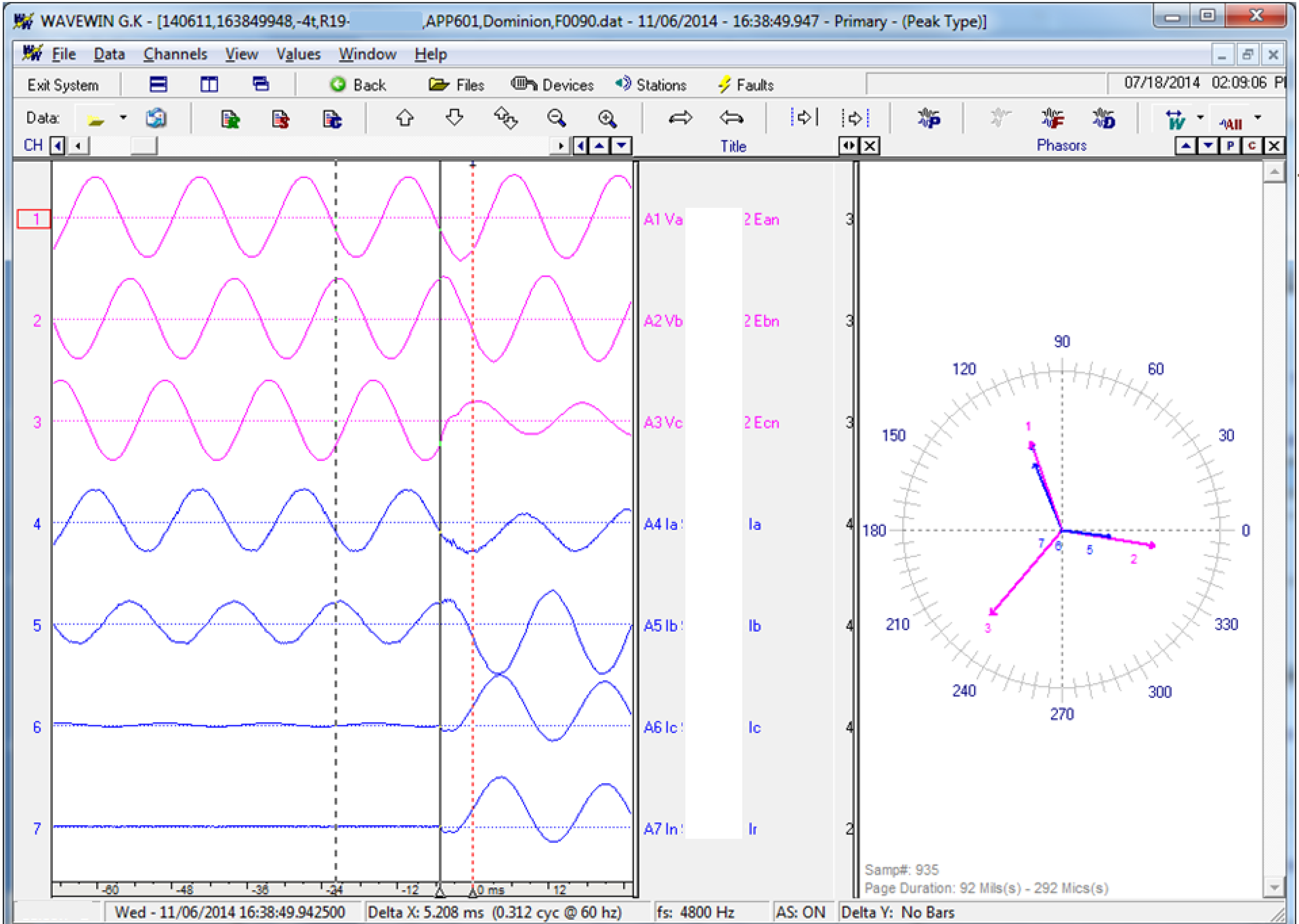
- Digital fault recorders (DFRs) (1 ms accuracy) - monitor the power flowing on the grid and take high sample rate snapshots of the currents and voltages. Time synchronized data can be matched with other recorders to analyze system events.



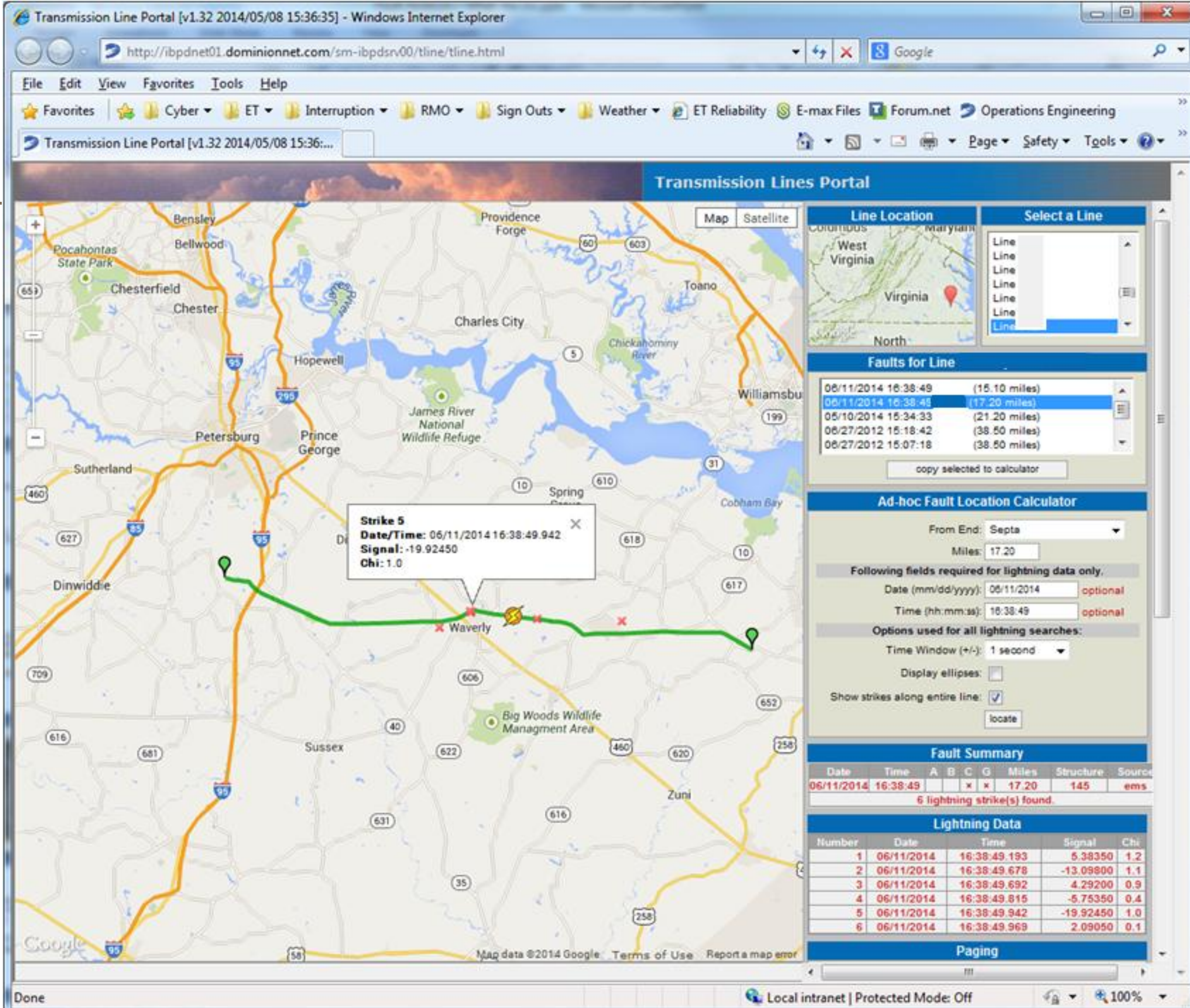
WAVEWIN H.2
File Data Channels View Values Window Help
Exit System
Back
Files
Devices
Stations
Faults
07/31/2015 10:46:30 AM
Data:
150727,073834361,-5t ,Director DFR,Dominion,PC37,DATA1015.RCD - 07/27/2015 - 07:38:34.361 - Primary - (Peak Type)
CH
Title RMS Phase Units
Phasors
EAN 123.281 -121.318° kVolt -170.
EBN 131.876 121.983° kVolt 45.9
ECN 133.154 0.000° kVolt 129.
Fault Location: FLns = 150727,073834361,-5t ,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
150727,073834347,-4
A2 Vb Ebn 143104.142 111.772° V
A3 Vc Ecn 135176.213 0.000° V
A4 Ia Ia 2606.049 172.613° A
A5 Ib Ib 233.450 -65.793° A
A6 Ic Ic 572.848 -177.647° A
A7 In Ir 3063.346 178.174° A
Samp#: 1132
Page Duration: 198 Mils(s) - 958 Mics(s)
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 correlation (1 ms) - DFR 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 (FALLS - Vaisala).



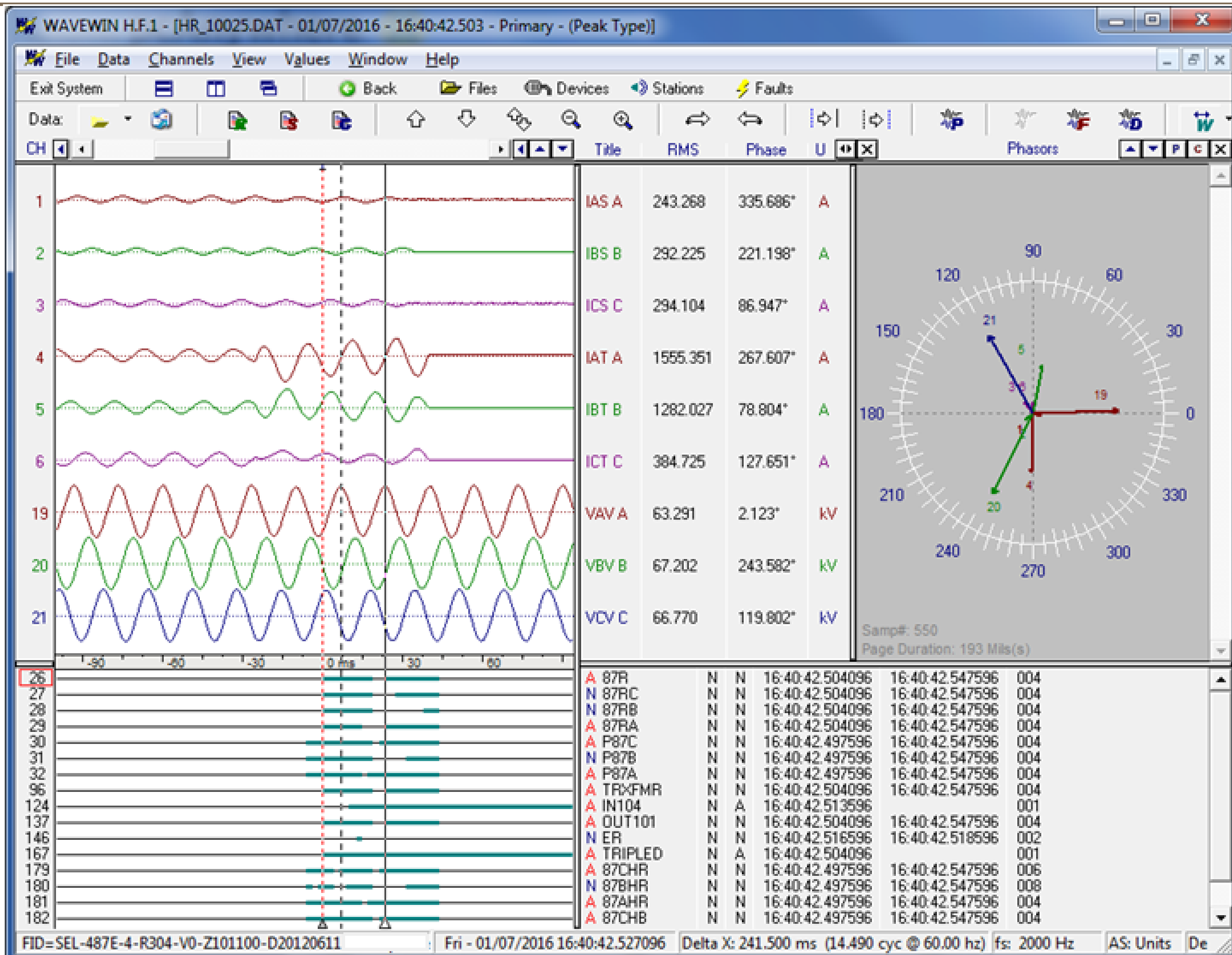
WAVEWIN G.K - [140611,163849948,-4t,R19- ,APP601,Dominion,F0090.dat - 11/06/2014 - 16:38:49.947 - Primary - (Peak Type)]
File Data Channels View Values Window Help
Exit System
Back
Files
Devices
Stations
Faults
07/18/2014 02:09:06 PI
Data:
CH
Title
Phasors
A1 Va
2 Ean
A2 Vb
2 Ebn
A3 Vc
2 Ecn
A4 Ia
Ia
A5 Ib
Ib
A6 Ic
Ic
A7 In
Ir
90
120
60
150
30
180
0
210
330
240
300
270
Samp#: 935
Page Duration: 92 Mils(s) - 292 Mics(s)
-60
-48
-36
-24
-12
0 ms
12
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
Line Location
Select a Line
Faults for Line
06/11/2014 16:38:49 (15.10 miles)
06/11/2014 16:38:49 (17.20 miles)
05/10/2014 15:34:33 (21.20 miles)
06/27/2012 15:18:42 (38.50 miles)
06/27/2012 15:07:18 (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 x x 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 0.4
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
Strike 5
Date/Time: 06/11/2014 16:38:49.942
Signal: -19.92450
Chi: 1.0
Map Satellite
Waverly
Petersburg
Dinwiddie
Sussex
Map data ©2014 Google Terms of Use Report a map error
Done
Local intranet | Protected Mode: Off
100%

Timing Applications

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

Timing Applications – Protective relay

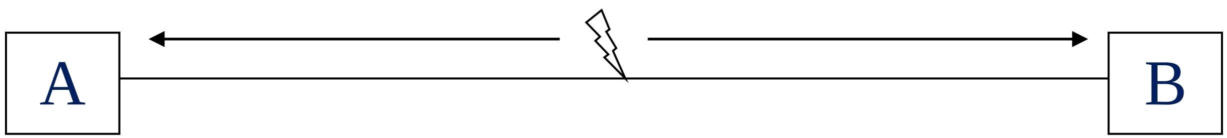


Timing Applications

- Traveling wave fault location (0.1 µs or around 100 ft) - 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.

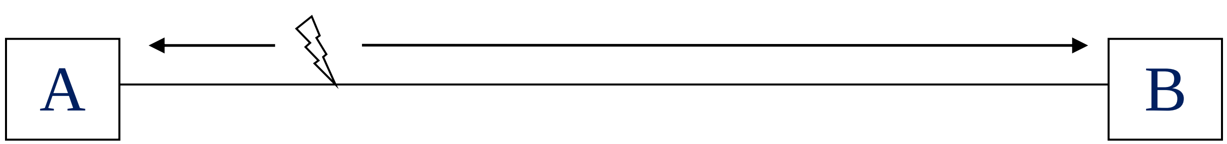
Travelling Wave Theory

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”

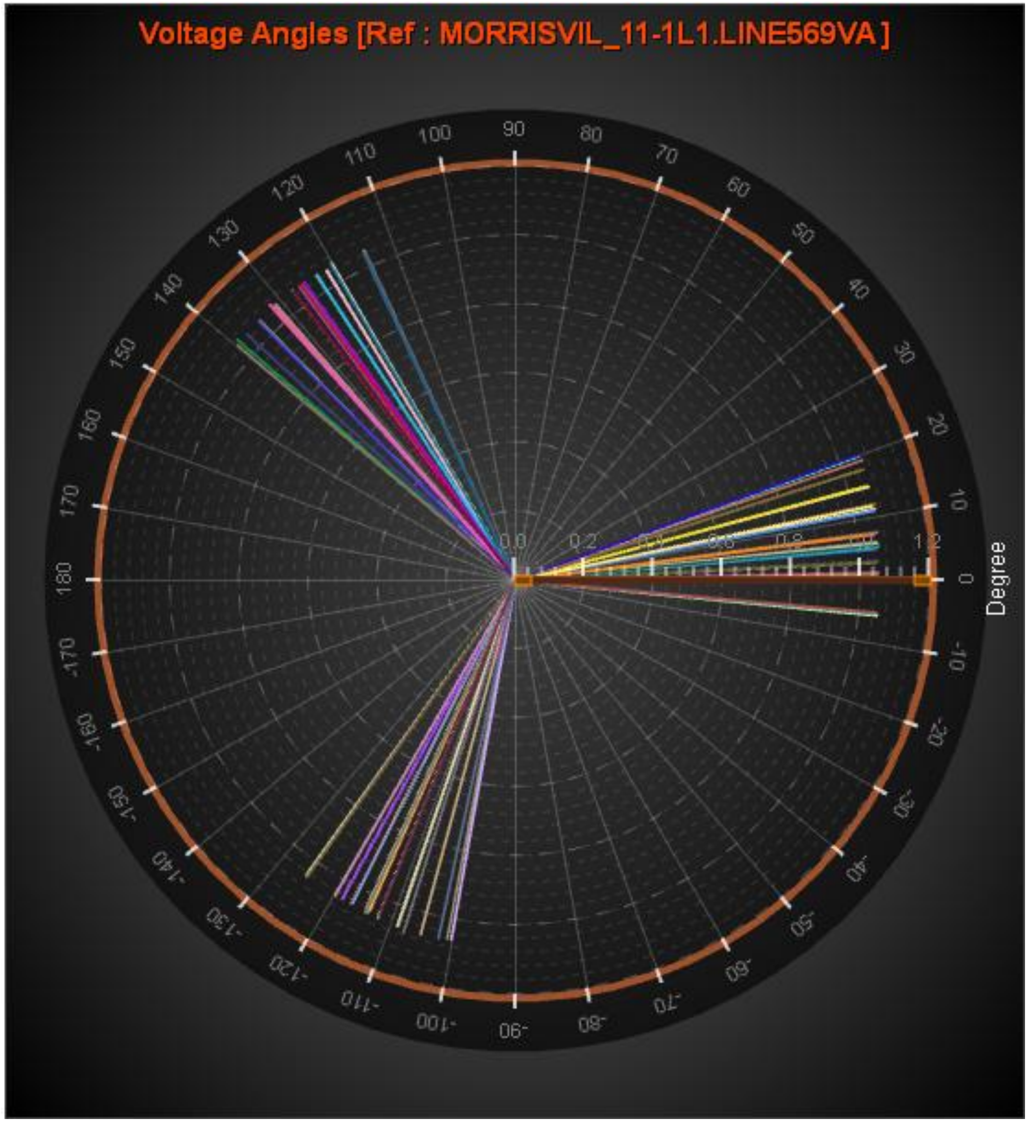
Travelling Wave Theory

Speed of light	Units
299,792,458	m/s
983,571,087.9	feet/sec
186,282.403	miles/sec
5.36819358	usec/mile
1.01670333	ns/foot
500.2180382	ns/492ft

Timing Applications

- Synchrophasor measurements. (1 µs, or 0.02 degrees at 60 Hz)
- 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



Synchrophasor magnitudes

Timing Applications

- 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.

Timing Distribution

- Timing within the substation is distributed mostly with an IRIG-B TTL signal using coaxial cable and BNC connectors. We have occasionally run into problems with cable lengths. 70-100 feet is the maximum run for this type of signal. There are a few devices using NTP.

Time Sync Fail Alarm

- We currently send an alarm to the operating center if one of the following conditions stays in the alarm state for 12 hours
  - Satellite clock alarm (hardware failure, loss of GPS, loss of power)
  - Invalid or missing IRIG signal
- Individual equipment (DFR, TWS) will alarm for time sync problems. Problems can be internal or external.

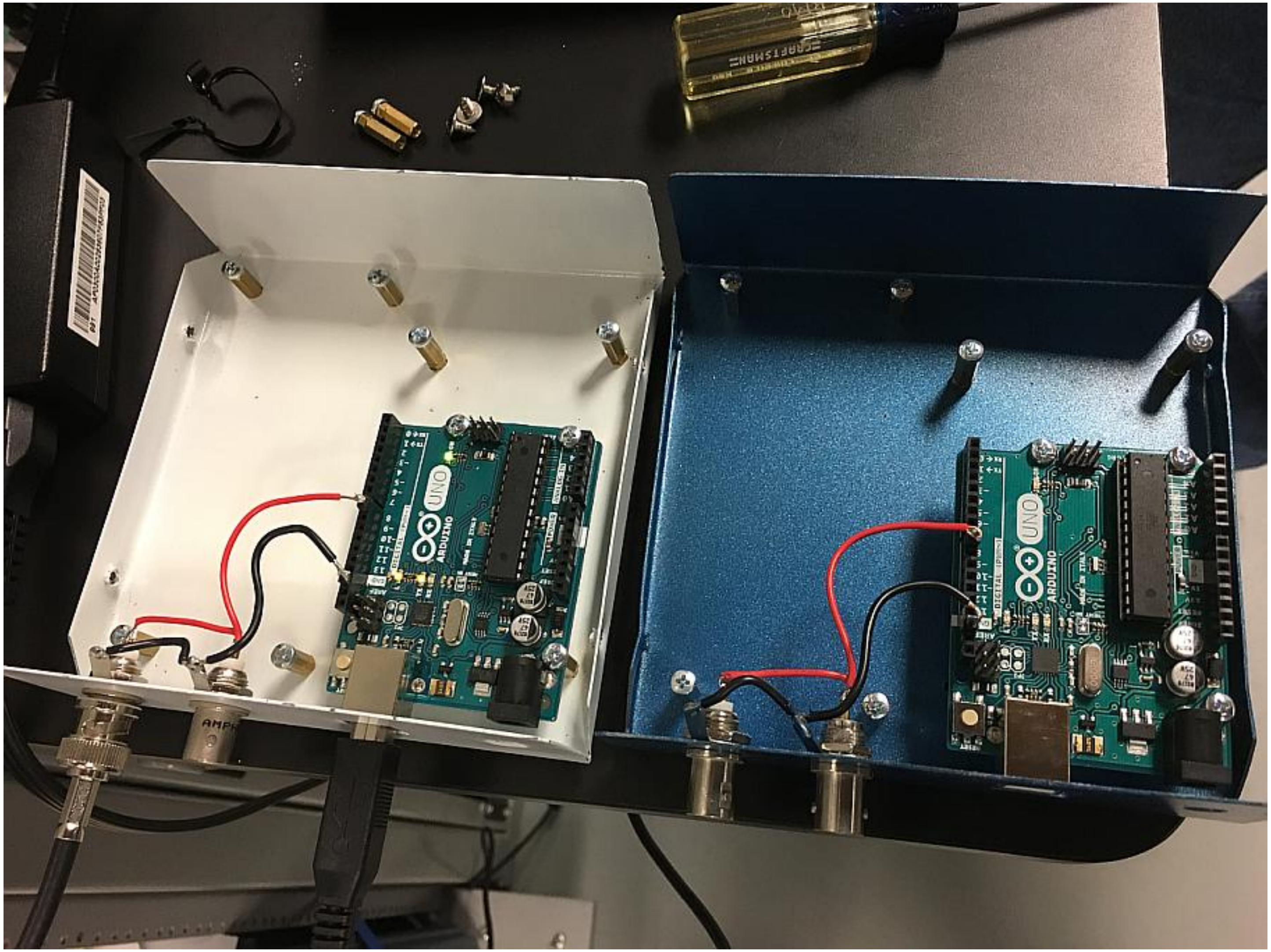
Timing Problems

- Firmware/clock testing.
  - Problems surrounding the changeover from Standard time to Daylight time.
  - 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.
- Monitoring and logging of the IRIG-B timing output is very insightful.
- 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

Future Timing Initiatives

- Evaluating new clocks and technologies. Our current clock model is >10 years old.
- Timing has been an afterthought. (Not treated with the same importance as other substation equipment)
- More rigorous testing of timing equipment. We have purchased a GPS simulator to test clocks and firmware updates.

Future Timing Initiatives

- Backup timing source (offsite PTP, for example).
- Appropriate holdover oscillator.
- Local distribution of timing – consider IRIG-B alternatives such as PTP, NTP, fiber.
- Possibly have a distributed timing approach inside the substations.

Future Timing Initiatives

- Remote firmware updates.
- Access control.
- CIP compliance.
- Anti-spoofing and jamming detection and handling.
- Data logging of time signals and sources.

Future Timing Initiatives

- Firmware lock on clocks. Review new firmware as it becomes available and decide if an upgrade is appropriate. Decide on new firmware implementation plan (immediate, during maintenance, as new equipment is purchased, etc).

- Thoroughly test new firmware with GPS simulator. Test edge cases – leap seconds, DST changes, year rollover, GPS week rollover, etc.

Conclusions

- Timing in electric substations is becoming more important as more technologies become available that rely on accurate time.

- Treat the timing system with the same thoroughness given to other substation systems.

- We need to keep up to date with industry developments in timing and the state of GNSS.

Conclusions

- We still have a lot to learn.