DOE/OE Transmission Reliability Program

Advanced Applications R&D
DOE/NIST Collaboration

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June 7, 2016
Washington, DC

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Project Objective

- **Background** – Industry dependence on PMUs is expected worldwide as their use increases
  - More than 20 PMU manufacturers
  - More than 50 different models of PMU
  - Recognition that conformance and metrology R&D are necessary elements for widespread industry acceptance
- **Objective** – Seek out opportunities for advanced applications R&D collaborations between DOE and NIST
  - Coordinate regular discussions between DOE labs and NIST
  - Investigate pressing issues facing PMU users
  - Identify future PMU-related instrumentation developments
  - Support the assessment of PMU data quality issues

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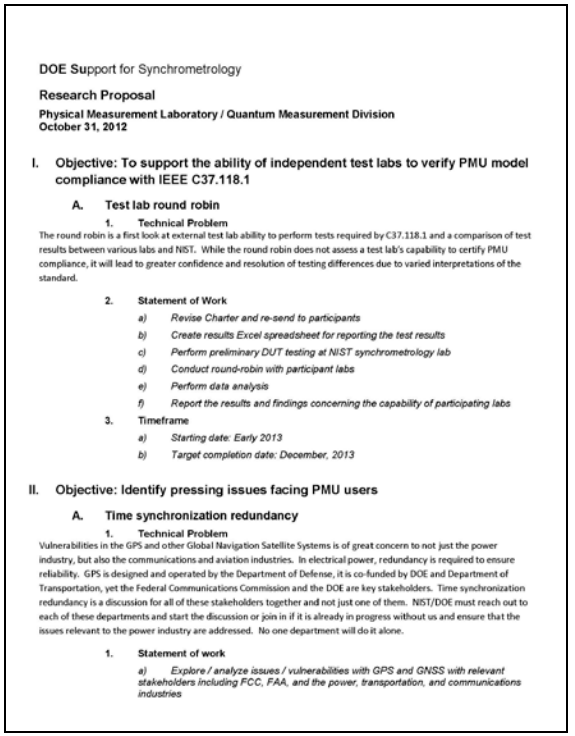
Looking Back

- Continuation of coordination discussions between NIST, ORNL, and PNNL regarding collaboration
- Participation in timing activities
- Planning "Next Generation Power Grid Instrumentation Workshop"
- Assessing the impact of measurement data quality (errors, GPS loss, and communications delay) on PMU-based applications

Interagency Agreement



DOE Support for Synchrometrology

Research Proposal

Physical Measurement Laboratory / Quantum Measurement Division
October 31, 2012

I. Objective: To support the ability of independent test labs to verify PMU model compliance with IEEE C37.118.1

A. Test lab round robin

1. Technical Problem

The round robin is a first look at external test lab ability to perform tests required by C37.118.1 and a comparison of test results between various labs and NIST. While the round robin does not assess a test lab's capability to certify PMU compliance, it will lead to greater confidence and resolution of testing differences due to varied interpretations of the standard.

2. Statement of Work

a) *Revise Charter and re-send to participants*
b) *Create results Excel spreadsheet for reporting the test results*
c) *Perform preliminary DUT testing at NIST synchrometrology lab*
d) *Conduct round-robin with participant labs*
e) *Perform data analysis*
f) *Report the results and findings concerning the capability of participating labs*

3. Timeframe

a) *Starting date: Early 2013*
b) *Target completion date: December, 2013*

II. Objective: Identify pressing issues facing PMU users

A. Time synchronization redundancy

1. Technical Problem

Vulnerabilities in the GPS and other Global Navigation Satellite Systems is of great concern to not just the power industry, but also the communications and aviation industries. In electrical power, redundancy is required to ensure reliability. GPS is designed and operated by the Department of Defense, it is co-funded by DOE and Department of Transportation, yet the Federal Communications Commission and the DOE are key stakeholders. Time synchronization redundancy is a discussion for all of these stakeholders together and not just one of them. NIST/DOE must reach out to each of these departments and start the discussion or join in if it is already in progress without us and ensure that the issues relevant to the power industry are addressed. No one department will do it alone.

1. Statement of work

a) *Explore / analyze issues / vulnerabilities with GPS and GNSS with relevant stakeholders including FCC, FAA, and the power, transportation, and communications industries*

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Participation in Timing Activities

- IEEE P1588 Working Group – updating Precision Timing Protocol (PTP) for applications requiring sub-nanosecond timing
- Time Aware Applications, Computers, and Communication Systems (TAACCS) Group – collection of individuals and organizations interested in addressing unique problems surrounding distributed timing
- Cyber-Physical Systems (CPS) Public Working Group, Timing Section – developing framework for correct timing by construction to allow large scale growth
- Invited talk on timing at I-PCGRID Workshop in San Francisco, March 30 – April 1, 2016

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IEEE P1588 Working Group

- **Charter** – Issue new edition of IEEE 1588-2008, *Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*

- **Organization** – PAR approved on June 14, 2013
- **DOE Lab Role** – Actively participating in working group
  - Hosted August 2015 meeting in Knoxville, TN
  - Attended January 2016 meeting in Paso Robles, CA
  - Sitting in on subcommittee telecons
  - Expecting release of draft standard at end of 2017

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TAACS Group

- **Charter** – Collection of people from academia, industry, and research labs interested in the unique problems surrounding distributed clock agreement
- **Organization** – Led by Carnegie Mellon University and NIST
- **DOE Lab Role** – Participated in writing white paper outlining the need for timing research; group has been quiet of late

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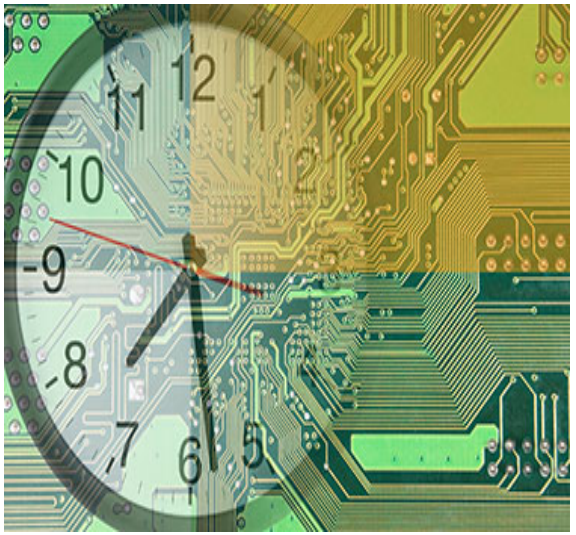
CPS Public Working Group – Timing Section

- **Charter** – Establishing the operational framework element for large scale interaction between cyber-physical systems for timing correction by construction
- **Organization** – Led by NIST; participants include government, academia, and industry
- **DOE Lab Role** – Actively participating in timing section
  - Completed draft CPS Framework
  - Public comment period ended November 2, 2015



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Next-Generation Instrumentation Workshop

- Tentative Dates: September 23, 2016 or March 24, 2017
- Tentative Locations: Cincinnati, OH or Gaithersburg, MD
- Chair: Yilu Liu, ORNL/UTK
- Attendance: Invitation only
- Potential agenda topics (sample)
  - Digital PMUs/sample value PMUs
  - Merging units and beyond
  - Requirements for distribution side vs transmission side
  - Measurement issues (data rates, delays, latency, limits, etc.)
  - Utilities' perspective
  - Impact of renewables

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Assessing Data Quality Issues

- GPS Timing Loss
- Impact of Thermal Sensitivity

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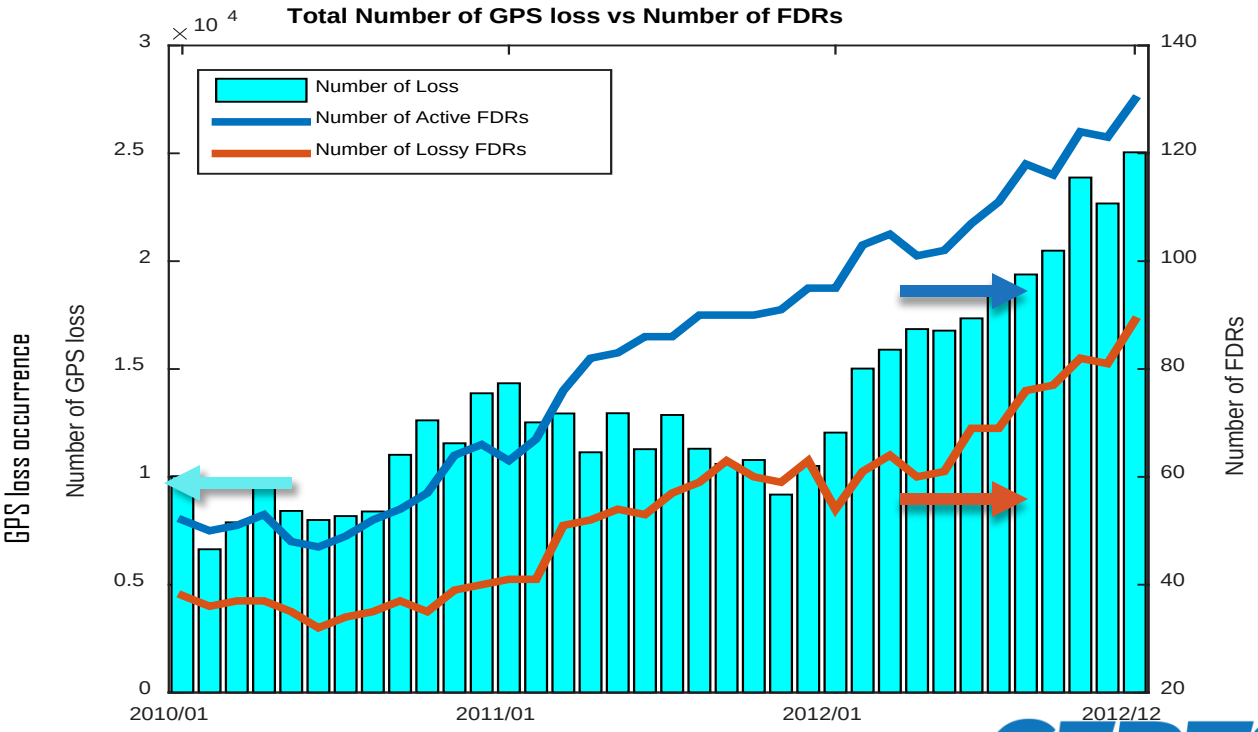
GPS Timing Loss of FDRs in 2010-2012

- Total number of frequency disturbance recorders (FDRs) increased from 53 to 131 from Jan 2010 to Dec 2012
- Over 50% of the FDRs suffer from GPS timing loss - average loss rate is about **6 to 10 times** /unit /day



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GPS Timing Loss of PMUs in 2009-2012

- From 2009 to 2012, synchrophasor units (PMUs) lost GPS signal **5 times per day** with average duration of **6.7 seconds per loss**
- Yearly data show significant difference in loss number and mean duration (possibly due to new installations)

Year	Number of PMUs	Loss Occurrence (per unit)	Mean Duration (per unit per loss, sec)
2009	26	2320	4.1
2010	34	838	3.9
2011	64	1744	15.4
2012	83	1517	1.7

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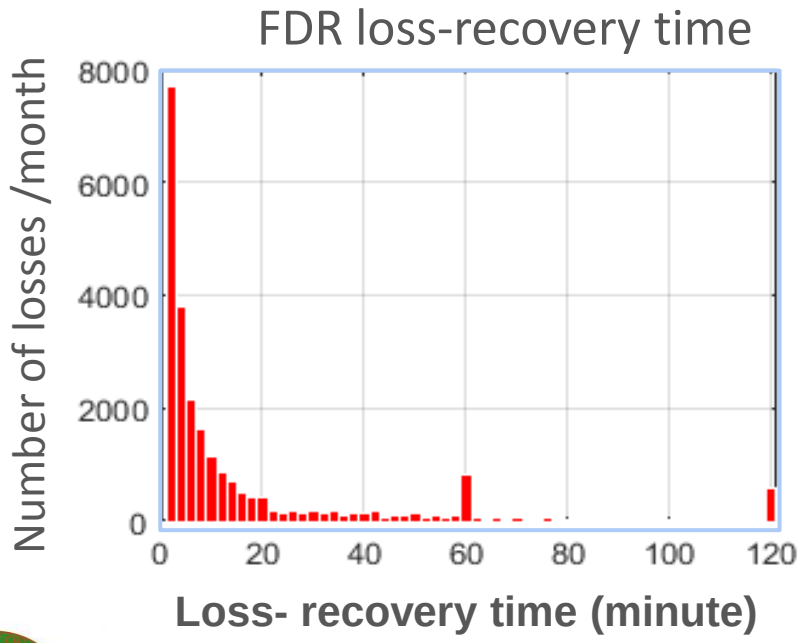
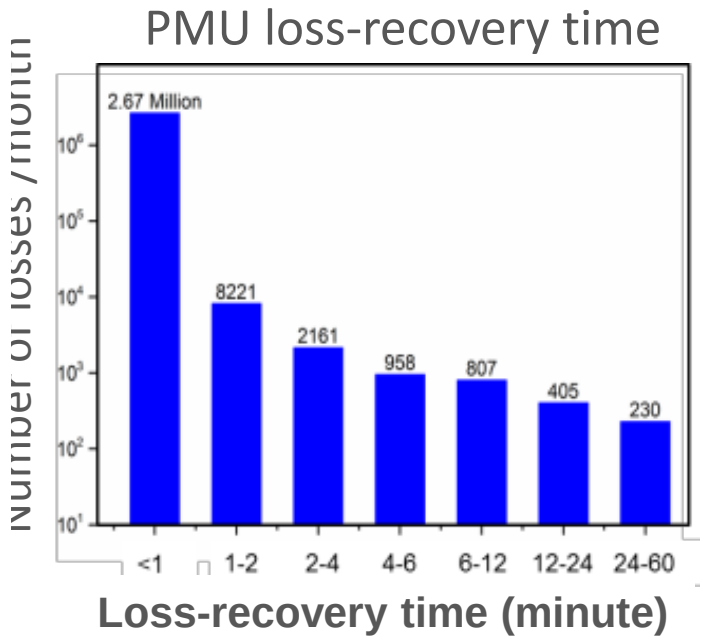
GPS Timing Loss-Recovery Time

- The monthly average number of losses decreases **exponentially** as recovery time increases
- Most GPS losses recover within 20 minutes
- FDRs are set to coast running without GPS for 1 or 2 hours





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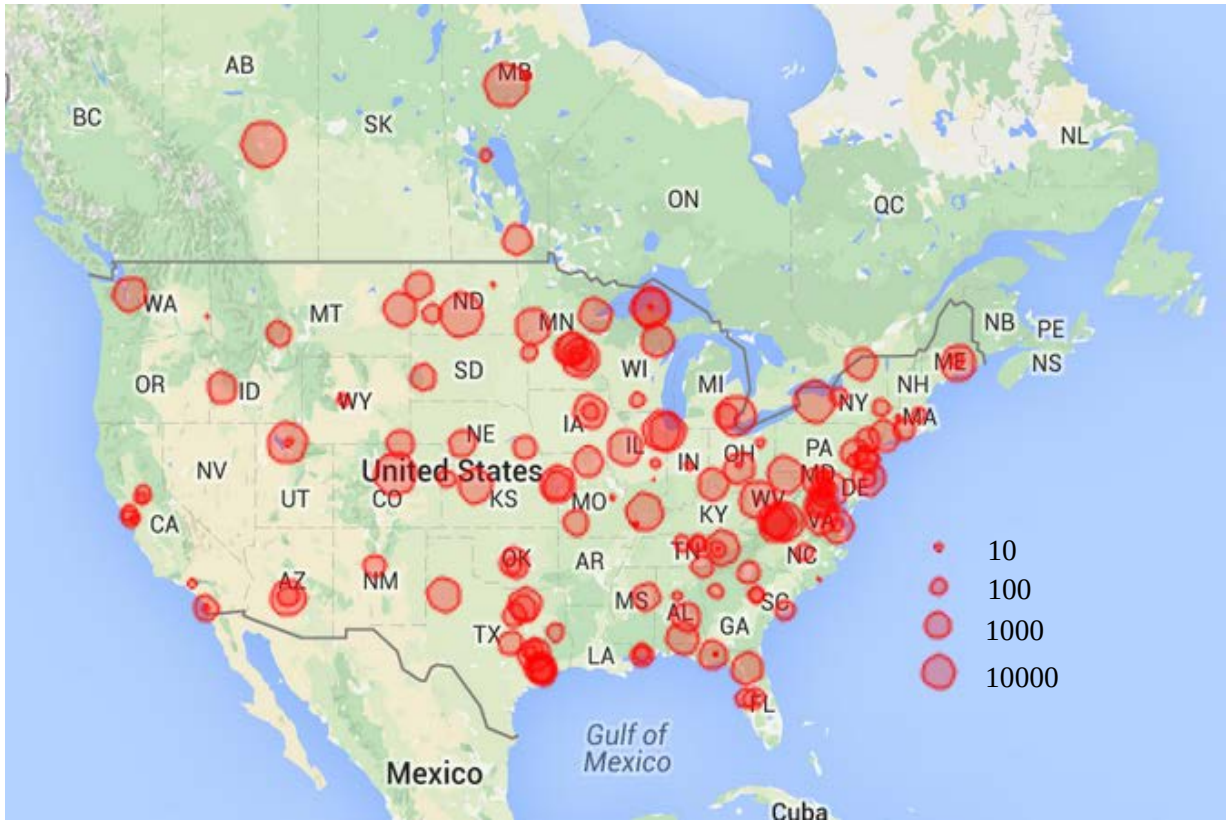
No Significant Spatial Pattern Observed

Map shows the average GPS losses/month for FDRs from 2010-2012 vs location



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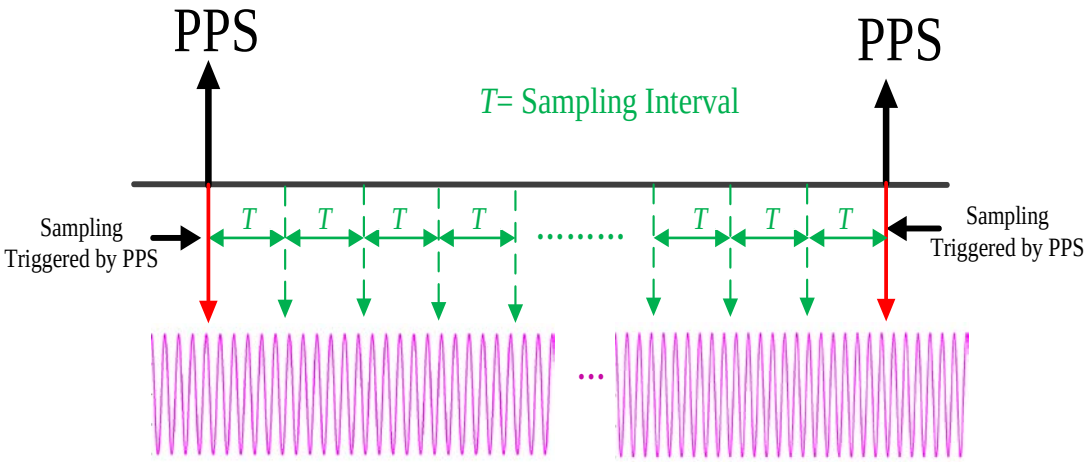
Thermal Sensitivity

- **Objectives**
  - Study the temperature impact on the drift of oscillator frequency
  - Study the temperature impact on the FDR measurement accuracy
  - Improve the reliability of FDR with oscillator frequency monitoring



1. PPS from GPS signal is used for time synchronization in PMU
2. Sample interval T between PPS is controlled by internal oscillator

$$N = \frac{f_{osc}}{f_s}$$

f_{osc}: oscillator frequency
f_s : desired sampling rate
N : DSP timer control

Temperature change can influence the oscillator frequency

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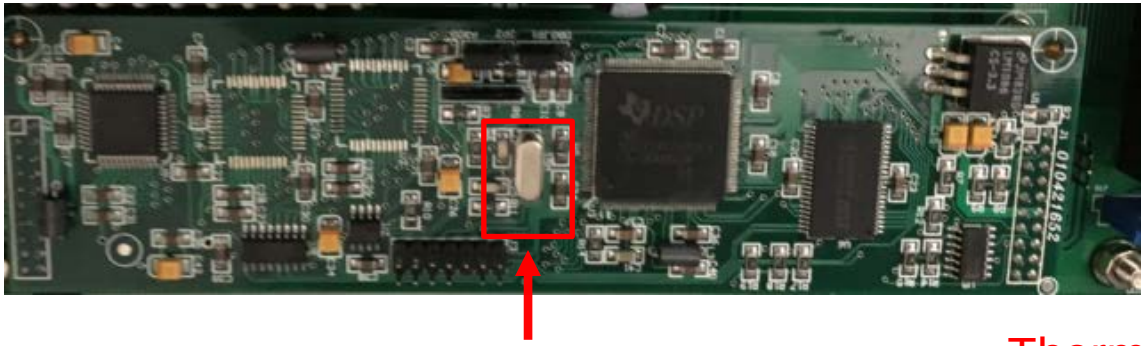
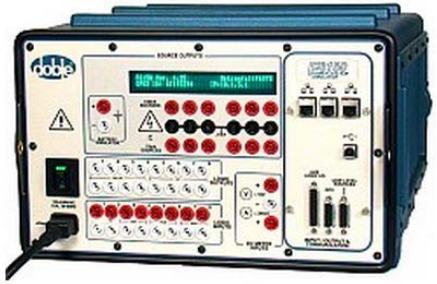
Test Setup



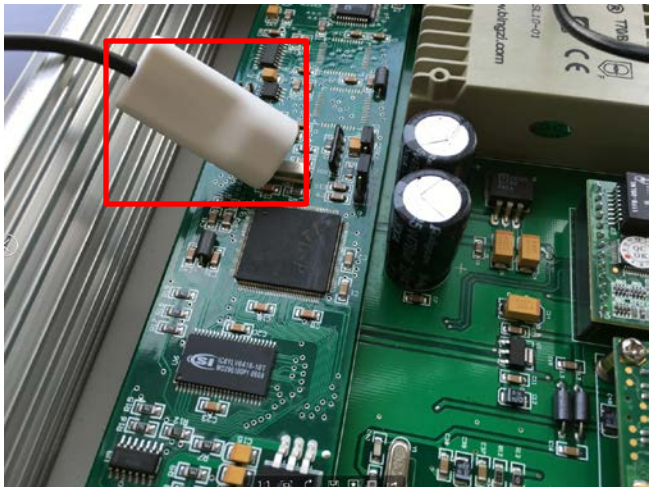
Oscillator: Nominal Value 30 MHz



Doble AC Source as Reference

Output：120V/60Hz

Thermal Meter



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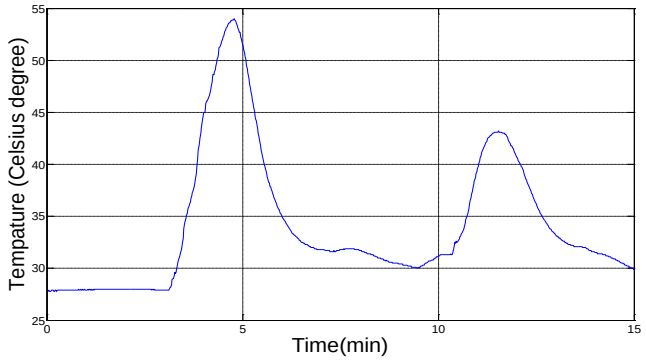
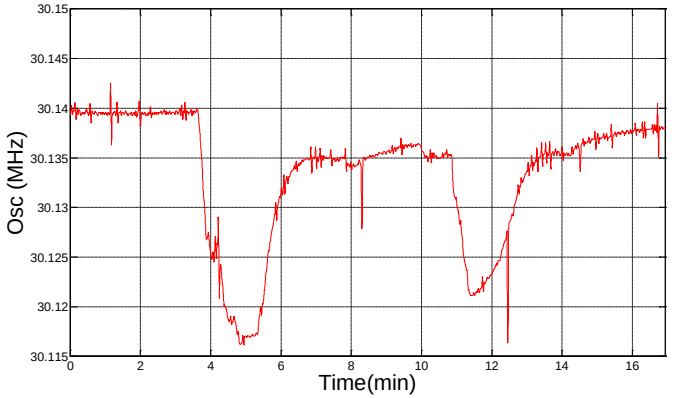
FDR Test Results

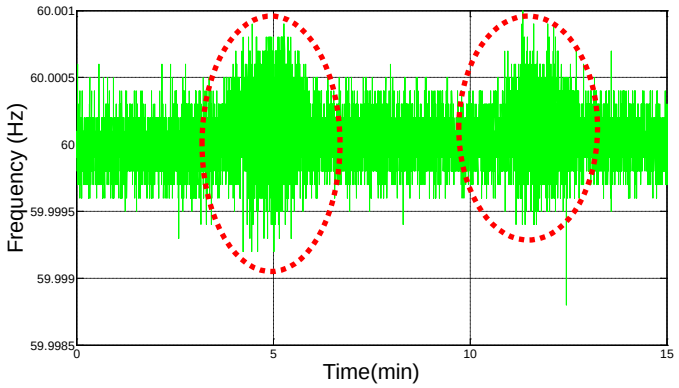
Normal temperature: 20 – 50°C



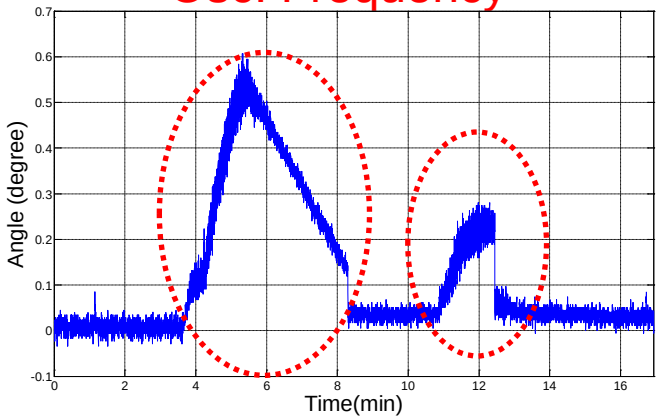
Temperature



Osc. Frequency



Frequency



Angle

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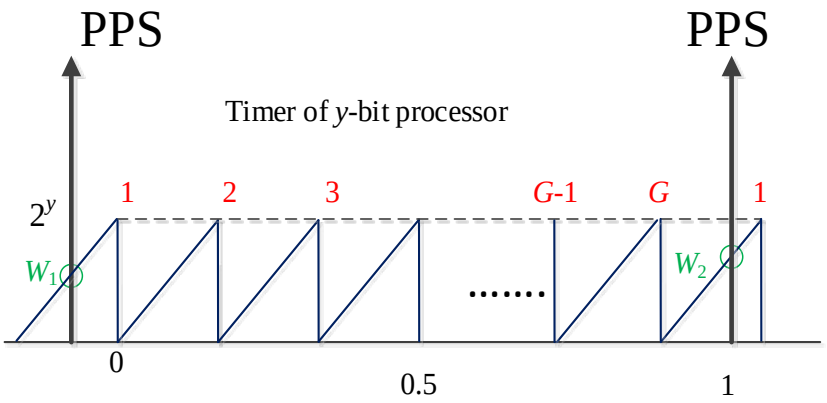
Oscillator Frequency Monitoring

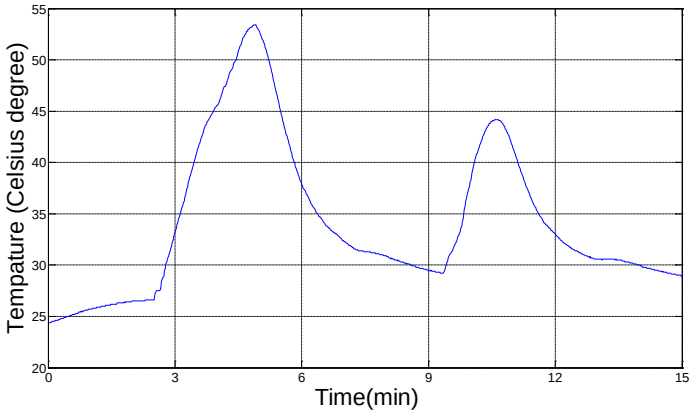
- Oscillator frequency is measured in FDR using PPS as timing reference
- Sampling control (N') is adaptively adjusted based on the measured oscillator Frequency



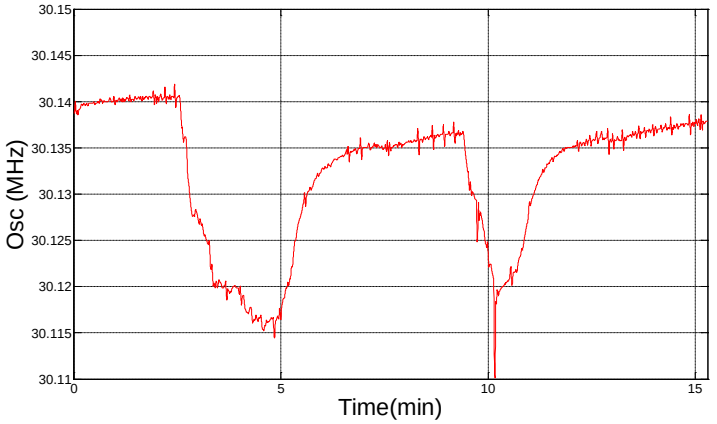
$$N' = \frac{f_{osc\_measurement}}{f_s}$$

Measurement gives real oscillator frequency vs assumed value

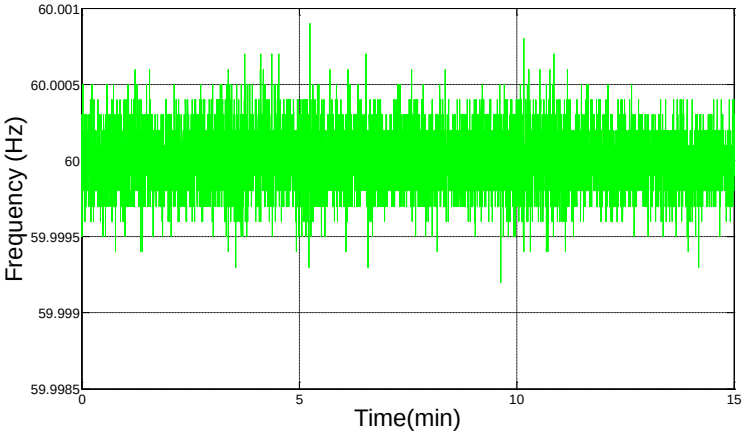
FDR Test Results with Monitoring



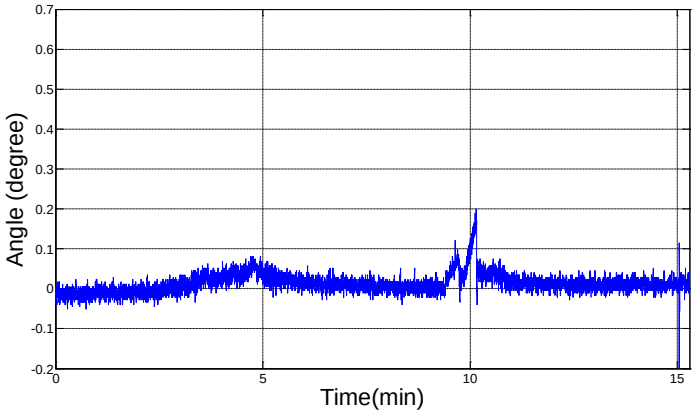
Temperature



Oscillator Frequency



Frequency



Angle

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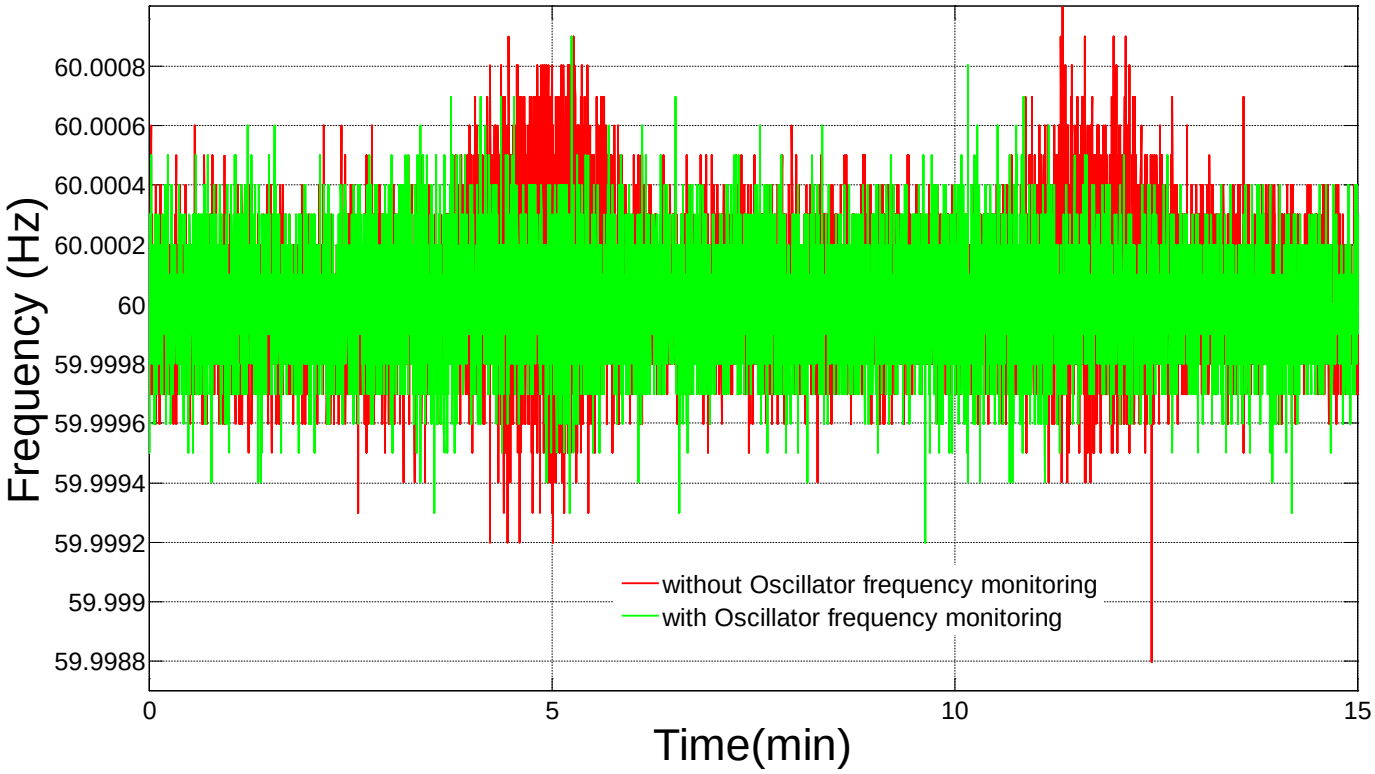
Comparison (Frequency)



Frequency Measurement Reliability is Improved

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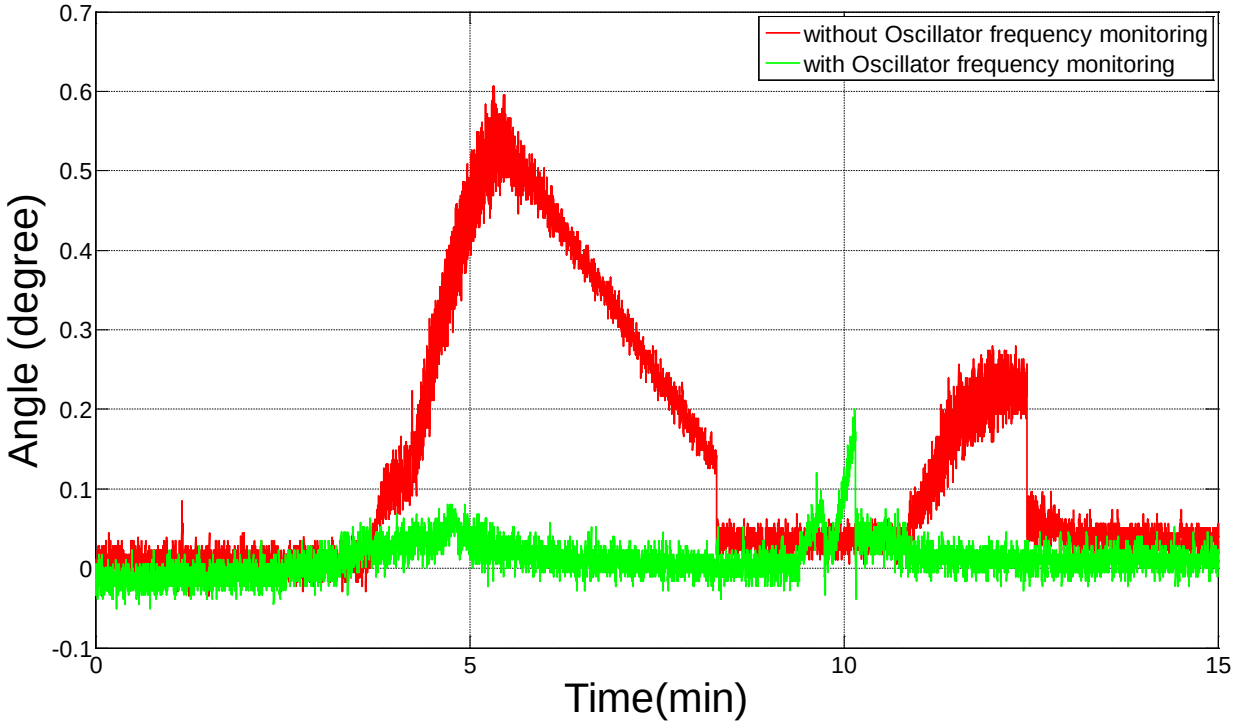
Comparison (Angle)



Angle Measurement Reliability is Improved

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Deliverables and Schedule

- **Collaboration between NIST, ORNL, and PNNL**
  - Participation in scheduled discussions on collaborative activities – ongoing updates
- **Timing Activities**
  - Meeting participation and technical input to working group documents – ongoing updates
- **Next Generation Power Grid Instrumentation Workshop**
  - Technical report on findings – depends on workshop date?
- **Assessment of Data Quality Issues**
  - Published ORNL report on impact of errors
  - Submitted journal articles on GPS loss and thermal sensitivity

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Looking Forward

Early thoughts on follow-on work that should be considered for funding in FY17

No identified source of funding

- Continuing coordination meetings
- Expanding collaboration efforts
- Continuing support of timing activities
- Hosting and documenting results from “Next Generation Power Grid Instrumentation Workshop”
- Continuing assessment of data quality issues

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