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Precision Timing Needs in the Electric Power Grid

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Outline

- Summary observations
- Application requirements
- Synchrophasors – one of the key drivers for precise time synchronization
- What is a “synchrophasor”?
- Why precise timing is important for measurement
- The dynamic response of a large power system
- The North American SynchroPhasor Initiative (NASPI)
- Synchrophasor applications
- Spoofing testing results
- Conclusions

Summary Observations

- An extended loss or degradation of satellite-based timing signals today would not be expected to result in a high-consequence reliability event
- Emerging measurement applications intended in increase reliability and enhance wide-area situational awareness could be impacted
- With the loss of wide-area time synchronization, utilities rely on the internal system clocks' holdover times
- The stability of the clock's oscillator determines this holdover capability
- In the future, electric utilities will require significantly higher availability, integrity, and redundancy in timing
- Control system applications that require wide-area time synchronization should consider the integrity and robustness of satellite-based timing signals in their design

Summary of Key Electric Power Applications that Require Precise Timing

Application Area	Time Synchronization Requirement	Application Notes
Control Room Applications	1 s	Data acquisition, supervisory control, state estimation, etc.
Event Recording	1 ms	Sequence of events and disturbance reporting requirements
Synchrophasors	1 µs	Wide area visibility
Advanced Protection	100 ns	Traveling wave fault location

Industry Standard for Disturbance Monitoring and Reporting Requirements

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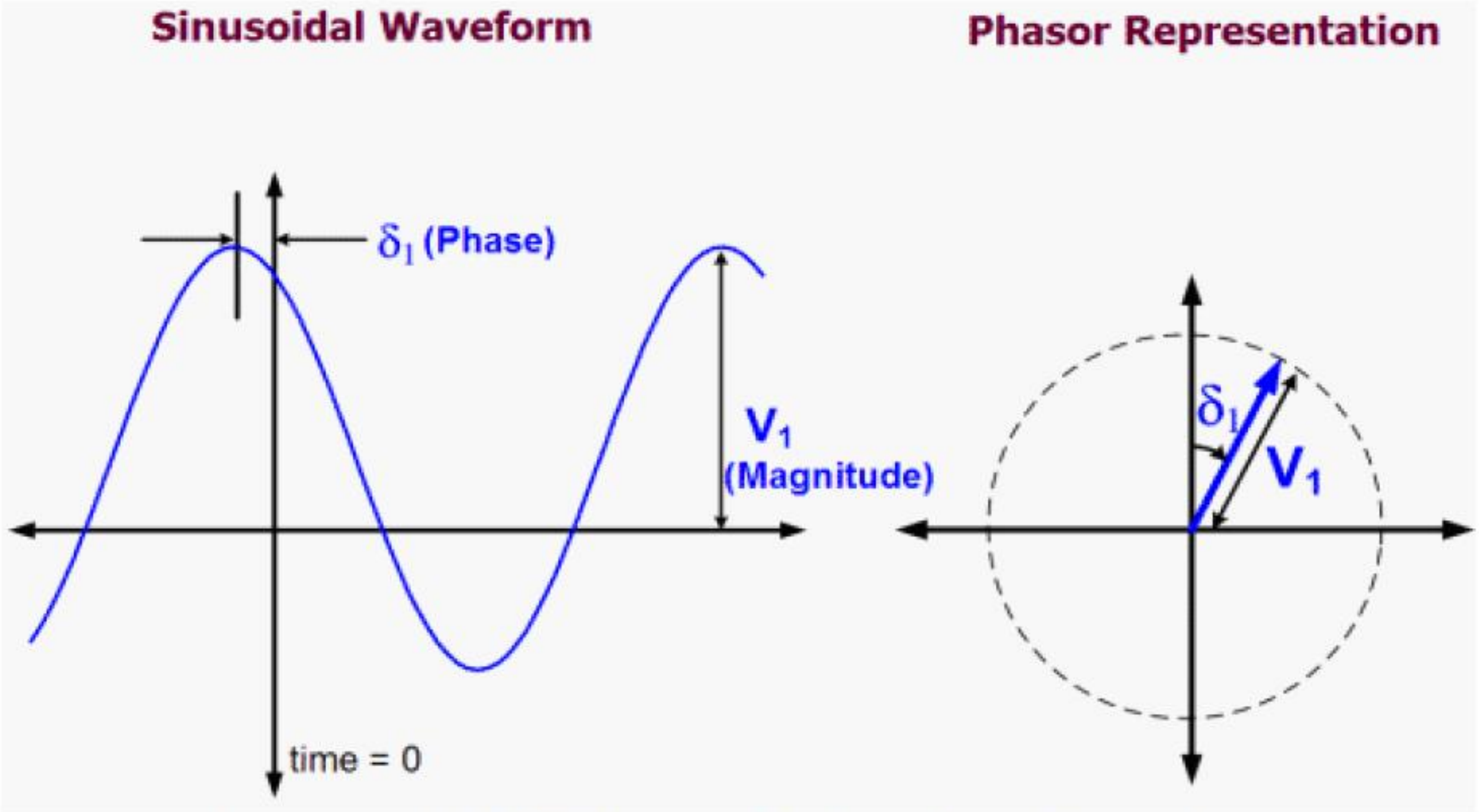
- The North American Electric Reliability Corporation (NERC) Standard for Disturbance Monitoring and Reporting Requirements
  - NERC Standard PRC-002-2
- For all sequence of events and fault recording data:
  - Requirement 10.2: Synchronized device clock accuracy within ± 2 milliseconds of UTC
- This applies to all dynamic disturbance recording data that is required by the standard
- Synchrophasor measurements require much greater precision

What is a "Phasor"?

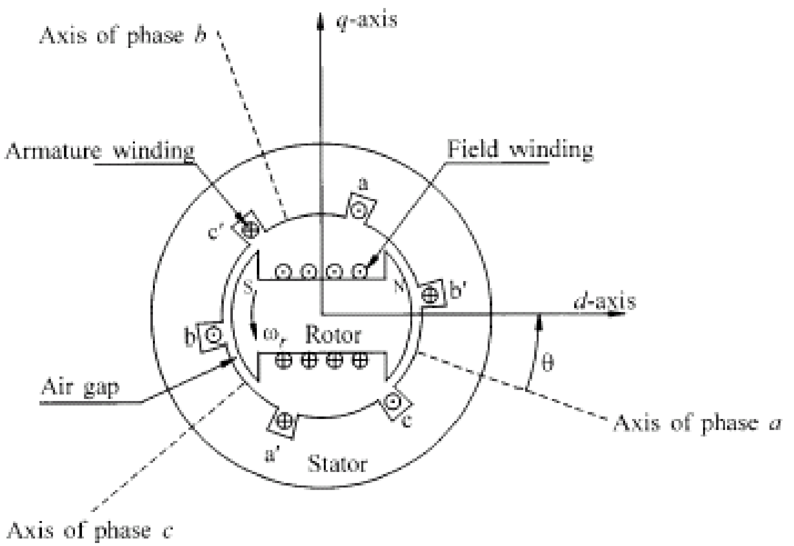
- Like a vector, a phasor represents both magnitude and relative phase angle

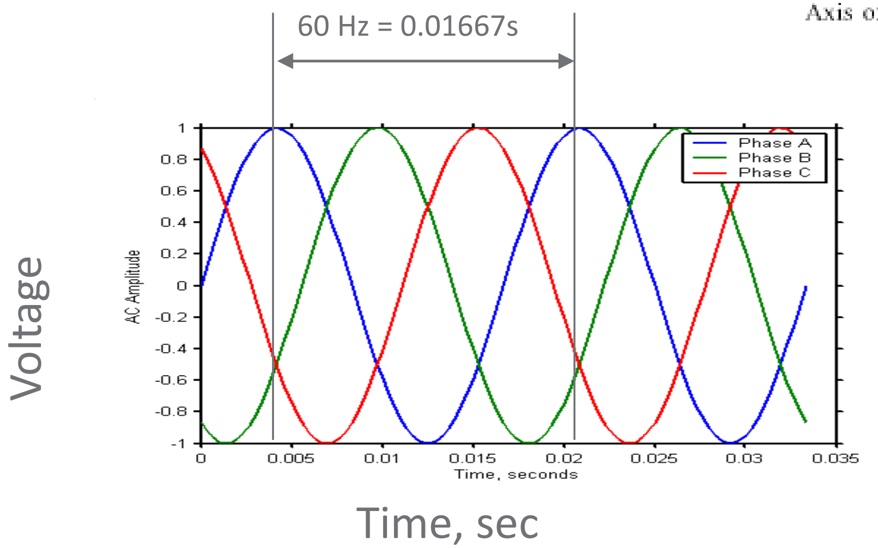


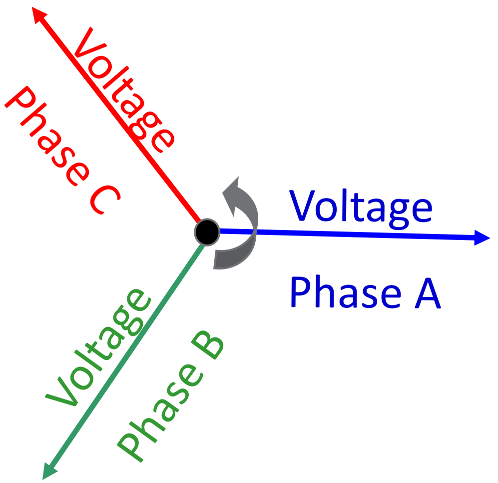
Source: CERTS, Phasor Technology Overview

Conceptual Overview

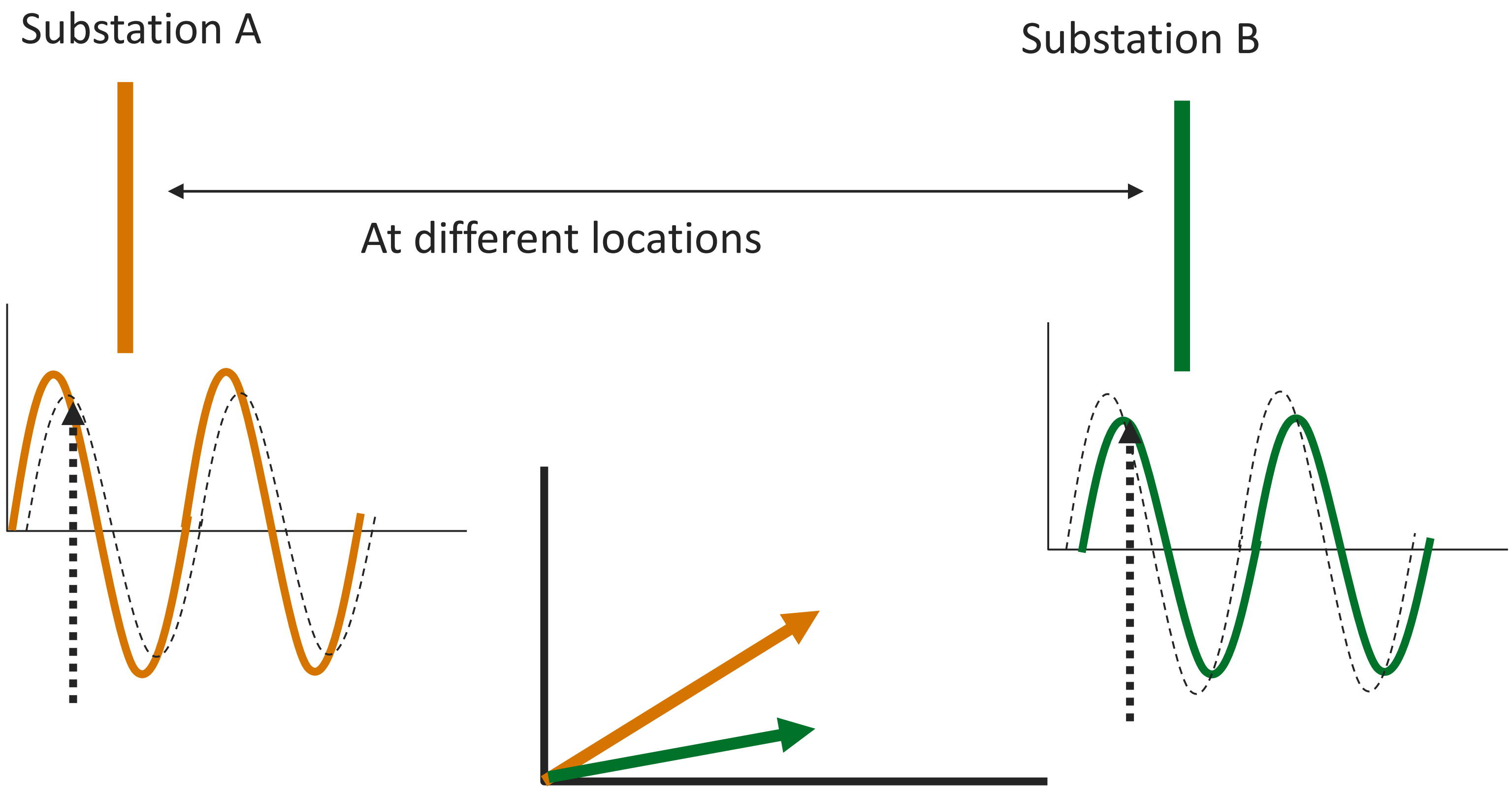
- Mathematical concept of physical quantities
- Phasors rotate counterclockwise, each corresponding to a sinusoidal parameter
- The rotating frame of reference can be modified (e.g., relative phase angle)







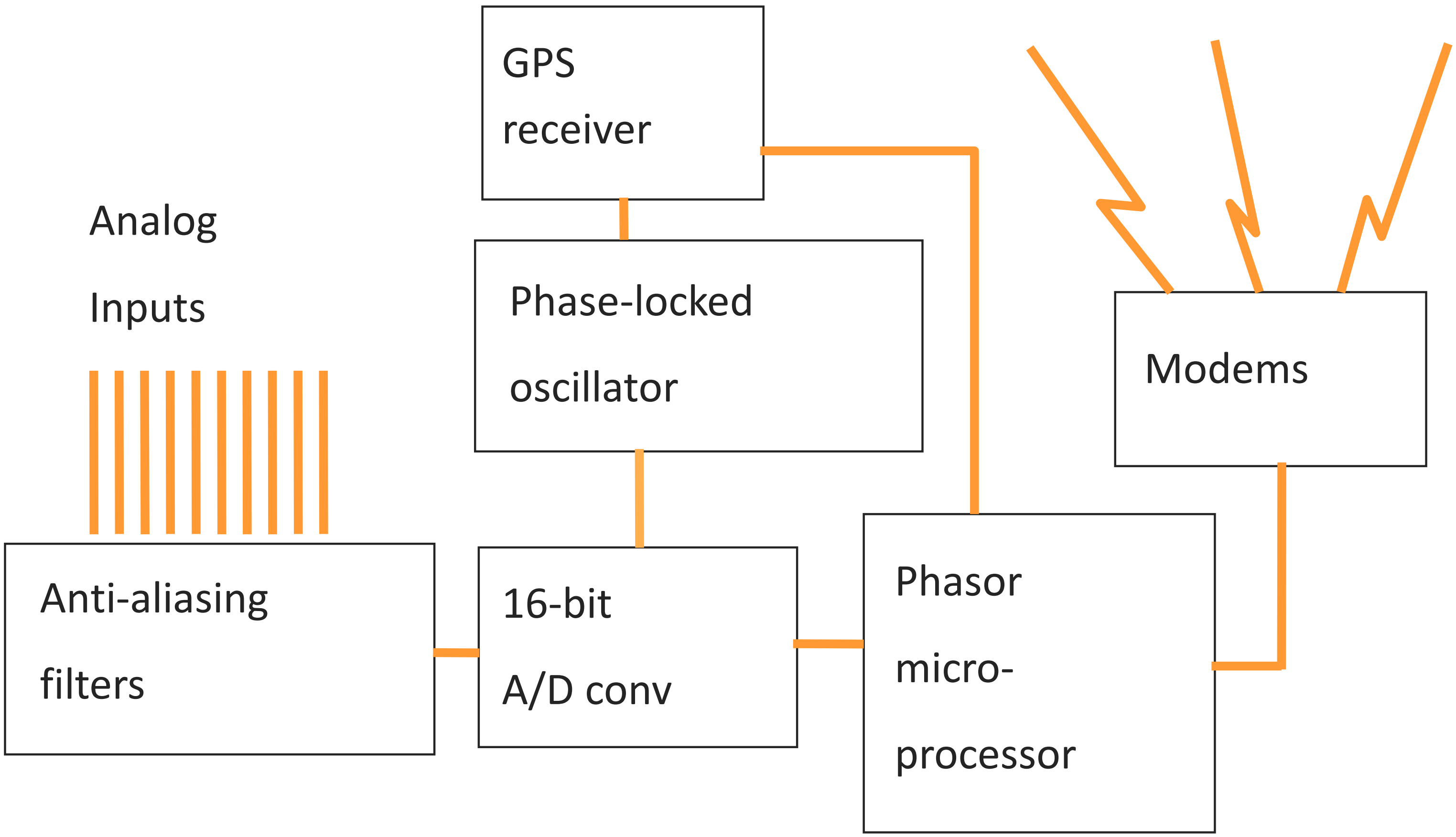
Time Synchronized Measurements



By synchronizing the sampling processes for different signals, which may be hundreds of miles apart, it is possible to put their phasors on the same phasor diagram.

Credit: A.G. Phadke

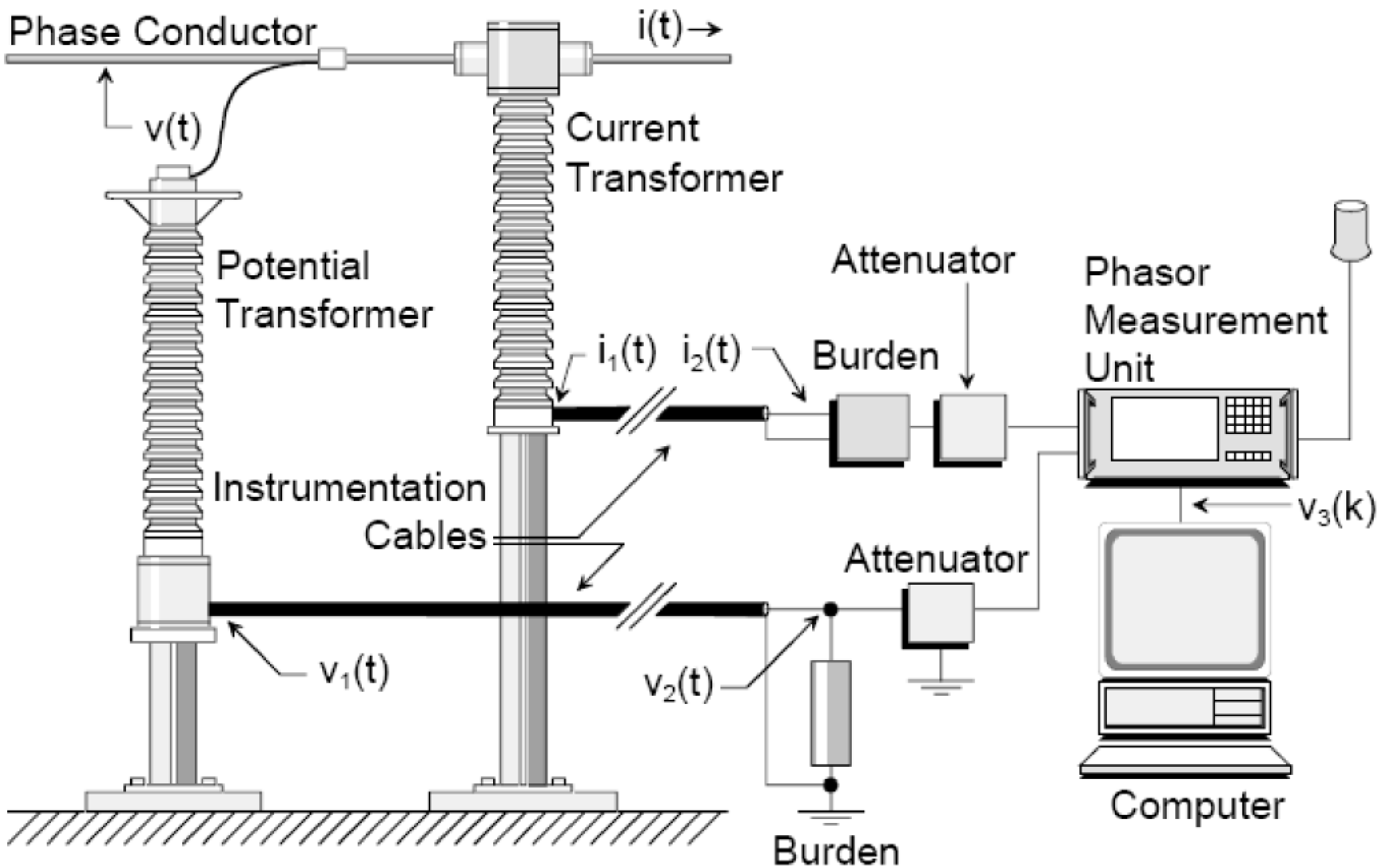
Phasor Measurement Unit (PMU)



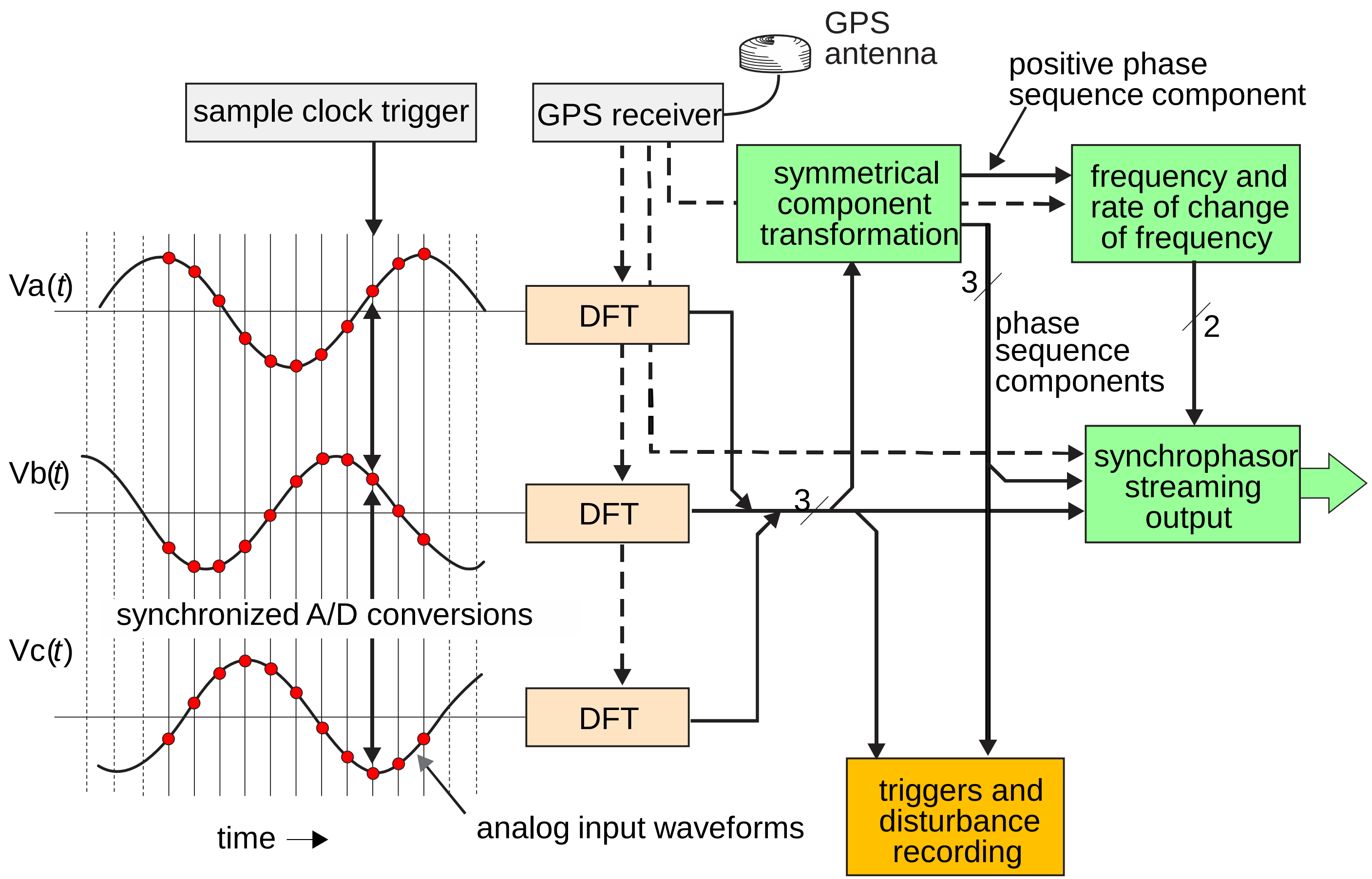
Except for synchronization, the hardware is the same as that of a digital fault recorder or a digital relay.

Credit: A.G. Phadke

Substation PMU Installation



PMU Measurement Approach



Credit: A.G. Phadke

Different Types of PMUs

- P class (protection)
  - Minimal filtering
  - Possible aliasing of higher frequency components
  - Less delay in estimation
  - Important for real-time controls requiring minimum delay
- M class (measurement)
  - Some anti-alias protection
  - Wider frequency response, lower noise
  - Latency longer (depends on reporting rate)
  - Important for situations with higher frequencies present

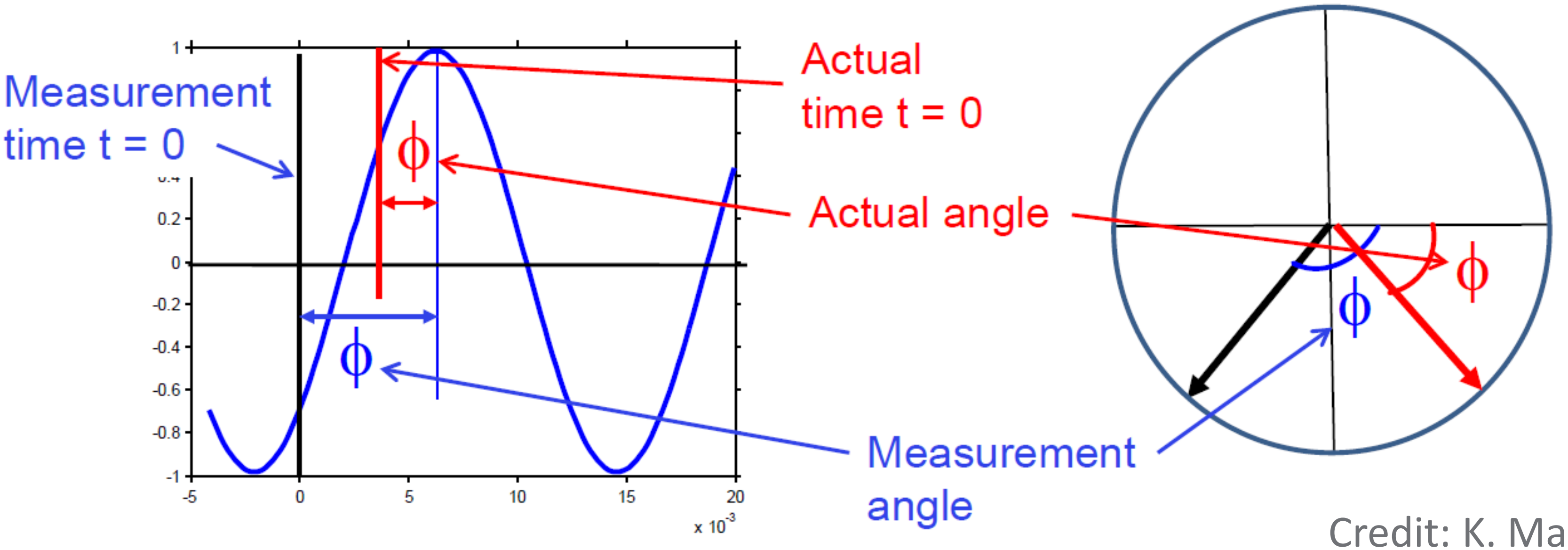
Credit: K. Martin

How accurate does your time need to be?

- The phase angle is determined by the time reference
- If t = 0 is displaced by *x* seconds, the phase angle will be rotated by $x/46\text{x}10^{-06}$ degrees (1° ~ 46 µs at f_0 = 60 Hz)
- Note the error ONLY effects phase angle – magnitude ok

$$v(t) = \sqrt{2}\, A \cos(2\,\pi\,\omega_0\, t + \phi)$$

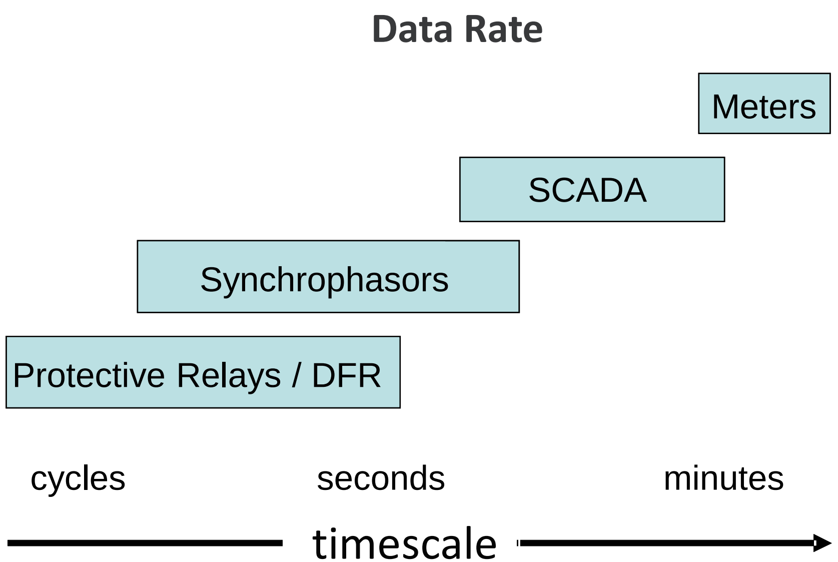
$$V = A\, e^{j\phi}$$



Credit: K. Martin

Technology to Meet Emerging Industry Needs

- Synchrophasor technology is being rapidly deployed by several utilities throughout the world and across North America
- Both on-line and off-line applications are emerging, particularly those that require faster time-synchronized measurements than are available from existing technology
- The measurement infrastructure is tailored to the requirements of the installation
- Vendors are providing new solutions including measurement technology, networking, and applications



Time synchronized data can be gathered at sample rates much faster than traditional supervisory control and data acquisition (SCADA) systems, and provide the missing link between localized digital fault recorders (DFR) and SCADA systems, which are much slower. However, unlike most SCADA systems, these emerging wide-area measurement technologies utilize Internet protocols to exchange measurement information.

Notional representation of the difference between synchrophasor and SCADA measurement

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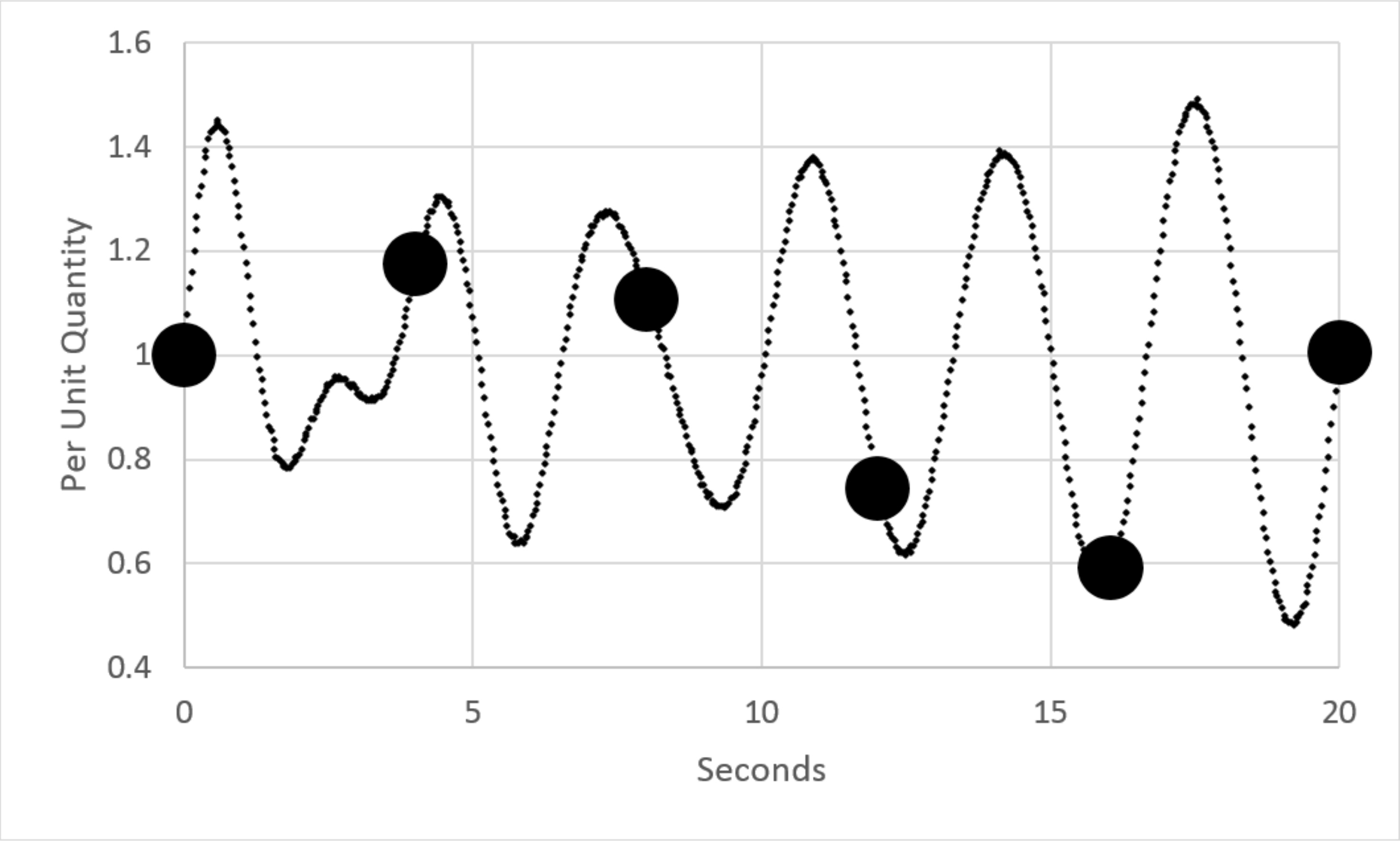
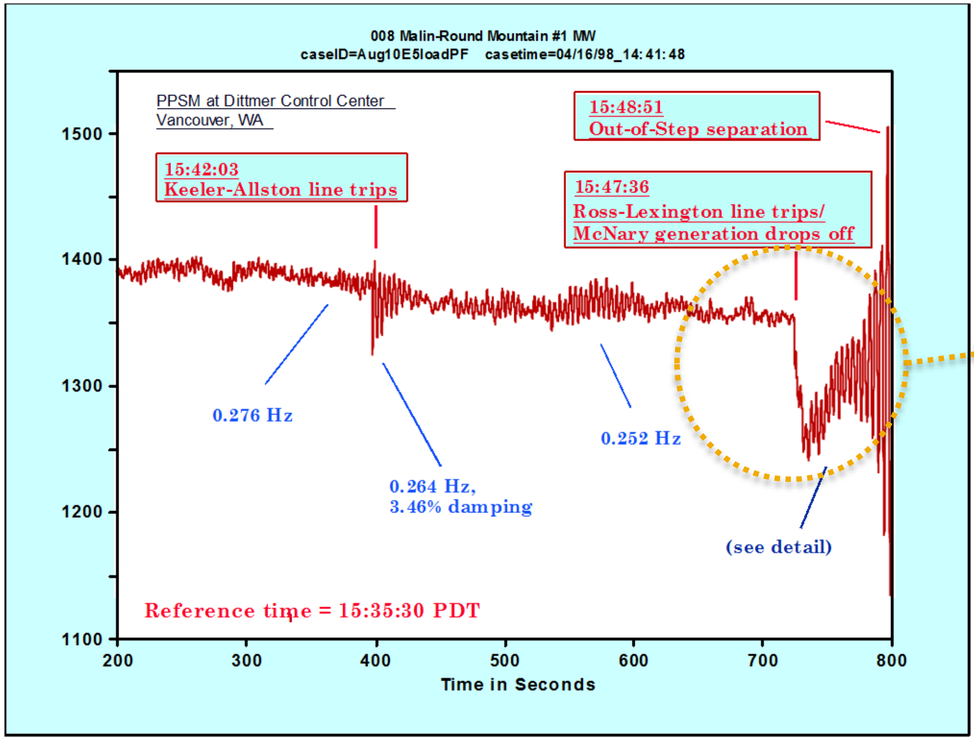
Supervisory Control and Data Acquisition (SCADA): every 4 seconds

Synchrophasors: 30 measurements per second

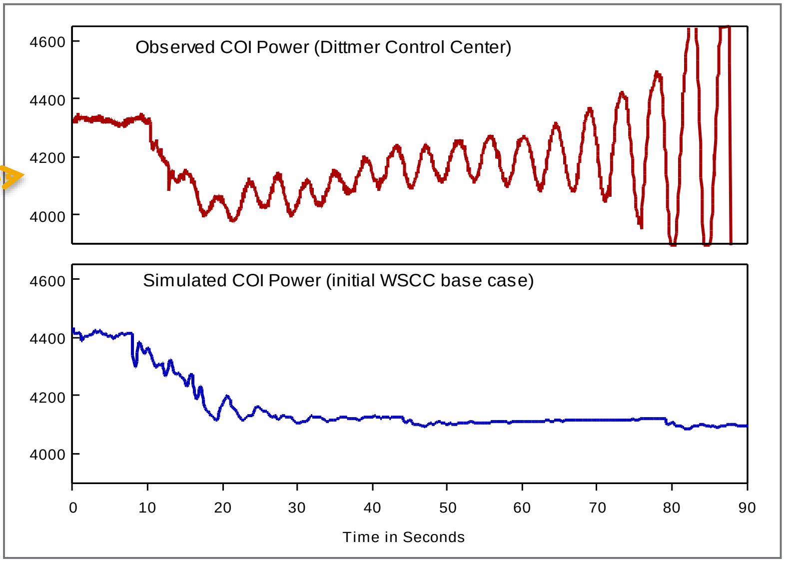


Lessons Learned from the August 10, 1996 Western Blackout

High-speed, time-synchronized data was essential to support the blackout investigation



The need for better model validation was demonstrated



North American SynchroPhasor Initiative

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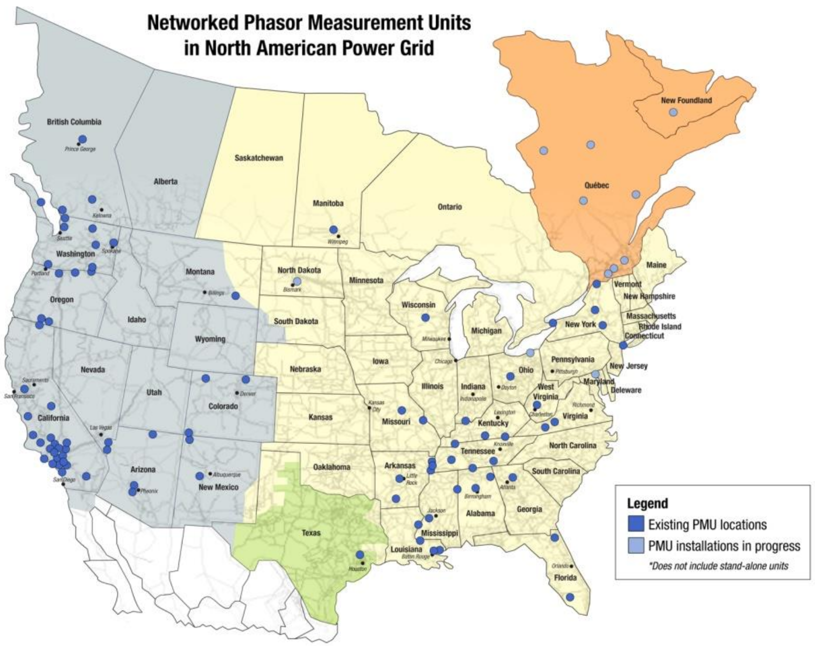
The U.S. Department of Energy (DOE) and EPRI are working together closely with industry to enable wide area time-synchronized measurements that will enhance the reliability of the electric power grid through improved situational awareness and other applications

April 2007



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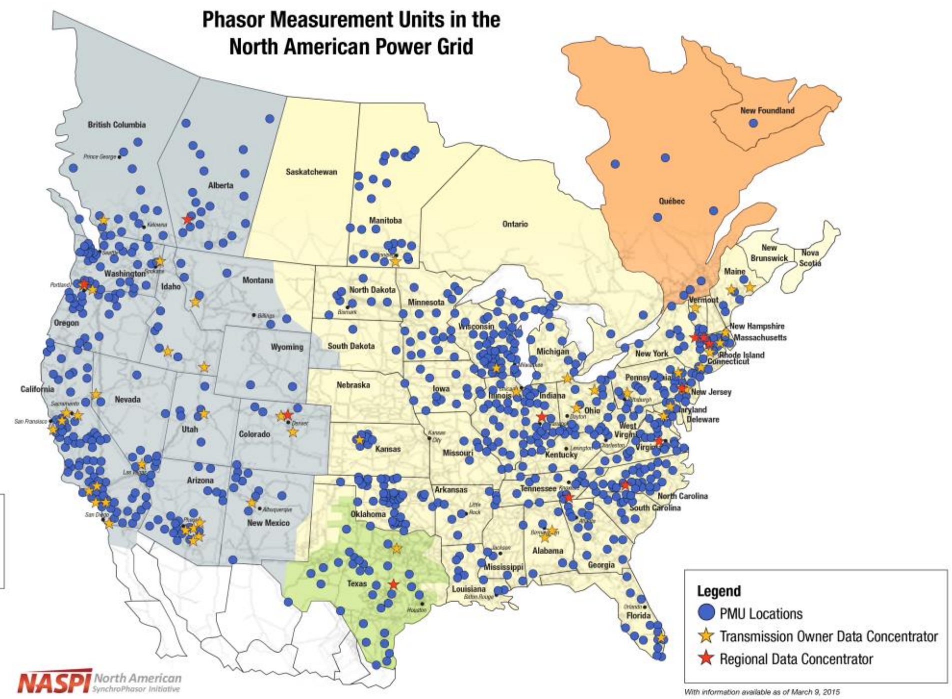

"Better information supports better - and faster - decisions."

NASPI North American SynchroPhasor Initiative | U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY DELIVERY & ENERGY RELIABILITY | EPRI ELECTRIC POWER RESEARCH INSTITUTE

Applications for Wide-Area Monitoring, Analysis, and Control

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Monitoring	Analysis	Control
• Frequency • Voltage • Oscillation Detection • Wide-area Visualization • Operator Decision Support • State Estimation (hybrid or linear state estimation / state measurements) • Renewables Integration	• Post-Event Analysis • Model Validation • State Estimation	• Adaptive Islanding • Adaptive Relaying • Power System Stabilizing / Power Oscillation Dampers • Black-Start Restoration • Automated Remedial Action Schemes

Testing Vulnerabilities Associated with Satellite Clocks for Precision Timing Applications in the Power System

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Test Objectives:

- Determine the susceptibility of GPS satellite clocks to spoofing that could undermine the accuracy of Phasor Measurement Units (PMU)
- Tests carried out at the PNNL Electricity Infrastructure Operations Center (EIOC) December 2011 with Northrop Grumman and University of Texas-Austin
- Three different satellite clocks were utilized in the testing

Schematic of the Test Setup

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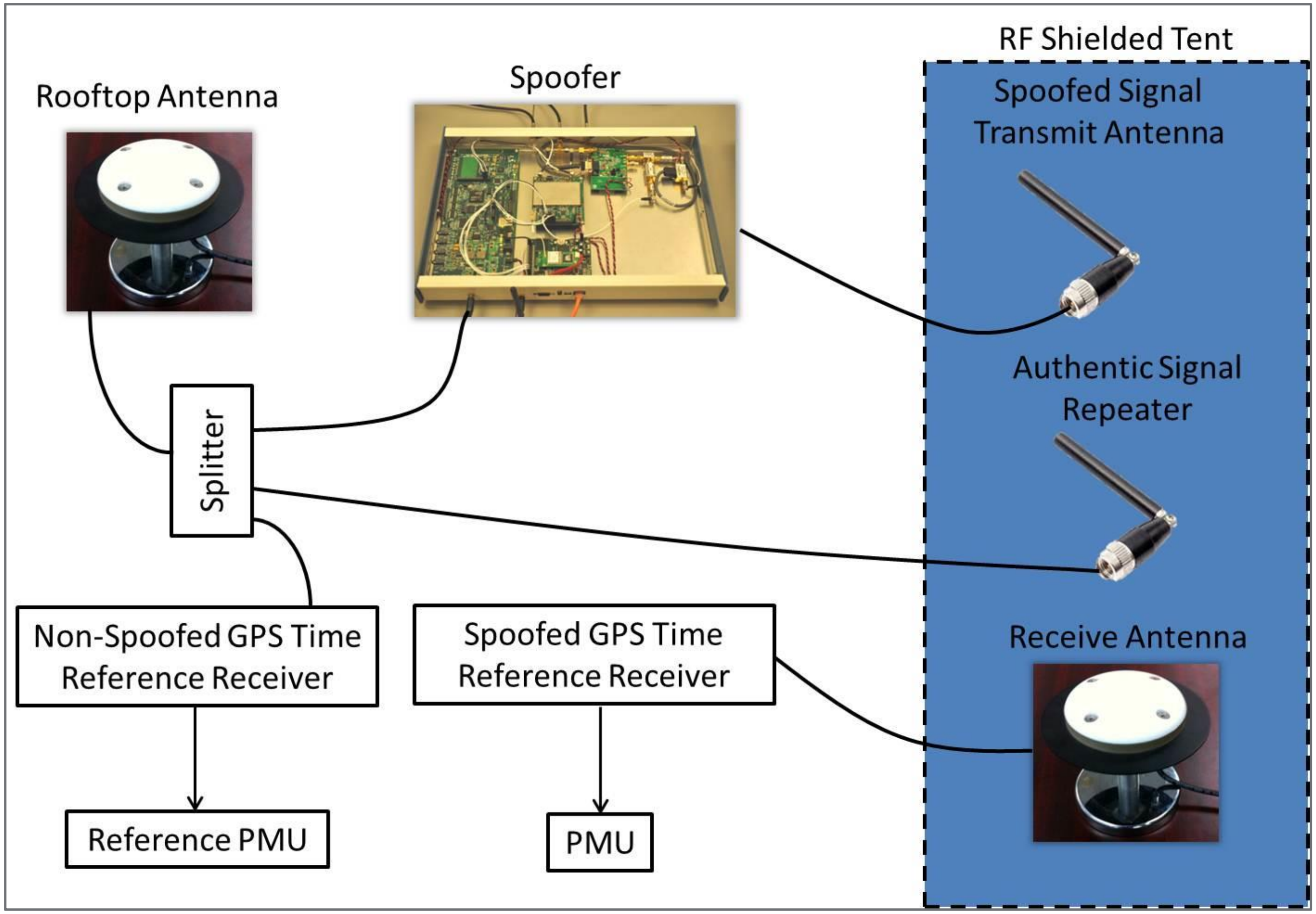

RF Shielded Tent

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Spoofing Test Result: Impacting the Phase Angle Measurement by Manipulating the Time Reference

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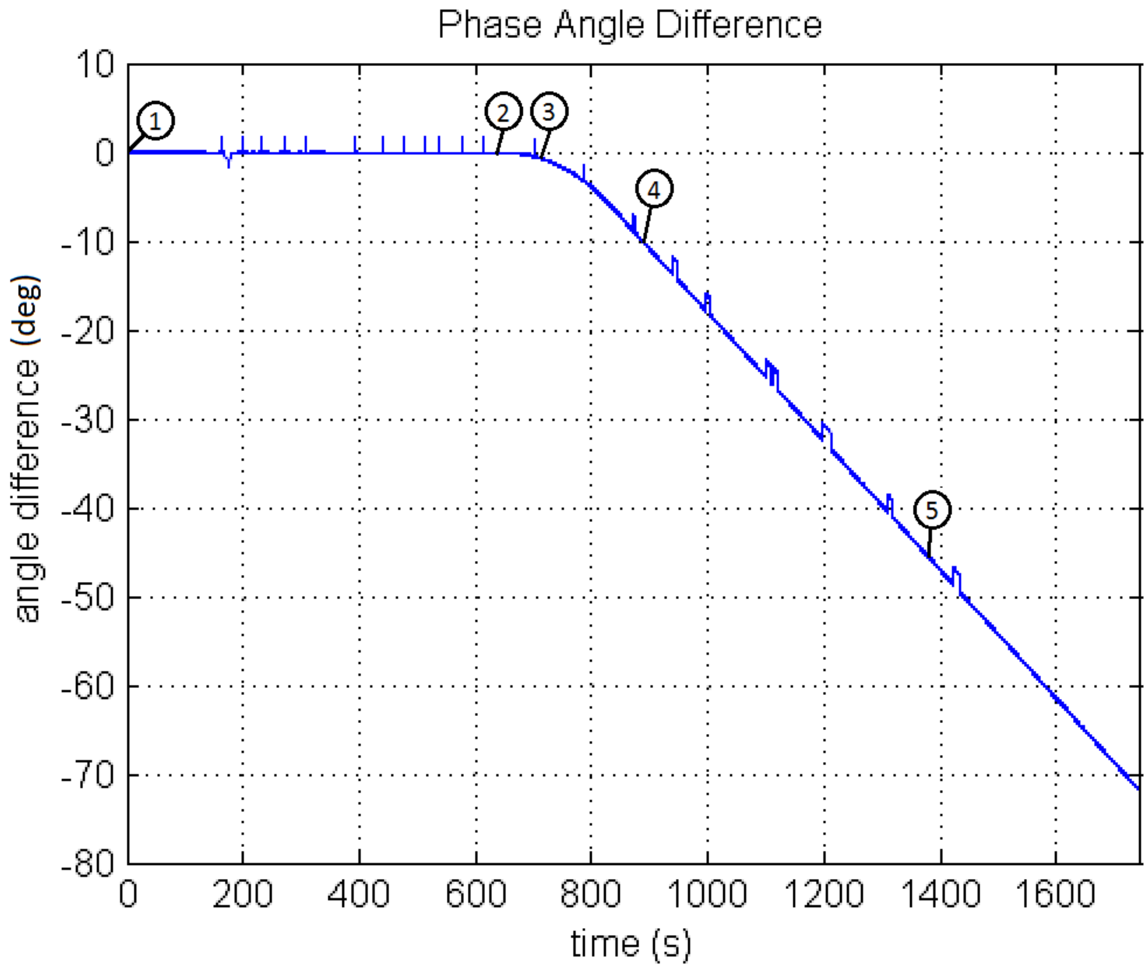

Test Results

- All three satellite clocks that we tested were susceptible to GPS spoofing
  - Some differences in the rate of change that could be implemented (defeating the internal error checking algorithms)
  - Some differences in how the clocks responded when the spoofing signal was turned off
- Recommending an alternative method for time synchronization associated with control applications that require secure timing
- The North American SynchroPhasor Initiative (NASPI) Time Synchronization Task Force is investigating various alternatives and recommended practices

Jamming Satellite Clocks

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- Jamming is easier to accomplish than spoofing
- Consequences are much less impactful:
  - Clocks will reliably set the “loss of synchronization” error flag
  - Time error will be based on internal clock holdover accuracy
  - Resulting timing errors will be somewhat random
  - Predictable behavior of the clock when jamming signal removed

Options for Increasing Time Synchronization Robustness

- Enhancing the satellite-based timing system
- Improved holdover oscillator accuracy
- Alternative radio-based technology (e.g, eLORAN)
- Network-based time synchronization
  - IEEE Standard 1588: Precision Time Protocol
- Atomic clocks

Conclusions

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- Precise timing is widely used to support synchrophasor applications in the electric power sector
- Synchrophasors have long been used for important applications, such as validating power system dynamic models
- There are emerging applications being deployed that utilize synchrophasors for operational applications
- Increased robustness of wide-area time synchronization is required to support these emerging applications

NASPI North American SynchroPhasor Initiative

http://www.naspi.org/