# Dynamic Performance Requirements for Phasor Meausrement Units

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Dmitry Kosterev
Transmission Planning
Bonneville Power Administration
dnkosterev@bpa.gov

# BPA Plans for Synchro-Phasor Infrastructure

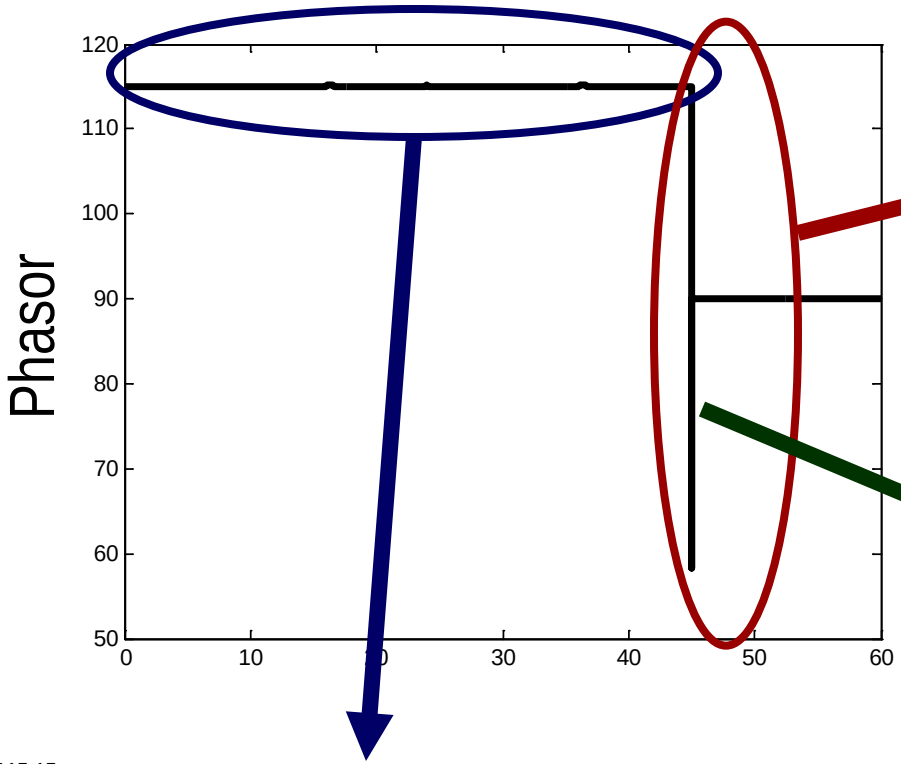
- 120+ PMUs planned to be installed at 70+ sites
  - Additional PMUs will be installed on Wind Power Plants
- PMUs will be streaming data continuously to both control centers
- “Control” PMUs will be stand-alone
  - Used for wide-area control and situational awareness applications
- “Data” PMUs may include several functions

# Planned Applications of Synchro-Phasor Data

- APPLICATIONS DRIVE REQUIREMENTS

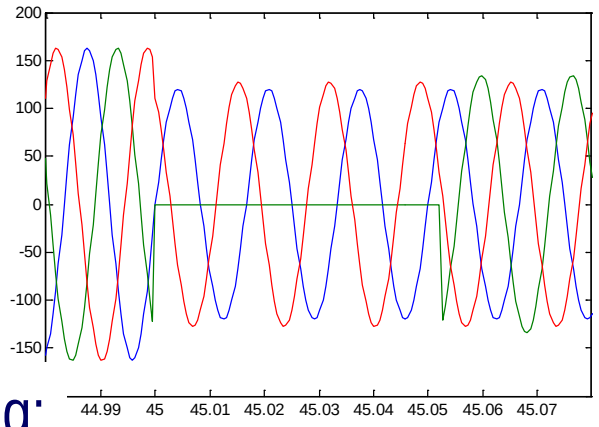
- Engineering applications
  - Disturbance analysis, performance base-lining
  - System model validation
  - Inter-area oscillation analysis
- Situational Awareness for Operators
  - Trending tools, phase angle alarms, etc
  - Mode Meter and Oscillation Alarms
- Wide-area stability controls
  - Response-based fast reactive switching
  - Continuous feedback power modulation

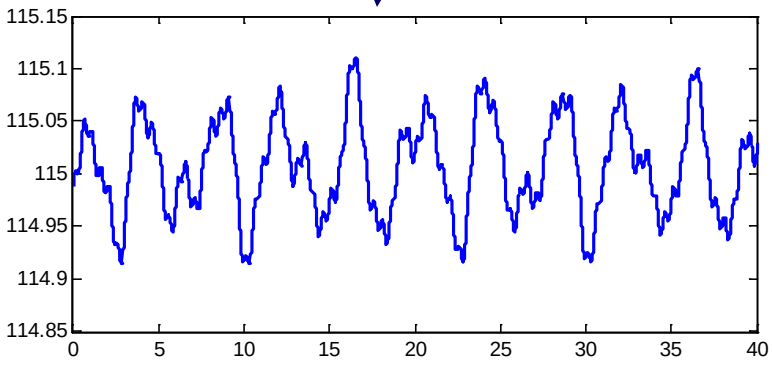
# PMU Dynamic Performance and Applications




System Protection and Control:
- large changes
- very fast response

Point of Wave Data:
- disturbance analysis




Oscillation Damping:
- small signals
- high precision

# PMU Dynamic Performance and Applications

- Various PMU applications may have different data requirements
- Oscillation damping
  - Small signal analysis – good filtering and high signal quality are required, response of up to 3 cycles is acceptable
- System protection and wide-area controls
  - Detect large changes fast, sub-cycle response
- Engineering analysis
  - Looking for all of the above
  - May be also interested in point-of-wave data (particularly loads, SVCs, HVDC, wind power plants, other controllers)

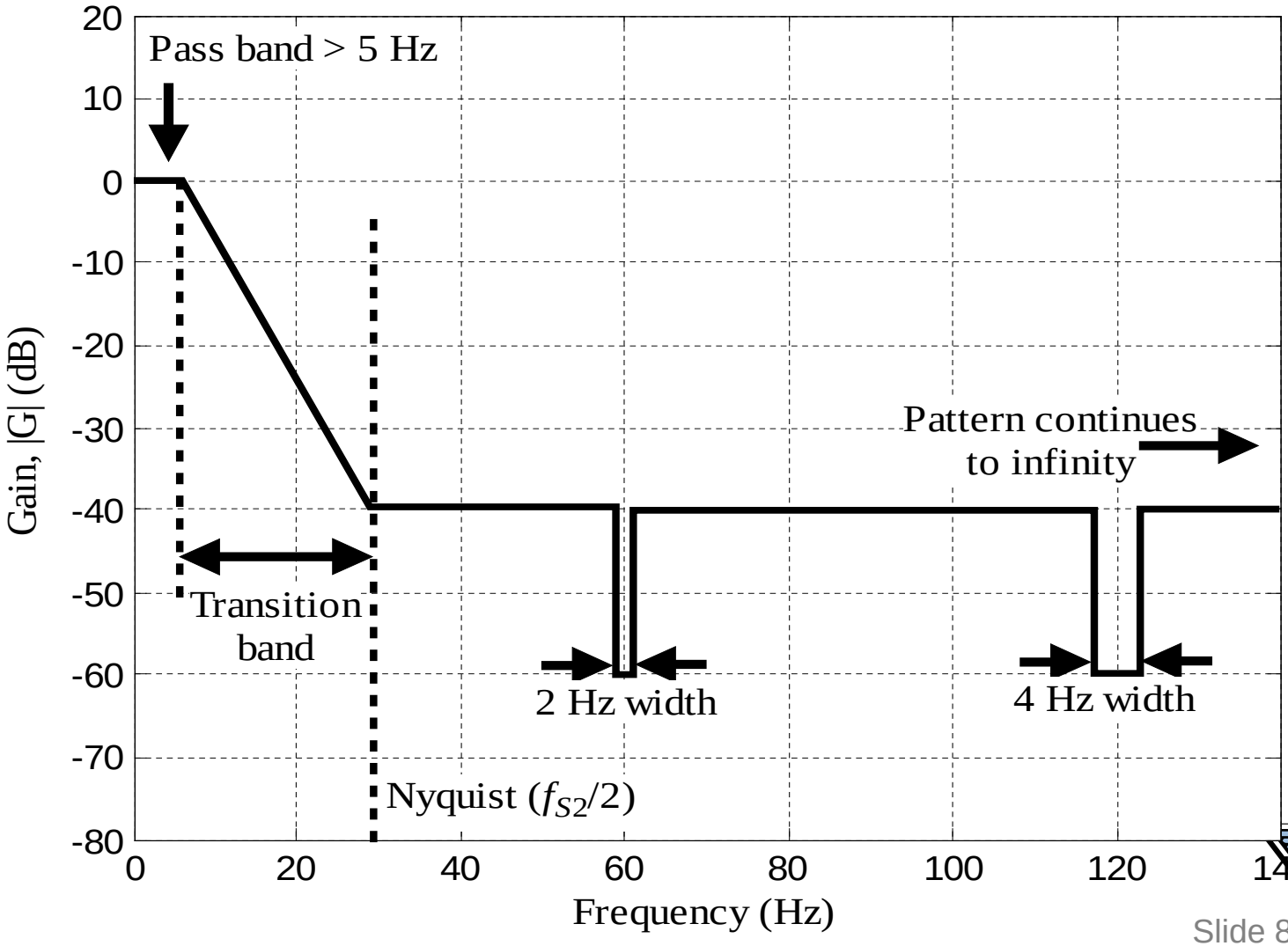
# PMUs for Dynamic Performance Analysis and Control

- Oscillation damping controls and mode meter are one of the most demanding PMU applications
- PMU filtering must meet somewhat conflicting requirements:
  - Must have fast response and wide bandwidth (not as fast as protection, 3 cycle response is acceptable)
  - Must reject out-of-band signals
- Dr John Hauer initially developed the PMU filtering standard for BPA and WECC
- Recently, Dan Trudnowski expanded the requirements and investigated the feasibility of designing PMU filter to meet these requirements

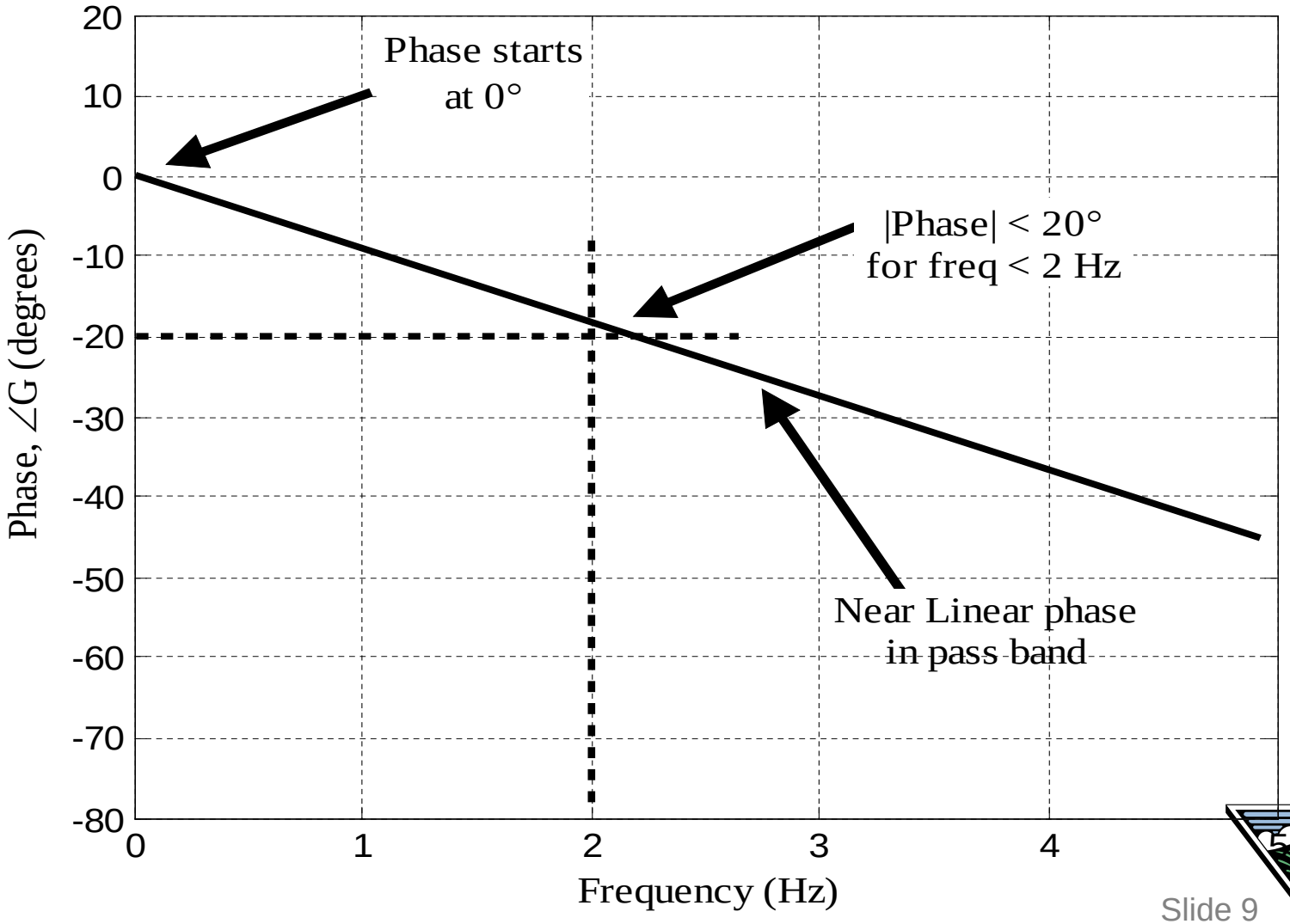
# It is not a pure 60 Hz wave-form

- Inter-area oscillations = 0.1 – 0.7 Hz
- Local generator oscillations = 0.5 – 2.0 Hz
- Wind turbine-generator torsional = 1.5 – 2.0 Hz
- HVDC control modes ~ 5 Hz, 30Hz ?
- Exciter control modes ~ 5 Hz
- Steam turbine torsional ~5Hz, 10Hz, 15Hz, 30 Hz, 50 Hz
- Harmonics

# Gain Requirements



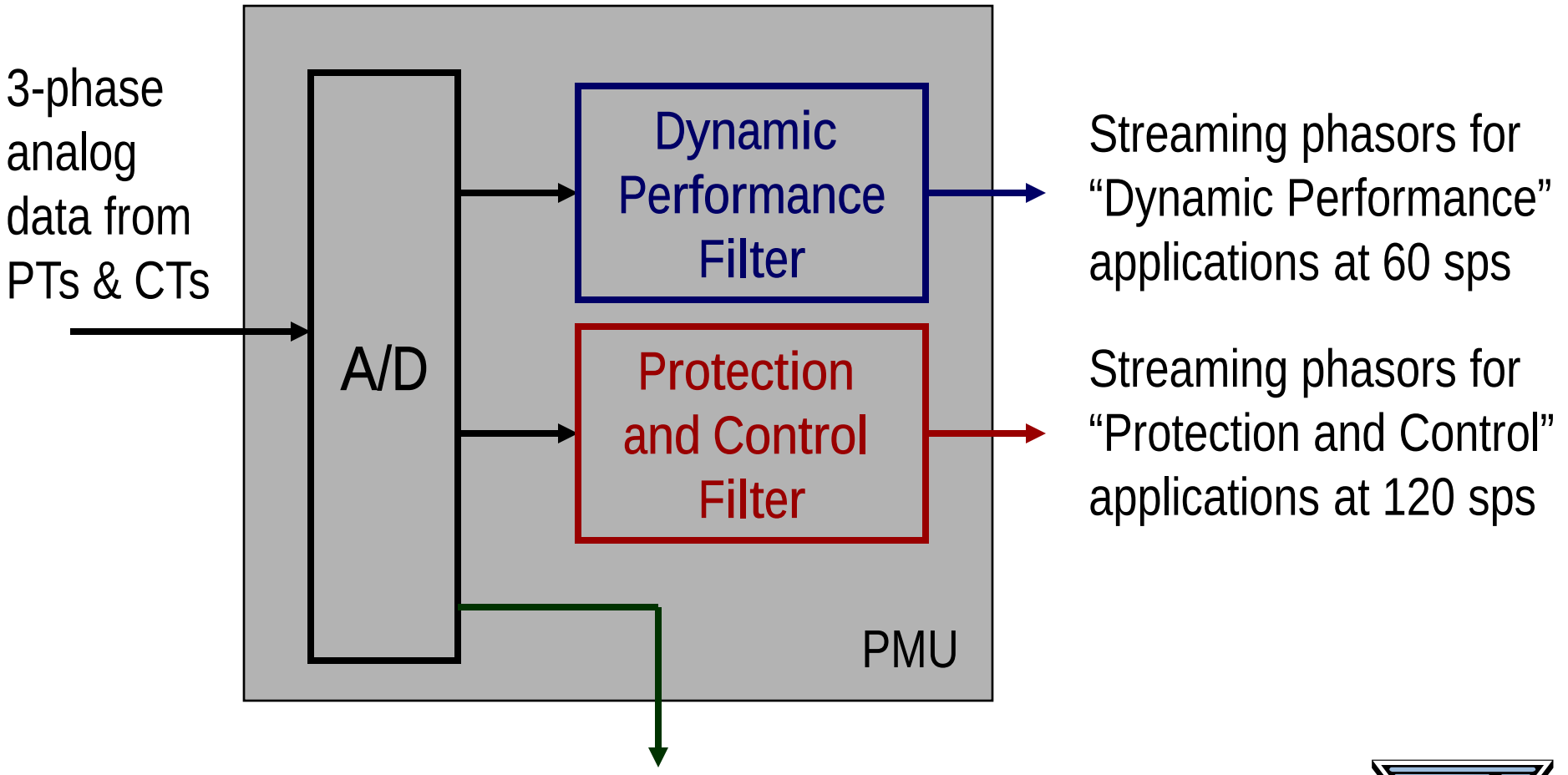
# Phase Requirements



# Where we are:

- Dynamic performance requirements are developed, and the feasibility of meeting these requirements is confirmed – paper by Dan Trudnowski
- Lab test procedures are developed by Tony Faris at BPA
- BPA is currently testing PMUs from 11 vendors for dynamic performance – Tony Faris
- We would like to make a recommendation on vendor selection by July 2010

# What we would like to see in a PMU




Point of Wave digital data at = or > 1920 sps, stored locally

# Additional Slides

# Technical References

- Dan Trundowski, Recommended PMU Dynamic Requirements for Small-Signal Applications, October 2009
  - Detailed technical requirements
  - Examples of the filters that meet dynamic performance requirements
  - Available at NASPI web-site

- For in-depth analysis, please refer to the library of papers by John Hauer, available from BPA and PNNL

# Dynamic Performance Requirements Summary

- Gain
  - REQUIRED: The gain does not exceed -40 dB at frequencies above the Nyquist frequency continuing to infinity.
  - REQUIRED: The gain does not exceed -60 dB at frequencies that are harmonics of 60 Hz. The notch at 60 Hz is 2 Hz with linearly increasing notches for higher harmonics.
  - REQUIRED: The pass band gain has no ripple and is within 0.5 dB out to 1.5 Hz.
  - REQUIRED: The corner frequency (-3 dB) must be greater than or equal to 5 Hz.
- Phase
  - REQUIRED: The phase start 0° at DC.
  - REQUIRED: The phase must be bound by $\pm$20° for all frequencies less than or equal to 2 Hz.
  - DESIRED: The phase is as linear as possible in the pass band.
- Step Response
  - REQUIRED: The 90% rise time occurs within 50 msec.
  - DESIRED: The percent overshoot does not exceed 10%.
  - REQUIRED: The 2% settling time is less than or equal to $3Tp$.
  - This includes any delay in the time tag

# Signal Quality

- Reliable performance is required for system frequency excursions ranging from 58 Hz to 62 Hz.
- Resolution of the analog-to-digital (A/D) conversion process must be 16 bits or higher.
- Scaling of signals entering the A/D conversion should assure that 12-14 bits are actively used to represent them. Signals for which this scaling may overload the A/D during large transients may be recorded on two channels, in which one has less resolution but a greater dynamic range.
- Measurement noise must be within the normal limits of modern instrument technology.

# Overall PMU Evaluation

- Determination of PMU performance is based upon integrated use of laboratory tests, model simulations, and comparative measurements under field operating conditions [A].
  Laboratory tests are necessary but not sufficient.
- PMU documentation must permit
  - overall quality of instrument processing to be assessed
  - acquired records to be compensated for known attenuation and delays

- [A] Evaluating the Dynamic Performance of Phasor Measurement Units: Experience in the Western Power System, J. F. Hauer, Ken Martin, and Harry Lee. Interim Report of the WECC Disturbance Monitoring Work Group, August 5, 2005. (Available at ftp.bpa.gov/pub/WAMS%20Information/)