

Phasor Measurement Testing at BPA & in the WECC

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PMU Testing

- Field Tests - comparison with traditional analog
 - Original VPI PMU, 1989-90
- Laboratory tests
 - VPI-PMU, 1990
 - Macrodyne PMU 1995
- WECC ‘monitors’
 - 2002—ongoing
 - Many new ‘PMU’ units



BPA test requirements

- Performance
 - Steady state accuracy
 - Reasonable transient response
 - Low-latency data reporting (real-time)
- Equipment reliability
 - SWC protection
 - Environmental requirements
- Compatibility in the system
- Focus is on system-wide, real-time, large signal view

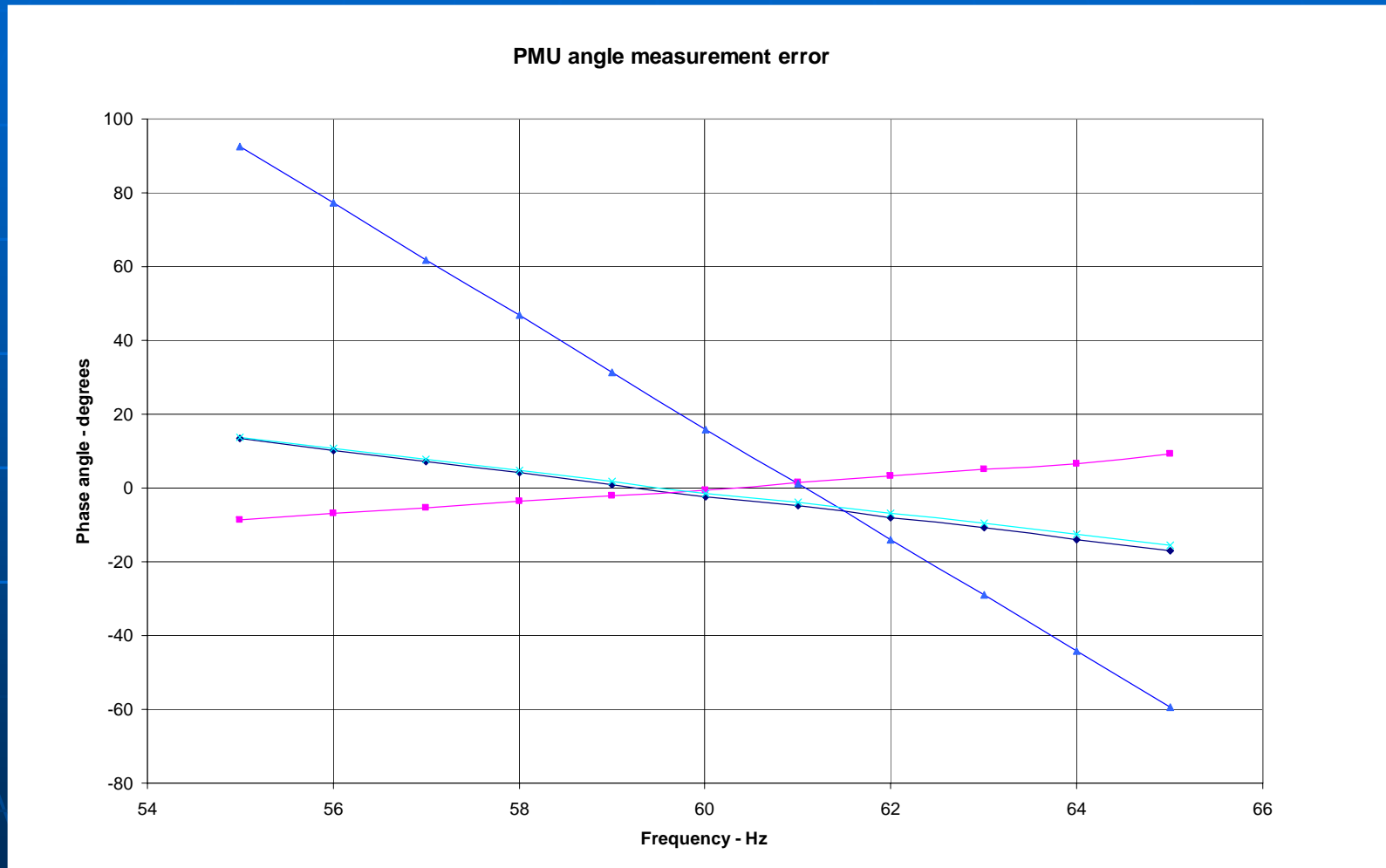
WECC test requirements

- Performance
 - 5 Hz frequency response
 - Good out-of-band signal rejection
 - 40 dB for all signals, 60 dB at harmonics
 - Adequate sample rate, 16-bit A/D, adequate scaling
 - Low measurement noise
 - Continuous data storage, compatible data format, & adequate data retrieval system
 - GPS synchronization
- Focus is small-signal, recorded data for analysis

Steady-state Accuracy

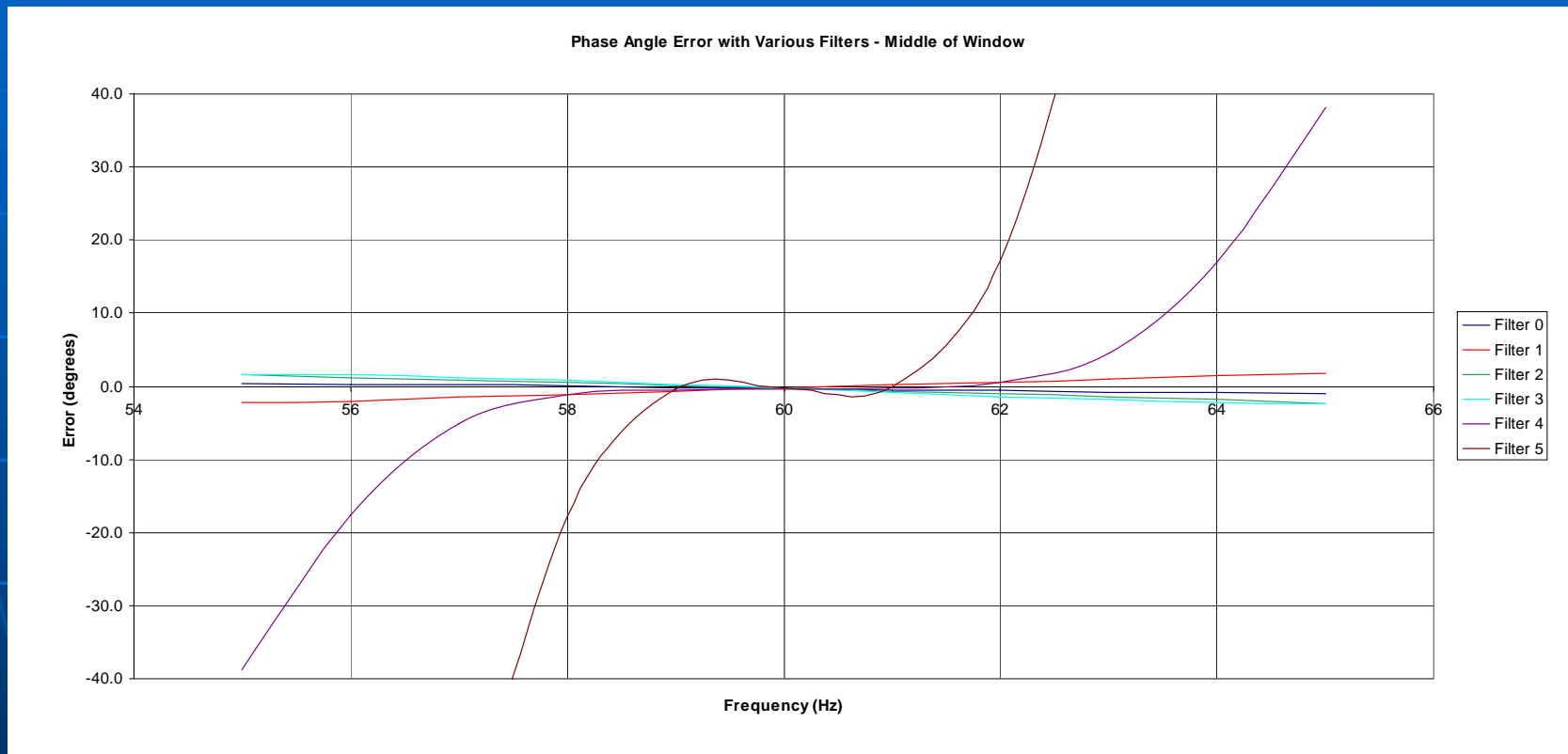
- Phasor Measurement (typical, w/ precise cal)
 - Magnitude – tested at performance levels
 - Results - 0.5%, 0.1%
 - Phase angle – between 2 phasors on same PMU
 - Results - 0.3 °, 0.1 °
 - Absolute phase angle – referenced to UTC
 - Difficult to test
 - Results - 1.2 °, 0.3 °
- Frequency – tested +/- 5 Hz
 - Results - 0.005 Hz, 0.001 Hz

Phase measurement vs frequency



**4 PMUs show difference in phase angle at different frequencies.
Example of importance of PMU testing and standards development.**

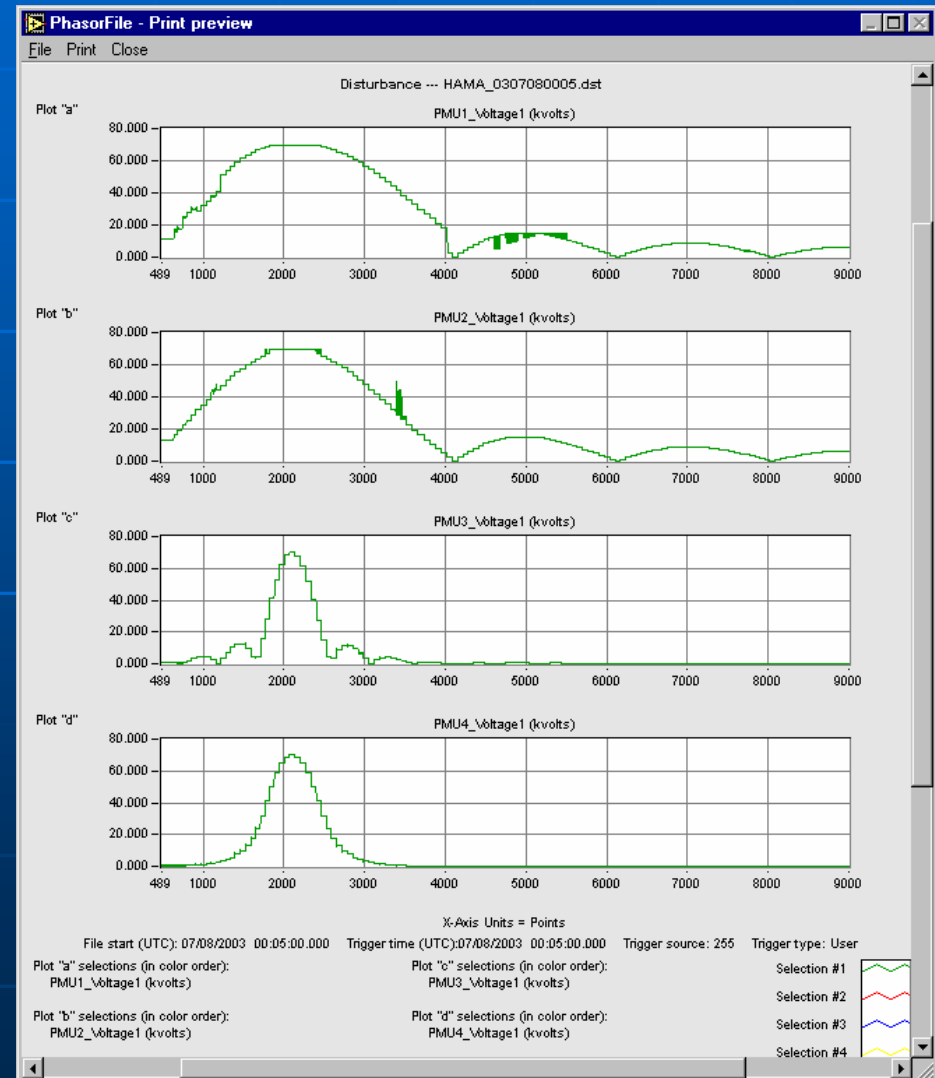
Phase measurement vs frequency



**Phase angle measurement from PMU with selectable filters.
1 cycle Filter 0 very linear, many order Filter 5 very difficult
to linearize over frequency band.**

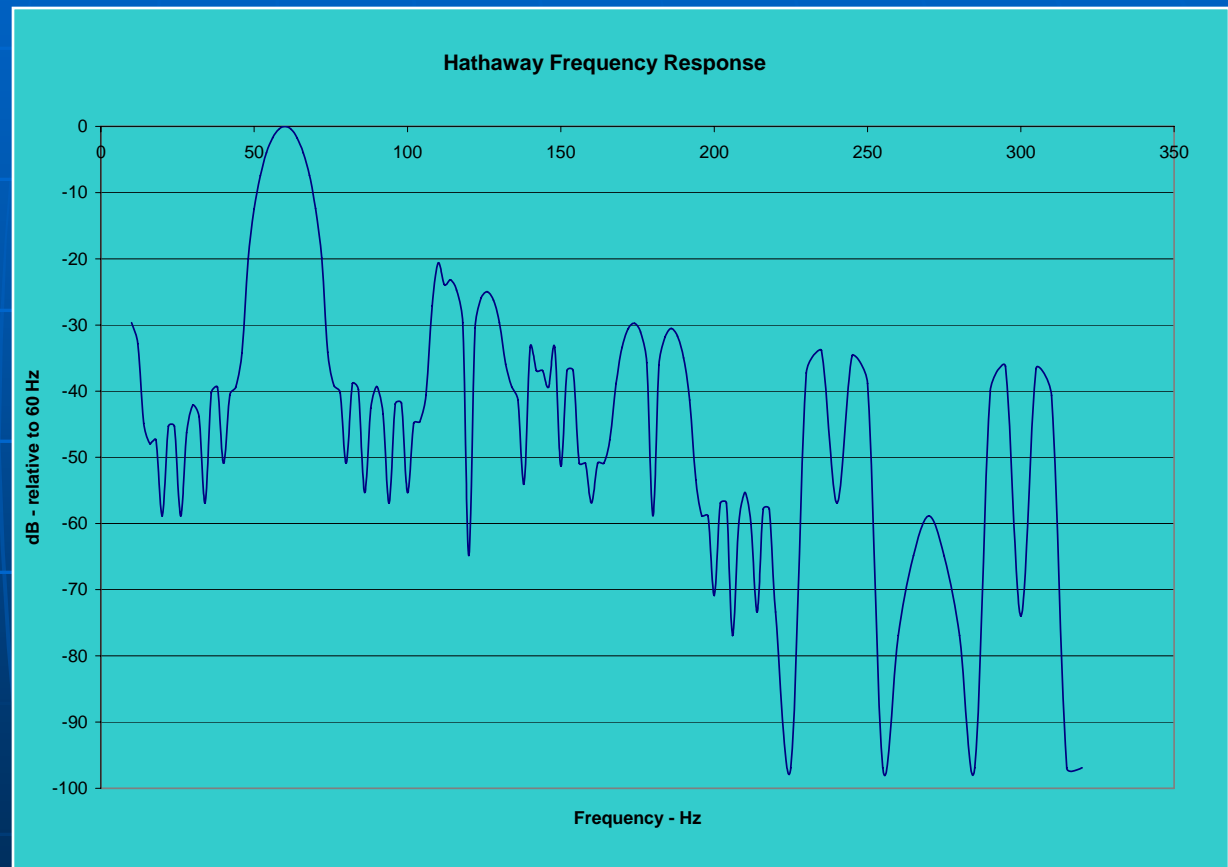
Wideband frequency tests

- Wideband gives good overview of filtering
 - Identifies response band
 - Provides indication of aliasing problems
- Running several PMUs together provides visual comparison



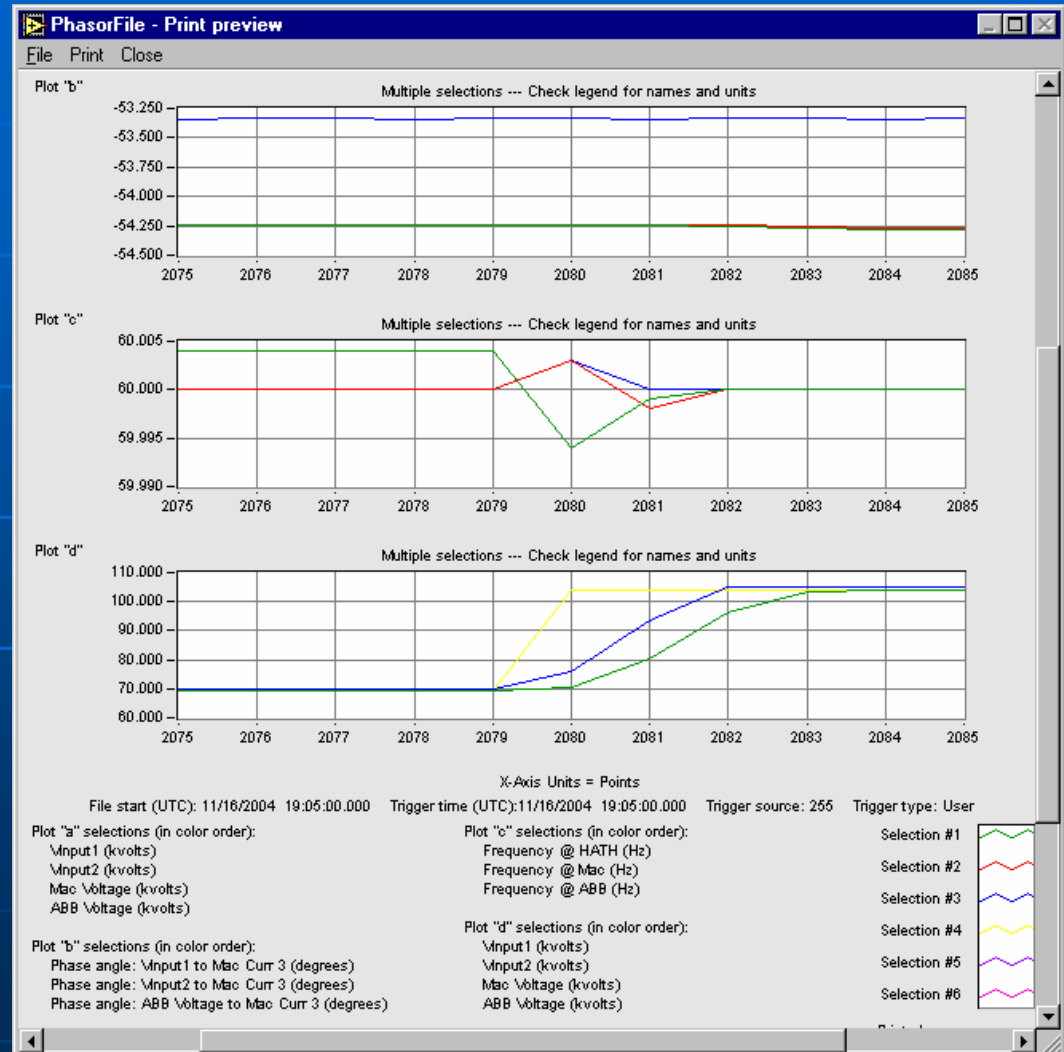
Wideband in dB

- Detailed frequency done at small steps, recorded in Excel
- Wideband in dB accurately shows rejection



Step tests

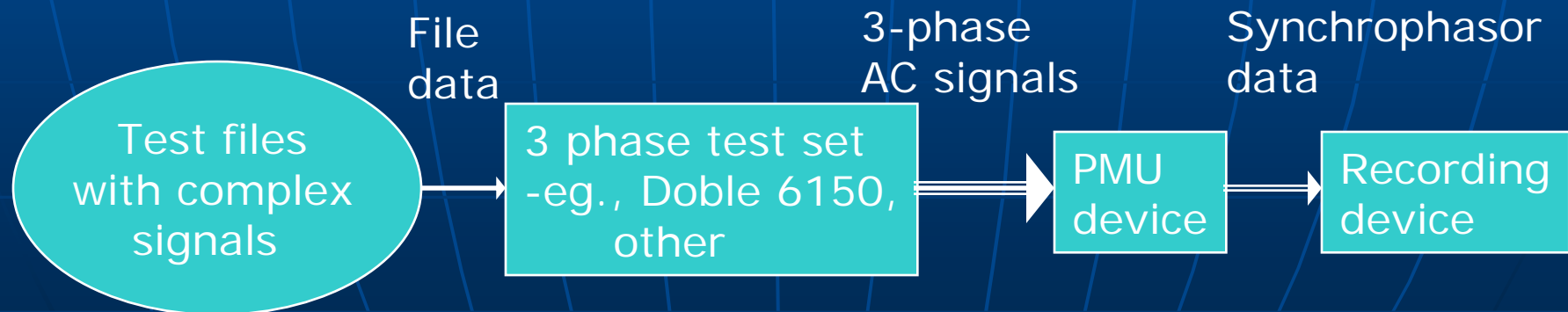
- Varied steps of mag, phase, freq
- Tests show speed and characteristics of response
- Testing several PMUs together eases comparison
- Does not provide easily quantifiable result



50 % magnitude step with 2 PMUs

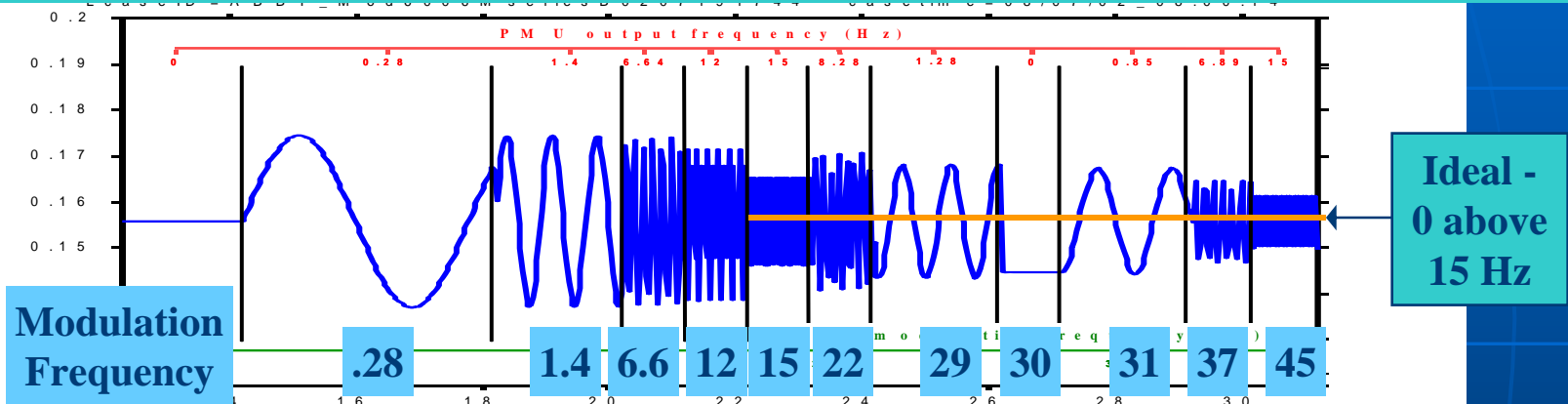
Complex signals

- Complex signals generated in Matlab
 - Include magnitude, phase, frequency modulation
 - Exported to compatible file format (COMTRADE)
 - Provides more quantifiable results
- Difficult to relate to real-time & stimulus

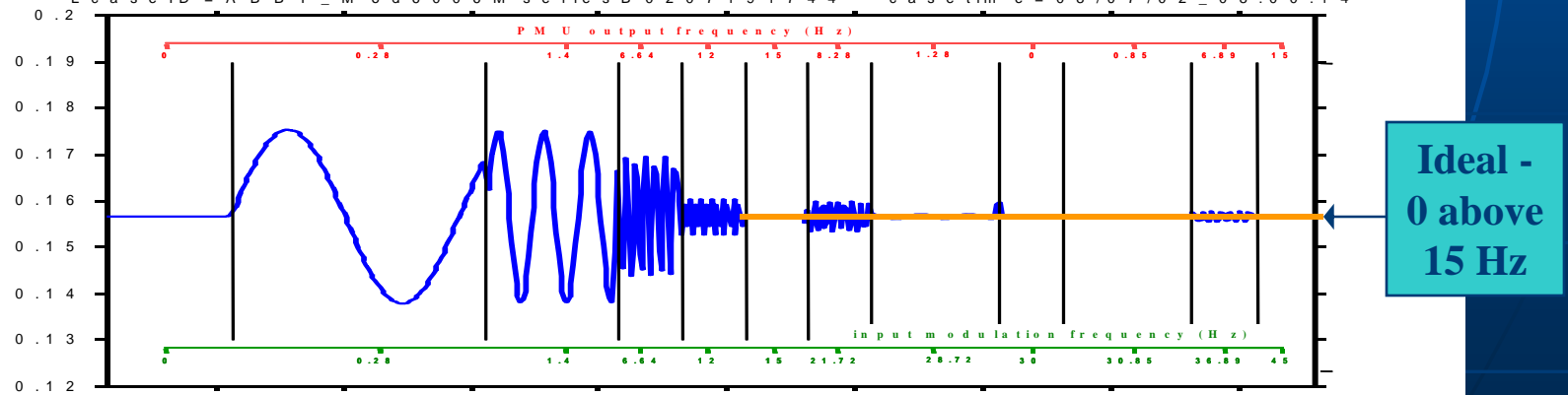


Test with Amplitude Modulation

60 Hz power signal modulated with frequencies from 0.28 to 45.0 Hz.
Measurement passband is limited to 15 Hz by 30 sample/sec data rate.
Ideal response is uniform magnitude to 12 Hz, zero response 15 Hz and above.



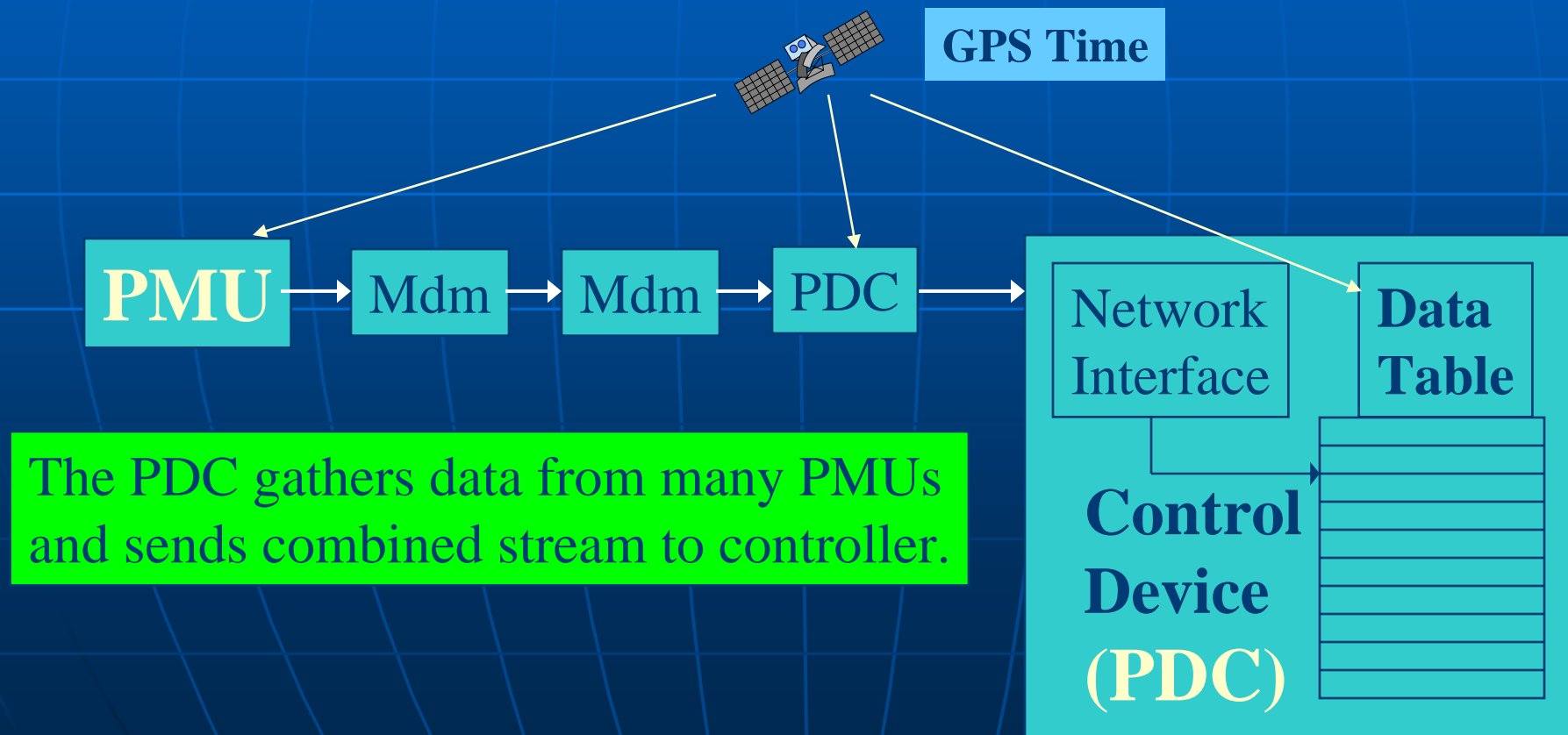
PMU A with wide filtering is flat in passband but aliases in higher frequencies.



PMU B with narrow filtering has more signal rolloff & rejects higher frequencies.

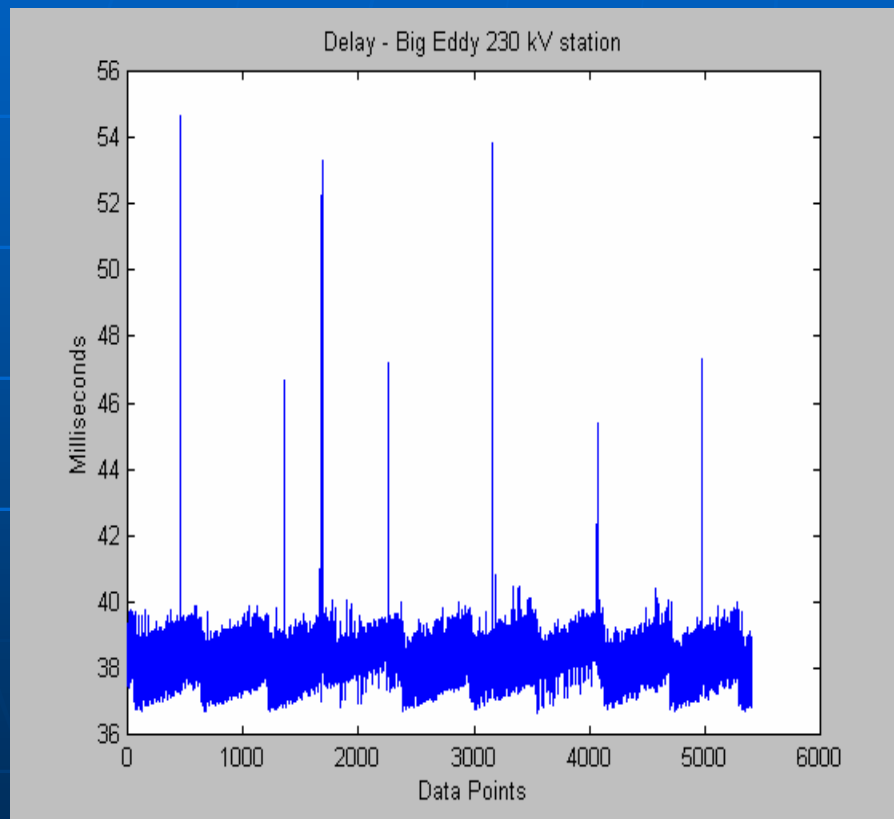
Data Communication Signal Delay

Time measurements have been made from PMU to PDC, and PDC to second device, here another PDC as it allows precise time measurement.

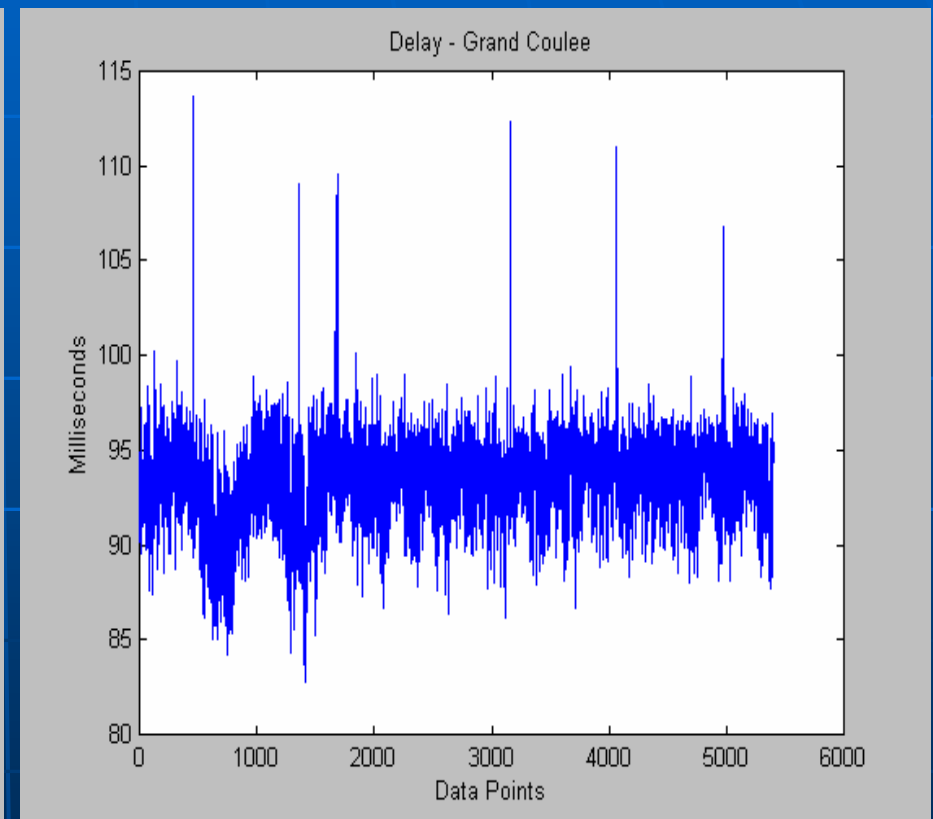


Signal Delay - PMU to PDC

- Communication time delay



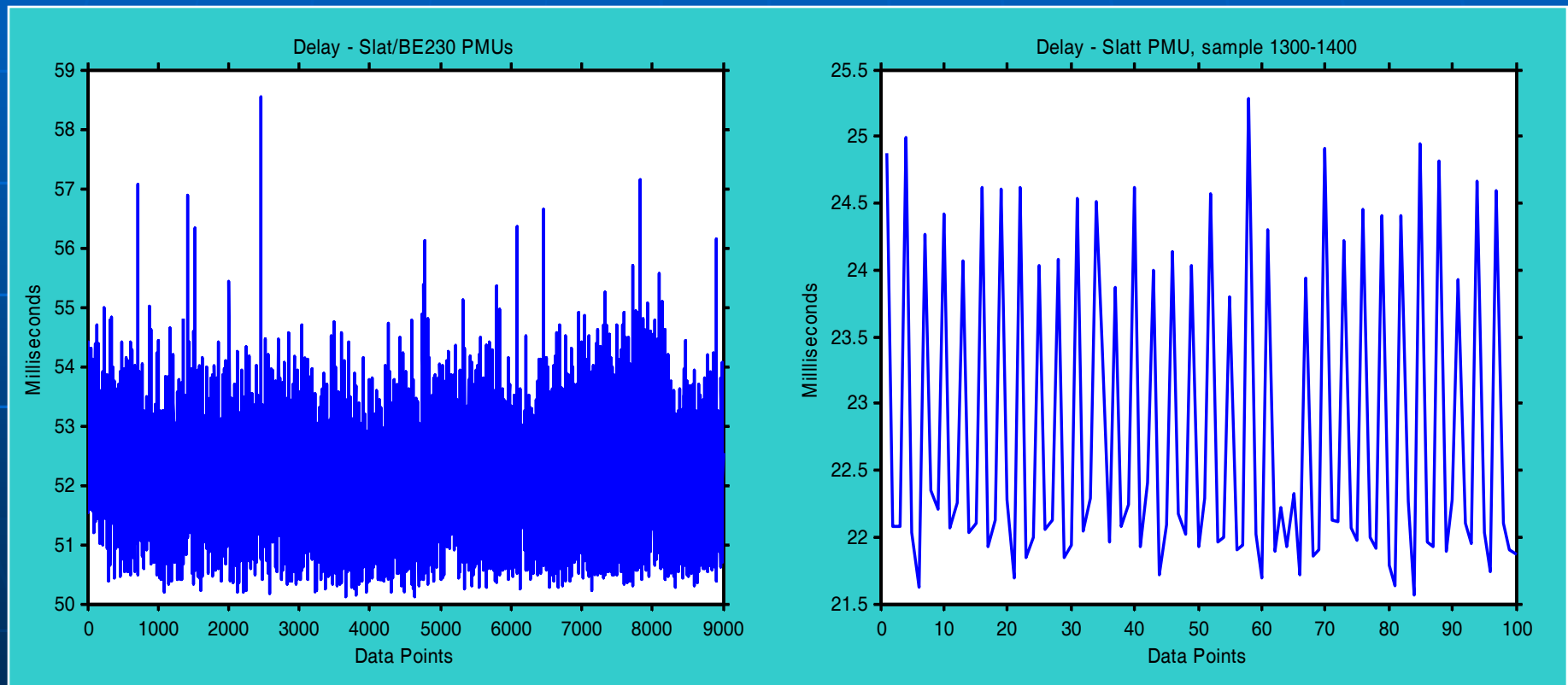
Using direct fiber link



Using V.34 analog modem

Signal Delay - PMU to Controller

- Combined communication time delay – PMU to PDC to PDC
- PDC processing adds 5-6 ms



Async interface to Sonet
53 ms overall

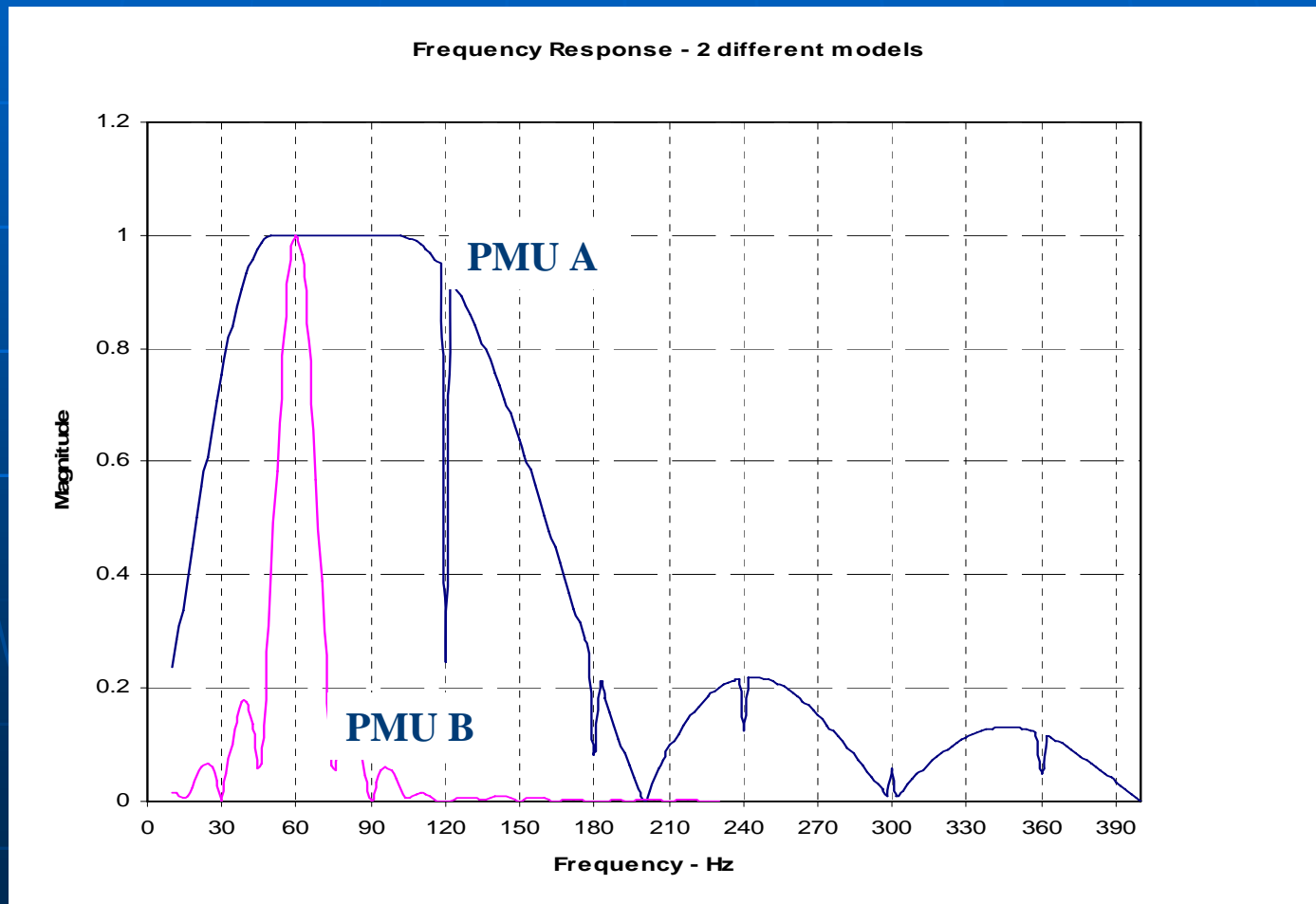
Direct async into Sonet
24 ms overall

Standard Test Summary

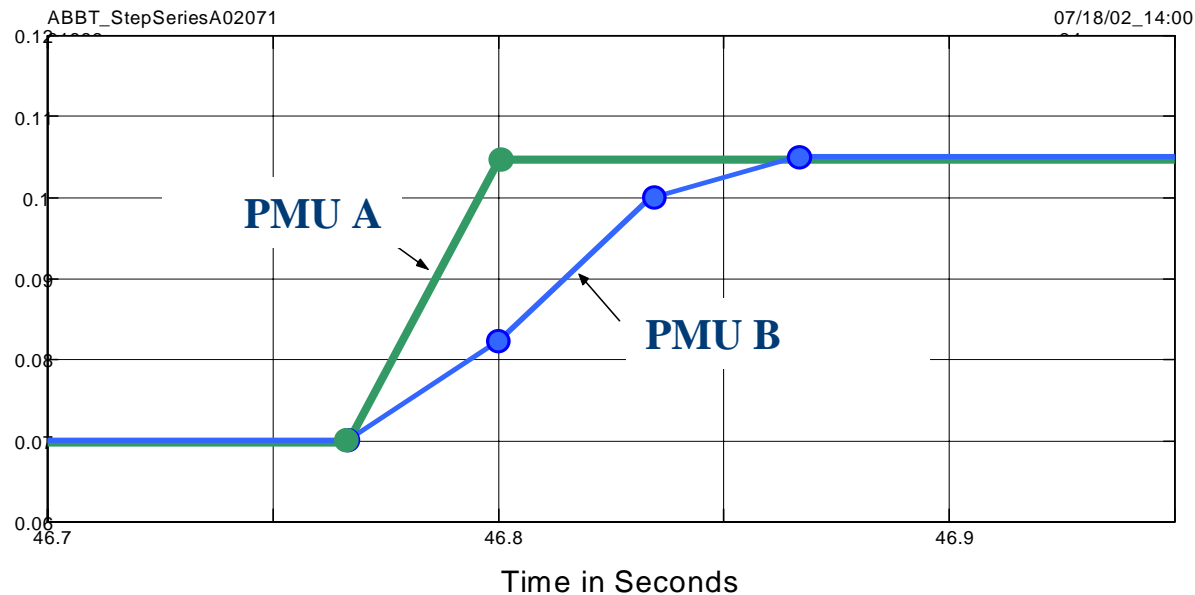
- Steady state performance & measurements excellent
- Dynamic response very good
 - Need better quantification
- Tests require close examination
 - Many characteristics are not obvious
 - Some problems surface only in special conditions
 - Some anomalies only appear occasionally

Characteristic relationships

Wideband frequency response shows filter characteristics



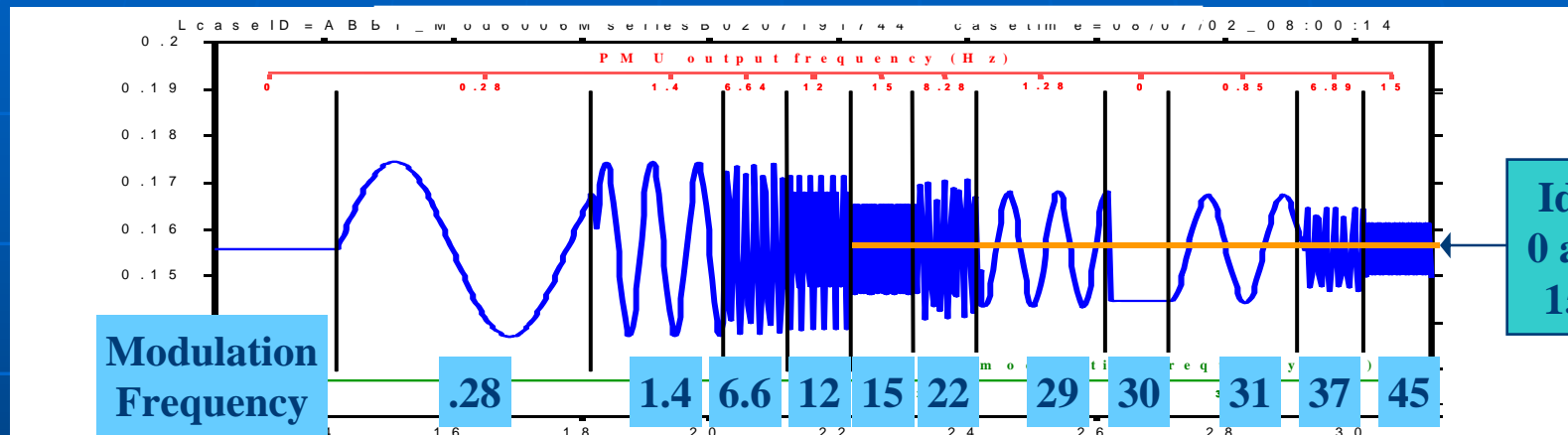
Filtering affects step changes



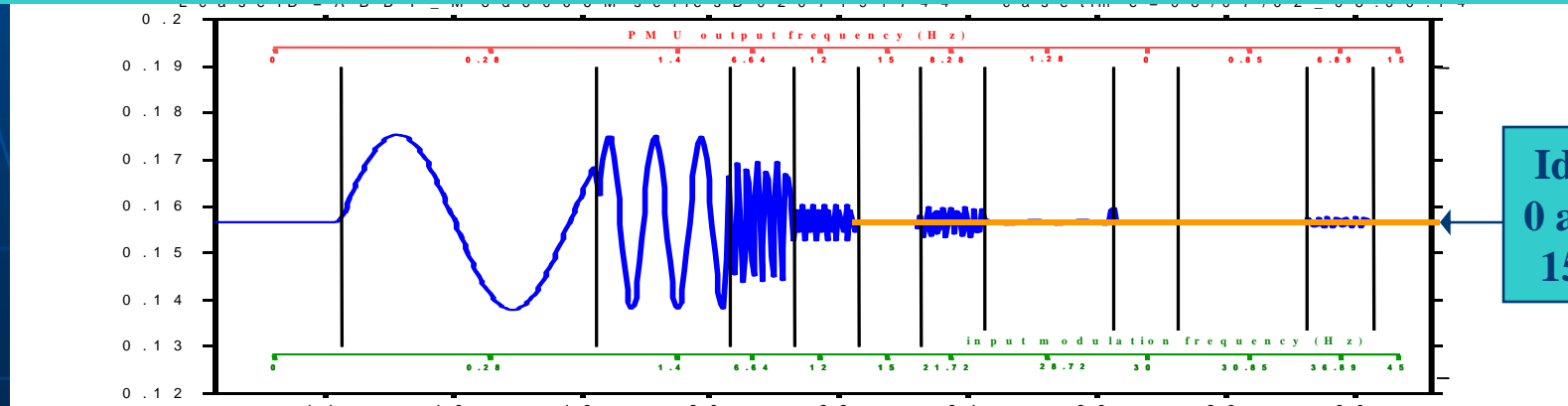
The PMU with wideband filtering responds to a step change in magnitude in one sample interval (2 cycles) while the PMU with output filtering responds in 3 sample intervals (6 cycles). The response time is the same regardless of the size of the step.

Filtering effect in modulated signal

Same curve as before. Another way to observe the wideband response or the step change.



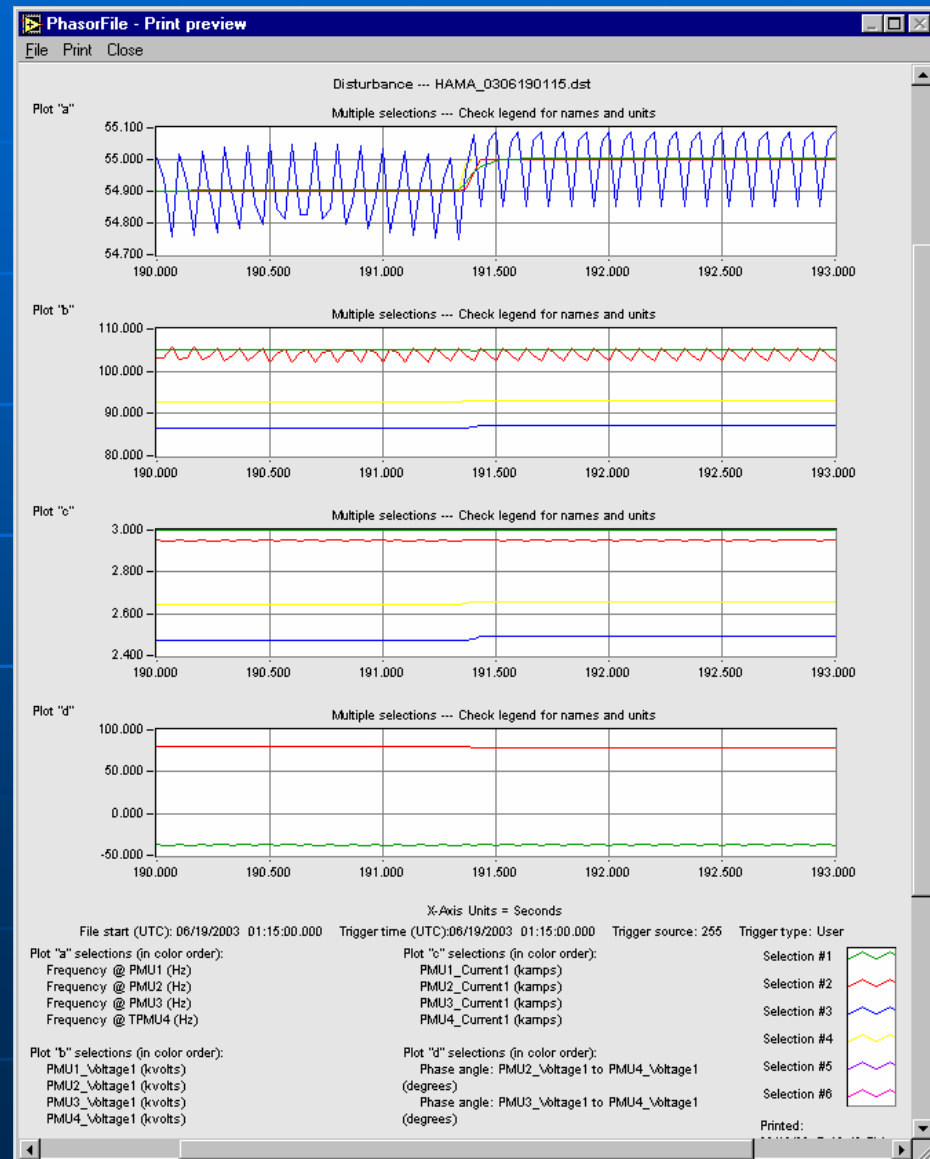
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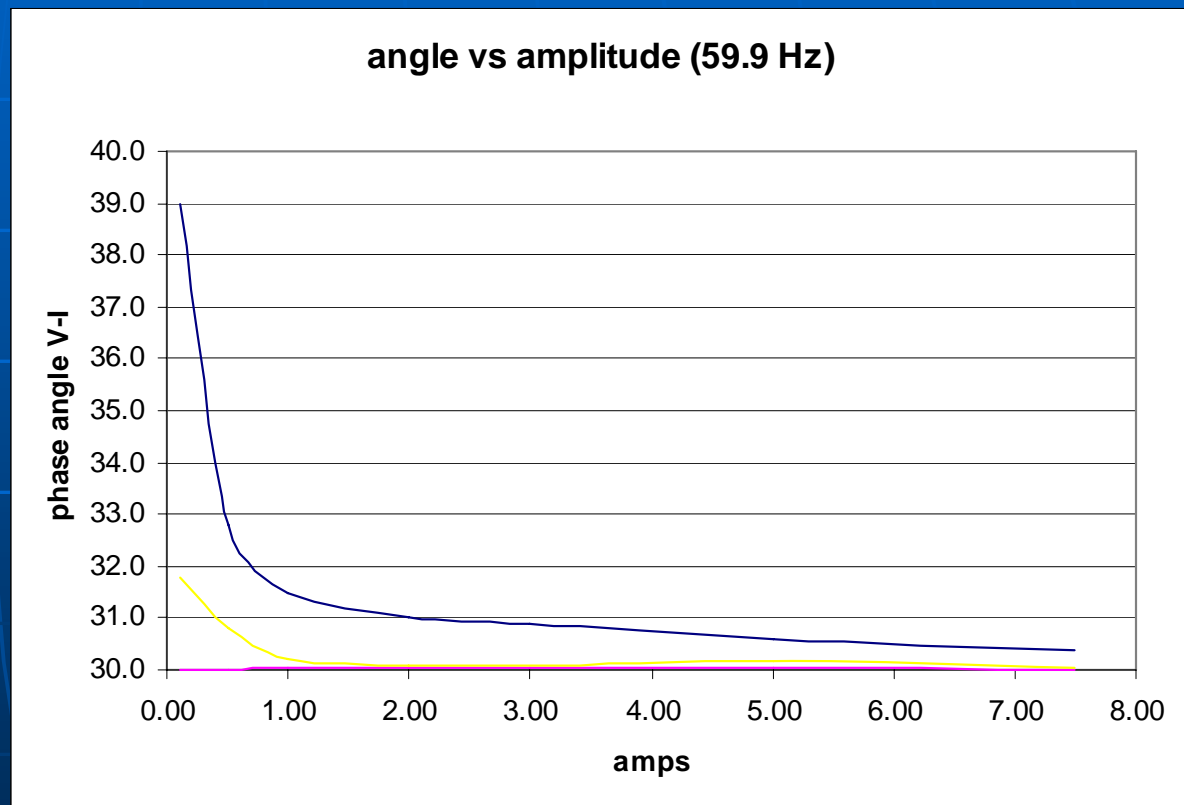
Studied examination needed

- There is an oscillation in the frequency measurement of PMU3 in plot_a
- There is an oscillation in the magnitude measurement of PMU1 in plot_b



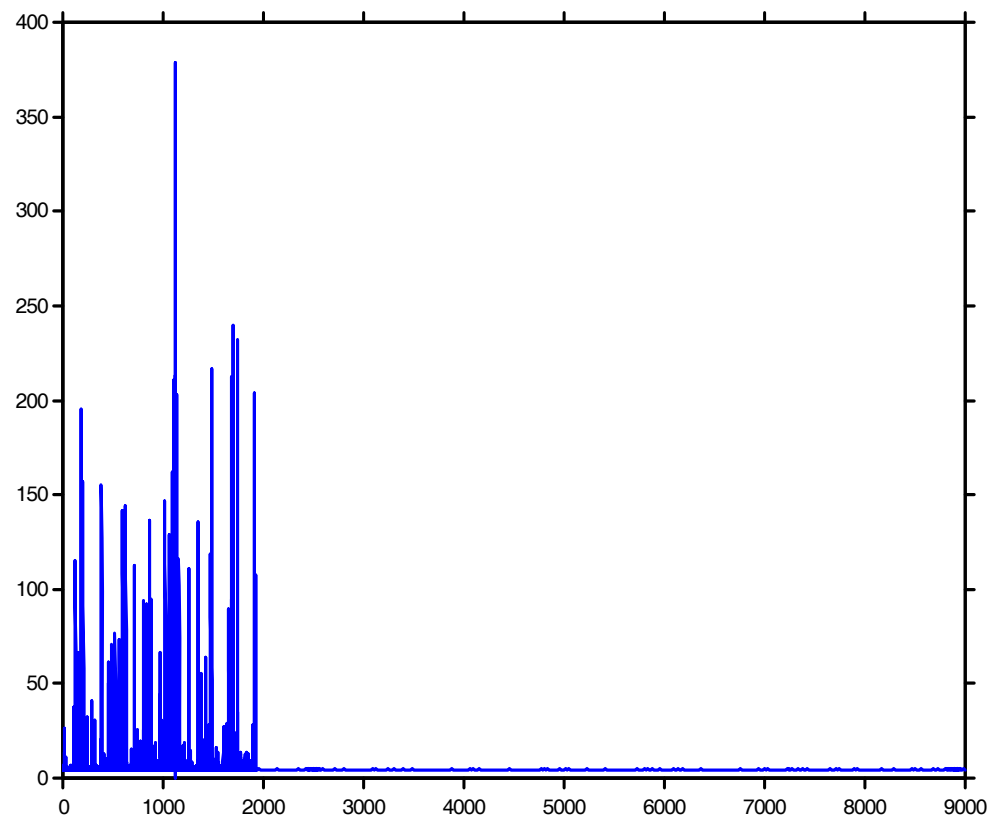
Examination leads to new tests

- Noticed variation of phase angle at low currents
- Test showed significant change
- 'Check' test added
- Not all PMUs have this problem



Communication issues

- TCP/IP offers reliability at expense of delay
- Delay here is greatly increased due to network traffic burst
- Better alternatives
 - Use isolated, private network
 - Use UDP/IP unicast



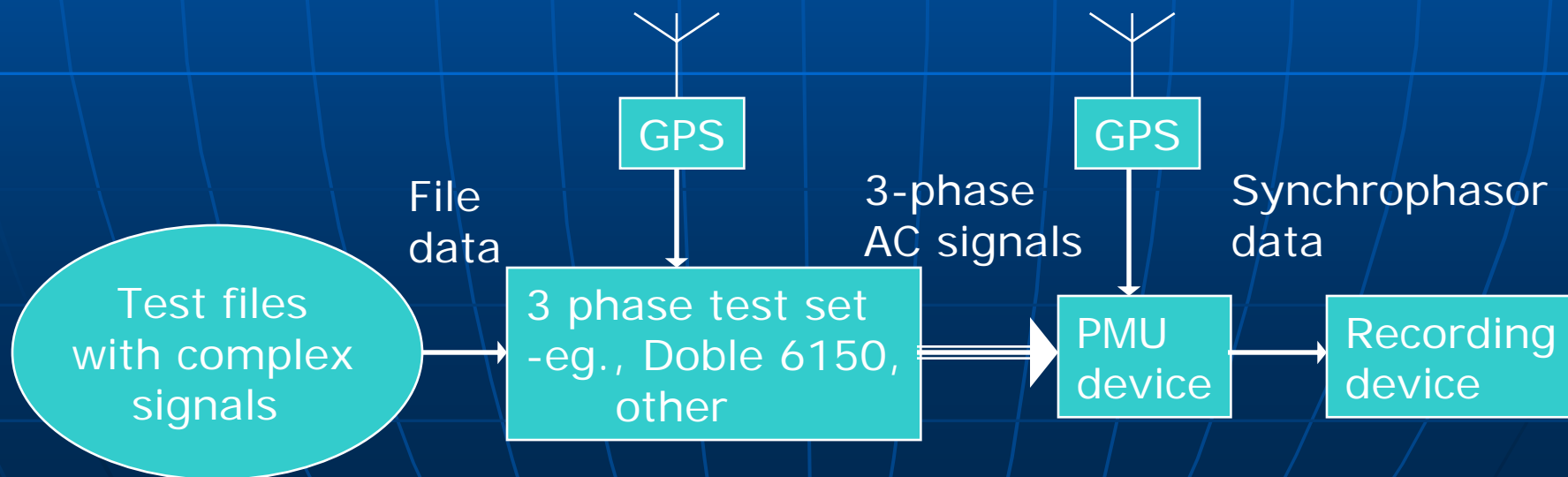
In-service reliability

- Statistics from PDC Monitor
 - Failure of PMU or communications
 - Failure of GPS synchronization

Station (PMU)	Reliability (%)		Notes
	Signal	Sync	
GCoul	97.52	99.974	PMU fail 2 days
JDay	99.929	99.996	Normal, modem
Malin	99.997	93.74	PMU clock failure
Colstrip	99.82	100	Comm sys problems
BigEddy	99.99	99.988	Normal, fiber, digital
MValley	99.983	99.74	PMU clock problems
Keeler	99.996	99.95	Normal, modem

New test plan

- Test signals generated in Matlab
 - Digital track marks input stimulus for analysis
 - Automated analysis relates result to test
- GPS timed signal correlates to measurement
 - Can make timed response measurements



PMU Test Summary

- PMU performance excellent in all respects
- Can be fitted to the application needs
 - Characteristics need to be to quantified better
 - Careful observation always required to observe unusual characteristics
- Be sure measurement characteristics meet expectations of the application