Synchrophasor Measurement Standard - IEEE C37.118.1

2011 Standard and 2014 Amendment

Presented by
Ken Martin
Chair, WG H11 IEEE PSRC

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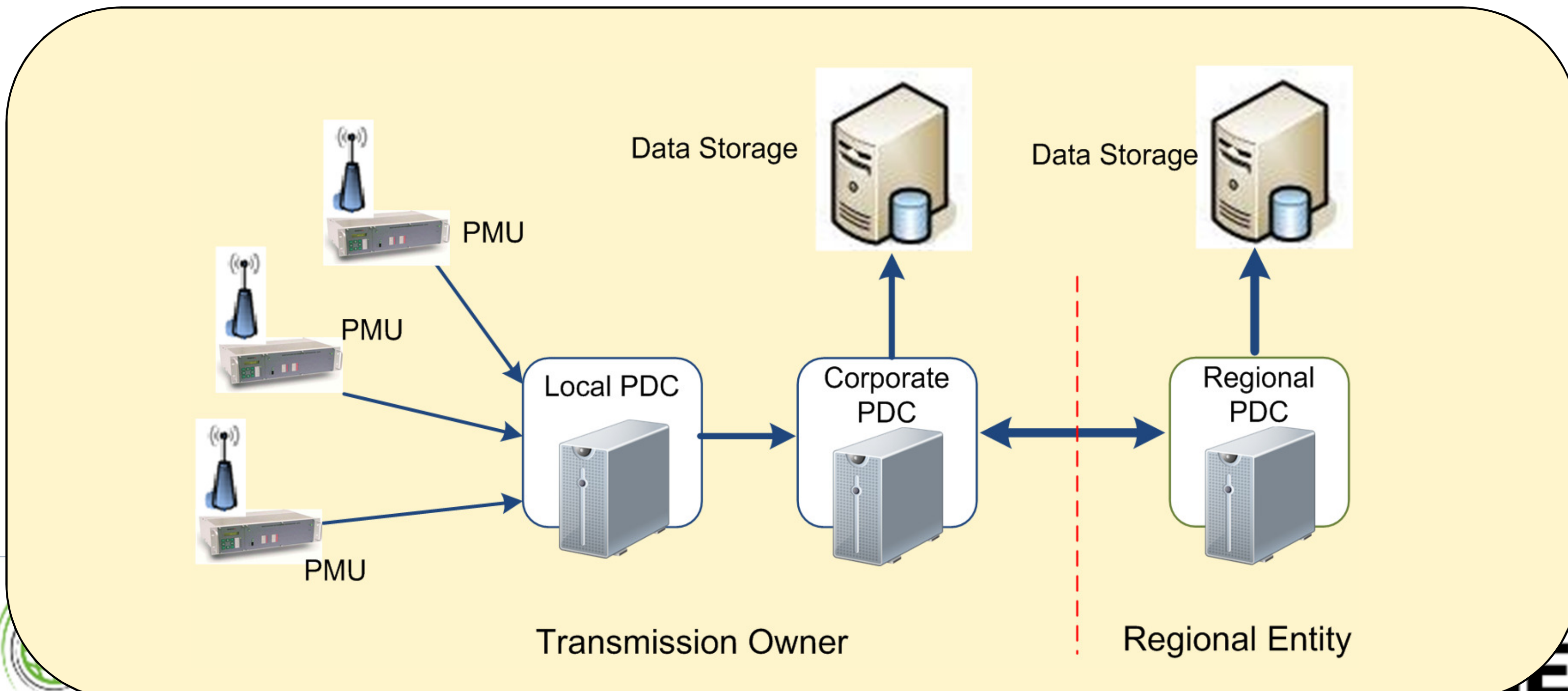
Outline

- Synchrophasor systems
- Synchrophasor standards history
  - IEEE 1344-1995
  - IEEE C37.118-2005
  - IEEE C37.118.1-2011
- Details of measurement standard
- Amendment modifications
- New joint IEC-IEEE standard 60255-118-1

Typical synchrophasor measurement system

- Measurements at substations, real-time data sent to control center
- Data collected & aligned, sent on to applications or higher level processing



First Synchrophasor Standard

- IEEE1344-1995
- Measurement requirements
  - Time synchronization specified
  - Data sampling requirements
  - No specification on resulting measurement
- Data transmission formats
  - Followed COMTRADE syntax
  - Adapted for single PMU & serial data
- Unresolved issues & not widely implemented

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Synchrophasor Standard C37.118-2005

- Measurement requirements
  - Test method & error limits specified
  - Steady-state phasor only
- Data transmission formats
  - Improved status and error indications
  - Includes single or multiple PMU data
  - Adaptable for network communication
- Widely used & very few problems

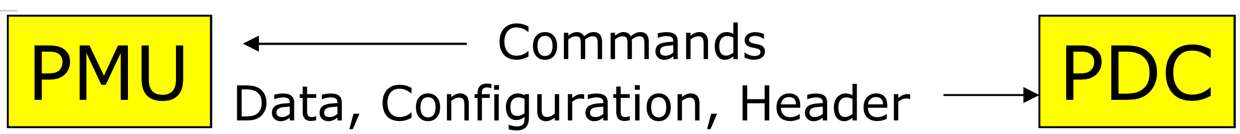
Synchrophasor measurement

- C37.118-2005
  - Basic compliance test is TVE
  - Phasor measurement accuracy over range of V, I, φ, & F
  - Rejection of harmonics and out of band signals (anti-aliasing)
- Steady-state conditions only
- No frequency & ROCOF requirements

Theoretical phasor value	$\mathbf{X} = \frac{X_m}{\sqrt{2}} e^{j\phi} = X_r + jX_i$
Measured (estimated) phasor value	$\mathbf{X}(t_0) = X_r(t_0) + jX_i(t_0)$
Total Vector Error (the RMS difference)	$TVE = \sqrt{\frac{(X_r(t_0) - X_r)^2 + (X_i(t_0) - X_i)^2}{X_r^2 + X_i^2}}$

C37.118 communication

- Messaging system, usable with many protocols
- Messages have same basic format, contents fully described
- Command frame sent to data source
  - Start/stop data, send other information
- Data frame
  - Phasor & frequency measurements
  - Analog & digital indication data types
- Configuration frame
  - Describes data frame, with scaling & naming
- Header frame
  - Text descriptions, user format



New 37.118 synchrophasor standards

- Existing C37.118-2005 split into two standards
- C37.118.1
  - Measurements only
  - Frequency & rate of change of frequency (ROCOF)
  - Dynamic operation
- C37.118.2
  - Preserves existing data exchange
  - Added needed improvements (flags & configuration)
- Both completed & published 2011

Synchrophasor Measurement Standard IEEE C37.118.1 – summary

- Retains existing steady-state requirements
  - Adds some enhancements
- Adds phasor measurement under dynamic conditions
  - Measurement bandwidth, tracking, and response time
- Extends measurement definitions
  - Phasor, frequency, & ROCOF
  - Steady state and dynamic conditions
- Latency test for data output delay

Synchrophasor definition extended

- Generalized case where all parameters change:
  - Amplitude = $X_m(t)$
  - Phase = $\varphi(t)$
  - Frequency = $f_0 + g(t)$
- The signal is defined:
- $x(t) = X_m(t)\cos[\psi(t)]$
  $= X_m(t)\cos(2\pi f_0\, t + (2\pi \int g\,dt + \varphi(t)))$
- The phasor value is:
- $\boldsymbol{X}(t) = (X_m(t)/\sqrt{2})e^{j(2\pi\int g\,dt + \varphi(t))}$

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Frequency & ROCOF defined

- For the signal defined:
- $x(t) = X_m(t)\cos[\psi(t)]$
- Frequency: $f(t) = 1/(2\pi)\, d\psi(t)/dt$
- ROCOF: $\mathrm{ROCOF}(t) = df(t)/dt$
- Follows usual definition of F & dF/dt
  - Not the same as rotor speed
- Derivative subject to noise; can make compliance difficult

Additional C37.118.1 features

- Required data reporting rates extended
  - Reporting 10 to 50 (50 Hz) and 10 to 60 (60 Hz)
  - Synchronized reporting defined for all rates (1/hr to nxf_0)
- Reporting latency defined & tested
- Classes changed into M & P
  - P class for minimal delay, no filtering (think Protection)
  - M class for more accurate reporting, may have delays (think Measurement)
  - Either class can be used according to needs

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Key steady-state points

- Amplitude measurement
  - Over frequency & temperature ranges
  - Voltage 10-120% (80-120% P class), current 10-200 %
- Phase angle confirmed
- Interference rejection
  - Harmonics
  - Anti-alias for M-class
- F & ROCOF requirements for all tests

Steady-state Synchrophasor measurement

Influence quantity	Reference condition	Minimum range of influence quantity over which PMU shall be within given TVE limit			
		Performance Class P		**Performance Class M**	
		Range	**Max TVE (%)**	**Range**	**Max TVE (%)**
Signal frequency range – f_{dev} (test applied nominal + deviation: $f_0 \pm f_{dev}$)	$F_{nominal}$ (f_0)	± 2.0 Hz	1	± 2.0 Hz for F_s<10 ± F_s/5 for $10 \le F_s < 25$ ± 5.0 Hz for $F_s \ge 25$	1
The Signal Frequency range tests above are to be performed over the given ranges and meet the given requirements at 3 temperatures: T = nominal (~23° C), T = 0° C, and T = 50° C.					
Signal magnitude - Voltage	100% rated	80 – 120% rated	1	10 – 120% rated	1
Signal magnitude - Current	100% rated	10 – 200% rated	1	10 – 200% rated	1
Phase angle with $\lvert f_{in} - f_0 \rvert$ <0.25 Hz	Constant or slowly varying angle	±π radians	1	±π radians	1

Report rate independent

Corrected for report rate

Test over temperature

Separate V & I tests

Steady-state Frequency & ROCOF

All new requirements

Error Requirements for compliance

Influence quantity	Reference condition	Class P		Class M	
Signal Frequency	Frequency = f_0 ($f_{nominal}$) Phase angle constant	Range: $f_0 \pm 2.0$ Hz		Range: $f_0 \pm 2.0$ Hz for $F_s \leq 10$ $\pm F_s/5$ for $10 \leq F_s < 25$ ± 5.0 Hz for $F_s \geq 25$	
		Max FE	Max RFE	Max FE	Max RFE
		0.005 Hz	0.01 Hz/s	0.005 Hz	0.01 Hz/s
Harmonic distortion (same as table 3) (single harmonic)	<0.2% THD	1 % each harmonic up to 50th		10% each harmonic up to 50th	
		Max FE	Max RFE	Max FE	Max RFE
	$F_s > 20$	0.005 Hz	0.01 Hz/s	0.025 Hz	6 Hz/s
	$F_s \leq 20$	0.005 Hz	0.01 Hz/s	0.005 Hz	2 Hz/s
Out-of-band interference (same as table 3)	<0.2% of input signal magnitude	No requirements		Interfering signal 10% of signal magnitude	
				Max FE	Max RFE
		None	None	0.01 Hz	.1 Hz/s

Dynamic requirements

- Confirm measurement capability under dynamic system requirements
  - Swings, switching, power imbalance
  - Not intended for fault or catastrophic conditions
- Tests to confirm measurement compatibility
  - Characterize instrument
  - Emulate conditions of power system

Modulation Tests

- Sinusoidal modulation of amplitude and phase angle of the fundamental signal
  - Assures sufficient measurement bandwidth
  - Emulates a system oscillation
- Applied as amplitude & phase or phase only
  - $X_a = X_m\,[1+k_x\cos(\omega t)] \times \cos\,[\omega_0 t+k_a\cos(\omega t-\pi)]$
- Phasor, F, & ROCOF responses (points at t = nT)
  - $X(nT) = \{X_m/\sqrt{2}\}[1+k_x\cos(\omega nT)]\angle\{k_a\cos(\omega nT-\pi)\}$
  - $f(nT) = \omega_0/2\pi - k_a\,(\omega/2\pi)\sin\,(\omega nT-\pi)$
  - $ROCOF(nT) = -\,k_a\,(\omega^2/2\pi)\cos\,(\omega nT-\pi)$

Frequency ramp tests

- Constant ramp in frequency
  - Determines measurement tracking system
  - $X_a = X_m \cos[w_0 t + \pi R_f t^2]$ where R_f is a constant ramp rate
  - Emulates a system separation causing power-load imbalance
- Ramp to frequency measurement limit
  - M class: $\pm F_s/5$ Hz up to 5 Hz
  - P class: ± 2 Hz
  - Ramp rate ± 1 Hz /s

Step tests

- Step change of amplitude or phase
  - Determines response time measurement
  - $X_a = X_m\,[1+k_x\,f_1(t)] \times \cos\,[\omega_0 t+k_a\,f_1(t)]$ where f_1 is a unit step
  - Emulates a switch action
  - Measurement values during the step are not evaluated—only response time, overshoot, & delay
- 10% amplitude, 10° phase
- Requires oversampling to get entire response

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Step illustration

- Response between leaving initial & achieving final values
  - Applied to phasor, Frequency, ROCOF
- Delay indicates correct timetag
- Overshoot limited

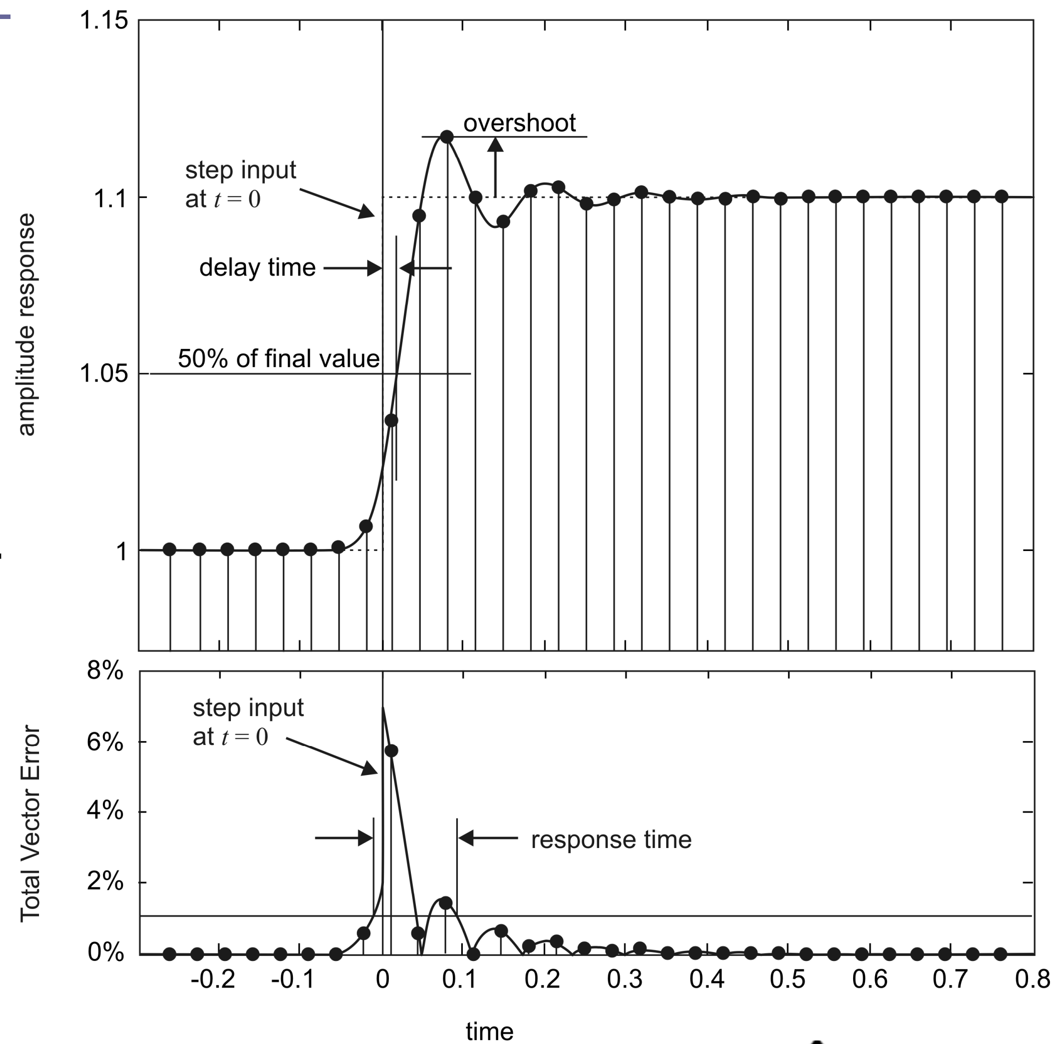

Illustration from IEEE C37.118.1

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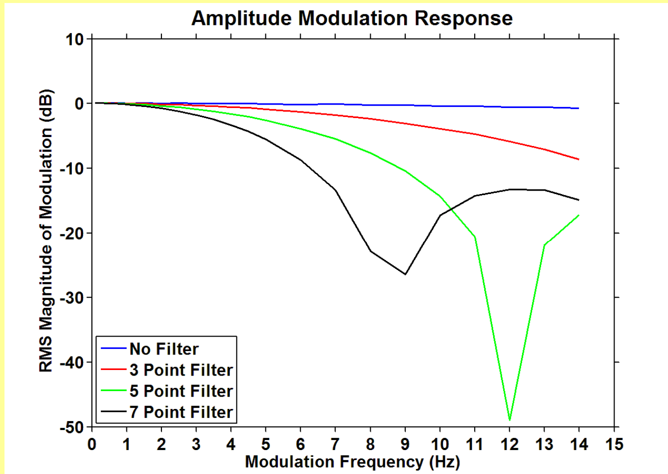
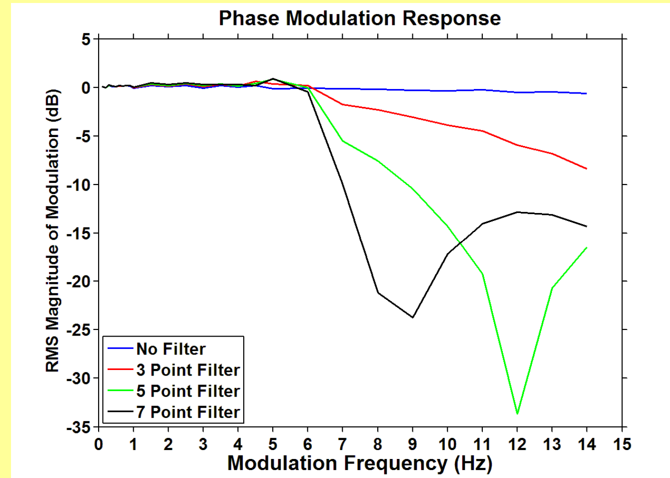
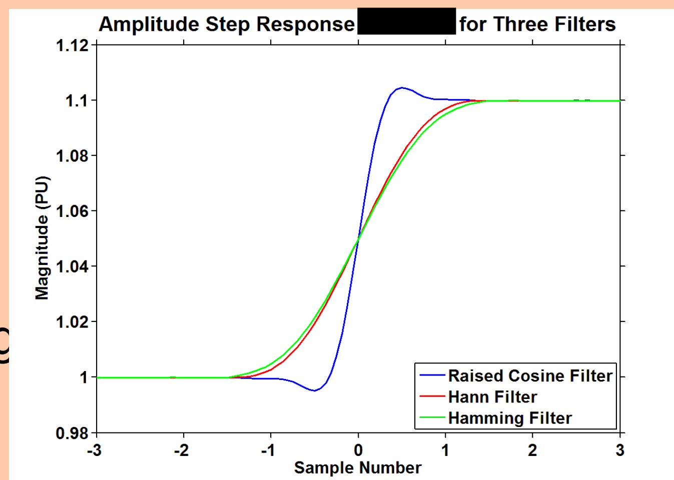
Modulation & step examples

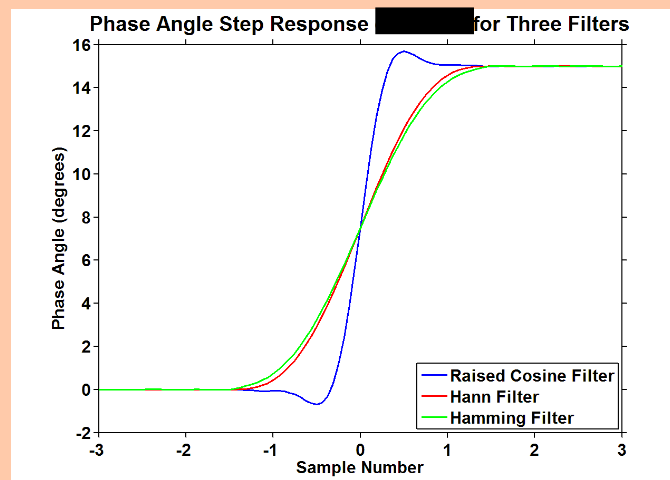
Amplitude & phase modulation – pass bands are similar for both.





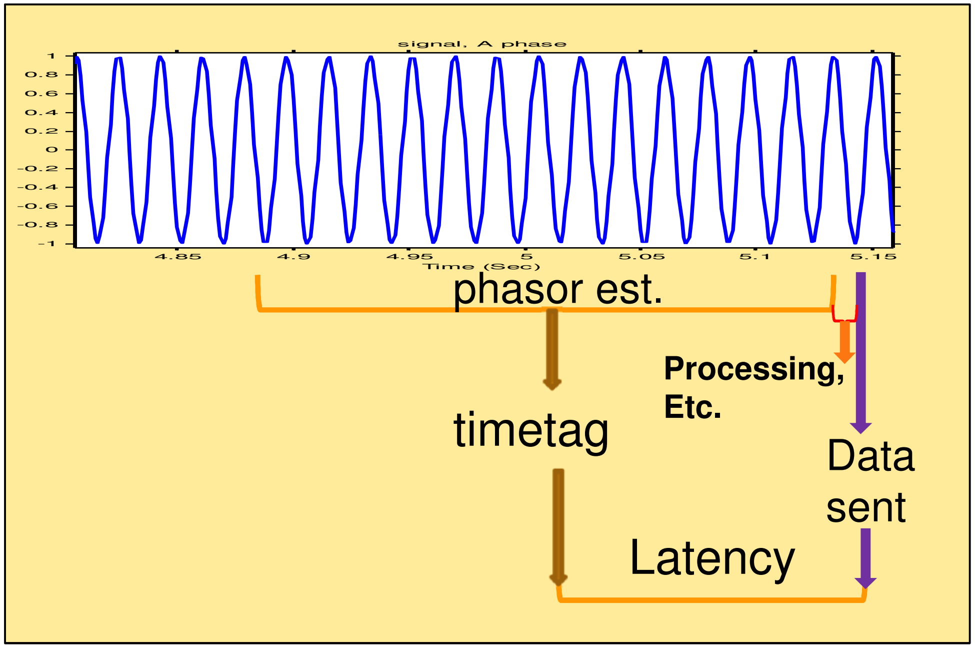
Amplitude & phase steps – differences in response clearly shown with delayed sampling (slip-sampling)





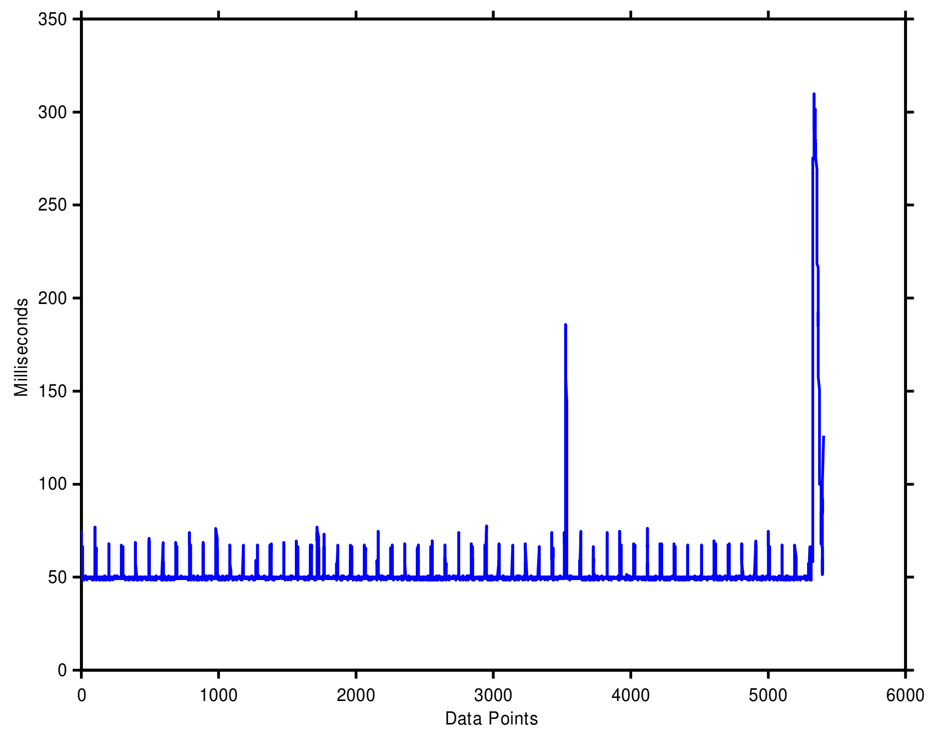
Latency test

- Delay from time of measurement to data transmission
- Includes algorithm, processing & communication delays
- Important for applications sensitive to delays (eg. Controls)



Latency test example

- Baseline is windowing delay ~50 ms
- Additional ~20 ms delay spikes every second due to processor or communication delays



Annex information

- Annex B
  - Reference examples for timetagging
- Annex C
  - Reference algorithms used to test requirements
  - Can be used for synchrophasors that will meet requirements
- Annex D
  - Updated time source information
  - Updated control bit profile for IRIG-B
- Annex F
  - Measurement of generator rotor combined with phasor measurements

Amendment development

- Problems in 2011 standard
  - F & ROCOF were new, requirements too difficult
    - Effects of interference very large
  - M class filter allowances too slim
  - Some wording was ambiguous
- Not enough allowance for PMU input & processing
- Amendment initiated & completed in 2013

Amendment modifications

- Changes in F & ROCOF requirements
  - Relax both for most tests
  - Suspend M class ROCOF for interference tests
- Longer responses for filters
  - Ramp transition longer, test simplified
  - Longer step test response
  - Longer latency test allowance
- Changed M-class reference algorithms
- Clarified wording & other small improvements

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IEC – IEEE Joint project

- IEC/IEEE 60255-118-1
  - Originally started in 2011, re-started in 2014
  - Joint IEC-IEEE Project
    - IEC TC95 WG1
    - IEEE PSRC H11
- Committee Draft starting with current C37.118.1a
  - Some test requirement simplifications
  - Removing environmental tests
  - More changes, but plan to keep the same basic requirements
- Expect completion in 2016

Summary

- PMU Measurement
  - Originally defined empirically in quasi steady-state
  - Now defined mathematically for all conditions
- IEEE C37.118.1
  - Steady-state over full operating range
  - Realistic dynamic operating conditions
- Extension to IEEE/IEC 60255-118-1
  - Expect further improvements