A Novel Arbitrary-Resampling-Based Algorithm for Synchrophasor Measurement in Compliance with IEEE C37.118.1a - 2014

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Key Takeaways

- Uncertainty within the error limits in IEEE C37.118.1a – 2014 based on in-house testing
  - TVE below 0.05% in steady-state tests
  - Nearly constant TVE (below 0.07%) in frequency ramp test
  - TVE below 0.25% and FE below 0.005Hz in out-of-band test
  - 29ms reporting latency for 60/60 P Class and 93ms reporting latency for 60/60 M Class
- Up to 24 measurements per cycle (up to 1200/1440 reporting rates)
- Specifically attenuate the magnitude oscillation in steady-state tests

Agenda

- Challenges of being compliant with IEEE C37.118.1a - 2014
- Arbitrary resampling - Our approach to solve the challenges
- Final results
- Something future standard should address
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Dilemma in IEEE C37.118.1

- A very narrow band-pass filter with long group delay must be applied to remove the out-of-band interfering signal
  - Much impact on the TVE/FE/RFE measurement accuracy as it is very close to the fundamental frequency
- A filtering with less group delay must be applied to meet the step test requirements and measurement reporting latency
- Removing RFE requirement of out-of-band test in amendment somewhat brings less challenges

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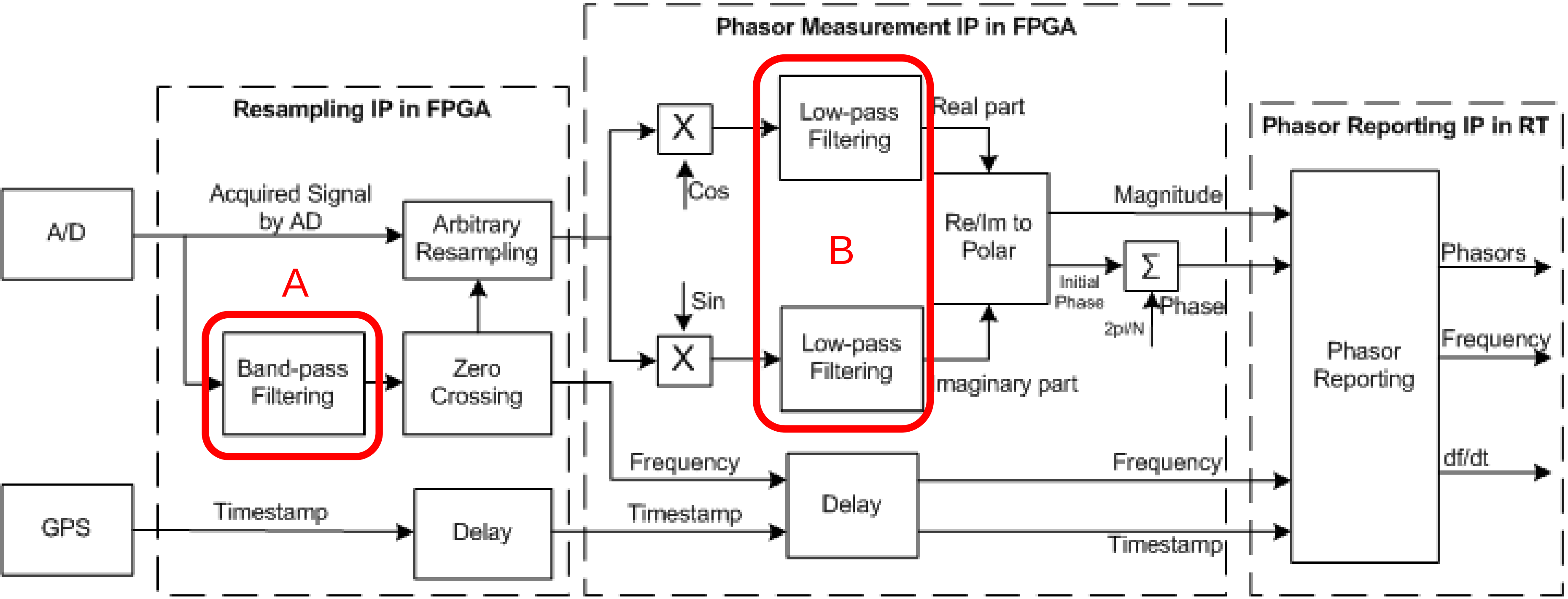
Arbitrary Resampling

- Resampling leads to the same number of samples per cycle regardless of the variable line frequency
- The same number of samples per cycle brings less spectrum leakage in order to estimate the fundamental phasor precisely
- Arbitrary resampling involves instantaneous real-time anti-aliasing filter redesign according to the variable line frequency

Resampling-Based PMU Algorithm



NATIONAL INSTRUMENTS

Different Filters for Different Reporting Rates

- Filter specification tweaks for different requirements

		Out-of-band		Modulation		Frequency ramp		Step		Latency
		TVE	FE	TVE	FE/RFE	TVE	FE/RFE	TVE	FE/RFE	
Frequency Filter A	Pass-band range				✔					
	Pass-band ripple				✔					
	Stop-band attenuation	✔	✔							
	Taps						✔		✔	
Phasor Filter B	Pass-band range			✔						
	Pass-band ripple			✔						
	Stop-band attenuation	✔								
	Taps					✔		✔		✔

Particular Tips for both M and P Class

- Compensate the magnitude error introduced by the pass-band ripple of phasor filter
  - Less group delay leads to larger pass-band ripple
- Compensate the input delay of analog input acquisition module
- Disable Nagle algorithm in TCP communication

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Uncertainty of Nominal Value - M Class (60/60)

	TVE (%) in C37.118	TVE (%)	FE(Hz) in C37.118	FE (Hz)	RFE in C37.118	RFE (Hz/s)
Signal frequency range/Signal magnitude/Phase angle	1	0.045	0.005	0.0004	0.1	0.03
Harmonic distortion	1	0.06	0.025	0.0007	N.A	0.045
Out-of-band interference	1.3	0.025	0.01	0.002	N.A	0.15
Amplitude modulation	3	0.4	0.3	0.002	14	0.08
Phase modulation	3	0.25	0.3	0.06	14	3
Frequency ramp	1	0.04	0.01	0.0008	0.2	0.05
Amplitude step test	117ms	23.3ms	233ms	75ms	233ms	108ms
Phase step test	117ms	46.7ms	233ms	86.7ms	233ms	120ms

	C37.118	Resampling-based M Class
Measurement latency	117ms	92.5ms

Uncertainty of Nominal Value - P Class (60/60)

	TVE (%) in C37.118	TVE (%)	FE(Hz) in C37.118	FE (Hz)	RFE in C37.118	RFE (Hz/s)
Signal frequency range/Signal magnitude/Phase angle	1	0.045	0.005	0.003	0.4	0.09
Harmonic distortion	1	0.044	0.005	0.004	0.4	0.11
Amplitude modulation	3	0.2	0.06	0.006	2.3	0.15
Phase modulation	3	0.12	0.06	0.006	2.3	0.7
Frequency ramp	1	0.07	0.01	0.003	0.4	0.07
Amplitude step test	33ms	10ms	75ms	38.3ms	100ms	55ms
Phase step test	33ms	11.7	75ms	41.7ms	100ms	58.3ms
	C37.118			**Resampling-based P Class**		
Measurement latency	33.3ms			29ms		

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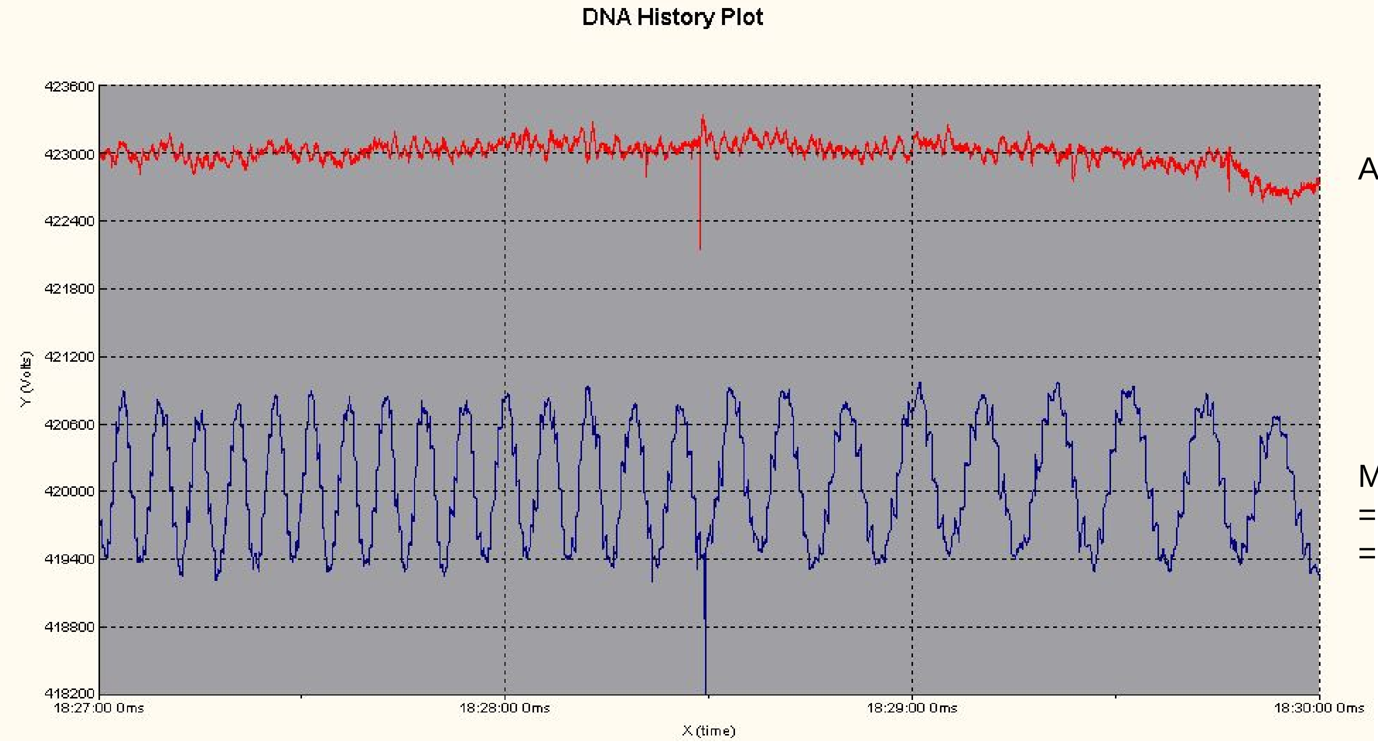
Magnitude Oscillation

- Magnitude oscillation could be unacceptable in the field although the TVE is within the standard requirement
  - Around 1000V magnitude oscillation on the primary side although TVE is 0.8%

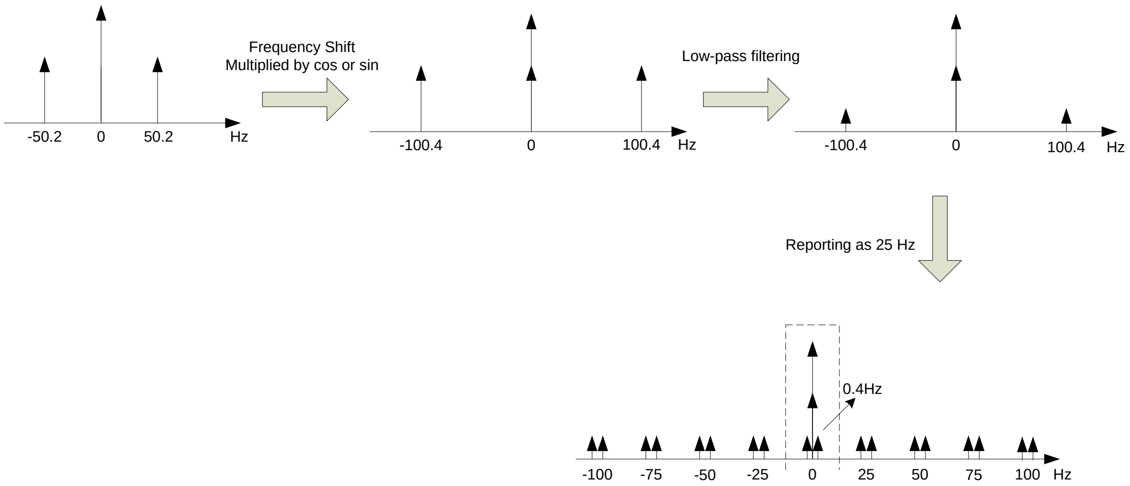


Assume true value is 423000 V

Magnitude error
= (423000-419400)/42300
= 0.8%

Magnitude Oscillation Deep Dive

- The oscillation frequency corresponds to 2*(instantaneous frequency – nominal frequency)



- Large attenuation in this specific frequency is necessary
  - Integer-cycle averaging is one option

Misleading DFREQ Definition

- The DFREQ should only be multiplied by 100 for 16-bit INTEGER data

FREQ	2 / 4	Frequency deviation from nominal, in mHz Range–nominal (50 Hz or 60 Hz) –32.767 to +32.767 Hz 16-bit integer or 32-bit floating point 16-bit integer: 16-bit signed integers, range –32 767 to +32 767 32-bit floating point: actual frequency value in IEEE floating-point format. Data type indicated by the FORMAT field in configuration 1, 2, and 3 frames
DFREQ	2 / 4	ROCOF, in hertz per second times 100 Range –327.67 to +327.67 Hz per second Can be 16-bit integer or IEEE floating point, same as FREQ above. Data type indicated by the FORMAT field in configuration 1, 2, and 3 frames

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  - 29ms reporting latency for 60/60 P Class and 93ms reporting latency for 60/60 M Class
- Up to 24 measurements per cycle (1200/1440 reporting rates)
- Future PMU standard may need to define the magnitude oscillation requirement and restate the DFREQ definition