DANOVO ENERGY SOLUTIONS
A QUANTA SERVICES COMPANY

# Impact Of PMU Reporting Rate on Oscillation Monitoring

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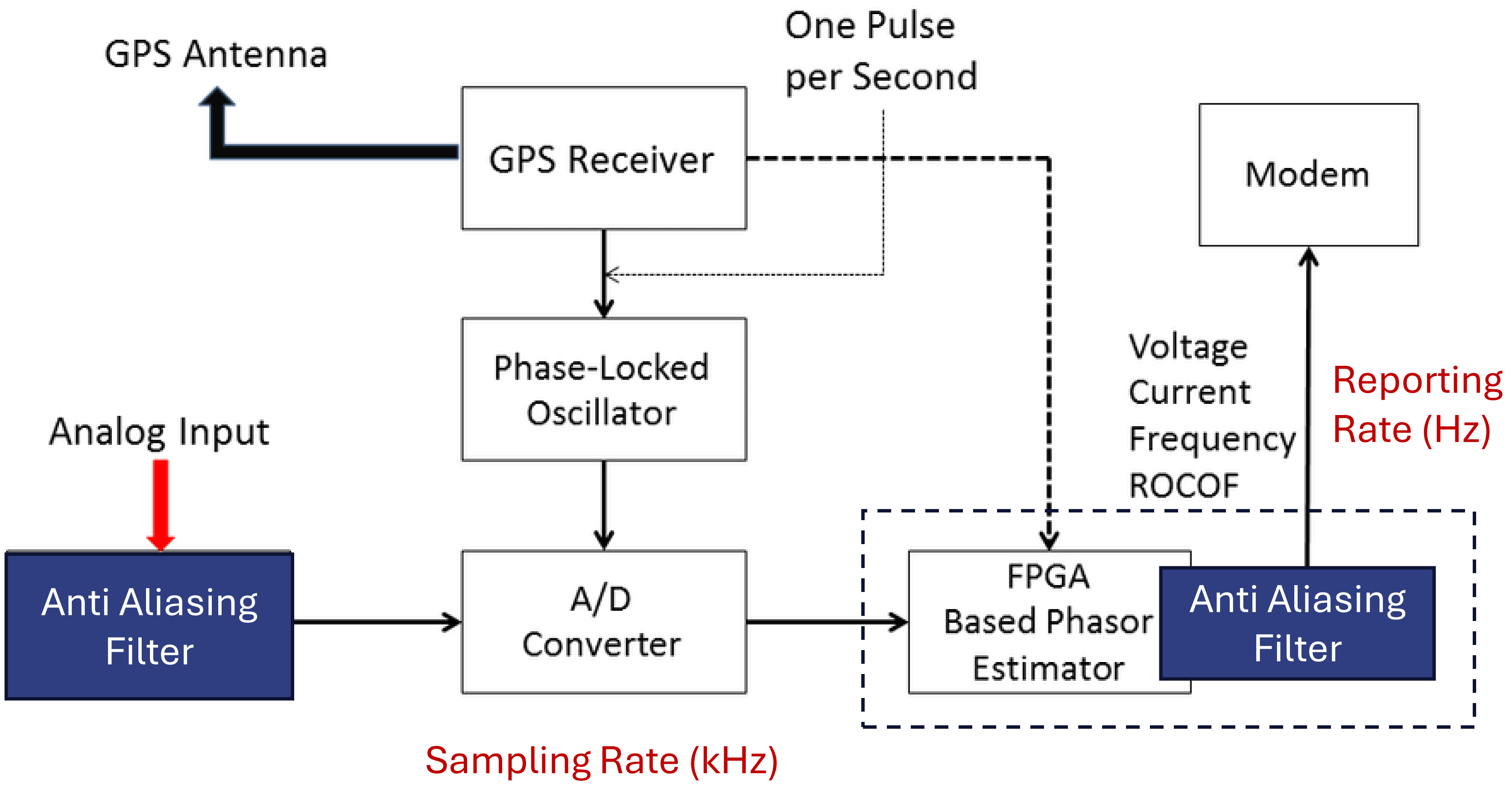
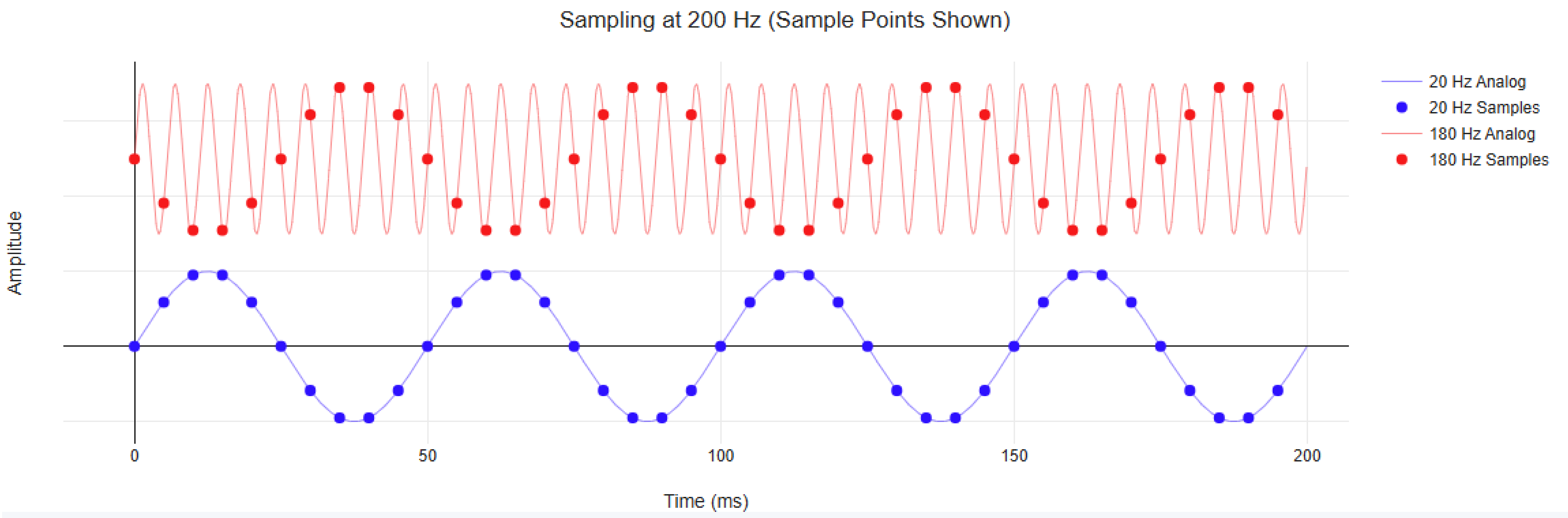
*June 2026*

JULY 17, 2026

# COMPONENTS AND TERMINOLOGY

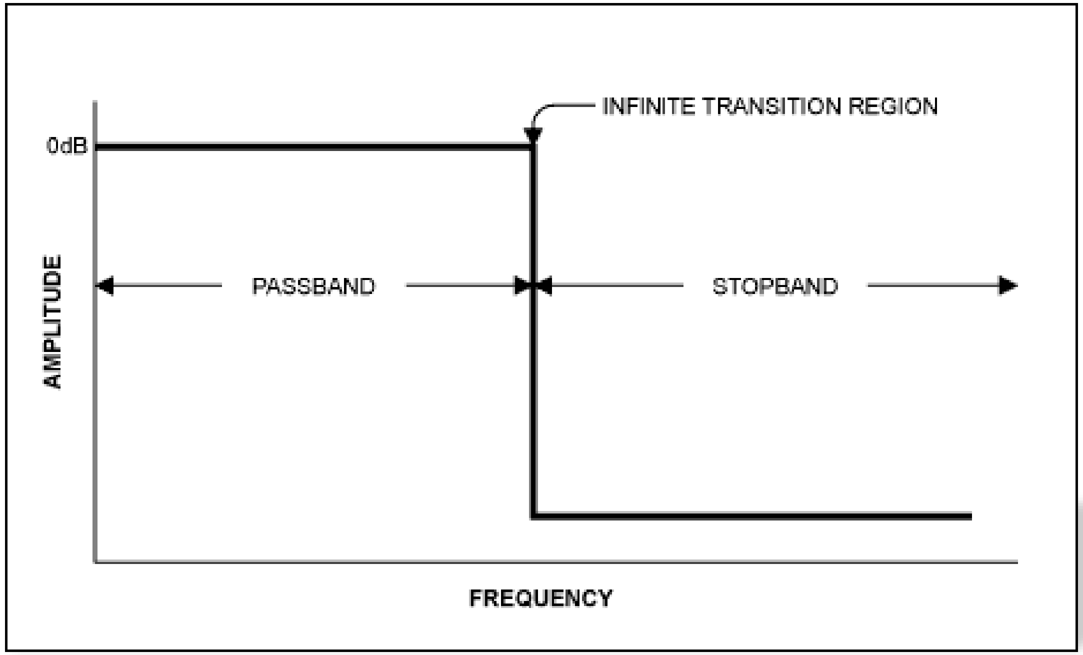


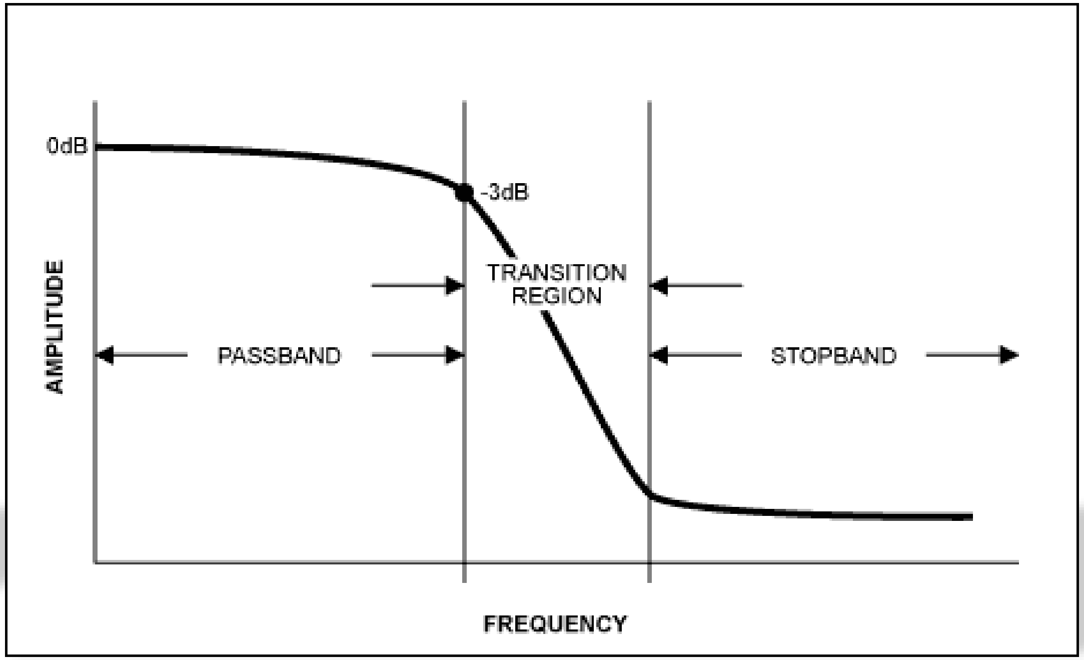
# ALIASING




Anti aliasing filter is to cancel out everything higher than the Nyquist rate

# FILTERING IS NOT IDEAL



# MAIN SOURCE

NASPI
A DOE-EPRI Joint Initiative

PNNL-39191

## Measurement Adequacy for Monitoring Data Center Oscillations

April 2026

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Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT of ENERGY

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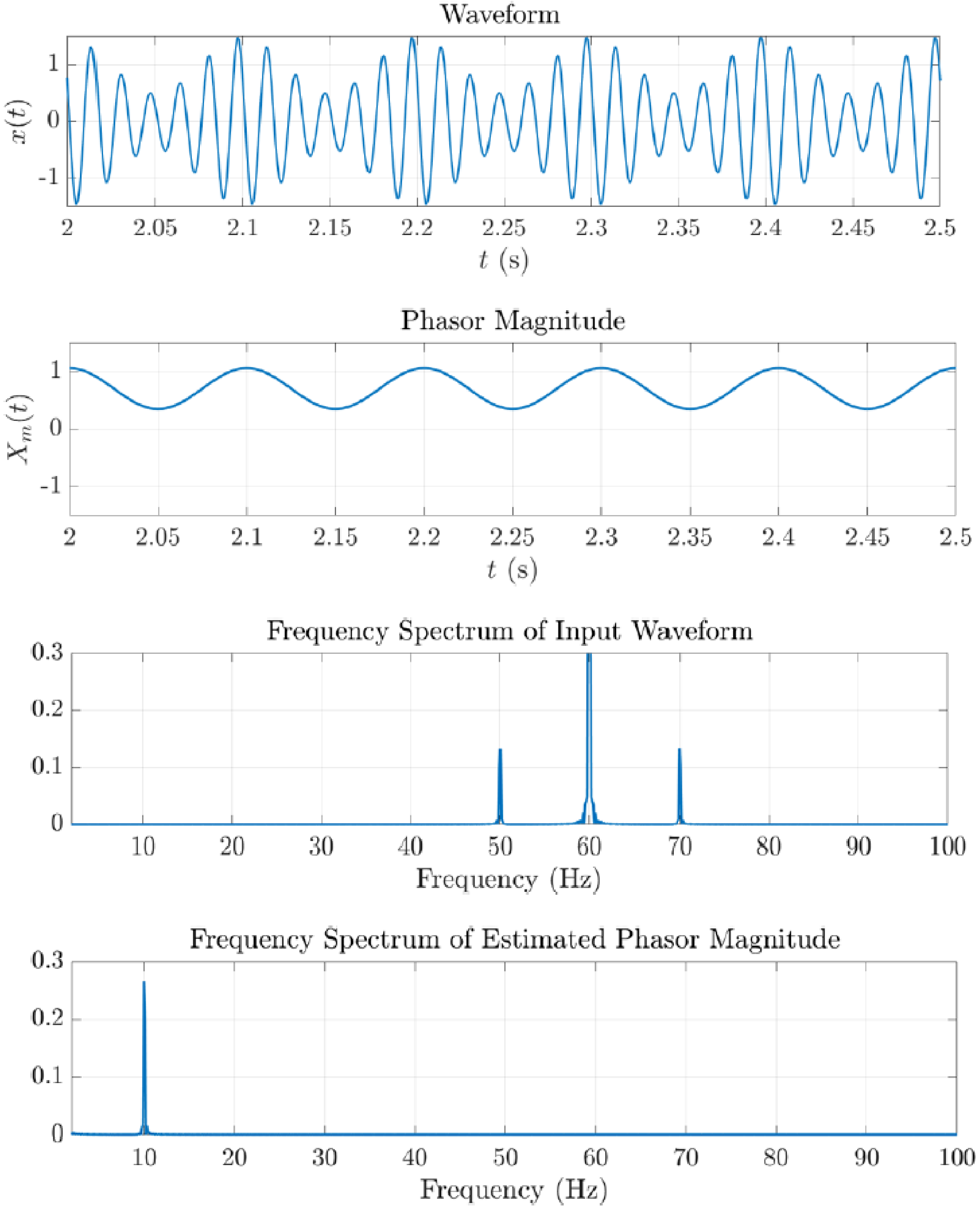
# OSCILLATORY SIGNALS REPRESENTATION

$$\tilde{X}(t) = X_m \angle\phi,$$

$$X_m = \frac{X_0}{\sqrt{2}}\{\,1 + k_m \cos(2\pi\,\Delta f\;t)\,\}\,,$$

$$\phi = \phi_0\{\,1 + k_a \cos(2\pi\Delta f\;t)\},$$

$$\begin{aligned} x(t) &= \sqrt{2}\,X_m \cos(2\pi f_0 t + \phi) \\ &= X_0\,\{\,1 + k_m \cos(2\pi\,\Delta f\;t)\,\} \cdot \cos\!\left(2\pi f_0 t + \phi\right) \\ &= X_0 \cos(2\pi f_0 t + \phi) \\ &\qquad + \frac{k_m X_0}{2} \cos(2\pi\,(f_0 + \Delta f)\,t + \phi) \\ &\qquad + \frac{k_m X_0}{2} \cos(2\pi\,(f_0 - \Delta f)\,t + \phi) \end{aligned}$$




**Source:** Chatterjee K., J.D. Follum, A. Varghese, S. Biswas, E. Farantatos, and L. Zhu. 2026.[Measurement Adequacy for Monitoring Data Center Oscillations.]

# CHALLENGES AND LIMITATIONS OF MONITORING HIGH-FREQUENCY OSCILLATIONS

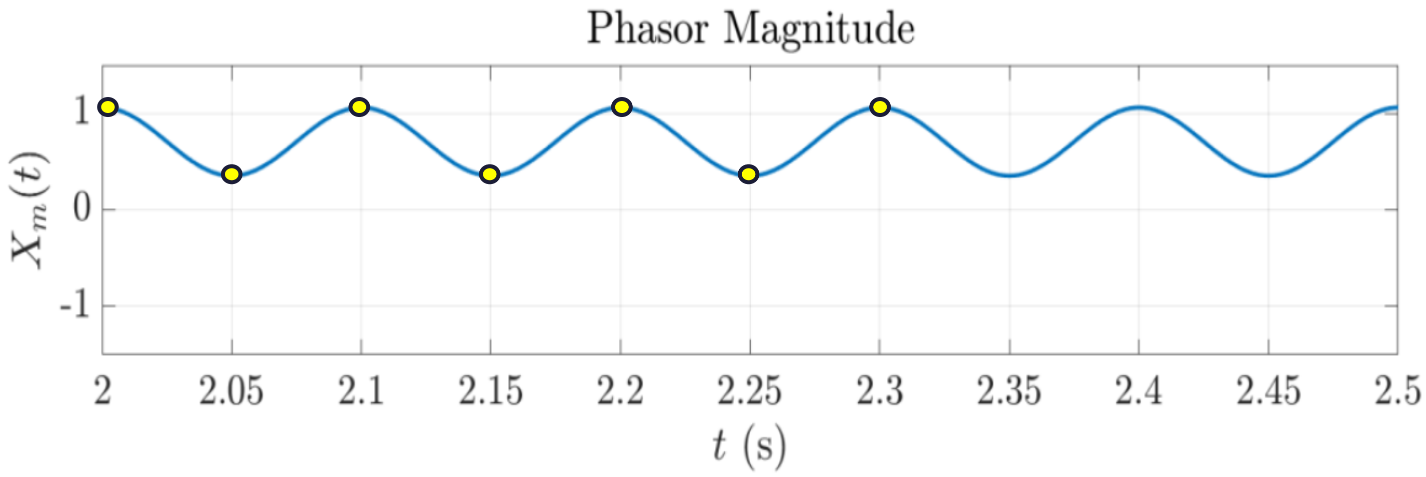
Two primary factors determine effective performance limits of PMUs when monitoring higher frequency oscillations:

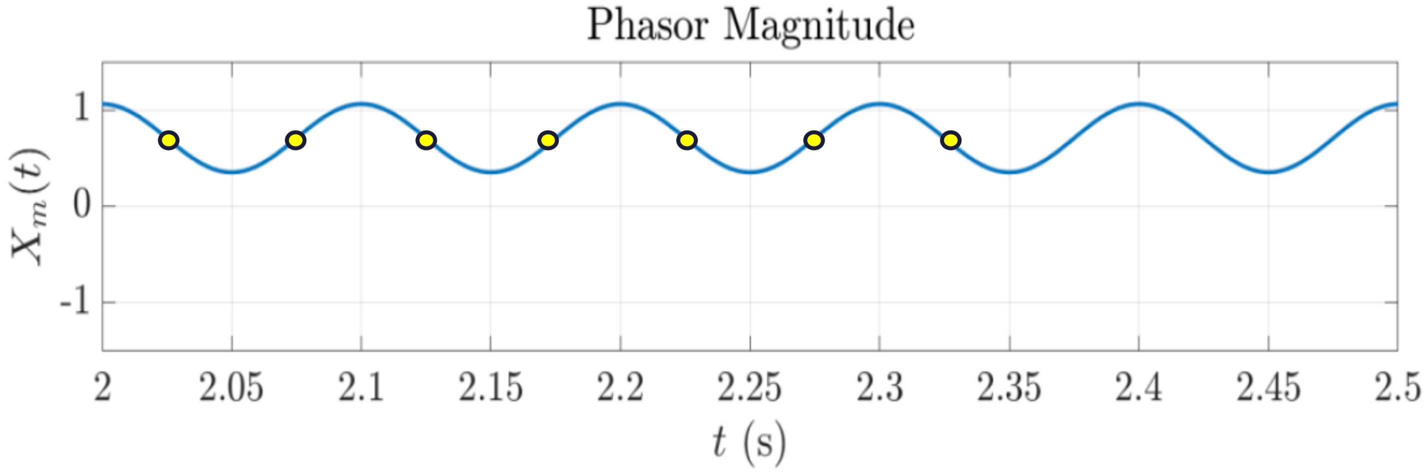
- Reporting rate, in frames per second (fps)
- Low-pass filtering

# IMPACT OF REPORTING RATE – ILLUSTRATIVE EXAMPLE

- Reporting rate is like sampling from the phasor estimation. Low sampling can miss some information.

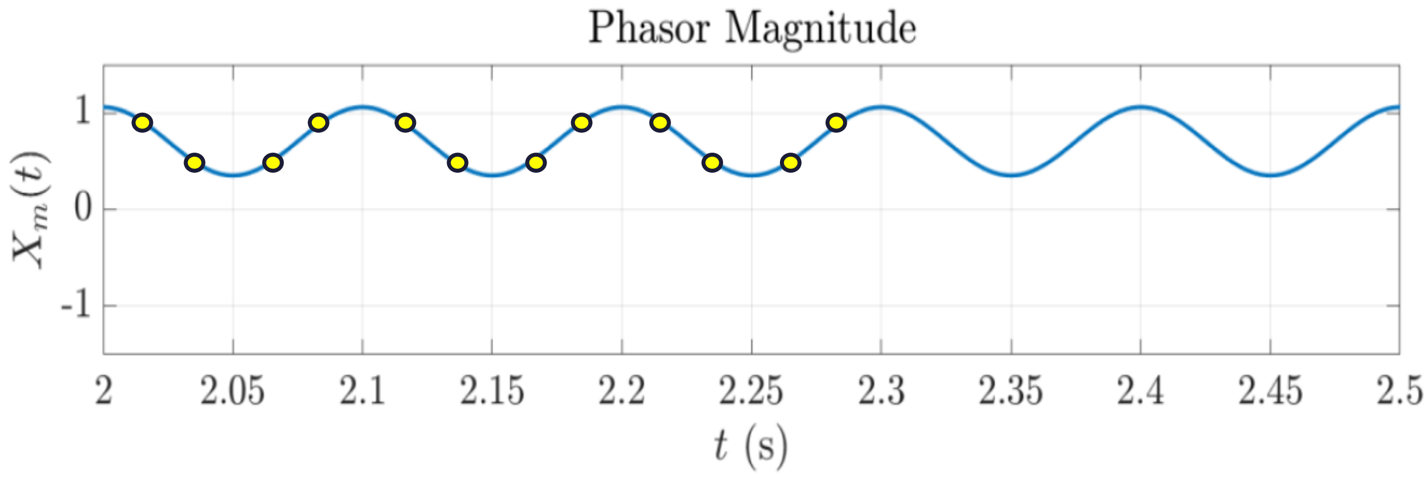
*20 Hz reporting rate:*



# IMPACT OF REPORTING RATE – ILLUSTRATIVE EXAMPLE

*40 Hz reporting rate:*



# IMPACT OF REPORTING RATE - DEMO

Demo case:

- 2 Hz at 30 fps
- 5 Hz at 30 fps and 60 fps
- 10 Hz at 30 fps and 60 fps
- 14 Hz at 30 fps and 60 fps
- 15 Hz at 30 fps and 60 fps

**Findings**

- Oscillatory signal might be seen as pricewise linear triangular sawtooth waves
- Estimated peak values can be very different from true values
- Reported values can be unsymmetrical around the base value → wrongly shifting base values
- Off-nominal power system frequency makes all these observations uncertain

# CONSIDERATIONS FOR MONITORING LOW- VS. HIGH-FREQUENCY OSCILLATIONS

- IEC/IEEE 60255-118-1 defines two performance classes for PMUs: P-class and M-class
- P-class PMUs are designed for applications that prioritize fast response and low latency.
- M-class PMUs are intended for applications where improved steady-state accuracy and stronger rejection of off-nomina components are emphasized.

**Table 4 – Synchrophasor measurement bandwidth requirements using modulated test signals**

| Modulation level | Reference condition | Minimum range of influence quantity over which PMU shall be within given TVE limit | | | |
|---|---|---|---|---|---|
| | | P class | | M class | |
| | | Range | Max. TVE | Range | Max. TVE |
| $k_x$ = 0,1, $k_a$ = 0 | 100 % rated signal magnitude, $f_{nominal}$ | Modulation frequency 0,1 to lesser of $F_s$/10 or 2 Hz | 3 % | Modulation frequency 0,1 to lesser of $F_s$/5 or 5 Hz | 3 % |
| $k_x$ = 0, $k_a$ = 0,1 | 100 % rated signal magnitude, $f_{nominal}$ | | 3 % | | 3 % |

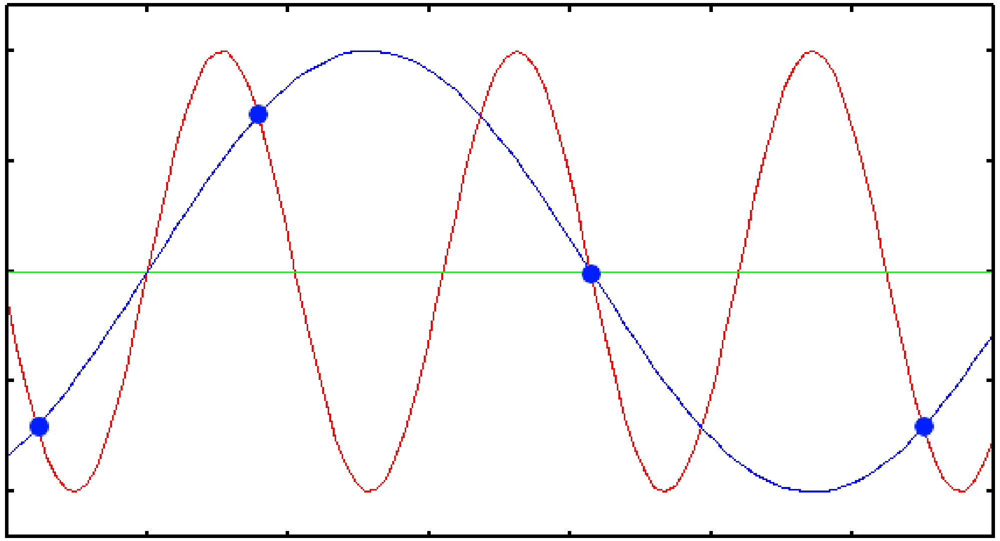
$F_S$ denotes the reporting rate

Effective measurement bandwidth increases with reporting rate only up to a certain point.

Business need to monitor higher frequencies is rapidly on the raise

# IMPACT OF LOW-PASS FILTERING

Aliasing might still happen



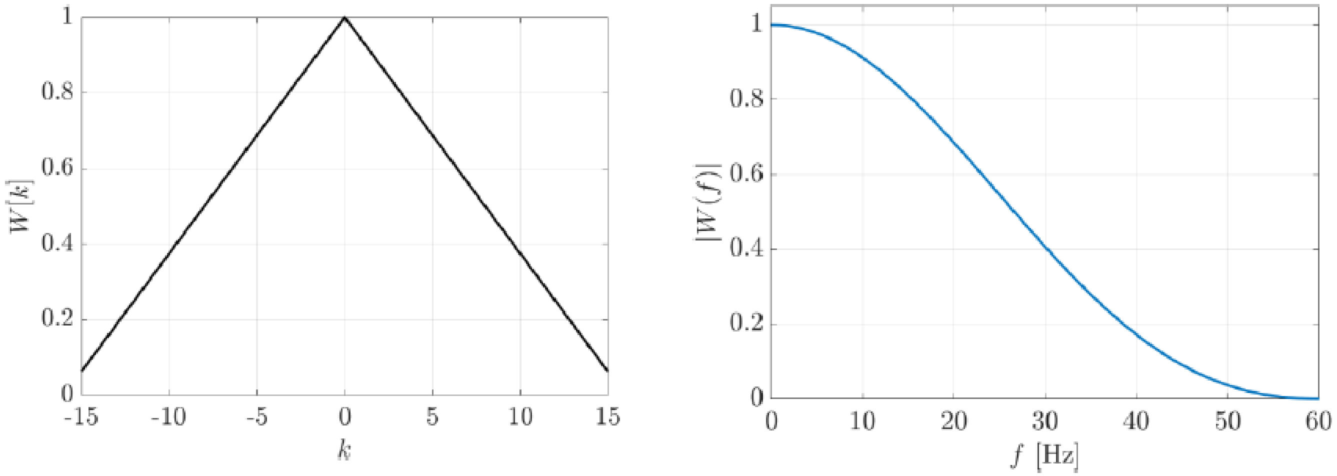



Figure 8. Window function and magnitude response of the P-class reference filter.

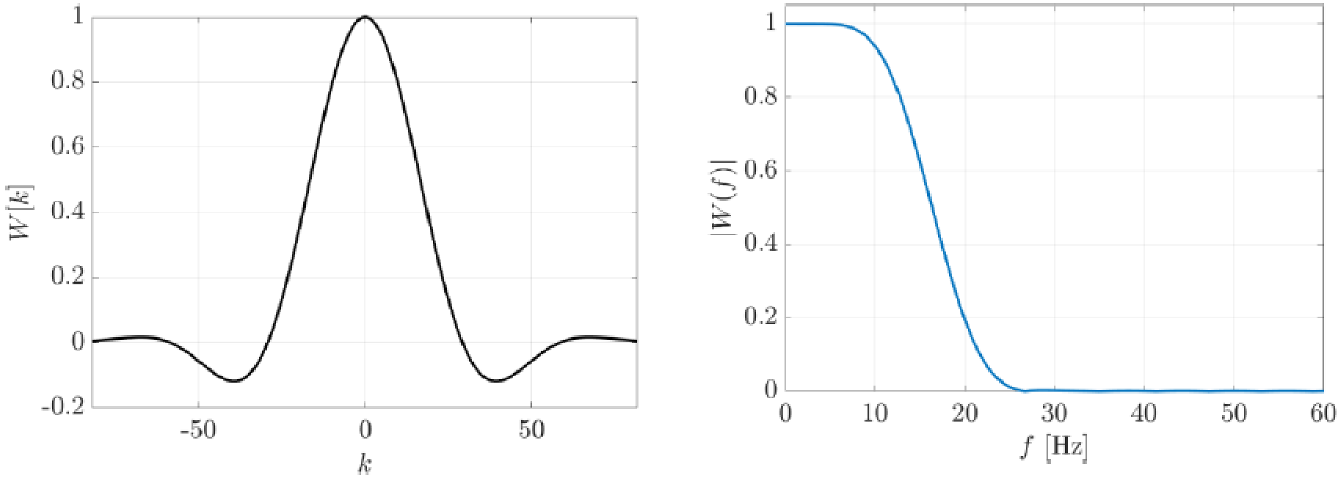



Figure 9. Window function and magnitude response of the M-class reference filter.

**Source:** Chatterjee K., J.D. Follum, A. Varghese, S. Biswas, E. Farantatos, and L. Zhu. 2026.[Measurement Adequacy for Monitoring Data Center Oscillations.]

# IMPACT OF LOW-PASS FILTERING

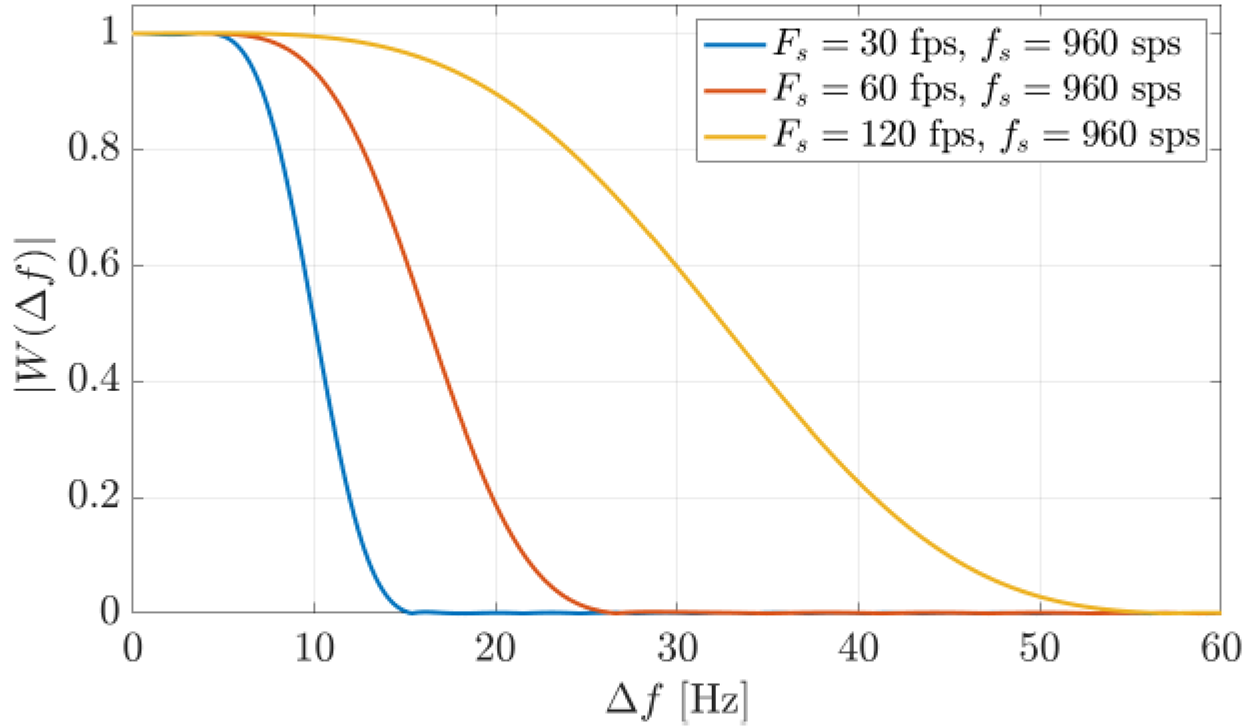
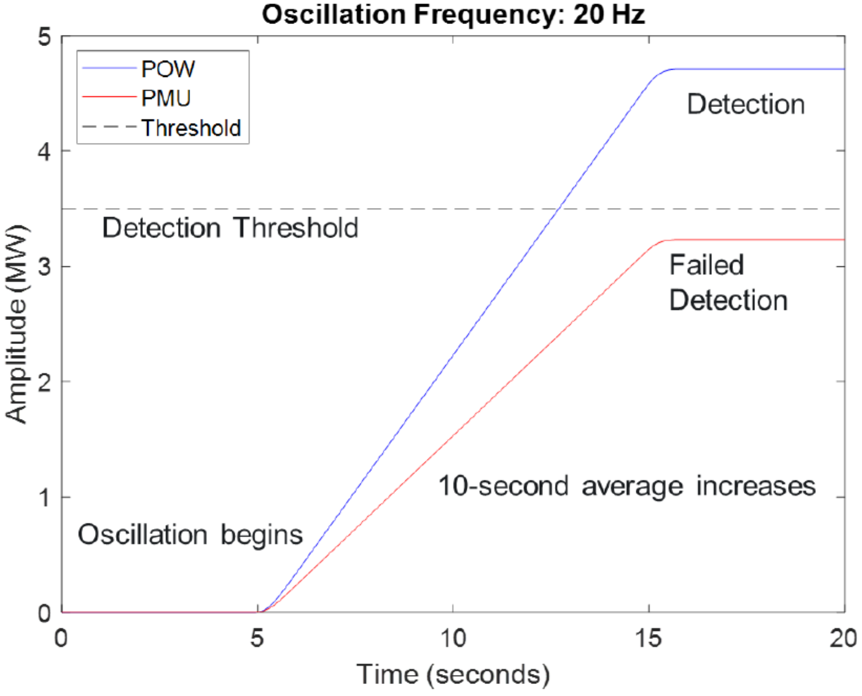


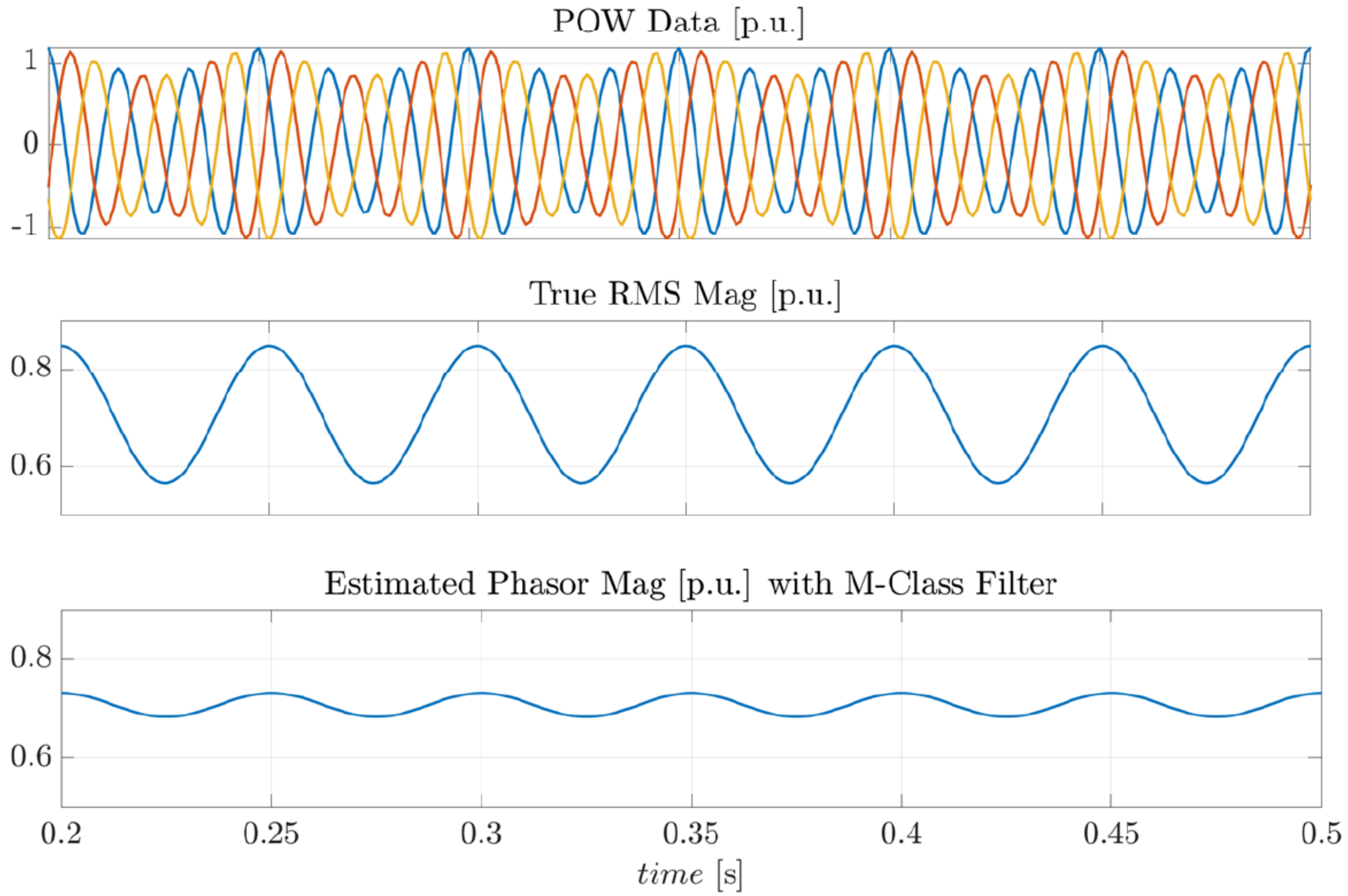

Figure 10. Impact of output reporting rate on the attenuation characteristics of M-class reference filters.

**Source:** Chatterjee K., J.D. Follum, A. Varghese, S. Biswas, E. Farantatos, and L. Zhu. 2026.[Measurement Adequacy for Monitoring Data Center Oscillations.]

# EXAMPLE

0.25 p.u. oscillation at




**Source:** Chatterjee K., J.D. Follum, A. Varghese, S. Biswas, E. Farantatos, and L. Zhu. 2026.[Measurement Adequacy for Monitoring Data Center Oscillations.]

Figure 13. Amplitude estimation and attenuation of a 20 Hz oscillation using the IEC/IEEE reference algorithm with M-class filter and 60 fps reporting rate.

# COMMERCIAL PMU RESPONSE

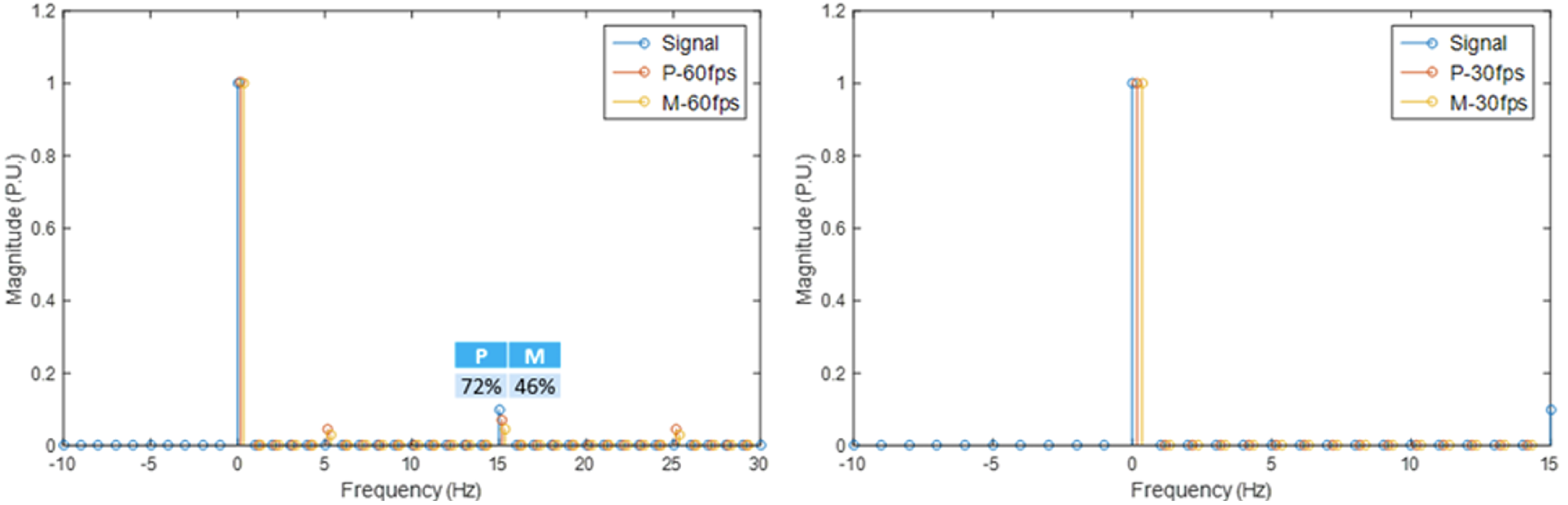



Figure 17. Amplitude estimate of a 15 Hz oscillation reported by a commercial PMU with P- and M-class filter designs for (a) 60 fps and (b) 30 fps reporting rates.

**Source:** Chatterjee K., J.D. Follum, A. Varghese, S. Biswas, E. Farantatos, and L. Zhu. 2026.Measurement Adequacy for Monitoring Data Center Oscillations.


Q&A