

Subsynchronous Oscillation Detection: Comparison of Methods

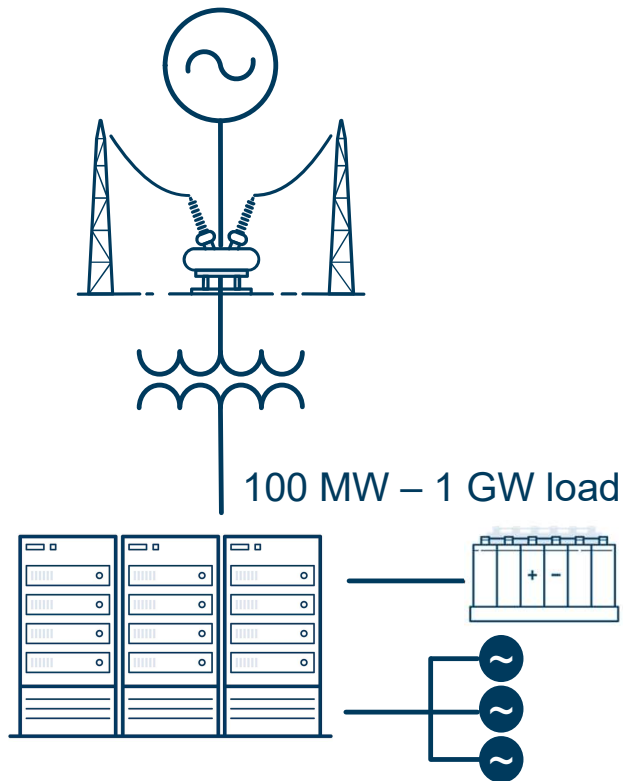


Drew Cannon

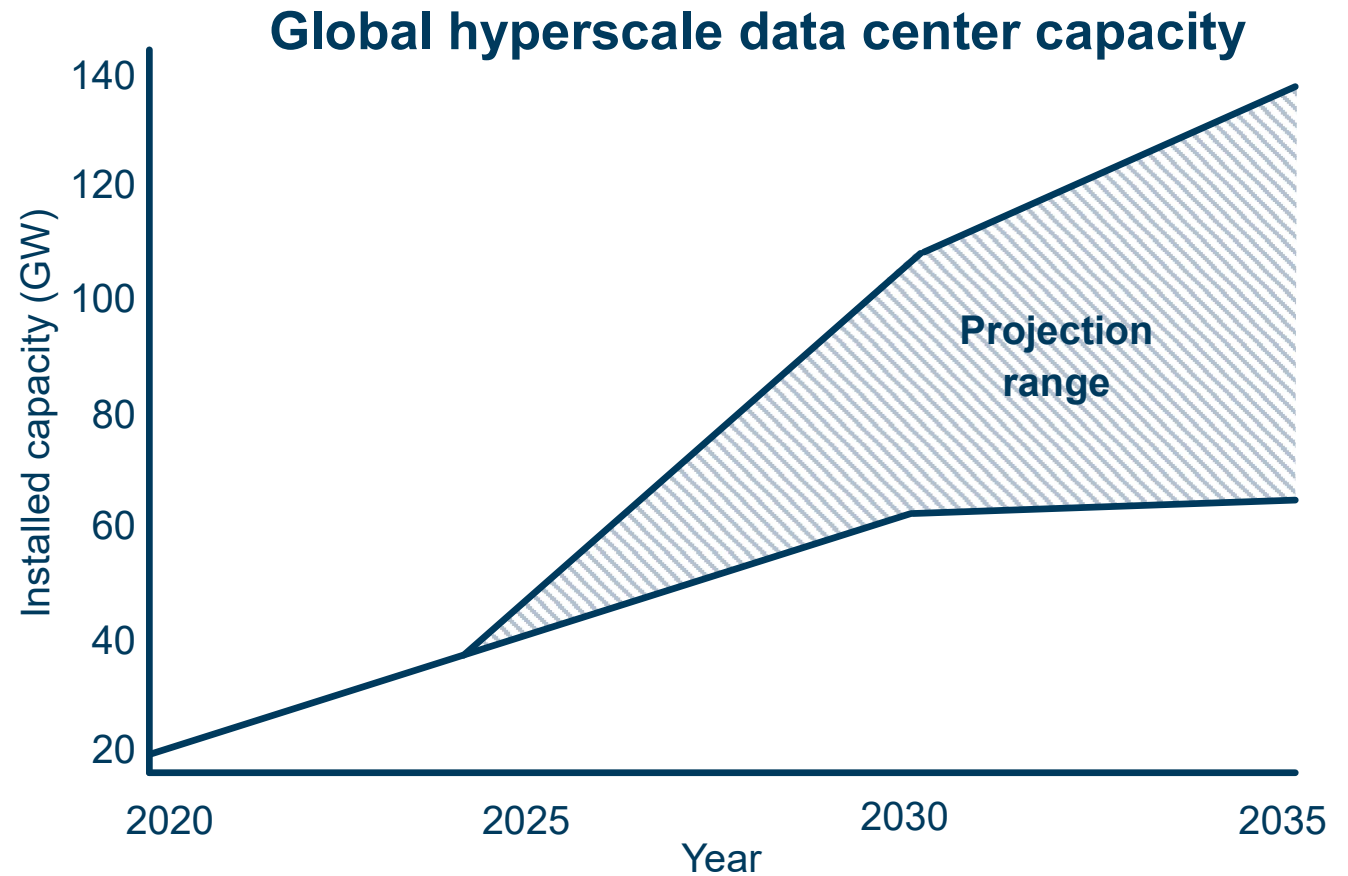
Outline

- Background on Oscillations
 - Types
 - Causes
 - Effects
- Overview of detection methods
 - Algorithm overview
 - Frequency-domain investigation
 - Evaluation

Modern load dynamics are changing how we monitor and control the power system

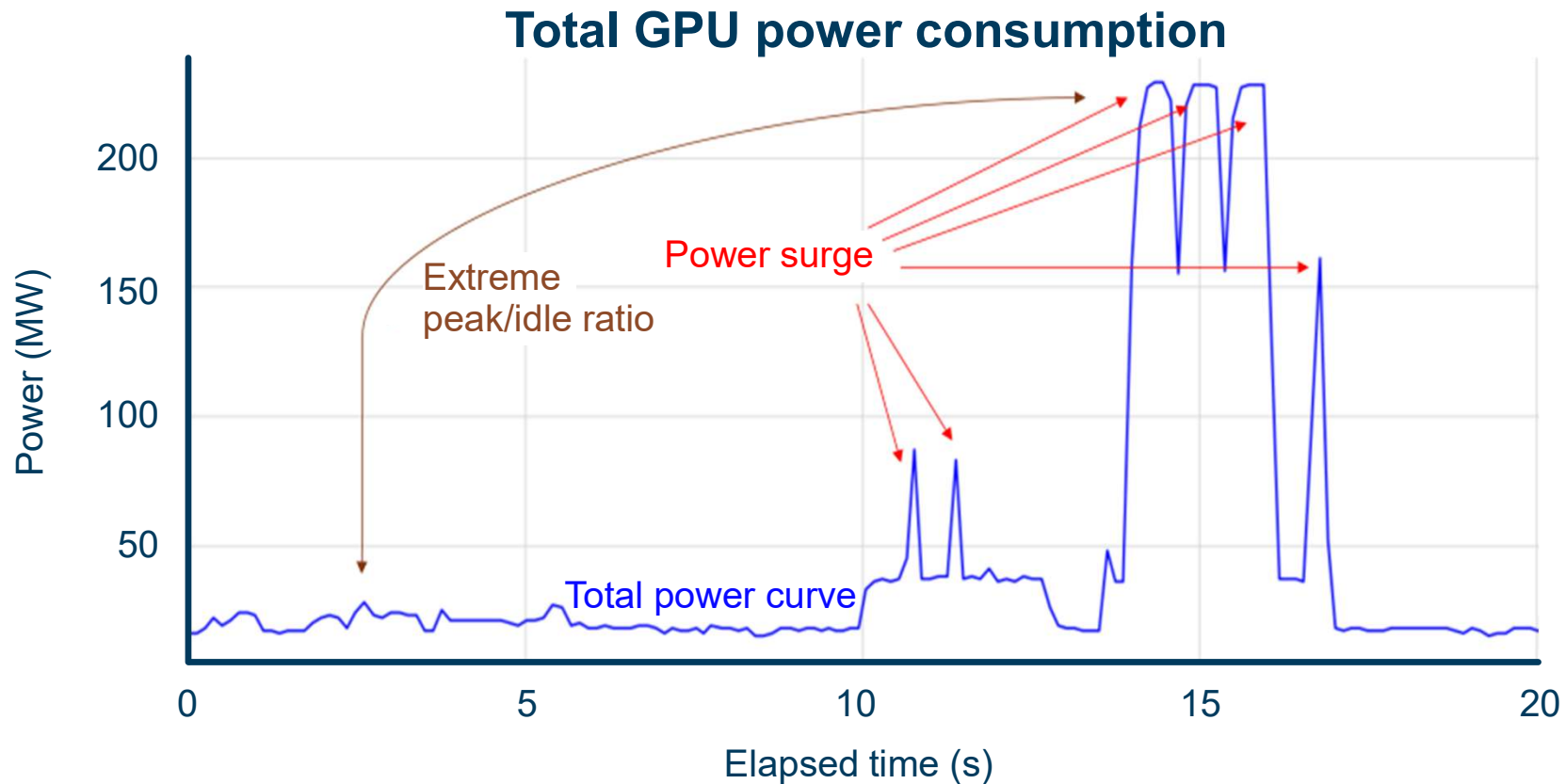


Hyperscaler loads are expected to double in seven years

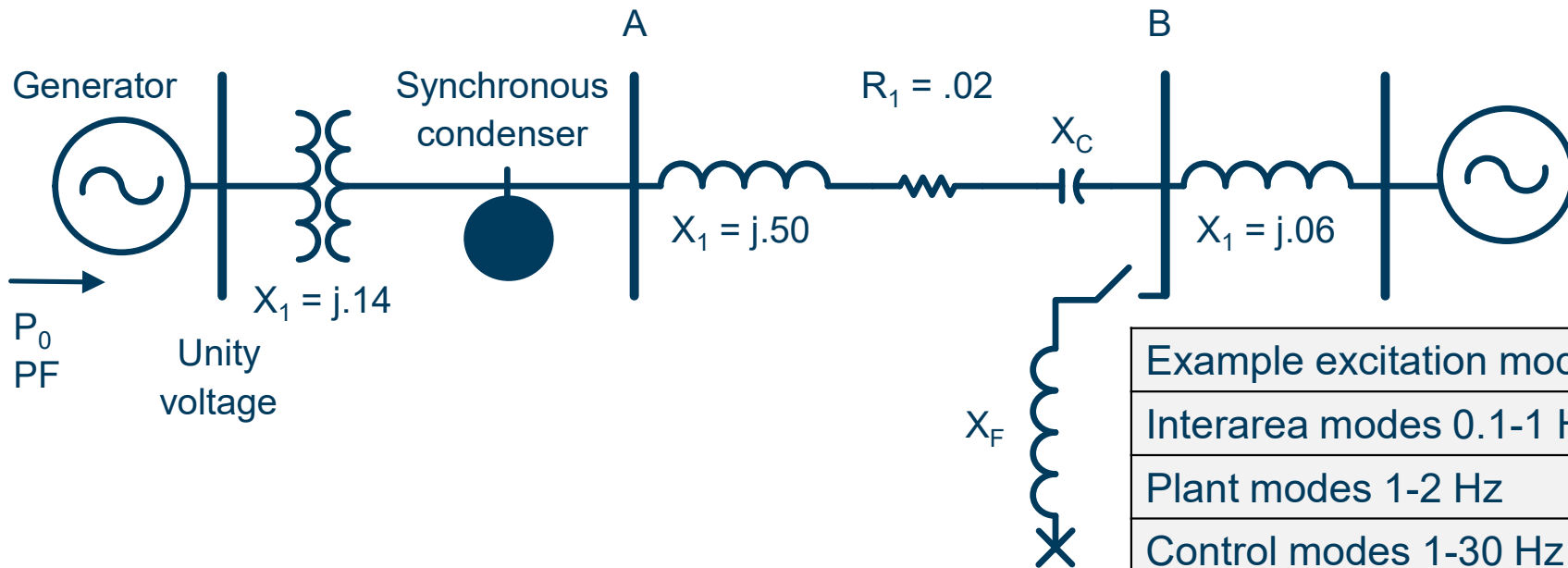


Based on IEA data from IEA (2025) Energy and AI, [iea.org/data-and-statistics](https://www.iea.org/data-and-statistics)
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AI training creates massive load changes



Modern dynamics are harder to model and can cause undesired resonances



Network for sub synchronous resonance studies

Example excitation modes
Interarea modes 0.1-1 Hz
Plant modes 1-2 Hz
Control modes 1-30 Hz
Generator torsional modes ~10-45 Hz

Types of Oscillations

- Amplitude-modulated:

$$X(t) = A(t) \cdot \cos(\omega t + \theta)$$

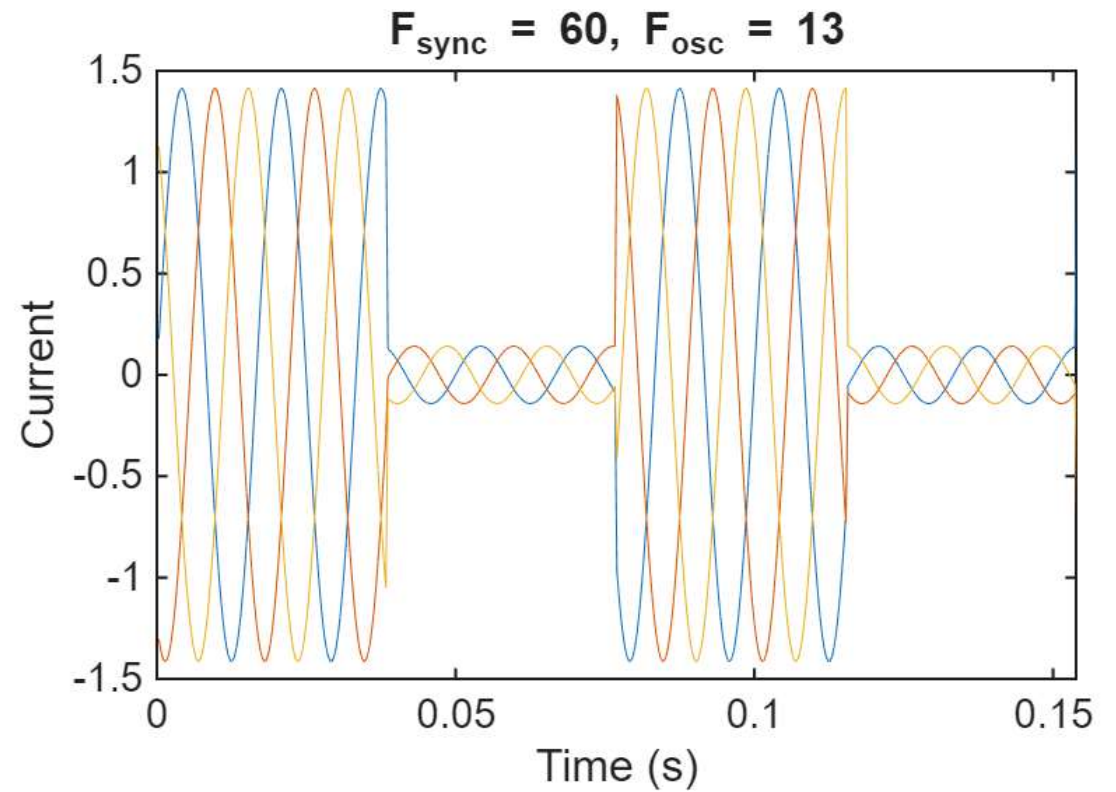
- Frequency-modulated:

$$X(t) = A \cdot \cos(\omega t + \theta(t))$$

- Additional signal:

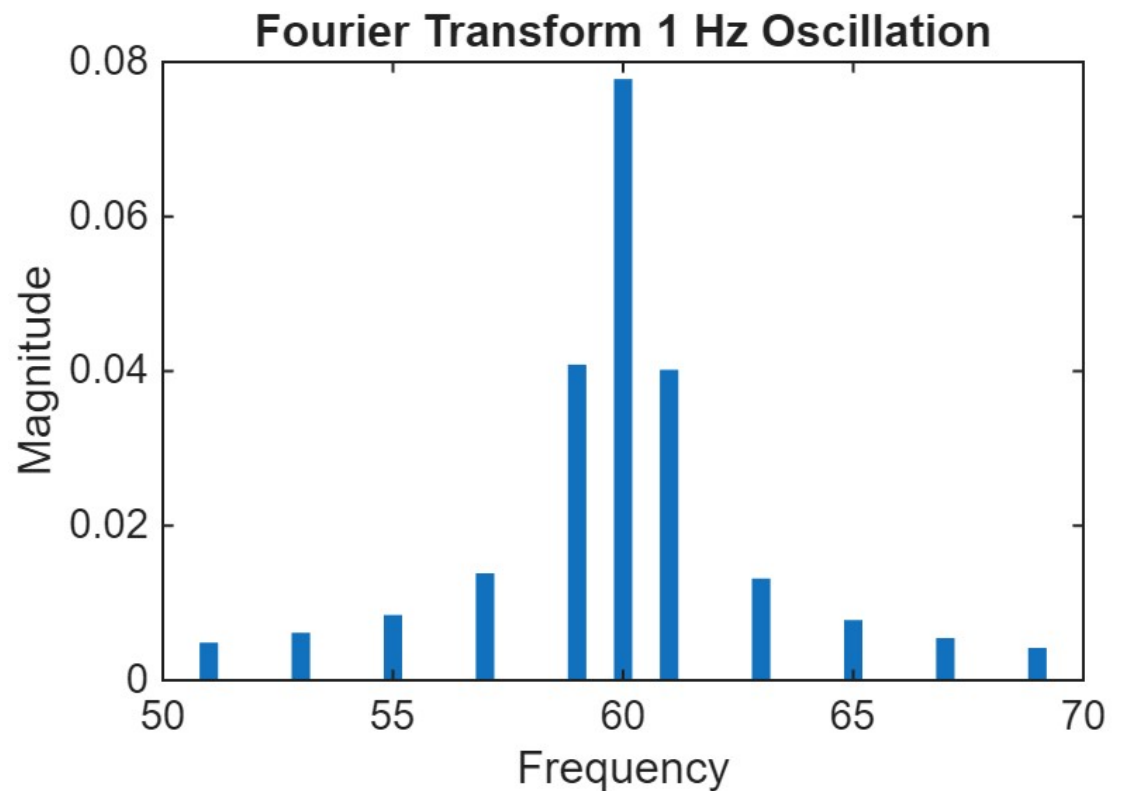
$$X(t) = A \cdot \cos(\omega t + \theta) + B \cdot \cos(\omega_2 t + \theta_2)$$

Amplitude-Modulated Oscillations

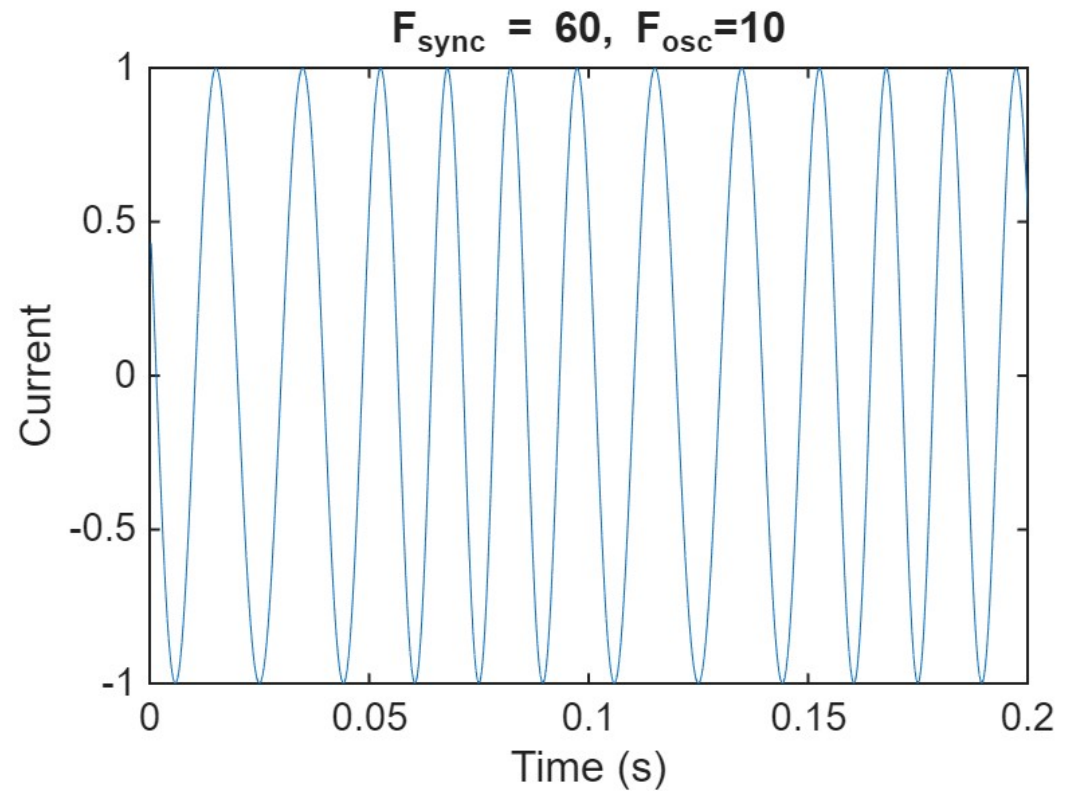


Amplitude-modulated signals appear as sidebands around nominal frequency

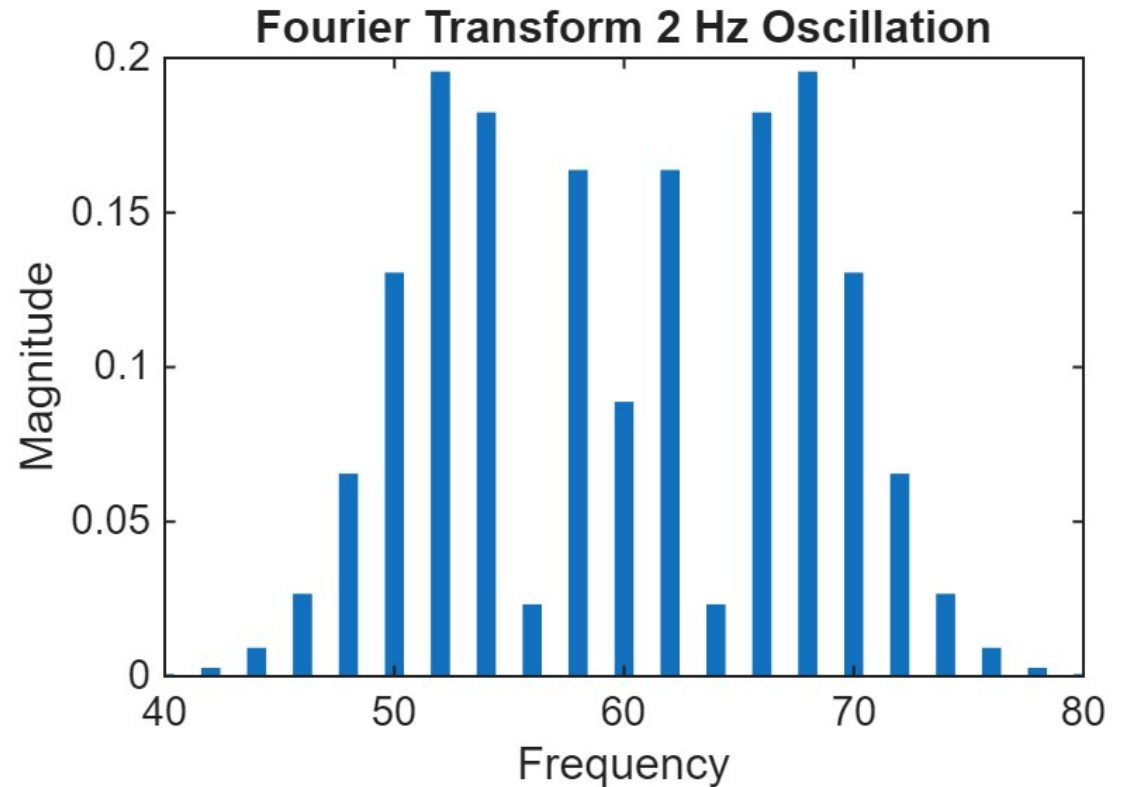
$$\sin \alpha \sin \beta = \frac{\cos(\alpha - \beta) - \cos(\alpha + \beta)}{2}$$



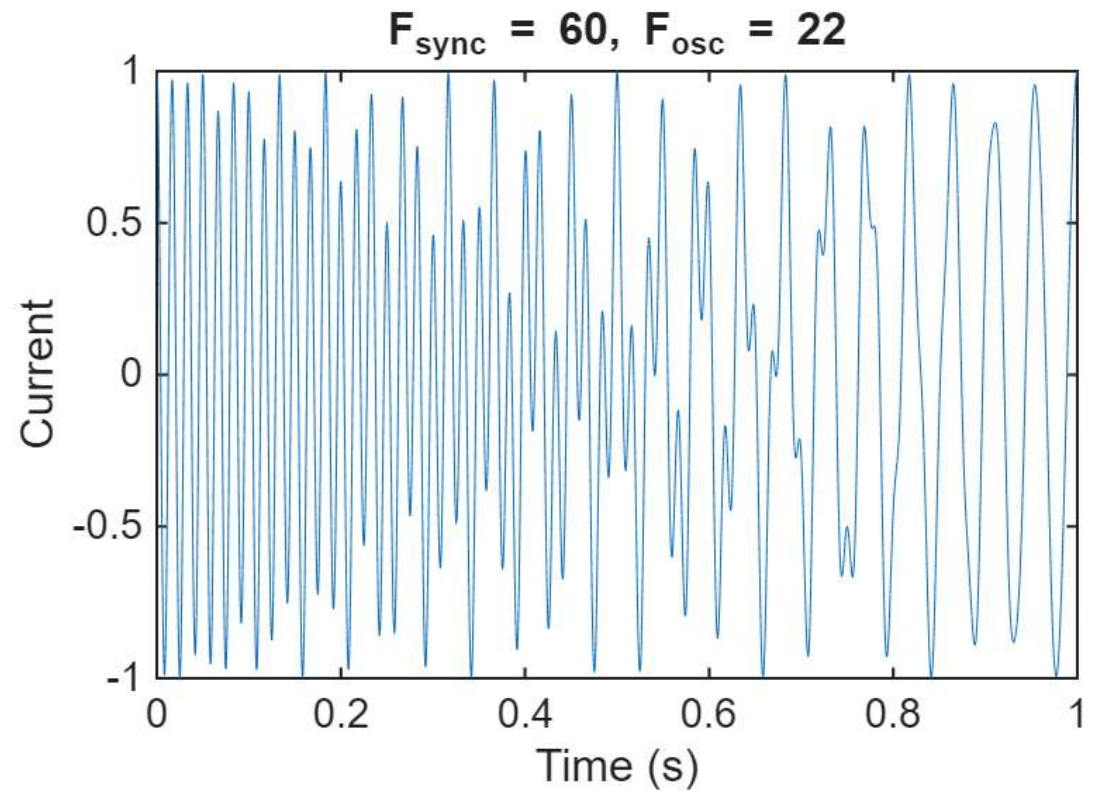
Frequency-Modulated Oscillations



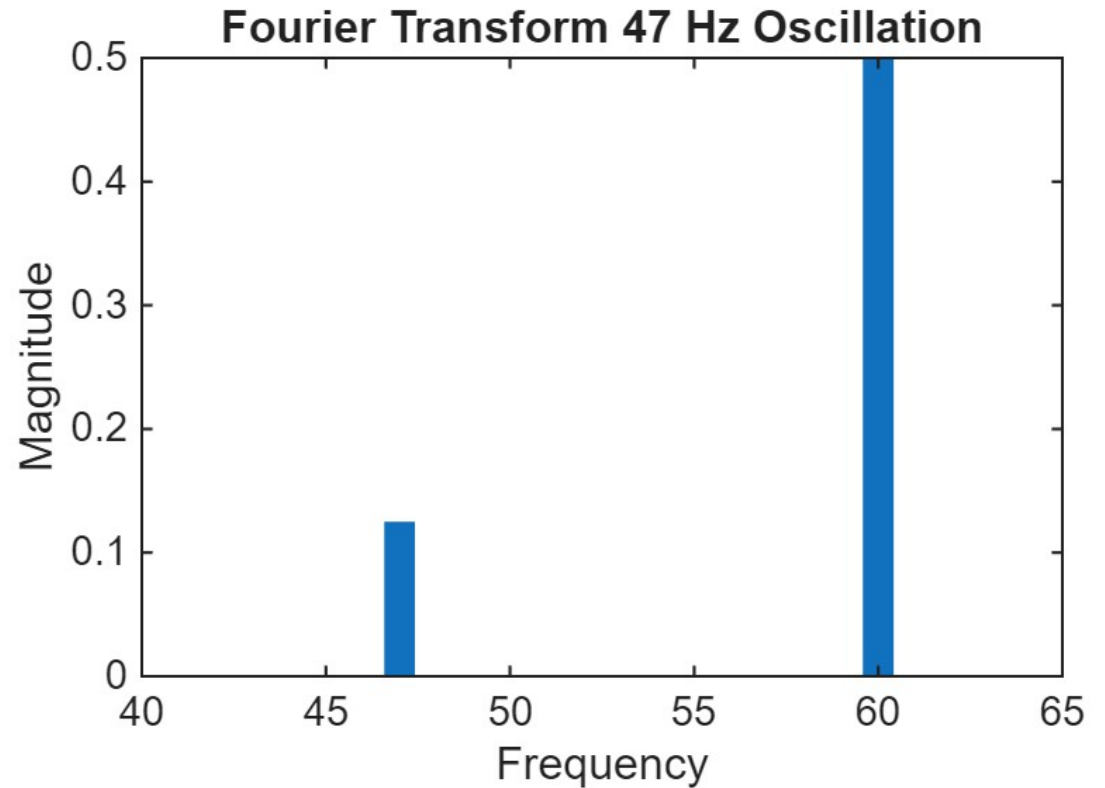
Frequency-modulated signals appear as sidebands around nominal frequency



Additional Signal Oscillations



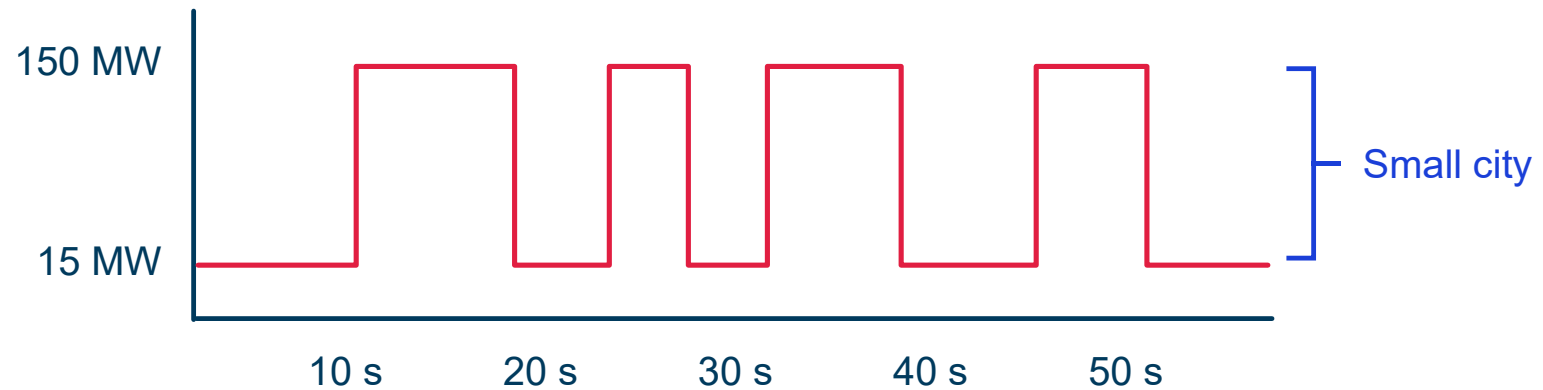
Additional Signals Have Simple Frequency Spectrum



Causes of Oscillations

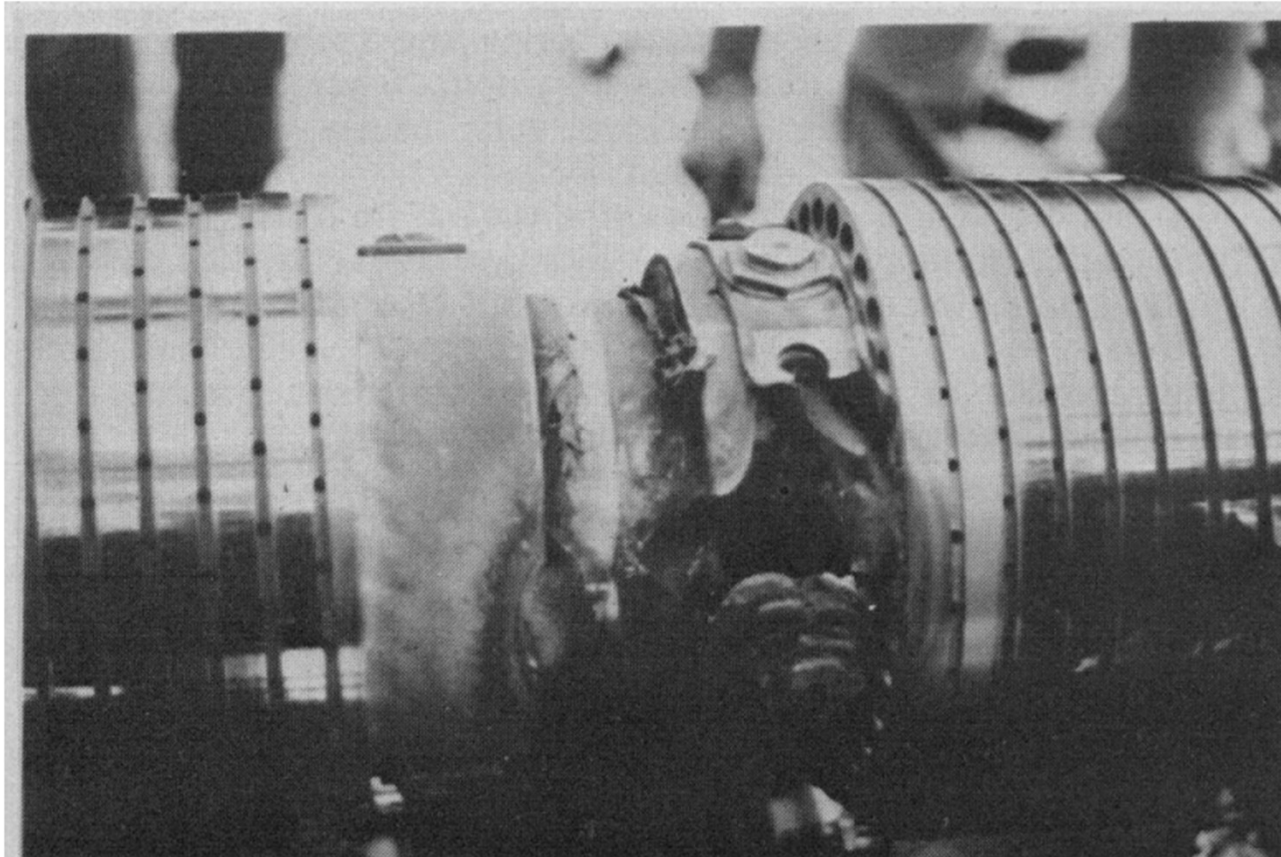
- Forced oscillations
- Resonant oscillations

AI training runs create large load changes that can induce resonance



Effects of Oscillations

- Damaged equipment
- Reduced capacity
- Light flicker
- Potential for cascading failure



Damaged shaft at Mohave power plant

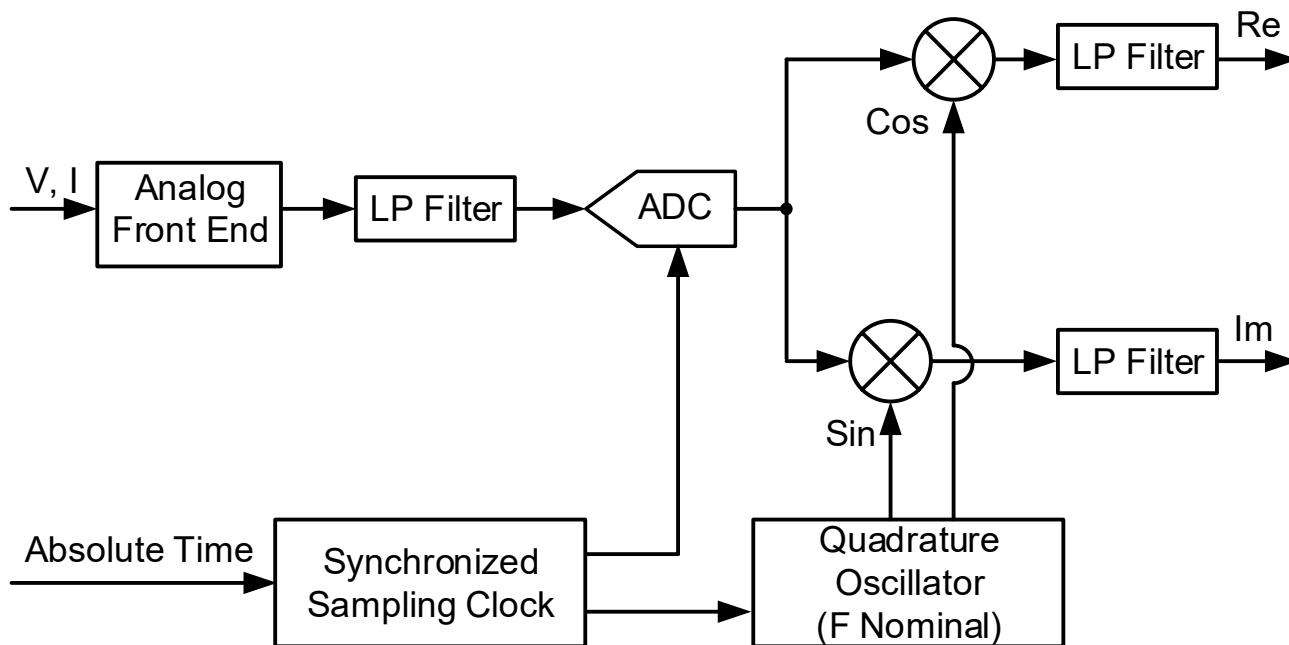
J.W. Ballance and S. Goldberg 1973

Data Processing

Possible Methods

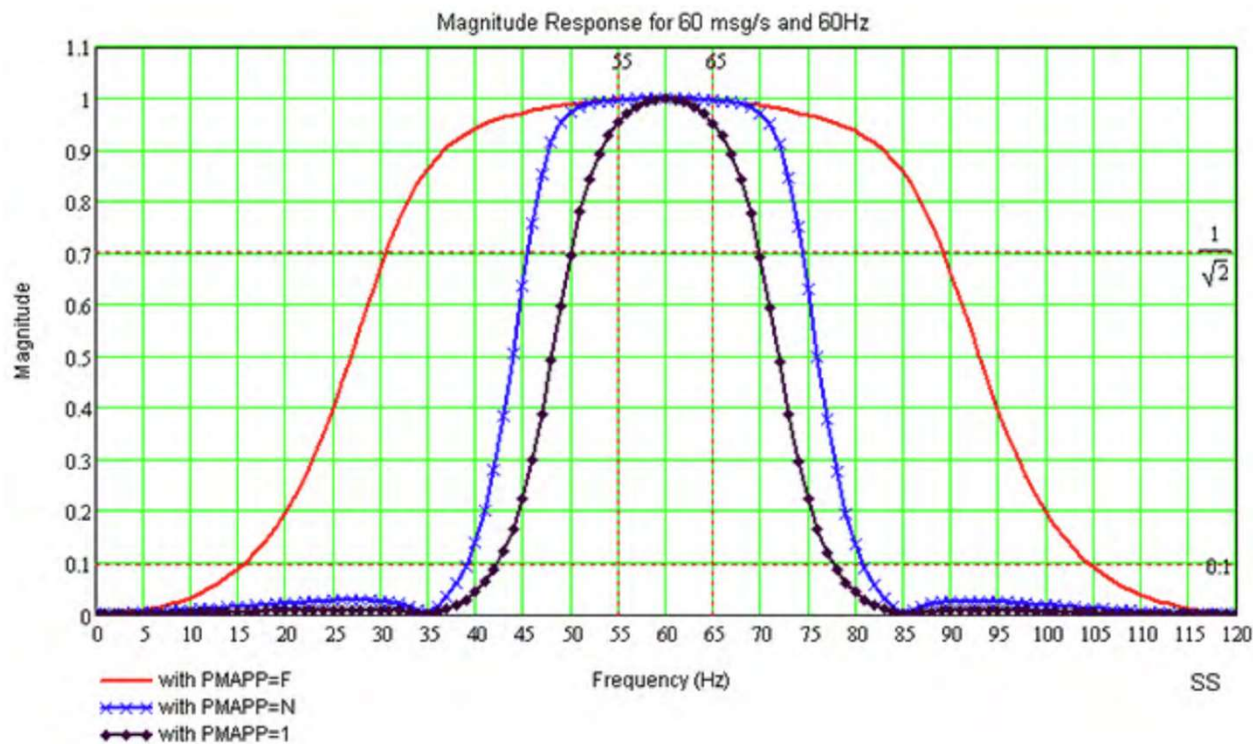
- Initial Processing
 - Synchrophasors
 - RMS
 - Flicker
 - Point on Wave
- Quantity Measured
 - Current
 - Voltage
 - Frequency
 - Power

Synchrophasor Processing



Low-pass filter design significantly affects the transfer function of a PMU

Synchrophasor Frequency Response



Three different low-pass filters in a commercial PMU

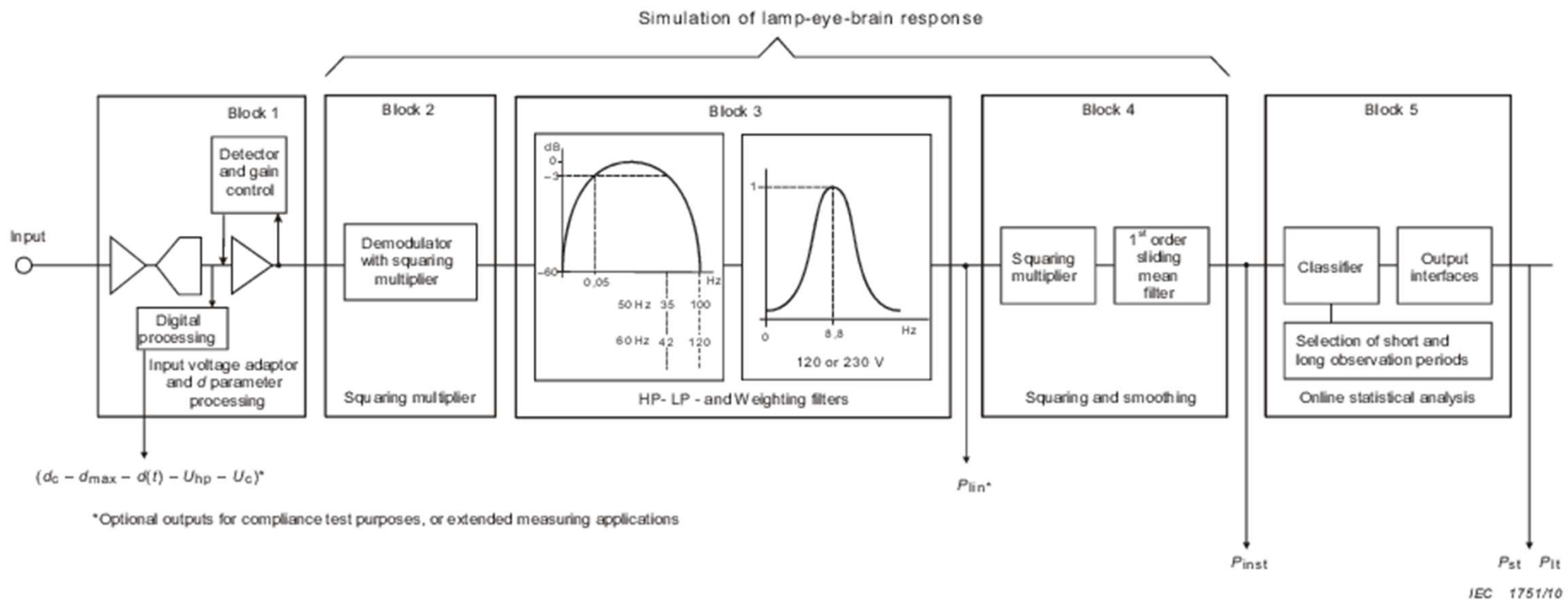
RMS Calculation

$$X_{rms} = \sqrt{\left(\frac{1}{T} \int_0^T X^2 dt\right)}$$

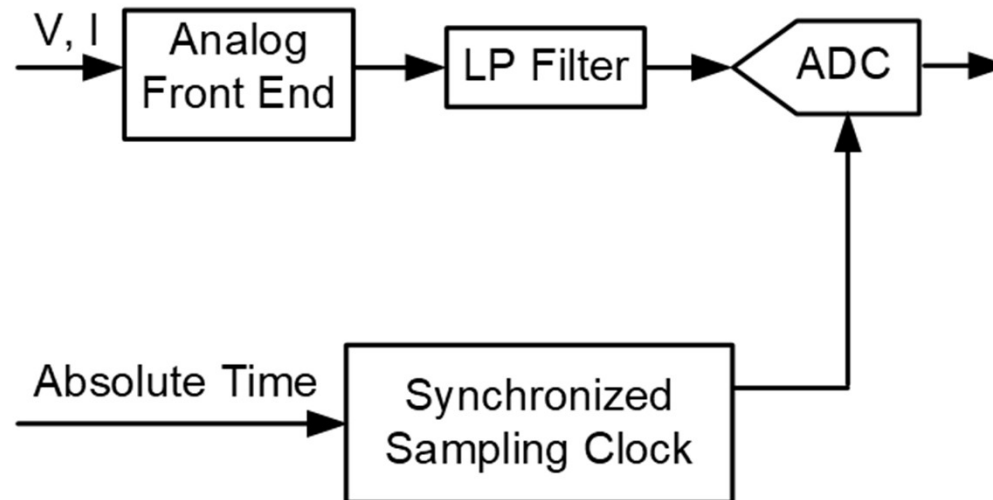
One-cycle Power Calculation

$$P = \frac{1}{T} \int_0^T V \cdot I \, dt$$

Flicker Calculation (IEC 61000-4-15)



Point on Wave Data



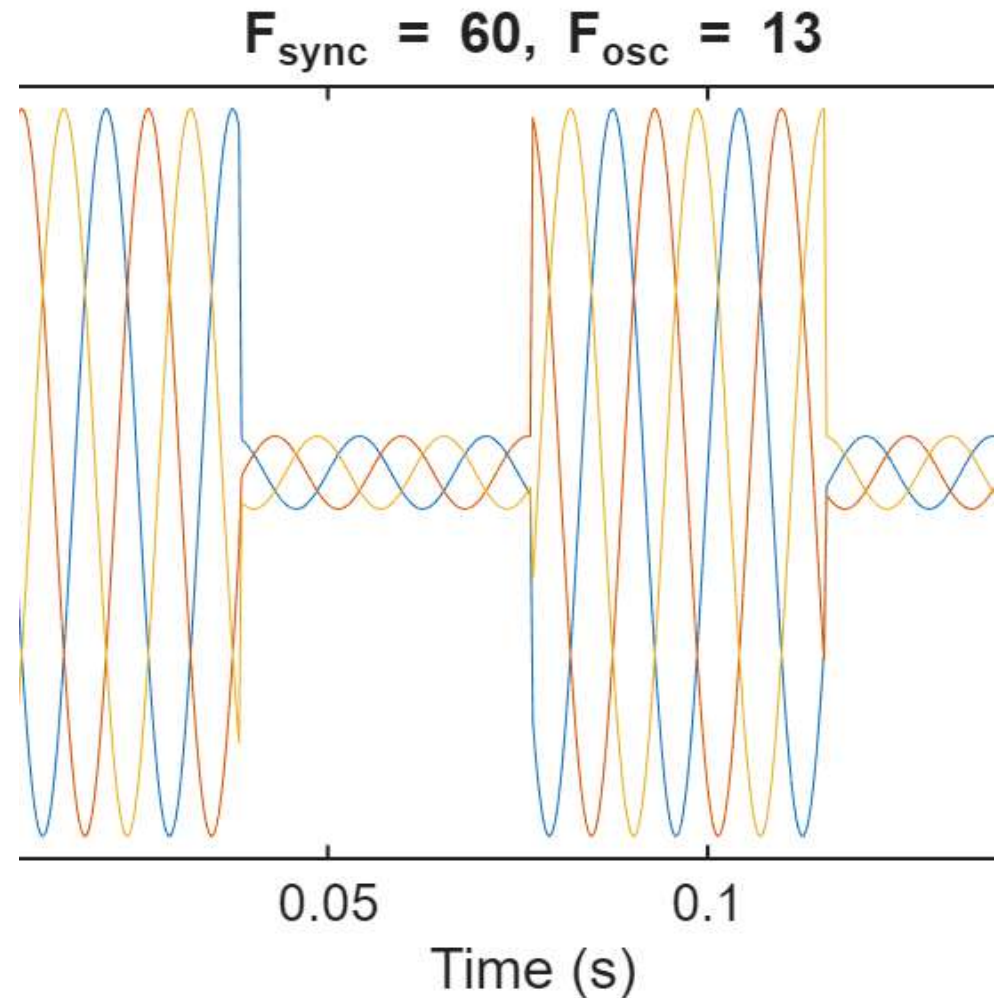
Measurands

- Voltage: Most direct measurement of effect on grid
- Current: Oscillations are larger
- Power: Modulates signal to near DC
- Frequency: Related to active power

Simulation Results

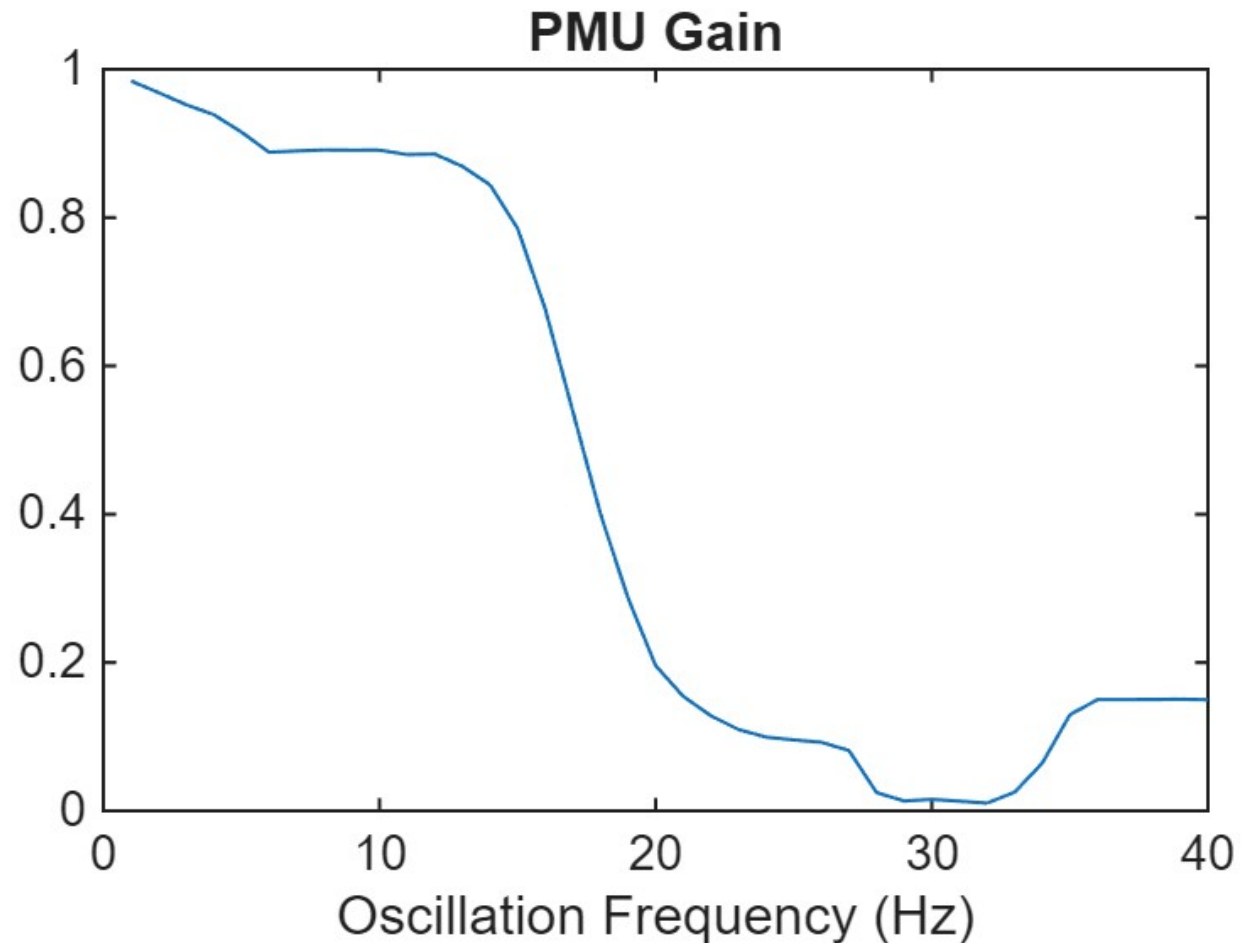
Method

- Sinusoid amplitude modulated by square wave to mimic AI load profile
- Modulation frequency from 0.5-40 Hz
- Gain calculated as measured energy from 0-50 Hz divided by theoretical value



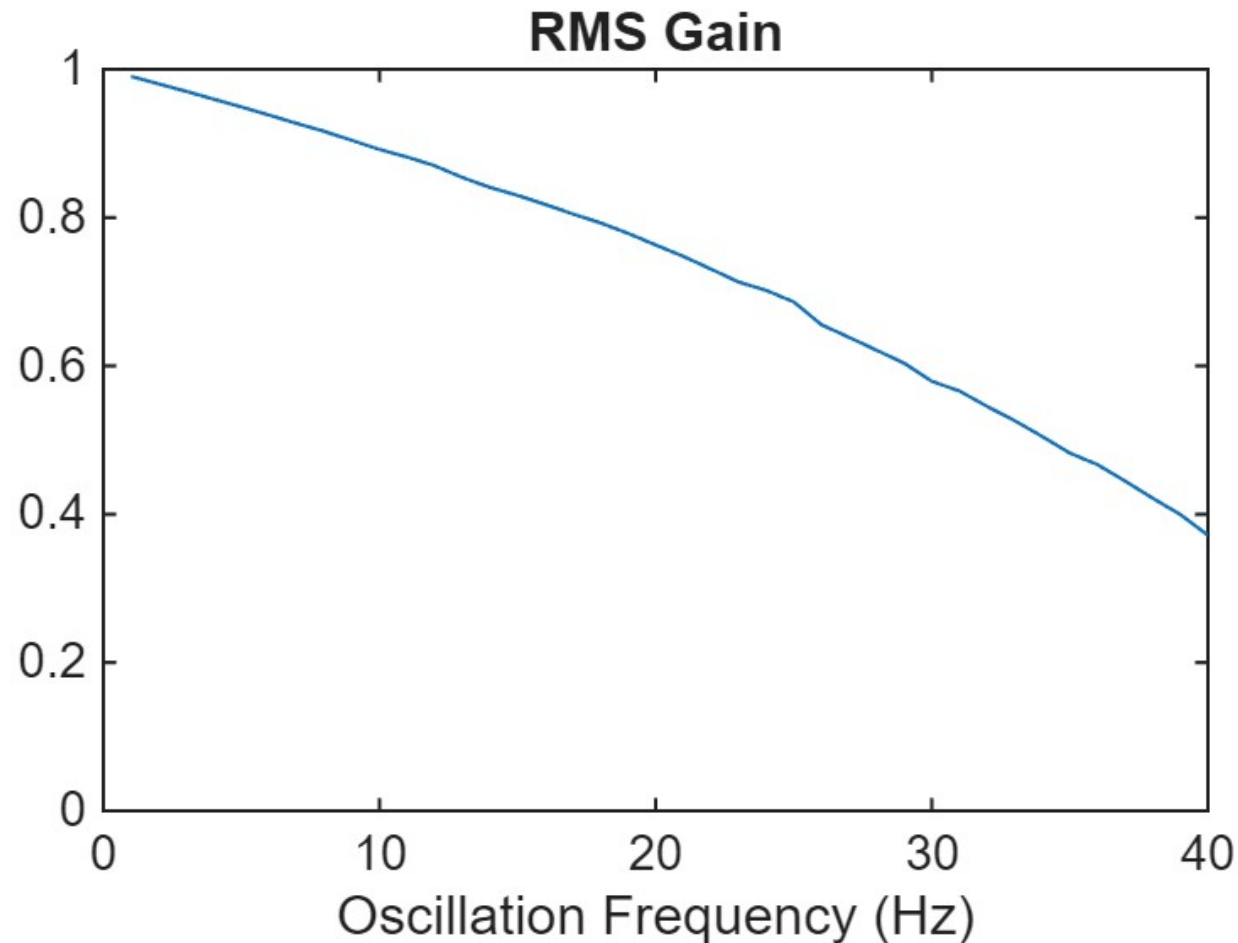
PMU Gain

- Relatively high gain at low frequencies
- Steep dropoff at filter cutoff (depends on filter)



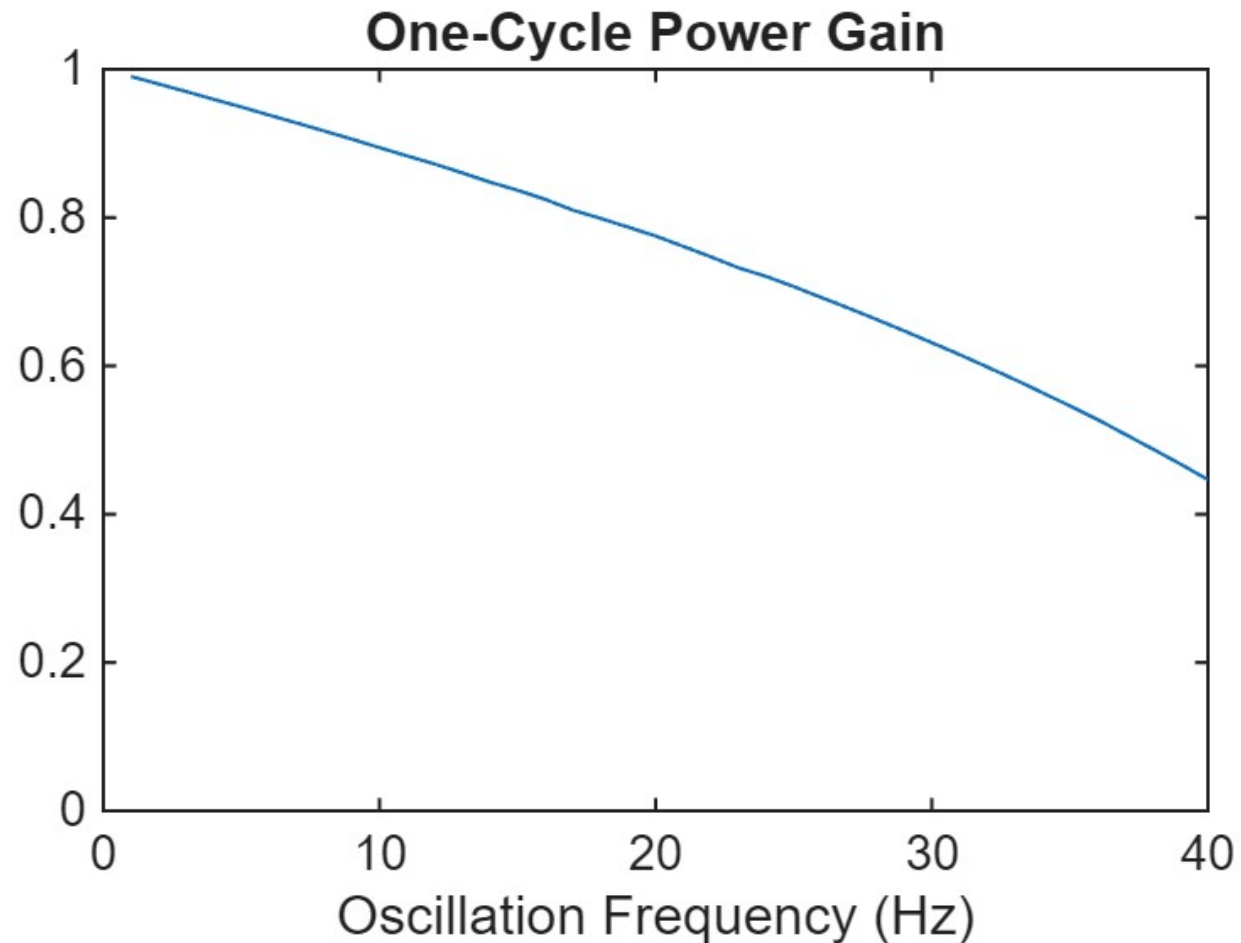
RMS Gain

- One-cycle RMS has near-linear falloff
- 12-cycle RMS (more common in metering equipment) has much narrower frequency range

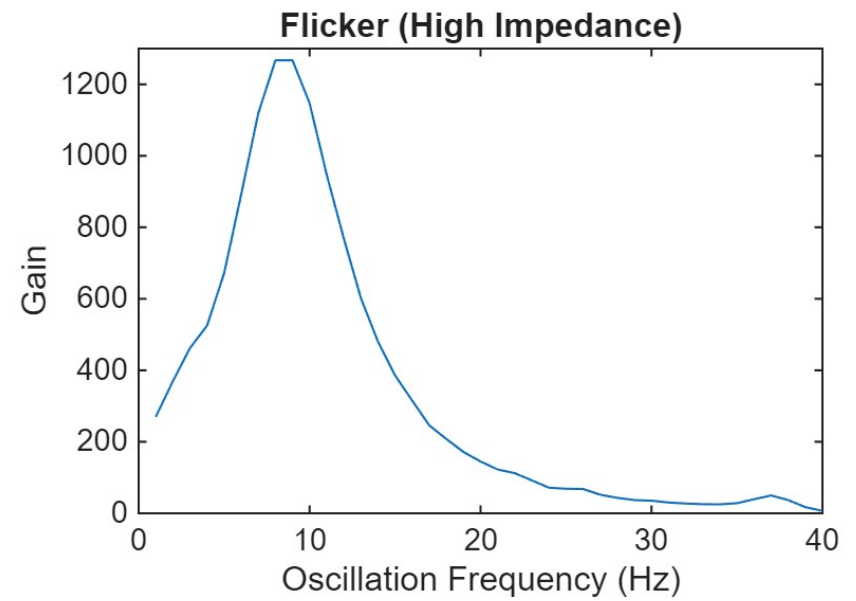
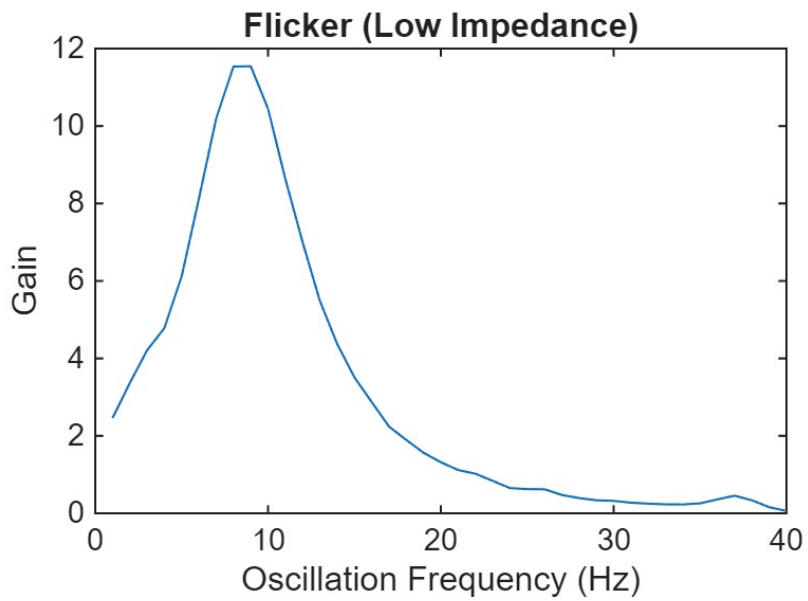


One-cycle Power Gain

- Similar to RMS
- Near-linear frequency rolloff
- Real systems use 12-cycle or longer windows

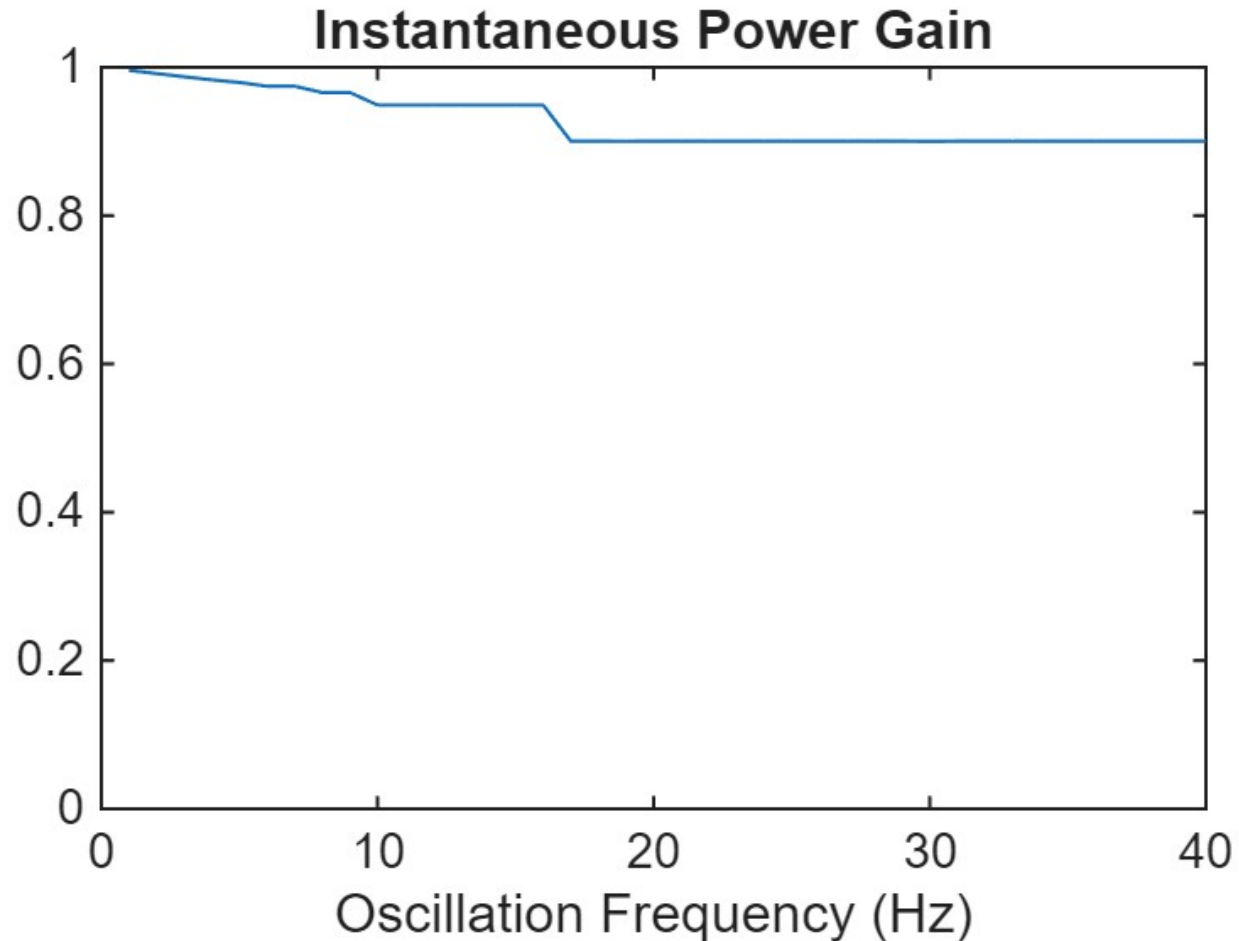


Flicker



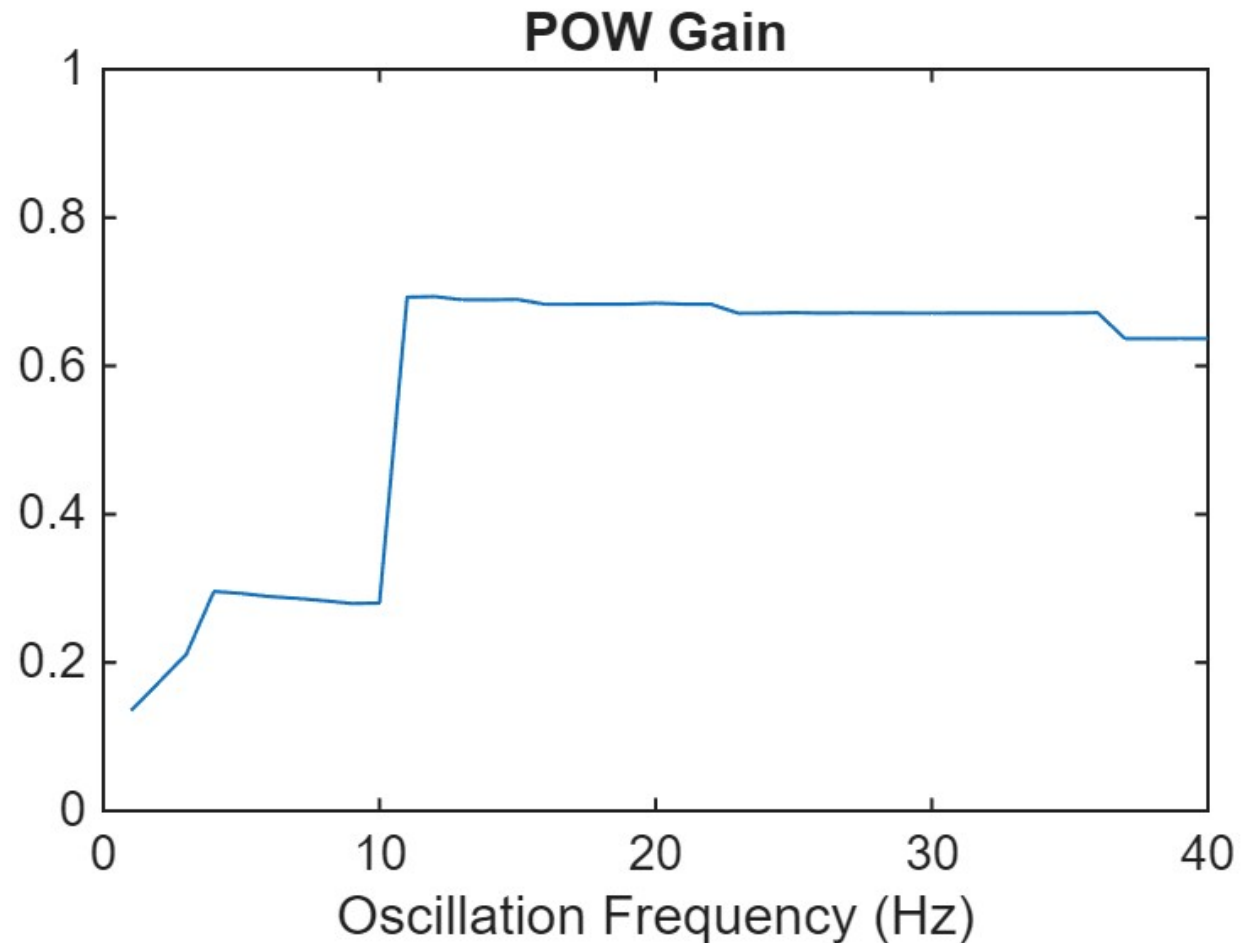
Instantaneous Power

- Much better than one-cycle power
- Falloff is caused by Fourier components leaving frequency range



POW Data

- Peak at $1/\sqrt{2}$ due to only capturing $\frac{1}{2}$ of frequency band
- Lower gain at lower oscillation frequencies due to signal modulation



Conclusion

- Point-on-wave data can be a valuable tool for oscillation monitoring
- Intermediate calculations between POW data and output matter
- Instantaneous power is a good measurand because it demodulates oscillations and has minimal rolloff at higher frequencies

Questions?