Active Magnetic Field Stabilization

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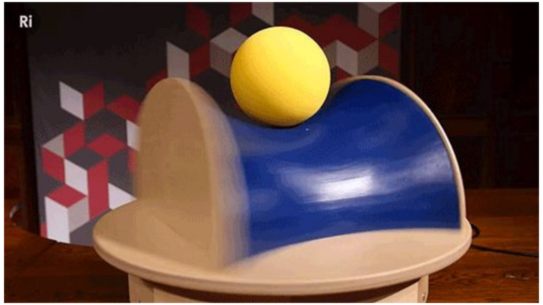
PHYS 13/15C Final Presentation
6/5/23

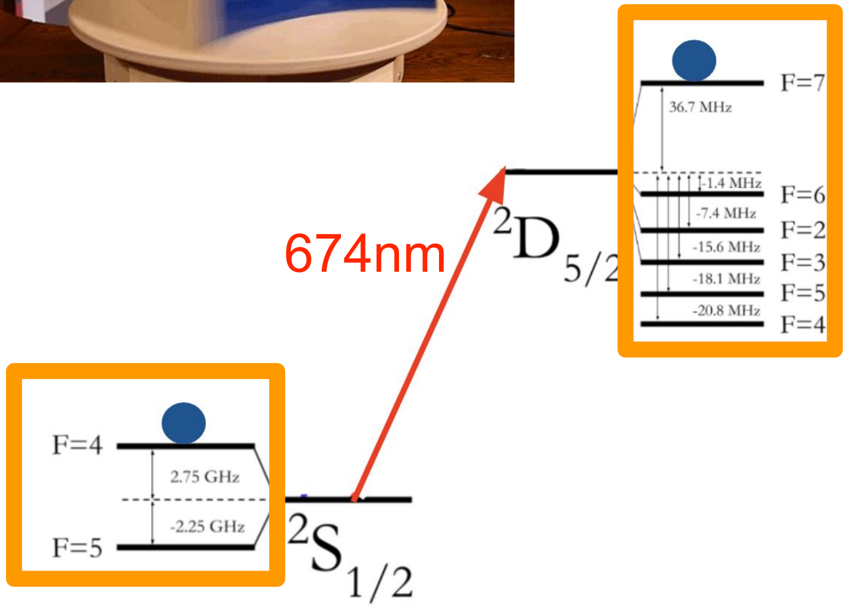
Why Stabilize?

Trapped Atom Experiments:

- Atomic Clocks
- State manipulation

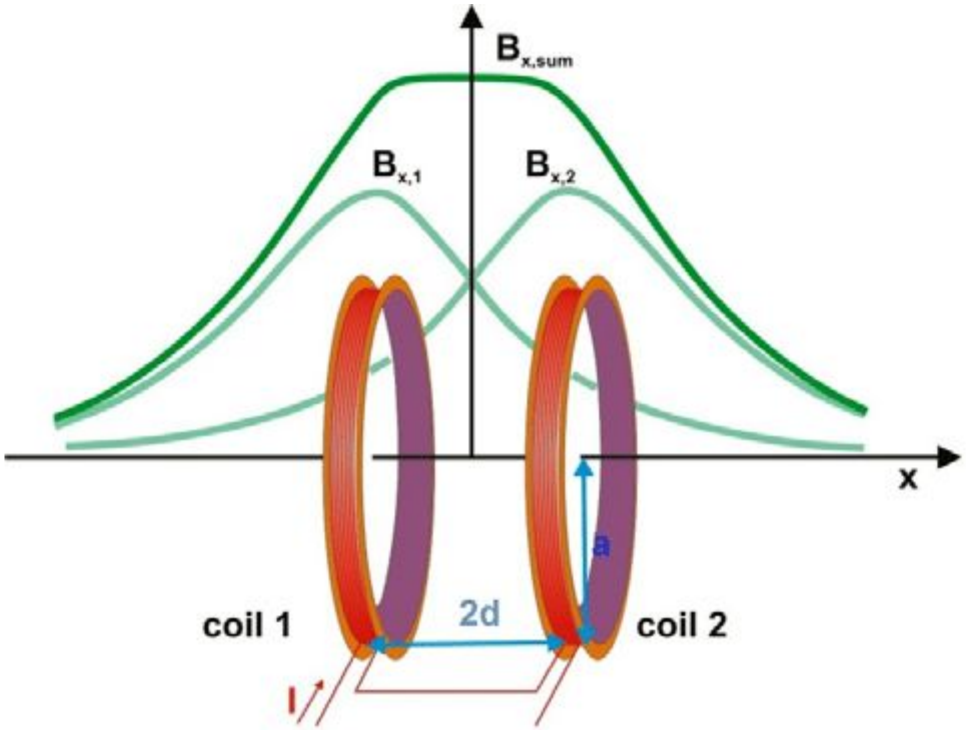


Zeeman Effect: shift energy levels



Foot, Atomic Physics, Ch5
Gebretsadkan, 87Sr+ Optical Clock presentation

Generating Helmholtz Field



When $a \approx 2d$,

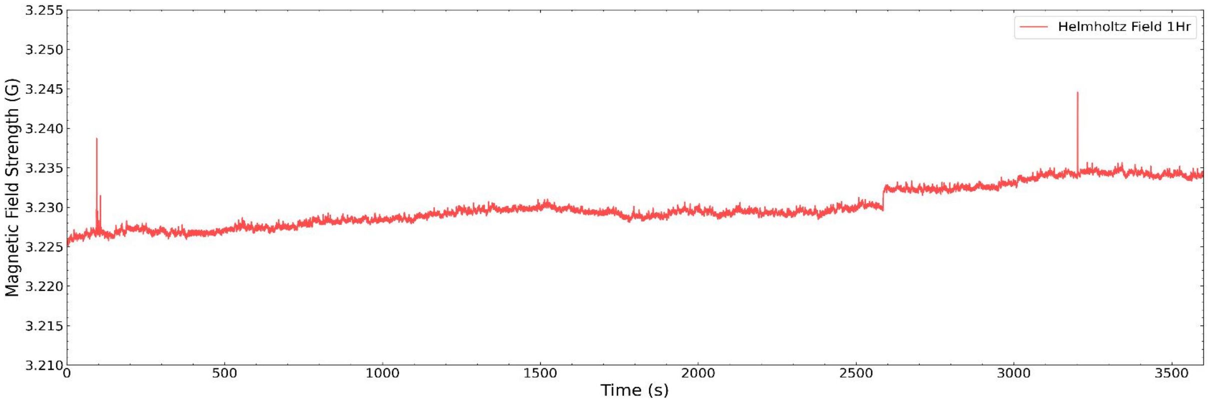
$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 n I}{a}$$

~3G Field for I=.25A

Kanata, Three-dimensional Mapping of Static Magnetic Fields over a Semi-anechoic Chamber

Helmholtz Field Drift

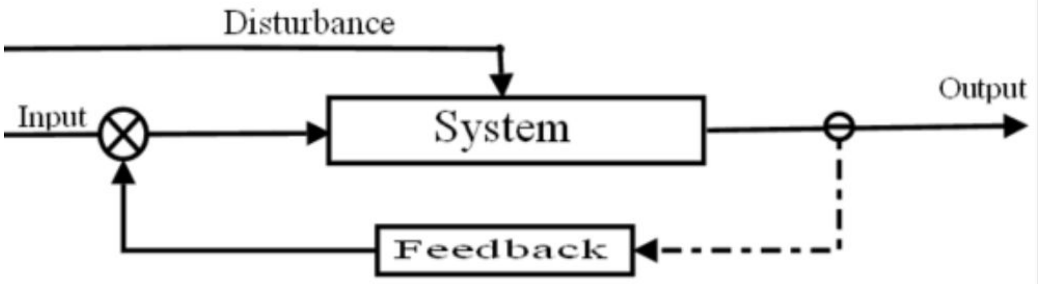
3600s Drift:
3.2300 ± 0.0025G



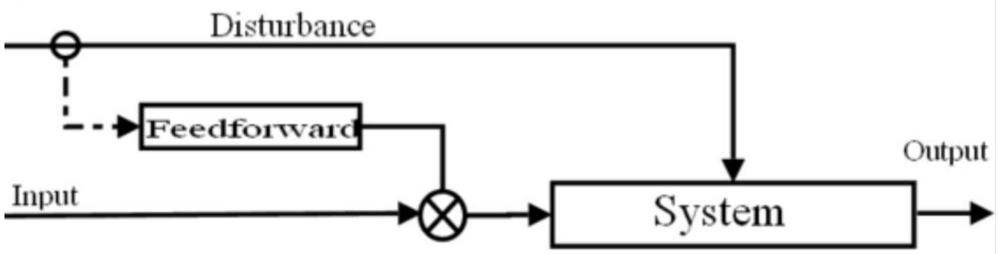
10s Drift
3.1107 ± 0.0017G

Feedback vs. Feedforward

- Feedback: modify input based on output

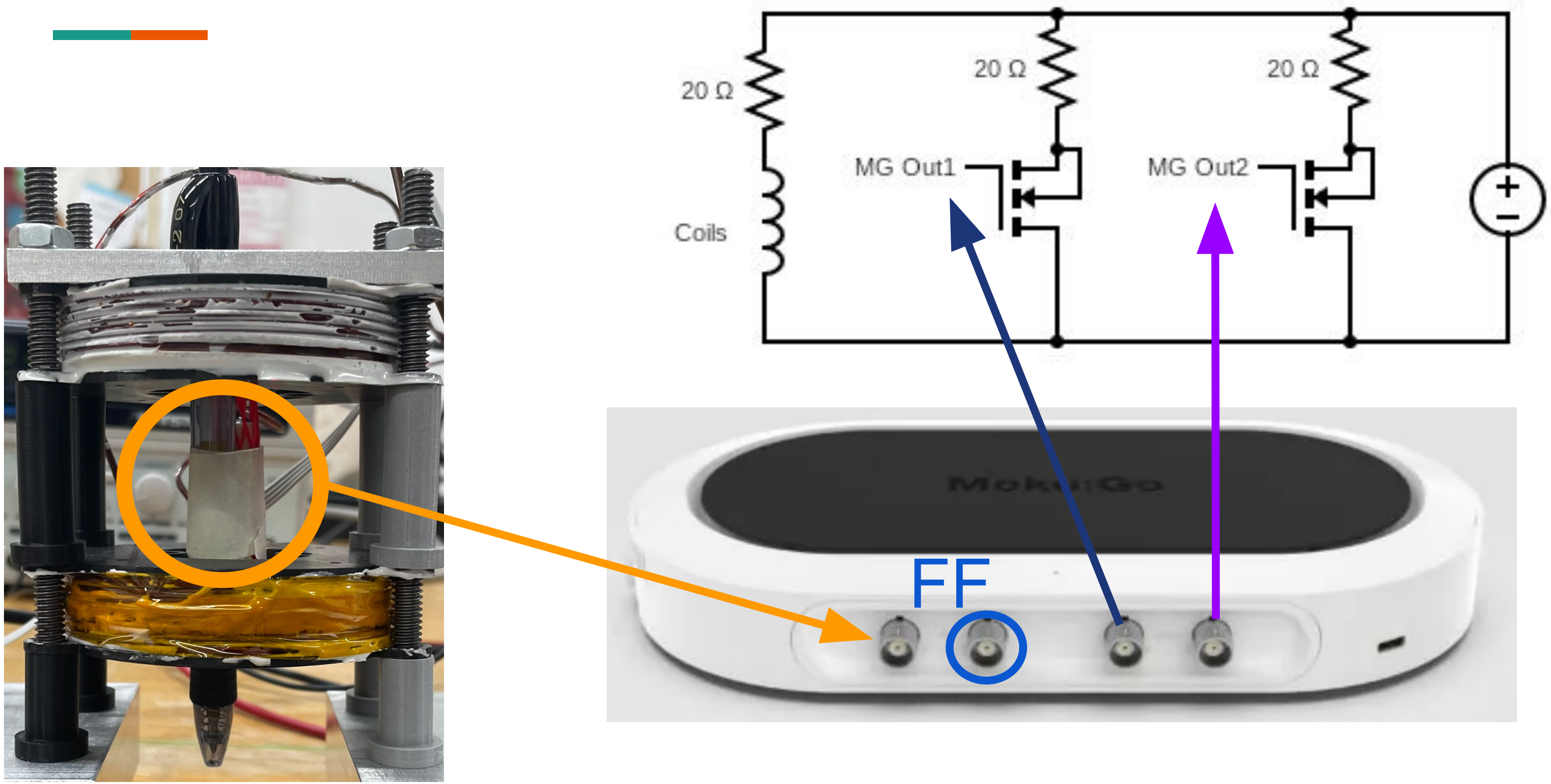


- Feedforward: modify input based on external trigger

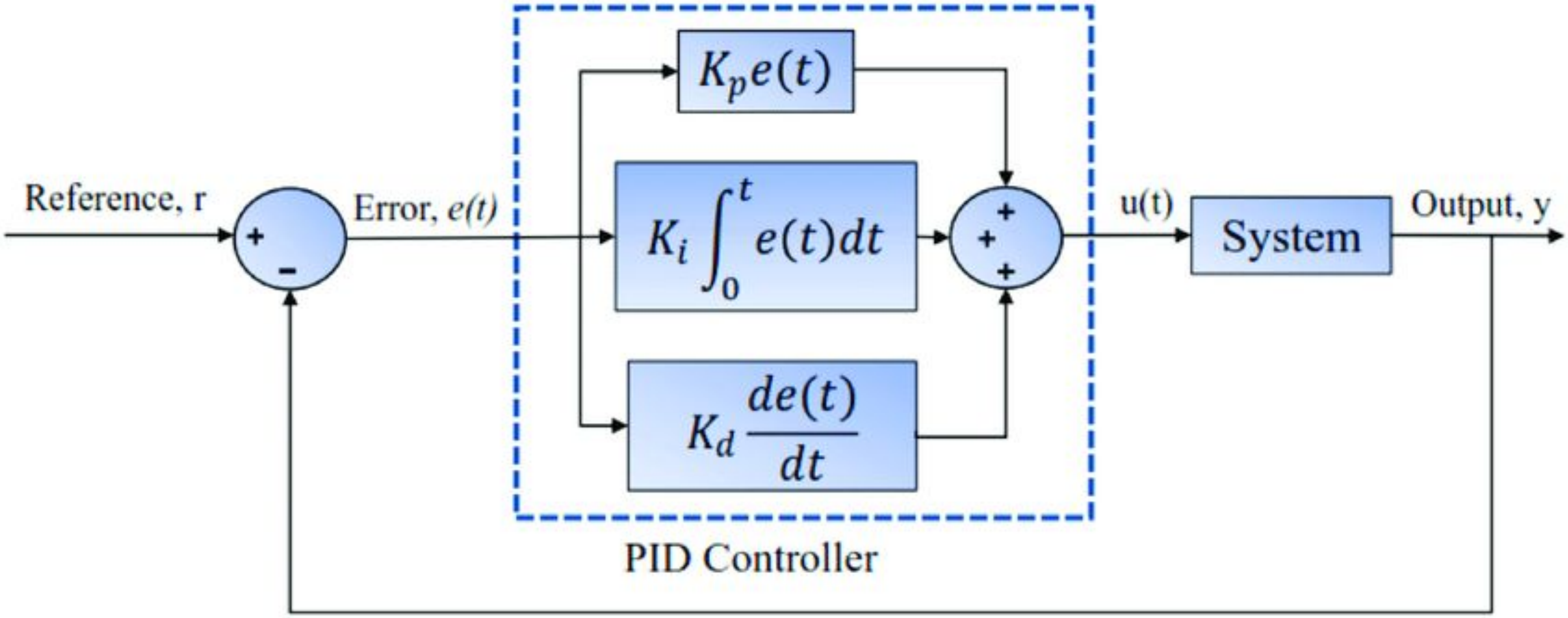


Merkel, Magnetic field stabilization system for atomic physics experiments, Oxford.
Tarlton, Probing qubit memory errors at the 10^{-5} level, Imperial College London
Fig: Feedforward (control), Wikipedia

Experimental Setup

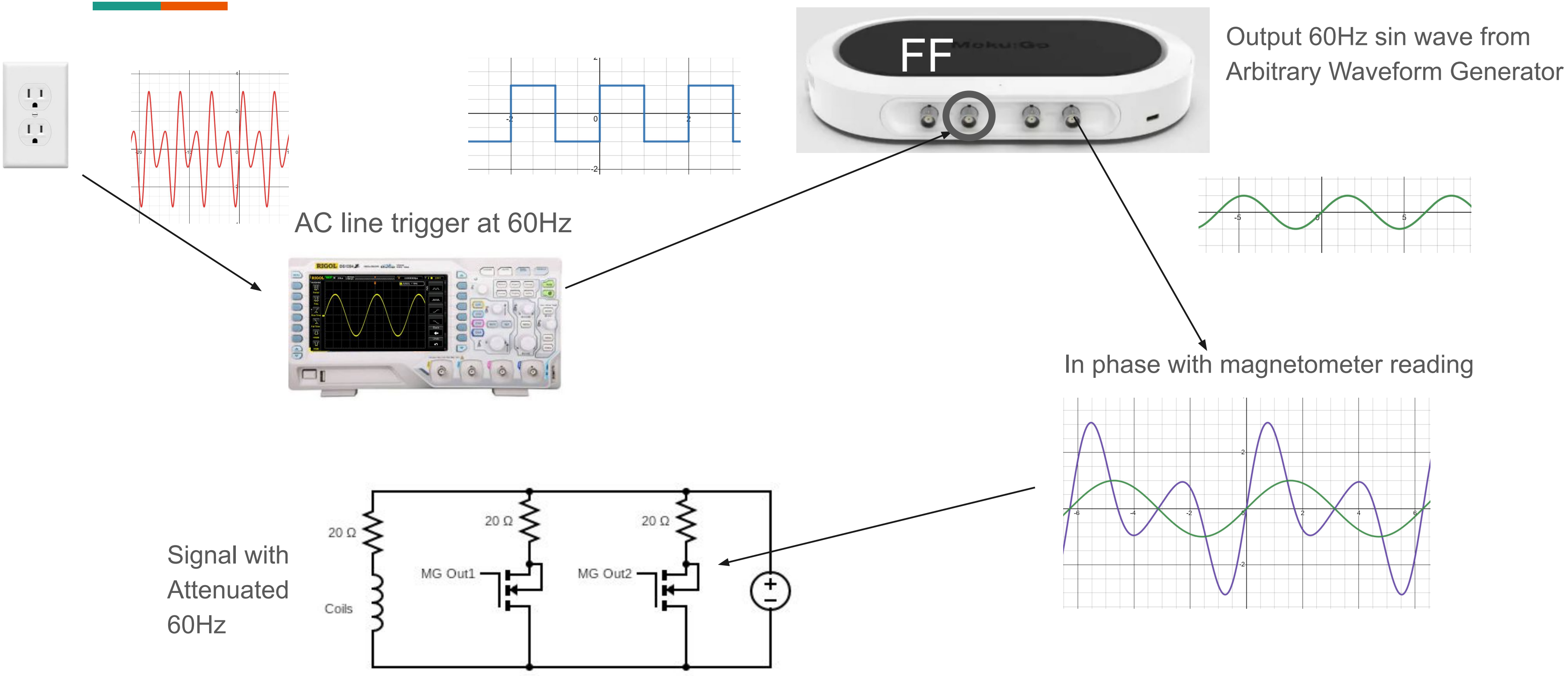


Proportional-Integral-Derivative (PID) Feedback:

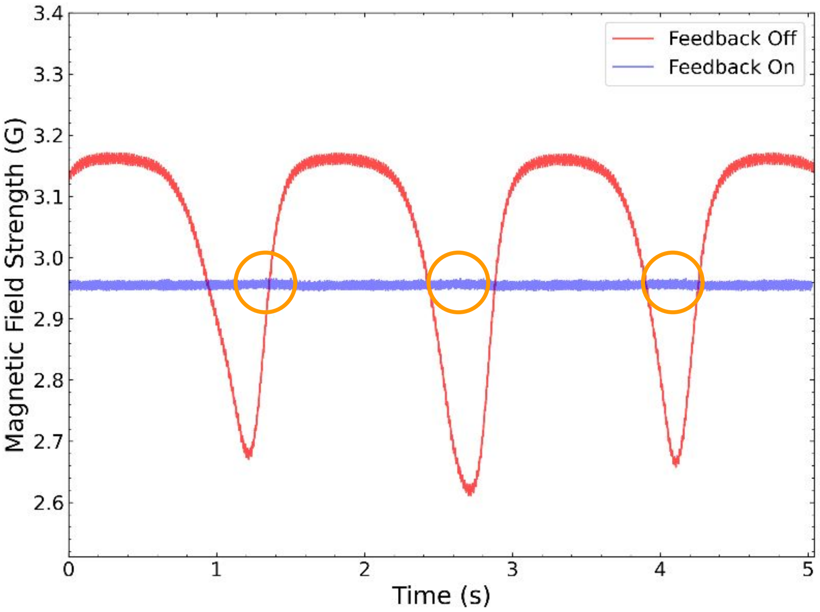


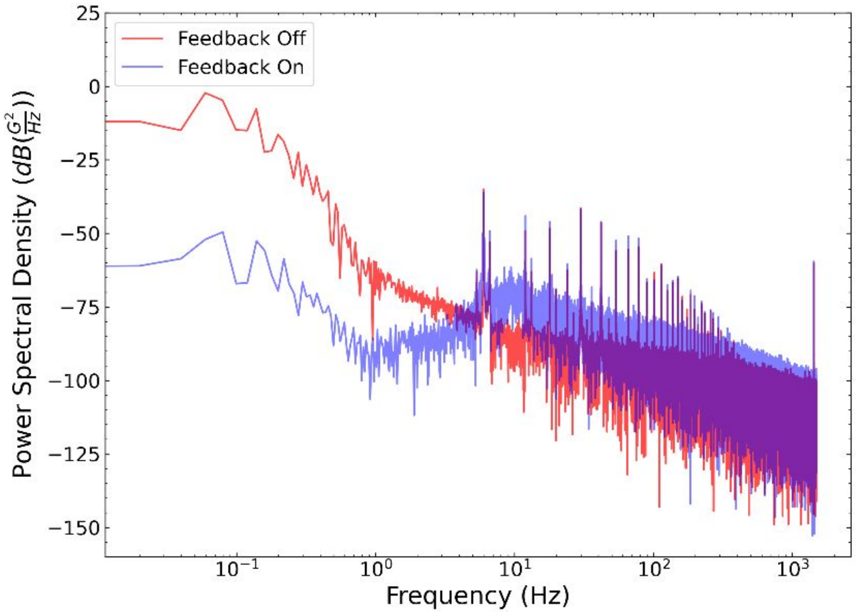
Sarkar, Hybrid Pitch Angle Controller Approaches for Stable Wind Turbine Power under Variable Wind Speed

Mains Electricity Feedforward



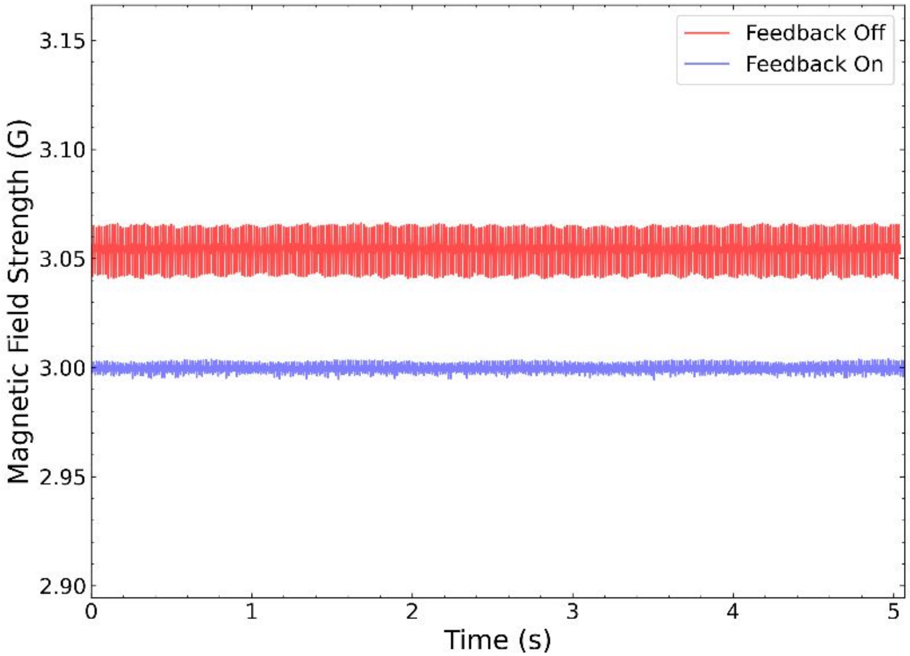
Magnetic Disturbance





Feedback off: 3.0427 ± 0.1623 G
Feedback on: 2.9553 ± 0.0037 G

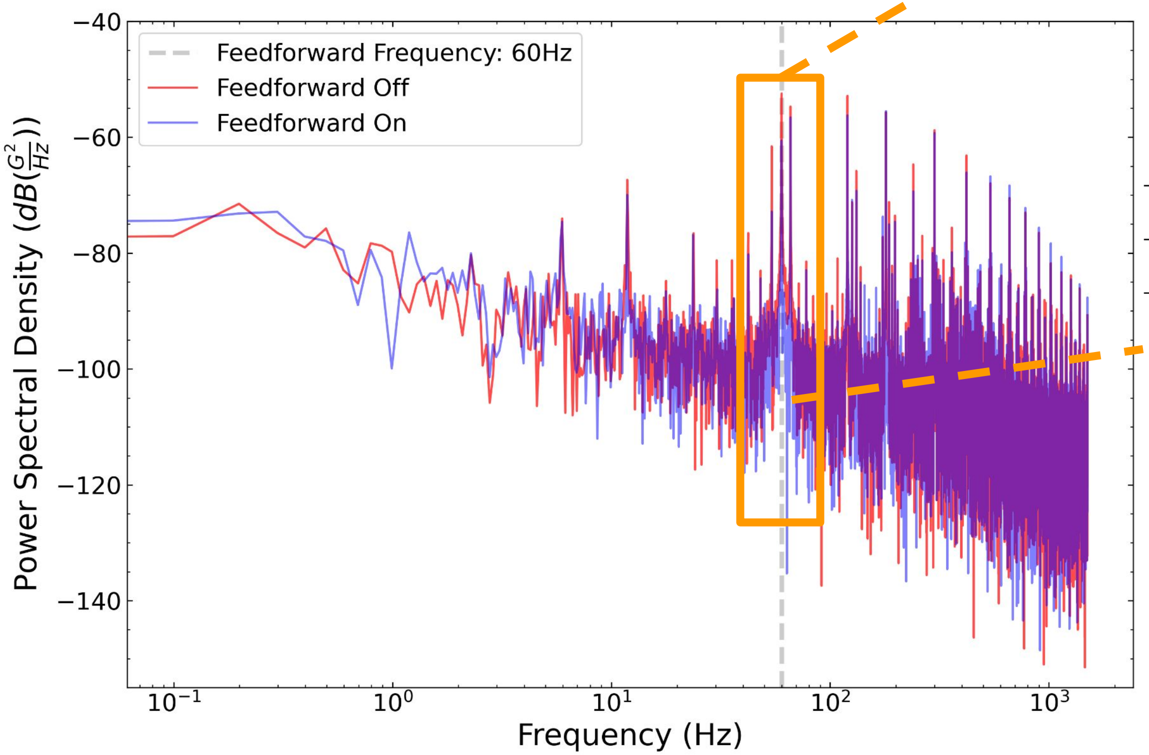
PID Feedback

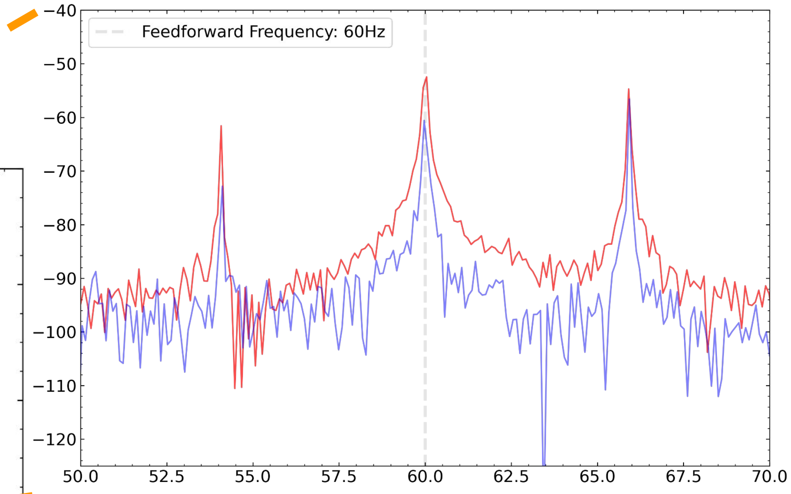


Feedback off: 3.0541 ± 0.0039 G
Feedback on: 2.9997 ± 0.0008 G

Area ratio (f < 300Hz): 163

Feedforward at 60Hz



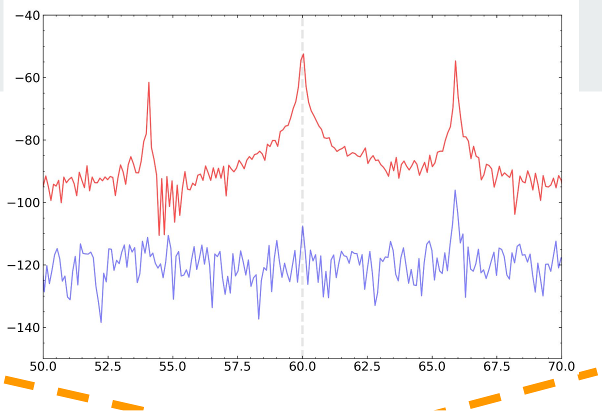


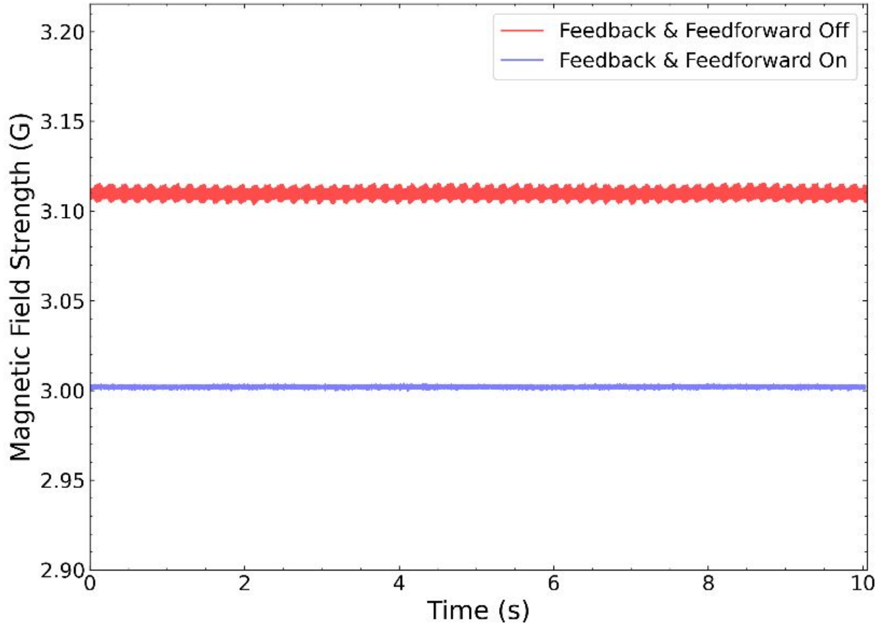
Feedforward On: ~8 dB attenuation at 60Hz

Feedback and Feedforward

Area ratio: 705 (f < 300 Hz) & 65 (f < 850 Hz)

Both off: 3.1107 ± 0.0017 G
Both on: 3.0020 ± 0.0004 G, ~35dB attenuation at 60Hz



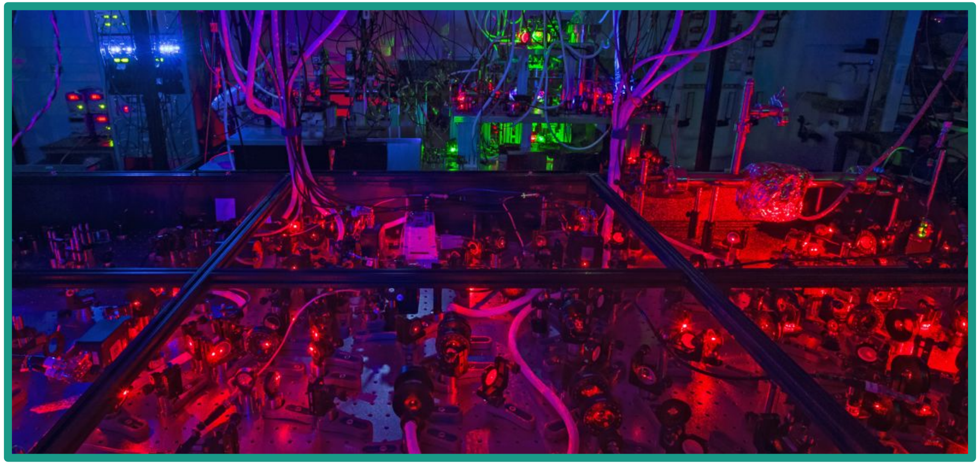


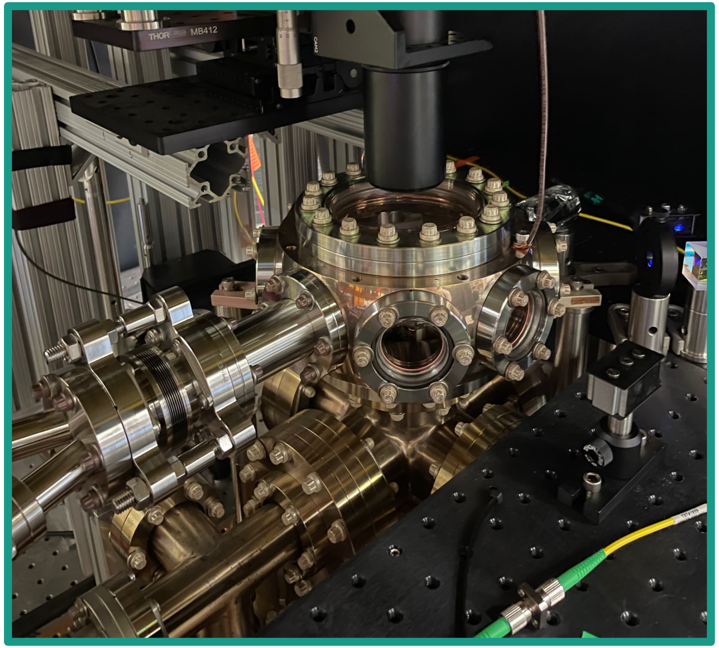
Conclusion:

	Dominant noise	Noise source
Both off	Slow drift + 60Hz Harmonics	Power supply + Ambient line noise
Feedback alone	60Hz Harmonics	Ambient line noise
Feedforward alone (60Hz)	Slow Drift	Power supply + Ambient line noise
Both on (60Hz)	60Hz Harmonics (120Hz or higher)	Ambient line noise

Future Plans

- Feedforward with superposition of 60Hz harmonics
- Print and optimize on PCB
- Implement on experiments





Acknowledgement

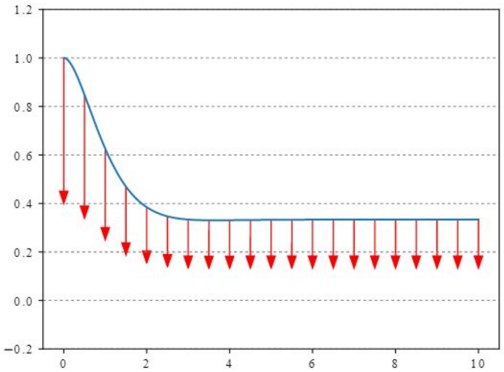


- Professor Jayich, Robert, Eric
- Chaoshen from Jayich Lab
- Peter, Quinn, Jeremy E. from Weld Lab

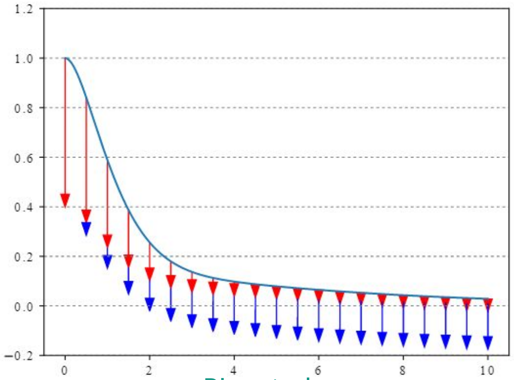



Questions?

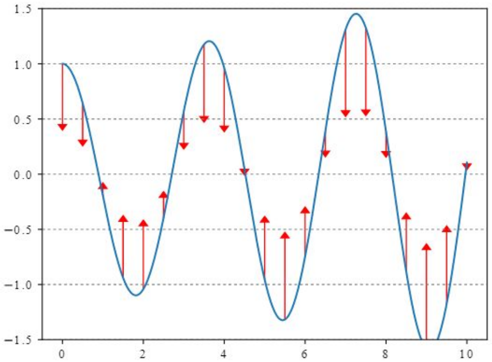
PID Feedback



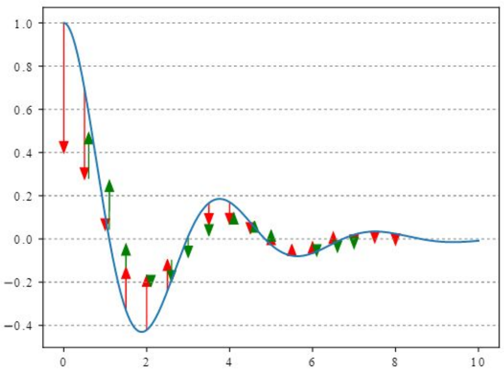
P control



PI control



P control



PD control

$$u = u_P + u_I + u_D$$

P Term - “spring”

$$u_P = -k_P(x - x_d)$$

I Term - counteract steady state errors

$$u_I = -k_I I(t)$$

$$I(t) = \int_0^t (x(t) - x_d(t))dx$$

D Term - damping effect

$$u_D = -k_D(\dot{x} - \dot{x}_d)$$

Stability in Linear Time Invariant Systems, Illinois

Power Spectral Density Derivation

$E = \int_{-\infty}^{\infty} \frac{|V(t)|^2}{R}\, dt = \int_{-\infty}^{\infty} |V(t)|^2\, dt$, with the convention R = 1

$P = \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} |V(t)|^2\, dt = \lim_{T\to\infty} \frac{1}{T} \int_{-\infty}^{\infty} |V(f)|^2\, df$

for discrete time Fourier Transform:

$|V(f)|^2 = lim_{N\to\infty} \left| \sum_{n=-N}^{N} V(n\Delta t) e^{-ifn\Delta t} \Delta t \right|^2$

$P = \int_{-\infty}^{\infty} \frac{1}{T} \lim_{N\to\infty} \left| \sum_{n=-N}^{N} V(n\Delta t) e^{-ifn\Delta t} \Delta t \right|^2 df = \int_{-\infty}^{\infty} P_f(f) \dot{d}f,$

where $P_f(f)$: Power spectral density in $\frac{V^2}{Hz}$

$P_f(f) = \frac{1}{T} \lim_{N\to\infty} \left| \sum_{n=-N}^{N} V(n\Delta t) e^{-ifn\Delta t} \Delta t \right|^2$

Scipy.signal.periodogram(data, sampling frequency, scaling='density')

Spectral Density, Wikipedia

Bartington-03 Fluxgate Magnetometer

Data Sheet:

- Noise levels down to <6pTrms/√Hz at 1Hz
- Measuring ranges from ±70μT to ±1000μT
- Bandwidth 3kHz