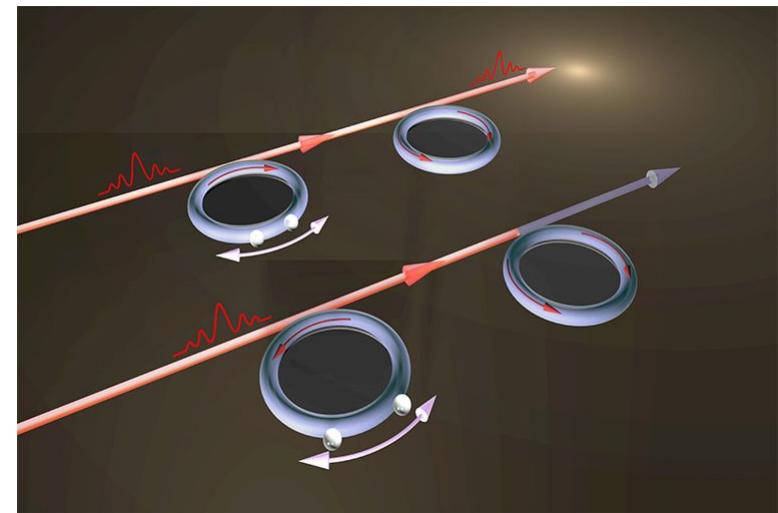
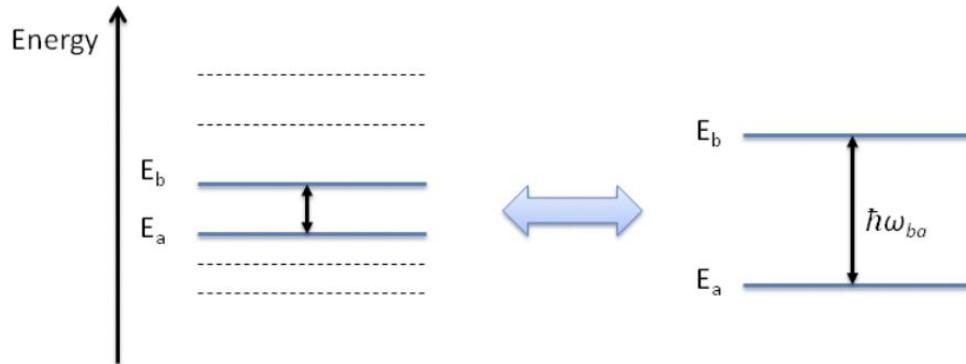


PDH laser locking

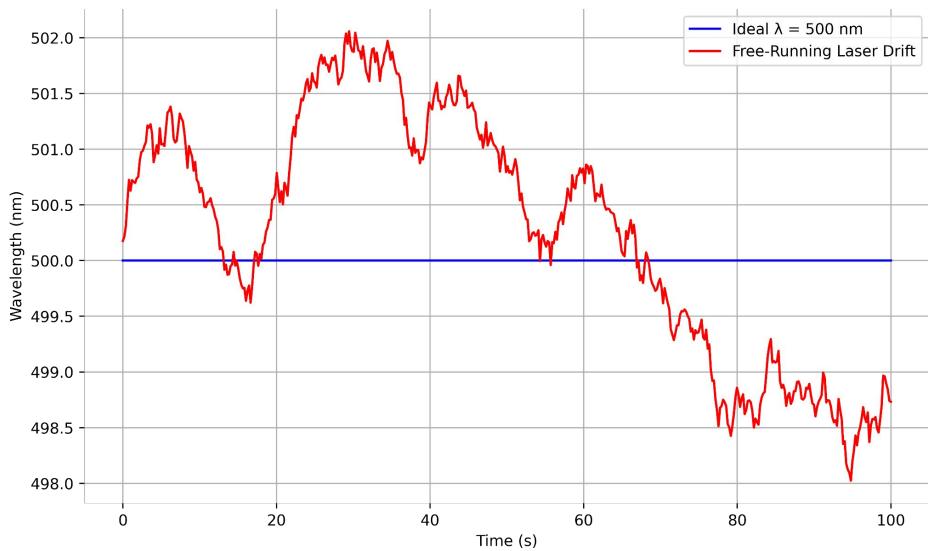
- Motivation
- Feedback Control (PID)
- Obtaining an Error Signal (PDH)
- Locking results

Motivation

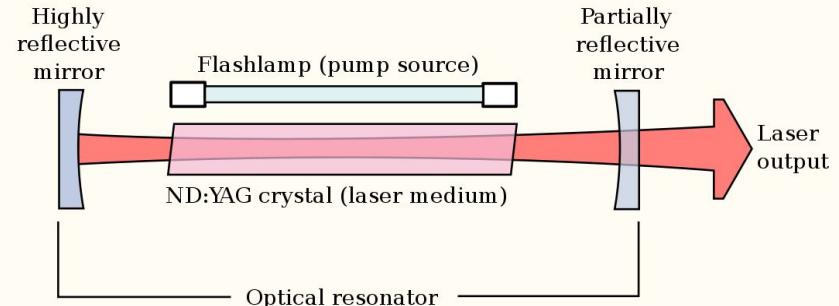
- Any sensitive system that requires an exact band gap to have some transitions benefits from this technique



Laser Drift



Nd:YAG solid-state laser



Laser diode current noise

Air pressure & humidity

Acoustics & vibrations

Environment temperature

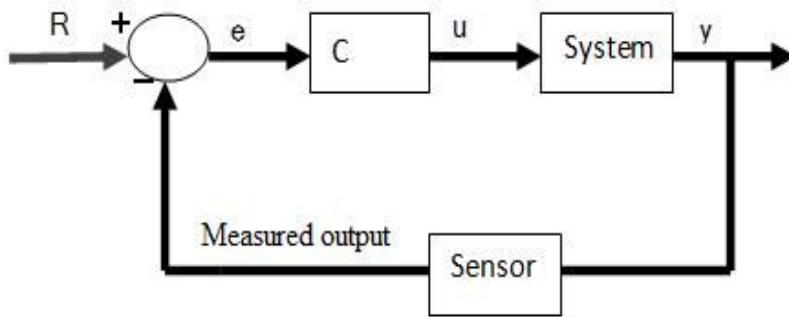
Temperature control

Piezo drifts

1 μ 10 μ 100 μ 1m 10m 100m 1 10 100 1k 10k 100k

Time scale [s]

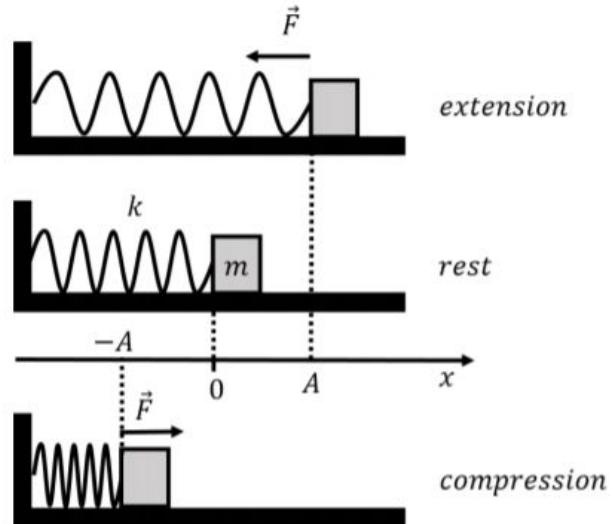
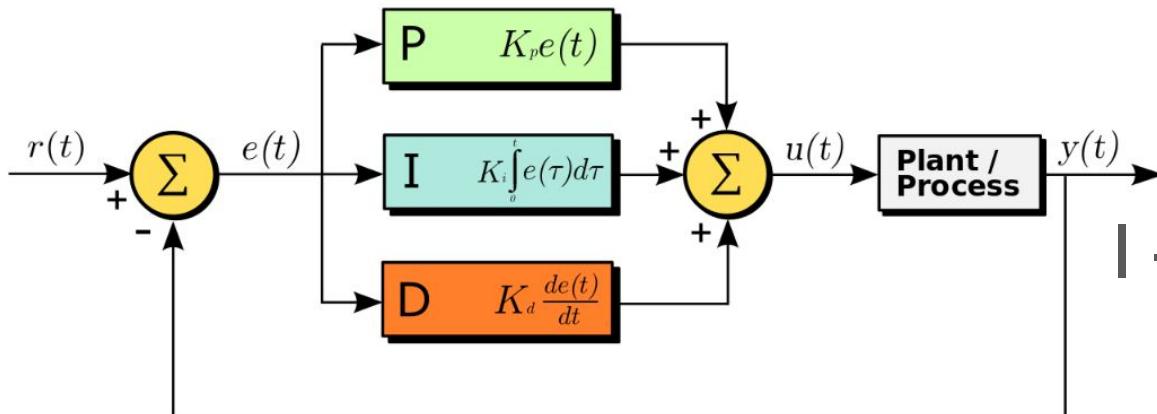
Feedback Control



- Feedback = Adjust output based on input
- Control = maintains the output at a constant
- **Input should be antisymmetric around the constant you want to maintain**

PID:Proportional-integral-derivative

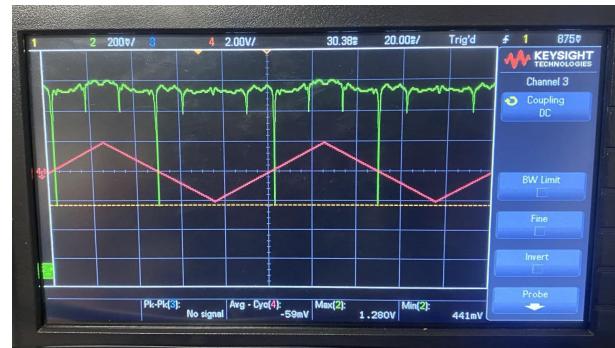
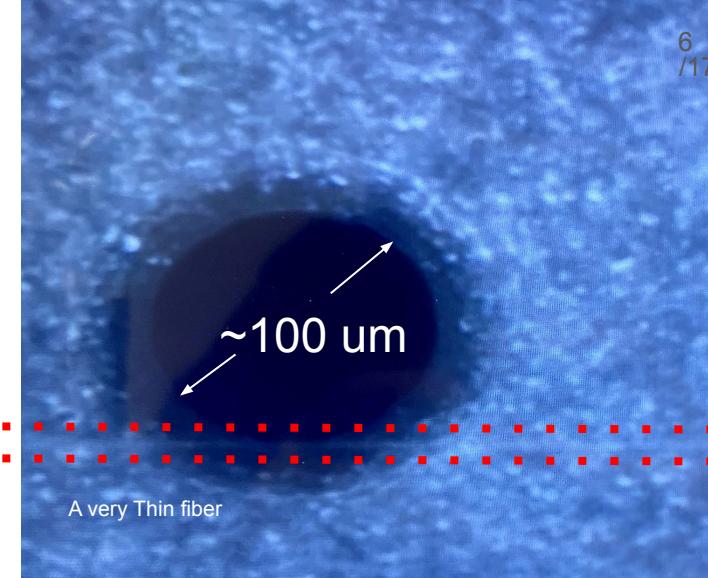
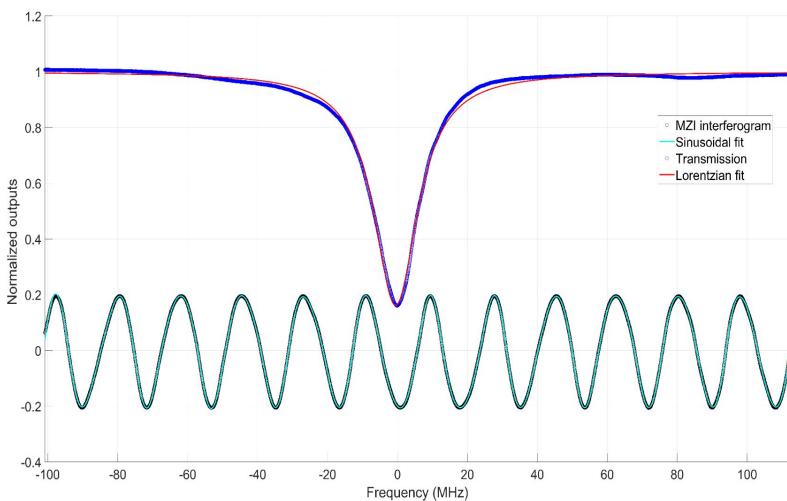
Damped harmonic oscillator



P - Spring
 I - counter steady state errors (inertia)
 D - Damping

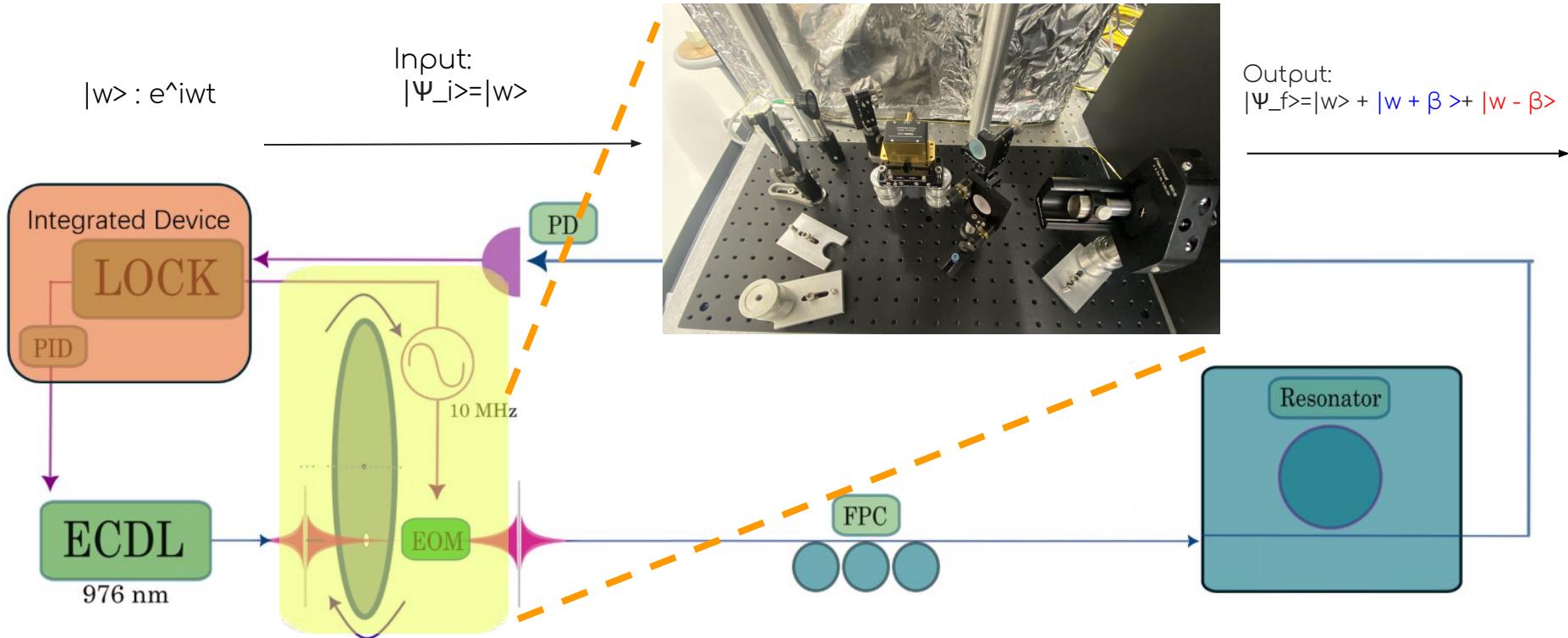
Transmission From Ring Resonator

Ringing the Resonator
Resulting Transmission
Not a good Error Signal...



Are we able to construct
an antisymmetric signal
around the resonance?

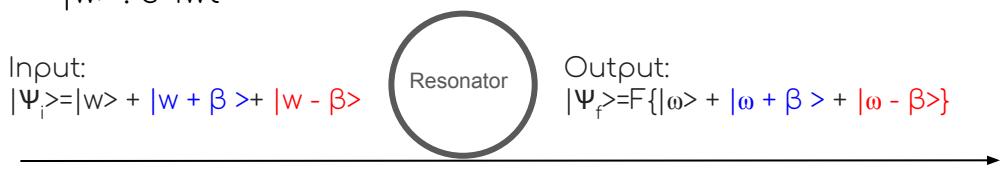
PDH: Pound Drever Hall



PDH: Pound Drever Hall

Interference among the sidebands!

$$|\omega\rangle : e^{i\omega t}$$



PD

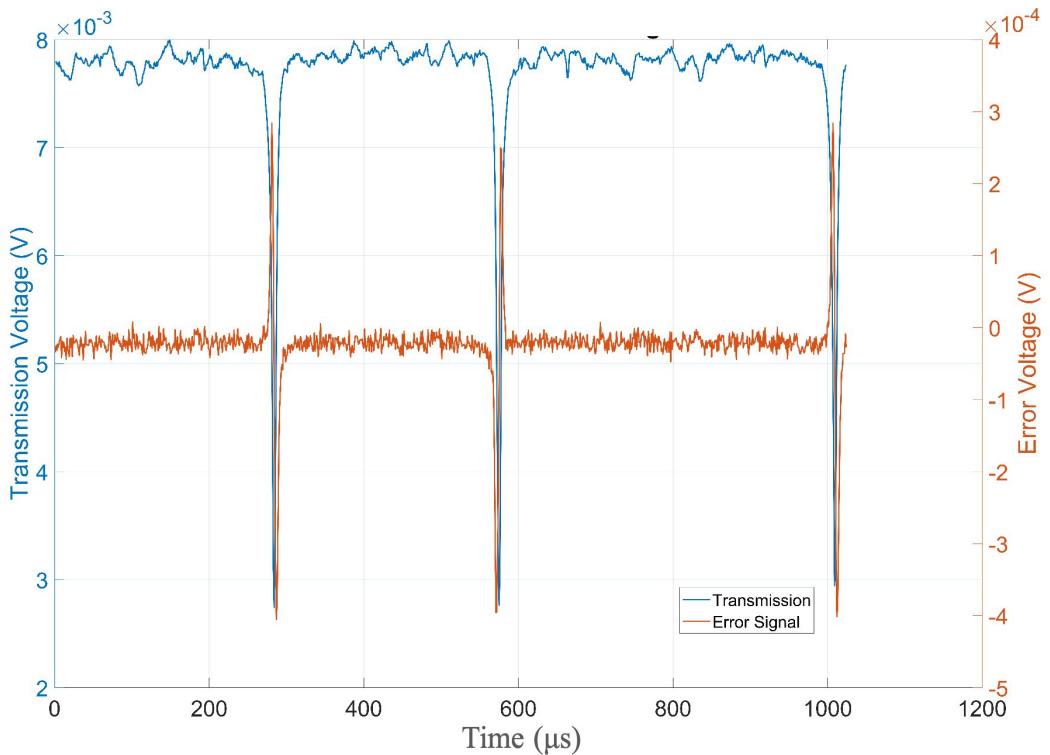
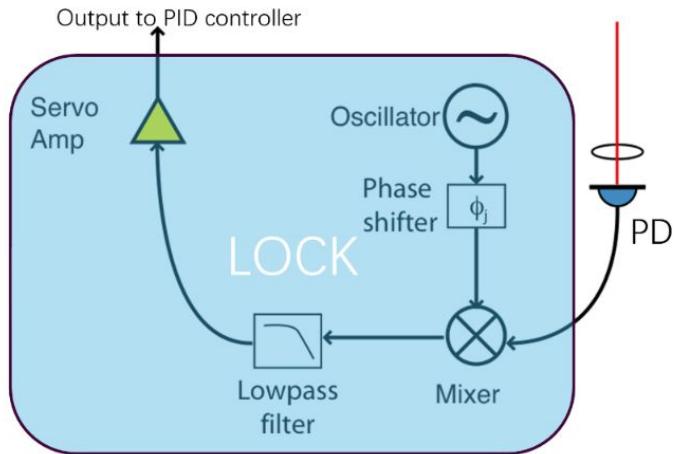
$$\mathbf{I}(t) = |\Psi_f(t)|^2 = \Psi_f(t) \cdot \Psi_f^*(t)$$

$$\begin{aligned}
 P_{\text{out}} &= |\hat{F}|\text{input}\rangle|^2 \\
 &= P_c|F(\omega)|^2 + P_s \{ |F(\omega + \beta)|^2 + |F(\omega - \beta)|^2 \} + \\
 &2\sqrt{P_c P_s} \operatorname{Re} \left\{ \left[F(\omega)F^*(\omega + \beta) - F^*(\omega)F(\omega - \beta) \right] \right\} \cos \beta t + \\
 &\operatorname{Im} \left\{ \left[F(\omega)F^*(\omega + \beta) - F^*(\omega)F(\omega - \beta) \right] \right\} \sin \beta t + \\
 &(2\beta \text{ terms})
 \end{aligned}$$

	ω	$\omega + \beta$	$\omega - \beta$
ω	0	β	$-\beta$
$\omega + \beta$	$-\beta$	0	-2β
$\omega - \beta$	β	2β	0

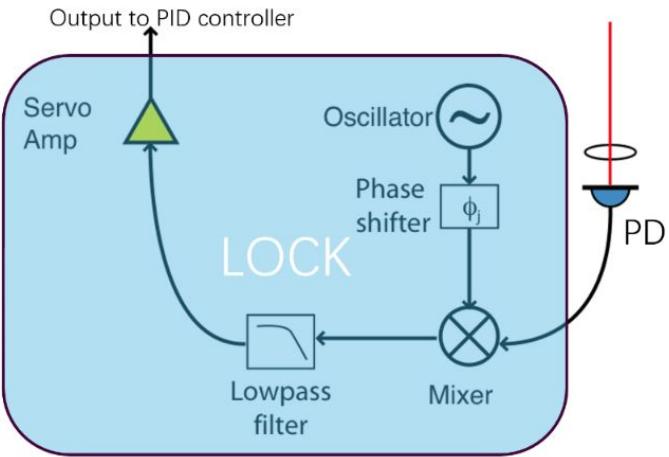
$$\langle \omega | \omega + \beta \rangle = e^{\{i\omega + \beta t\}^*} e^{\{-i\omega t\}} = e^{i\beta t}$$

Error Signal



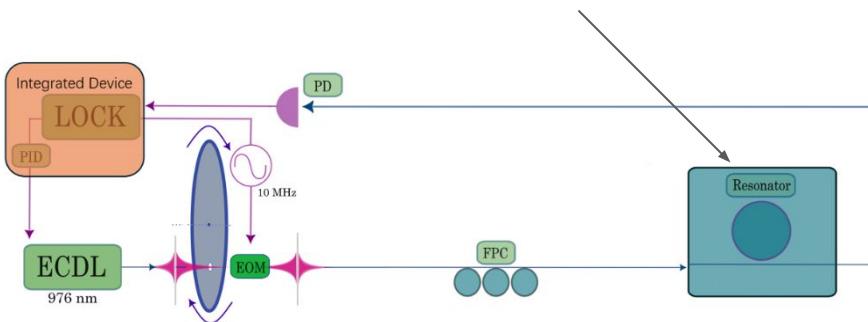
What happens after photodiode.

$$\begin{aligned}
 P_{\text{out}} &= |\hat{F}|\text{input}\rangle|^2 \\
 &= P_c|F(\omega)|^2 + P_s\{|F(\omega + \Omega)|^2 + |F(\omega - \Omega)|^2\} + \\
 &2\sqrt{P_c P_s} \operatorname{Re} \left\{ \left[F(\omega)F^*(\omega + \Omega) - F^*(\omega)F(\omega - \Omega) \right] \right\} \cos \Omega t + \\
 &\operatorname{Im} \left\{ \left[F(\omega)F^*(\omega + \Omega) - F^*(\omega)F(\omega - \Omega) \right] \right\} \sin \Omega t + \\
 &(2\Omega \text{ terms}).
 \end{aligned}
 \tag{5}$$



Intensity of light is proportional to E^2
This is taking the inner product

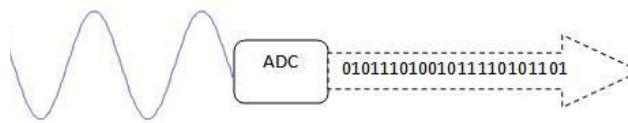
Taking the inner product of our signal we obtain 9 terms where 3 are DC and 6 are changing in frequency
Applying a low pass filter are left with error signal oscillating at our modulation frequency from our EOM



	ω	$\omega + \beta$	$\omega - \beta$
ω	0	β	$-\beta$
$\omega + \beta$	$-\beta$	0	-2β
$\omega - \beta$	β	2β	0

With all these information given,
here is our experiment result

Implement PID



Main Clock

[View on GitHub](#)

13CL_Lock_Box_Project Public

1st main · 1st 1 Branch 0 Tags

Go to file Add file Code About

WyndHy uicnrd · last commit 2 weeks ago 29 Commits

Laser Lock Box based on TEENSY 4.1

- DAC code · first commit
- Data_Sheet · first commit
- Miscellaneous · Rename Screenshot 2024-05-07 225112.png to sc · last month
- polcadST91 · first commit
- RSD4ME.mel · uicnrd · 2 weeks ago
- laser_locking_v1.ino · uicnrd · 2 weeks ago
- untitled2.m · first commit · last month

No releases published Create a new release

Packages · No packages published Build your first package

Languages · C 80.9% C++ 38.2% MATLAB 0.7%

Suggested workflows · Based on your tech stack

- SLSA Generic generator · Configure · Generates SLSA provenance for your software source codefiles
- CMake based, multi-platform projects · Configure · Build and test a CMake based project on multiple platforms
- CMake based, single-platform projects · Configure · Build and test a CMake based project on a single platform

More workflows · Dismiss suggestions

Laser Lock Box Project

Software and documentation developed by Alexander Nazeen & Zhaohong Cao (alexanderazeen@ucsb.edu, zhaohongcao@umrtr.ucsbd.edu)

Hardware made by Hongrui Yan (hongrui.yan@ucsb.edu)

This repository contains all the software that is needed to operate the laser lock box based on TEENSY 4.1. In this document a complete overview is given of how to use the software and how the backend software is structured.

NOTE: This setup involves a CW laser operating at 976nm. Though working at invisible band, please still be careful with your eyes!

This code is developed in Arduino IDE and in the language of C++. The code is summarized into three parts: 1) Use ADC to read the error signal, 2) Apply PID to the error signal, 3) Use DAC to output the control signal

How to setup the software

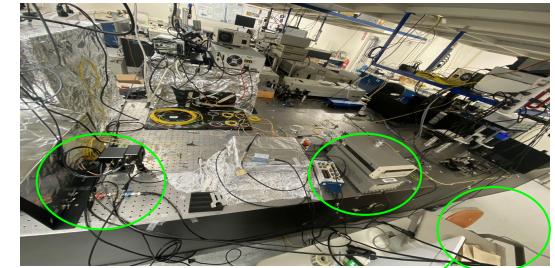
One has to realize that this software is not a complete, one click compiled program. I recommend to run and compile on the TEENSYduino, Version 1.59. This is an add-on to the Arduino IDE and the detailed installation can be found at https://www.pjrc.com/teensy/tz_download.html

- Step 1: clone repo
- Step 2: setup the environment
- Step 3: run program

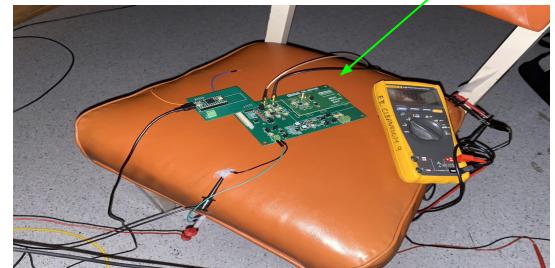


Laser Piezo

CPU Timer 1: Scanning

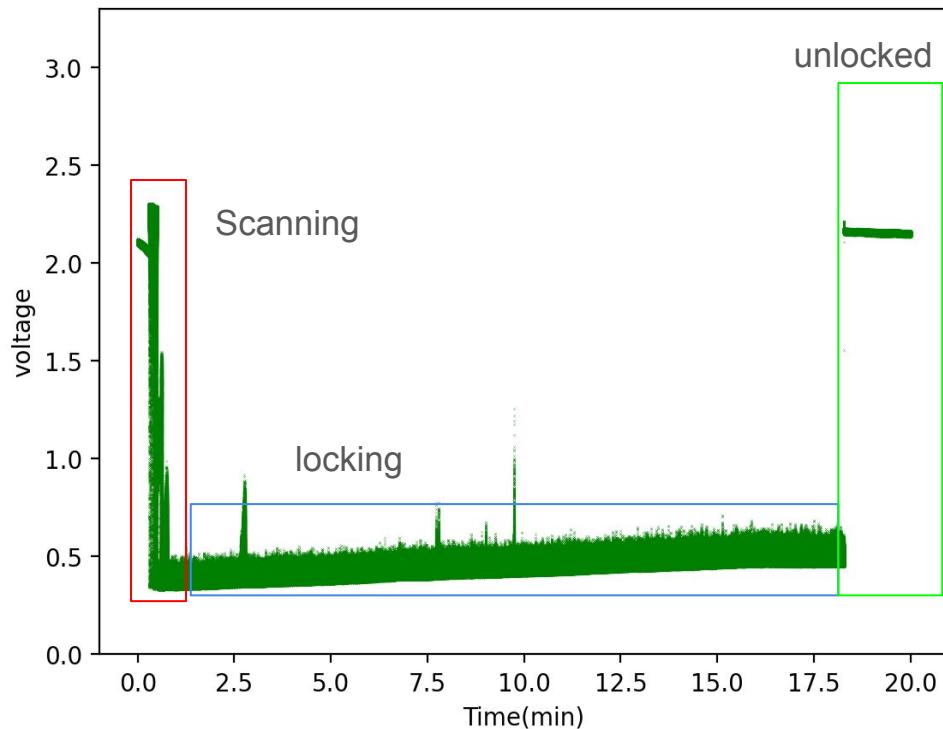


CPU Timer 2: PID

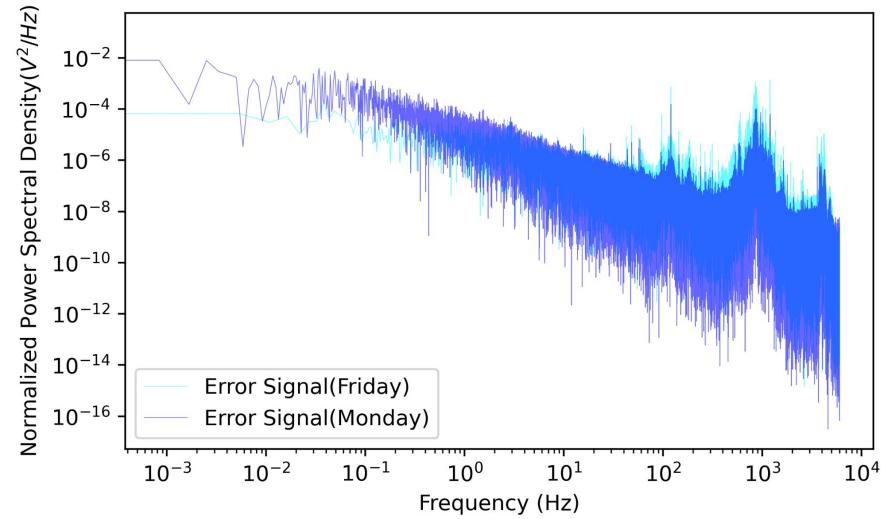
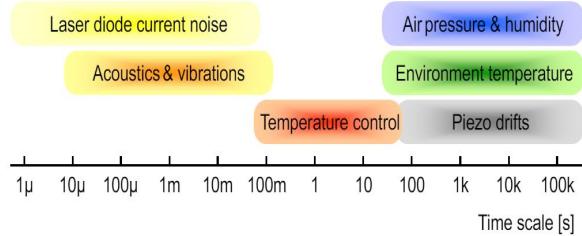
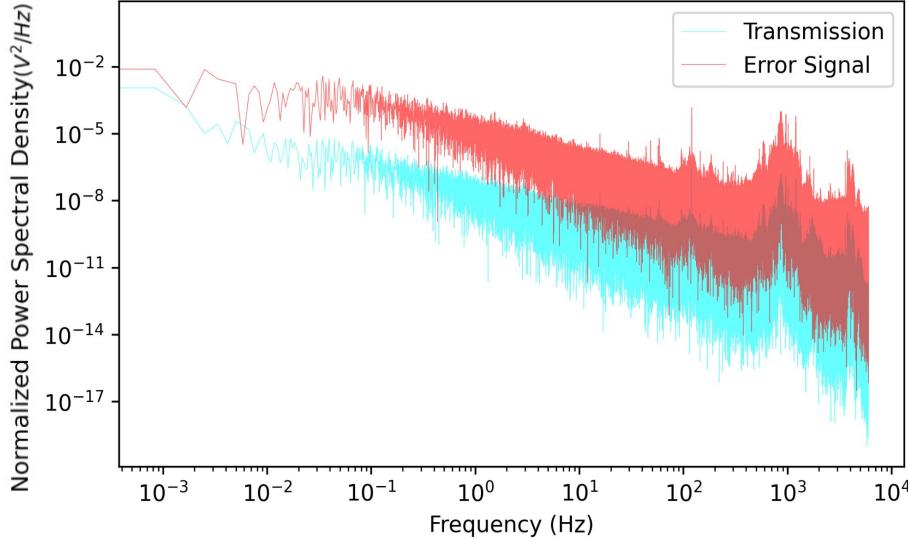


CPU Timer 3:
Read Instruction Set from
the User

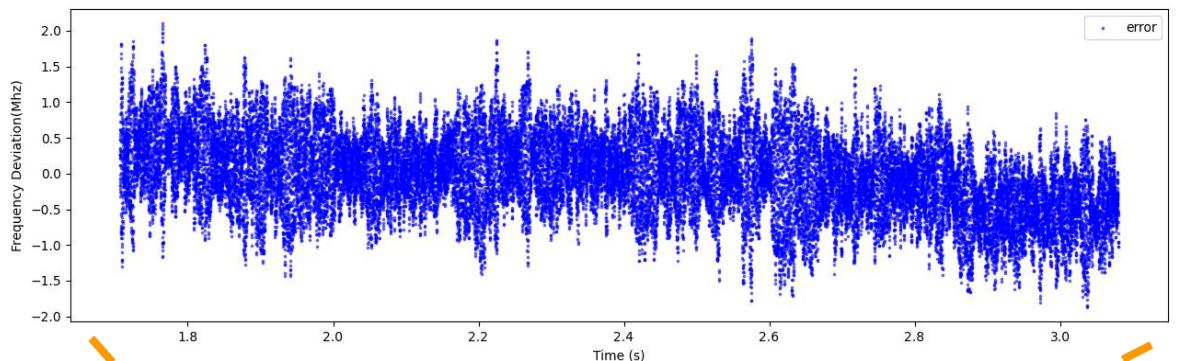
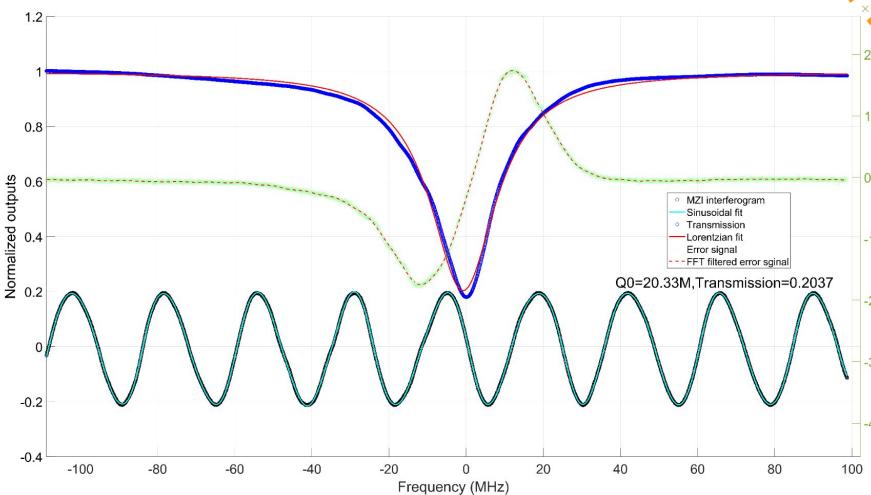
Time Domain Measurement



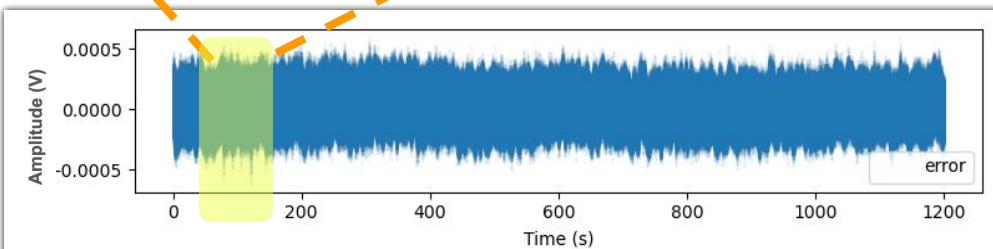
Power Spectrum Density



Quantify Frequency Deviation



$$f_0 \pm 2.822125\text{Mhz}$$



Future work

1. Isolate the setup in vacuum chamber
2. Auto Tuning PID
3. GUI interface that is more user friendly

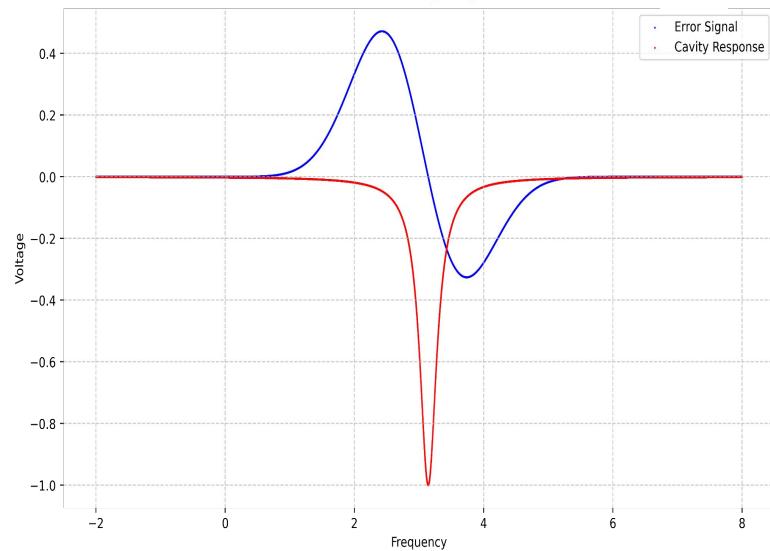
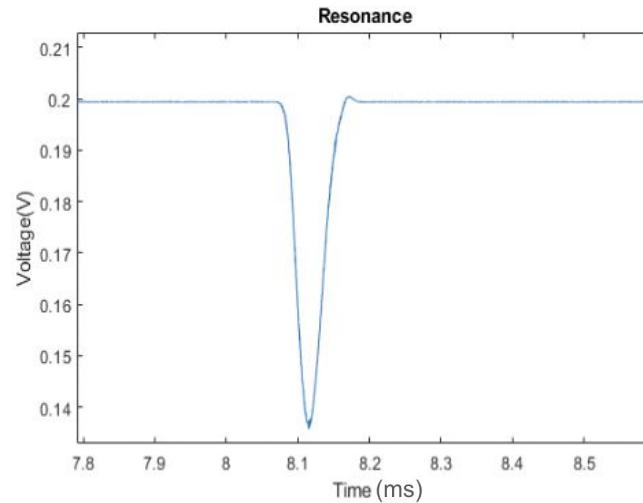
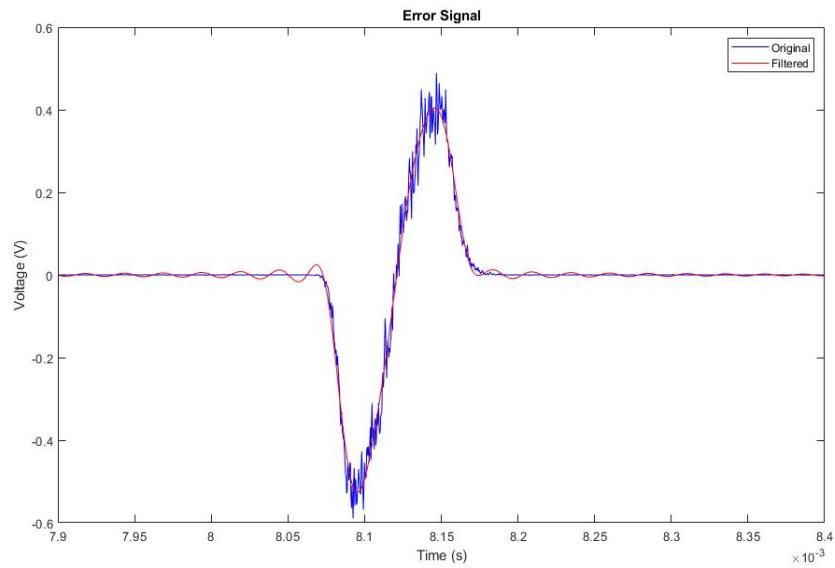
Reference

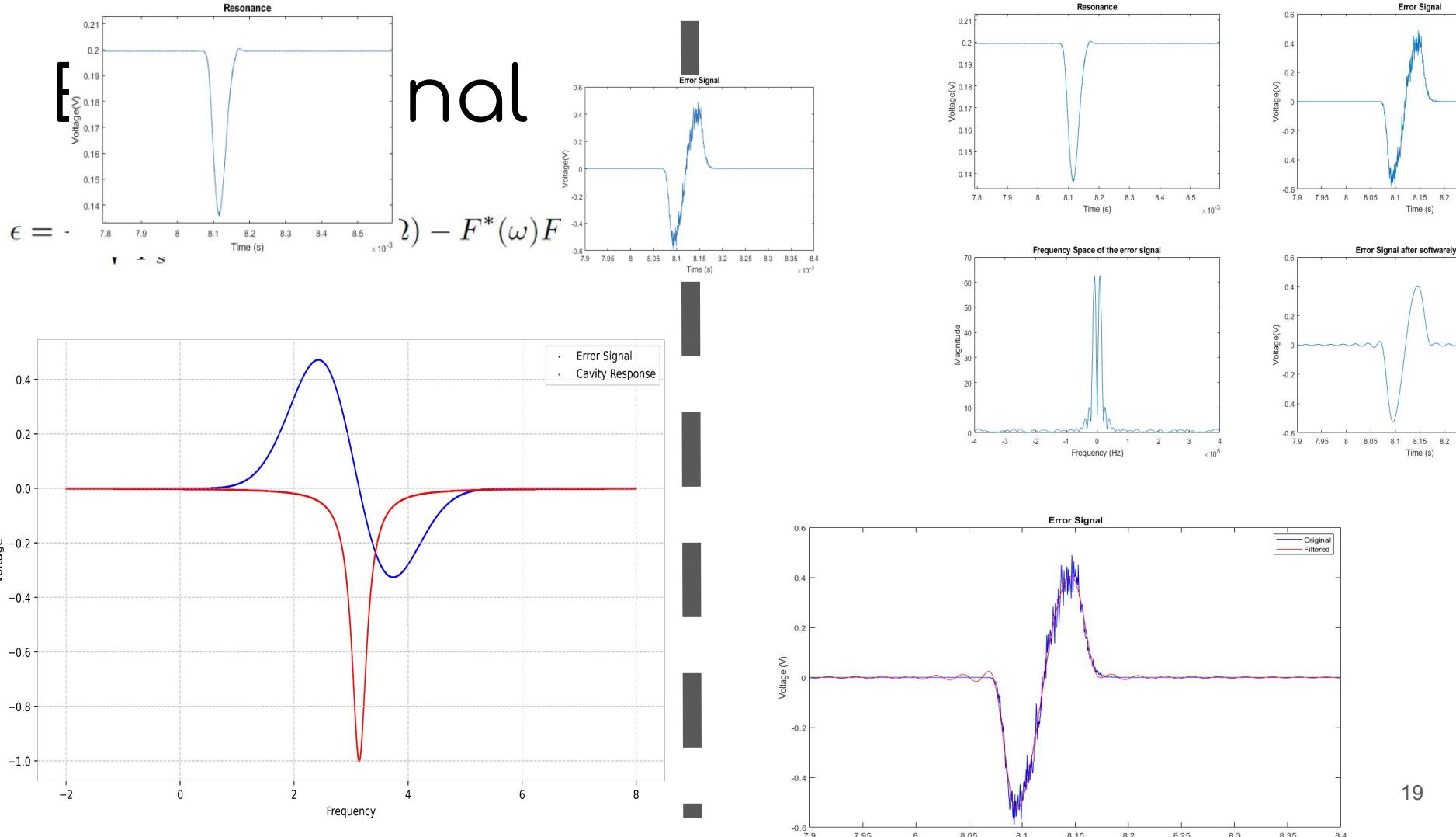
Black, Eric D. "An introduction to Pound–Drever–Hall laser frequency stabilization." *American journal of physics* 69.1 (2001): 79-87.

https://www.toptica.com/fileadmin/Editors_English/12_literature/05_HighFinesse/toptica_Diode_Laser_Locking_and_Linewidth_Narrowing.pdf

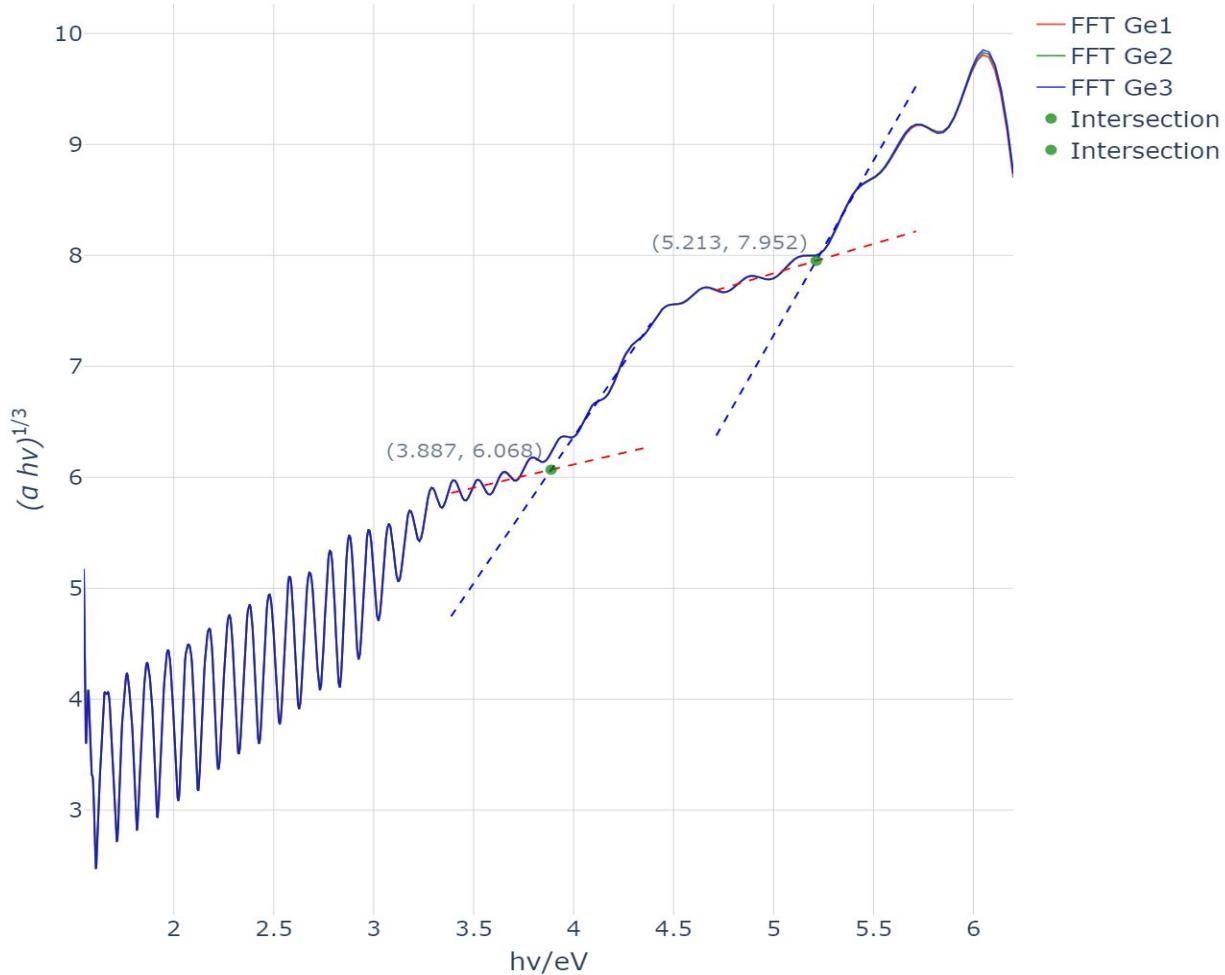
Error Signal

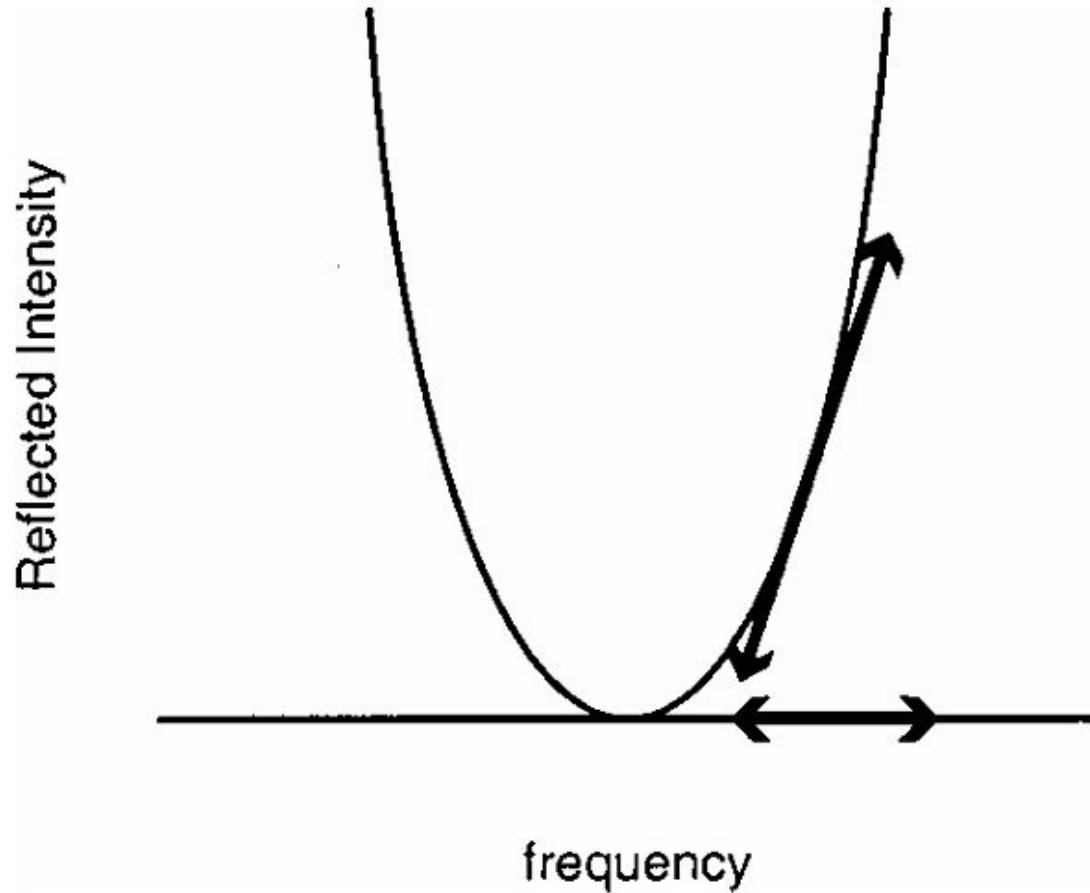
$$\epsilon = -2\sqrt{\frac{P_c}{P_s}} \Im \{ F(\omega)F^*(\omega + \Omega) - F^*(\omega)F(\omega - \Omega) \}$$





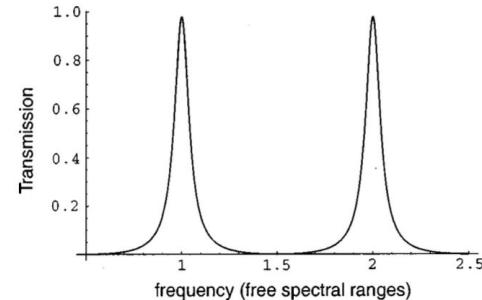
Indirect (Forbidden) Bandgap





PDH motivations

- Need an accurate way to measure the laser's frequency
 - Send to cavity, check transmitted (or reflected)
 - fsr: free spectral range of cavity $\Delta\nu_{\text{fsr}} \equiv c/2L$
- Cannot distinguish between fluctuations in the frequency (that affects transmitted intensity) and fluctuations in the intensity of the laser itself
- Measure reflected intensity (and hold that at zero) to decouple intensity and frequency noise

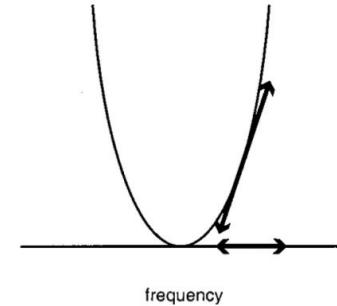


Error signal



- ?: Reflected intensity is symmetric about resonance
- The derivative of it is antisymmetric about resonance
- Measure the error signal of the derivative by varying the frequency
 - Above resonance: sinusoidal - sinusoidal
 - Below resonance: sinusoidal - 180 degrees out of phase
 - At resonance: no change in the reflected intensity

Reflected Intensity



How to measure the error signal?

- The reflected beam is sent into a (ms) **photodetector**
- The product of the **output of the photodetector** and the **local oscillator's signal** is generated via a mixer (which will contain signals with **low frequency** and **twice the modulation frequency**)
- The low frequency error signal is isolated from the combined output by the **low-pass filter**

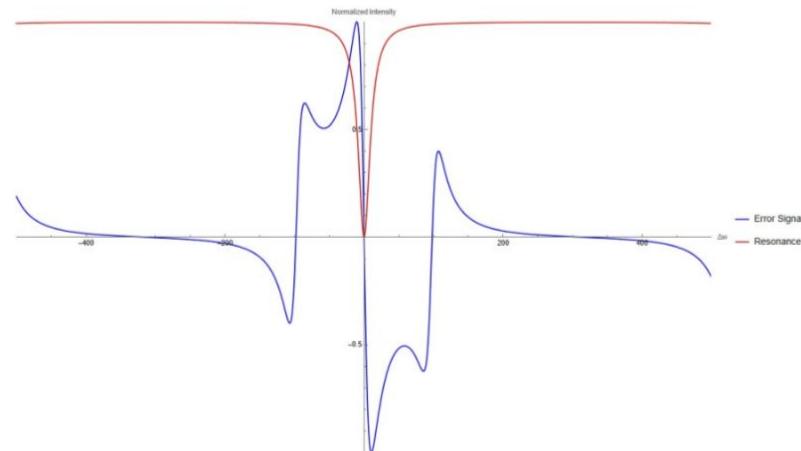
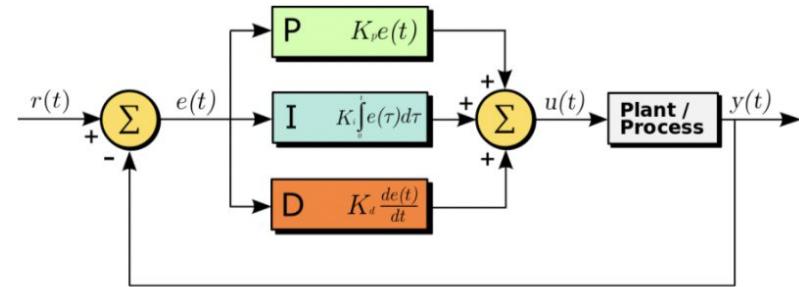


Figure 7: Calculated normalized resonance transmission signal and imaginary part of the error signal as a function of the deviation from the resonance frequency δw [1]. This should be experimentally observed on the oscilloscope.

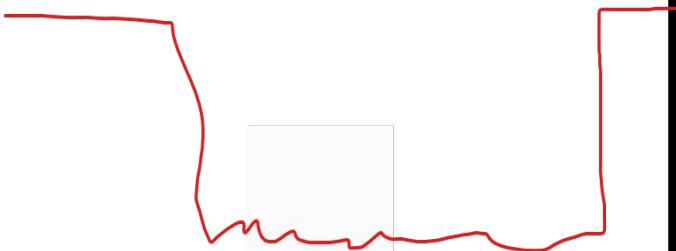
PID

- Proportional-Integral-Derivative algorithm
- $u(t)$ (controlled input): **voltage** to the piezo in the laser cavity
- $e(t)$: error between the measured output and the desired output
- P, I, D account for
 - P: magnitude
 - I: magnitude and time (reduce the error during a period of time)
 - D: Predicting future behavior using derivative (reduce the magnitude of overshoot)



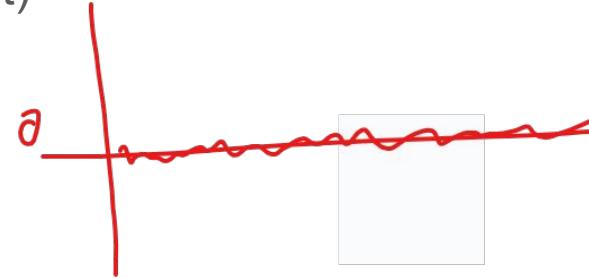
Result

Long term Trans
 $\psi(t)$

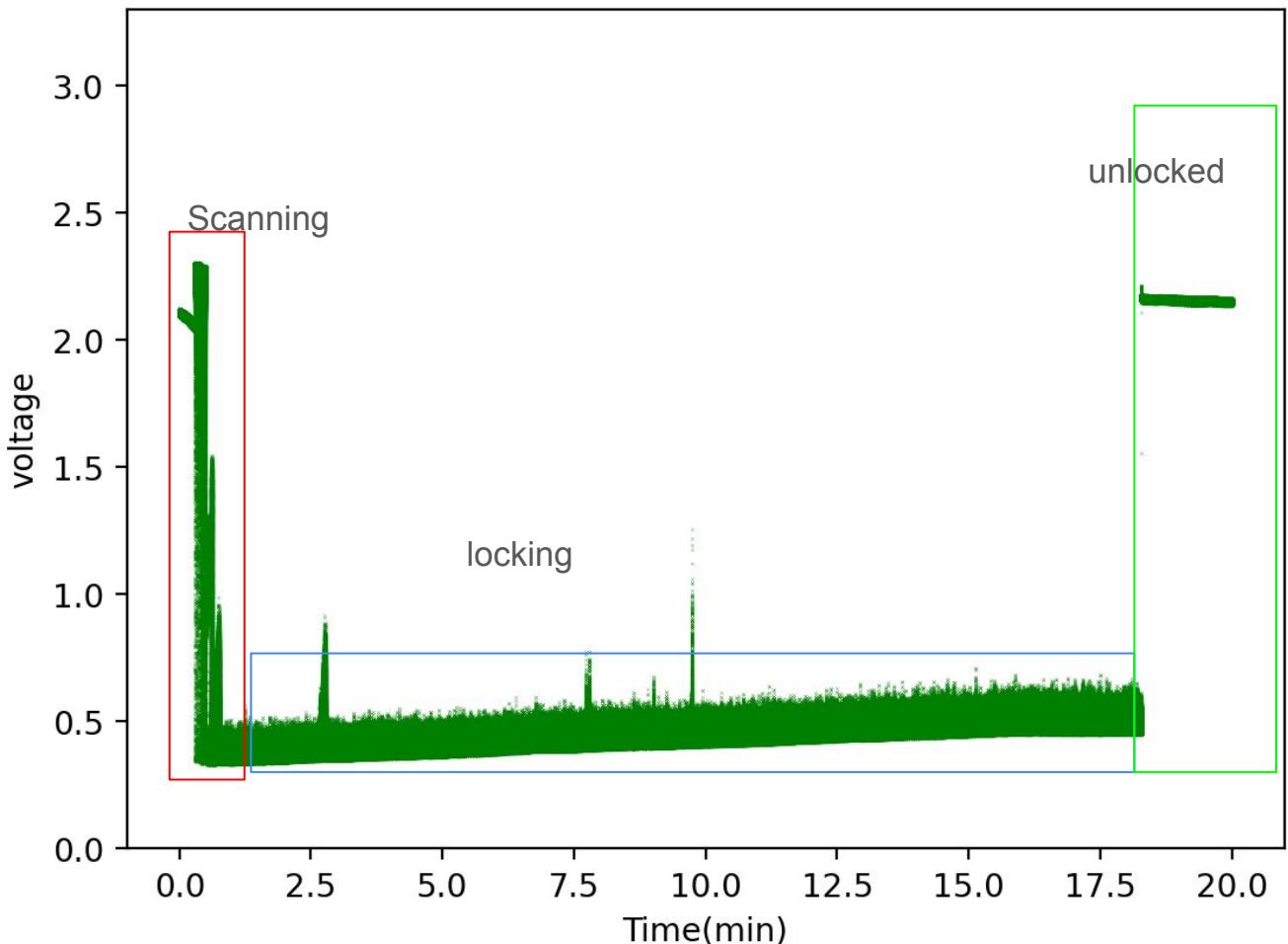


Long term Trans
 $\phi(f)$

Long term error
 $\psi(t)$



Long term error
 $\phi(f)$



Scanning

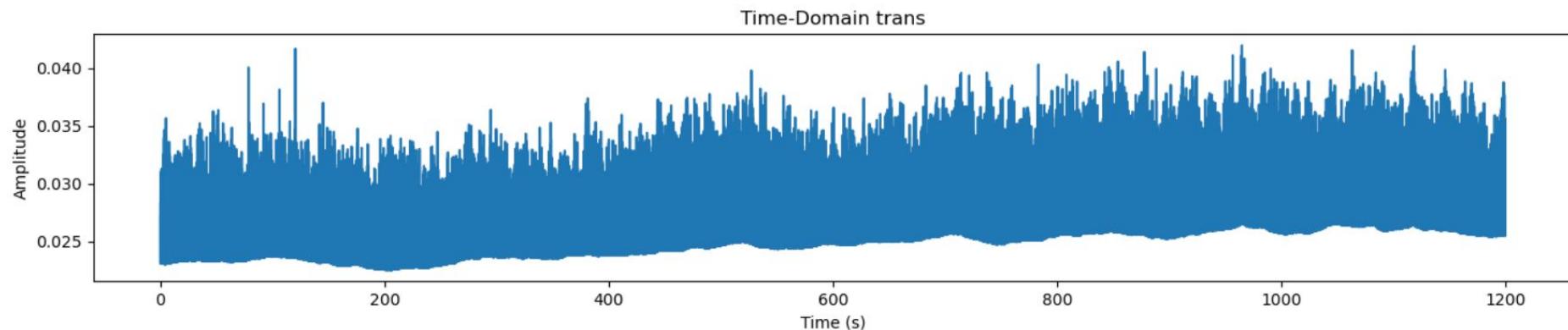
Locking

Unlocked

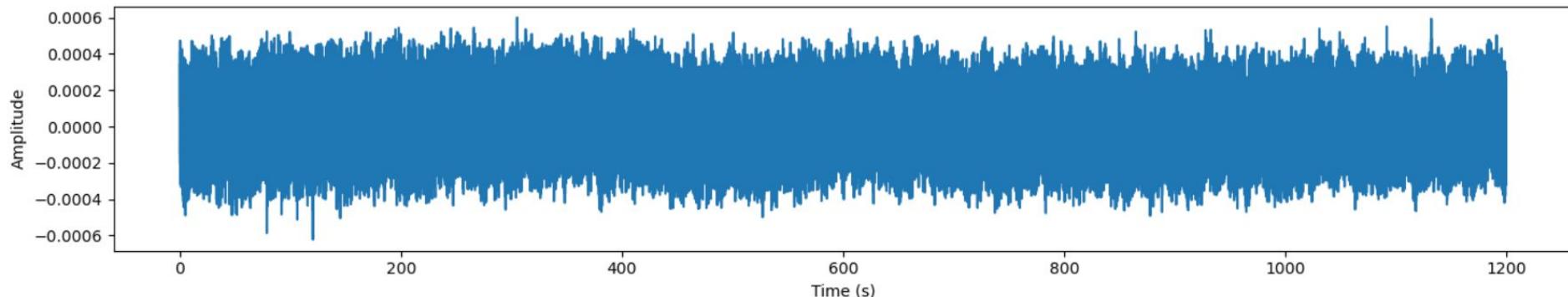
The reason it gradually lifts up is the change in polarization as time proceeds. This change the peak transmission

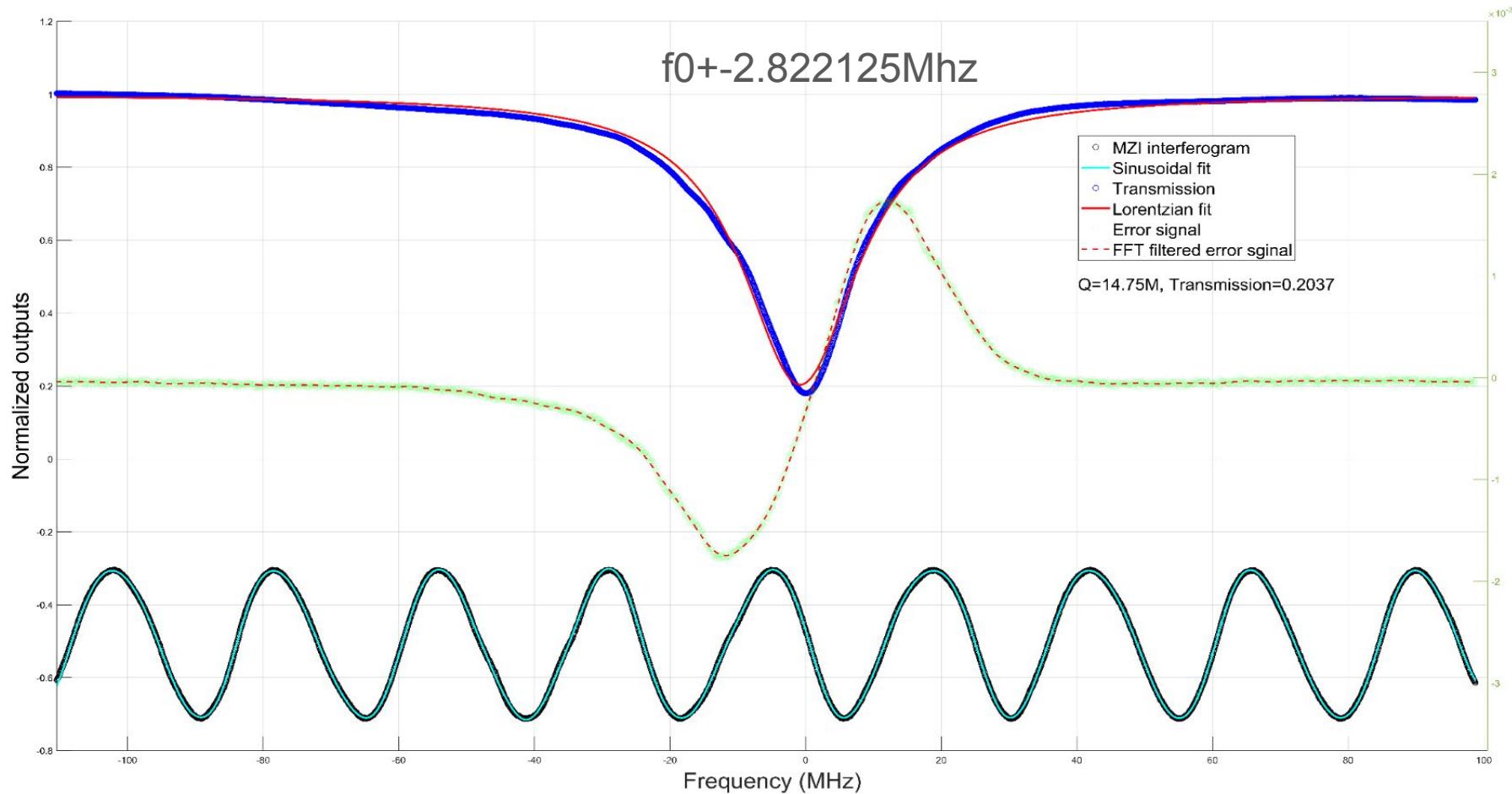
For this one(package1), it has a error in short term, and a long term transmission measurement

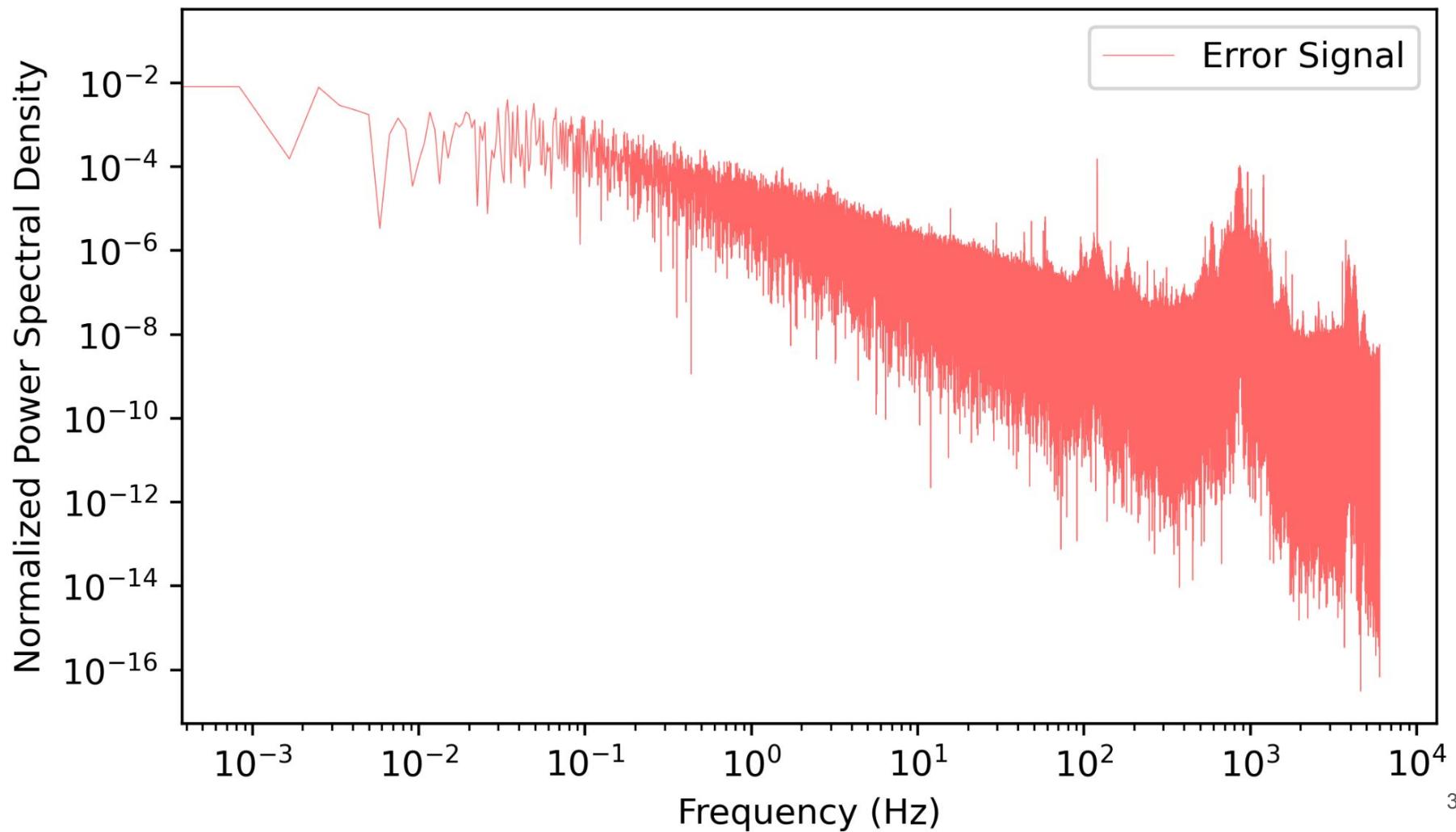
$f_0 + -2.822125\text{Mhz}$, Replace these two with alpha



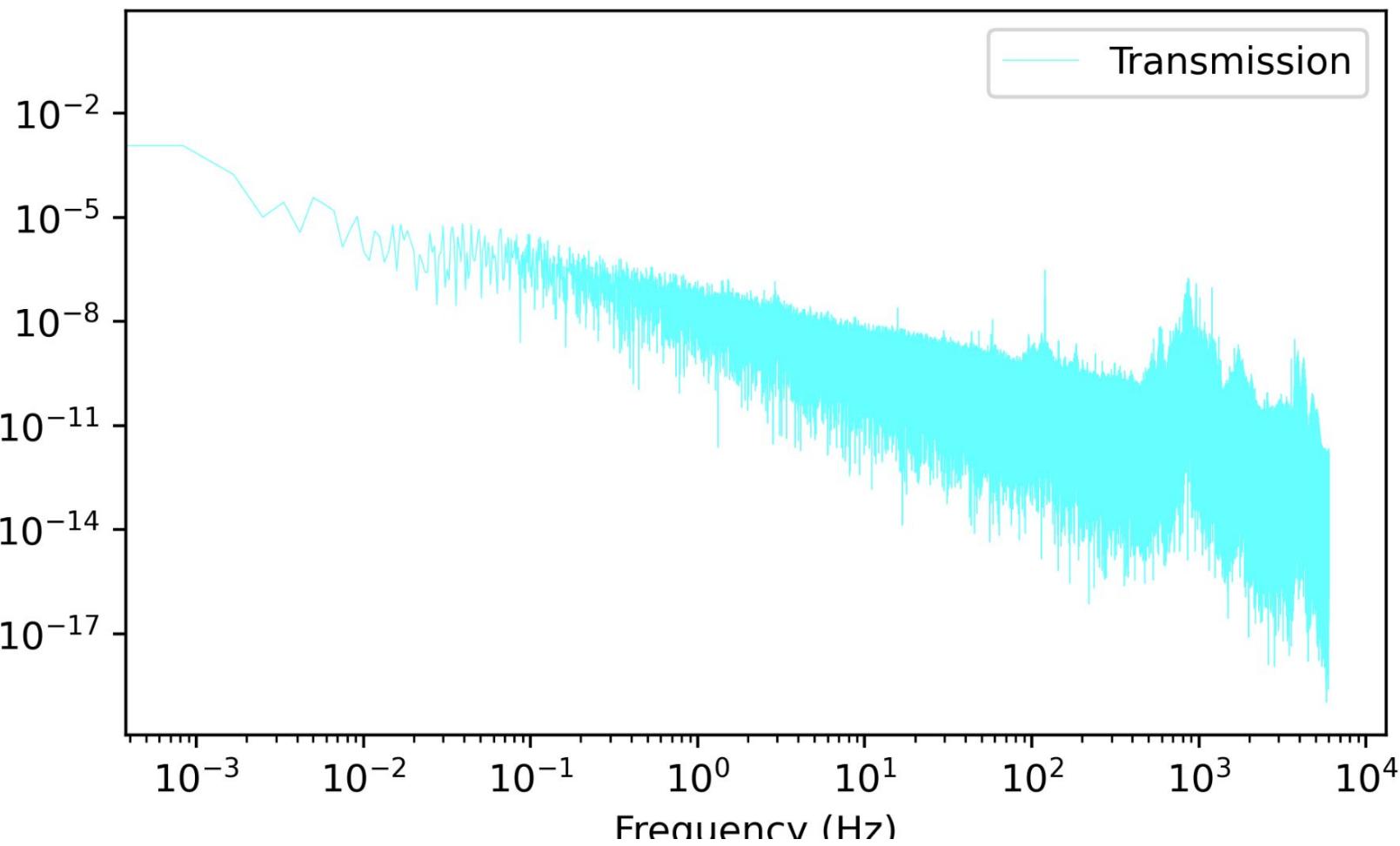
Time-Domain error

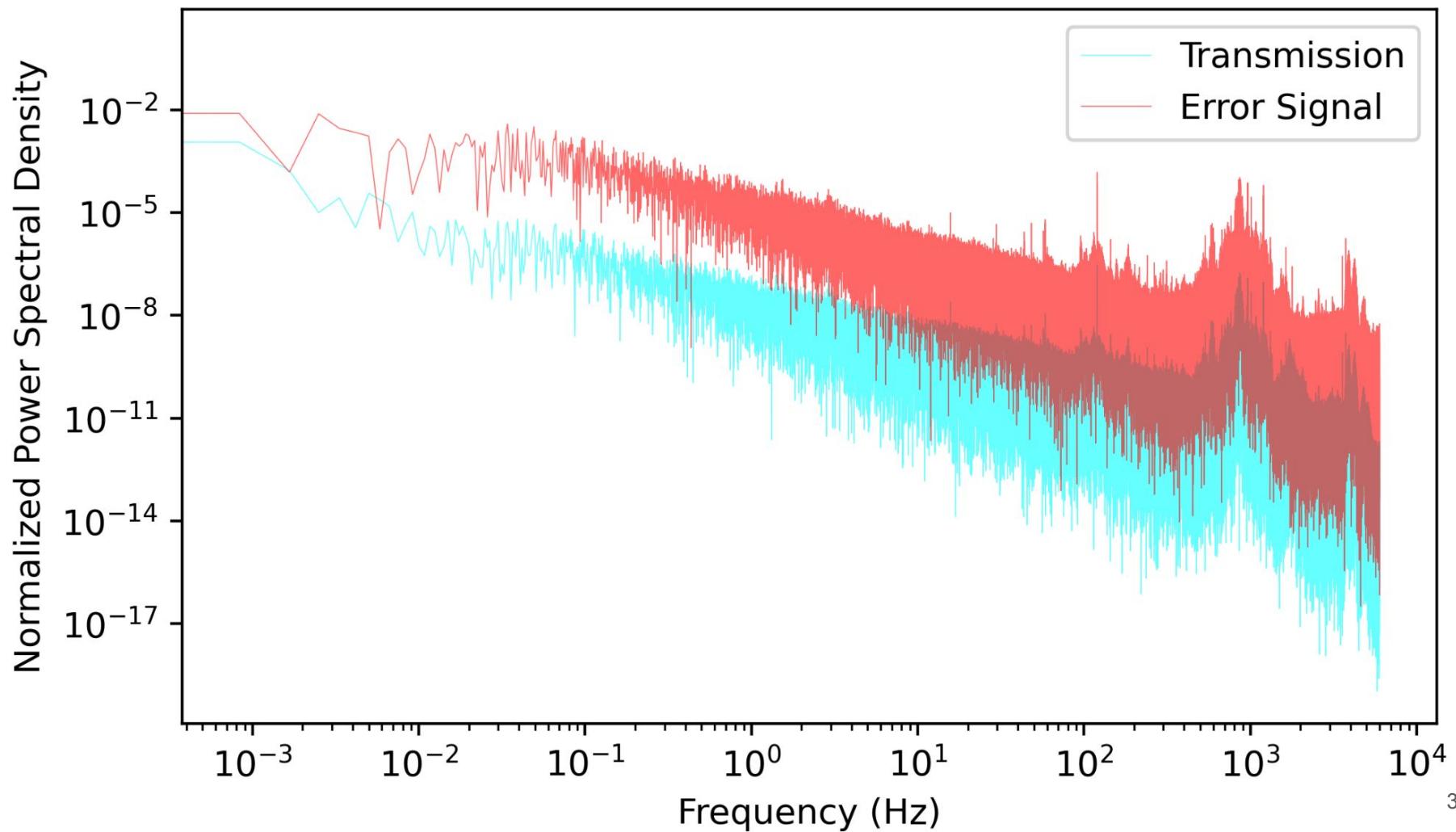






Normalized Power Spectral Density





Compare the two measurements