Laser Offset Lock

Michael Sprague
Thywissen Lab

http://www.alex.ricksastro.com/laserlock.htm $9, an *excellent* stocking stuffer

Overview

- Why frequency locking?
- How to do it?
  - Frequency/filter method
  - Phase lock loop
- What we have done
- What we could do better/future work

Laser locking

- Absolute frequency:

  Spectroscopy (Saturation, polarisation)

- Relative frequency:

  Offset lock, phase and frequency

  Why? Replace AOMs, flexible

- **Goal:** Address F = 11/2 to F = 9/2 ^{40}K hyperfine transition for imaging, 0 to 225 G

: 820 to 1130 MHz offset from ^{39}K $_{3/2}{}^{2}S_{1/2}$ to $_{3/2}{}^{2}P_{3/2}$

Definition of Terms

Linewidth: Frequency fluctuations less than measurement time (< ms)

Drift: Frequency fluctuations greater than measurement time (> seconds)

Phase vs Frequency Lock

Phase is time integral of frequency

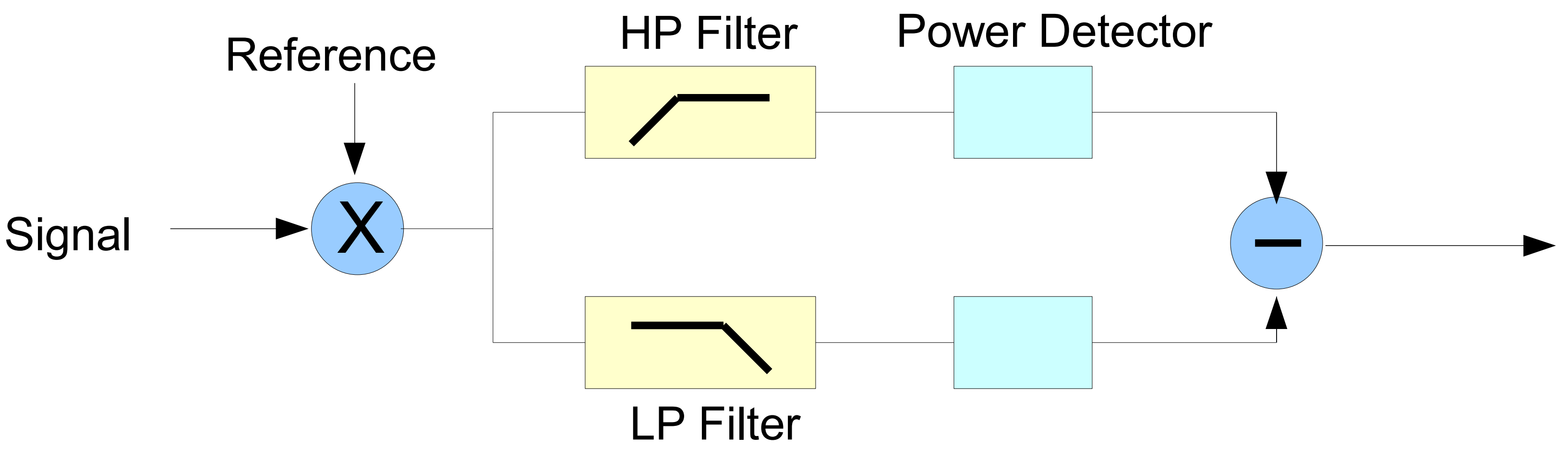
Phase fluctuations cause frequency sidelobes

Can frequency locking give same performance as phase locking? Practically, no..

What makes a PLL so special?

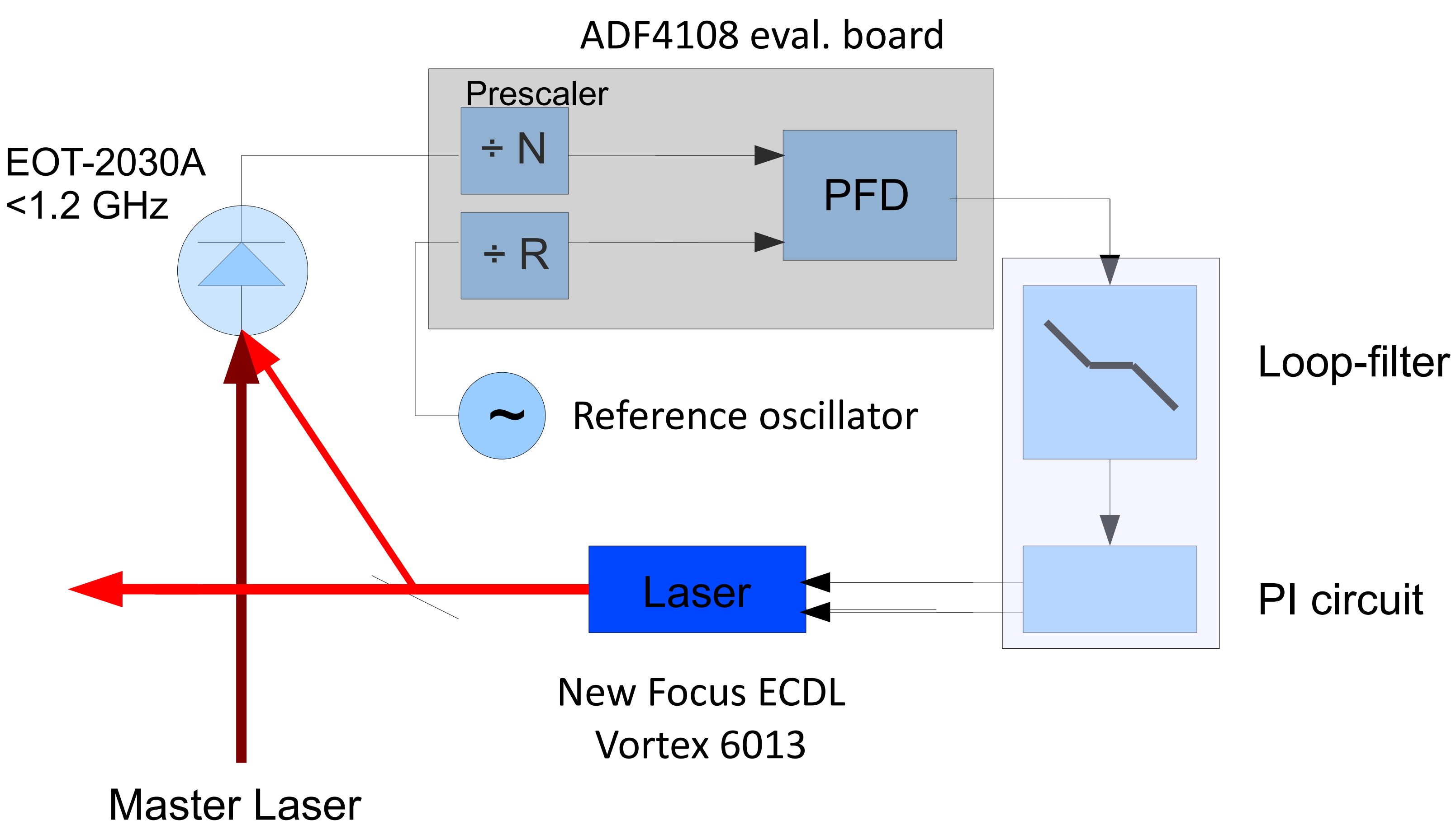
Frequency/Filter Lock Method

- Convert Frequency to voltage
  - Buy Frequency to voltage converter (max = 1 MHz)
  - Make one, filter method (MIT/Harvard group)



Optical Phase Lock Loop

Prescaler, Phase Frequency Detector/Charge Pump, Loop Filter/Servo circuit, Laser controller



Prescaler

- Divides down beat signal from GHz to 10s MHz

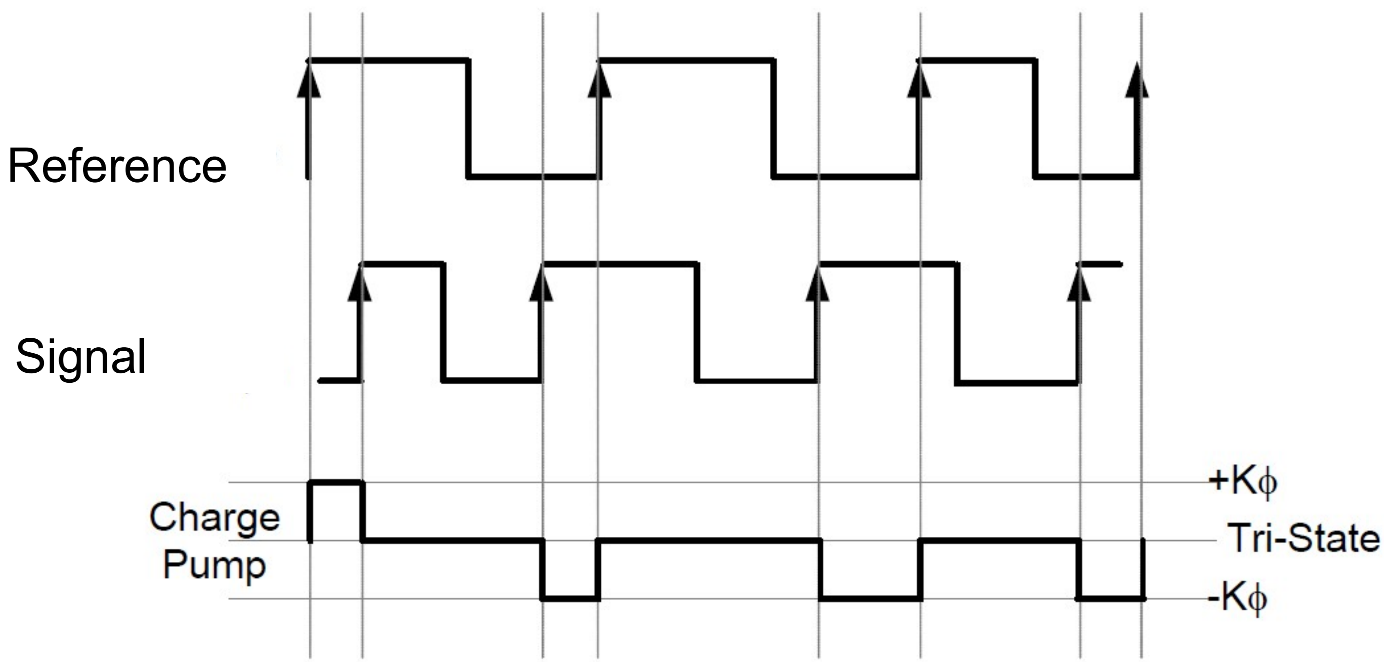
- Simple pulse counter: $f_{out} = f_{in}/(A*P)$, A =1,2...
- Dual modulus: $f_{out} = f_{in}/(A*P+B)$, $B<A$, $P = 2^n$

- Example: f_{in} = 1 GHz, want f_{out} = 20 MHz, P (set by prescaler) = 8

  A=6, B=2. Count (P+1)*B pulses (pulse swallower), then count (P)*(A-B) pulses, then outputs one pulse.

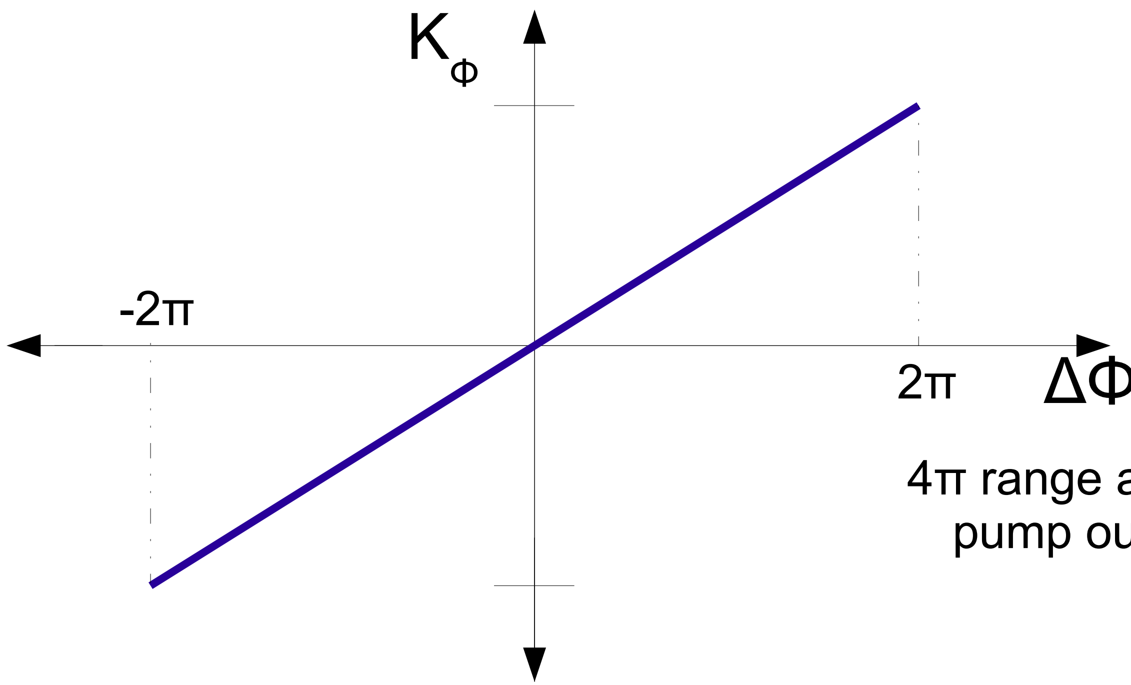
Phase Frequency Detector (PFD)

- Have two signals (Reference and Beat Signal), need to detect phase/frequency difference
- Options: I) Mixer II) PFD
- PFD implemented with XOR or JK Flip-flops



D. Banerjee. PLL Performance, Simulation and Design

Phase Frequency Detector

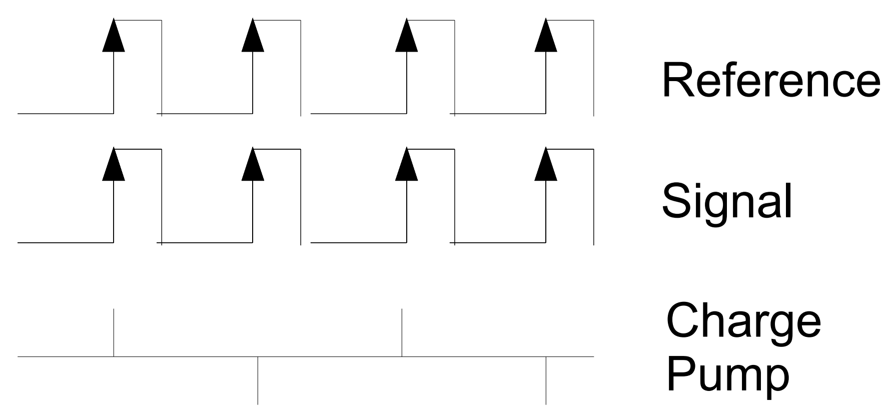


K_Φ = Charge Pump Gain

4π range as two possible charge pump outputs at each phase difference

$\Delta\Phi = 0$

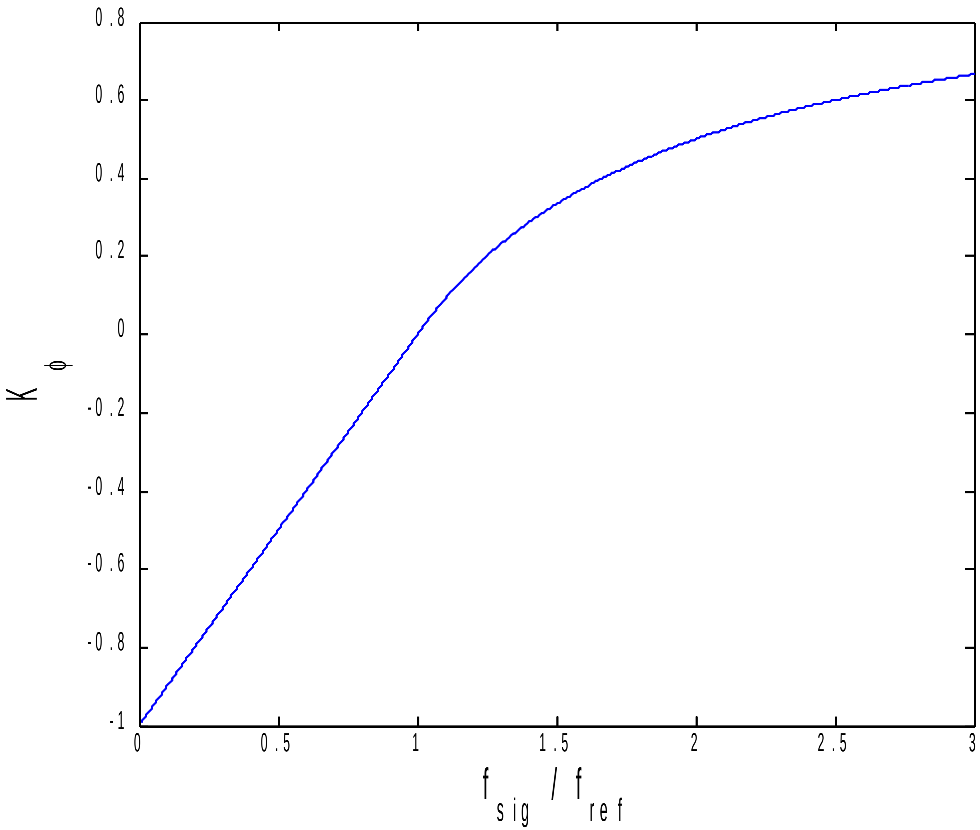
- Spurs at divided down reference frequency



Phase Frequency Detector

What about different frequencies?

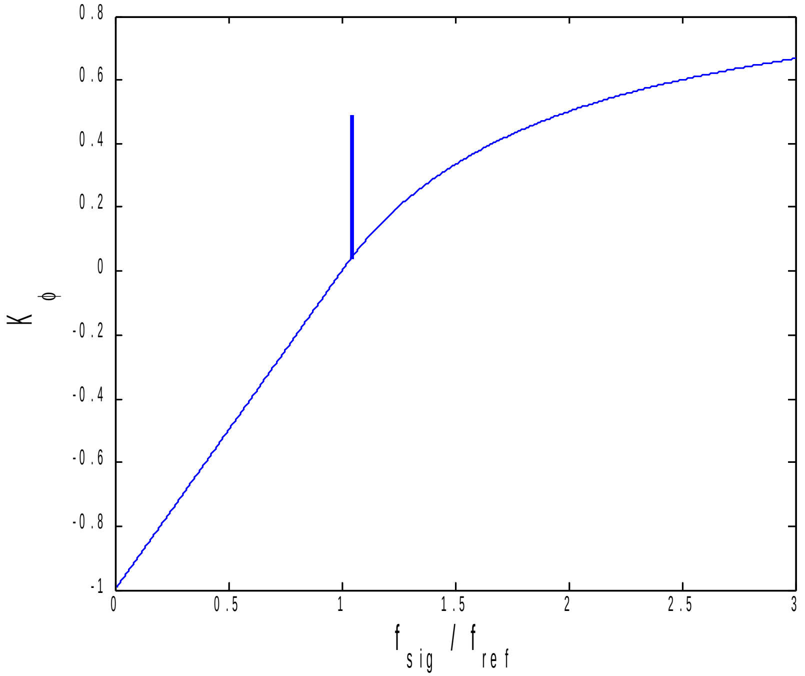
$$\Delta\phi = (1 - f_{sig}/f_{ref}) \qquad \text{for } f_{sig} < f_{ref}$$



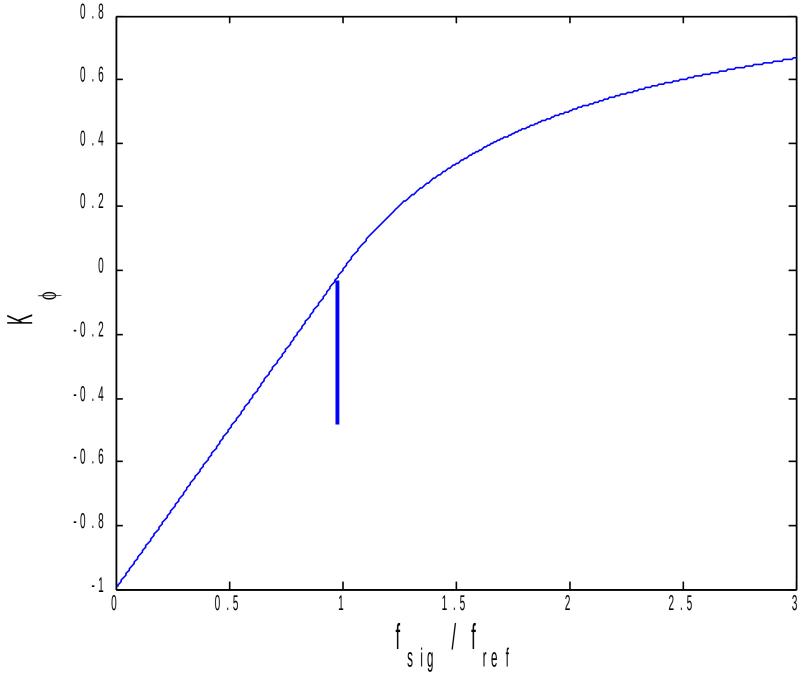
Assumed initial phase relation (identically zero)

If relation varied, structure apparent = phase correlations

Initial Δϕ = π

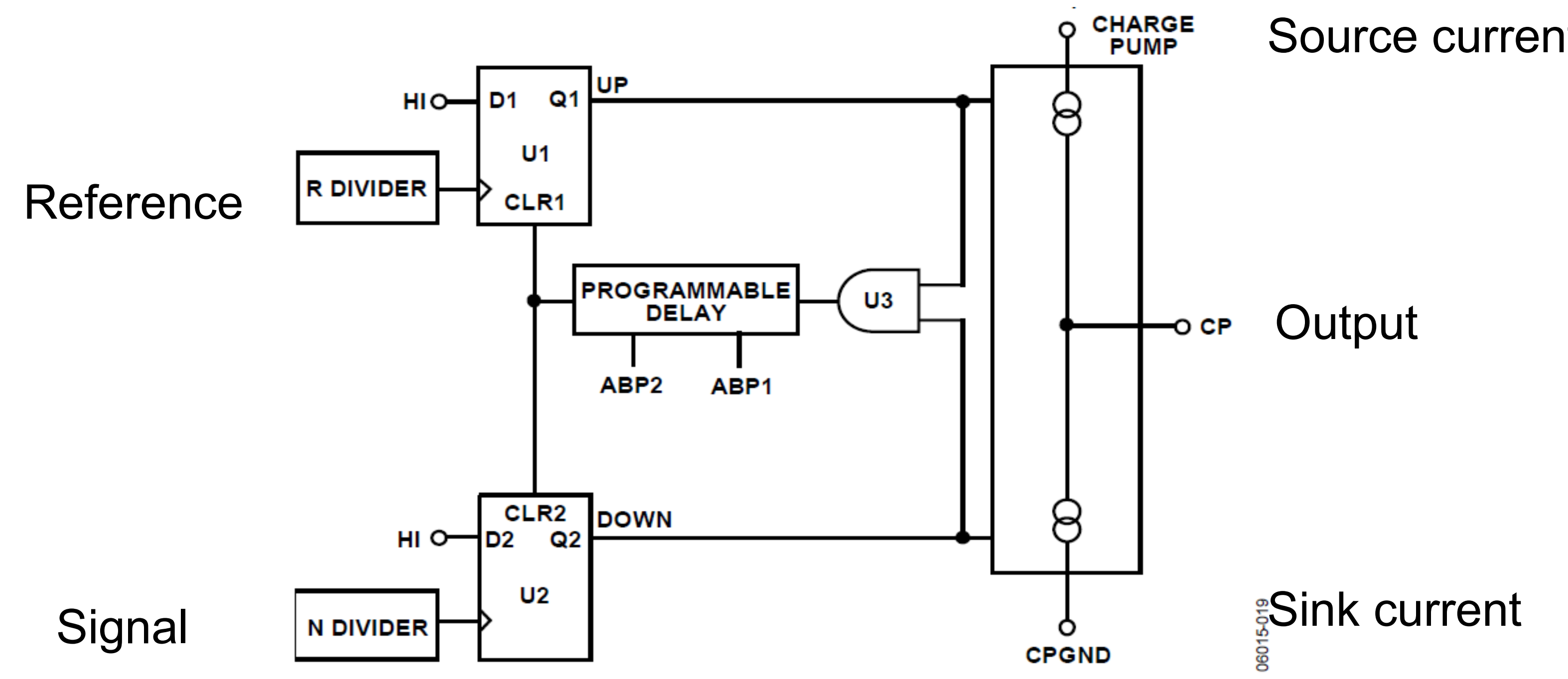


Initial Δϕ = -π



Charge Current Pump

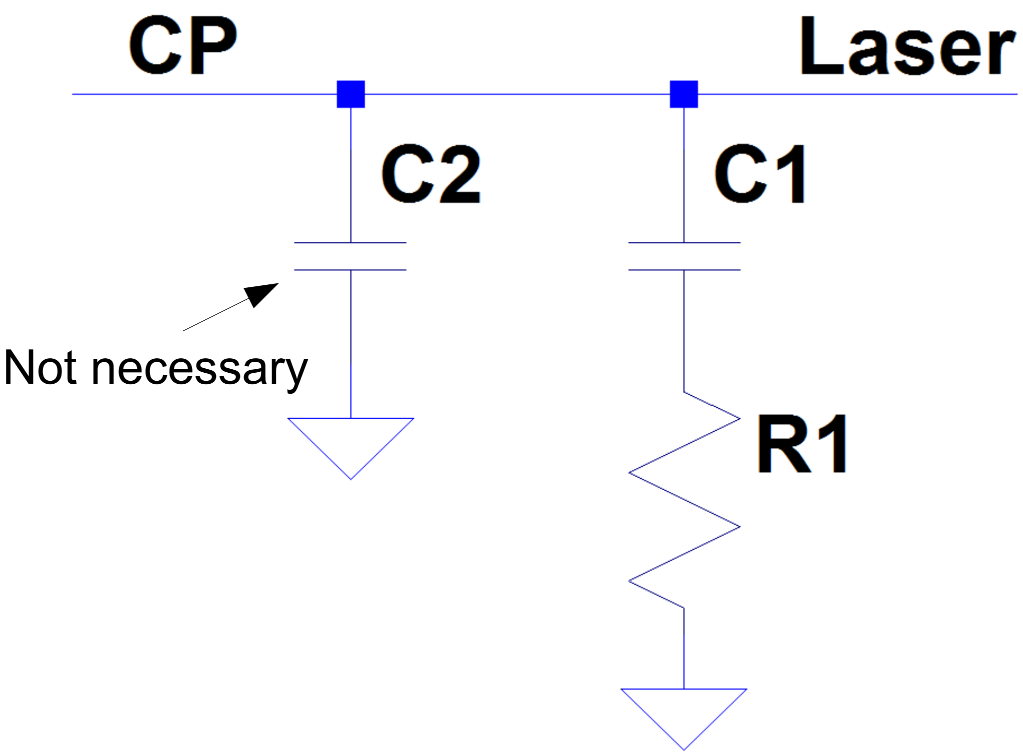
- Phase difference proportional to time average of current pulses

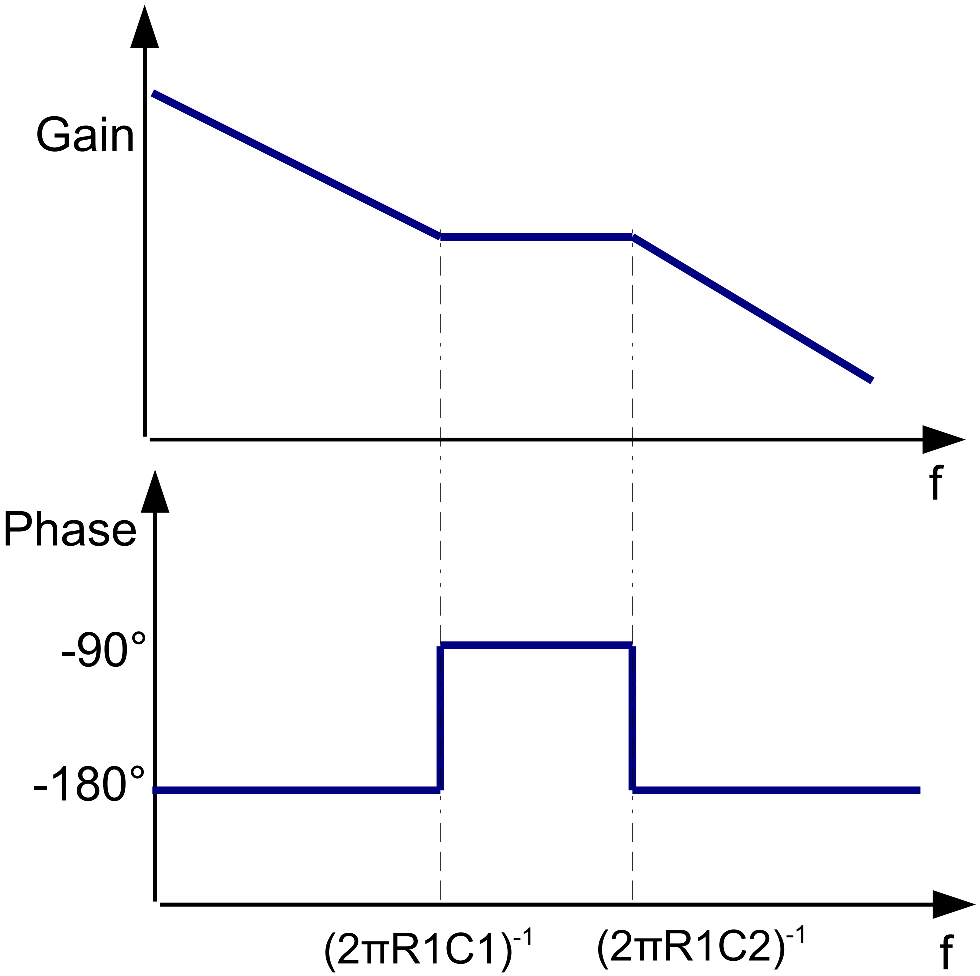


Analog Devices AD4108 Data Sheet

Loop Filter

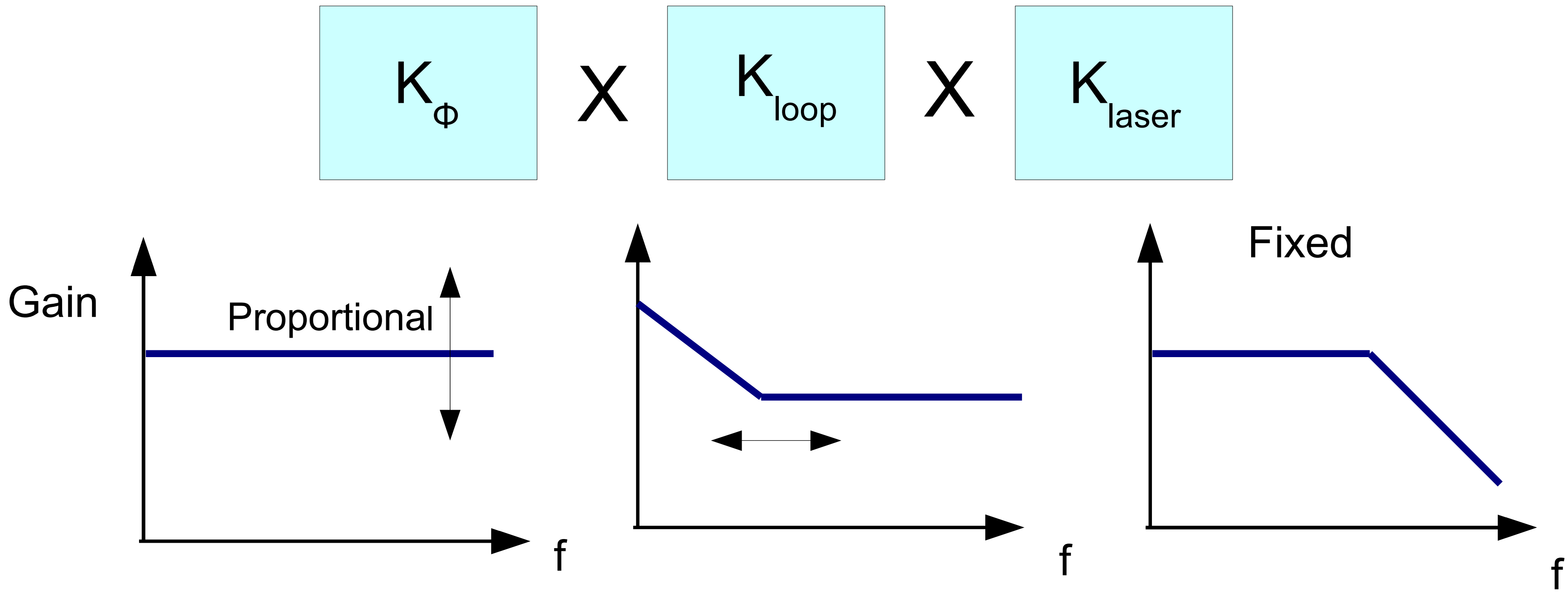
- Need to eliminate high-frequency component from charge pump current





Can use higher order filters as well

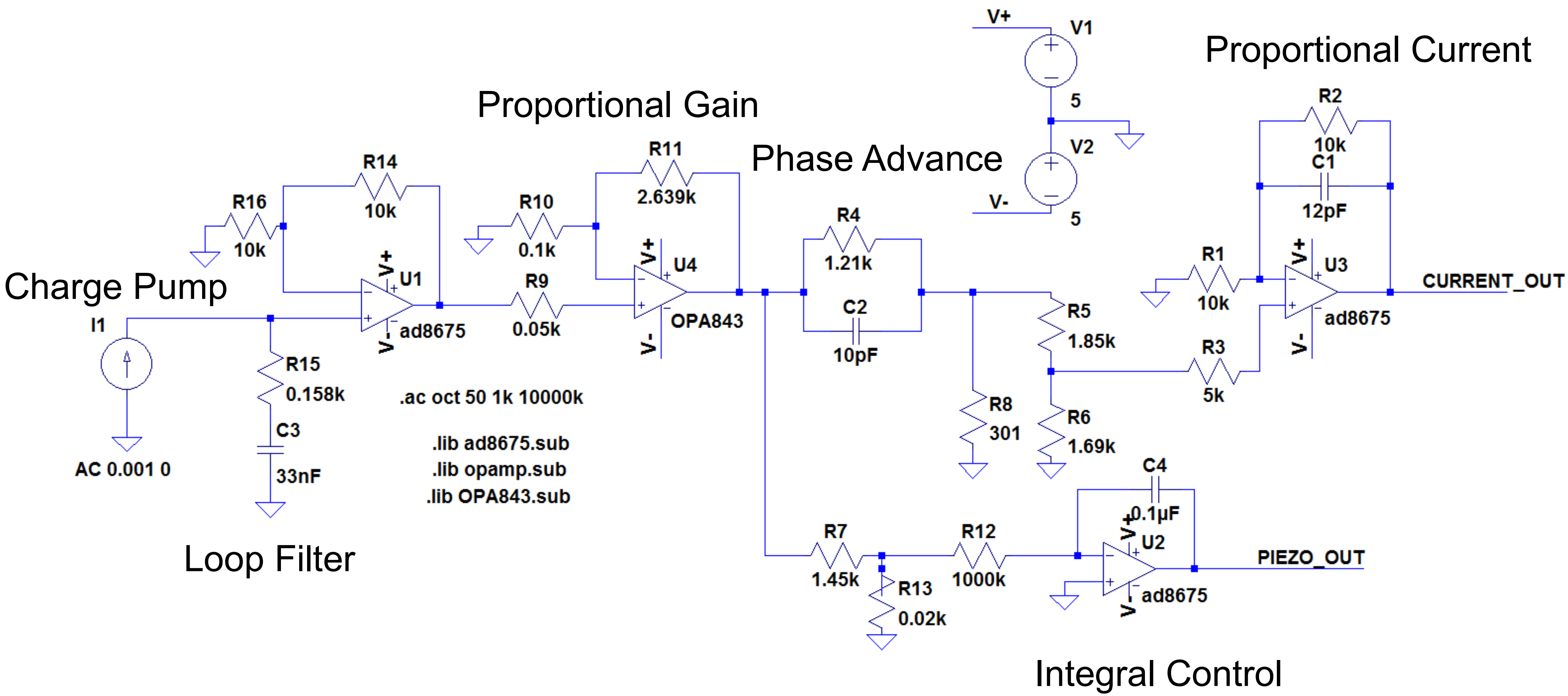
PLL OL Transfer Function



Closed Loop Gain

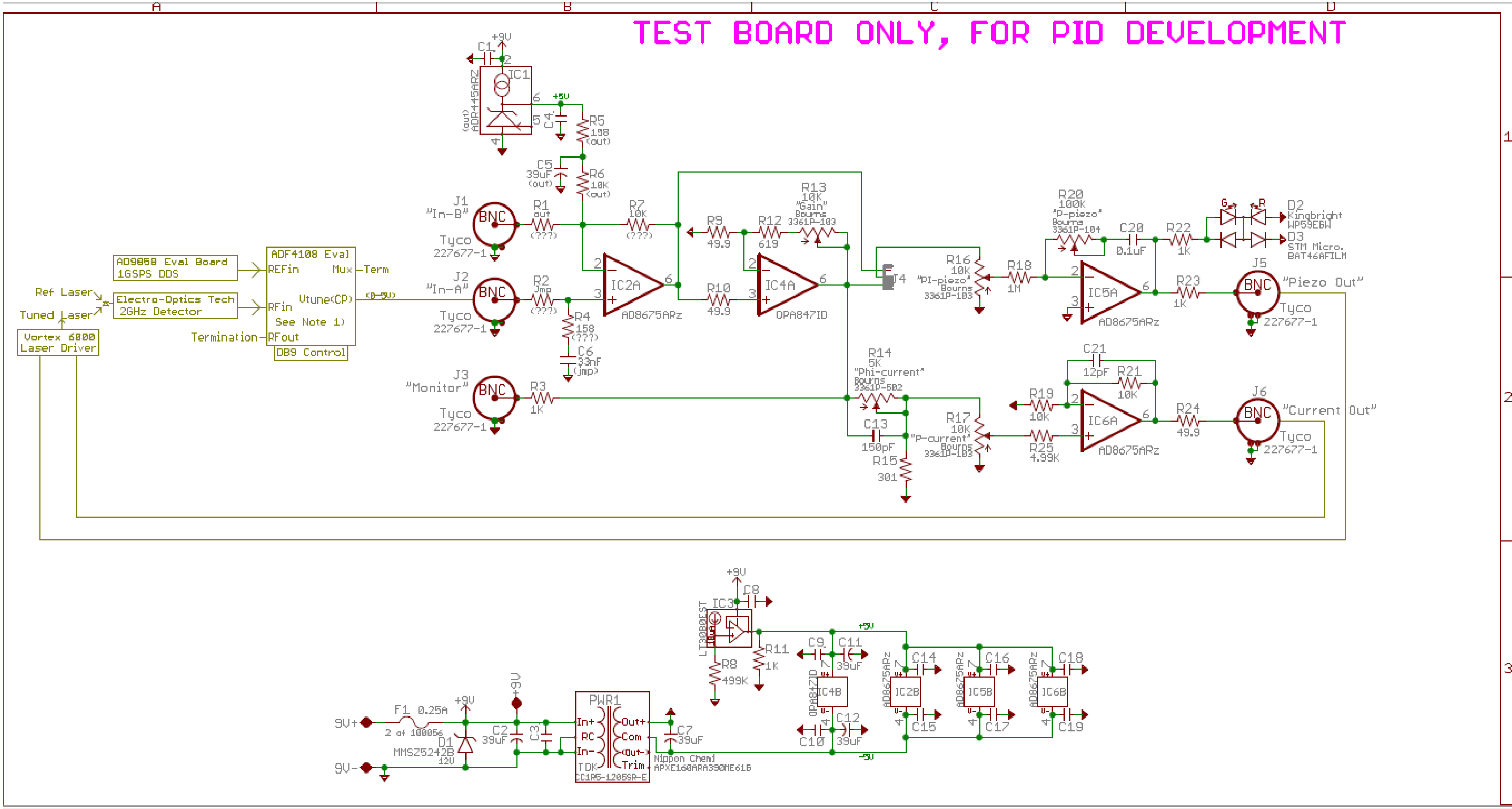
$$CL(s) = \frac{OL(s)}{1 + \frac{OL(s)}{N}}$$

Implementation



cf. Appel F. et al. Meas. Sci. Technol. **20** (2009) 055302

Circuit



TEST BOARD ONLY, FOR PID DEVELOPMENT
AD9858 Eval Board 1GSPS DDS
ADF4108 Eval
REFin
Mux
Term
Electro-Optics Tech 2GHz Detector
RFin
Vtune(CP)
See Note 1)
Termination
RFout
DB9 Control
Ref Laser
Tuned Laser
Vortex 6000 Laser Driver
IC1
ADR445ARZ
IC2A
AD8675ARz
IC4A
OPA847ID
IC5A
AD8675ARz
IC6A
AD8675ARz
"Piezo Out"
"Current Out"
"In-B"
"In-A"
"Monitor"
Tyco 227677-1
D2 Kingbright WP59EGW
D3 STM Micro. BAT46AFILM
PWR1
TDK CC1R5-1205SR-E
Nippon Chemi APXE160ARA390ME61G
LT3080EST
MMSZ5242B 12V
F1 0.25A
9V+
9V-

Stability and Barkhausen Criteria

Open loop stability criteria, phase and gain margin

Phase margin: $180° + \phi$ at $G = 0$ dB

Gain margin: $-(G)$ at $\phi = -180°$

'Nominal' values = 15 dB GM, 50° PM

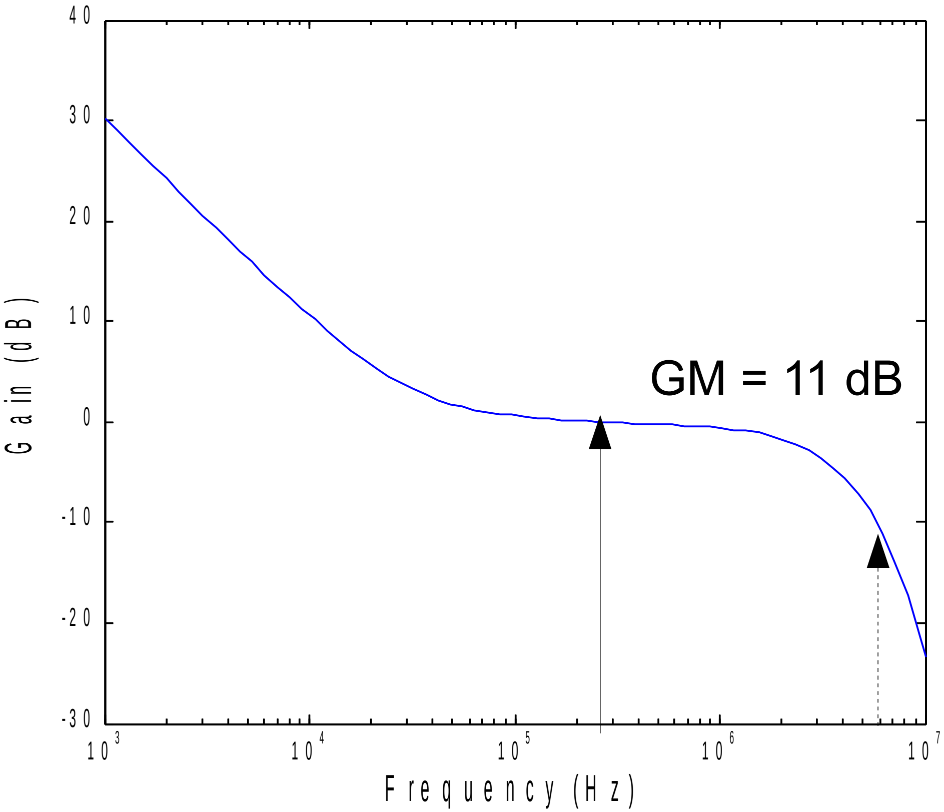
Intuitive, but not sufficient criteria for *instability**

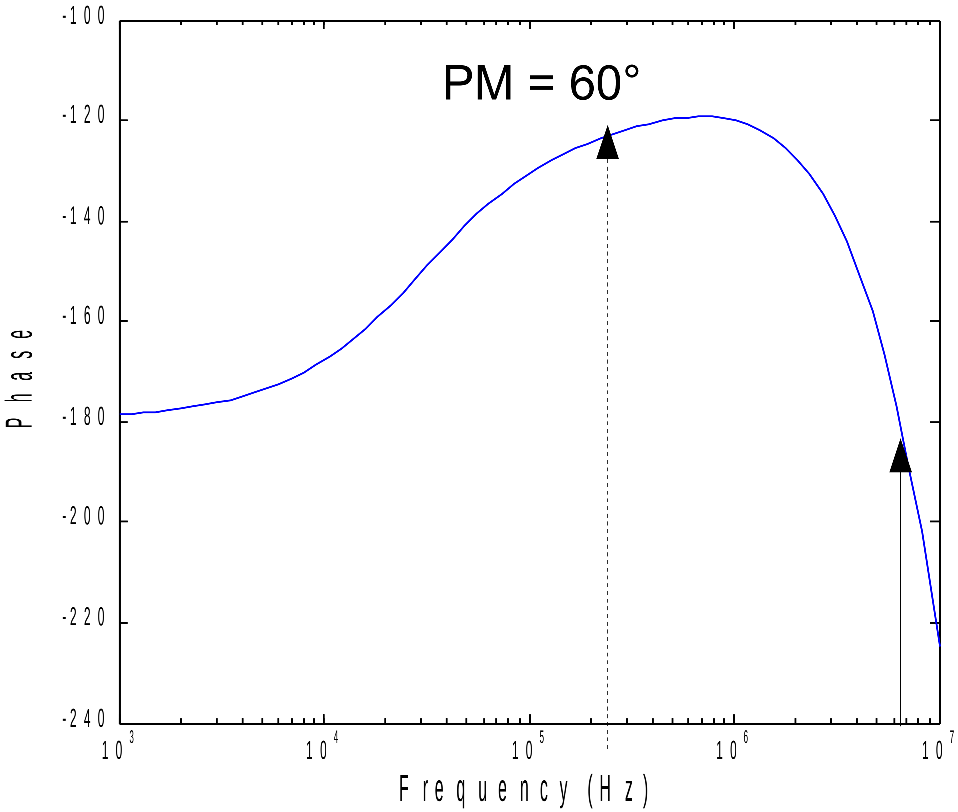
Use Nyquist criteria: $OL(j\omega)$ remains to right of $OL(j\omega) = -1$ for increasing frequency. Rigorously Contour integration about -1 related to number of OL poles in real positive plane

* Nyquist criteria necessary and sufficient

Jacobs OLR. Introduction to Control Theory.

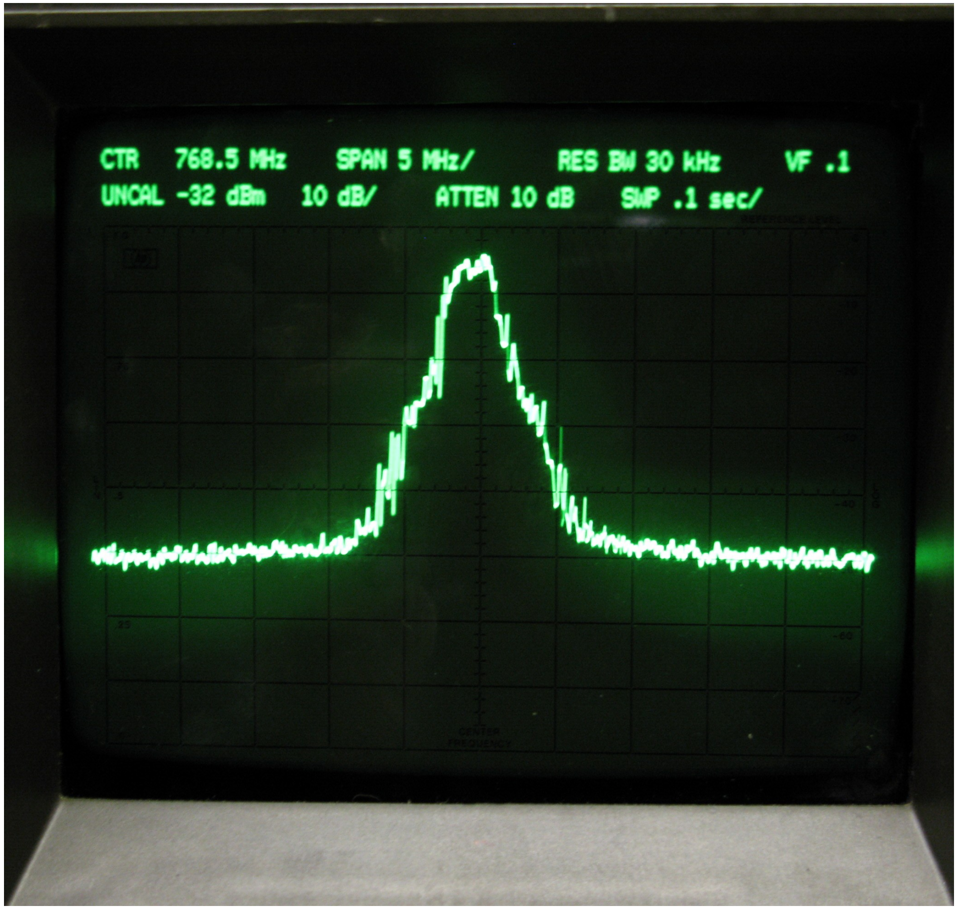
Transfer Function



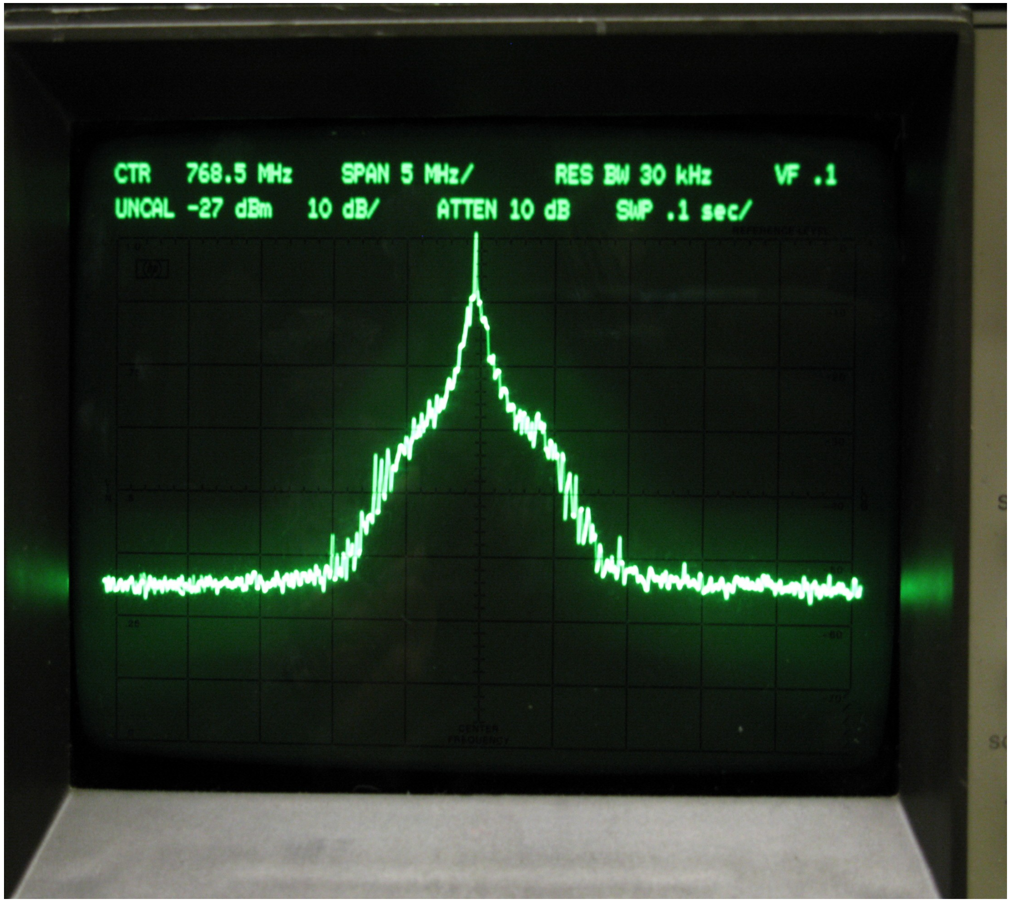


Loop Filter + Servo control circuit + Laser Transfer Function

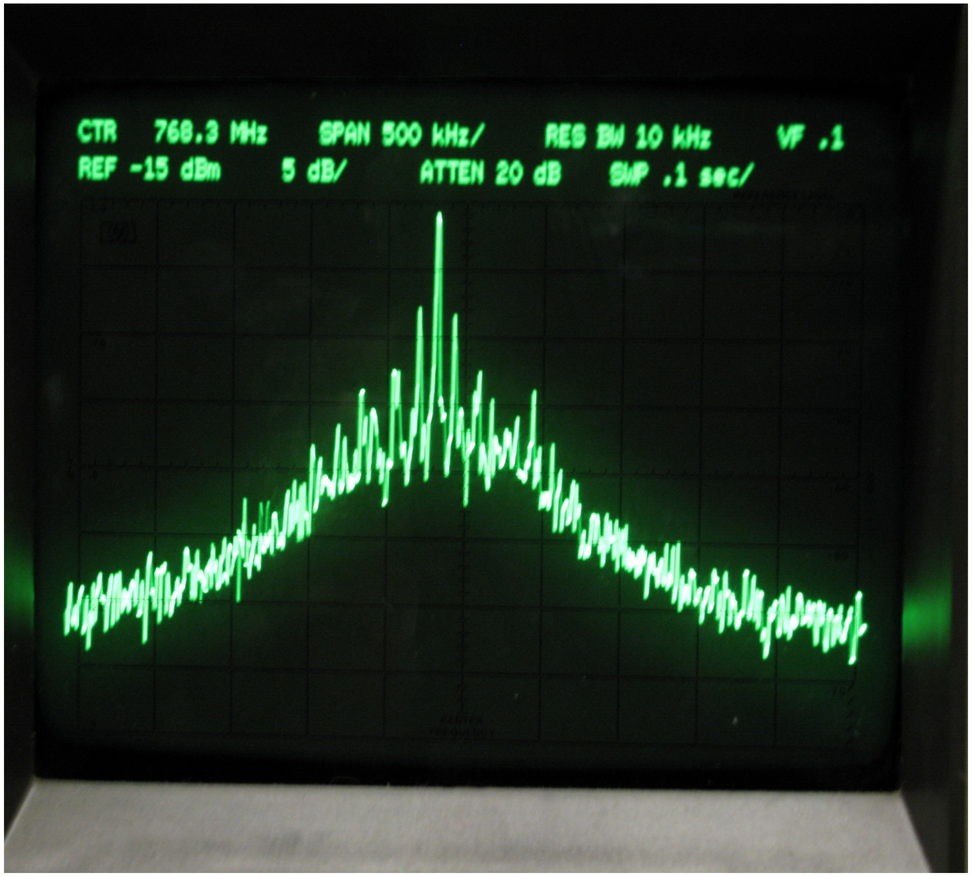
Values above few MHz probably not reliable

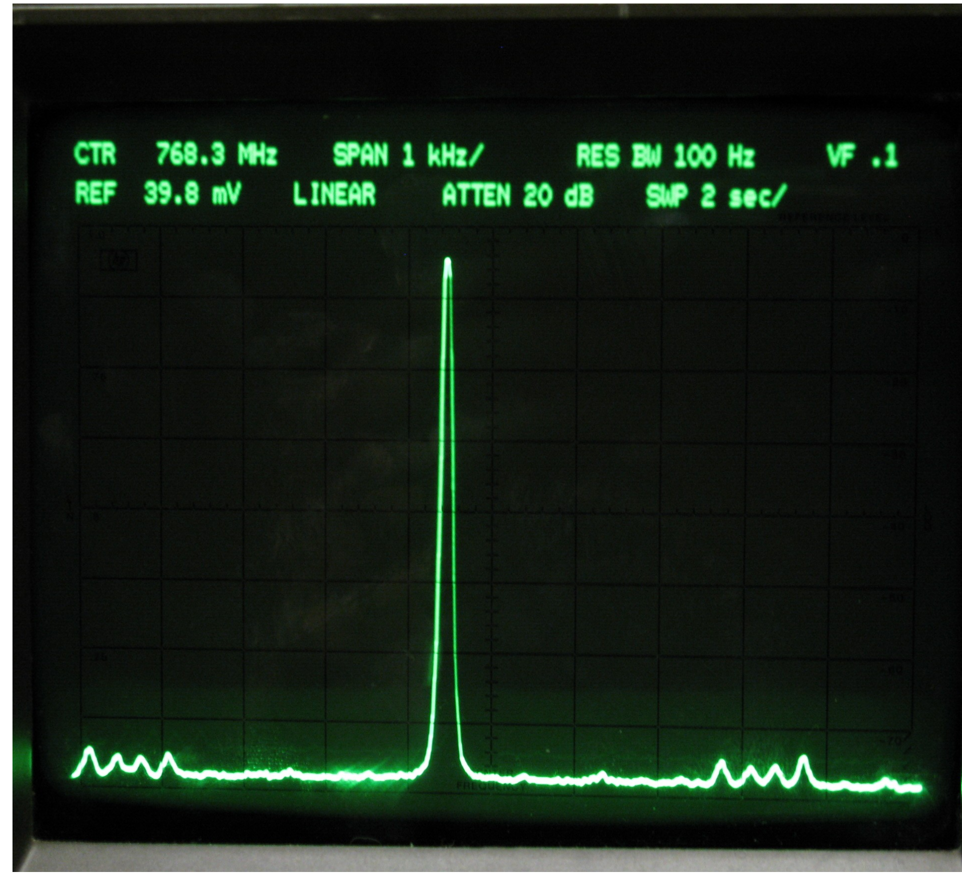


PIEZO Feedback only, Span = 5 MHz/div
Resolution BW = 30 kHz, 10dB/div



PIEZO + Current Feedback, Span = 5 MHz/div
Resolution BW = 30 kHz, 10dB/div





PIEZO + Current Feedback , Span = 0.5 MHz/div, Resolution BW = 10 kHz

PIEZO + Current Feedback, Span = 1 kHz/div, Resolution BW = 100 Hz, **LINEAR**

110 kHz Spurs

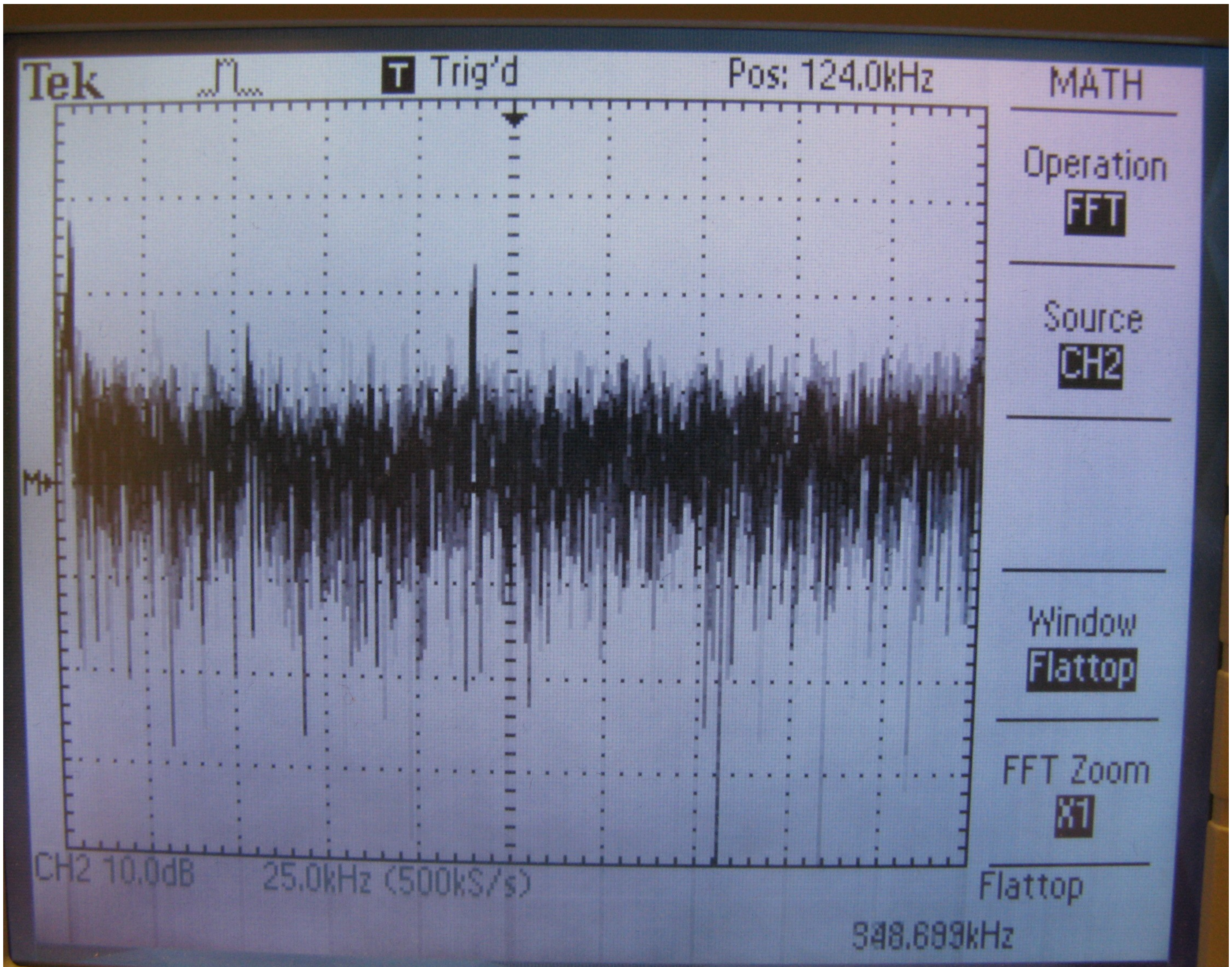
Major problem for phase coherent exps.

Remaining considerations:

- Remove all switching power supplies
- Connect ground of laser to table
- Circuit instability, Replace op-amps
- Laser controller

Love to hear any other suggestions

Error Signal Spectrum



Sweep Rate

- ~10 MHz / ms. Might not be fast enough.
- Limited by? Time constant of Piezo integrator
- Solution? Fix stability of Piezo path, other possibilities

Practical Tips

- Be paranoid
- Mind grounding, switching power suppliers/ converters, oscilliscopes etc..
- Don't try expect it to work on breadboard
- Make sure circuit is stable before building it, ie use Spice to estimate transfer function
- Use ADIsimPLL to get rough idea of desired transfer function (measure laser controller transfer function)

Future Work

- New board, make Piezo arm stable.
- Filter method (probably not)
- 110 kHz sidelobes

Thanks!

Jason, Alan

Alma, Dave, Dylan, Joseph, Joon, Karl, Lindsay, Matthias

References

Banerjee D. PLL Performance, Simulation and Design. 4th Edition. 2006

Best RE. Phase Lock Loops. 5th Edition. McGraw Hill; New York 2007

Jacobs OLR. Introduction to Control Theory. 2nd Edition. Oxford University Press; Oxford 1993

Appel F. et al. Meas. Sci. Technol. **20** (2009) 055302

Analog Devices ADF4108 Manual.