PI Controllers, Lock-ins and PLLs

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nc-AFM Summer School, Osnabrück, Sept. 14th, 2016

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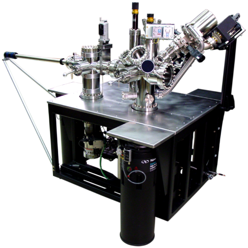
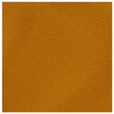
RHK nc-AFM at a Glance



Beetle VT UHV STM/AFM

- Low drift, low noise, high resolution imaging across broad range of environments and condition and applications
- Extremely flexible and expandable system for broadest experimental flexibility
- Cantilever and qPlus nc-AFM

HOPG (2048 x 2048 pixels)



AFM-qPlus image[1]
- 80nm x 80nm
- qPlus sensor f_0 = 20.6kHz Q = 5,800
- T = 16K
- Feedback on the frequecy shift Δf = 21Hz (Repulsion)
- Scan speed : 32nm/s

R9.5 SPM Controller

- Fully Integrated One Box Solution
- Ultra Low Noise HV Outputs
- 2 PLLs can be linked or independent
- PLL LockGuard
- Time Based Data Acquisition (TBDA)
- Full Diagnostics Suite

PanScan Freedom LT UHV STM/AFM

- LHe-Free
- Cryogen Cost-Free
- Interruption-Free
- Hassle-Free
- Atomic Resolution 9-400 K
- qPlus nc-AFM

Why do I talk about control electronics

For best results the operator needs to:

- know his microscope and electronics well
- be confident in operating it
- able to interprete symptoms for diagnose

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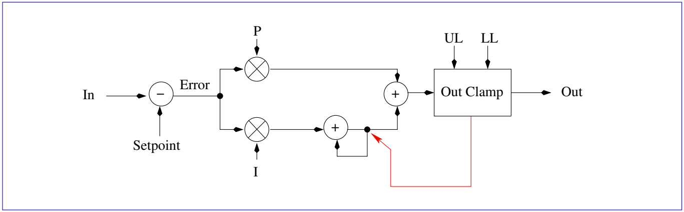
Feedback Control Systems

A lesson about Control Systems,
learned in the shower

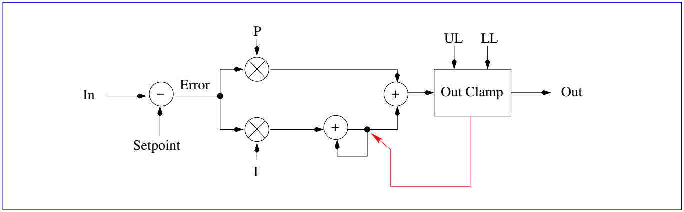
Proportional and Integral gain



Gains: P and I

$O = Pe + I \int e \, \mathrm{d}t$, e = error

Proportional and Integral gain



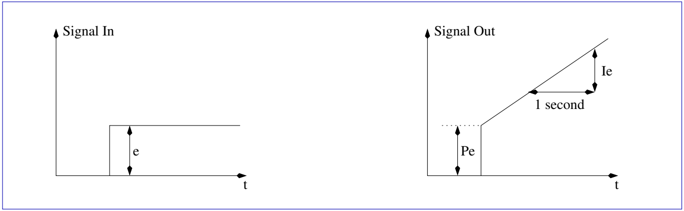
Gains: P and I

$O = Pe + I \int e \, \mathrm{d}t$, e = error

Gain K and cutoff f_c

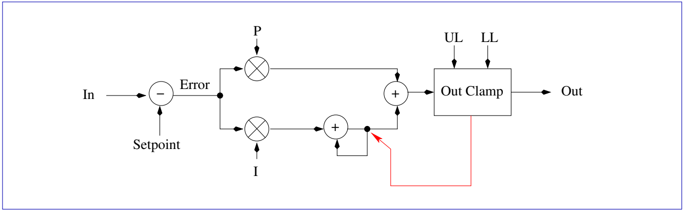
$Out = K(e + \pi f_c \int e \, \mathrm{d}t)$, $K = P, f_c = \frac{I}{\pi P}$

Open loop step response



An error signal at the input creates a ramp at the output

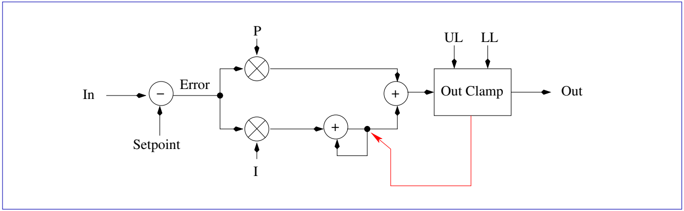
Output Limits



lower and upper output limit

sweepable limits squeeze the output and force it to any value

Output Limits



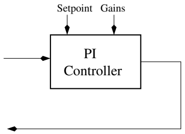
lower and upper output limit

sweepable limits squeeze the output and force it to any value

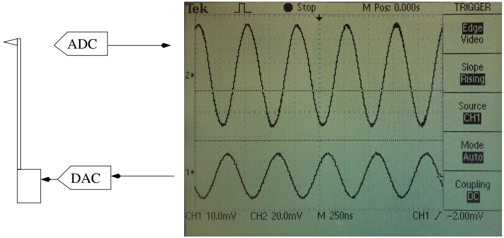
output limits affect the integrator

Output stays until integrator starts running

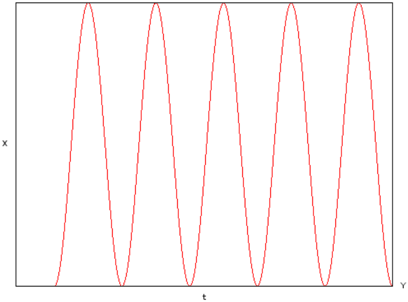
PI Controller Block



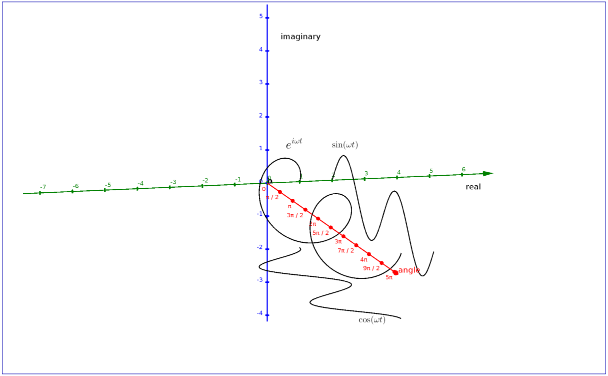
Signals in and out of the Microscope



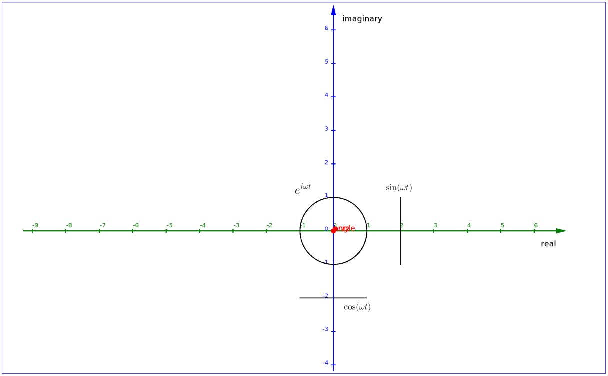
Another View on Oscillations



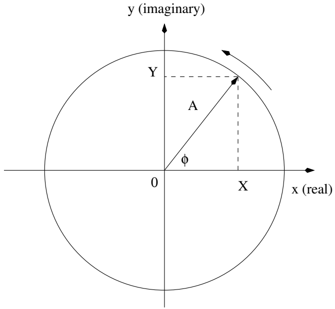
Phasors: Welcome to Complex Signal Processing



Phasors: Welcome to Complex Signal Processing



Phasors

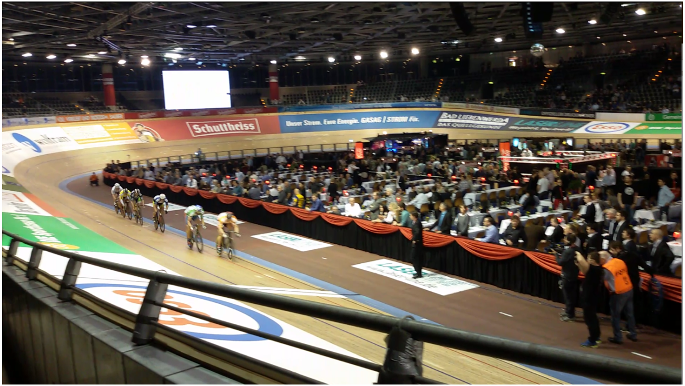


$X = A\cos(\phi)$

$Y = A\sin(\phi)$

$\phi = 2\pi ft$

It’s like in the Velodrome



Instantaneous Frequency

Instantaneous Frequency [1]

- speed of change on the phase $f = \frac{d\phi}{dt}$
- Unit: deg/s, divide by 360 deg/cycle and get Hz
- can change within a cycle (non-sinusoidal oscillation)

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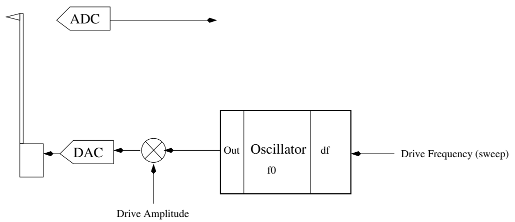
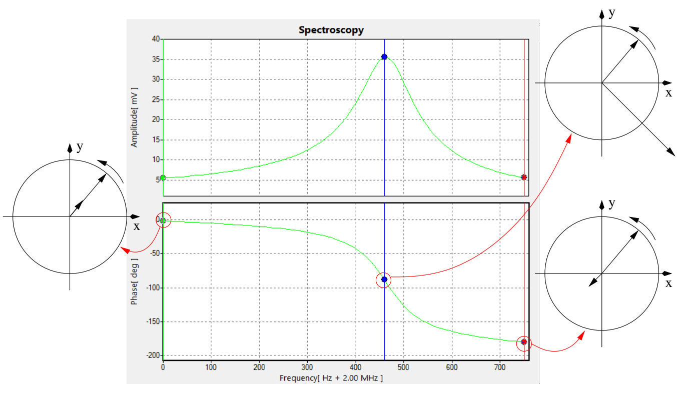
Fourier Transform Frequency

- frequency $f = \frac{1}{T}$
- does not change over oscillation cycle
- Frequency changes show as sidebands in spectra

Driving a Cantilever with a Sine Wave



Cantilever Resonance Plot



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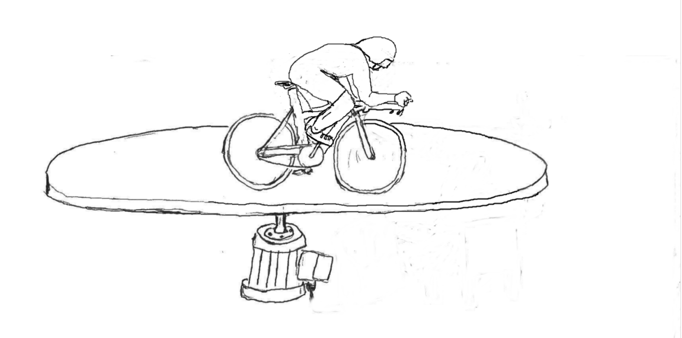
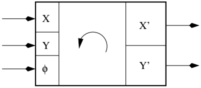
Mixing is Spinning Around the Velodrome's Track



Rotator Logic

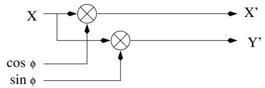


$$X' = X\cos\phi - Y\sin\phi$$
$$Y' = X\sin\phi + Y\cos\phi$$

or

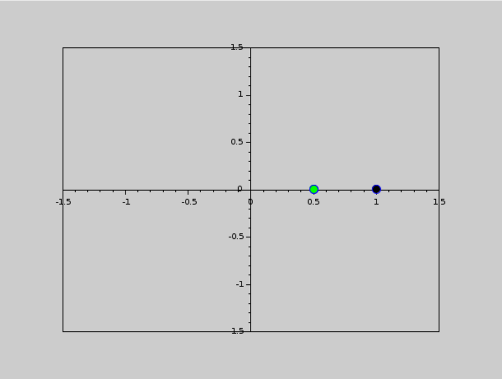
$$X' + iY' = (X + iY)\,e^{i\phi}$$

Y Input is set to zero

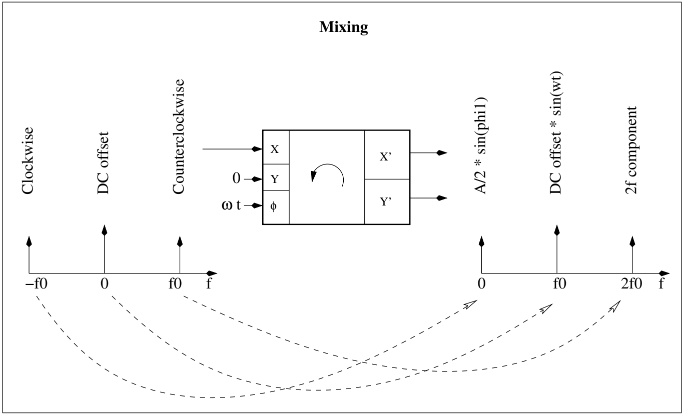


$$X' = X \cos \phi$$
$$Y' = X \sin \phi$$

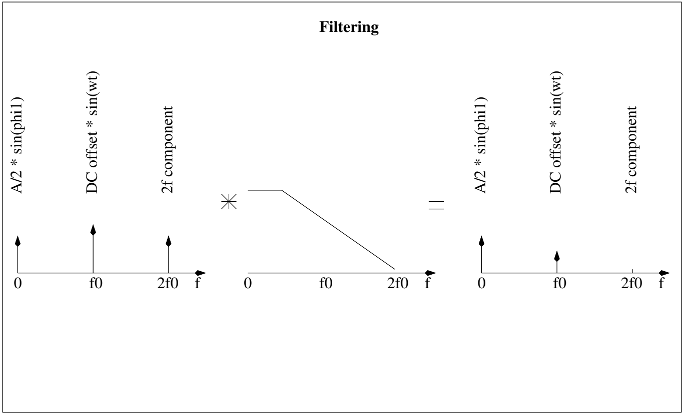
The Mixer's Misinterpretation



Mixing shifts frequencies



Mixing and Filtering



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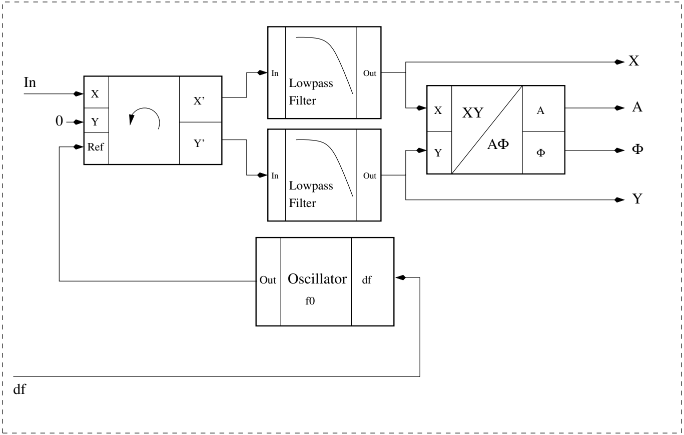
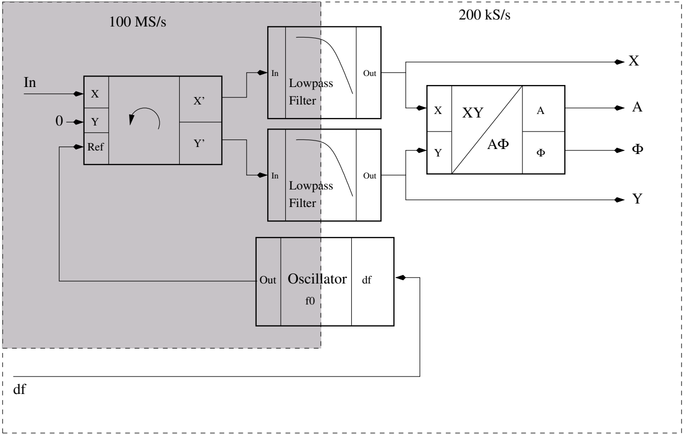
The AFM Lock-in



Decimation



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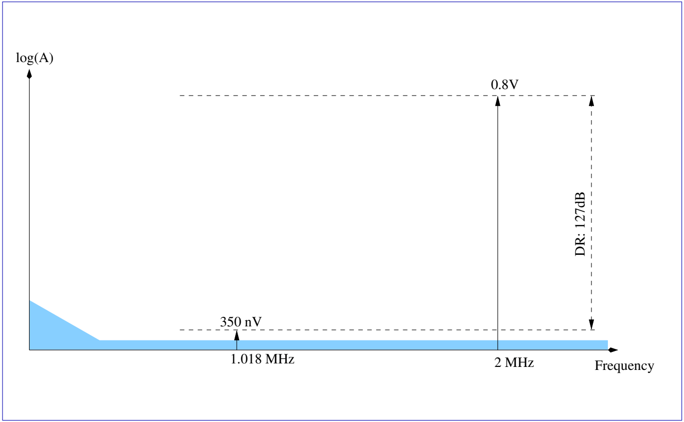
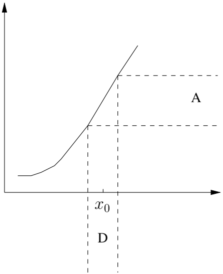
Dynamic Reserve: Measuring 350nV next to a 0.8V Distortion



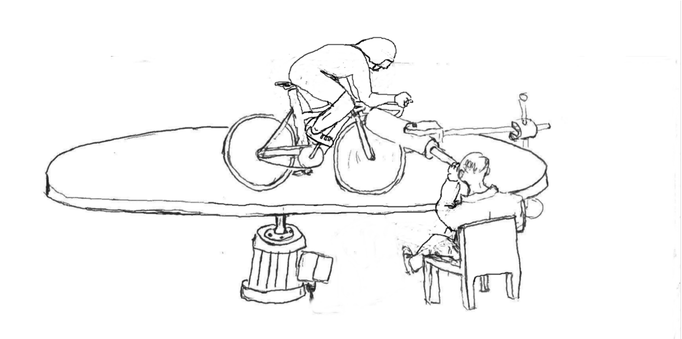
A lockin can measure slopes



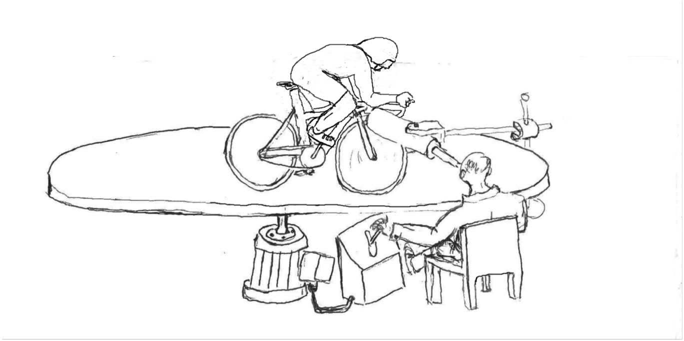
$f'(x_0) \approx \frac{\Delta y}{\Delta x}$

$f'(x_0) \approx \frac{A}{D}$

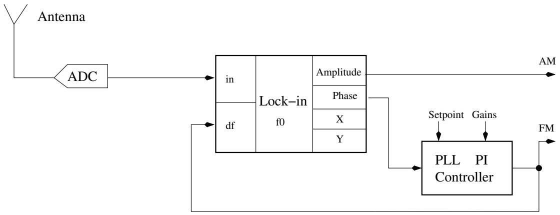
Cartoon Lock-In



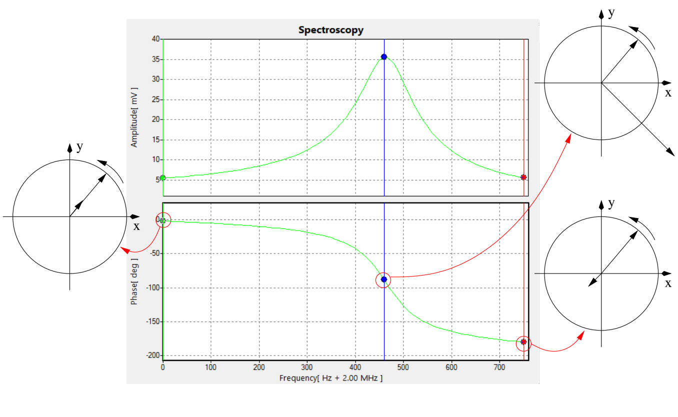
Cartoon PLL



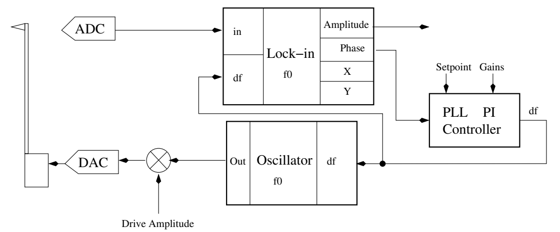
PLL in FM Radio Receiver



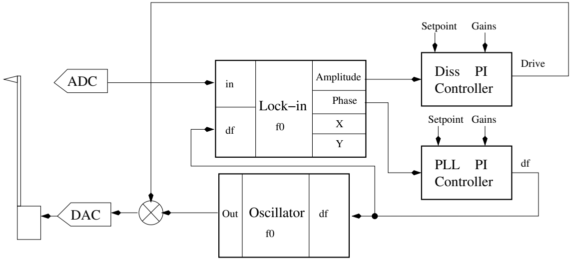
Cantilever Resonance Plot Again



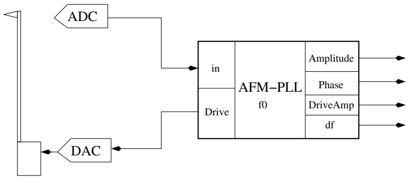
PLL in Constant Drive (CD) Mode



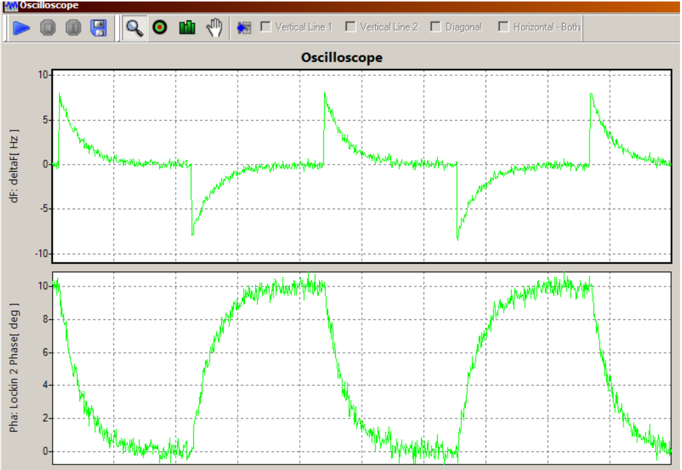
PLL in Constant Signal (CS) mode



PLL Block



Tuning the PLL



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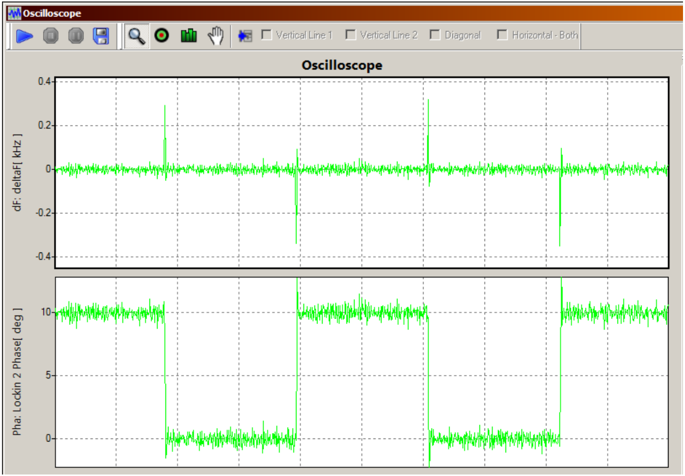
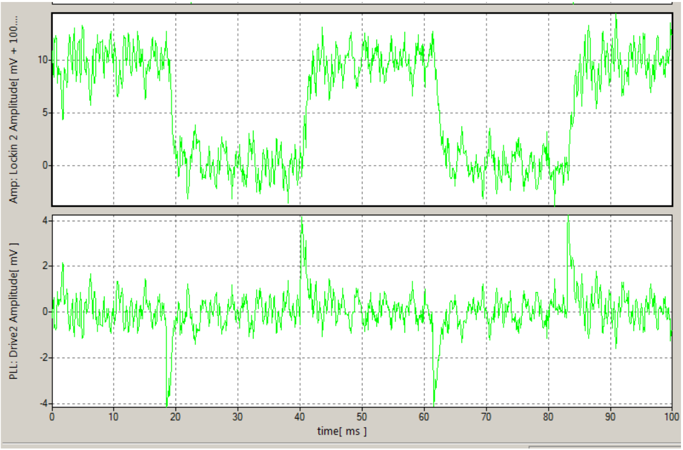
Tuning the PLL



Tuning the Amplitude Controller



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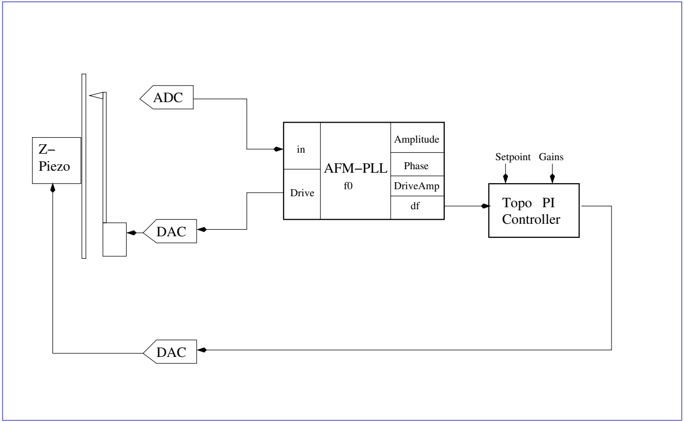
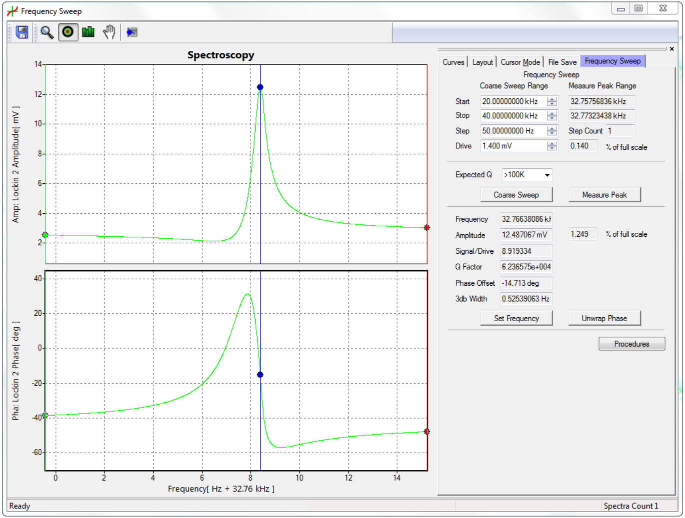
PLL Block and Z Control loop



Pitfalls

Cross Talk



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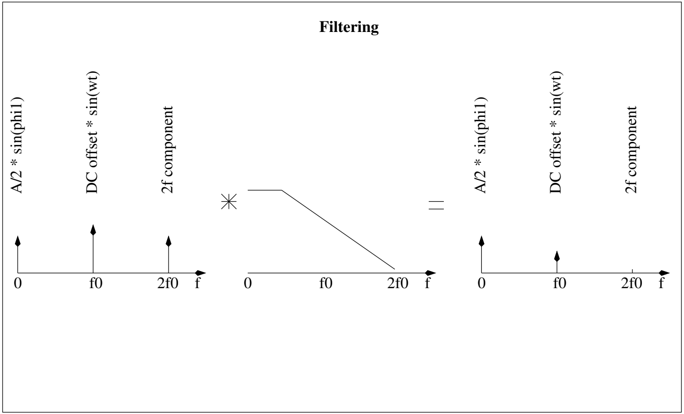
more examples in the R9 webinar on [3]

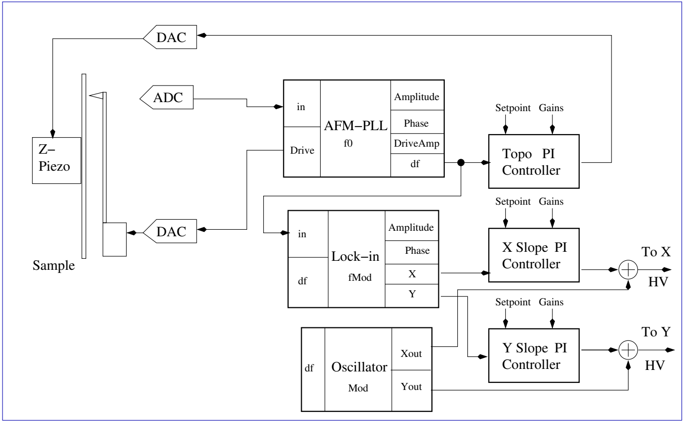
Input Offsets



Exampes of more complex systems

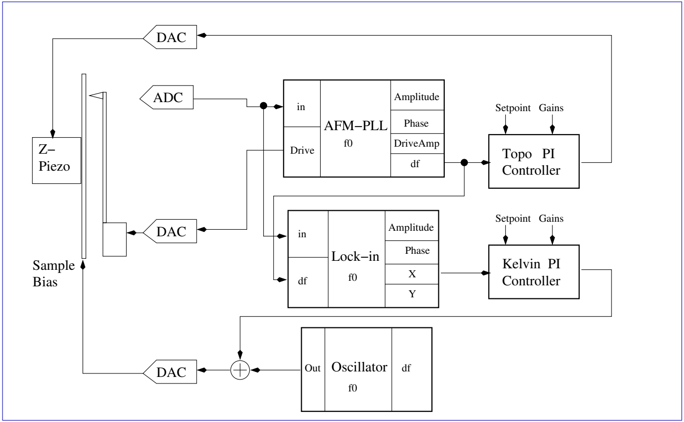
Feature Tracking
Sideband Kelvin

Feature Tracking



B. S. Swartzentruber, Phys. Rev. Lett. 76, 459, 1996

Sideband Kelvin



Instantaneous Frequency: Boualem Bouashash
Estimating and interpreting the instantaneous frequency of a signal. I. Fundamentals and II. Algorithms and Applications
PROCEEDINGS OF THE IEEE, 80, (4), 1992.

Lockin Amplifiers: Mike. L. Meade
Lockin Amplifiers: Principles and Applications
https://sites.google.com/site/lockinamplifiers/home

RHK Webinars: http://www.rhk-tech.com/support/tutorials/

Thank you for your attention