General Narrowband Noise Cancellation Development at the APS

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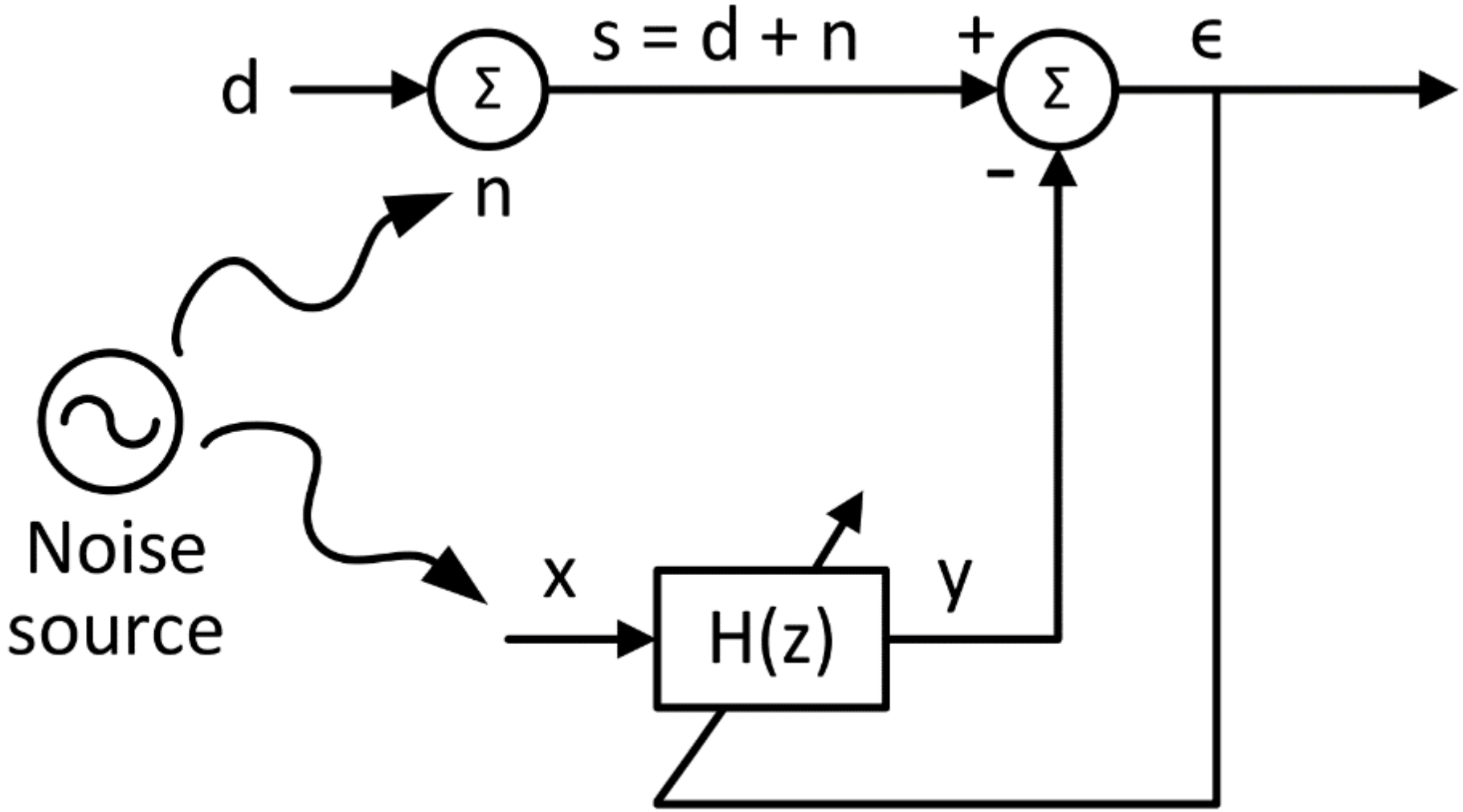
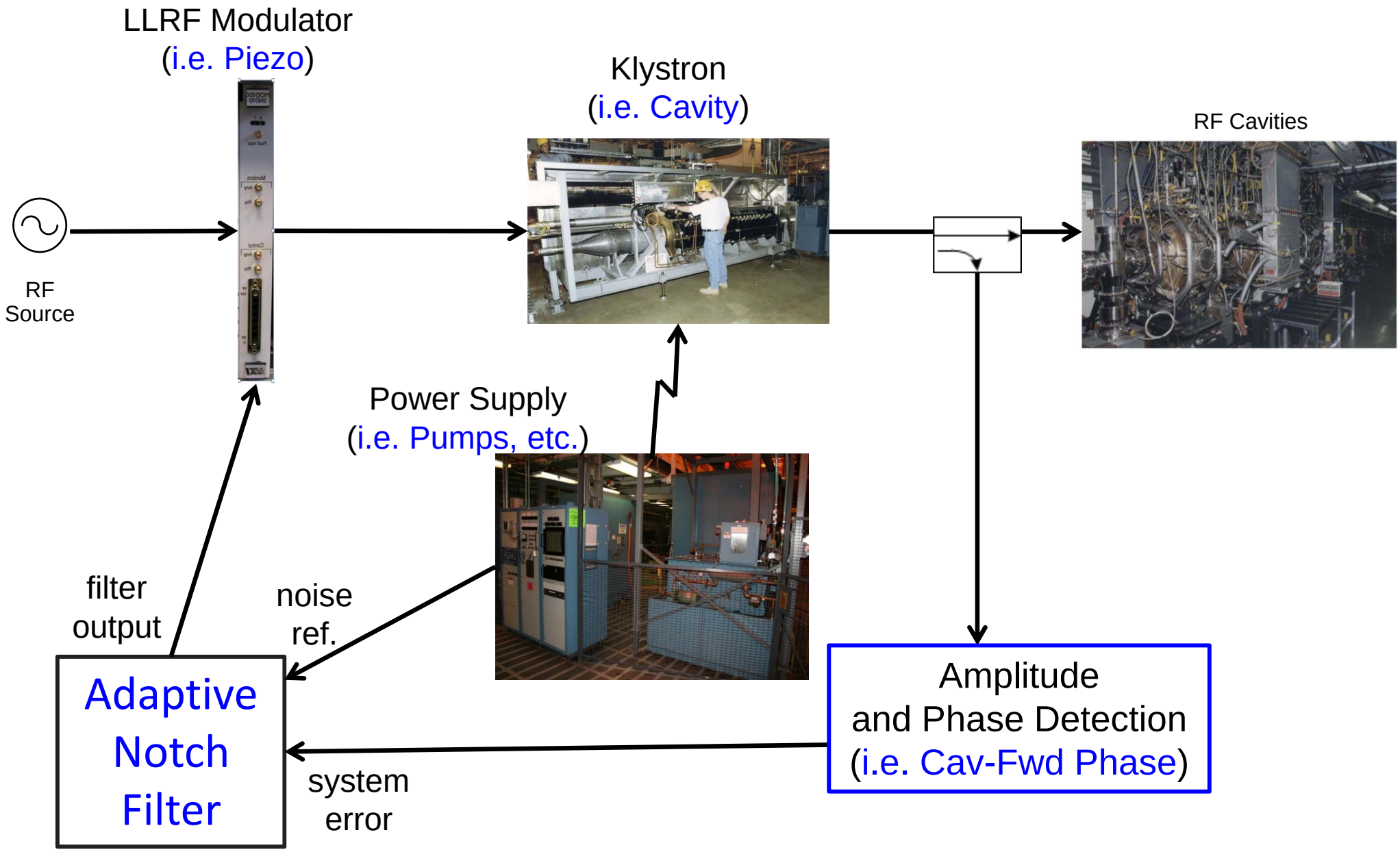
U.S. DEPARTMENT OF ENERGY
Office of Science

Adaptive Noise Canceller

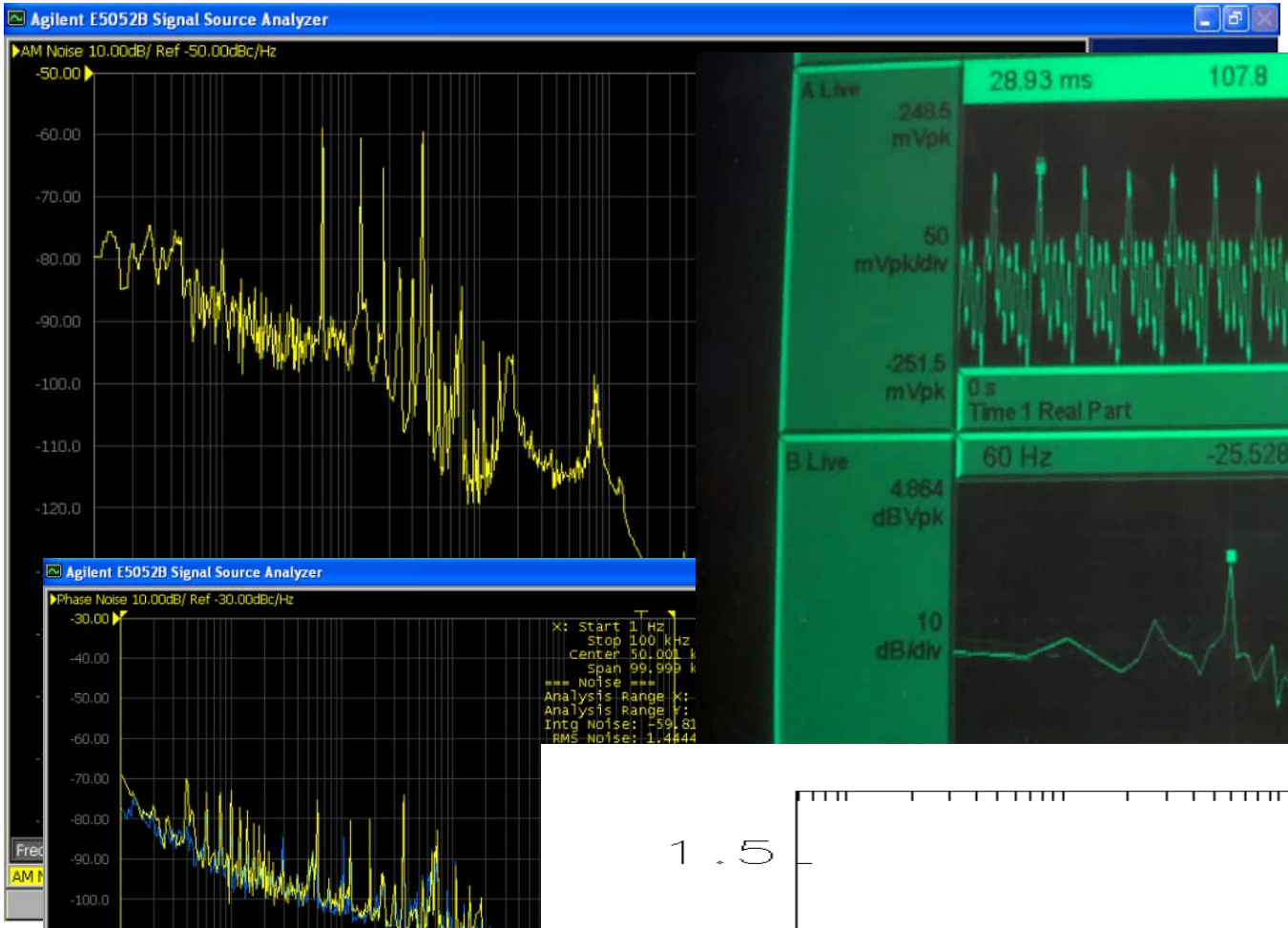


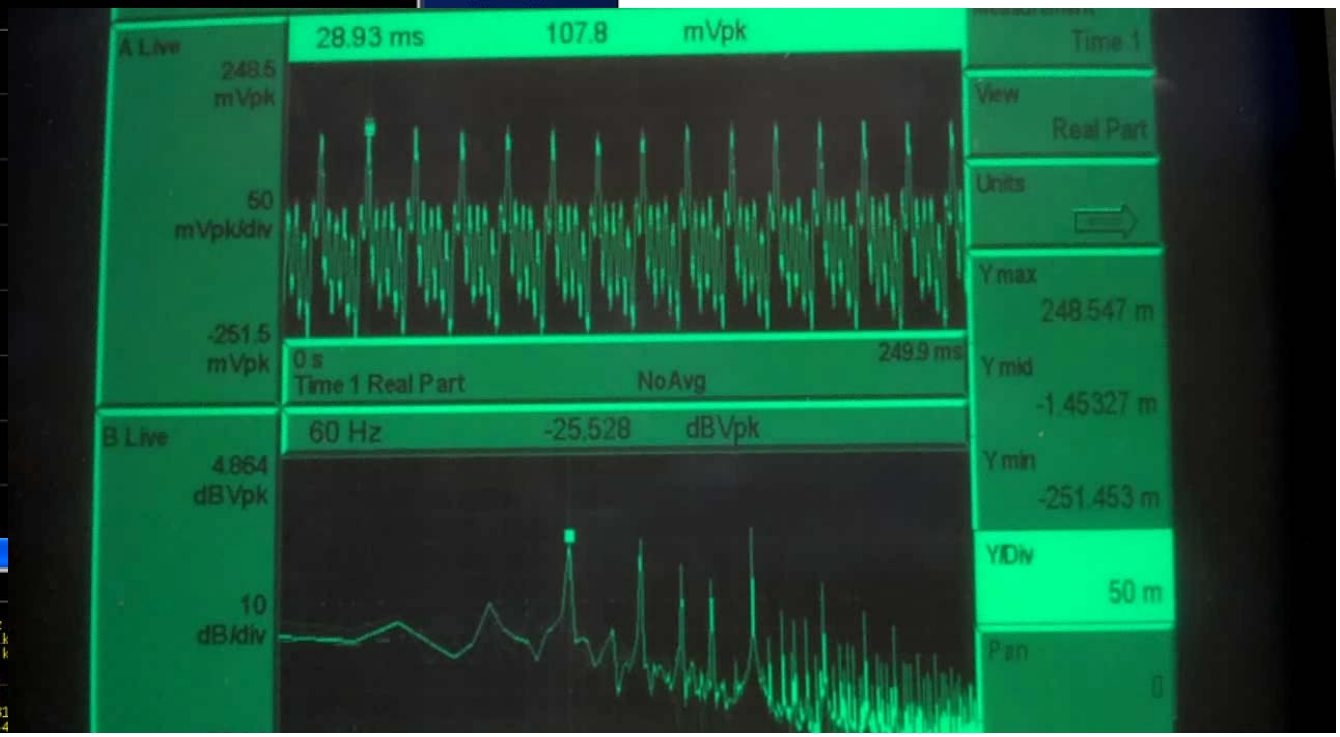
Extremely difficult to match H(z)'s amplitude and phase to the noise coupling path over a large bandwidth. This limits ANC for addressing multiple discrete lines.

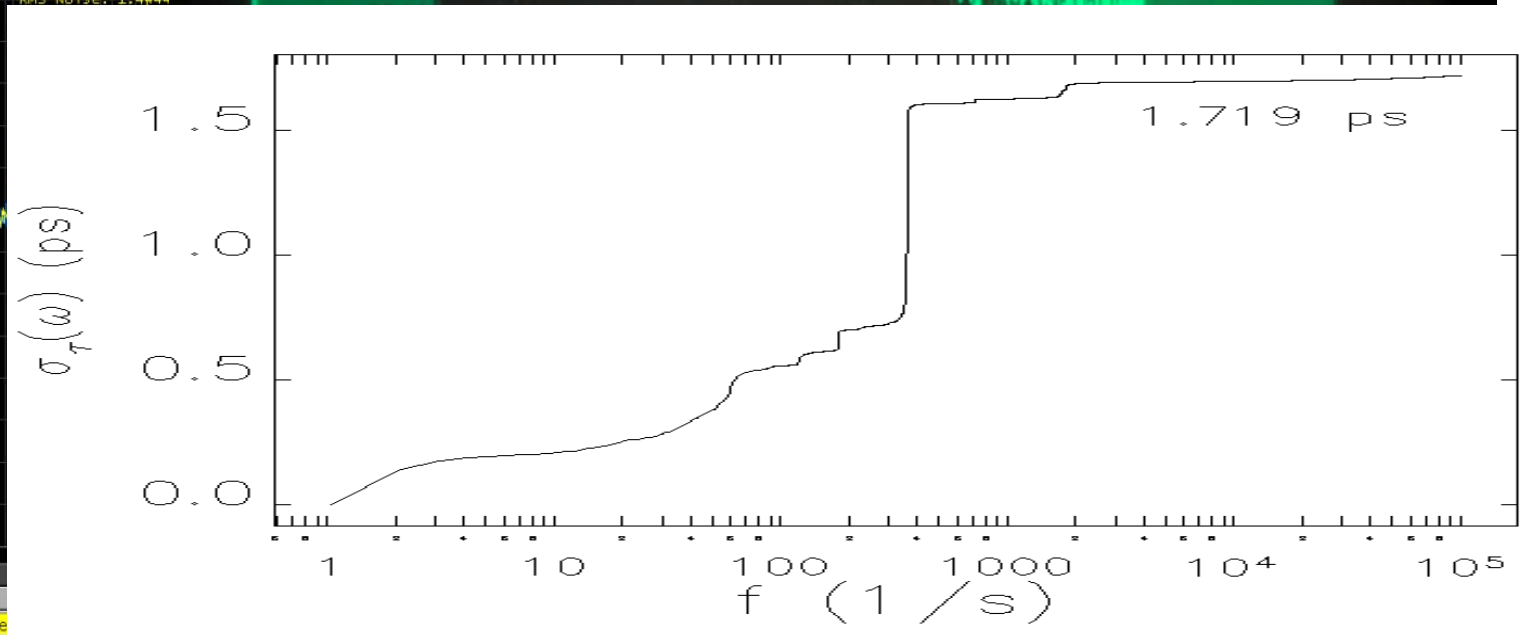
Specific Example but concept applies in general



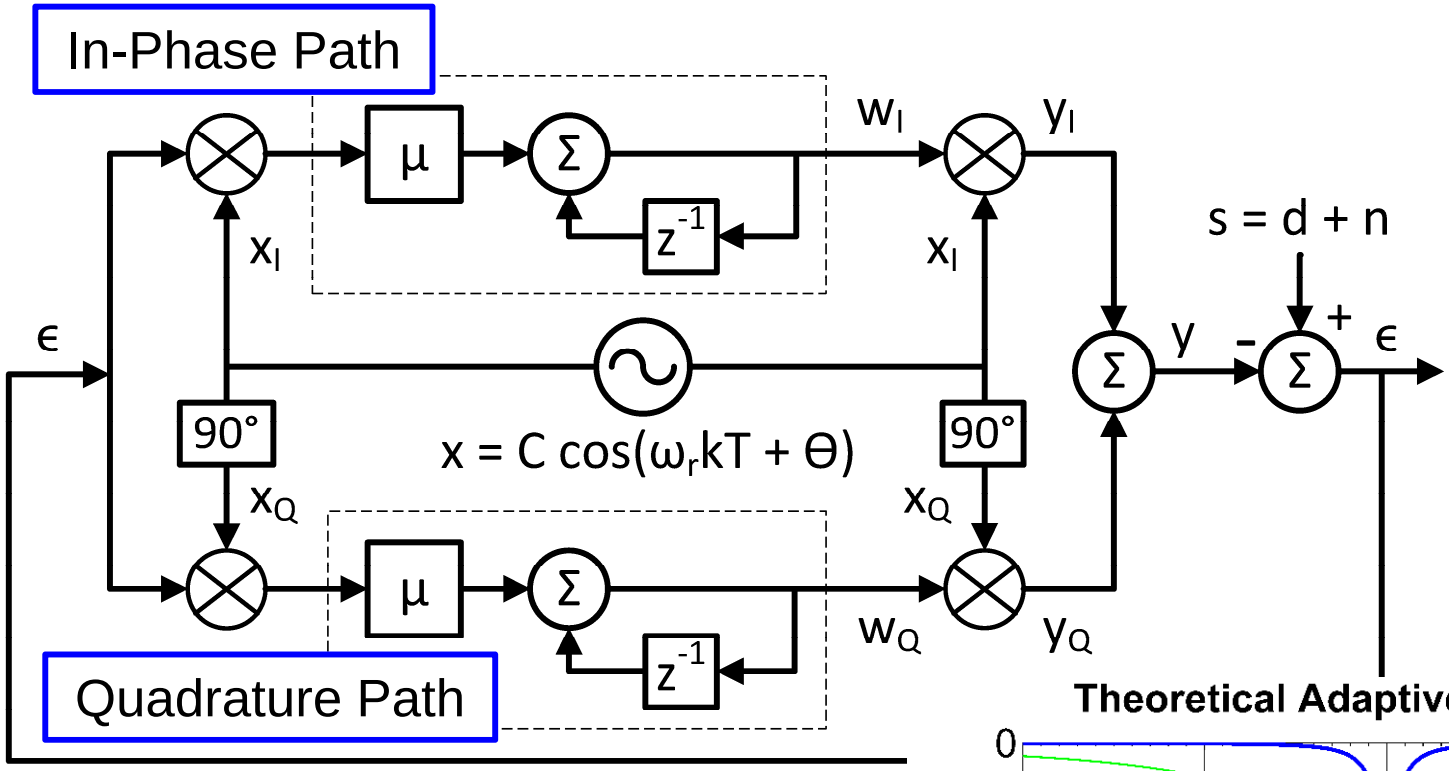
Discrete Spectral Lines – can dominate

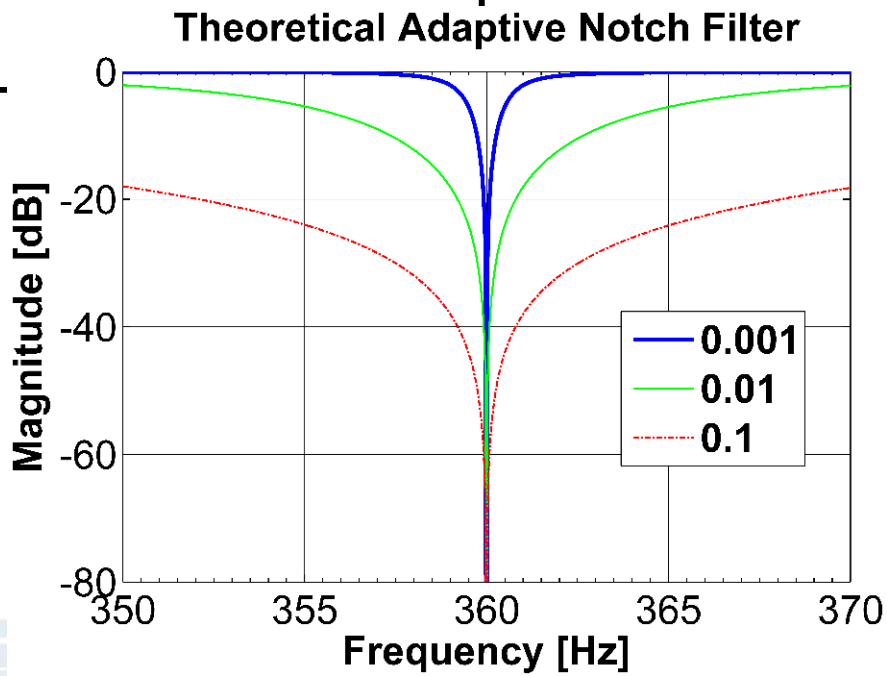




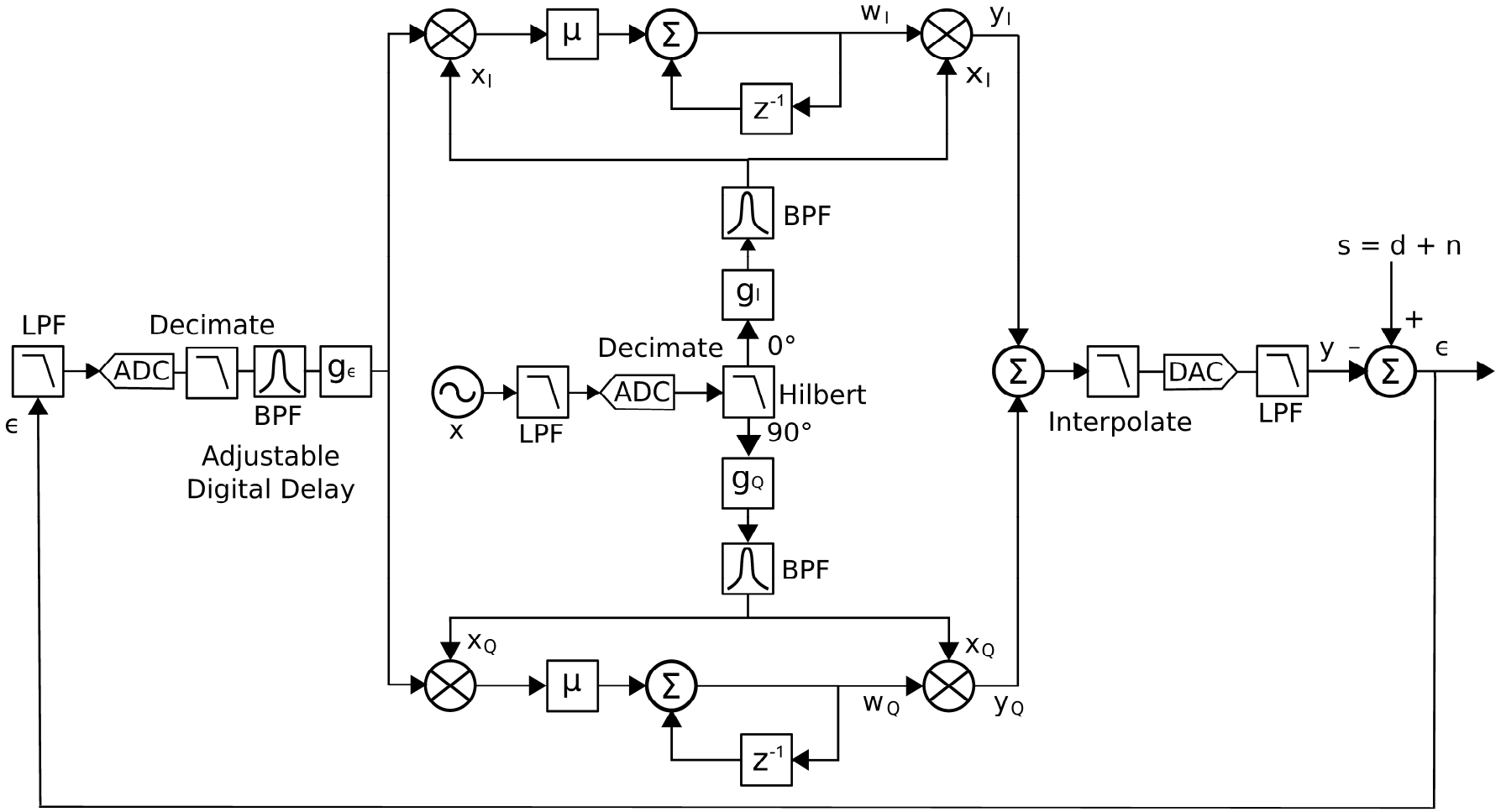


2-Weight Filter = Tracking Notch Filter = LLRF system with Integral Gain





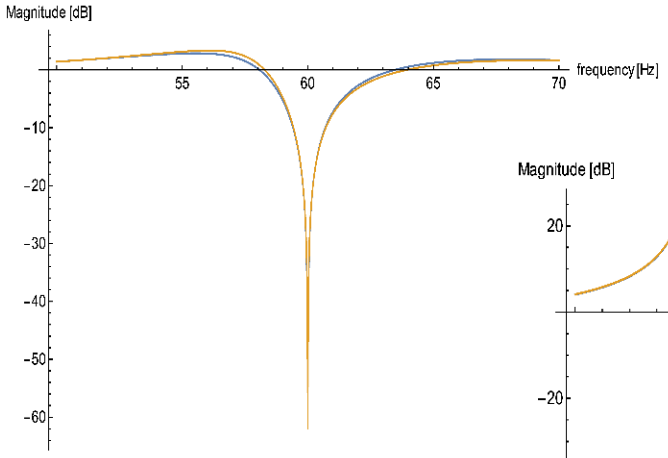
Single Narrowband Channel (1 of many)

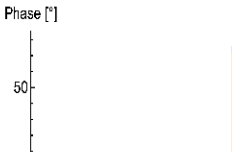


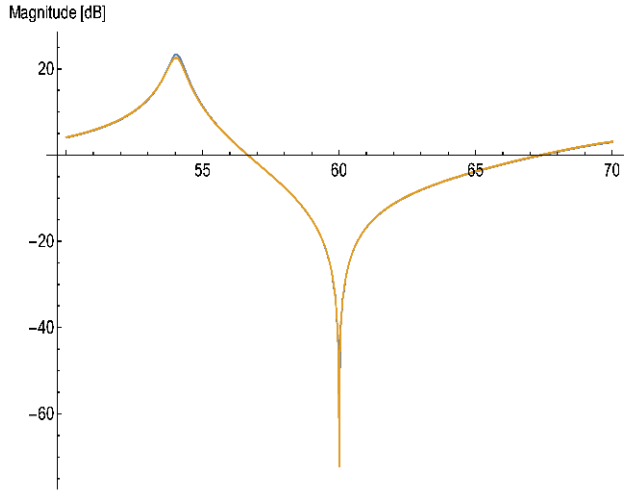
- There is NO NEED for frequency estimation as used in other implementations
  - use reference signal
  - wideband Hilbert filter is used to generate quadrature reference signals
- Narrow band-pass filters (400th order) used to select discrete lines (ref & error)

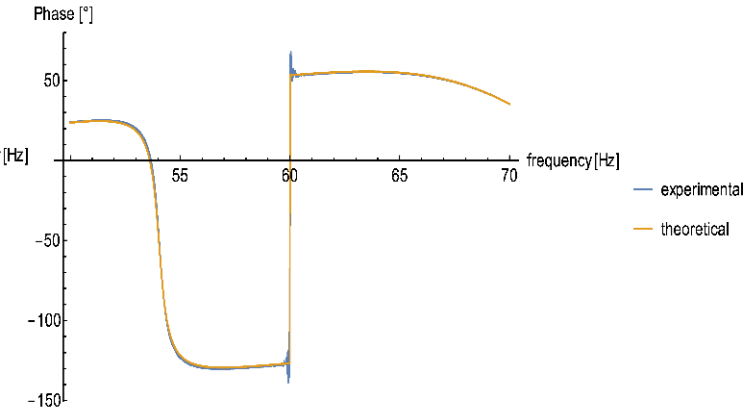
Response & Nyquist Stability Analysis

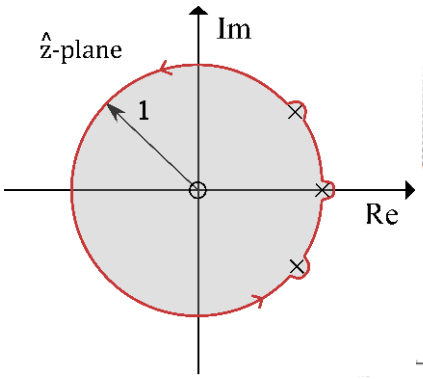
Note: analysis can be made at the carrier
(i.e., there is no need to analyze 2x2 (I/Q) system)

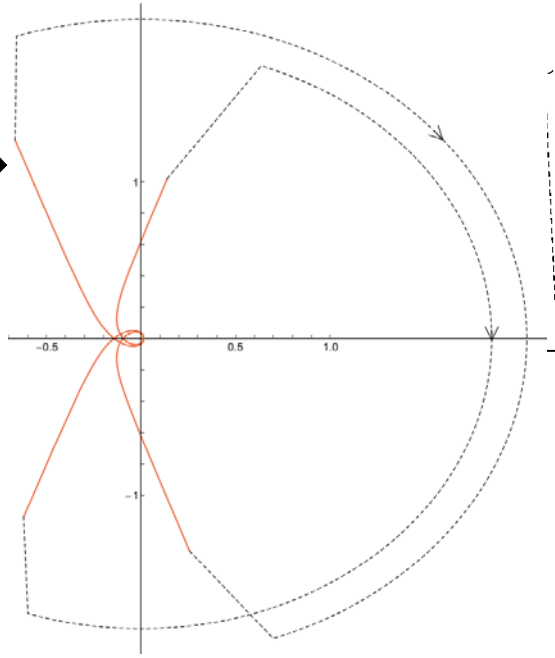


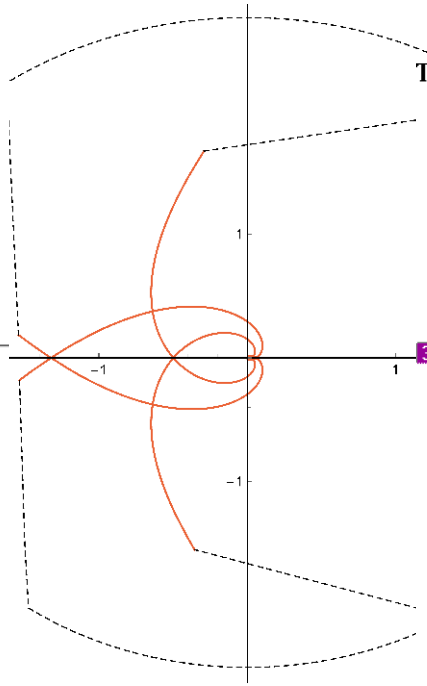


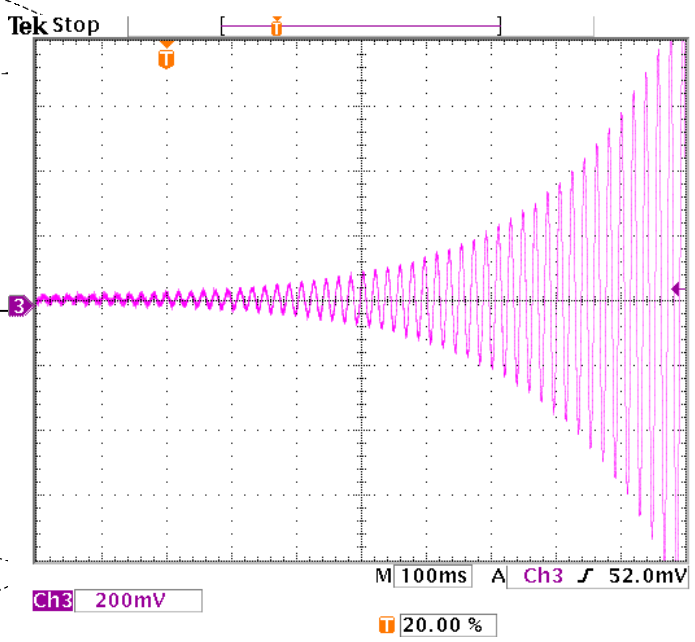




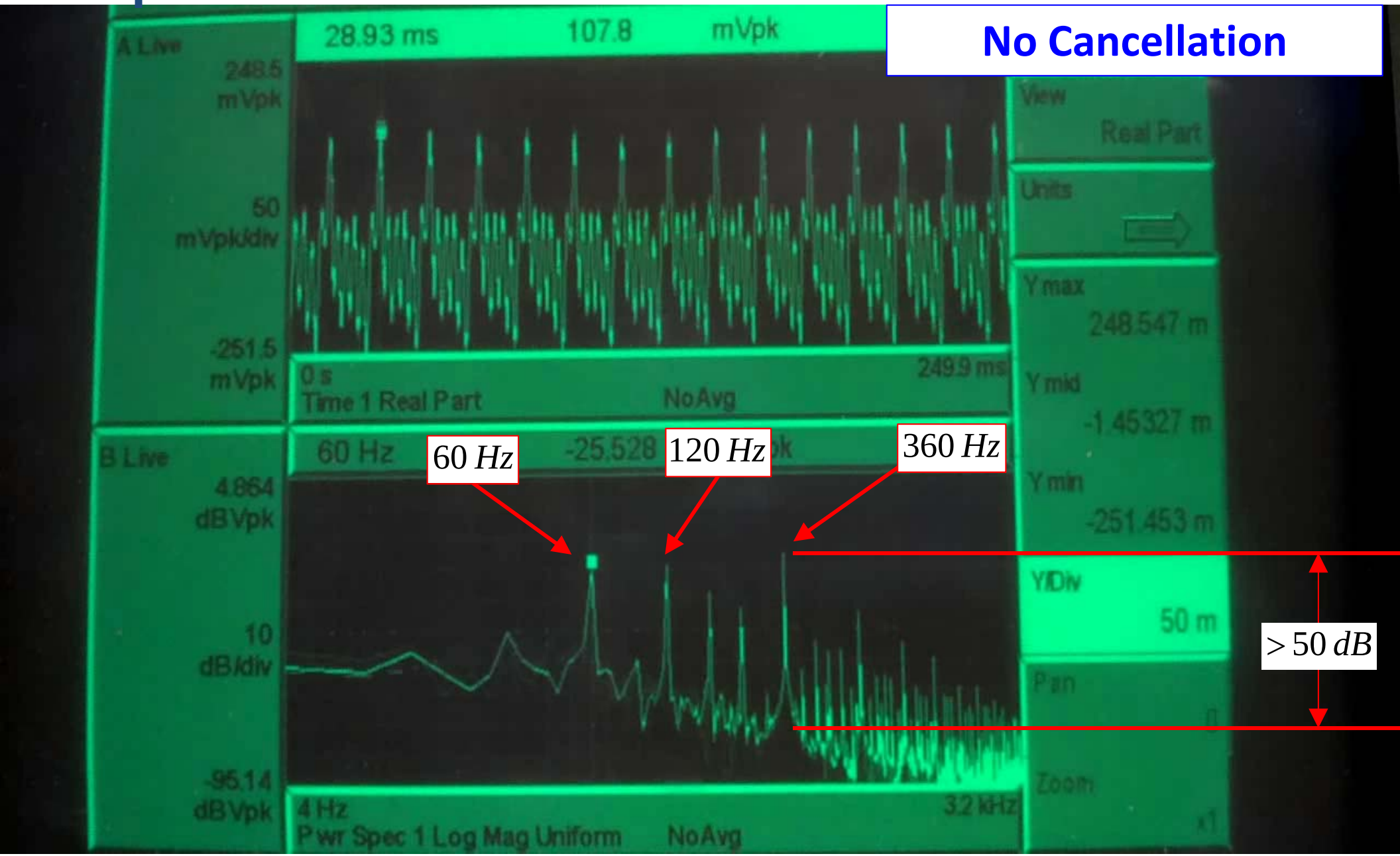








Adaptive Noise Cancellation – Demo at RF Test Stand



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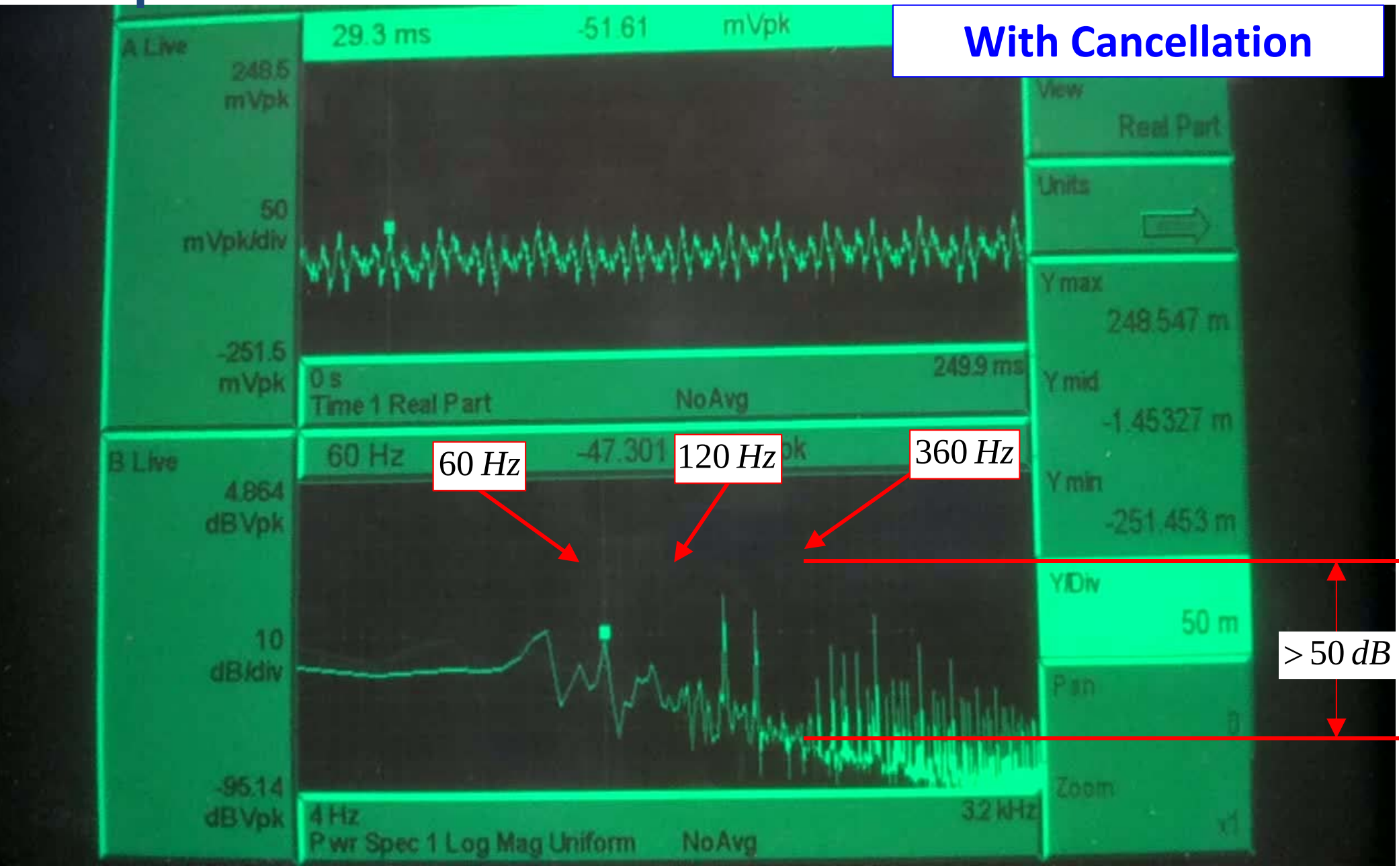
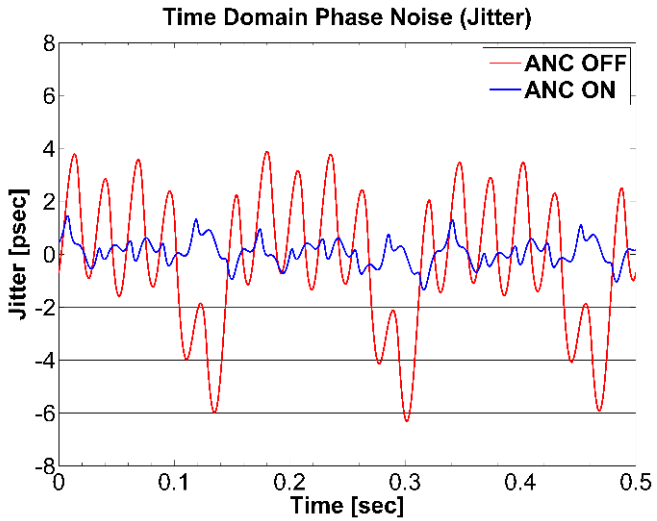
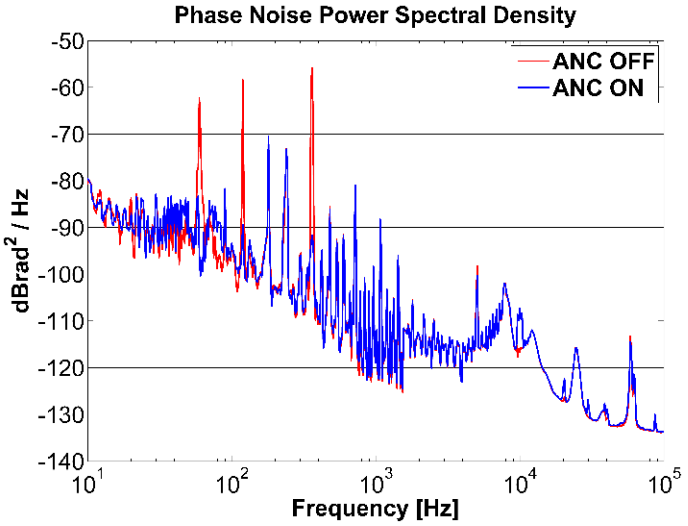
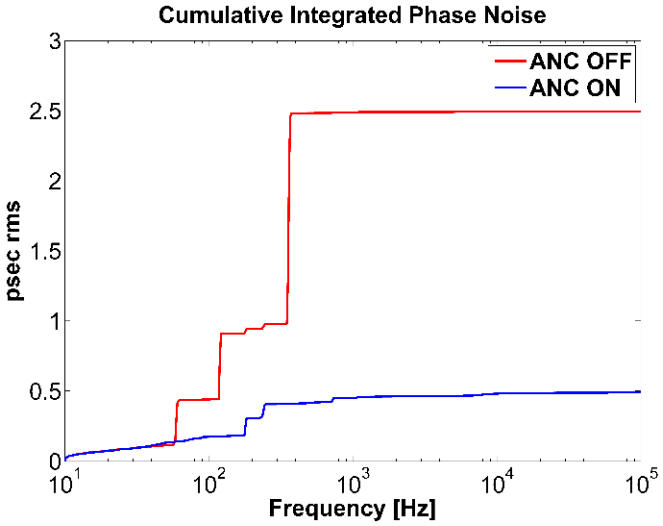
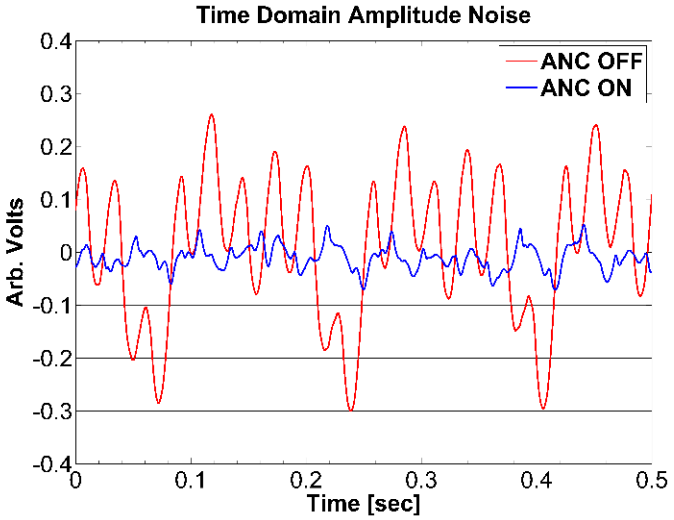
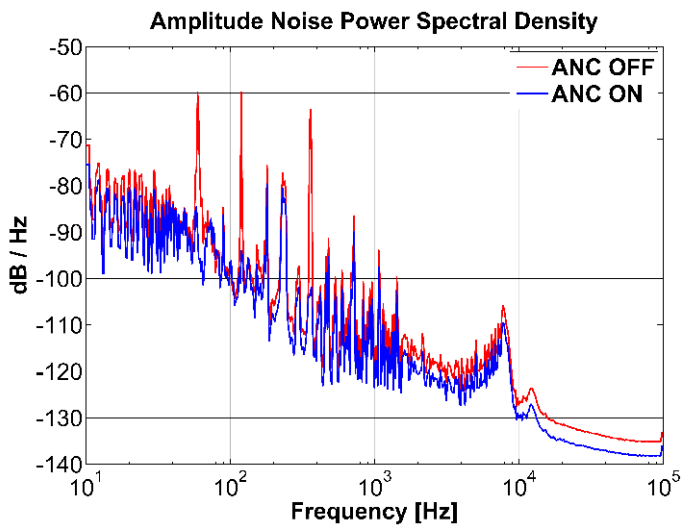


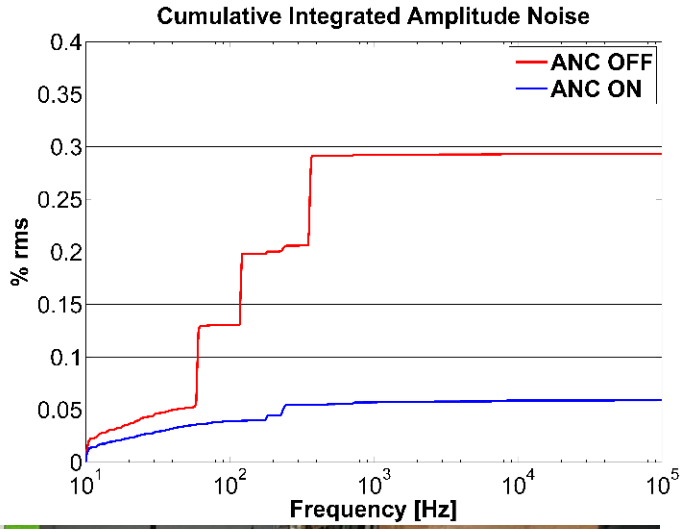

Time Domain Phase Noise (Jitter)
ANC OFF
ANC ON
Jitter [psec]
Time [sec]

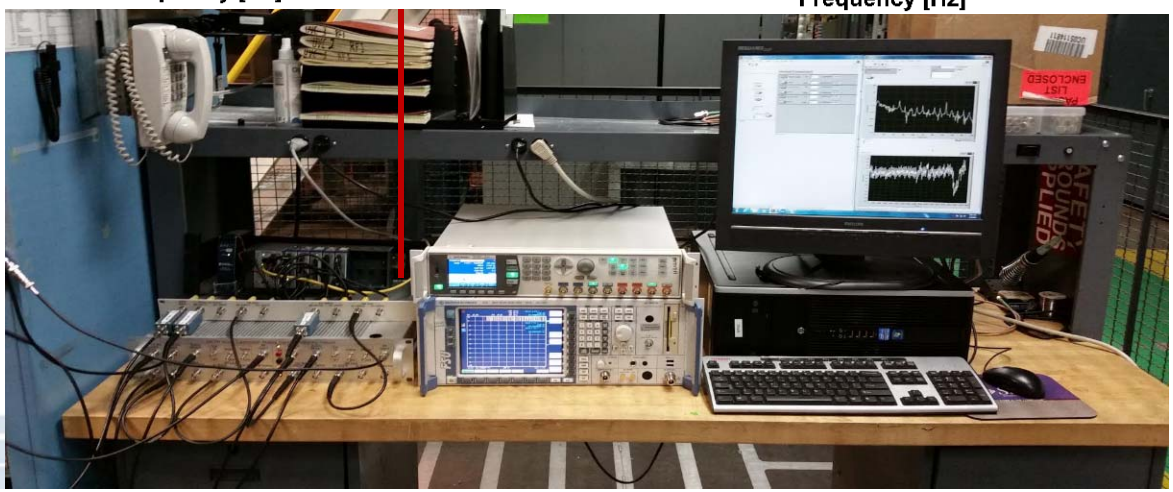

Phase Noise Power Spectral Density
ANC OFF
ANC ON
dBrad^2 / Hz
Frequency [Hz]


Cumulative Integrated Phase Noise
ANC OFF
ANC ON
psec rms
Frequency [Hz]


Time Domain Amplitude Noise
ANC OFF
ANC ON
Arb. Volts
Time [sec]


Amplitude Noise Power Spectral Density
ANC OFF
ANC ON
dB / Hz
Frequency [Hz]

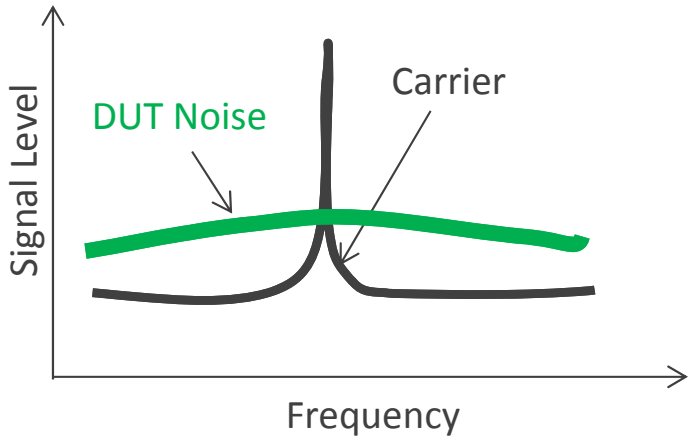

Cumulative Integrated Amplitude Noise
ANC OFF
ANC ON
% rms
Frequency [Hz]

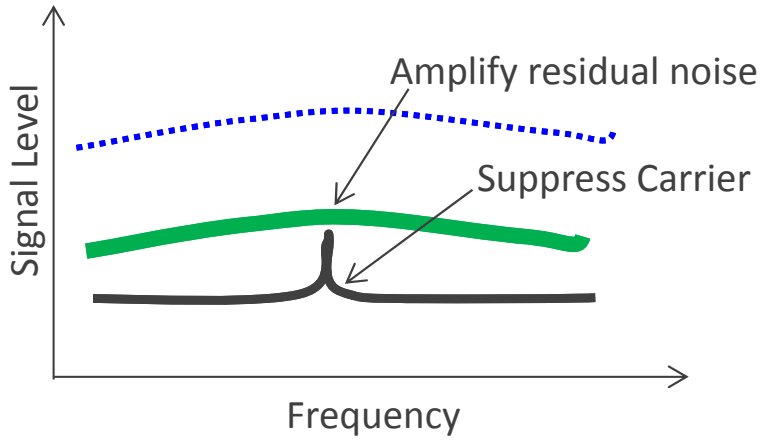


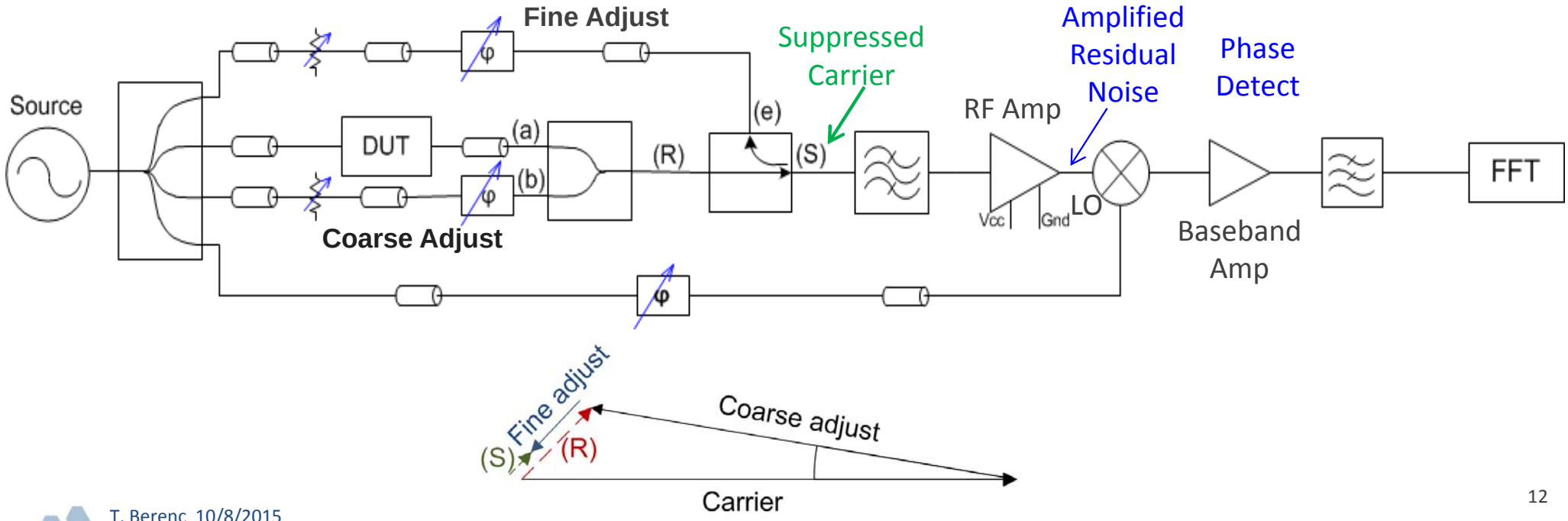
Towards State of the Art in RF Noise Measurements

Interferometric Noise Measurement

Suppress the carrier and AMPLIFY !

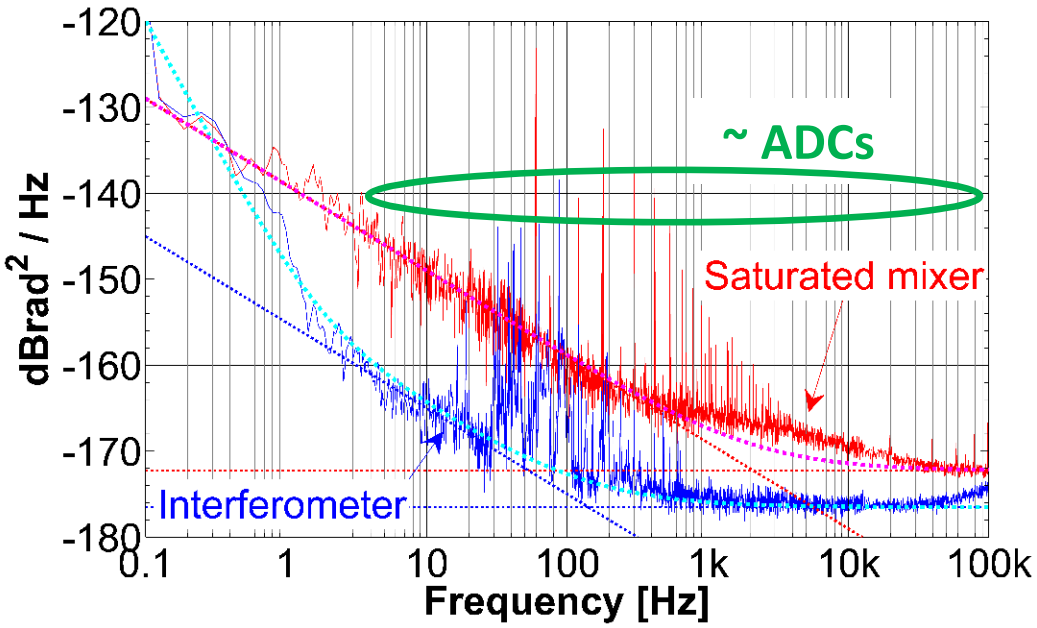


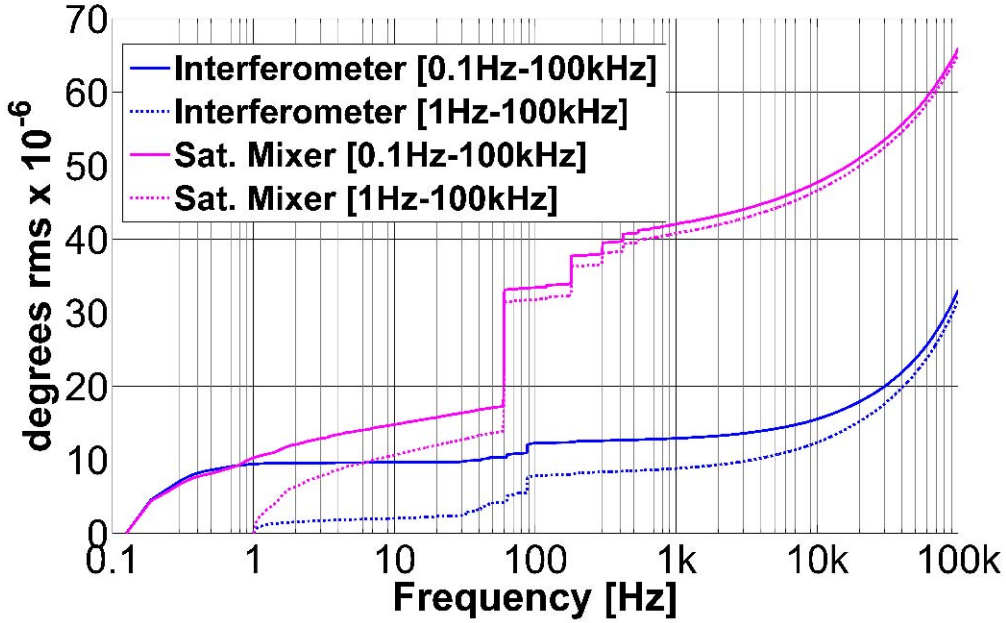


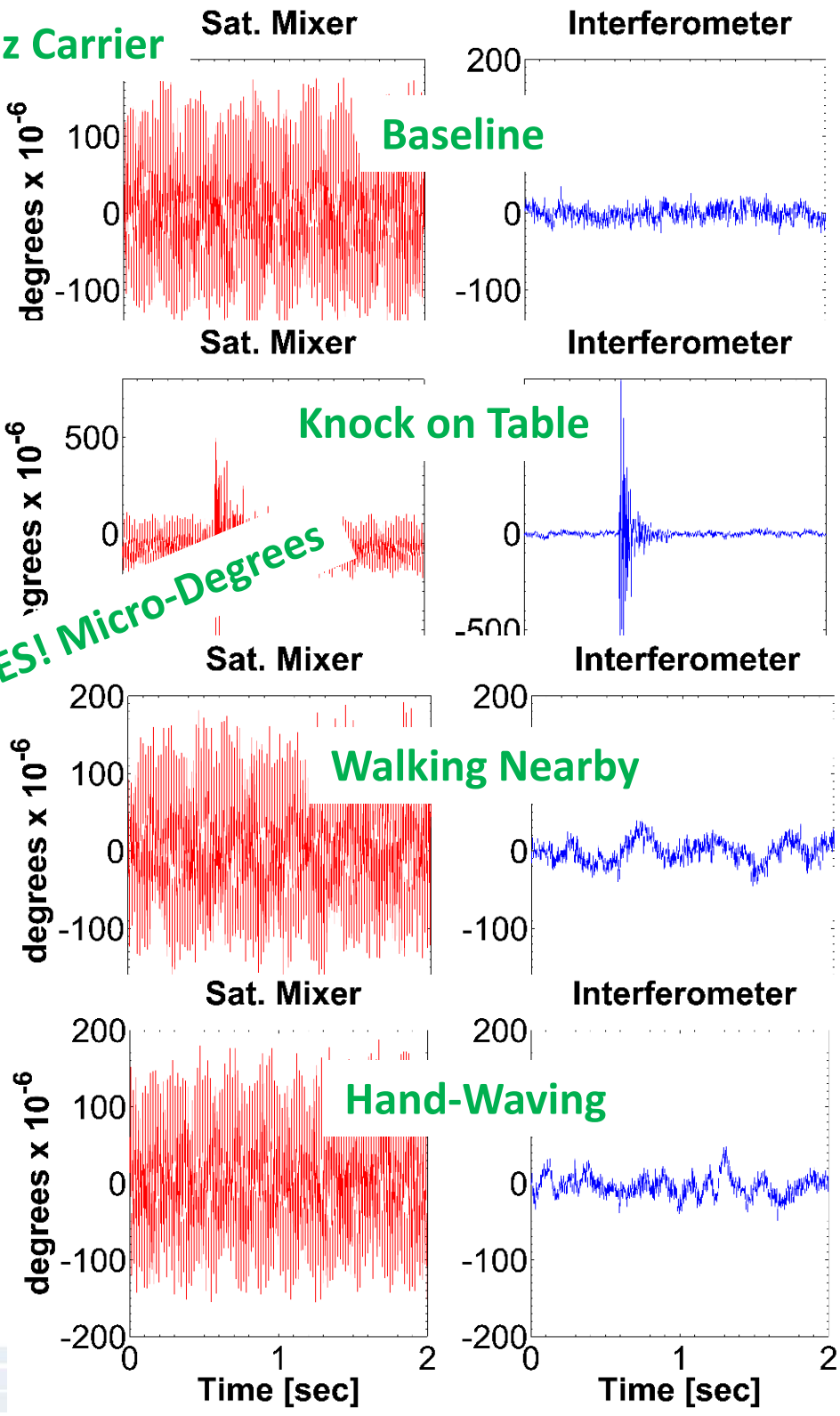


Comparison to Saturated Mixer

2816 MHz Carrier







Summary

- If narrowband spectral lines dominate the noise, treat them just like LLRF integral control of a carrier.

- There is NO NEED for frequency estimation, just use the reference signal with appropriate narrow band-pass filtering and Hilbert filter

- Interferometric measurement technique offers state-of-the-art measurements. Can be used for cavity phase and/or for cavity resonance detection
  - Consider a dual bandwidth system ??
    - ADCs for ~DC, mixer/interferometer for >DC noise

References:

T. Berenc, K. Cook, “RF Noise Suppression for the APS Storage Ring”, 2014 Lee Teng Internship,
http://www.illinoisacceleratorinstitute.org/2014%20Program/student_papers/Kevin_Cook.pdf

T. Berenc, T. Vannoy, “Stability Analysis of an Adaptive Notch Filter for RF Noise Suppression”, 2015 Lee Teng Internship,
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T. Berenc, P. Buabthong, “Interferometric Residual Noise Measurement System”, 2013 Lee Teng Internship,
http://www.illinoisacceleratorinstitute.org/2013%20Program/student_papers/Pakpoom_Buabthong.pdf

For a wealth of amplitude and phase noise metrology resources go to:
www.rubiola.org

E. Rubiola, “Advanced interferometric phase and amplitude noise measurements”, Rev. Sci. Instrum. Vol.73 No.6, June 2002.
http://www.rubiola.org/pdf-articles/journal/2002rsi(rubiola)advanced-phase-noise-metrology.pdf