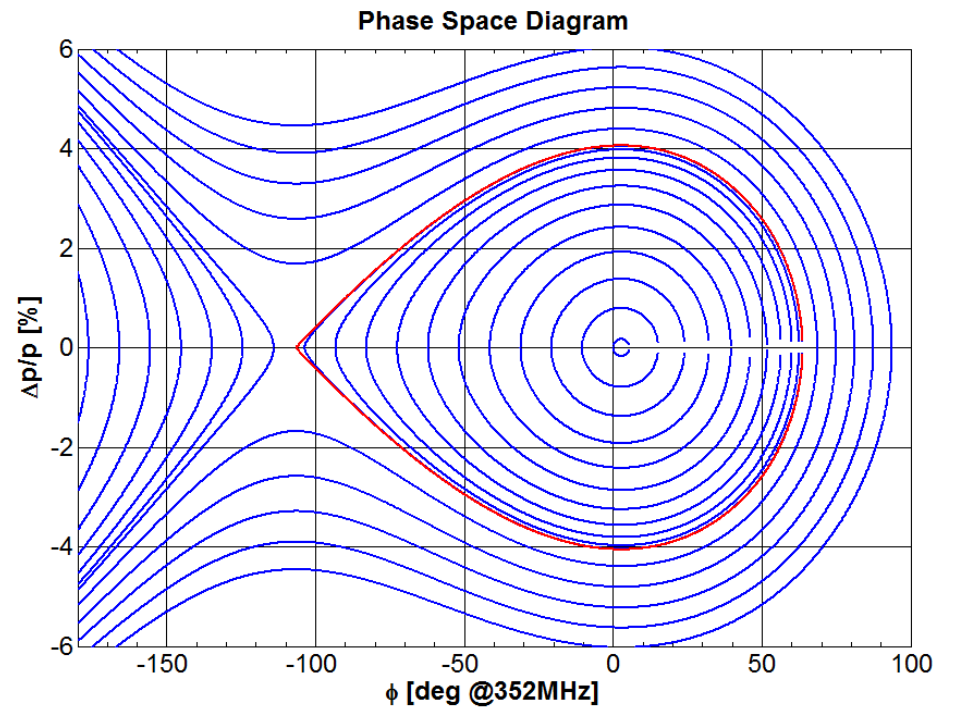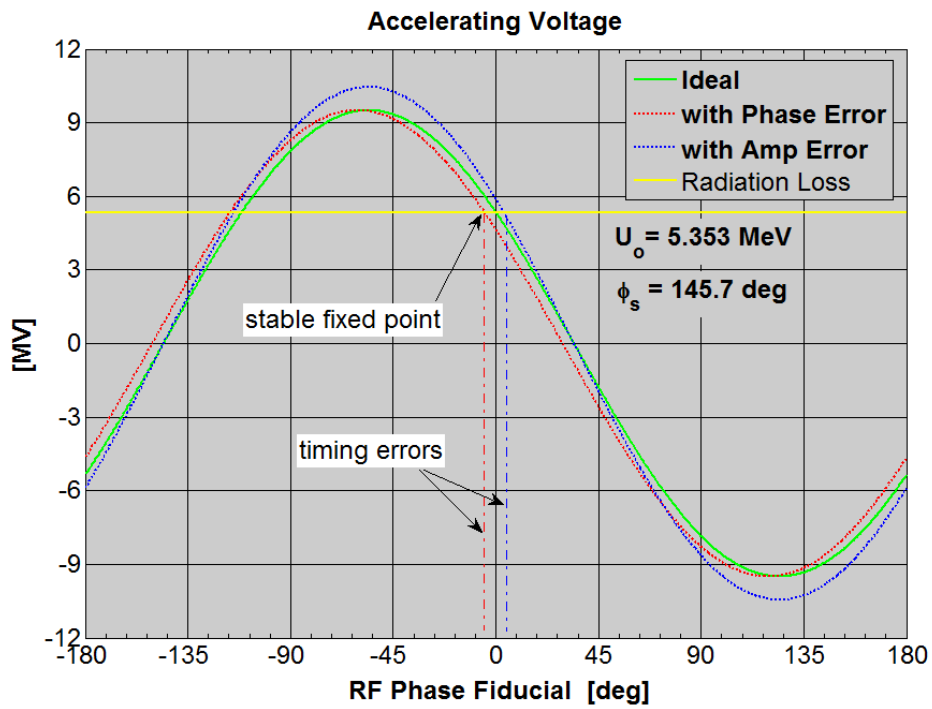# RF Noise Suppression
# for the APS Storage Ring

Increasing longitudinal beam stability through a more stable RF system
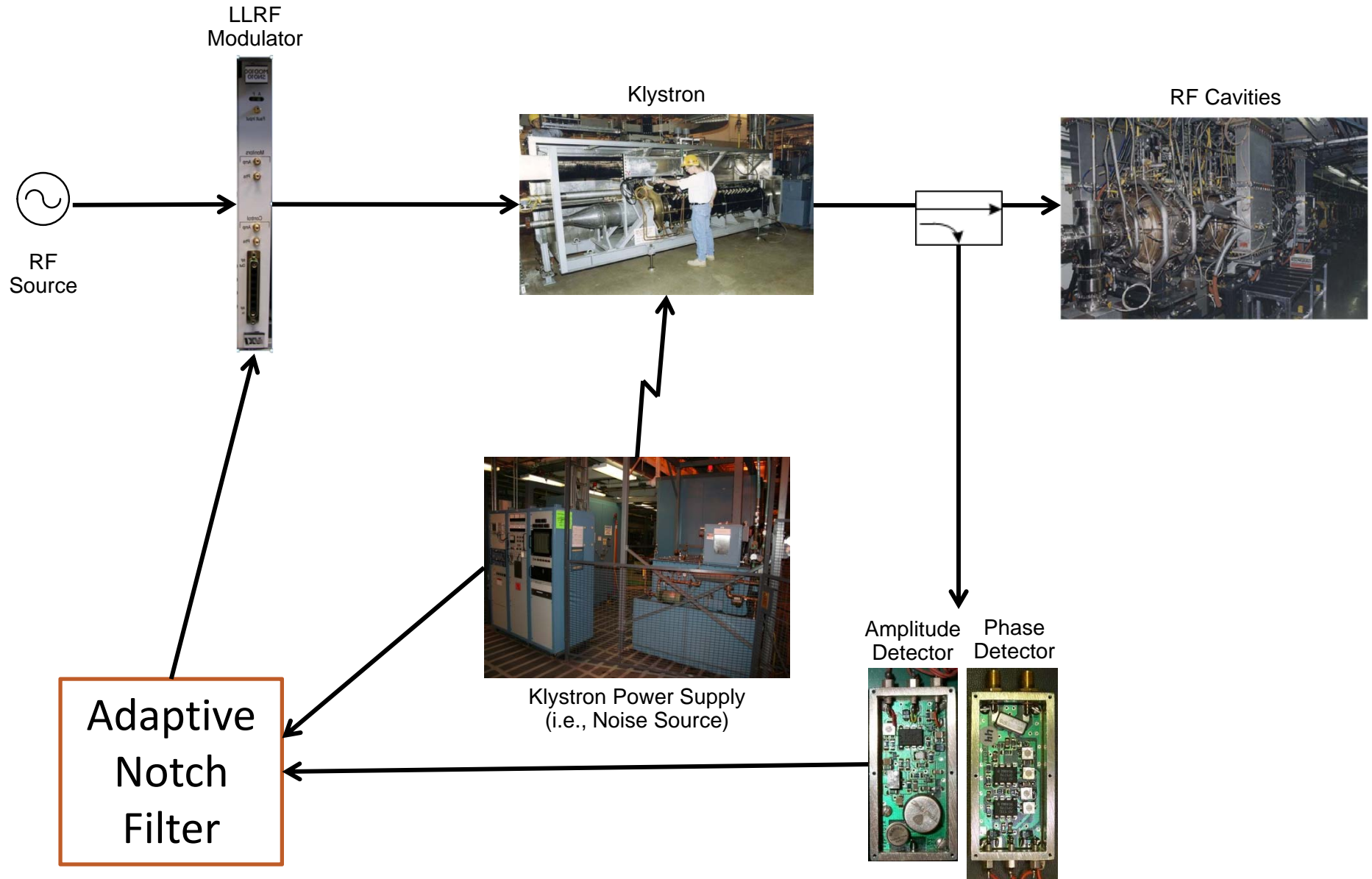
Kevin Cook

Tim Berenc

# Longitudinal Stability



Accelerating Voltage

$U_o$ = 5.353 MeV

$\phi_s$ = 145.7 deg

stable fixed point

timing errors



Phase Space Diagram

# Noise Cancellation Scheme



LLRF Modulator

RF Source

Klystron

RF Cavities

Klystron Power Supply (i.e., Noise Source)

Amplitude Detector    Phase Detector

Adaptive Notch Filter

# The Adaptive Notch Filter
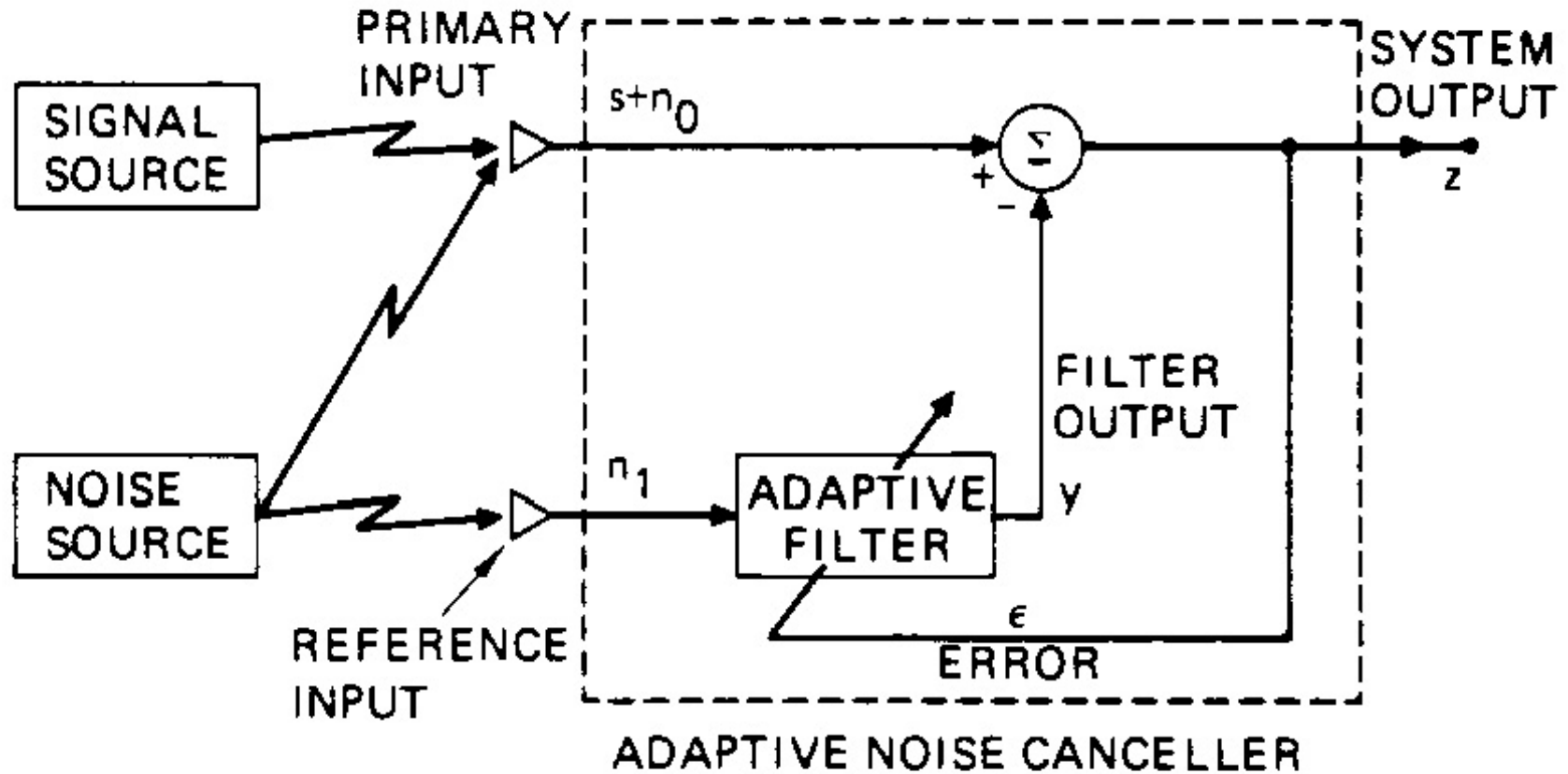


Fig. 1. The adaptive noise cancelling concept.

Widrow et. al, "Adaptive Noise Cancelling:  Principles & Applications"  IEEE Vol. 63, No. 12, Dec. 1975
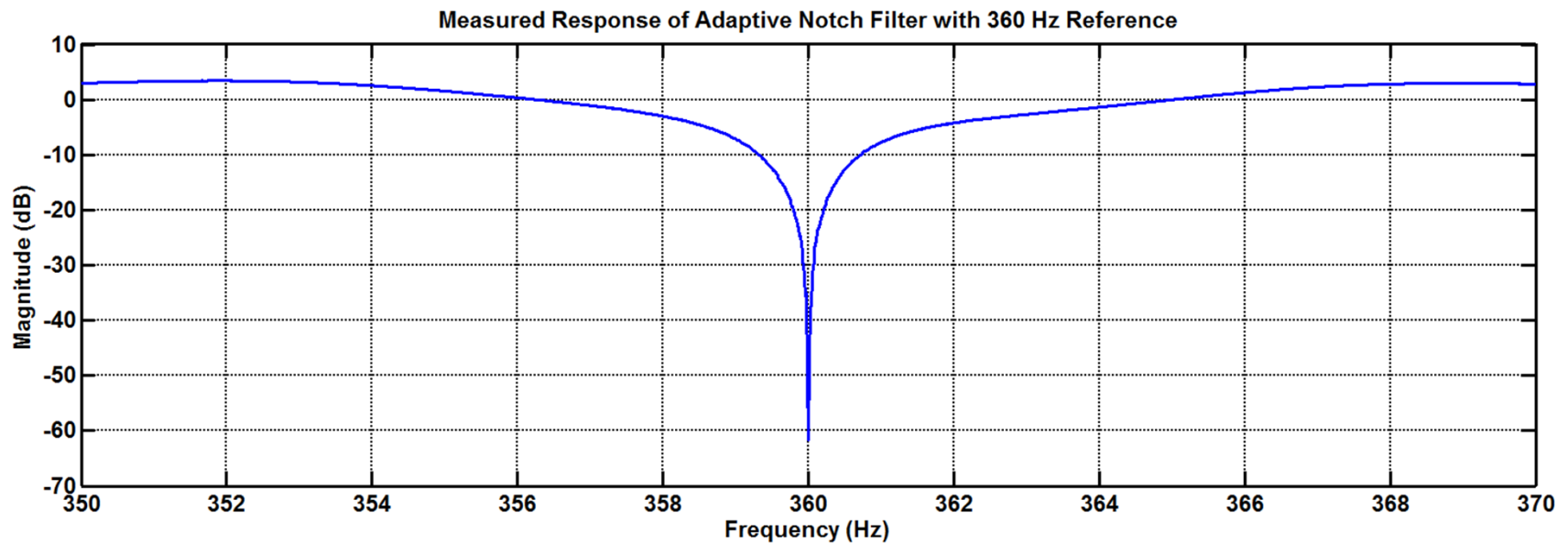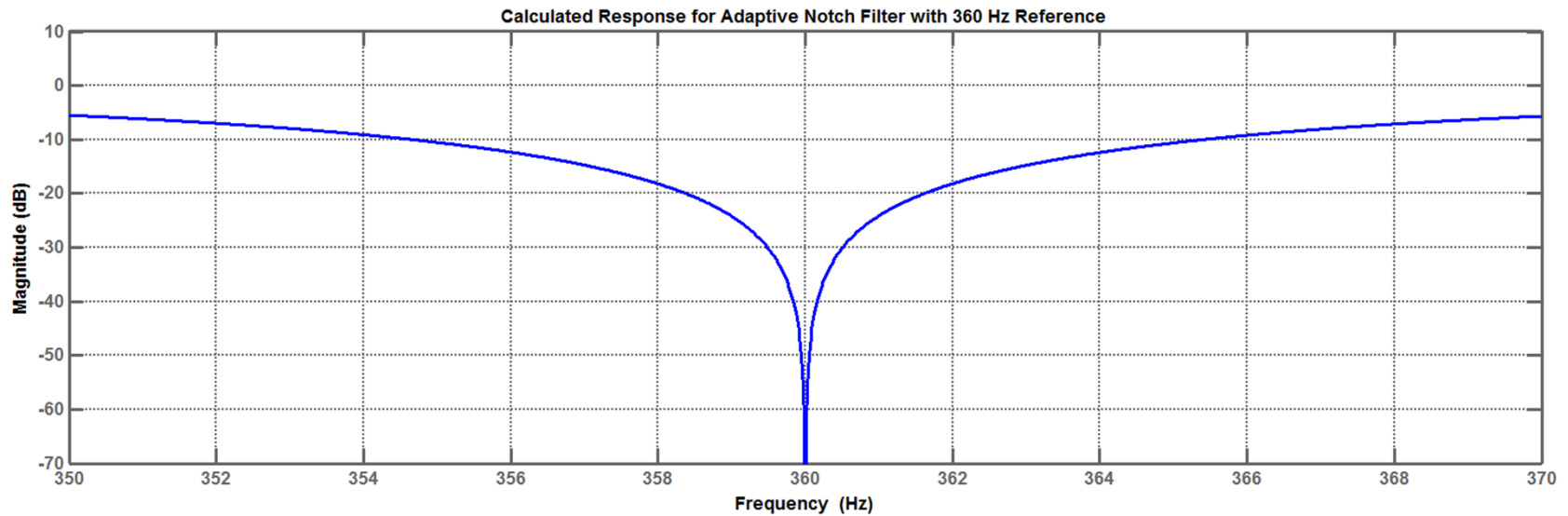
# Adaptive Notch Filter Diagram
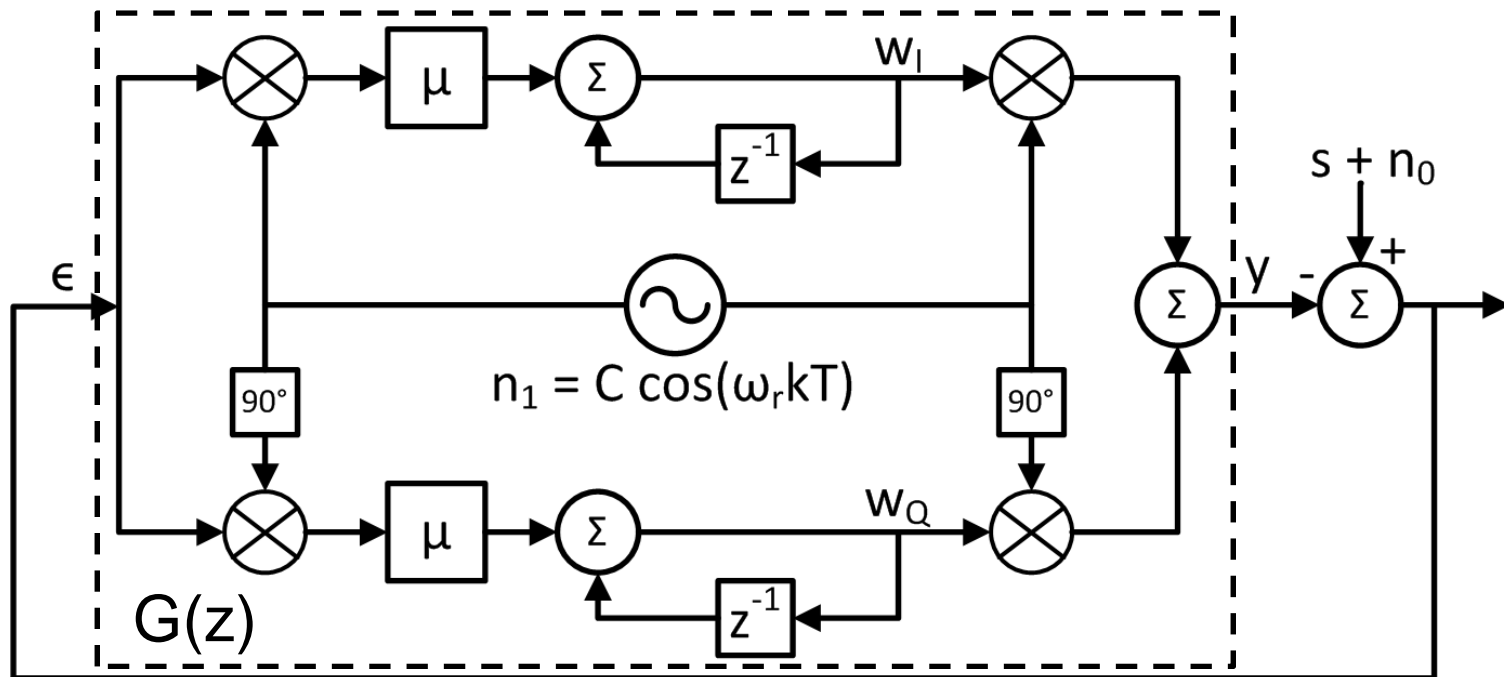


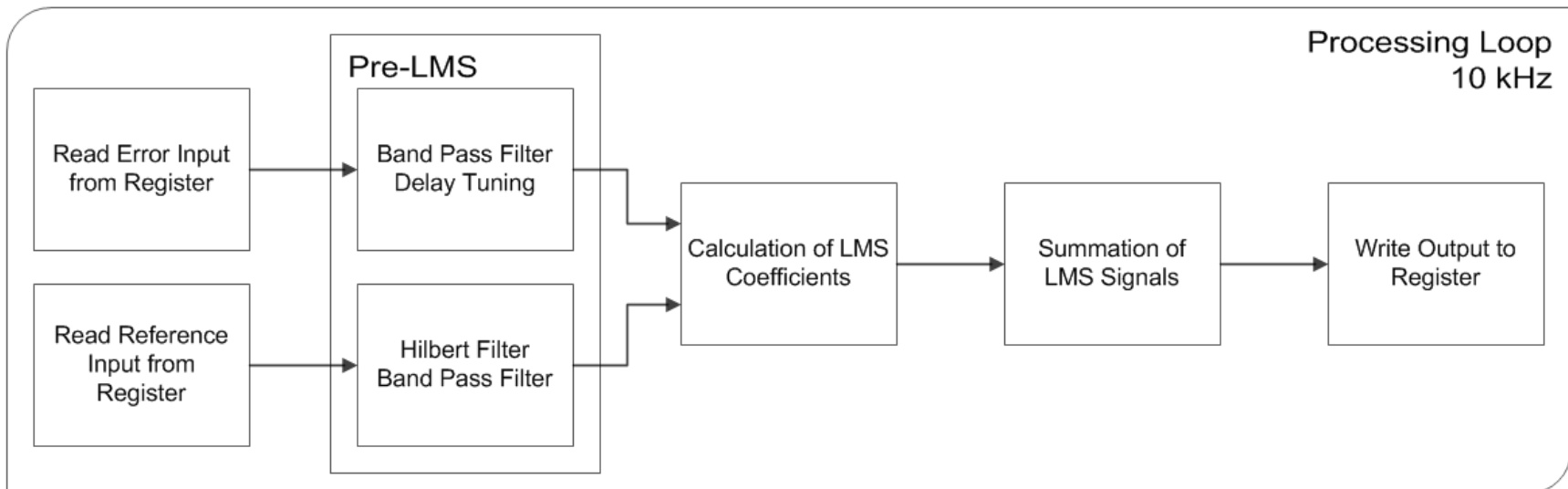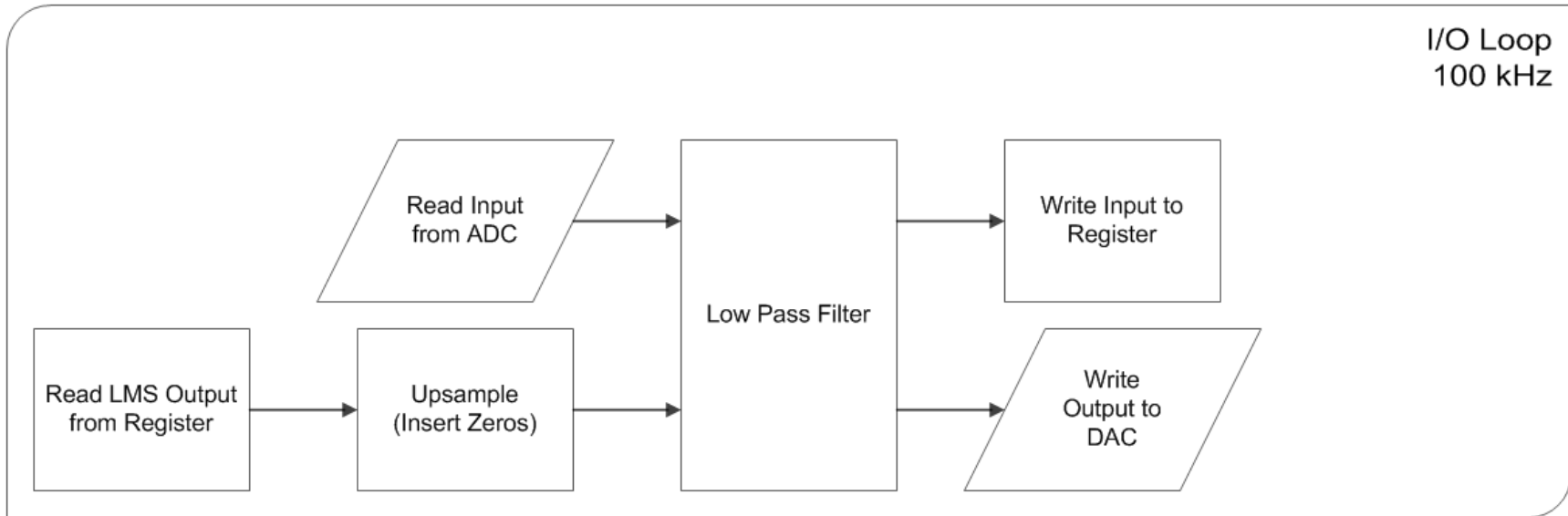$$G(z) = \mu C^2 \frac{z^2 - z\cos(\omega_r T)}{z^2 - 2z\cos(\omega_r T) + 1}$$

$$H(z) = \frac{1}{1 + G(z)} = \frac{z^2 - 2z\cos(\omega_r T) + 1}{(1 + \mu C^2)z^2 - (2 + \mu C^2)z\cos(\omega_r T) + 1}$$
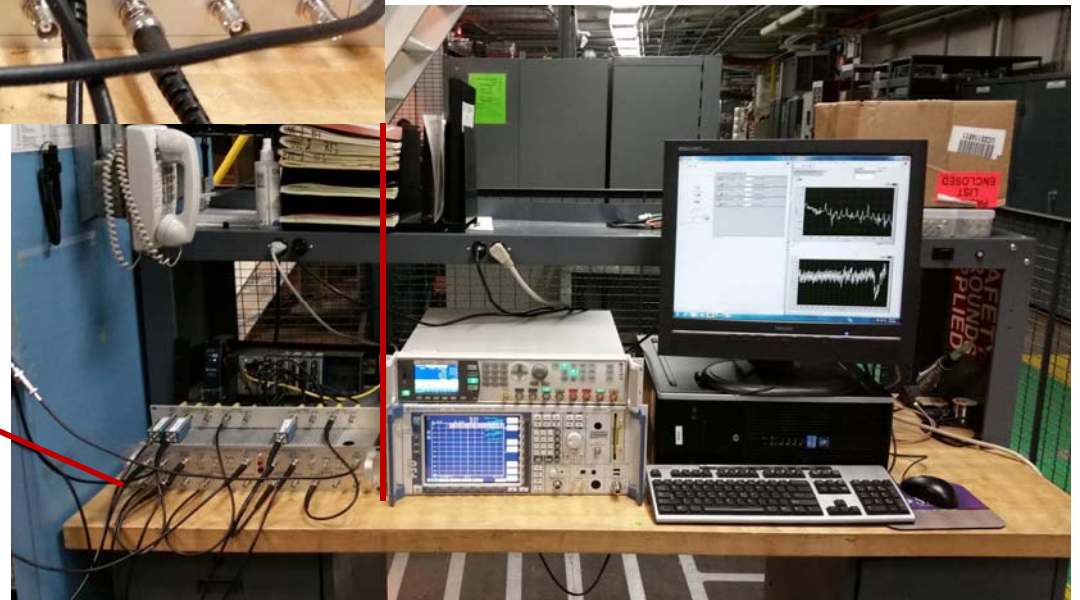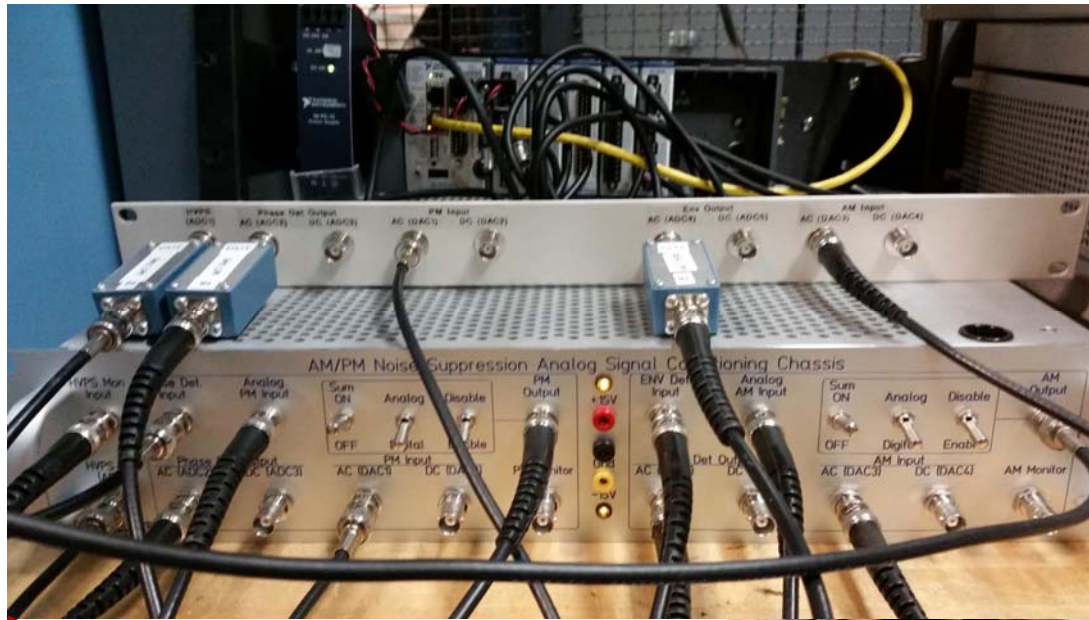
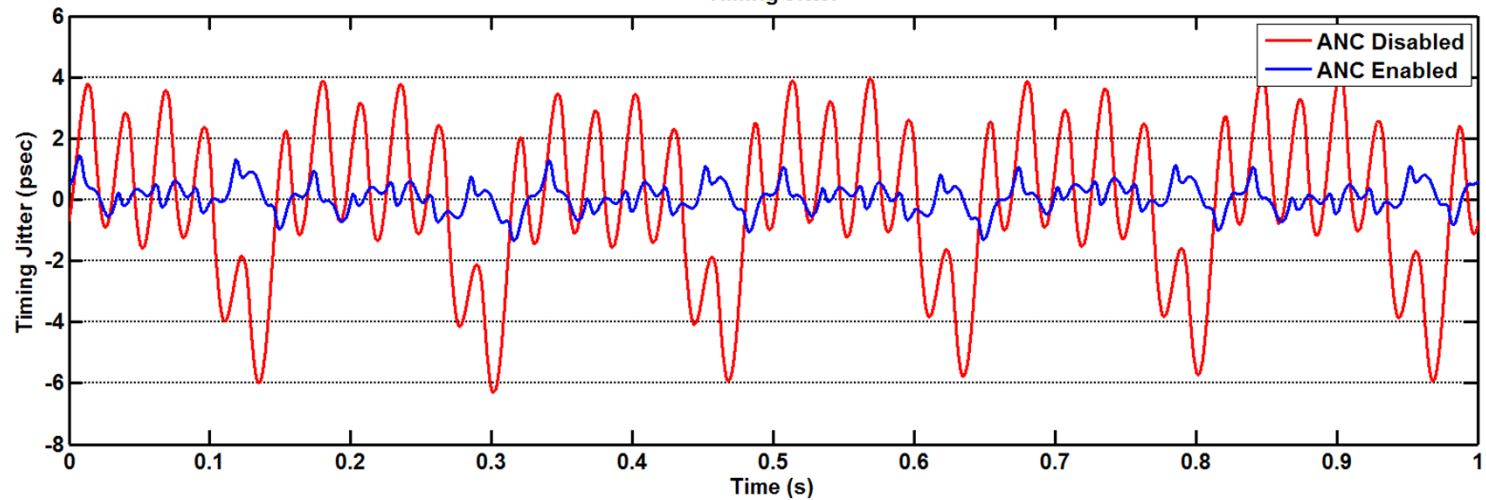# Frequency Response Simulation and Measurement
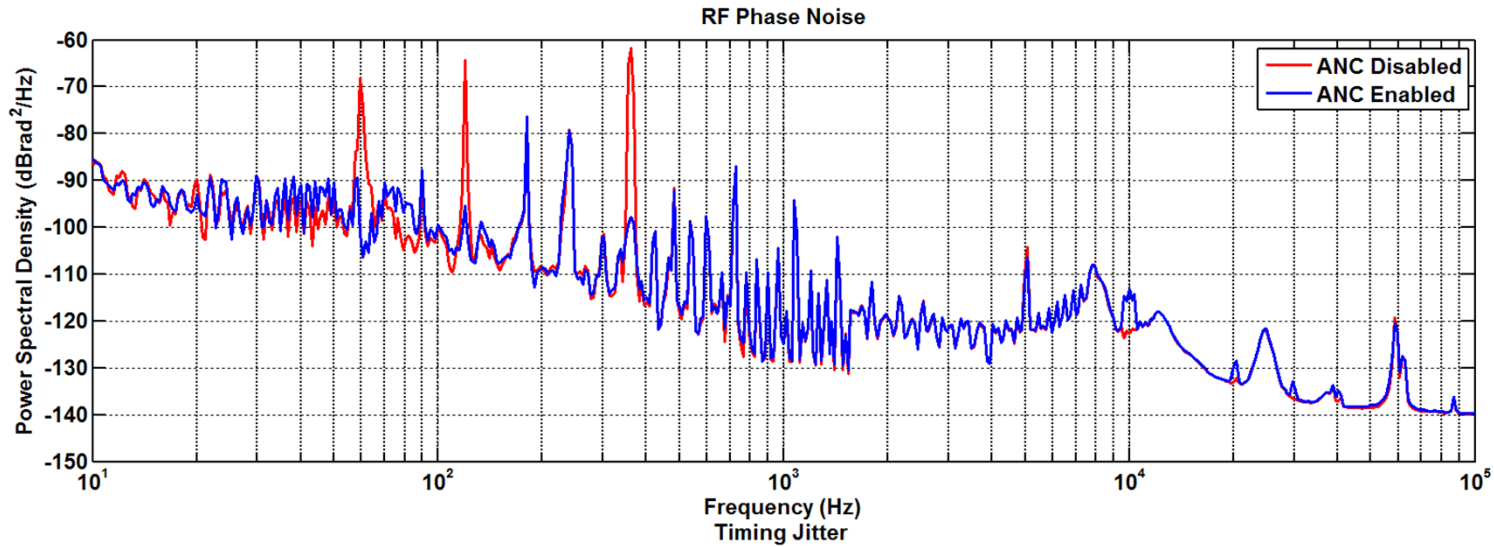


Calculated Response for Adaptive Notch Filter with 360 Hz Reference



Measured Response of Adaptive Notch Filter with 360 Hz Reference

# FPGA Implementation

# Adaptive Noise Cancellation System
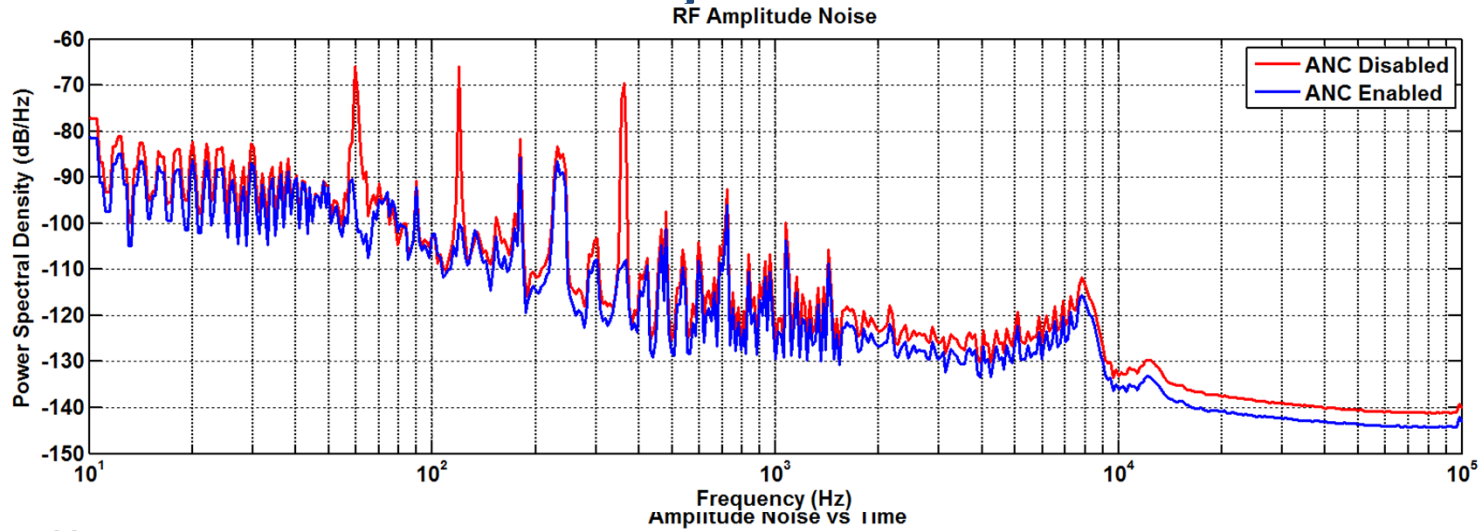
# RF Test Stand Trial - Phase



| ANC Disabled RMS Jitter | 2.472 ps |
|---|---|
| ANC Enabled RMS Jitter | 0.8085 ps |

# RF Test Stand Trial - Amplitude
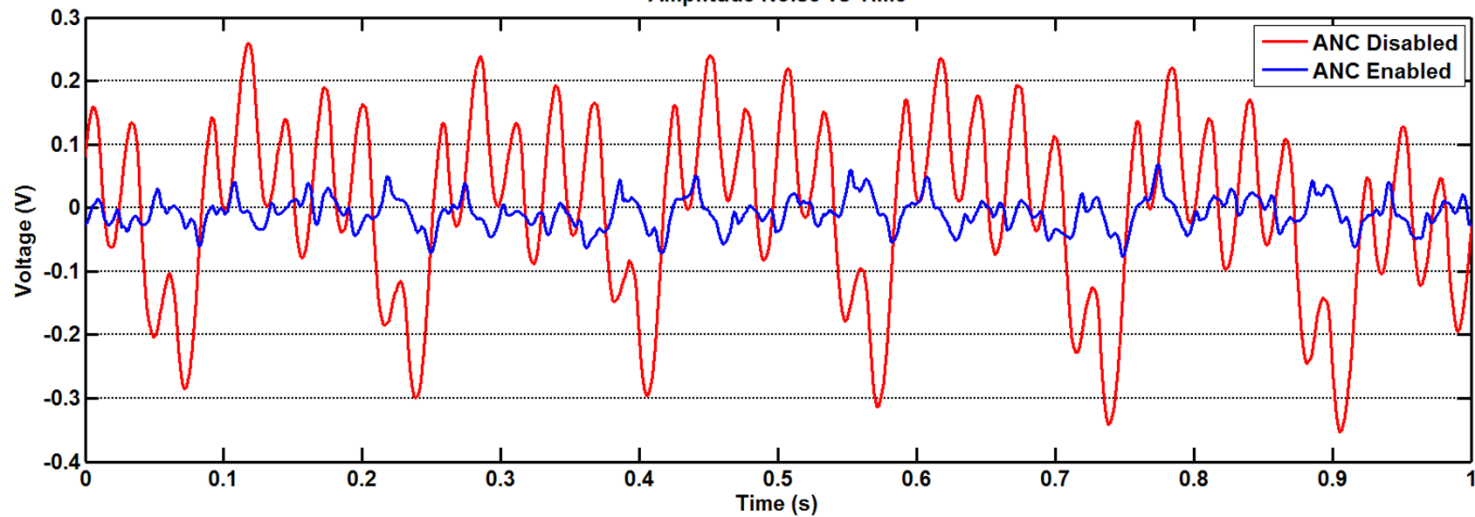


| ANC Disabled RMS Voltage | 0.4330 V |
|---|---|
| ANC Enabled RMS Voltage | 0.1281 V |

# Results

| Frequency | Phase Noise Reduction | Amplitude Noise Reduction |
|-----------|----------------------|--------------------------|
| 60 Hz | -33.31 dB | -29.92 dB |
| 120 Hz | -31.02 dB | -34.21 dB |
| 360 Hz | -35.94 dB | -38.95 dB |



Phase Noise Difference After ANC



Amplitude Noise Difference After ANC
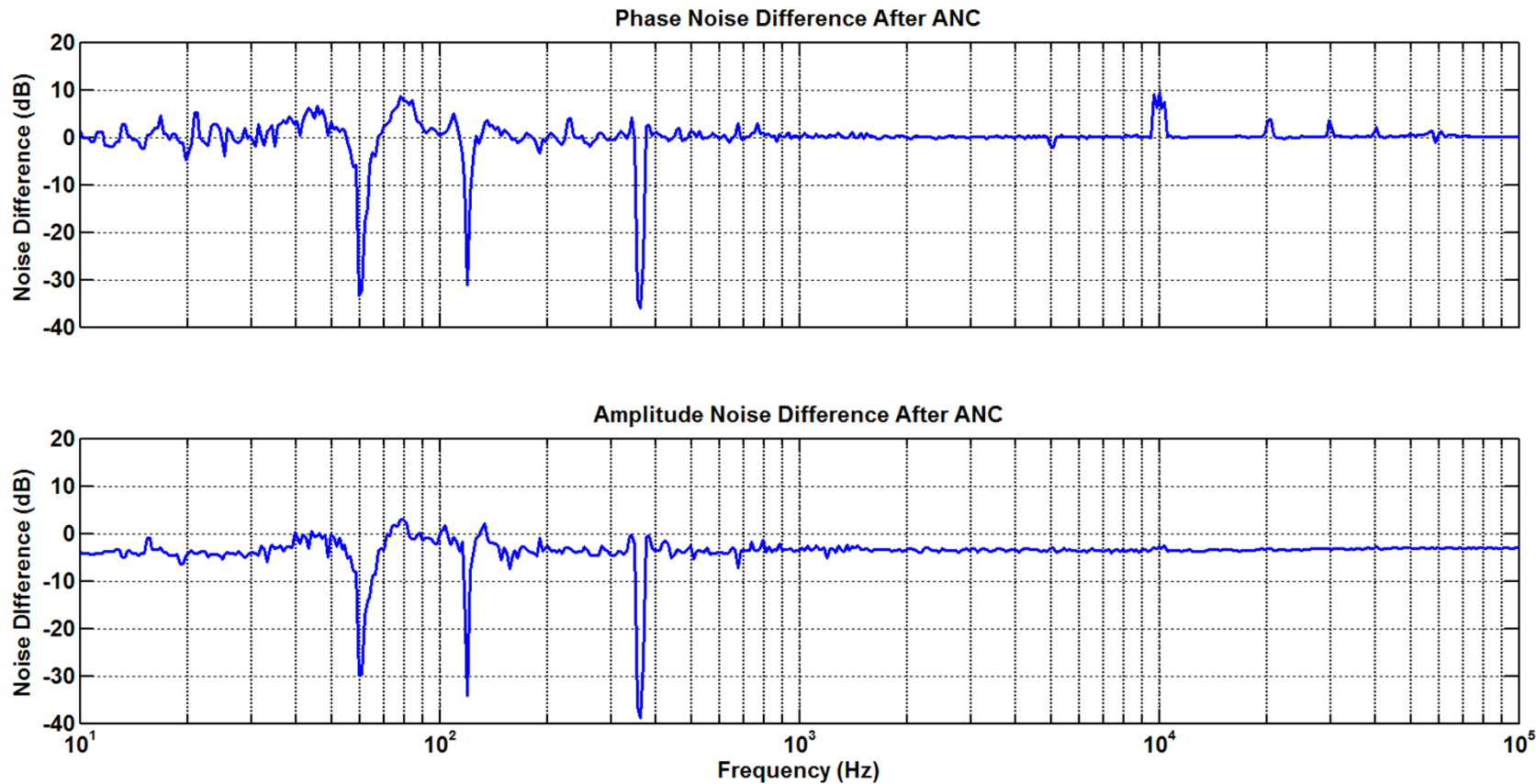
# Future Work

- Add channels for 180 Hz, 240 Hz, and 720 Hz

- Test in live SRF system

- Migrate to MicroTCA system for production
  - Increased flexibility for digital LLRF
  - Easier integration into EPICS