



Radio Frequency Noise Reduction in the LIGO Hanford Observatory

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2019 Caltech SURF Program

Mentors: Dick Gustafson and Keita Kawabe

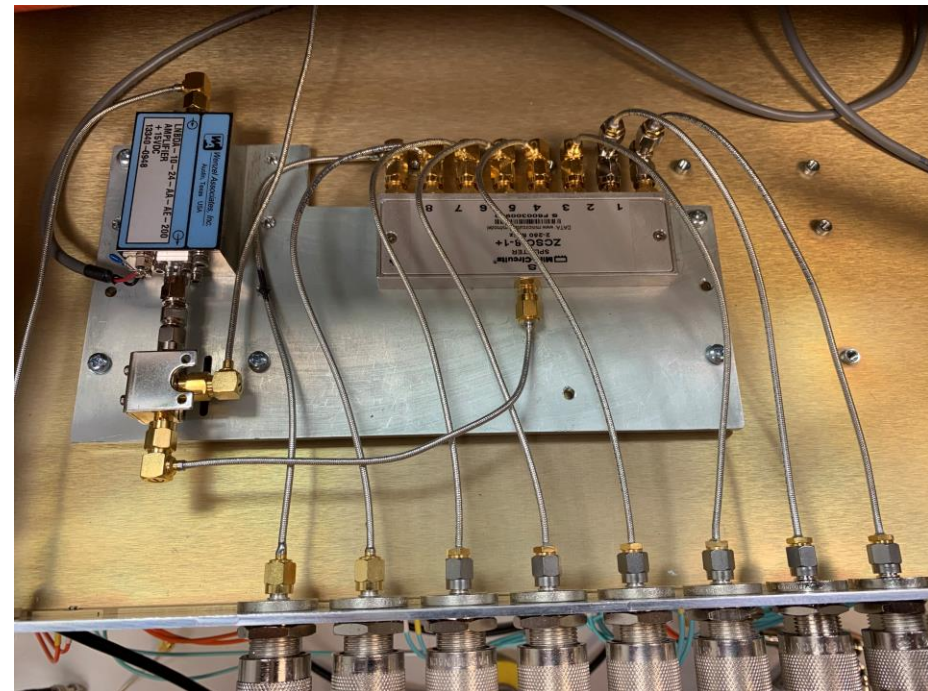
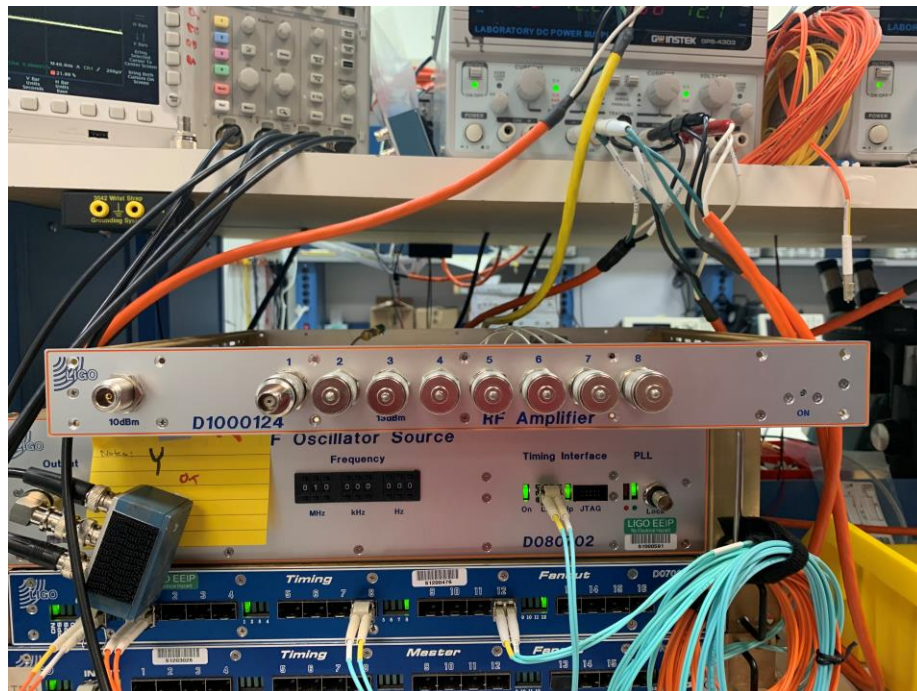
Overview

- RF Distribution System Overview
- Project #1 – Eliminating Harmonic Generation in the RF Distribution Amplifier
- Project #2 – Mapping RF Cable Noise to DARM
 - » Mapping Methodology
 - » Experiment #1: Cable Characterization
 - » Experiment #2: RF Noise Injections
 - » Experiment #3: Cable Noise Profile Collection
- Future Work

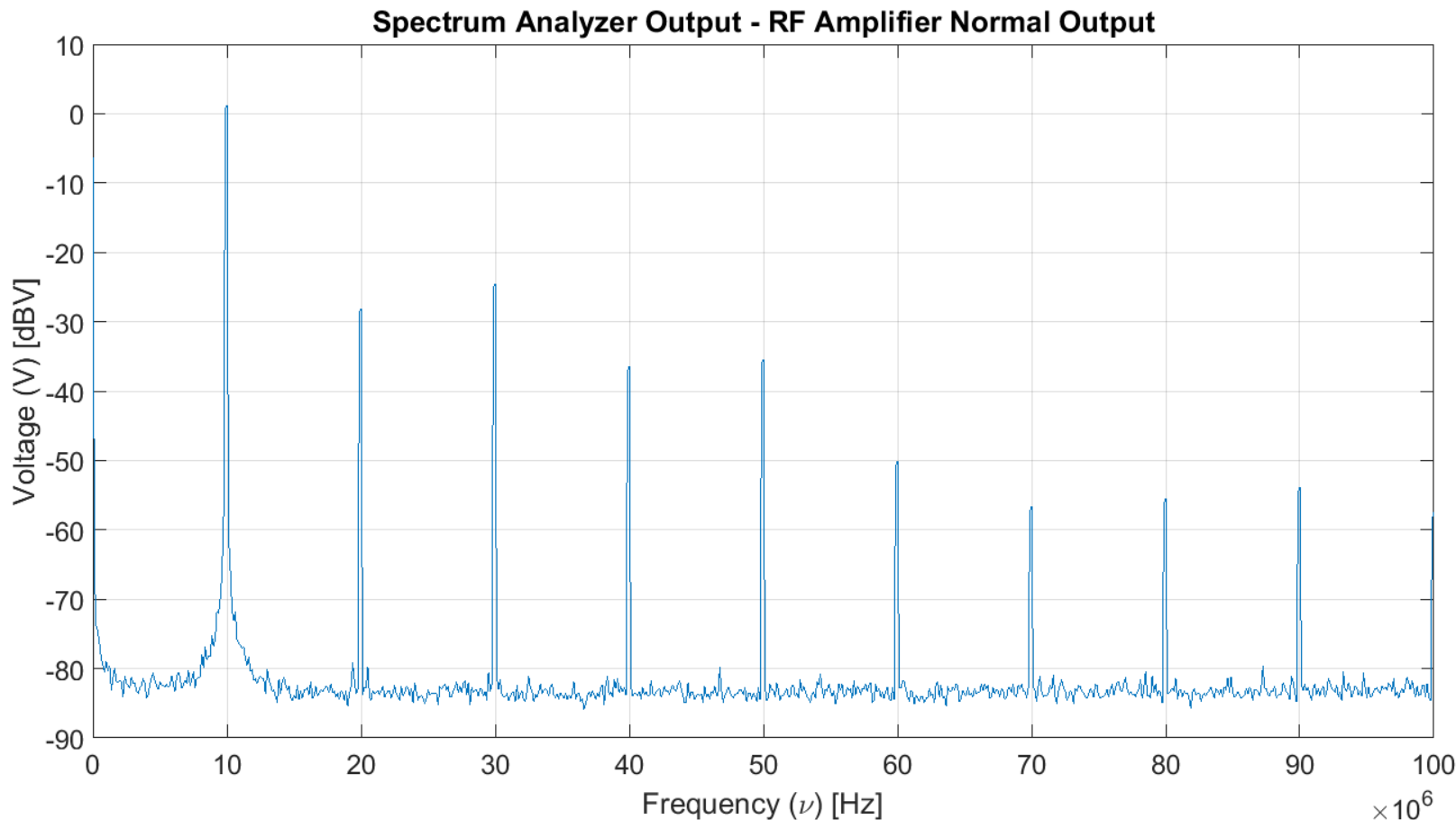


- The aLIGO RF Distribution System produces and distributes a variety of radio frequency signals, which are used to modulate/demodulate the signal channels used to monitor and control the IFO
 - » Main Modulation Frequencies: 9.10023 MHz and 45.50115 MHz
- RF Distribution affects a multitude of IFO subsystems (e.g., ISC, PSL, etc.)
- Noise reduction in the RF Distribution system is critical – ensures that RF noise does not propagate to other IFO systems

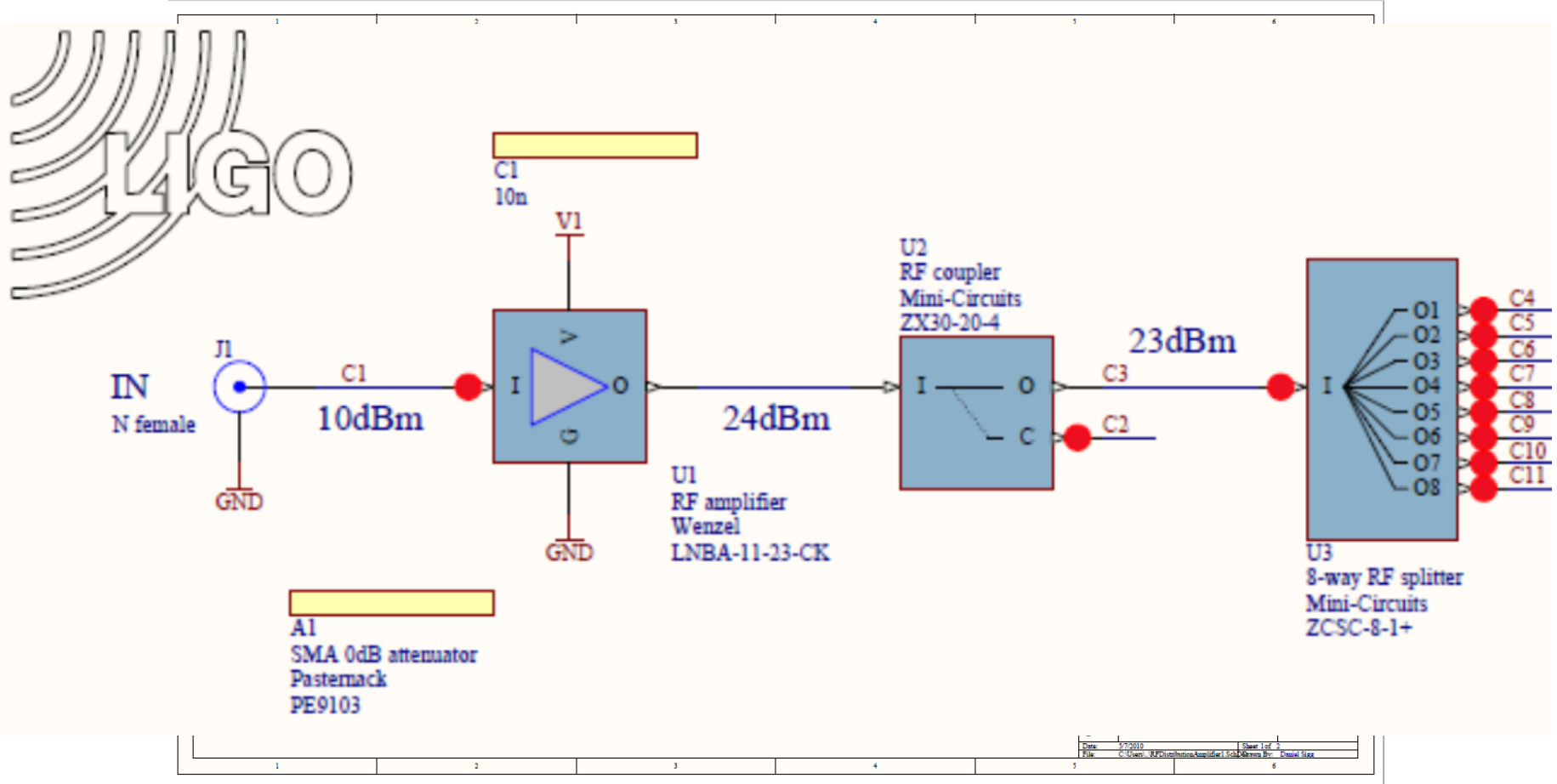
□ The RF Distribution Amplifier (D1000124)



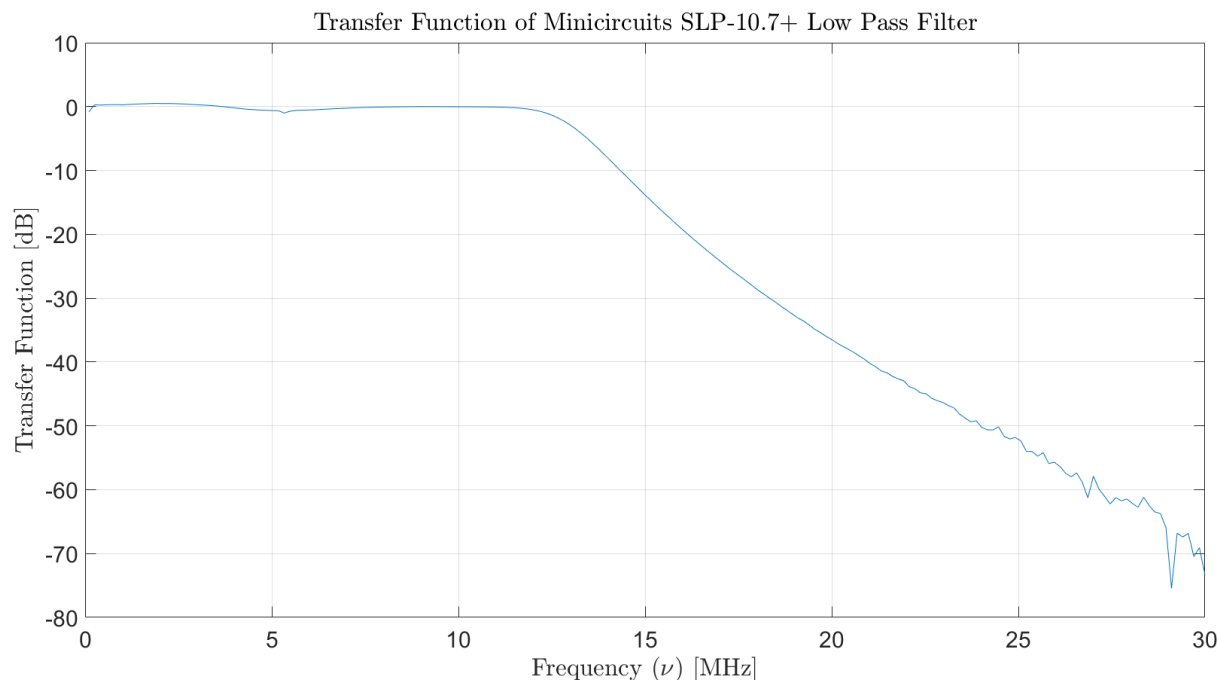
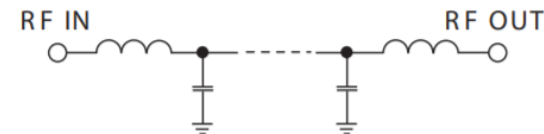
□ Sample Harmonic Noise Profile (10 MHz Amp)



RF Distribution Amplifier

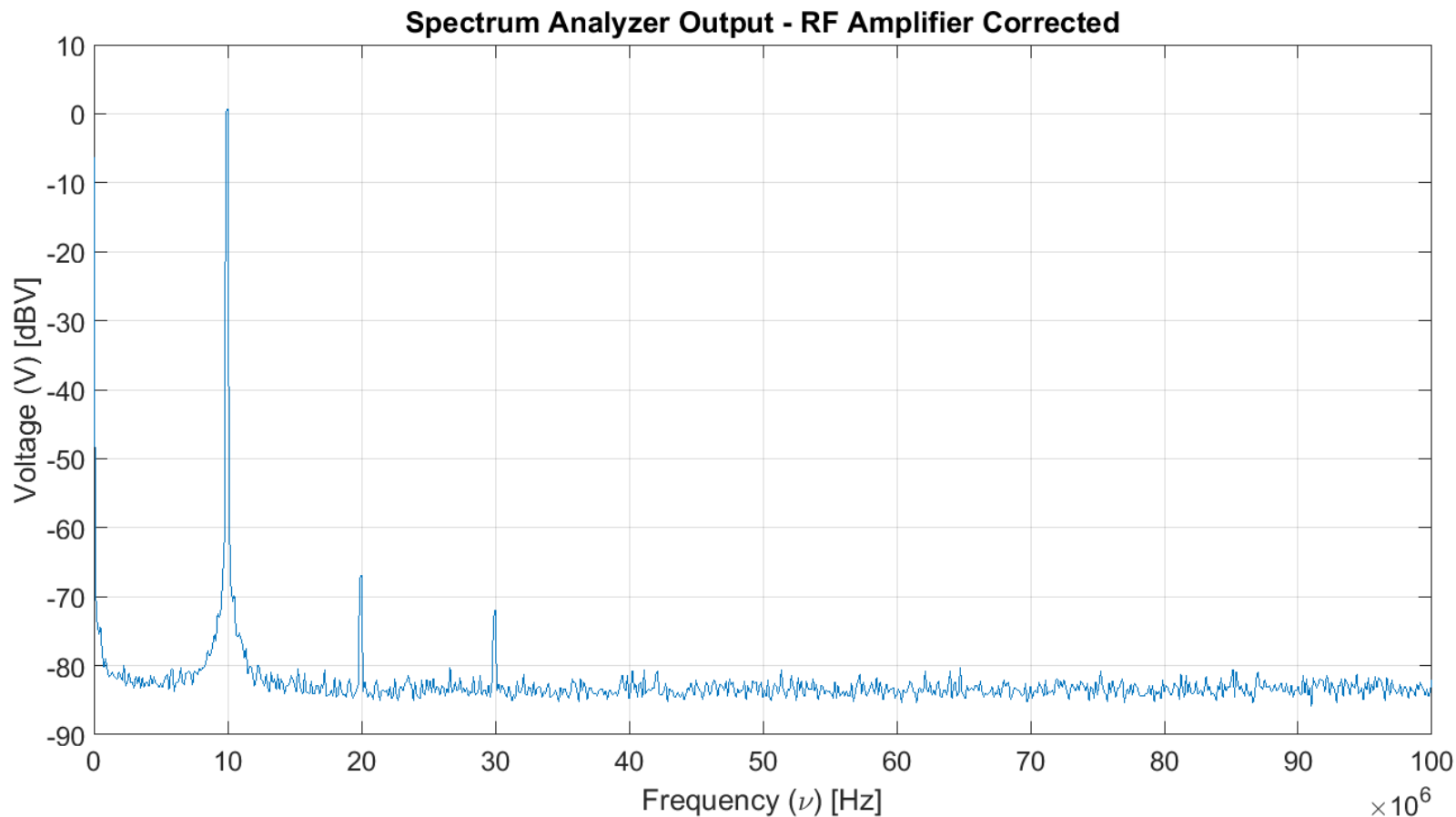


□ Solution: RL Filtering



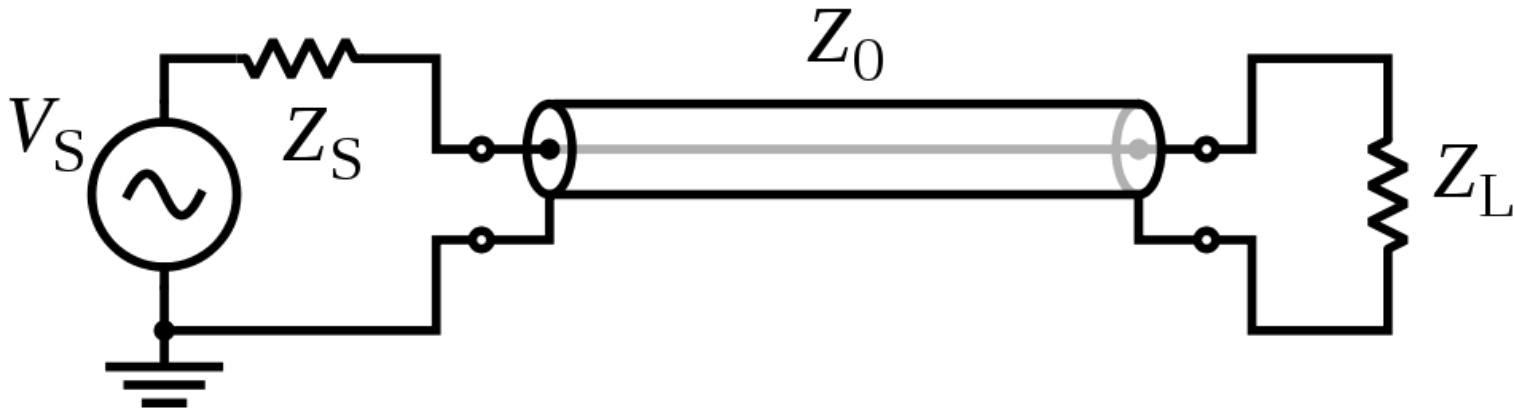
- Filter Requirements:
1. Fundamental Freq. Falls before -1 dB Cutoff
 2. Second Harmonic Falls after -20 dB Cutoff

□ Corrected RF Amplifier Output (10 MHz Amp)

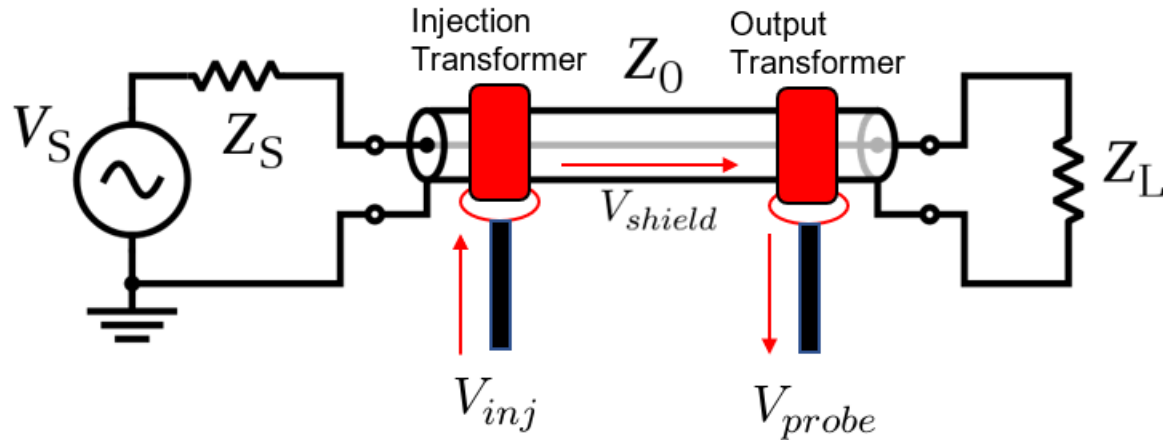


Shield Noise Overview

- » H1 uses HELIAX LDF4-50A cables from Andrew

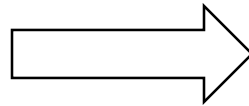


□ Mapping Methodology:



$$V_{shield} = aV_{inj}$$

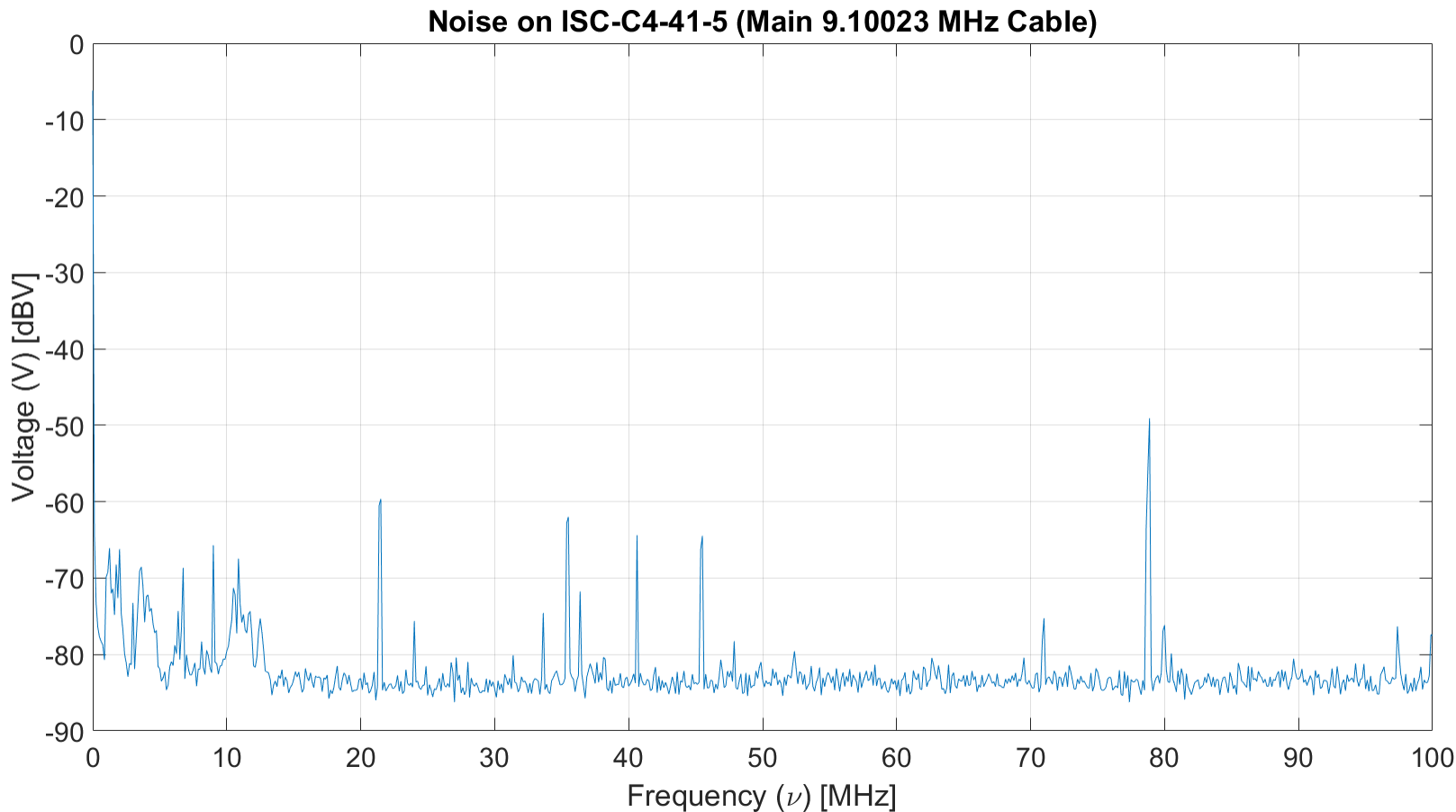
$$V_{probe} = bV_{shield}$$



$$V_{shield} = \frac{V_{probe}}{b}$$

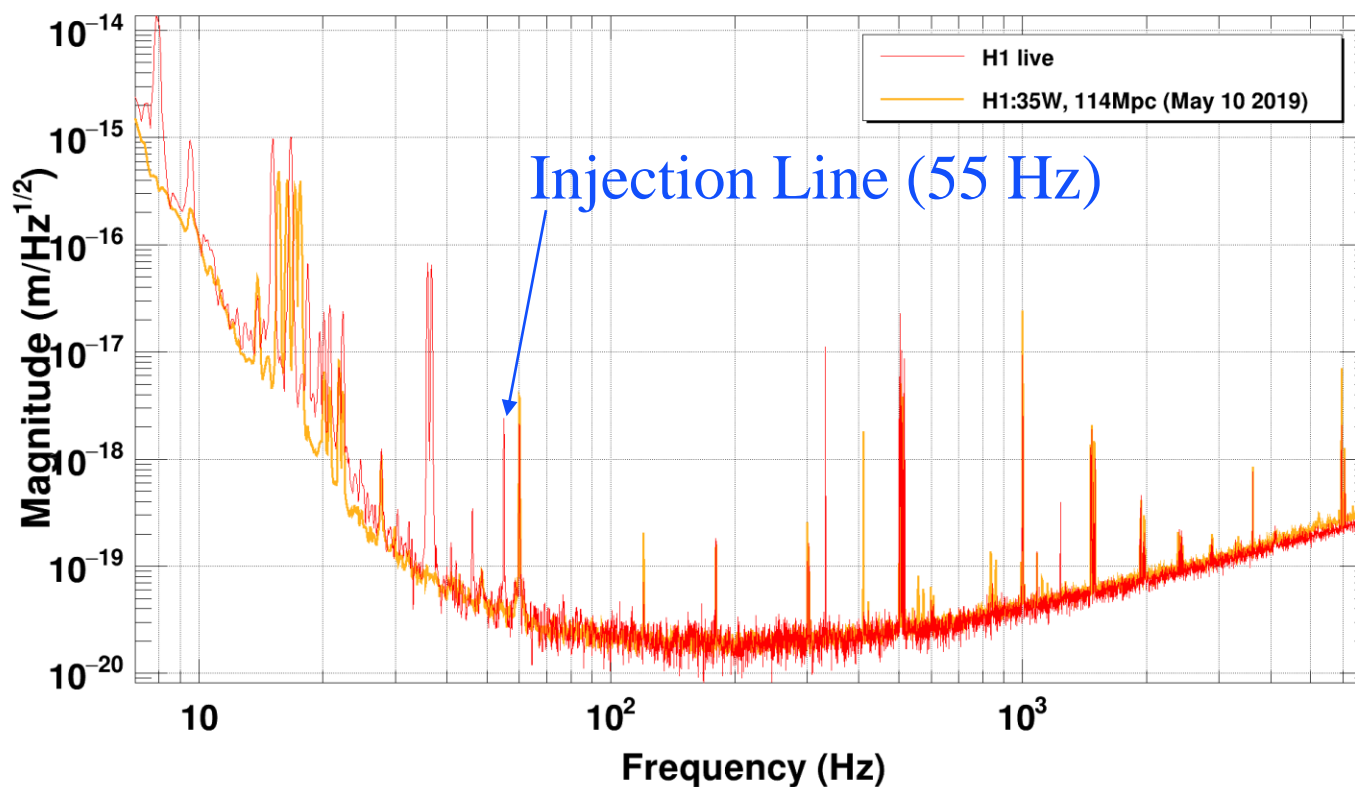
$$ab = \frac{V_{probe}}{V_{inj}}$$

□ Sample Shield Noise Profile



□ DARM Response of March 2019 RF Signal Injection

H1 DARM during 9.100285 MHz Injection on Main 9.10023 MHz Line



*T0=15/03/2019 20:50:45

Avg=5/Bin=5L

BW=0.187493

□ Mapping Methodology:

$$\frac{\text{ASD}(D)}{\text{ASD}(V_{shield})} = \frac{D}{V_{shield}}$$

$$\text{ASD}(D) = \frac{D}{aV_{inj}} \text{ASD}(V_{shield})$$

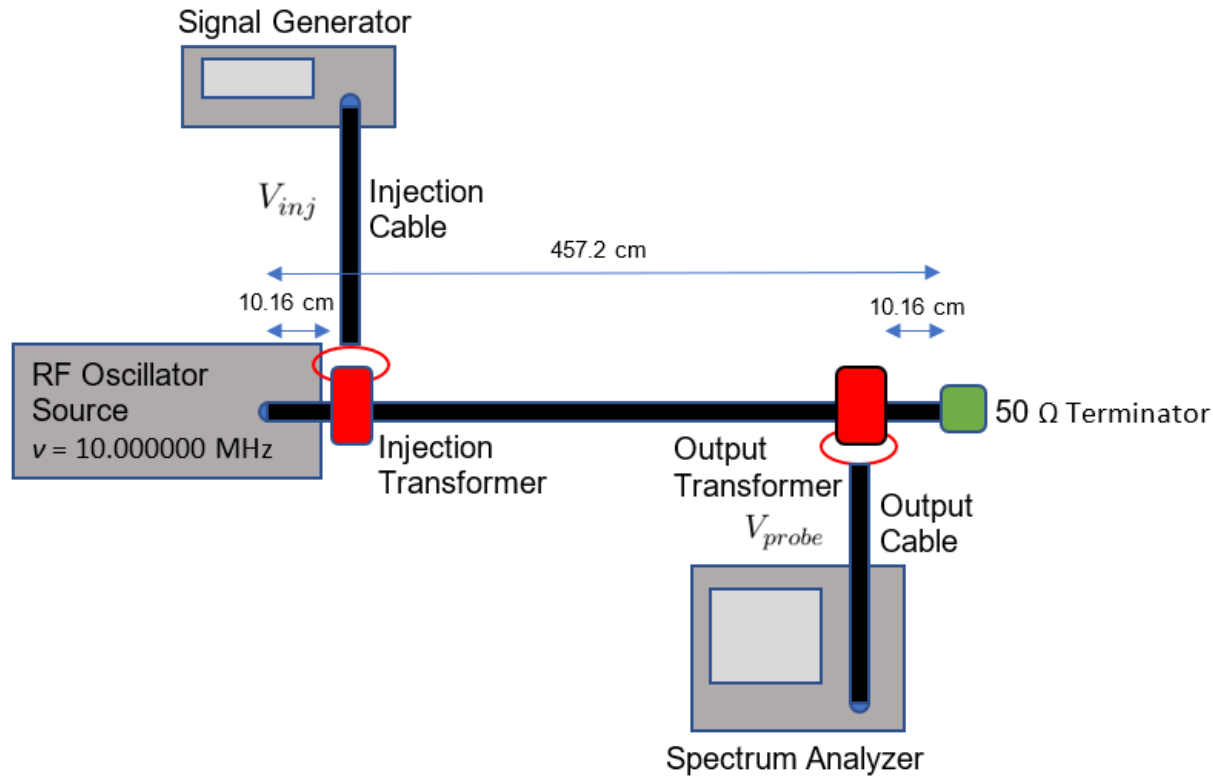
$$\text{ASD}(D) = \frac{1}{ab} \frac{D}{V_{inj}} \text{ASD}(V_{probe})$$

Experiment #1: Cable Characterization

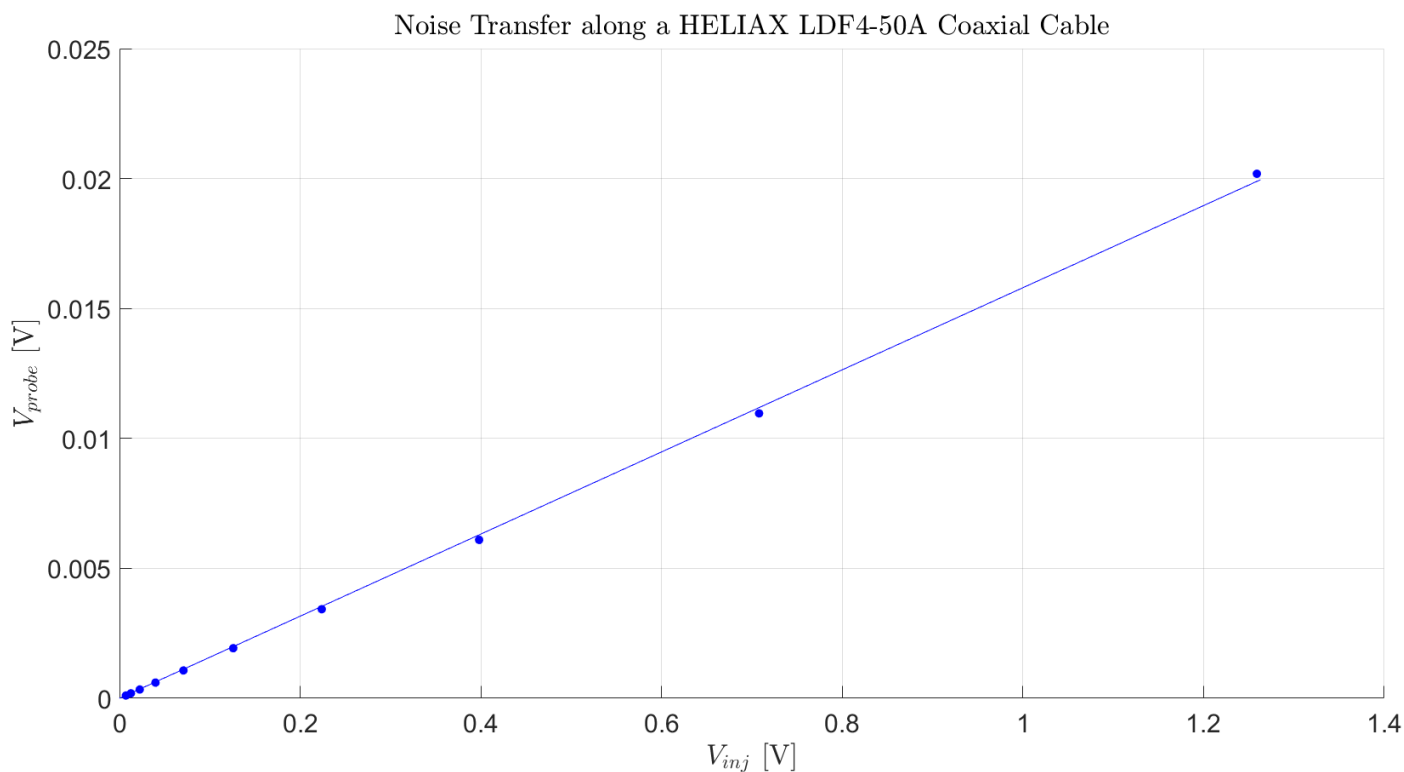
Experiment #2: RF Noise Injection

Experiment #3: RF Noise Profile Collection

Experiment #1: Cable Characterization - Setup



□ Experiment #1: Cable Characterization - Results



$$ab = 0.0158$$

$$\frac{\text{ASD}(D)}{\text{ASD}(V_{shield})} = \frac{D}{V_{shield}}$$

$$\text{ASD}(D) = \frac{D}{aV_{inj}} \text{ASD}(V_{shield})$$

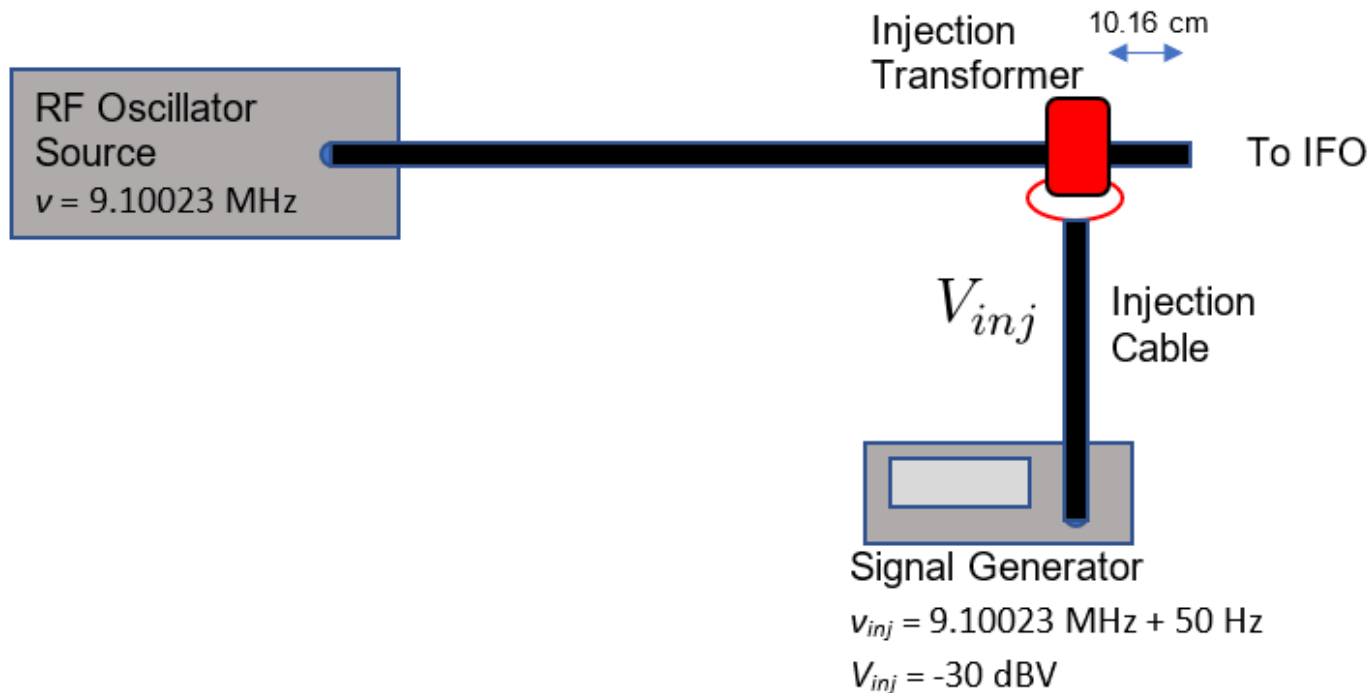
$$\text{ASD}(D) = \boxed{\frac{1}{ab} \frac{D}{V_{inj}} \text{ASD}(V_{probe})}$$

Experiment #1: Cable Characterization

Experiment #2: RF Noise Injection

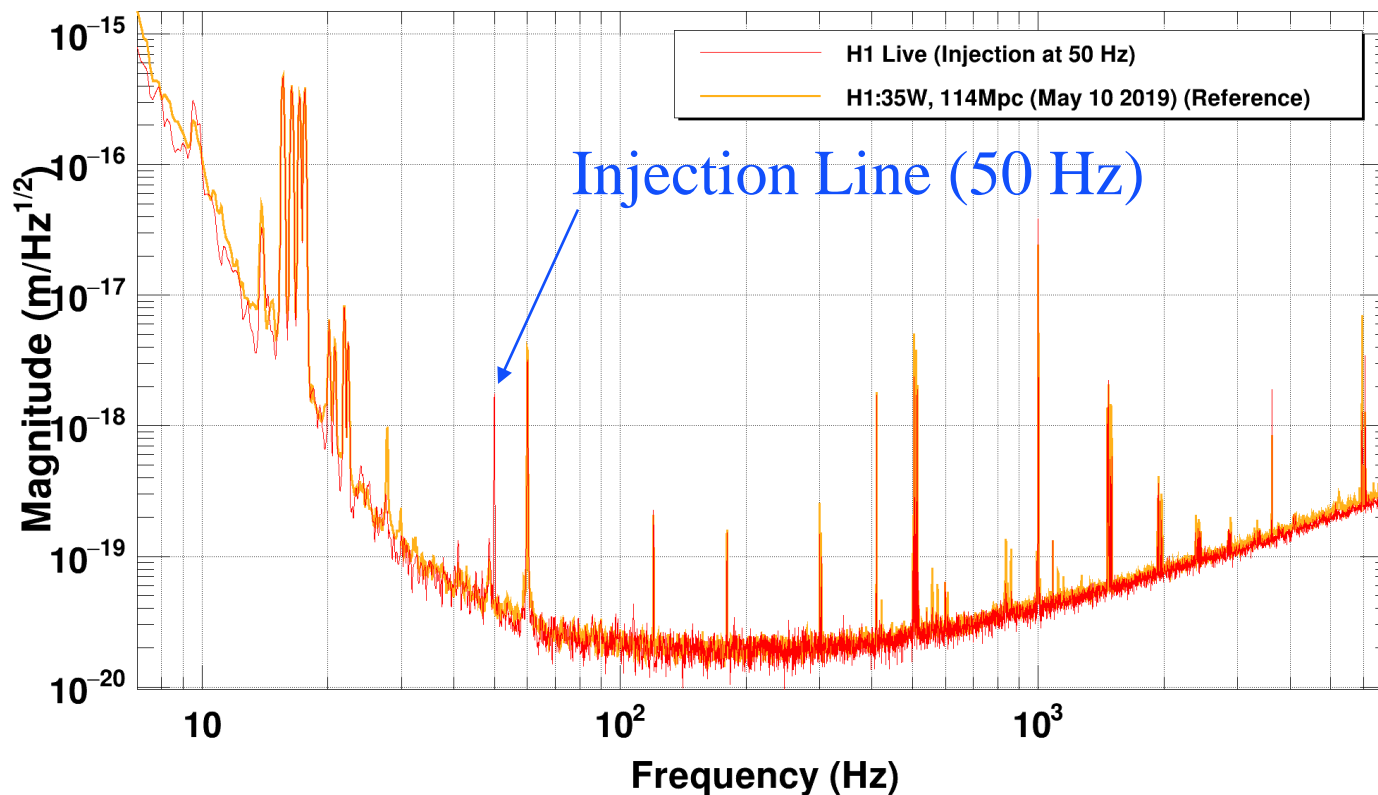
Experiment #3: RF Noise Profile Collection

Experiment #2: Noise Injections - Setup



Experiment #2: Noise Injections - Results

9.10023 MHz + 50 Hz Injection on ISC-C4-41-5 (Main 9.10023 MHz Line)



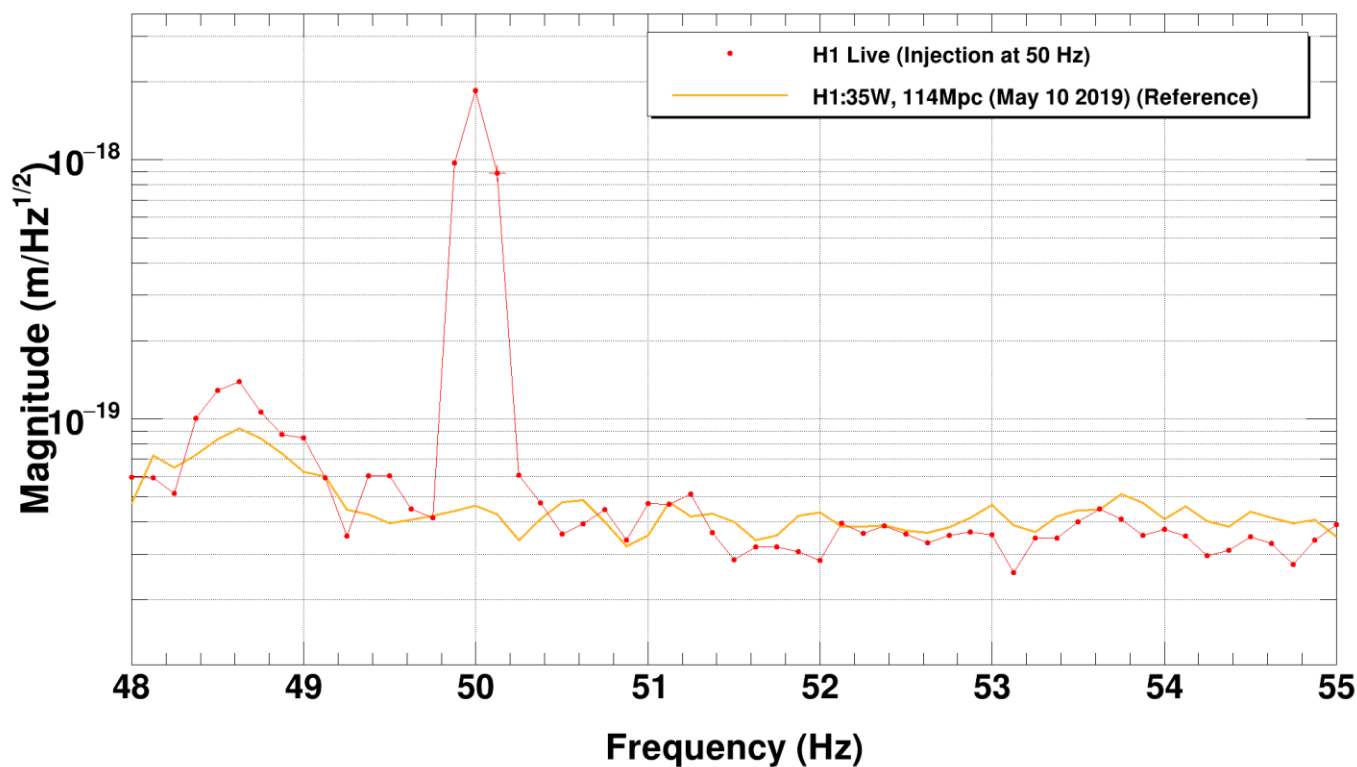
*T0=30/07/2019 15:57:00

Avg=10/Bin=5L

BW=0.187493

□ Experiment #2: Noise Injections - Results

9.10023 MHz + 50 Hz Injection on ISC-C4-41-5 (Main 9.10023 MHz Line)



$$D = \sqrt{\left(\sum_i d_i^2\right) BW}$$

$$= 5.77 * 10^{-19} \text{ m}$$

*T0=30/07/2019 15:57:00

Avg=10

BW=0.187493

Project #2: Mapping Cable Noise to DARM

$$\frac{\text{ASD}(D)}{\text{ASD}(V_{shield})} = \frac{D}{V_{shield}}$$

$$\text{ASD}(D) = \frac{D}{aV_{inj}} \text{ASD}(V_{shield})$$

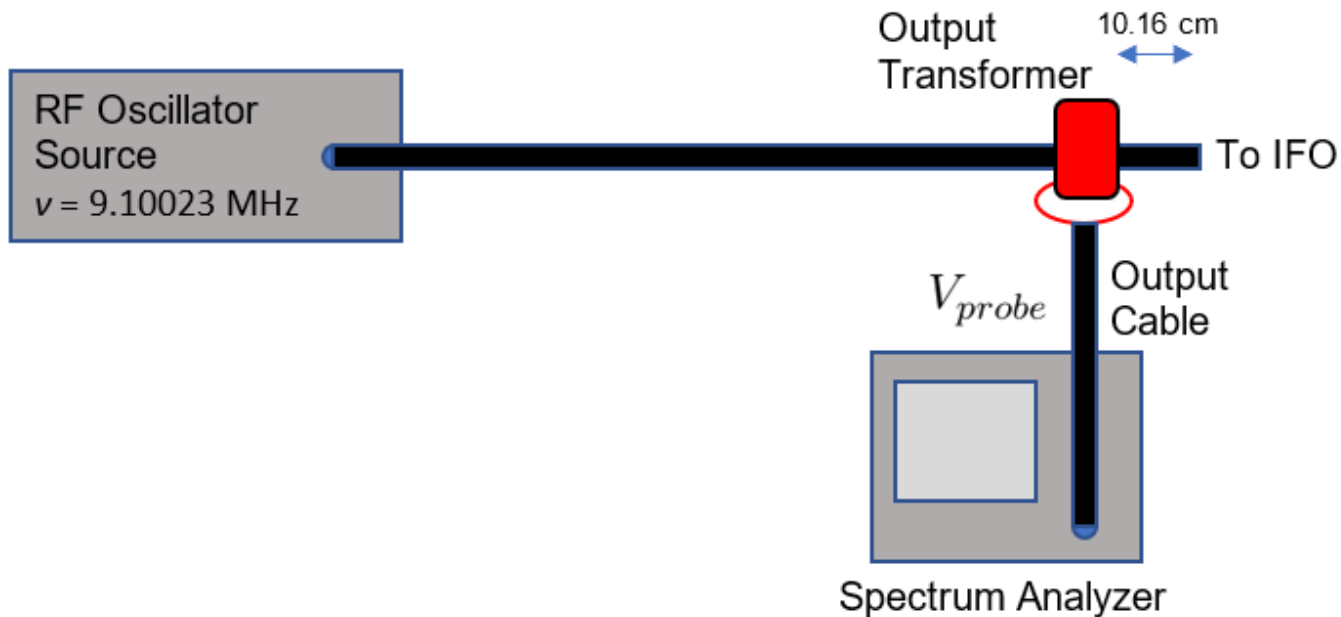
$$\text{ASD}(D) = \frac{1}{ab} \frac{D}{V_{inj}} \text{ASD}(V_{probe})$$

Experiment #1: Cable Characterization

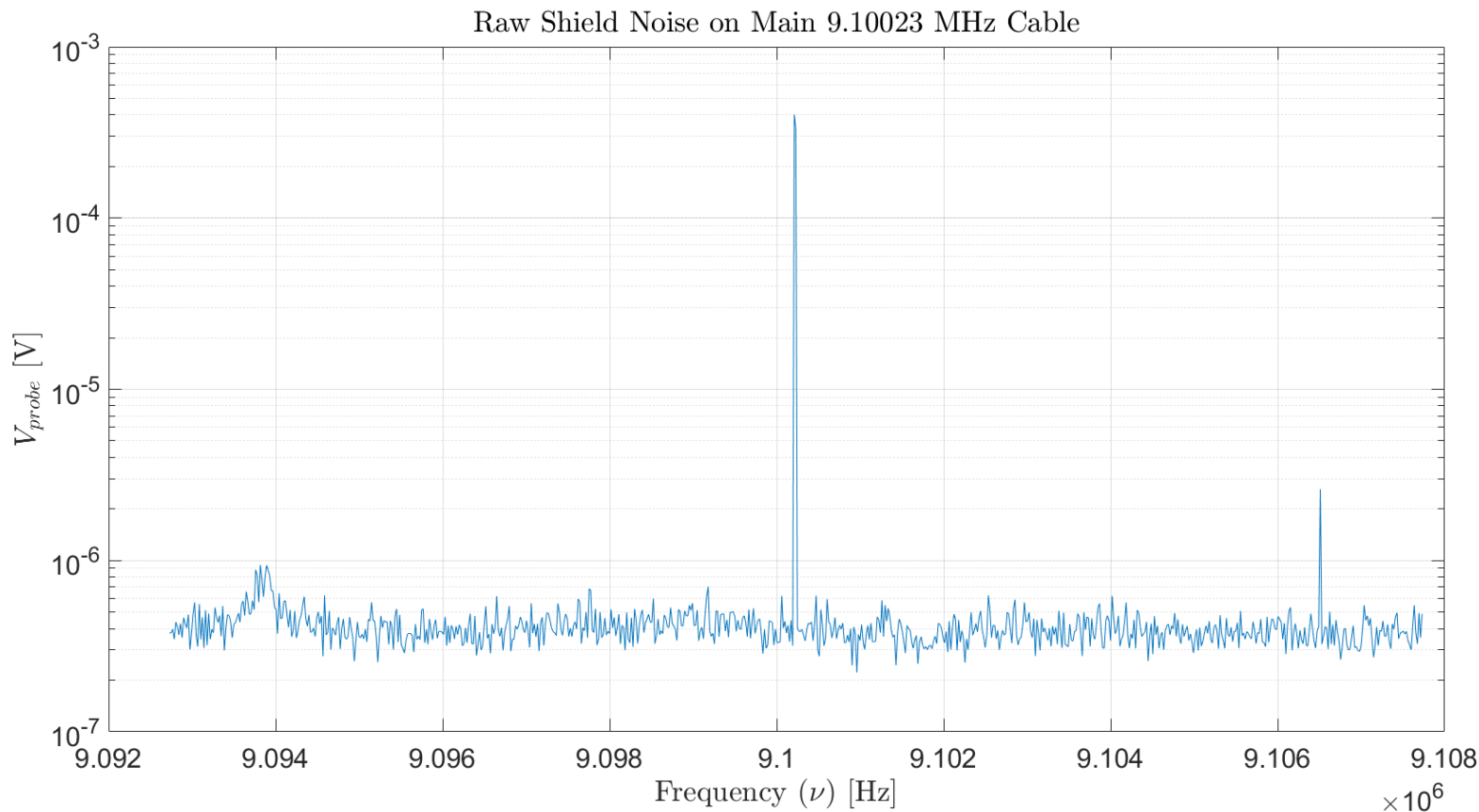
Experiment #2: RF Noise Injection

Experiment #3: RF Noise Profile Collection

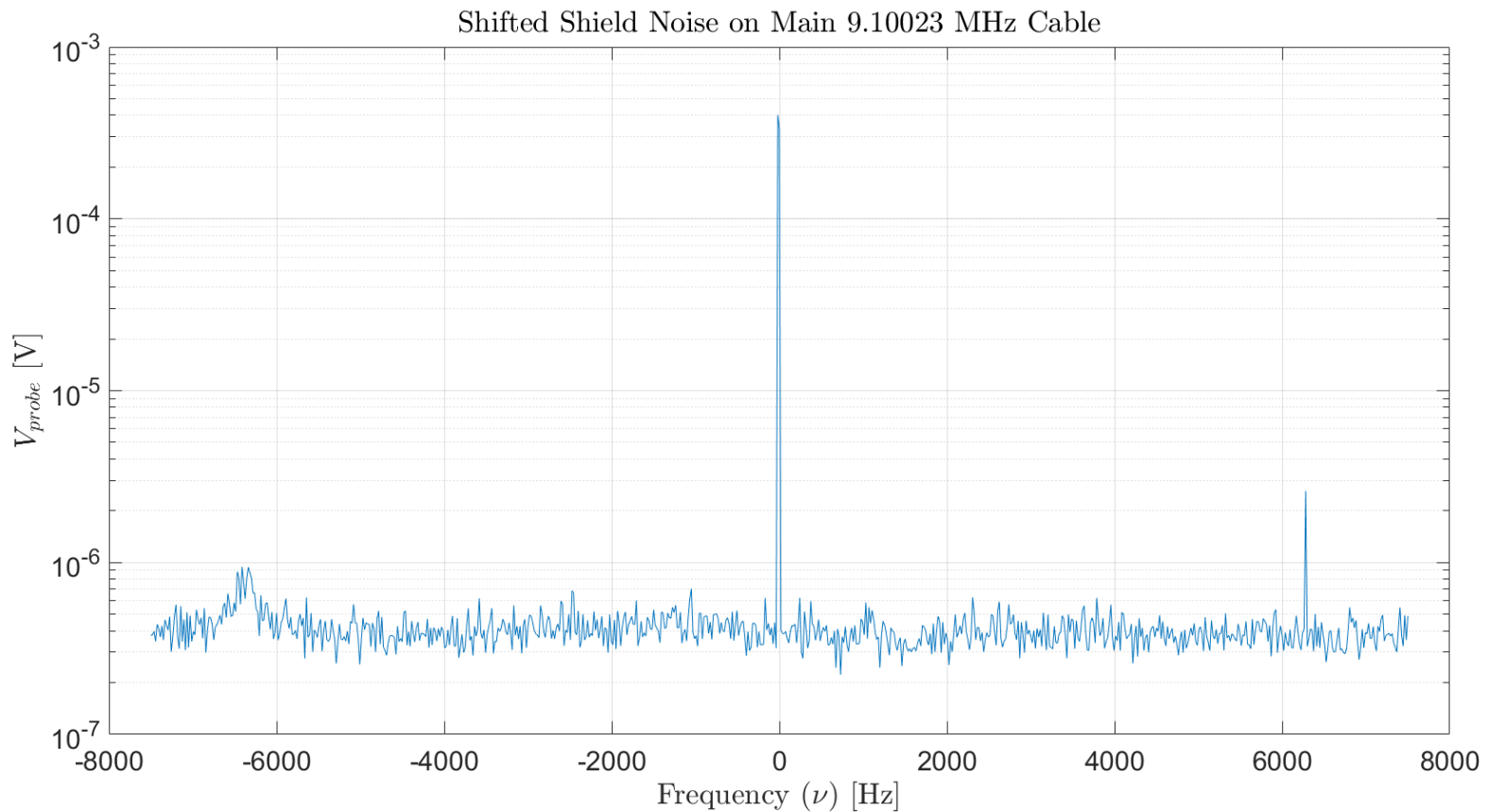
Experiment #3: RF Noise Profile Collection - Setup



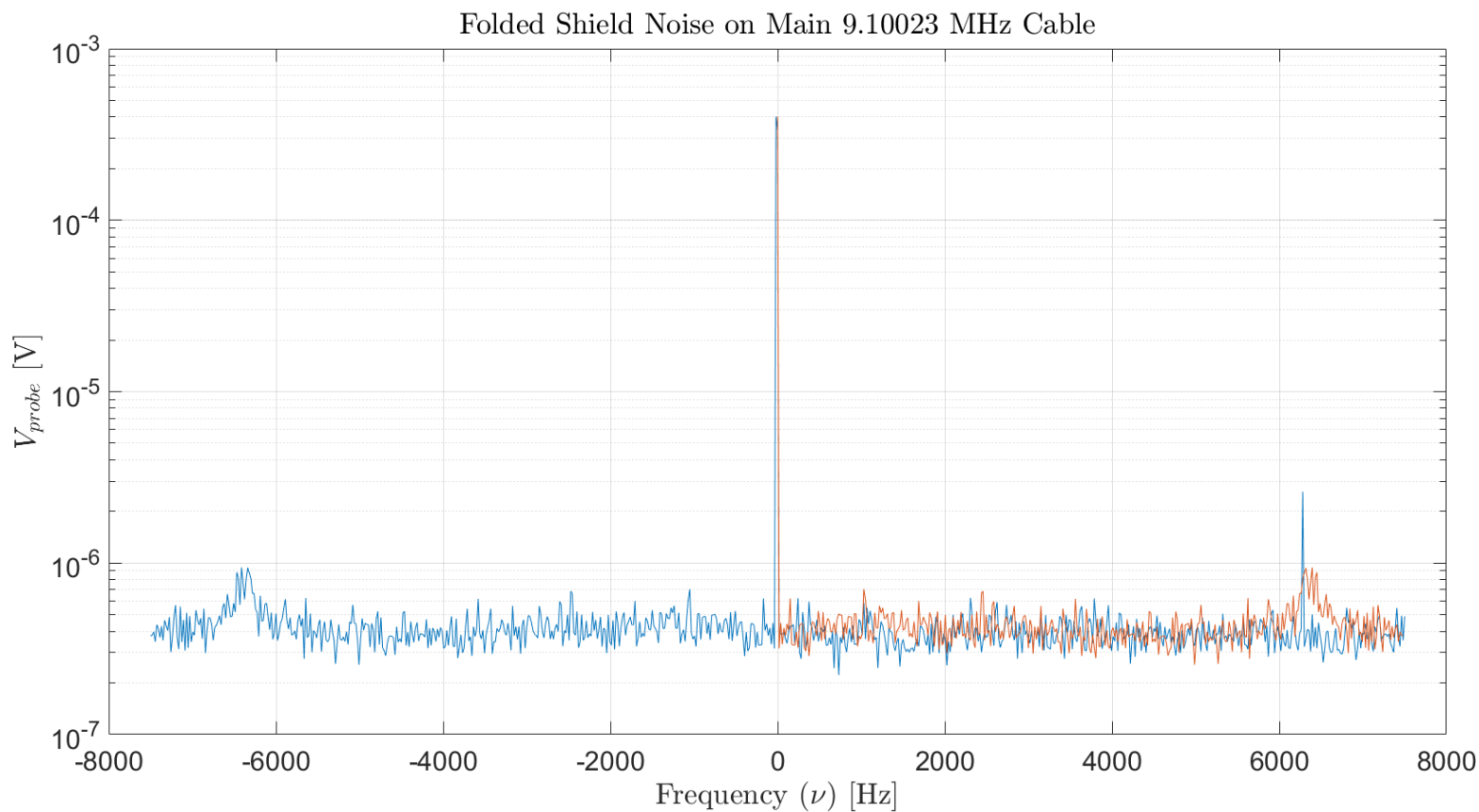
□ Experiment #3: RF Noise Profile Collection - Results



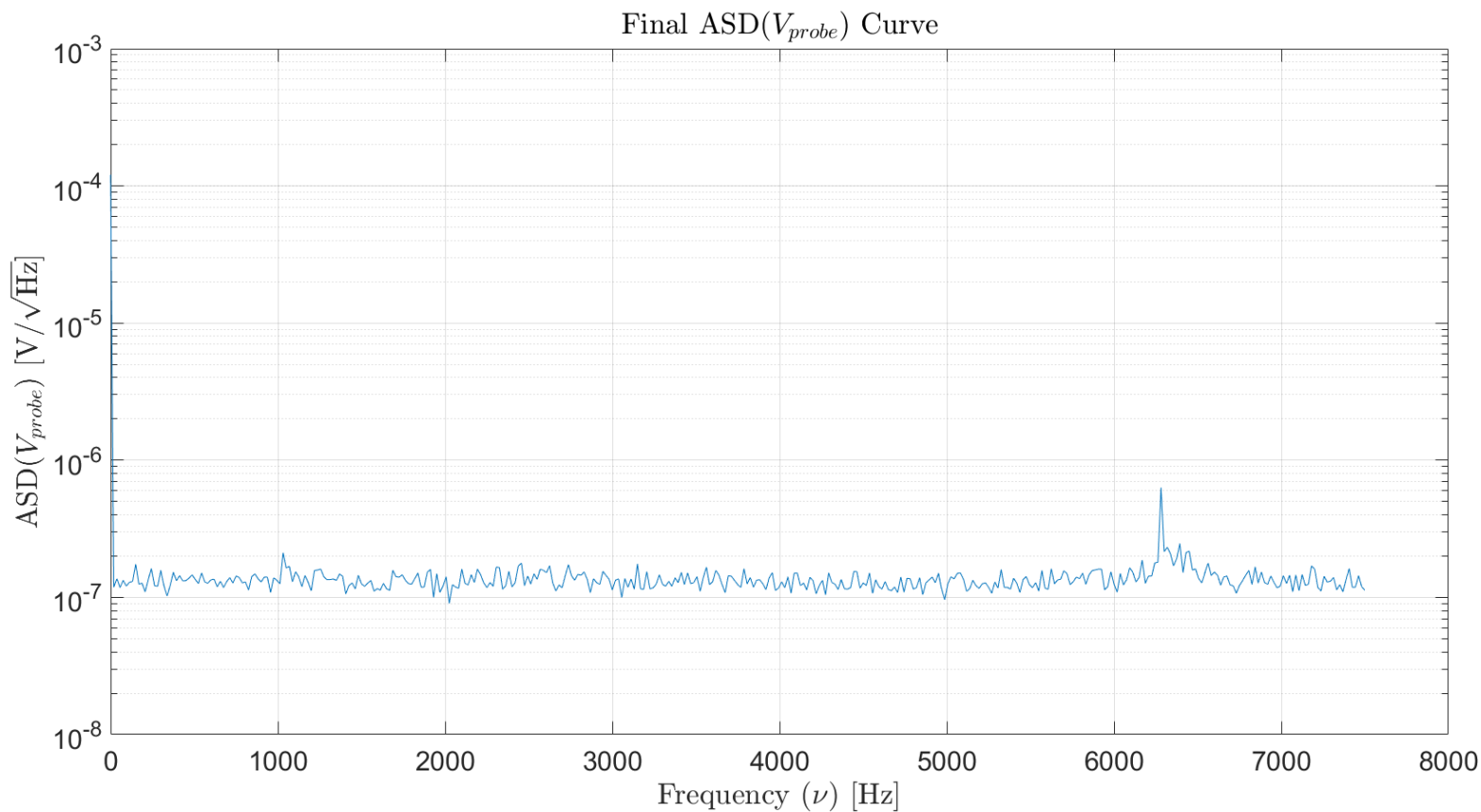
□ Experiment #3: RF Noise Profile Collection - Results



□ Experiment #3: RF Noise Profile Collection - Results



Experiment #3: RF Noise Profile Collection - Results



Project #2: Mapping Cable Noise to DARM

$$\frac{\text{ASD}(D)}{\text{ASD}(V_{shield})} = \frac{D}{V_{shield}}$$

$$\text{ASD}(D) = \frac{D}{aV_{inj}} \text{ASD}(V_{shield})$$

$$\text{ASD}(D) = \frac{1}{ab} \frac{D}{V_{inj}} \text{ASD}(V_{probe})$$

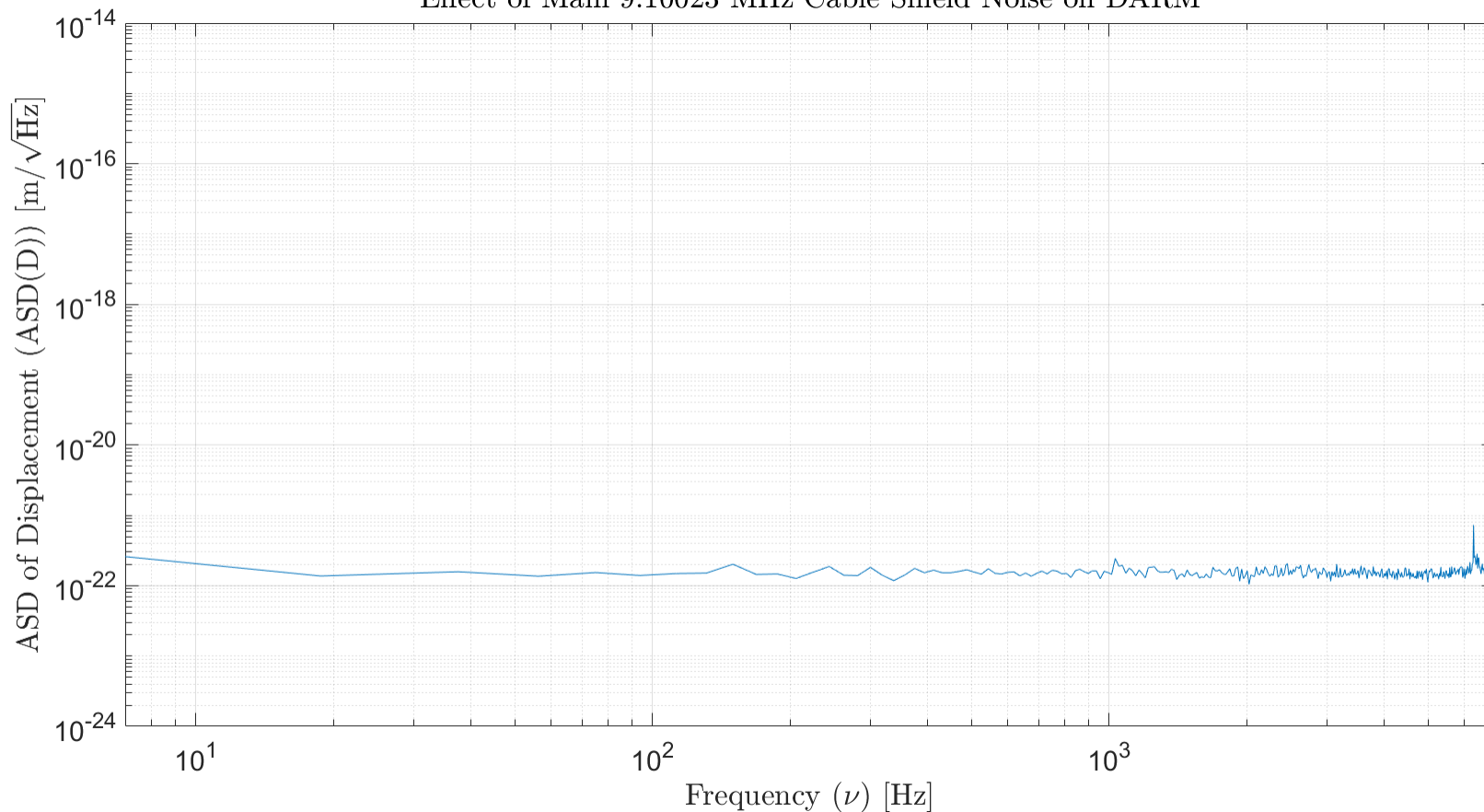
Experiment #1: Cable Characterization

Experiment #2: RF Noise Injection

Experiment #3: RF Noise Profile Collection

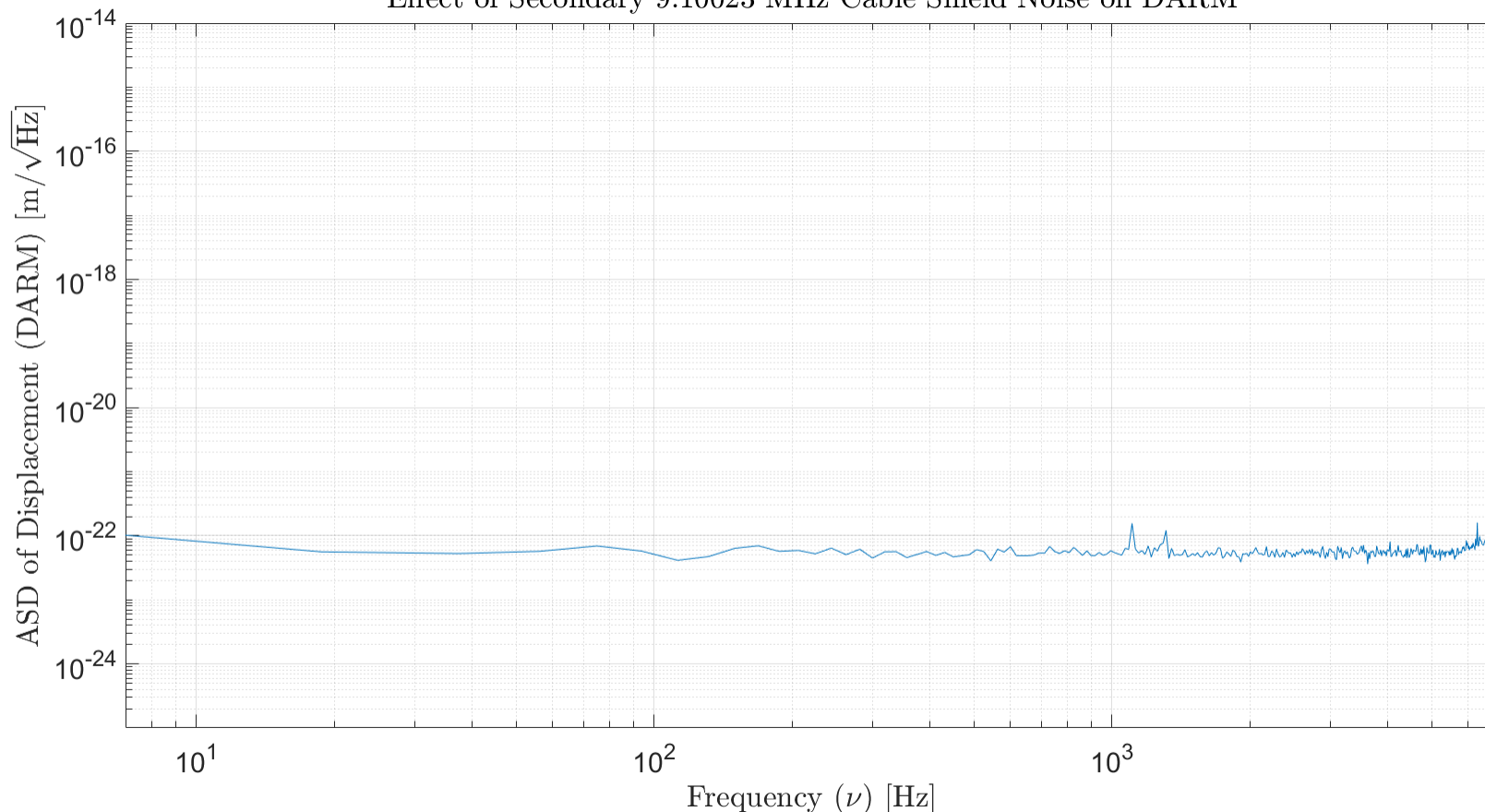
Final Results: Main 9.10023 MHz Cable

Effect of Main 9.10023 MHz Cable Shield Noise on DARM



Final Results: Secondary 9.10023 MHz Cable

Effect of Secondary 9.10023 MHz Cable Shield Noise on DARM



Future Work

- Project #1:
 - » Investigate the phase shift introduced by each filter to determine the impact of filter insertion on the phasing of the RF Distribution System
- Project #2:
 - » Perform mapping process on other RF frequencies, especially the 45.5 MHz lines
- Combination:
 - » Develop a method for mapping the harmonic noise present in the RF Distribution Amps to DARM

Acknowledgements

- Special Thanks Goes to the Following Individuals for their Contributions to the Project
 - » Mentors: Dick Gustafson and Keita Kawabe
 - » EE Lab Help: Marc Pirello and Filiberto Clara