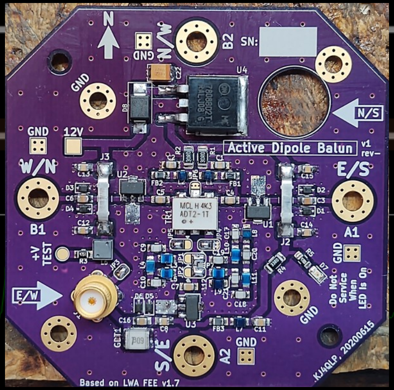
# Active HF Dipole Balun

## Candidate Active Antenna for HamSCI's PSWS

## Presented at the TAPR DCC, 20200912

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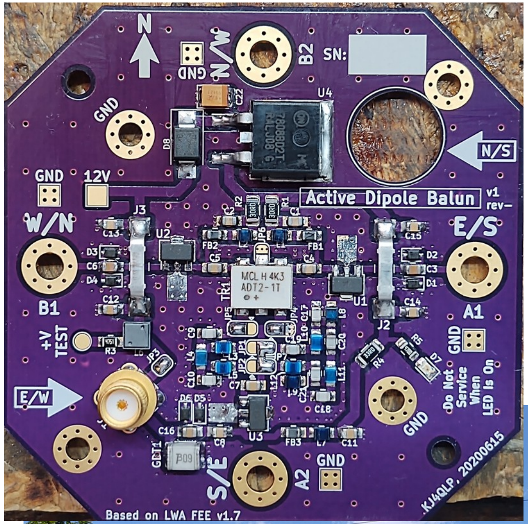
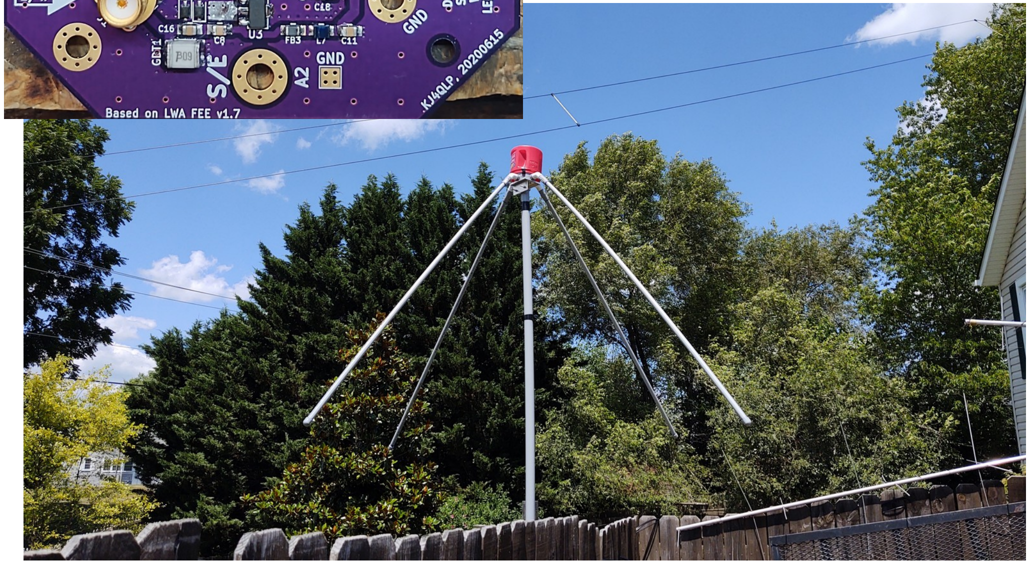
www.github.com/zleffke

# Agenda

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

- Introduction & Overview
- Schematic & PCB
- Bench RF Measurements
- On Air Comparisons Selected Screengrabs
  - T2FD
  - DXE-RF-PRO-1B



# Introduction & Overview

# Introduction – Who is this guy?

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

- Zach Leffke, KJ4QLP (zleffke@vt.edu)
- Research Associate (Faculty) at VT’s Hume Center for National Security and Technology
- Principal Investigator of the VT Ground Station
- VT Alumni, BS EE (2011), MS EE (2013)
  - N4HY was my advisor
- Primary research interests include RF engineering, antenna design, software radio, ground stations and networks, RF propagation, all mainly with a focus on DoD/IC applications
- Prior to VT, US Marine Corps, 0627 SatCom Operator.

# References, Links, and Initial Info

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

- Long Wavelength Array
  - Memo Series: www.faculty.ece.vt.edu/swe/lwa/
  - Collected Engineering Memos for LWA-FEE (used heavily):
    - www.faculty.ece.vt.edu/swe/lwa/memo/lwa0190.pdf
- AHFDB Github
  - **www.github.com/zleffke/kicad_active_balun** (current design, might rearrange a bit)
  - kj4qlp.wordpress.com (coming soon…definition of ‘soon’ TBD...)

| Item | Cost | Note |
|---|---|---|
| 3 PCBs | $37.85 | Osh Park (x3 rule) |
| 1 PCB | $12.62 | Per PCB |
| Single Balun BOM | $36.03 | Mouser/Digikey |
| Dual Balun BOM | $71.17 | Dual Pol |

Estimating **~$150-$200** for complete Dual Polarization system (everything in picture, not coax or backend systems)

| LWA-FEEv1.7 | AHFDB, v1, rev- |
|---|---|
| Freq: 10-88 MHz | Freq: 1.5-50 MHz |
| 180º Hybrid | MC RF Transformer |
| Low Pass Filter | LPF, BPF, Bypass |
| 12V Vreg | 8V Vreg |
| LWA-FEEv1.7 size | More Compact |

# RF Performance Summary

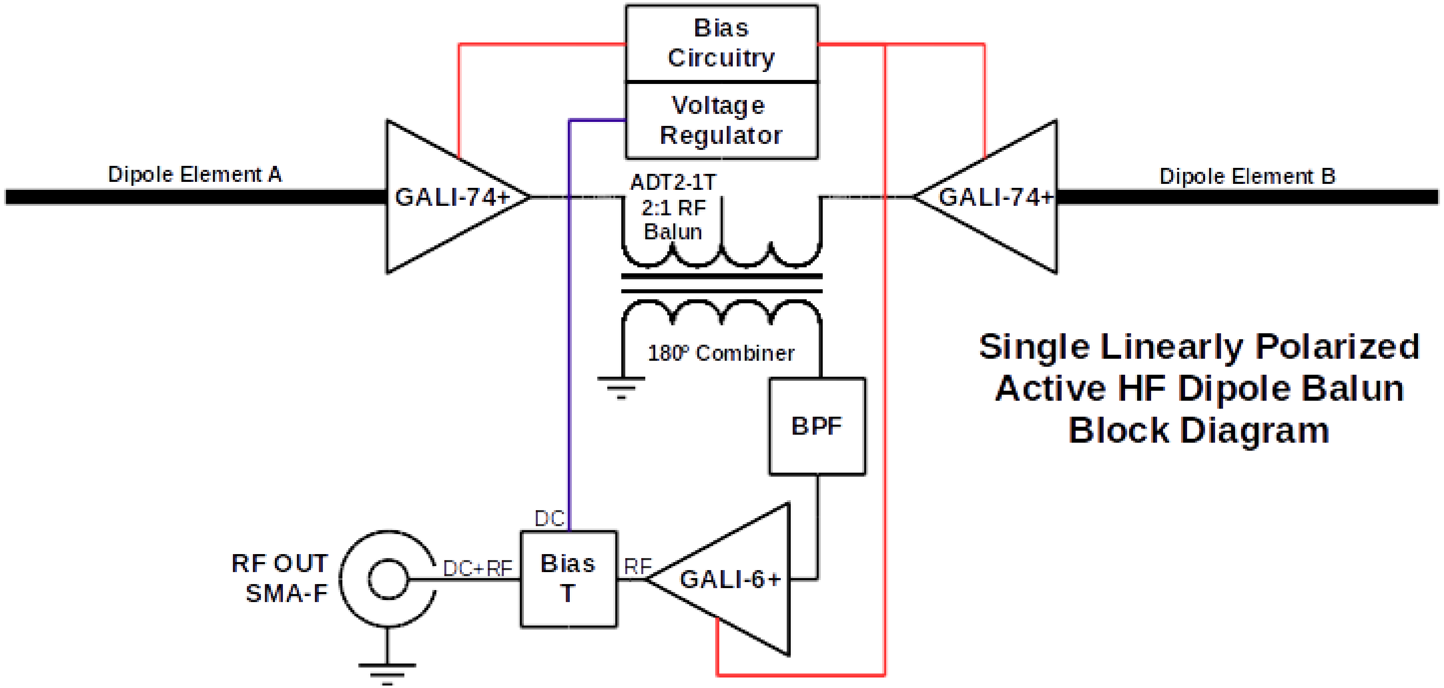
$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

| Parameter | Unit | Value |
|---|---|---|
| Design Frequency of Operation (-3dB) | MHz | 1.5 to 50 |
| Realized Frequency of Operation (-3dB) | MHz | 4.0 to 47.5 |
| Average Gain (passband) | dB | 36.1 |
| Average Noise Figure (passband) | dB | 3.87 |
| Input 1dB Compression Point (P1dB)* | dBm | -18.41 |
| Input Third Order Intercept Point (IIP3)* | dBm | -2.5 to -3.0 |
| DC Input Voltage Range | V | 10.0 to 35.0 |
| DC Input Voltage, Nominal | V | 13.8 |
| DC Supply Current, Nominal | mA | 0.250 |
| DC Supply Method, Nominal | n/a | Bias-T via coax |
| DC Supply Method, Alternate | n/a | external |

Note *: Linearity numbers *without* output protection diodes installed

# Active Dipole Balun - Simplified Block Diagram

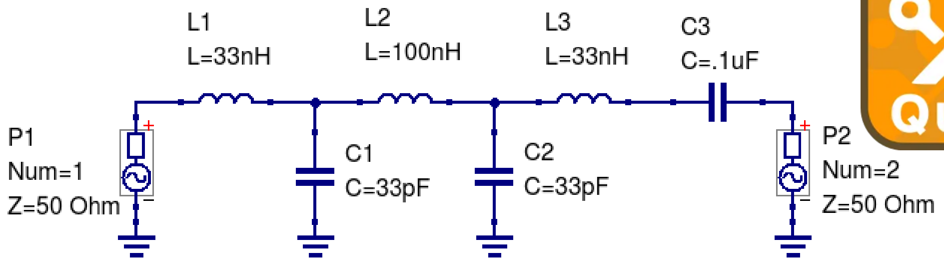
$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$

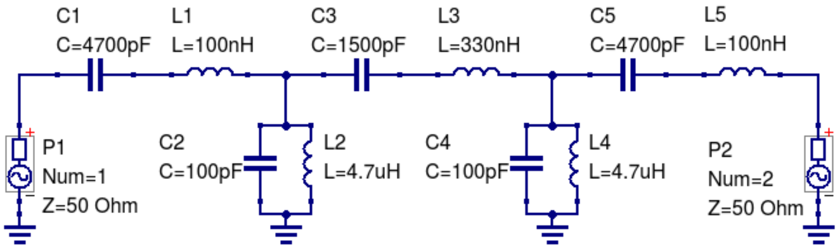


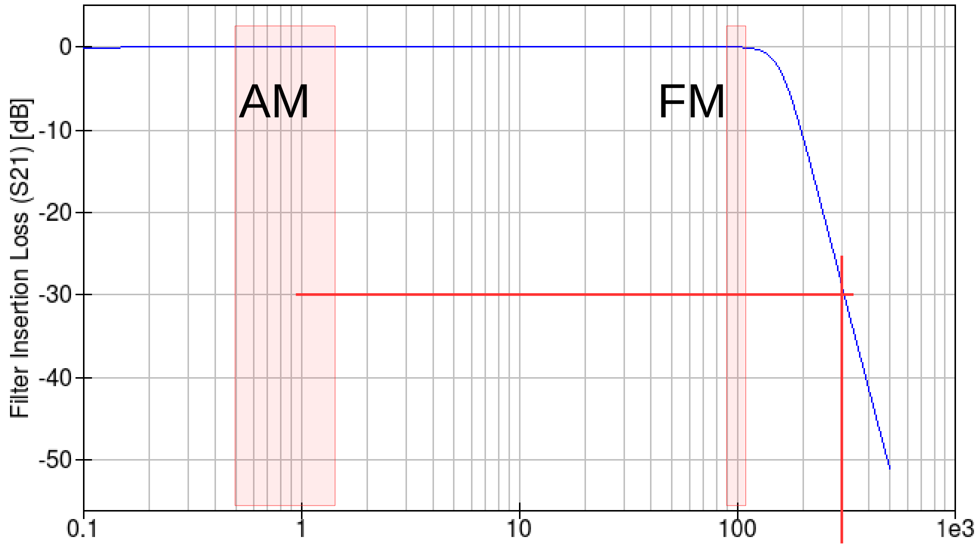

**Single Linearly Polarized Active HF Dipole Balun Block Diagram**

# LWA-FEEv1.7 LPF vs AHFDB BPF - Simulated

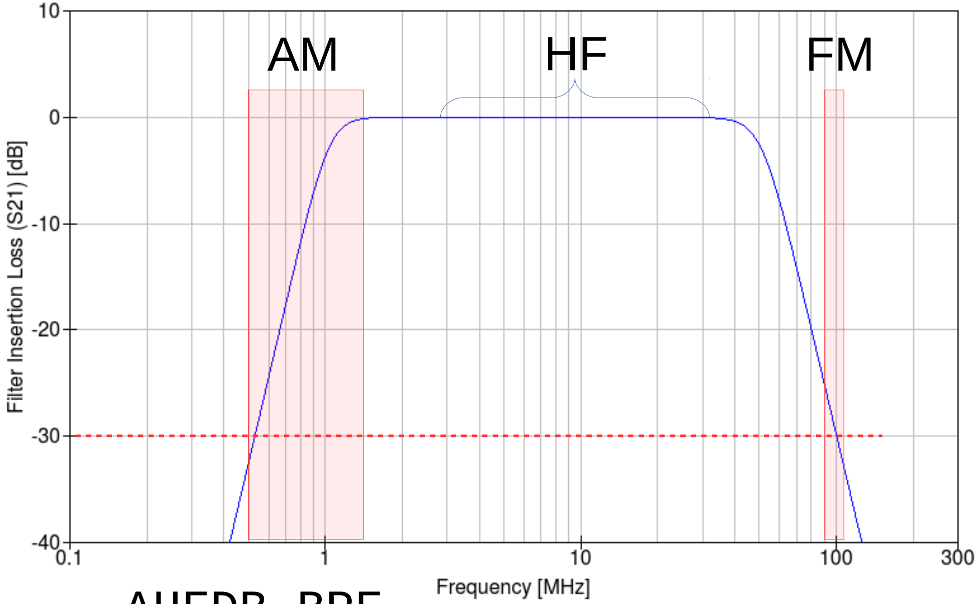
$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



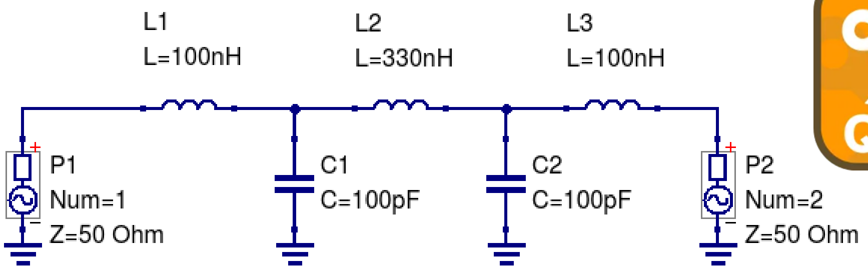

LWA LPF

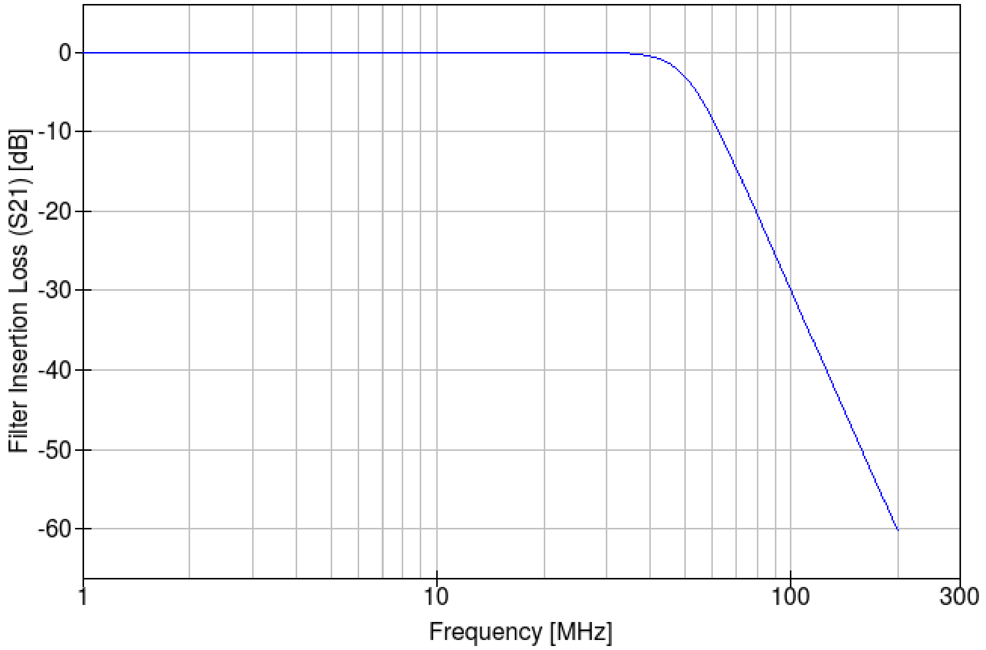


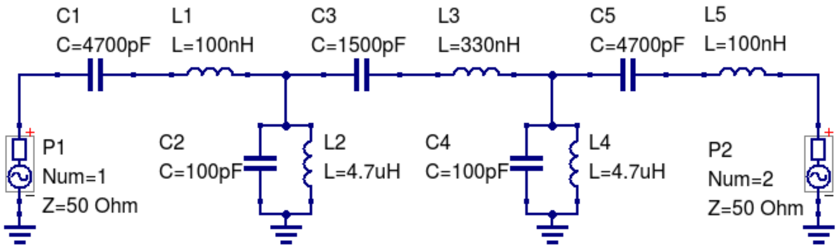

AHFDB BPF

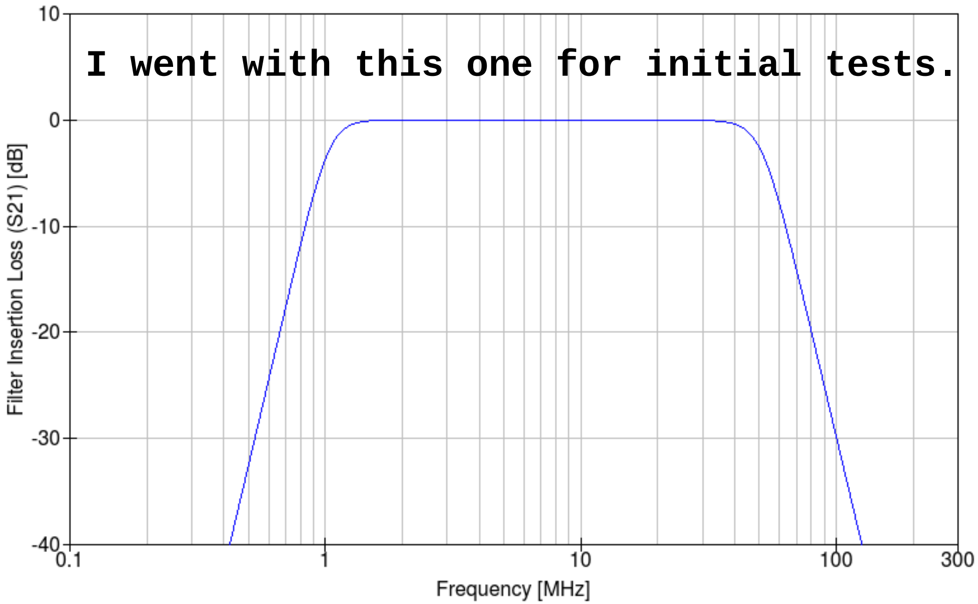
# AHFDB Filter Simulations - QUCS

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



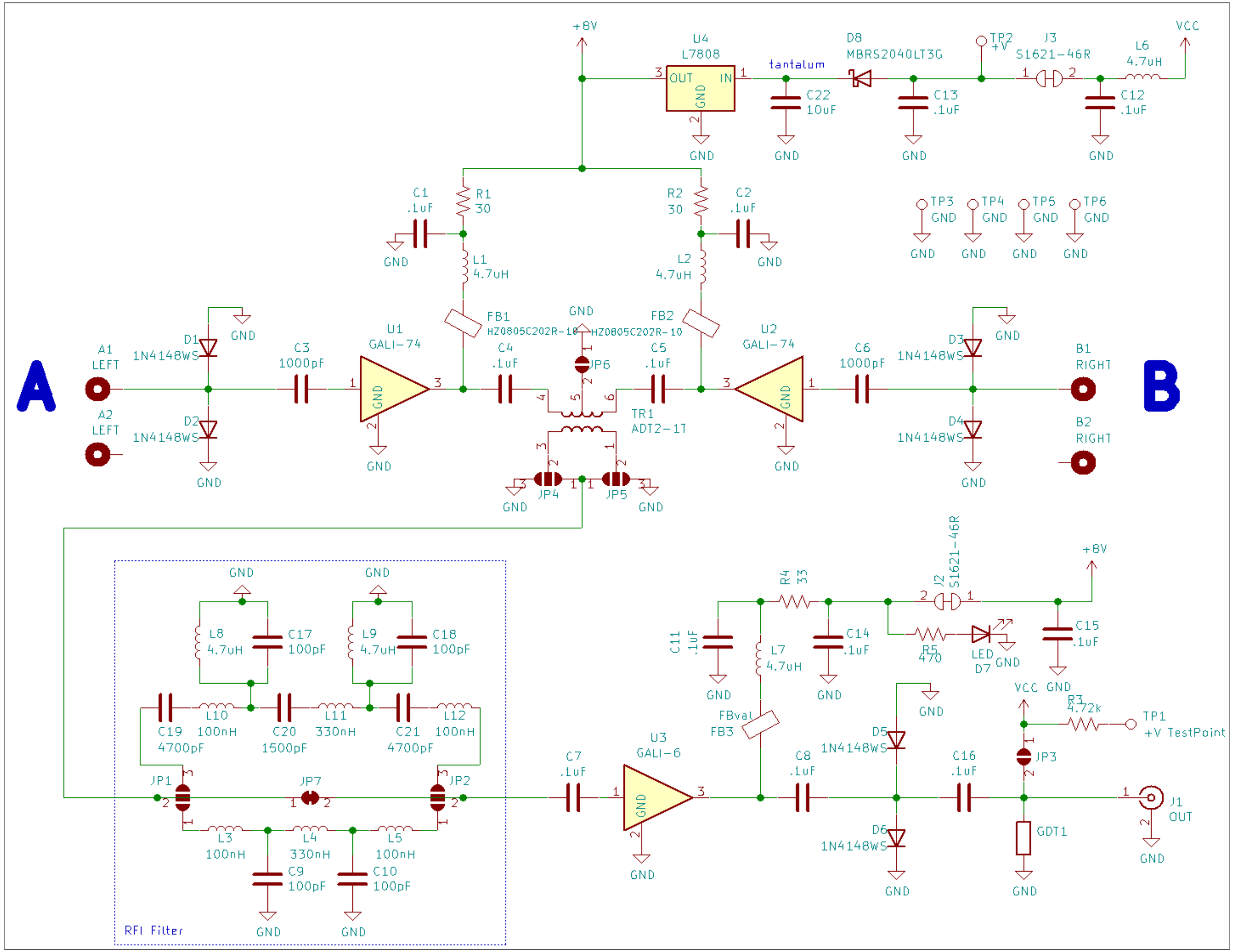



# Schematic

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

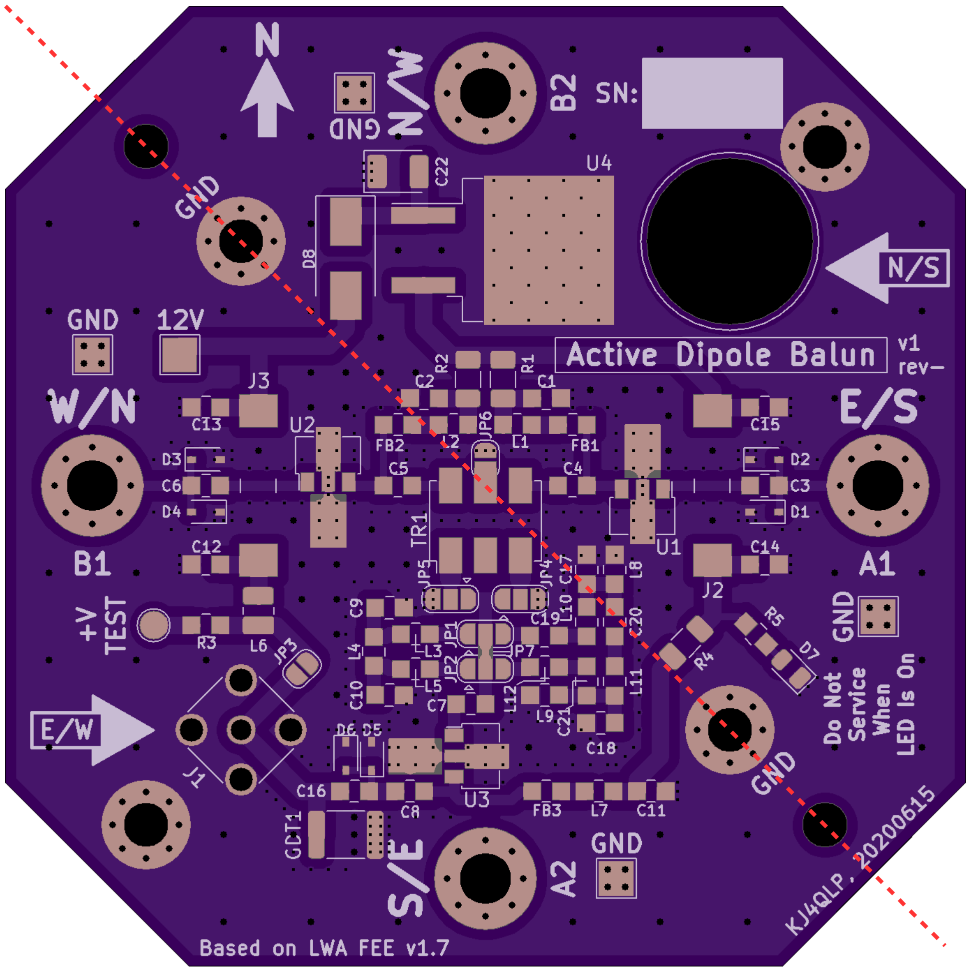


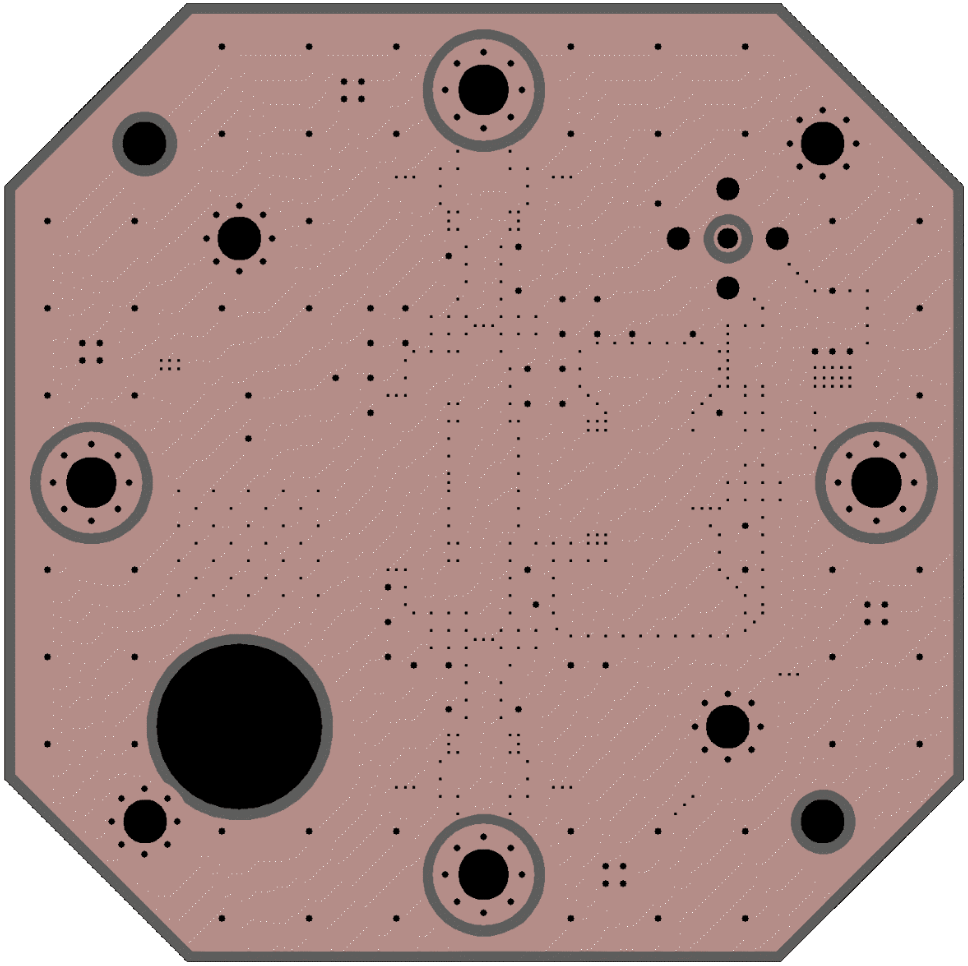

NOTES:

- Amp bias resistors R1, R2, & R4 Have been updated to 39Ω
- This is to match datasheet recommended values

# PCB Layout – Osh Park Images

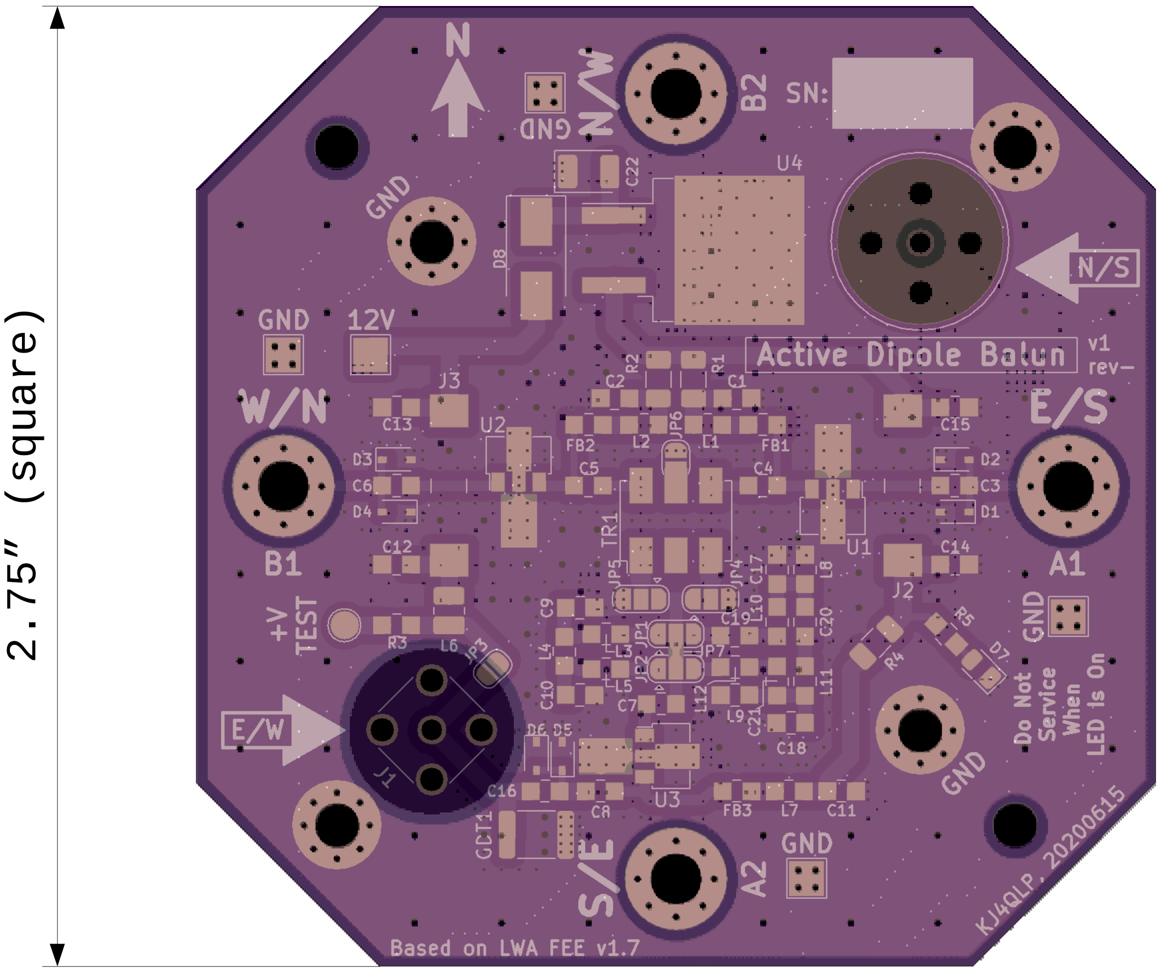
$$\nabla\cdot\boldsymbol{D}=\rho$$
$$\nabla\cdot\boldsymbol{B}=0$$
$$\nabla\times\boldsymbol{E}=-\frac{\partial\boldsymbol{B}}{\partial t}$$
$$\nabla\times\boldsymbol{H}=\boldsymbol{J}+\frac{\partial\boldsymbol{D}}{\partial t}$$



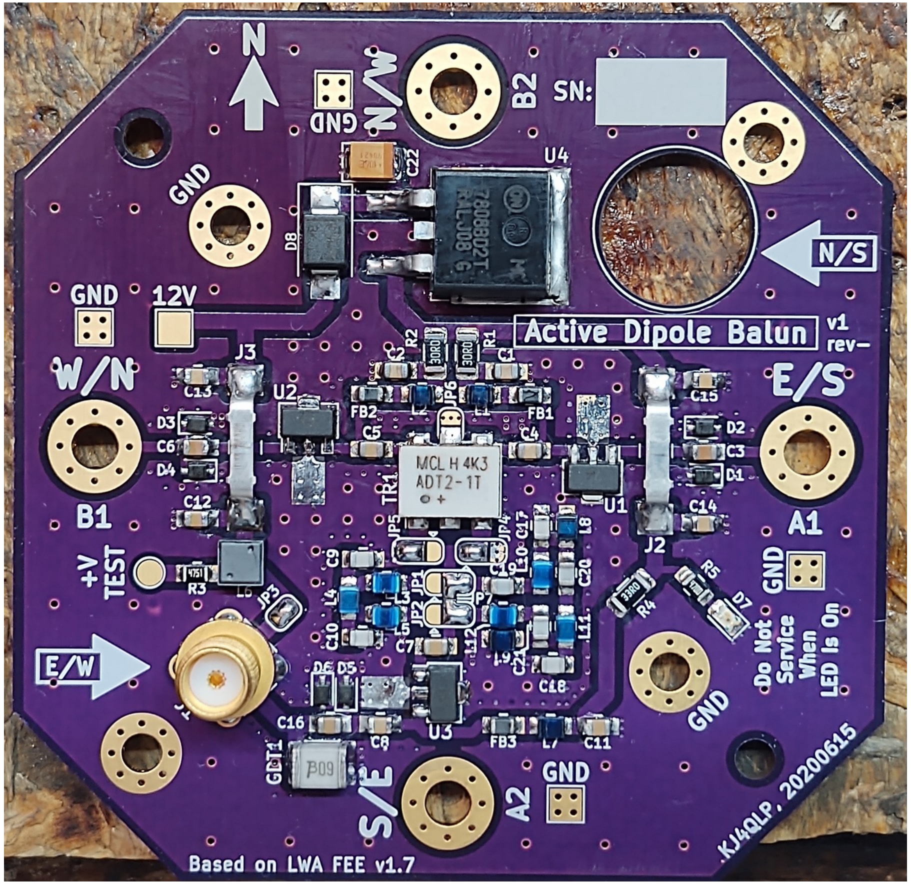
# Back to Back PCBs – Dual Polarization

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$

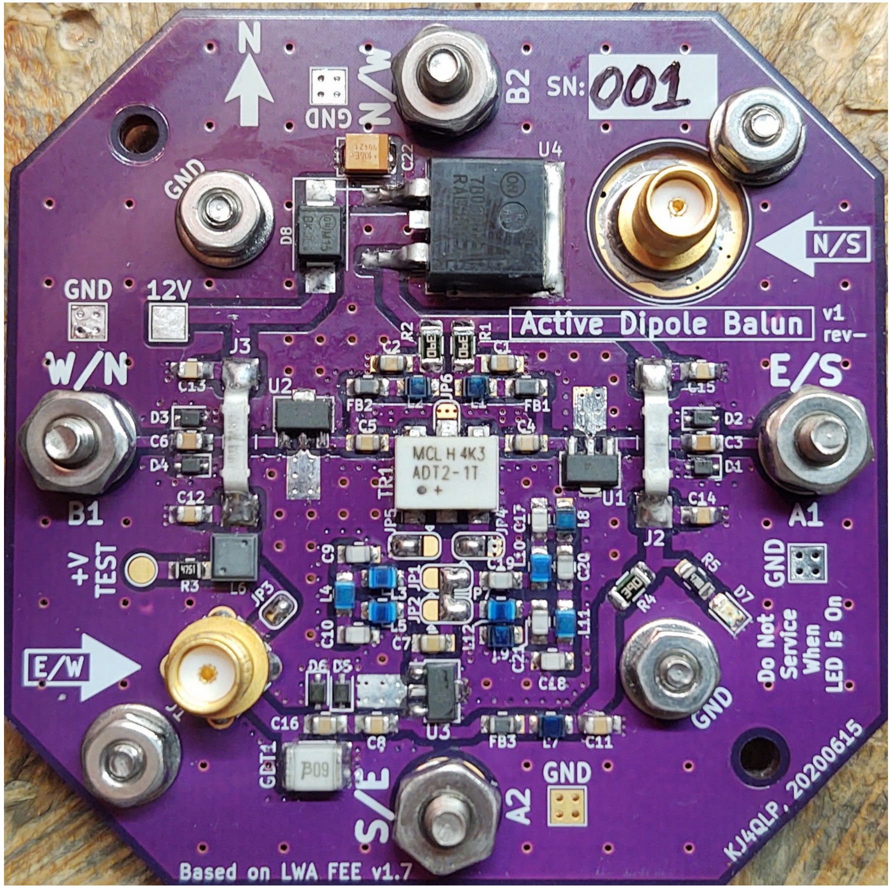


# Populated PCBs

## Single Balun

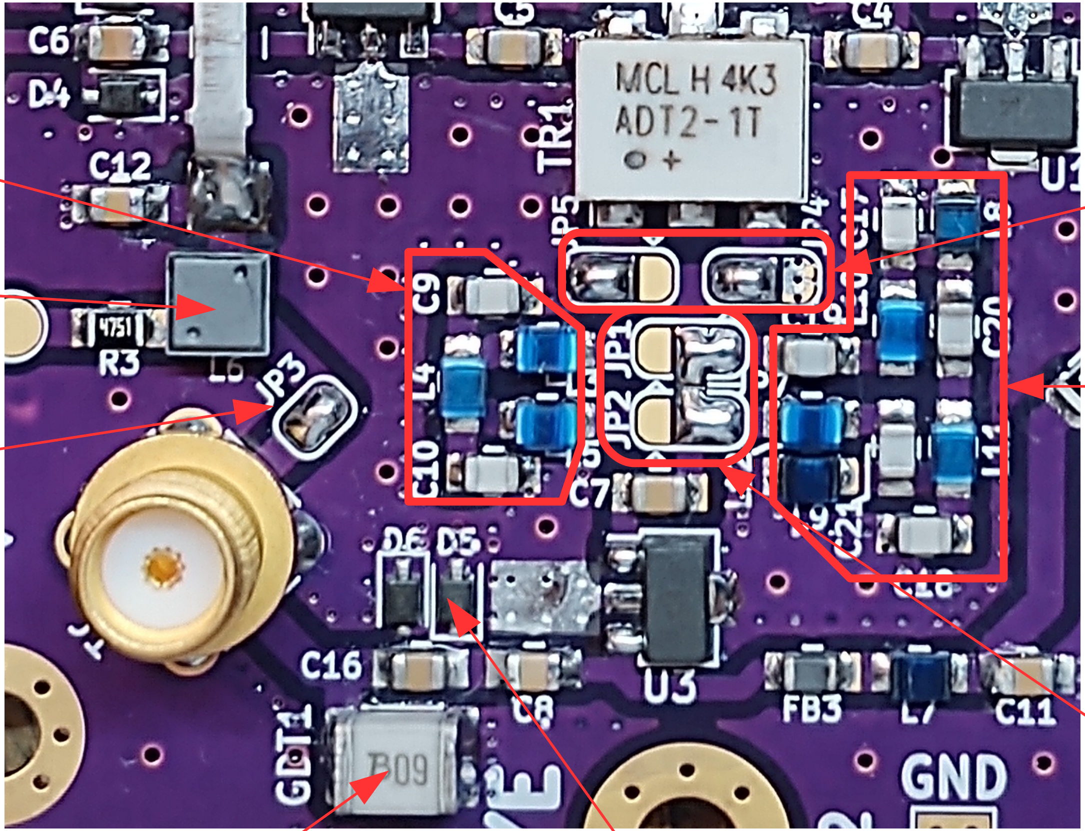



## Double Balun



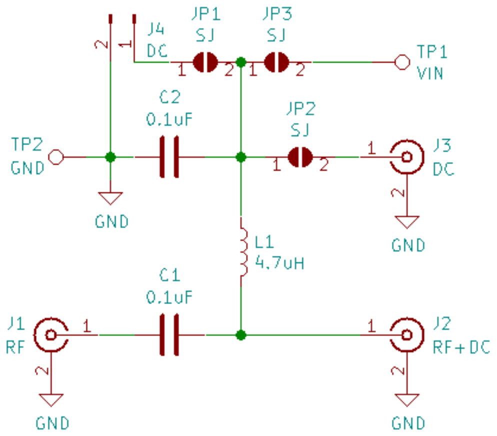
# Solder Jumpers & some other details

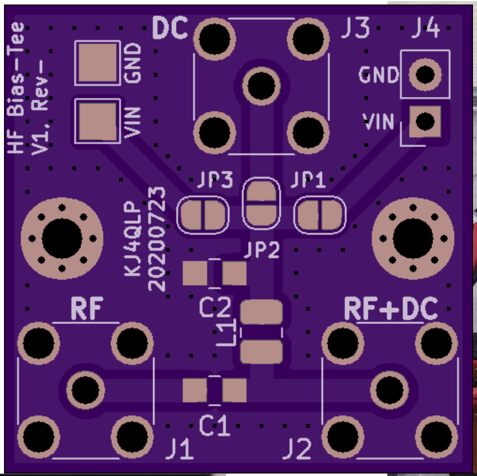
$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

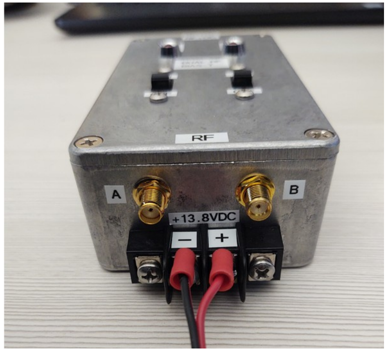


# Dual HF Bias-T – LWA Design, KJ4QLP Layout

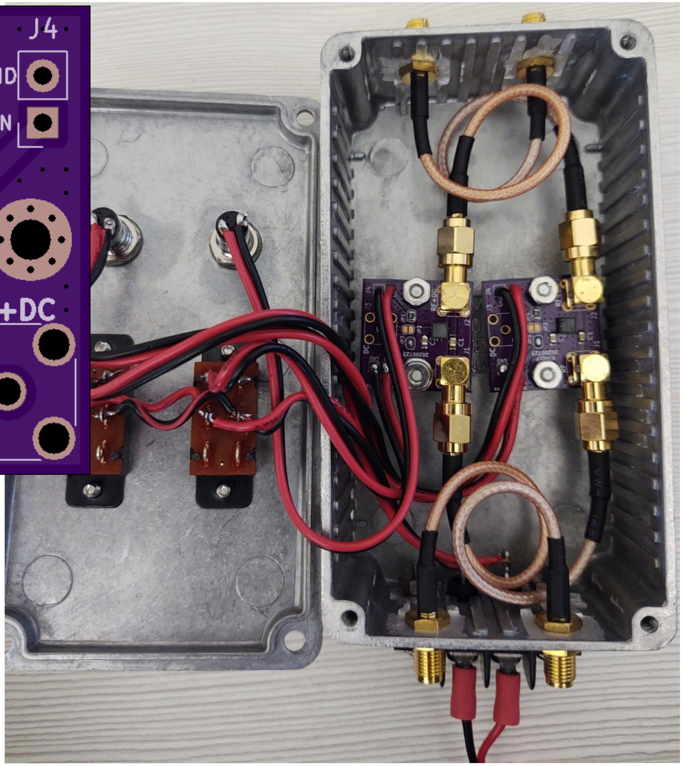
$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$

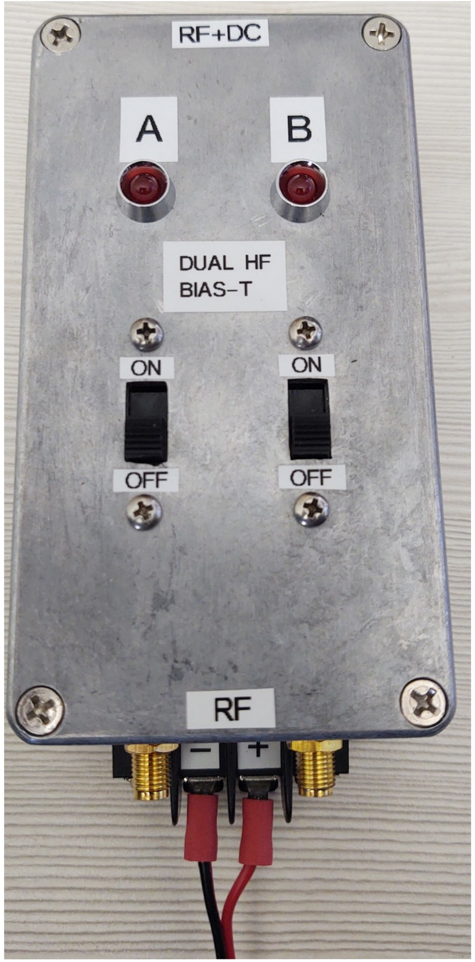




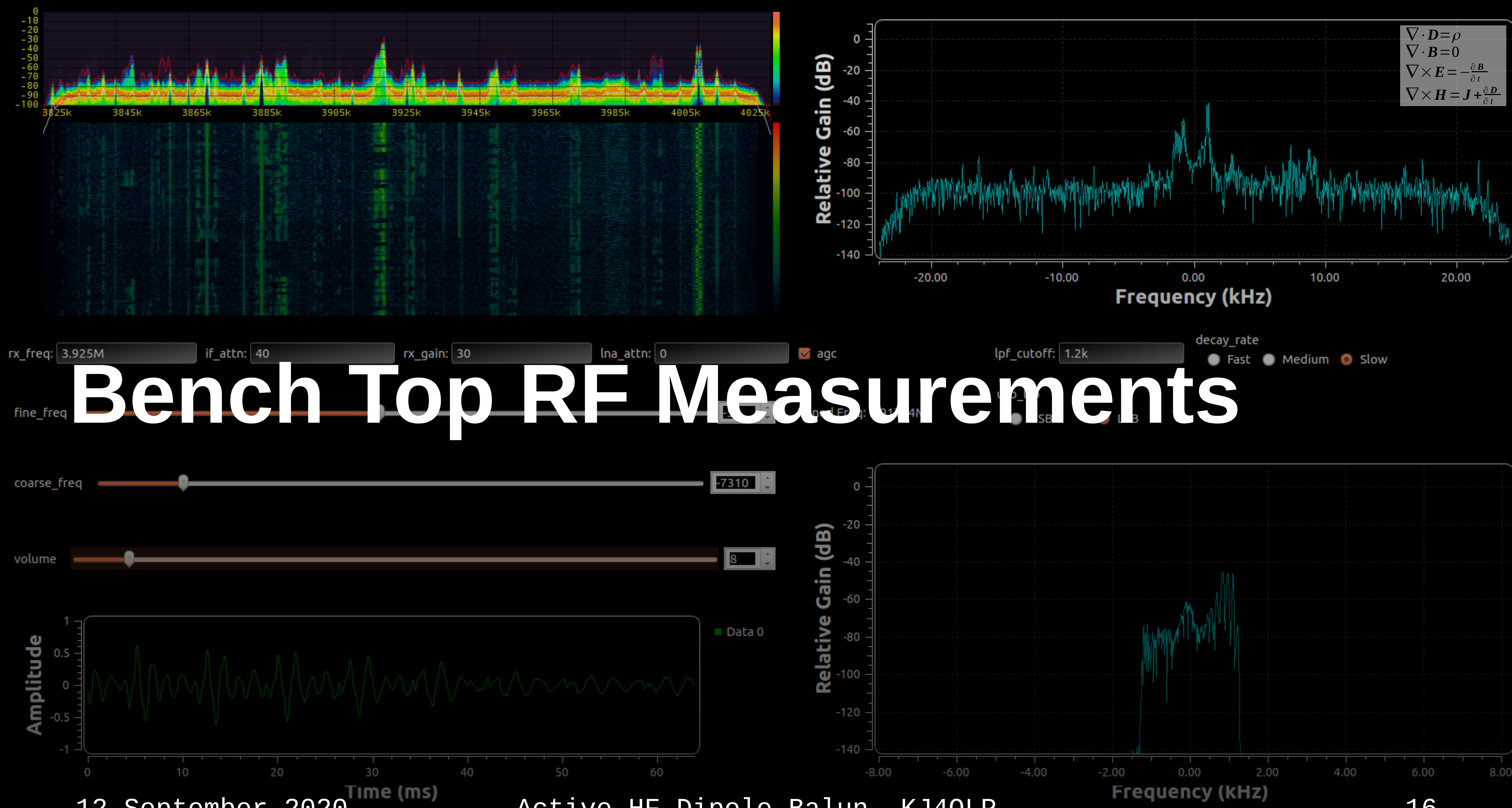





$5 for 3 boards
From Osh Park

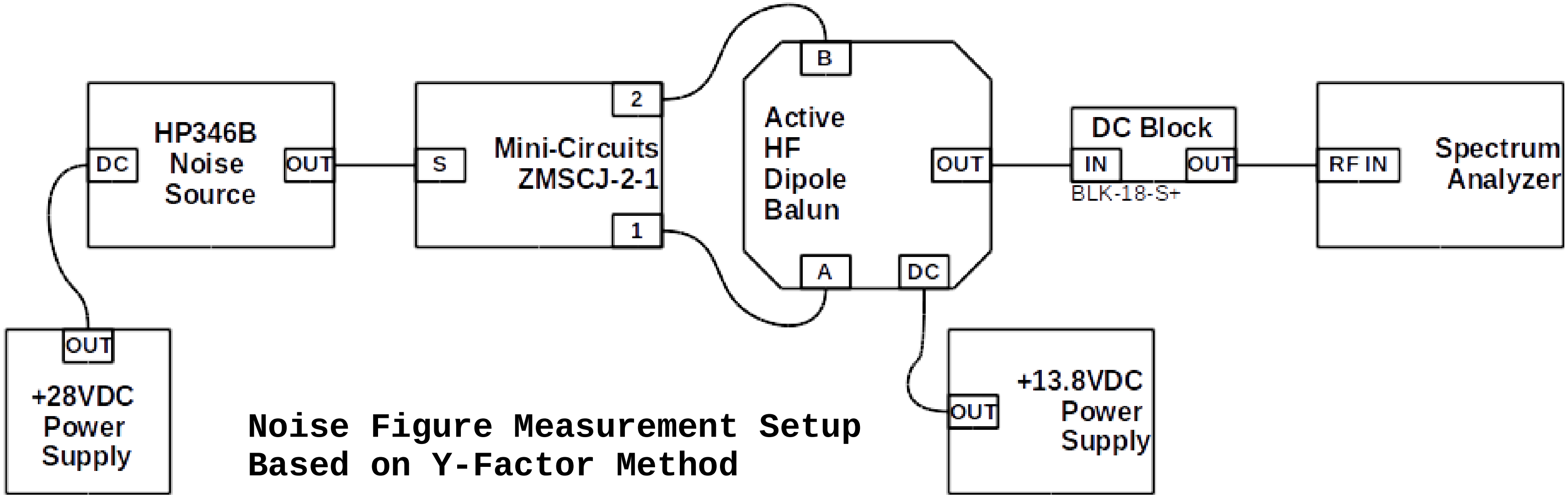
Design taken straight from the LWA Memo Series document LWA0135:
B. Hicks and B. Erickson, Bias-T Design Considerations for the LWA, May 21, 2008.
Available: https://www.faculty.ece.vt.edu/swe/lwa/memo/lwa0135.pdf
KJ4QLP KiCAD Design: https://github.com/zleffke/kicad_bias_tee

# Bench Top RF Measurements



# Noise Figure Measurement Setup

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

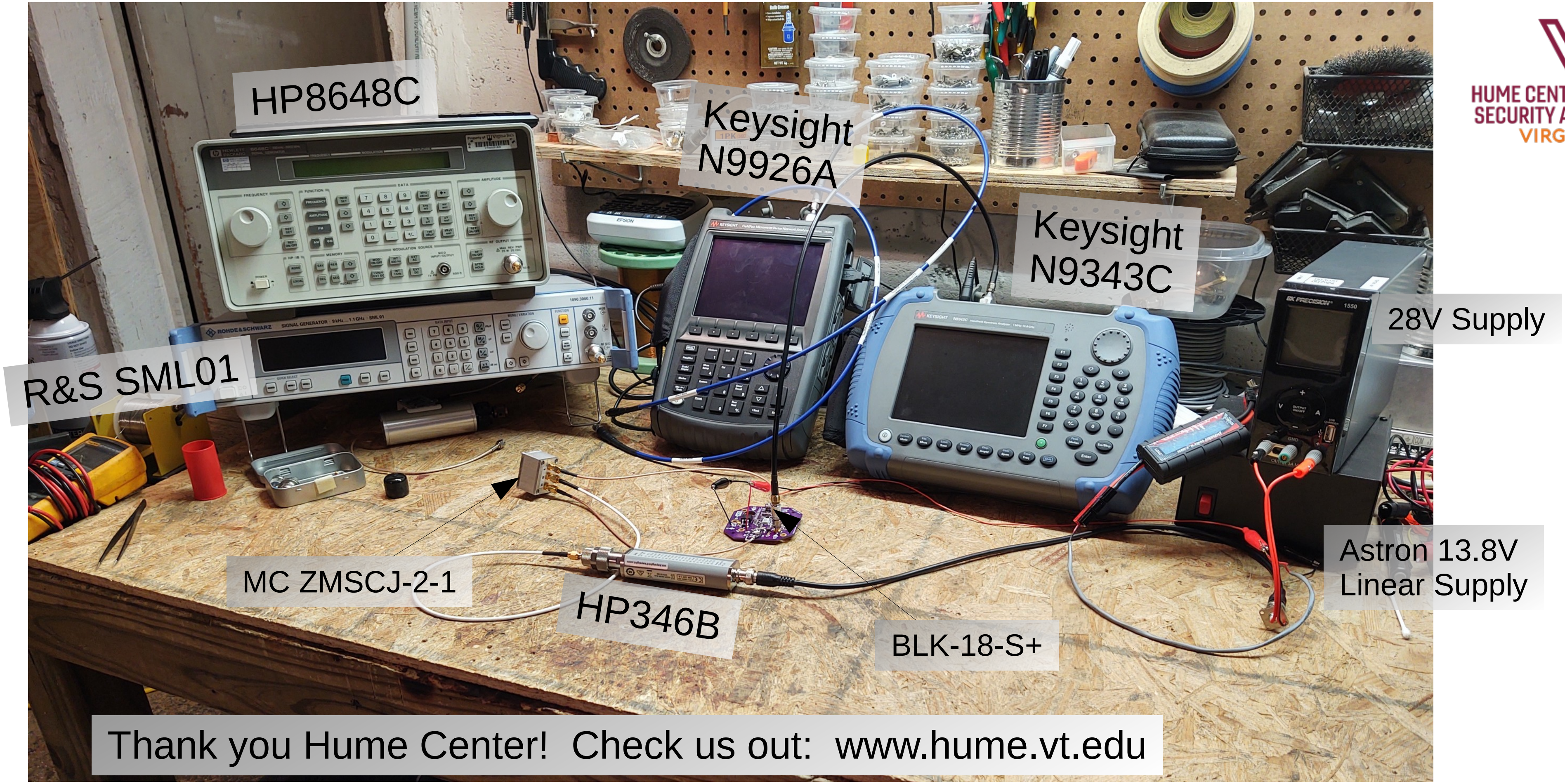



**Noise Figure Measurement Setup**
**Based on Y-Factor Method**

- I don’t have time to present each configuration for each measurement type.
- All measurements included component calibration, which are factored into the results presented.
- More details may be presented in future documentation focused on the measurement process.

# The Test Equipment

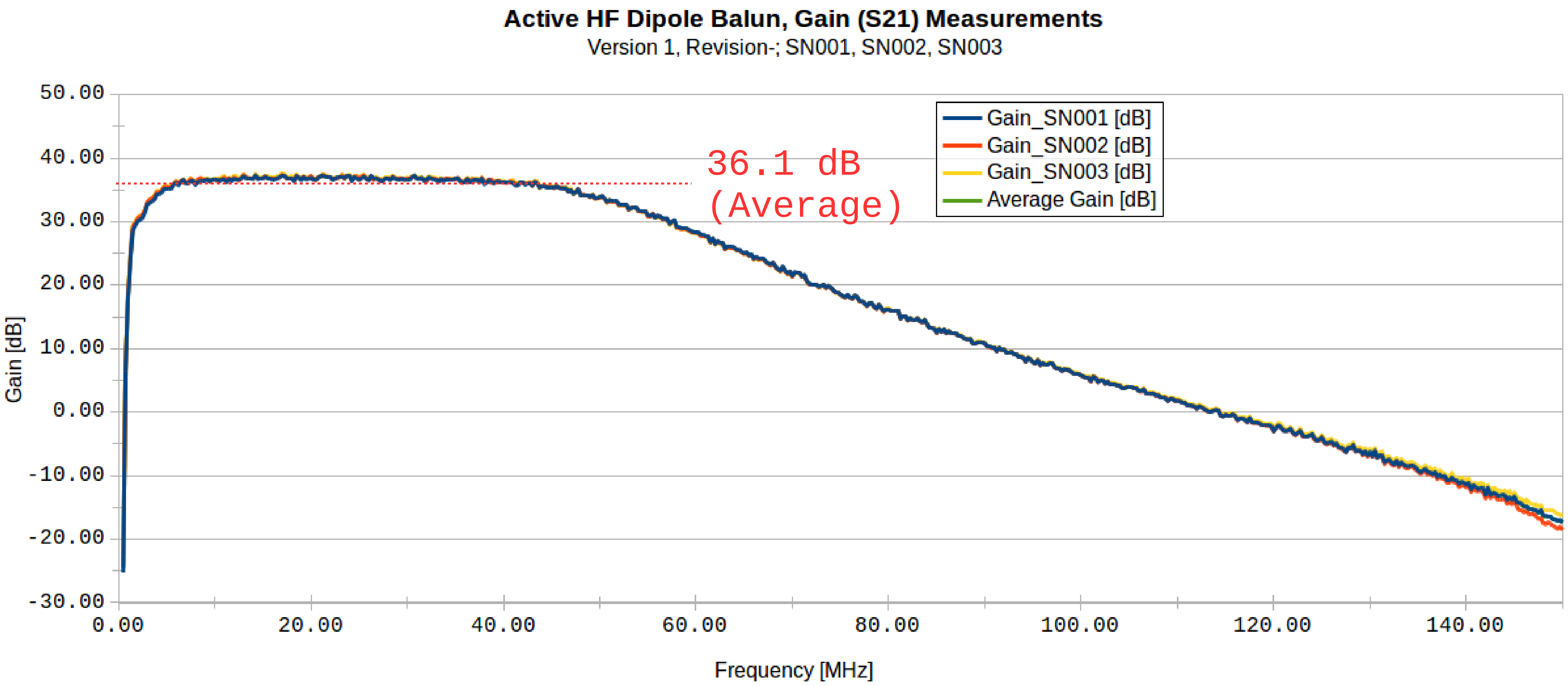
$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$




HUME CENTER FOR NATIONAL SECURITY AND TECHNOLOGY
VIRGINIA TECH

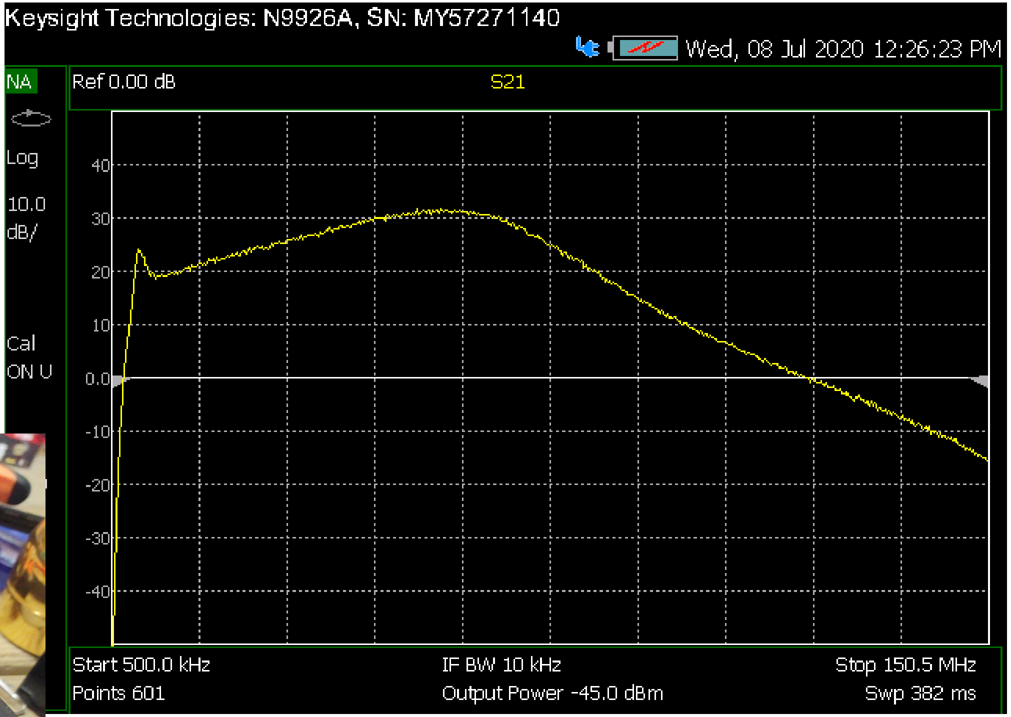
# Gain, S21

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



# Bad SMT Solder Job = Bad Filter Response

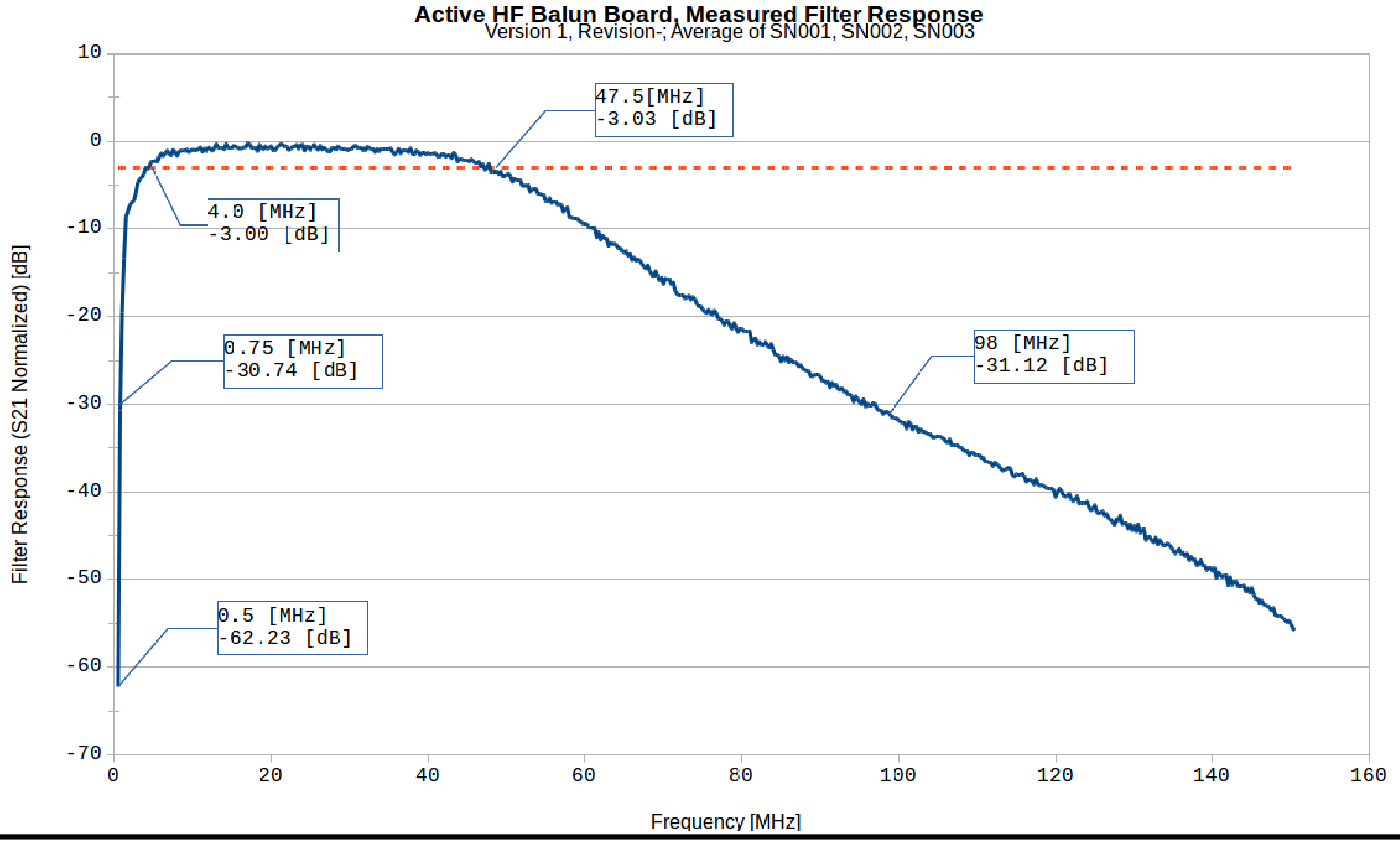
$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$


With surface mount soldering by hand (no stencil)…**Less is More!**

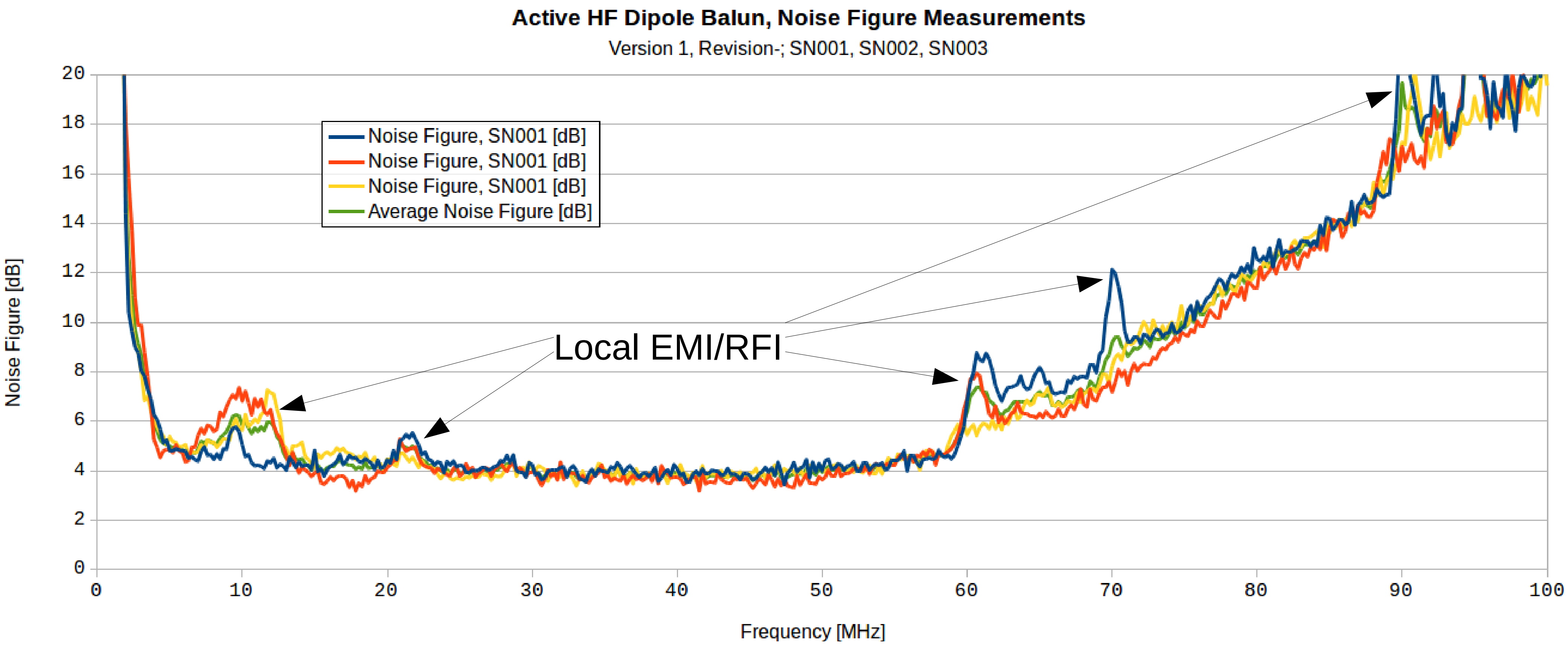
# Integrated Band Pass Filter Response

$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$



# Noise Figure

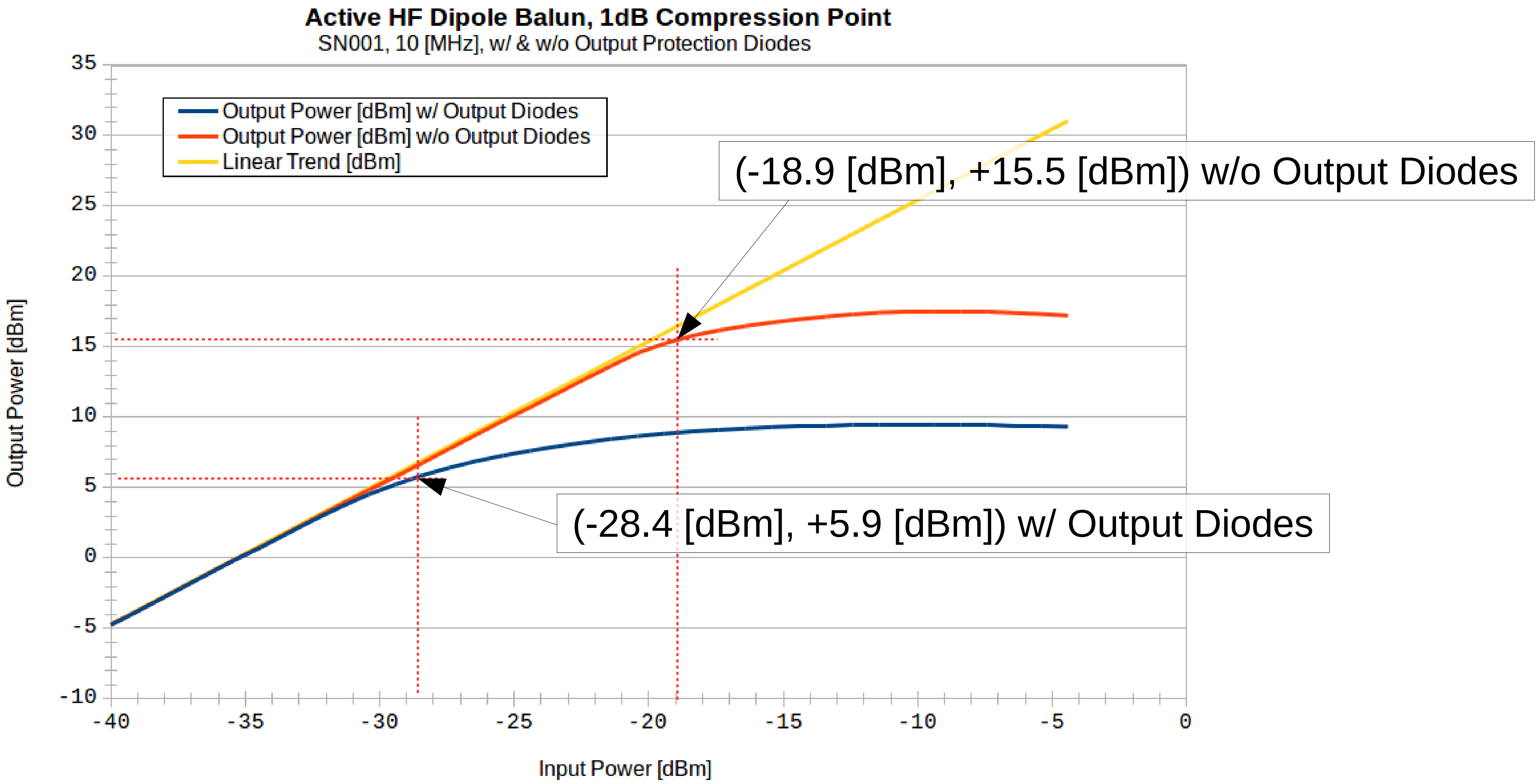
$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$




Notice the RFI/EMI Spikes, may retake measurements in Faraday Cage

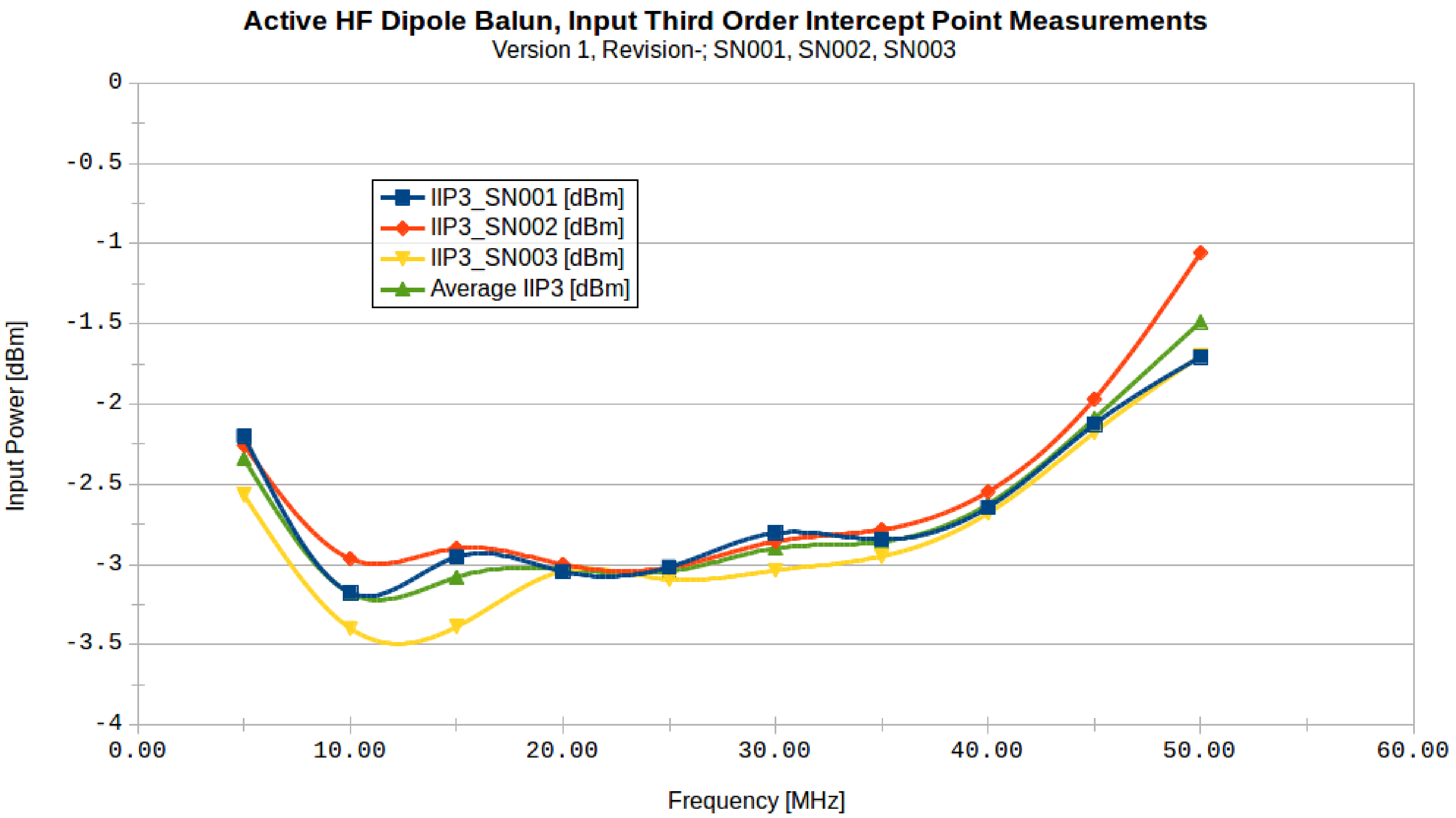
# 1dB Compression Point @ 10 MHz, SN001

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$



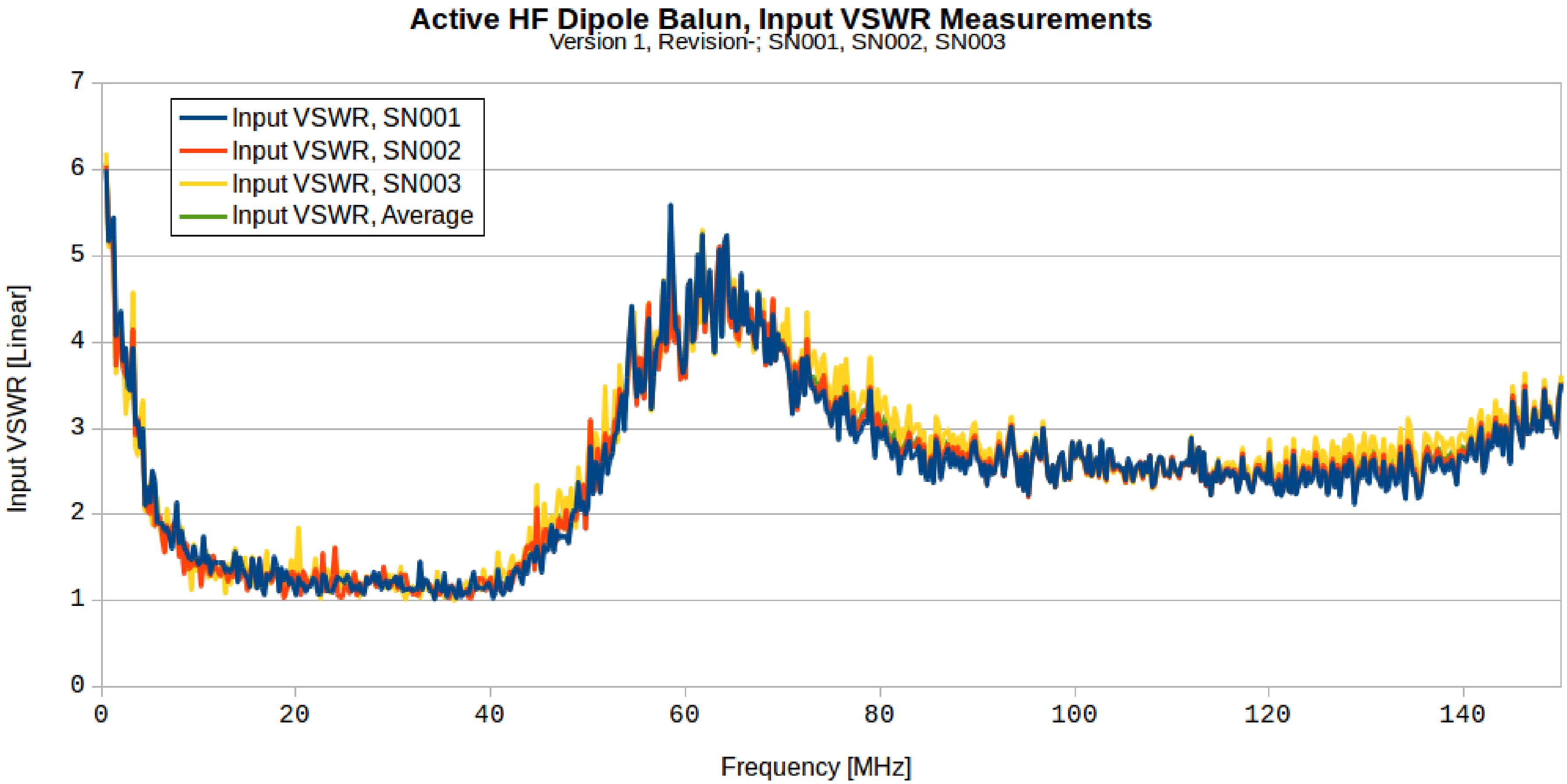
# Input Third Order Intercept Point (IIP3)

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



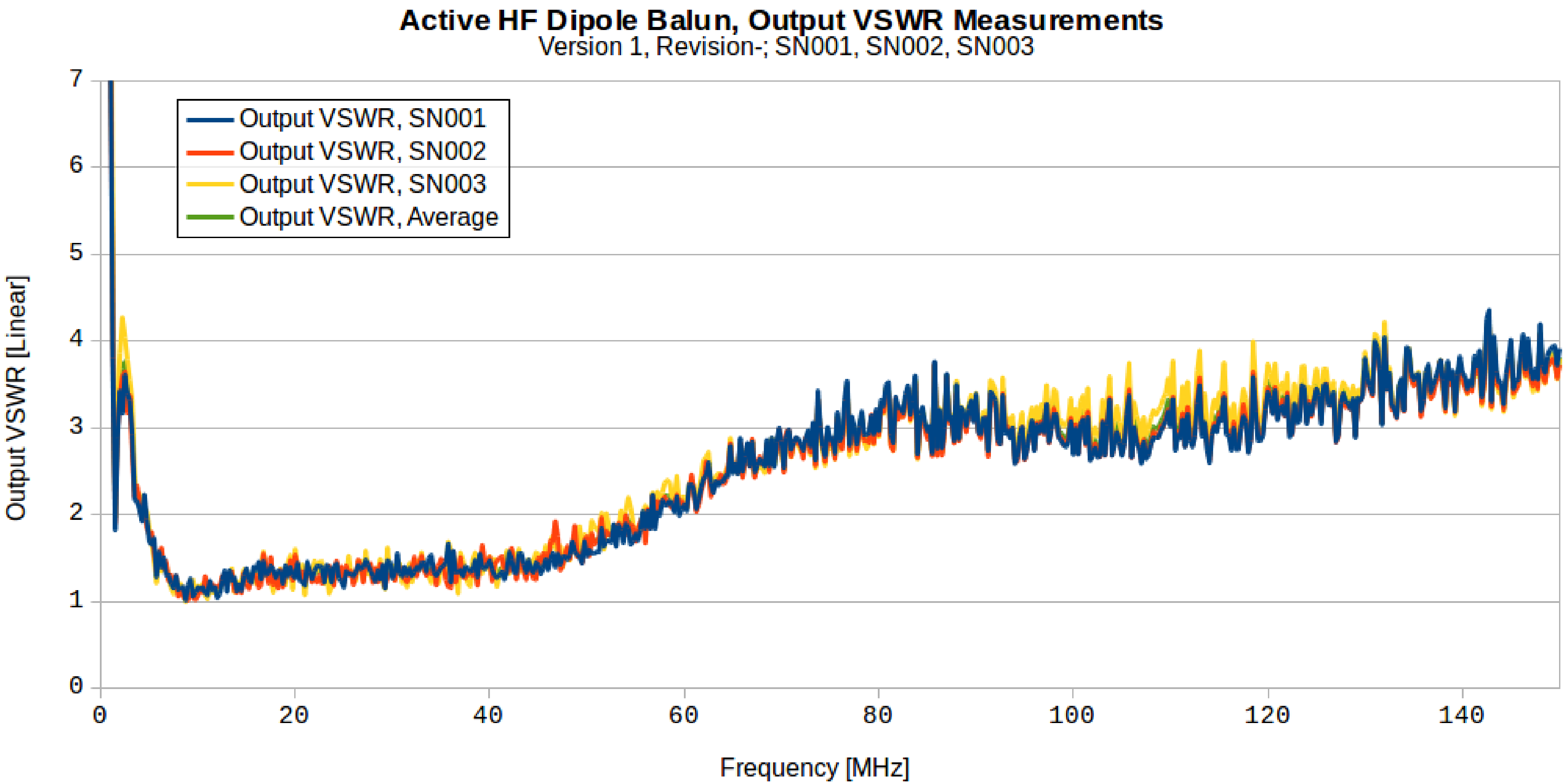
# Input VSWR

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



# Output VSWR

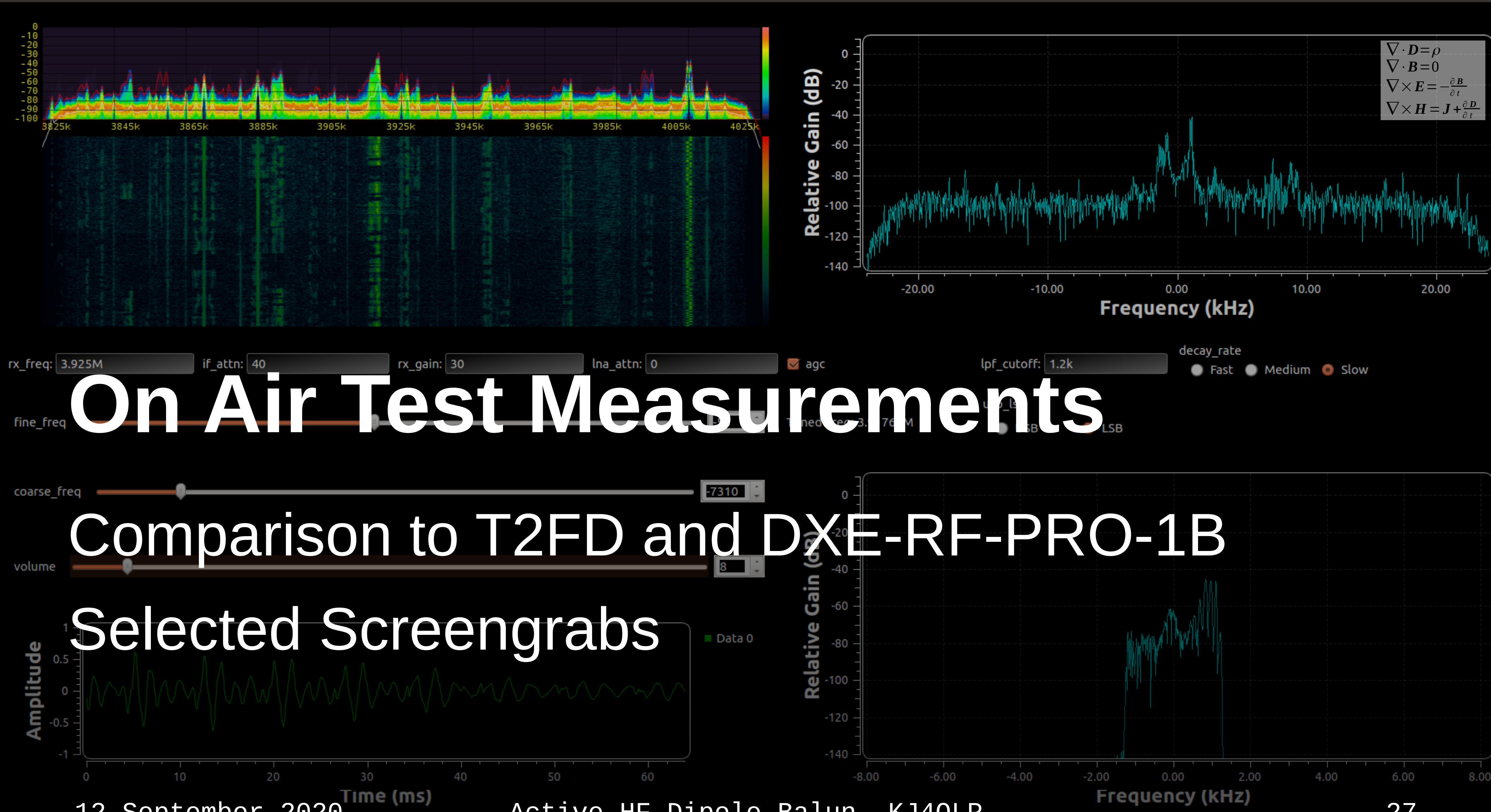
$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



# On Air Test Measurements

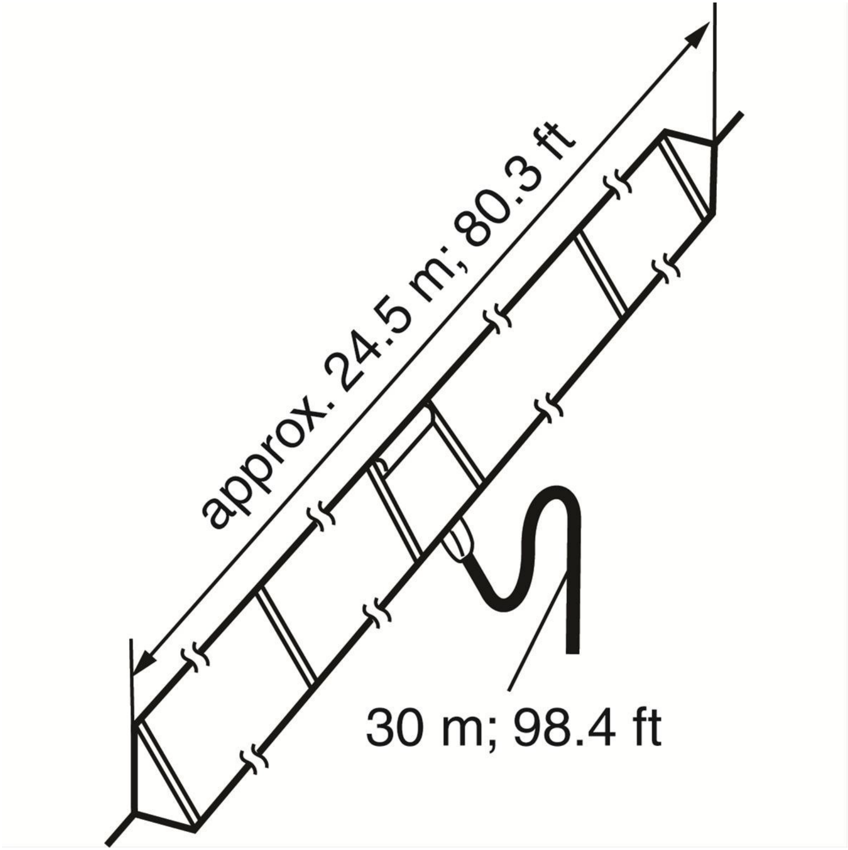
Comparison to T2FD and DXE-RF-PRO-1B

Selected Screengrabs



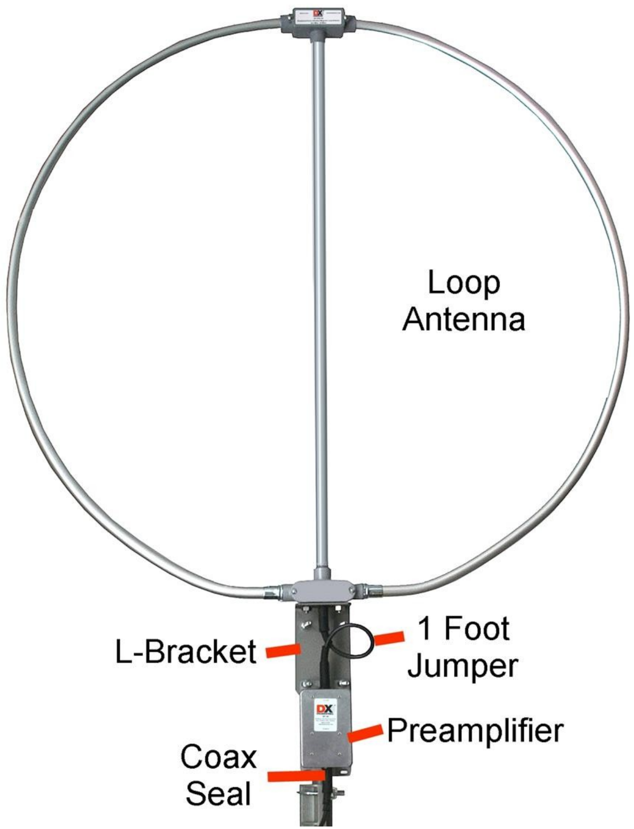
# T2FD and Active Magnetic Loop

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$




**ICOM AH-710 T2FD**

https://www.dxengineering.com/parts/ico-ah-710

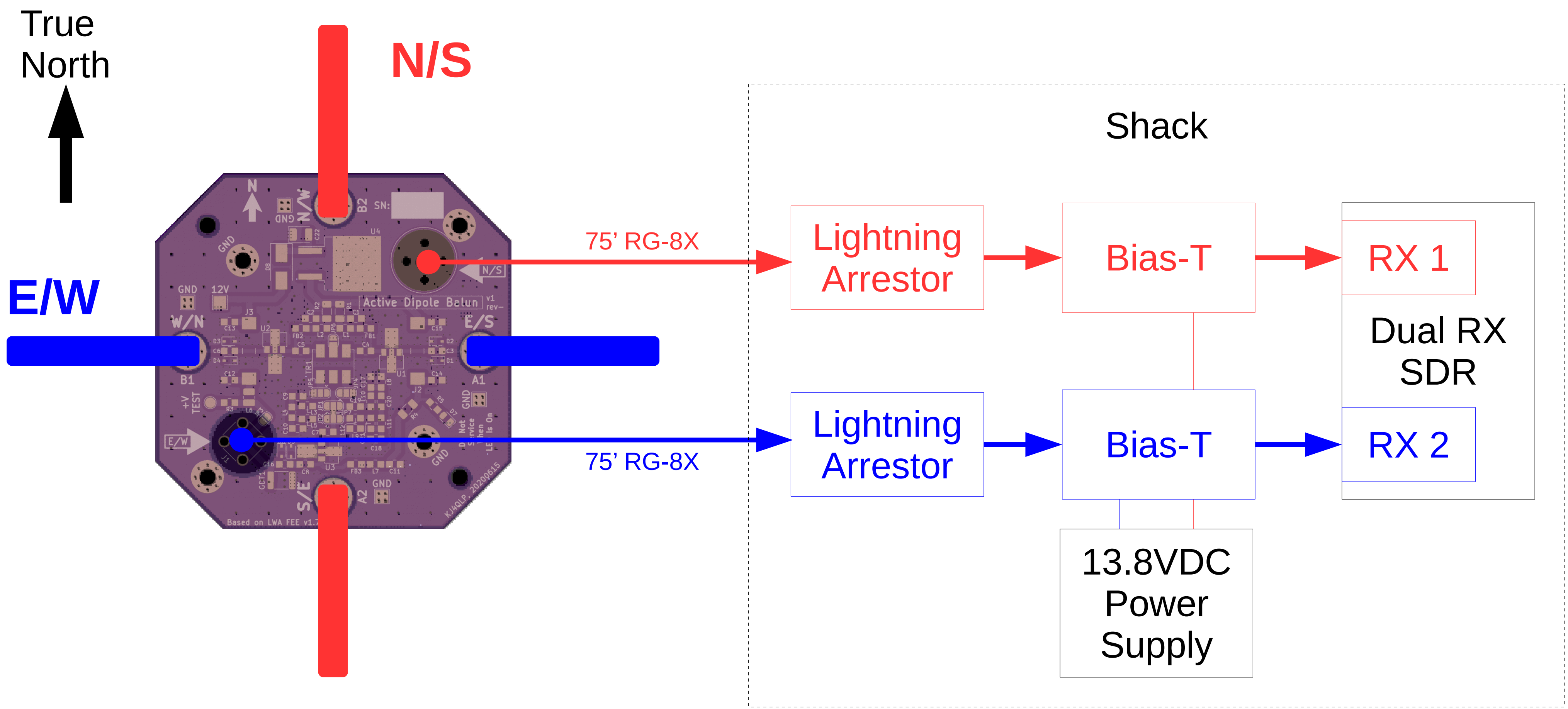



**DX Engineering DXE-RF-PRO-1B**

https://www.dxengineering.com/parts/dxe-rf-pro-1b

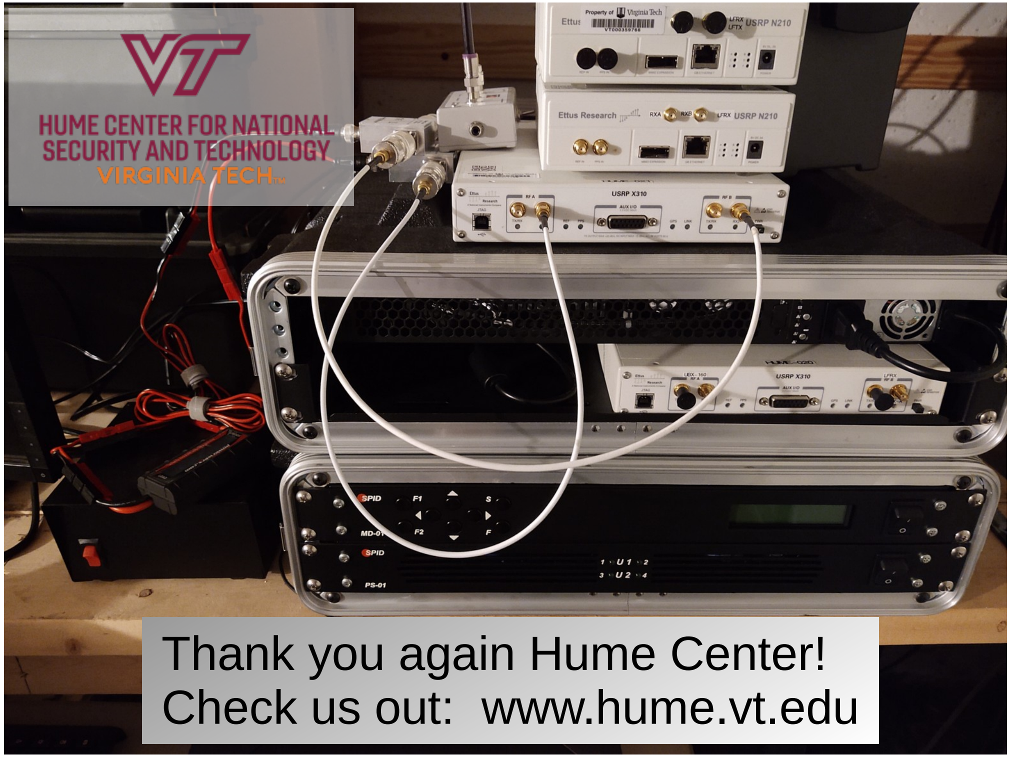
# Dual Polarization High Level System Diagram

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



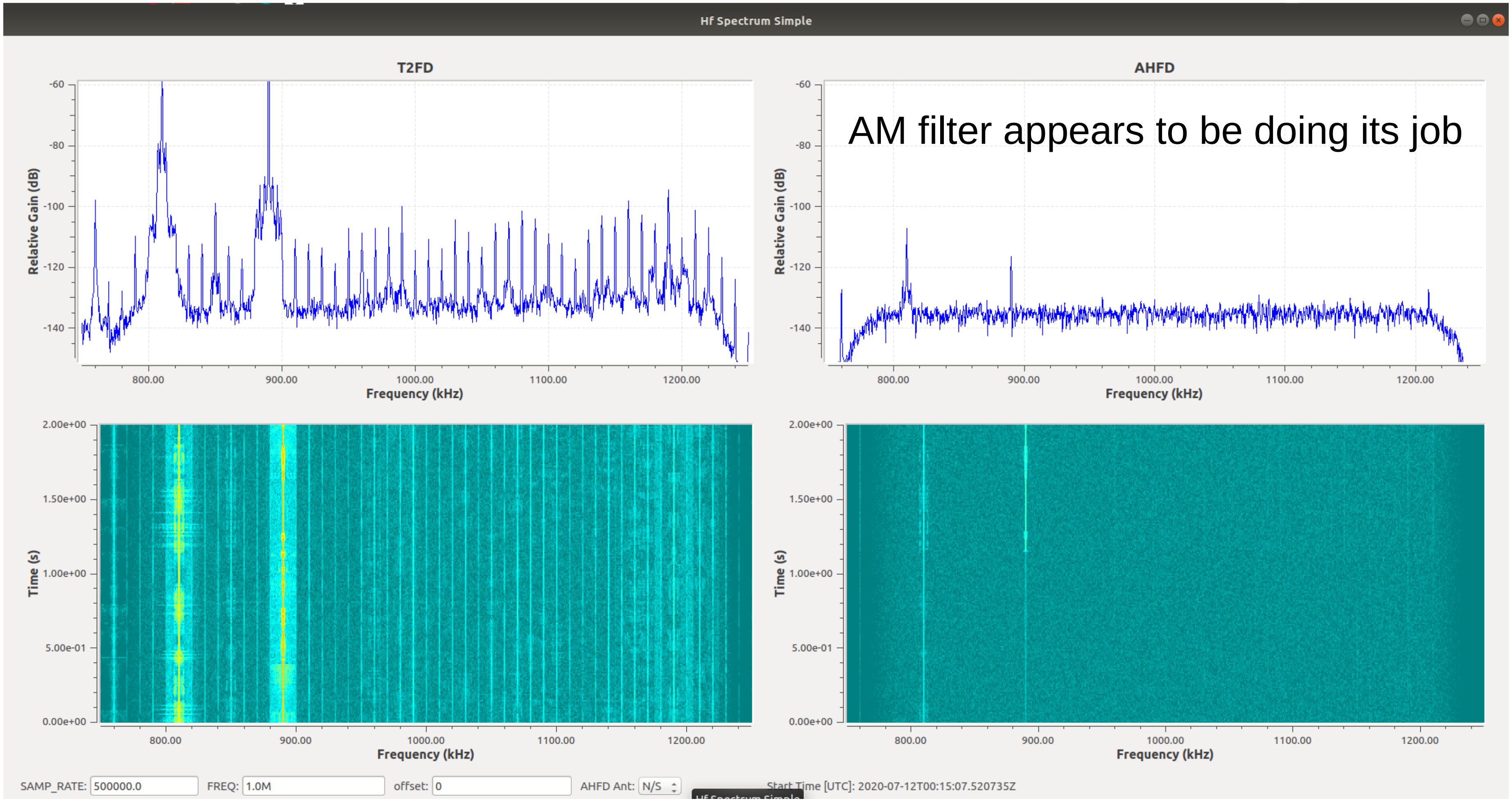
# On Air Measurement Setup

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



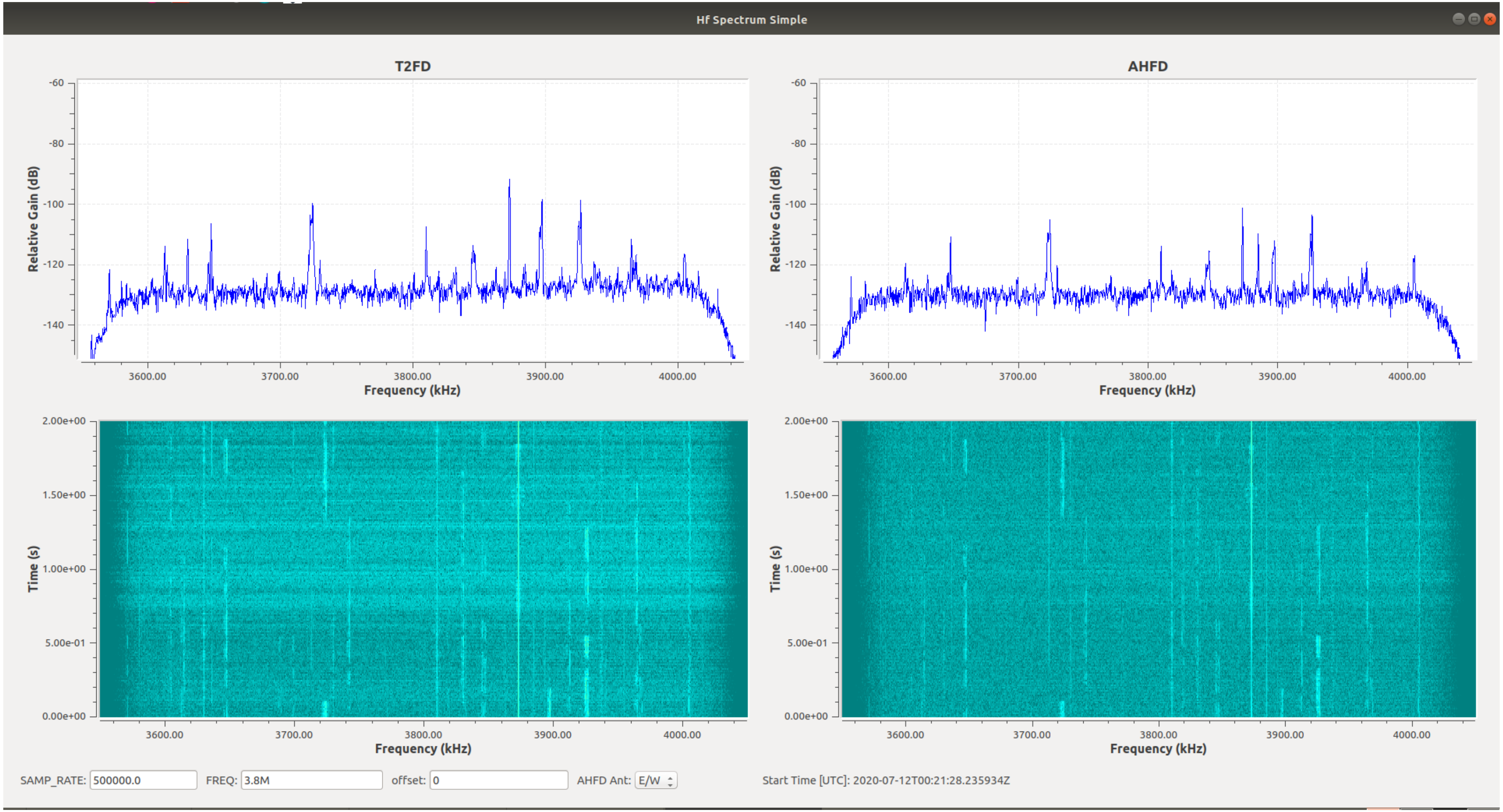
# T2FD vs Active HF Dipole – 1.0 MHz

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



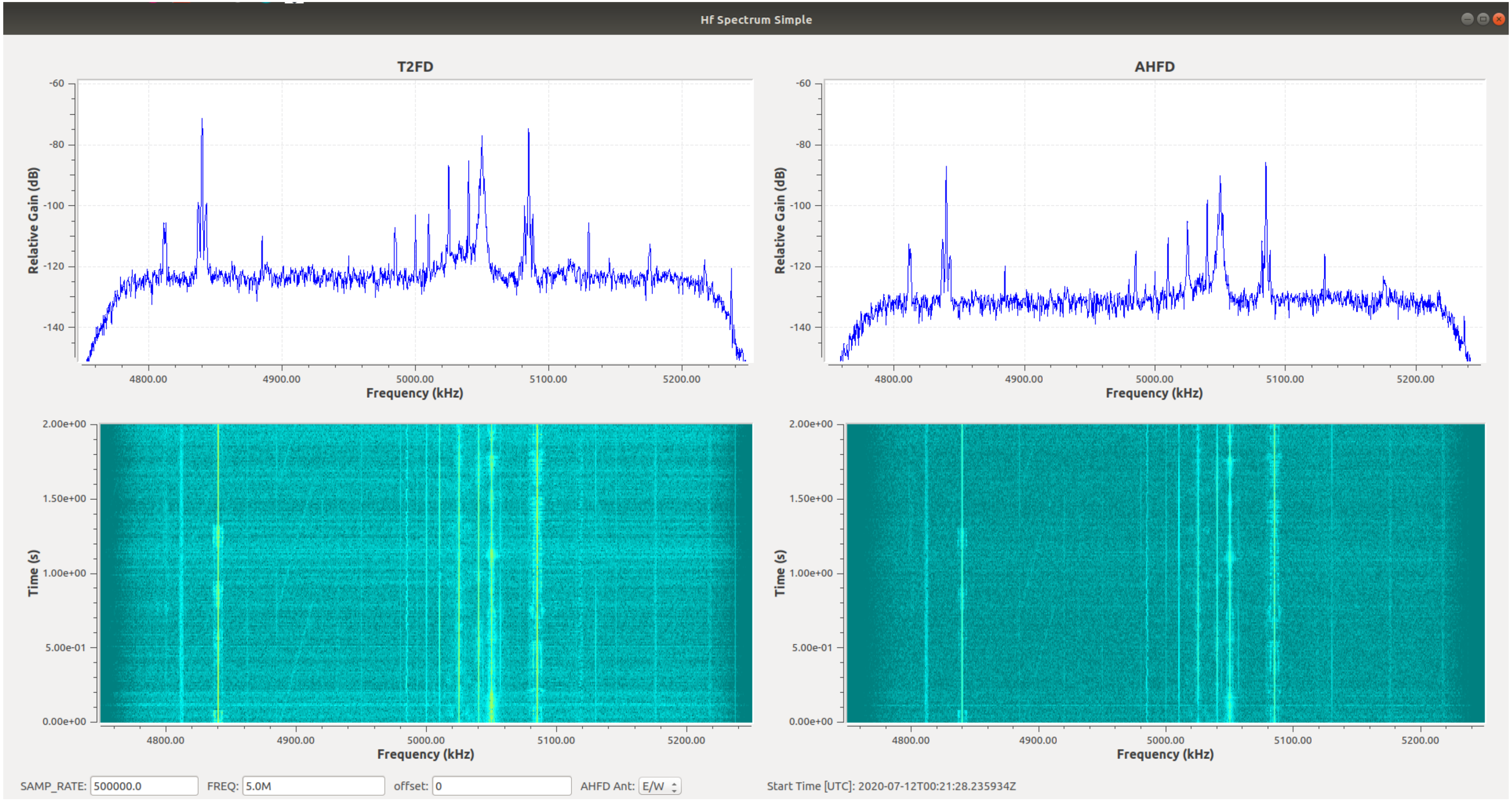
# T2FD vs Active HF Dipole – 3.8 MHz

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



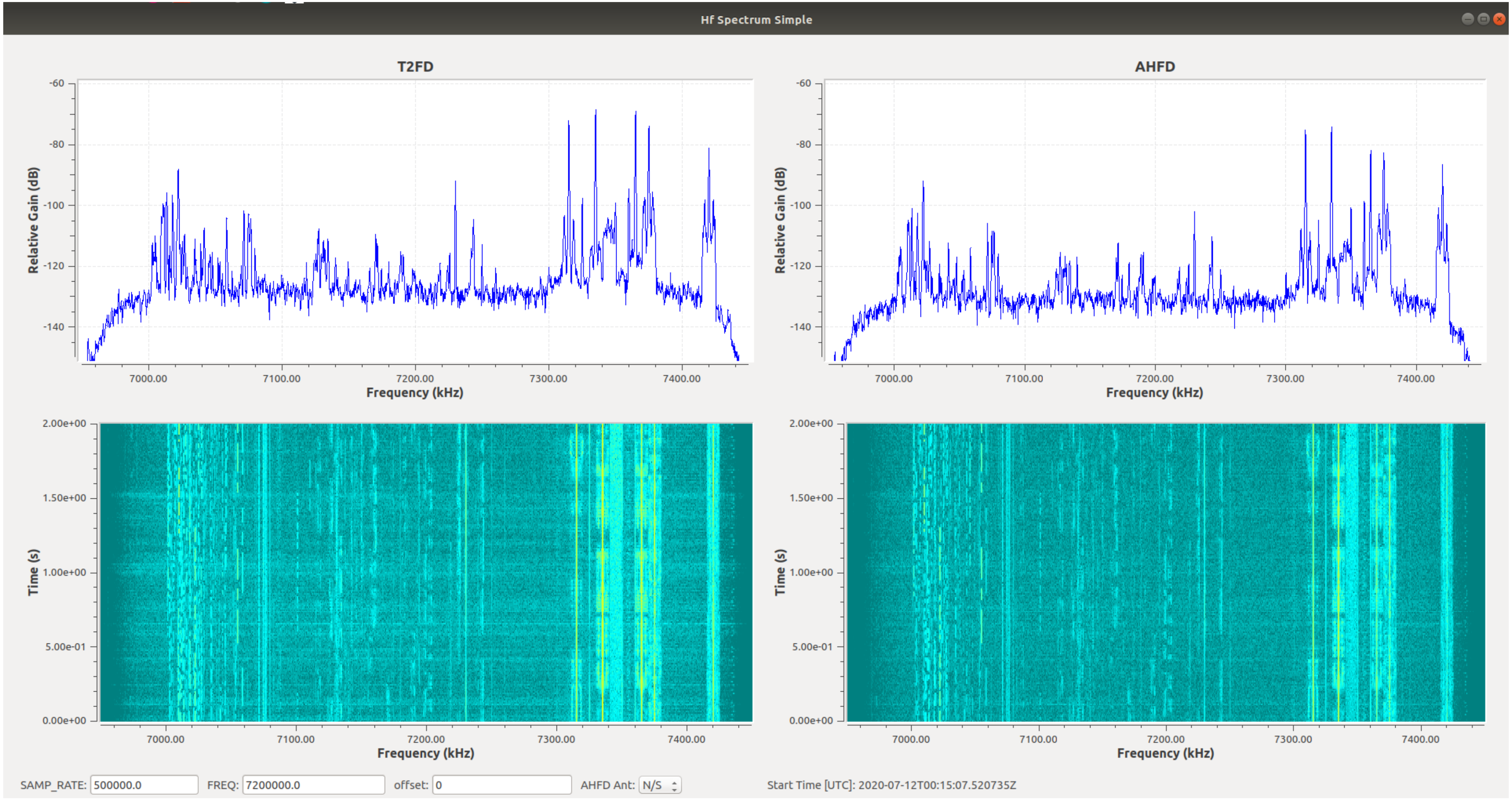
# T2FD vs Active HF Dipole – 5.0 MHz

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



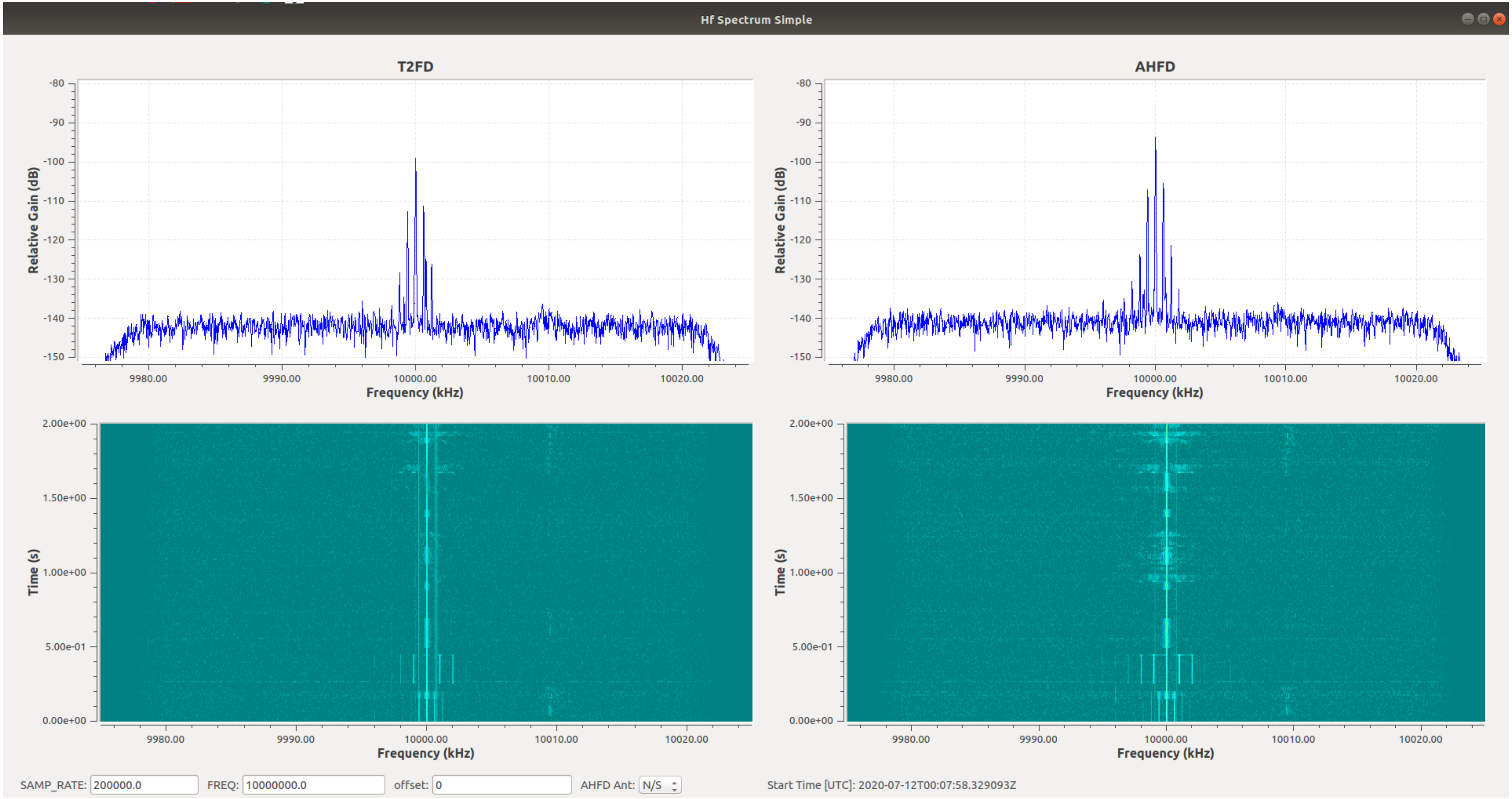
# T2FD vs Active HF Dipole – 7.2 MHz

$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$



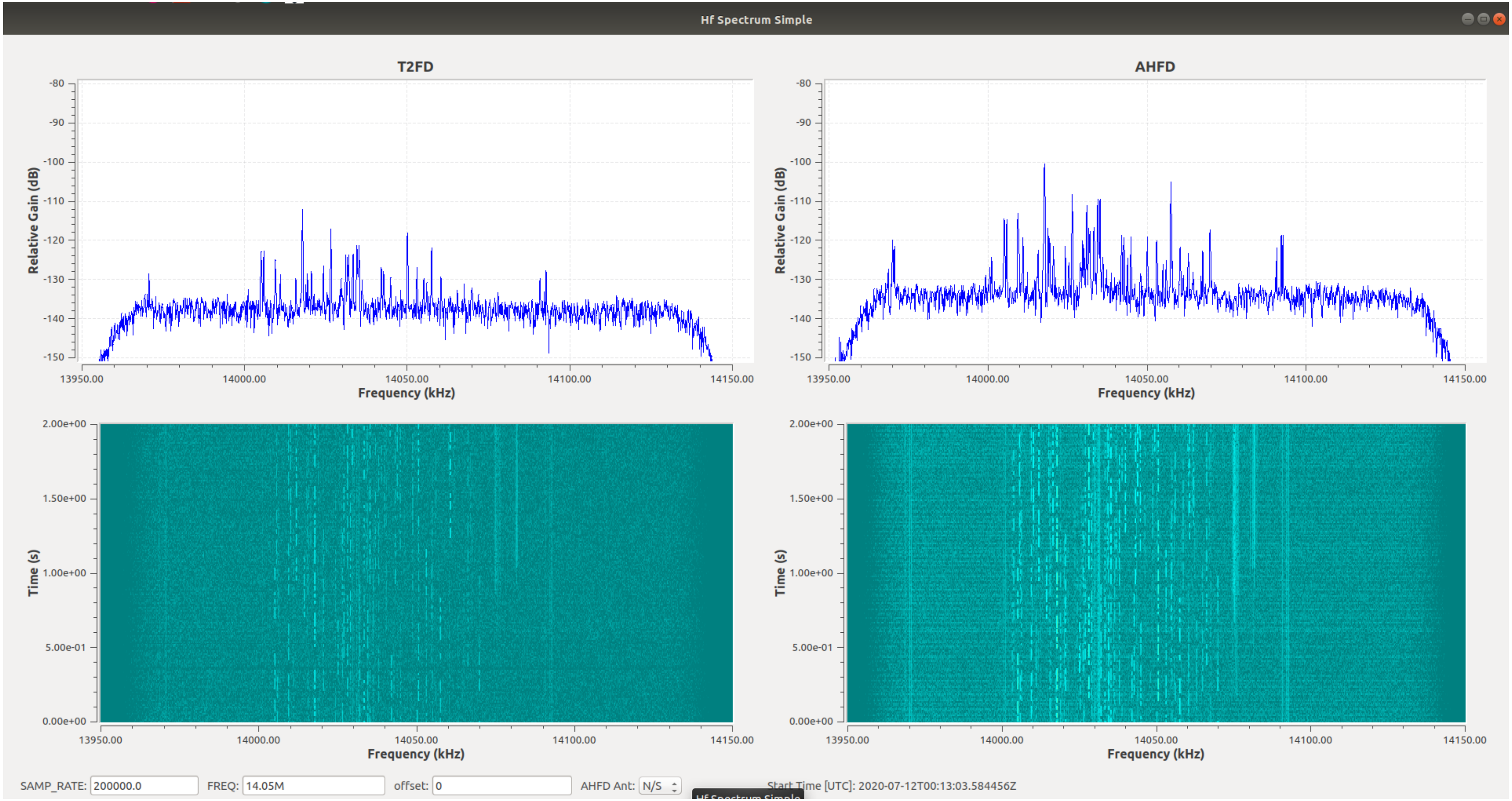
# T2FD vs Active HF Dipole – 10.0 MHz

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



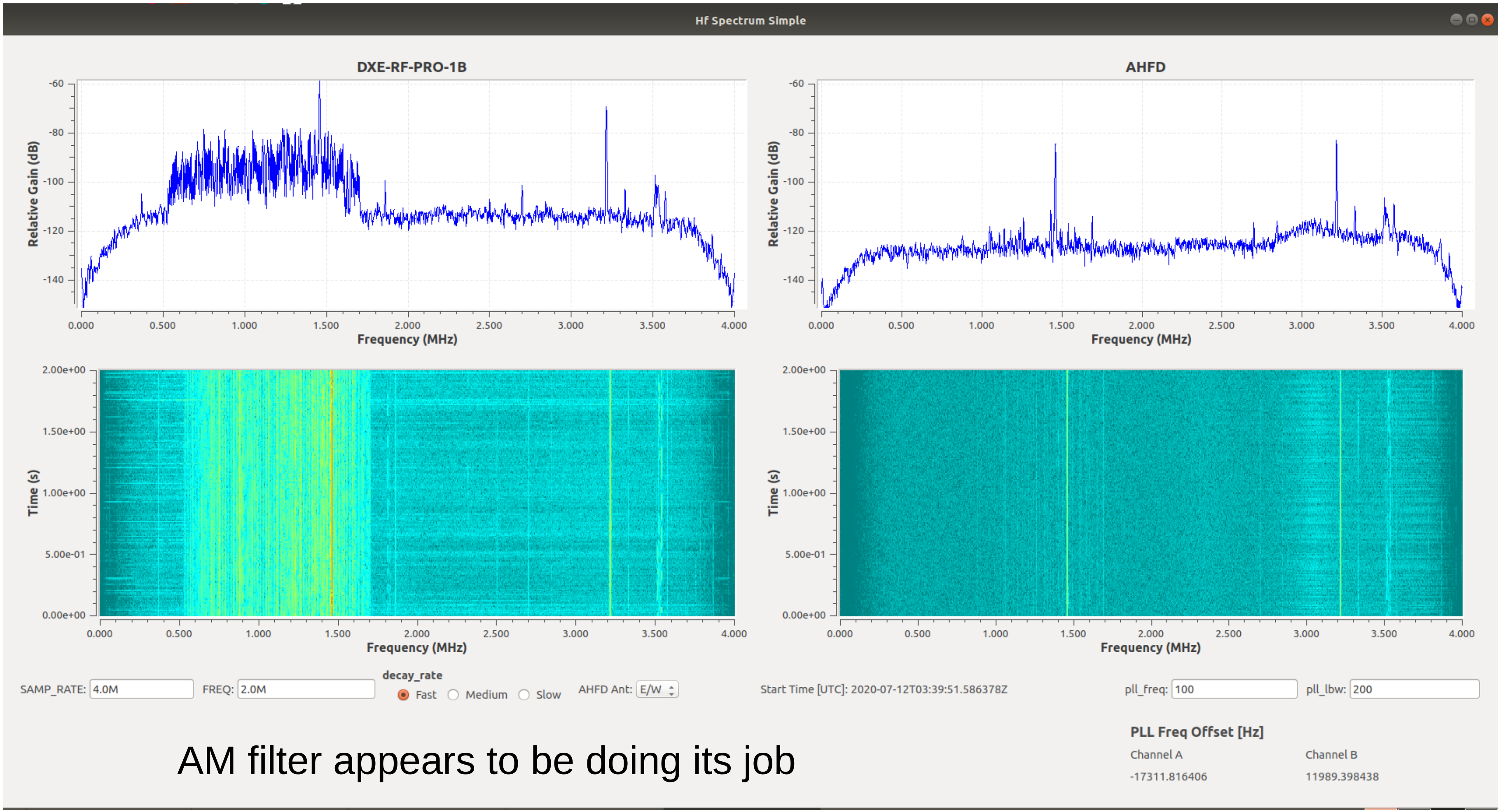
# T2FD vs Active HF Dipole – 14.05 MHz

$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$



# DXE-RF-PRO-1B vs Active HF Dipole – 2.0 MHz

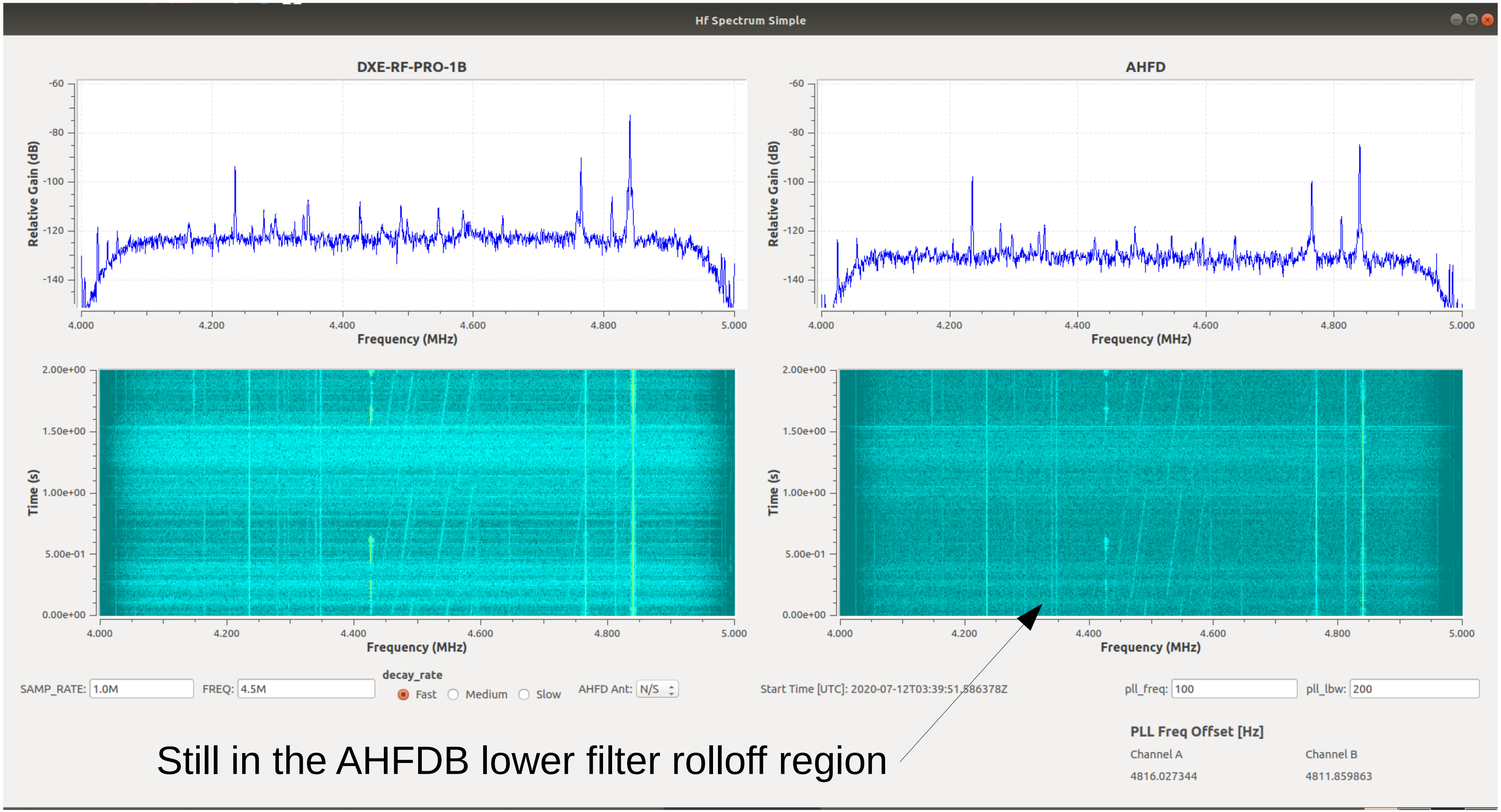
$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$




AM filter appears to be doing its job

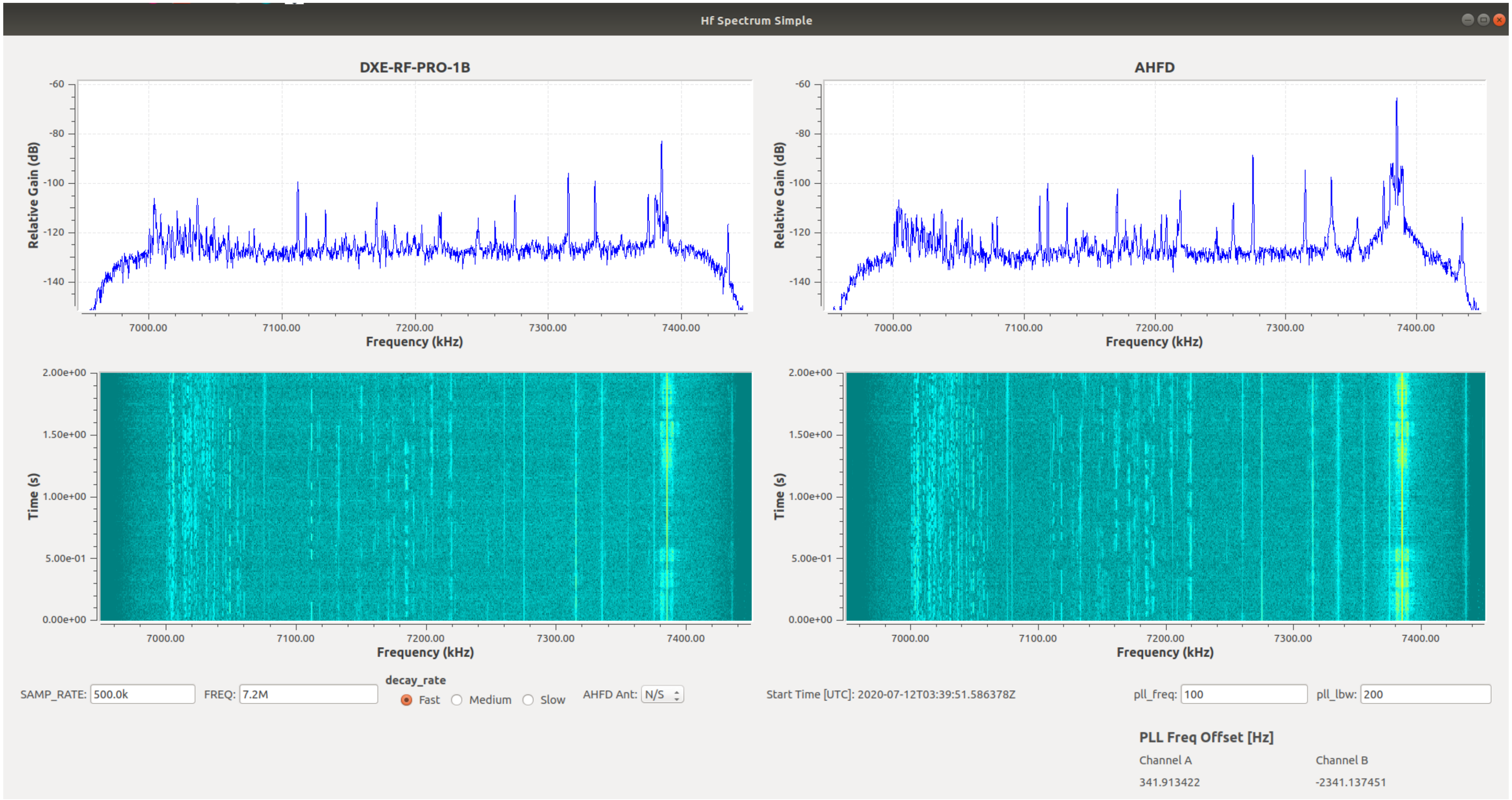
# DXE-RF-PRO-1B vs Active HF Dipole – 4.5 MHz

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$



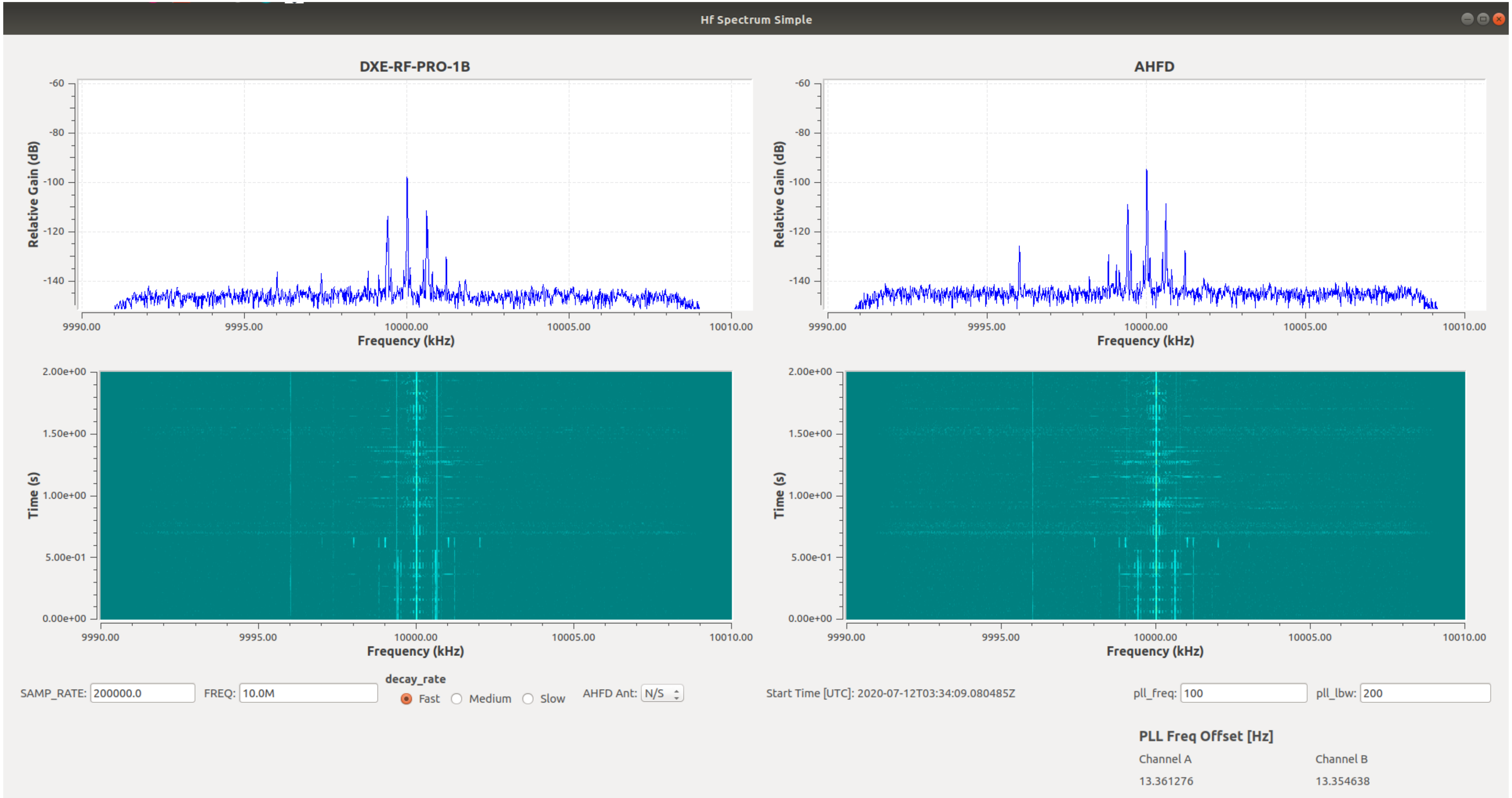
# DXE-RF-PRO-1B vs Active HF Dipole – 7.2 MHz

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



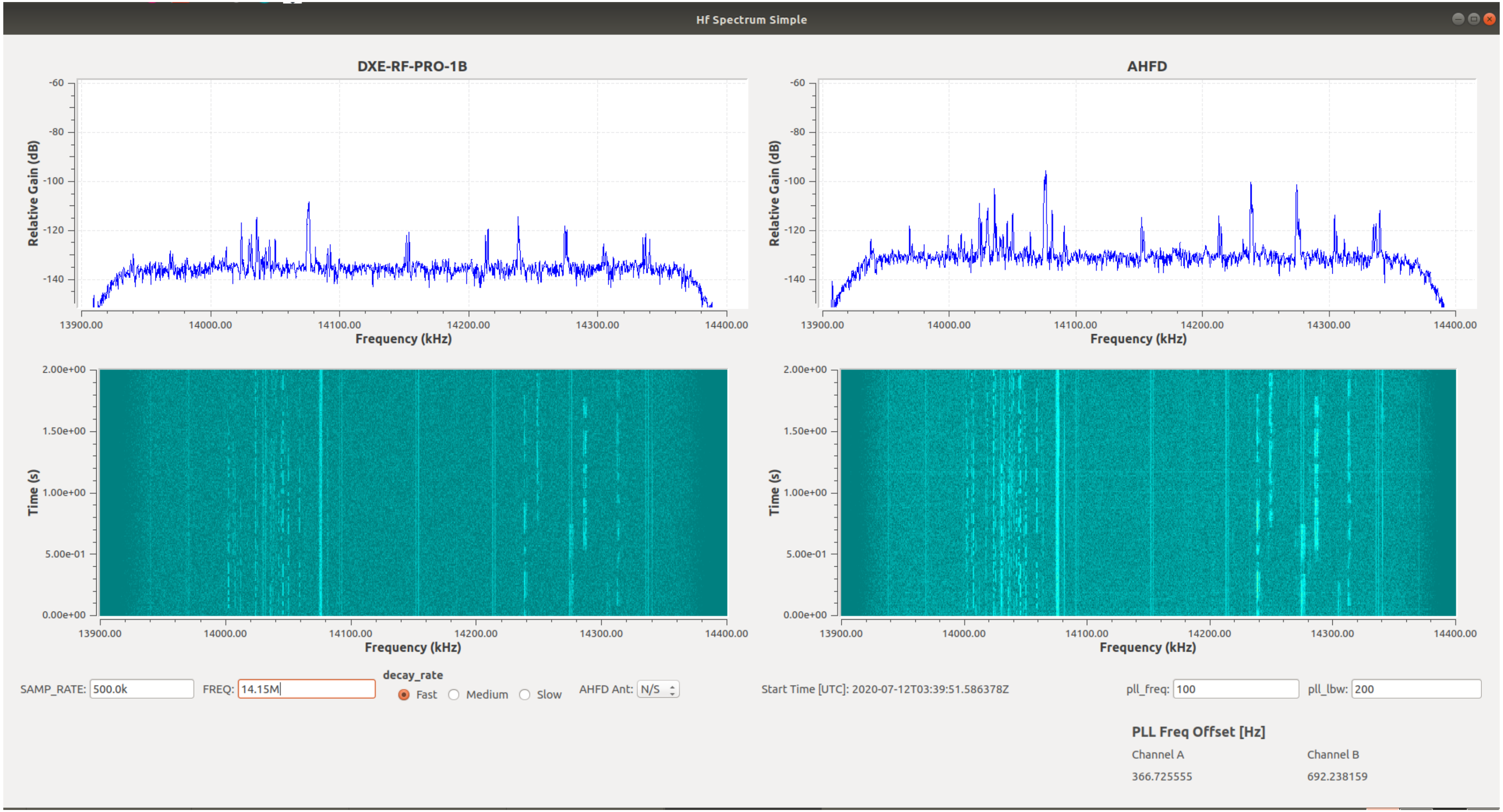
# DXE-RF-PRO-1B vs Active HF Dipole – 10.0 MHz

$\nabla \cdot \boldsymbol{D} = \rho$
$\nabla \cdot \boldsymbol{B} = 0$
$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$



# DXE-RF-PRO-1B vs Active HF Dipole – 14.15 MHz

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$



# Next Steps / To Do



- Documentation!
  - Documentation!
    - Documentation!
      - Documentation!
- Investigate PGA-103 replacement for GALI-74s
  - Initial prototyping done….too hot!, needs more investigation.
- Future PCB Revisions
  - Bigger keepout around antenna element mounting holes
  - Wire to PCB terminal (screw lock)?
- And bunch of other areas for experimentation…
  - Antenna patterns and element selection (better than the ~5ft 14AWG wire...4NEC2!)
  - Ordinary and Extraordinary Mode discrimination!

# Thank You!

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$


LWA Long Wavelength Array
Qucs
KiCad
GNU Radio THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM
HamSCI
LibreOffice The Document Foundation
VT HUME CENTER FOR NATIONAL SECURITY AND TECHNOLOGY VIRGINIA TECH