RadioSonic™

RF in Slow Motion: Using Acoustics for SDR Education

by SigPro Labs, LLC

Overview

- "RF in Slow Motion"
- Results from early experiments on the RadioSonic platform
- Where the analogy breaks down
- Where the analogy pays off

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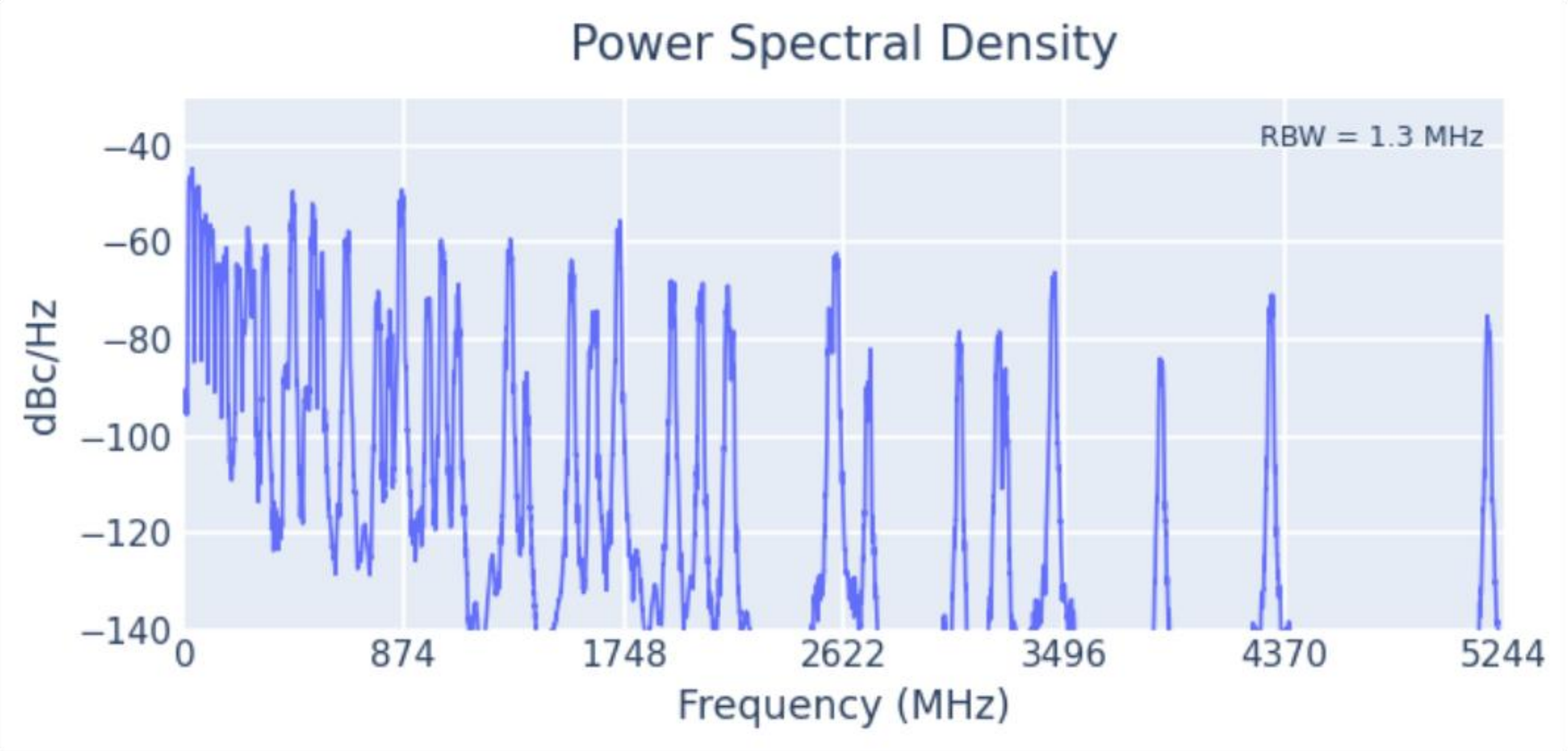
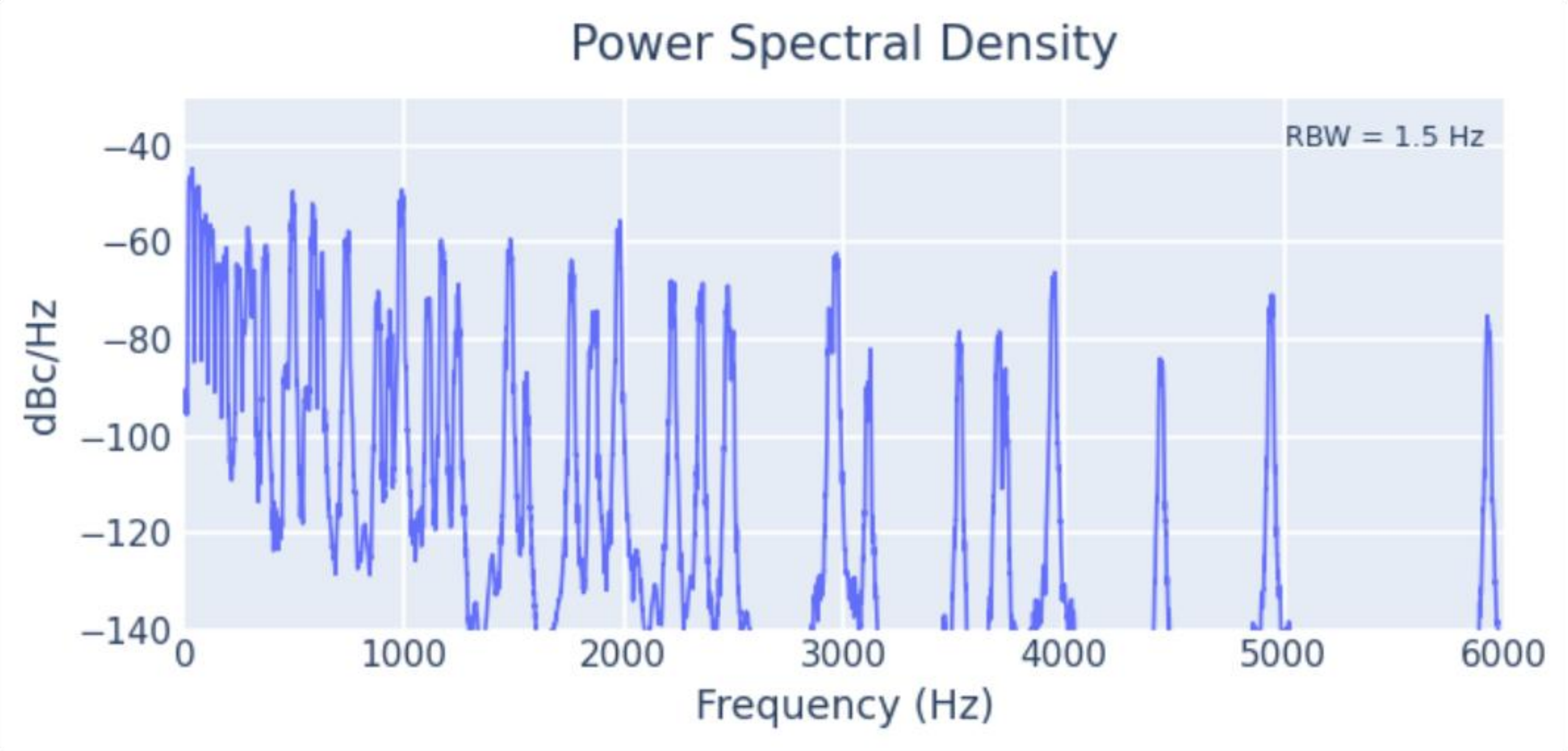

Power Spectral Density
RBW = 1.3 MHz
dBc/Hz
−40
−60
−80
−100
−120
−140
0
874
1748
2622
3496
4370
5244
Frequency (MHz)


Power Spectral Density
RBW = 1.5 Hz
−40
−60
−80
−100
−120
−140
dBc/Hz
0
1000
2000
3000
4000
5000
6000
Frequency (Hz)

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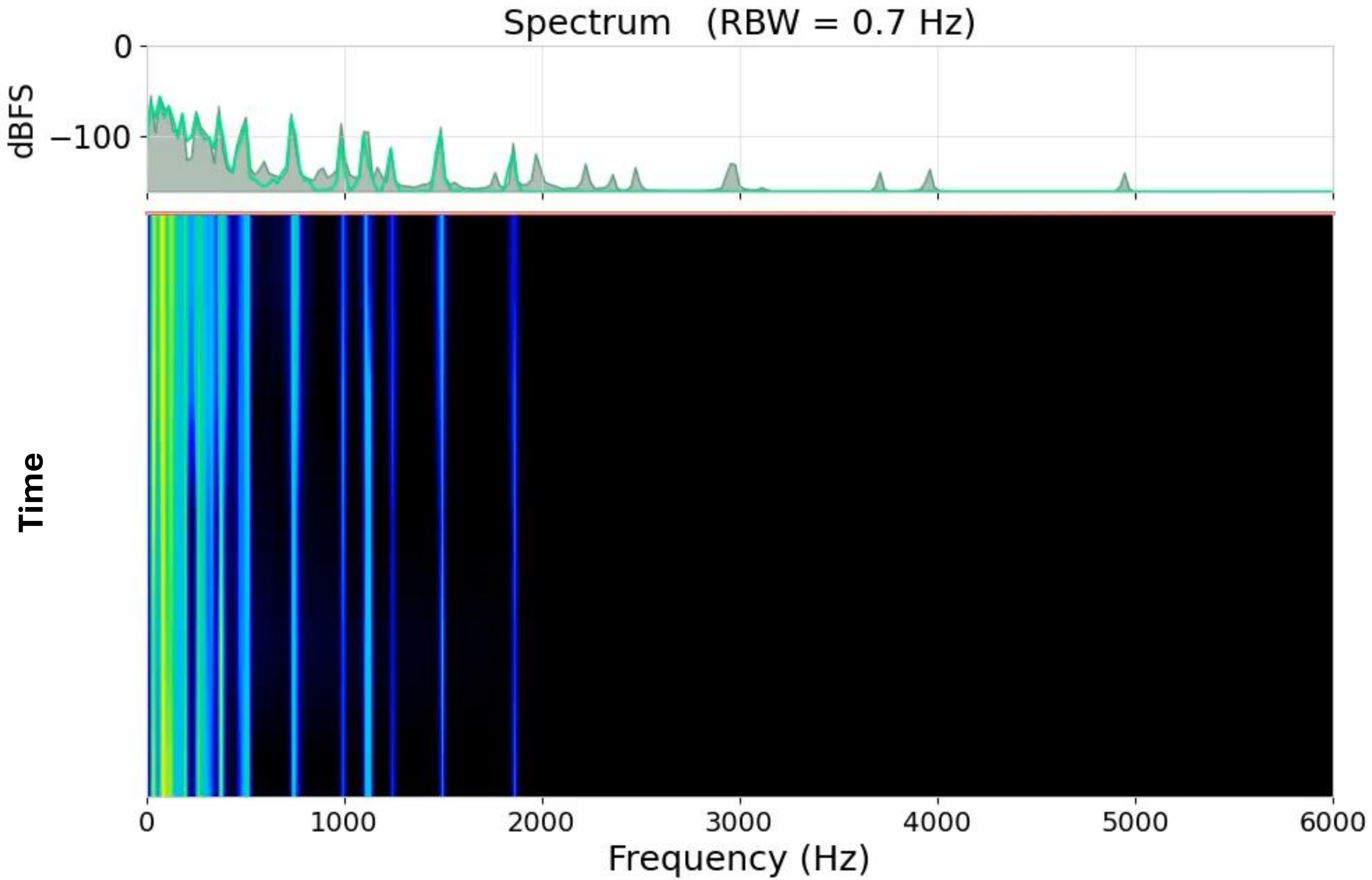

Spectrum (RBW = 0.7 Hz)
0
−100
dBFS
Time
0
1000
2000
3000
4000
5000
6000
Frequency (Hz)

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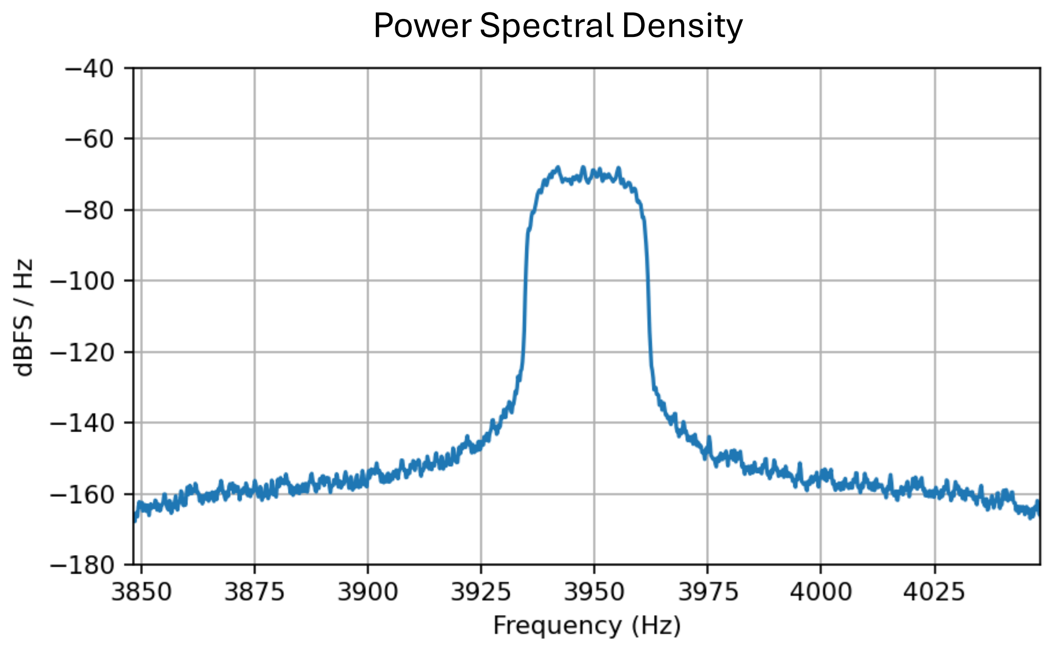
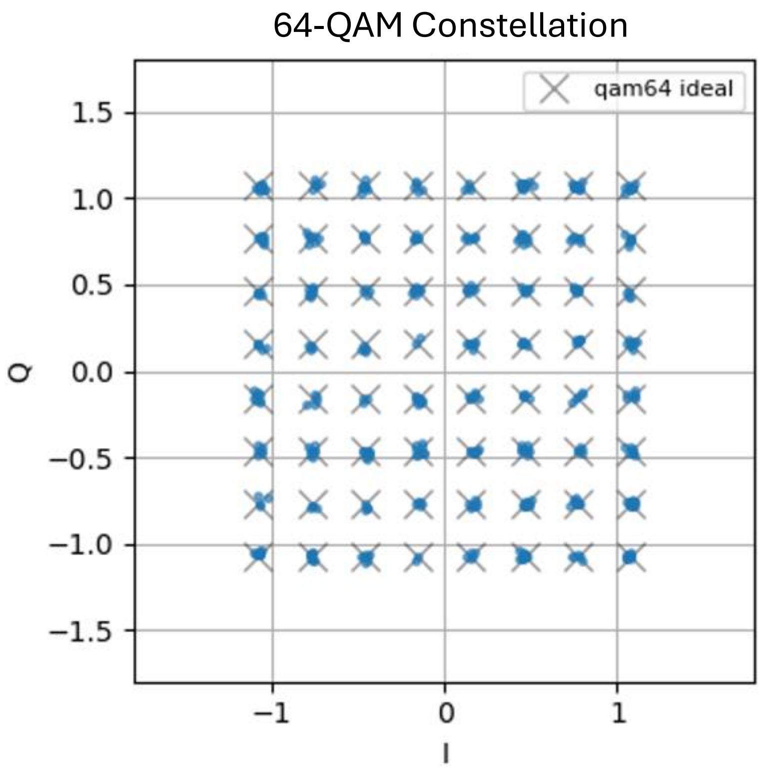
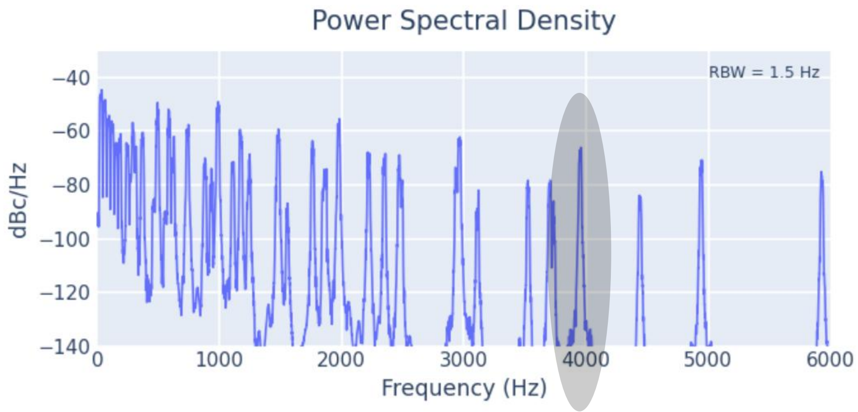
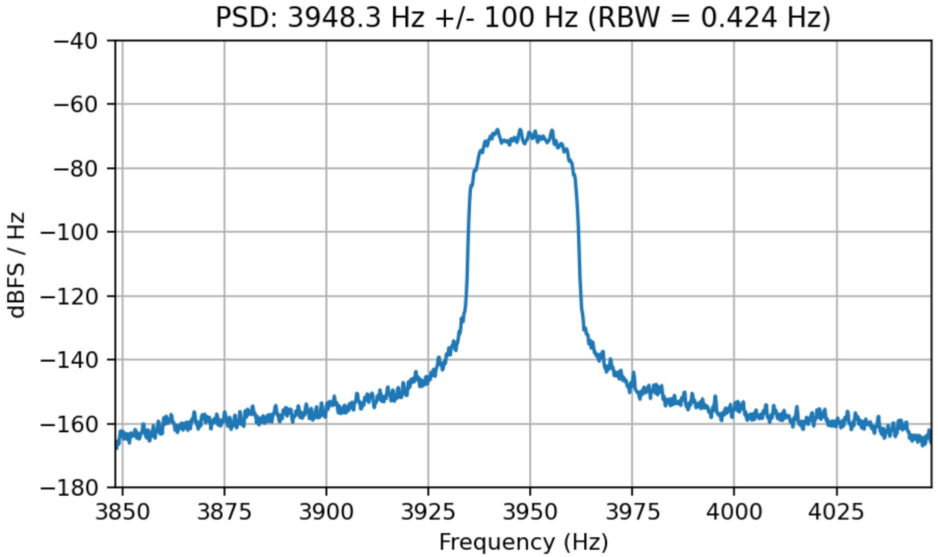
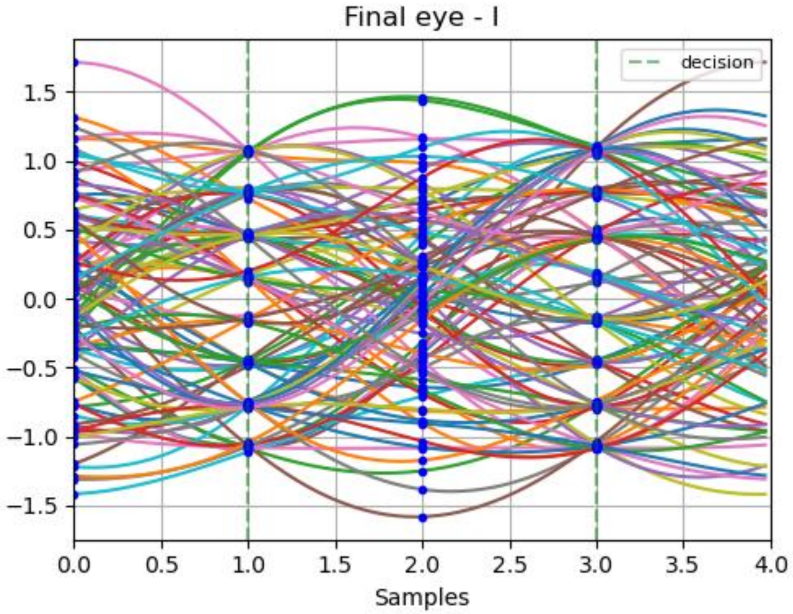
64-QAM Modulation

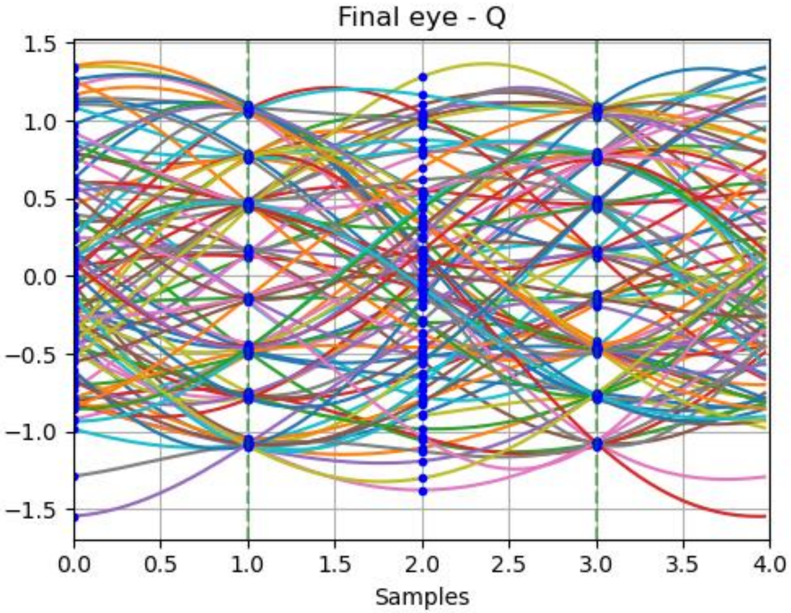


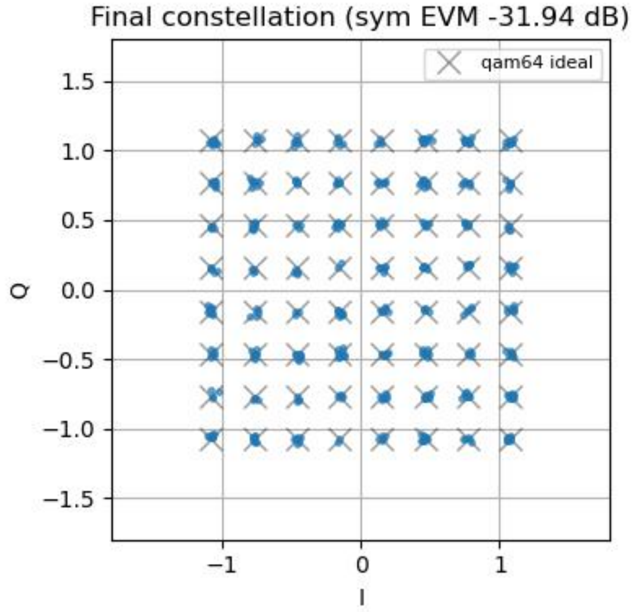



Power Spectral Density
RBW = 1.5 Hz
dBc/Hz
Frequency (Hz)


PSD: 3948.3 Hz +/- 100 Hz (RBW = 0.424 Hz)
dBFS / Hz
Frequency (Hz)


Final eye - I
decision
Samples


Final eye - Q
Samples


Final constellation (sym EVM -31.94 dB)
qam64 ideal
Q
I

Motivation: A Teaching Platform

- Make real-time hardware implementation accessible
- Enable extremely low-cost solutions with wide capability
- Equivalent to a Software Defined Radio (SDR) with
  - 10 MHz to 20 GHz operational frequency
  - 20 GHz of instantaneous bandwidth
  - Dual 24-bit receive and transmit, no regulatory licensing required
  - Multiple antennas for beam-steering, MIMO, diversity
- Process real waveforms with actual SDR algorithms

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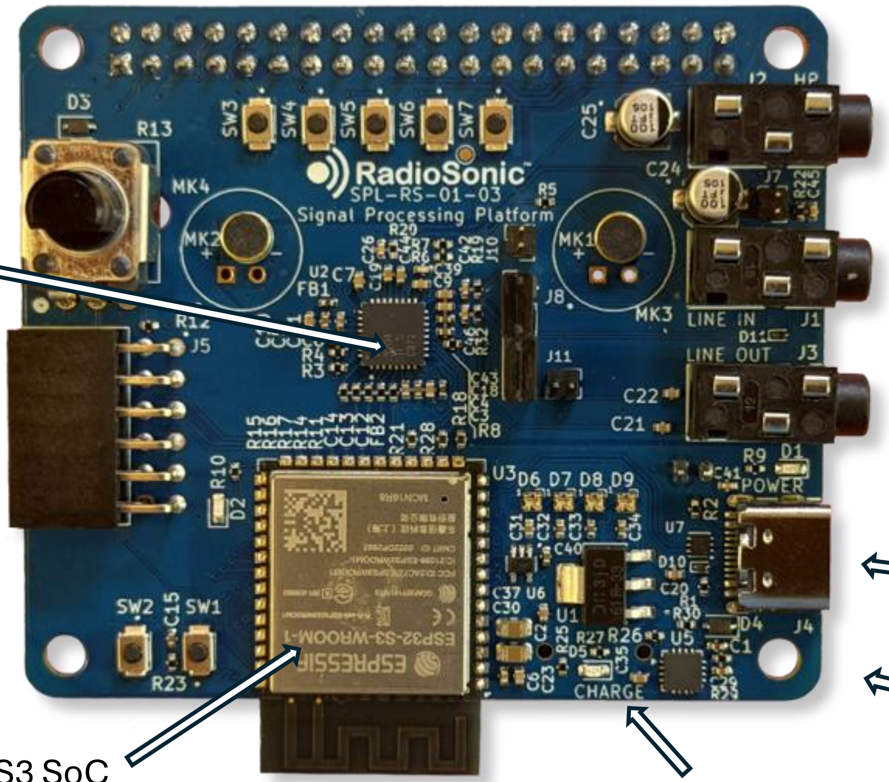
A signal processing education platform built on open-source hardware

Raspberry Pi HAT form factor

TI AIC3204 Codec

Microphone Expansion (up to 6 mics total)



Audio Line-In, Line-Out, Headphones

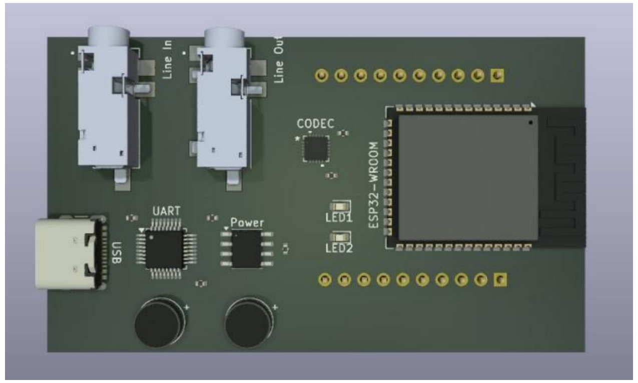
USB 2.0 High Speed

Battery charger

ESP32-S3 SoC

WiFi

MicoSD / battery on back



RadioSonic Concept GRCon 2025

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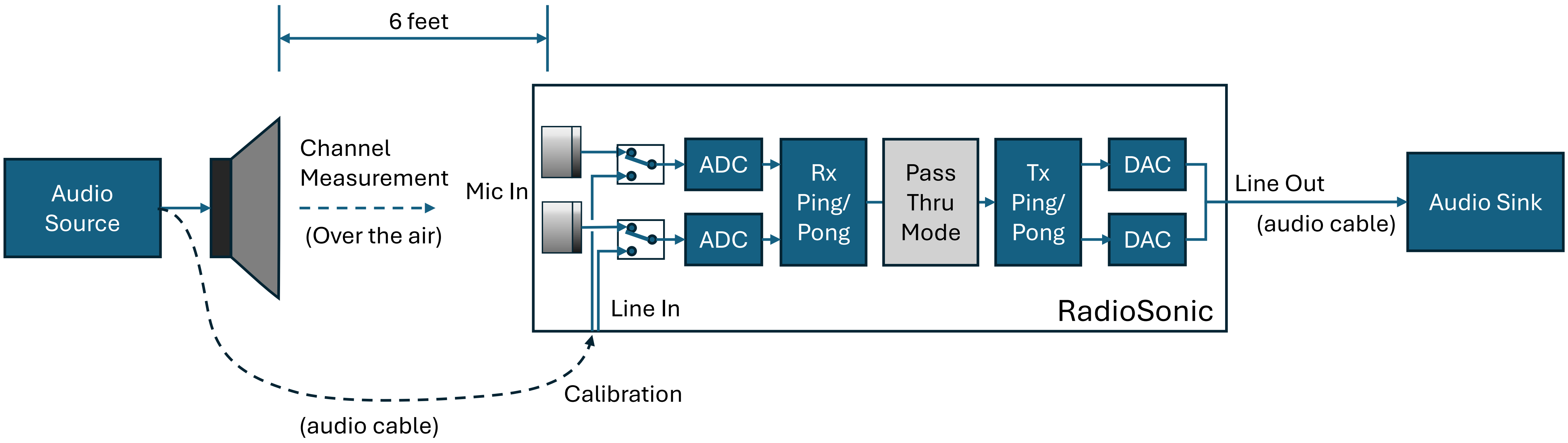
Experiments with 64-QAM Modulation

Experiments with 64-QAM Modulation



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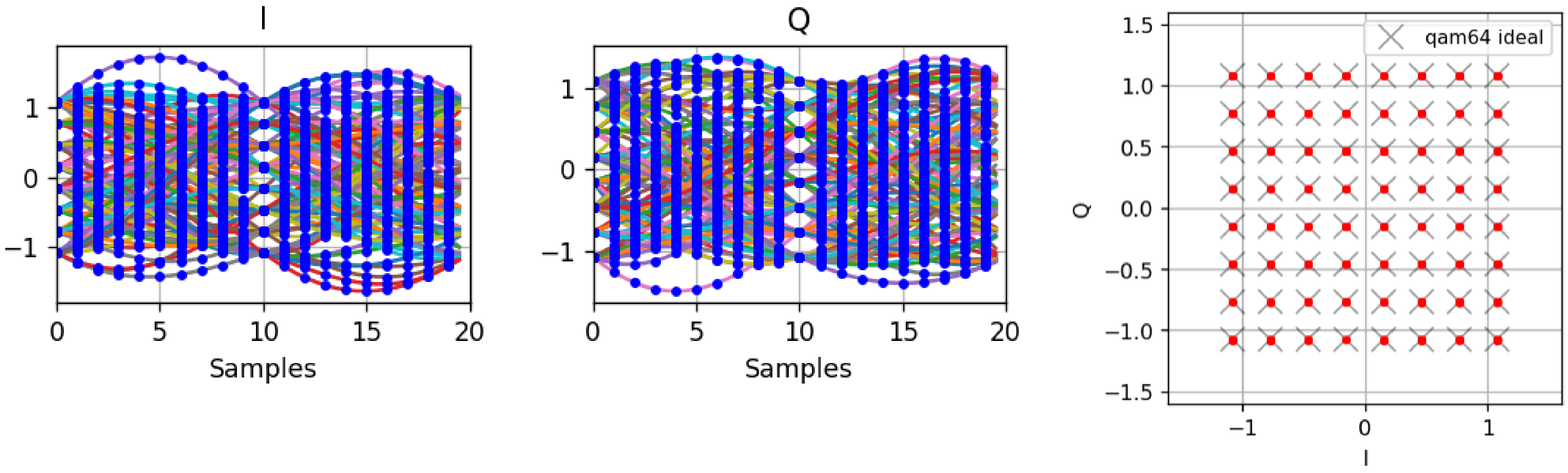
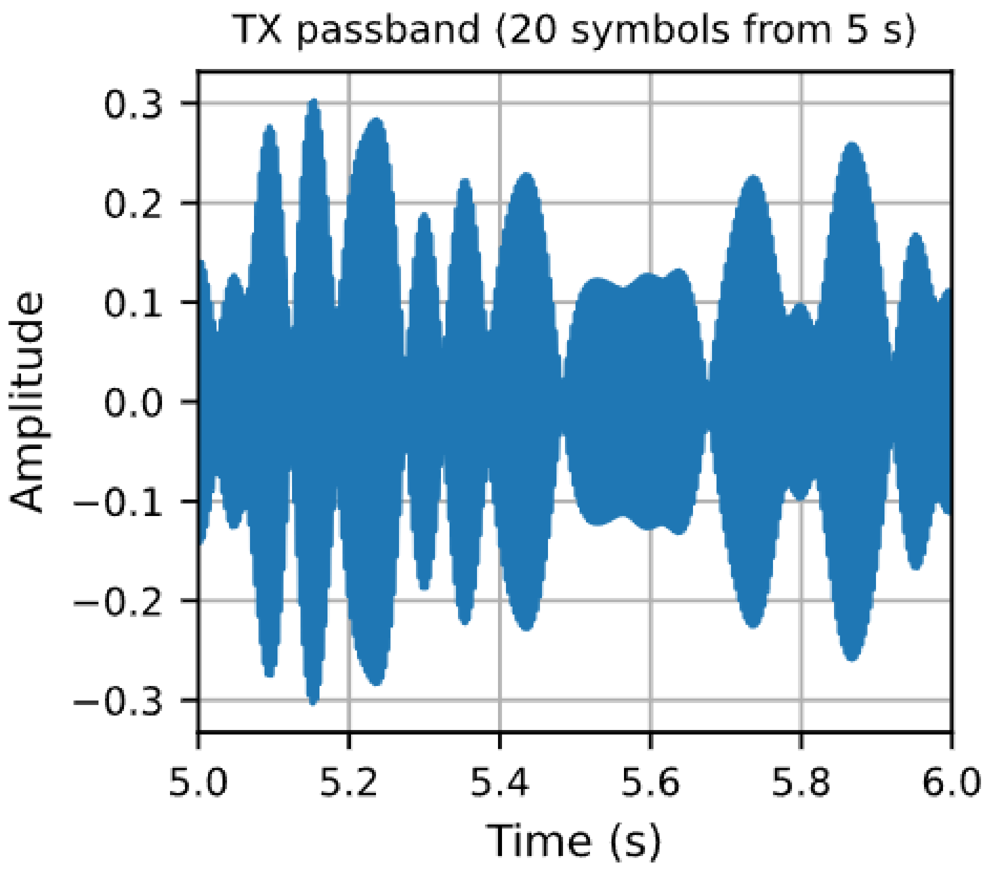
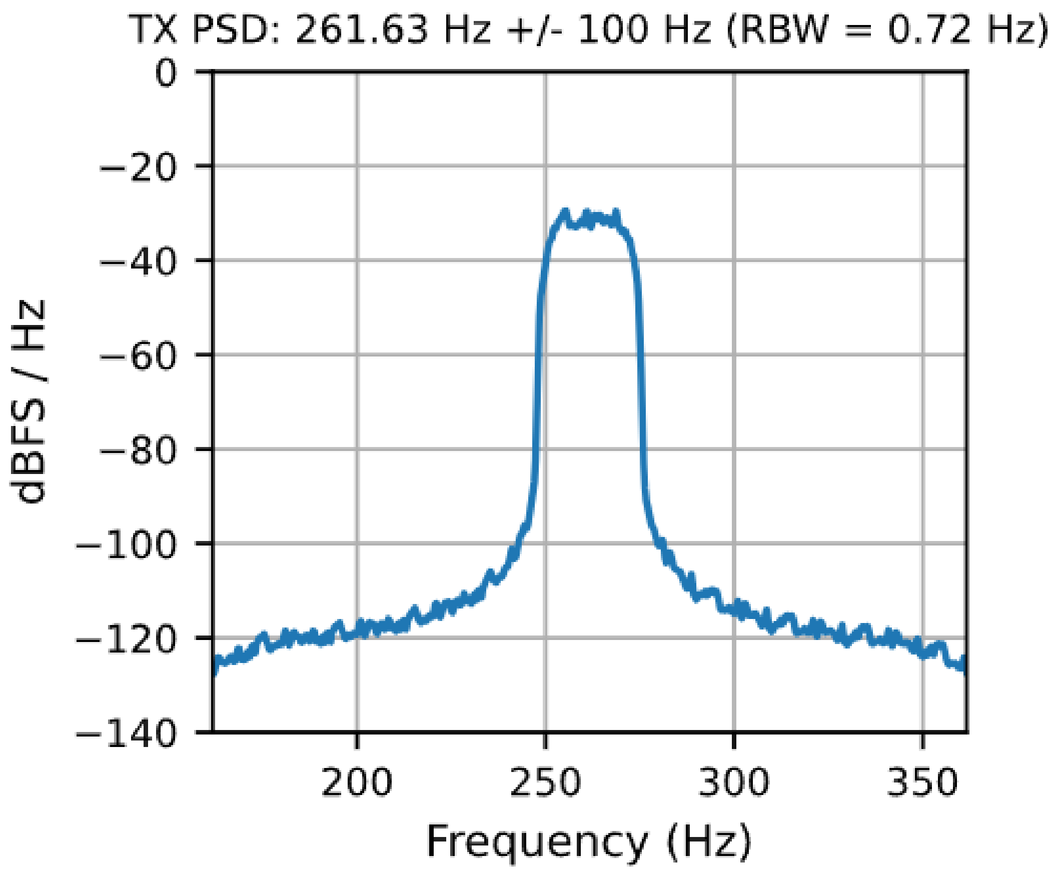
Audio Source
Speaker
RadioSonic Microphones Rx

64-QAM at Baseband



64-QAM Waveform as Transmitted





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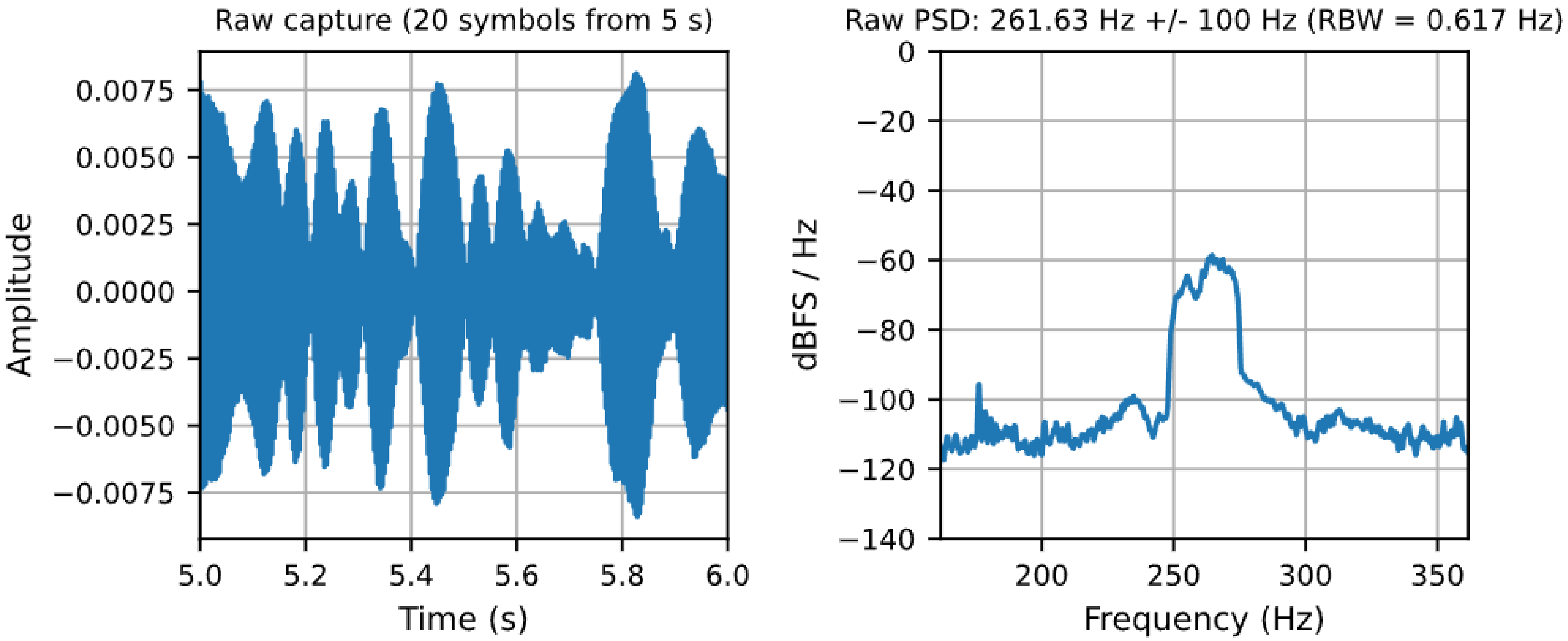
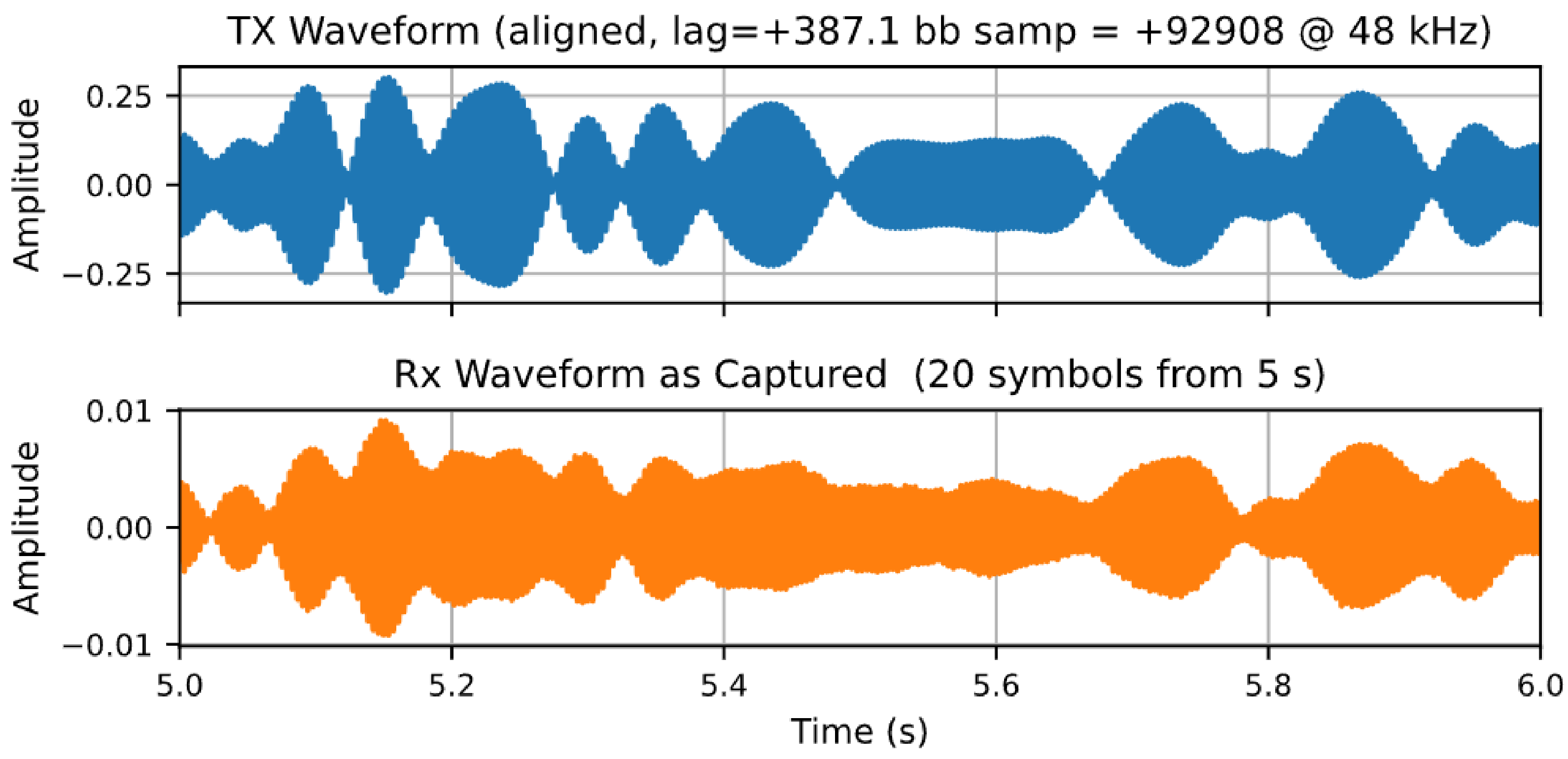
What We Actually Receive



Tx and Rx Waveforms – Time Aligned



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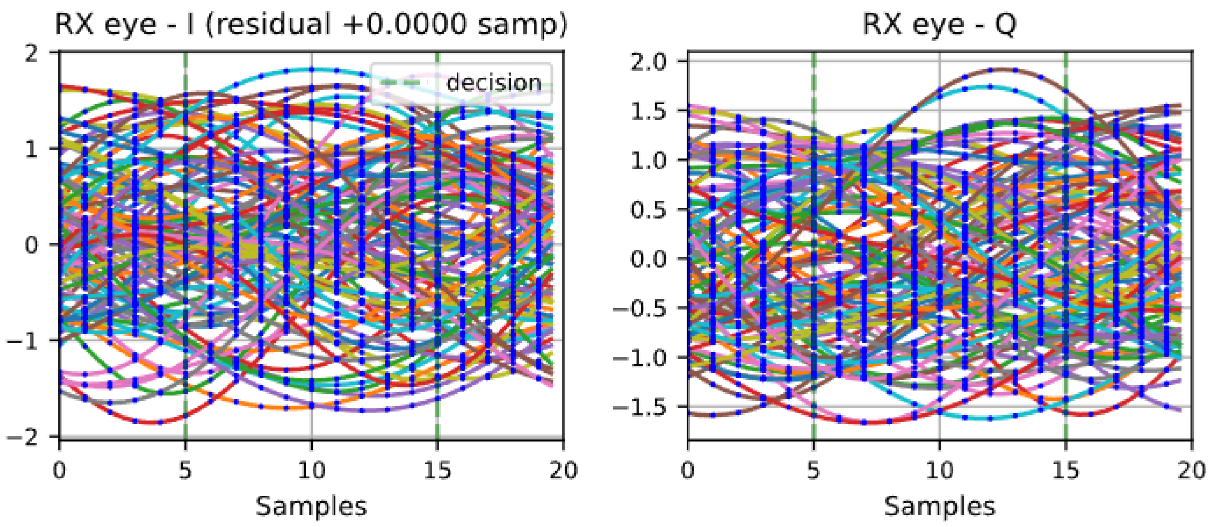
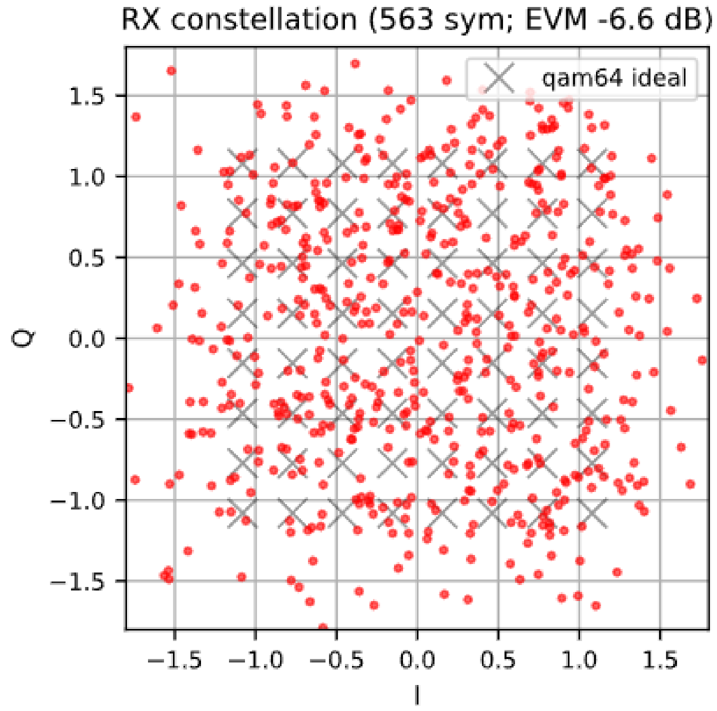
Baseband Waveform





Eye Diagram and 64-QAM Constellation as received **after** phase/frequency correction and timing recovery

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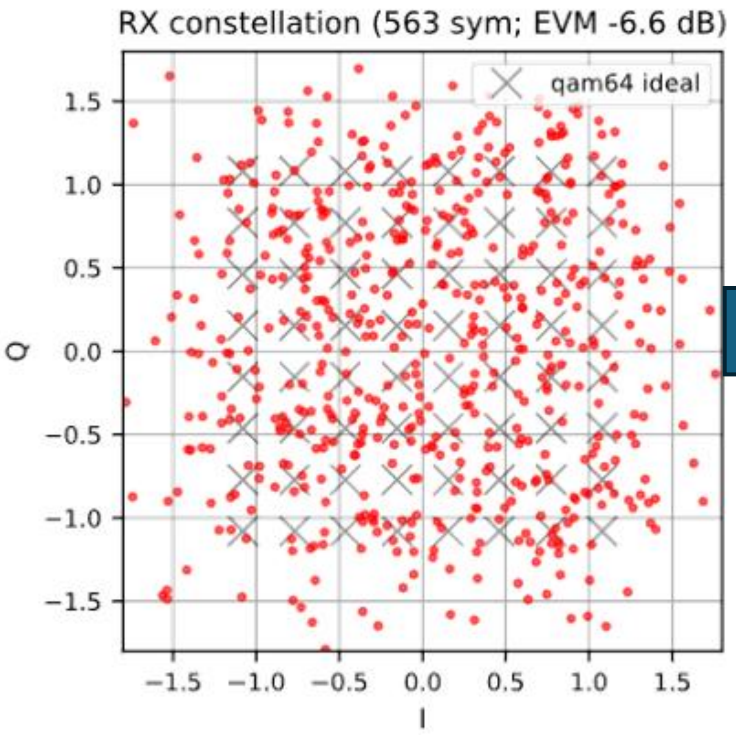
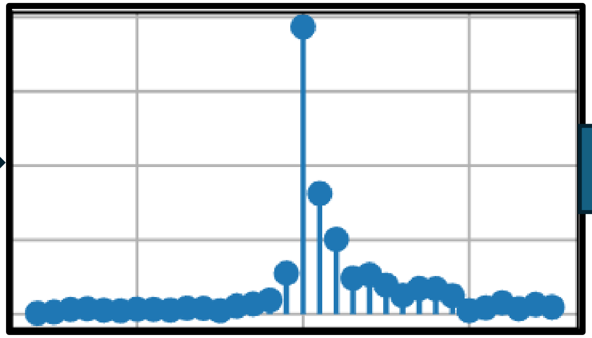
Equalized Results

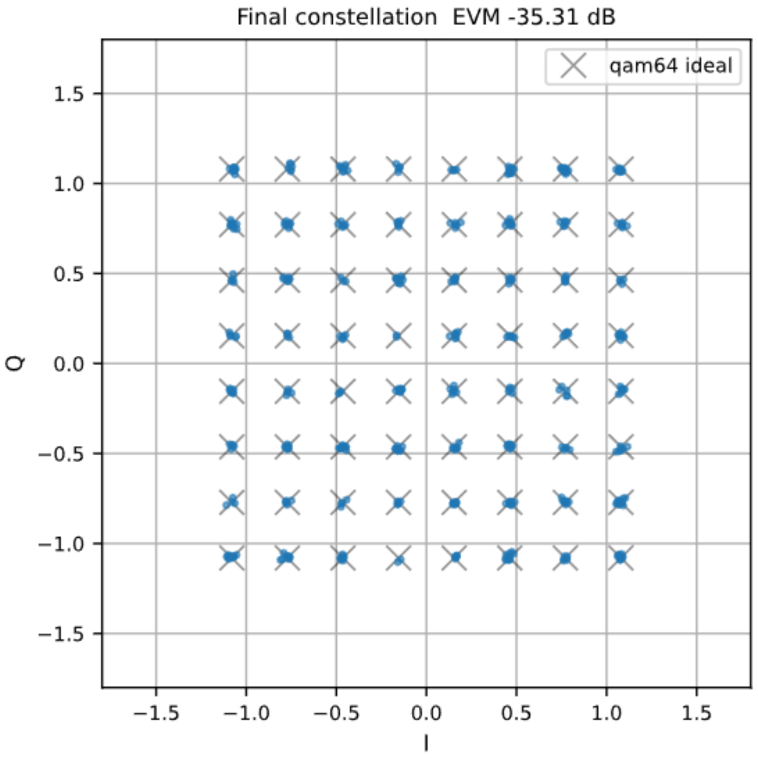
Rx Before Equalizer: -6.6 dB EVM



Equalizer: 32 tap complex FIR filter



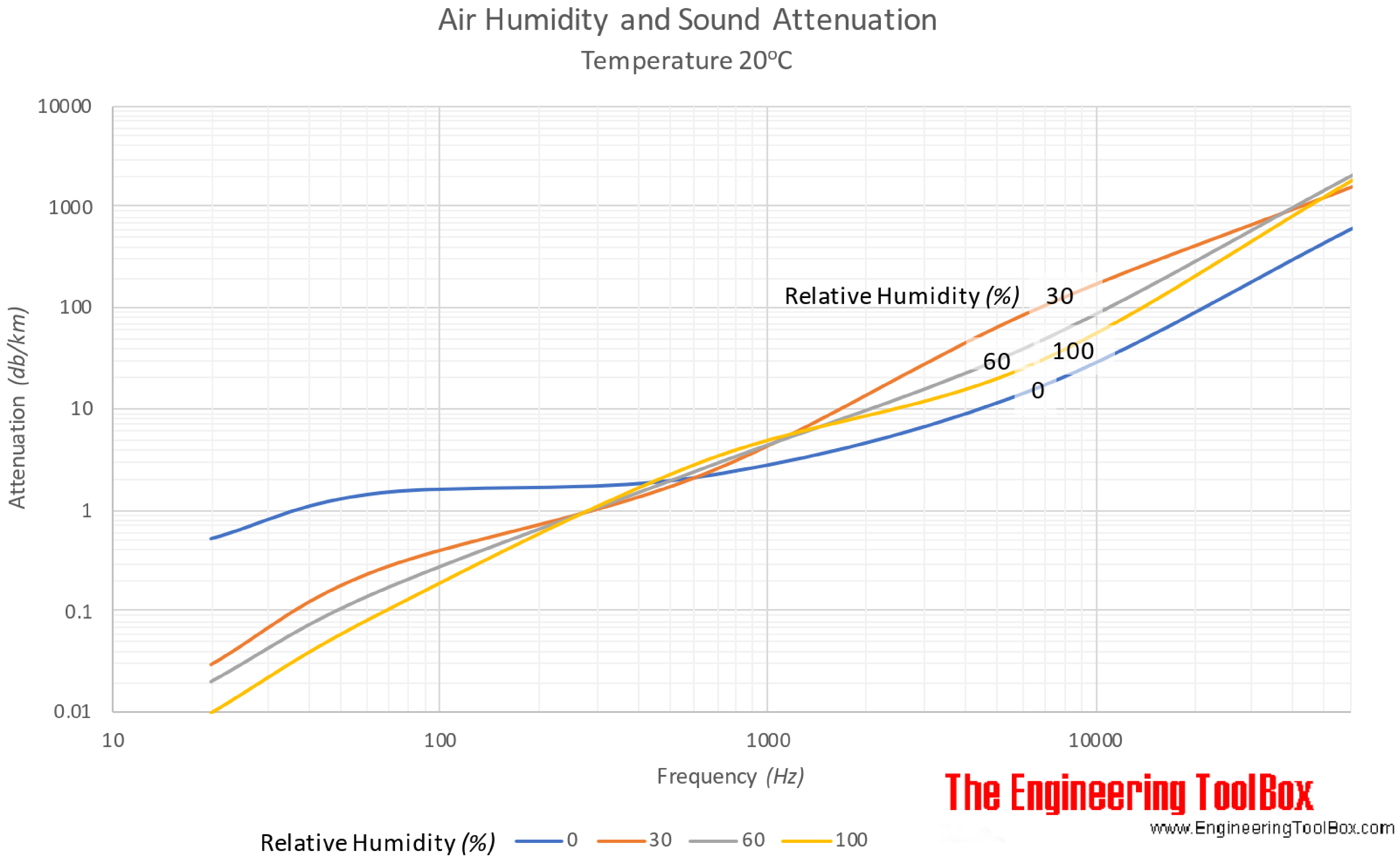
Rx After Equalizer: -35.3 dB EVM



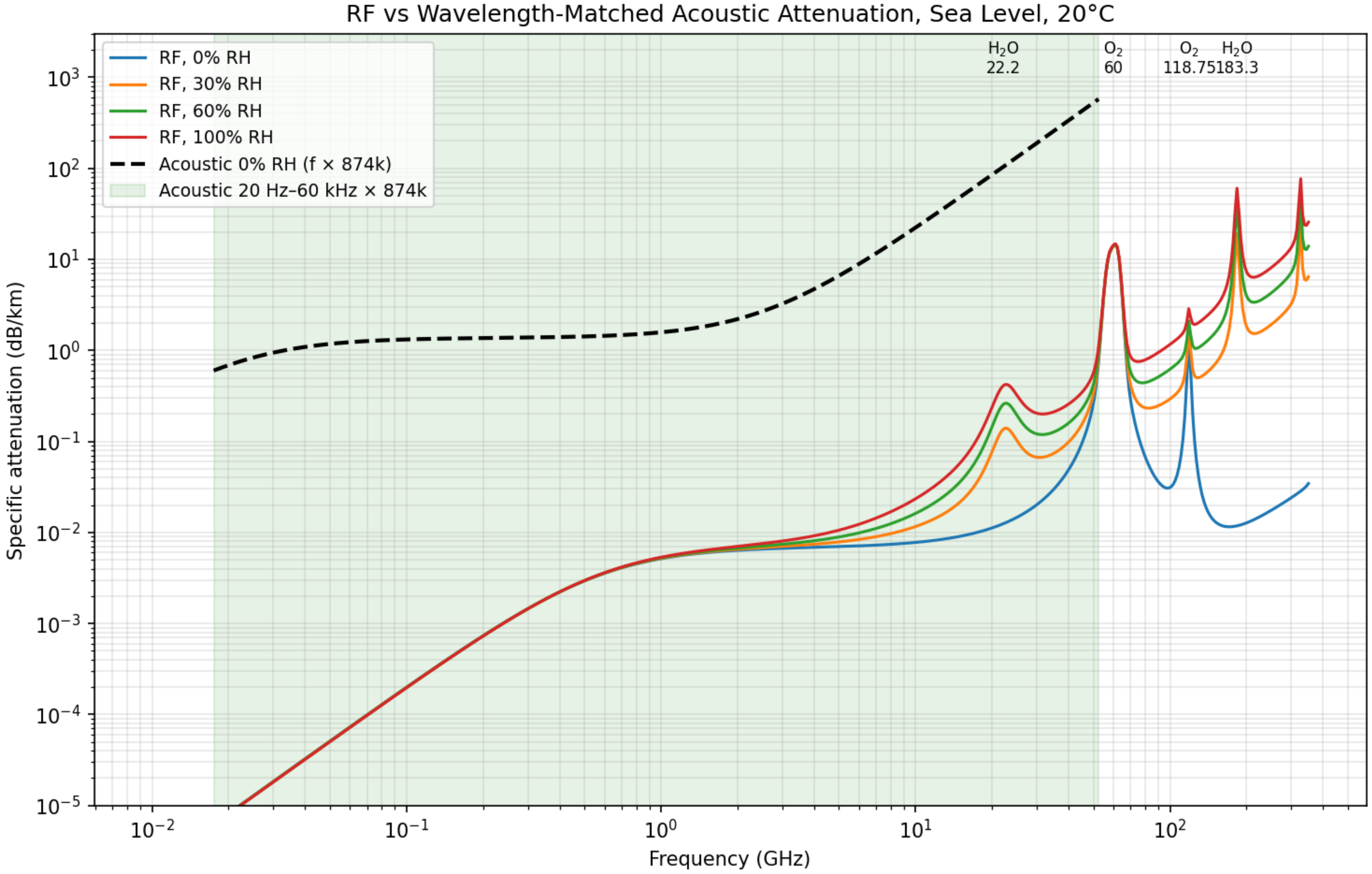
Where the Analogy Breaks Down

Where Acoustics and RF Differ

- Medium Propagation Loss
- Velocity vs temperature
- Surface Reflection and Absorption
- Doppler and Mode Sensitivity
- Coherence Time
- Background Noise


Air Humidity and Sound Attenuation
Temperature 20°C
10000
1000
100
10
1
0.1
0.01
Attenuation (db/km)
10
100
1000
10000
Frequency (Hz)
Relative Humidity (%)
30
60
100
0
Relative Humidity (%)
0
30
60
100
The Engineering ToolBox
www.EngineeringToolBox.com

Air Humidity and RF Attenuation



Computed from ITU-R Rec. P.676-13 (2022)

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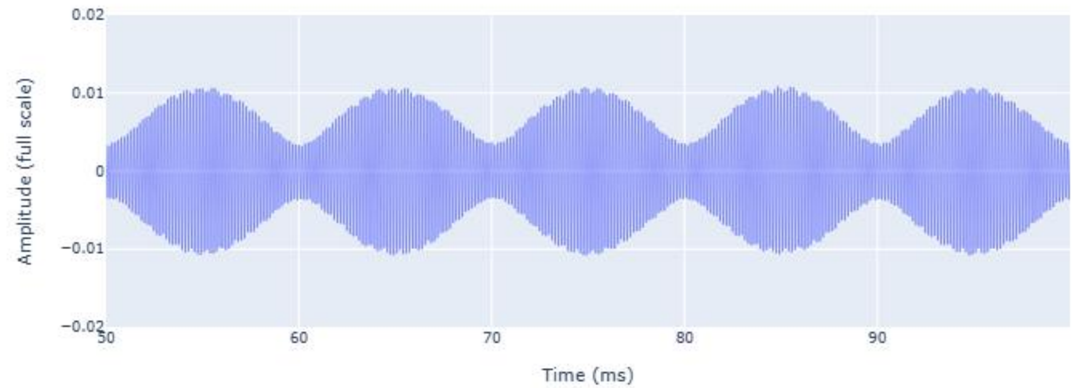
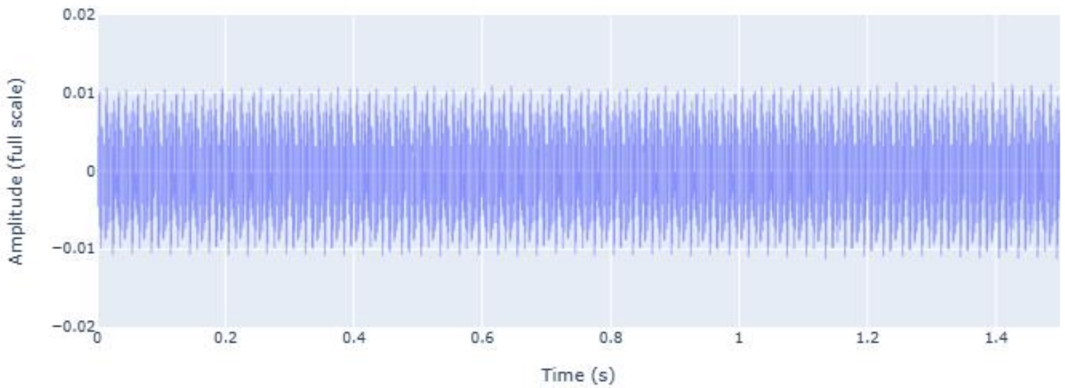
6 kHz, 6.2 kHz Two-Tone Testing

Room perfectly still

Two-tone capture (50 ms window) - peak 0.011 (-38.8 dBFS)

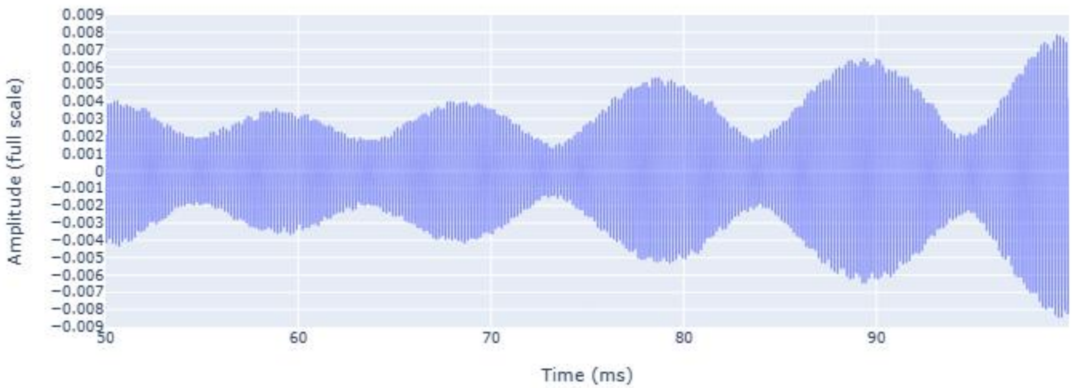


Two-tone capture (full 1.50 s) - confirm continuous level, no dropouts (peak 0.011)

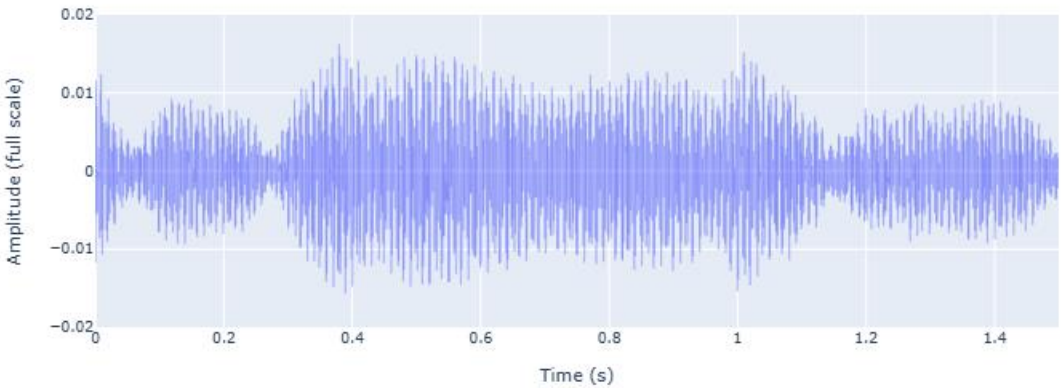


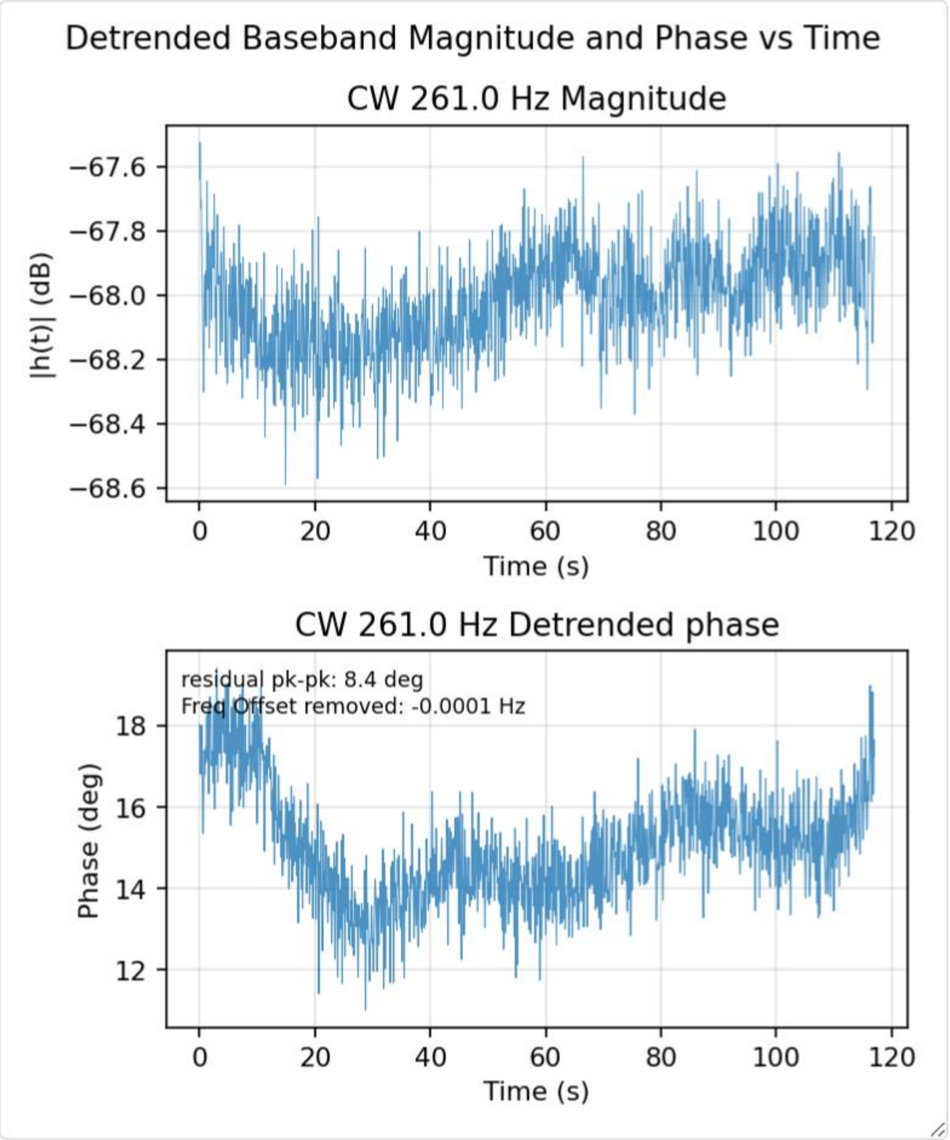
Moving arms while capturing

Two-tone capture (50 ms window) - peak 0.016 (-35.7 dBFS)

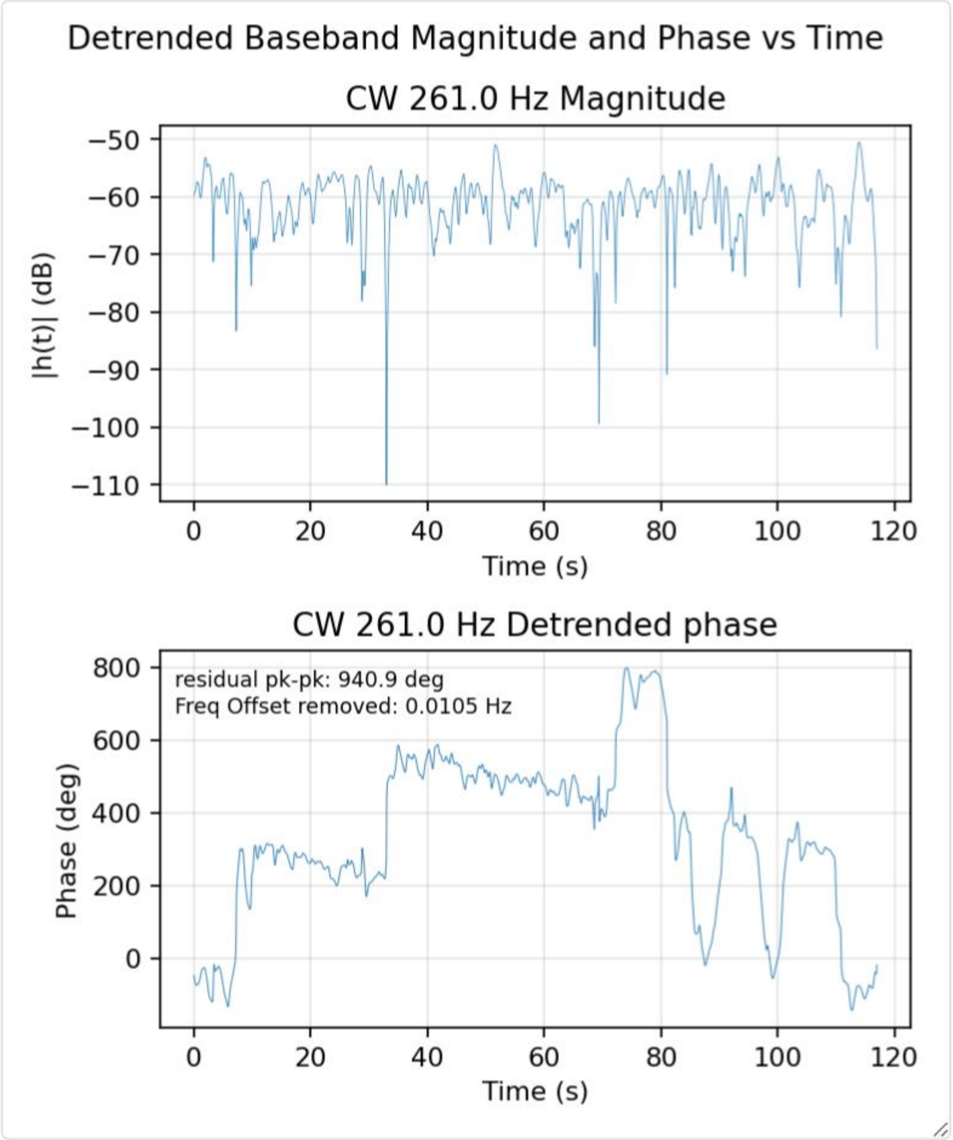


Two-tone capture (full 1.50 s) - confirm continuous level, no dropouts (peak 0.016)





Empty, Still Room, T_c (1/e) = 7.5 s



Human in Room, Moving

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Where the Analogy Pays Off

For SDR Education

Where Scaled Waveforms Work Well

- Operation in Fading Channels
- Transceiver Architectures, Components and System Design
  - Digital Up- and Down-converters
  - Multirate processing
  - Non-linearity effects; P1dB, IP3
- Rx Algorithms
  - Carrier Recovery, Timing Recovery, Equalization, AGC, Diversity Rx
- Tx Algorithms
  - Predistortion, Crest Factor Reduction
- Waveforms and Modulations
- Beamforming and MIMO

Conclusion

- RF in Slow Motion
  - *Acoustic waveforms let students run real SDR algorithms on real hardware in real time.*
- Early results using RadioSonic
  - *64-QAM over the air: −6.6 dB EVM raw, −35.3 dB after equalization.*
- Where the analogy breaks down
  - *Path loss, Doppler, and coherence time differ. Useful lessons regardless.*
- Where the analogy pays off
  - *Most of the SDR curriculum: Rx/Tx algorithms, carrier and timing recovery, equalization, beam-steering, equalization, non-linear effects …*

Course starts Oct 13, Register by Sept 30

Want More DSP?

https://dsp-coach.com

Scan for more details

Signal Processing for Software Radio

Course Kick-off: **October 1, 2026**

Early registration deadline: **September 24, 2026**

Late registrations allowed up to: **November 5, 2026**

Python Applications for Digital Design and Signal Processing

Course Kick-off: **October 8 , 2026**

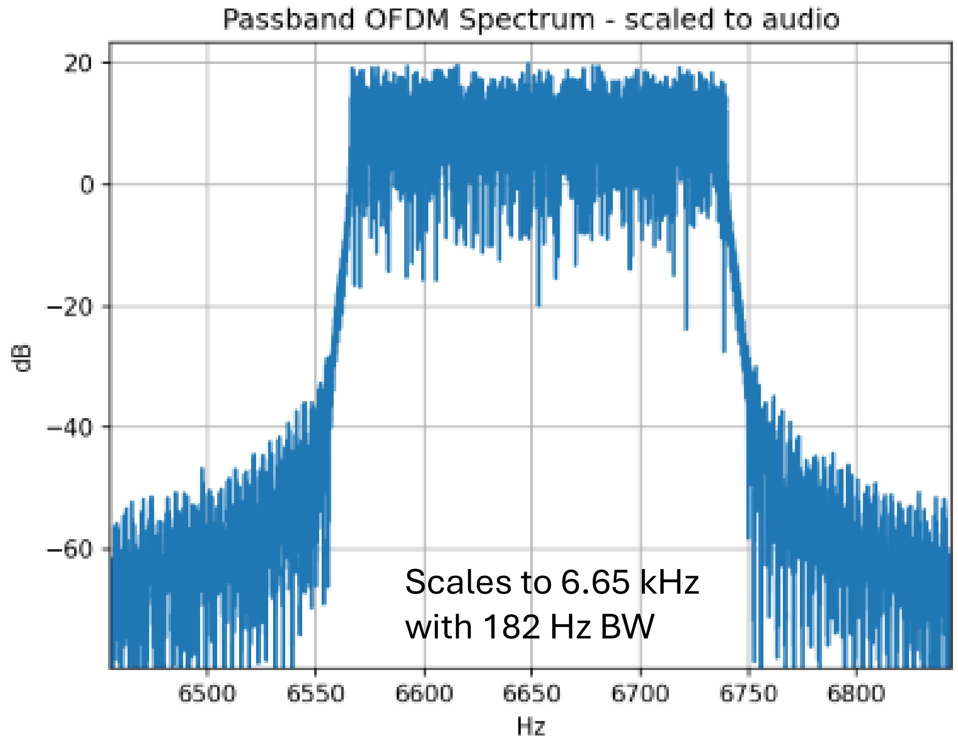
Early registration deadline: **October 2, 2026**

Late registrations allowed up to: **November 5, 2026**

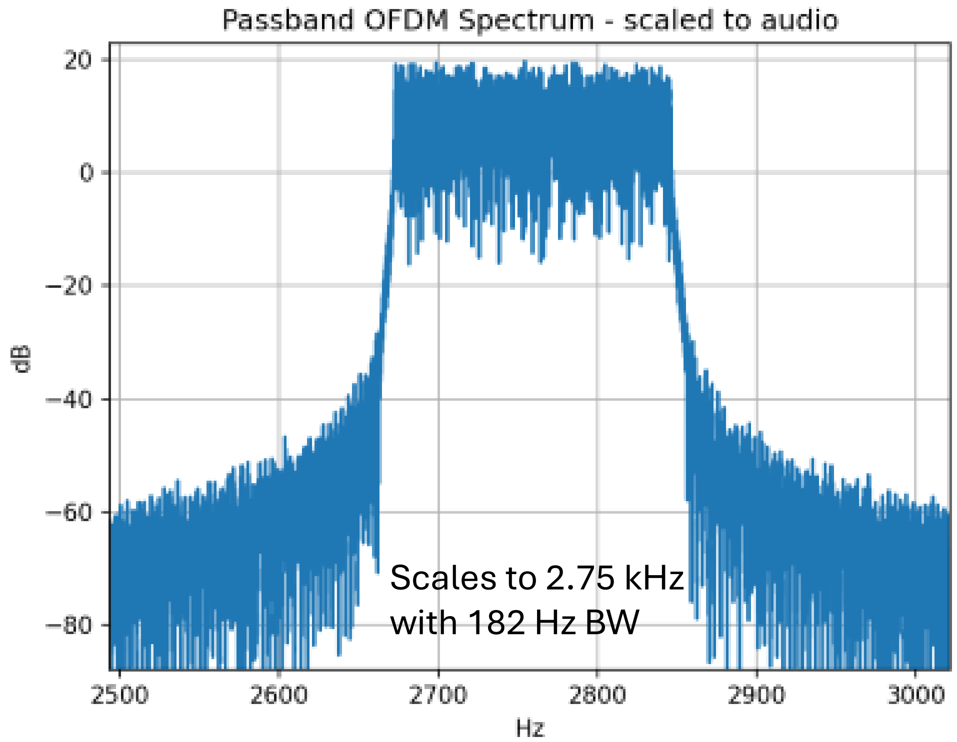
BACKUP SLIDES

RF in Slow Motion: Sonified RF Waveforms

Wi-Fi 7 5.815 GHz with 160 MHz BW



OFDM at 2.412 GHz



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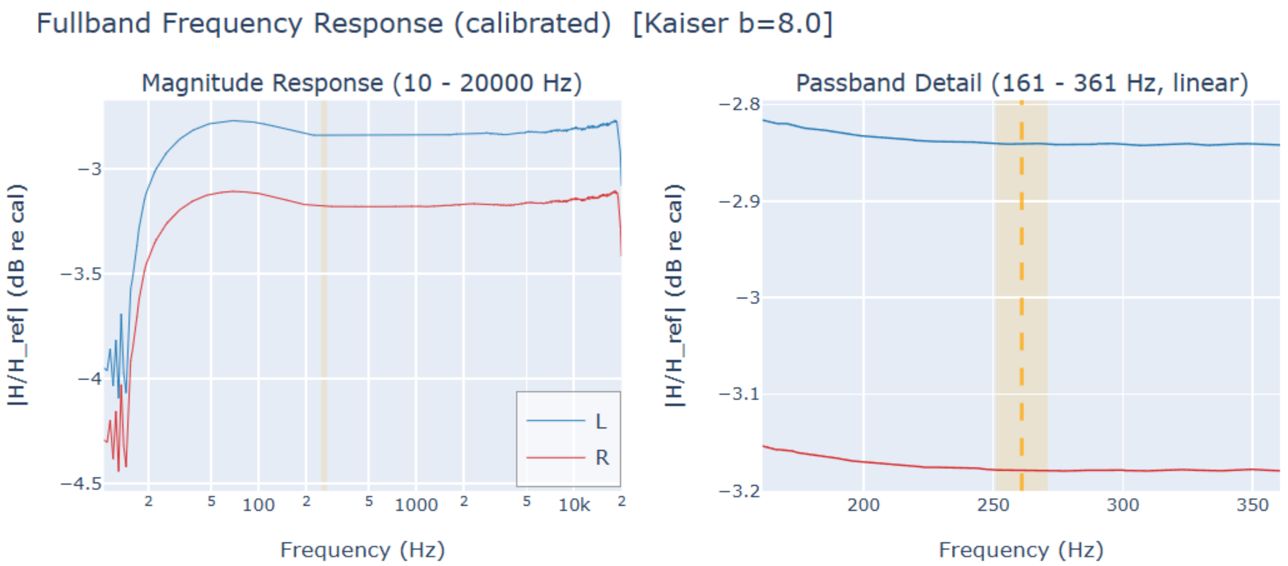
Speaker Used

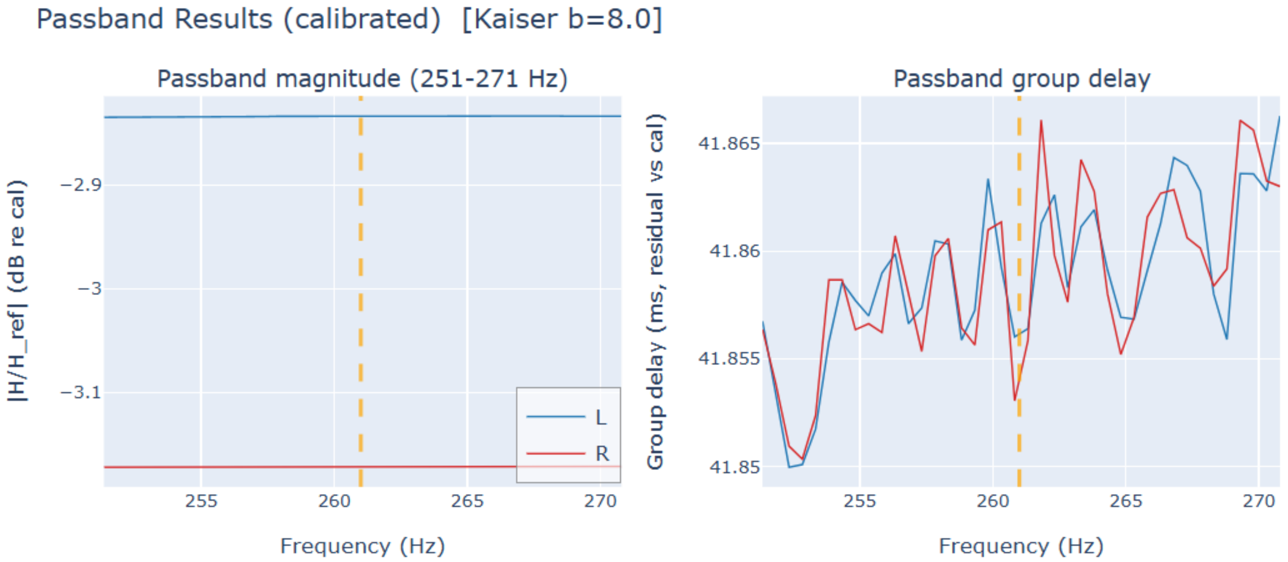
OontZ Angle3
6.5" x 3" x 2.75" high

Two 1.75" drivers spaced 2" apart plus, a downward-facing bass radiator

At a 261 Hz carrier, $\lambda = 51.7$ inches:
The two speakers are spaced approximately $\lambda/26$ so effectively a point source.
Could space two units 25.9" for MIMO experiments.



Frequency Response through
RadioSonic Line-In to Line-Out



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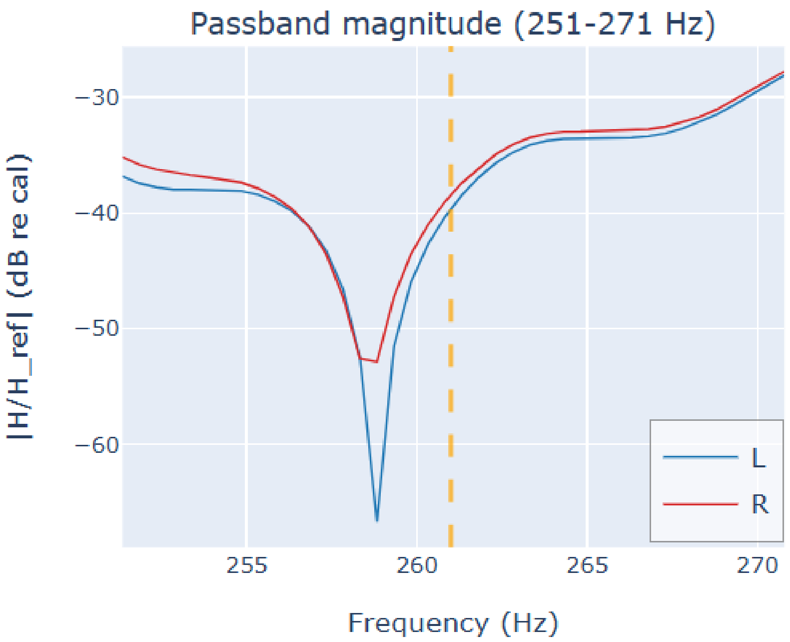
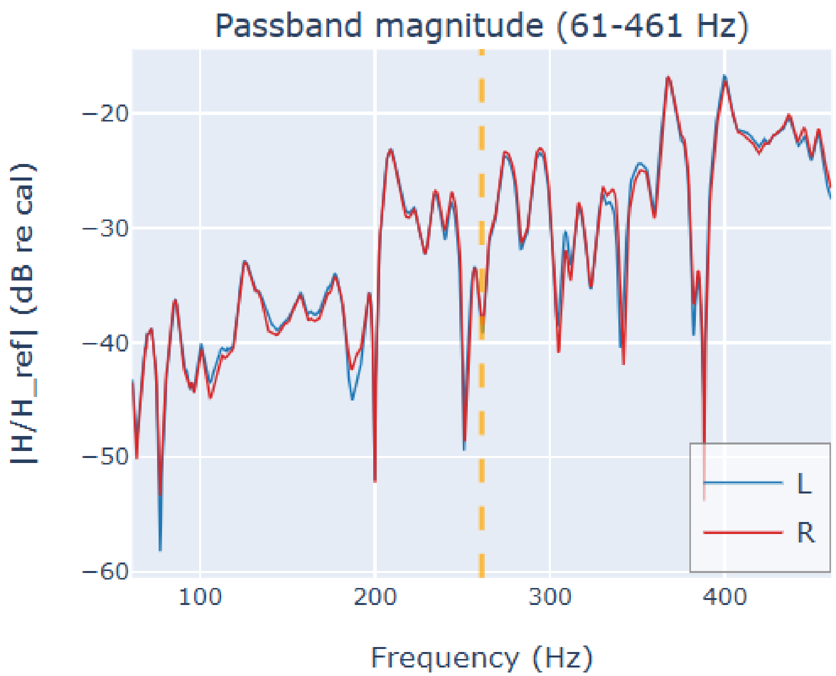
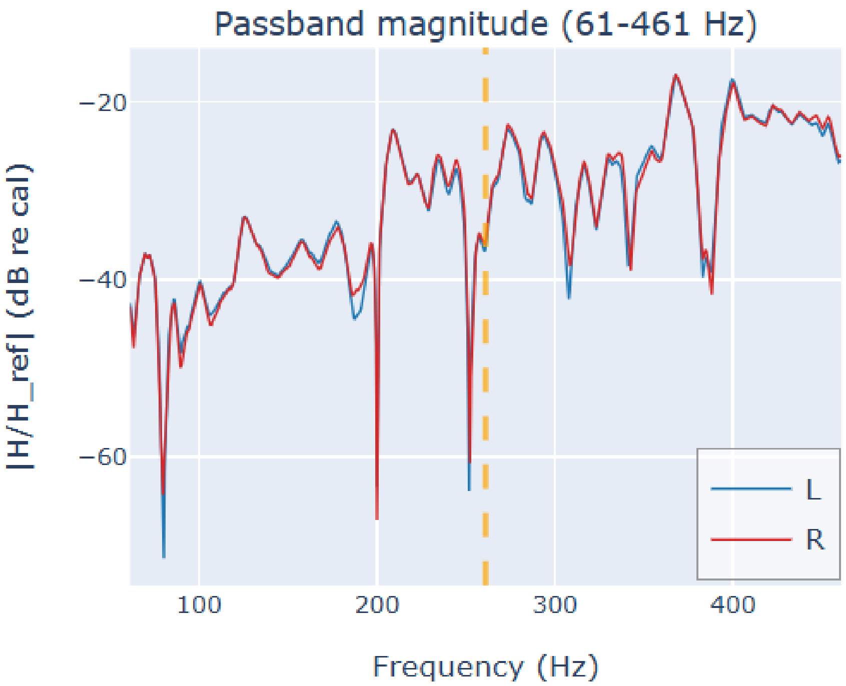
Passband Frequency Response
Speaker + Over-the-air only
(line measurement calibrated out)







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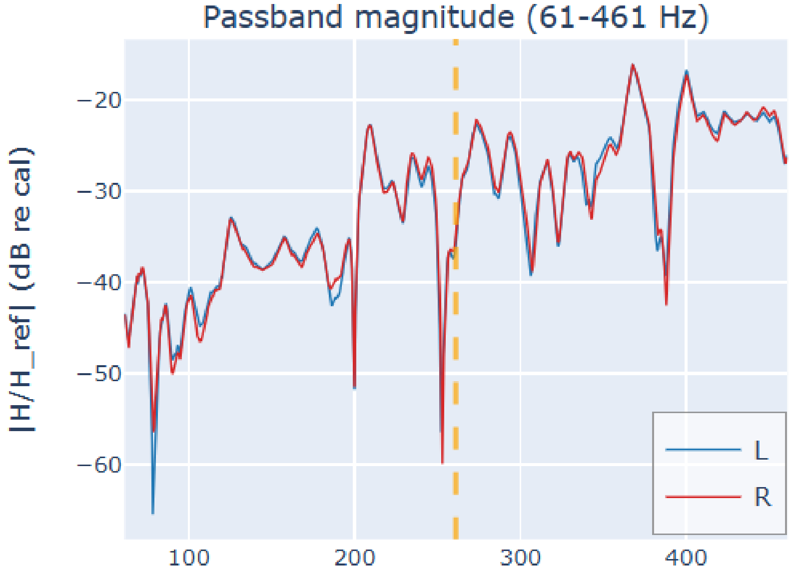
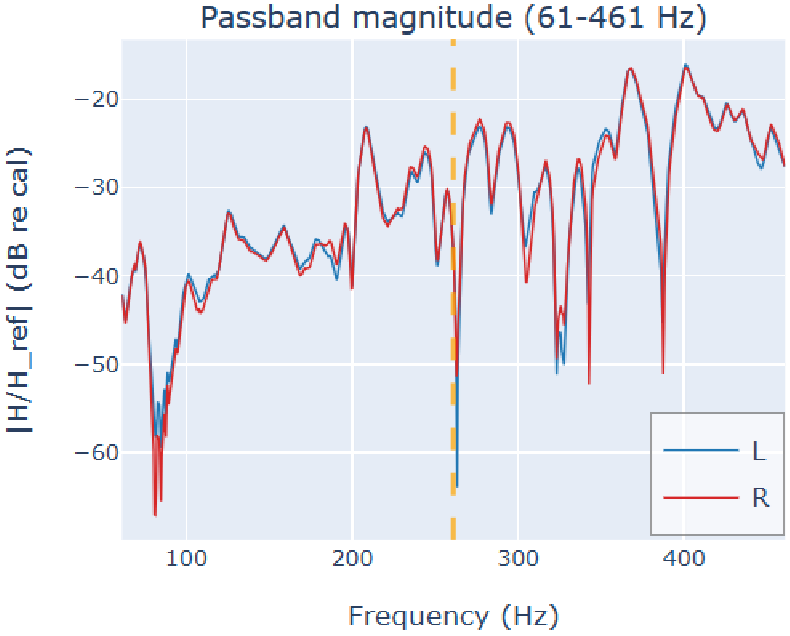
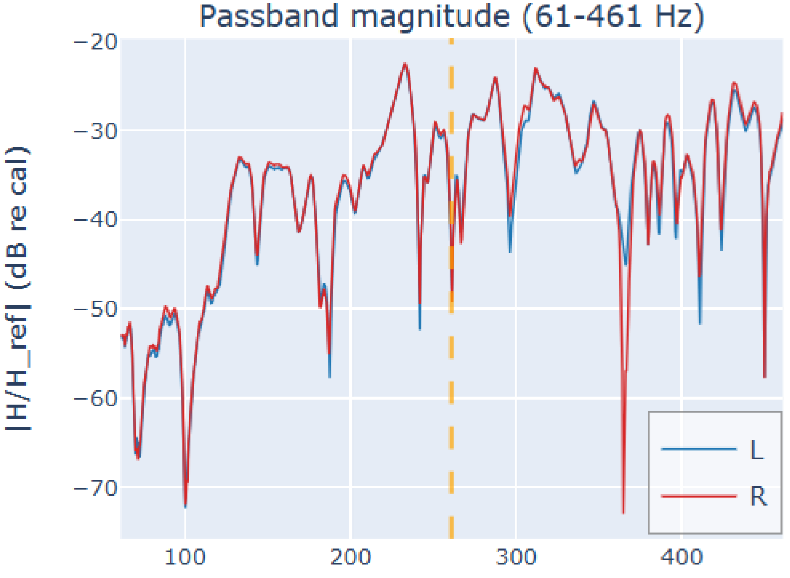
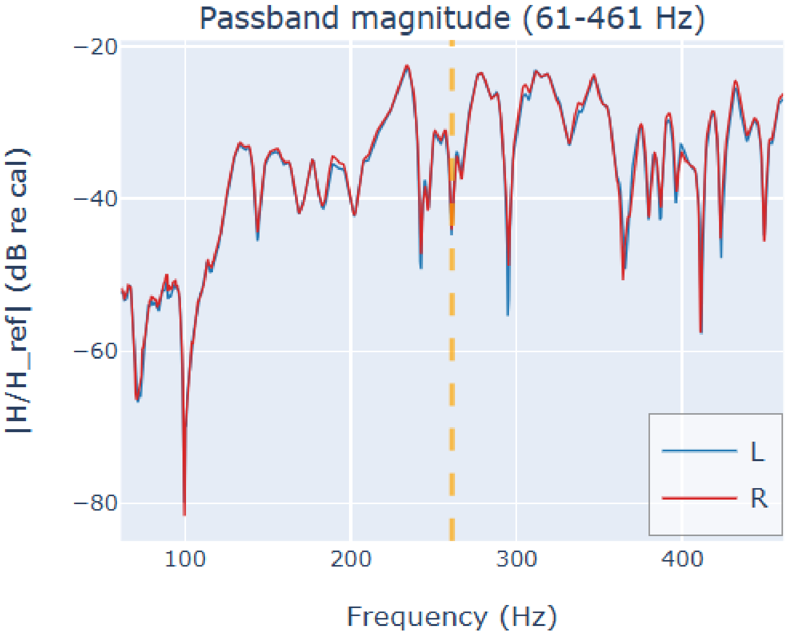
4.5' on desk





6' across room





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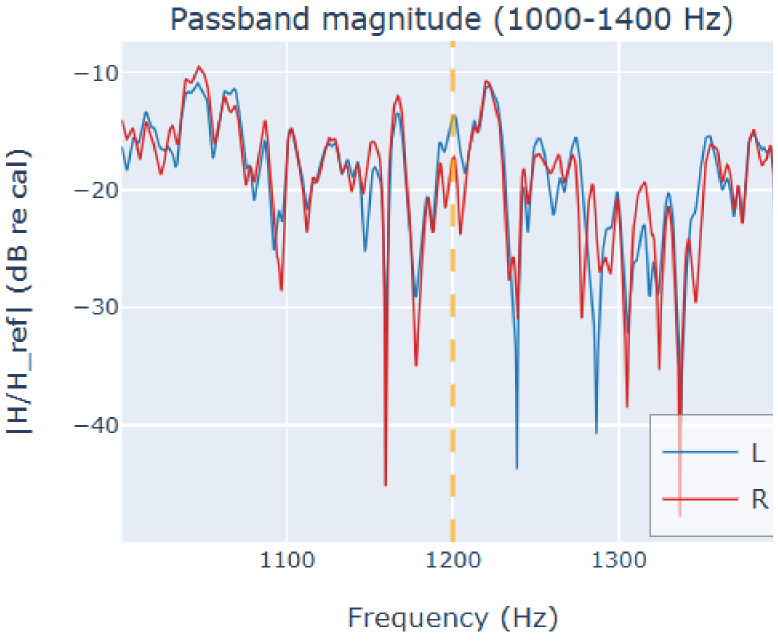
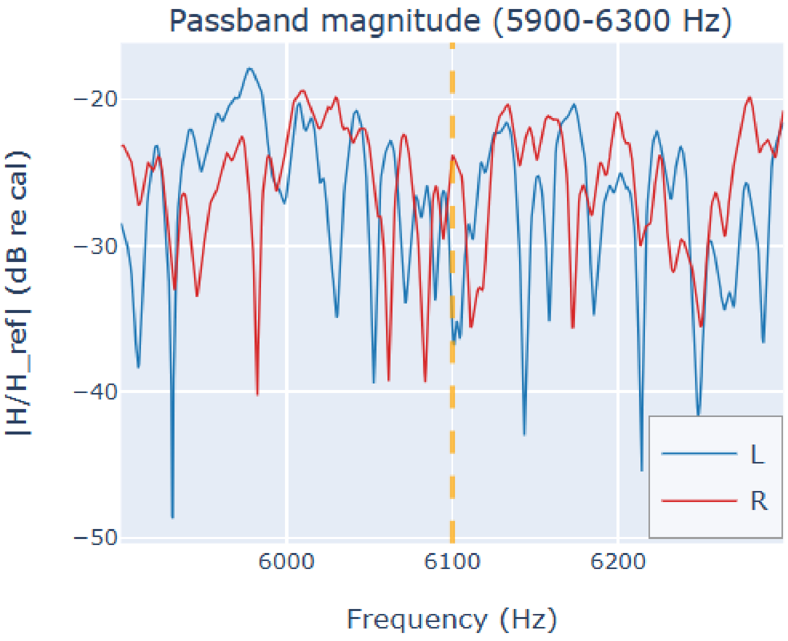
6' across room



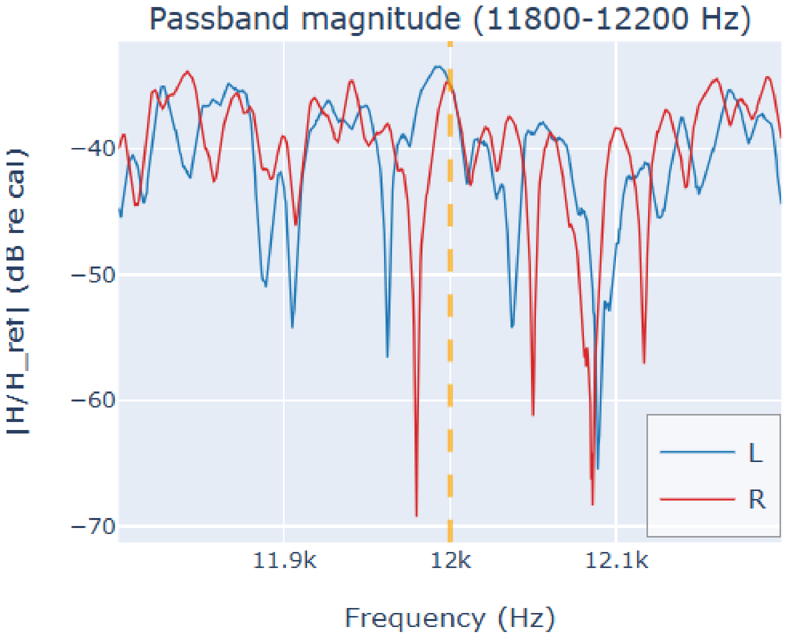
$\lambda/10$

6' across room



$\lambda/2$

6' across room



λ

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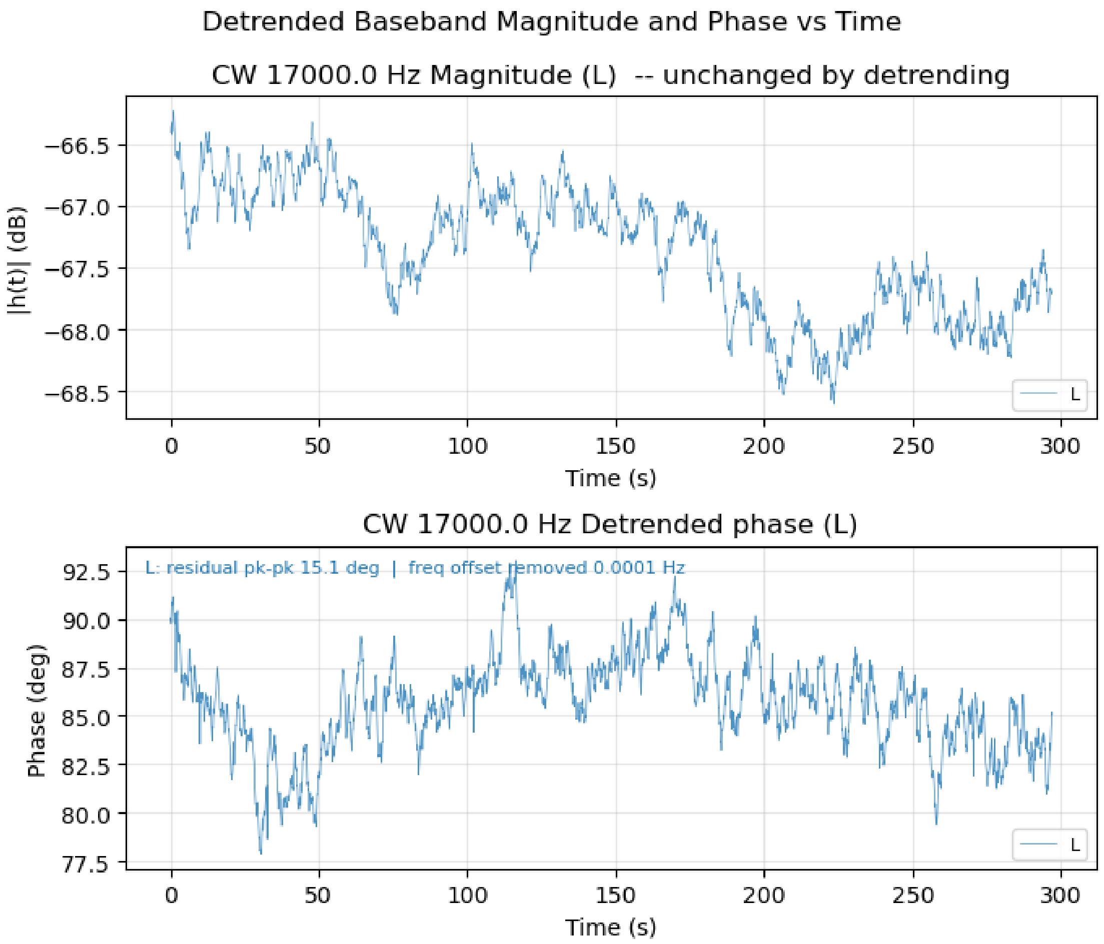
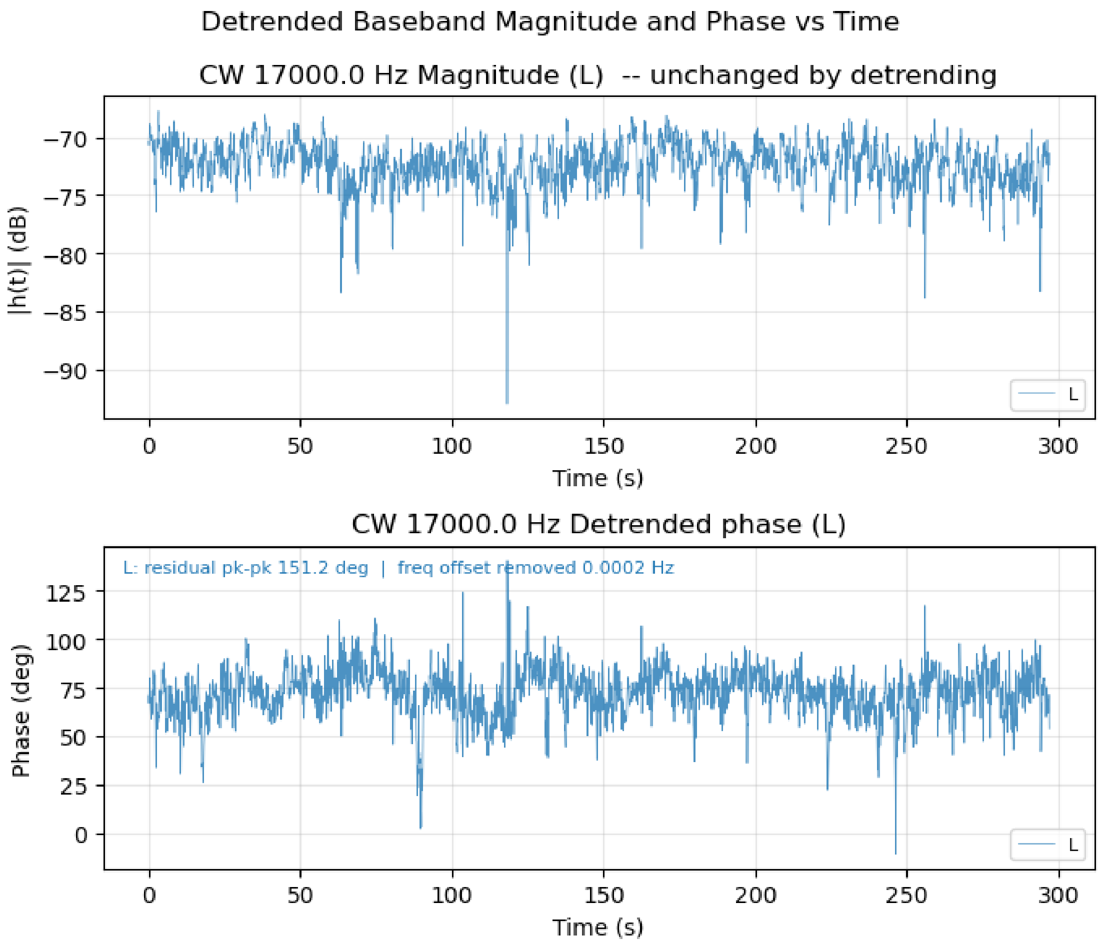
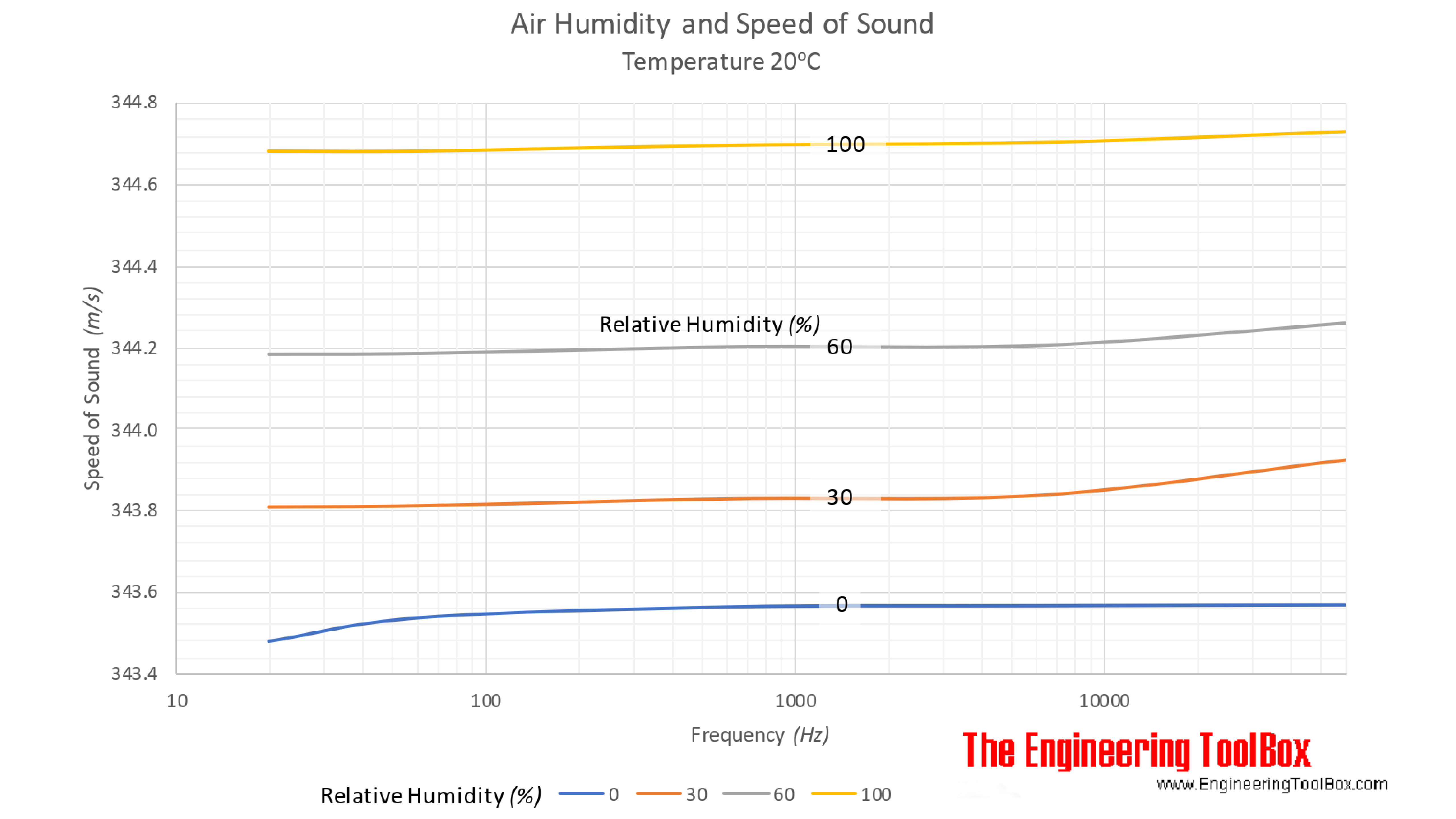
Single Tone, 17 kHz, 300 seconds

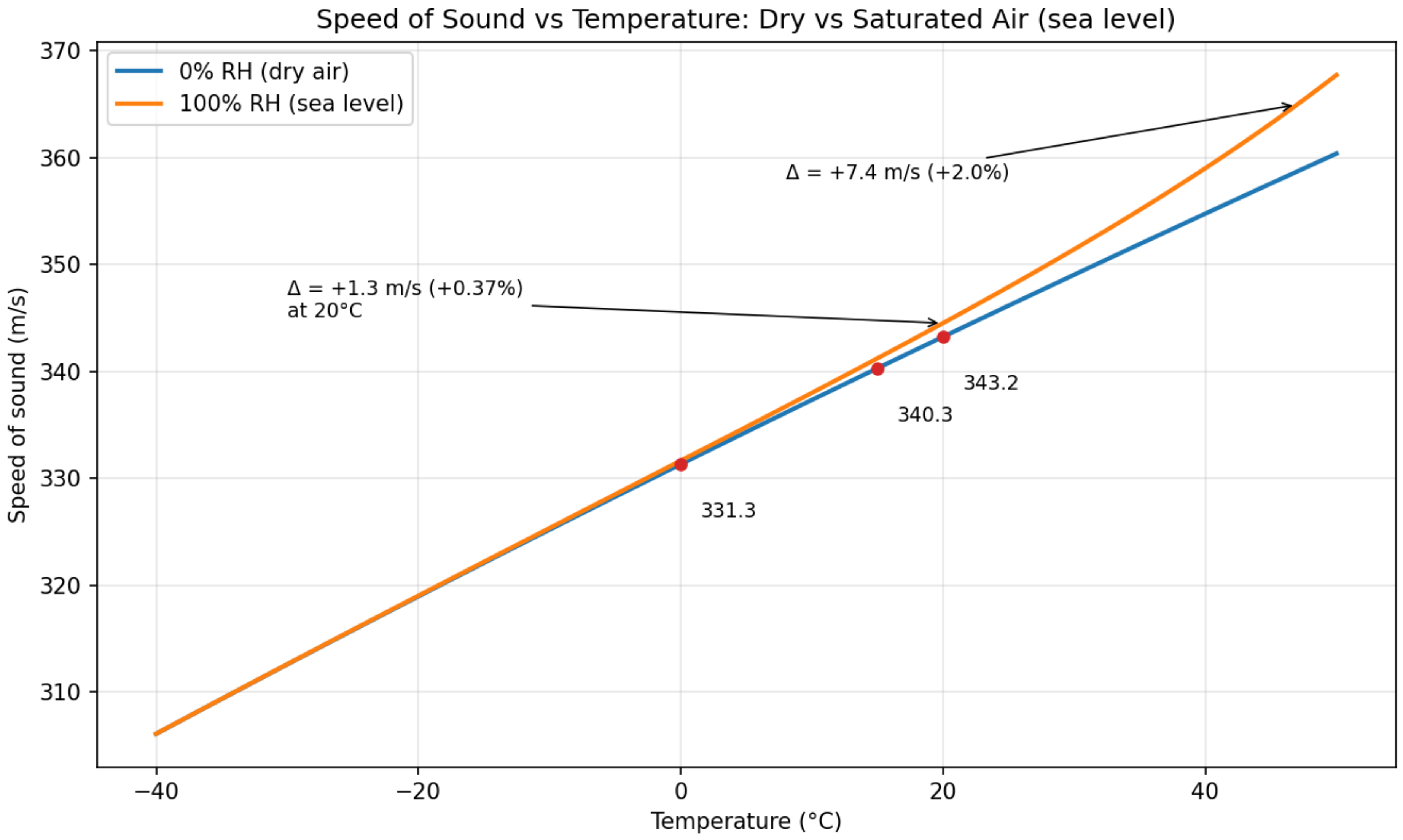
Left room. Room perfectly still



Walking around, moving arms while capturing




Air Humidity and Speed of Sound
Temperature 20°C
Speed of Sound (m/s)
344.8
344.6
344.4
344.2
344.0
343.8
343.6
343.4
10
100
1000
10000
Frequency (Hz)
Relative Humidity (%)
100
60
30
0
Relative Humidity (%)
0
30
60
100
The Engineering ToolBox
www.EngineeringToolBox.com



computed from ideal-gas mixture theory; cf. Cramer (1993): https://doi.org/10.1121/1.405827

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Existing Soundcard Based Solutions

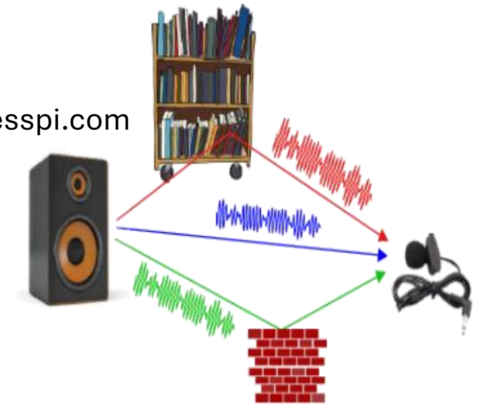
- Qasim Chaudhari:

https://wirelesspi.com/sdr-course/

- Maximilian Matthé:

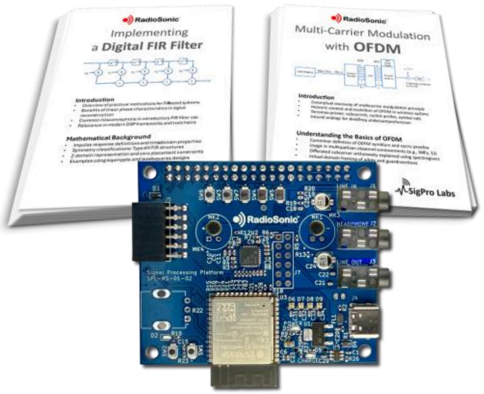
https://dspillustrations.com/pages/pages/practical-ofdm-tutorial-using-your-soundcard.html

wirelesspi.com

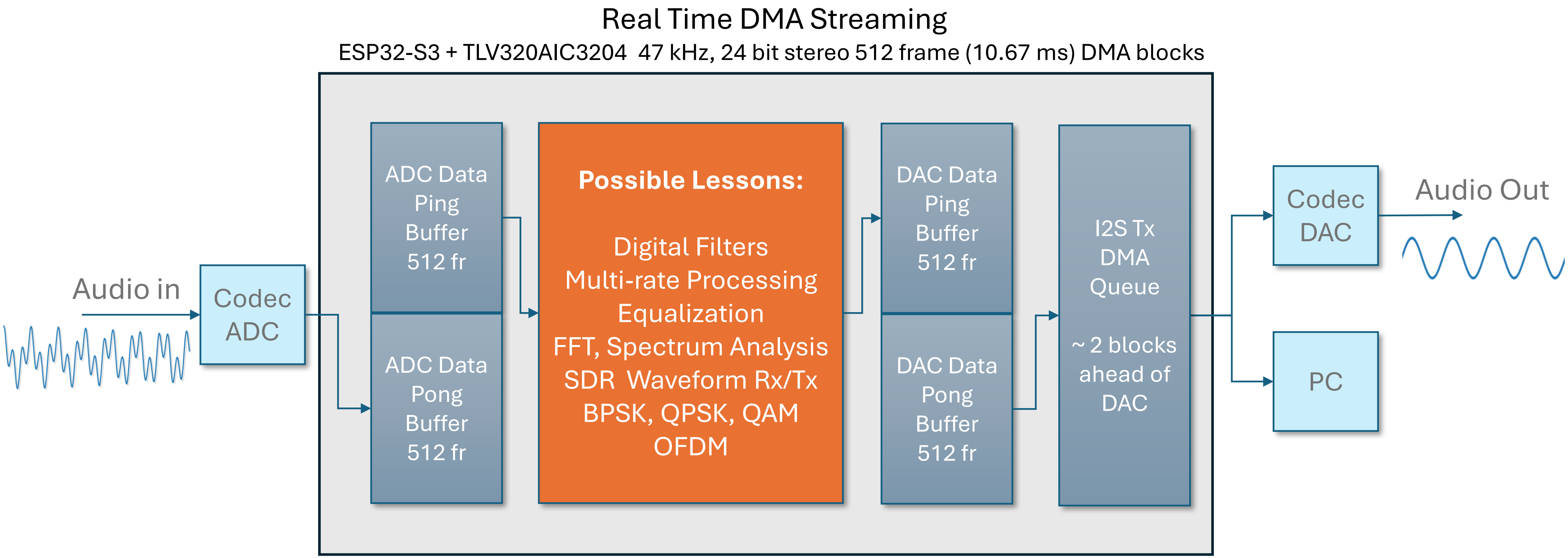


Send and receive wireless signals over the air without expensive SDR hardware through a speaker (Tx) and a microphone (Rx)

RadioSonic is a **low-cost** real-time **stand-alone** platform purpose-built for **teaching** hands-on **Signal Processing** and **SDR**.



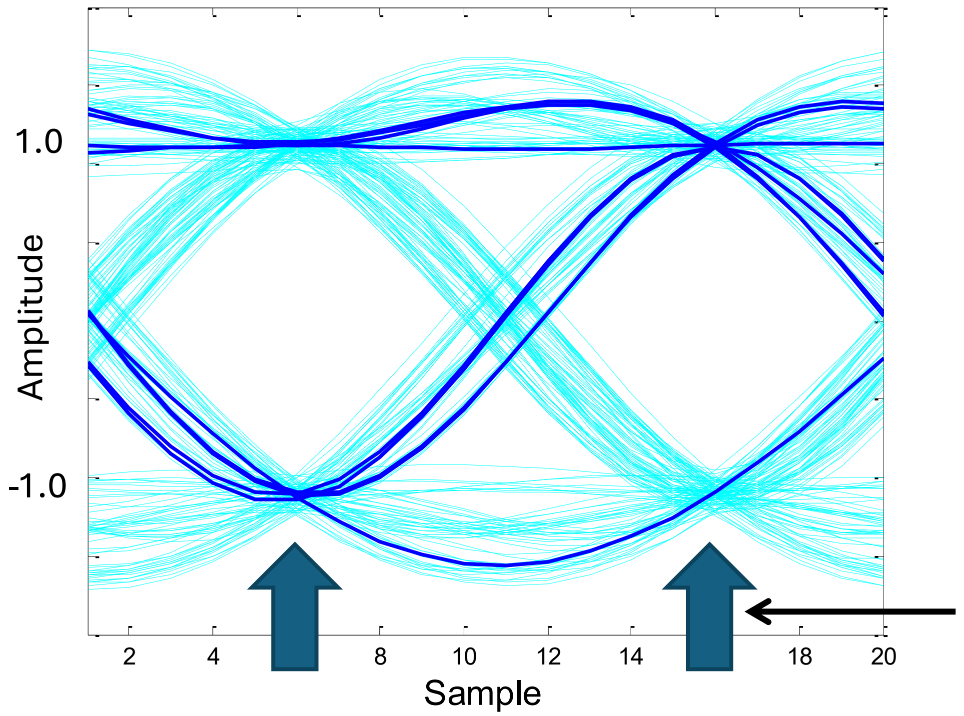
Core Platform Framework



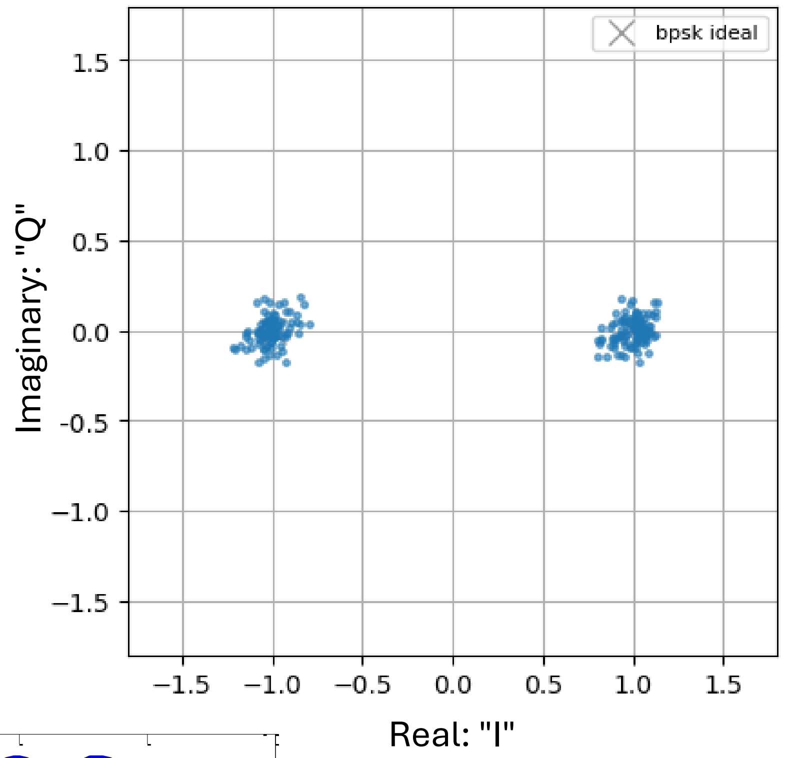
Functional software for sample-by-sample DMA transfer from audio input to audio output, allowing for "drop-in" lessons customized to target learning experience.

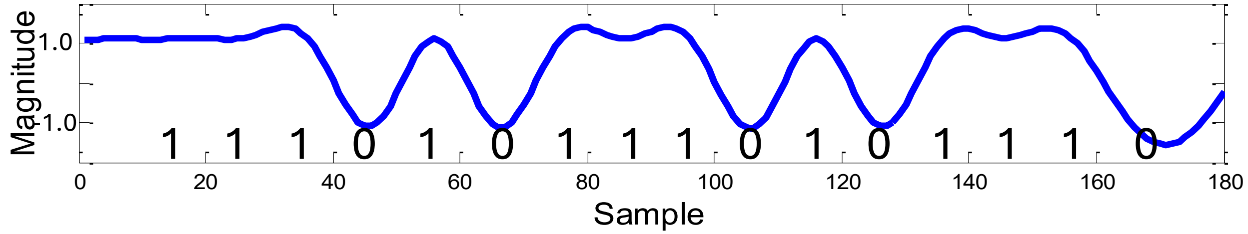
Reading Eye Diagrams and Constellations

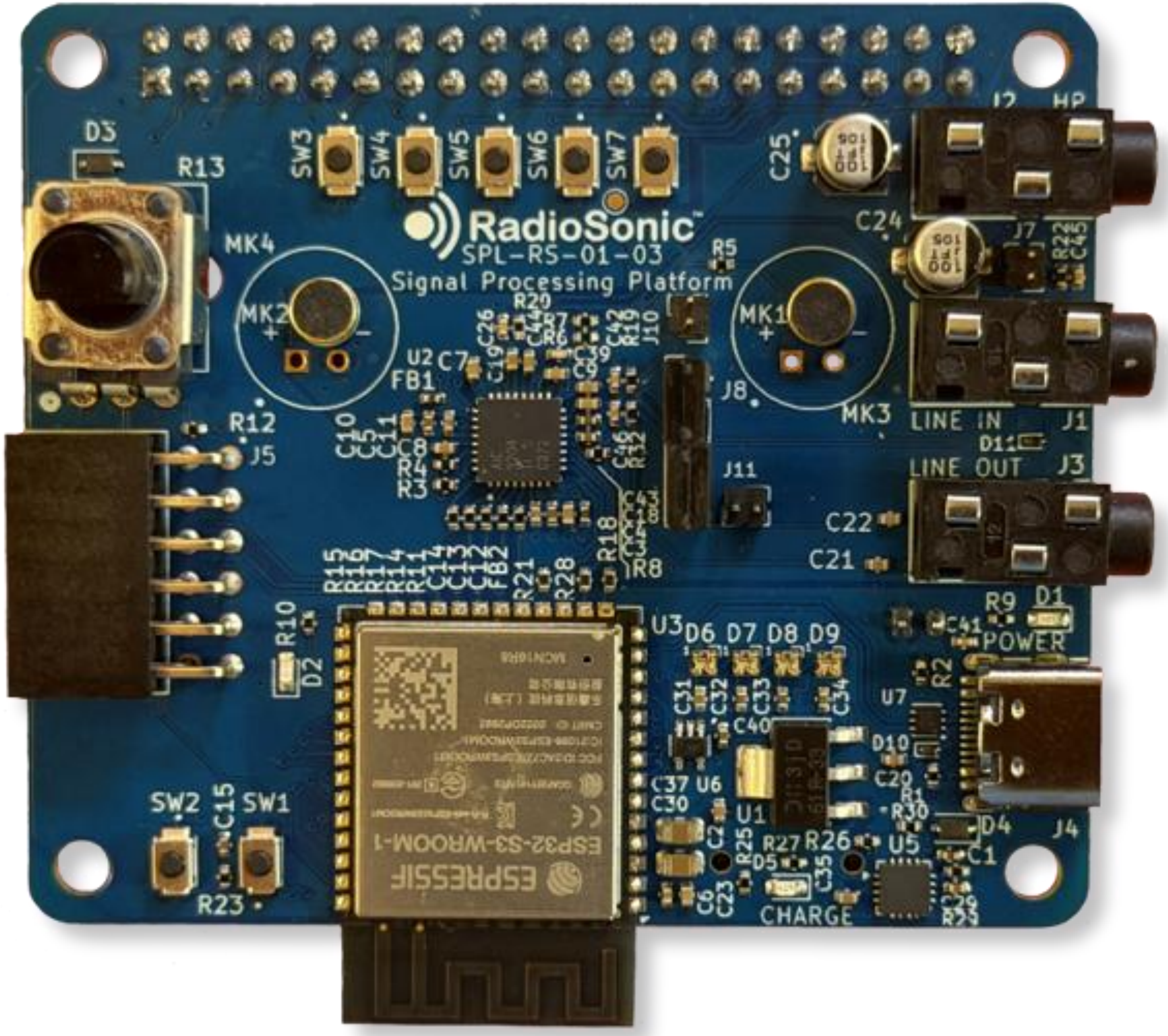
Eye Diagram



Constellation






RadioSonic™
SPL-RS-01-03
Signal Processing Platform
LINE IN
LINE OUT
HP
POWER
CHARGE
ESP32-S3-WROOM-1
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