An Amateur Radio HF Channel Sounder

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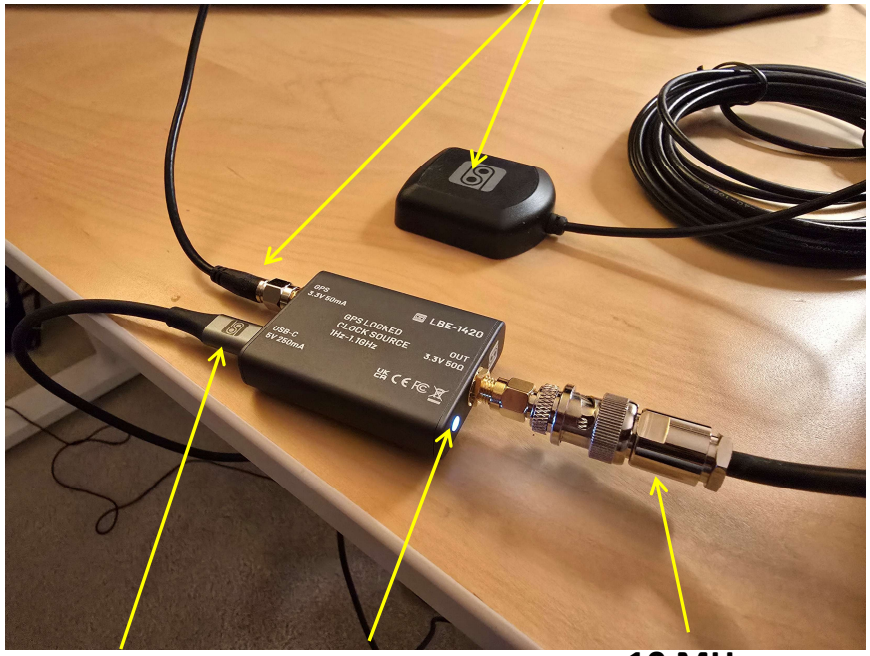
Introduction

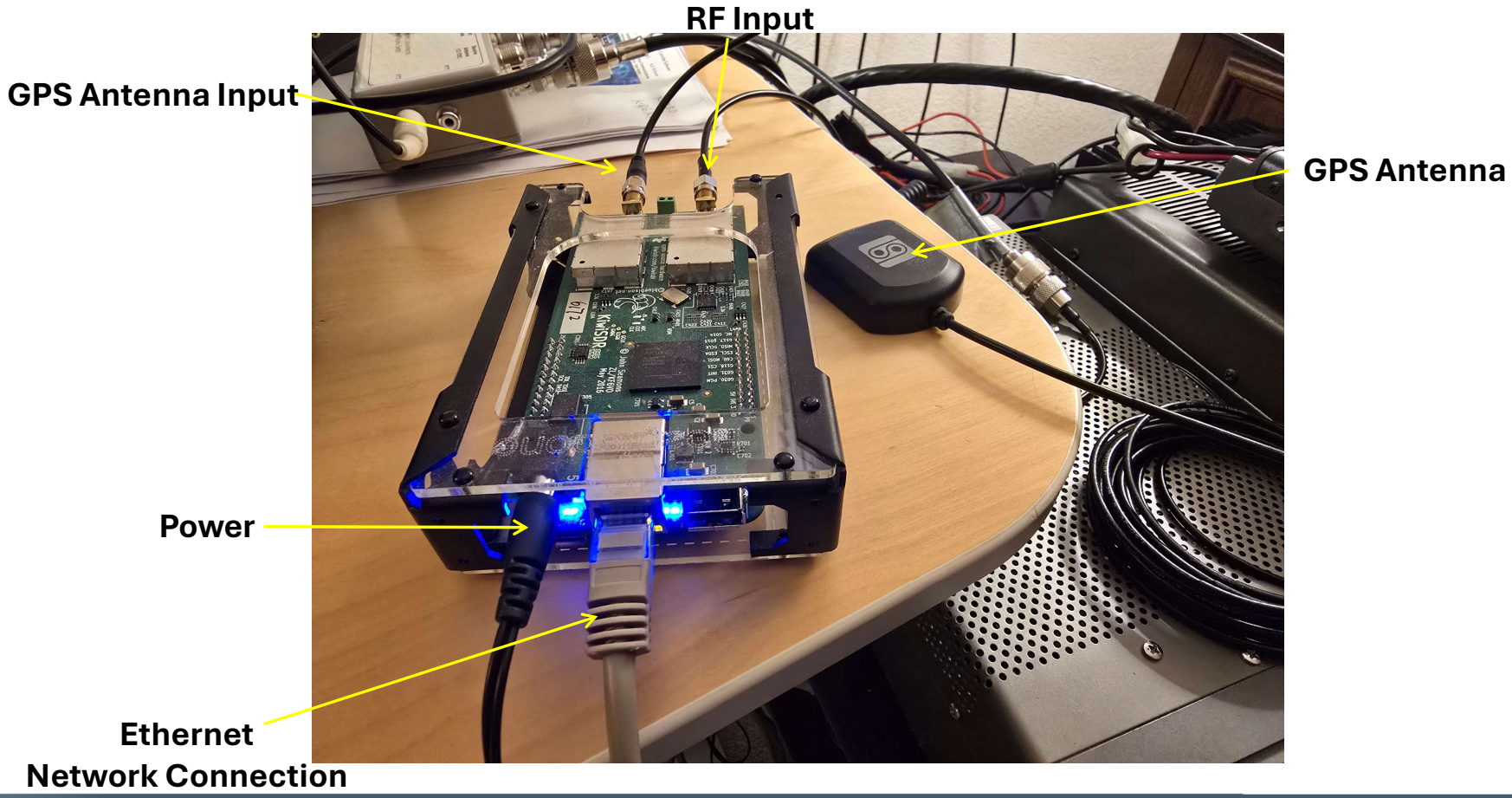
- Provide the amateur radio community access to ionospheric channel sounding
- System architecture based on post-processing software, an amateur ham transceiver (upper sideband), and an Internet-connected remote SDR
- Play a .wav file into the audio input of an amateur transceiver
- Record the over-the-air (OTA) transmission using a selected Kiwi SDR
- Use post-processing software to cross correlate transmitted and received waveforms to yield a channel impulse responses
- Delay, Doppler, time variability
- This is a relative time measurement tool

Transmitter

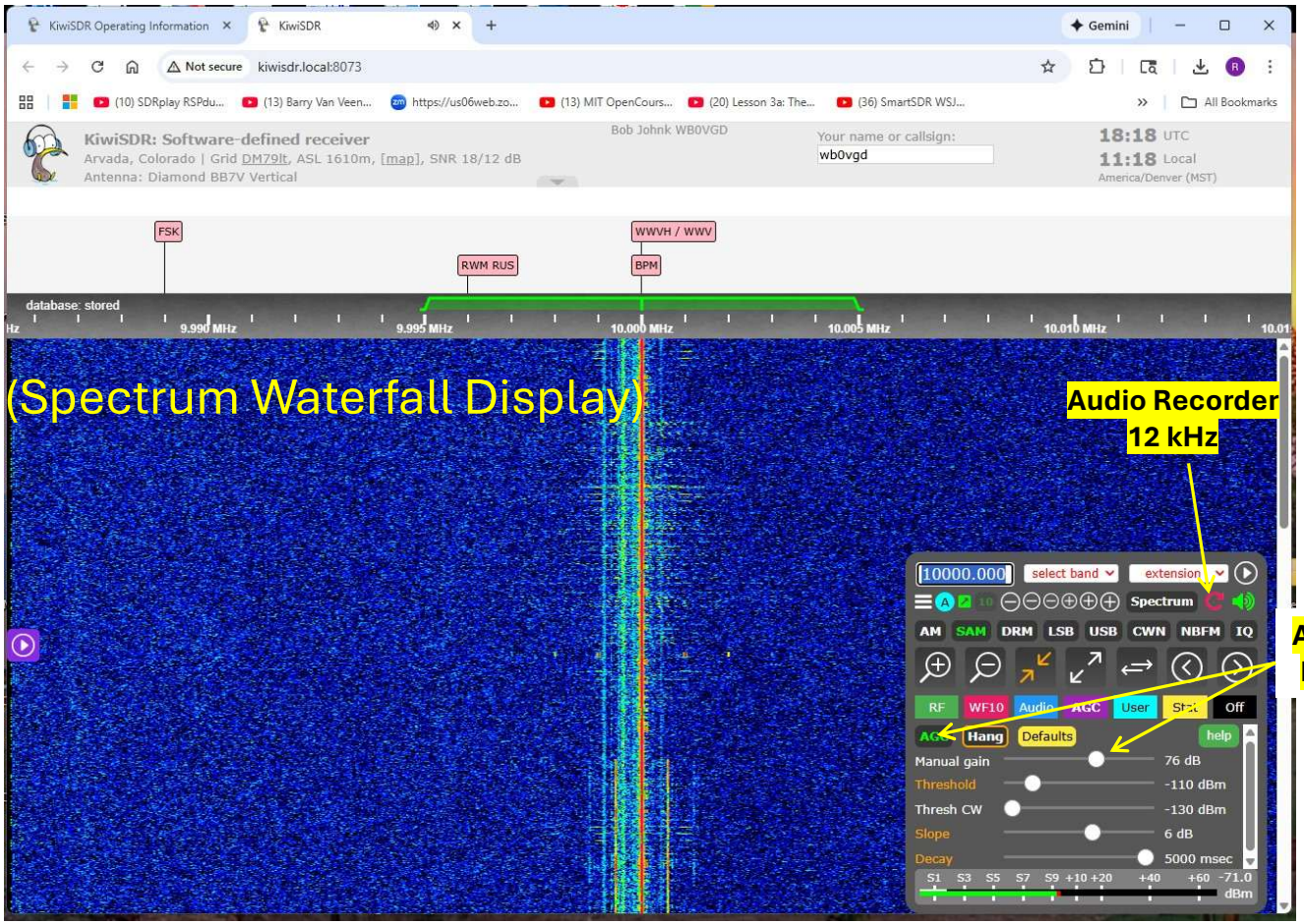
FLEX 6700 SDR TRANSCEIVER & LEO BODNAR GPSDO



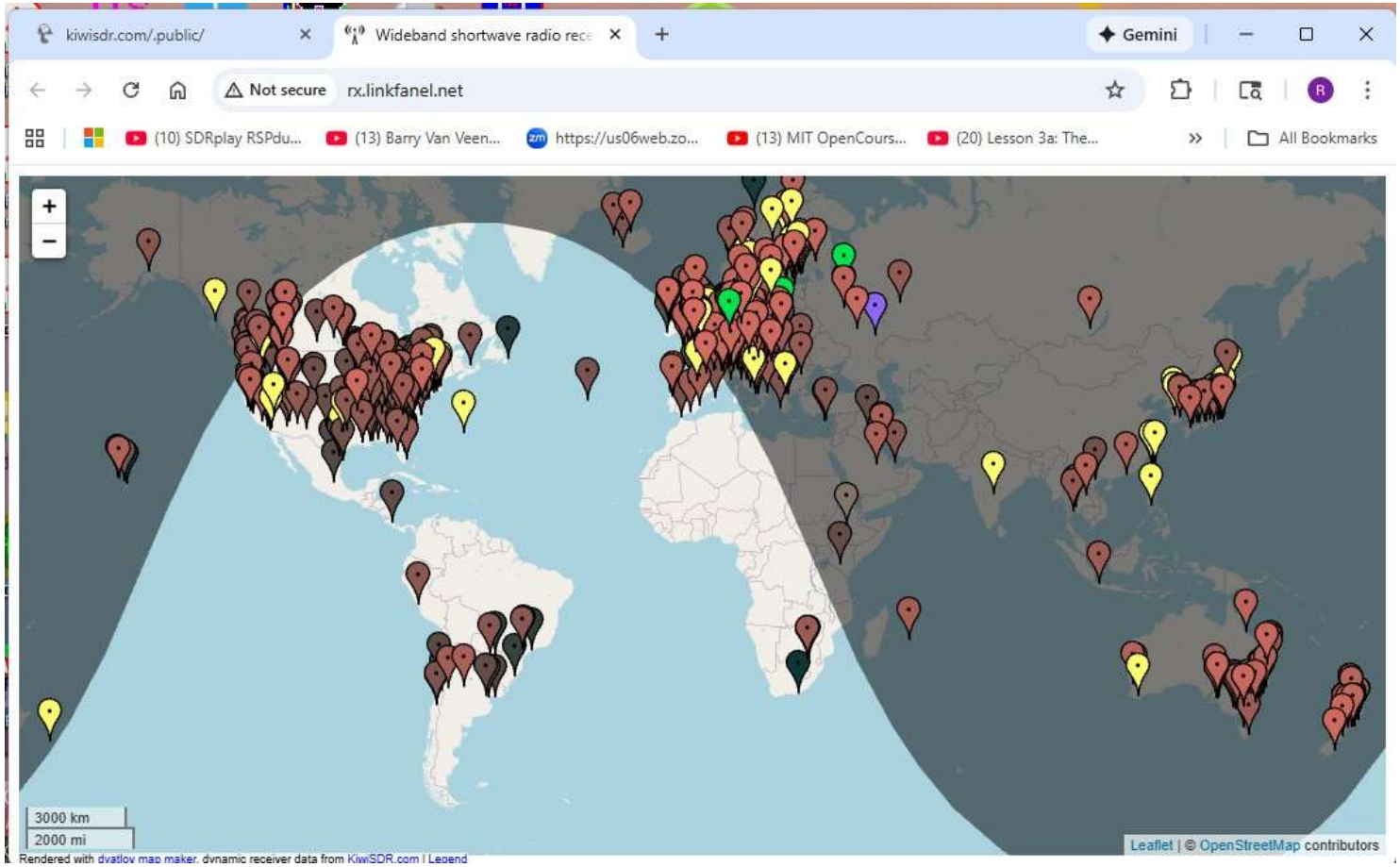
Remote Kiwi SDR



Kiwi SDR Web Browser GUI

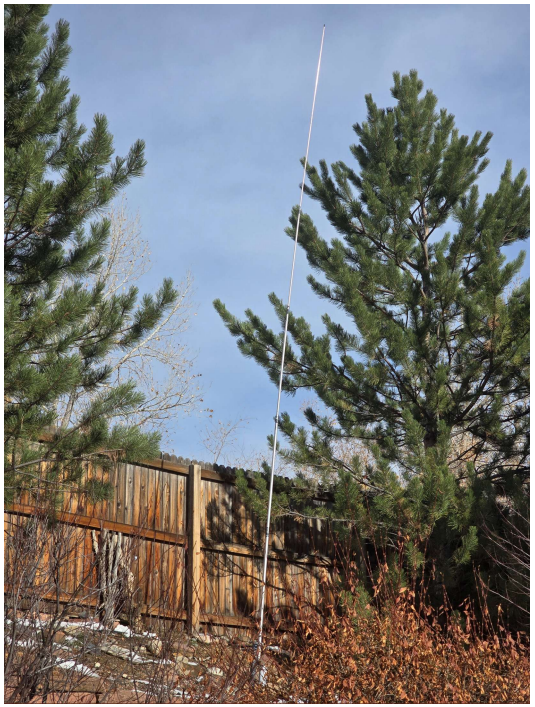


World-Wide Kiwi SDR Network (913 receivers 12/31/25)[6]



Transmitting and Receiving Antennas

Vertical Tx Antenna

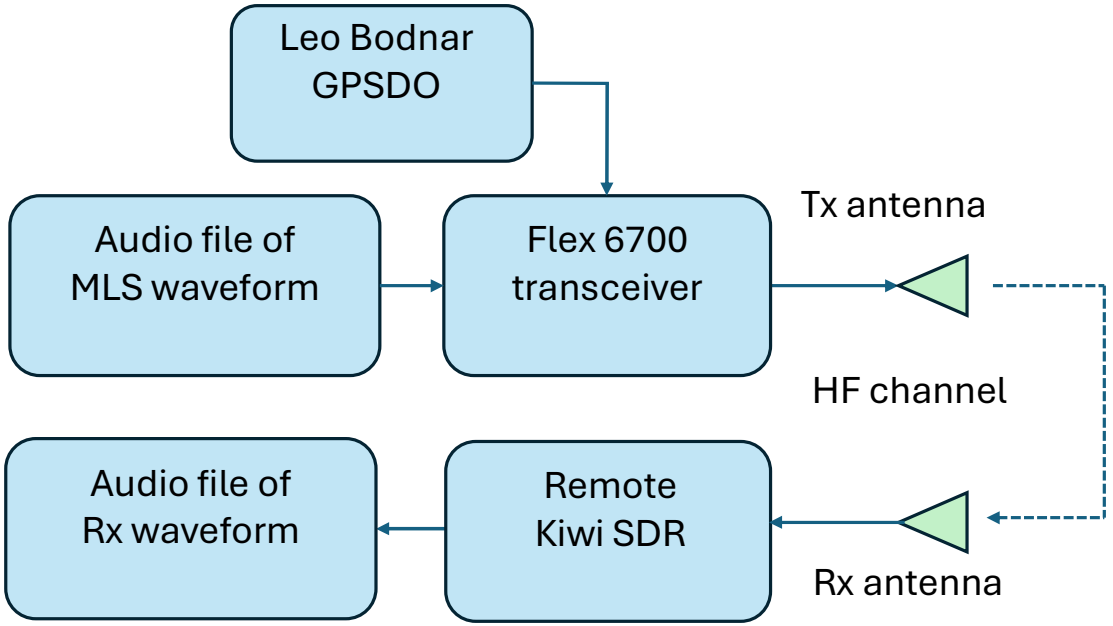


NVIS Tx Dipole

Vertical Antenna Base Feed

Active Rx Loop at Remote Kiwi SDR

Over-the-Air Configuration

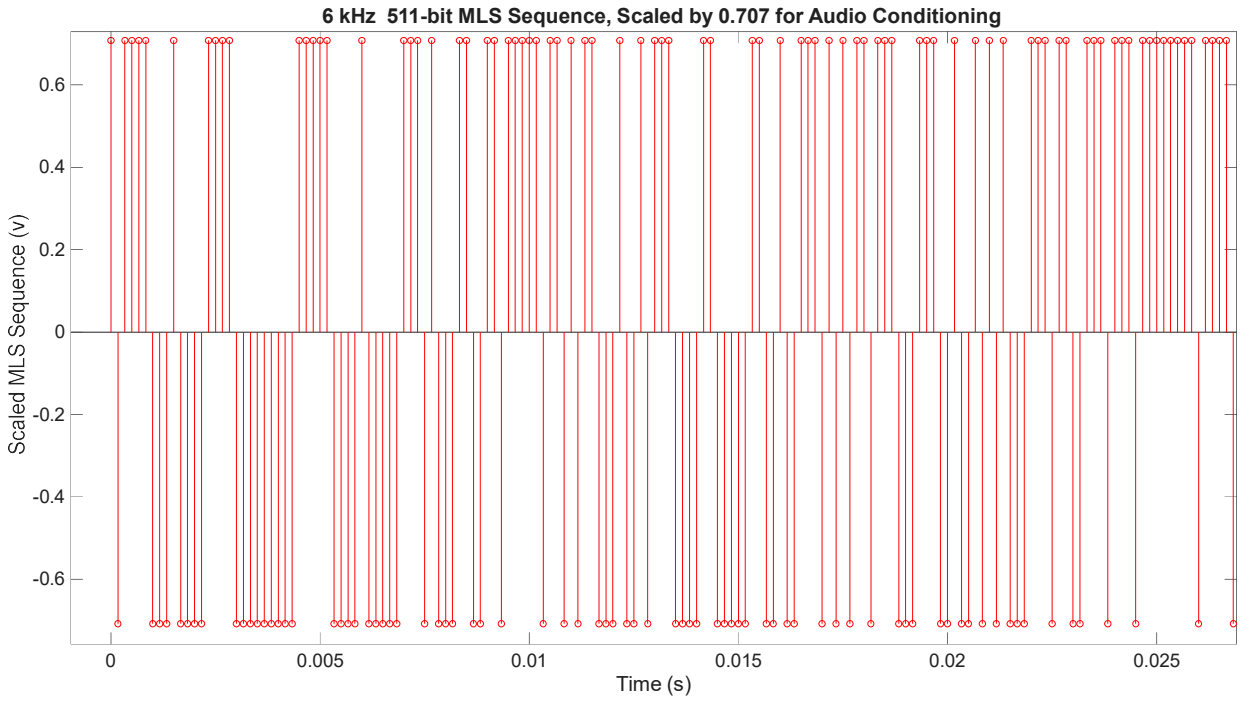


Maximum Length Sequence and Key Post Processing steps

- Generate maximum length sequence of length 511 (fs=6 kHz, duration 85ms)
- Repeat the sequence 800 times to generate a 68 sec transmission
- Apply a Root-Raised Cosine (RRC) filter and upsample to fs=48 kHz to generate a suitable OTA waveform
- Save this waveform in .wav format for later transmission via Flex 6700
- In post processing, the recorded waveform is, once again, RRC filtered and down sampled back to a fs=6 kHz sequence
- Cross correlate one period of the transmitted MLS sequence with the received sequence = **Channel Impulse Response**
- See Appendix for diagram and my 2026 NRSM summary for details:
- https://www.usncursi.org/archive/nrsm/2026/papers/1011.pdf

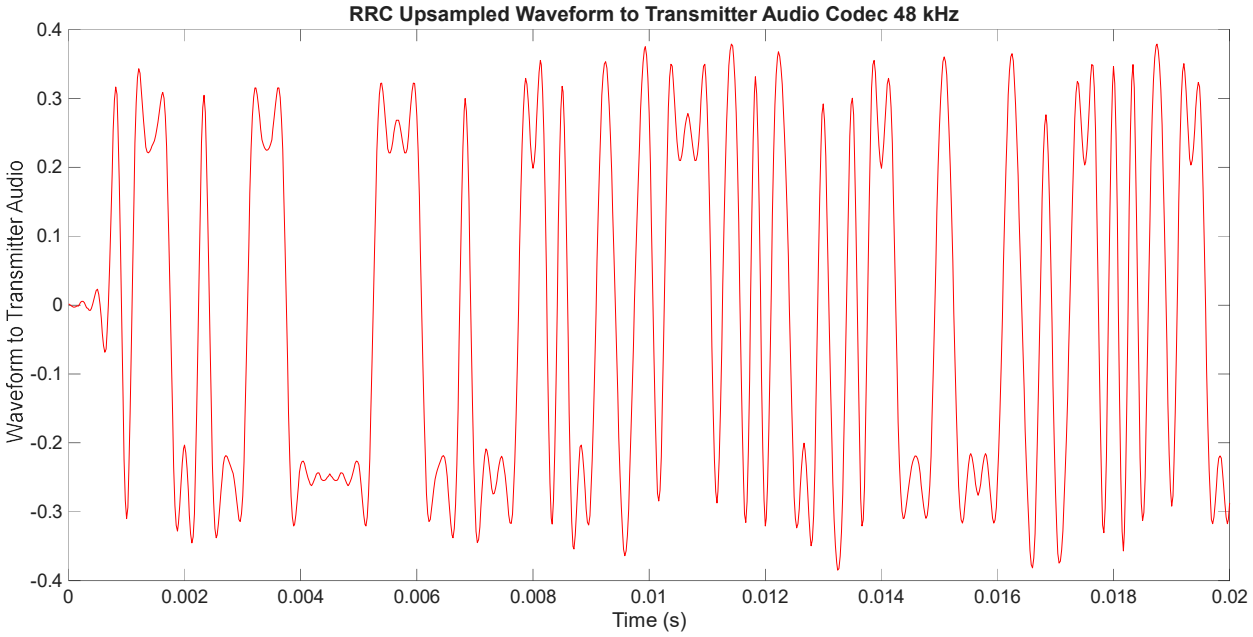
Length 511 Maximum Length sequence

Note the
± 0.7v discrete Impulses



Filtered and upsampled waveform for OTA Transmission

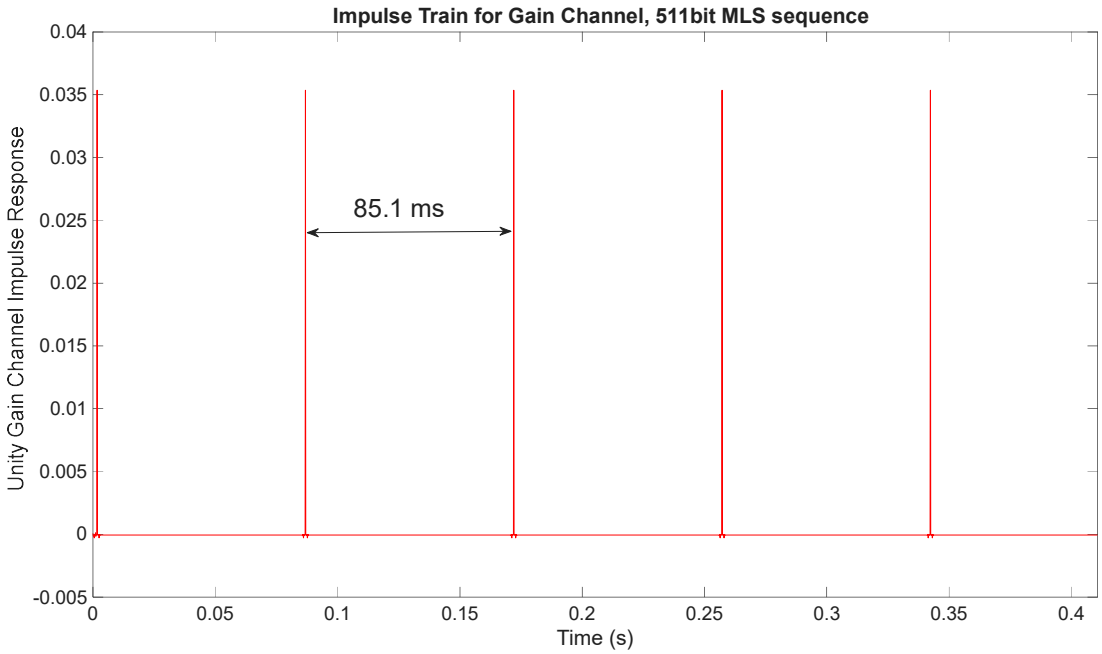
Note the smooth Transitions for Spectrum Control & Reduction of Intersymbol Interference



To Flex 6700 Transceiver

Correlator Output Obtained by Processing Tx .wav File – No Channel yet

Final Correlated Output
Periodic Impulse Train T=85.2 ms
For 6 kHz, 511-bit MLS, 800 Periods



Mathematical Equivalent of
A train of Impulses
Illuminating the ionosphere

Big Benefits:
1) Conserves Spectrum
2) Low-Power Tx requirement

Validation Using Watterson Channel Simulators

Generated Audio wfm input to Tx 48 kHz

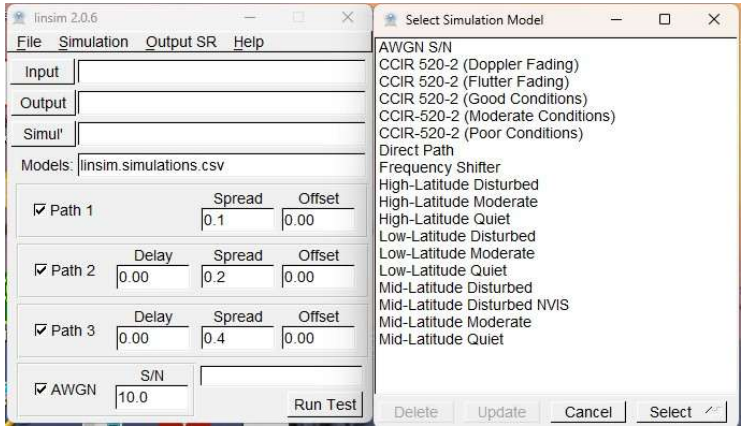
Baseband Channel Simulators

48 kHz Channel Faded Waveform

Linsim Software Simulator

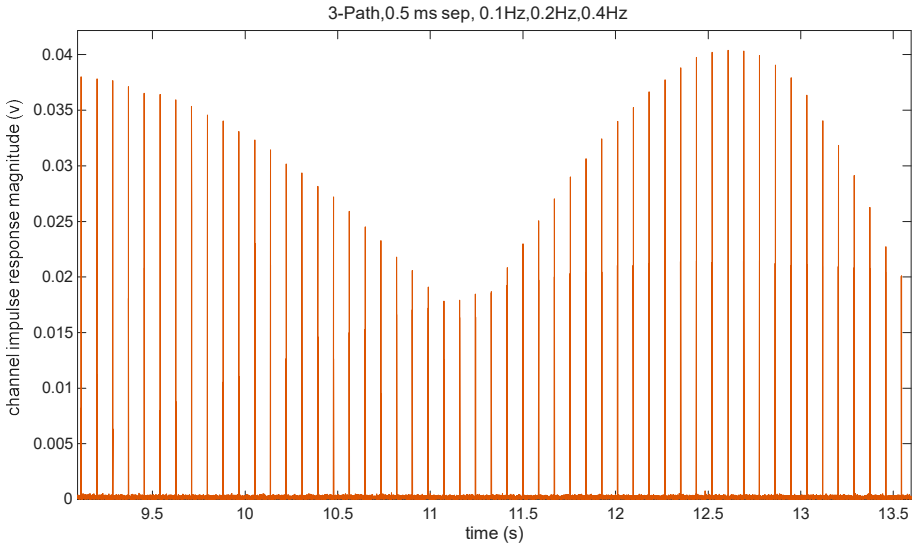
Ionos Baseband HF/VHF Hardware Channel Simulator

Matlab Rayleigh Channel Object
Configurable
Number of Paths
Path Gains & Delays
Doppler Spreads & Offsets

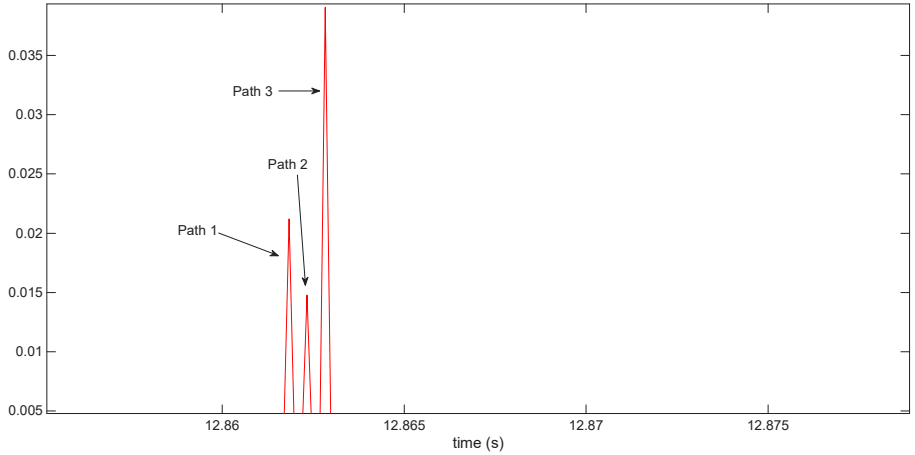


Matlab Channel Object, 3 paths, delay=0.5ms, Doppler Spreads=0.1 Hz, 0.2 Hz, 0.4 Hz

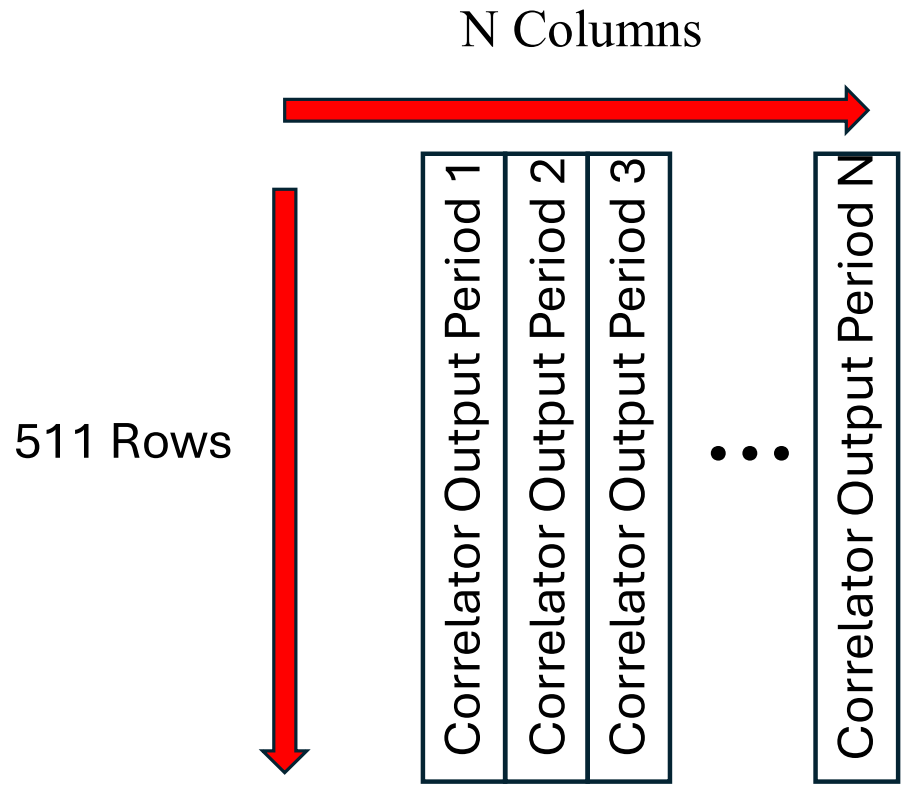
Note the time variability caused by Doppler spreading



A closer Look Reveals 3 Separate Paths spaced 0.5 ms apart



Complex Impulse Response Matrix (CIRM)

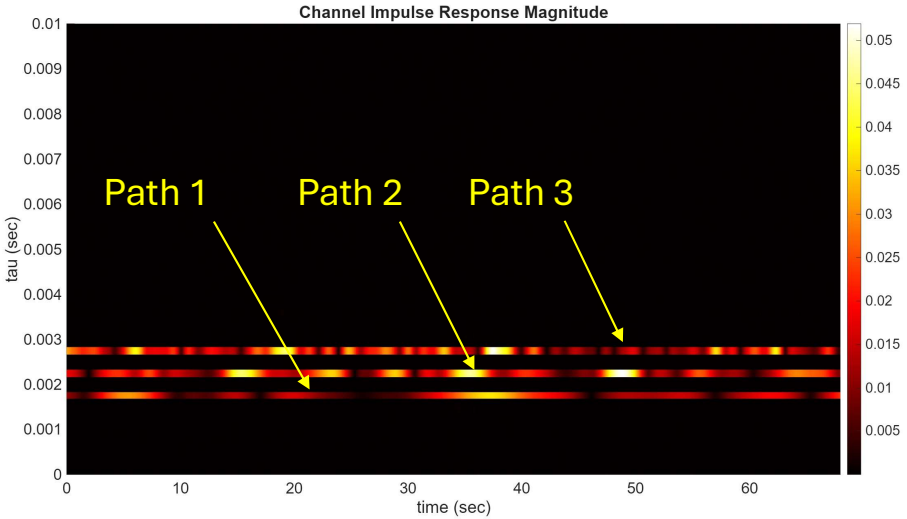


Foundation for
Radio Channel Analysis:

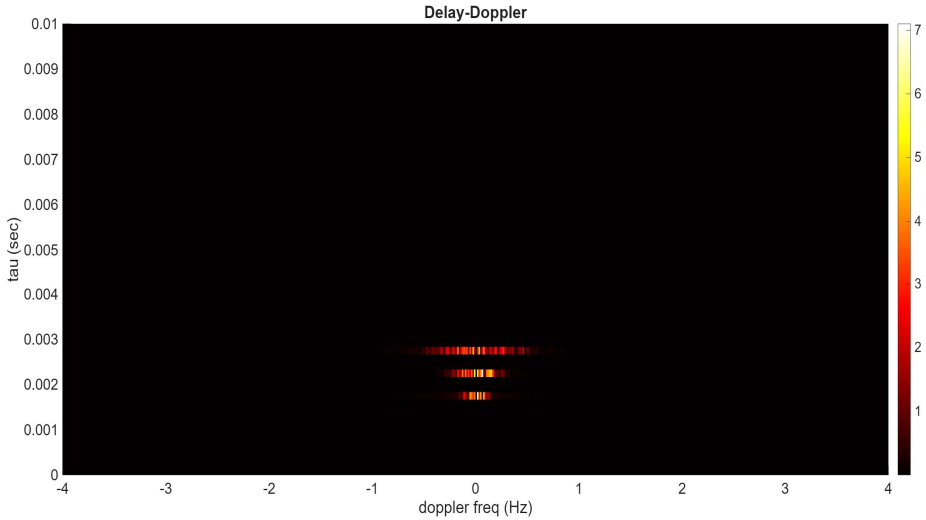
Delay-Time
Delay-Doppler
Time-varying Transfer Function
(Spectrogram)

3-Path Channel Impulse Response & Delay-Doppler

CIRM Voltage Amplitude



Delay-Doppler Amplitude Spectrum

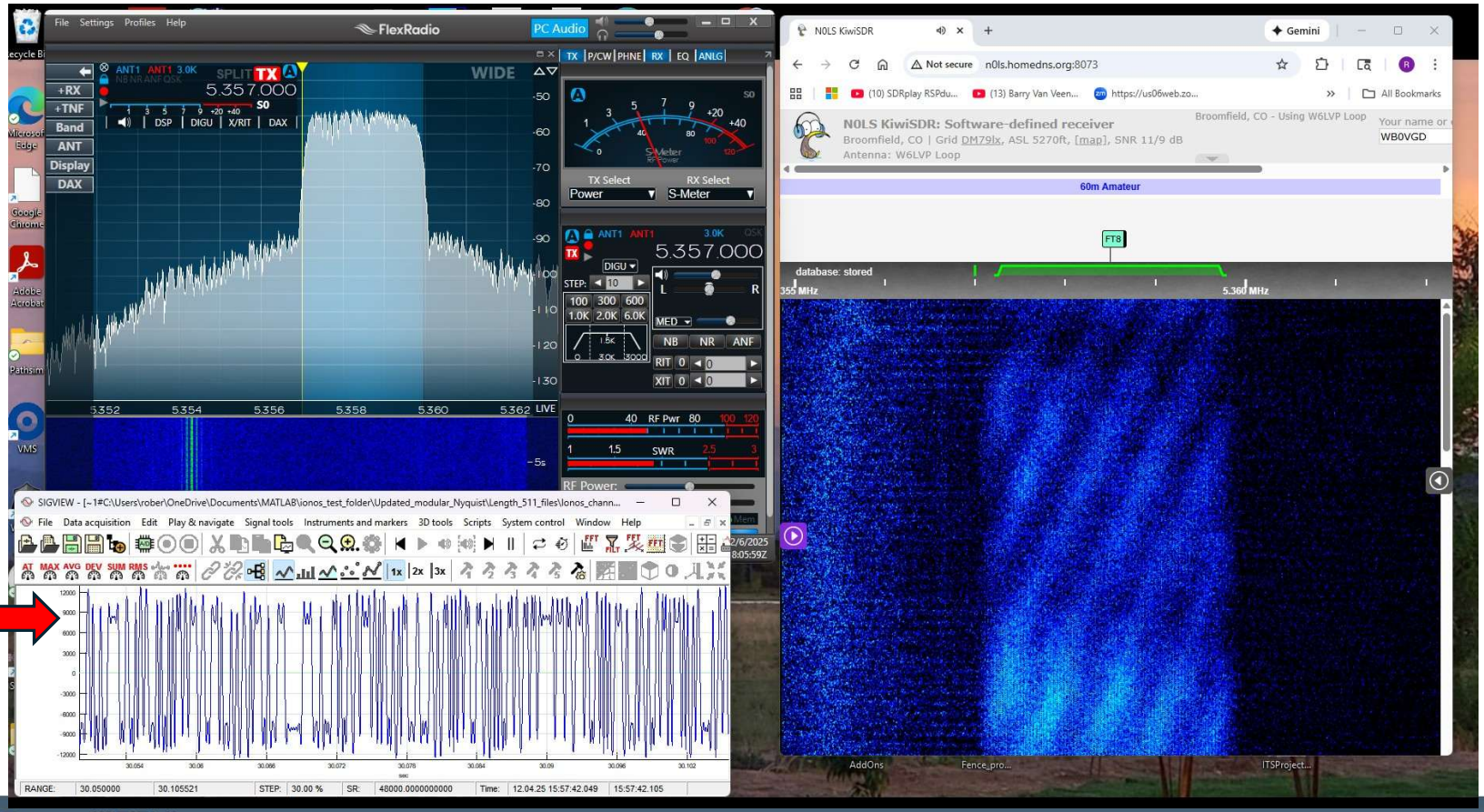


Here is what a live OTA test looks like (5.357 MHz, USB):

FLEX Smart SDR Control Interface

Kiwi SDR Web Interface-recording

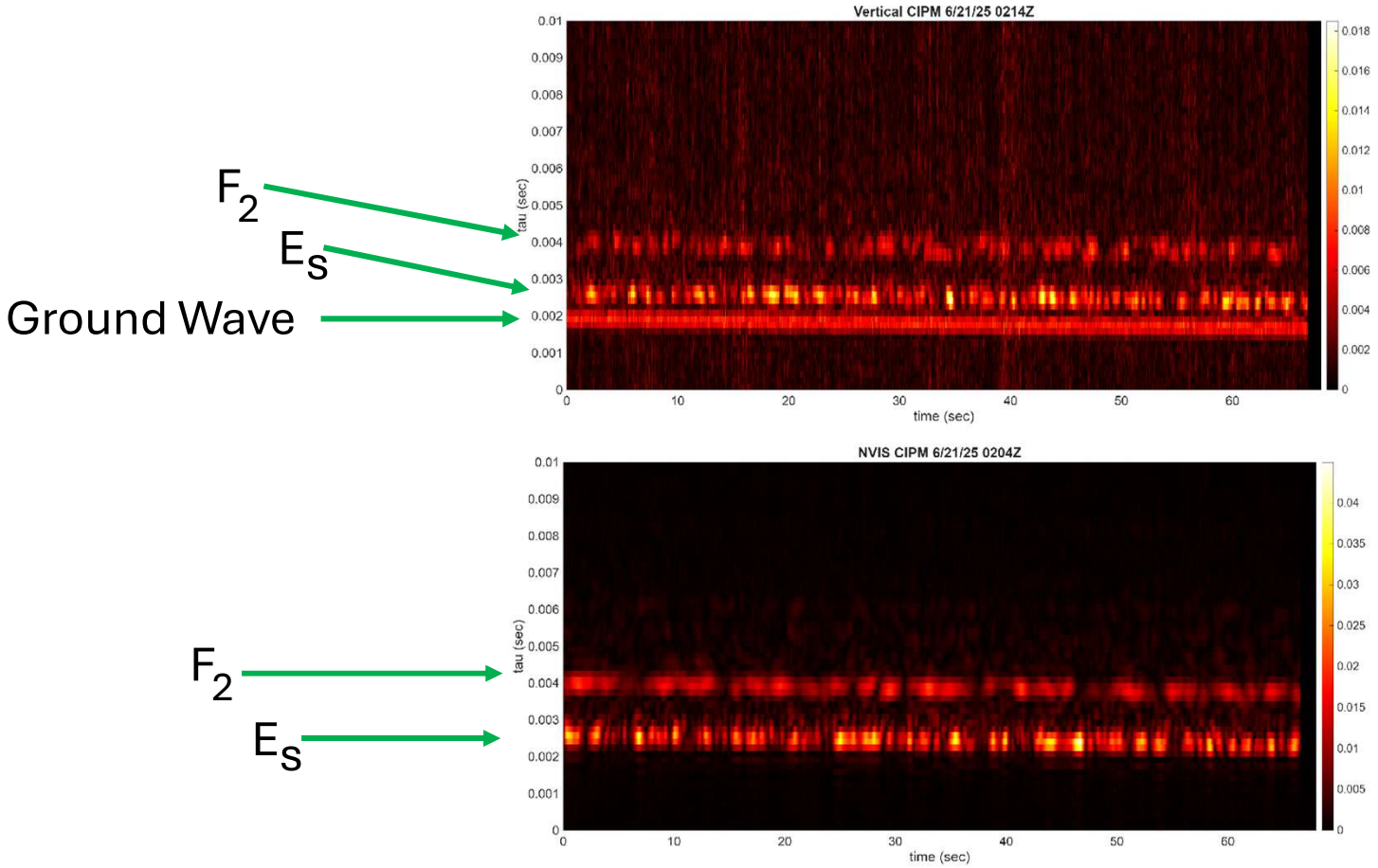
Sigview .wav Player



OTA Tests Conducted with a Nearby Kiwi SDR 6/21/25

- Conducted between my station and a Kiwi SDR located in Broomfield, Colorado 20 km NW of my location
- Asked the Kiwi owner (Scott, N0LS) to boresight the active loop antenna at my station
- Performed first test at 0204z with the NVIS dipole antenna and noticed two strong reflections with one reflection not seen in earlier experiments - Sporadic E???
- I then switched to the vertical antenna and noticed a ground wave component and two skywave reflections—I now had a reference!!!

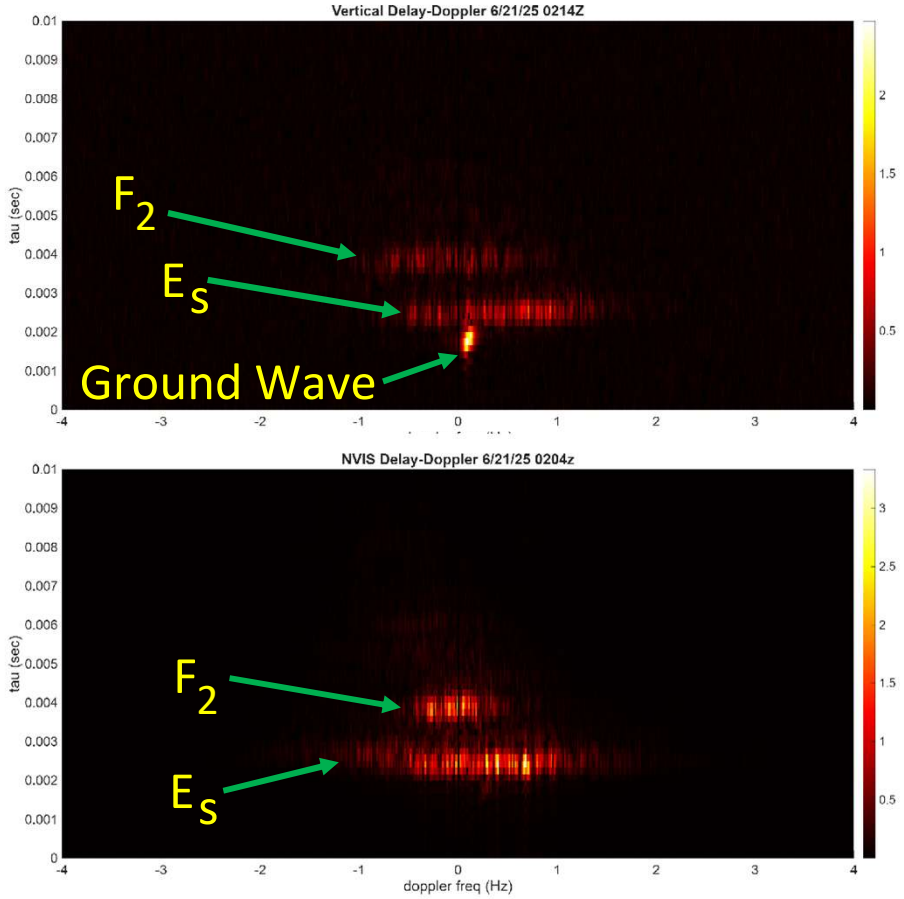
Channel Impulse Responses Vert and NVIS - 5.346.5 MHz



Vertical Antenna

Half Wave Dipole
NVIS

Delay-Doppler Vert and NVIS - 5.346.5 MHz



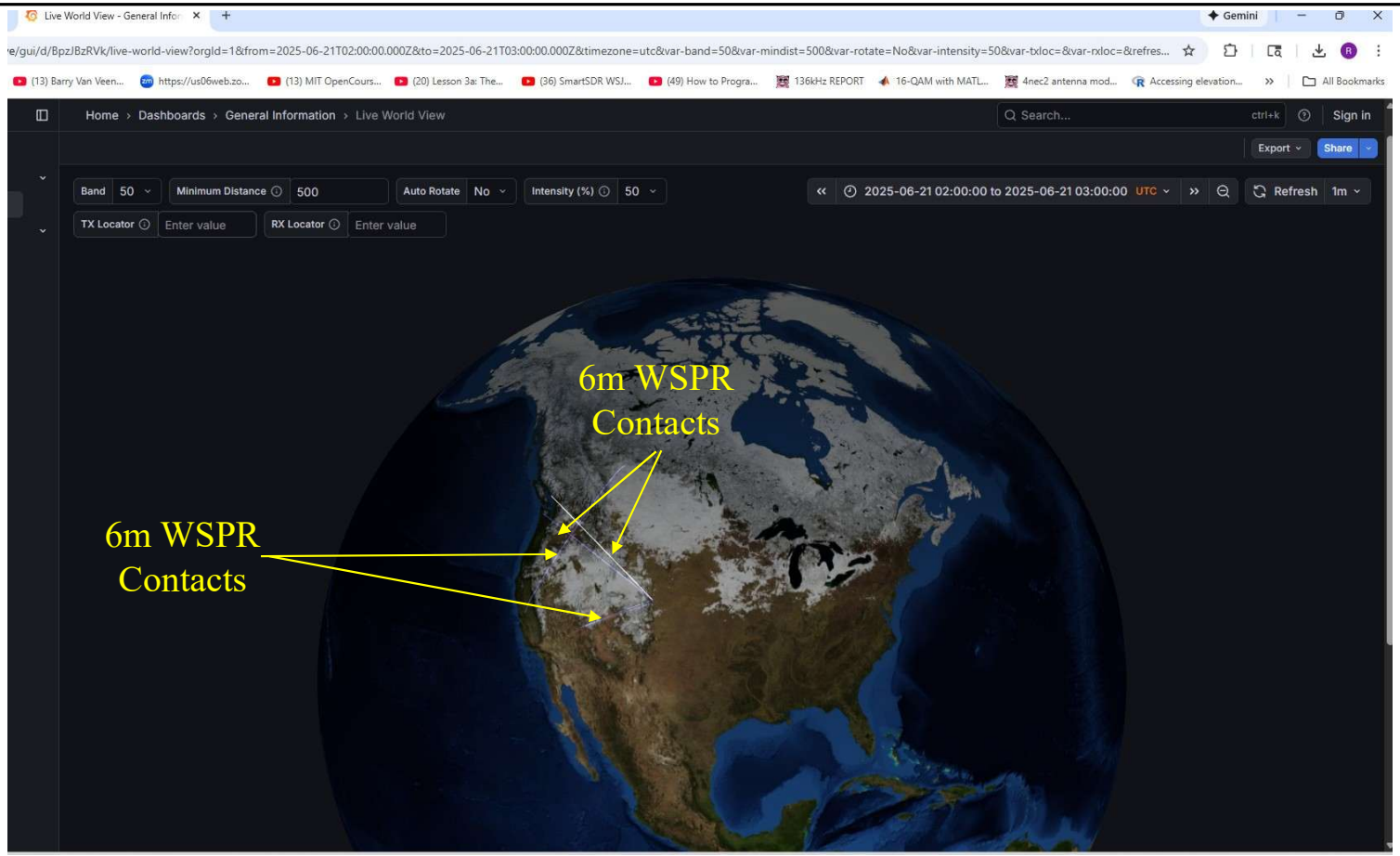
Vertical Antenna

Half Wave Dipole
NVIS

Evidence of Sporadic E?

- Lots of signal traffic on the 6m FT-8 digital Channel 50.313 MHz
- Checked Lowell Giro Web Page and searched for Es critical frequencies
- Idaho National Labs sounder data indicated critical Es frequencies > 6 MHz, which would support 50 MHz Propagation
- Went to the Weak-Signal Propagation Reporters Network (WSPR)
- Looked at 6m WSPR data (50.29 MHz) on WSPR database

WSPR Live Web Interface-Es Propagation was Active on 6m!



Conclusions

- Meaningful time/frequency channel sounder measurements can be made with amateur radio equipment and a remote SDR
- Was able use a groundwave component to establish a timing reference to verify sporadic E reflections
- Performed a test transmission to 4 Kiwi SDRs-simultaneously (See Appendix)
- Useful tool for the Ham science community for ionospheric measurements-solar events, intercomparisons with other measurement methods
- **Would the MLS sequence be a good candidate for incorporation into the WWV special test propagation waveform?**
- Thanks to Scott Hudson (N0LS) for his Kiwi SDR support, and Ted Albert, AB8FJ, for encouraging me to submit to HamSCI

Acknowledgments

The HamSCI Community is led by The University of Scranton Department of Physics and Engineering W3USR, in collaboration with Case Western Reserve University W8EDU, the University of Alabama, the New Jersey Institute of Technology Center for Solar Terrestrial Physics K2MFF, the MIT Haystack Observatory, TAPR, additional collaborating universities and institutions, and volunteer members of the amateur radio and citizen science communities.

We are grateful for the financial support of the United States National Science Foundation, NASA, and Amateur Radio Digital Communications (ARDC).

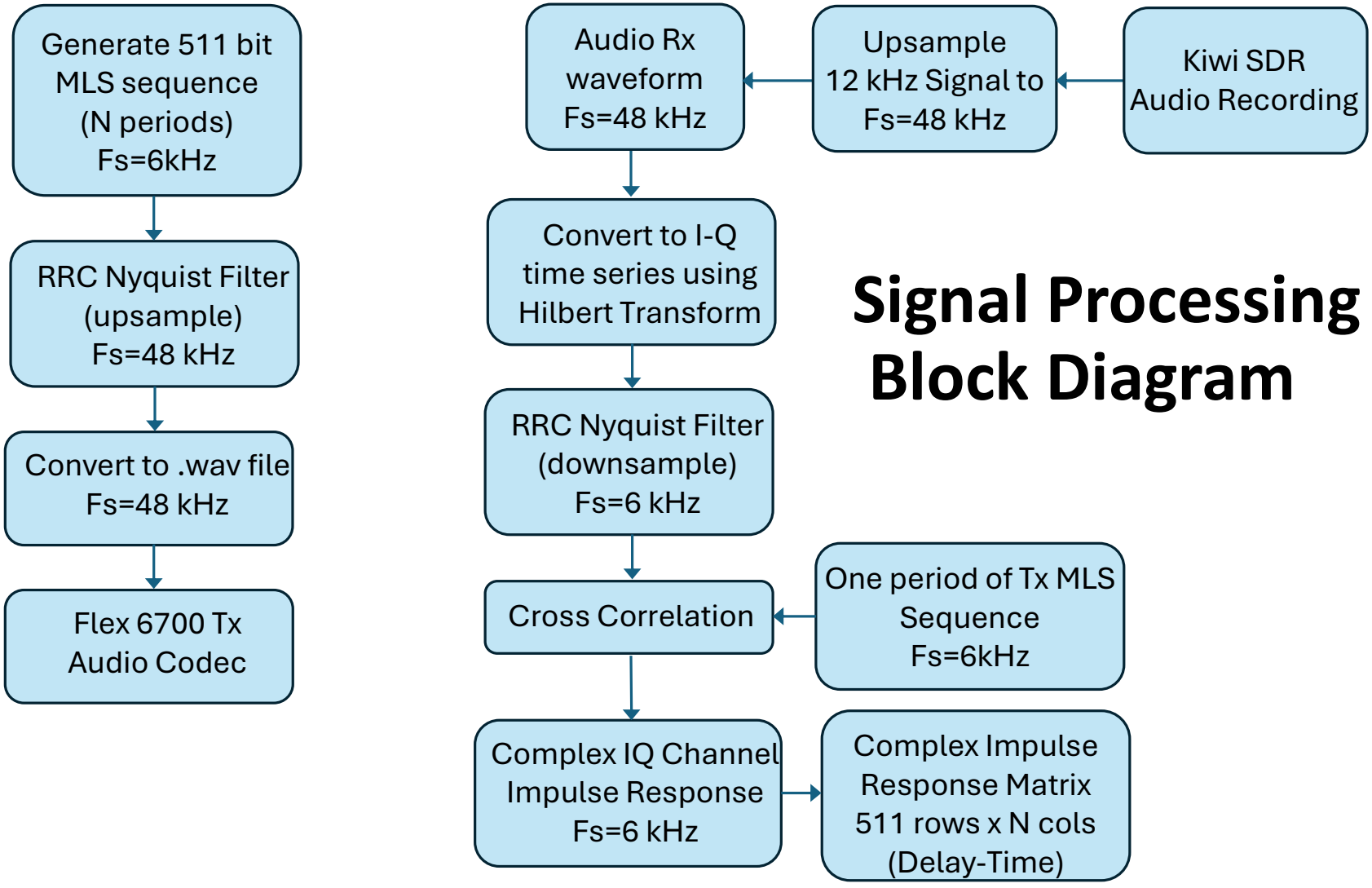
HamSCI silhouette photo by Ann Marie Rogalcheck-Frissell KC2KRQ.

Thank you!

Appendix

1) Signal processing block diagram
2) Stem Plot Movie of a Matlab Channel Object 3 paths 0.5 ms separation, Doppler=0.1Hz, 0.2Hz, 0.4 Hz
3) Reduced resolution of seen using Limsim due to SSB filter-same parameters as in 2)
4) Movies of Sporadic-E Measurements on 6/21/2025
5) Kiwi Audio Output NVIS dipole 6/21/2025 0204Z
6) Kiwi Audio Output vertical antenna 6/21/2025 0214Z
7) Correlation outputs for both NVIS dipole and vertical antenna tests 6/21/2025 (0214Z &0204Z)
8) Map of 4-simultaneous sounding measurements carried out on 1-17-26 on 5.330.5 MHz
9) Movies obtained at 4 receiving locations from 5).
10) IONOS baseband Watterson channel simulation results obtained for a 4-path scenario.

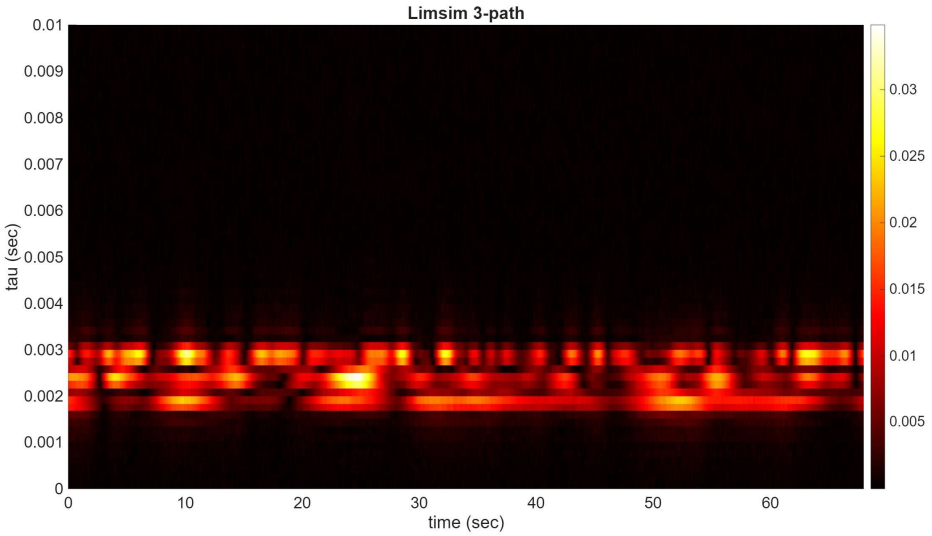
Signal Processing Block Diagram



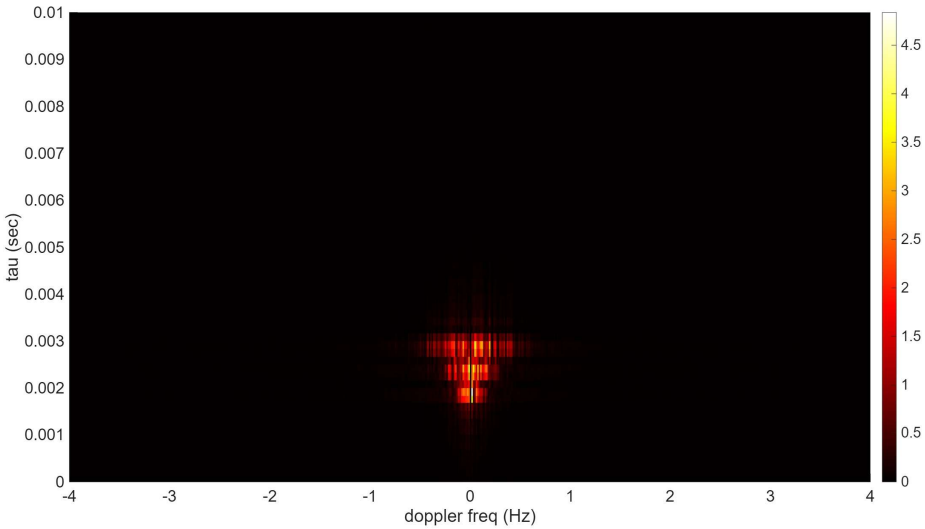
Stem Plot Movie of a Matlab 3-Path Simulation

- URL for Stem Plot Movie using a 3-Path Matlab Watterson channel object with 0.5 ms separation with Doppler = 0.1 Hz, 0.2 Hz, 0.3 Hz:
- https://www.youtube.com/watch?v=1wzN-qS-B3Q&list=PLk5MP7ov8lMGFbA1n8kgXc33SzhQRNa1N&index=1

Impact of 3 kHz Front End Filter on a 3-path Simulation
Linsim Channel Simulator 0.5 ms sep, Doppler=0.1HZ,0.2Hz,0.4Hz
Same Simulator Parameters as Channel Object-Reduces Resolution



Delay-Time

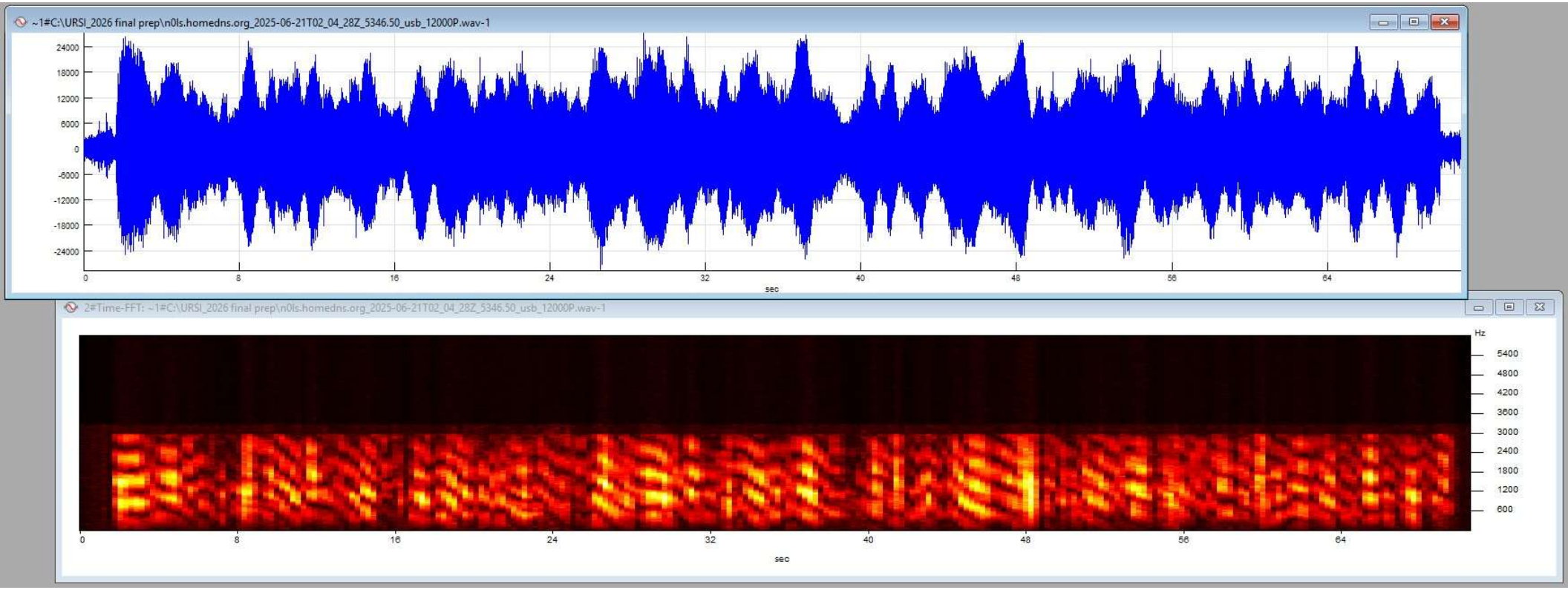


Delay-Doppler

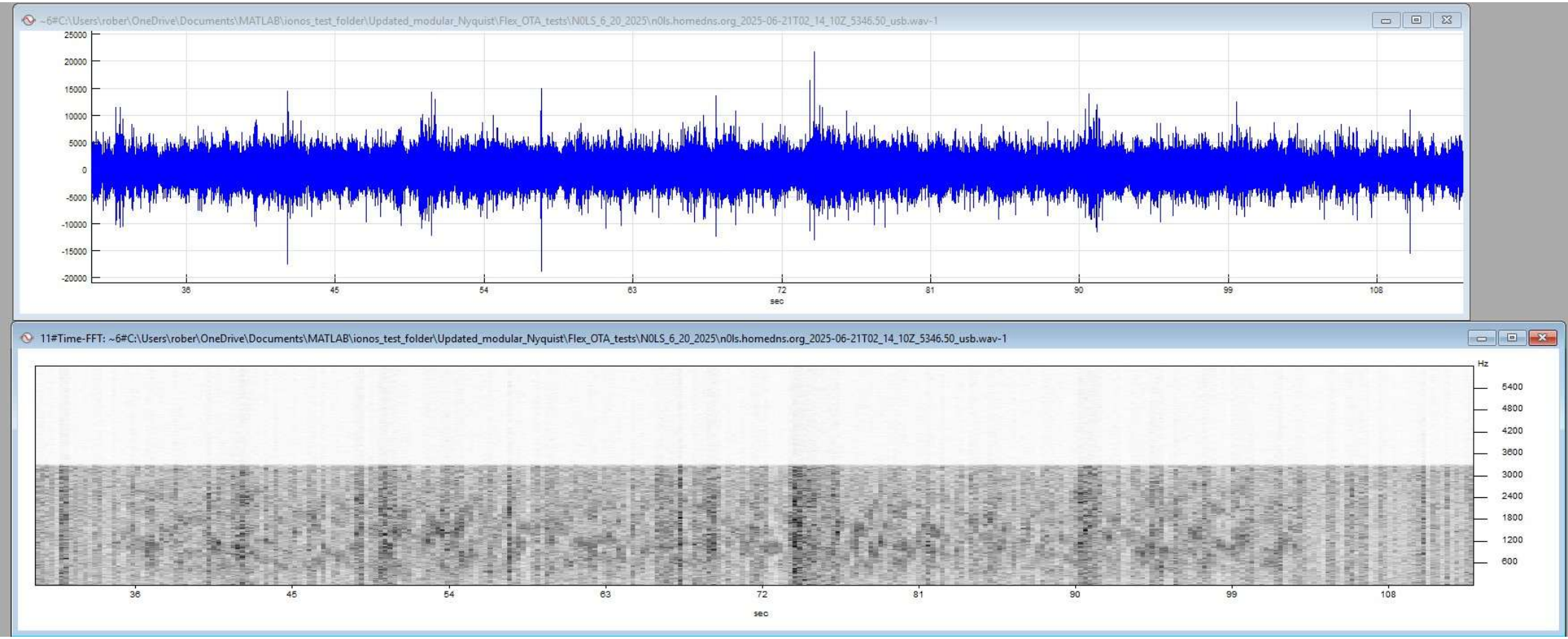
Channel Sounder Movie Links from Sporadic-E Event 6/21/2025

- Vertical Antenna URL: https://youtu.be/OPEymUC3Rc8
- NVIS Dipole Antenna URL: https://youtu.be/XGVT0wZgKJU

Kiwi Audio: June 21, 2025 0204z Test - NVIS Dipole HPOL

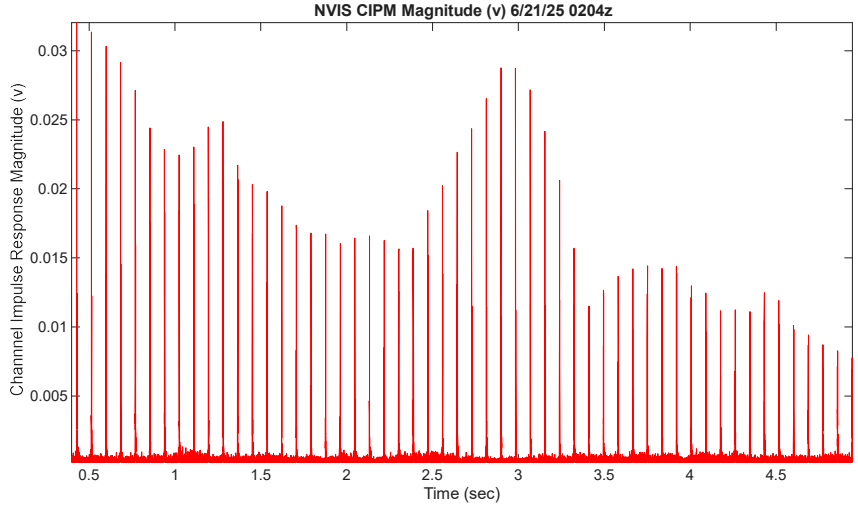


Kiwi Audio: June 21, 2025 0214z Test – Vertical Antenna

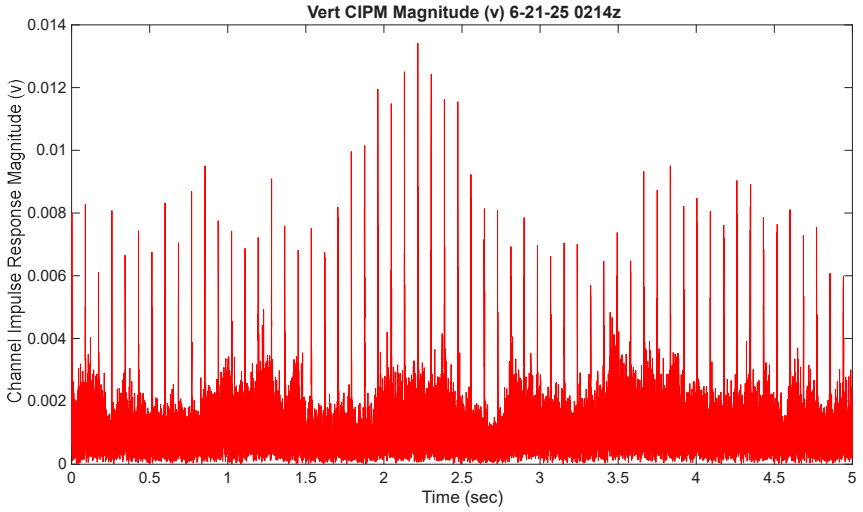


Correlation Brings Signals out of the Noise…

NVIS Dipole Transmission
6-21-25 0214z
Correlation Output

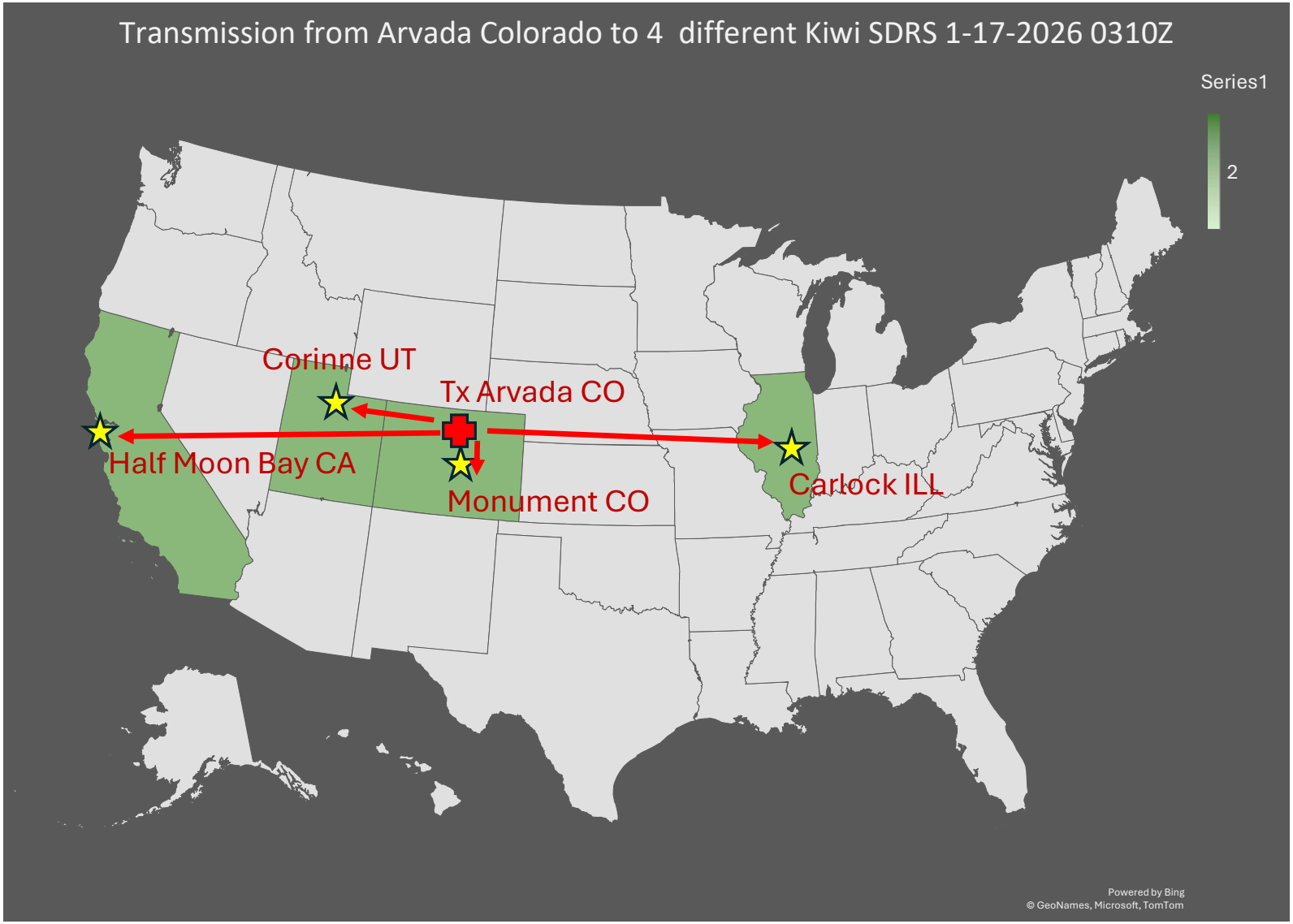


Vertical Ant Transmission
6-21-25 0214z
Correlation Output



Simultaneous Recordings at Multiple Kiwi SDR Locations

- On 1/17/2026 0309z, Recordings were initiated with Kiwi SDRs at 4 different locations: Monument Colorado, Corinne Utah, Half-Moon Bay California, Carlock Illinois from the QTH of WB0VGD
- Initiated a Transmission of the MLS waveform: 800 repetitions, duration 68 sec
- Post processed the received Kiwi audio files from 4 widely separated Kiwis for the same transmission
- So let's look at the layout & results…


Transmission from Arvada Colorado to 4 different Kiwi SDRS 1-17-2026 0310Z
Series1
2
Corinne UT
Tx Arvada CO
Half Moon Bay CA
Monument CO
Carlock ILL
Powered by Bing
© GeoNames, Microsoft, TomTom

Movies of CIRM from WB0VGD to Remote Kiwi SDRs

- Arvada to Monument, CO: https://youtu.be/c2G-ZDtL3rw
- Arvada to Corinne, UT: https://youtu.be/QyvgaDyTe-g
- Arvada to Carlock, ILL: https://youtu.be/dx6sd16fxes
- Arvada to Half Moon Bay, CA: https://youtu.be/-CrifPn5m-k

4-Path Simulation Using IONOS Channel Simulator

- MPM setting, SNR=15 dB, 4 paths, 1 ms separation, 1 Hz Doppler spread on all paths: https://www.youtube.com/watch?v=waQfHApuin8