TURN ISLAND SYSTEMS

- Optimizing wide-band SDR receiver performance
- Development of a multi-channel research transmitter

Introduction

- Paul Elliott / WB6CXC
- VP, TAPR Board of Directors
- Turn Island Systems (AKA “TIS”)
- Retired engineer, RF / digital / telecom / fiber optics
- Ham since 1975 (WN6CXC, then Advanced, Extra)
- Not much of an operator, I like designing stuff
- I live in Friday Harbor, WA, closer to Vancouver Island than the mainland

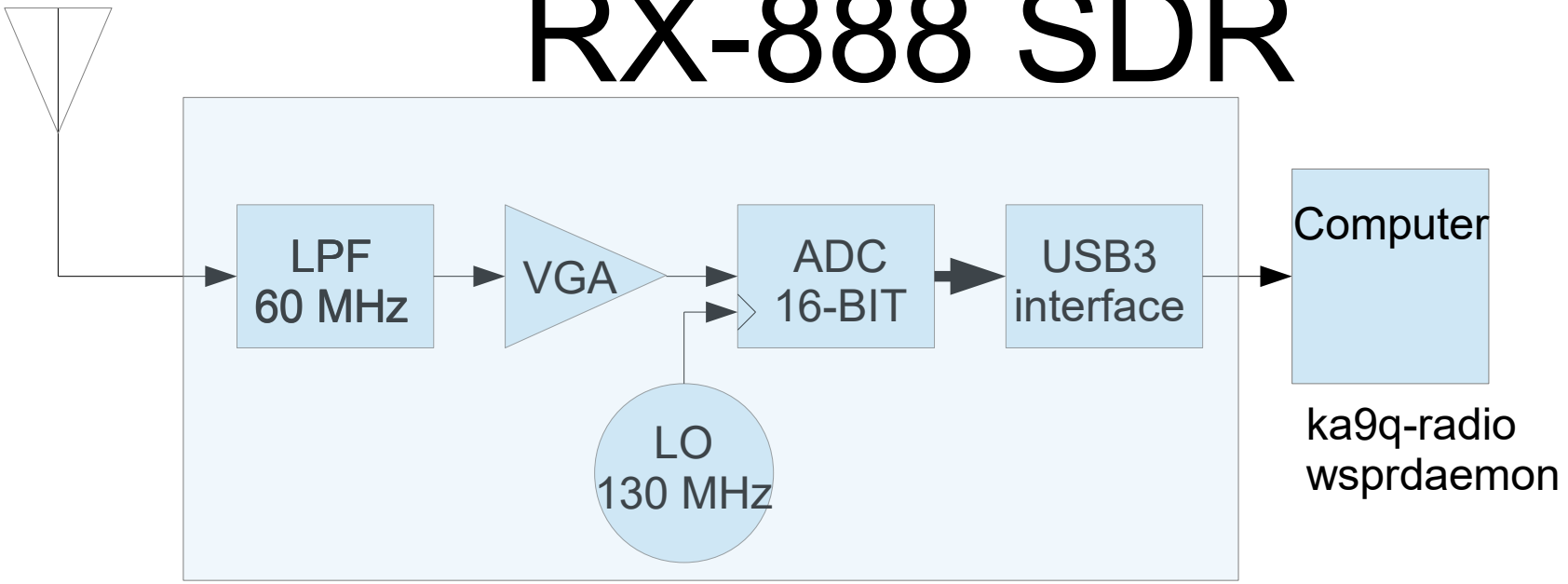
SDR Receiver Performance

- Full MF / HF(+) reception requires dynamic range optimization for best performance
- Careful filtering is needed to avoid aliased sampling artifacts (Nyquist)
- Frequency accuracy and stability of “stock” receiver (or transmitter) may be inadequate for some modes and tasks.

RX-888 SDR

- The RX-888 is the current choice for capture and decoding of the entire 1-30/60 MHz range
- The principles discussed here also apply to many other SDR receivers

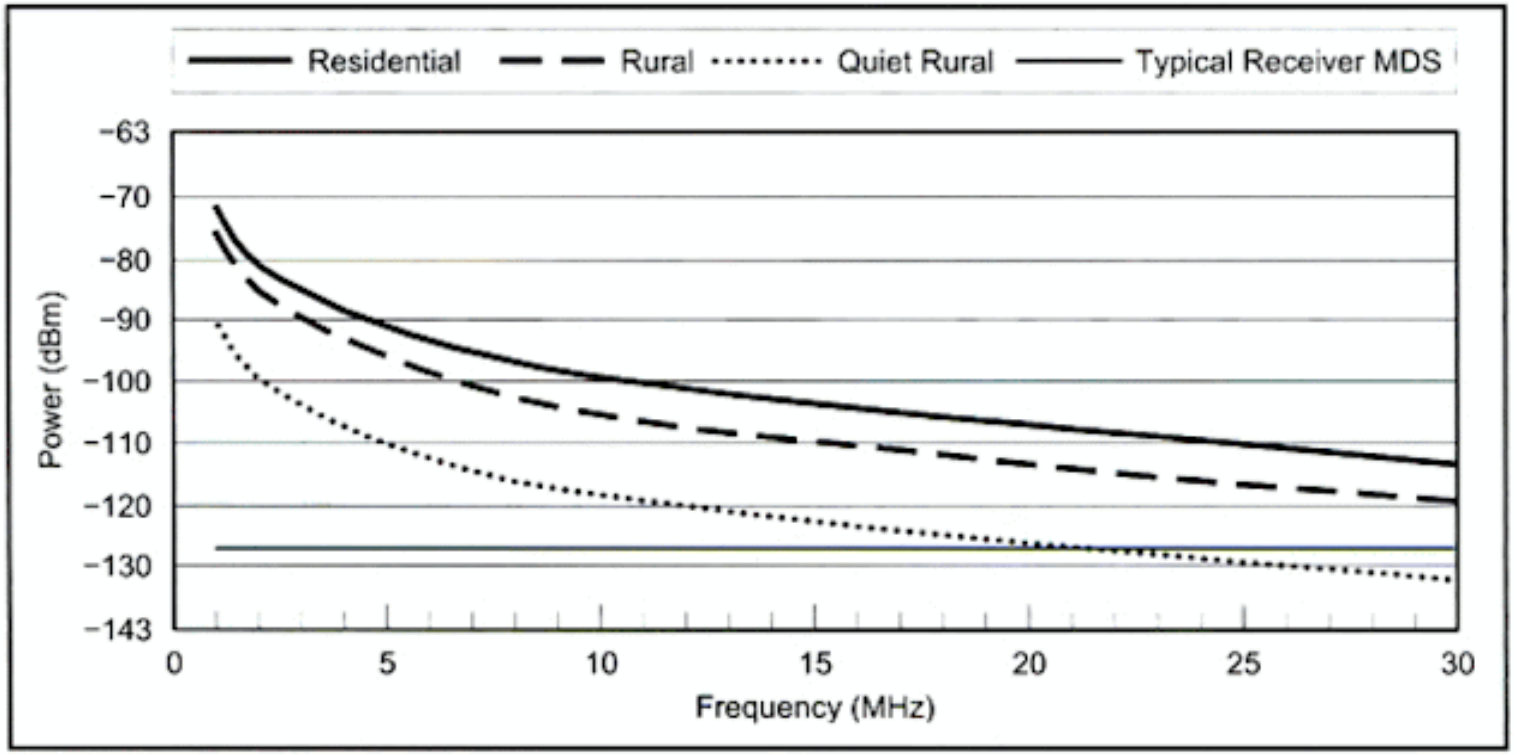
RX-888 SDR



130 million samples per second x 16 bits = **2.08 G bits/s**

- The sample rate is often dropped to half that to reduce thermal issues and to work with slower computers
- LPF is marginal, and obviously inadequate for half-rate sampling (there will be aliasing), input stage has a fairly high noise floor
- 16 bit samples: 2^{16} = 96 dB dynamic range (actually a bit more)

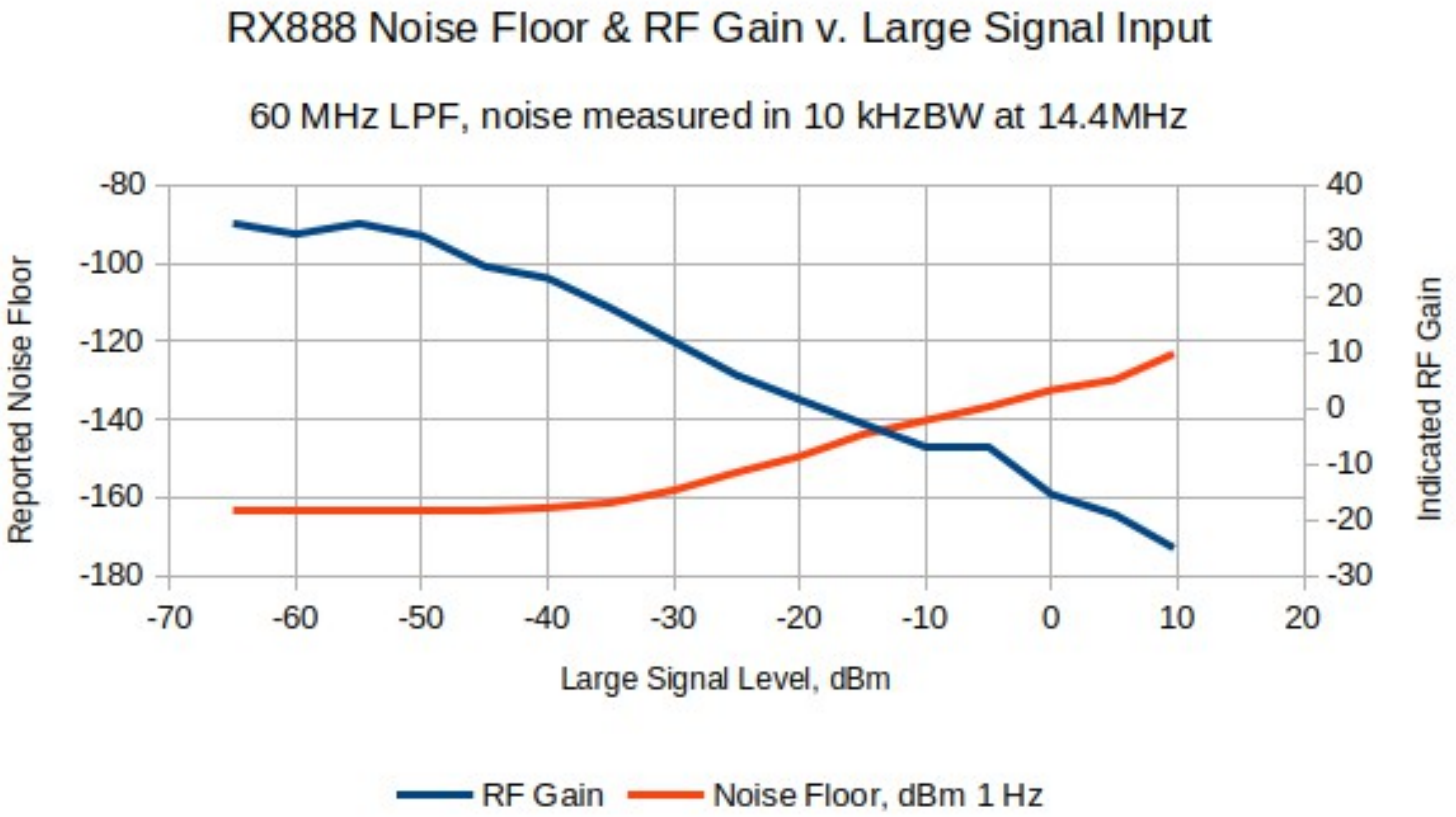
ITU Noise Floor



Typical noise levels versus frequency for various environments.
(Man-made noise in a 500-Hz bandwidth, from Rec. ITU-R P.372.7, *Radio Noise*)

These days, with the prevalence of digital devices, switching power supplies, solar-panel regulators, etc, we should probably raise that “residential” noise floor several dB.

Noise Floor vs Signal Strength



- Noise floor affected by gain-control attenuator and variable-gain amplifier

Chart: Glenn Elmore, N6GN

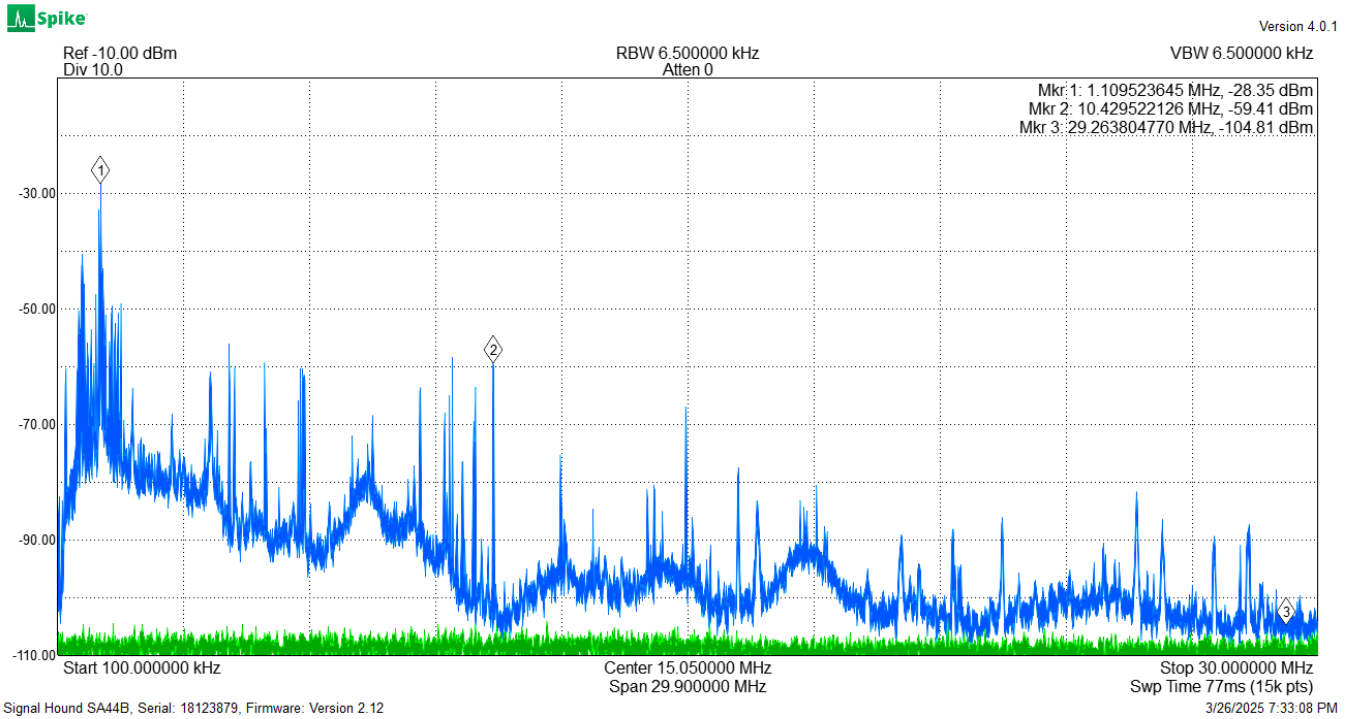
RX-888
Measured Noise Floor and Dynamic Range
(measured at 17 MHz, 30 MHz is within 1dB)

• Gain setting (dB)	• Noise floor (dBm/Hz)	• Noise floor (dBm in 500Hz)	• Apparent Clipping level (dBm)	• Dynamic Range (dB, 500 Hz)
-25	-106	-79	>+13	> 66
+0	-140	-113	+3	110
+10	-151	-124	-8	114
+20	-155	-128	-18	110
+25	-157	-130	-23	107
+33	-158	-131	-31	100

- Noise floor is very close to the ITU “quiet rural” level, sensitivity is marginal at the higher frequencies.
- Dynamic range is easily exceeded in many RF environments

Measurements courtesy of Clint Turner, KA7OEI

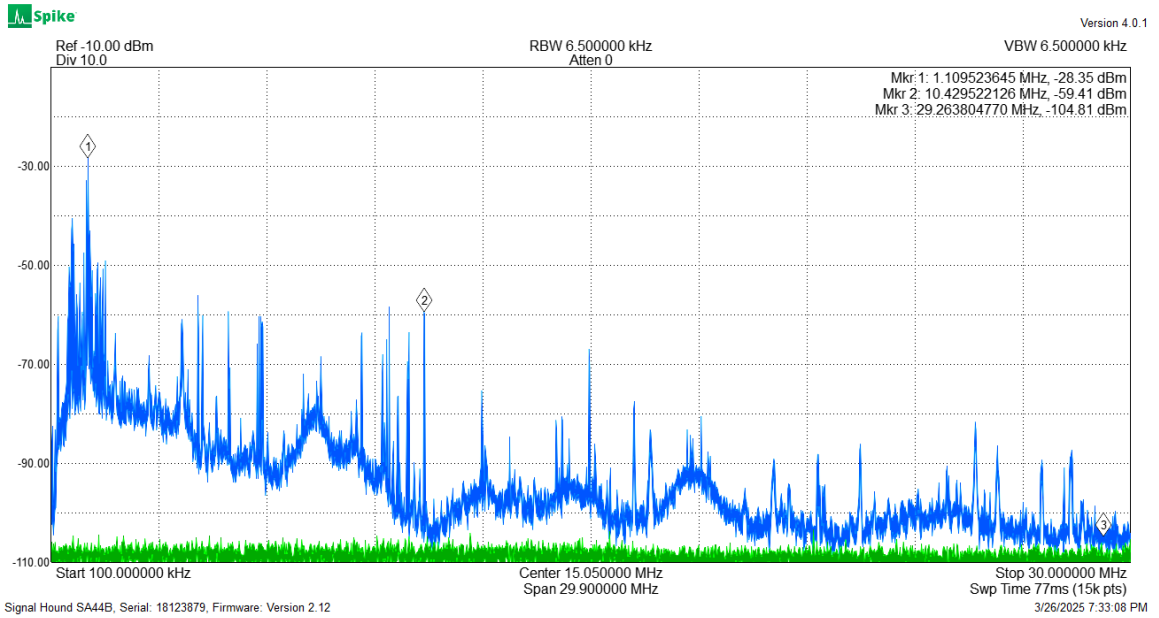
Real-World Signals
(OCF 80m dipole)



Here is a spectrum analyzer plot of what is picked up by one of my Friday Harbor WA home antennas (an off-center fed 80 meter dipole.) The green trace is the analyzer noise floor. The strongest signals here are:

- AM broadcast band – the strongest is a 500W station about 20 miles from my location.
- W W V 10 MHz

I live in a pretty quiet location.



There are huge differences in signal strength between the AM BCB stations and the weak signals at the higher frequencies

In even my quiet location there is about a 77 dB difference, and this measurement is made with my spectrum analyzer, having about a 20dB higher noise floor than the RX-888, so that becomes a 97 dB difference.

For many locations in the USA these AM stations will be much stronger: a 50 kW station at 20 miles distance would be 20 dB stronger: a **117 dB** difference, which is beyond the limits of the 16-bit analog-to-digital converter of the RX-888.

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TIS Filter-Preamp

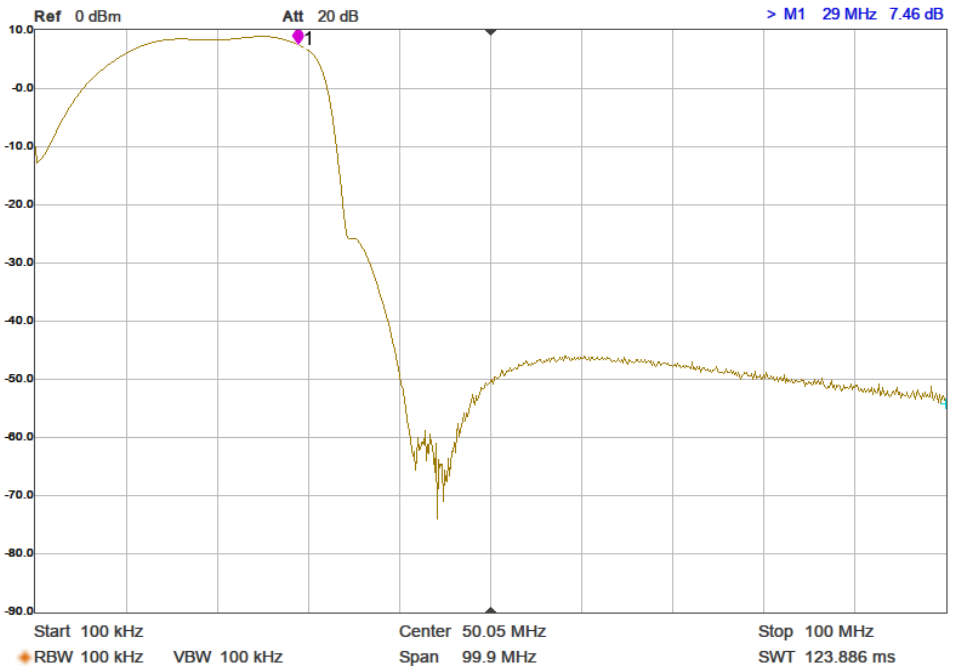
- 30 MHz LPF, shelf HPF,+9dB gain
- Unamplified version also available
- 60 MHz and +20 dB gain versions on the way

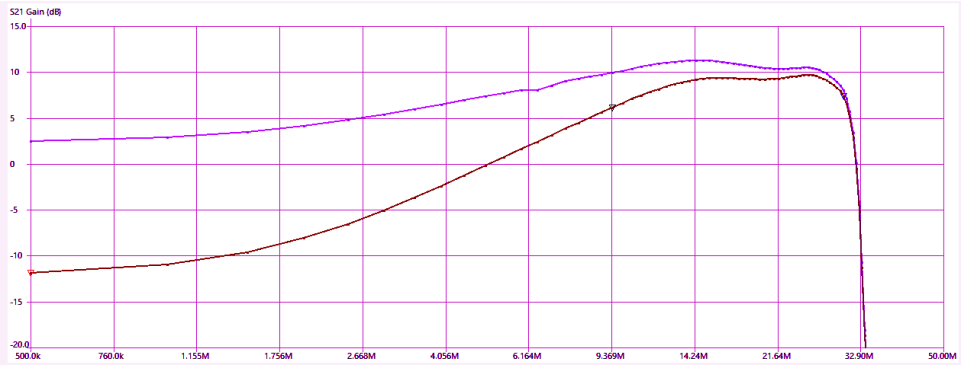
TIS Filter-Preamp Response

Here are two response plots for the Filter-Preamp

The preamp has about 9dB of gain at 28 MHz, then rapidly falls off to provide filtering against 33 MHz sampling aliases.

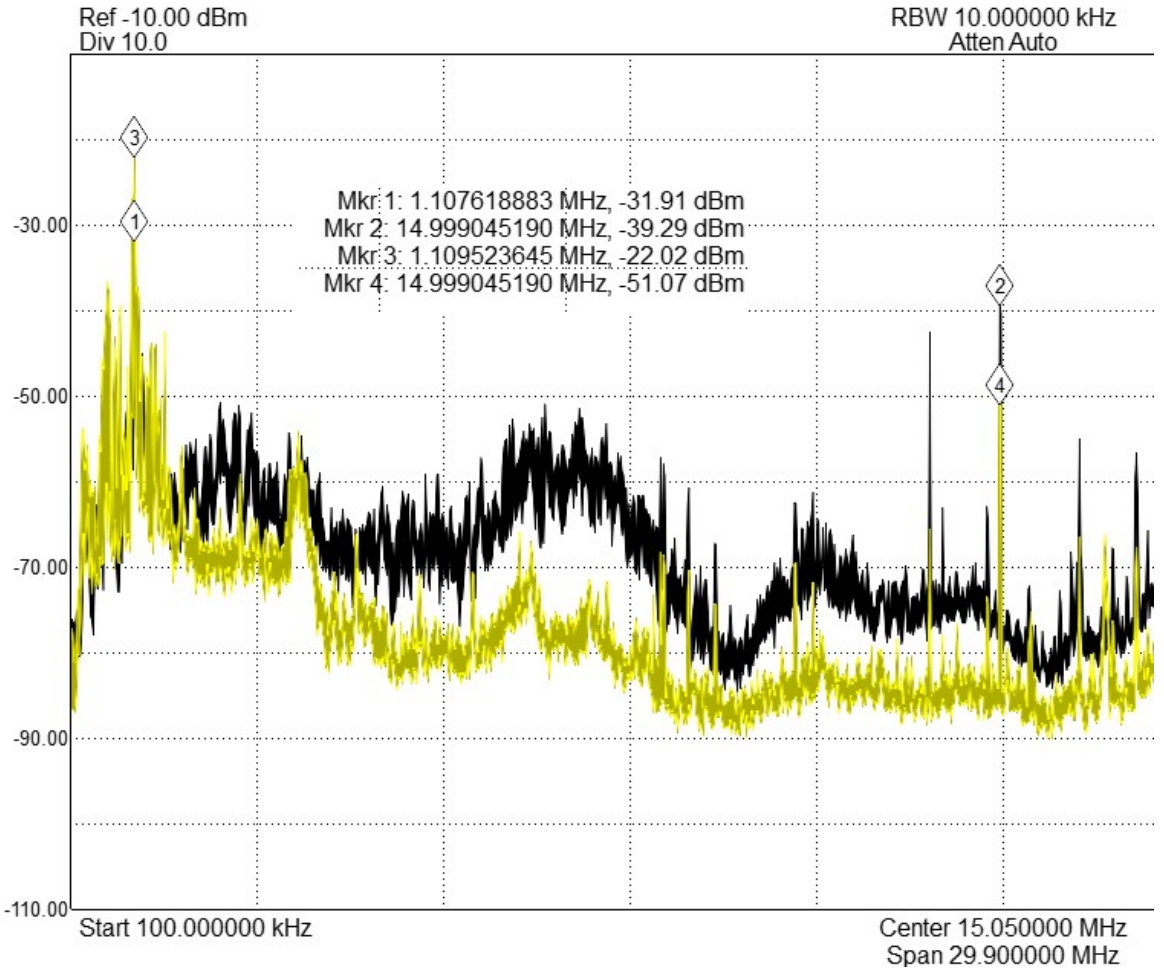
The lower plot better shows the two-section shelf filter characteristics. One section can be jumper-plug bypassed.



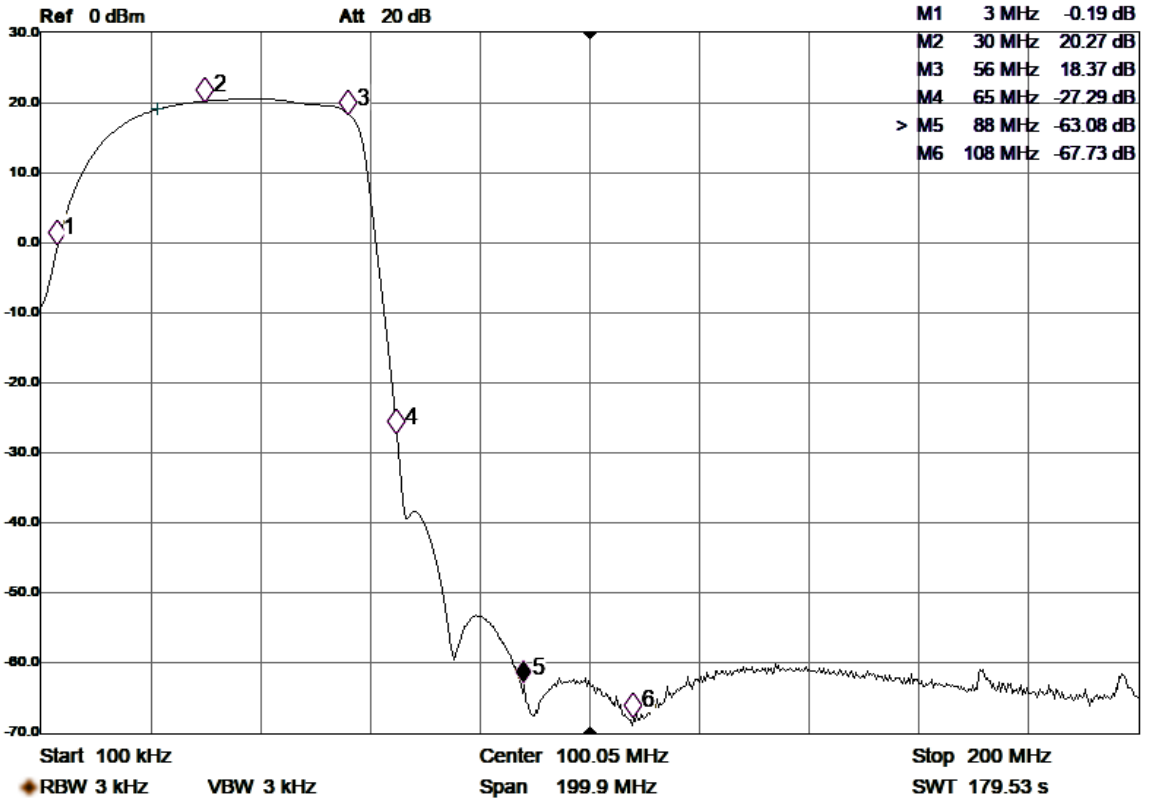


Antenna With TIS Filter-Preamp

- Green: unfiltered
- Black: Filter-Preamp
- AM BCB -10 dB
- 15 MHz +10 dB
- **This gives a +20 dB improvement in dynamic range performance.**



6-Meter Filter-Preamp



- 20 dB gain
- >80 dB FM BCB rejection
- 2-stage shelf filter (jumper-select one stage bypass)

Other Dynamic Range Considerations

- MF Broadcast – Not so much in the USA, but in Europe there are many high-power AM broadcast stations, often very close in frequency to the ham bands
- There is no general solution to this, as the filters that will attenuate the broadcast bands ase essentially impractical
- Specific notch filters may be useful, and of course antenna directivity can help
- Full-range SDR receivers, such as the RX888, are particularly vulnerable to this problem.
- Narrower-range SDRs with switched band filters can be less prone to overload.

More on the Noise Floor

- Noise isn't just from atmospheric and distant sources
- Much of it can come from local sources and is often coupled to the receiver via common-mode methods
- Commmon-mode chokes on the coax feed can help a little, but are far from sufficient to achieve the far-field noise level
- Even double-shielded coax can couple common-mode noise to the receiver
- For receiving, short balanced “probe” antennas with well-designed balanced amplification and twisted-pair cables are proving very effective in reducing local common-mode interference

SDR – Reference Clock Interface

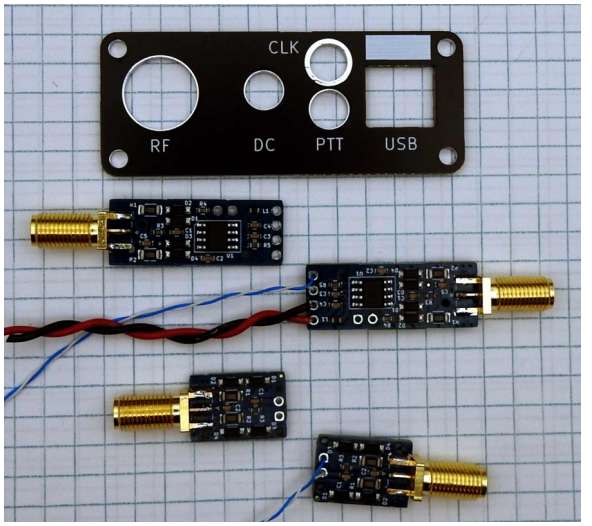
- For precision measurement of ionospheric propagation Doppler-shift, or just for the stability required by FST4W, many receivers and transmitters will require a stable external reference clock.
- TAPR and Turn Island Systems make convenient reference clock adaptors for the RX-888 receiver and for the QRP Labs “QDX” transceiver.

Reference Clock Interface Adaptors

Adaptors for QRP Labs QDX

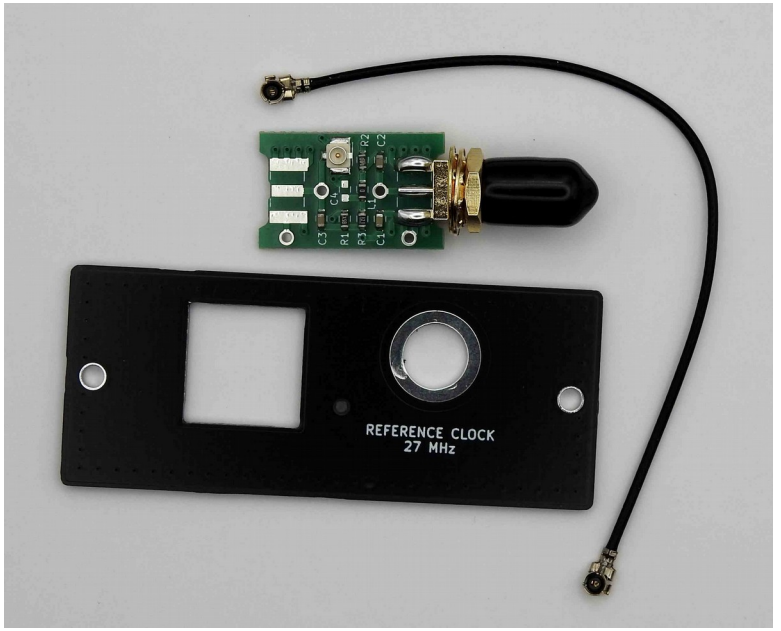
Two versions from TIS:

- 25 MHz direct input
- 5 /10 MHz input with PLL



Adaptor for RX-888 from TAPR:

- 27 MHz direct input

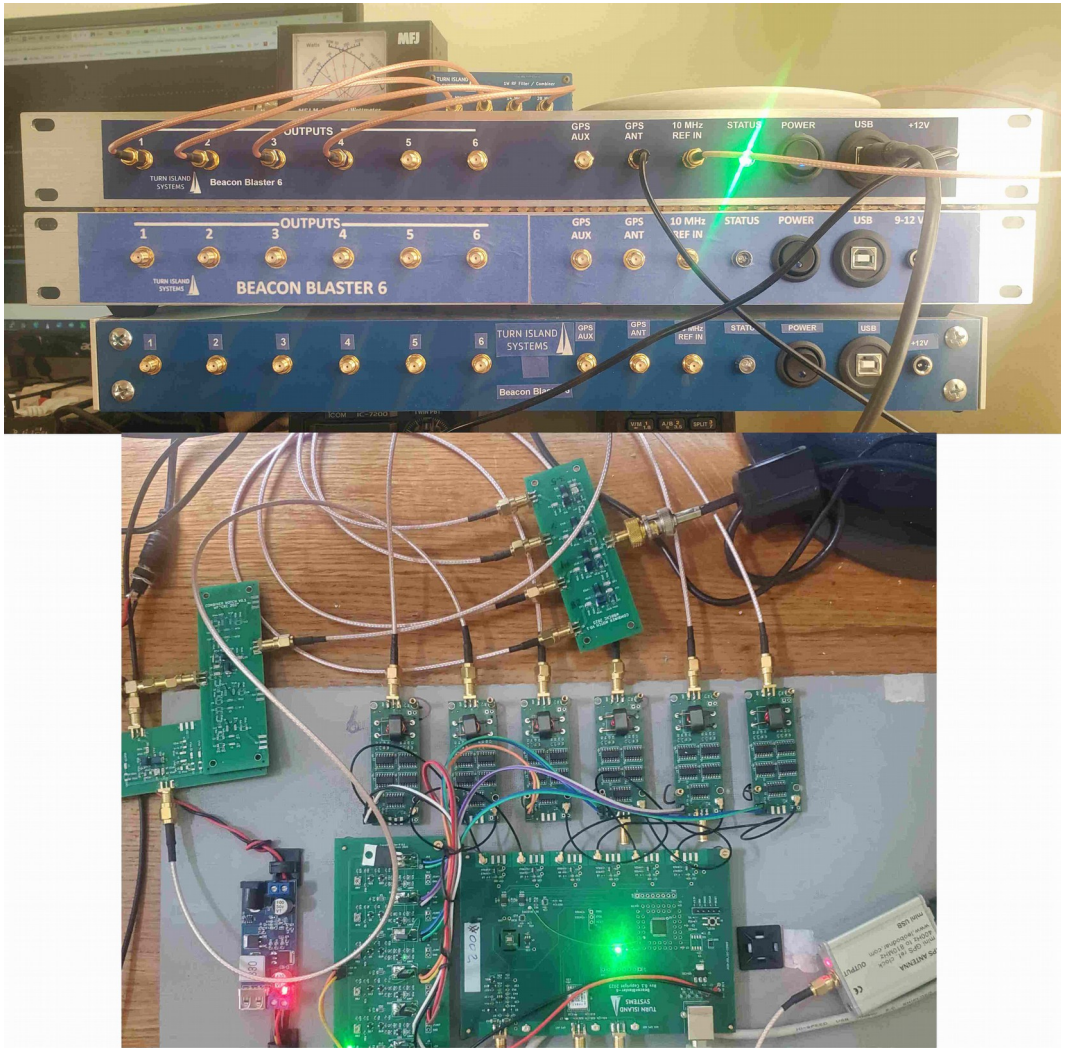


What About the Transmitter?

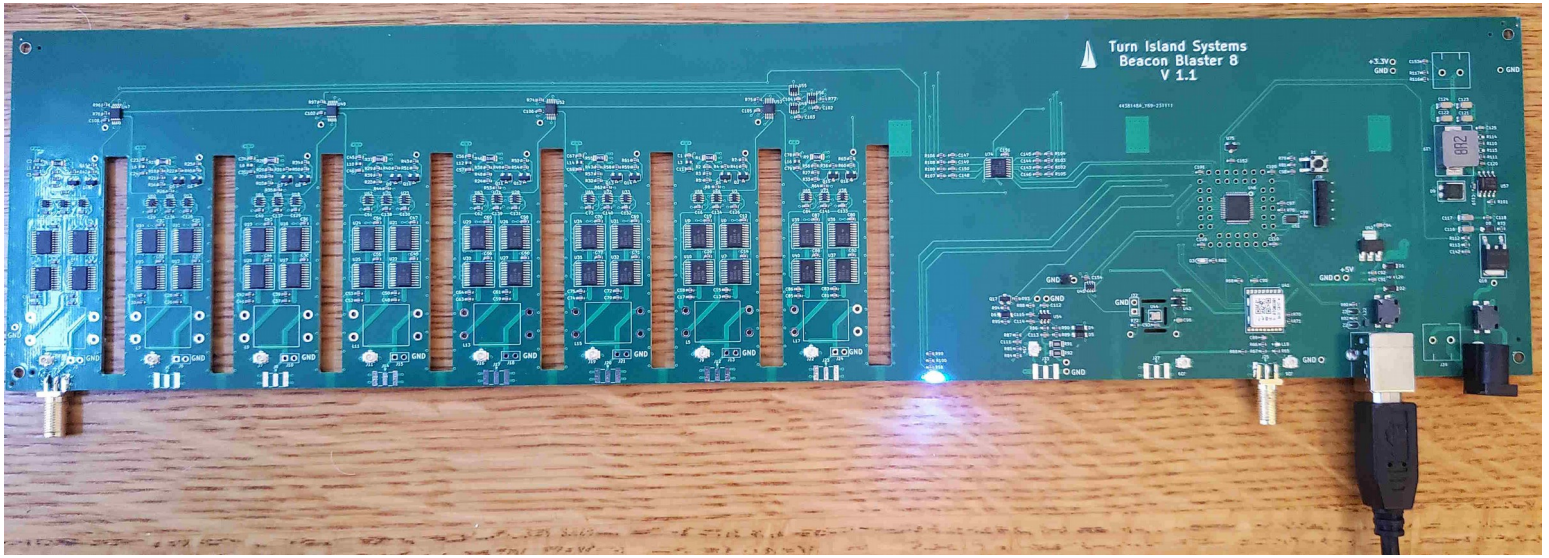
- In studying ionospheric propagation it became obvious that a single band-scanning transmitter was missing important details during rapidly changing conditions
- A solar eclipse was rapidly approaching
- I offered to build a six-band simultaneous-output transmitter – the **BeaconBlaster-6**
- Multiple BB6 units were deployed in time for the eclipse

Evolution of the BeaconBlaster

- Modular design allowing rapid development
- uController design a clone of the Adafruit “ItsyBitsy” (Arduino)
- 10 MHz GPSDO Reference input driving output frequencies and symbol timing / shaping
- Two Si5351 clock generators, using output divider frequency control (-45 dBc spurious)



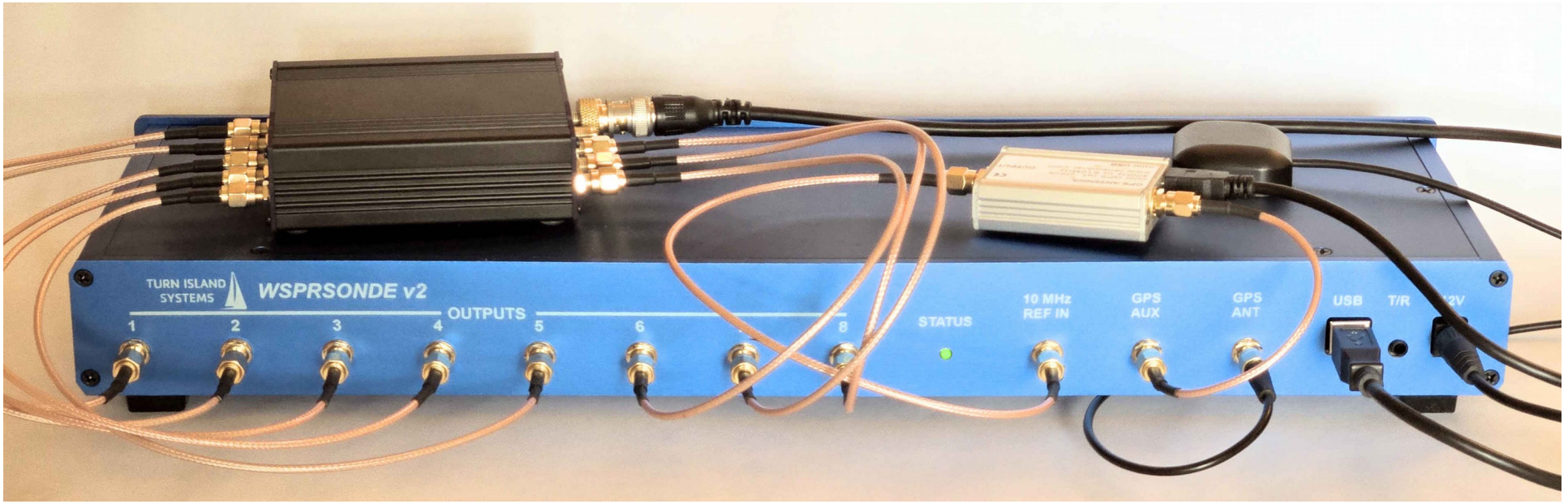
More Channels, Better Spurious, Simpler Physical Design?



- The BeaconBlaster was tedious to build and a bit fragile.
- Six bands good, Eight bands better!
- Better output spurious levels obtained using Si5351 PLL feedback divider frequency control

WSPRSONDE

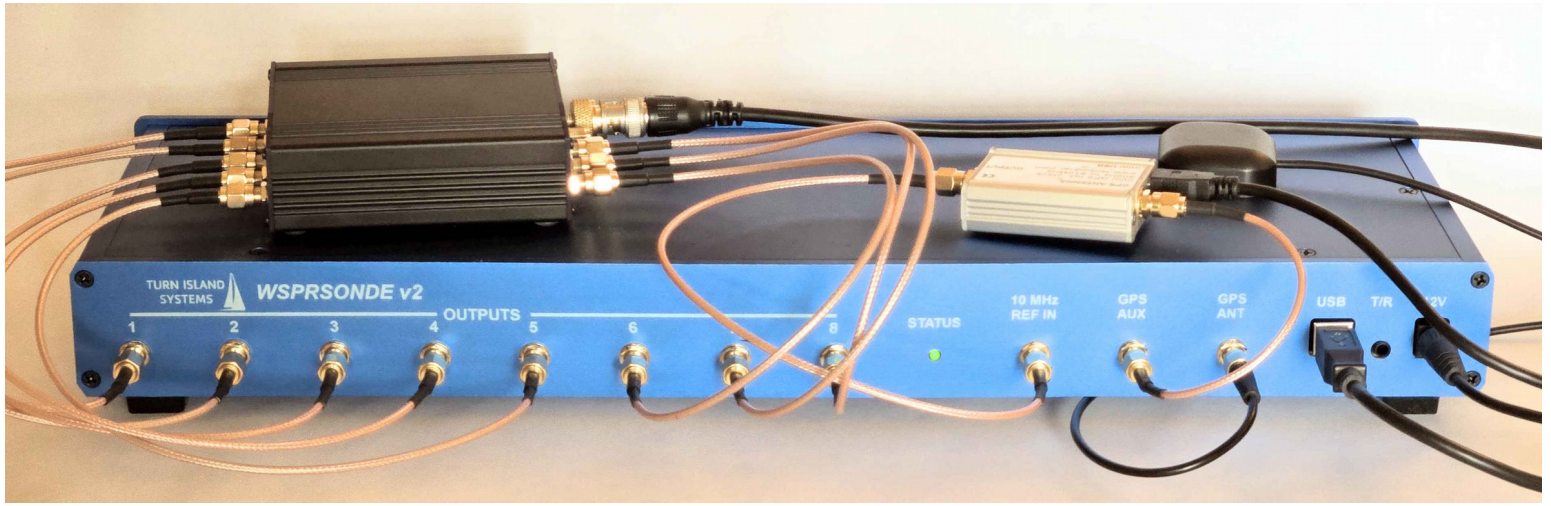
Multiband Research Transmitter



- Accurate / stable WSPR / FST4W / CW signals
- Eight frequency-flexible output channels, 1 to 60 MHz
- Flexible transmit and mode scheduling
- One Watt per-channel output power

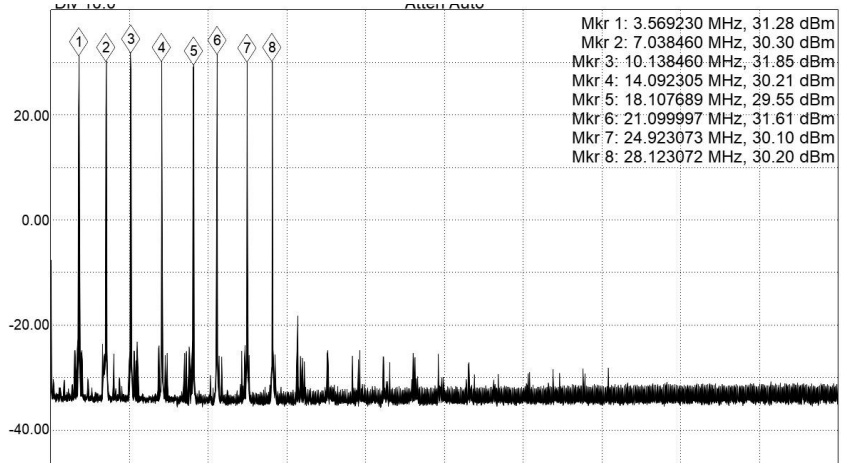
WSPRSONDE-8

Multiband Research Transmitter



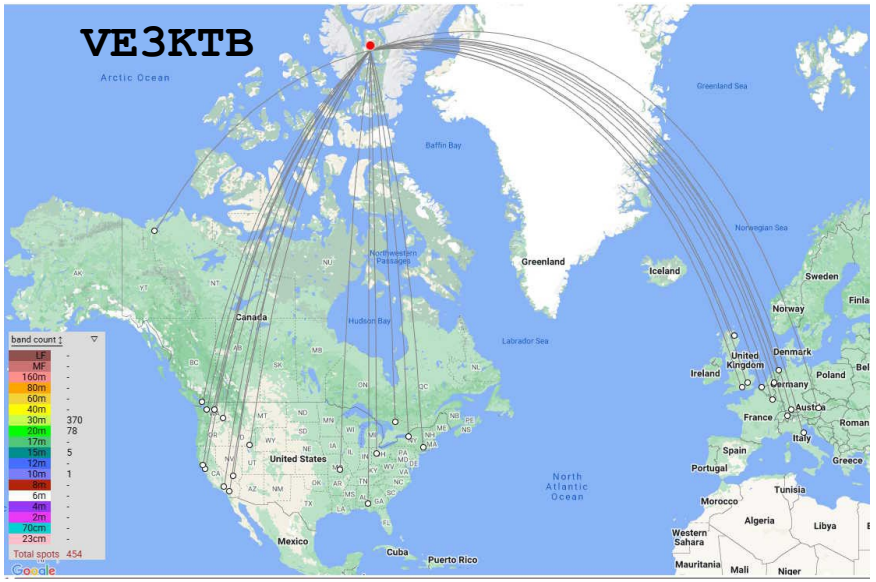
- 8-channels WSPR / FST4W / CW
- Simultaneous 1W squarewave outputs
- Frequency range 1 – 60 MHz continuous
- External 10 MHz reference clock
- Excellent stability and spectral purity
- USB interface, or stand-alone operation
- Used in HamSci and other propagation studies.
- Operating in Antarctica, Ellesmere Island, W W V (Colorado), and elsewhere.

Output through Filter-Combiner



WSPRSONDE-8

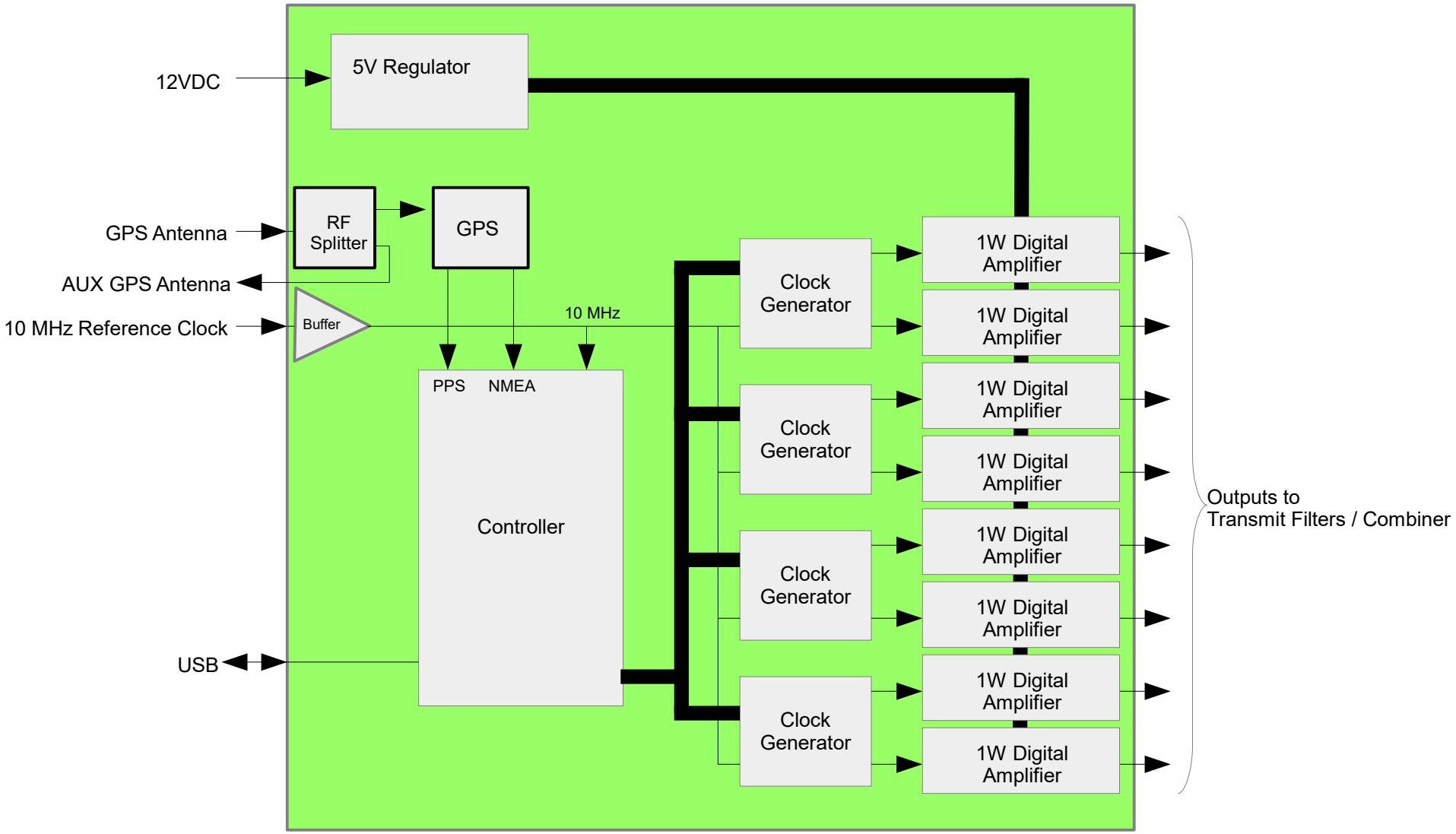
Ellsemere Island, Antarctica, W W V



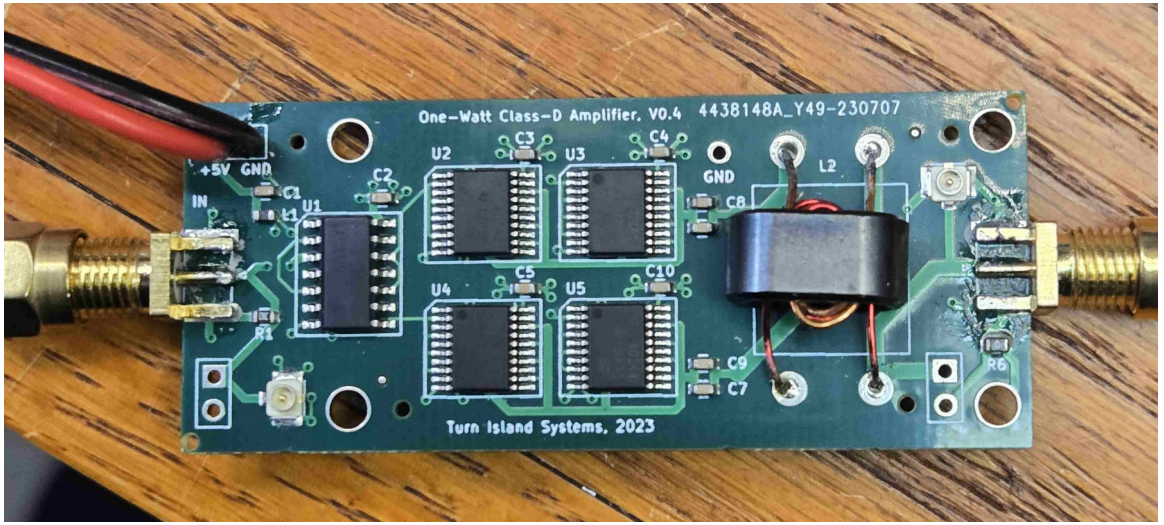
- 1 Watt
- Simultaneous Multiband
- WSPR
- FST4W-120

WSPRSONDE-8

Multiband Research Transmitter

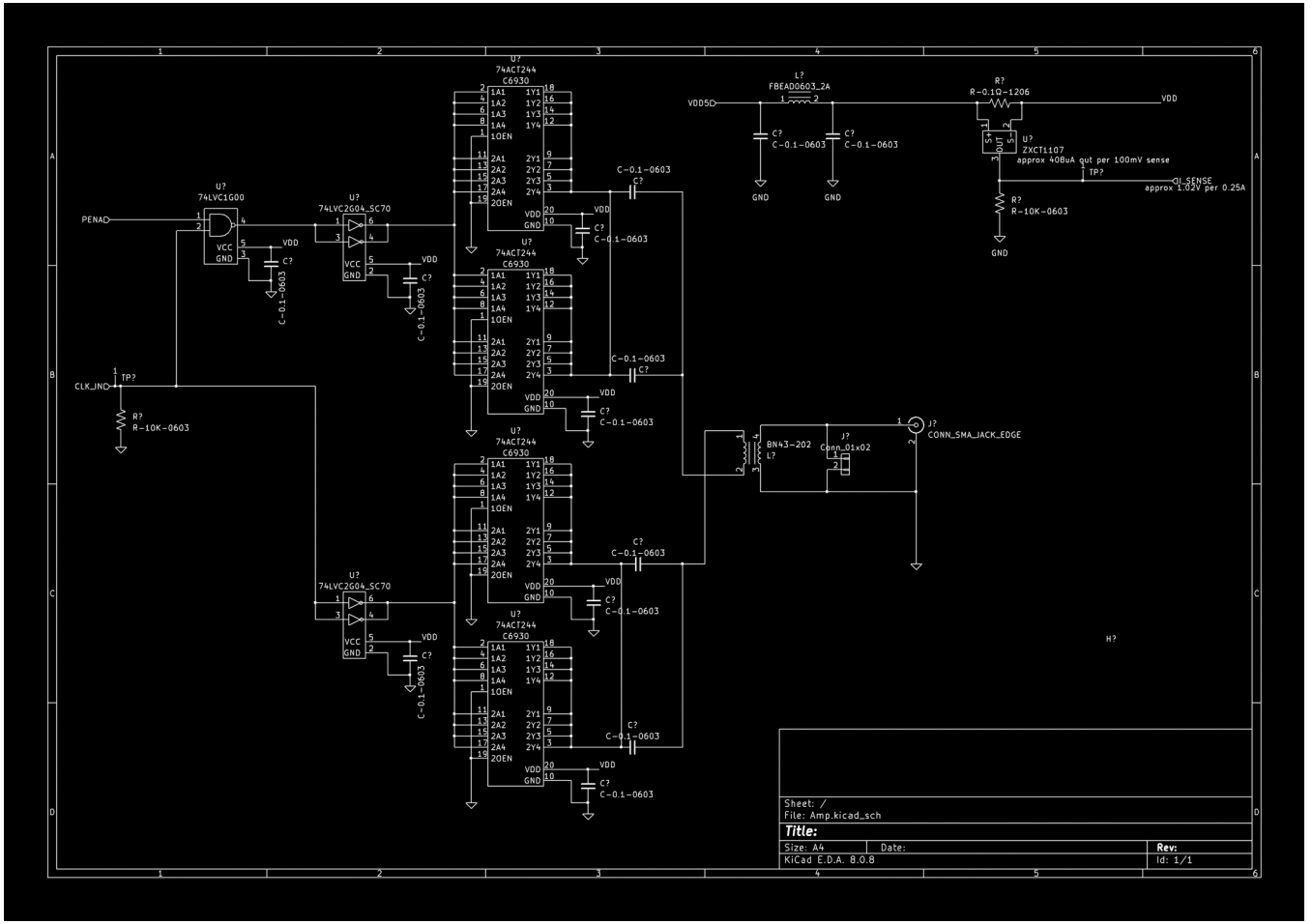


1-Watt Amplifier
(prototype)



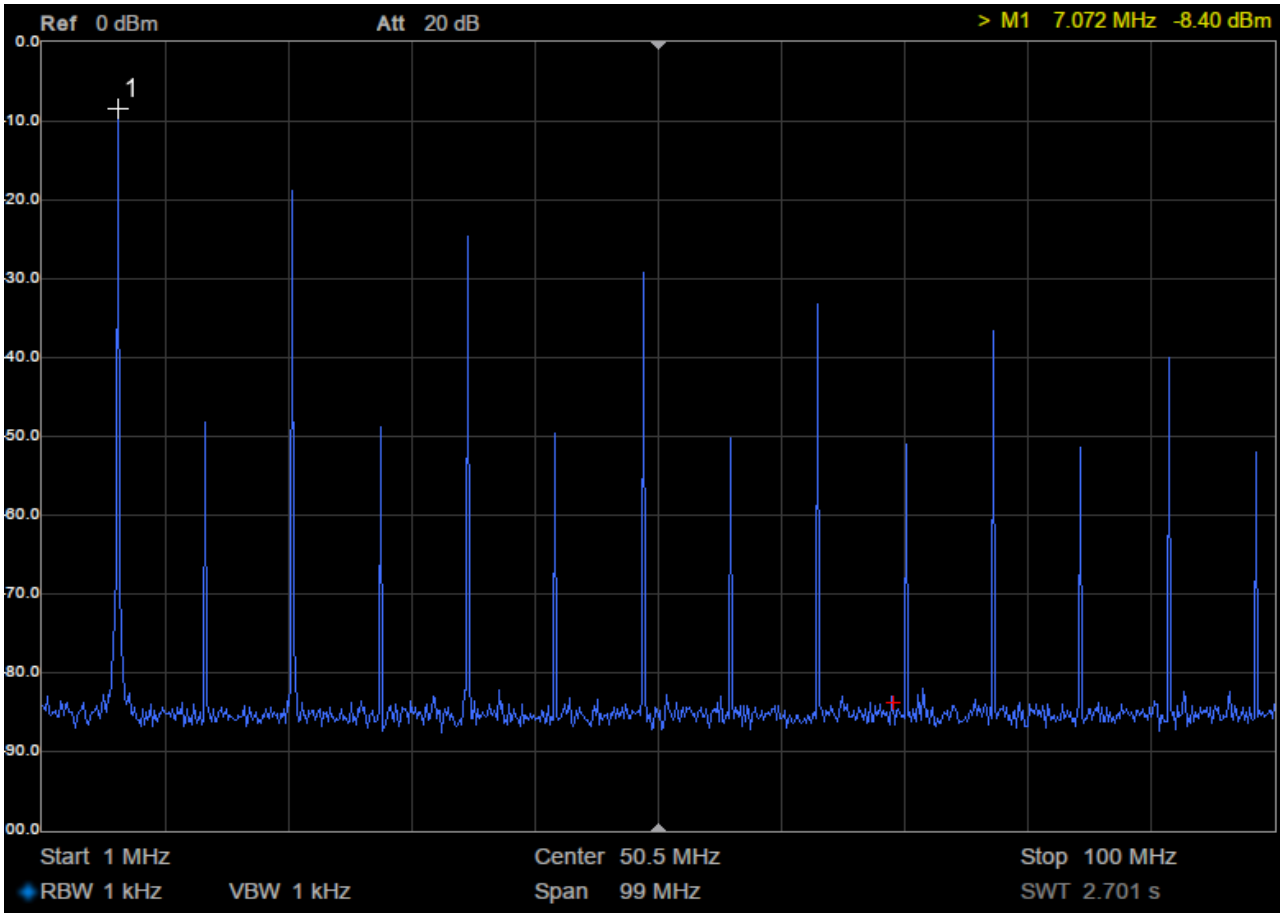
- Class D (sort of), 1 – 60 MHz range
- Digital 8x buffer packages provide complimentary 5V drive to 1:2 transformer
- Digital 3.3V input, square-wave output
- Switchable to ¼ W

1W Amplifier



Includes supply-current monitoring, automatic per-channel overload detection and shutdown

Unfiltered Square-Wave Output

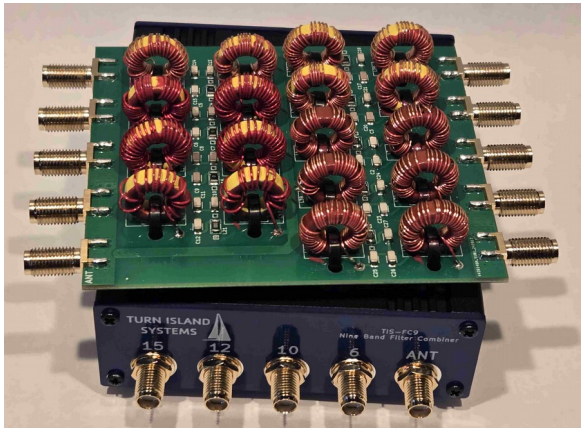


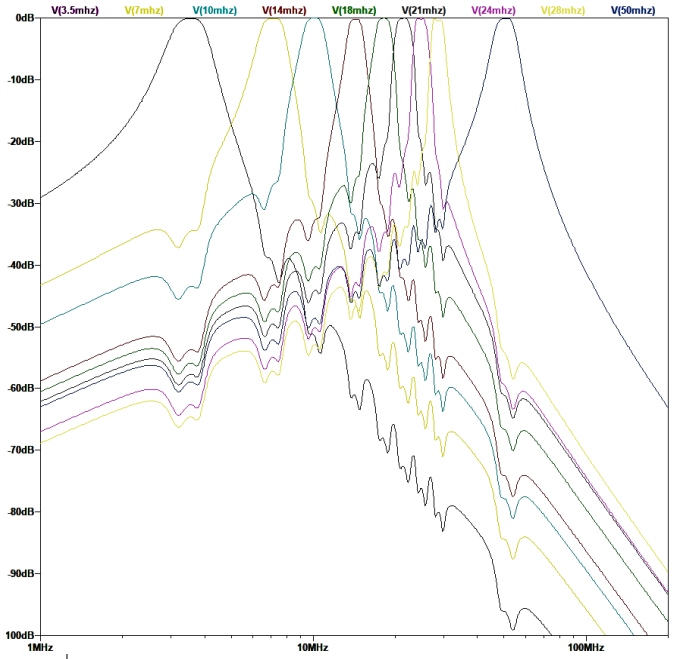
Nine-Band Filter-Combiner

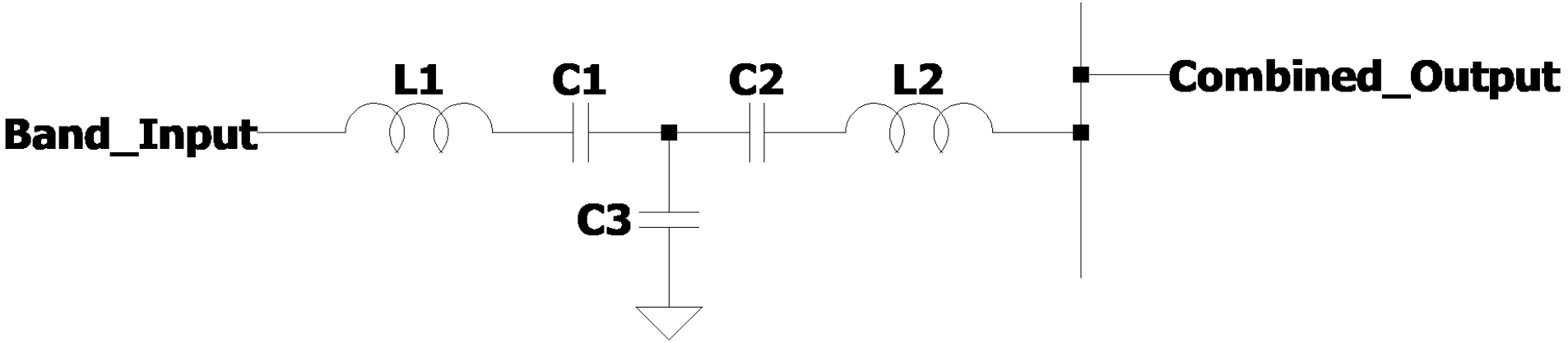
80 / 40 / 30 / 20 / 17 / 15 / 12 / 10 / 6 meters

The 9BFC attenuates harmonics and allows multiple transmitters to share one multiband antenna.

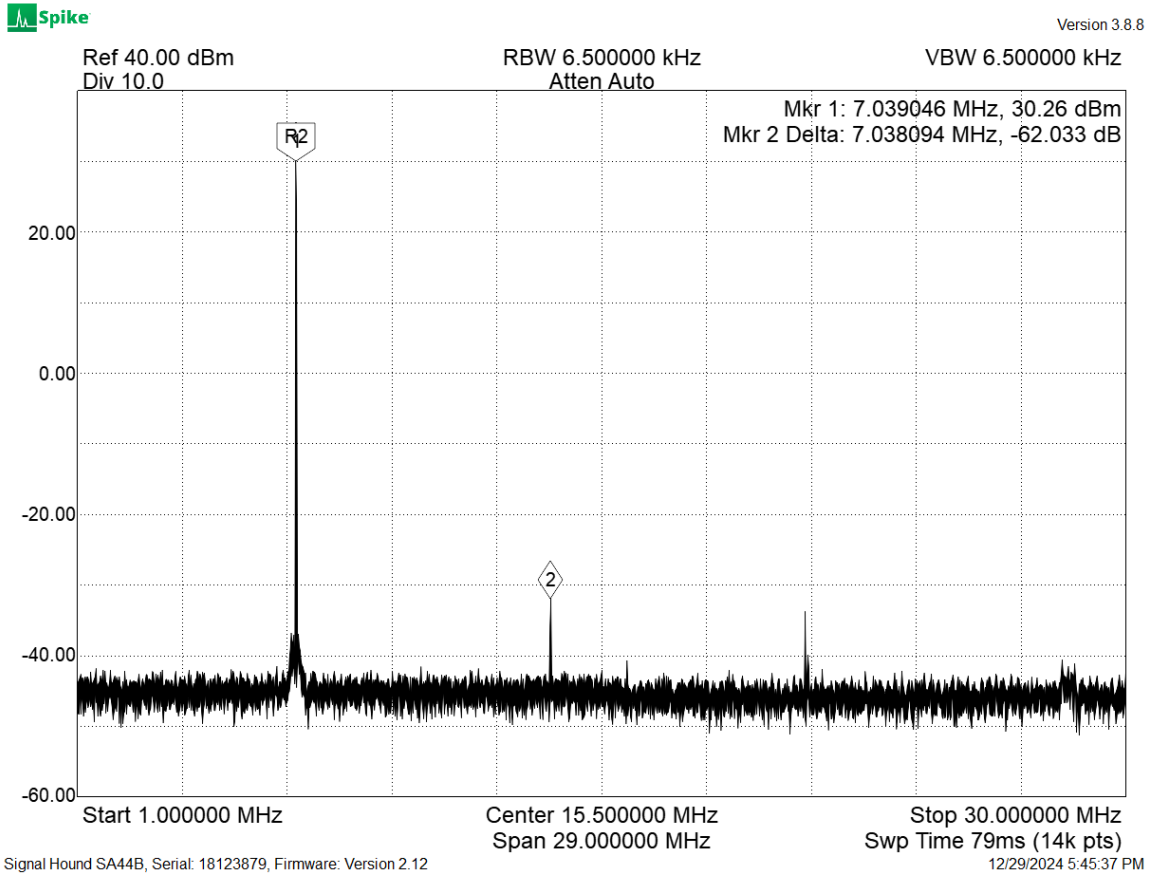
Single-band filters are available for 160 through 6 meters.



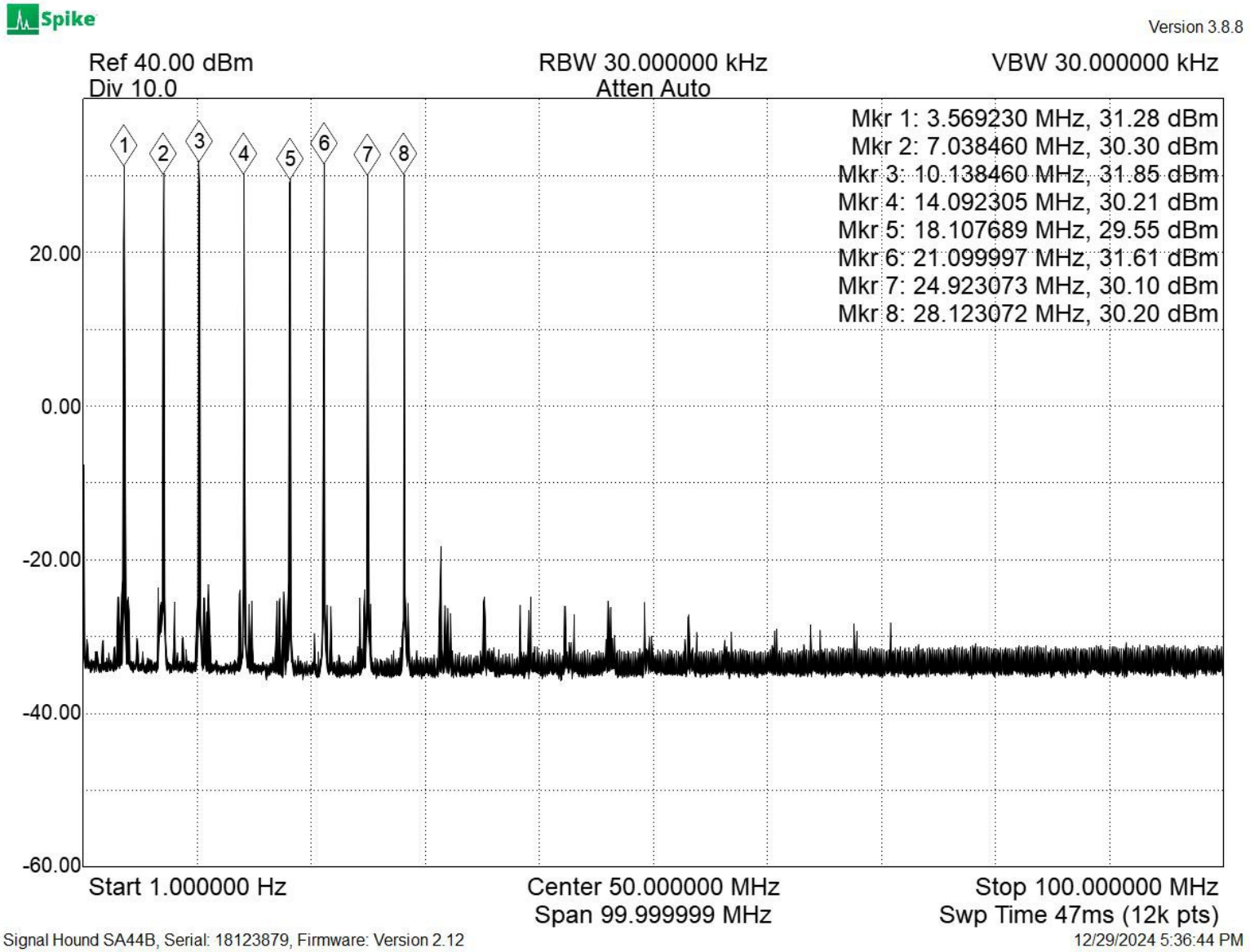




9BFC Harmonic Filtering



Eight Ham Bands into One Antenna

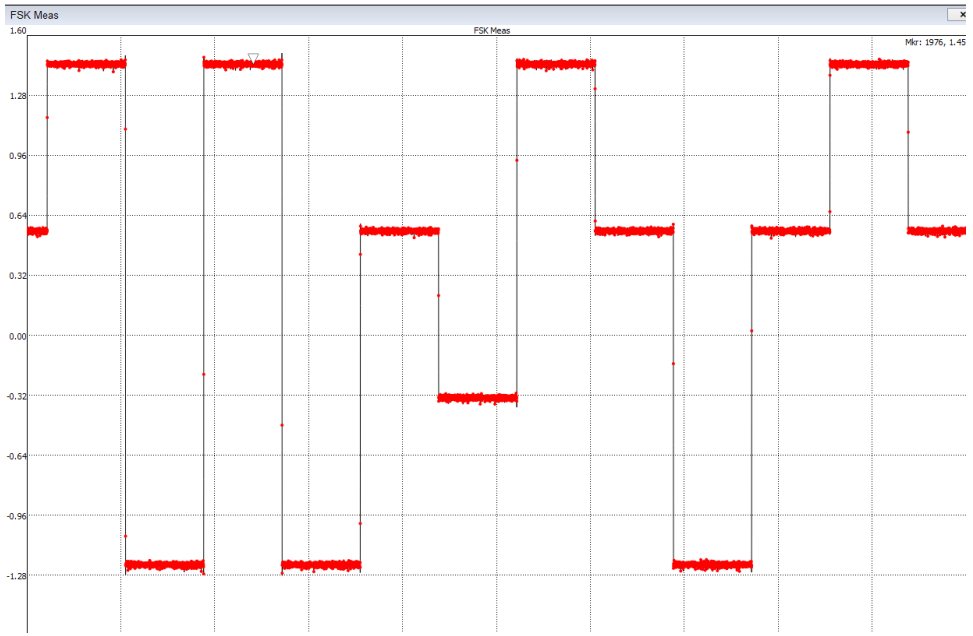


GFSK
(Gaussian Frequency Shift Keying)

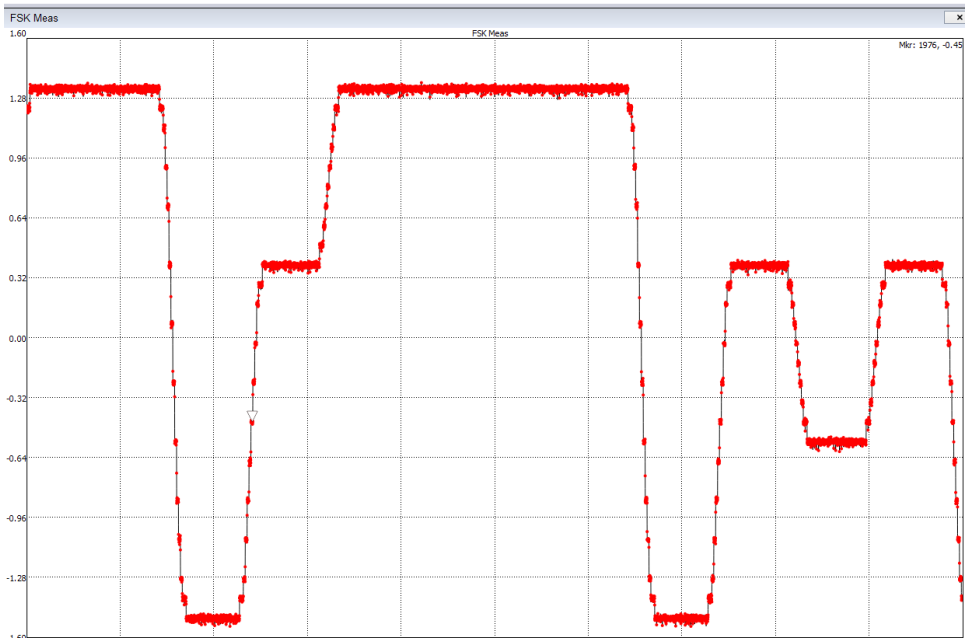
- WSPR : “bang-bang” 4FSK has wide spectrum
- FST4W : Filtered 4FSK reduces sidebands
- WS8 GFSK is done using many small frequency steps (41 steps per symbol for FST4W-120)
- Software uses DSP filtering to calculate the steps, each transmit frequency requires different values to be written to the Si5351 clock generators.
- WS8 FSK frequency accuracy is typically better than 1 uHz (micro Hz) when given an accurate 10 MHz reference clock.
- WS8 symbol timing is essentially perfect, driven by the reference clock.

4FSK vs 4GFSK

Frequency vs Time



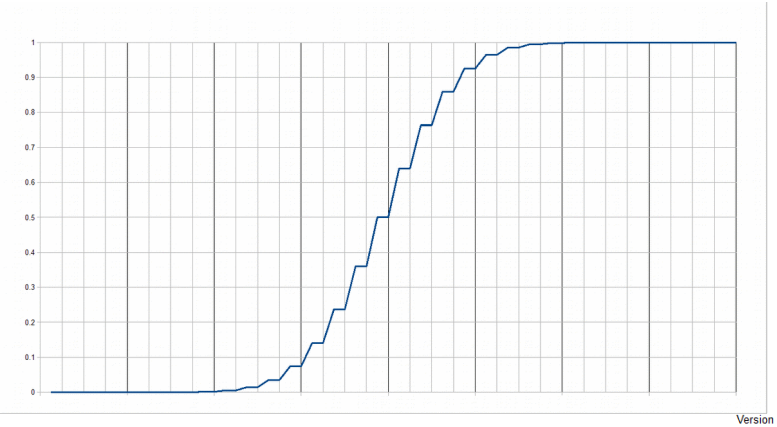
4FSK



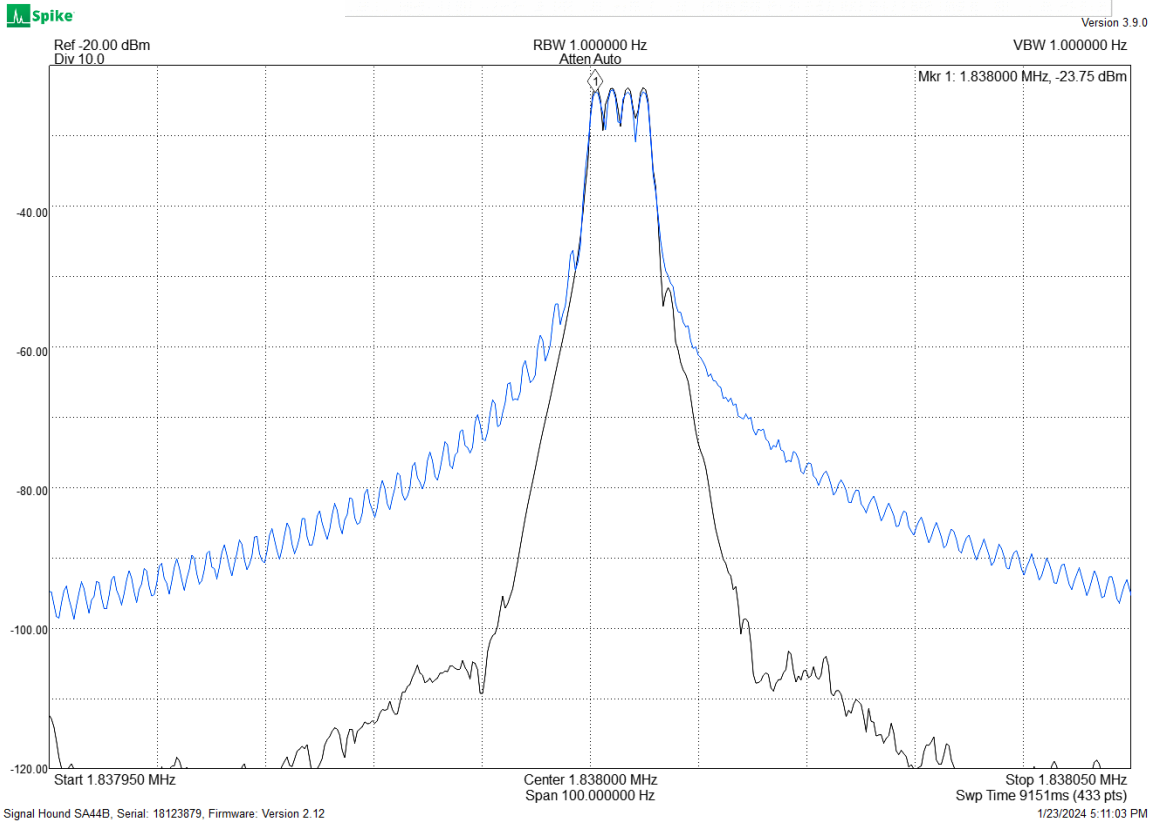
4GFSK

4FSK vs 4GFSK

Sampled GFSK step response:



- GFSK modulation sidebands fall off much more rapidly than with raw FSK
- Matched filter at receiver improves detection



Resources

- https://tapr.org/
- https://turnislandsystems.com/
- http://wb6cxc.com/
- http://wsprdaemon.org/

KA7ZOI blog:

- https://ka7oei.blogspot.com/2023/09/measuring-signal-dynamics-of-rx-888-mk2.html
- https://ka7oei.blogspot.com/2020/08/revisiting-limited-attenuation-high.html
- https://ka7oei.blogspot.com/2024/12/frequency-response-of-rx-888-sdr-at.html