North Texas NTMS Microwave Society

Using the RFzero™ as a beacon driver for VHF, UHF, and beyond

Central States VHF Society
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NTMS beacons[1] 50 MHz through 24 GHz

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Freq (MHz)	Call	Grid	Power	Antenna	Height above Ground	Status		Frequency Stabilization	Freq Reference	Keying
50.073	W5HN/B	EM13sj	.5 W	Halo	180 ft	OFF THE AIR (1)	HB	Crystal	12.51825 MHz	on/off
144.280.2	W5HN/B	EM13sj	1.5 W	Halo	180 ft	ON THE AIR	HB	Crystal	12.0233 MHz	on/off
222.060	AA5C/B	EM13se	8 W	Folded Dipole	53 ft	ON THE AIR	HB	PLL	10 MHz	on/off
432.370	N5PYK/B	DM93bm	50 W	Yagi towards DFW	70 ft	ON THE AIR		XCVR		on/off
432.380	W5HN/B	EM13kf	.8 W	Halo	280 ft	ON THE AIR	HB	ADF4351	10 MHz OCXO	on/off
903.050	W5HN/B	EM13kf	9 W	Alford Slot	280 ft	ON THE AIR	HB	N5AC PLL	10 MHz OCXO	on/off
1296.375	W5HN/B	EM13kf	3 W	Alford Slot	280 ft	ON THE AIR	HB	N5AC PLL	10 MHz OCXO	on/off
2304.366	W5HN/B	EM13kf	4 W	Alford Slot	280 ft	ON THE AIR	HB	Crystal		FSK
3456.380	W5HN/B	EM13kf	250 mW	Alford Slot	280 ft	OFF THE AIR	DB6NT	Crystal X 27	128.014 MHz	FSK
3400.380	W5HN/B	EM13kf	250 mW	Alford Slot	280 ft	BEING UPGRADED (2)	DB6NT	ADF4351	125.94 MHz	on/off
5760.364	W5HN/B	EM13kf	158 mW	Alford Slot	280 ft	ON THE AIR	DB6NT	Crystal X 48	120.0079 MHz	FSK
10368.368	W5HN/B	EM13kf	2.5 W	Alford Slot	280 ft	ON THE AIR	DB6NT	Crystal X 96	108.00395 MHz	FSK
24192.300	AA5C/B	EM13sf	500 mW	16-slot WR42	75 ft	ON THE AIR	HB	Crystal	112.0015 MHz	on/off
24192.380	W5HN/B	EM13kf		10 slot Alford	280 ft	Under Construction (3)	HB	ZL PLL		on/off
47088.300	W5HN/B	?				Under Construction				

Actual 10 digit grid squares
EN13sj = EM13sj91mr
EM13se = EM13se55vi
DM93bm = DM93bm46su
EM13kf = EM13kf45pb
EM13sf= EM13sf89tb

Notes

(1) Waiting for a tower climb to put antenna back up at 60ft

(2) Working on cleaning up spurs

(3) ETA 2025

Modern beacon design

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- Our strategy is to add higher powered mmWave beacons that can be remotely controlled since they do not need to run 24/7
- The original plan:
  - Use Wavelab 24 GHz system (there are many “bad RX” modules)
    - Drive Wavelab with 144 MHz sig gen with CW keyed by Arduino
  - Tom’s WA1MBA quadrupler and DB6NT LO for 47 GHz
    - 47 GHz CW string is loaded into DB6NT LO
  - Arduino controlled Hologram card for remote control
- Then we learned about the RFzero™

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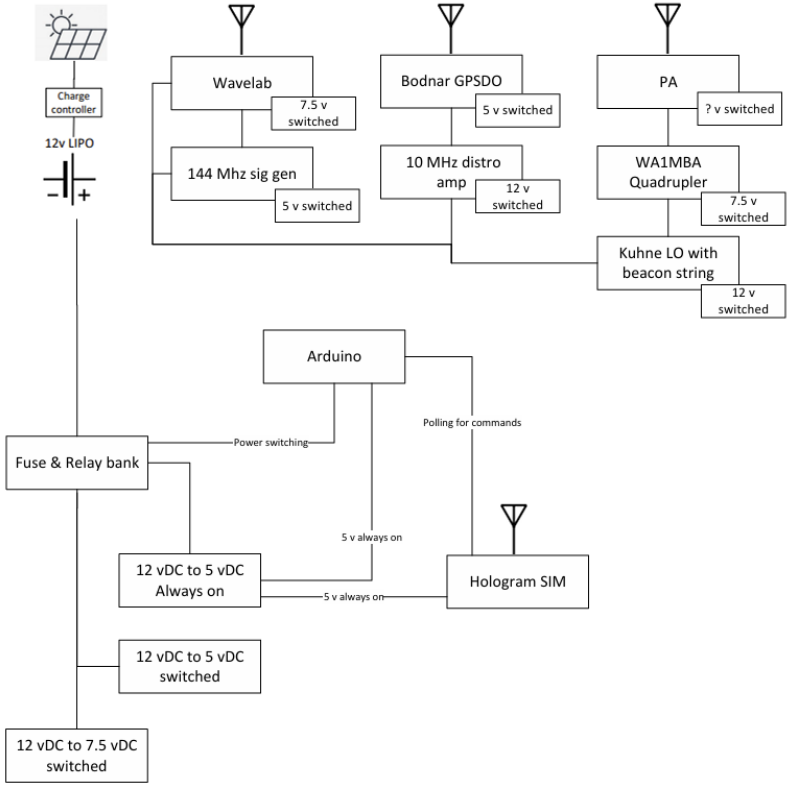
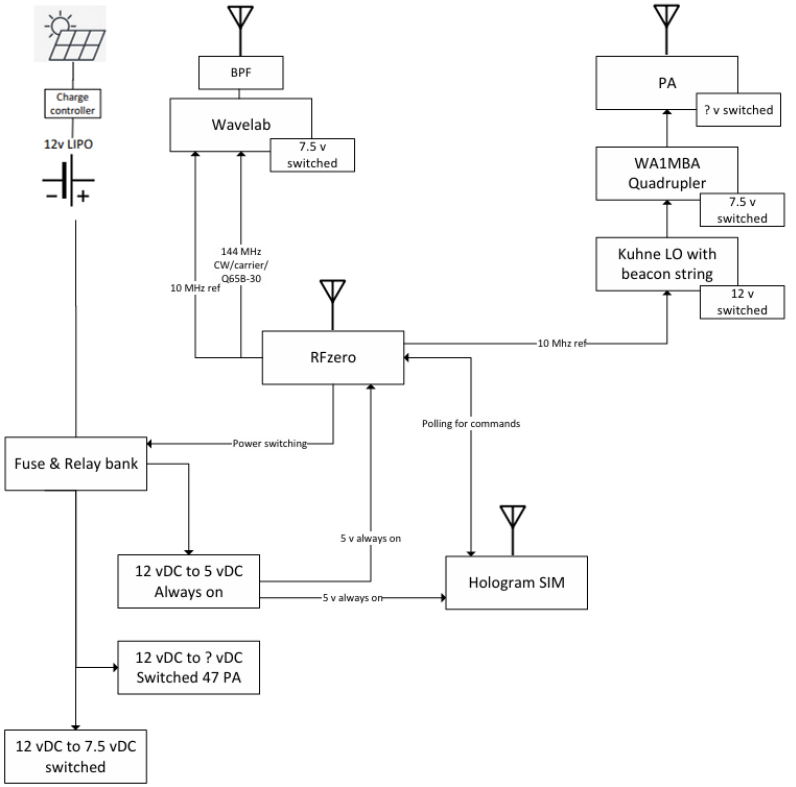
Potential design change

24/47 GHz Beacon v1



24/47 GHz Beacon v2



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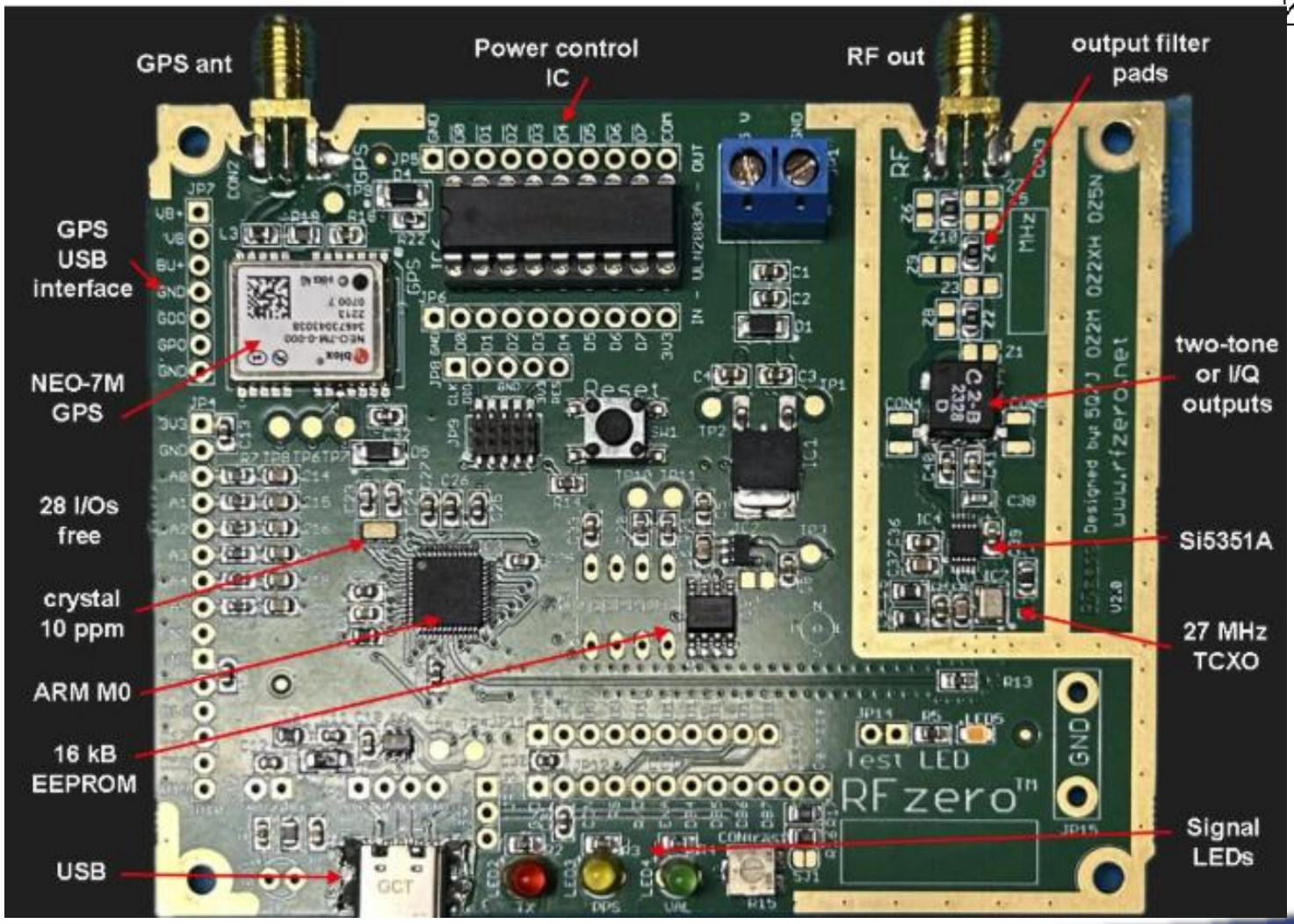
The RFzero™ board



RFzero™ beacon modes

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Frequencies from 2289 Hz to ~ 300 MHz (or harmonic)
CW + carrier
FT4 + CW + carrier
FT8 + CW + carrier
JS8 + CW + carrier
JT4 + CW + carrier
JT65 + CW + carrier
Q65 + CW + carrier
RTTY x 5 + CW + carrier
WSPR
Frequency compensation for multipliers up to 72 GHz
Beacon modes (not all modes shown)

RFzero™ Manager²

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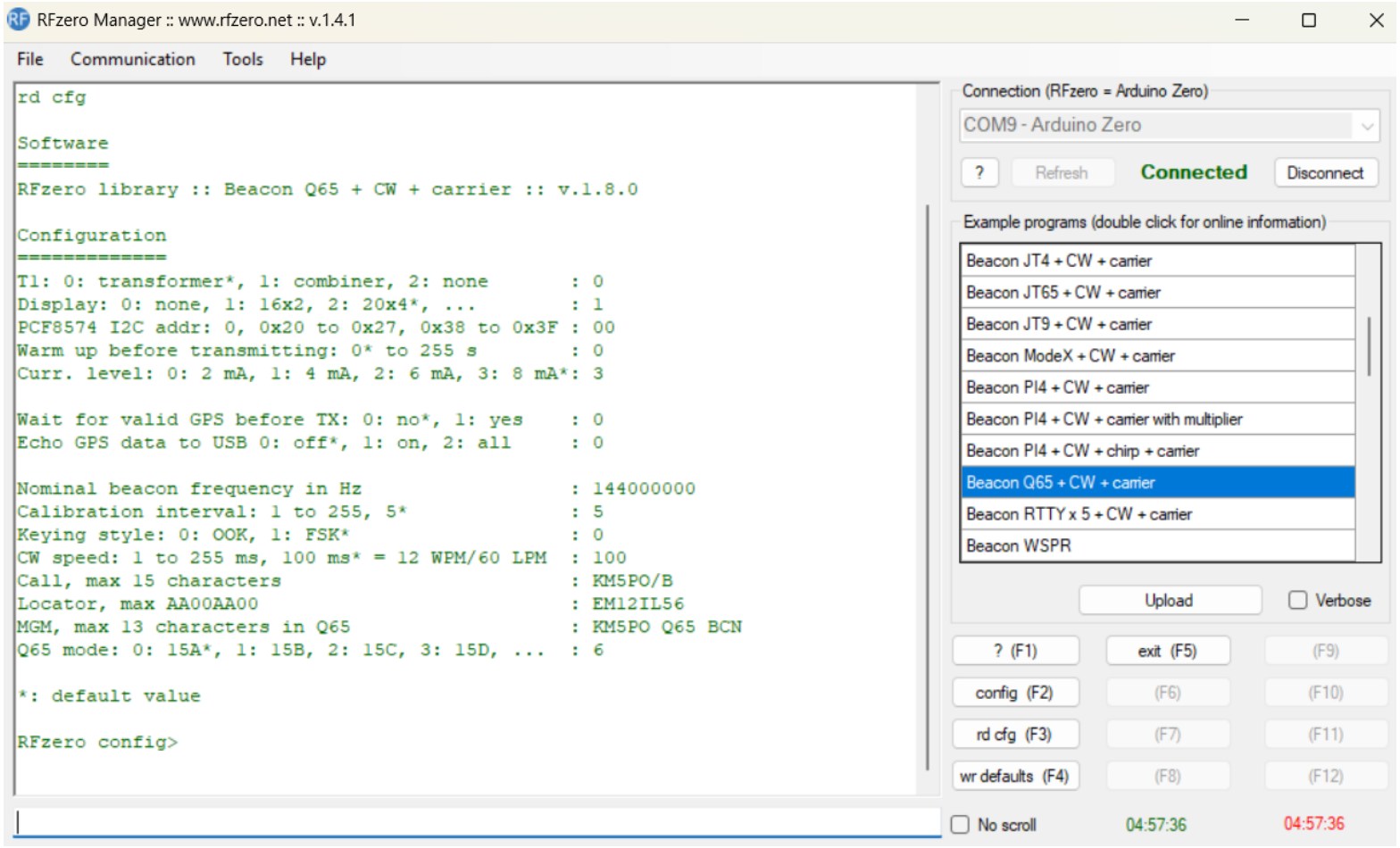
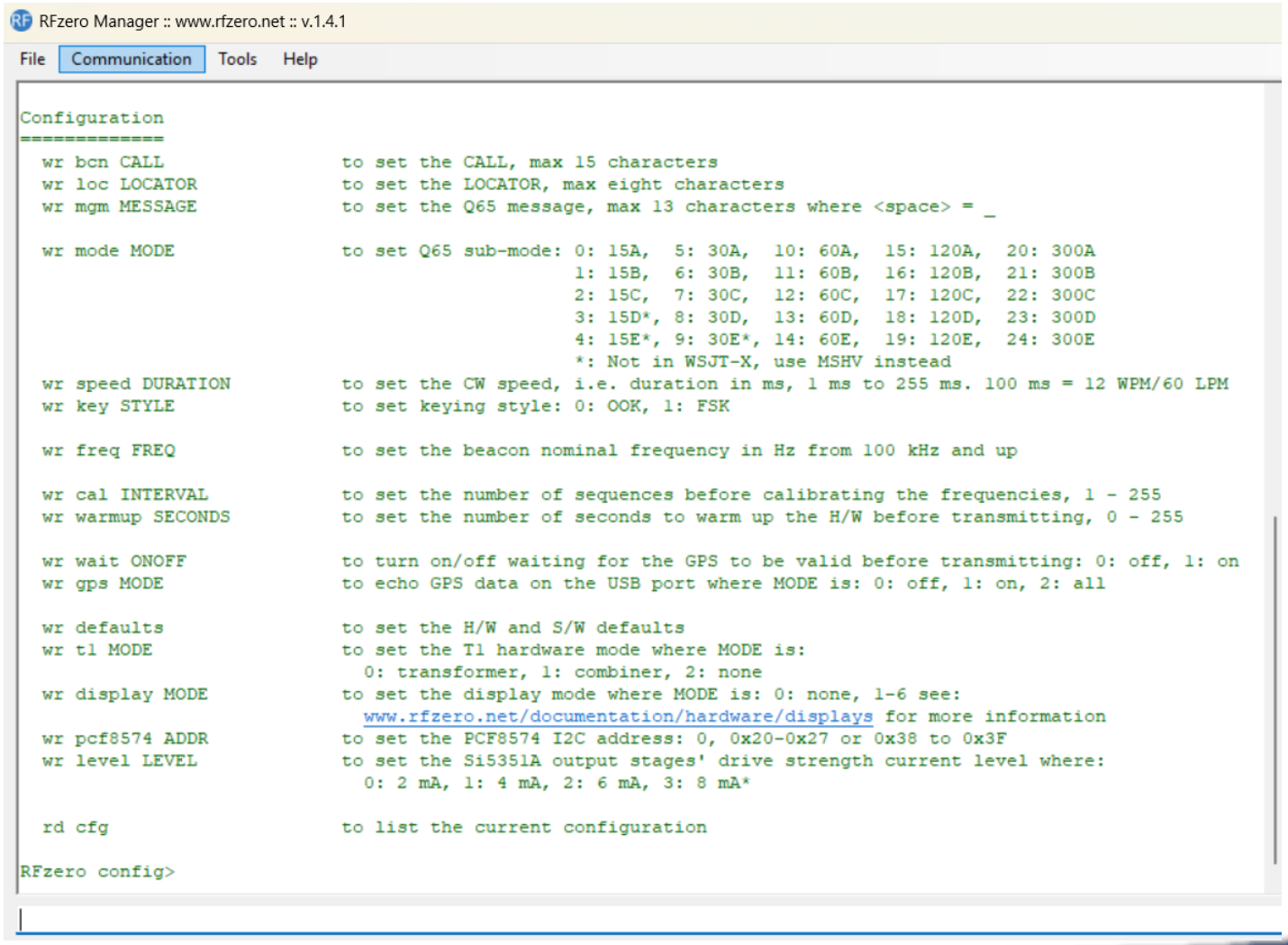


RFzero™ Manager



Check tone spacing bandwidth

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- The RFzero™ over the air WSJT-X signal at 144 MHz decoded 100%
- The 144 MHz signal generated is fundamental from the RF chip (not a harmonic)
- Observed proper timing through GPS clocking
- Observed no drift in ambient shop conditions

Check tone spacing bandwidth

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- Referring to the Q65 Quick Start Guide[3] we noted that the Q65 30 seconds T/R Period had bandwidth spreads ranging from 433 Hz (sub-mode B) to 1733 Hz (sub-mode D)

T/R Period (s)	A Spacing (Hz)	A Width (Hz)	B Spacing (Hz)	B Width (Hz)	C Spacing (Hz)	C Width (Hz)	D Spacing (Hz)	D Width (Hz)	E Spacing (Hz)	E Width (Hz)
15	6.67	433	13.33	867	26.67	1733	N/A		N/A	
30	3.33	217	6.67	433	13.33	867	26.67	1733	N/A	
60	1.67	108	3.33	217	6.67	433	13.33	867	26.67	1733
120	0.75	49	1.50	98	3.00	195	6.00	390	12.00	780
300	0.29	19	0.58	38	1.16	75	2.31	150	4.63	301

Check tone spacing bandwidth

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- Q65B seemed like a good place to start
- Side note: we have made contacts with Q65B-30 on 24 and 47 GHz so a digital mmWave beacon is viable
- A 10 MHz referenced HackRF module and SDR Console was used to make observations of tone spacing.

Check tone spacing bandwidth

- We used 6 dBm 10 MHz ref from Spectracom Ageless GPSDO as input to the HackRF.
- The CLKIN port on HackRF One is a high impedance input that expects 3.3 V square wave at 10 MHz. Do not exceed 3.3 V or drop below 0 V on this input3.

Configure CLKIN port on HackRF

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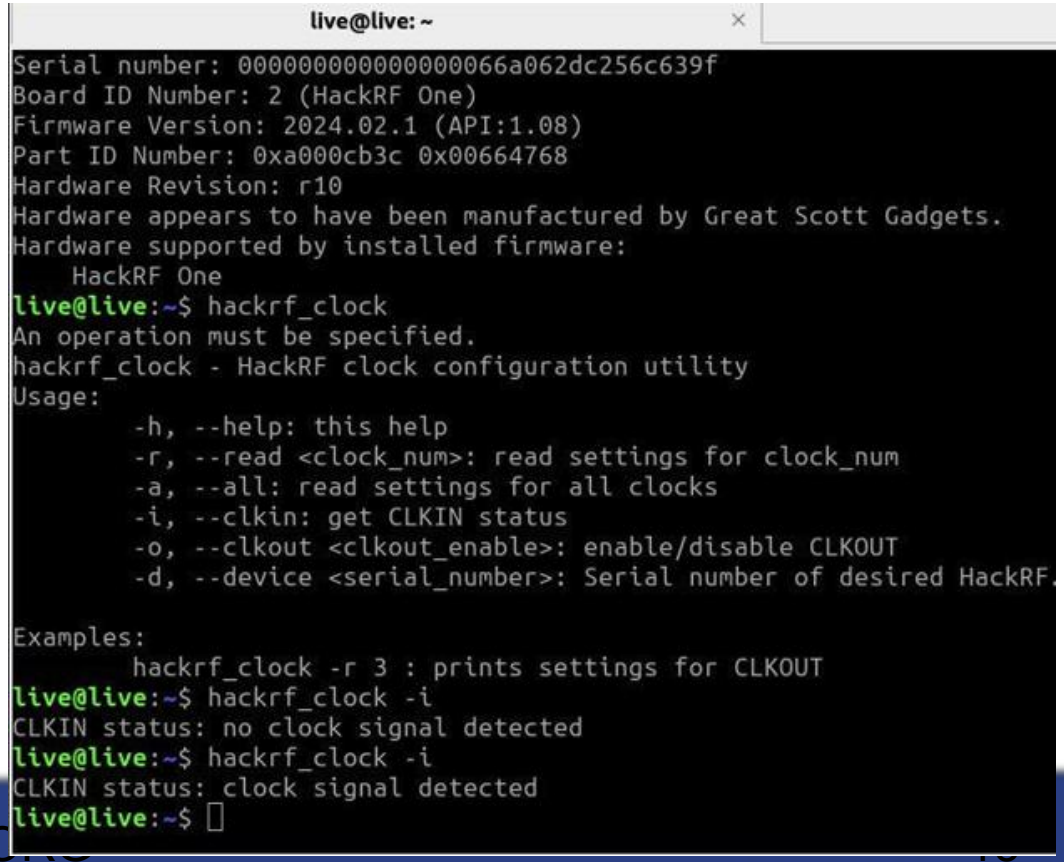
- Use Linux command line to config CLKIN port and verify reference clock signal detect



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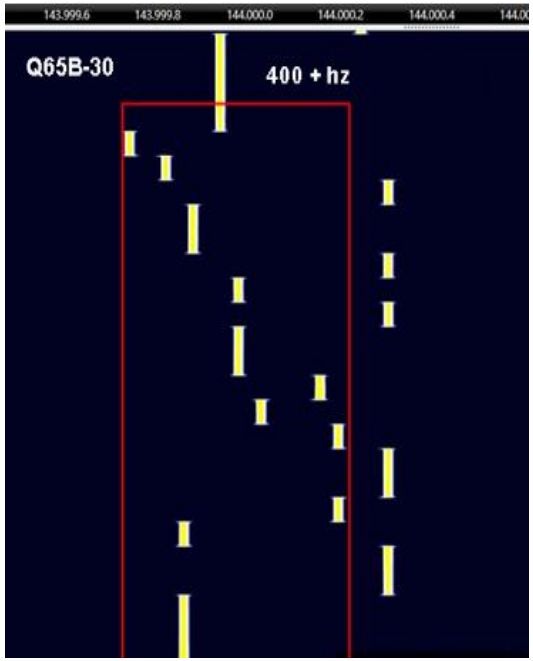
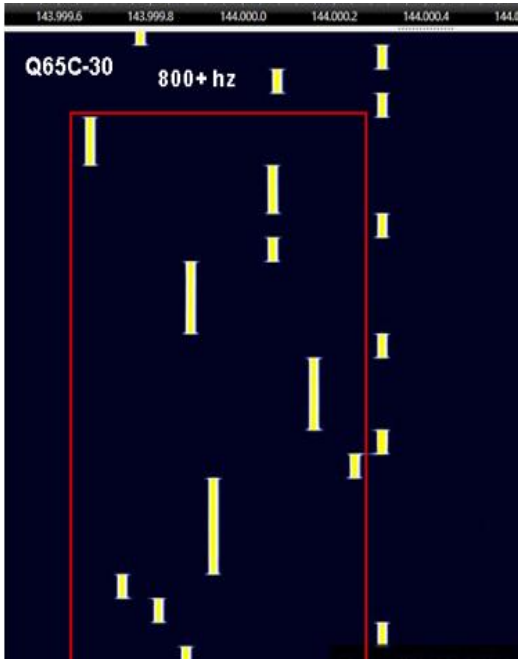
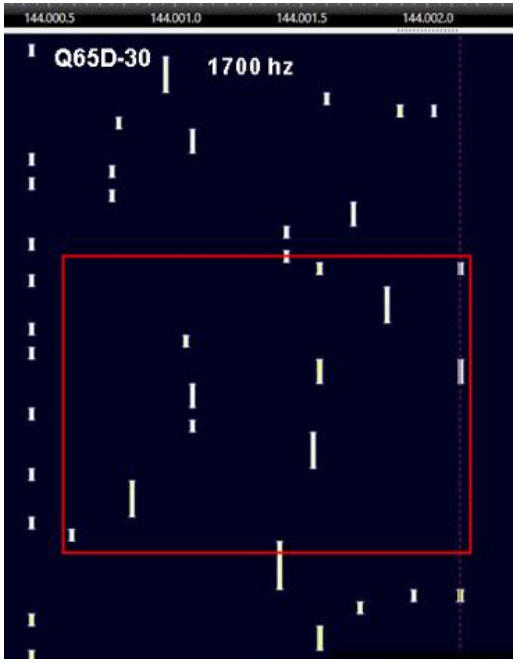
Tone spacing confirmed

- Q65B Q65C Q65D modes accurately spaced as observed in SDR receiver







Managing harmonics

- We then moved on to harmonic testing and working to understand the “multiply” feature noted in RFzero™ documentation[4]
- Setting the SDR to receive at 1296 MHz and keeping all the same variables as the last test (Q65D-30 at 144 MHz) we expected to see 9 x 1733 Hz spacing (9th harmonic of 144 MHz) and this was confirmed with observation of approximately 15.6 KHz bandwidth

144 MHz harmonic at 1296 MHz (9th harmonic)

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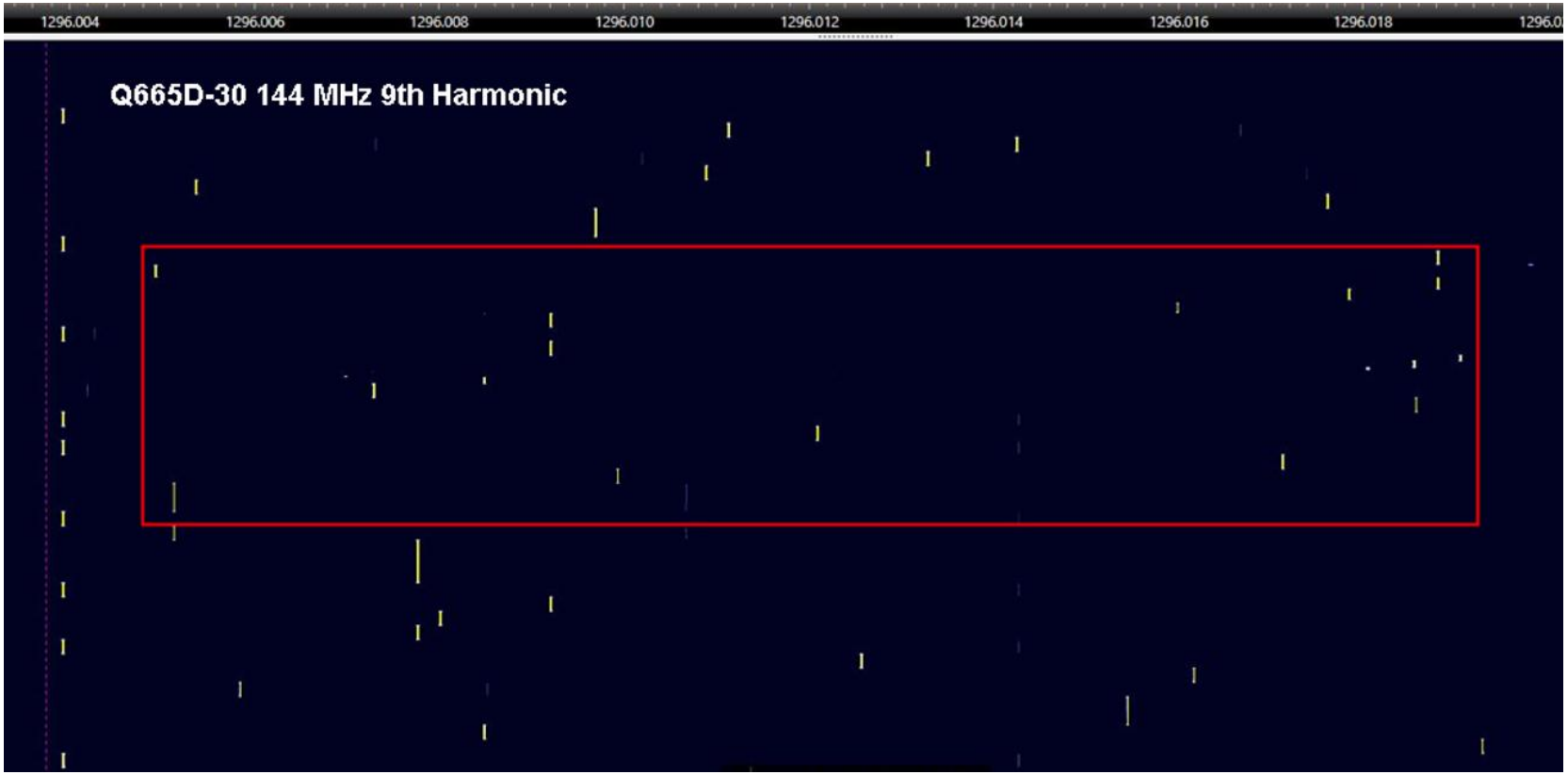

Managing harmonics

- Digging into the documentation we found that the correct method for programming 1296 MHz output is to write the configuration frequency as 1296 MHz and let the RFzero™ program library do the work
- The *calculateTonesMulti* function contains the math that resolves the tone spacing and bandwidth and selects the appropriate frequency (under 300 MHz) to drive the RF synthesizer.

Managing harmonics

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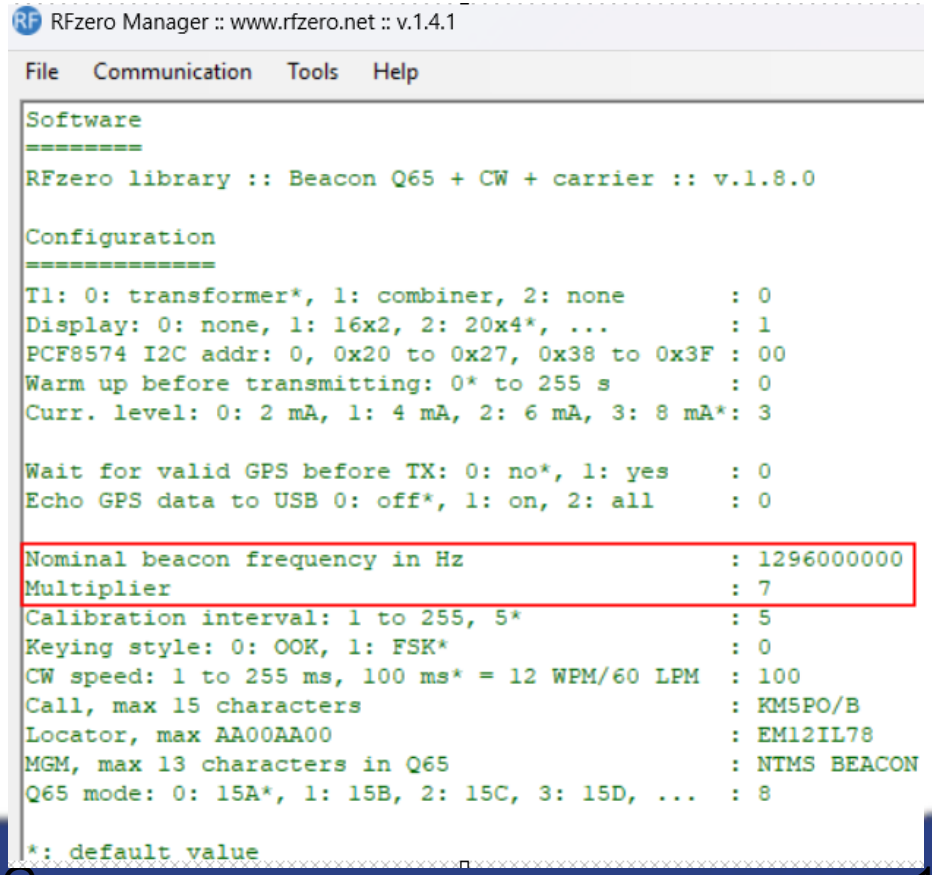
- Note Multiplier of 7 which means fundamental is at 185.14 MHz



Managing harmonics

- Observe correct tone spacing of 7th harmonic

Managing harmonics

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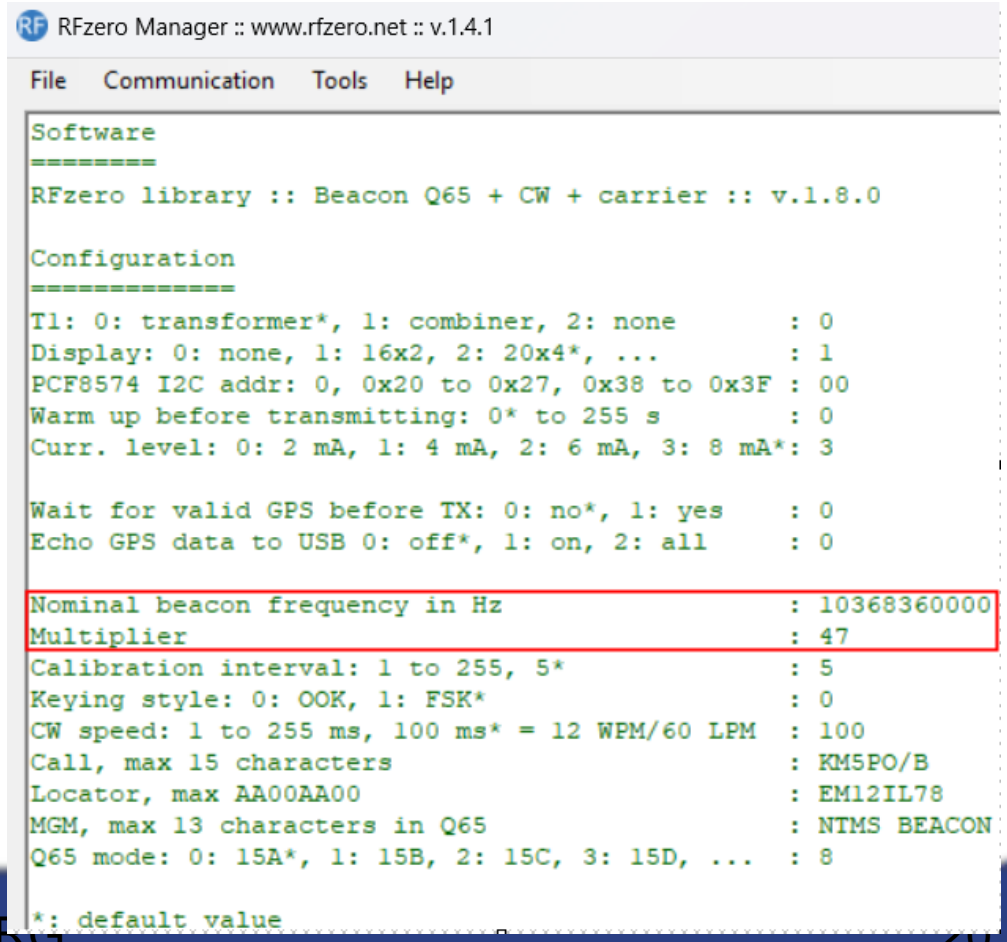
- 2nd test – set output frequency to 10368.300 MHz



Managing harmonics

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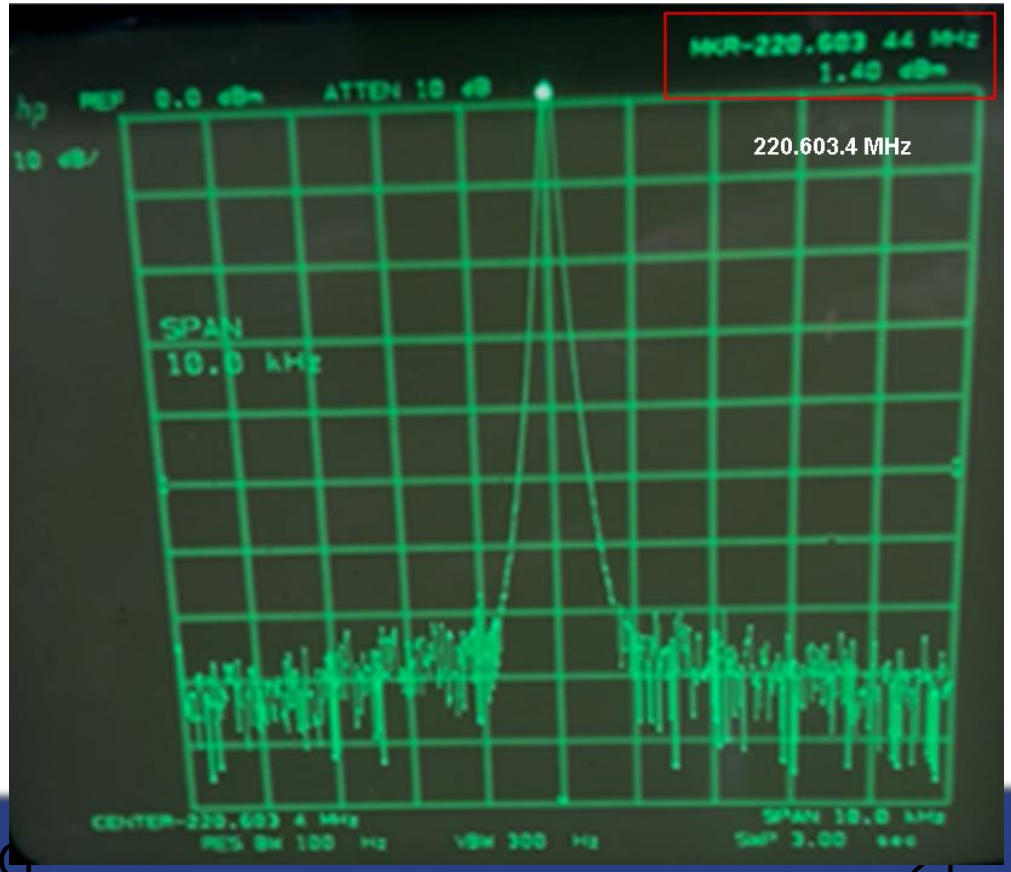
- Observe the fundamental of 220.6034 MHz



Adding filters

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- To suppress harmonics there are filter pads on the board in the RF output section and standalone filter PCB boards available.
- We tested both.
- First was a band pass filter 100–150 MHz built directly on the board.

100 – 150 MHz BPF

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- The Elsie filter design program[5] is free to use and has several good features that enable filter design.
- Elsie design parameters for the 100–150 MHz band pass filter.

fmin	fmax	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
100 MHz	150 MHz	15 pF	1 pF	33 pF	3,9 pF	33 pF	3,3 pF	12 pF	68 nH	68 nH	68 nH

100 – 150 MHz BPF

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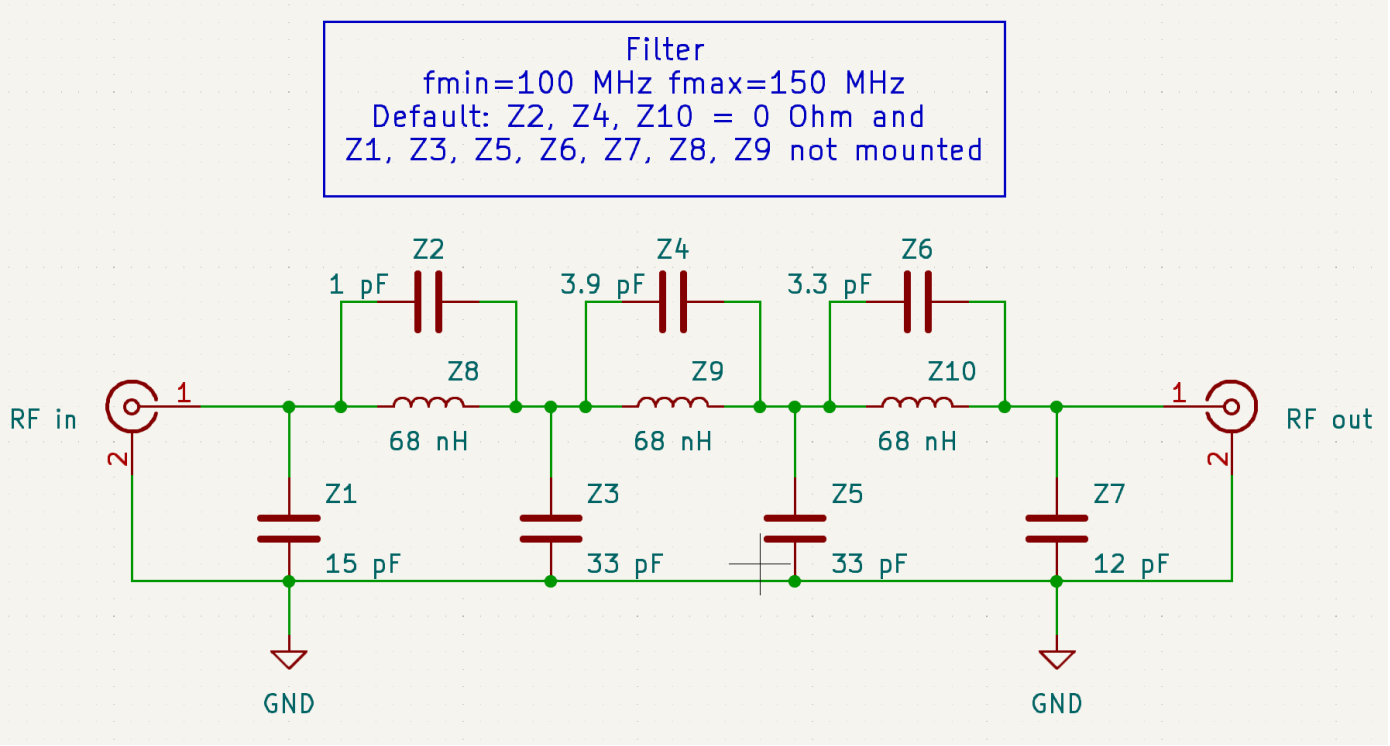
- KiCad schematic of Elsie design



100 – 150 MHz BPF

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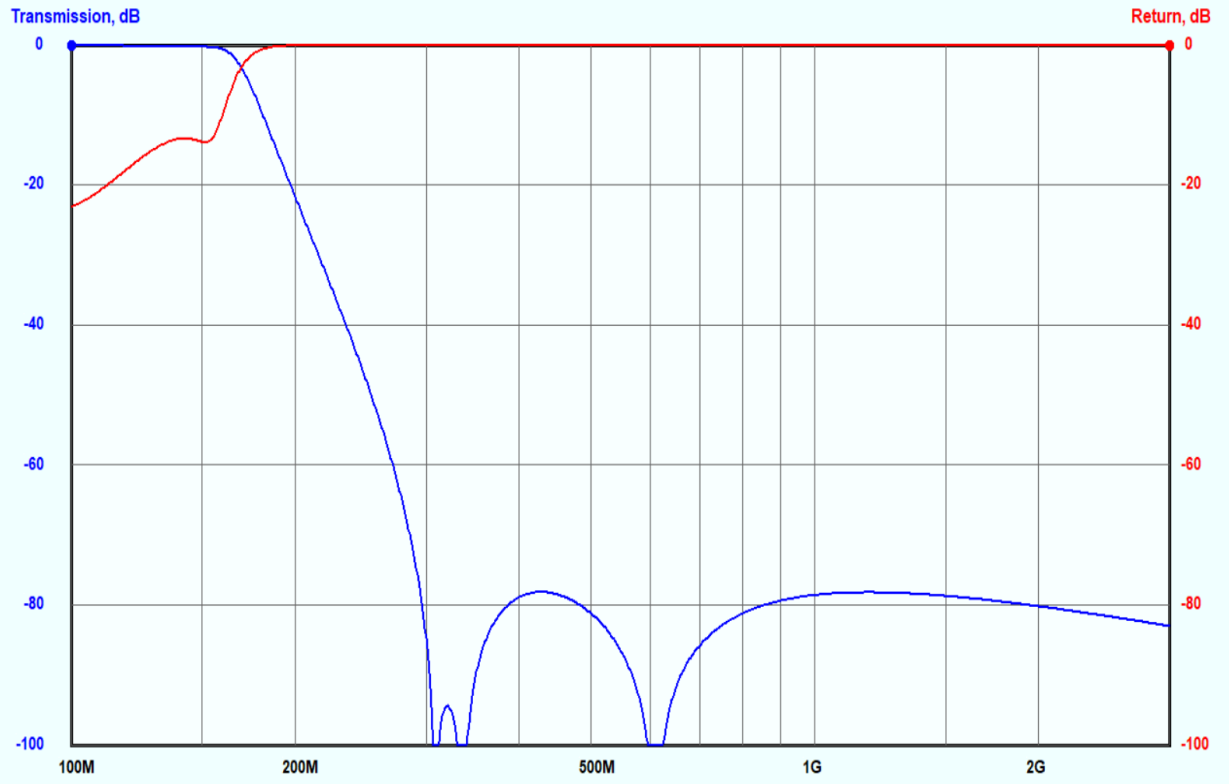
- Elsie theorized plot



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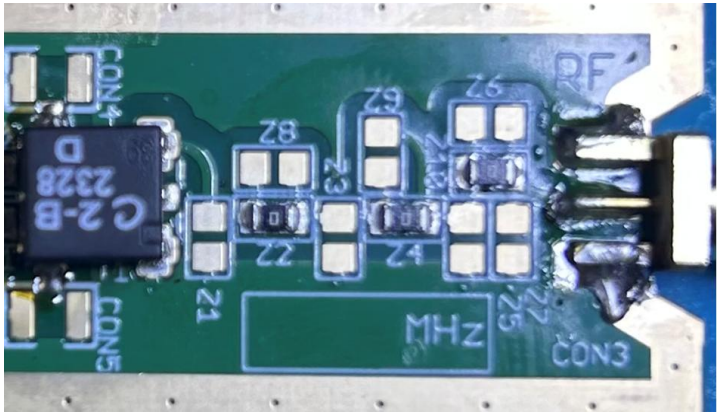
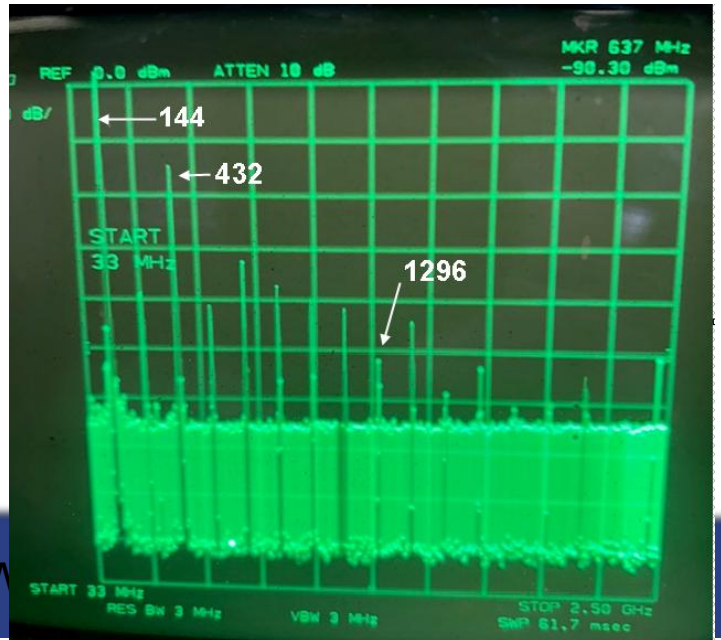
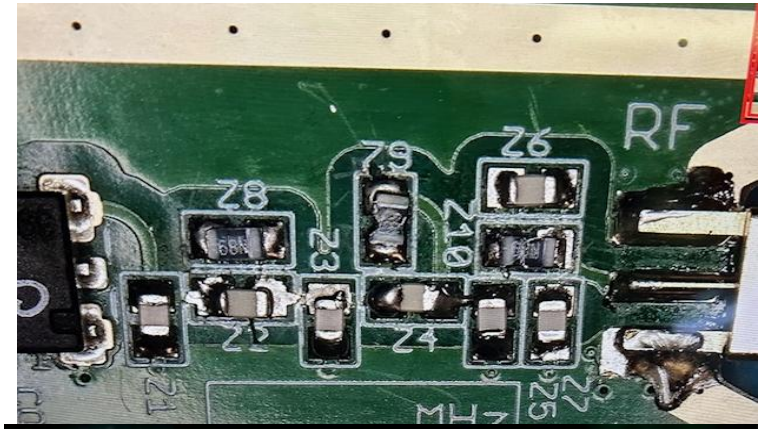
100 – 150 MHz BPF

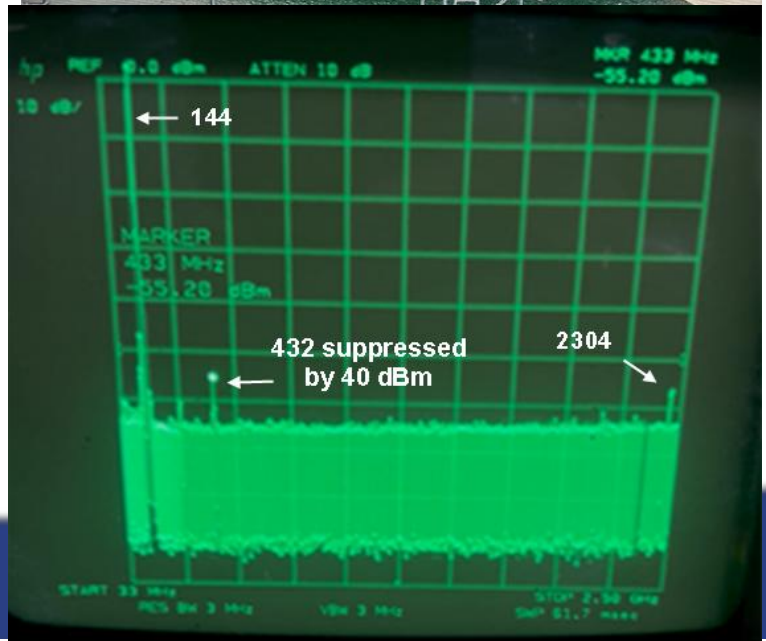
Before filter





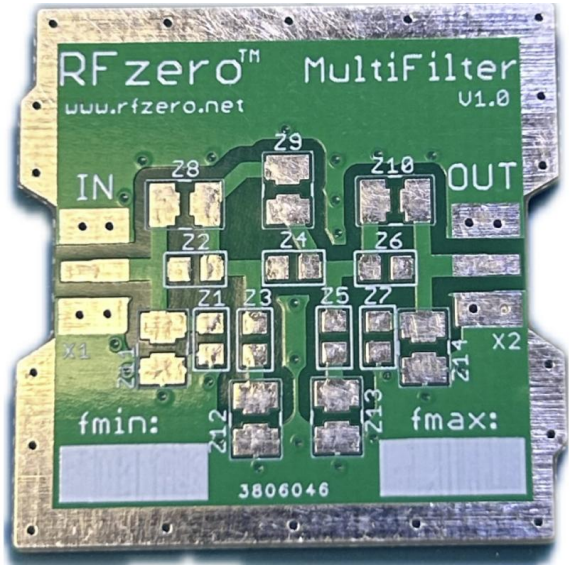
After filter

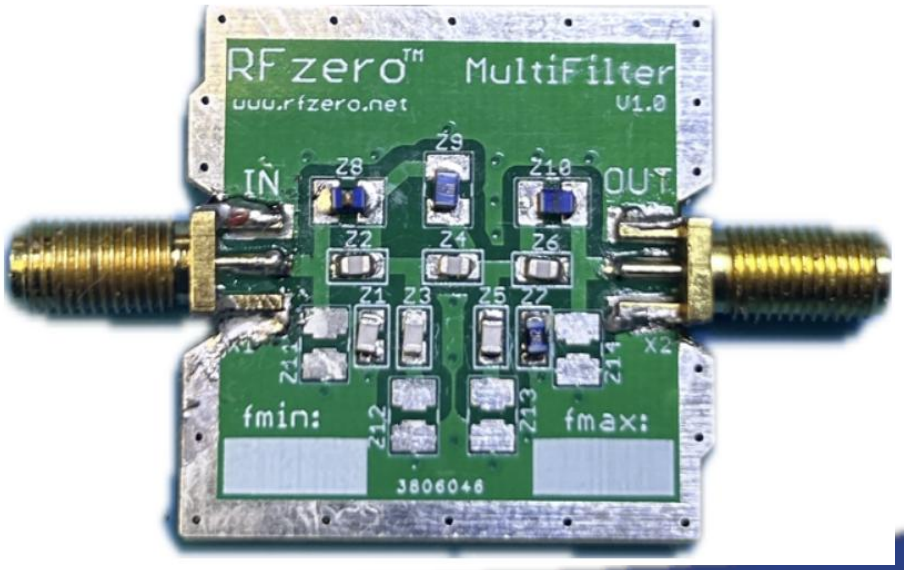




400 MHz High Pass Filter

- Next, we built a 400 MHz high pass filter which would suppress below 400 MHz yet allow harmonics above 400 MHz to be usable. See standalone external filter board below.





400 MHz HPF

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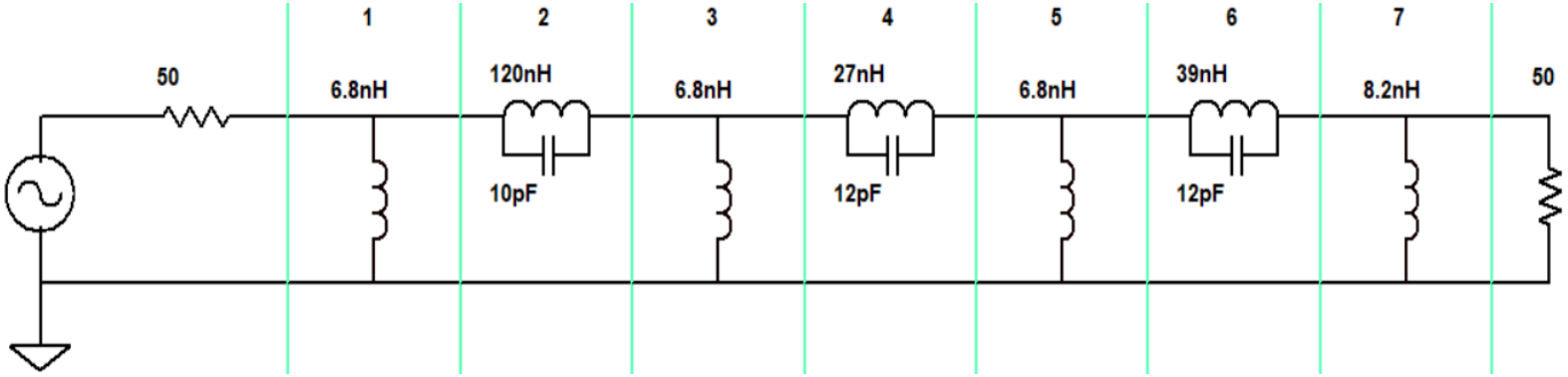
- Elsie design parms and Elsie schematic

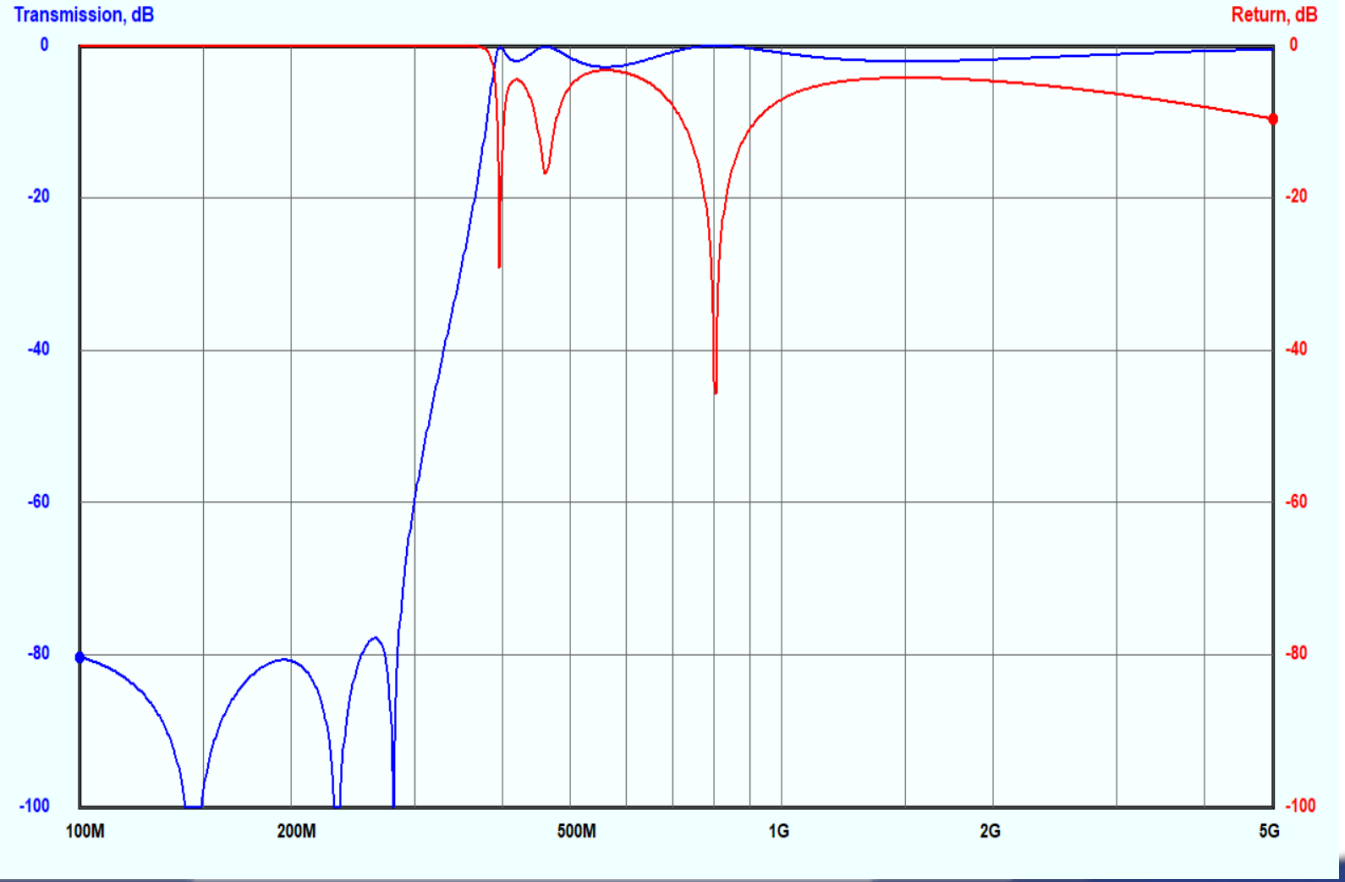
fmin	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
400 MHz	6,8 nH	130 nH	6,8 nH	27 nH	6,8 nH	39 nH	8,2 nH	10 pF	12 pF	12 pF



Had to sub 120 nH inductor for 130

400 MHz HPF

- Elsie theorized plot



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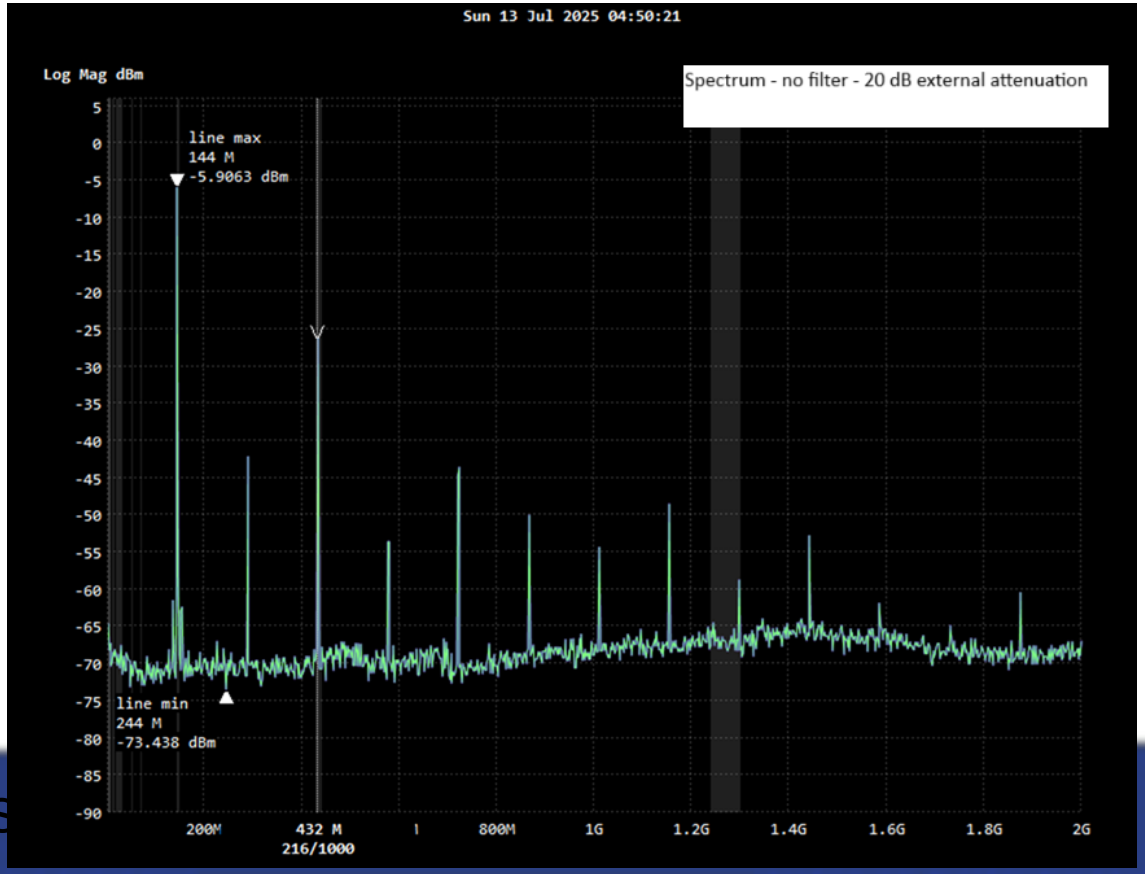
432.300 programmed no filter

- RFzero™ programmed for 432.300, no output filter.
- 144.100 fundamental is +14.1 dBm
- 432.300 harmonic is -7 dBm



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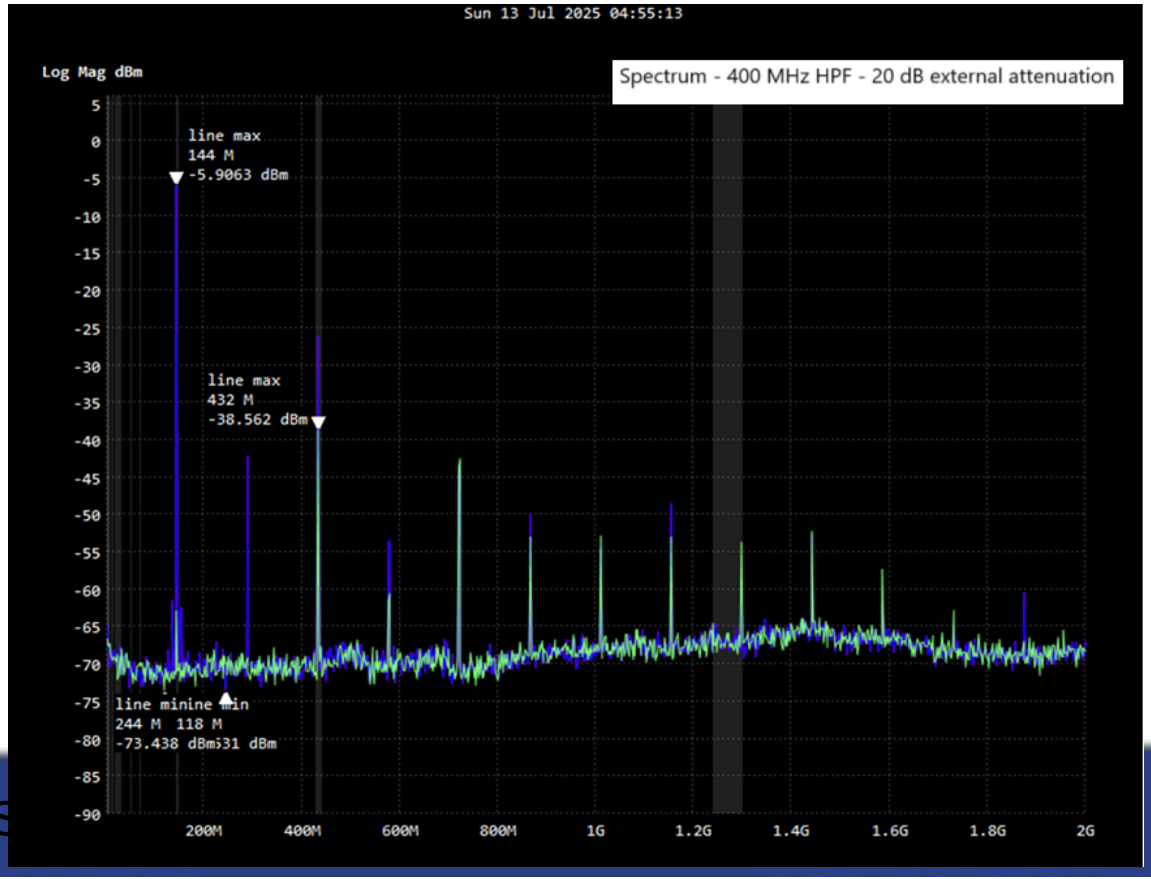
High pass filter in place

- 400 MHz High Pass Filter (external) added
- 144.100 fundamental is -43 dBm – suppressed 57 dB
- 432.300 harmonic is -18 dBm – dropped 11 dB



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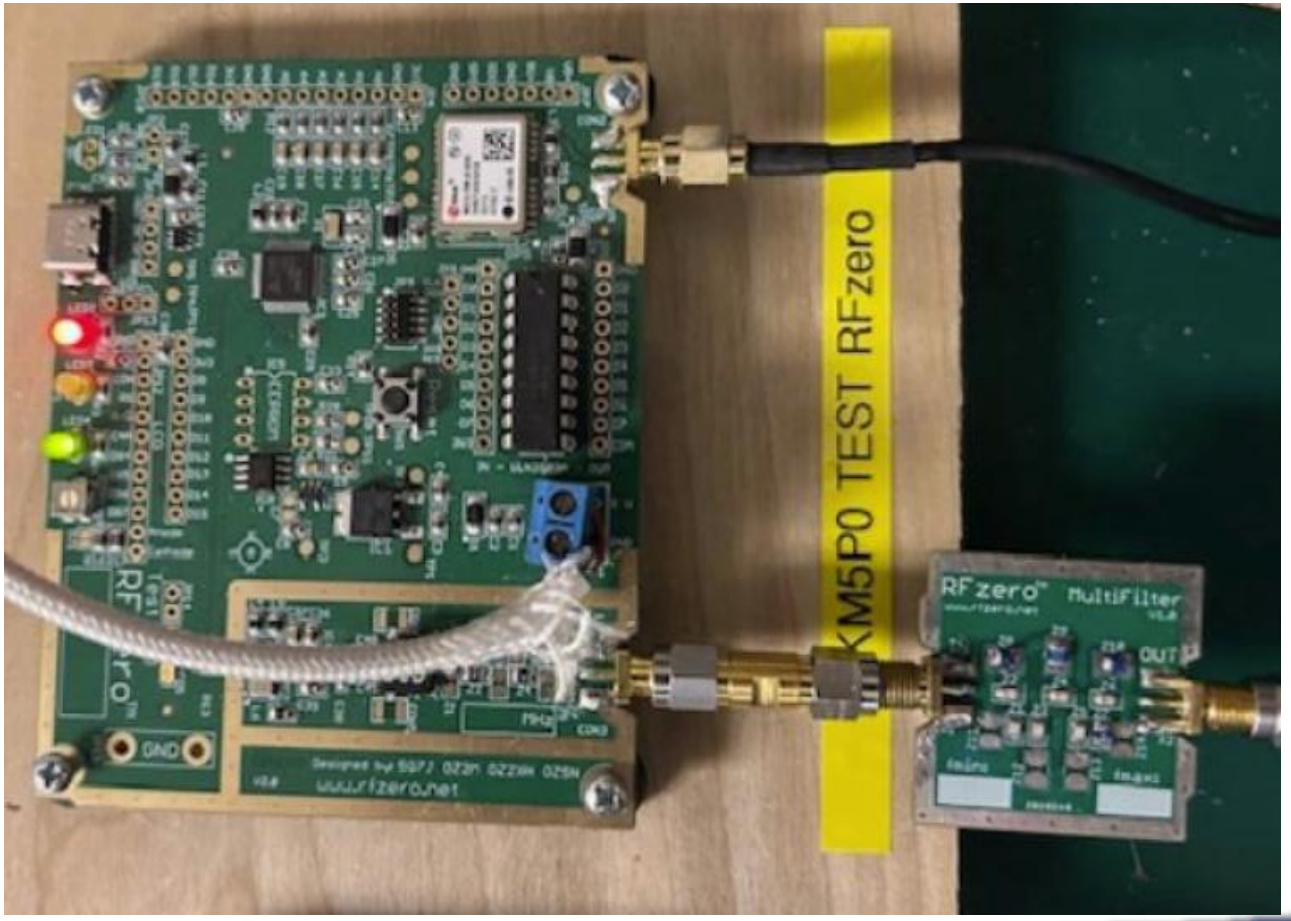
Test setup

- Test setup with external 400 MHz HPF



Driving a 24 GHz Wavelab unit

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- Use RFzero™ board with 100-150 MHz BPF
- Program and adjust RFzero™ to 144.360 MHz output to 10 dBm
- Program the mode to use “Q65B-30/Carrier/CW”
  - Digital first half of even minute
  - Carrier second half of even minute
  - CW string first half of odd minute
  - Remainder of odd minute is carrier
- Inject the 144.360 MHz signal ahead of the Wavelab mixer
- This will drive the Wavelab to full output (approx. 31 dBm) at 24192. 360

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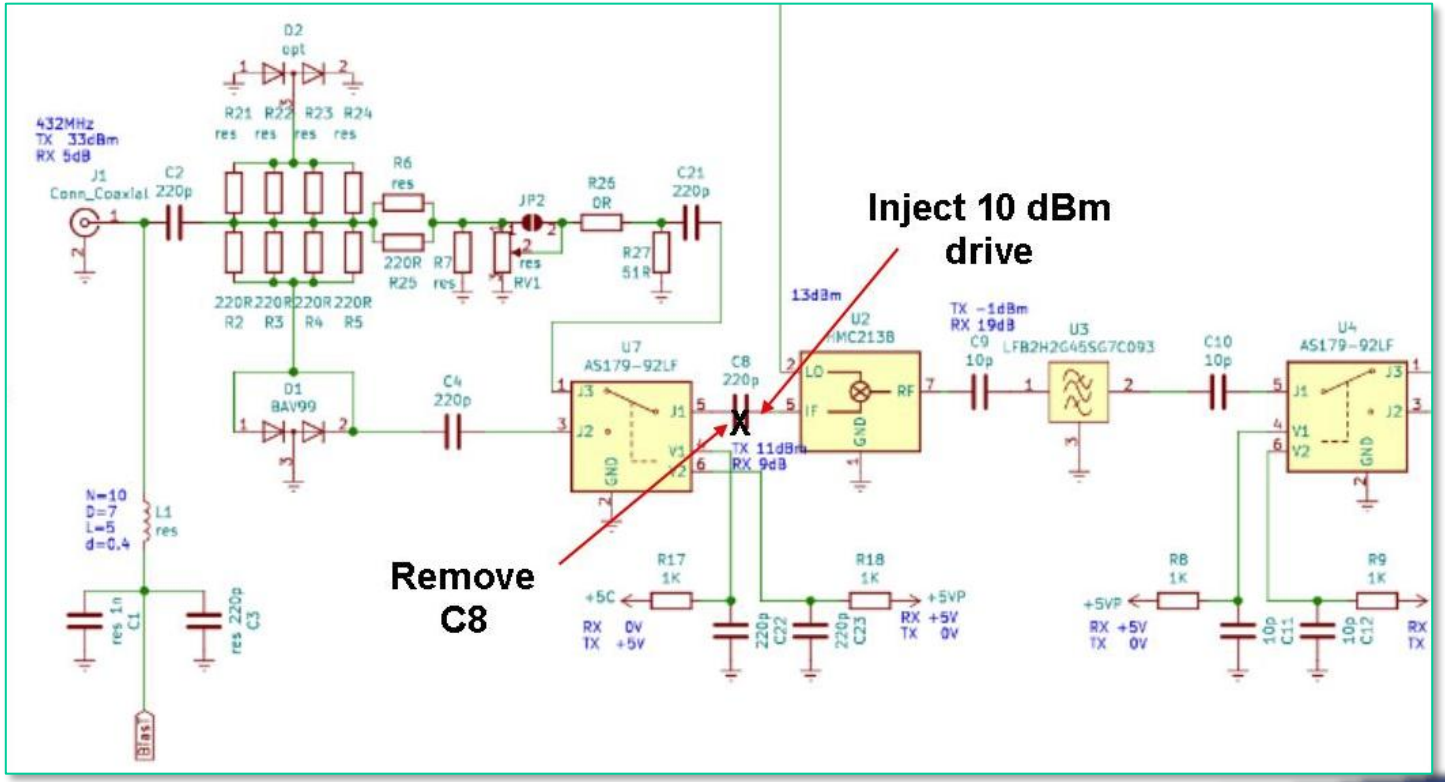
Driving a 24 GHz Wavelab unit

- Remove C8 and inject on pad closest to mixer
- Put Wavelab into TX mode



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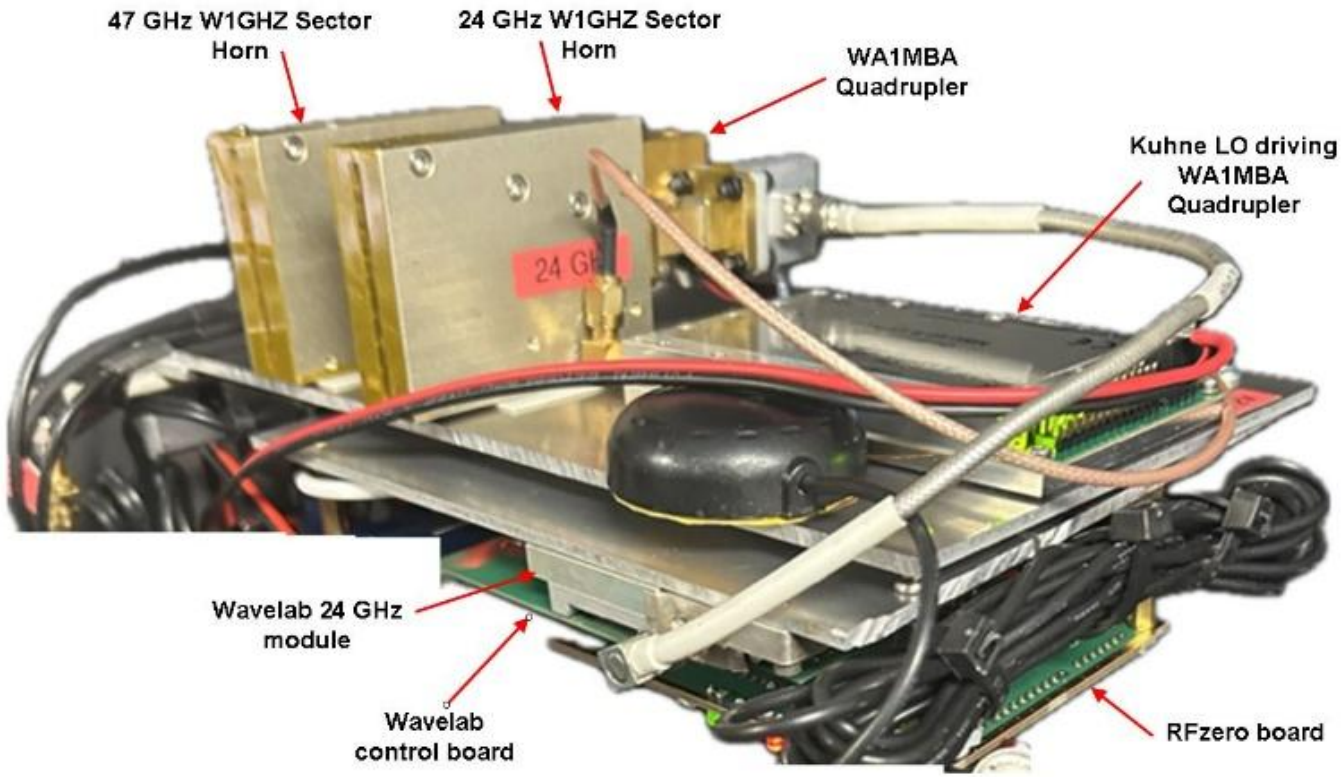
Empirical testing

- Use W1GHZ sector horn for both 24 and 47 GHz



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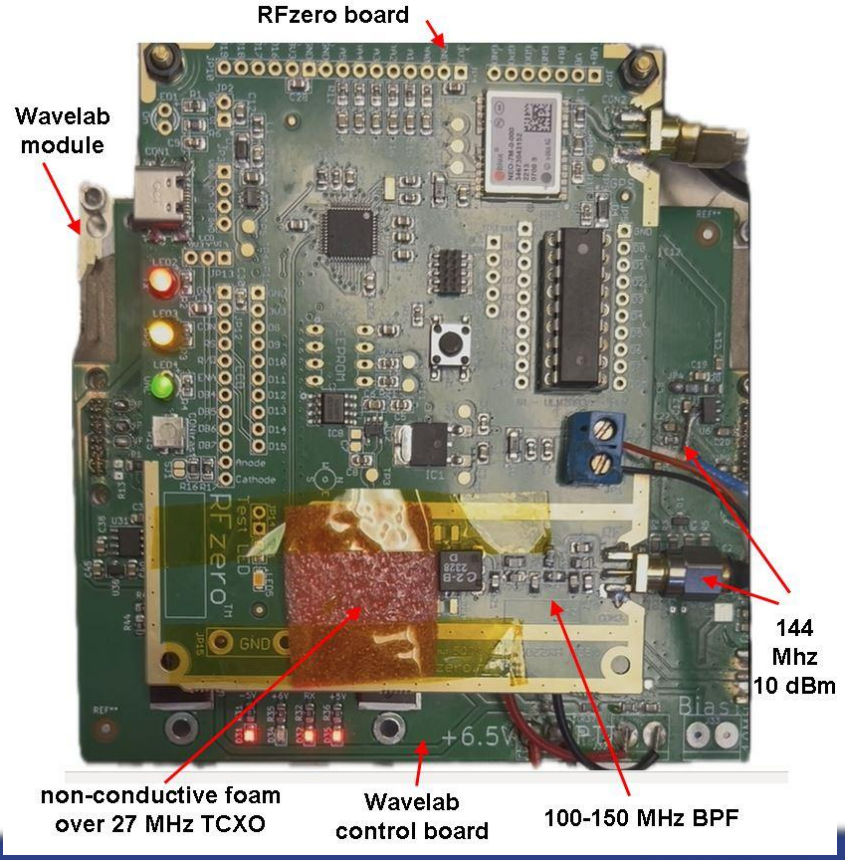
Empirical testing

- RFzero™ and Wavelab board/module. Note perturbation shield[6] over 27 MHz TCXO



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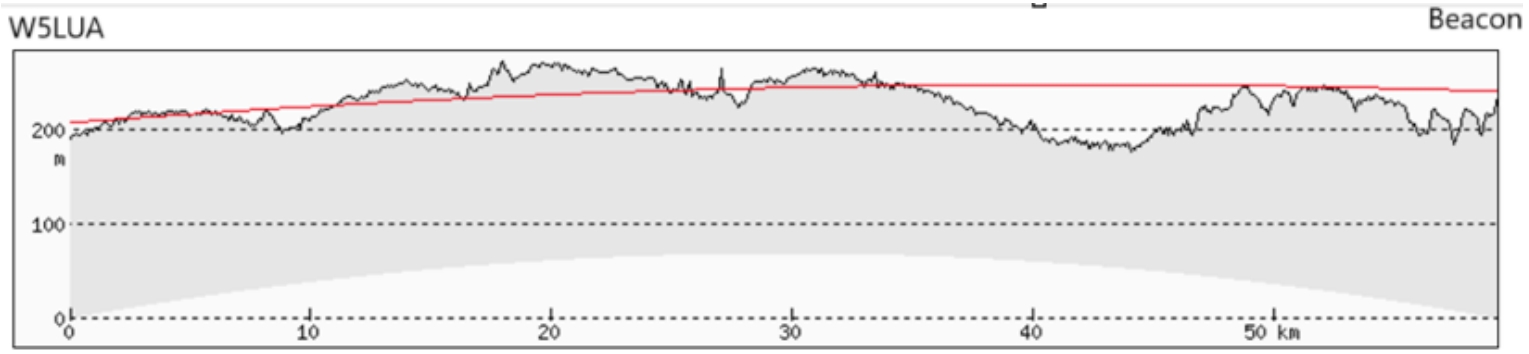
Empiracal testing

- Using a trailer mounted telescoping mast, the beacon assembly was raised to approximately 30 feet.
- The WSJT-X Q65B-30 signal was strong at 60 km and decoded 100% by Al Ward, W5LUA.



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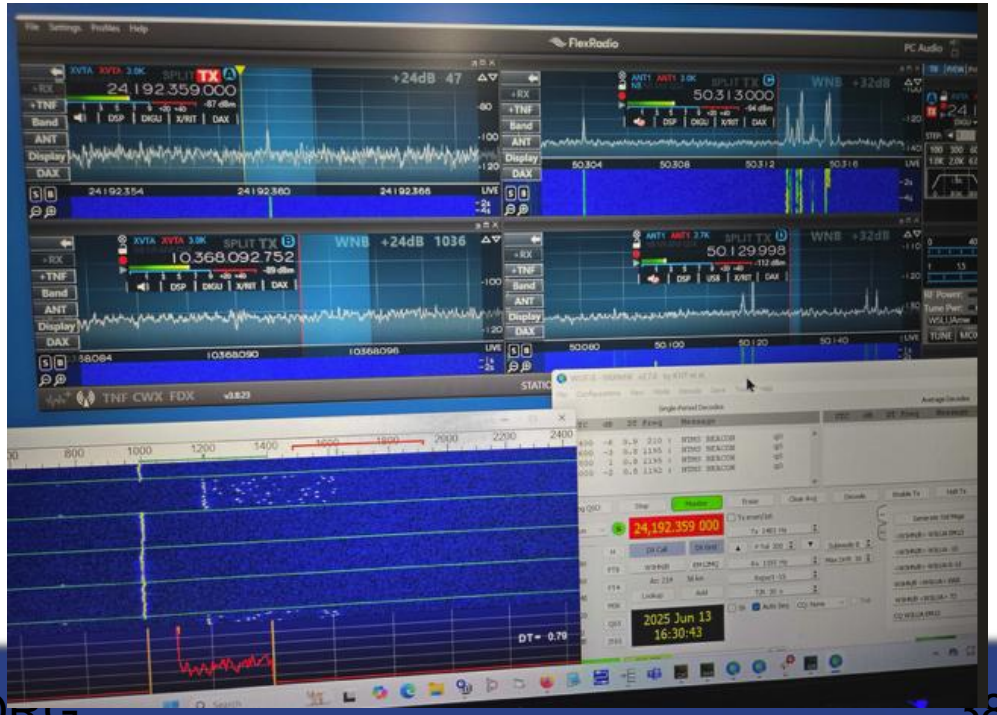
Empiracal testing

- Rotating the beacon 180 degrees, the WSJT-X Q65B-30 signal was decoded at -23 illustrating the W1GHZ broad pattern Sector Horn. Video is available[7]



Field setup

Conclusion

- The RFzero™ has been available for several years and offers a good choice as a beacon driver as well as other functions.
- A large user group exists, and the company provides prompt responses to questions.
- New releases of the Arduino scripts are made as corrections are found to be necessary.
- Note: use the latest release of the RF Manager which is version 1.9.0 (May 31, 2025 release)

Conclusion

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- Stability is sufficient to enable WSJT-X modes at VHF, UHF and microwave frequencies with attention paid to shielding the 27 MHz crystal oscillator.
- NTMS will implement the power control IC, the on-board GPS and the Arduino C++ coding (allowing modification of existing sketches) to reduce the parts count in our original design.

References

1. NTMS Beacon listing, http://www.ntms.org/files/NTMS_Beacons_Oct_30_2022.pdf
2. RFzero Manager app, https://rfzero.net/documentation/rfzero-manager/
3. Quick Start Guide to Q65, pp 2, and https://wsjt.sourceforge.io/Q65_Quick_Start.pdf
4. Tones Multiply functions https://rfzero.net/documentation/software/library/
5. Elsie filter designer, https://tonnesoftware.com/elsie.html
6. Perturbation shield, http://www.rfzero.net/documentation/modifications/
7. Video of 24 GHz beacon reception by W5LUA at 60 km, https://youtu.be/NDserMUyc6s?si=IoTrqHPPTpt2Sn5d

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Questions?