

Modern beacon design for mmWave incorporating WSJT-X

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Microwave Update 2025

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Modern Beacon Design

North Texas Microwave Society Beacon Strategy

It is a goal of the North Texas Microwave Society to maintain VHF, UHF and microwave beacons as a service to the ham community. Many of us have experienced unusual propagation effects while in operation over the air and the usefulness of beacons is well known for checking conditions and studying propagation. Beacons may also be used to verify equipment performance. NTMS has established a wide range of beacons¹ and are planning to install additional beacons at 24 and 47 GHz. As we drew up requirements for the new beacons, new options became available which deserved attention including the use of Wavelab modules and control board for 24 GHz and Tom William's (WA1MBA) Quadrupler for 47 GHz. We also require remote control of the beacons as we may not need to power the units 24/7. The final design required several devices including an Arduino to handle remote control polling and a custom 144 MHz oscillator with a separate PIC to key the beacon CW string and carrier. In visiting with Kevin Hobbs VE3KH, we learned of the RFzeroTM board which in theory would reduce our device count for the beacons plus add the functionality of modulated WSJT-X modes. See Figure 1 for block diagrams of version 1 and version 2 beacon designs. Adding Q65 mode to the 24 GHz beacon appeared to be possible and would take the propagation studies to a new level with *weaker than can be heard* signal detection and S/N values identified for documentation. The frequency synthesis in the Wavelab control board was already locked to GPS but would the RFzeroTM board provide adequate stability as a 144 MHz driver?

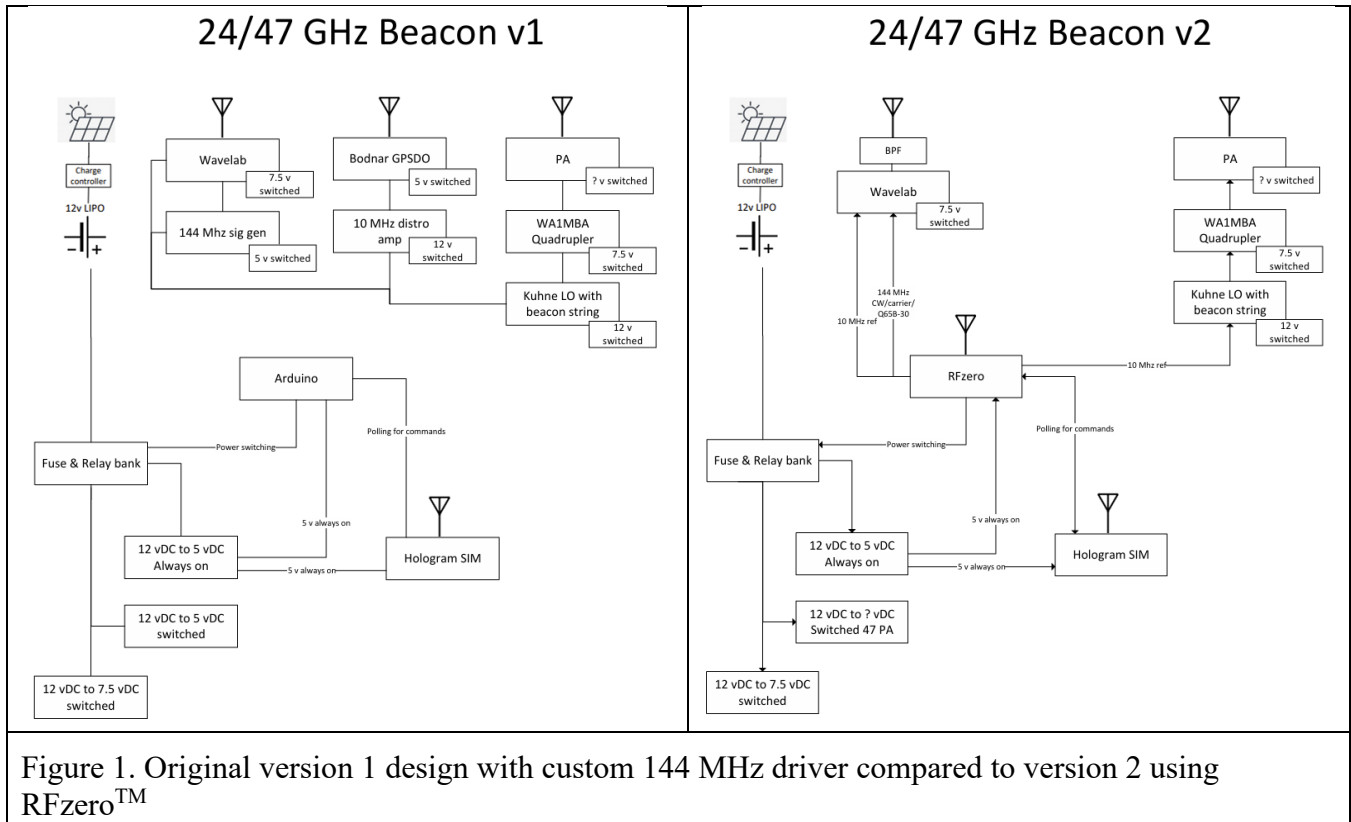


Figure 1. Original version 1 design with custom 144 MHz driver compared to version 2 using RFzero™

The RFzero™ board functionality and features

Figure 2 illustrates the parts of the board. A NEO-7M GPS receiver is tied to an ARM M0 processor which controls the Si5351A clock generator for frequency synthesis. The Si5351A is clocked by a 27 MHz crystal oscillator with continuous correction from the M0 processor once GPS is valid. On board EEPROM is updated with frequency correction factors for use in restarts. There are recommendations to provide a perturbation shield⁴, e.g. foam cover, over the Si5351A 27 MHz crystal oscillator which we found to be effective. A set of filter pads on the RF output stage allow for filters to be designed as needed. The USB port is used with a PC to program the board. There are several means of programming. For straightforward use, the app RFzero Manager³ can be used which permits configuration of supplied Arduino sketches and downloading them to the board. For customization, the Arduino IDE may be used along with the provided RFzero™ Arduino sketches or a sketch you create. The board is multi-function with ability to be a GPSDO on frequencies up to 280 MHz, a VFO with 1 mHz resolution, a standalone WSPR transmitter and beacon driver with a large selection of modulation modes (see Figure 3).

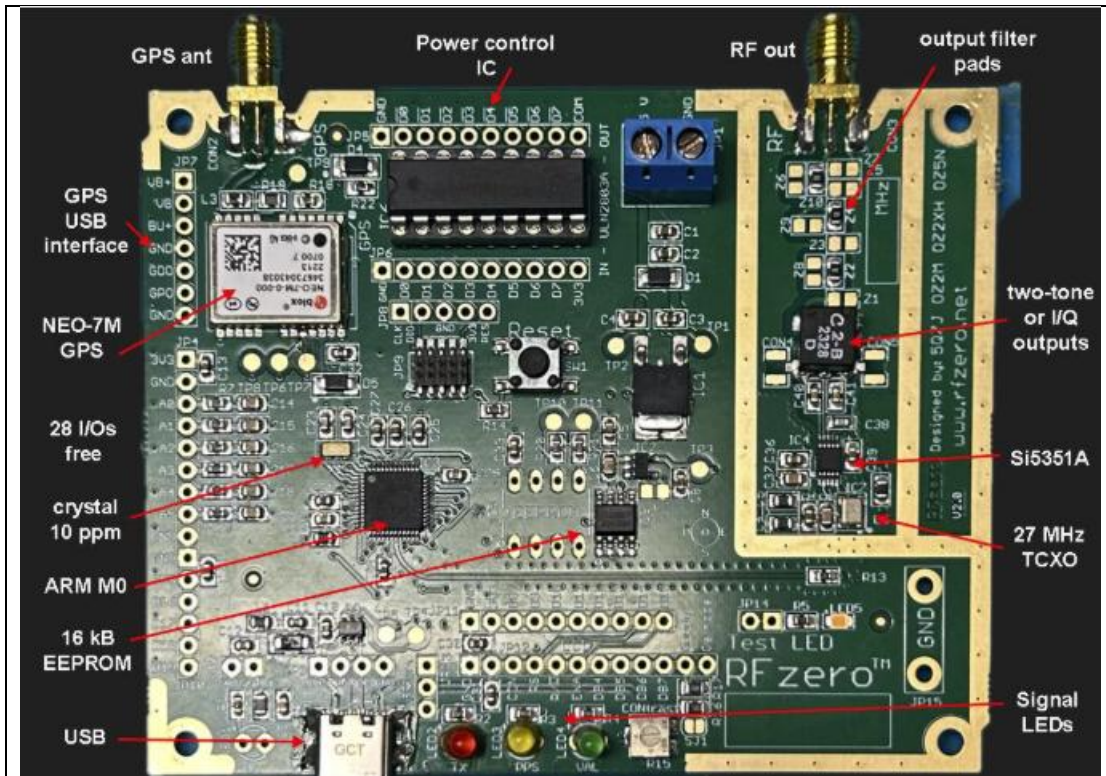


Figure 2. Features of the board

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

Figure 3. Beacon modes (not all modes shown)

Programming using RFzero Manager

The first task was to use the RFzero Manager to program the board for Q65B-30 at 144 MHz and observe the decode success over the air to a receiver ported to WSJT-X. Figure 4 shows the RFzero Manager interface which has the usual COM port selection, a long list of beacon modes that can be selected, a group of shortcut keys that can be used, and an input line at the bottom of an output window. In the illustration, the “rd cfg” [read configuration] command has been entered by pressing F2 (or could have been typed on the input line) which caused a response in green text within the large window identifying the current values of the board configuration. Pressing F1 or typing a “?” brings up the pertinent commands and value options for configuring the selected beacon mode type (see Figure 5).

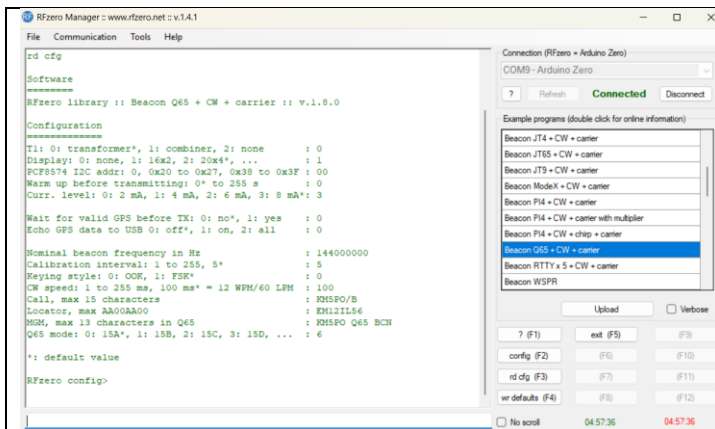


Figure 4. RFzero Manager interface with a config listing current state of the board

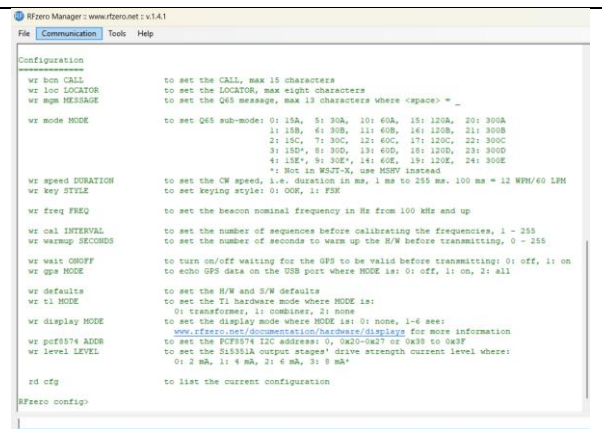


Figure 5. List of commands pertinent to Q65

Checking tone spacing bandwidth

Over the air tests proved that the WSJT-X mode was being transmitted correctly, in proper timing through GPS clocking, not drifting in ambient shop environment and decoding 100% on every transmission. But this was at 144 MHz. We moved on to checking WSJT-X tone spacing bandwidth before dealing with harmonics. Referring to the Q65 Quick Start Guide³ we noted that the Q65 30 seconds T/R Period (figure 6) had bandwidth spreads ranging from 433 Hz (sub-mode B) to 1733 Hz (sub-mode D). This seemed like a good place to start. As a side note, we have used Q65B-30 to complete contacts on both 24 and 47 GHz. To capture tone bandwidth spacing we used a 10 MHz referenced HackRF SDR with SDR Console software. After programming the board for Q65B-30 at 144 MHz, the tone bandwidth spacing was spot on in the SDR waterfall which was no surprise because the signal was decoding 100% in WSJT-X (Figure 7). Changing the sub-mode to Q65C-30 (Figure 8) and then Q65D-30 (Figure 9), we observed correct tone spacing in the SDR waterfall and WSJT-X decoding.

T/R Period (s)	A		B		C		D		E	
	Spacing (Hz)	Width	Spacing (Hz)	Width	Spacing (Hz)	Width	Spacing (Hz)	Width	Spacing (Hz)	Width
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

Figure 6. WSJT-X Q65 by T/R period and sub-mode designation

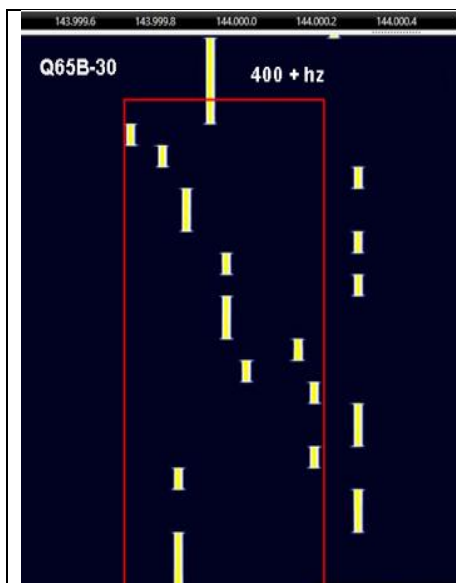


Figure 7. Q65B-30 spacing 433 Hz

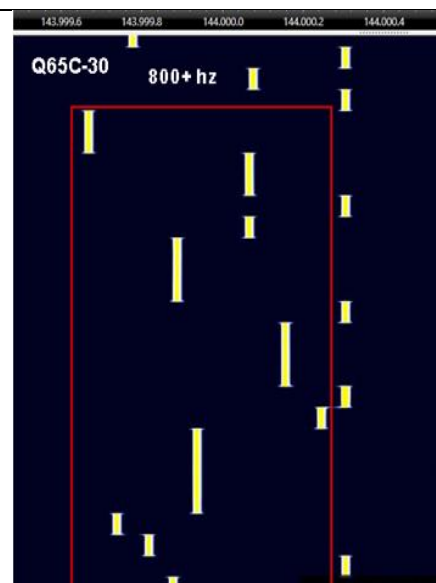


Figure 8. Q65C-30 spacing 867 Hz

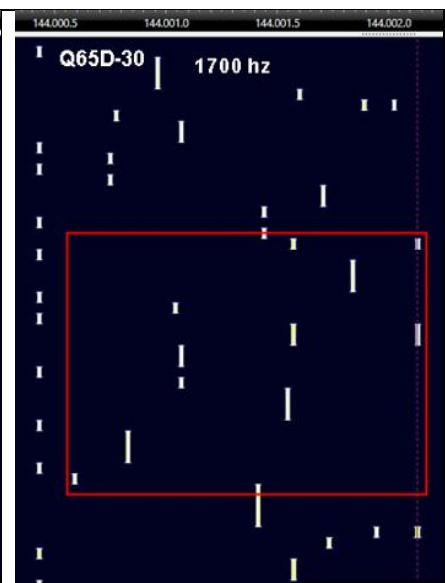


Figure 9. Q65D-30 spacing 1733 Hz

Managing harmonics

We then moved on to harmonic testing and working to understand the “multiply” feature noted in RFzero™ documentation. Simply 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 (see Figure 10).

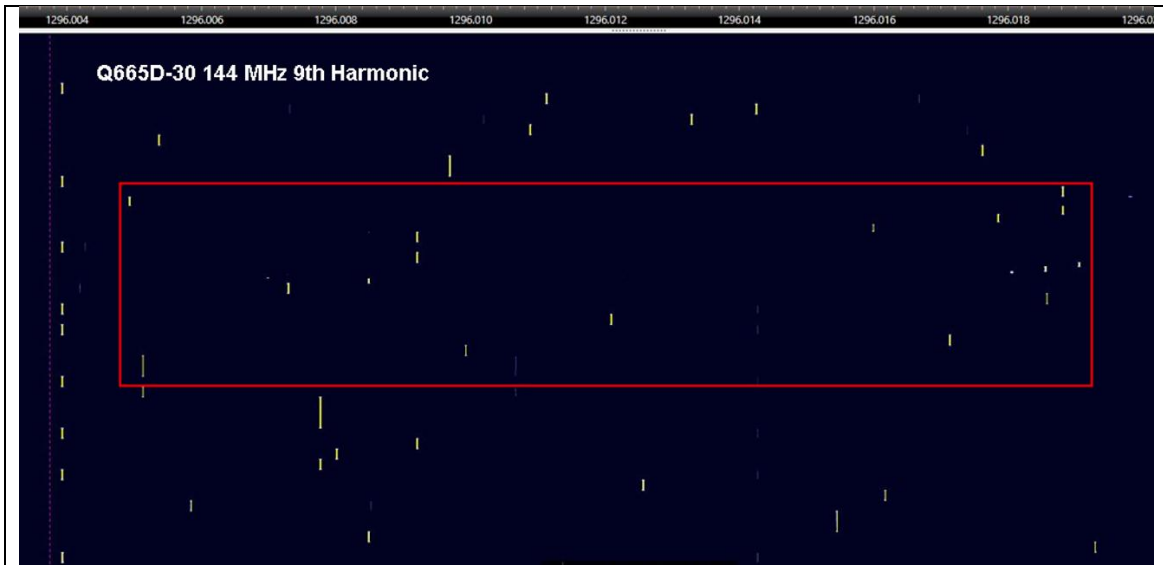


Figure 10. Q65D-30 9th Harmonic of 144 MHz. Occupying approx. 15.6 KHz

Digging in to 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. See Figure 12 for the RFzero Manager configuration report that now shows 1296 as output frequency and a multiplier of '7' which means the board output is 185.14 MHz producing a 7th harmonic signal with tone spacing adjusted. Figure 13 shows the correct tone spacing bandwidth for Q65D-30 at 1296 MHz. *Note: as of the time of this revision for 2025 Microwave Update, a newer version of the RFzero library is available (v.1.9.0) which we evaluate later in this document.*

```

RFZero Manager :: www.rfzero.net :: v.1.4.1
File  Communication  Tools  Help

Software
=====
RFzero library :: Beacon Q65 + CW + carrier :: v.1.8.0

Configuration
=====
T1: 0: transformer*, 1: combiner, 2: none      : 0
Display: 0: none, 1: 16x2, 2: 20x4*, ...      : 1
PCF8574 I2C addr: 0, 0x20 to 0x27, 0x38 to 0x3F : 00
Warm up before transmitting: 0* to 255 s     : 0
Curr. level: 0: 2 mA, 1: 4 mA, 2: 6 mA, 3: 8 mA*: 3

Wait for valid GPS before TX: 0: no*, 1: yes  : 0
Echo GPS data to USB 0: off*, 1: on, 2: all   : 0

Nominal beacon frequency in Hz                : 1296000000
Multiplier                                    : 7
Calibration interval: 1 to 255, 5*           : 5
Keying style: 0: OOK, 1: FSK*                : 0
CW speed: 1 to 255 ms, 100 ms* = 12 WPM/60 LPM : 100
Call, max 15 characters                       : RM5PO/B
Locator, max AA00AA00                        : EM12IL78
MGM, max 13 characters in Q65                : NTMS BEACON
Q65 mode: 0: 15A*, 1: 15B, 2: 15C, 3: 15D, ... : 8

*: default value

```

Figure 12. Correct configuration for 1296 MHz. Note Multiplier value of 7.



Figure 13. Correct tone bandwidth (1733 Hz) at 1296 MHz for Q65D-30 by using 7th harmonic of 185.14 MHz.

To make one final confirmation we set the board configuration for 10368.360 and observed a multiplier factor of 47 which calculates to be a fundamental of 220.6034 MHz which is exactly what we observe as output from the board (see Figures 14 and 15). Measurements were made with an external 10 dB attenuator in place on the SA input.

```

RFzero Manager :: www.rfzero.net :: v.1.4.1
File  Communication  Tools  Help

Software
=====
RFzero library :: Beacon Q65 + CW + carrier :: v.1.8.0

Configuration
=====
Tl: 0: transformer*, 1: combiner, 2: none      : 0
Display: 0: none, 1: 16x2, 2: 20x4*, ...      : 1
PCF8574 I2C addr: 0, 0x20 to 0x27, 0x38 to 0x3F : 00
Warm up before transmitting: 0* to 255 s     : 0
Curr. level: 0: 2 mA, 1: 4 mA, 2: 6 mA, 3: 8 mA*: 3

Wait for valid GPS before TX: 0: no*, 1: yes   : 0
Echo GPS data to USB 0: off*, 1: on, 2: all   : 0

Nominal beacon frequency in Hz                : 10368360000
Multiplier                                    : 47
Calibration interval: 1 to 255, 5*           : 5
Keying style: 0: OOK, 1: FSK*                : 0
CW speed: 1 to 255 ms, 100 ms* = 12 WPM/60 LPM : 100
Call, max 15 characters                       : RM5PO/B
Locator, max AA00AA00                        : EM12IL78
MGM, max 13 characters in Q65                 : NTMS BEACON
Q65 mode: 0: 15A*, 1: 15B, 2: 15C, 3: 15D, ... : 8

*: default value
  
```

Figure 14. Programmed output of 10368.360 yields a Multiplier of 47.

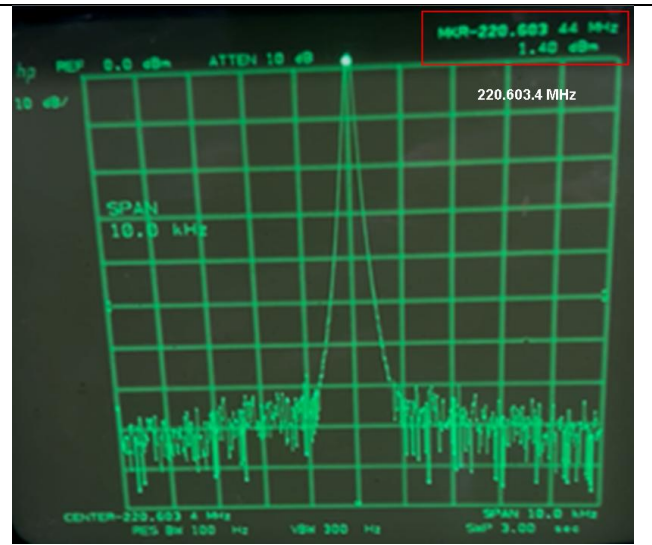


Figure 15. Observed fundamental output from board at 220.603.4 MHz

Adding Filters

To control the 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. The Elsie filter design program⁵ is free to use and has several good features that enable filter design. See Figure 16 for Elsie design parameters for the 100 – 150 MHz band pass filter, Figure 17 depicts a KiCad schematic of the filter and Figure 18 the Elsie theorized plot.

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

Figure 16. Filter design parameters for 100 – 150 MHz band pass filter

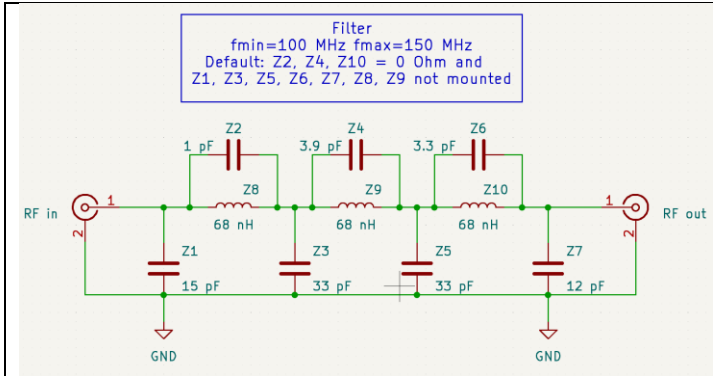


Figure 17. KiCad schematic of 100 – 150 MHz band pass filter

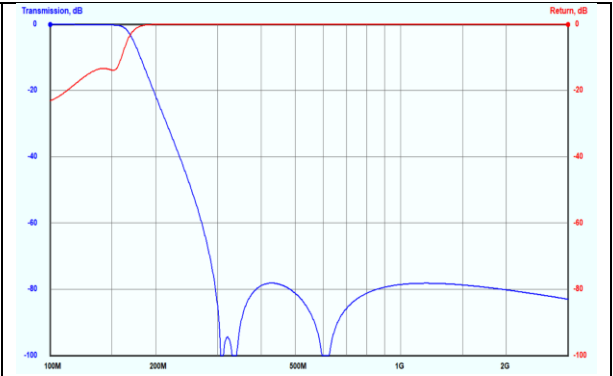


Figure 18. Elsie plot of 100 – 150 MHz band pass filter

Figure 19 shows the on-board filter pads in the RF output section with three shorting components placed by default. Figure 20 shows the filter SMD components placed after removing the default shorts. Figures 21 and 22 illustrate the before and after spectrum from 33 to 2500 MHz. Most of the harmonics are gone with a few significantly attenuated. Measurements were made with an external 10 dB attenuator in place on the SA input.

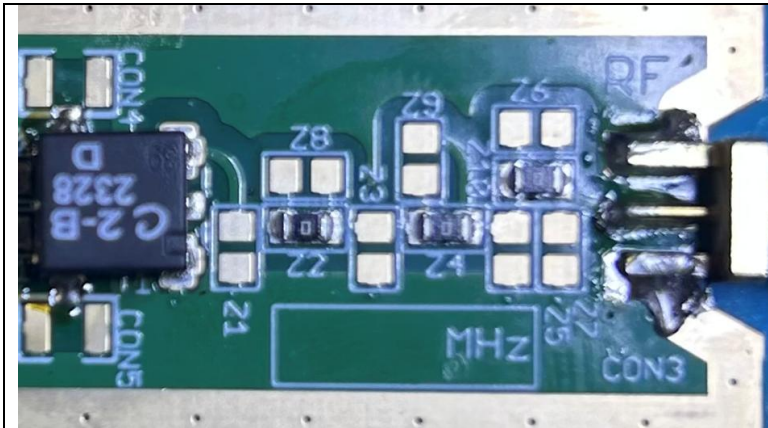


Figure 19. Filter pads in RF output section with default shorts placed

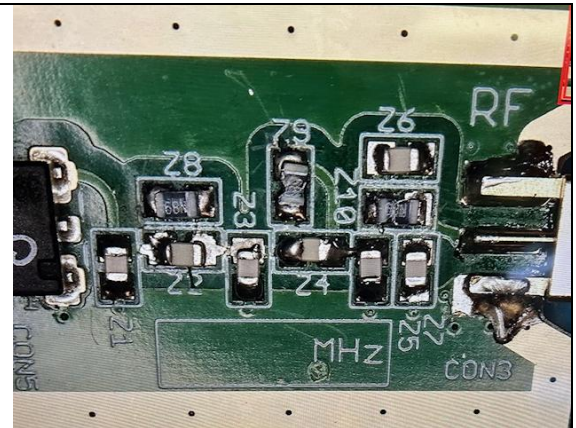


Figure 20. Components placed for band pass filter

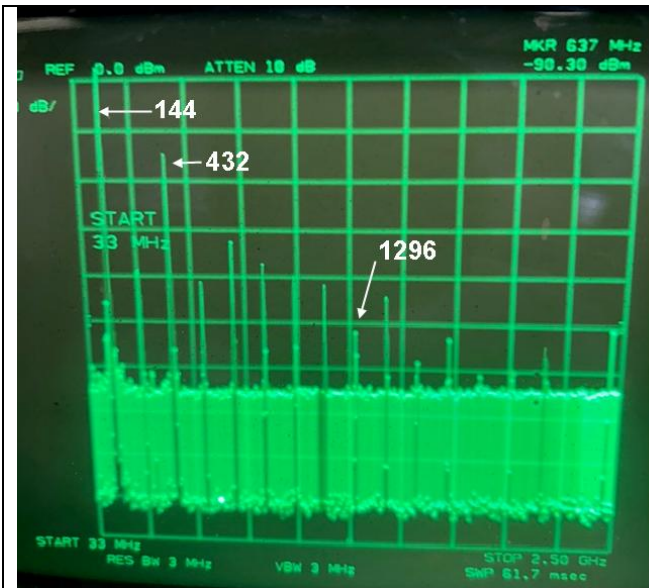


Figure 21. Spectrum (33-2500 MHz) before 100 – 150 MHz band pass filter.

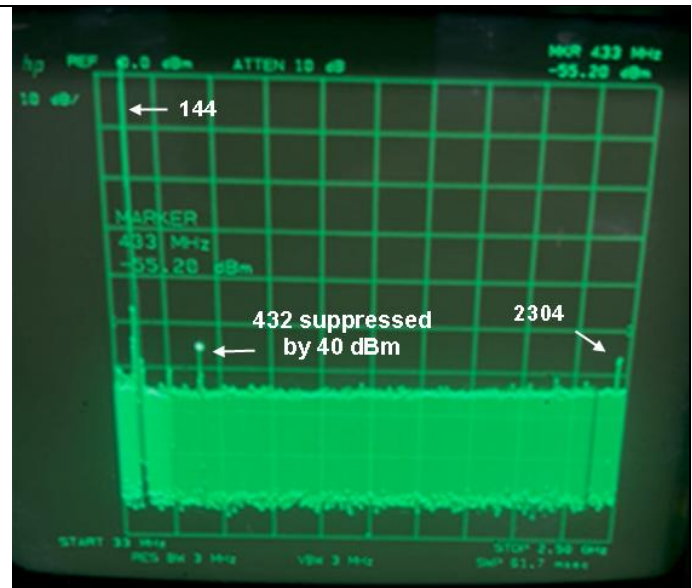


Figure 22. Spectrum (33-2500 MHz) after 100 – 150 MHz band pass filter.

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 Figure 23 for Elsie design parameters for the 400 MHz high pass filter, Figure 24 shows the Elsie schematic of the filter and Figure 25 the Elsie theorized plot.

.	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

Figure 23. Filter design parameters for 400 MHz high pass filter

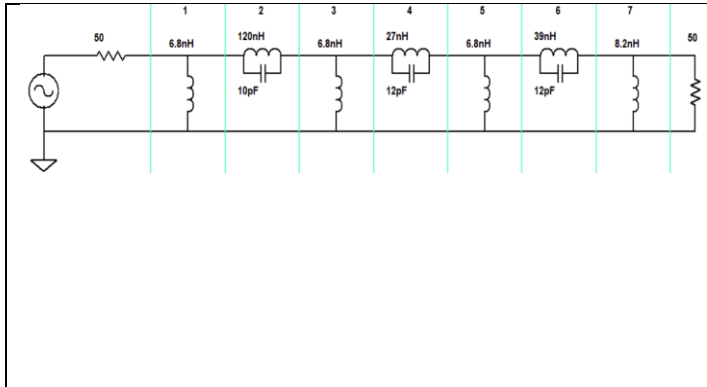


Figure 24. Elsie design schematic for 400 MHz high pass filter

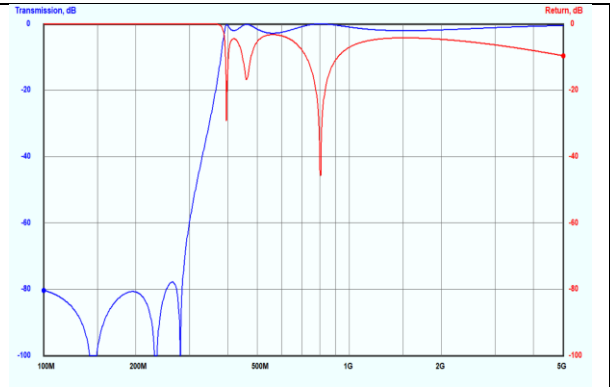


Figure 25. Elsie plot of 400 MHz high pass filter

Figure 26 shows the standalone “MultiFilter” PCB board available⁴. Figure 27 shows the high pass filter SMD components placed and SMA connectors added. Figures 28 and 29 illustrate the before and after spectrum from 33 to 2500 MHz. The 144 MHz fundamental is attenuated over 50 dB while the 1296 MHz harmonic has increased in strength by 10 dB. Measurements were made with an external 10 dB attenuator in place on the SA input.

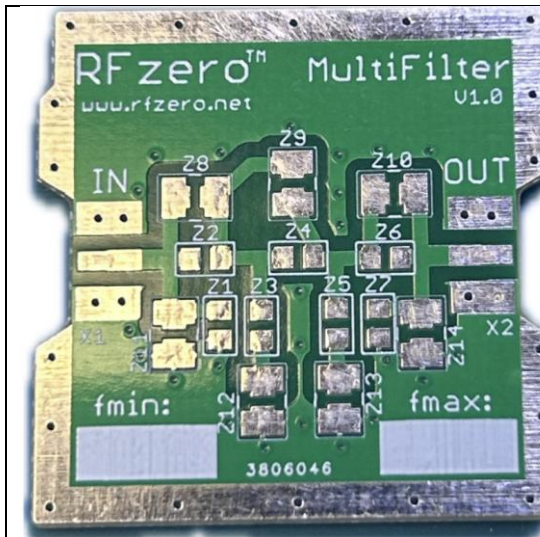


Figure 26. Standalone filter PCB

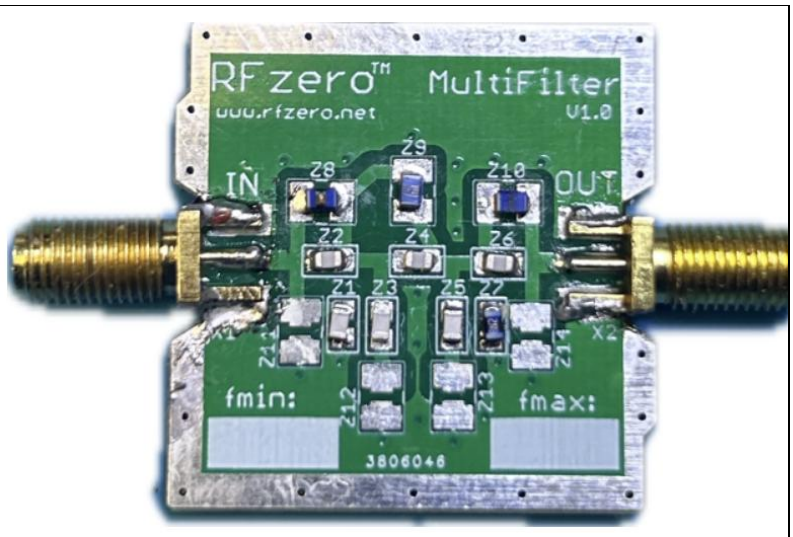


Figure 27. Components placed for high pass filter

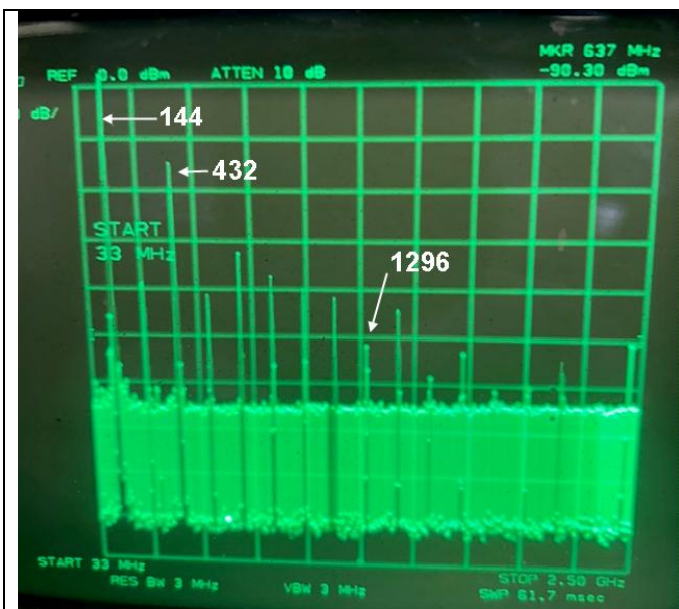


Figure 28. Spectrum (33-2500 MHz) before 400 MHz high pass filter

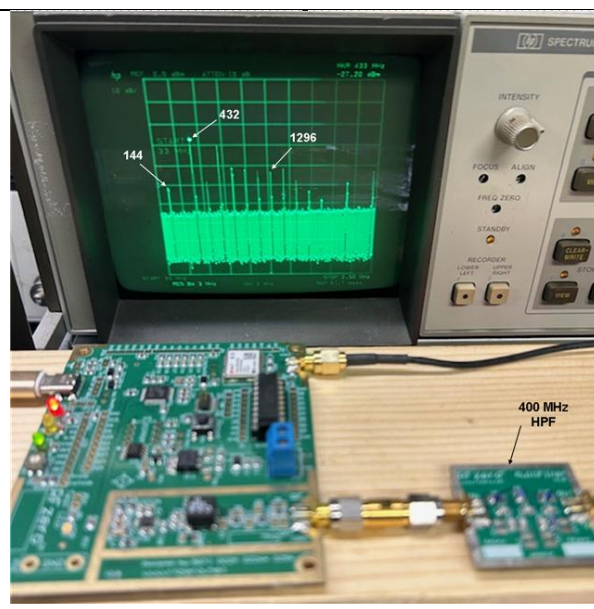


Figure 29. Spectrum (33-2500 MHz) after 400 MHz high pass filter

Empirical Testing

Real results are best, so we set out to use the board with the 100 – 150 MHz filter and adjust it's 144.360 MHz output to a level of 10 dBm and inject this ahead of the mixer in the Wavelab board (see Figure 30). This configuration drives the Wavelab board to full output (approx. 31 dBm) at 24192.360 MHz. Mounting the 24 GHz parts crowded the beacon prototype staging platform but was securely attached sufficient to take the beacon to the field and run OTA tests. Using a trailer mounted telescoping mast, the beacon assembly was raised to approximately 30 feet and was observed with strong signals (Figure 31) by Al Ward, W5LUA at a DX of 60 km (see Figure 32). Rotating the beacon in azimuth to point nearly 180 degrees away from Al, he was still able to decode the WSJT-X Q65B-30 signal at -23 dB. This illustrates the W1GHZ Sector Horn pattern which would seem to make a good antenna for our purposes. See Figure 33 and 34 for images of the test location with beacons deployed and the beacon assembly with parts notation.

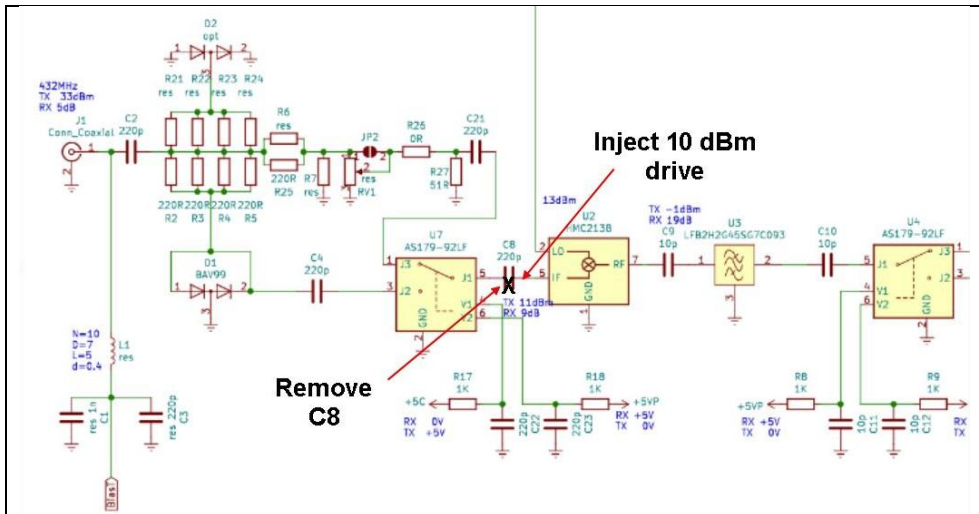


Figure 30. Wavelab control board IF RF injection point. Remove C8 and inject 10 dBm on empty C8 pad to pin 5 (IF) of U2 mixer.

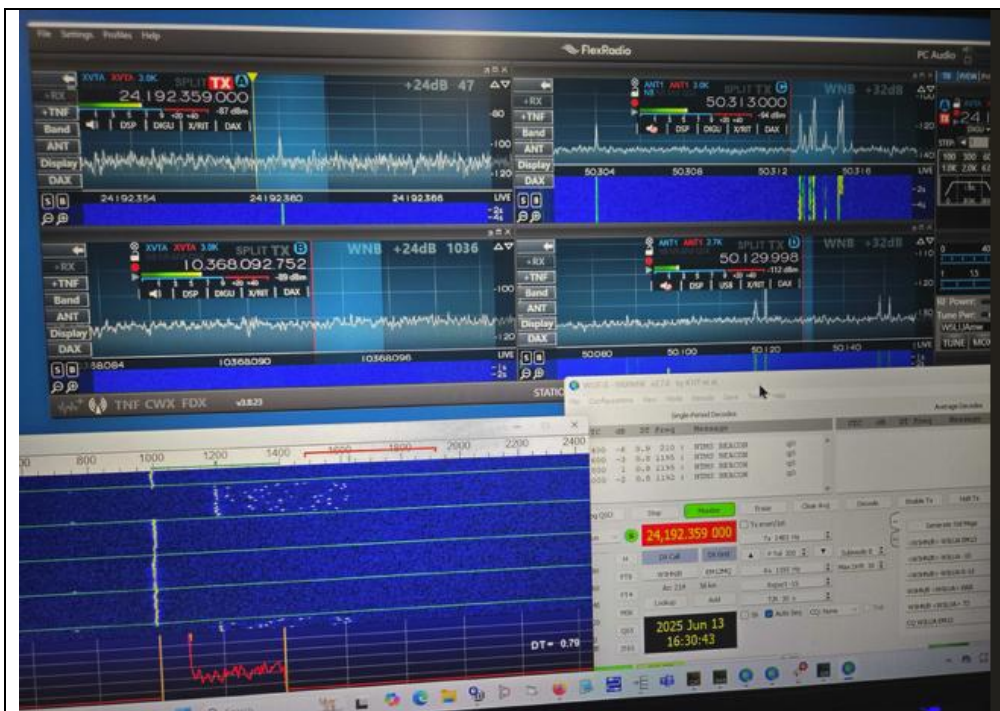


Figure 31. WSJT-X reception and decode of 24 GHz beacon at W5LUA. Video is also available⁶

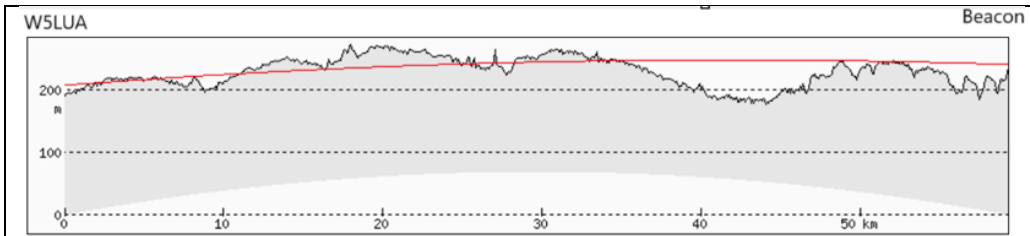


Figure 32. Path profile from beacon test location to W5LUA



Figure 34. Test location with beacons deployed

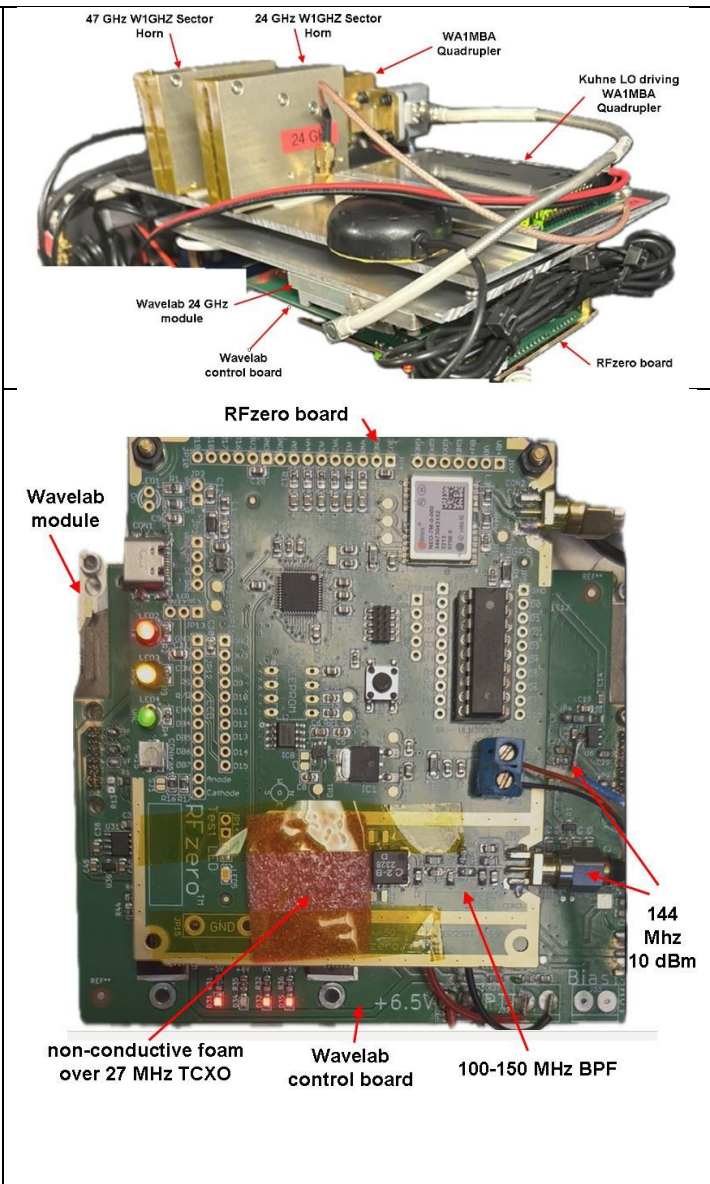
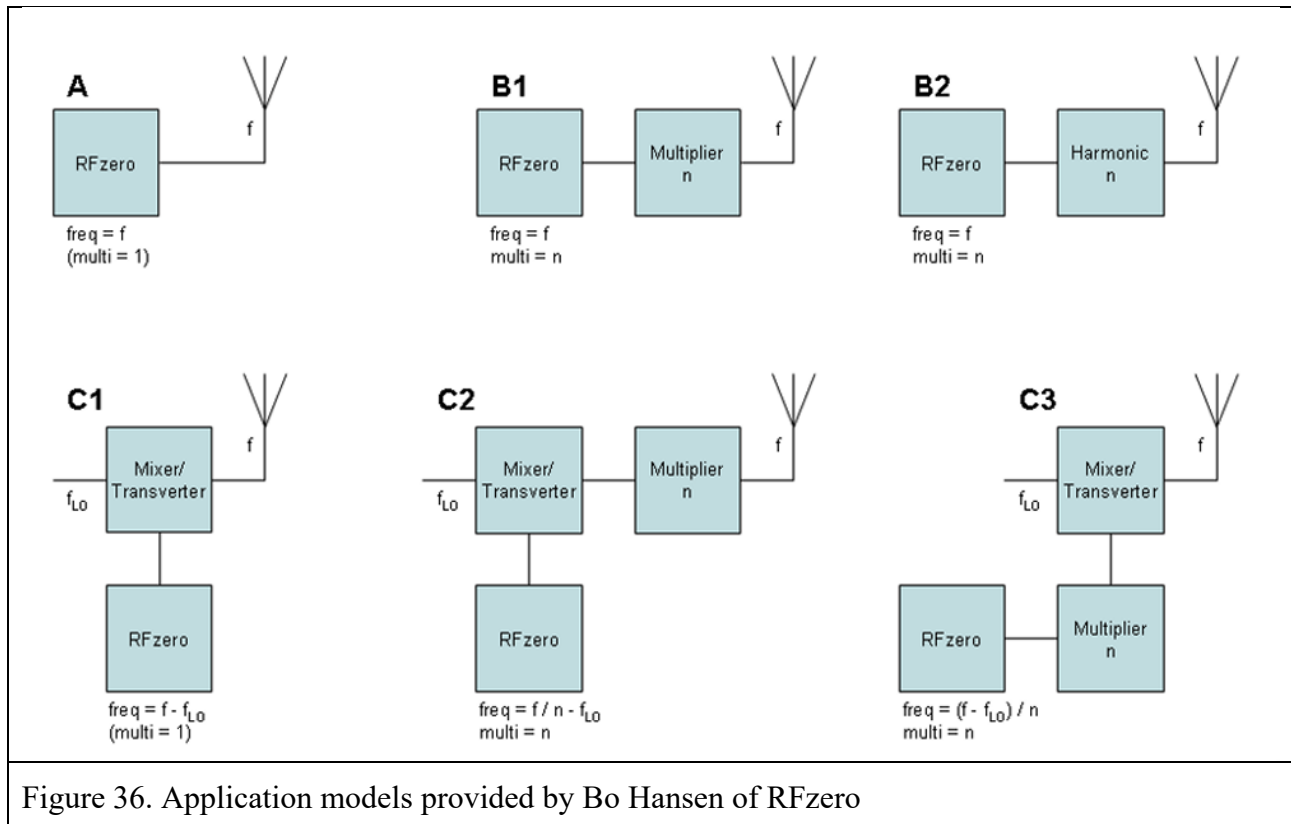


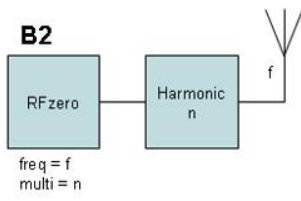
Figure 35. (top) upside of beacon assembly (bottom) underside of beacon

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Building on our understandings of the RFzero™ as implemented successfully in a 24 GHz beacon, it was our goal to add digital capability to our 47 GHz beacon which was CW/Carrier using a Kuhne 8-13 LO and Tom William's Quadrupler. We also felt it was appropriate to build a 10 GHz beacon with digital capability. For building beacons at these new frequencies that are driven by the RFzero™ required an understanding of the principles for different types of implementations. Figure 36 depicts the implementation designs which cover most installations.



For our 10 GHz beacon implementation we experimented with the B2 model which would use only the harmonic of the RFzero™. See Figure 37. We found that the transmitted 10 GHz signal would decode over the air but the stability was not great. See Figure 38.



10368360000/47=
 220.603404 MHz
 Fundamental
 Multi=47
 Q65 tone width and
 bandwidth is 1/47th of
 required tone width and
 bandwidth at the
 fundamental signal.

```

Software
=====
RFzero library :: Beacon Q65 + CW + carrier :: v.1.9.0

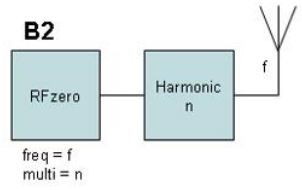
Configuration
=====

T1: 0: transformer*, 1: combiner, 2: none      : 0
Display: 0: none, 1: 16x2, 2: 20x4*, ...      : 1
PCF8574 I2C addr: 0, 0x20 to 0x27, 0x38 to 0x3F : 00
Warm up before transmitting: 0* to 255 s     : 0
Curr. level: 0: 2 mA, 1: 4 mA, 2: 6 mA, 3: 8 mA* : 0

Wait for valid GPS before TX: 0: no*, 1: yes  : 0
Echo GPS data to USB 0: off*, 1: on, 2: all  : 0

Nominal beacon frequency in Hz                : 10368360000
Frequency multiplication: 1 to 255, 1*        : 47
Calibration interval: 1 to 255, 5*          : 5
Keying style: 0: OOK, 1: FSK*               : 0
CW speed: 1 to 255 ms, 100 ms* = 12 WPM/60 LPM : 200
Call, max 15 characters                       : W5HN/B
Locator, max AA00AA00                         : EM12IL78
MGM, max 13 characters in Q65                 : W5HN/B EM12IL
Q65 mode: 0: 15A*, 1: 15B, 2: 15C, 3: 15D, ... : 12
  
```

Figure 37. 10 GHz beacon using B2 model.



RFzero signal
 transmitting OTA at 47th
 harmonic is decoding
 100% but is “wiggling”
 (1 pps freq correction)
 in frequency (24 hours
 of testing)

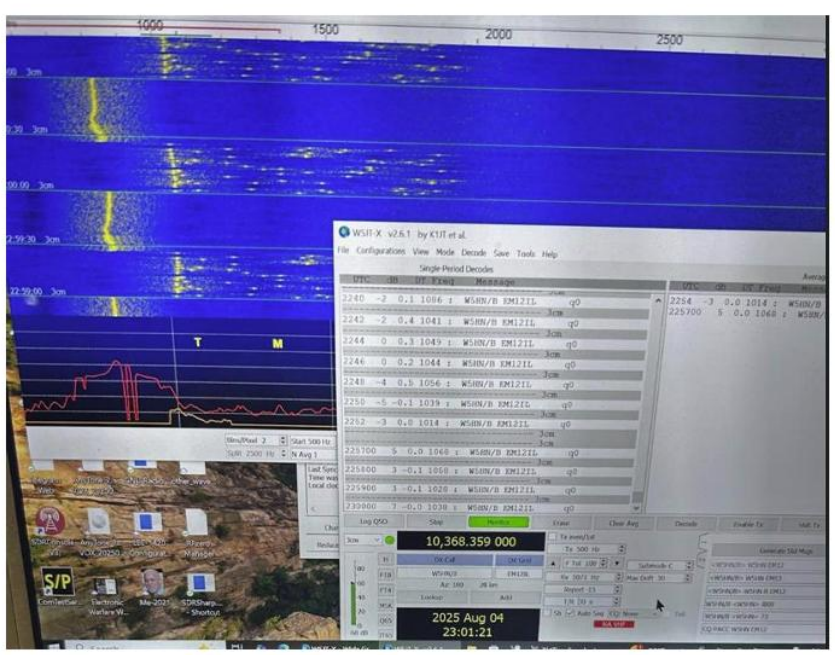


Figure 38. Q65 signal decodes but exhibits modest instability.

Next, we integrated a C2 model for 10 GHz employing a mixing stage using the RFzero as IF, a DEMI DigiLO as LO, and then driving into a W1GHZ LO multiplier board followed by a JCA 2 watt PA. This integrated well but we will add a waveguide filter in front of the PA before permanent deployment. See Figure 39.

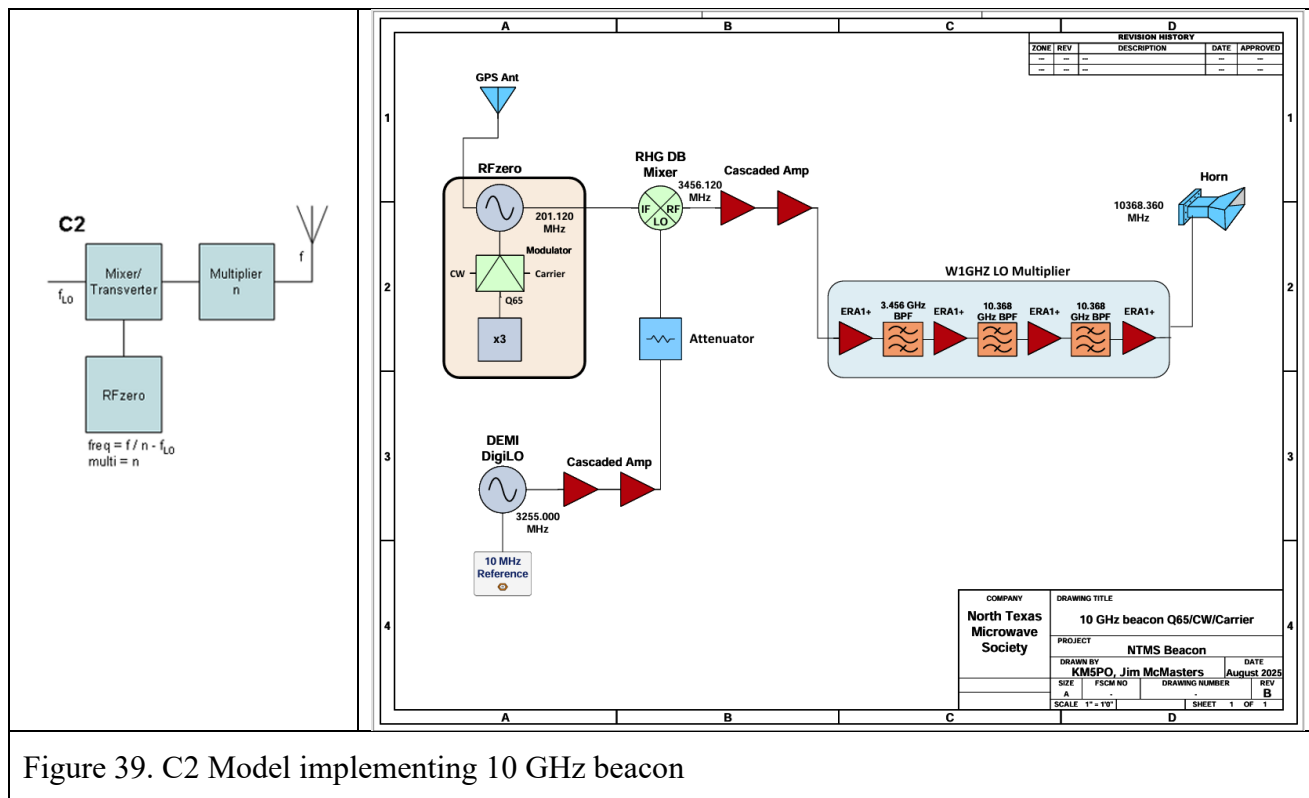


Figure 39. C2 Model implementing 10 GHz beacon

Reviewing our 24 GHz beacon which was successfully implemented we identify the strategy as C1, without harmonic usage. See Figure 40.

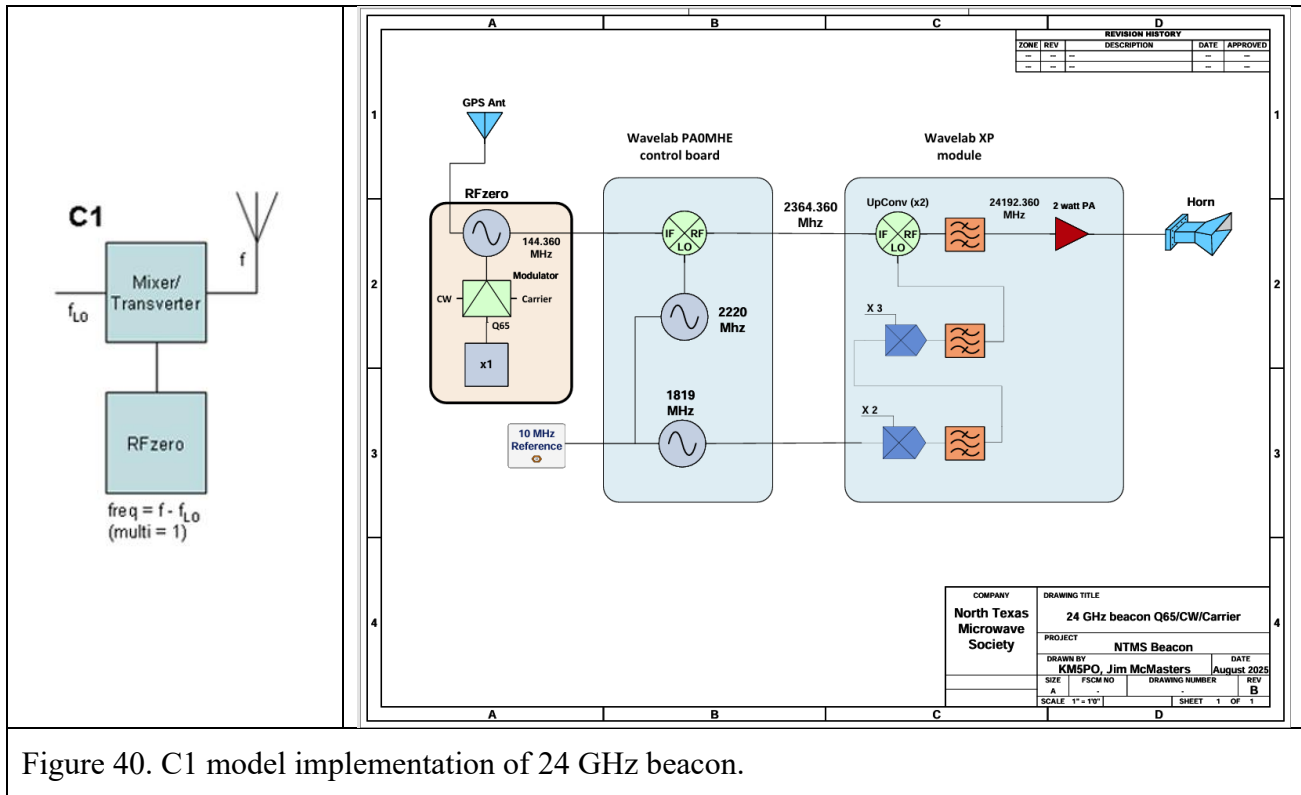


Figure 40. C1 model implementation of 24 GHz beacon.

47 GHz

Moving on to the 47 GHz beacon, Tom Williams provided the RF design and worked to implement the correct RFzero™ configuration. We found that a new configuration model was evident as shown in Figure 41. Tom's RF design is shown in Figure 42.

As shown in figure 36 there are several ways to create signals for beacons when starting with a VHF signal. Those ways (models) involve multiplication and mixing. One problem with multiplication is that phase noise sidebands increase in amplitude twice as fast as the multiplier. For example, when doubling the frequency, the noise sideband at any particular offset has 6 dB more noise. If multiplying by 200 such as might be done by choosing a VHF frequency in the RFzero™ normal range of 235.4418 MHz to achieve 47.088360 GHz (in figure 36, model choices B1 or B2), then at any particular offset the phase noise would increase by 43dB. The RFzero™ does have a pretty clean signal, but this phase noise increase is quite large. Furthermore, any GPS-induced warble is multiplied by 200 which can become noticeable in the output.

Another base model is taken that uses a lower multiple of the RFzero™ and mixes it before final multiplication from 11 GHz range to 47 GHz range as is shown in Figure 36 as choice C2. This approach generates a harmonic of the RFZero™ at 435 MHz which can be well filtered by inexpensive connectorized filters easy to obtain (\$13 or less on Amazon). It is also possible to arrange a filter design on the RFzero™ board to serve this purpose, but the inexpensive SAW filter seemed very effective and cheap. 435 MHz can be mixed with a local oscillator from a synthesizer at 11337.090 MHz to produce

11772.090 MHz which can then be fed into a quadrupler to generate 47088.360 MHz. This is a bit more complex than simply multiplying the VHF up to 11 GHz then EHF, but it is likely to have less phase noise (results should always be measured to be sure). Also, this approach that multiplies the RFZero™ fundamental by 12 or 16 would have considerably less warble at 47 GHz than a purely multiplied approach as mentioned above.

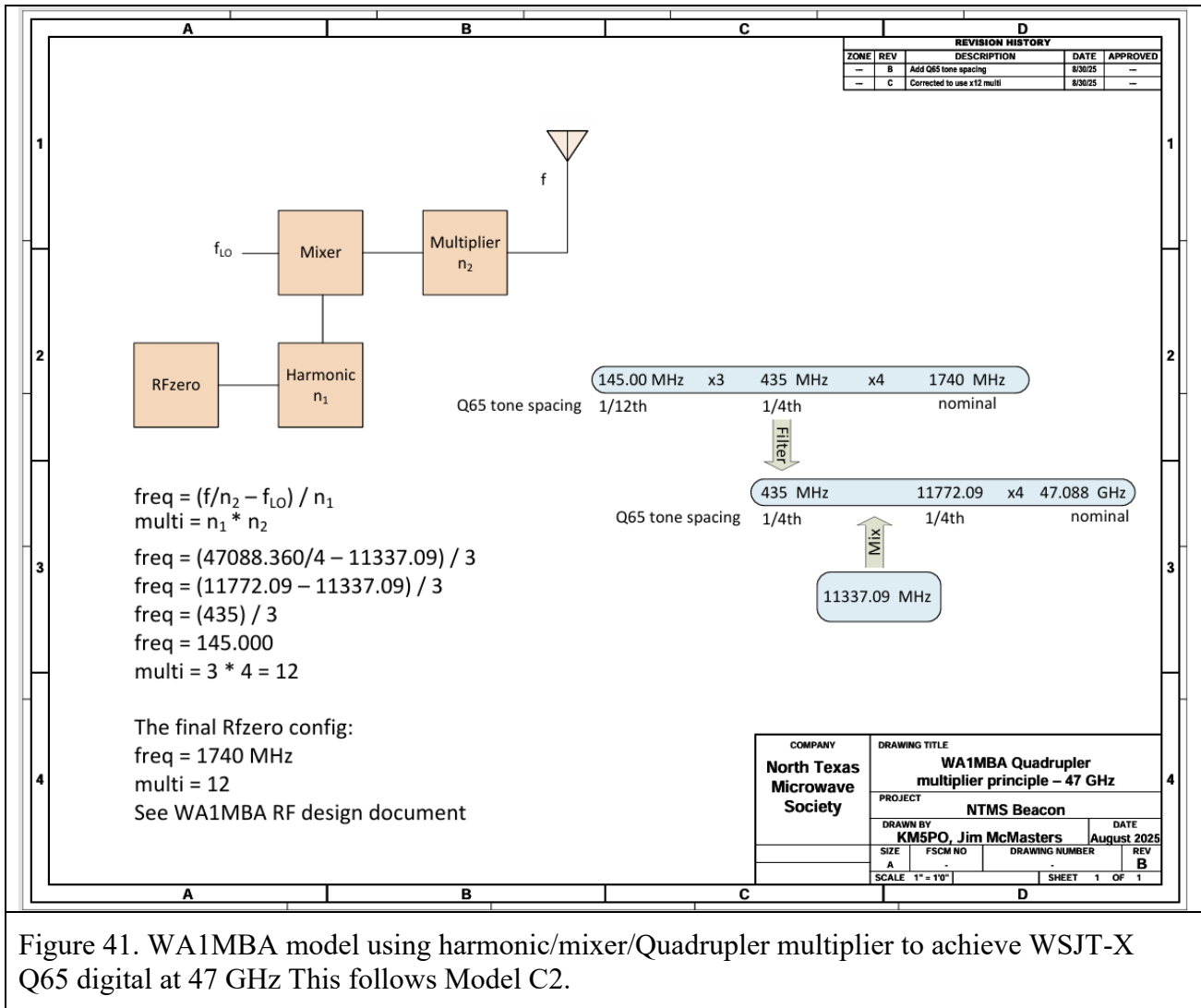


Figure 41. WA1MBA model using harmonic/mixer/Quadrupler multiplier to achieve WSJT-X Q65 digital at 47 GHz This follows Model C2.

Choosing the final frequency and multiple for the configuration

The total multiplication is the harmonic times the Quadrupler. The RFzero™ config software has to know the multiplier and final frequency so that it can 1) choose a harmonic, 2) set the fundamental frequency, and 3) divide the Q65 tone spread. The RFzero™ can operate well up to the 200 MHz region. To let the configuration software do its job, we have to tell it the final frequency and the multiple.

Our “final” frequency is not the actual frequency being mixed at the mixer, but is 4 times that because of the quadrupler. We know we want to get some harmonic from the RFZero™ to be at 435 MHz, and will

tell the configuration software that we are trying to get to $435 \times 4 = 1740$ MHz. Then we have to choose a multiple which when used to divide 1740 by 4 falls into a harmonic of the RFzero™ range. One might think to simply tell the RFzero™ to operate at something that generates 435 MHz, but remember the modulator must know the total multiplication in order to divide the Q65 tone spread so that after multiplication the modulation is correct.

For instance, x16 would mean the 4th harmonic of the RFzero™ multiplied by the quadrupler equals 1740 MHz. If we tell it “16” the config software would choose 108.75 MHz, which has a 4th harmonic of 435 MHz. If instead we choose “12”, that means the 3rd harmonic of the RFzero™ would be needed and the RFzero™ would be set at 145 MHz. Both were tried and both worked. It is a good practice to try these possible multipliers out and use a spectrum analyzer to see where the software sets the RFzero™ fundamental frequency. We found that the RFzero™ output power on the 3rd harmonic of 145 MHz was at a higher power level than the 4th harmonic at 108.75 MHz. We chose x12 for this reason. When trying out possible multiples which will force different fundamentals in the RFzero™, we recommend measuring the output levels to see how they fit your system design.

Because the RFzero™ is using a 3rd harmonic in our beacon design, then based on the overall multiple of 12, just under 22 dB of noise will be added to the original 145 MHz RFzero™ signal phase noise at any offset. That is considerably less than the 43 dB that a direct multiplier (model B1 or B2) would likely generate as described earlier. This approach also uses an LO for up conversion, and phase noise of the LO has to also be considered as it is multiplied by 4 in the quadrupler yielding 12 dB of added noise at any offset to its output.

How bad might phase noise be?

For comparison, I think of what kind of phase noise is generated by a typical 47 GHz radio. Most synthesizers have fairly low phase noise, and any modern 47 GHz transceiver would of course have its own synthesized local oscillator with the same amount of multiplication. So, as signals go, the actual phase noise from this beacon is likely to be more (worse) than most amateur's radios (because of the multiplied modulated IF), but less (better) than a purely multiplying beacon. Until actual measurements are made, this thought experiment is little more than that.

The circuit for the mixer approach

Back to reality, the model (see Figure 41, based on model C2) consists of the RFzero™ (GPS disciplined) operating at 145 MHz, and its 3rd harmonic mixed with an LO and that product multiplied by 4 (quadrupled) to 47 GHz. This model diagram gives us the overall picture of operation showing that the frequencies being used work to generate the desired output.

Figure 42, a schematic of the device connections provides detail of how the system is wired. The RFzero™ has its output driven through an inexpensive “433 MHz” SAW filter (which is about 10 MHz wide), and the resulting 435 MHz further amplified (surplus gain block) and fed into the IF port of a double balanced mixer. A synthesizer (such as an ADF5355 based circuit) which could be a relatively expensive Khune 8-13LO or possibly another source, is set to 11337.090 MHz and drives the LO port of the mixer at +7 dBm. There is plenty of power from this synthesizer and needs to be adjusted down and/or attenuated to the right level. I found that operating it at full power and adding a 6 dB attenuator

set the level to +7. Some inexpensive synthesizers might need a small amount of amplification to serve as an LO. In this circuit, amplification was required after the mixer to bring the 11.77+ GHz level up to the required input level of +5 dBm for the Quadrupler. Two inexpensive W1GHZ LNAs were used because they were handy. See Filtering below regarding future thoughts on amplification of this signal.

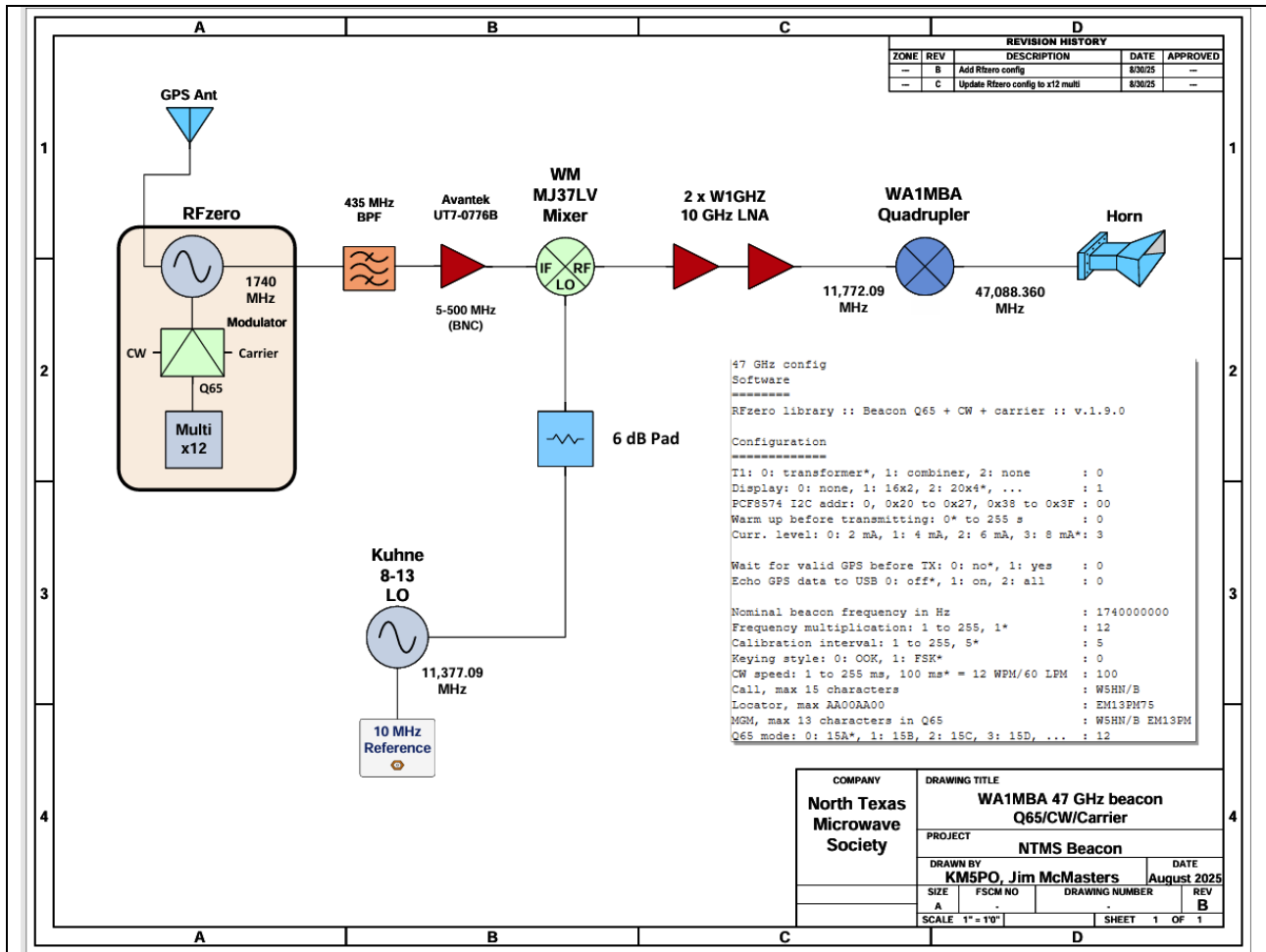


Figure 42. WA1MBA RF design for RFzero™ driven 47 GHz beacon.

Filtering

The output of the mixer will have some residual LO, the $LO+435 = 11772.090$ MHz which is the desired output, and the undesirable image at $LO-435 = 10902.09$ MHz. Some of the LO and much of the image must be filtered to keep their levels far beneath the desired beacon signal. This is especially true of the image as $10902.09 \times 4 = 43608.36$ is far outside the 47 GHz amateur allocation. Even the LO is at 44908.36 is outside the amateur 47 to 47.2 GHz band. Double balanced mixers usually have pretty good LO/RF isolation better than 20 dB. A good target would be to attenuate the LO by another 30 dB and the image by 60. This kind of filtering can be done with pipe-cap filters. Two of them in

series, with amplification between and after can achieve the kind of filtering we want. This filter was not available when the system was constructed for initial tests, and so it is not shown in the diagram Figure 42. Given the filter losses, further amplification is probably needed to achieve the +5 dBm at 11772.090 required as input to the WA1MBA Quadrupler. That Quadrupler will output about +13 dBm (20 milliwatts) at 47 GHz into WR22 waveguide for direct connection to a sector horn (or further amplification).

Fortunately, there is a circuit board with a two pipe-cap filter at X band with amplification available. It is part of the W1GHZ 10 GHz LO / Personal Beacon Board. At the time of this writing, that filter has not been employed for this purpose. However, one of these should be ready and measured before the conference. If so, it will be presented.

See figure 43 for the new implementation of the 10 GHz beacon.

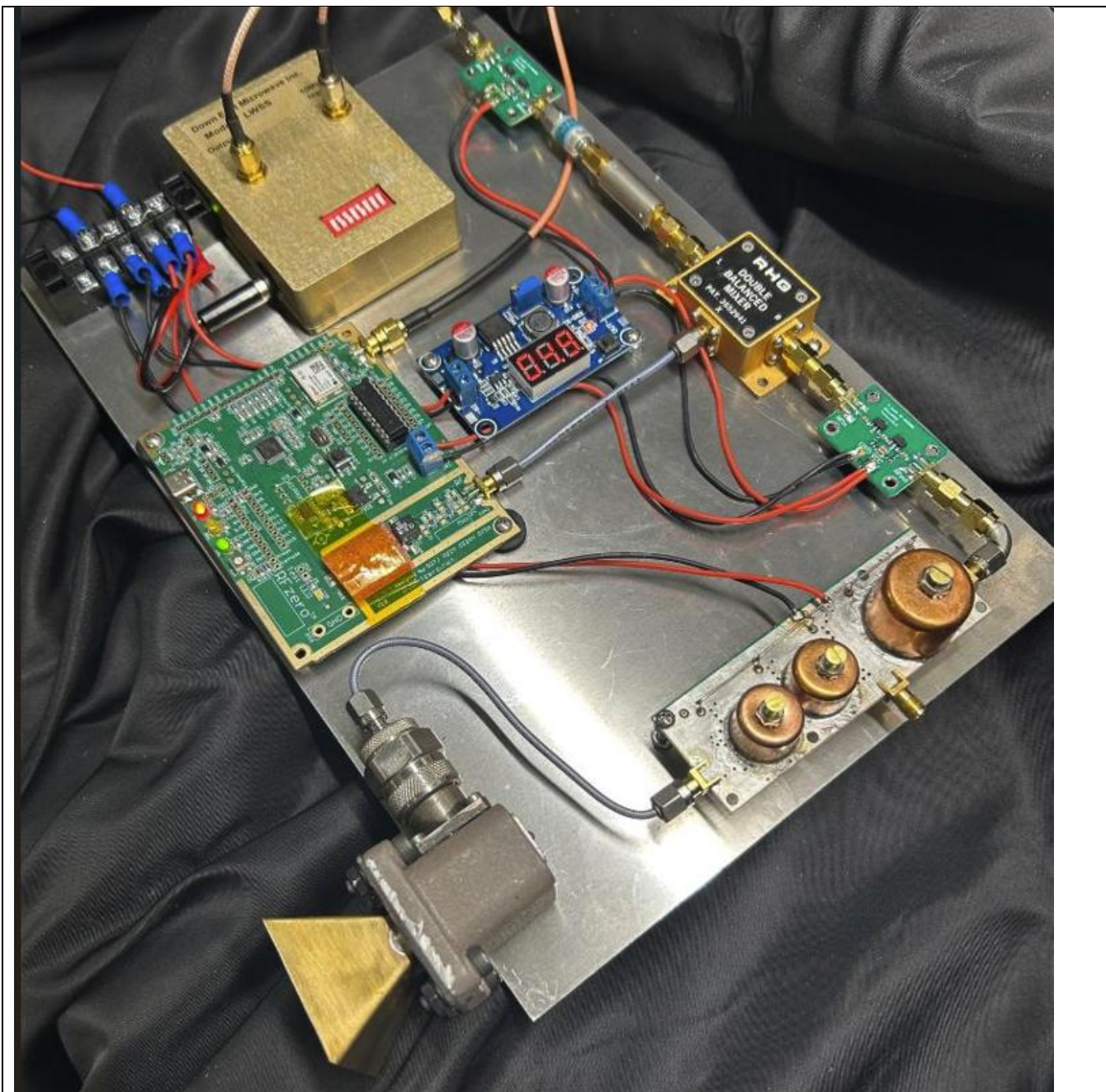


Figure 43. 10 GHz beacon driven by RFzero with Q65 / CW / Carrier modulation

See figure 44 and 45 for the new implementation of the WA1MBA 47 GHz design.

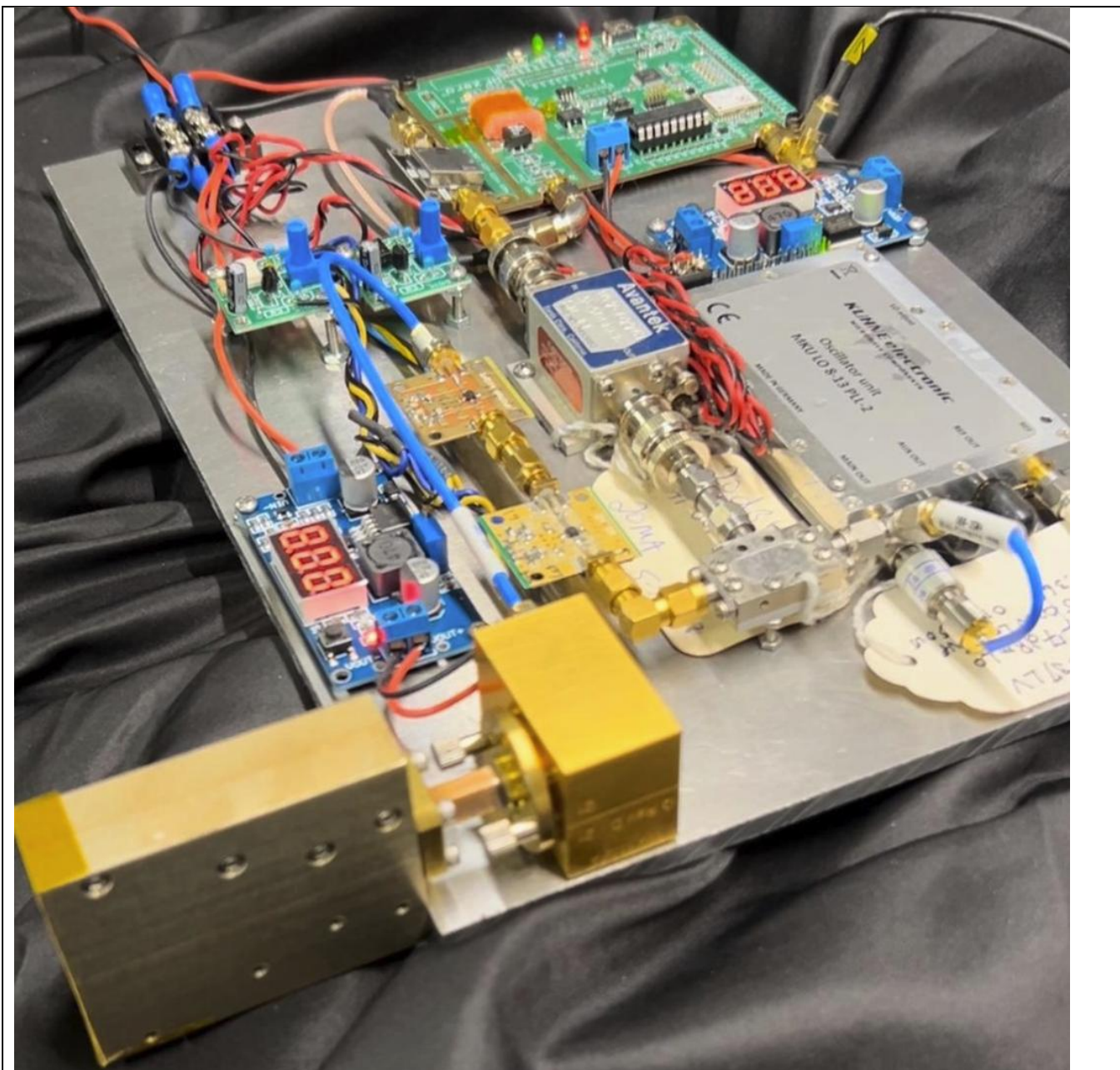


Figure 44. WA1MBA 47 GHz beacon implementing WSJT-X Q65 mode

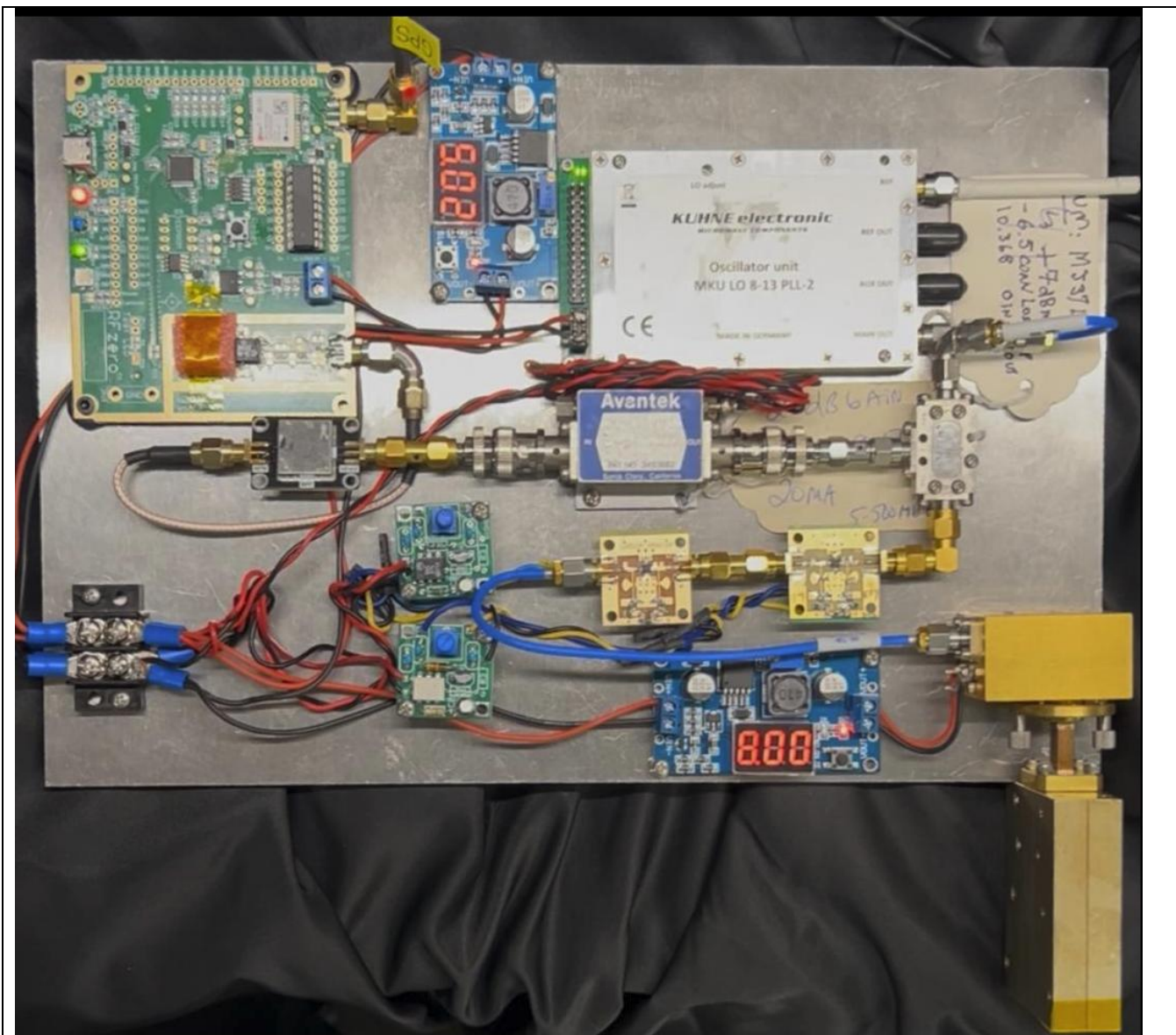


Figure 45. WA1MBA 47 GHz beacon implementing WSJT-X Q65 mode

See Figure 46 for continuous decode of Q65 60=C at 47 GHz with acceptable drift values.

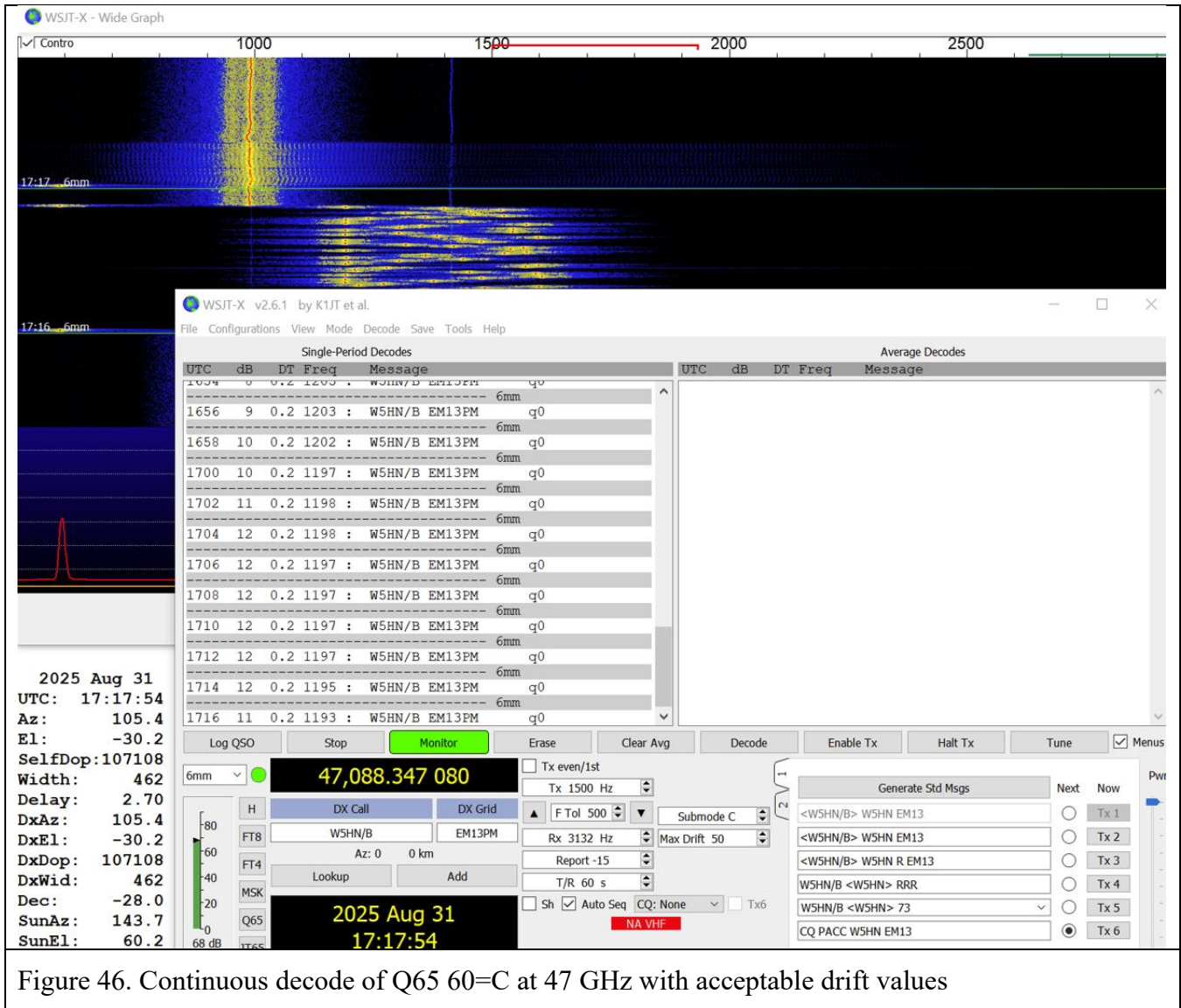


Figure 46. Continuous decode of Q65 60=C at 47 GHz with acceptable drift values

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. 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.

Additional work to do:

1. Add JCA 10 GHz 2-watt PA

2. Add 10 GHz waveguide filter
3. Add Qorvo QPA0524 PA and bias board for 24 GHz
4. Add 24 GHz waveguide filter
5. Add a multiple pipe-cap filter to the 47 GHz design, test and measure
6. Add 47 GHz PA

References

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3. Quick Start Guide to Q65, pp 2, and https://wsjt.sourceforge.io/Q65_Quick_Start.pdf
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