An Approach to 5.7, 10, 24 and 47 GHz Q65 Mode Beacons

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Modern beacons can do more than Morse Code ID

Although the efforts and results presented in this paper were a team project, one of us had to write the article you are reading, and that is Tom WA1MBA. So, when you read “I” or “me” it is Tom speaking.

Over the years amateurs have set up many beacons on many frequencies for a variety of purposes. Most obvious are perhaps propagation testing and home station receive assurance. Additionally, we have grown to know which beacons are more likely to be on frequency. We are able to align or adjust the position indicators for our antennas, as beacons are stationary at well-defined locations. To further those uses, and to increase the activation of some of the higher frequency bands, some amateurs have built and installed beacons on the higher microwave bands. These help portable stations considerably as they offer comfort and certainty regarding receive performance, frequency and antenna pointing.

Now that we have various digital modes, it is possible to detect, decode and quantify signals that are difficult or even impossible to hear by ear. That capability increases the range over which such beacons can be useful, and increases the number of stations that can use them to include those with lower performance receiver systems (such as smaller antennas).

A common set of modes for weak signal work which is gaining popularity on the microwave bands are the WSJT Q65 modes. Also, the WSPR modes are being added to beacons. These modes require a bit more sophistication in the beacon design as the modulation must be impressed on the signal somewhere in the microwave transmit chain, and then preserved in a way that allows the modulated final frequency microwave signal to contain the originally intended structure. This is of course more difficult than simply keying some signal source on and off for Morse identification.

Most ways of building a microwave transmitter require some stable frequency source, usually starting at 10 MHz or a VHF region, followed by a chain of amplifiers and multipliers to get to the final stage. Impressing the modulation on a VHF signal and then subsequently multiplying it many times to get to the ten + GHz range can produce many unwanted effects, especially adding phase and amplitude noise. Most of our transmitters use an IF where modulation is applied. Then this IF is mixed at some relatively high frequency, often arriving at the final frequency in that mixing step. Although this can be done at all bands, it is usually less expensive to obtain some RF power by mixing at some frequency around 10 GHz and then multiplying that to 24 or 47 GHz for final output. One of the reductions in costs is the advantage of filtering at 10 GHz range rather than 24 or 47 GHz. The 10 GHz or lower frequency bands can be filtered with inexpensive and easily tuned pipe-cap filters, whereas 24 and 47 GHz must be dealt with in either very sophisticated printed filters or multistage precision waveguide assemblies.

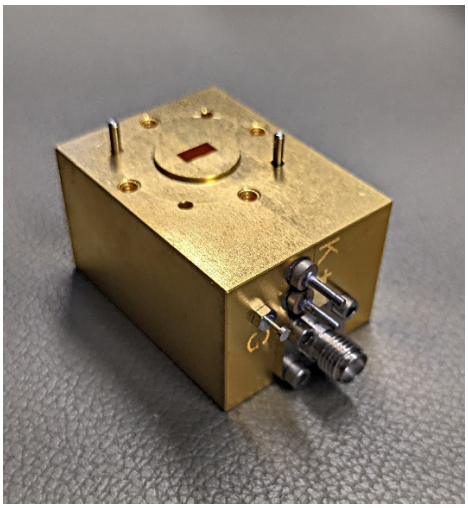


Figure 1 the WA1MBA Quadrupler, produces 20 mW output
on 47 GHz band from 11.77+ GHz at 4 dBm – see Ref 1

This multiplier idea is what was originally considered in order to build a 47 GHz beacon using the WA1MBA quadrupler (see figure 1), capable of 20 milliwatts output. Although straightforward on paper, there are several important considerations. One is that the modulated signal, correctly matching the modulation at the 10 GHz range would suffer "frequency spread" and possibly serious intermodulation when it is multiplied again by 2 or 3 for 24 GHz or by 4 for 47 GHz.

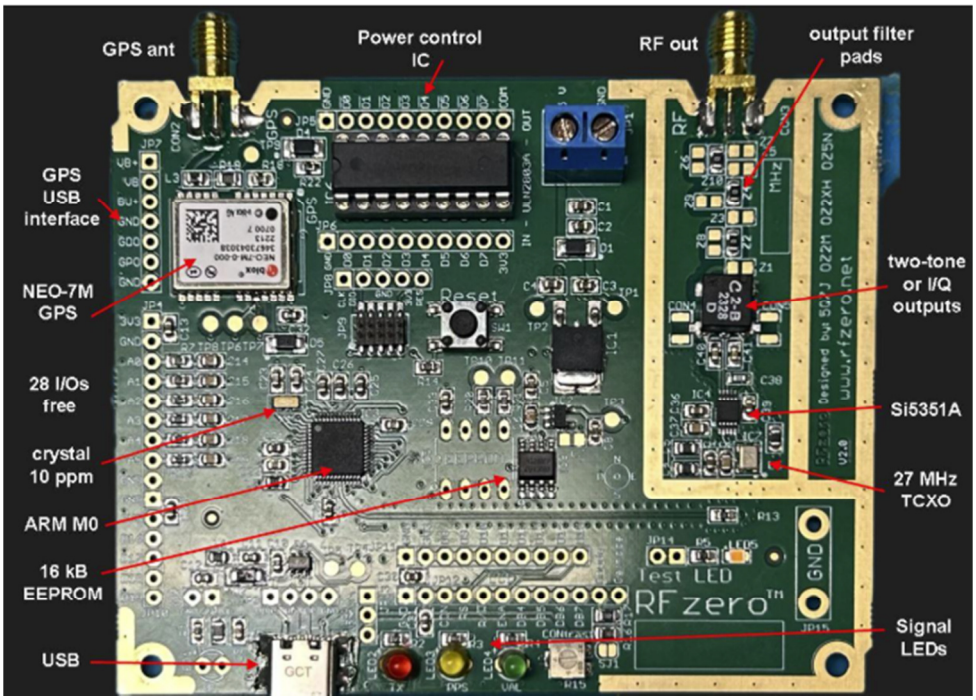


Figure 2. Features of the RFzero™ board – Photo & notation courtesy of Jim McMasters KM5PO

Fortunately, the Q65 (and many digital modes) only transmit one frequency at a time, so for the most part do not suffer IMD from the non-linearities in multipliers. Their tone frequencies (in the audio rage), however, are precisely defined, and a subsequent RF multiplier spreads those tones further apart than they are supposed to be, making them impossible to decode.

All that is needed to fix this is to "tell" the Q65 software modulator to "squeeze" the tones together by some factor that accommodates all the subsequent multiplications, and so it should arrive at the final frequency exactly as expected. Fortunately, there is an available PC Board, the RFzero™ which can be purchased fully assembled (except that you may add the LEDs and headers to connect a display if desired). The cost is only $80 plus shipping (as of this writing) and free beacon programming is already available for the Q65 modes or WSPR as well as a Morse message. The RFzero™ is locked by its own internal GPS disciplined oscillator, is controlled by an Adrino, and has a synthesizer that puts out any frequency between a couple of kHz to just under 300 MHz in milli-Hertz steps. This makes a perfect IF source to mix with an LO to produce RF which can be used directly on 5.7 or 10 GHz, or subsequently multiplied to 24 or 47 GHz.

Figure 2 shows the RFzero™ board. A 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. An on-board EEPROM is updated with frequency correction factors for use in restarts. Following recommendations, the 27 MHz crystal oscillator should be covered with a small piece of foam plastic, and then the entire RF section with an RF cover. This cover can be fashioned from sheet copper or brass, or 3D printed in plastic and then covered with conductive copper tape (See figure 3). It need only be tack soldered in a few places along the ground ring.

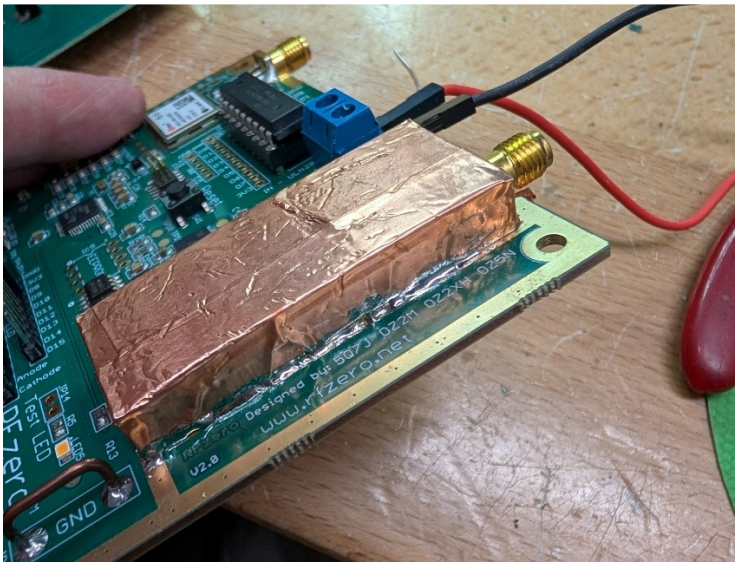


Figure 3 A cover for the RF section fabricated from a 3D printed plastic form covered with copper tape and tack soldered to the ground plane around the edges.

There are filter pads on the RF output stage filters to be built as needed. In my application we found an inexpensive connectorized filter (about $10 from Amazon) that removes all the unwanted harmonics

when a frequency around 435 MHz is desired. If the filter circuit on the RFzero™ board are left untouched, the RF passes directly through to the output SMA connector.

You use a PC to program the board through a USB connection, and while the board is connected this way the USB port supplies sufficient power for operation. The app "RFzero Manager" available from the website where you purchase the RFzero Manager app https://rfzero.net/documentation/rfzero-manager/ It can be used to configure the supplied Arduino sketches and download them onto the board. The board is capable of many functions with output to above 280 MHz, and frequency resolution to 1 milli-Hz. It can be configured as a standalone WSPR transmitter and beacon driver with a large selection of modulation modes as shown in Figure 4.

If you are programming Q65 then a particular mode must be chosen (see Figure 5). The modes are arranged according to the transmit time (in seconds) and the tone spacing (with a Letter designator). Longer times allow for more integration and therefore better s/n. So, for digging out very weak signals a longer time should be chosen. Unfortunately, during QSOs long periods might be cumbersome. Although beacon listening might not be impeded by long listening times, to some operators having a single mode that can be used for QSOs and for beacons has some advantages. Also, for those who are listening to the beacon for an ID and do not care about Q65, it could be several minutes wait if a mode that spends 300 seconds (5 minutes) in digital needs to complete before a 30 second morse ID is heard. Another consideration is whether frequency spread is important. Wider tone spacing allows for some distortion in the path and some instability in the signal source itself. In some situations, rain scatter may be part of the path, and often winds carrying rain will cause doppler shift and some smearing. These are reasons to choose a wider tone spacing rather than a narrow one.

Modes to Configure the RFzero™ board for Beacons
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

Figure 4. Beacon modes (not all modes are shown)

Over the air tests conducted by NTMS proved that the WSJT-X mode was being transmitted correctly, in proper timing and decoding 100% on every transmission. Several Q65 modes were checked.

Although you may choose any particular mode it is probably wise to do some coordination in each geographical region.

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

Figure 5. WSJT-X Q65 by T/R period and sub-mode designation

Below are some observations regarding mode choices.

- NTMS North Texas Microwave Society
  - For Tropo QSO's 30-A and 15-A. Reason = Quick QSO
  - For Beacons 60-C, the same as is used for 1296 EME Reason = Longer Integration Time for S/N and some tone spread for doppler/multipath scatter smearing
- NEWS North East Weak Signal Group
  - W1FKF built 2x 10GHz Beacons with 30-D
  - Although 60-C has 3 dB better s/n, much of the beacon cycles are spent in digital while continuous tone and morse are also valuable
  - The 10GHz EME beacon is on 60-E
- You
  - Whatever your choice, post it, including the WZ1V Beacon list

Multiplication

You need to specify in the RFzero™ configuration the multiplication factor that the fundamental signal being produced by the board will undergo to its final output frequency. In our configurations, mixing does not multiply, but subsequent multiplier such as may be used for 24 and 47 GHz must be accounted for. Furthermore, if a harmonic of the fundamental from the RFzero™ is employed, that harmonic is a multiplier as well.

Here are some examples – in them the actual final frequency is going to be where we want to place beacons in the band, but for simplicity in these examples the target is at a nominal band frequency.

1) If we are building a 10 GHz beacon with a 200 MHz range IF, then we will be using an IF that is inside the maximum 280 MHz range of the RFzero board, so no multiplying of the IF is necessary to get

all the way to 10 GHz. The mixer/ filter board simply mixes a 10,168 MHz LO with a 200 MHz (range) IF to produce 10,368 MHz (range) output. We tell the RFzero that the multiplication factor is 1 and the final frequency is 280 MHz.

2) If we are building a 10 GHz beacon and want to use a 430 MHz range IF, then we will be using an IF that is outside the 280 MHz range of the RFzero board. Even harmonics of the RFZero are much attenuated, so it is better to use an odd harmonic. Let's assume we will use a 438 MHz range IF. This is the 3rd harmonic of 146 MHz. Just like the first example, it is mixed with an LO, this time at 10,222 MHz to produce something in the range of 10,368 MHz. Because the RFzero fundamental needs to be multiplied by 3, we tell it that the multiplication factor is 3 and the final frequency is 438 MHz.

3) In our third example we end up telling the RFzero something not "right looking," but it is actually correct and works. Here we want to use a third harmonic of the fundamental, at 435 MHz, so the fundamental we want is at 145 MHz. That 435 MHz (harmonic) signal is mixed with aa 11,337 MHz LO to produce 11,772 MHz out of the mixer/filter board. This is then fed into a Quadrupler (x4) to generate the final 47,088 MHz signal. So, the total multiplication is 3x4=12. This is how many times the IF is multiplied along its path to the beacon's output.

Here is the tricky part. What do we tell the RFzero to be the target final frequency? It is 145 x 12 = 1,740 MHz. Nowhere in our circuit is there actually any 1,740 MHz, but the RFZero needs to figure out what the fundamental is, and use the multiplier to squeeze the tones accordingly. If instead, the RFZero software configuration simply asked the fundamental frequency and the multiplier, it would all make sense, but it does not work that way – it "back calculates" assuming that there is no mixing going on and that you are simply multiplying to a final beacon frequency.

In the RFZero Manager Application, on the right side is the selection of the particular program (See figure 6). In our case we select "Beacon Q65 + CW + carrier". Then the configuration is loaded and you can edit the entries that parameterize the beacon information (see figure 7).

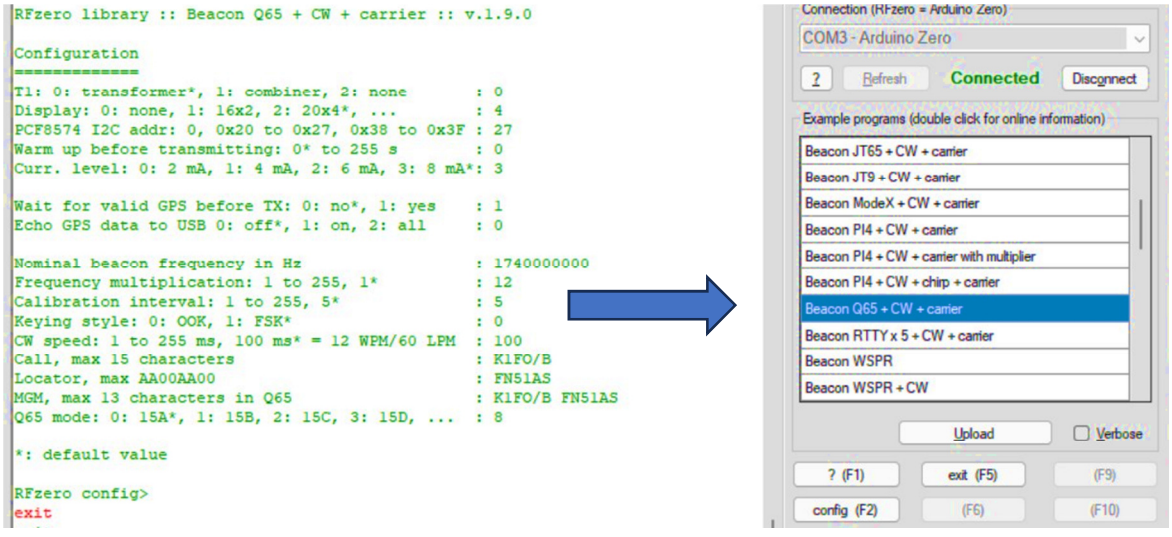


Figure 6. The Manager Application interface shows configuration choices for beacons on the right, and then the configuration code on the left where parameters are entered

```
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*, ...        : 4
PCF8574 I2C addr: 0, 0x20 to 0x27, 0x38 to 0x3F : 27
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    : 1
Echo GPS data to USB 0: off*, 1: on, 2: all     : 0

Nominal beacon frequency in Hz                  : 1740000000
Frequency multiplication: 1 to 255, 1*          : 12
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                         : K1FO/B
Locator, max AA00AA00                           : FN51AS
MGM, max 13 characters in Q65                   : K1FO/B FN51AS
Q65 mode: 0: 15A*, 1: 15B, 2: 15C, 3: 15D, ...  : 8

*: default value

RFzero config>
exit
```

Figure 7. Above is the detail of the programmed parameters for a 47 GHz beacon using the frequencies as described in example #3. If you use a display you will need to fill in Display and PCF8574 info. This is all explained in various documents on the site.

Design and Construction of the mixer/filter board

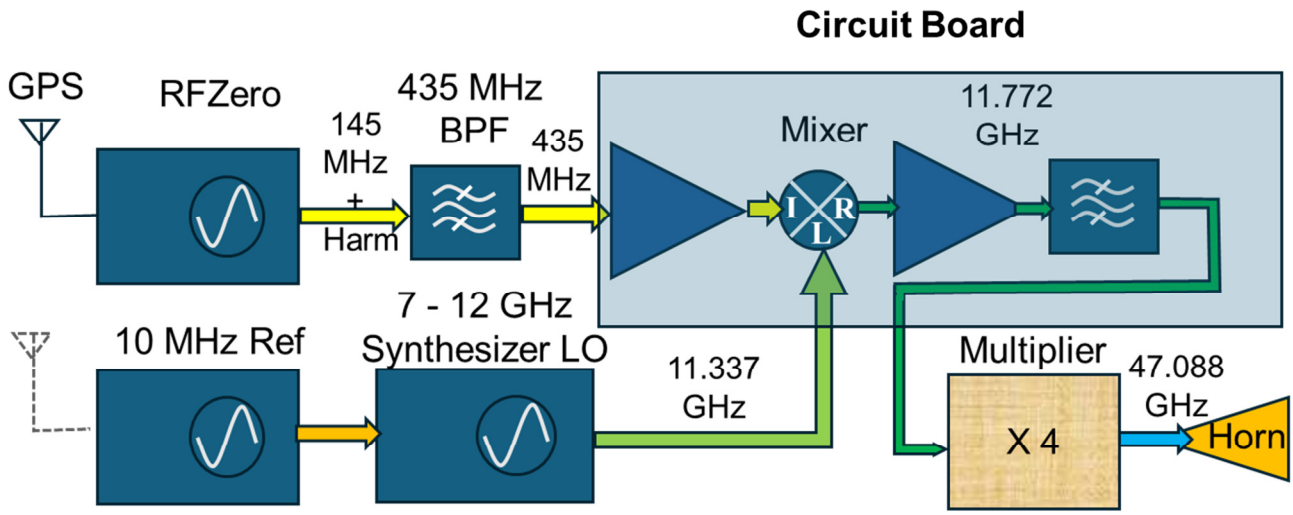
I knew that we wanted a mixer that operates at least up to about 12 GHz and would take VHF type IF signals and LO in a moderate power range of perhaps the standard +7 dBm (See figure 8).

I also knew that I wanted decent filtering. This is, after all, a beacon – perhaps on 24/7 from some high spot, not a microwave ham radio transmitter, which is likely to be on infrequently and then usually from some high spots at well. The point is that brief transmissions outside of the band might be tolerated even if they are accidentally above the FCC limit for spurious transmissions. Continuous transmissions, like from a beacon would and should be scrutinized for interference. In particular, a 47 GHz beacon is just

below a cellular millimeter wave band and just above a military satellite band. For these reasons I was serious about keeping unwanted LO and Image radiation to a minimum.

Hacked Simple Transverter Board

Fortunately, Paul W1GHZ had developed and sold a single board that contains a mixer and two pairs of amplifier filters for the 10 GHz band – the Simplified Transverter. I discussed my ideas and needs with Paul and decided together that a hack of that Simplified Transverter would probably lead to a board dedicated to this purpose.



LO	RF	MULTIPLIER	BEACON
9.993.200	10.368.200	1	10.368.200
7.629.060	8.064.060	3	24.192.180
11.661.090	12.096.090	2	24.192.180
11.337.090	11.772.090	4	47.088.360

Figure 8. The overall schematic of a beacon, with some frequency suggestions

The first modifications were to put 3 pipe cap filters in series (along with 5 amplifier stages) in order to get sufficient filtering, learn to use pipe-cap filters, and see what the problems are (See figure 9). Although the final hack was a messy board, it included an IF amplifier to deal with the low 3rd harmonic output level from the RFzero board, and it worked.

Then in testing, I found that the image and LO rejection were not adequate (see Figure 10.

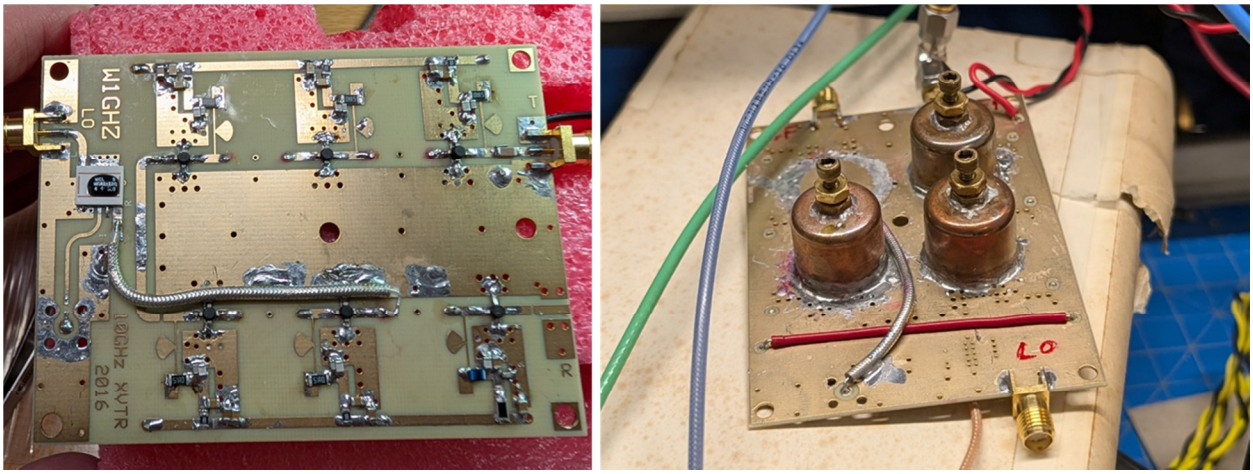


Figure 9 – The Hacked Simple Transverter Board worked, but had poor LO and Image rejection

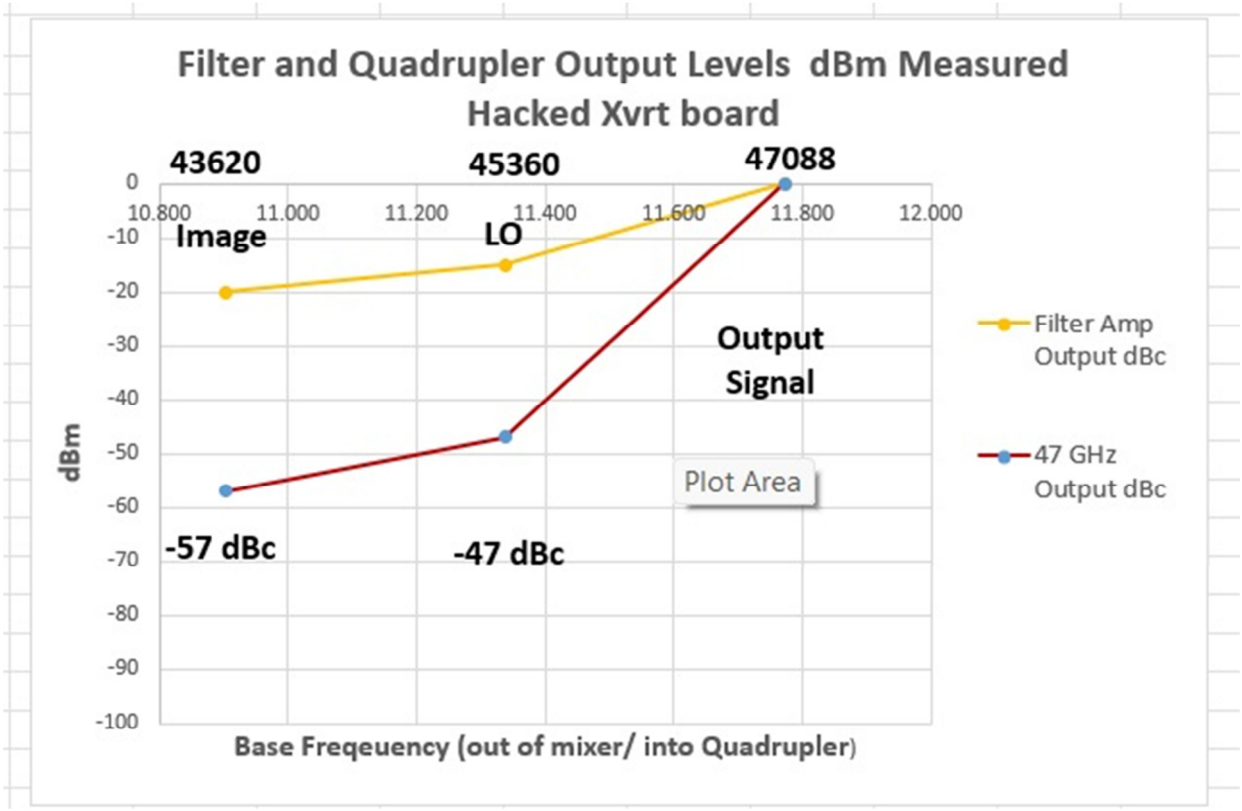


Figure 10 The Filter Amp and subsequent 47GHz output measuring LO and Image in dBc. The Quadrupler further buried the LO and Image signals because it is non-linear, but even so, it was inadequate for the purpose of a good clean beacon on this band

Version 1 & 2 Board

Next a Version 1 board was developed by Paul, constructed and tested by me, and I soon learned things which were already published. I learned that signal probes into the pipe-cap filters had to be adjusted in length in order to trade between filtering skirts and insertion loss. Also, the mechanics of adjusting

those lengths, or even making them consistent was very difficult. A set of commercially fabricated brass plated pins of the right length was obtained and this greatly simplified the probe length issues.

Paul convinced me that the fifth amplifier stage was not needed and along with some design clean-up, the V2 board was produced (See figures 11 & 12). This board was put into an enclosure for further analysis.

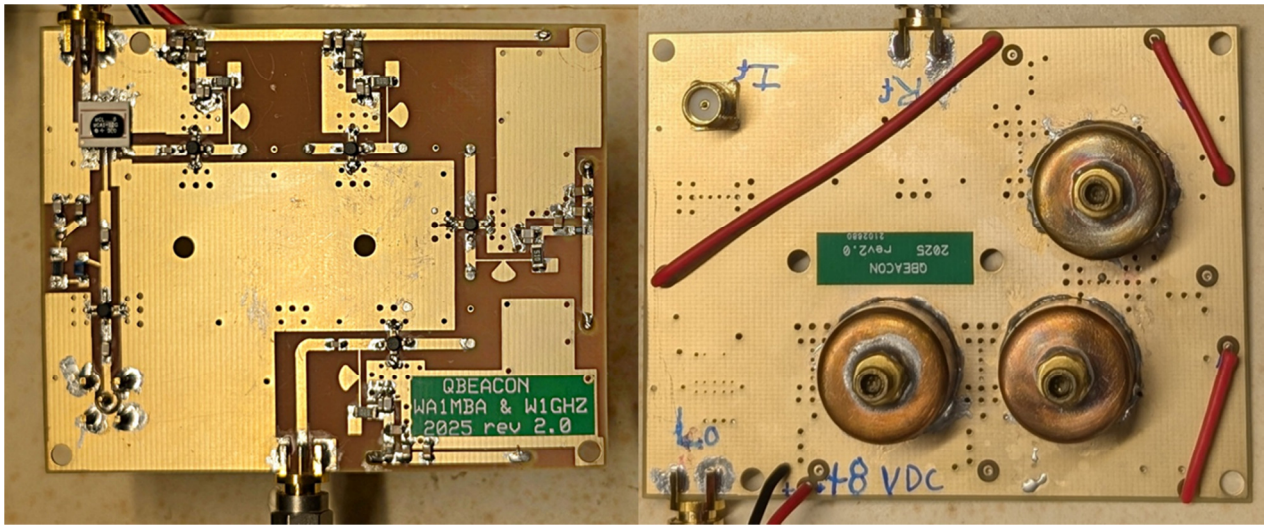


Figure 11. The final Version 2 board, assembled, tested and being evaluated.

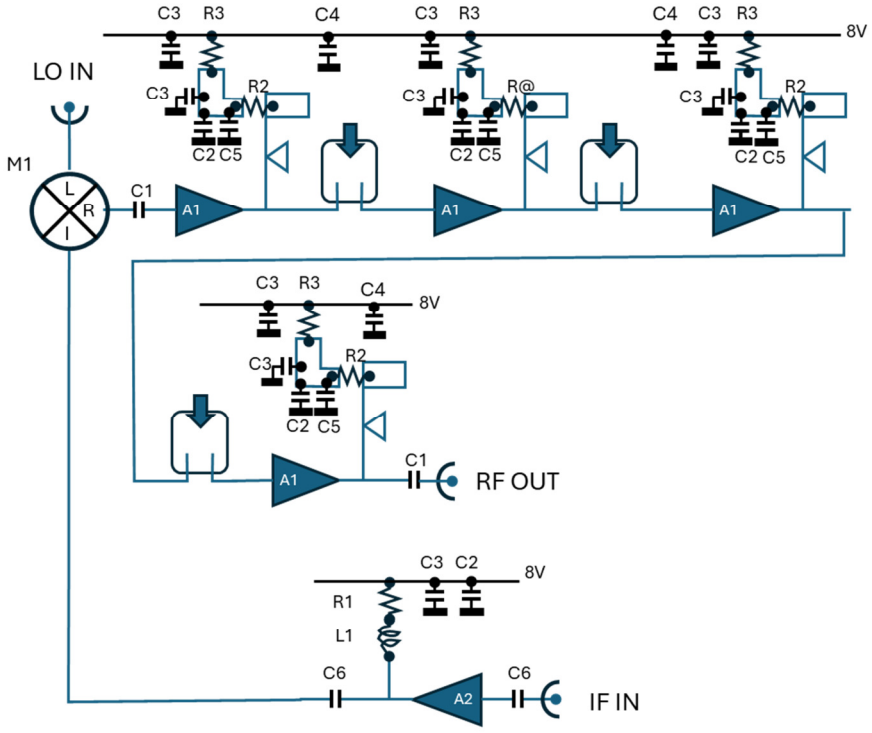


Figure 12. Schematic for the V2 board.

Enclosure

An aluminum enclosure (suggested by W1FKF) was tried but I soon found out that the LO leakage was considerably greater than in free space. After some movement of pieces, I became convinced that it was due to reflections of the LO from the input (+7dBm) being amplified by the final RF stages and subjected to only one filter or none at all. I had some relatively inexpensive thin (1 mm) elastomer ferrite absorber available from Laird. These types of absorbers actually attenuate the RF at a reflecting boundary. So, I tried it starting on the bottom, where it would absorb the most. Unfortunately, although possibly affordable (at over $50 a box, over $200 minimum) this material did not have much loss at 10 to 12 GHz range, only about 5 dB. I covered all inside surfaces and obtained sufficient LO rejection to call it a limited success, but was not happy with the expense and effort that others would doing the same (Figure 11). Then I ran across a material on-line that sold for considerably less and has much more effect with just one layer on the bottom (underneath the board). The source is TOJOIN and it is a 2mm thick product (.080 inch). One piece is considerably larger than what is needed, and the seller provides 2 pieces (see figure 12)

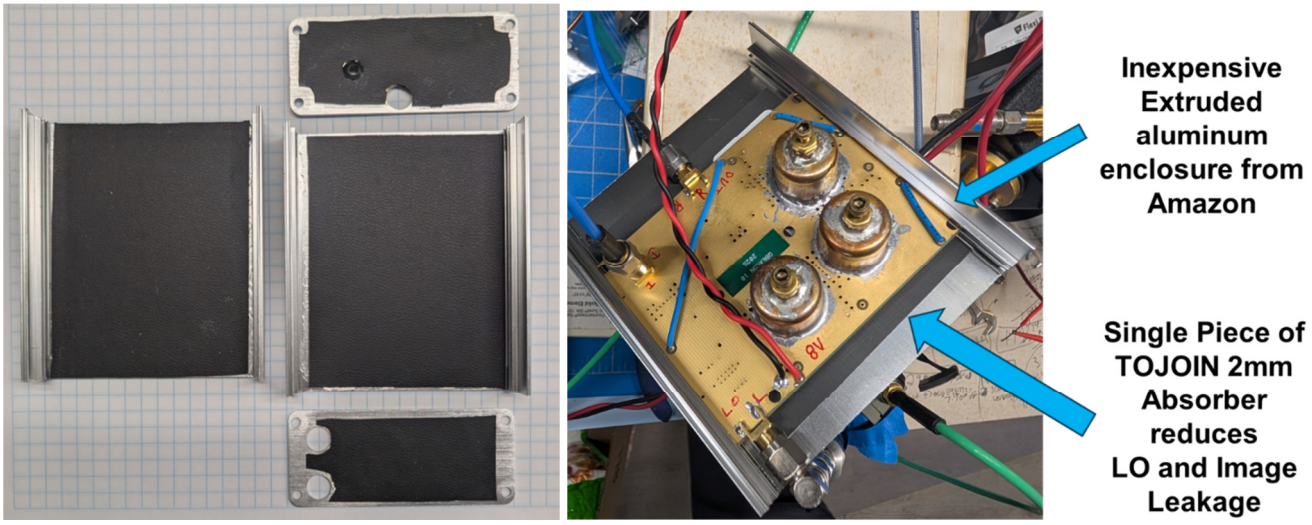


Figure 11. I Tried a surface absorber on the inside of the box. A different material did it in one spot.

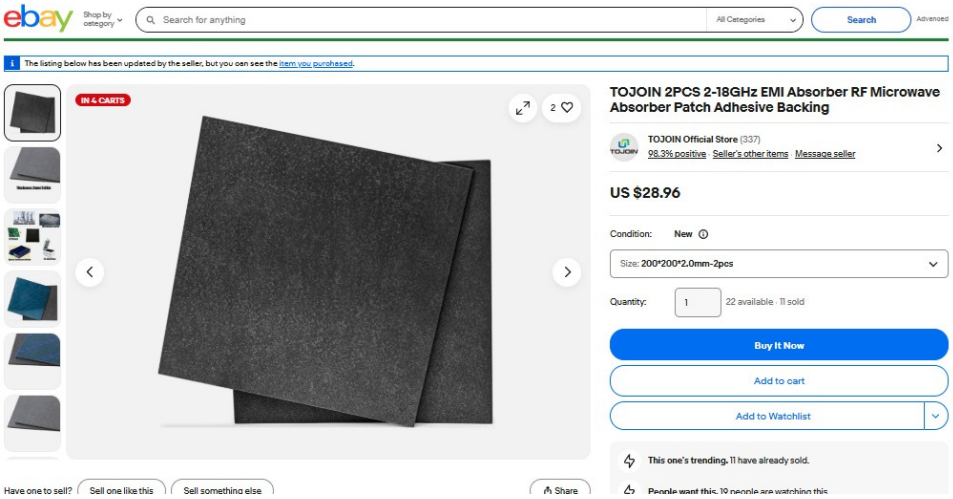


Figure12. Tojoin 2-18 GHz EMI absorber available through ebay

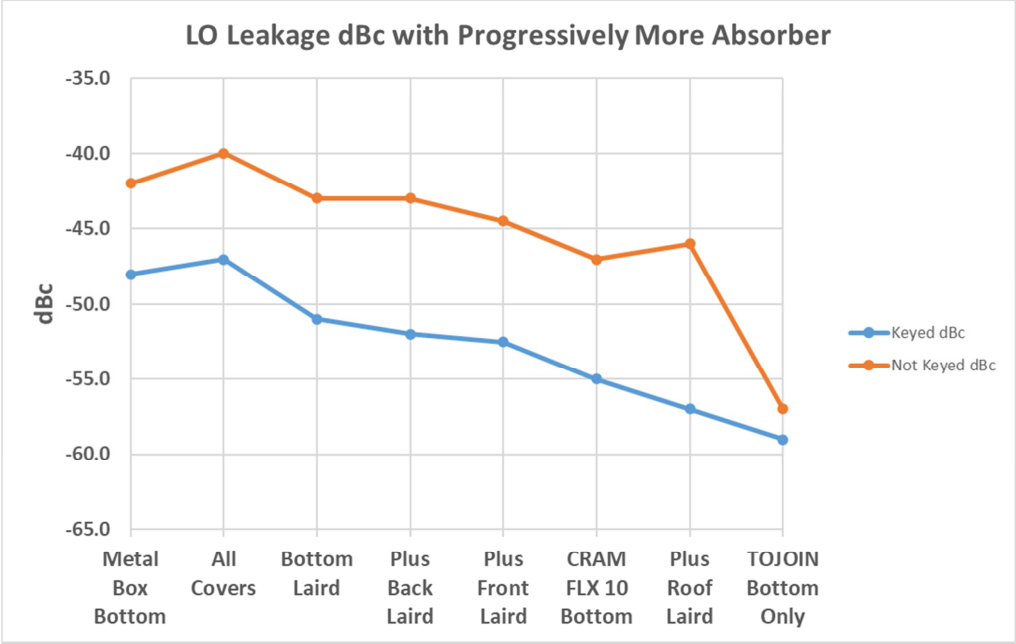


Figure 13. Applying more of the thin absorber to all walls of the enclosure didn't do as well as one piece of TOJOIN absorber on the bottom

Final Results

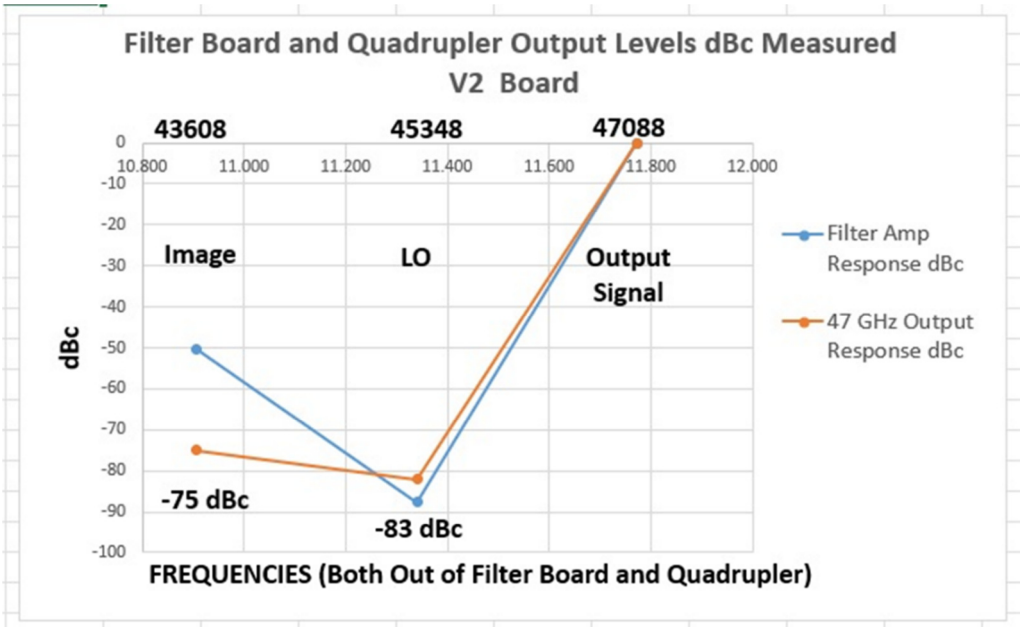


Figure 14. Here we see the LO and Image rejection in dBc out of the Filter Amp Board and out of the quadrupler producing 47 GHz. Both LOs are actually in the instrument's noise. The image is superior to the LO at 47 GHz because the Quadrupler is non-linear, having more conversion loss at lower amplitude inputs.

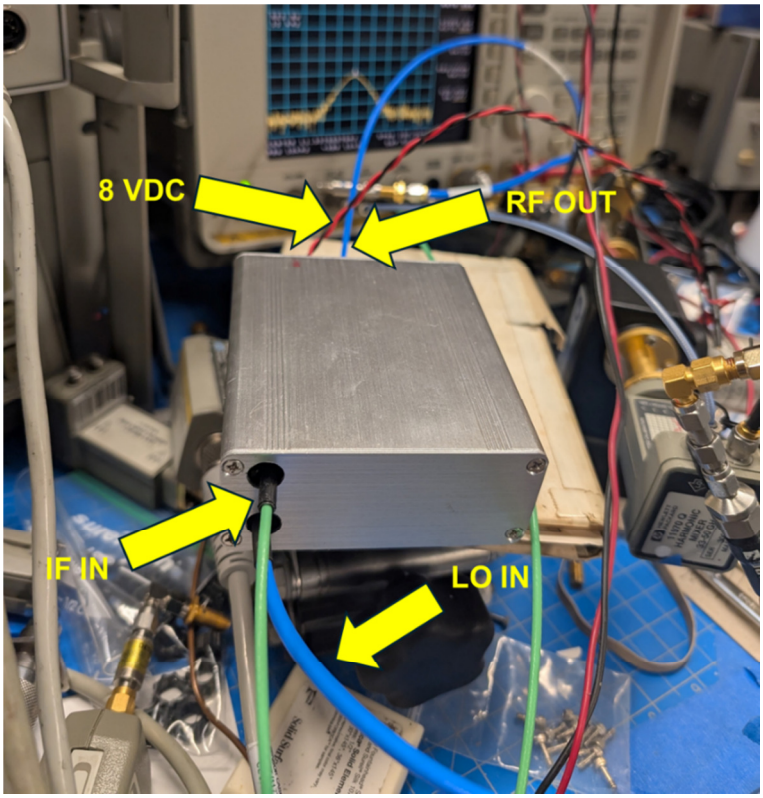


Figure 15. An enclosed V2 board

Available

From WA1MBA (tomw@wa1mba.org)

Bare Board	$15
Bare Board + 3 prepared pipe caps	$30
Kit = Above + all parts, connectors	$100
Above, Assembled, Tuned to your frequency, in enclosure, tested, with 435 MHz filter	$250
RFZero™ Board (only with kit or assembled purchase)	$80

Assembly instructions available on-line at wa1mba.org. Ask if you have questions.

From W1GHZ (w1ghz@arrl.net)

Sector Horn	$ ask
WG Adapter	$ ask

You must supply Power (+8V and +12-14V), Control, Enclosure, program configuration, etc

Figures 16 and 17 show the W1GHZ Sector Horn for 24 and 47 GHz beacons Reference 5https://www.w1ghz.org/new/Sectoral_Horn_Antennas_for_Microwave_Beacons.pdf

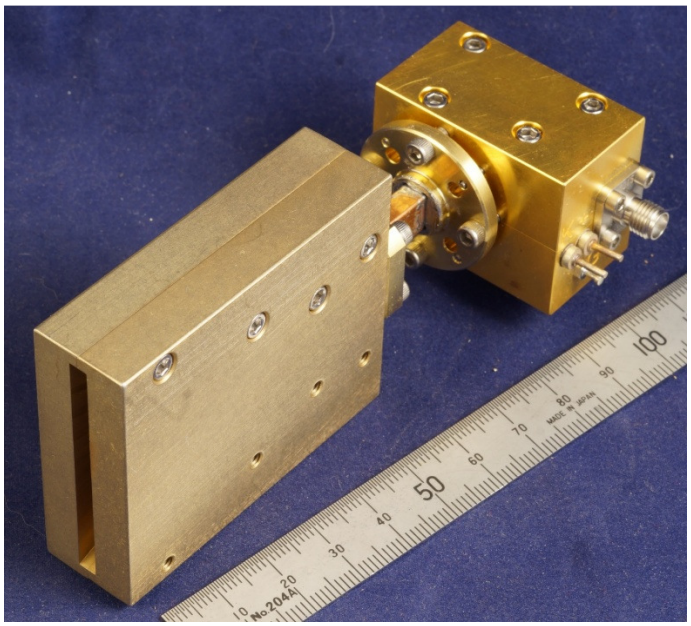


Figure 16. W1GHZ Sector Horn connected to the WA1MBA Quadrupler, in correct orientation for Horizontal Polarization

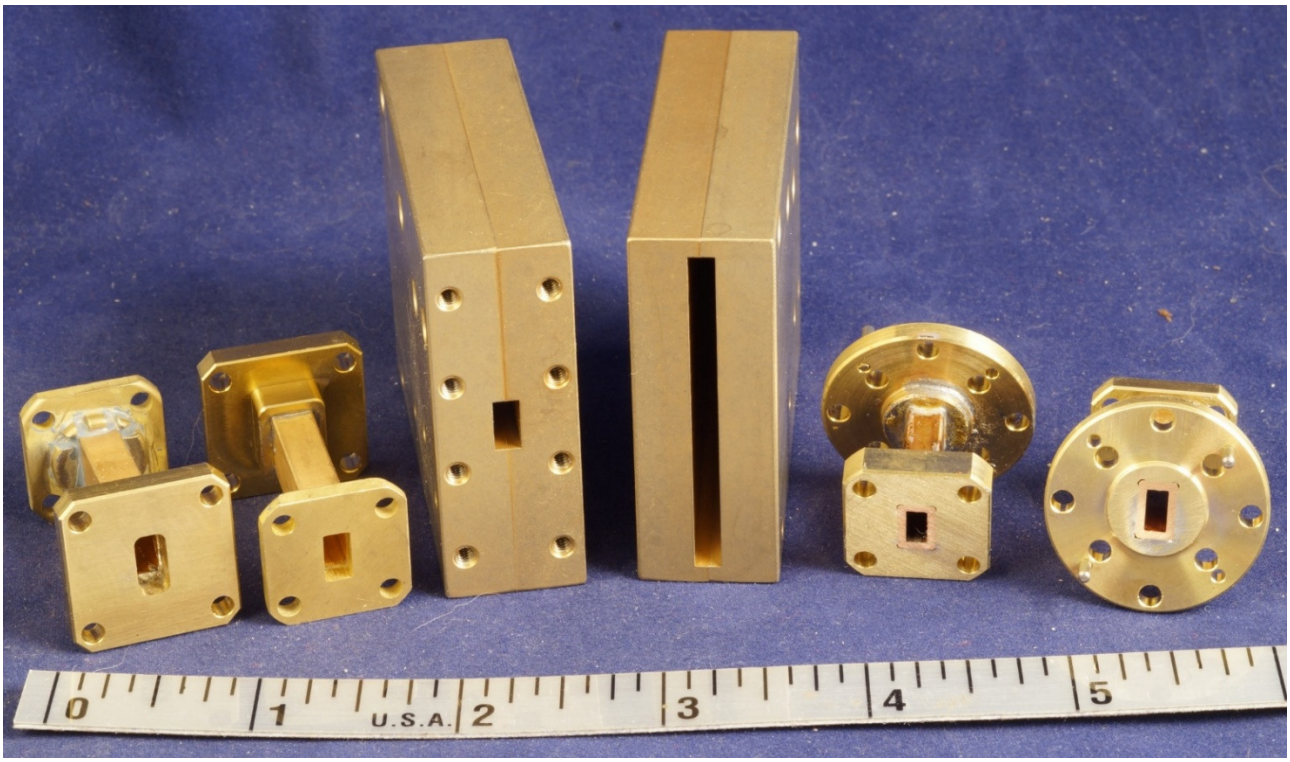


Figure 17. W1GHZ Sector horn, back and front, surrounded by WG adapters for WR42 and WR22/19

References

1. Tom Williams WA1MBA, A 10-12.5 GHz in, 40-50 GHz out Quadrupler – Final Report**,** Microwave Update 2023

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