Large W2IMU Feedhorns for Improved G/T on Offset Dishes

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The W2IMU dual-mode feed has been popular for many years. It offers high performance and is relatively easy to make. The classic version, 1.31λ aperture diameter, offers best performance for an ***f*/D** around 0.5 to 0.6, which gives a pattern which is a bit wide for common offset dishes, leading to excess spillover.

In his original article[1], Dick Turrin, W2IMU, also described a larger version, 1.86λ diameter. The larger version is best for an ***f*/D** of around 0.7 to 0.8, reducing spillover to provide better efficiency and G/T for offset dishes. For Microwave Update 2023, W1FKF and I submitted a paper[2] describing a practical technique for fabricating these larger horns for 47, 78, and 122 GHz. These appear to work well, but it is difficult to make thorough measurements at these higher frequencies.

At 10 GHz, it is more practical to make good measurements and it is possible to machine the horns with reasonable accuracy using a CNC lathe. It is also possible to make EME contacts with a medium-sized offset dish; a good feedhorn would optimize performance, especially G/T. Sun noise measurements are an indicator of G/T.

W2IMU Dual-Mode Feedhorn

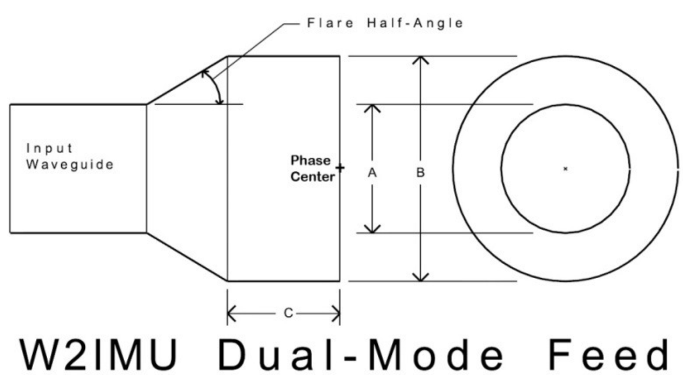


Figure 1

A sketch of the W2IMU feed is shown in Figure 1. The feed flares out in a cone from an input waveguide to an output cylindrical horn section. The conical flare generates a second waveguide mode, TM_{11} , in addition to the TE_{11} mode in the input waveguide with relative amplitudes controlled by the flare angle. The two modes have different guide wavelengths in the cylindrical horn section -- the length of the horn (**C**) is chosen so that the two modes arrive at the aperture in the proper phase to cancel currents in the horn rim and generate a good axisymetrical radiation pattern with very low sidelobes. The classic amateur version has a horn diameter of 1.31 λ while the larger one has horn diameter of 1.86λ. But any horn diameter between 1.22λ and 1.9λ or so will work. Smaller diameters are beyond cutoff for the TM_{11} mode, and diameters greater than 1.9λ allow more modes to propagate – simulations show poor results. The output horn diameter (**B**) is inversely proportional to beamwidth and can be chosen to feed the desired ***f*/D** . Flare angle and horn length for the chosen diameter is easily calculated using the **HDL_ANT2_Winforns** program available at w1ghz.org.

Years ago, I fabricated two large W2IMU horns using copper water pipe, shown in Figure 2. The larger horn used 2-inch copper pipe for an aperture diameter diameter of 1.78λ at 10 GHz, with 3/4-inch pipe as the input waveguide. The flare section is made from copper sheet, using the calculated dimensions. Performance measured on sun noise was excellent at 10 GHz, with efficiency well over 60%. (I have lost the original photo and data, so must rely on the *W1GHZ Microwave Antenna Book – Online* at w1ghz.org.)

Figure 2 – Large W2IMU dual-mode feedhorns for 10.368 GHz

The smaller horn used copper pipe with 2 inch outer diameter, an oddball size that I must have found somewhere. Copper pipe is sized by the nominal inner diameter. This horn has an aperture diameter of 1.65λ. I used it on a 1-meter offset dish as part of my periscope antenna system.

Feed Fabrication

The calculated flare angle for the Large W2IMU feed, with a horn diameter of 1.7 to 1.9 λ, is about 25 degrees. Simulations suggest that the optimum flare angle is around 28 degrees. However, 30 degree tooling is much more readily available, and the simulated efficiency is only about 1% lower if the horn length is adjusted to compensate. Figure 3 shows the excellent performance of the horn with a 30 degree flare angle. The small backlobe in the H-plane probably accounts for the slight reduction in efficiency. For an offset dish with ***f*/D** around 0.6 to

0.7 there is low spillover and only a slightly lower efficiency. Input waveguide diameters between 0.7λ and 0.81λ make almost no difference in performance.

At the local Makerspace, I have access to a good size CNC lathe to machine these horns. At 10 GHz, boring out a 2-inch diameter to a depth greater than four inches is moving a lot of metal. Using 2-inch ID pipe copper pipe is an easier and possibly more economical solution. To make a more robust feed than the ones in Figure 2, I could machine just the flare section to attach to the pipe. I had intended to machine the flare section in brass and solder to the copper pipe, but brass is heavy and expensive. Instead, I found some some 2.25 inch o.d. aluminum round for the flare section, available in short custom lengths from metalsdepot.com at reasonable cost.

For the output section, aluminum pipe of tubing of the desired diameter is needed. At metalsdepot.com, I found some possibilities:

- 2 inch OD aluminum tubing, .065" wall, 1,875" ID (1.62λ diameter, length 3.14λ)
- 2 ¼ inch OD aluminum tubing, .125" wall, 2.00" ID (1.76λ diameter, length 3.8λ)
- 2" Schedule 10 structural pipe, 2.375" OD, .109" wall (~1.88λ diameter, length 3.94λ)

I decided to try all three and test them on offset dishes.

While waiting for delivery, I found some smaller scrap aluminum and machined a small W2IMU feed, 1.34λ diameter, using a shorter, heavier boring bar than used for the 24 GHz horn, with much better results. The same boring bar also worked well for the flare section of the larger horns.

The large 10 GHz feedhorn is made in two parts, the input and flare section and the cylindrical horn. Joining them together is the tricky part, since aluminum doesn't solder well. A technique that I used successfully on another horn is to heat the outside section enough so that the diameter becomes larger than the cold inside piece and slip it over the cold piece – once they cool, the joint is permanent. Aluminum has a thermal coefficient of expansion of 25.5 ppm; a 2-inch diameter will expand 5 mils per 100ºC, so the difference in diameters must be less than 5 mils for a reasonable temperature difference. I machined a short cut in the outer horn section that just barely fit over the flare section (taking cuts 1 mil at a time), then made a longer cut 3 mils smaller, which wouldn't fit when cold. I started with the largest size, so that when I missed, I could try again with the next size. I also learned to let the metal cool down before measuring – cutting generates heat and the metal expands.

For assembly, the outer horn was heated on a hotplate set to melt solder with the joint end on the hotplate – the horn is a pretty big heatsink, so the far end will never get hot enough. (I could have used the kitchen oven, but I've gotten in trouble before!) When solder melted (~185C) at the base of the horn, I figured it was hot enough with some margin, grabbed it with a silicone potholder and slipped it over the flare section. It joined immediately, since the cold piece cools the hot one. The finished horns are shown in Figure 4, with the smaller 1.3λ W2IMU horn and a matching plate (WA6KBL design[3]) from WR-90 waveguide to the circular input section of the horns.

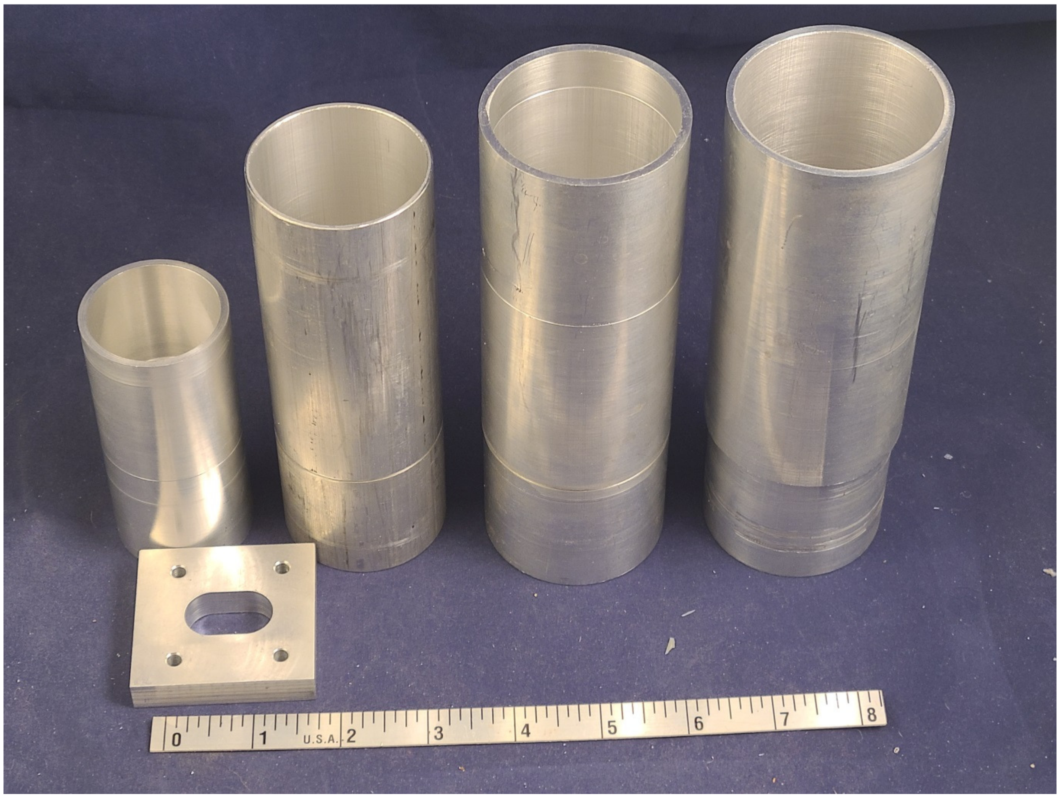


Figure 4 – Four sizes of W2IMU Dual-mode Feedhorns, with WR-90 Matching Plate

Figure 5 is the aperture view of a small and large horn, showing the flare section and input waveguide.

Figure 5 – Aperture view of small and large horn

Sun Noise Measurement

Sun noise is best measured in a wide bandwidth to get stable readings with reasonable response time. EME operators often use an ancient General Radio GR-1236 Tuned IF meter to display noise at 30 MHz. I have used homebrew noise meters at IF frequencies of 144 MHz or 432 MHz. One problem is sufficient accuracy over a wide signal range while having enough resolution for small differences.

Much better is a computer program, **TotalPower**[4], developed by Mario Natali, I0NAA, which plots noise with time on the screen. All that is required is a laptop and a low-cost RTL-SDR dongle. Make sure to buy an official one (https://www.rtl-sdr.com/buy-rtl-sdr-dvb-t-dongles/). The dongle connects to the IF output of a transverter to detect noise and display a plot of the noise level.

For each antenna and feedhorn combination, I plot a drift scan – peak on the sun noise, then record as the earth's rotation moves the sun out of the beam until a background level is reached, which is very close to cold sky noise. I wasn't able to find an area of the sky with measurably lower noise. The difference between maximum noise from the sun and cold sky in dB will be referred to as sun noise in this paper. A screenshot of the TotalPower main screen and plot window is shown in Figure 5. Each plot is saved for comparison – no eyeballing the number from a twitchy meter. I also record the solar flux for the day; version 7 of TotalPower promises to do performance analysis.

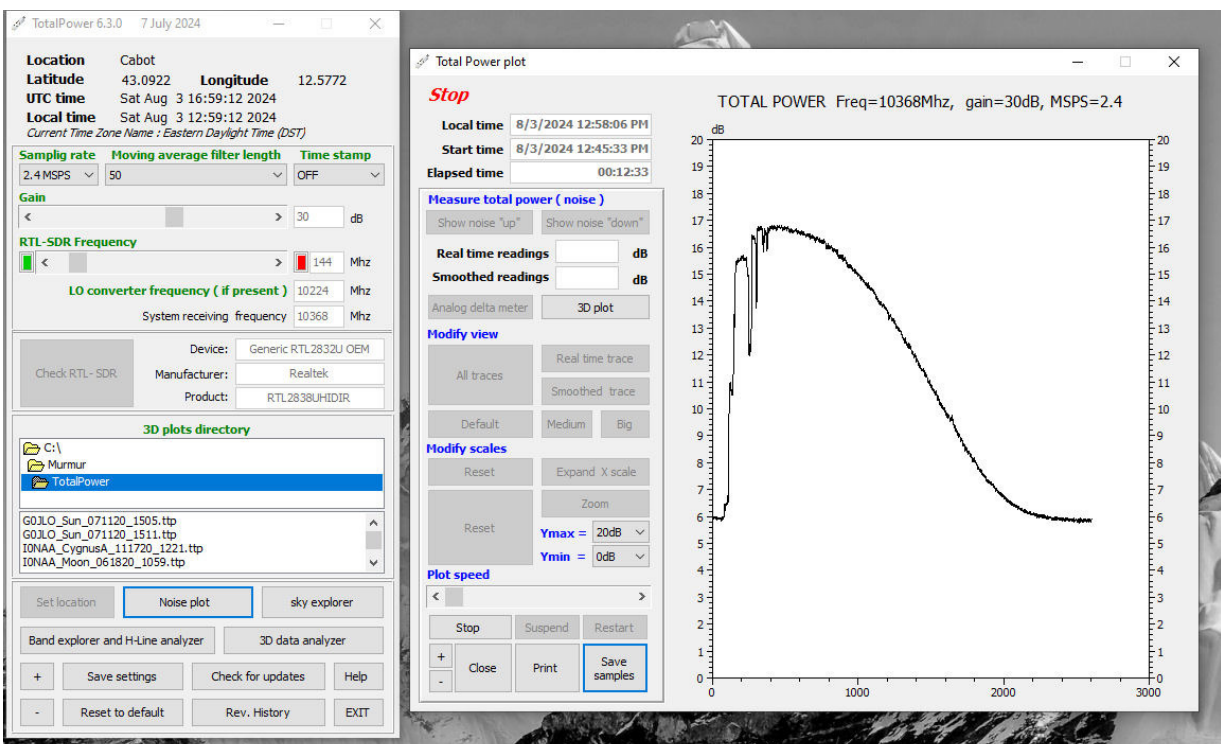


Figure 6 – Screenshot of TotalPower main screen and plot window

Feedhorn Comparison

I have two medium-sized offset dishes, a 1-meter diameter and a 1.2 meter diameter (narrow dimension of the ovals). The ***f*/D** of each is about 0.6, typical of most offset satellite dishes, so these results should be applicable to almost all offset dishes.

All measurements were made with a DU3T XLNA connected to the feedhorn by a short length of WR-90 waveguide and a matching plate[3] from the 20.6mm diameter circular waveguide of the feedhorns to WR-90. Return loss with the matching plate is 20 dB or better. The XLNA is rated at 0.6 dB noise figure, and noise measurements of cold sky and ground noise with just a feedhorn suggest that the rating is accurate.

For each dish, I started with the 1.62 λ feedhorn at the approximate focal point, measured sun noise, then adjusted the location in increments, taking sun noise at each increment, to better locate the focal point. A plot of these adjustments in Figure 6 shows that the peak is very broad, as we expect for an offset dish. Since simulations suggested that the phase center is very close to the aperture for all these feeds, I used that focal point for all of them. A subsequent focal point check with the best feed showed a small difference but not enough to change the results.

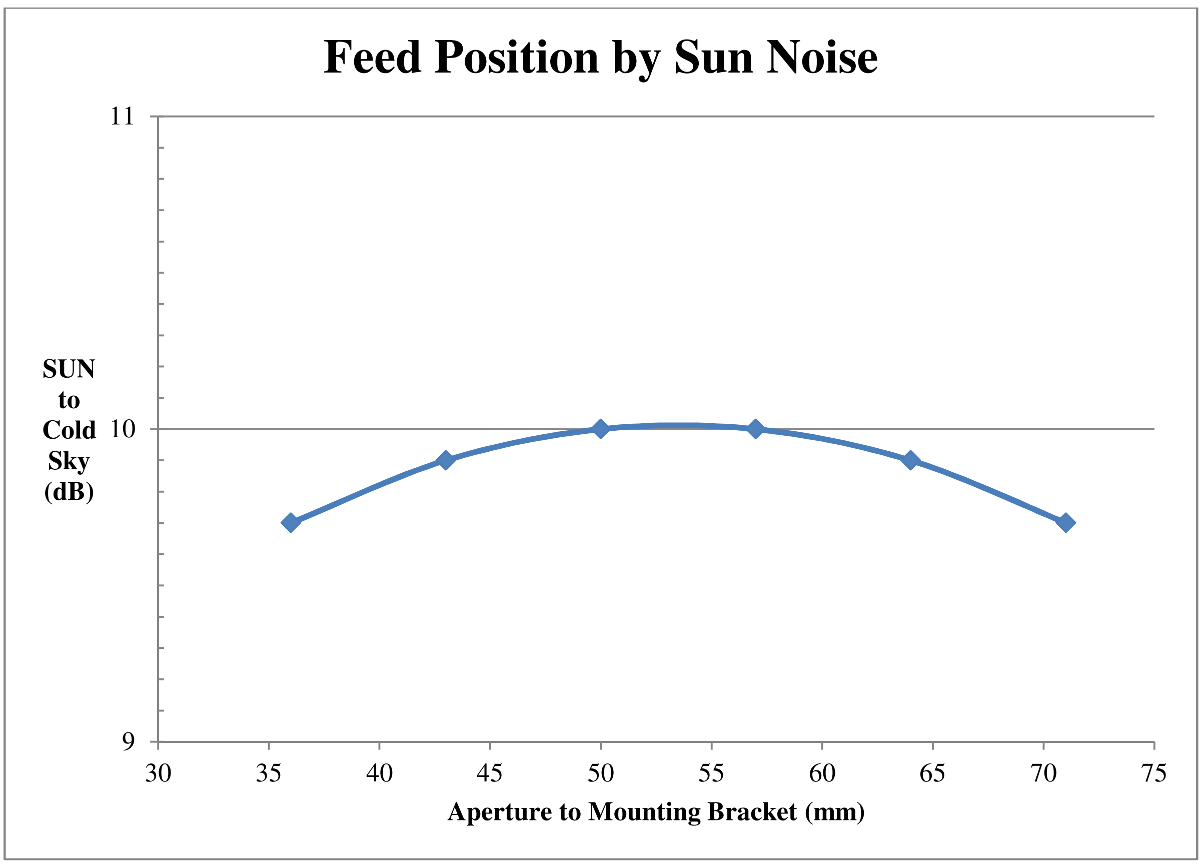


Figure 6 – Effect of feed position

I tried to do each set of comparisons in one session, to avoid changing solar flux or equipment. This summer, it has been hard to find a day with long enough clear sky for measurement – I really need the feed shadow to find the sun with the narrow dish beamwidth. During one session, a drift plot showed a sudden 2 dB drop, just before I felt raindrops.

The first feed comparisons were on the the 1.2 meter dish. The drift plot of the 1.62 λ feed is shown in Figure 7, showing 10.1 dB difference between sun noise and cold sky. Comparing this to the drift plot for the small 1.34λ W2IMU horn in Figure 8, with 8.7 dB sun noise, shows that the larger horn is significantly better. The 1.75λ feed plot in Figure 9, with 10.1 dB of sun noise, is equal to the 1.62 λ feed, while the largest feedhorn, 1.88 λ in diameter is even better in Figure 10, with 10.9 dB of sun noise. Adjusting the position of this feed found a slightly better location, 10mm closer to the dish with 11.0 dB of sun noise plotted in Figure 11. Solar flux for these measurements was 247.

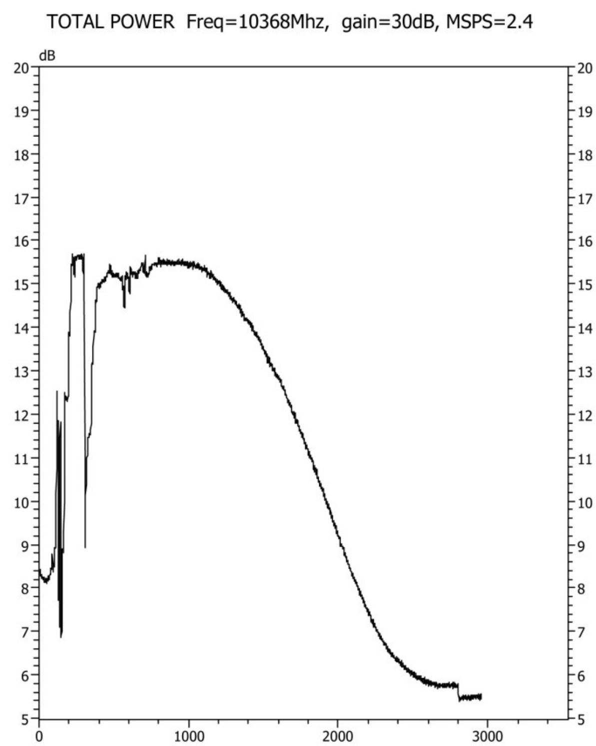


Figure 7 – 1.2M Dish, 1.62λ Horn

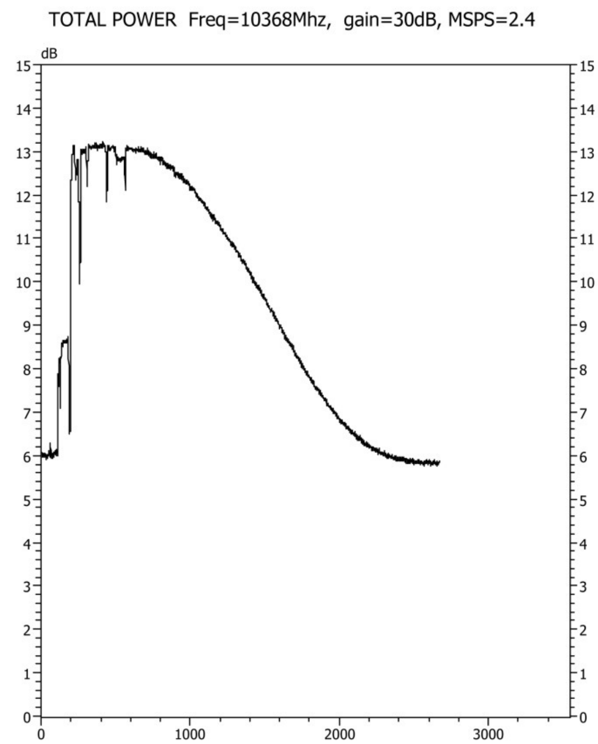
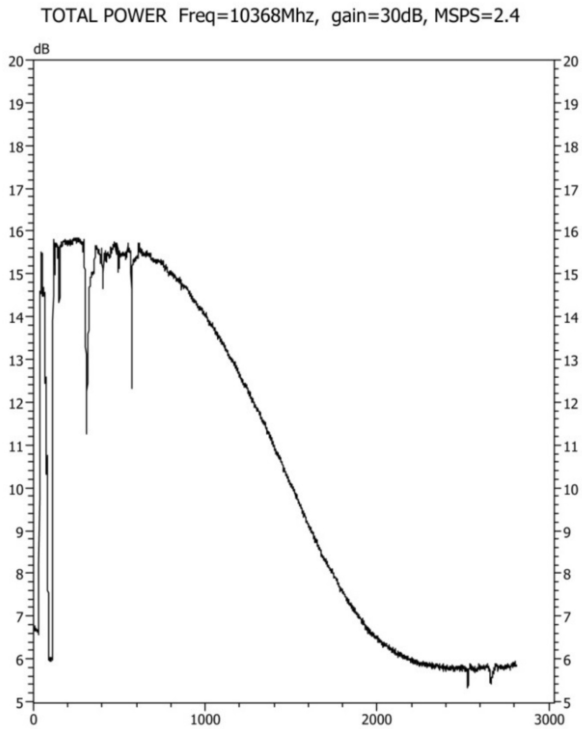


Figure 8 - 1.2M Dish, 1.34λ Horn



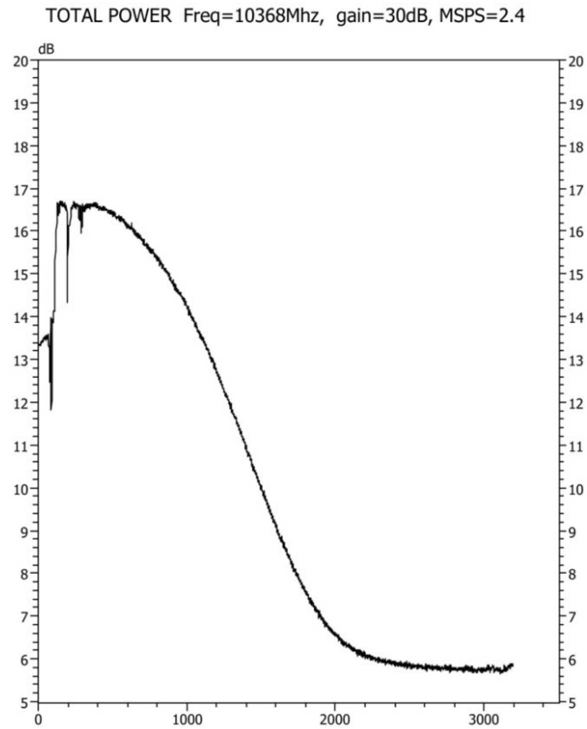


Figure 9 – 1.2M Dish, 1.75λ Horn

Figure 10 1.2M Dish, 1.88λ Horn

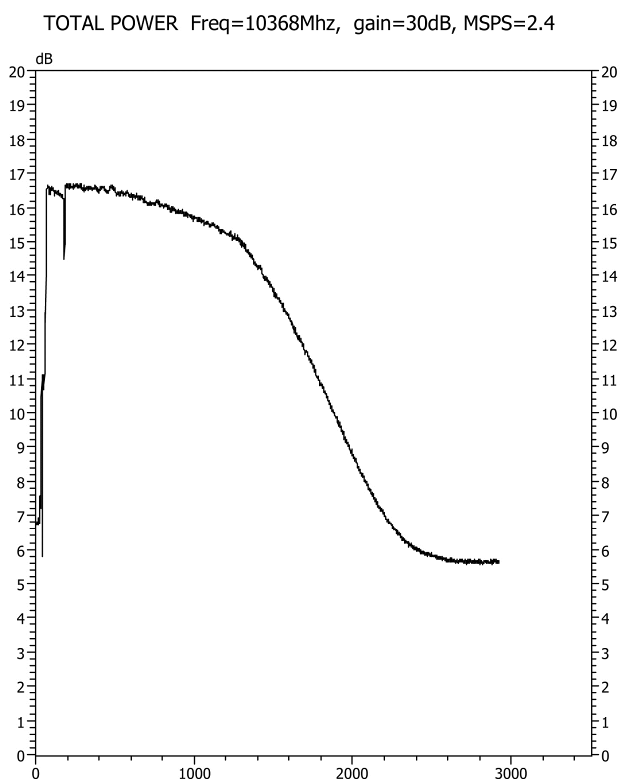


Figure 11 – 1.2M Dish, 1.88λ Horn in best location

On the 1-meter dish, I started with the old copper feed in Figure 2, 1.65λ diameter, which has been on the dish for about 25 years. I assumed that it was located at the focal point that I had found back then. The plot for this horn is Figure 12, with 8.2 dB of sun noise. A similar machined aluminum feed with 1.62λ diameter also measured 8.2 dB sun noise at the same location. Then I adjusted the location and found the best location ~10mm closer to the dish, with 8.4 dB sun noise in Figure 13.

The new location was used for all the other feeds. The 1.75λ diameter horn measured 8.6 dB sun noise in Figure 14, and the 1.88λ diameter horn measured 8.9 dB in Figure 15. The small W2IMU size, 1.34λ diameter, measured 7.3 dB sun noise in Figure 16. Solar flux for the 1-meter dish measurements was 244.

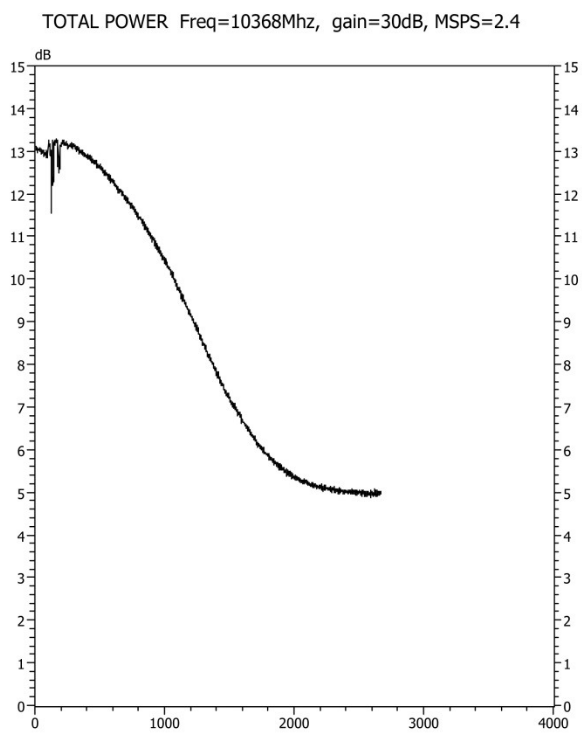


Figure 12 – 1.0M Dish, 1.65λ Copper Horn

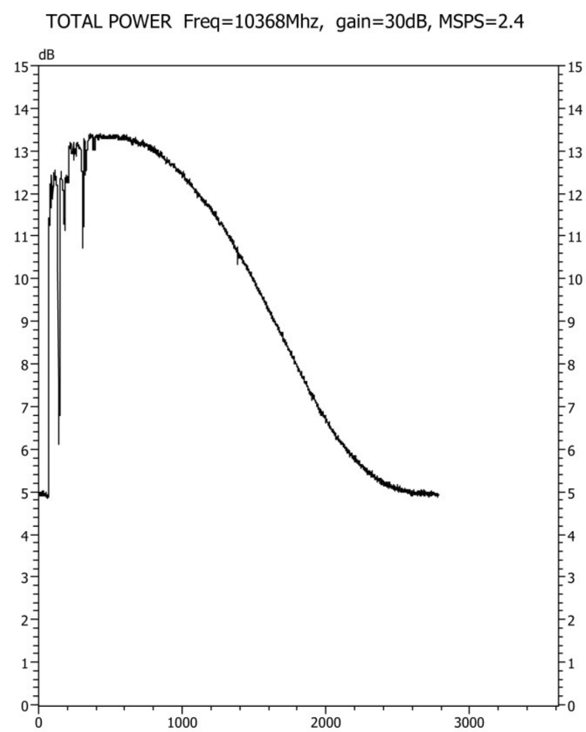


Figure 13 - 1.0M Dish, 1.62λ Horn

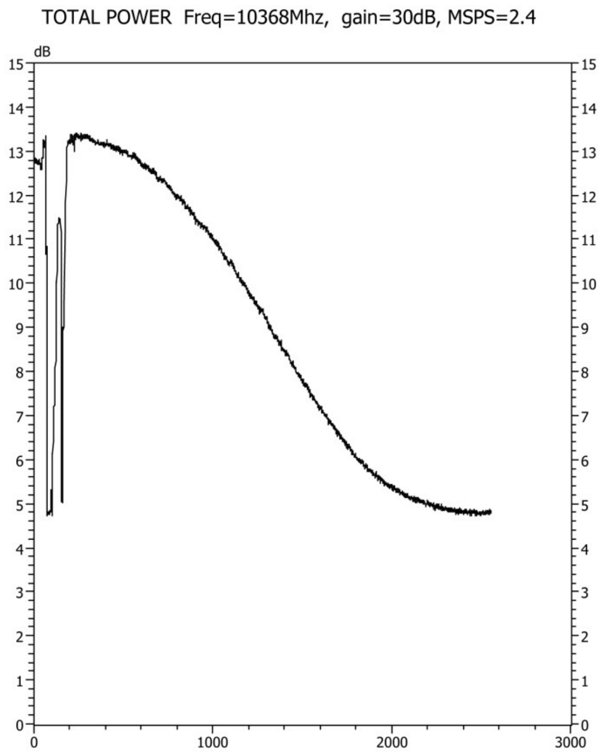


Figure 14 – 1.0M Dish, 1.75λ Horn

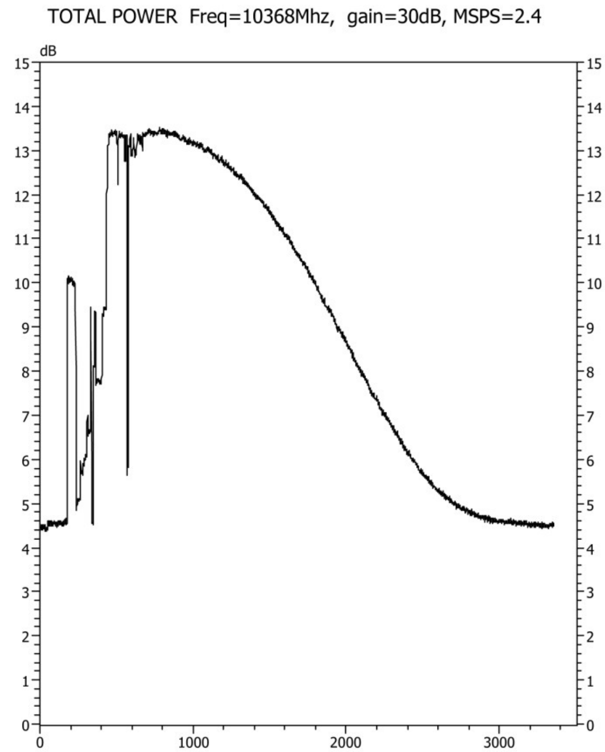


Figure 15 - 1.0M Dish, 1.88λ Horn

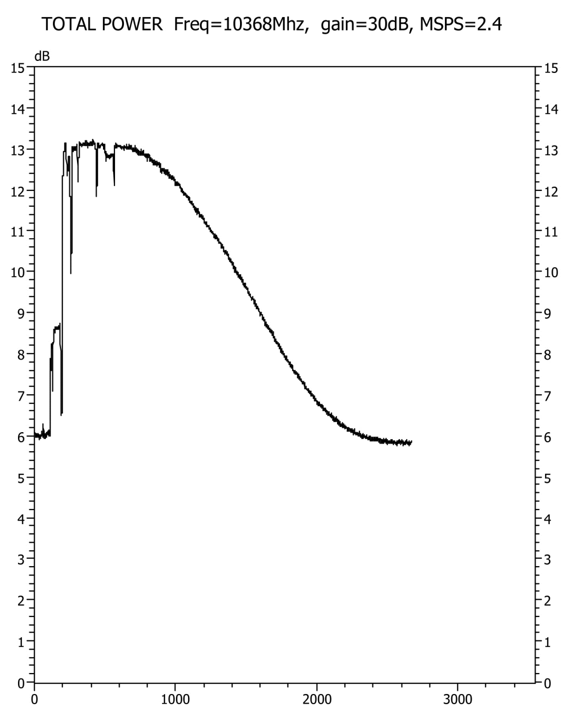


Figure 16 – 1.0M Dish, 1.34λ Horn

Summary

The assumption is made that increased sun noise will produce better G/T. The larger feedhorns have narrower beamwidth, so the dish efficiency might be slightly lower, but hearing should be improved. EME echo tests and moon noise tests are also needed.

Sun noise increases with increased feedhorn diameter – narrower beamwidth should reduce feed spillover. The largest W2IMU dual-mode feedhorn provides a significant improvement in sun noise, 2.3 dB on the 1.2 meter dish. .

The dimensions shown may not be completely optimum, but should be close. These horns were made using CNC machining, but it isn't essential. Ham ingenuity will find a way.

Notes

1. R.H. Turrin, (W2IMU), "Dual Mode Small-Aperture Antennas," *IEEE Transactions on Antennas and Propagation*, AP-15, March 1967, pp. 307-308. (reprinted in A.W. Love, Electromagnetic Horn Antennas, IEEE, 1976, pp. 214-215.)
2. Paul Wade, W1GHZ & Don Twombly, W1FKF, "Large W2IMU Dual-Mode Feeds for 47, 78, and 122 GHz ," https://newsvhf.com/conf2023/2023papers/MUD23/W1GHZ-Large_W2IMU_Dual-Mode_Feeds_for_10,47,78,and_122GHz.pdf
3. Jeffrey Pawlan, WA6KBL, "Very Compact and High Performance Transition for Circular to Rectangular Waveguide," ***DUBUS***, III/26, 2015.
4. https://i0naa.altervista.org/index.php/downloads