Large W2IMU Dual-Mode Feeds for 47, 78, and 122 GHz

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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 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. 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 the higher microwave bands, these are easy to make with a small lathe and simple tooling.

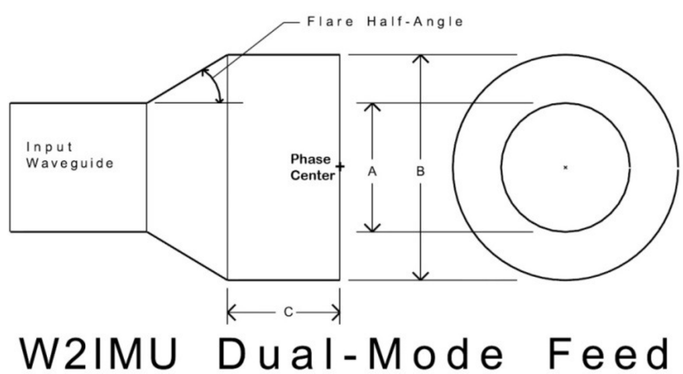

Figure 1

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 1.22 λ and 1.9 λ or so will work; 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.

The horn diameter of 1.78λ is for 2-inch copper pipe at at 10 GHz. I fabricated one some years ago from 2-inch pipe with 1-inch pipe as the input waveguide; the flare section is made from copper sheet, using the calculated dimensions. This horn is the larger one in Figure 2. 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

Practical 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. Input waveguide diameters between 0.7λ and 0.81λ make almost no difference in performance.

For the 47, 78, and 122 GHz bands, the Large W2IMU feeds are easily machined from brass or aluminum rod using a small lathe. What is needed is a tool that can bore the desired diameter. The answer is standard 60 degree (60° included angle = 30° flare angle) center drills which are available in diameters useful for these bands. A reasonably priced set shown in Figure 4 is available from Amazon. The 30 degree flare half-angle is on each side of the diameter, so the center drill tool with 60 degree included angle cuts it exactly. Long center drills are needed to bore the full horn length. Table 1 lists the center drill size, diameter, and horn length for each band. The horn length dimension has a modest amount of tolerance. The thick horn wall at the aperture reduces performance slightly, but tapering the outside of the horn rim at a 45° angle to a thin rim restores performance.

Metric center drills are also available which can provide more choices for the higher bands. Some of these are also shown in Table 1.

Large W2IMU Dual-mode Feed Dimensions

with 30 degree flare angle

W1GHZ Jan-23

Input Waveguide diameter 0.7 to 0.81λ

Frequency	Flare	Tool	Horn diameter		Horn Length		Gain	BW - 10
	degrees		inches	λ	inches	λ	dB	degrees
10.368	30		2.00	1.78	4.215	3.7	13.9	35
24.192	30	#9	0.875	1.79	1.806	3.7	13.9	35
47.088	30	#5	0.4375	1.74	0.928	3.7	13.9	35
76	30	#3	0.250		0.439		13.9	39
78	30	#3	0.250	1.65	0.439	2.9	13.1	39
122	30	#2	0.1875	1.94	0.415	4.3	14.6	32
122	30	4mm	0.157	1.63	0.281	2.9	13.1	39
241	30	2mm	0.079	1.66	0.142	2.9	13.1	39
HDL_ANT	25			1.78		3.5		
small IMU	30			1.31		1.37		

Table 1

NOTE: Flare and -10 dB beamwidth are half-angles, as shown in Figure 1.

Figure 4 – Long Center Drill Set

My machining process is as follows:

1. Chuck the rod in the lathe, face it, and start the hole with the center drill.
2. With an ordinary drill bit, drill out the horn to a diameter slightly less than the center drill, slightly deeper than the horn length.
3. Bore the horn to size with the long center drill until the full flare is cut.
   NOTE: Run the lathe at high speed with a very light feed. Cutting oil helps. The center drill only has short flutes so back it out frequently or the chips will jam.
4. Measure the length of the output horn section and trim to desired length.
5. Bore the input circular waveguide with appropriate size drill.
6. If you started with a large diameter rod to make the waveguide flange, turn down the outside of the horn to a reasonable wall thickness.
7. Part off the horn, turn it around, and face the waveguide flange.
8. Drill holes for waveguide screws and tap threads if desired. Alignment pins optional.
   NOTE: Milling machine with DRO improves flange hole accuracy.

Several finished 47 GHz horns made by W1GHZ are shown in Figure 5, each with one of the three flange types used by hams at 47 GHz. These were machined with a #5 center drill shown in Figure 4. A sketch of the 47 GHz feed is shown in Figure 5.

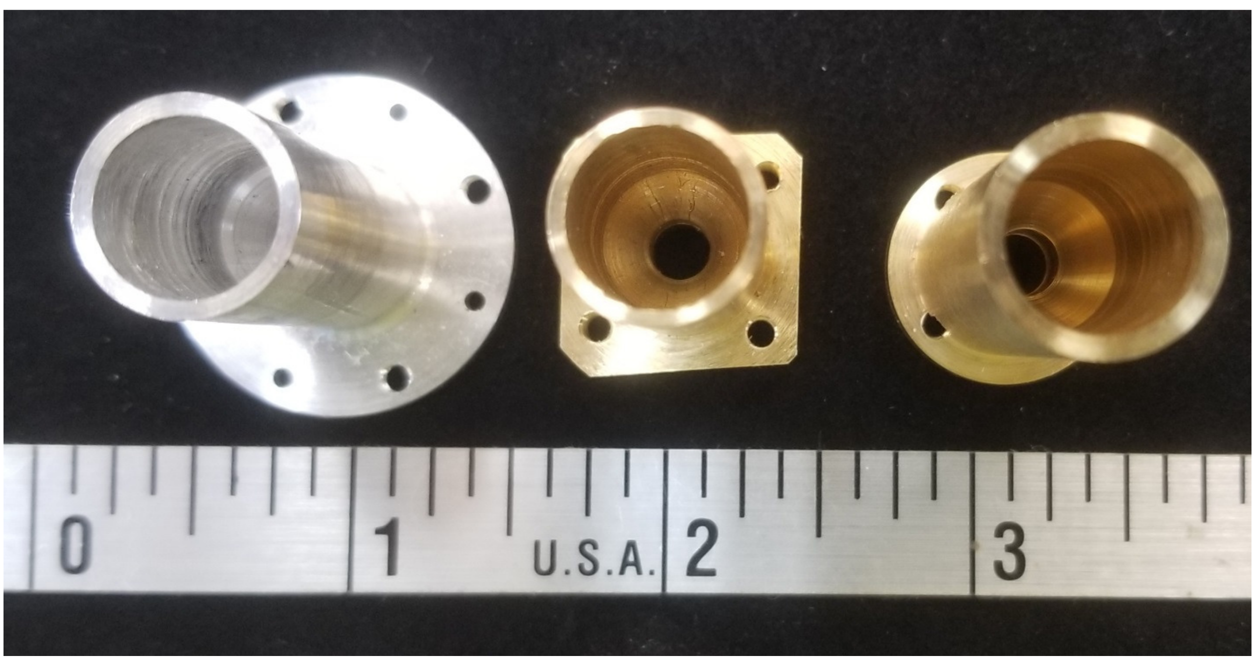

Figure 5 – Large W2IMU dual-mode feedhorns for 47 GHz

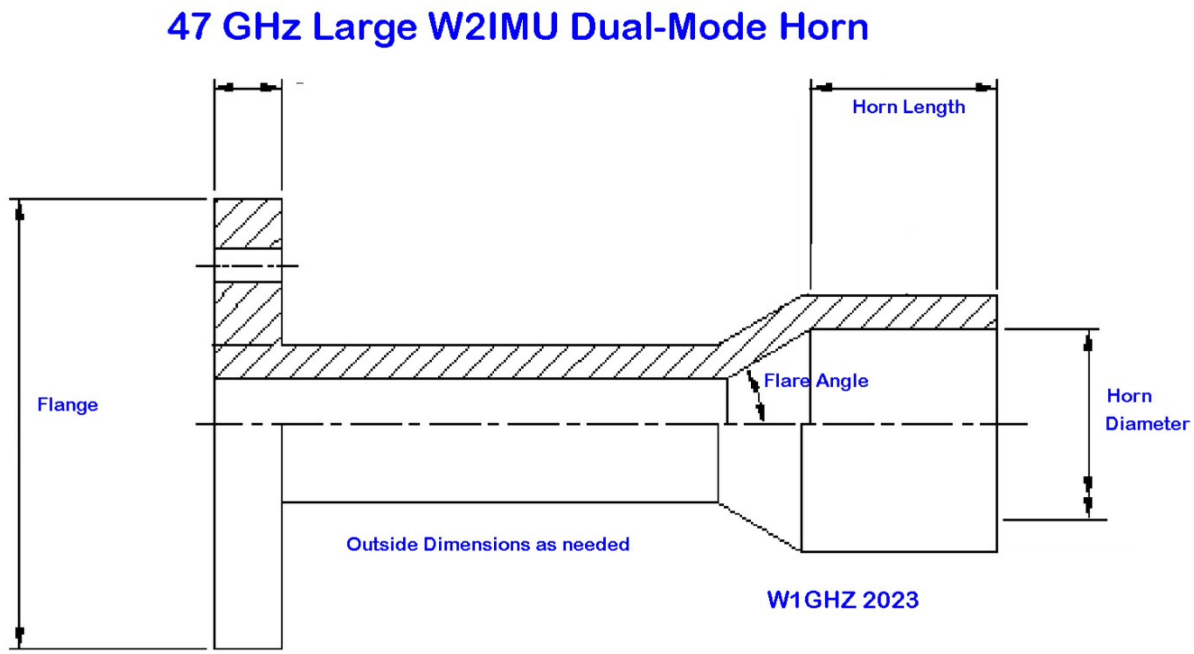

Figure 6 – sketch of 47 GHz W2IMU dual-mode feedhorn

Machining an integral flange wastes a lot of metal and adds machining time. Don, W1FKF, uses thin-wall tubing as waveguide and drills the back end of the feed to fit. Figure 7 shows his feedhorns for 122, 78, and 47 GHz.

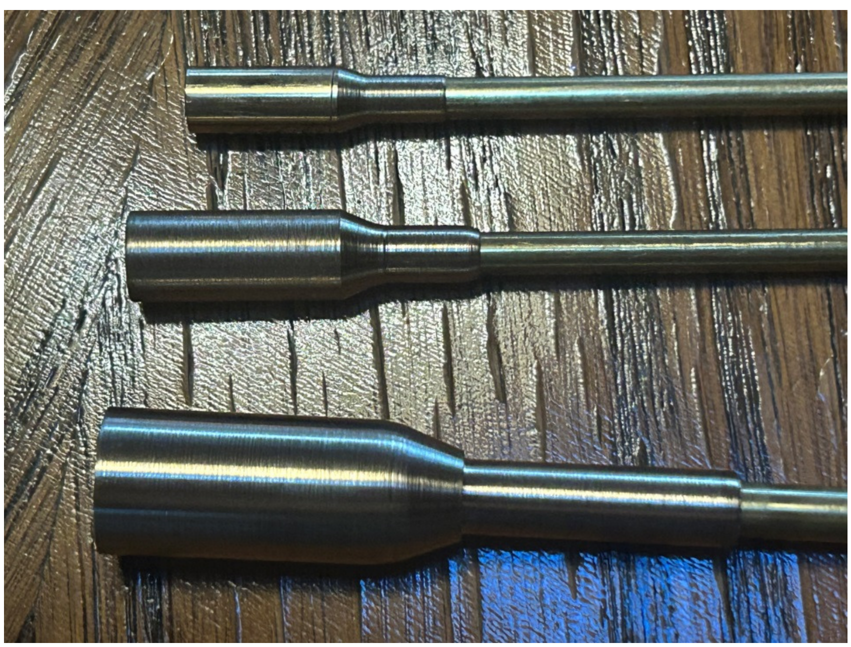

Figure 7 – Large W2IMU dual-mode feedhorns for 122, 78, and 47 GHz by W1FKF

Figure 8 shows Don's 122 GHz Cassegrain antenna, a 12-inch Edmund dish, with the large IMU feedhorn illuminating a subreflector made by W1GHZ. The mounting technique here, brass rods threaded into the subreflector, is an adaptation of one pioneered by Ken Schofield, W1RIL (SK), shown in Figure 9.

Figure 8 – Cassegrain antenna for 122 GHz with large IMU feedhorn by W1FKF

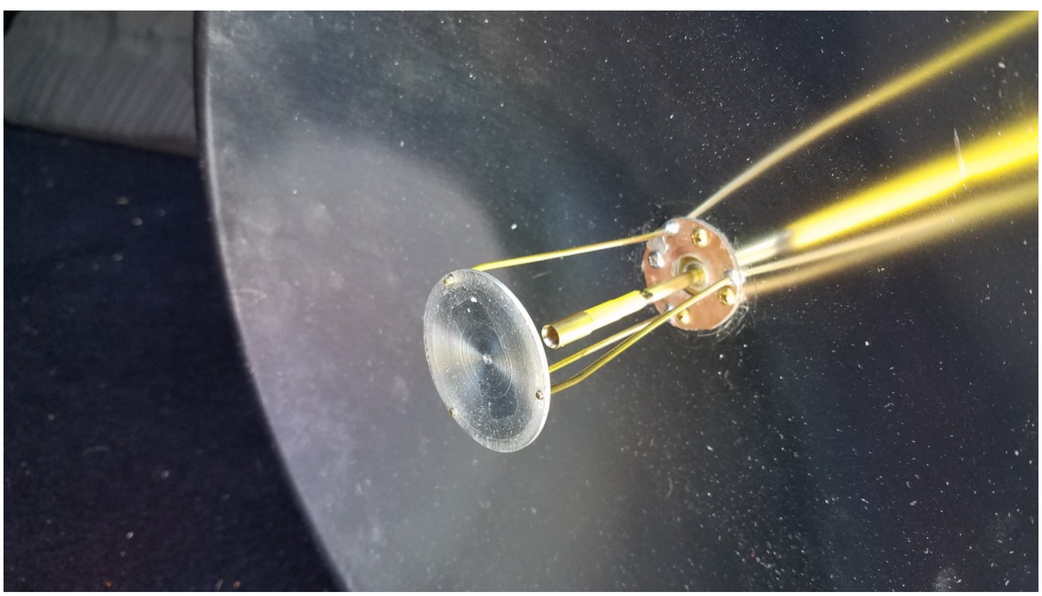

Figure 9 – Cassegrain Feed assembly by W1RIL

Don's 78 GHz dish, shown in Figure 10, is also a 12-inch Edmund dish with the subreflector illuminated by a large IMU feed. The subreflector is identical to the 122 GHz one – reflectors and subreflectors are not frequency sensitive. If the reflector ***f*/D** and the feedhorn radiation pattern are the same, the geometry is the same at any frequency and the subreflector will work as long as it is large enough (roughly >10λ) to avoid diffraction losses.

The support for the feed and subreflector is 3D printed plastic with threaded adjustment, a technique suggested by Rene Barbeau, VE2UG.

Figure 10 - Cassegrain antenna for 78 GHz with large IMU feedhorn by W1FKF

10 and 24 GHz

For 24 GHz, a #9 center drill is 0.875 inches in diameter, or 1.78λ, which is perfect for the feed. However, these are pretty pricy. The alternative is to use a boring bar in the lathe. I have made one this way, but a long boring bar was needed. The long boring bar was not rigid enough, resulting in some chatter and the resulting surface wasn't great. More work on the technique is needed here.

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 i.d. pipe copper pipe is an easier and possibly more economical solution. I'm working on machining just the flare section to attach to the pipe, to make a more robust feed than the ones in Figure 2. 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 2-inch schedule 10 aluminum pipe, ~2.15 inch i.d. (1.88λ), and some 2.25 inch o.d. aluminum round, available in short custom lengths from metalsdepot.com at reasonable cost.

While waiting for delivery, I found some smaller scrap aluminum and machined a small W2IMU feed, 1.31λ 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 horn.

The large 10 GHz feedhorn is made in two parts, the 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. 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 three of each piece and was able to make two pair close enough.

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 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 xxx, and slipped it over the flare section. It joined immediately, since the cold piece cools the hot one. The finished horn is shown in Figure 11, with the smaller W2IMU horn and a matching section to WR-90 waveguide.

Figure 12 is the aperture view of the horns, showing the flare section and input waveguide

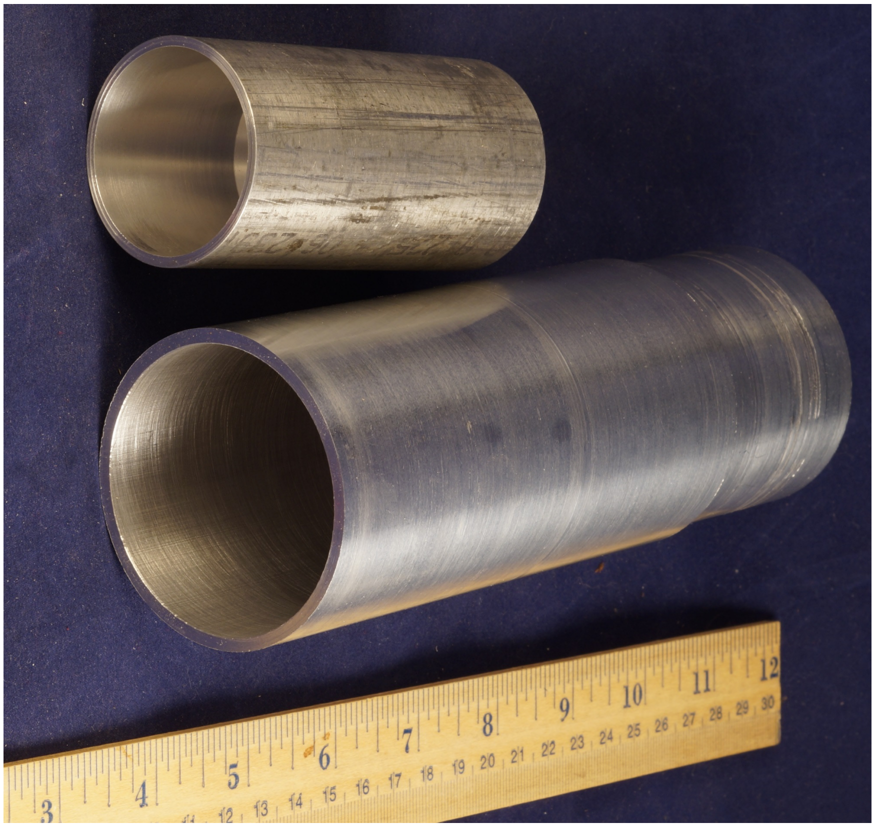

Figure 11 – Large (1.88λ) and Small (1.31λ) W2IMU Feedhorns for 10 GHz

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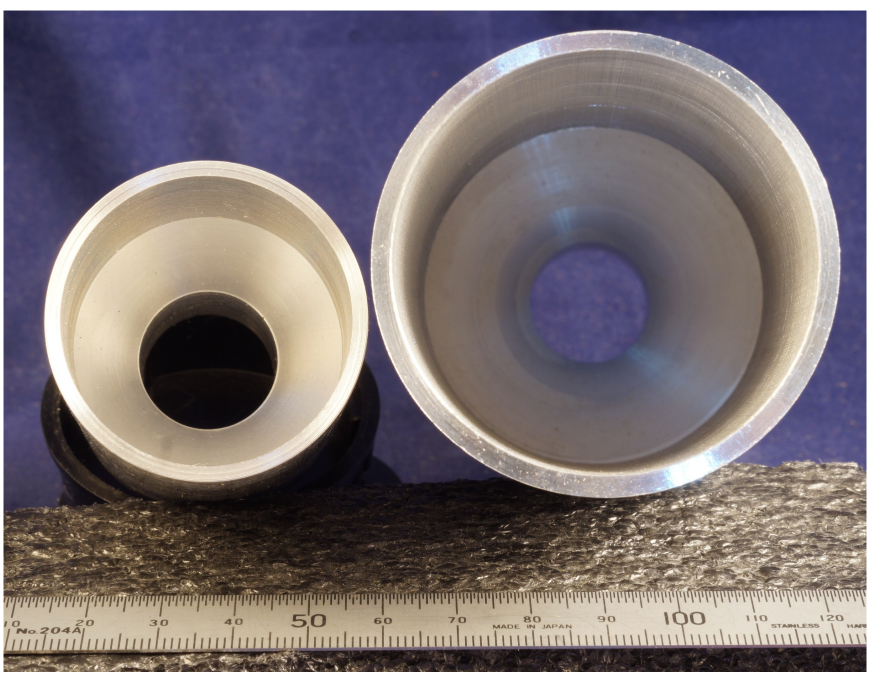

Figure 12 - Small (1.31λ) and Large (1.88λ) W2IMU Feedhorns for 10 GHz

Cassegrain Feeds

For very deep dishes there are no good prime focus feeds that fully illuminate the reflector. The inexpensive Edmund[2] dishes are available in 12, 18, and 24 inch diameter with a shiny, near-optical finish. They have an f/D = 0.25, very deep, but we have have found that they can have good performance with a Cassegrain feed using a high performance feedhorn like the Large W2IMU feed. A 12-inch Cassegrain antenna for 122 GHz by Don, W1FKF, is shown in Figure 8 and a 24 inch Cassegrain antenna for 47 GHz by Rene, VE2UG is shown in Figure 11. Both use Edmund dishes and Large W2IMU feedhorns. I machined the subreflectors on a CNC lathe. VE2UG has also made subreflectors with a 3D printer, coating the plastic with foil.

Figure 13 – 24 inch Cassegrain Antenna with Large W2IMU feedhorn for 47 GHz from Figure 5 by VE2UG

Details of the Cassegrain design and implementation are in another paper.

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. https://www.edmundoptics.com/f/large-parabolic-reflectors