Improving the Dual-band 10 & 24 GHz Feedhorn for Offset Dishes

Paul Wade W1GHZ ©2004

Operating multiple bands in the 10 GHz and Up contest is difficult with separate antennas – after locating a station on 10 GHz and peaking the dish, we must start over on a higher band, usually with a narrower beamwidth. Using a dual-band feedhorn for 10 and 24 GHz would very attractive; the dish may first be pointed and peaked up on 10 GHz, then switched over to 24 GHz with no repositioning required.
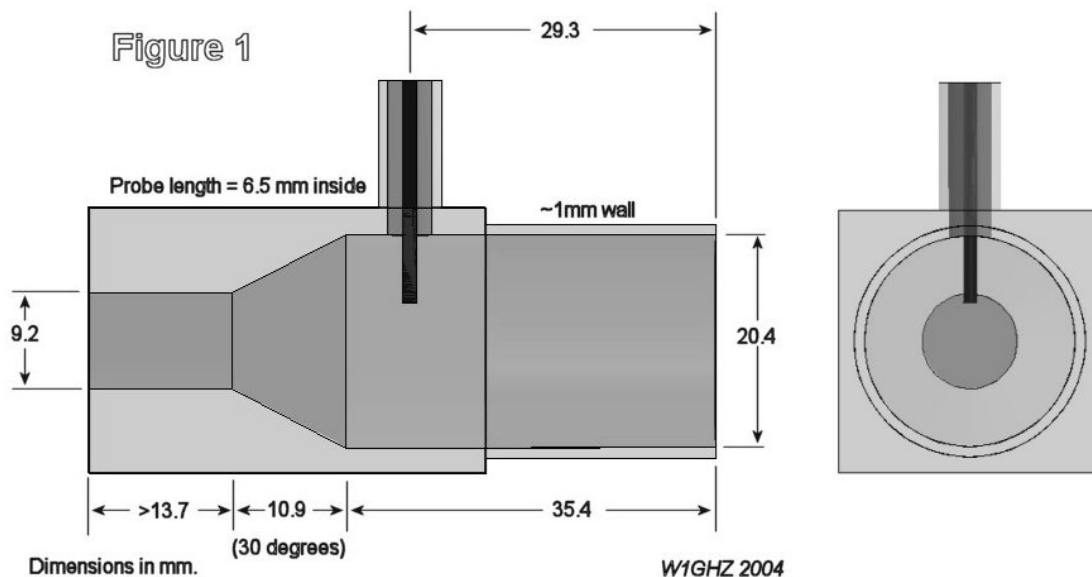
At Microwave Update 2001, AD6FP and AA6IW described[1] a dual-band 10 and 24 GHz feedhorn for shallow and offset dishes. The design was based on previous work of W5LUA[2] and W5ZN[3,4] to develop a dual-band feedhorn more suitable for conventional deep dishes. With the offset dish, we have a distinct advantage – the equipment may be located very near the feedhorn without being in the radiation pattern, minimizing the large feedline losses at the higher microwave frequencies without decreasing gain. Other advantages include higher efficiency feedhorns, less critical focusing, and the ready availability of modest-sized DSS dishes with good surface accuracy.

Gary and Lars included computer simulated radiation pattern plots which look like potentially good feeds, but did not do dish efficiency calculations. However, they did include more important results – sun noise measurements and on the air performance! To calculate efficiencies, I took the published dimensions and resimulated. The results were good, so I wanted to make a feed.

Dualband feedhorn operation

The basis of the dual-band feedhorn design is the W2IMU dual-mode feedhorn[5], dimensioned to feed an offset dish at 24 GHz and excited from the rear with a circular waveguide section. For 10 GHz, an excitation probe fed by an SMA connector is added on the side of the output section of the dual-mode horn. The tapered section of the dual-mode horn acts as a closed end at 10 GHz, so that the output section behaves like a simple "coffee-can" feed at 10 GHz. Figure 1 is a sketch with the dimensions I used.

While the 24 GHz dual-mode horn has a pattern (Figure 2) suitable for an offset dish, the simple 10 GHz horn has a much broader pattern (Figure 3), better suited to a deep dish, so it would have a lot of spillover feeding an offset dish. AD6FP improved the 10 GHz performance by adding a conical horn to narrow the beam, and AA6IW enhanced it further by using a corrugated horn. The dual-mode horn is intended to eliminate edge currents in the rim of the horn, so the addition of the conical horn outside the rim has a much smaller effect at 24 GHz. By varying the horn dimensions, it might be possible to make the patterns and efficiencies very close on the two bands. I had four different corrugated horns on hand, so I tried simulating with each of them. Results were promising, so I bored out the circular waveguide end of each horn on my lathe so that it could be slipped over the end of the dual-band horn.

Figure 1

Probe length = 6.5 mm inside

29.3

~1mm wall

9.2

20.4

>13.7

10.9

(30 degrees)

35.4

Dimensions in mm.

W1GHZ 2004

Construction

Gary and Lars built their horns with copper plumbing and hobby brass, soft-soldered together. I tried this construction, but wasn't happy with the dimensional accuracy, and it certainly didn't feel robust enough for rover operation. Then I experimented with turning the tapered section out of solid brass, but found it difficult to get the taper right. Finally, I ran out of time before the 2004 contest and simply used a 25 dB horn on 24 GHz; at least it was easy to point.

Last fall, I was browsing through a tool catalog from MSC[6] and found some 60° countersinks (normal is 82° or more). This would make a 30° flare angle for the tapered section, while Gary and Lars used my HDL_ANT program to calculate a 27.8° taper angle. The 60° countersink would be an easy way to machine a 30° taper, but is 30°close enough to 27.8°?"

I simulated the horn with 30° taper using Ansoft[7] HFSS software. The results are shown in Figure 2 at 24 GHz: the rear lobe is a couple of dB worse than with the 27.8° taper, but the calculated efficiency of 76% is close, and the best *f*/D is about 0.7, just right for a DSS offset dish. At 10 GHz, calculated efficiency is still good, about 70%, but best *f*/D is about 0.38, as shown in Figure 3. At the 0.7 *f*/D needed for an offset dish, efficiency is down to about 47%, or nearly 2 dB worse. A few additional trials at 24 GHz suggested that a slightly longer output section might be a little better, if the countersink were long enough, but the improvement was not significant.

Another problem is that the nearest countersink size is ¾ inch, or 19.05 mm. I simulated with the inner diameter of the output section reduced from 20.4 mm. This change did not work well at all — the larger diameter is required.

The other mechanical problem is robust feedline attachment: WR-42 waveguide for 24 GHz and an SMA connector for 10 GHz. Using brass or copper for the feedhorn would allow soldering, but both are heavy and expensive. Turning the feed from aluminum rod was the best choice, but the size would have to be large enough for the WR-42 hole pattern: 7/8" square, or 1.25 inch diameter.
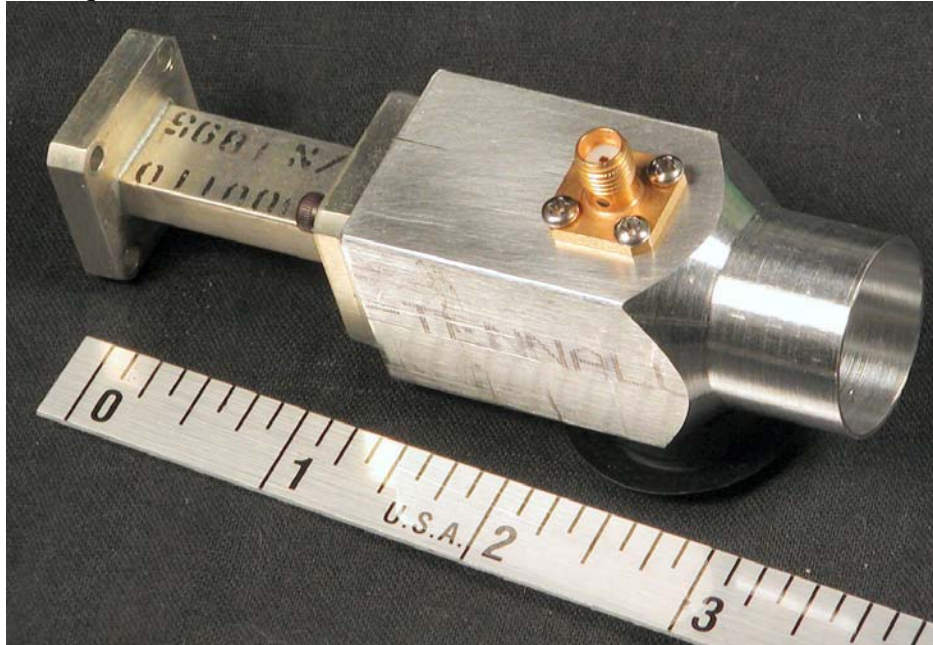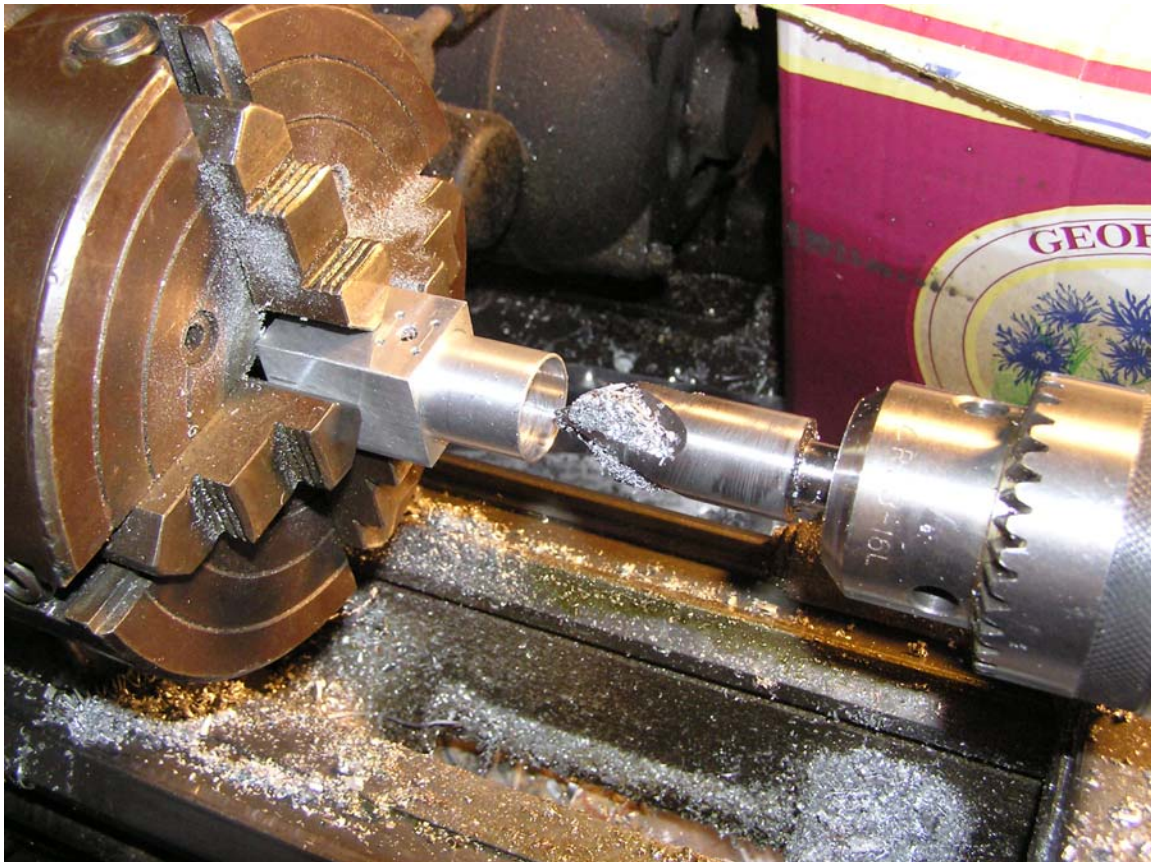

Figure 4

I found that 1" square aluminum was readily available in short lengths, so I ordered some, along with a ¾" 60° countersink. After a couple of hours with the lathe, my first attempt is shown in Figure 4. The machining was possible, but the ¾" countersink diameter is smaller than the 20.4 mm inner diameter that a small shoulder was left. I fiddled with a boring bar to minimize the shoulder so that I could at least measure the VSWR and make sure I was on the right track.

Some improvement was necessary to make a proper taper. Matt, KB1VC, attempted to make a custom cutting tool, but the results were not encouraging – the countersink is clearly the right tool. I went back to the MSC catalog and found a 7/8" countersink, slightly oversized. The HSS tool steel is too hard to cut with ordinary tooling, so I used a toolpost grinder to grind the countersink to the exact 20.4 mm diameter. Now we are able to machine the correct taper cleanly.

The basic machining procedure is:

1. Cut a piece of 1" square aluminum to about 2.6" long.
2. True up in 4-jaw chuck and face ends.
3. Drill a hole about ¼" diameter down the center, all the way through.
4. Drill ¾" diameter about 35 mm deep.
5. Bore out to 20.4 mm diameter. This leaves a small shoulder at the taper.
6. Countersink with 20.4 mm, 60º countersink to form the taper.
7. Turn down outside diameter to leave about 1 mm wall, about 16 mm long.
8. Trim end to leave output section length of 35.4 mm.
9. Drill out circular waveguide diameter to 9.2 mm diameter.
10. Mark out WR-42 holes in back end, drill and tap 4-40 thread.
11. Mark out and drill SMA holes in one side, with center 29.3 mm from open end.
12. Tap mounting holes for SMA 2-56 thread.
13. Clean up and degrease.
14. Fit SMA.

The countersink setup on the lathe is shown below:

Corrugated horns

The four corrugated horns I have ready to try are shown in Figure 5. I simulated the feedhorn with each of these, as well as with a plain conical horn. Patterns and calculated efficiencies are shown in the following figures at 24 GHz, and at 10 GHz with the phase center at the best location for 24 GHz:

- Figure 6 – plain conical horn
- Figure 7 – RCA DSS horn
- Figure 8 – Chaparral 11 GHz offset feedhorn
- Figure 9 – horn from CD-80 dish (0.8m, $f/D = 0.8$)
- Figure 10 – surplus corrugated horn

The calculated efficiencies and phase centers are summarized in the table below. At 10 GHz, efficiencies are listed at the 24 GHz P.C. (phase center) as well as the optimum, assuming that the feed position would be more critical at 24 GHz. Phase centers are measured from the center of the aperture; negative numbers are inside the horn.

Dual band 10&24 GHz Feed - Calculated Horn Performance

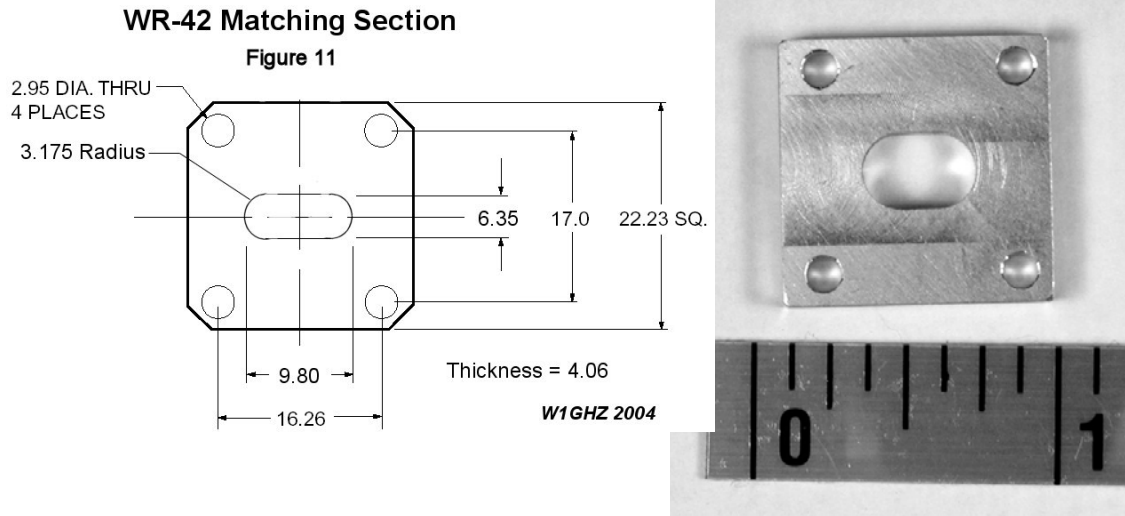| HORN | 24 GHz | | | 10 GHz | | | Offset f/D = 0.7 at 24 GHz P.C. | |
	Efficiency	f/D	Ph. Cen.	Efficiency	f/D	Ph. Cen.	24 GHz	10 GHz
none	76%	0.72	1.2 mm	71%	0.38	0 mm	76%	47%
Conical	76%	0.8	-26	67%	0.7	-31.2	74%	66%
RCA	75%	0.93	-24.8	77%	0.7	-5.8	69%	68%
Chaparral	78%	0.81	-23.6	75%	0.65	-24.9	76%	74%
CD-80	77%	0.88	-29.1	78%	0.76	-4.9	68%	65%
Surplus	79%	0.8	-6.2	76%	0.7	-22	77%	70%

All of the horns improve the performance at 10 GHz while maintaining high efficiency at 24 GHz. However, the best f/D and the phase centers for the two bands are not the same. The best choice appears to be the Chaparral horn, with phase center differing by only 1.3 mm, so that the optimum position for 24 GHz is only 0.04λ off at 10 GHz. The result is excellent calculated efficiency for both bands, 76% at 24 GHz and 74% at 10.368 GHz. This is comparable to the best single band feeds – a dual-band feed that does not compromise performance.

Performance

The temperature in New England is considerably below freezing, and the sun will not be high enough for sun noise measurements until well after the deadline for this paper. I hope to have some results before you read this.

Thus, the only testing so far is for VSWR. At 10.368 GHz, the VSWR is about 1.25 with no tuning. At 24.192 GHz, the VSWR is about 2.5 with the circular waveguide connected directly to WR-42 rectangular waveguide. This was predicted in simulation, since the characteristic impedance of circular waveguide is different from rectangular guide. A matching section, shown in Figure 11, was simulated and optimized; it is a quarter-wavelength section of rectangular guide with the dimensions chosen to provide the required impedance to match the circular guide to WR-42. To make machining easier, a radius was added at the corners, and increased until the ends are simply ¼ inch diameter; a slight increase in the wide dimension was required for the same impedance. The matching section improves the measured VSWR to about 1.05. I believe European 24 GHz operation is at 24.048 GHz; VSWR there is about 1.04. Adding the various corrugated horns to the basic feed has only a small effect on the VSWR on either band.

Isolation between connectors is not a problem at 10 GHz, since the 24 GHz waveguide is beyond cutoff, but is not good enough at 24 GHz. With one watt input at 24 GHz, more than 10 mw leaks out the 10 GHz SMA connector – more than I want my preamp to see. I'm working on a low-pass filter.

WR-42 Matching Section
Figure 11

2.95 DIA. THRU 4 PLACES

3.175 Radius

6.35   17.0   22.23 SQ.

9.80

Thickness = 4.06

16.26

W1GHZ 2004

Conclusion

The dual-band feedhorn for 10 and 24 GHz by AD6FP and AA6IW looks very promising, and should provide excellent offset-dish performance on both bands. I have made some small improvements to make construction easier and more robust, and plan to have one on the air as soon as warm weather returns.

References:

1. Gary Lauterbach, AD6FP, and Lars Karlsson, AA6IW, "Dual-Band 10/24 GHz Feedhorns for Shallow Dishes," *Proceedings of Microwave Update 2001*, ARRL, 2001, pp. 181-190.
2. Al Ward, W5LUA, "Dual Band Feedhorns for 2304/3456 MHz and 5760/10368 MHz," *Proceedings of Microwave Update 1997*, ARRL, 1997, pp. 158-163.
3. Joel Harrison, W5ZN, "W5ZN Dual Band 10 GHz / 24 GHz Feedhorn," *Proceedings of Microwave Update 1998*, ARRL, 1998, pp. 189-190.
4. Joel Harrison, W5ZN, "Further Evaluation of the W5LUA & W5ZN Dual Band Feeds," *Proceedings of Microwave Update 1999*, ARRL, 1999, pp. 66-73.
5. 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.)
6. www.mscdirect.com
7. www.ansoft.com