Waveguide is just Metal

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As we get into the higher microwave and mm-wave bands, waveguide is the only way to go. But these small waveguides are scarce and pricey. Even at ham prices, they go pretty high – someone was recently offering some simple bits for €100 and up. Putting together a system can get expensive.

47 GHz

Over the years, I have picked up a fair selection of WR-42 pieces for 24 GHz use, but only acquired smaller waveguide bits when they were real bargains, since I wasn't doing anything at higher frequencies. But I couldn't resist the new DB6NT MKU 47 G2 transceiver for 47 GHz. When the 47 GHz transceiver arrived two years ago, I found that it uses WR-19 waveguide. A quick search of the junkbox found zero usable waveguides.

Since the 10 GHz and Up Contest was only a few weeks away, I had to find a way to get it on the air. Would open waveguides be enough to make some contacts? Or could I make an antenna?

A dish was out of the question – I didn't have a waveguide switch. How about two horns, one for transmit and one for receive? I reviewed my paper[1] on Skobelev Optimized Dual-Mode Horns – they are compact and not too complex to make – and estimated that horns 5.5λ in diameter would fit side-by-side and provide about 23 dB of gain.

I took my sketch to the local Makerspace[2], The FoundryVT, to do the machining. I've been learning basic CNC machining there, mostly by trial and error, but I had never tried the CNC lathe. With a lot of help, I was able to make a CAD drawing and generate the CNC code. Then we found that the CNC lathe doesn't have a working data interface, so I had to punch in the G-code into a keypad six feet off the ground, over my head. But we finally got the horns machined, with only a couple of broken tools.

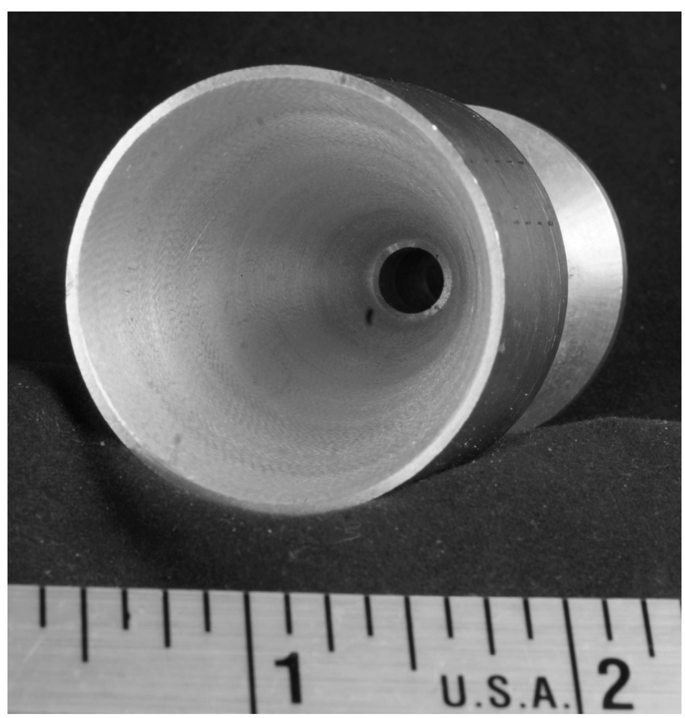

Figure 1 – 24 GHz Skobelev Horn

I bolted the round horn input directly to the rectangular WR-19 on the transverter. The mismatch should not be too bad, and I don't have a way to measure or improve it.

At the NEWS Group picnic we usually do some MDS testing, and we did 47 GHz that year for the first time. Seven 47 GHz stations showed up. Everyone else had a dish, but my horns were only about 10 dB down from the dishes. The difference should be closer to 20 dB. We aren't sure why; either none of the dishes was working properly, or the test range had problems. Anyway, the rig works with the two horns. During the subsequent contest, I was able to work 90km, over the horizon, and the horns sure are easier to aim than a dish.

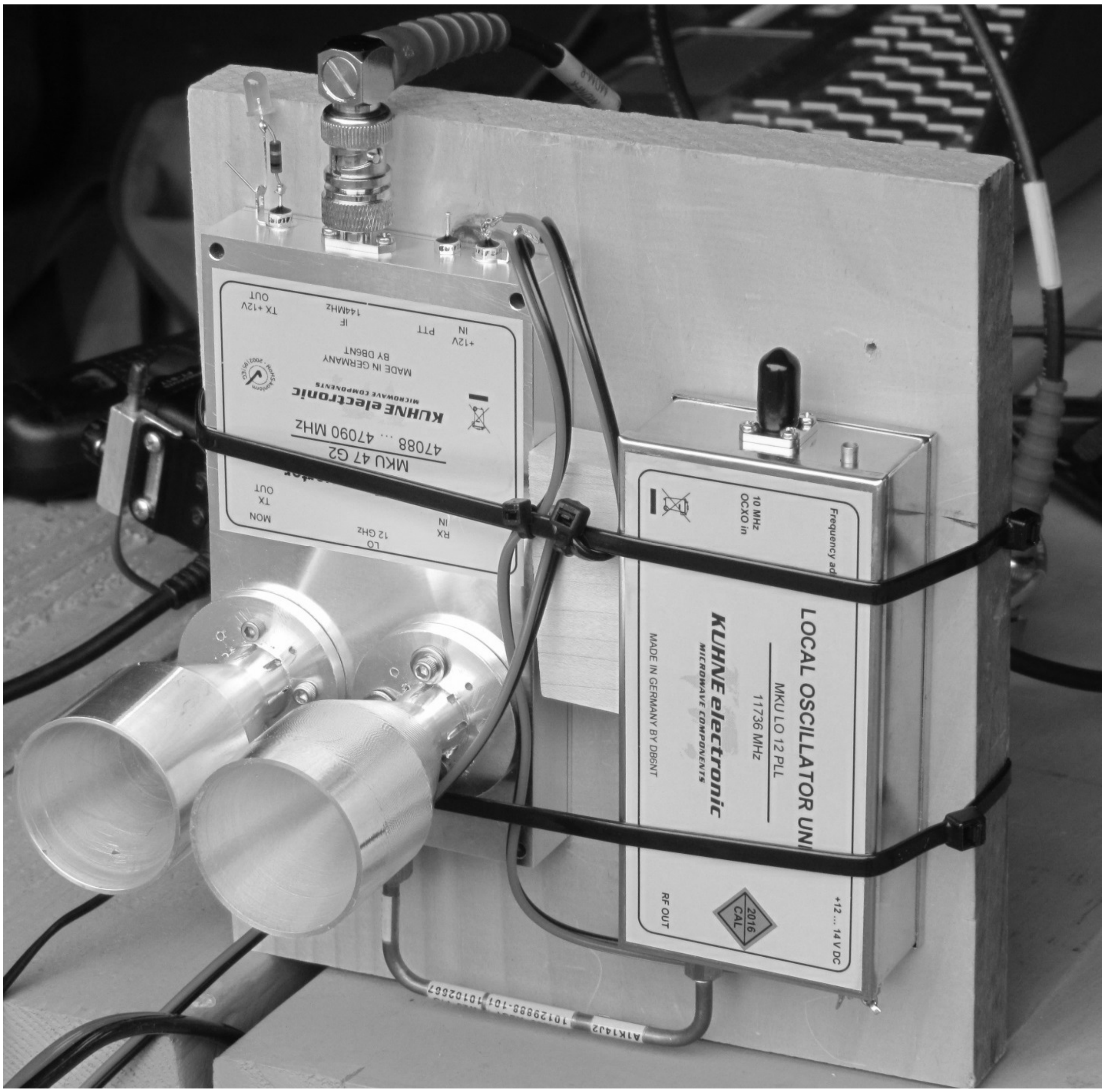

Figure 2 – DB6NT 47 GHz transverter breadboard with two horns

Waveguide Switch

The next step was to see if I could machine a waveguide switch. Commercial WR-19 switches have radial waveguide connections, inconvenient locations for the integrated transverter. Figure 3 shows how Ray, VE3FN, put one into his system – it took a lot of plumbing. Rene, VE2UG, has figured out how to bend waveguide, and he and Ray did the plumbing.

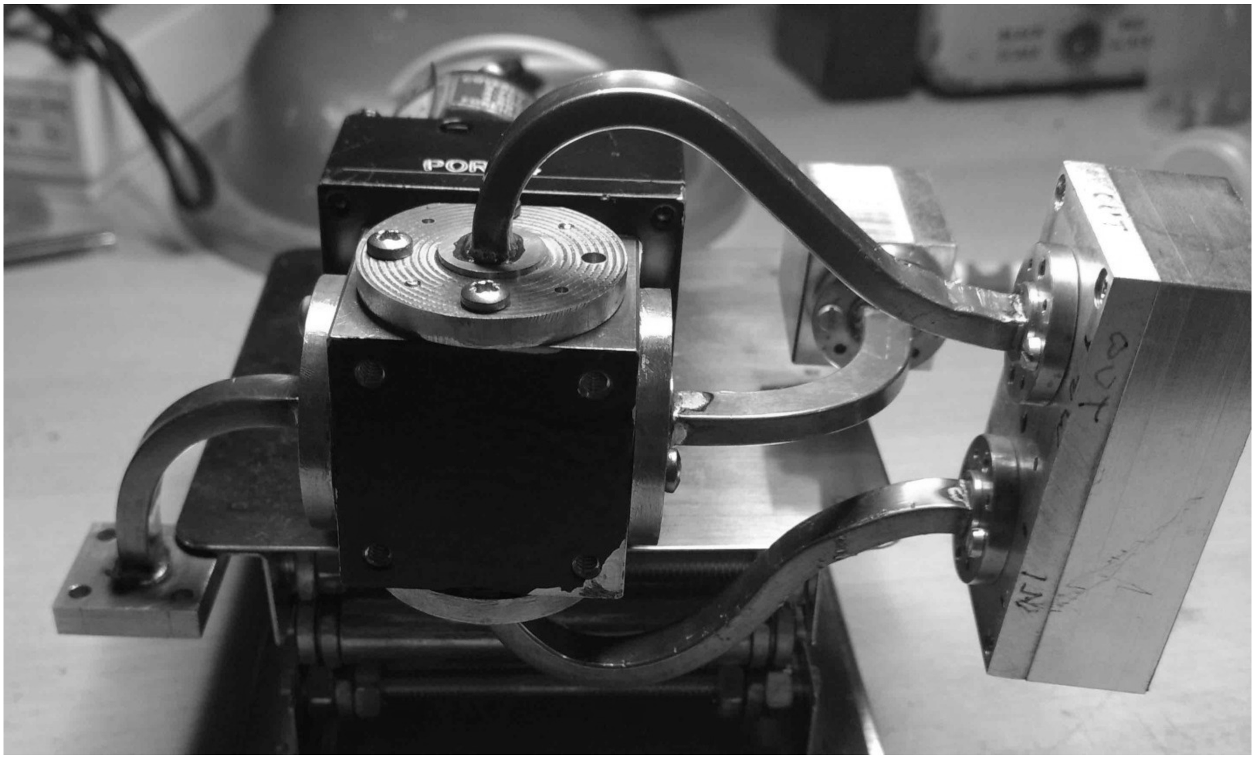

Figure 3 – WR-19 47 GHz waveguide switch plumbing by VE3FN and VE2UG

I sketched out a WR-19 waveguide switch with 3 ports, two spaced to mate up with the DB6NT transverter, and the antenna port on the far side. It took a little fiddling with the geometry on paper and in CAD to get everything to line up. The CNC milling machine cuts what it is told, and it is possible to make clean curves with a smooth surface. The machined switch is shown in Figure 4. I haven't got the rotation mechanics worked out yet, but a static test shows less than 2 dB loss.

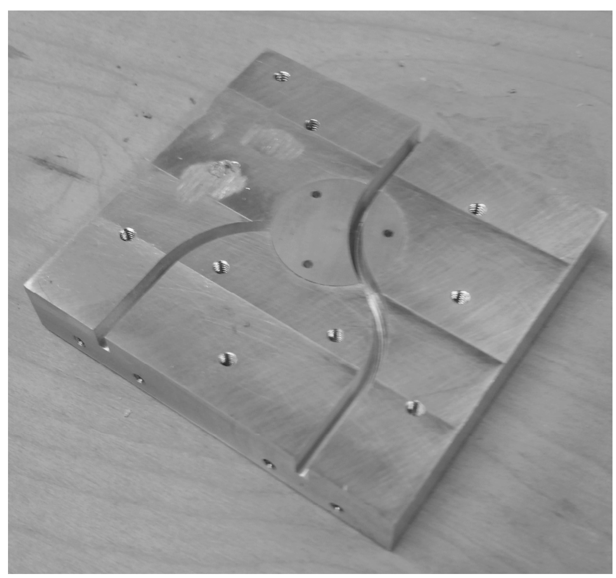

Figure 4 – Three port waveguide switch

Waveguide Components

Other waveguide components are needed to build a system. There is little magic for most of them, since waveguide dimensions are standard. Commercial mm-wave stuff is made by plating onto a mandrel, but plating is messy and uses nasty chemicals.

For hams, the waveguide can be machined. Just a matter of removing metal until a waveguide appears. It might be a few tenths of a dB worse than commercial stuff, but think about the dBs per $$.

Waveguide-to-coax Transitions

The next pieces I made were some coax-to-waveguide transitions for WR-19. The coax port should be a fancy mm-wave connector, but I don't have any and couldn't find any, so I used SMA connectors. No microwave engineer would use SMA connectors, but we are hams – we use what we have. Some of the uncertainty in the loss of the waveguide switch is due to these transitions.

These are descended from the coax-to-waveguide transitions I made for lower frequencies[3]. I made some for 24 GHz in WR-42 some time back by having the aluminum blocks made at emachine.com, then tapping the holes and finishing myself. I ordered enough blocks to get a reasonable quantity price and sold some, but still have a few left.

A couple of WR-42 transitions are shown in Figure 5. Measured performance is very good, with return loss better than 30 dB.

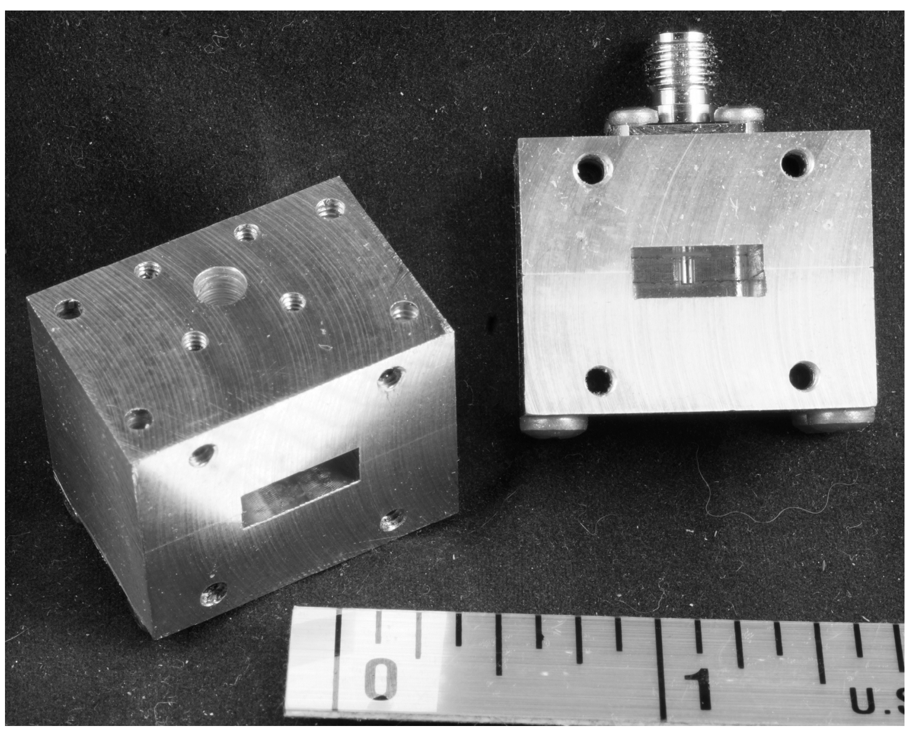

Figure 5 – WR-42 waveguide to coax transitions for 24 GHz

Waveguide Filter

Another waveguide component is a filter. At 24 GHz, it is easy to build a waveguide post filter, but the dimensions are too small at 47 GHz. A filter that does work at 47 GHz is the OEPMJ filter. I had played with these in simulation when I had access to HFSS software – now I have machinery to actually build them. I made several for 24 GHz, where I have test equipment and was able to verify the simulations, and then for 47 GHz and 78 GHz, shown in Figure 6. I was able to test the 47 GHz filters at the 2017 Eastern VHF/UHF Conference on a Rohde & Schwarz VNA provided by Greg Bonaguide, WA1VUG – performance was excellent. I described these filters at Microwave Update 2017[4]. However, filters for 78 GHz were less successful – perhaps the limits of my machining skills have been reached.

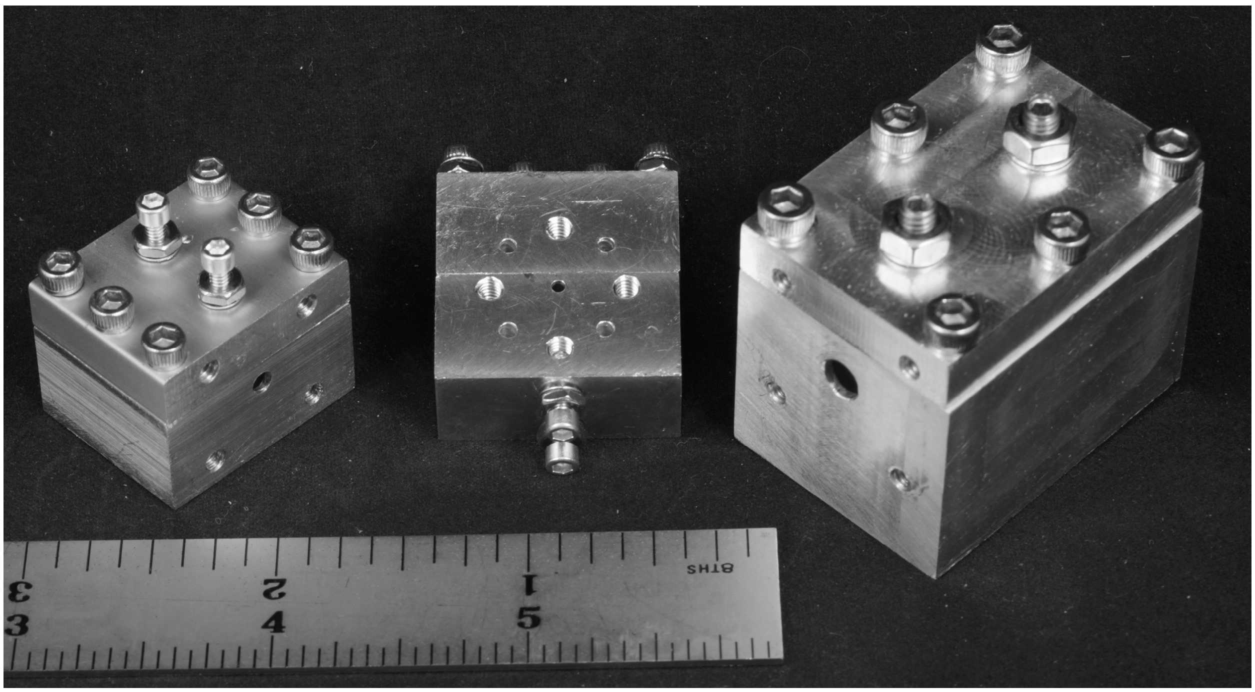

Figure 6 – OE9PMJ Filters for 47 GHz, 78 GHz, and 24 GHz

Waveguide Flanges

To make waveguide connections, flanges are needed. Flanges are easily machined out of rectangular brass bar stock, like Figure 7. I made some for WR-19, WR-22, WR-28, and for hobby brass tubing which has the same internal dimensions as WR-22. WR-22 is close to WR-19 in size and uses identical flanges, so they can be mated together without serious mismatch, and the hobby brass is an inexpensive substitute for expensive waveguide. Both round and rectangular flanges are used for these waveguides, so I made some of each – make a CAD drawing of one, replicate it, put the program in the CNC machine, and watch it work. Then cut them up, finish the holes, and file out the rectangle to fit around the waveguide.

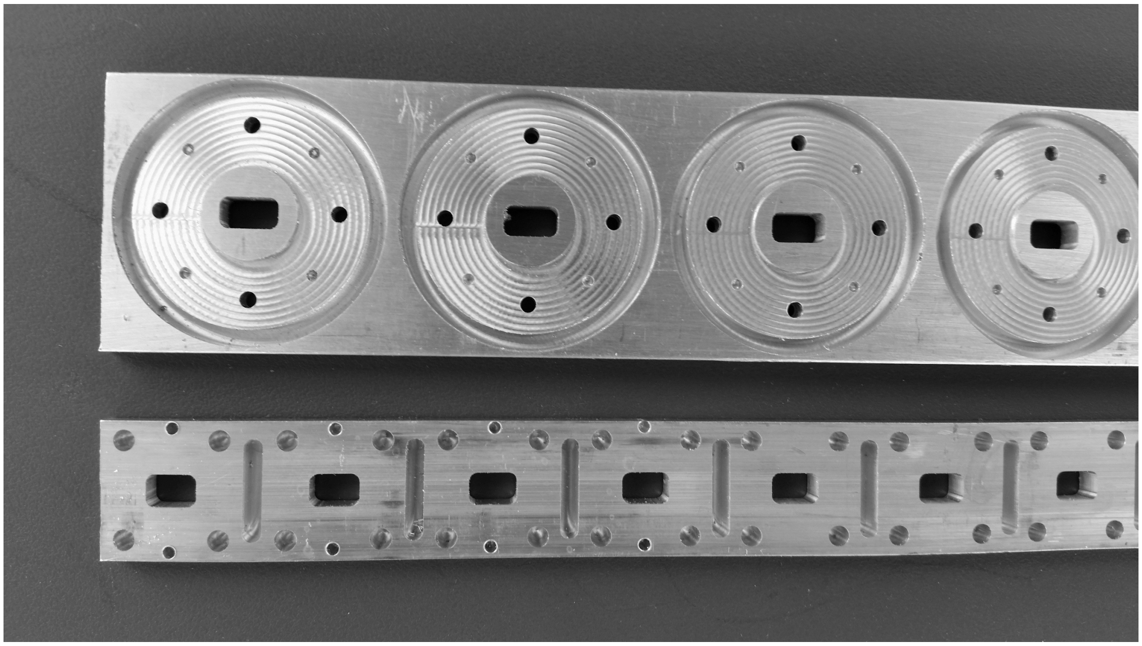

Figure 7 – Waveguide flanges machined in brass bar stock

The flanges are made of brass rather than aluminum so that they can be soldered. Some of these, both round and rectangular, may be seen in VE3FN's rig in Figure 3.

I also made some WR-19 round to rectangular flange transition shown in Figure 8. The screws for the round flange have clearance holes with the screw head buried in the transition, while the rectangular flange holes are threaded. So the transition is bolted to the round flange, then the rectangular flange bolted to the transition.

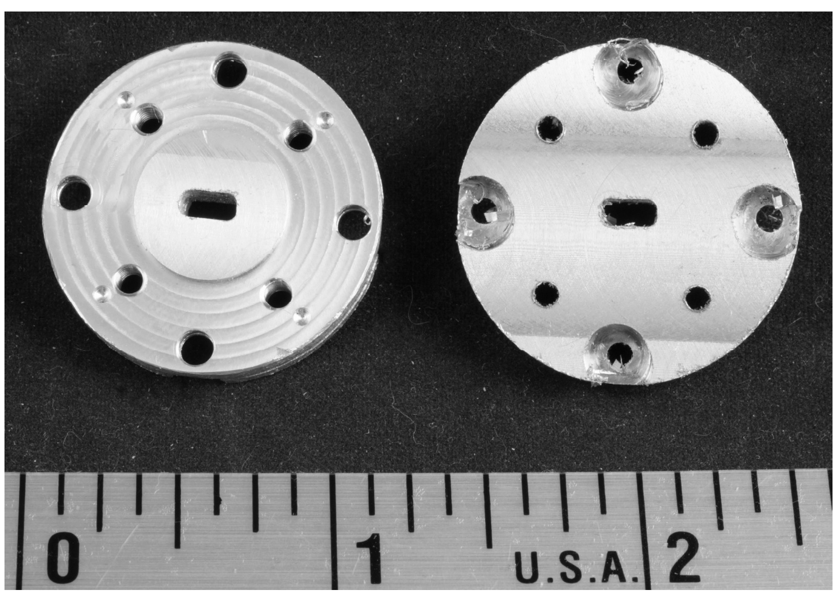

Figure 8 – WR-19 flange converter – round to rectangular

Waveguide Bends

Ray and Rene were able to make E-plane bends in copper waveguide, but H-plane bends would be much more difficult. I think it is easier to machine a waveguide bend with mating flanges. Figure 9 shows both E-plane and H-plane bends. These are 90° bends, but any angle could be machined if needed.

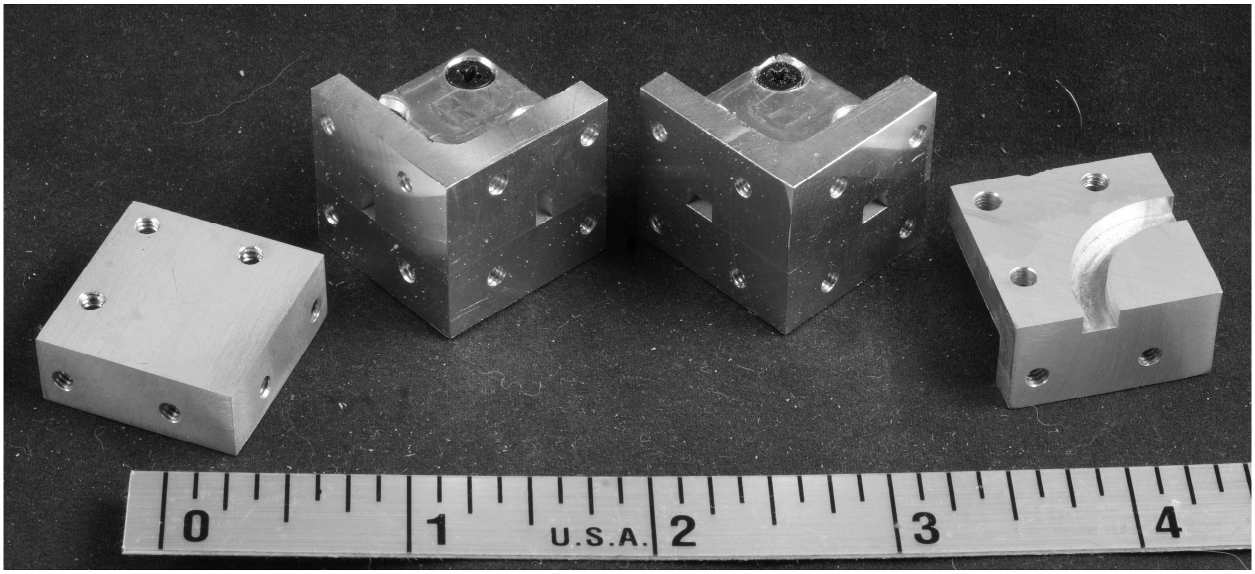

Figure 9 – Waveguide bends in WR-19 – E-plane andH-plane

The bends in Figure 9 are machined into one piece of metal, with a separate piece providing the fourth wall of the guide. This means that two different pieces must be machined and fit together – one needs microwave tolerances, but the other is only a flat surface.

Waveguide Transitions between sizes

I did find some useful waveguide test components in the junkbox, including a WR-28 power meter head that works at 47 GHz. It would work better with a proper waveguide transition – a simple taper longer than a wavelength should work fine. Barry, VE4MA, has done some work on using WR-28 at 47 GHz[4]. I have made tapered transitions for several combinations, shown in Figure 10. The designs here use two identical halves mated together, so I only have to get one CAD drawing right.

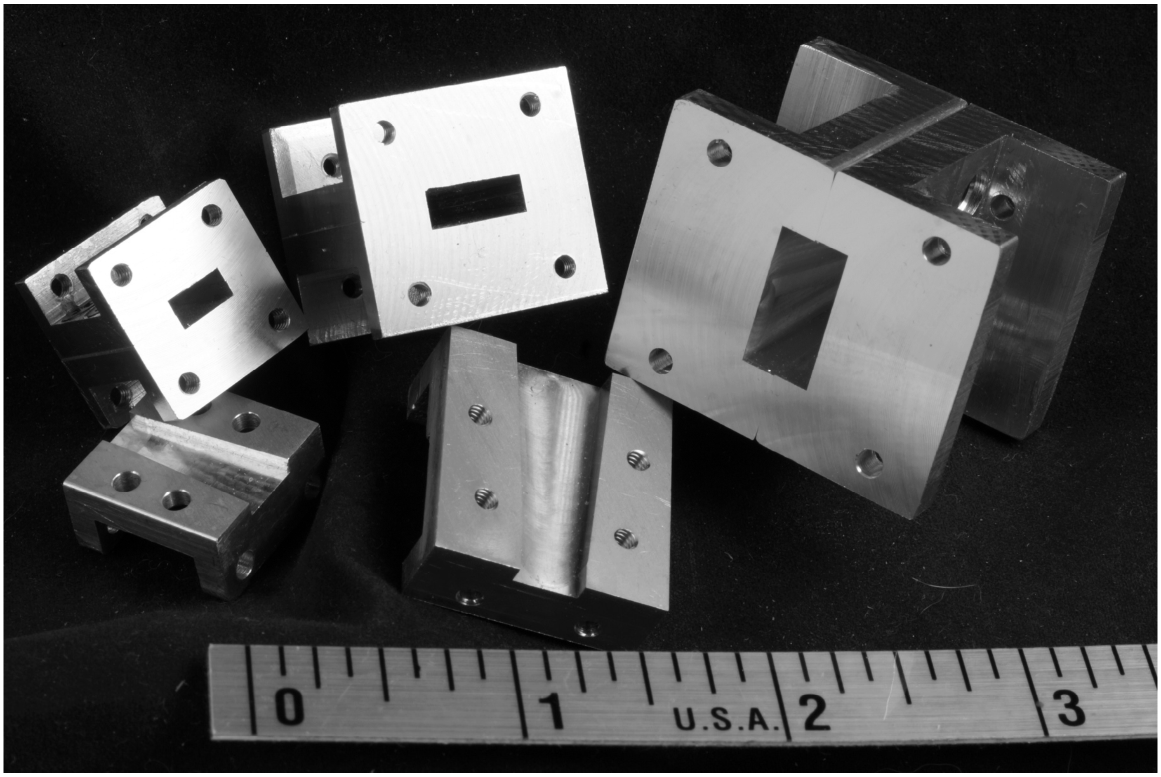

Figure 10 – Waveguide taper transitions between sizes

Rectangular Horn Antennas

Since a waveguide transition looks like a small rectangular horn antenna, I went on to make a few rectangular horns. Not only is a horn antenna useful for testing, it makes a pretty well-matched termination. At 24 GHz, where real power amplifiers are available but power loads are not, I simply pointed a horn out the window to test amplifiers.

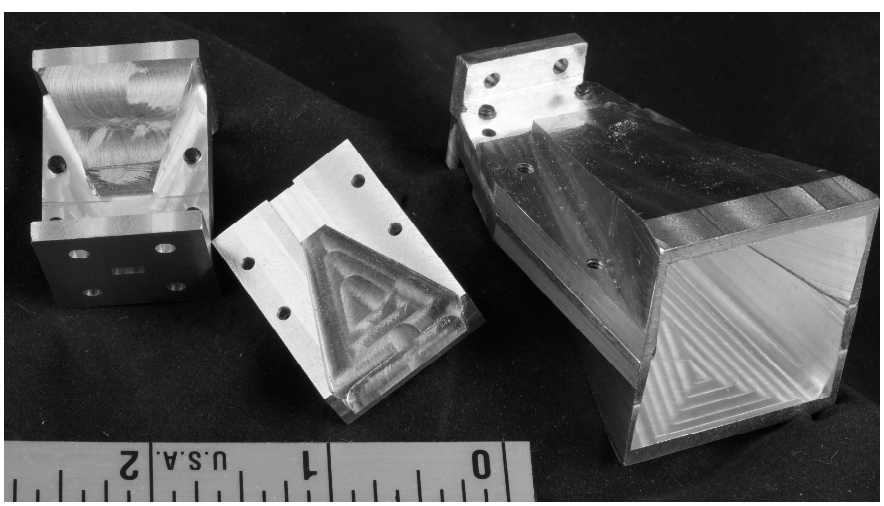

Figure 11 – WR-19 Rectangular horn antennas for 47 GHz

Figure 11 shows two WR-19 horns, a small one with about 19 dBi gain and a larger one with about 22 dBi gain. The horns are made with two identical halves. Machining a taper in two dimensions for horns or taper transitions is a bit tricky – an angle block sets the vertical taper dimension, while the CNC machine cuts the horizontal taper, cutting a triangular pattern. The pattern is clear in the WR-42 horn in Figure 12. This horn, with about 17 dBi gain, is intended to have a broader azimuth pattern, around 30°, for a beacon.

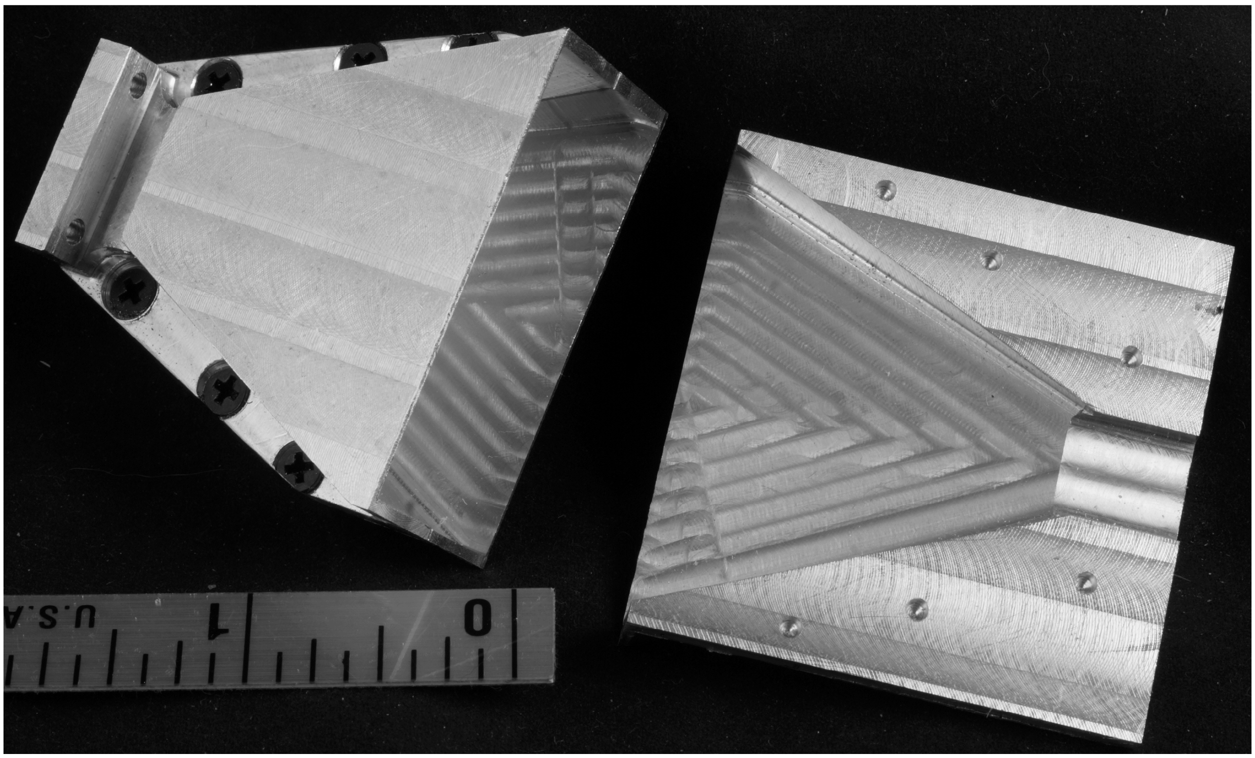

Figure 12 – WR-42 rectangular horn antenna for beacon

Directional Coupler

Directional couplers are useful for measuring both power and VSWR – essential unless one has a network analyzer. At 47 GHz, a good VNA will cost as much as a small house. Why not make a directional coupler?

I've seen two types of waveguide coupler: crossed guides and sidewall couplers. The sidewall version seems difficult to machine, while the cross-guide coupler seems simple – just some coupling holes. However, there is almost nothing published on these couplers. All I could find was two charts in the Microwave Handbook[4]. One was for a Moreno coupler, which requires X shaped holes. The other was for a round hole coupler with 3 holes. I was able to arrange some simulations of the round-hole version, which showed that the dimensions from the chart would make a pretty crappy directional coupler.

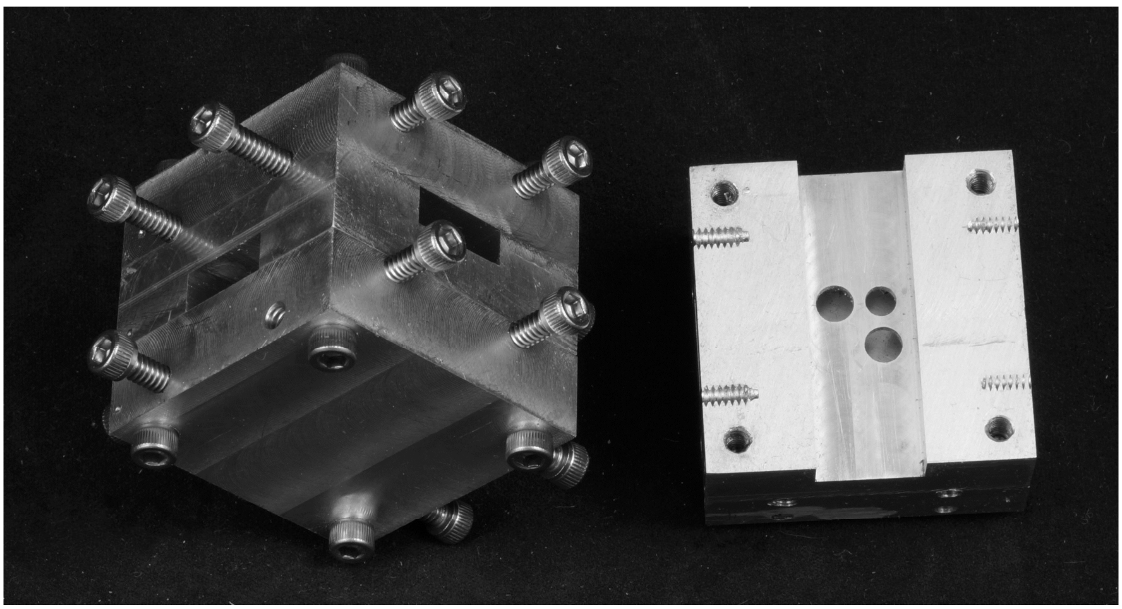

Figure 13 – WR-42 three hole cross-guide directional coupler

But the chart was a good starting point. Fiddling the hole dimensions yielded some for good 30 dB and 40 dB couplers in both WR-42 and WR-19. I built the WR-42 couplers shown in Figure 13 and was able to test the 40 dB version at Microwave Update last year, with the results shown in Figure 14 – coupling of 39 dB and directivity >40 dB. I haven't tested the WR-19 couplers yet, but the WR-42 results seem to validate the simulations.

The couplers comprise two waveguides at right angles with a thin wall between them. Three holes in the wall provide the coupling mechanism: the diameter of the two symmetrical large holes determines the coupling, and the diameter of the small hole determines the directivity. Hole locations set the center frequency – we don't need to cover the whole waveguide range, so we can tune for the ham band. The hole dimensions are pretty critical, and I used pin gauges to get the hole diameters right. Dimensions will be published after I finish testing and verification.

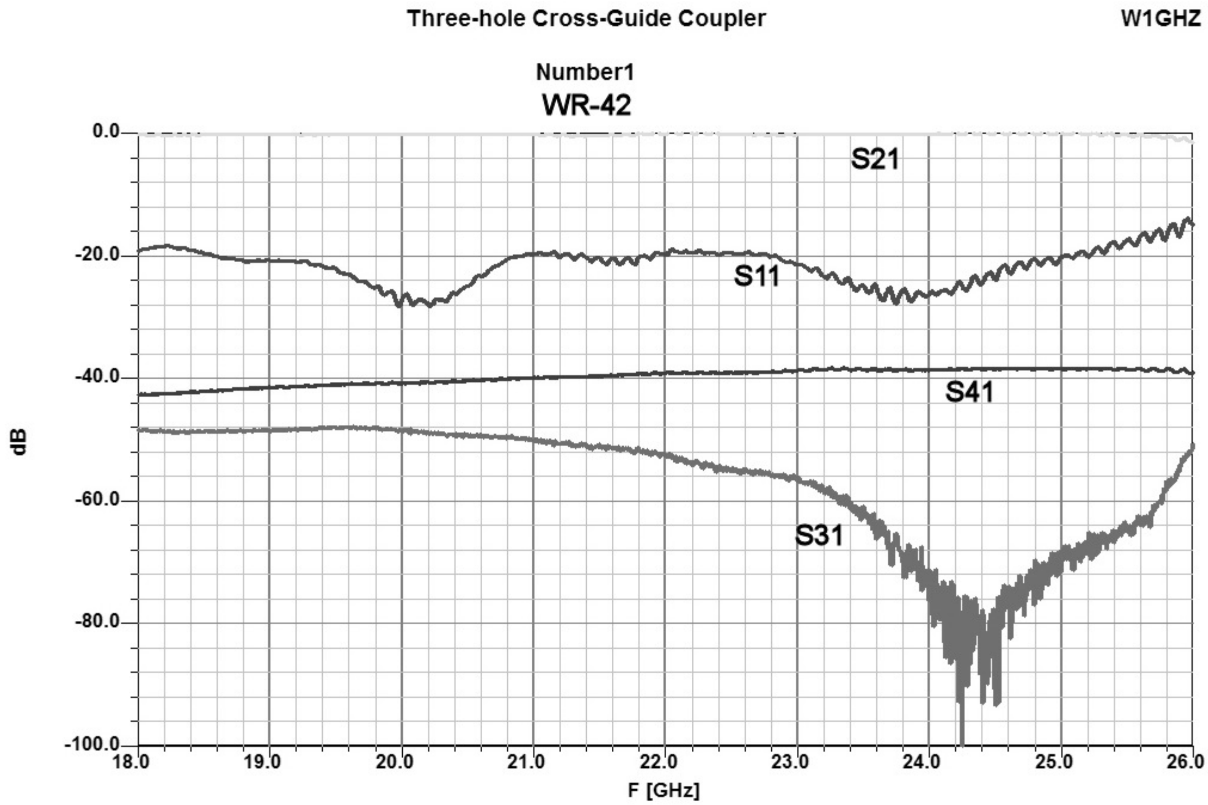

Figure 14 – Performance of WR-42 three hole cross-guide directional coupler

Hobby Brass

Hams have been making their own homebrew waveguide at lower frequencies for a long time. Copper pipe makes good circular waveguide, and rectangular guide can be soldered up using hobby brass or even copper PC board material. Rectangular hobby brass tubing[7] is available with inside dimensions close to WR-34, usable at 24 GHz, and close to WR-22, usable at 47 GHz. Since the wall thickness is less than standard waveguide, standard flanges won't fit, but we probably don't have flanges anyway – they can be made from hobby brass with a drill press and a file. But the flanges are much easier on a CNC machine, like the one in Figure 15. Machinery still can't make square holes, so a needle file is still needed to square up the corners.

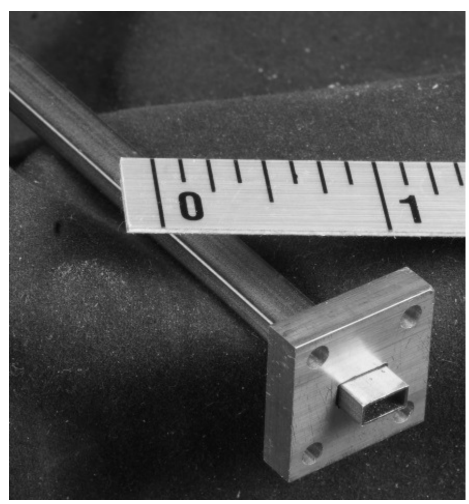

Figure 15 – Hobby brass waveguide and flange

Machining

I started doing machining as a young technician, some 50 years ago. I was sent to the model shop to make some parts, and a kind co-worker showed me the basics. He only had three fingers on one hand, so I quickly figured out that these machines could be dangerous. But I could never claim to be a machinist, just a metal basher.

When our local Makerspace opened, I had the opportunity to use good machinery with some expert guidance, if you are willing to ask for it – otherwise, you are free to learn by doing. I've learned enough about CNC machining to make the parts shown here, as well as some best kept for scrap metal.

There are a number of Makerspaces around the country – just do a Google search. Some of them have machining facilities. There are also thousands of guys with a home machine shop – I get *The Home Shop Machinist* magazine, and it is obvious that many of them have a great shop in need of something to make. Find one, get him enthused about your project, or just offer some beer.

A CNC machine isn't really necessary. Many of the waveguide pieces could be made on manual machinery with a little ingenuity. The nicest thing about the CNC results is that the holes line up – no filing needed. What is still needed is to thread the holes, fit the pieces together, and do some finishing. Wet-or-dry sandpaper does a fine job, and comes in grits up to 2000 (auto parts stores) which leaves a polished surface.

Summary

I have demonstrated that it is possible to make waveguide bits yourself. Are they as good as real waveguide? These are all aluminum – copper is a better conductor, but a bitch to machine. C Conductivity of aluminum is about half that of copper, but is roughly the same as gold. I think the commercial stuff is gold-plated to help justify the price. So don't bother.

Am I going to sell this stuff? No, but I might consider trades. There is still too much labor involved to make it affordable with the machinery I have available. A modern shop with a 6-axis machine could turn these out with very little labor, but the economy is good and they are busy and not interested small jobs.

If anyone wants to make their own, or make parts for sale to hams, I'd be glad to provide my drawings and files.

Acknowledgement

Very little of this machining would have been possible without the assistance and mentoring of Tom Bishop of The FoundryVT and other members of this fine Makerspace.

References

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