Waveguide Matching Plates

Connecting different size waveguides

Paul Wade W1GHZ © 2022
w1ghz@arrl.net

Waveguide is very useful at microwaves, especially for exciting antennas – most microwave antennas are derived from waveguide. At the higher frequencies, as we approach mm-wave, waveguide is essential both for antennas and transmission lines – coaxial cable is too lossy.

As amateurs, we are usually limited to waveguide bits that we can locate surplus or at swap meets. Commercial waveguide components are usually far too expensive; mm-wave bits are often gold-plated, but priced like they are solid gold.

For most amateur microwave bands, there are two or three standard waveguide sizes[1] that will work. However, the components we might have for a given band are typically not all the same size waveguide, so we are left to find a way to fit them together. Since waveguide characteristic impedance is a function of wavelength in each size guide, the impedance of each size guide is different at a given frequency. Simply connecting two adjacent sizes together often works well, but some impedance matching is required for best performance.

Commercial transitions between waveguide sizes have a long gradual taper, providing a gradual impedance match over the wide frequency range covered by the waveguides. I have acquired a few of these for various sizes, and have also machined[2] a few at the local Makerspace for guide sizes useful at 24 and 47 GHz. The tapered transitions work, but can add significant length to an assembly that might already be cumbersome on a dish.

Waveguide Matching Plates

Some time ago, a VHF group in New Zealand offered some Relcom waveguide switches in WR-28 waveguide. These seemed useful at 24 GHz and possibly 47 GHz, so I acquired a couple. At a Microwave Update, Paul Drexler, W2PED sold some waveguide matching plates from WR-28 guide to the WR-42 guide commonly used at 24 GHz. Recently, Al Ward, W5LUA, asked if I could machine a few of these so he could use the New Zealand waveguide switches, and provided some measured dimensions.

I had been intending to assemble a new 24 GHz system, so I dug out my New Zealand waveguide switches. With them, I found two of the W2PED matching plates, shown in Figure 1. Alas, they had the wrong clearance recess for mounting to the switches; to attach directly to the waveguide switch, the screw heads for the M3 screws to the WR-28 pattern must fit in a recess inside the plate, while these plates had clearances for the WR-42 screw heads (USA 4-40). Still, did not seem difficult to machine more with the desired clearances for mounting to the switches.

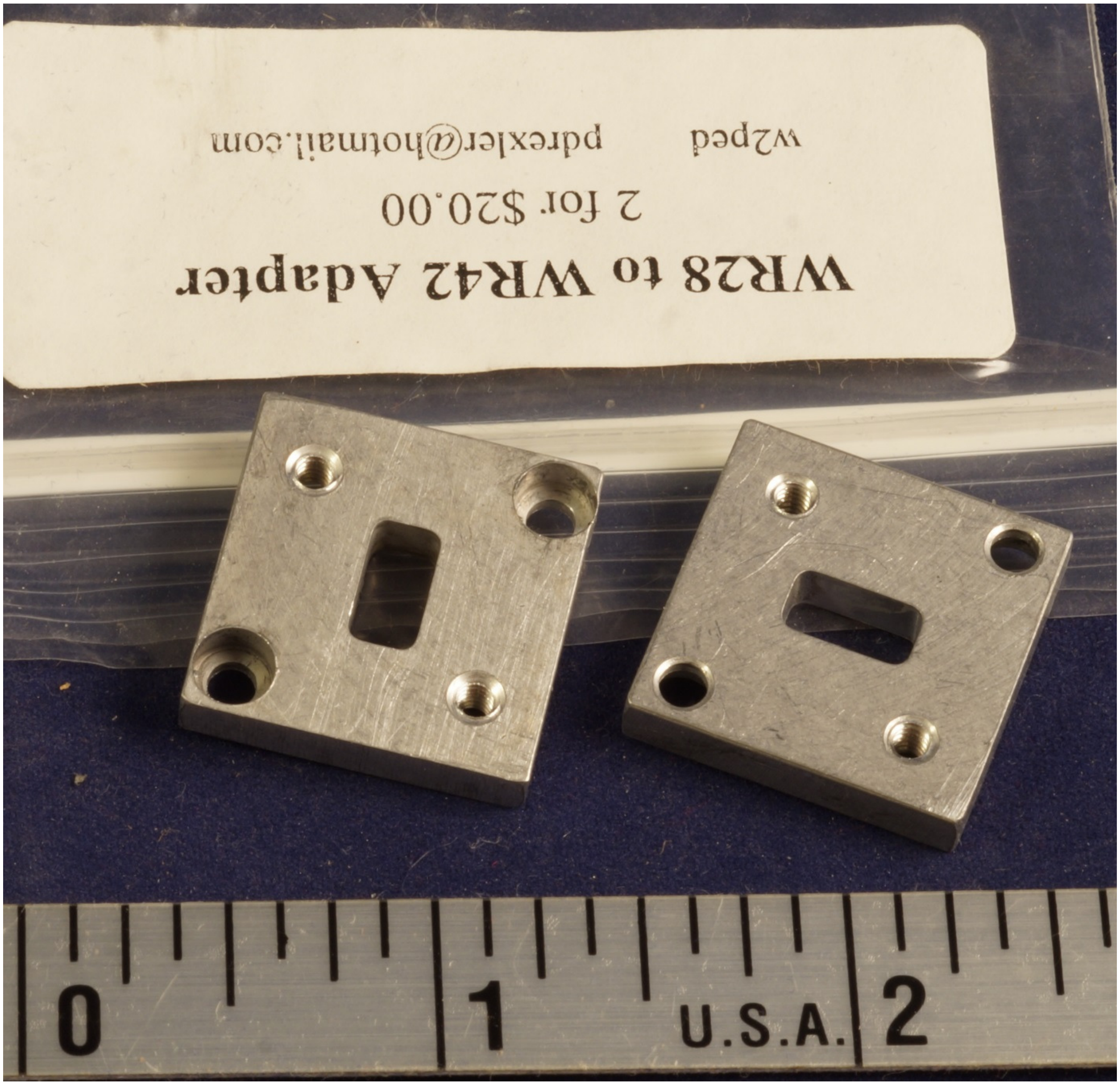

Figure 1 – WR-28 to WR-42 waveguide matching plate by W2PED

The waveguide matching section is shorter in the width (long (a) dimension) than WR-42 waveguide, but taller than the height (short (b) dimension) of either guide size (Figure 2). Further examination found that the corner radius of the waveguide matching section was 1/64 inches (0.4 mm), requiring an end mill diameter of 1/32 inch. I didn't have an end mill long enough to cut all the way through the matching plate thickness, and new ones in such a small diameter are both expensive and fragile.

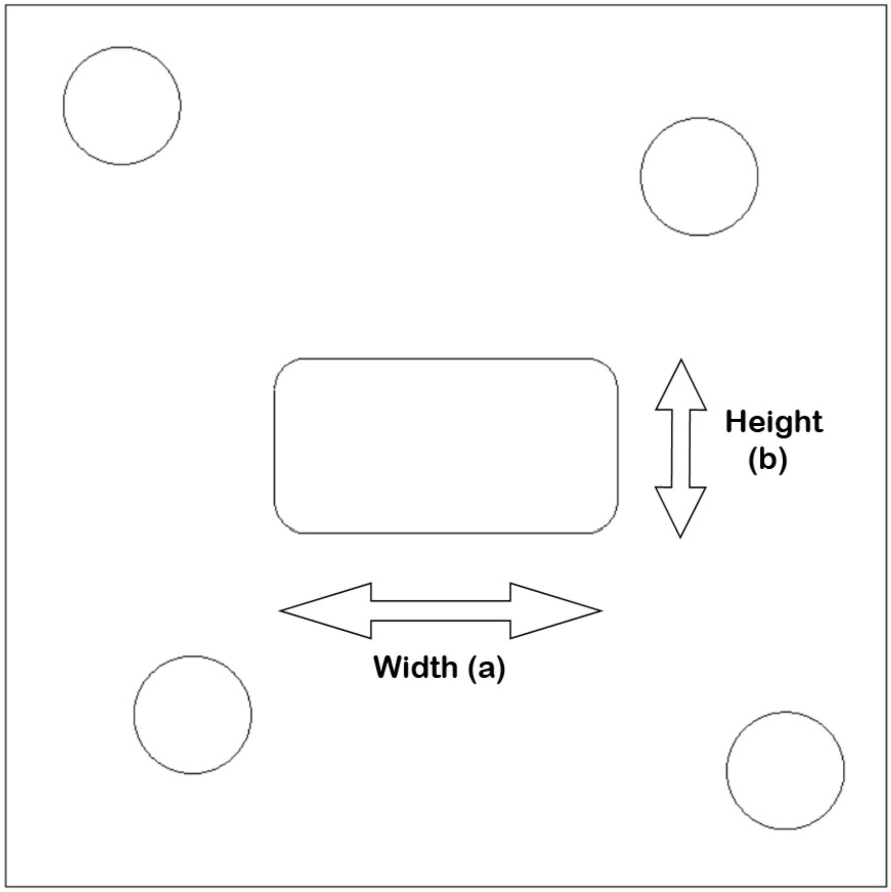

Figure 2 - Sketch of waveguide matching plate for rectangular waveguides. Note the hole pattern difference for the two waveguide sizes

Would changing the corner radius make much difference? Simulation showed that the original dimensions offer very good performance at 24 GHz, but changing the diameter would require a small change in the height (smaller (b) dimension) of the matching section. The smallest available end mill long enough for the matching plate thickness was 3/32 inch diameter (2.38 mm), for a corner radius of 3/64 inch, and I found the height required for this radius.

Machining a matching plate is fairly straightforward, once the dimensions are determined. There is a rectangle in the center with rounded corners, plus four holes, two for each size waveguide, with the holes for at least one size counter bored for the screw heads. I used a CNC milling machine at the local Makerspace, which easily turns out multiple copies. But the plates would be easy to make on a manual machine, and it should be possible to make one by drilling a set of holes, then cleaning up the rectangle with a file.

24 GHz Results

Accurate measurements in waveguide with a VNA (Vector Network Analyzer) are difficult because it is hard to get a good calibration for the VNA – waveguide calibration kits are rare (see solid-gold pricing above). I usually use a WR-24 directional coupler to measure Return Loss; I am confident down to about 20 dB return loss, but that is not good enough to tell if the matching plate is working properly.

Instead of the VNA, I set up a waveguide slotted line, shown in Figure 3, that I found in surplus years ago – since everyone uses a VNA, no one wants them anymore. These were traditionally used with a diode detector and a VSWR meter like the HP-415, but neither of my VSWR meters seem to work anymore. Instead, I used logarithmic detector chip, the HMC662, which I received as a prize at Microwave Update a couple of years back. This one works up to 30 GHz, and is very sensitive, with 54 dB dynamic range down to about -50 dBm, enabling the slotted line to run at low power levels, far lower than with the traditional diode detector.

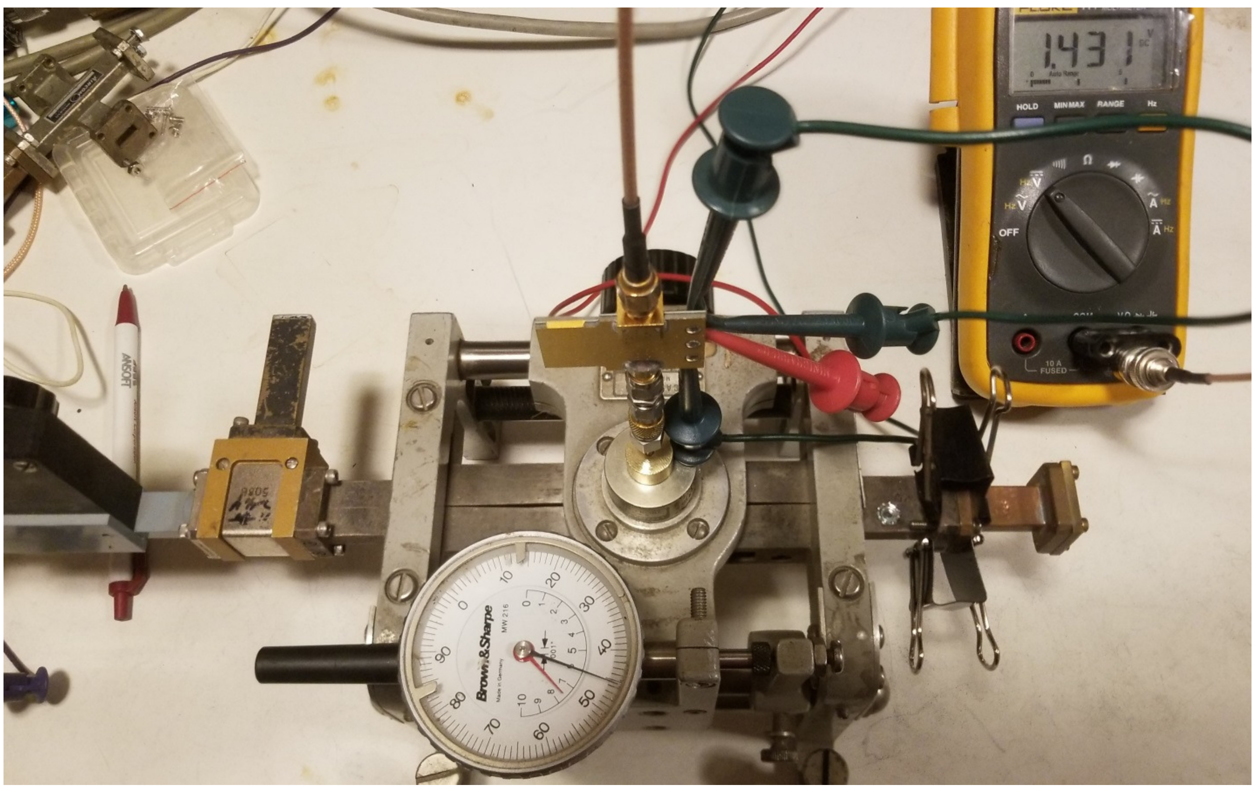

Figure 3 – Waveguide setup at 24 GHz for measurement of matching plates

I made a new probe for the slotted line; the extended center conductor of 0.086" semi-rigid coax is the probe. The coax fits into an adapter I made to fit into the movable carriage of the slotted line, and is adjusted up or down to set the probe length inside the waveguide. Figure 4 shows the detector board and probe. The detector output is linear in dB, 13 millivolts per dB, read by the digital voltmeter. The detector is moved along the slotted line and the detected voltage difference between minimum and maximum output is converted to dB, then to a voltage ratio which is the VSWR. The distance between two minima is a half wavelength in the waveguide, always longer than the free space waveguide.

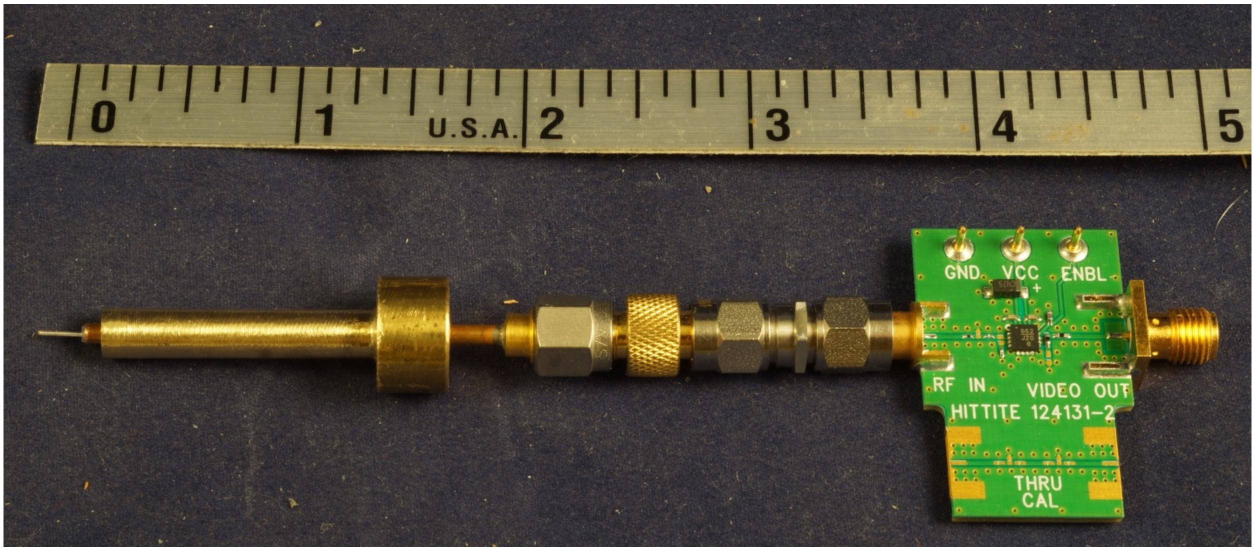

Figure 4 – Probe for waveguide slotted line with HMC662 sensitive detector

I have slotted waveguide sections for both WR-42 and WR-28 waveguide, so I can measure the matching plates from both sides. However, I only have good waveguide terminations for the WR-42 size, so some measurements could only be made from the WR-28 side with the termination on the WR-42 side. The slotted-line measurements are summarized in the table below:

Measurement	**ΔV** dB	**VSWR**	**RL** dB
WR-42 Waveguide Slotted Line, 24.192 GHz			
WR-42 Short	40	100	0.17
WR-42 Open Waveguide	4	1.58	13
WR-42 Termination (marked 1.03)	0.5	1.06	30.7
WR-42 Termination (marked 1.05)	0.61	1.07	29.4
WR-42 to WR-28 Matching plate, WR-28 Open Waveguide	3.1	1.42	15.2
Relcom WG switch, Matching plate each end, WR-42 Short	29	29	0.6
Relcom WG switch, Matching plate each end, WR-42 Termination (marked 1.03)	1.76	1.22	20.1
WR-42 Waveguide Slotted Line, 24.048 GHz			
Relcom WG switch, Matching plate each end, WR-42 Termination (marked 1.03)	1.92	1.25	19.1
WR-28 Waveguide Slotted Line, 24.192 GHz			
WR-28 Short	37	71	0.24
WR-28 Open Waveguide	3.38	1.48	14.3
WR-42 Termination (marked 1.03) butted to WR-28	3.62	1.52	13.7
WR-42 Termination (marked 1.03) with WR-28 to WR-42 Matching plate	0.5	1.06	30.7
WR-42 Termination (marked 1.05) with WR-28 to WR-42 Matching plate	0.7	1.08	28.3
WR-42 Termination (marked 1.05) with W2PED Matching plate	1.46	1.18	21.7

What do these measurements tell us? The shorted waveguides have a very high VSWR, or very low return loss – the loss in the slotted line is half of this return loss, or about a tenth of a dB. The open waveguide radiates like an antenna, and the return loss is about what one would expect from an open waveguide.

The two sizes of waveguide butted together result in a VSWR of about 1.5, but adding the matching plate improves the VSWR to nearly as good as the termination, so the matching plate is doing a good job.

The Relcom WR-28 waveguide switch measured in WR-42 waveguide with matching plates on all ports, shown in Figure 5, has a VSWR under 1.25, quite adequate. When the output matching plate is shorted, the return loss is 0.6 dB, so the loss of the switch is 0.3 dB or less.

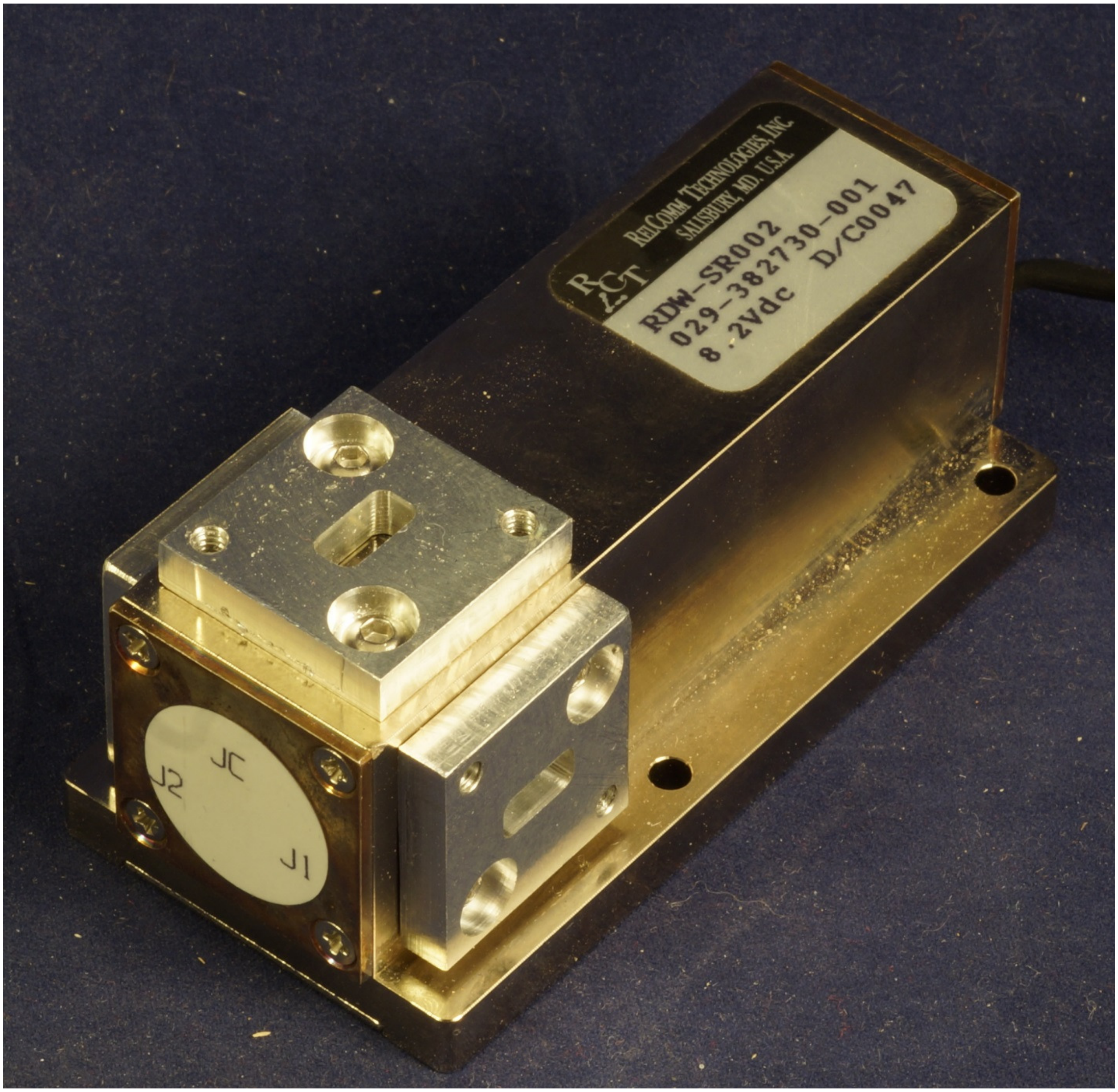

Figure 5 – Relcome WR-28 waveguide switch with WR-42 matching plates

10 GHz Waveguide Matching Plates

There are three common waveguide sizes that work at 10 GHz: WR-75, WR-90, and WR-112, with WR-90 as the preferred size. Most components for WR-90 are designed for the 9 to 11 GHz range, while those for the other two sizes are designed for higher or lower frequencies, but may still be usable. WR-62 can also be used, but at 10.368 GHz it is very close to waveguide cutoff

For instance, the input to satellite TV LNBs is WR-75. Some work well at 10 GHz, or can be modified into an LNA. But adding one to a system that otherwise uses WR-90 requires some sort of transition – the hole patterns in the flanges are different, but overlap slightly, making it difficult to just drill additional holes.

I learned from the 24 GHz matching plate that there is a combination (or at least one combination) of length (plate thickness), width, height, and corner radius that provides good impedance matching around a desired frequency. A bit more simulation work found dimensions for both WR-90 to WR-75 and WR-90 to WR-112 matching plates. These larger sizes are easier to machine using larger end mills, and the plates are thick enough to have counterbores for both sizes of screw heads, so they can be used in either direction.

10 GHz Measurements

At 10 GHz, it is possible to make good measurements with a VNA, using a waveguide-to-coax adapter. Most adapters have a return loss of 20 dB or so, fine for amateur use, but not good enough for accurate measurements. However, a precision WR-90 waveguide-to coax adapter, the HP X281C, showed a 40 dB return loss connected to a WR-90 sliding termination, and nearly as good at 10.368GHz with an HP X910C WR-90 termination, the black line in Figure 6.

Butting a good WR-75 termination to the WR-90 adapter resulted in a usable return loss >20 dB from 9.5 to 10.8 GHz, and a much better peak around 10.4 GHz; having this peak is probably due to specific hardware and not generally repeatable. Adding the matching plate resulted in a broad improvement from 9.9 to 10.6 GHz, centered around the design frequency of 10.368 GHz.

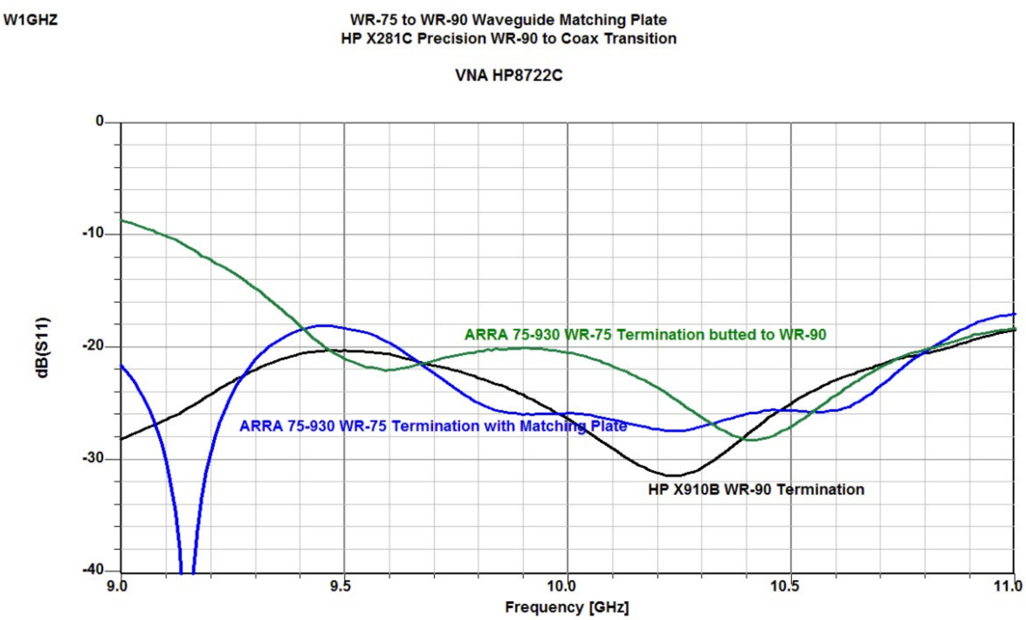

Figure 6 – Measurements of WR-75 to WR-90 matching plate from WR-90 end

This result may be confirmed by measuring from the WR-75 end. For WR-75, I don't have a precision adapter, but I have made several homebrew waveguide-to-coax adapters[2], which are much better than most commercial adapters, as shown in Figure 7 – the commercial ones are usually designed for the 11 to 14 GHz range.

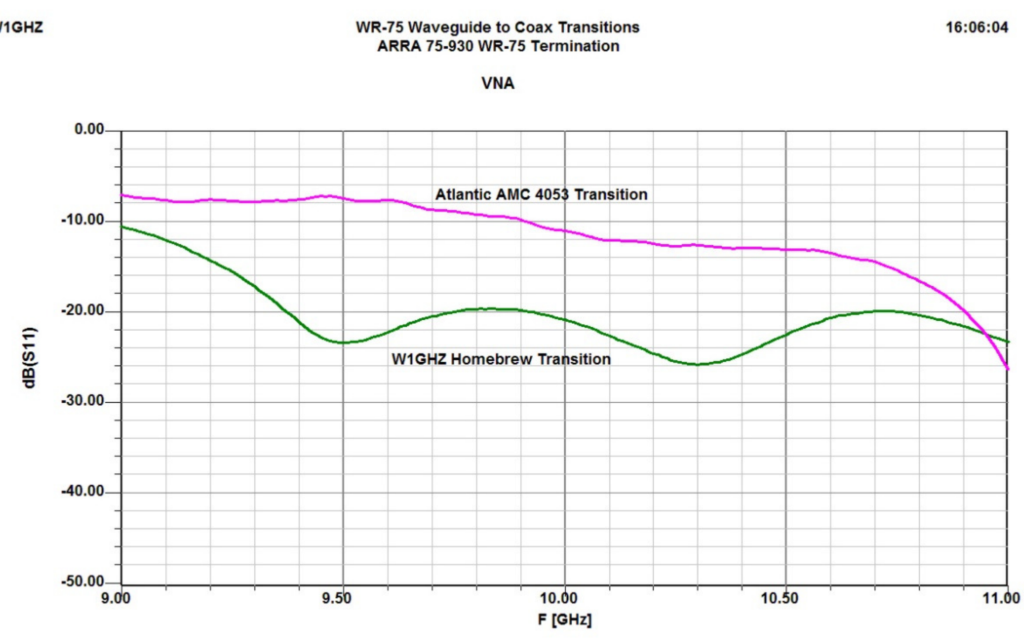

Figure 7 – Homebrew WR-75-to-coax adapter designed for 10.368 GHz compared to commercial adapter

This homebrew adapter was used for the measurements plotted in Figure 8. The matching plate withWR-90 termination was several dB better than the WR-75 termination connected directly, while the WR-90 termination butted directly to the WR-75 adapter was also much better in a narrow peak around 10.3 to 10.4 GHz.

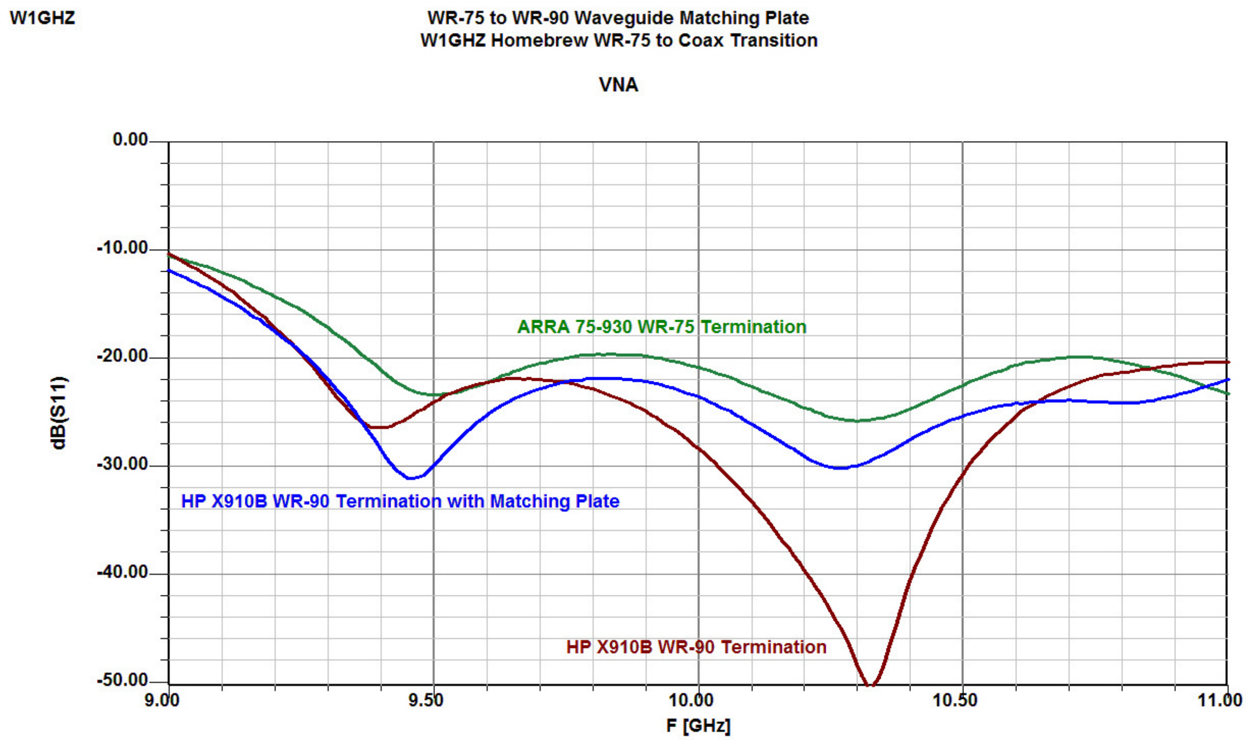

Figure 8 - Measurements of WR-75 to WR-90 matching plate from WR-75 end

I have not had much use for the other 10 GHz waveguide size, WR-112. Then an old friend, Emil, W1GGM, asked if I had any transitions from WR-90 to WR-112. Since I was already working on matching plates, I worked out dimensions and machined a couple. Emil reports that they work well.

For measurements, I do not have good WR-112 terminations or waveguide-to-coax adapters; some surplus adapters proved to be poor at 10.368 GHz. Then I found a WR-112 slotted-line section in the barn – an elf must have left it. Using the WR-112 slotted line, I measured a VSWR of 1.08 with the WR-90 termination butted to WR-112 and a VSWR of 1.02 with the matching plate.

We can conclude that for 10 GHz, butting the different waveguide sizes will work adequately and the matching plates provide some improvement. The main advantage is probably providing a better mechanical connection.

47 GHz Matching Plates

The preferred waveguide size for 47 GHz is WR-19, but some available waveguide components, like the Relcom switches, are in WR-28 waveguide. Since the two waveguide sizes use the same flange pattern, they can easily be butted and bolted together. Simulation predicts a VSWR of about 1.4 for this combination, but adding a matching plate can reduce the VSWR to under 1.05. Whether this is necessary is debatable, since few hams can make serious measurements at this frequency.

I am able to make measurements using a WR-19 directional coupler[3] but limited dynamic range limits the capability to maximum return loss of about 20 dB, or VSWR of about 1.25. Thus, I couldn't really tell if the matching plate made a difference, so I didn't make measurements. A sensitive detector for 47 GHz would make accurate measurements possible with the WR-28 slotted line – I may investigate using a spectrum analyzer with a waveguide mixer as the detector.

I calculated matching plate dimensions for two plate thicknesses, 0.060 and 0.090 inches, so they could be machined from common hobby brass stock. Since the flange pattern is the same for both sizes of waveguide, only through holes are needed, making machining much easier. I machined some of the 0.060 inch thickness for the rectangular flange style, but have not tried to measure them.

Suggested Dimensions for Rectangular Waveguides:

A collection of the rectangular waveguide matching plates is shown in Figure 9. The dimensions that provide good performance are shown in Table 2 below. There are possibly other combinations that work as well or better, but these have been tested and shown to work.

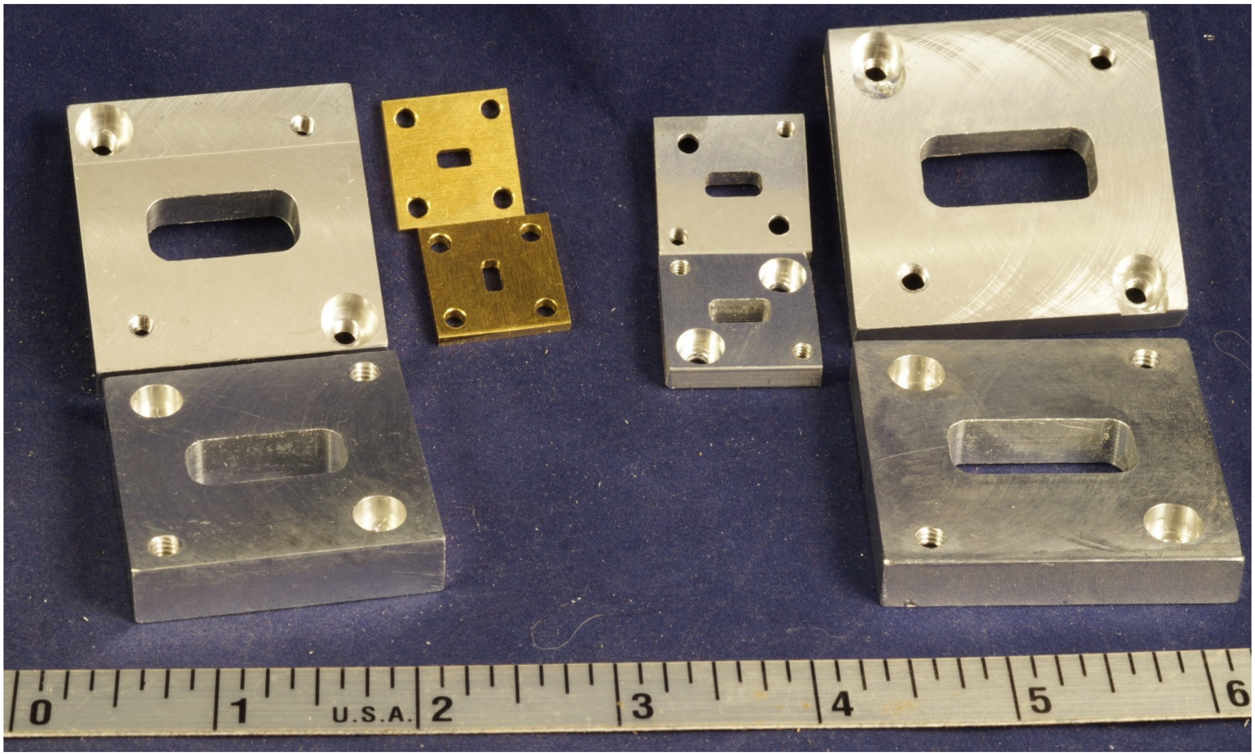

Figure 9 – Rectangular waveguide matching plates, L to R: WR-75 to WR-90, WR-19 to WR-28, WR-28 to WR-42, WR-112 to WR-90

Waveguide Matching Plate Dimensions

W1GHZ 2022

Waveguide	to	Waveguide	Width	Height	Radius	Thickness
		Dimensions in inches				
WR-90	to	WR-75	0.840	0.380	0.125	0.360
WR-90	to	WR-112	1.000	0.450	0.125	0.310
* WR-42	to	WR-28	0.338	0.178	0.016	0.180
WR-42	to	WR-28	0.338	0.160	0.047	0.180
WR-28	to	WR-19	0.265	0.120	0.031	0.060
WR-28	to	WR-19	0.215	0.115	0.031	0.090

* = W2PED dimensions

Table 2

Rectangular to Circular Waveguide Matching Plates

Most good microwave feedhorns are axisymmetric and are fed with circular waveguide. Connecting a circular guide directly to rectangular waveguide can result in a significant mismatch, which can be corrected by a long tapered section or by a matching plate.

For 10 GHz operation, the common circular waveguide in the USA is ¾ inch copper water pipe, used for plumbing, which has an inner diameter of 20.6 mm, while European pipe has an inner diameter of 20.0 mm. A matching plate for WR-90 rectangular waveguide to European pipe was described in DUBUS by Jeffrey Pawlan, WA6KBL. The same dimensions also work well for the USA pipe in both simulation and measurement.

Ric, CX2SC, has put together a successful 10 GHz EME using WR-75 waveguide – I was able to help him acquire some of the pieces. He recently asked if I had dimensions for a WR-75-to-circular waveguide transition to use with a new feedhorn. I started from the WA6KBL WR-90 design and modified the dimensions using simulation for a similar matching plate for WR-75. After I machined some and tested them, I sent dimensions to Ric. He reports a 2 dB increase in output power and almost 1 dB improvement in moon noise with the matching plate.

To test the matching plates, I used a circular waveguide slotted line which I made 20+ years ago to empirically develop circular waveguide-to-coax transitions, shown in Figure 10 with the WR-90 termination directly connected to the circular waveguide. The slotted line uses USA water pipe, 20.6mm inner diameter. Also shown in the photo is the sensitive detector, an inexpensive AD8317 board found on ebay. For WR-90 waveguide, the measured VSWR was 2.47 with the waveguides directly connected and 1.07 with the WA6KBL matching plate. For WR-75 waveguide, the measured VSWR was 2.3 with the waveguides and 1.14 with the W1GHZ matching plate. The rectangular waveguides were terminated using the same terminations used for the previous tests. The matching plates offer a clear improvement for circular waveguide.

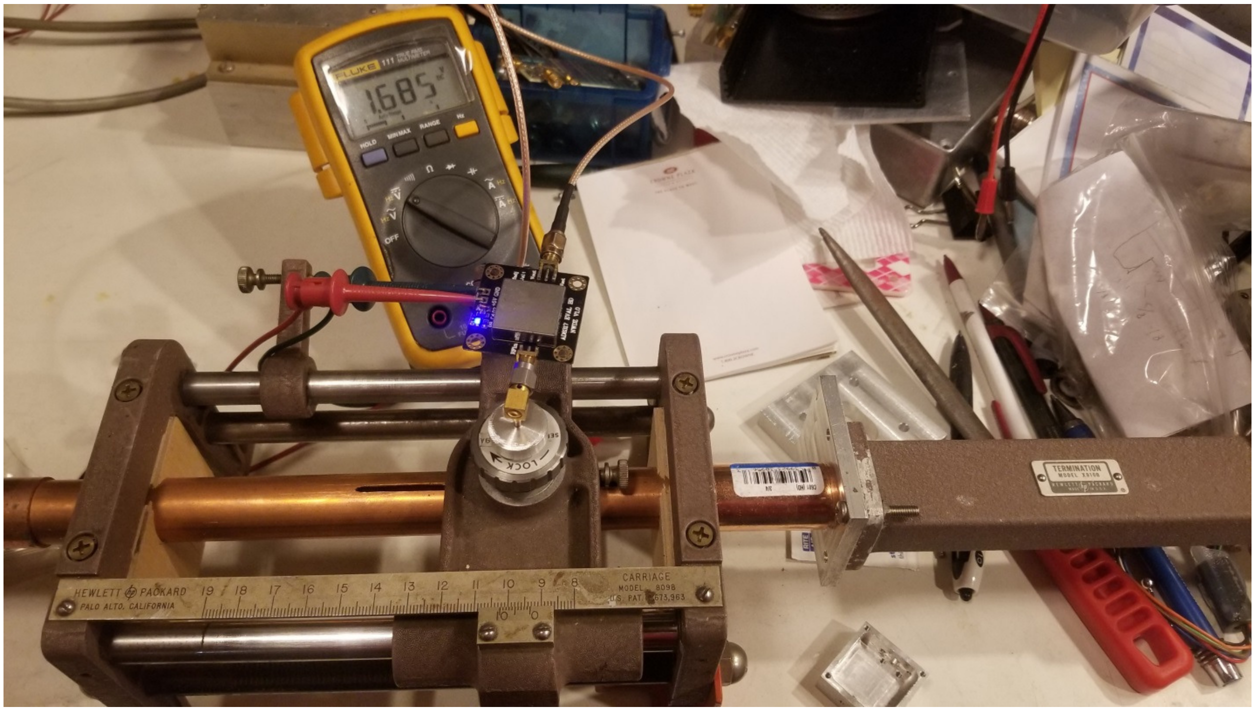

Figure 10 – Circular waveguide slotted line with sensitive detector used to measure circular-to-rectangular waveguide matching plates

Both of the circular-to-rectangular waveguide matching plates are machined with a corner radius equal to half of the height, so that the ends are semi-circles, as sketched in Figure 10.

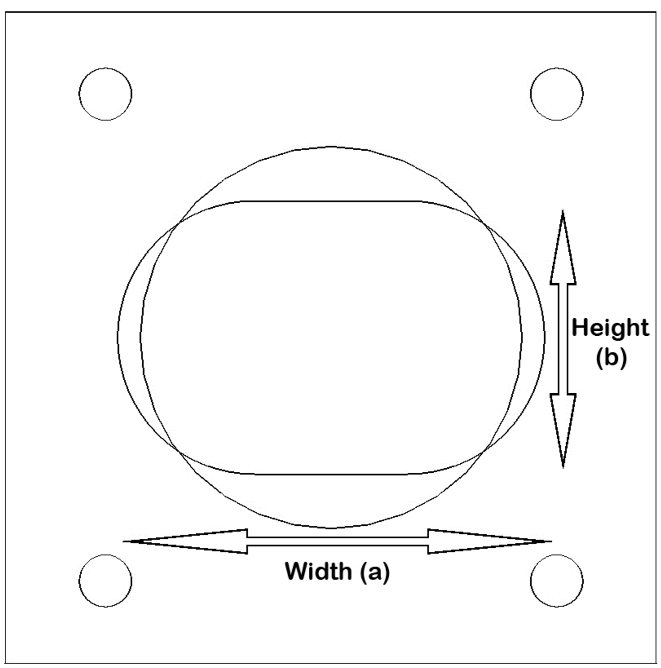

Figure 11 – Sketch of circular-to-rectangular waveguide matching plate showing intersection with circular waveguide

More recently, I received a copy of a paper[6] by DMitry Dmitriev, RA3AQ, which describes matching plates from circular to rectangular waveguide at 10, 24, 47, and 77 GHz.

Suggested Dimensions:

Waveguide to Circular Matching Plate Dimensions

W1GHZ 2022

Waveguide	to	Diameter	Width	Height	Radius	Thickness
		Dimensions in mm				
** WR-90	to	20 (EU)	26.386	16.136	8.068	10.687
WR-90	to	20.6 (USA)	26.386	16.136	8.068	10.687
WR-75	to	20.6 (USA)	24.8	15.8	7.9	10.1
WR-42	to	9.2	9.8	6.35	3.175	4.52

** = WA6KBL dimensions

Table 3

Notes:

1. http://wa1mba.org/wavegd.htm
2. Paul Wade, W1GHZ, "Rectangular Waveguide to Coax Transition Design," ***QEX***, Nov/Dec 2006, ARRL, 2006. http://www.w1ghz.org/QEX/Rectangular_Waveguide_to_Coax_Transition_Design.pdf
3. Paul Wade, W1GHZ, "Waveguide is just Metal," *Proceedings of Microwave Update 2018*, ARRL,2018. http://w1ghz.org/waveguide/Waveguide.htm#WGmetal
4. Jeffrey Pawlan, WA6KBL, "Very Compact and High Performance Transition for Circular to Rectangular Waveguide," ***DUBUS***, III/26, 2015.
5. Paul Wade, W1GHZ, "Understanding Circular Waveguide – Experimentally," ***QEX***, Jan/Feb 2001, ARRL, 2001. http://www.w1ghz.org/QEX/circular_wg.pdf
6. DMitry Dmitriev, RA3AQ, "simple and a compact crossover from round to rectangular waveguide," < publication status unknown >