# Use of WR-28 Waveguide on 47 GHz

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## Introduction

This paper originated as an unpublished presentation made at Microwave Update in 2004 when preparations were being made for the first 47 GHz EME attempts by VE4MA, W5LUA, AD6FP and RW3BP. Today with so many more amateurs preparing for 47 GHz operation, it is felt that although dated, the information is still of significance.

Waveguide is the standard transmission line used for the amateur 47 GHz band. Several waveguide sizes (WR-22 & WR-19) are designed for possible use at this frequency, and WR-15 will also work, however none of these are commonly available on the surplus markets and when found is rather expensive. Fortunately in 2019 Kuhne Electronic is now selling straight pieces of WR-19 waveguide and corresponding round waveguide flanges, so at least one easily accessible source exists. Several amateurs have been able to bend these pieces after heat treating them, so that some construction flexibility is gained.

There is however a large surplus supply of low cost WR-28 waveguide, designed for 26 to 40 GHz, and is known to work down at 24 GHz. WR-28 comes with round and square waveguide flanges, which are compatible with WR-22 round & square flanges and the round WR-19 flanges commonly seen on Kuhne Electronic modules. There has been however very little information about WR-28 behavior above 40 GHz and in particular at 47 GHz.

From previous work it is known that non-standard oversized waveguides operate with very low loss at 24 GHz, as long as straight runs are used. Bends in the H plane are believed to be susceptible to operating in higher modes as the operating frequency is increased beyond the designed range. This paper will cover the Insertion and Return Loss testing of a variety of WR-28 pieces as shown in Figure 1 to a WR-22 system. It will not however examine the losses associated with mating WR-28 waveguides to a WR-19 system but the findings with WR-22 testing suggests this can be quite low on a narrowband basis.

## Waveguide Moding Problems Anticipated With WR28

The dominant $TE_{10}$ propagation mode is dependent on the width of waveguide used at any particular frequency. The standard operating ranges are defined for the reliable operation of the $TE_{10}$ propagation mode. If we operate out of the standard range the $TE_{10}$ mode may continue to operate reliably as long as there are no discontinuities in the waveguide. So straight waveguide should be more reliable than if we have bends, twists, etc.

Referring to Figure 2, you will see the various fields associated with the dominant $TE_{10}$ waveguide mode. The Cut-off Frequency (lower) is 21.1 GHz for WR-28.

In Figure 3 you will see the next higher waveguide mode $TE_{11}$. The cut-off Frequency for this mode in WR-28 is 47.2 GHz…..which is an obvious concern for 47 GHz operation!

Figure 4 shows another possible higher mode $TE_{21}$. The cut-off Frequency for this mode in WR-28 is 59.6 GHz so it's not a concern.

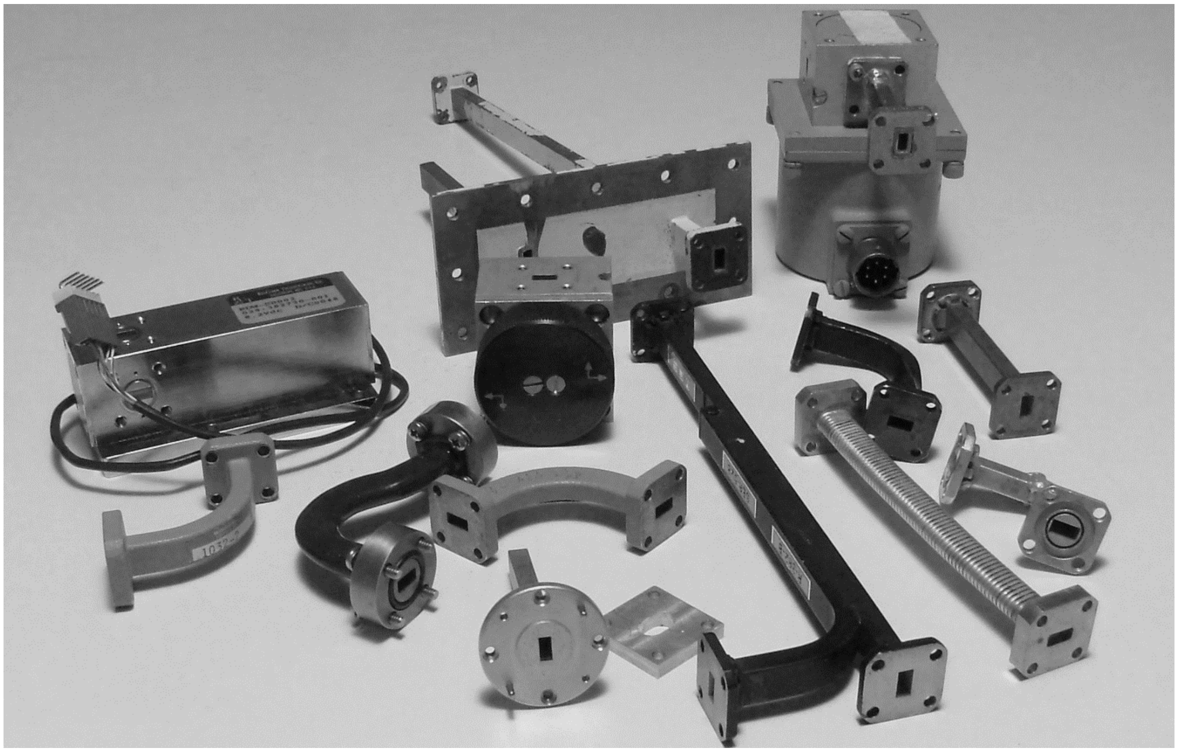

Figure 1 Assortment of WR-28 Waveguide Parts for Testing

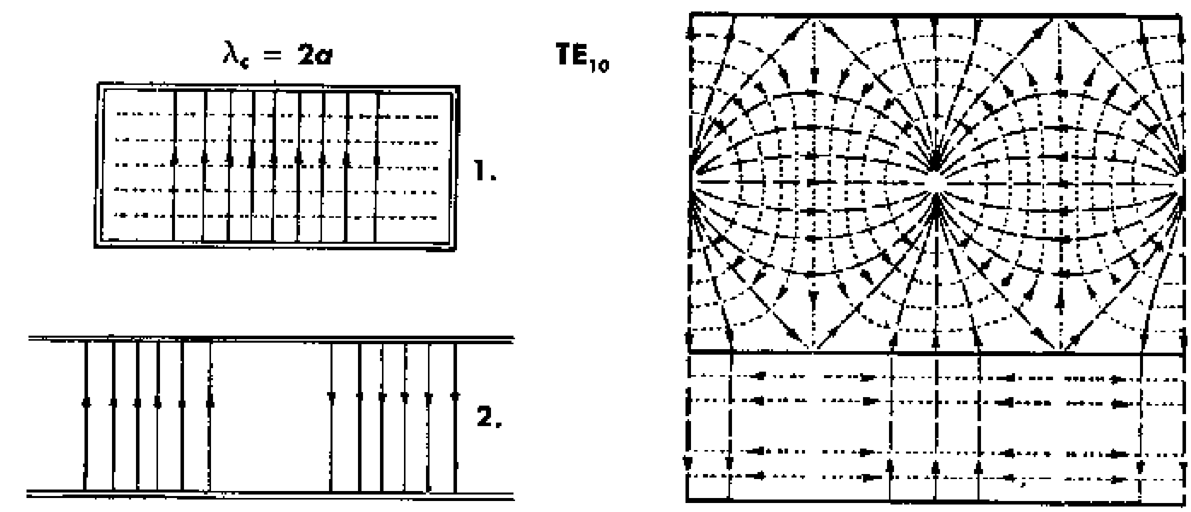


**Figure 2 $TE_{10}$ Propagation Mode (Cut-off Frequency = 21.1 GHz)**

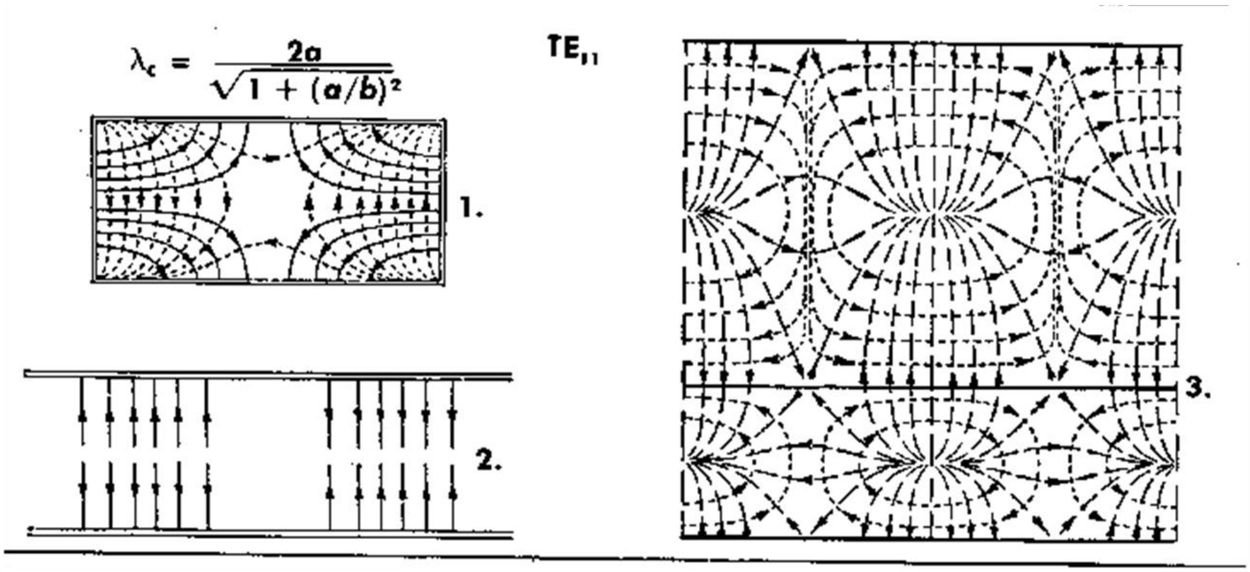


**Figure 3 $TE_{11}$ Propagation Mode (Cut-off Frequency 47.2 GHz)**

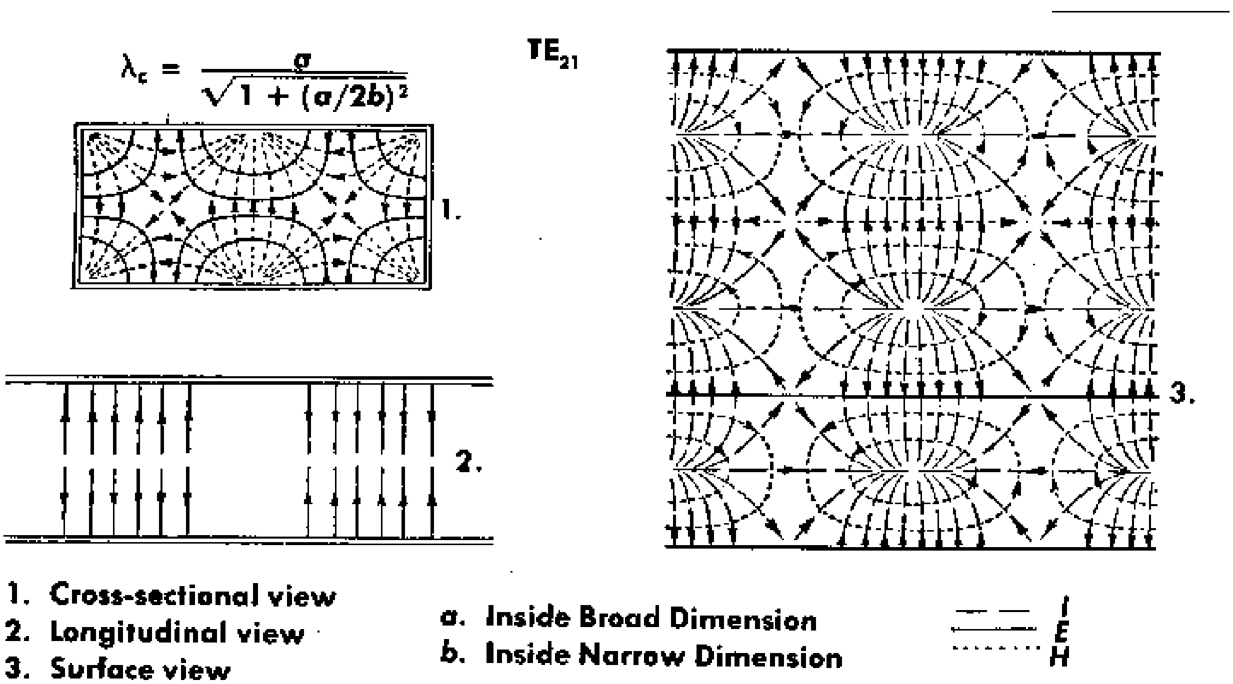


**Figure 4 $TE_{21}$ Propagation Mode (Cut-off Frequency 59.6 GHz)**

**Measurement Test System Details**

The test system was assembled to do measurements in WR-22, and contained the following parts:

- HP 8757A Scalar Network Analyzer
- HP 82025 Q Band WG Detectors (WR22)

- HP 8697A-H50 Sweeper 33-50 GHz
- Baytron WR22 20 dB Broad wall Coupler
- Various Q Band Loads, Attenuators
- Test System in WR22 WG Round Flanges
- Commercial Round to Rectangular Adaptors
- Tests Conducted
  - Return Loss & Insertion Loss (Through Attenuation)
  - 40 to 50 GHz

Some of the tests required the use of the "Bare" detector modules, which limits the Return Loss to approximately 20 dB. Other measurements allowed the insertion of a 10 dB waveguide attenuator and resulted in much improved Return Loss results.

**Test Results**

The first item tested was a 2 inch (5 cm) straight piece of WR-28 since this is the most basic requirement for connectivity. Both waveguide flanges are flat without any choke grooves and the results in Figure 5.

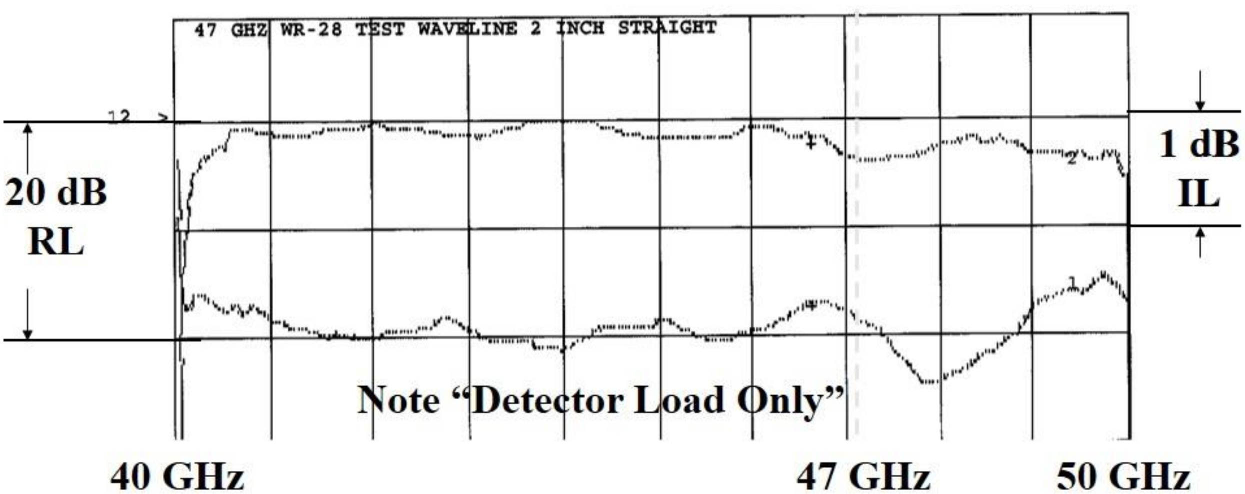


**Figure 5 2 inch (5 cm) Straight WG Test Result**

The next test was on a longer 9 inch (23 cm) straight waveguide as shown in Figure 6. Both of the straight sections show reasonable insertion loss and good return loss up to 47 GHz

Figure 7 shows the test result for a 4 inch (10 cm) corrugated "Flex" waveguide. It exhibits considerably higher ripple in the Insertion Loss than a straight waveguide but still has good Return Loss. The Insertion loss at 47 GHz is still reasonable, but we cannot be sure that will always be the case.

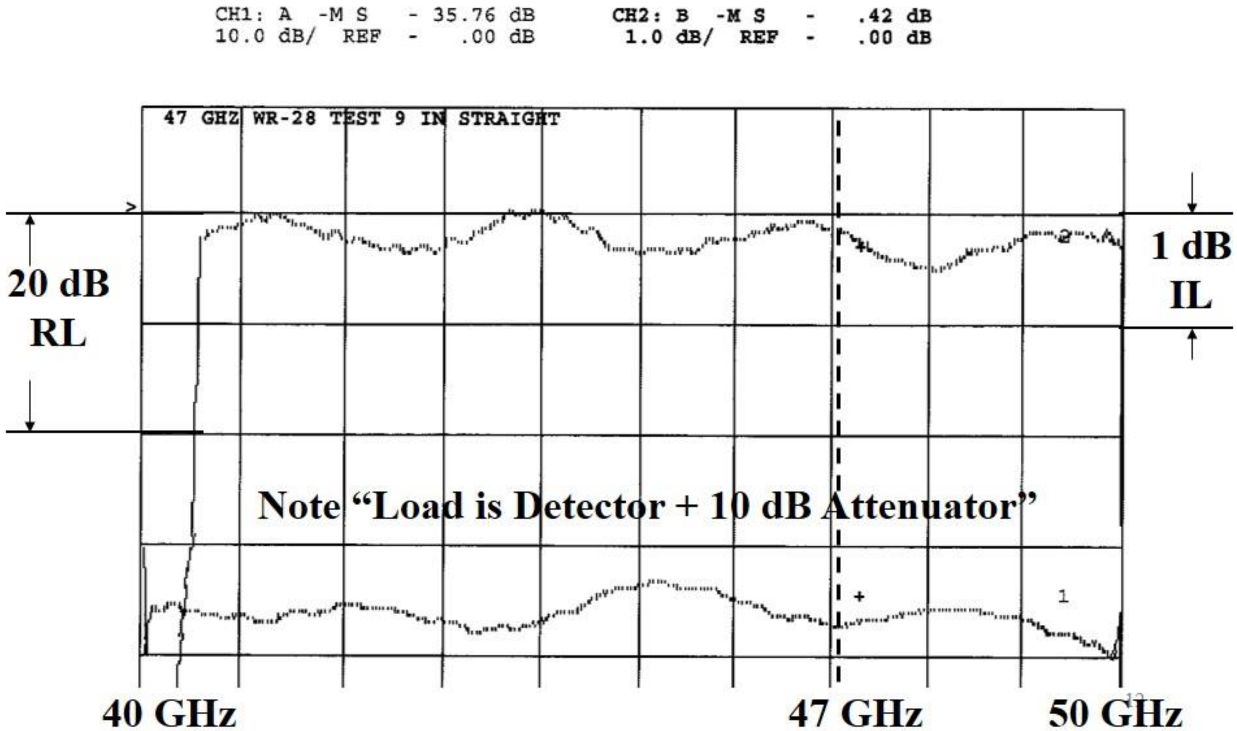


Figure 6 9 inch (23cm) Straight Waveguide

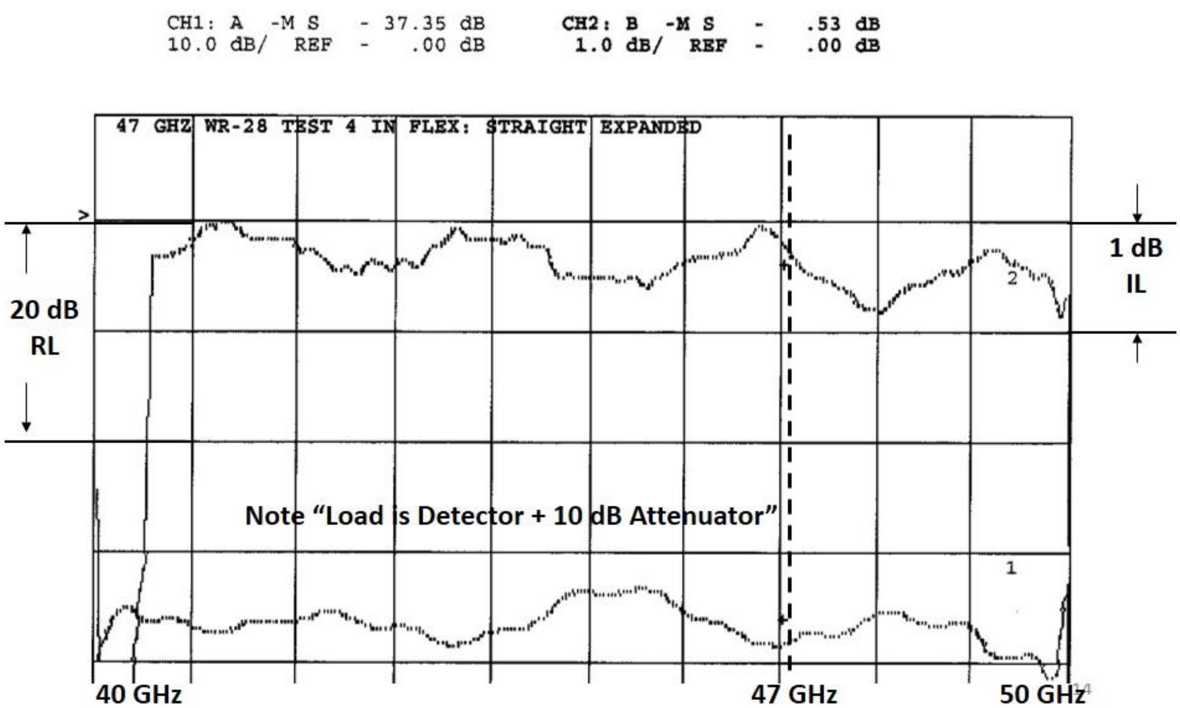


**Figure 7 4 Inch (10 cm) Flex Waveguide**

Figure 8 is the test result for a 39 GHz Dish Flex waveguide that has a 90 degree H plane bend. The ripples in the Insertion loss are even more volatile than for the straight flex waveguide although the Insertion Loss at 47 GHz is still reasonable (about 0.5 dB) and the Return Loss remains very good and in excess of 30 dB.

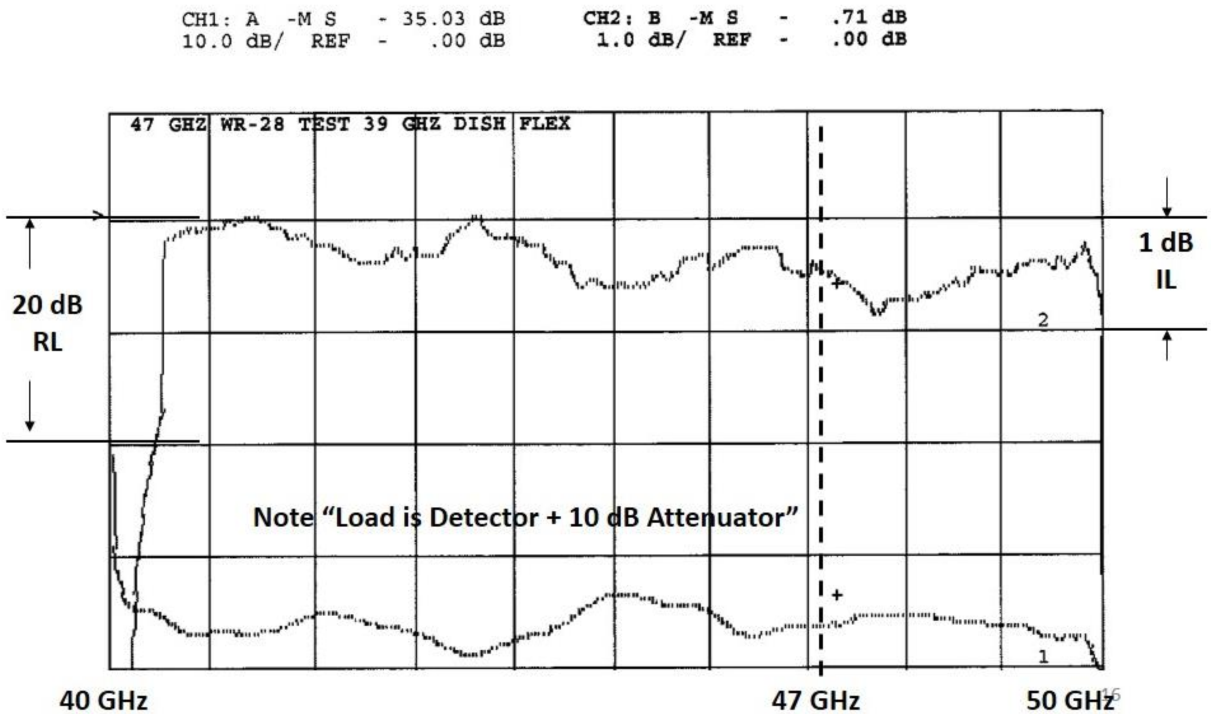


**Figure 8 39 GHz Dish Flex Waveguide with 90 degree H Plane bend**

Figure 9 shows a Waveline 90 degree E plane bend. Notably the Insertion Loss is very low (approx. 0.1 dB) at 47 GHz but there is still significant ripple, but the Return Loss is very good at over 30 dB.

Figure 10 shows a rigid waveguide with a 90 degree E plane bend, plus a 90 degree Twist. The result is a flatter Insertion Loss curve, with approximately 0.2 dB loss at 47 GHz and a good Return Loss right up to 49 GHz, and then the response deteriorates significantly.

Figure 11 is a Waveline 90 degree H plane bend. The performance actually appears better than all the others up to 45 GHz, is quite acceptable at 47 GHz but really deteriorates above 49 GHz.

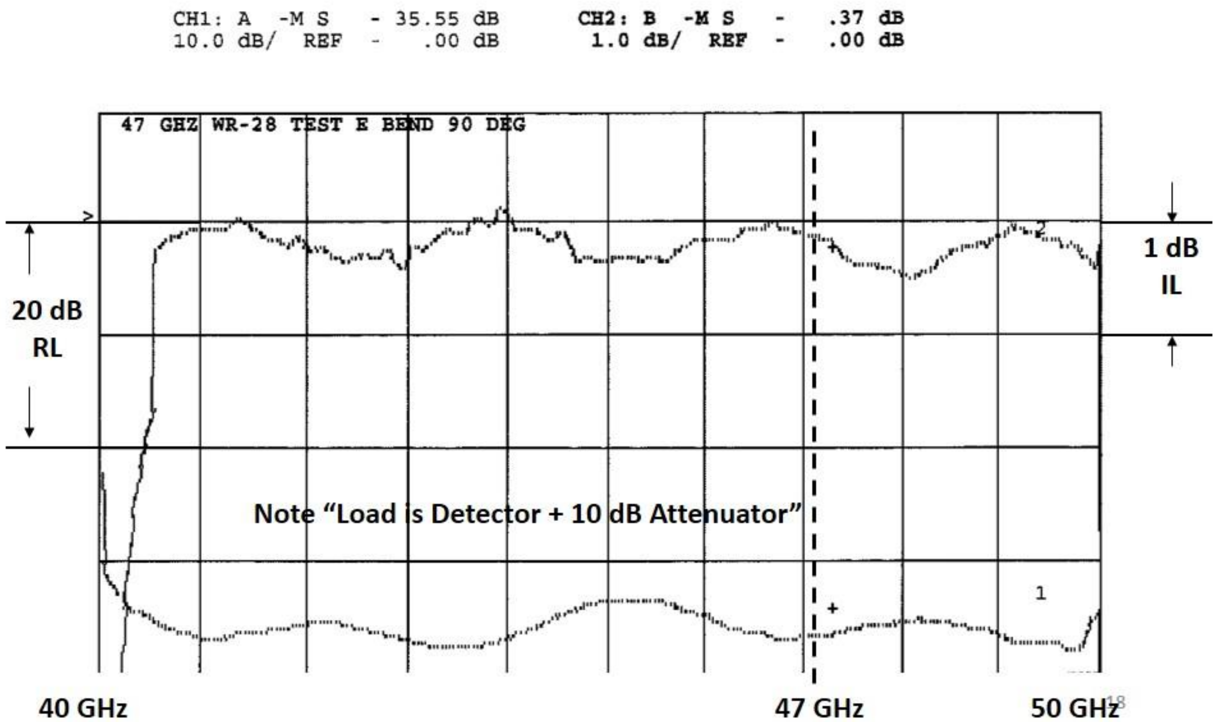


**Figure 9 Rigid Waveguide E Plane Bend**

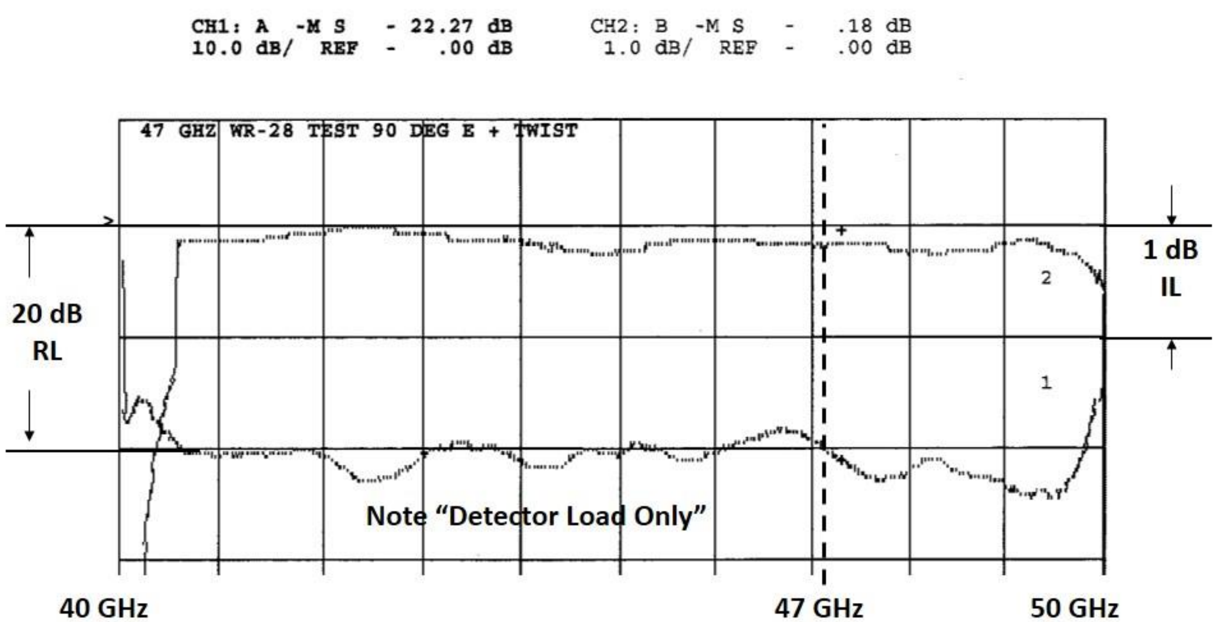


**Figure 10 Rigid Waveguide E Plane Bend + Twist**

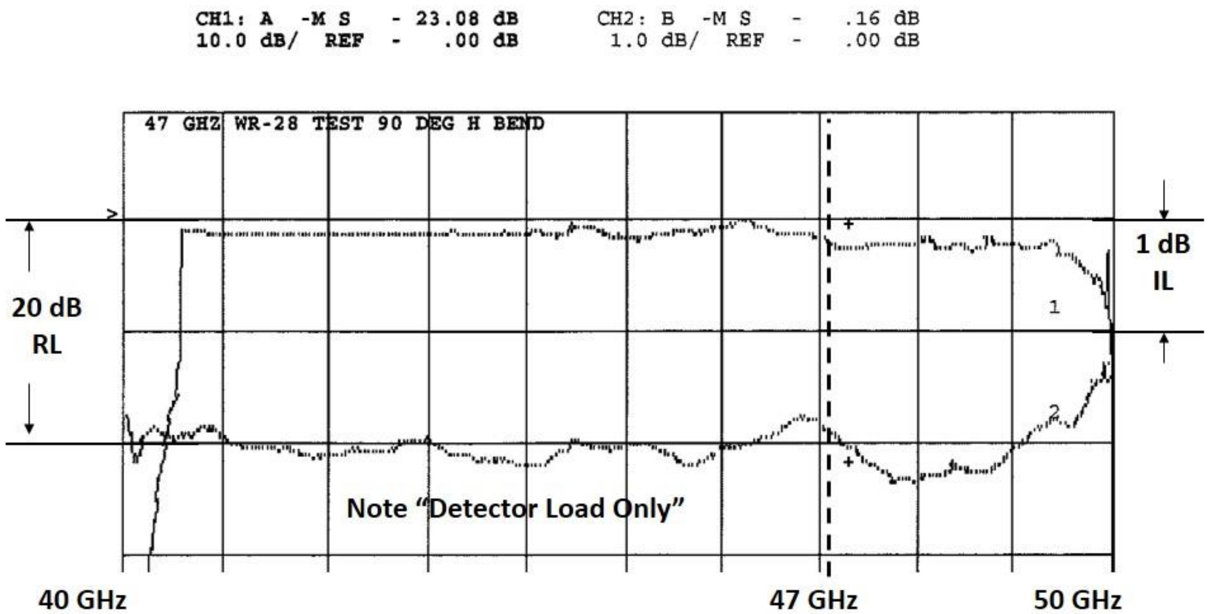


**Figure 11 Rigid Waveguide 90 degree H Plane bend**

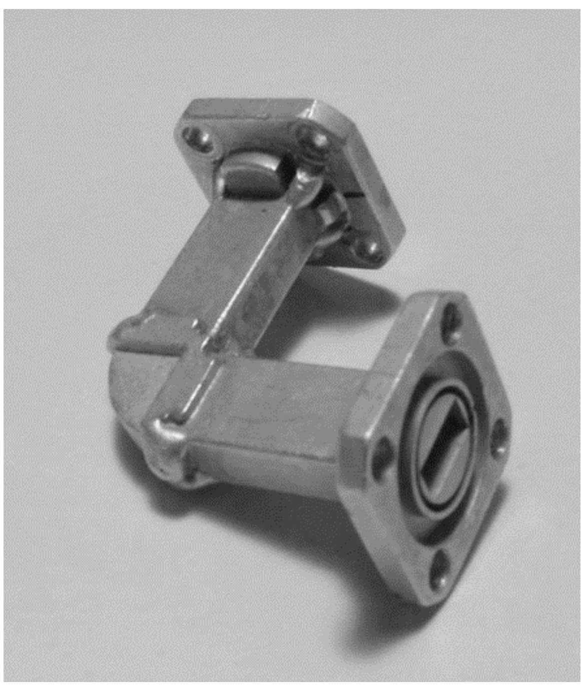

Figure 12 is a picture of an H plane 90 degree bend with a "cast elbow" bend. This piece also has a choke flange which the previous 90 degree bends did not have. The response shown in figure 13.

Very clearly the Insertion Loss response falls off very quickly above 40 GHz with approximately 1 dB of loss at 47 GHz, and with a minimum at 48.5 GHz. Looking at the Return Loss curve at 48.5 GHz there is a very strong resonant looking response and then again near 50 GHz.

We were concerned with the possibility of moding with an H Plane bend and this would appear to be it. The previously shown H plane bends (Figures 8 & 11) were of swept radius (gentle bends). The cast bend is abrupt with a short radius.

**Figure 12 Cast Elbow H plane bend with Choke Flange**

This is also the first response of a waveguide using a choke flange. Al W5LUA has suggested that the choke flanges do have an influence and perhaps a better response could be obtained by filling in the cavity of the choke in order to change its frequency response. More on this later.

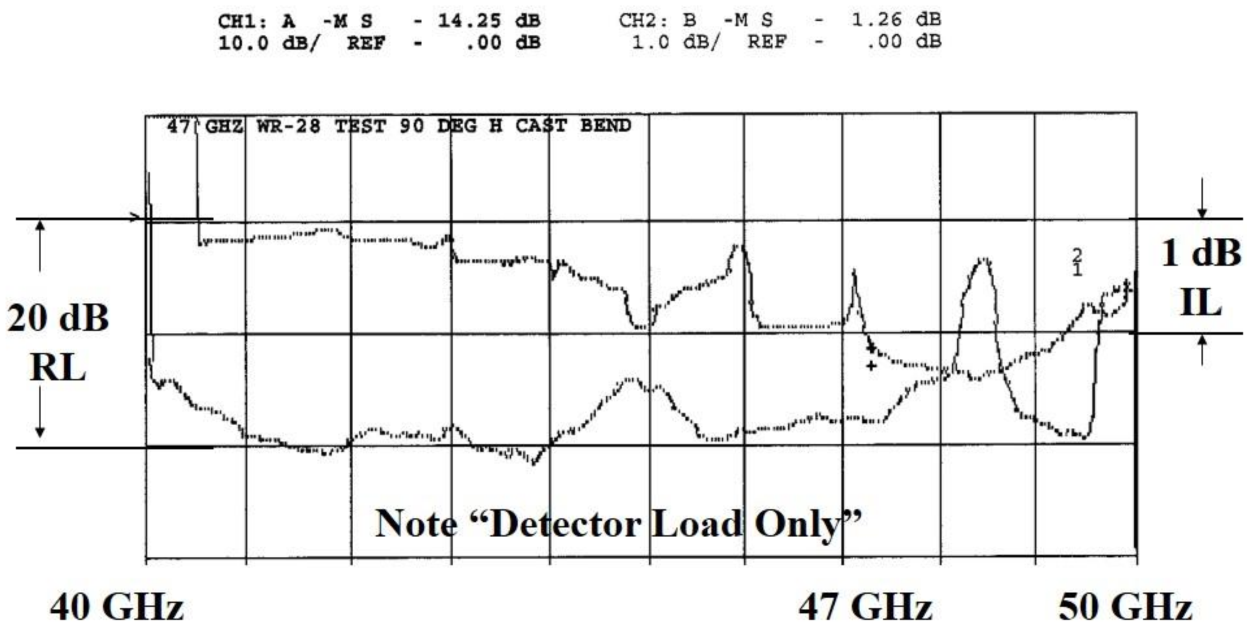


Figure 13 Cast Elbow H plane Bend

The next tests were of various waveguide loads. The first is a low power (1W) unit and its response is quite good at over 20 dB Return Loss as shown in Figure 14.

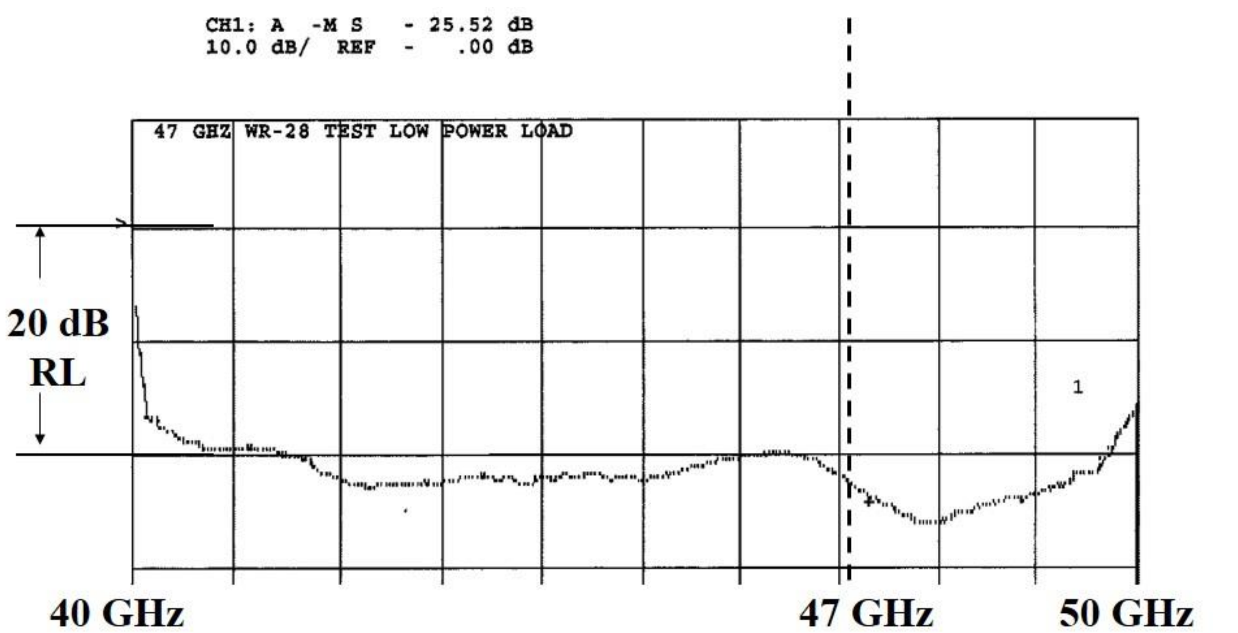


Figure 14 Low Power Load

The next load to be tested was a 50 Watt unit with large fins.  Its response is shown in Figure 15.

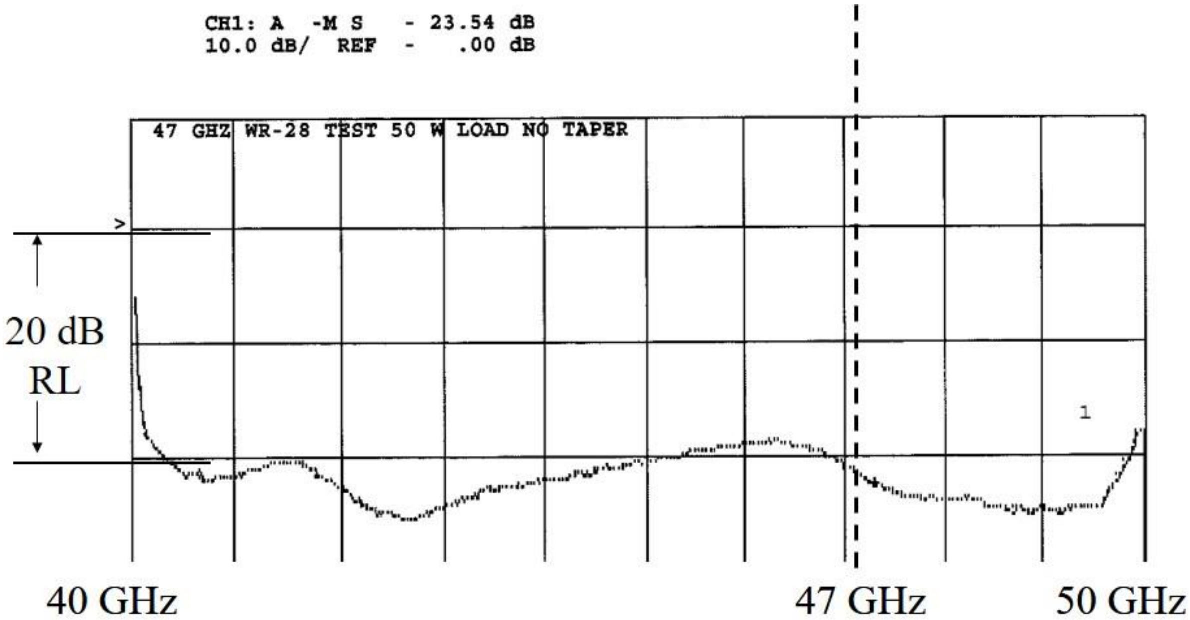


Figure 15 50 Watt Load

In an effort to improve the frequency response, a smooth taper transition from WR-28 to WR-22 was inserted and the result is shown in Figure 16.  That is a very nice improvement from22 to 26 dB and a much flatter response! Another alternative would be to use a ¼ wavelength thick metal step transformer as shown in Figure 17.  The bandwidth will not be as good as with a taper, but sufficient for our use.

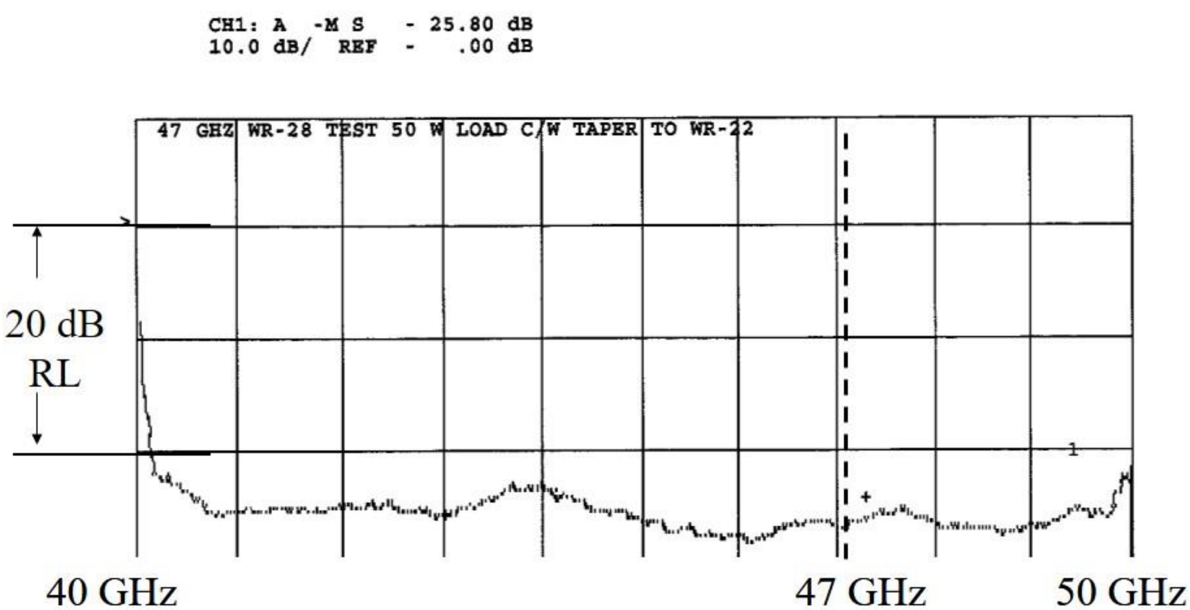


Figure 16 50 W Load with Taper Transition to WR-22

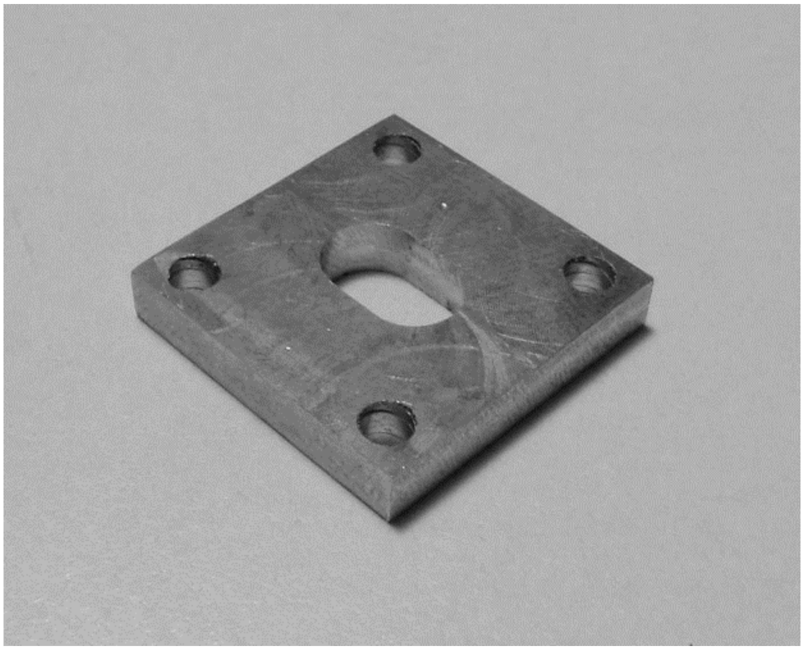

**Figure 17 Waveguide Step Matching Transformer**

The next category of equipment that was tested was waveguide switches. The situation may have improved slightly in the past 15 years as some 47 GHz switches are now being made for the amateur market in Europe, however commercial switches are still necessary for high power operation.  Finding motorized WR-19 or WR-22 units is extremely difficult, although manual switches are more common and can be motorized.  Some WR-28 switches have appeared on the surplus market and are highly prized! The first switch to be tested was a Waveline 1077 E plane unit, which has only flat faced waveguide flanges and the results are shown in Figure 18.

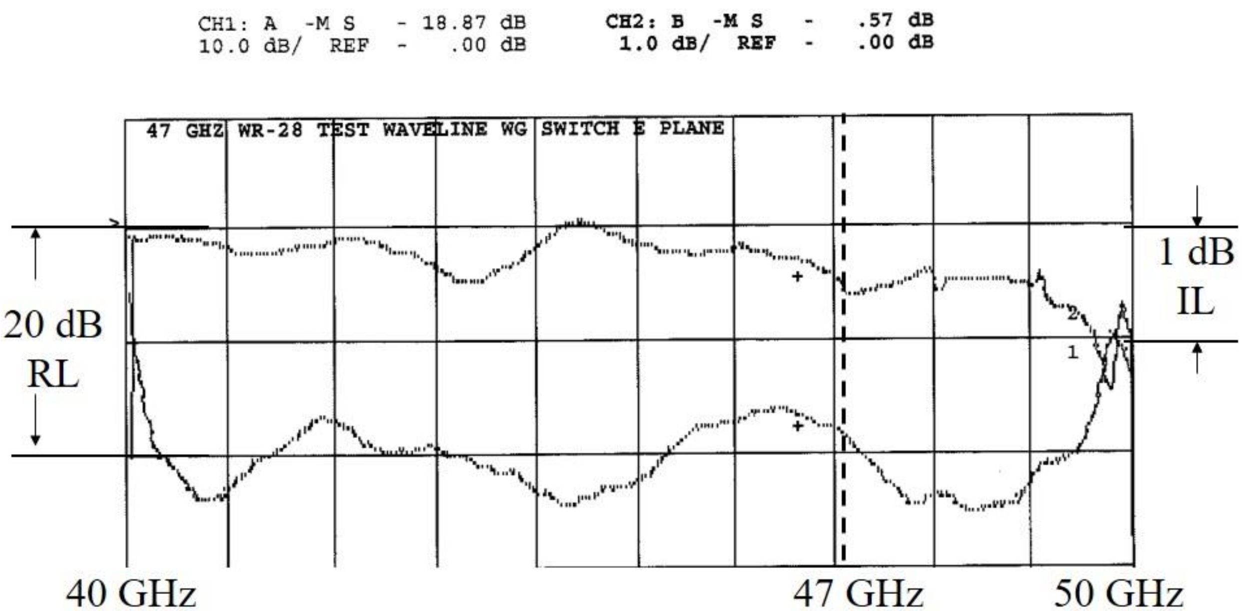


**Figure 18 Waveline 1077 E Plane WG Switch**

This switch shows approximately 0.5 dB Insertion Loss, not much different than a straight piece of WR-28 waveguide, but the Return Loss is only about 18 dB and has significant ripples vs frequency. Notably the response of Insertion Loss and Return Loss deteriorate significantly between 49 and 50 GHz. We had seen similar behavior with nearly all of the waveguide pieces tested previously! I had attempted to do some waveguide tuning to improve both responses at 47 GHz but was unsuccessful.

The next switch tested was a Waveline 1078-H Manual H plane unit with flat faced flanges and its response is shown in Figure 19. The response of the switch is quite remarkable with decent Insertion Loss of 0.4 dB and Return Loss of 18 dB, but the response deteriorates considerably at 47.5 GHz and then again at 49.5 GHz. It appears that internally the switch is probably has a fairly abrupt H plane bend.

The final waveguide switch was a Relcomm Tech E Plane unit shown in Figure 20, which appeared as a "New Old Stock" surplus from New Zealand. These units were small, powered from 8Vdc and had latching characteristics, which made it ideal for amateur portable operation. This switch does have choke flanges.

The response varies very dramatically with a serious deterioration peaking at about 47.8 GHz. The Insertion Loss is about 2.2 dB and Return Loss of 12 dB. This was very disappointing! I made no attempt to tune this out. Since it internally is an E Plane Switch it is surprising to see this response. As discussed earlier Al W5LUA had questioned the role the choke flanges has had in this poor response. It still is a terrific switch for 24 GHz!

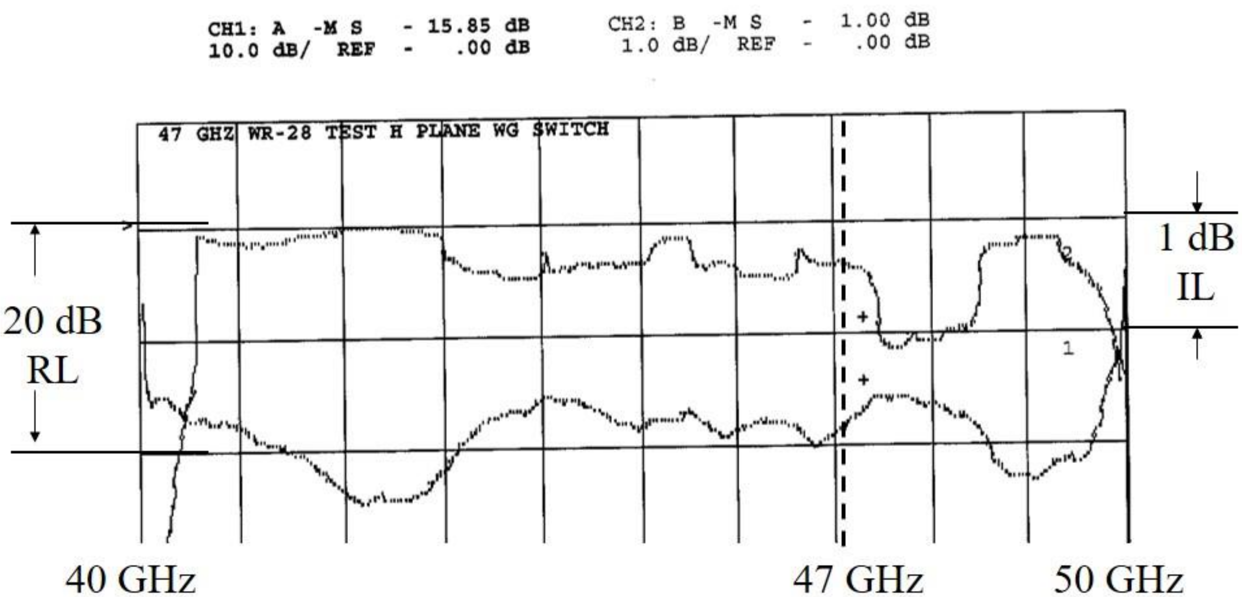


**Figure 19 Waveline 1078-H H plane Waveguide Switch**

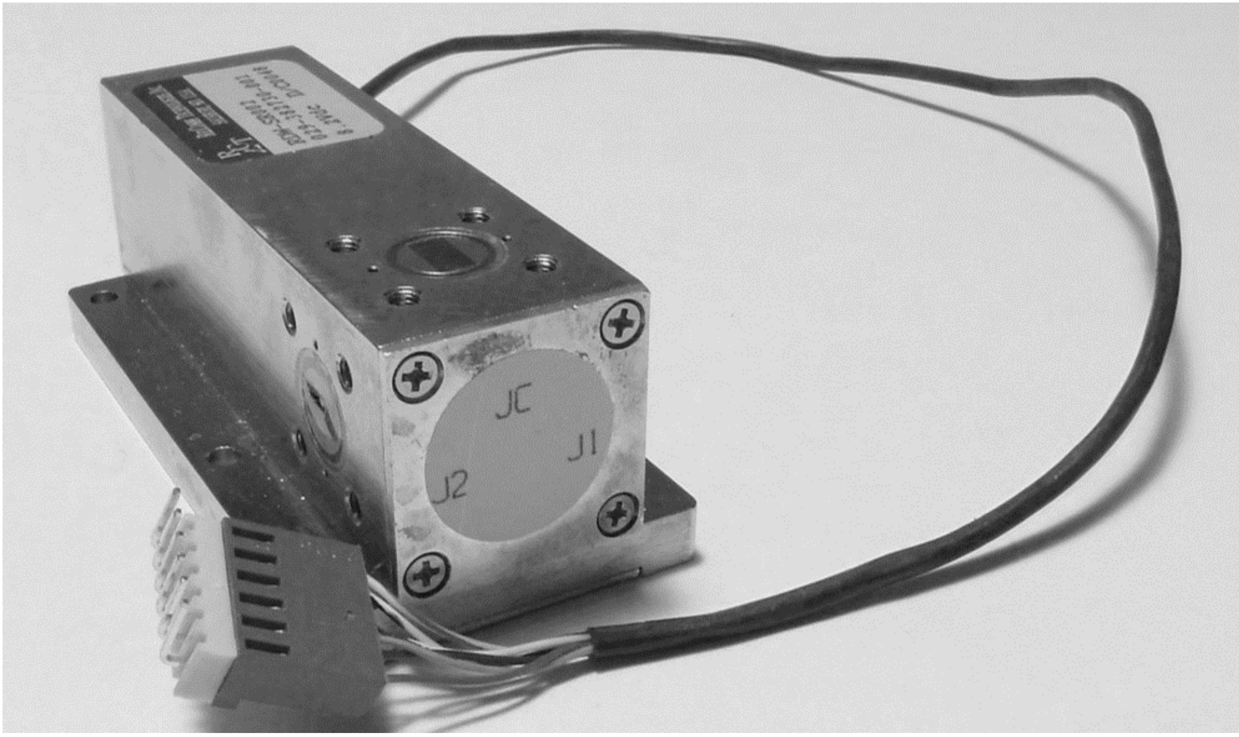

Figure 20 Relcomm Tech E Plane Waveguide Switch

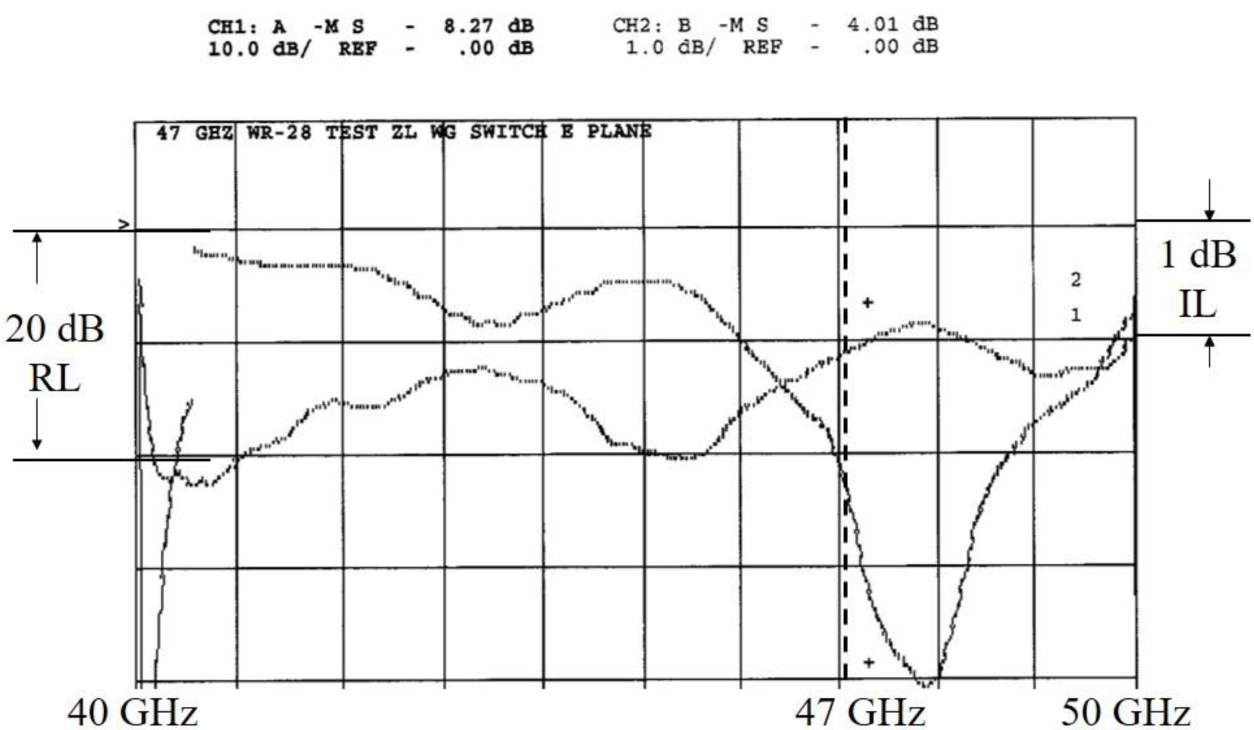


Figure 21 Relcomm Tech E Plane WG Switch

The final part that was tested was an MCS R382-B Broad wall Directional Coupler shown in Figure 22  I could not find a data sheet but from the part number I assumed it was a 6 dB coupler. The response is shown in Figure 23.  The coupling factor looks as if it's about 12 dB instead of 6 dB, and at 47 GHz the coupling is 7 dB. The Return Loss of the transmission port is about 36 dB and does show a peak decline at just over 48 GHz. Through port Insertion Loss was not examined.

**Figure 22 MCS 382B Broad Wall Directional Coupler**

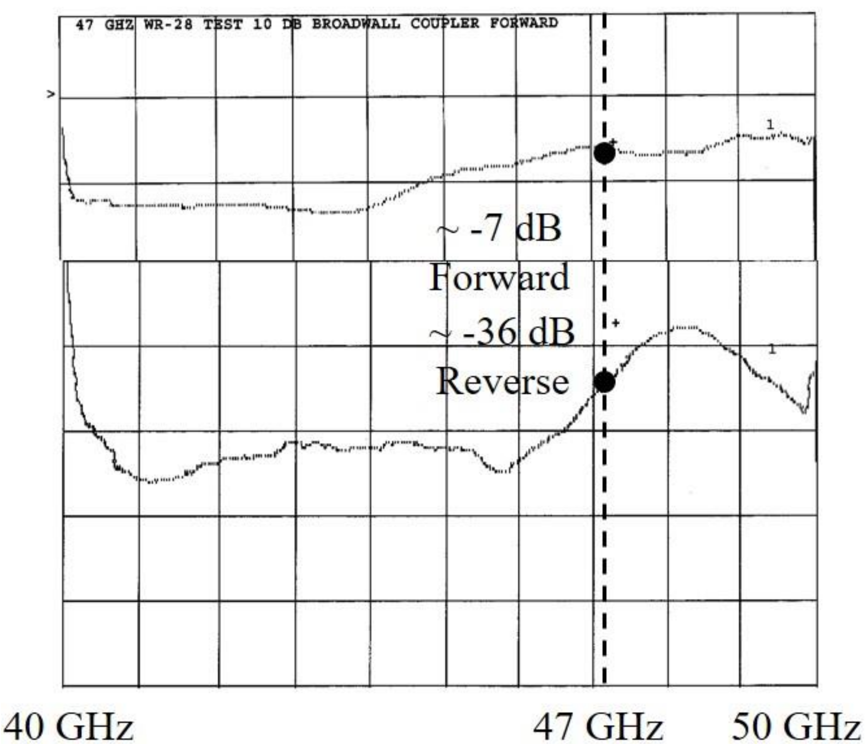


**Figure 23 MCS 382B Directional Coupler**

**47 GHz WR28 Waveguide Summary and Recommendations**

- OK to use WR28 If the lowest loss is not required
- Use only short and straight sections If possible
- "E" plane bends are best, and large radius bends are preferred
- "H" plane bends may be OK….but test them!
- "Cast" 90 Degree H plane bends are very bad. E Plane bends may be OK, but were not tested.
- High power loads are OK, but are better with a taper or step transition to WR-22
- Waveline switches are generally OK, with E plane types being the best. The Relcomm Tech waveguide switch was very poor.
- Waveguide components with Choke flanges are suspect. Test them!

**Possible Follow-up Work**

- Perform similar Insertion Loss and Return Loss tests with interface to a WR-19 test system