Elevation Patterns of Waveguide Slot Antennas

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Waveguide slot antennas are popular as beacon antennas – one of the few horizontally polarized omnidirectional antennas with gain. Typical radiation patterns, shown in Figure 1, are nearly omnidirectional in azimuth but much sharper in elevation, providing gain at elevations near the horizon. Hams have made and used them for beacons on bands from 1296 MHz to 24 GHz. They are also useful for other applications where a directional antenna is not convenient – Doug, K4LY, has a 10 GHz slot antenna on his car for quick contacts from hilltops.

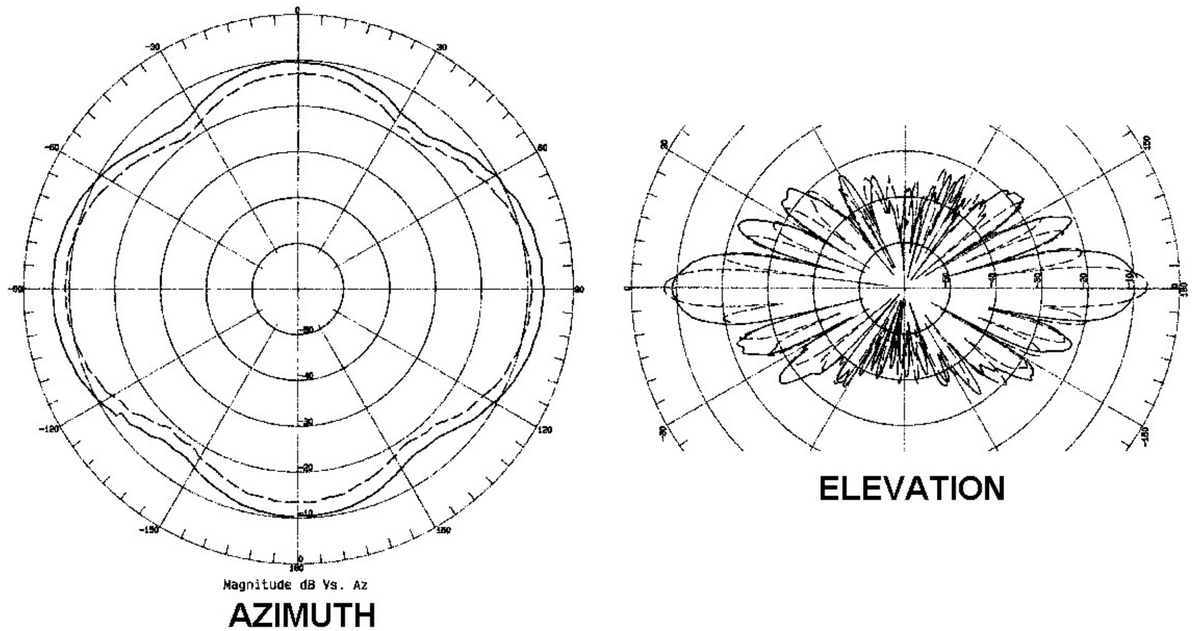

Figure 1- Measured Radiation Patterns for 12 and 24 slot antennas at 10.368 GHz

Recently, Kent, WA5VJB, has reported measurements on waveguide slot antennas with elevation peaking tilted downward. These results are at odds with all published measurements and simulations results. However, Kent has significant expertise with antennas and measurements, so his reports cannot be easily dismissed.

I asked Glenn Robb, KV4SA, of Antenna Test Lab[1], if he would measure some waveguide slot antennas on his professional antenna range to verify the radiation patterns one way or the other. He agreed to make the measurements. I had some slot antennas on hand from various sources. At the same time, I had been working with Jim Miller N8ECI, on some slot antennas in inexpensive aluminum rectangular tubing. Jim agreed to make a couple of more on his CNC machine to the exact dimensions from my slot antenna spreadsheet[2], https://www.w1ghz.org/software/slotantenna.xls . These two are for an experiment I've been meaning to try for years: One antenna has uniform slot offset spacing, while the other has a tapered offset spacing, which is intended to reduce sidelobe levels.

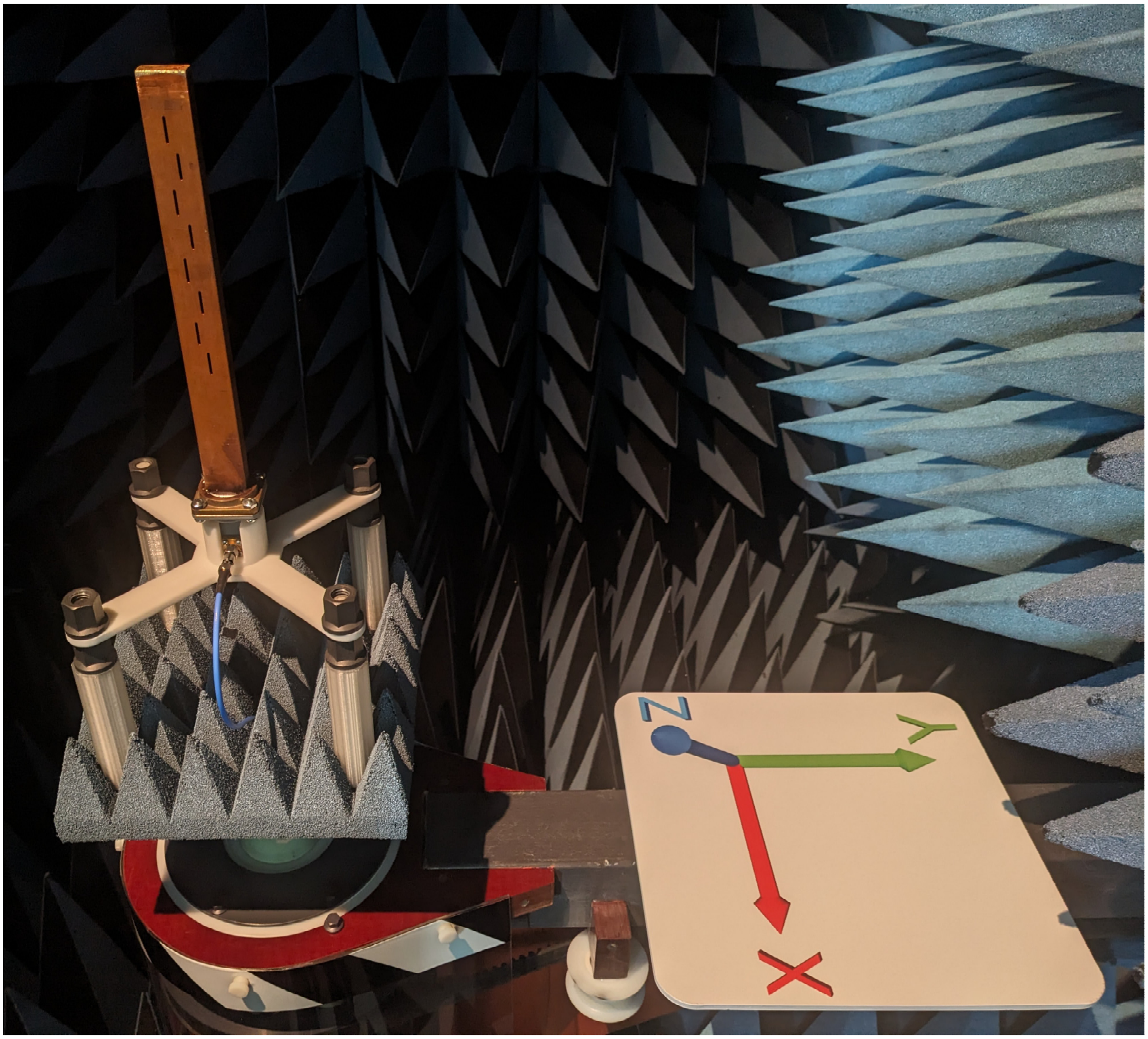

Figure 2 – Slot antenna measurement setup at Antenna Test Lab Co

Elevation Patterns

A total of seven waveguide slot antennas, for two different amateur bands, were tested, shown left to right in Figure 3, with elevation patterns shown in Figures 4 thru 10.

Figure 3 – Waveguide Slot Antennas, from Left to Right:

1. 8-slot WR-137 for 5760 MHz
2. 16-slot WR-137 for 5760 MHz
3. 24-slot WR-90 for 10368 MHz
4. 16-slot Aluminum Tubing for 10368 MHz (N8ECI)
5. 16-slot WR-90 for 10368 MHz (N8ECI)
6. 16-slot WR-90 for 10368 MHz with tapered slot distribution (N8ECI)
7. 12-slot WR-90 for 10368 MHz

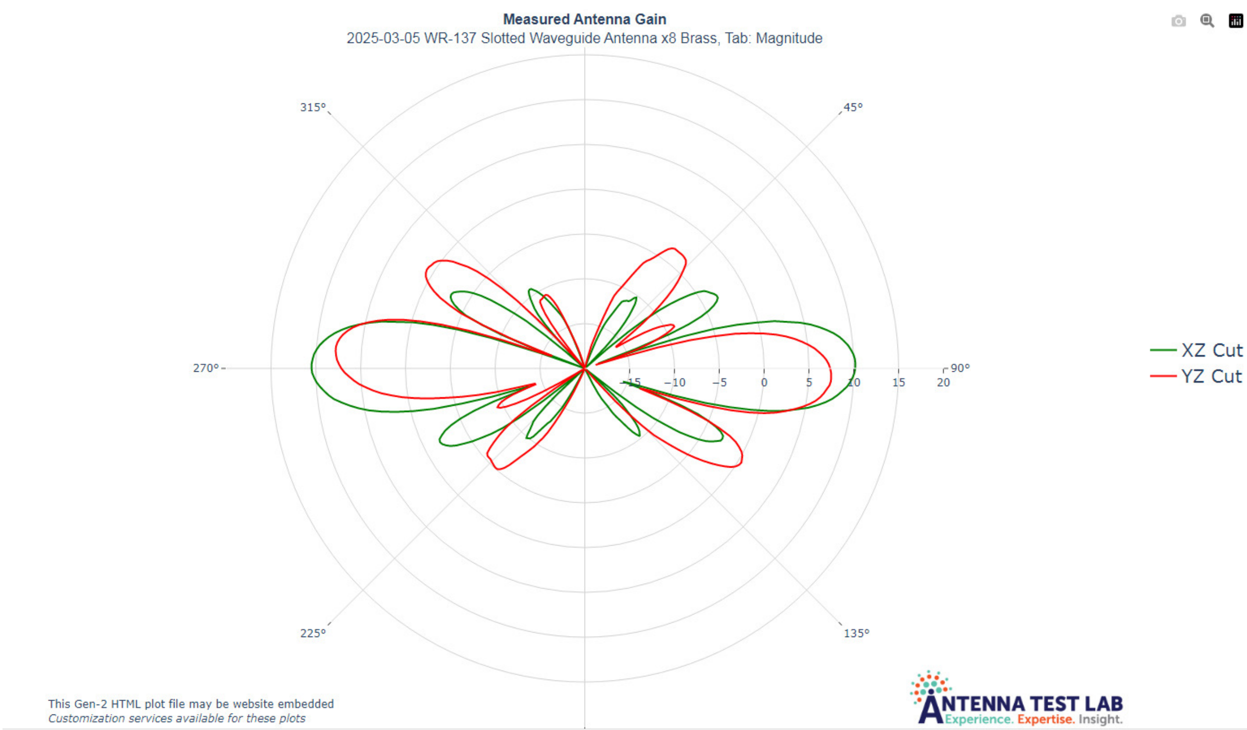

Figure 4 – Elevation pattern of WR-137 waveguide 8-slot antenna at 5760 MHz

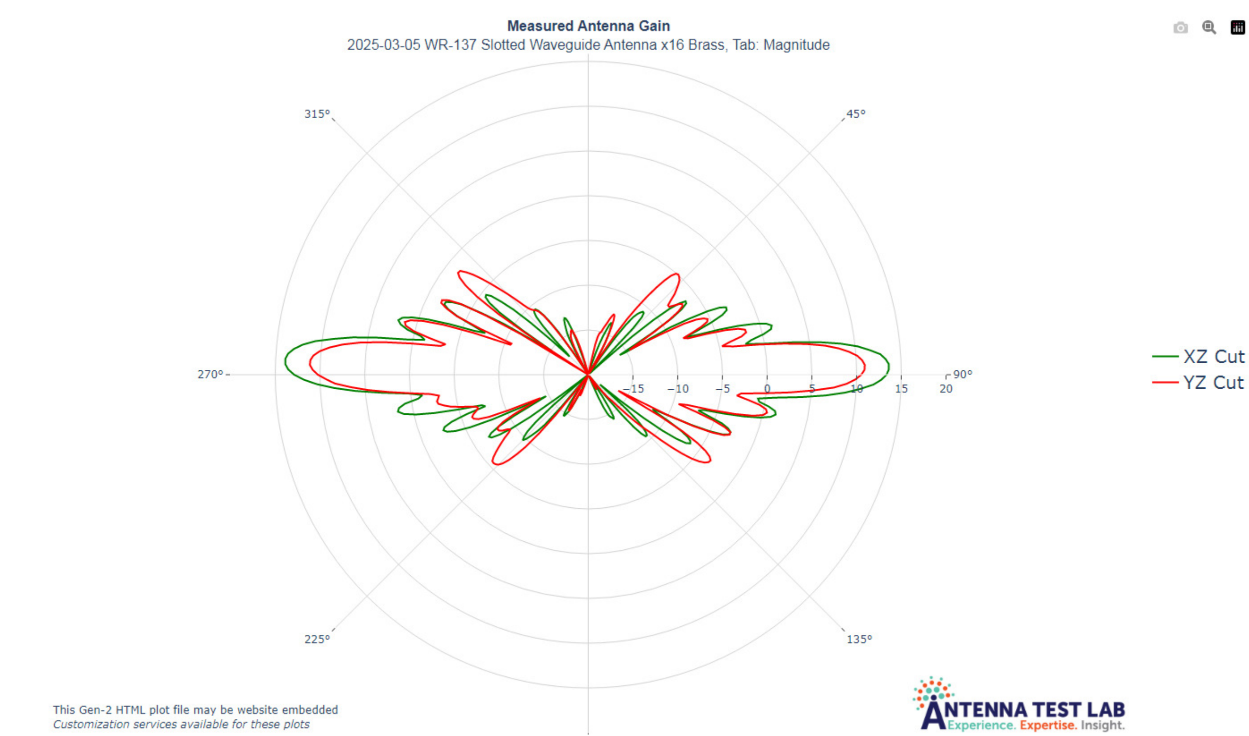

Figure 5 - Elevation pattern of WR-137 waveguide 16-slot antenna at 5760 MHz

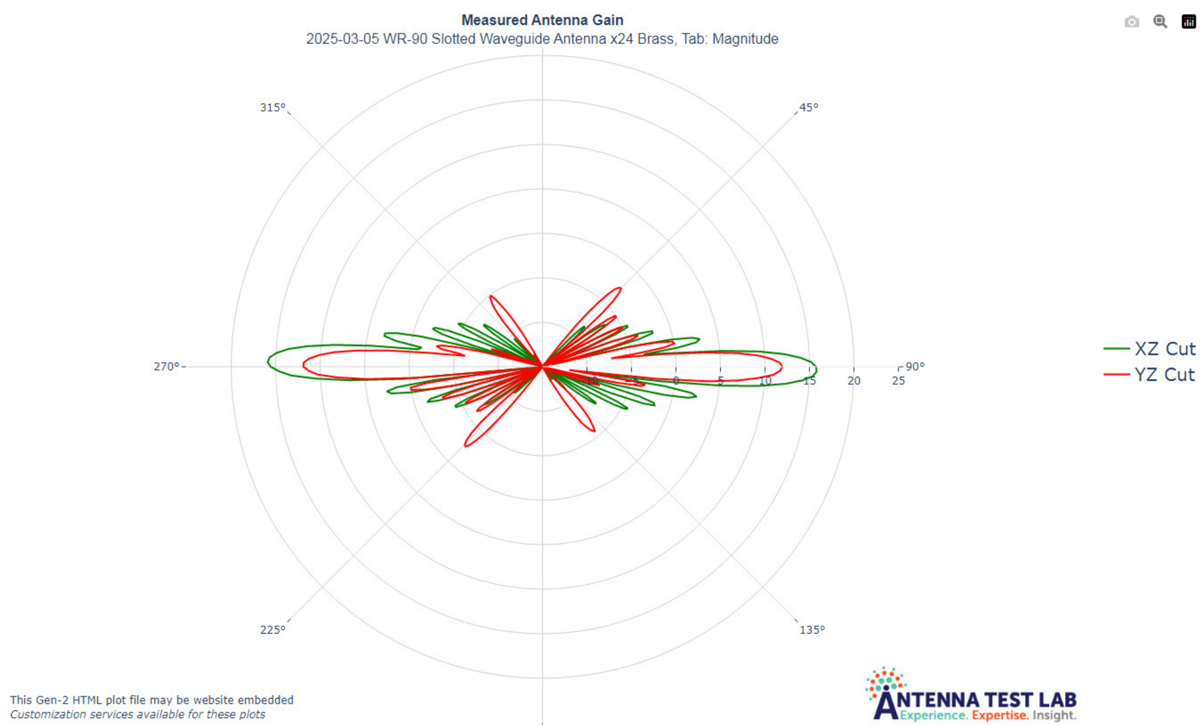

Figure 6 - Elevation pattern of WR-90 waveguide 24-slot antenna at 10368 MHz

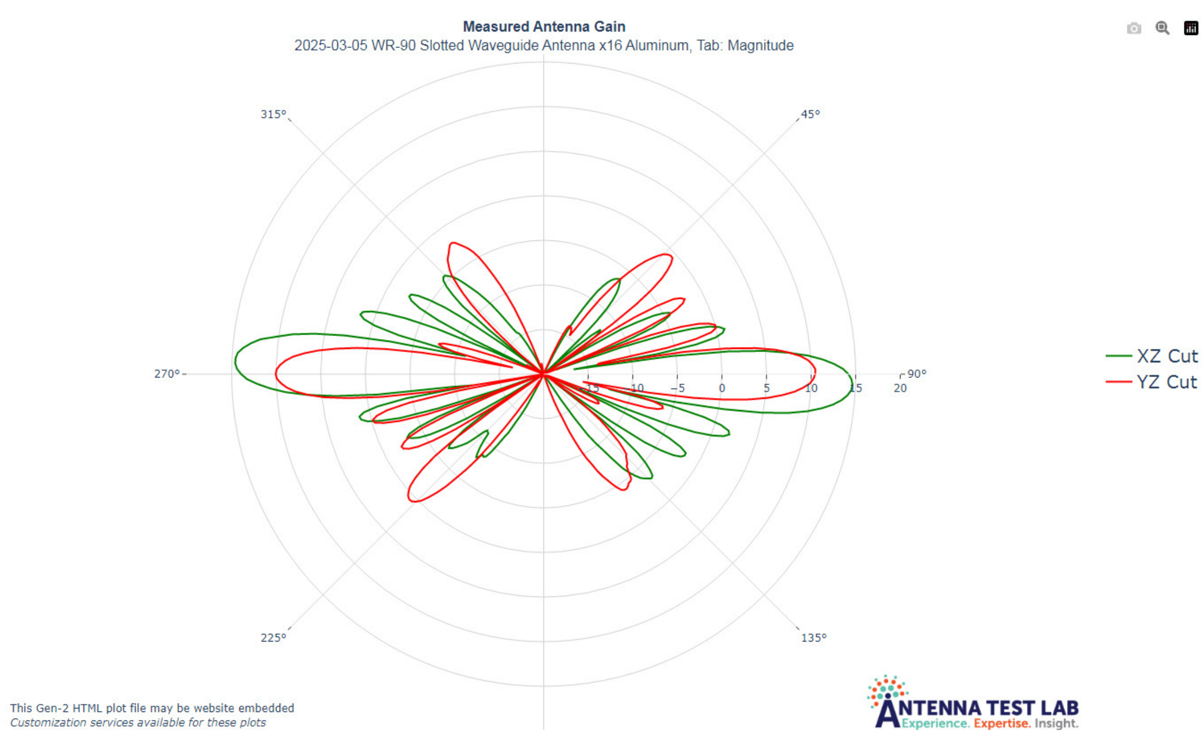

Figure 7 - Elevation pattern of waveguide 16-slot antenna at 10368 MHz in ½ by 1 inch Aluminum tubing

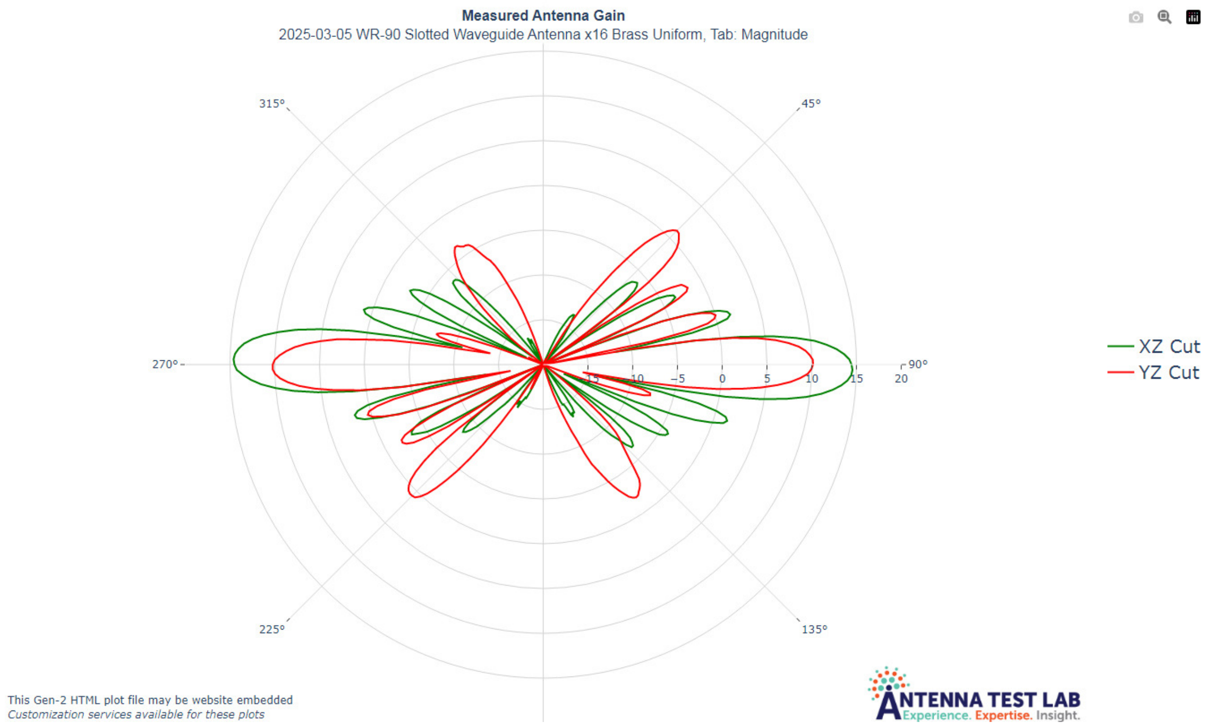

Figure 8 - Elevation pattern of WR-90 waveguide 16-slot antenna at 10368 MHz with no taper

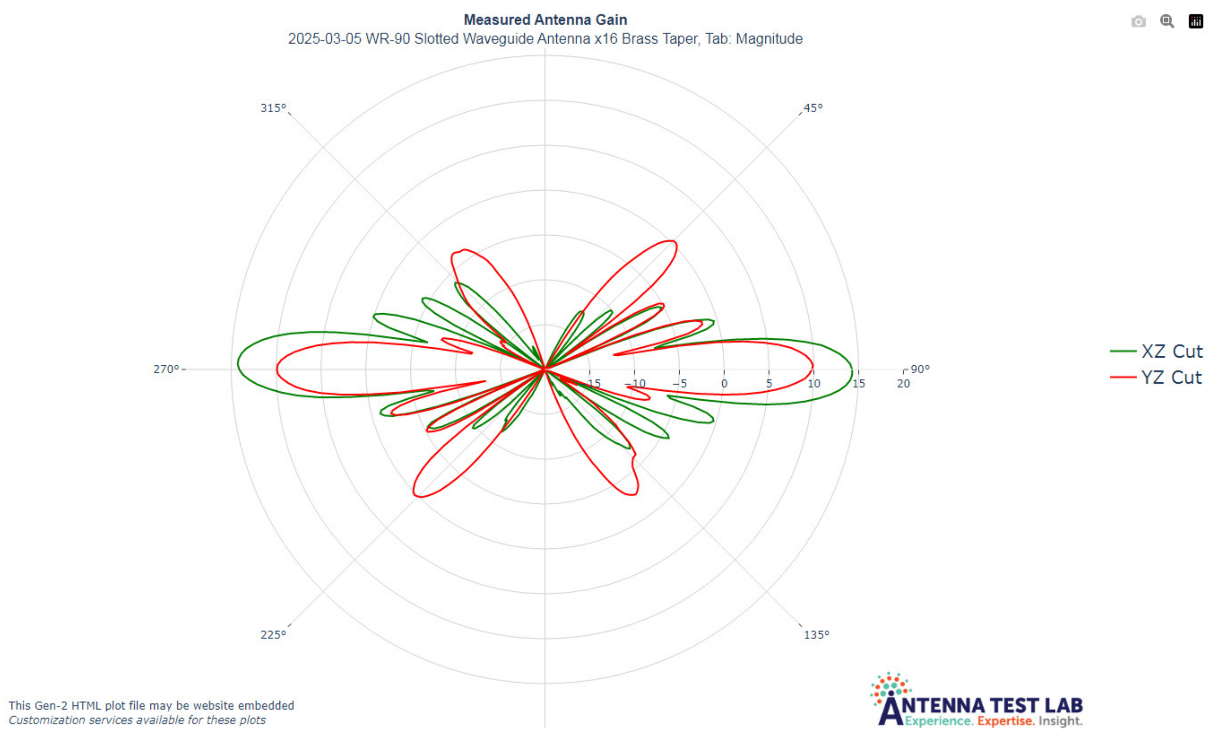

Figure 9 - Elevation pattern of WR-90 waveguide 16-slot antenna at 10368 MHz with tapered slot offset

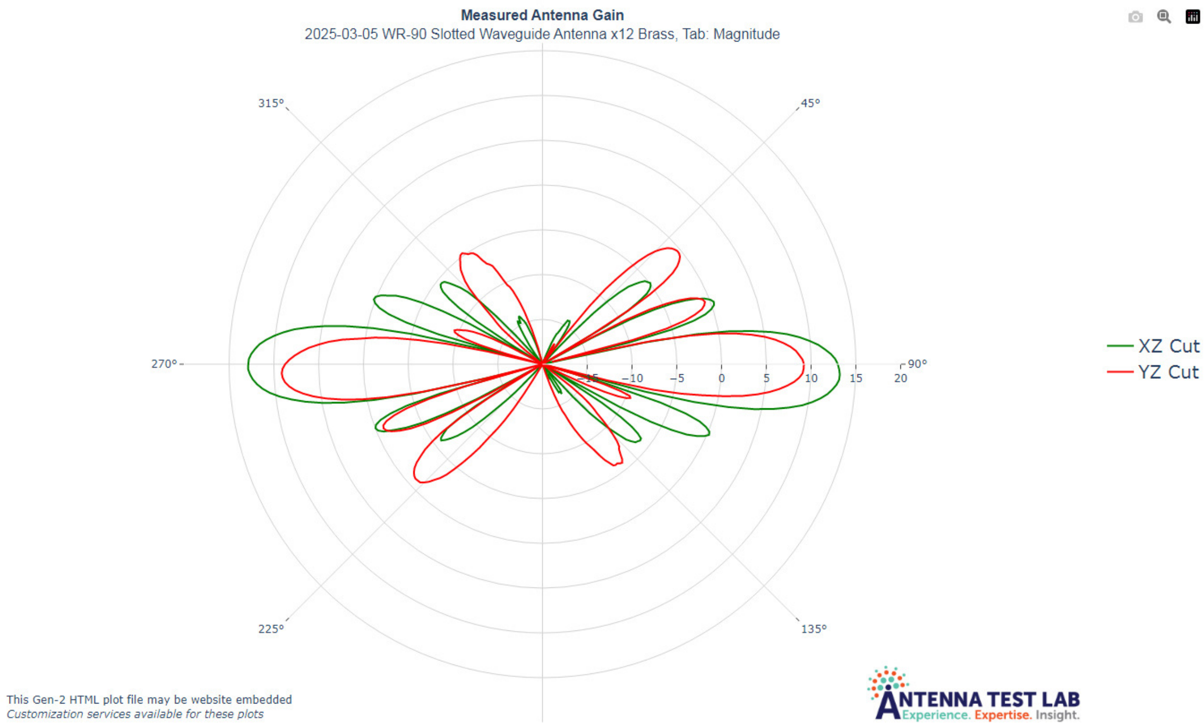

Figure 10 - Elevation pattern of WR-90 waveguide 12-slot antenna at 10368 MHz

The elevation patterns are as expected, with larger numbers of slots producing a more gain and a sharper elevation pattern. All patterns are very near the horizon, with no significant up or down tilt. Some patterns have an asymmetrical tilt, like Figure 7 in the YZ Cut and Figure 4 in the XZ Cut – Glenn attributes this to the press-fit aluminum waveguide tube-to-flange joint being loose, and not perfectly perpendicular to the plane of the mounting flange.

The tapered slot version in Figure 9 does have a slightly broader pattern and slightly lower sidelobes compared the uniform slot version in Figure 8, but the differences are small and not worth the trouble. The improvement might be greater on an antenna with more slots.

The elevation patterns do show a tilt at frequencies away from the design frequency, where the slot spacing is no longer 1/2 wavelength so the slots are not in phase. Figure 11 shows a downtilt at 5% lower frequency and Figure 12 shows an uptilt at 5% higher frequency, for an 8-slot antenna. A version with 16 slots in Figures 13 and 14 shows more pronounced tilts, with the pattern starting to break up into multiple lobes. At larger frequency excursions, both effects become more pronounced.

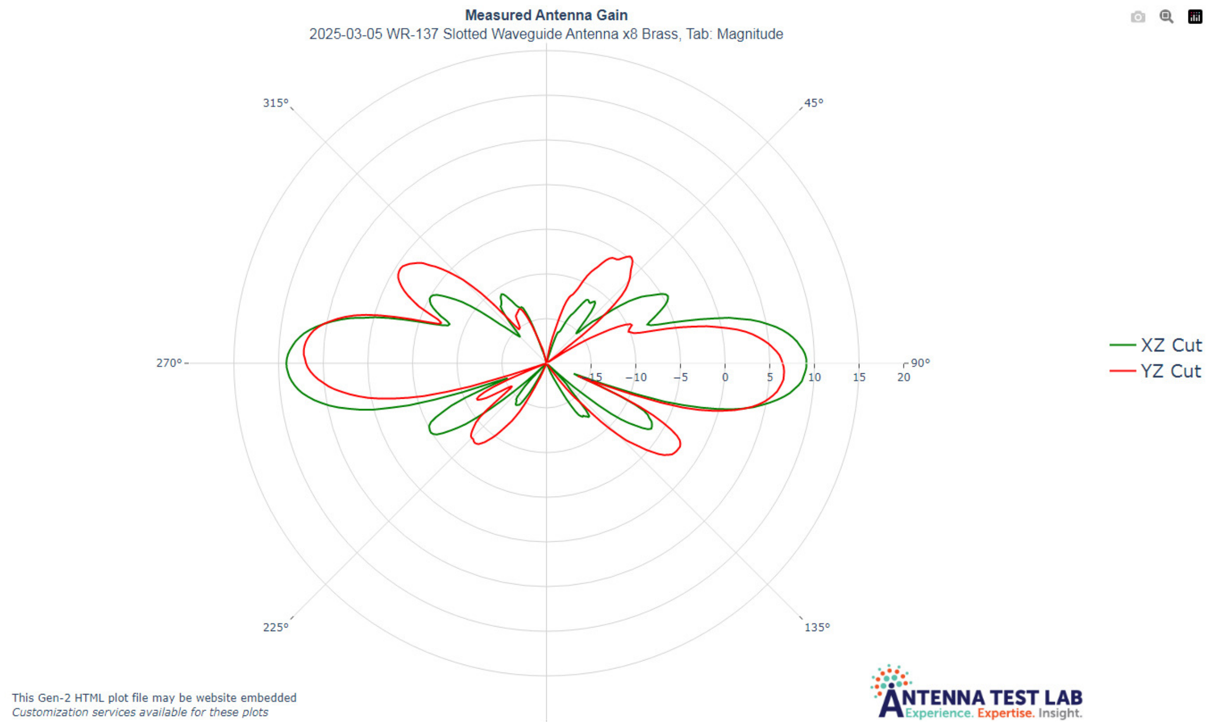

Figure 11 - Elevation pattern of WR-137 waveguide 8-slot antenna at 5480 MHz

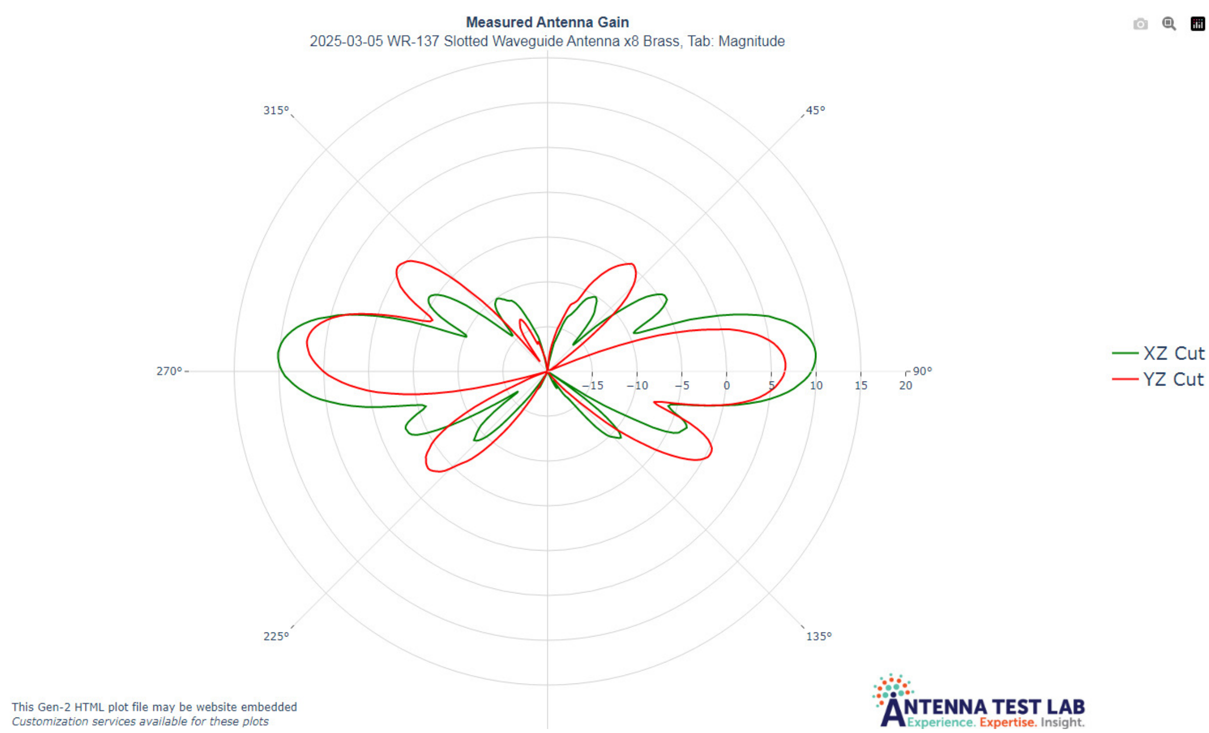

Figure 12 - Elevation pattern of WR-137 waveguide 8-slot antenna at 6040 MHz

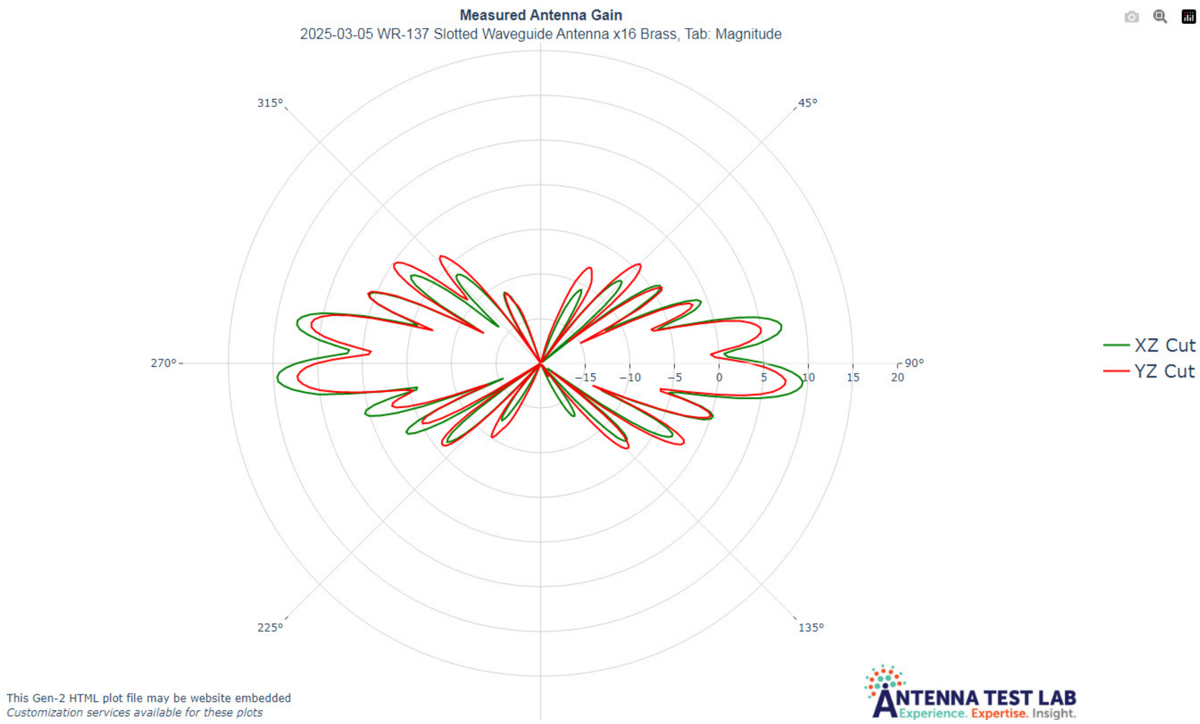

Figure 13 - Elevation pattern of WR-137 waveguide 16-slot antenna at 5480 MHz

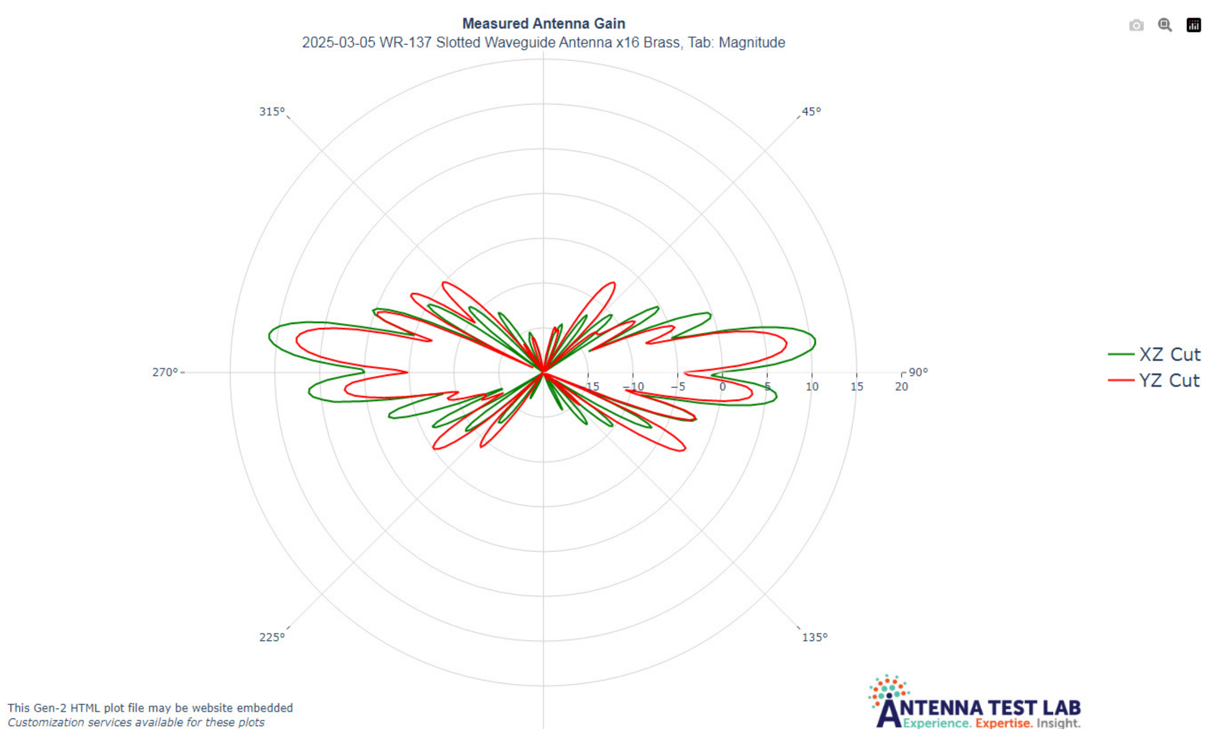

Figure 14 - Elevation pattern of WR-137 waveguide 16-slot antenna at 6040 MHz

If an elevation tilt is desired, the slot length should be resonant at the desired frequency but the spacing changed: less than ½ λ for down tilt or more than ½ λ for up tilt. Changing the spacing would also upset the impedance match that depends on ½ λspacing.

The equivalent circuit of a waveguide slot antenna is shown in Figure 15 if the slots are all spaced ½ λ, so that the admittances of the slots all appear in parallel with no phase shift (admittance is the inverse of impdance, so parallel admittances add) . If the slots are also resonant, then they appear resistive and simple addition determines the input impedance 1/Y , and each slot receives the same amount of power. It should be apparent each individual admittances should Y/(# of slots) and add up to the characteristic admittance of the waveguide (NOT 50Ω). Some folks have gotten confused on this point and tried to adjust the slot offset so that the first slot gets less power so the rest flows further, with poor results.

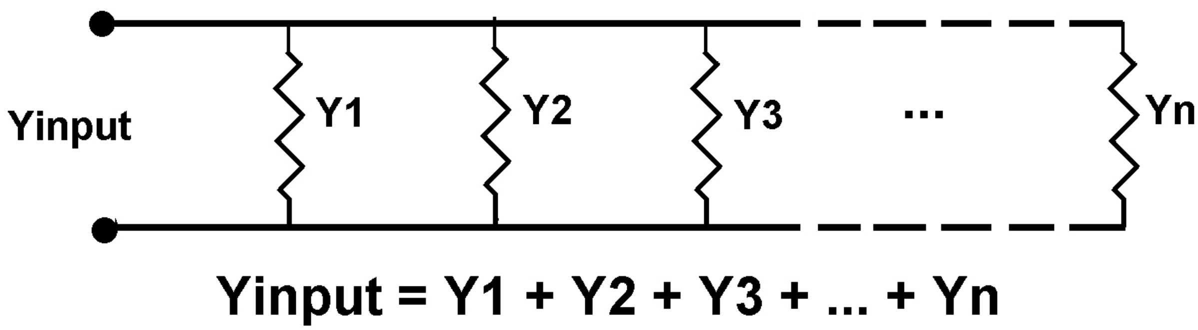

Figure 15 – Equivalent circuit of waveguide slot antenna with resonant slots spaced ½ λ

The slot electrical spacing may also be changed by filling the waveguide with dielectric, increasing the electrical spacing and producing uptilt. But the admittances will no longer be in phase so we end up with a mismatched complex impedance at the input.

Why Do Antenna Range Measurements Appear to Point Downward?

Almost all ham antenna ranges are ground reflection ranges. We would like to do antenna measurement between two high points, with no obstructions or reflections, but this is rarely possible; certainly not in a parking lot at a conference or hamfest. A ground reflection range, shown in Figure 16, has two signal paths – direct and reflected from the ground. If the source antenna height is chosen correctly, the two signals will add in phase at the height of the AUT, the Antenna Under Test. The apparent source point of the combined signals will be halfway between the source and the image, or at ground level. Thus, the beam of the AUT appears to be pointing down.

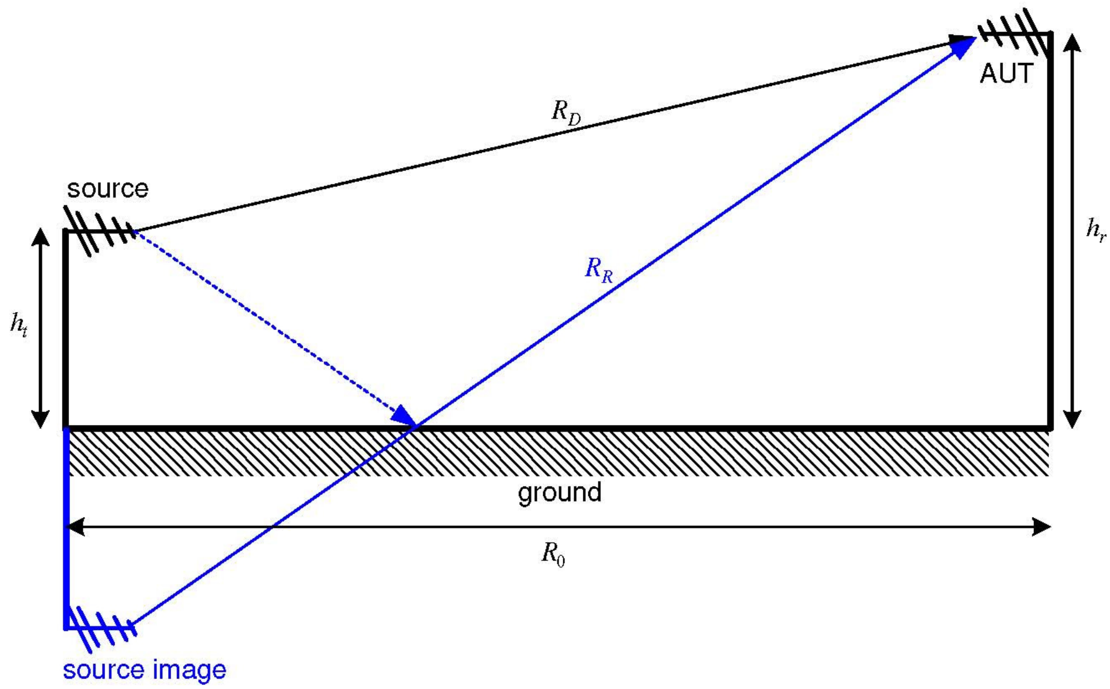

Figure 16 – Sketch of ground reflection antenna range.

This beam tilt is not very obvious for a well-designed range. Range calculations are easily made by the HDL_ANT program[3] (For instance, a range long enough for a 2-foot dish at 10 GHz, about 85 feet, for an AUT height of 6 feet, would have a source antenna height of about 4 inches. It would be very hard to differentiate between the source height and the ground level, a difference of less than one degree.

A much higher source antenna, perhaps 4 feet high, might put the image signal in the first null of the pattern of a dish, so that the direct path would dominate. But a lower gain antenna with a broader pattern would receive both signals and the signal would appear to come from ground level. For a small horn, the tilt angle is not obvious, but a waveguide slot antenna, with a clear vertical reference, would have an obvious tilt. Finally, an offset dish has no clear horizontal or vertical reference, so tilt is not obvious by eye.

Slot Antenna VSWR and Tuning

Many waveguide slot antennas include three tuning screws. It is not clear to me how anyone can tune one without producing enough reflections to change the VSWR significantly. I tried raising the slot antenna above the surroundings with some waveguide, shown in Figure 17 and measuring with a VNA, but I am not able to do a proper waveguide calibration, so results were unsatisfactory.

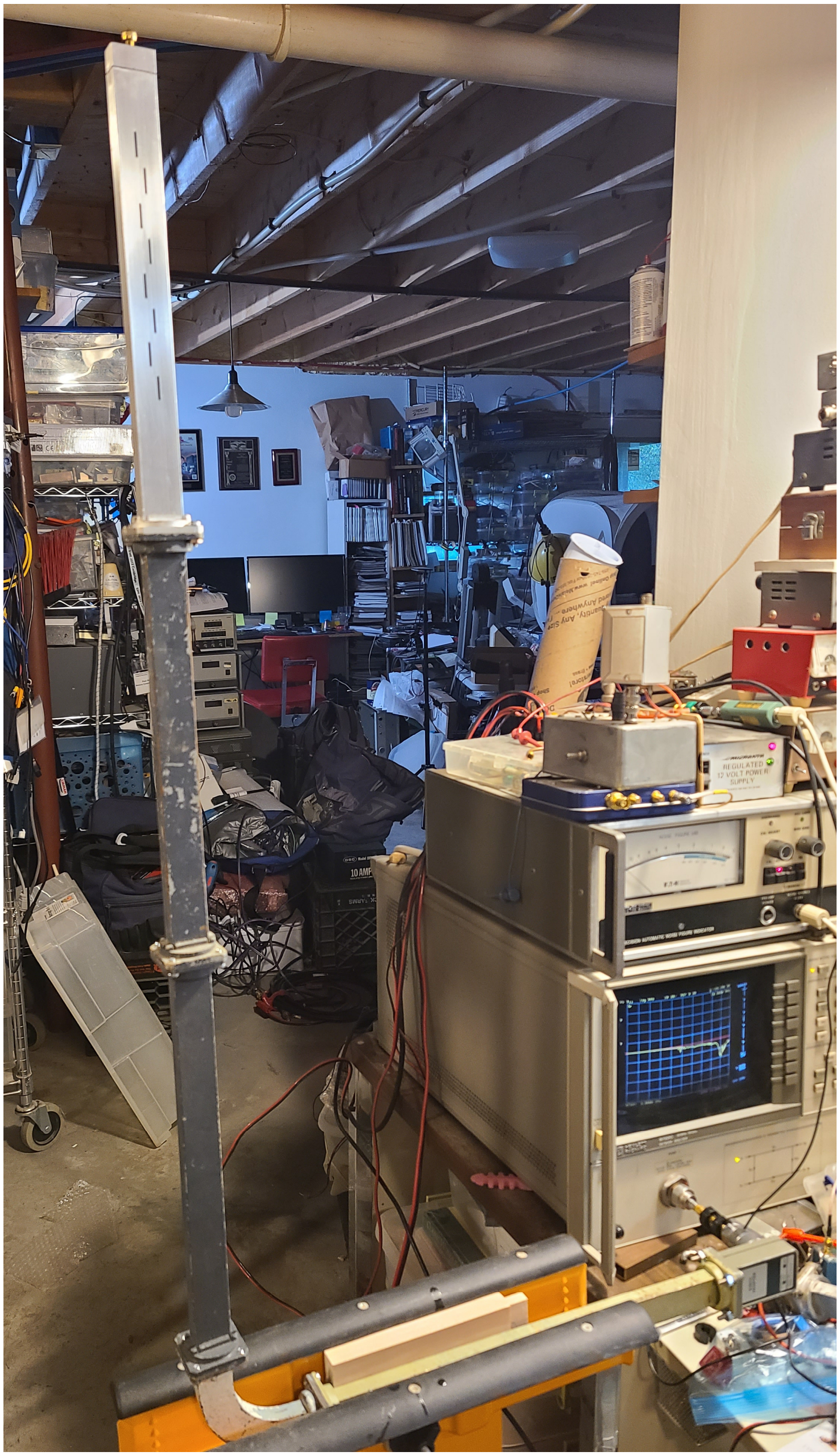

Figure 17 – Elevating the slot antenna high enough to tune

I resorted to the surplus waveguide directional coupler in Figure 18, known to have extremely high directivity, to measure the VSWR. Most 10 GHz coaxial directional couplers have directivity of 15 to 20dB, so any VSWR measurement < 2:1 will have significant error[4] and make tuning meaningless.

For instance, a directivity of 20 dB means that leakage is 20 dB down, so a perfect load will measure 20 dB Return Loss (VSWR 1.22). A reading of better than 20 dB RL means that the reflected power is out of phase with the leakage – you are tuning the coupler and the waveguide transition, not the antenna. For an antenna with VSWR of 1.5, the measured return loss with a directional coupler with directivity of 20 dB can be anywhere between 10.5 dB and 20.2 dB (VSWR 1.22 to 1.86).

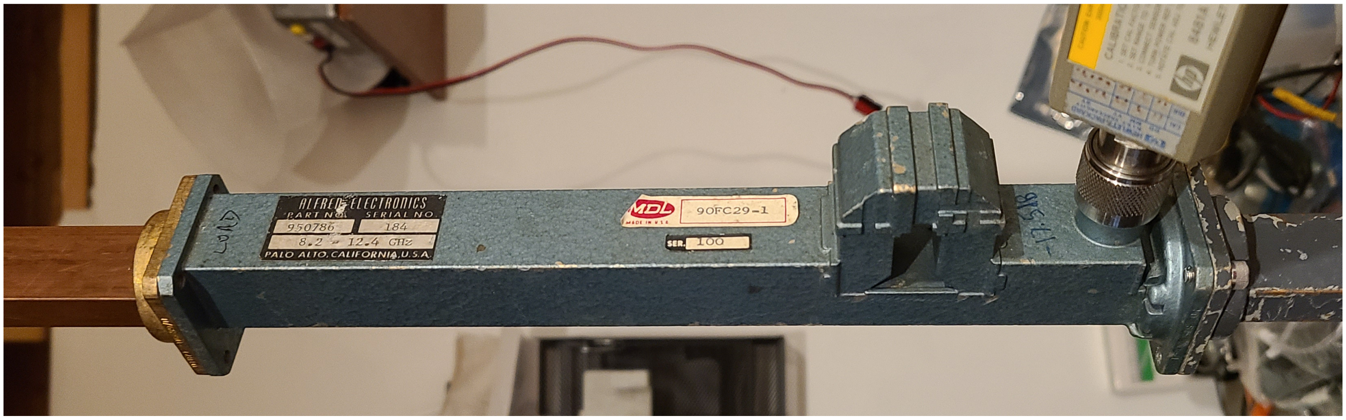

Figure 18 – Alfred Electronics X-band directional coupler with high directivity

Another good waveguide directional coupler that you are more likely to find surplus is the HP X752 series, shown in Figure 19.   I just found this one at a hamfest. It is specified (and individually swept by HP) at better than 40 dB directivity, resulting in a RL error of less than 1 dB for any reasonable value.

Other waveguide coupler configurations usually have lower directivity.

Figure 19 – HP X752c waveguide directional coupler with high directivity

If the waveguide slot antenna dimensions are reasonably accurate, the VSWR will be less than 1.5:1 over a good bandwidth. Adding a waterproofing housing will probably change the VSWR. Unless it can be mounted in a very clear location, the surroundings will also have an effect. My suggestion is to leave out the tuning screws, put the antenna up, and get it on the air.

Summary

If the slot antenna is made using the spreadsheet in Note 2, it will work as expected with no elevation pattern tilt. The VSWR at the waveguide input will be better than the measurement uncertainty, so leave out the tuning screws. Just put it on the air.

Notes

1. https://antennatestlab.com/
2. https://www.w1ghz.org/software/slotantenna.xls
3. https://www.w1ghz.org/software/HDL_ANT2_Winforms.zip
4. Marki Microwave, "Directivity and VSWR Measurements," https://markimicrowave.com/technical-resources/white-papers/directivity-vswr-measurements/