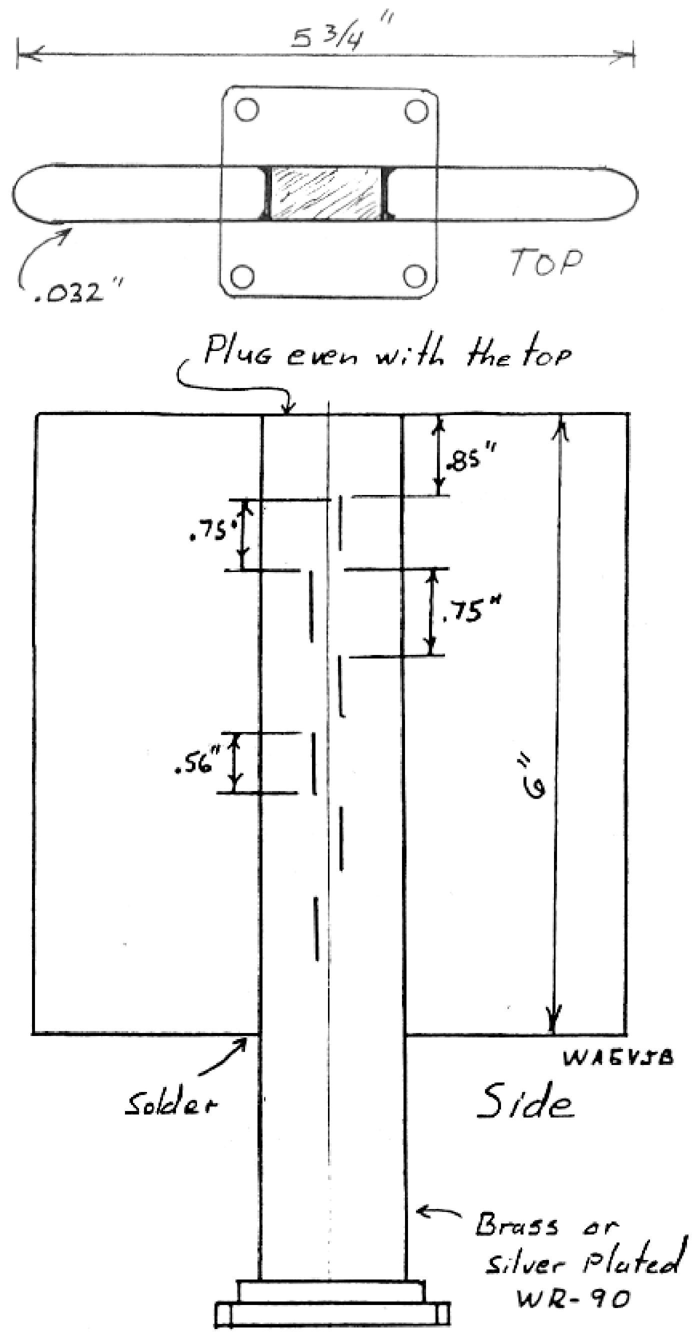
7.2.7 Performance Enhancements

The antenna patterns we saw in Figures 7-8 and 7-9 are not really good omnidirectional antennas, with significant variation in gain in different directions — as much as 10 dB. Furthermore, the elevation plots show significant sidelobes at high angles, wasting energy into space. As the number of slots increases, the number and magnitude of lobes will increase also.

We previously saw how improved dimensional calculations may improve the VSWR of a waveguide slot antenna. Is it possible to also improve the radiation patterns for better performance?

K5SXK and WA5VJB[10] added "wings" to the waveguide for a more even azimuth pattern. A sketch of the wings is shown in Figure 7-10. The dimensions aren't critical; Harold, K5SXK, explained to me that the wings enlarge the ground plane for the slots and reduce the amount of energy that wraps around the waveguide. The larger the wings, the better they work. The wings in Figure 7-10 extend for roughly two wavelengths on each side and seem to work pretty well. The azimuth pattern calculated using the Zeland Fidelity[7] software, in Figure 7-11, shows only about 4 dB variation in gain in different directions, matching pretty well with the data measured by K5SXK and WA5VJB. The elevation patterns are about the same as the antenna without wings, so the wings only affect the azimuth pattern.



Waveguide slot antenna with "wings"
Figure 7-10

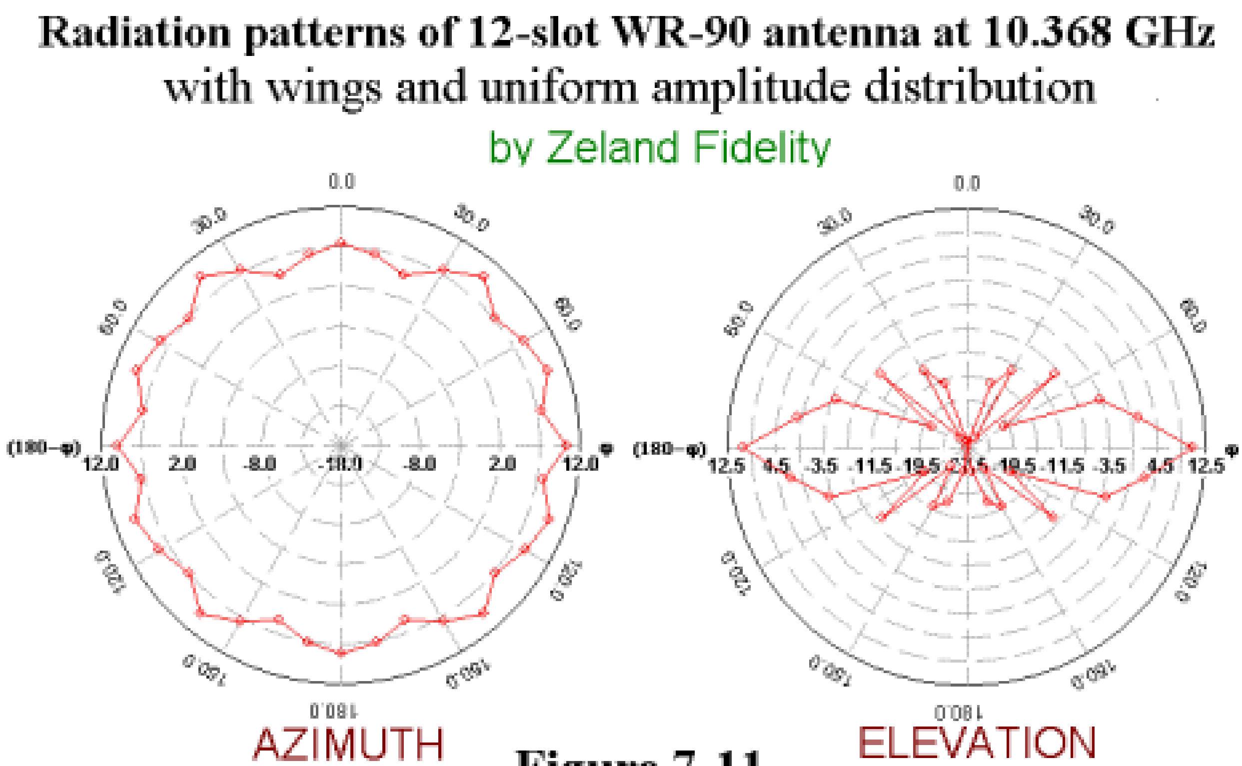


Figure 7-11

An alternative wing construction adds a single thin plate on each edge of the waveguide. Figure 7-12 is a photo of a 24 GHz slot antenna by PA∅EHG[19]. I have no data on how well this construction works.

The large slot spacing in the array causes the high sidelobe levels in the elevation patterns in Figures 7-8 and 7-9. Since the slot spacing is fixed at $1/2\lambda_g$ (in the waveguide), it must be greater than $1/2\lambda_0$ in free space, and we can't improve the pattern by reducing the spacing. An alternative method of pattern shaping for antenna arrays is to vary the amplitude at each element in the array. The desired amplitude taper distributes more power to the center elements and less toward the ends of the array. T. T. Taylor described[20,21] a technique for calculating the array amplitudes for any desired sidelobe level. Since the amplitude at each slot is controlled by the displacement of that slot from the centerline, we can simply calculate a displacement from the waveguide centerline for each slot individually to arrive at the desired amplitude distribution.

I modified the previous computer model, for a twelve-slot antenna, from constant slot displacement for uniform amplitude distribution, to a tapered slot displacement providing a Taylor distribution of amplitude designed to have all sidelobes at least 20 dB down. With six slots on each side, the two end slots receive 5.1 dB less power than the center two slots, and the two intermediate slots are 2.2 dB down from the center. The resulting elevation pattern in Figure 7-13, calculated using Zeland Fidelity, shows sidelobes significantly reduced from Figure 7-10; the azimuth pattern was unchanged. An added benefit to the Taylor distribution is a broader main elevation lobe with only 0.1 dB reduction in gain.

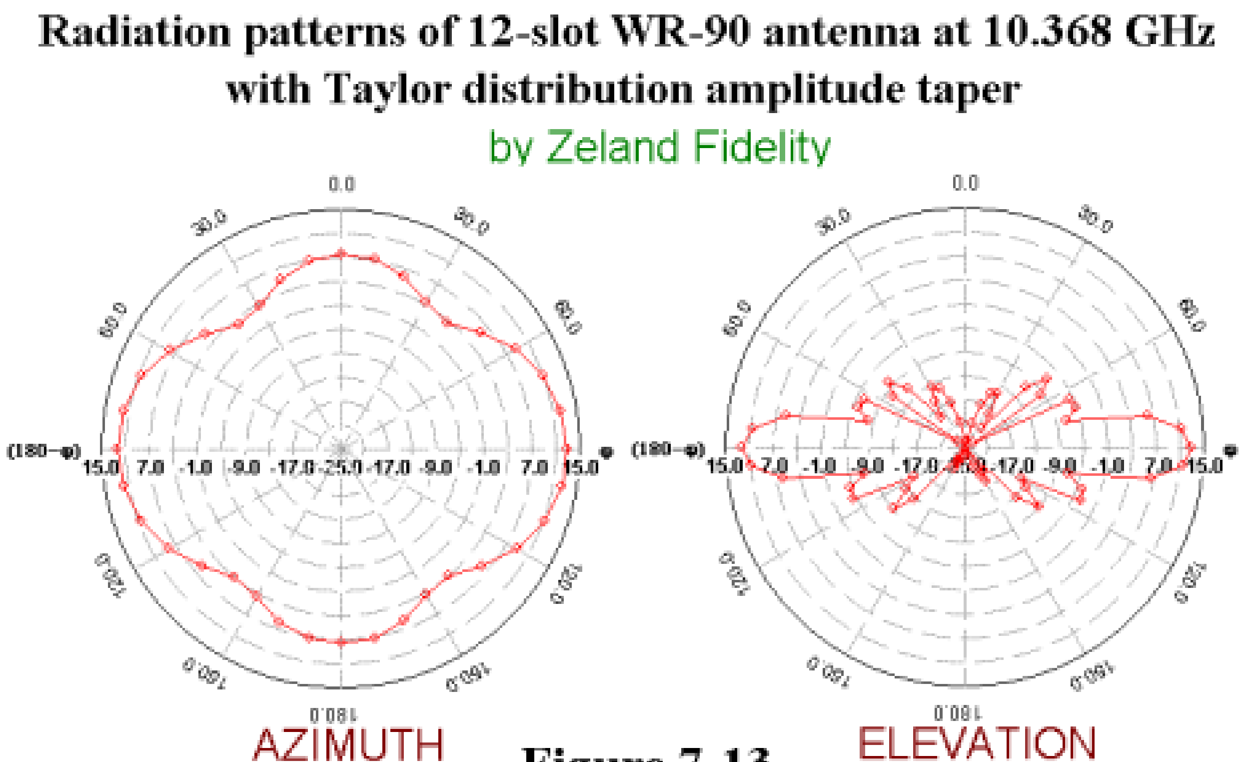


Figure 7-13

The amplitude levels and slot admittances required for a 20 dB Taylor distribution are shown in Table 7-1. Working from this table, a slot displacement and slot length must be calculated for each admittance in the table. The calculation may be made using the **slotantenna.xls** spreadsheet: enter an admittance from the table as the quantity **"Gslot"** in the box highlighted in magenta and record the resultant slot displacement and resonant length. This change will over-write the formula in the box, so make a backup copy of the spreadsheet first.

A Taylor distribution may be calculated for any desired maximum sidelobe level, so we have good control of the elevation pattern. Other distributions are also available, with different attributes; the Dolph-Chebyshev[21] distribution is also frequently used in array antennas.

Waveguide slot antenna with 20 dB Taylor distribution

Table 7-1

A: Relative amplitude at each slot

SLOT #	8slots	12 slots	16 slots	20 slots	24 slots	32 slots	*total*
1	-4.4	-5.1	-5.4	-5.5	-8.1	-5.6	dB
2	0.0	-2.2	-3.4	-4.2	-6.7	-5.1	dB
3	0.0	0.0	-1.3	-2.3	-4.5	-4.1	dB
4	-4.4	0.0	0.0	-0.8	-2.4	-2.9	dB
5		-2.2	0.0	0.0	-0.8	-1.8	dB
6		-5.1	-1.3	0.0	0.0	-1.0	dB
7			-3.4	-0.8	0.0	-0.3	dB
8			-5.4	-2.3	-0.8	0.0	dB
9				-4.2	-2.4	0.0	dB
10				-5.5	-4.5	-0.3	dB
11					-6.7	-1.0	dB
12					-8.1	-1.8	dB
13						-2.9	dB
14						-4.1	dB
15						-5.1	dB
16						-5.6	dB

B: Gslot for each slot for above amplitude

1	0.0943	0.0594	0.0437	0.0346	0.0287	0.0214
2	0.1557	0.0833	0.0547	0.0405	0.0322	0.0229
3	0.1557	0.1073	0.0703	0.0500	0.0382	0.0257
4	0.0943	0.1073	0.0813	0.0595	0.0451	0.0293
5		0.0833	0.0813	0.0654	0.0511	0.0332
6		0.0594	0.0703	0.0654	0.0546	0.0368
7			0.0547	0.0595	0.0546	0.0396
8			0.0437	0.0500	0.0511	0.0411
9				0.0405	0.0451	0.0411
10				0.0346	0.0382	0.0396
11					0.0322	0.0368
12					0.0287	0.0332
13						0.0293
14						0.0257
15						0.0229
16						0.0214

In the azimuth plane, only the wings affect the radiation pattern; the Taylor distribution pattern is identical to the original. Similarly, only the elevation pattern is different for the Taylor distribution. The two enhancements appear to independently affect the azimuth and elevation patterns, respectively. Figure 7-14 plots all three patterns together for comparison.

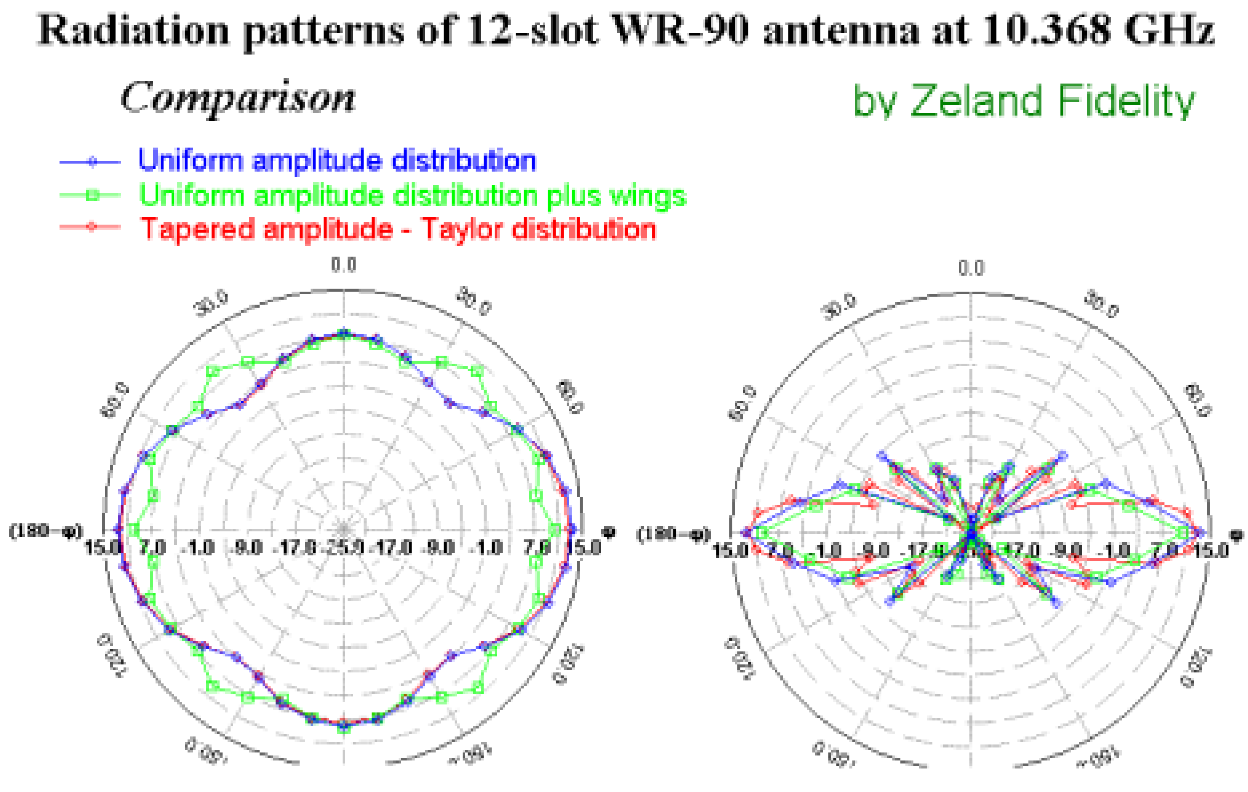


Figure 7-14

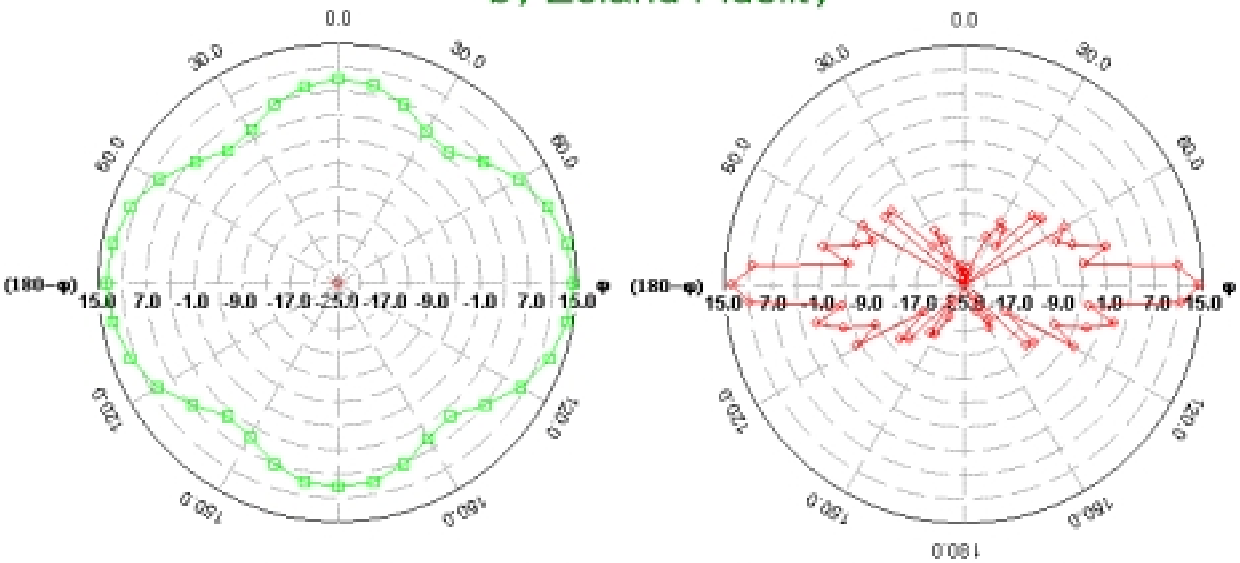
A close look at Figures 7-13 and 7-14 reveals that the elevation pattern for the 12-slot antenna with tapered distribution has first sidelobes that are only about 14 dB down, better than the uniform distribution but not as good as the expected 20 dB. I reviewed some simple calculated elevation patterns and saw that the Taylor distribution only provided good sidelobe reduction with an array length of eight or more, or a waveguide slot antenna with 16 or more slots (at least 8 on each side). A 16-slot antenna should meet the design goal of having all elevation sidelobes at least 20 dB down.

To see how good a slot antenna we can design, I made computer models for two 16-slot antennas in WR-90 waveguide: a plain one with uniform slot displacement, and an enhanced one with both wings and tapered slot displacements. The displacements were calculated for a 20 dB Taylor distribution using Table 7-1. For each model, I calculated radiation patterns using Zeland Fidelity[7] software.

The plain 16-slot antenna has patterns in Figure 7-15 similar to the 12-slot antenna patterns in Figure 7-9, with large elevation sidelobes and amplitude varying by 10 dB around the azimuth. The gain is about 3 dB higher than the 12-slot.

Radiation patterns of 16-slot WR-90 Antenna at 10.368 GHz with uniform amplitude distribution

by Zeland Fidelity

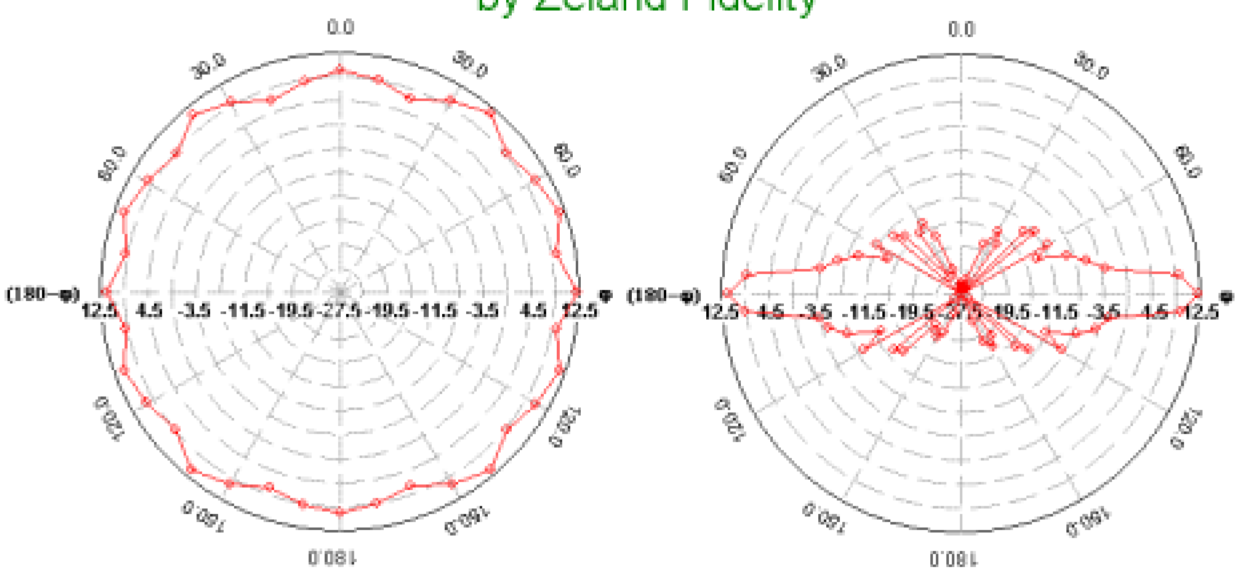


AZIMUTH **Figure 7-15** ELEVATION

The enhanced 16-slot antenna shows improved patterns in Figure 7-16. The elevation sidelobes are at least 20 dB down, exactly as designed, and the azimuth is also more uniform, with only about 5 dB of variation. The price for azimuth uniformity is a small decrease in peak gain — we have lowered the peaks and filled the valleys, to make the antenna more omnidirectional.

Radiation patterns of 16-slot WR-90 Antenna at 10.368 GHz with wings and Taylor amplitude taper

by Zeland Fidelity



AZIMUTH **Figure 7-16** ELEVATION

The final result of our enhancements is a better antenna, with improved patterns in both azimuth and elevation. We can see a direct comparison in Figure 7-17, which includes radiation patterns for the plain 16-slot antenna, a 16-slot antenna with amplitude taper using the Taylor distribution, and a 16-slot antenna with both amplitude taper and wings. The cost for these enhancements is a bit of additional complexity in calculating the dimensions, a few more dimensions to measure during construction, and the addition of the wings.

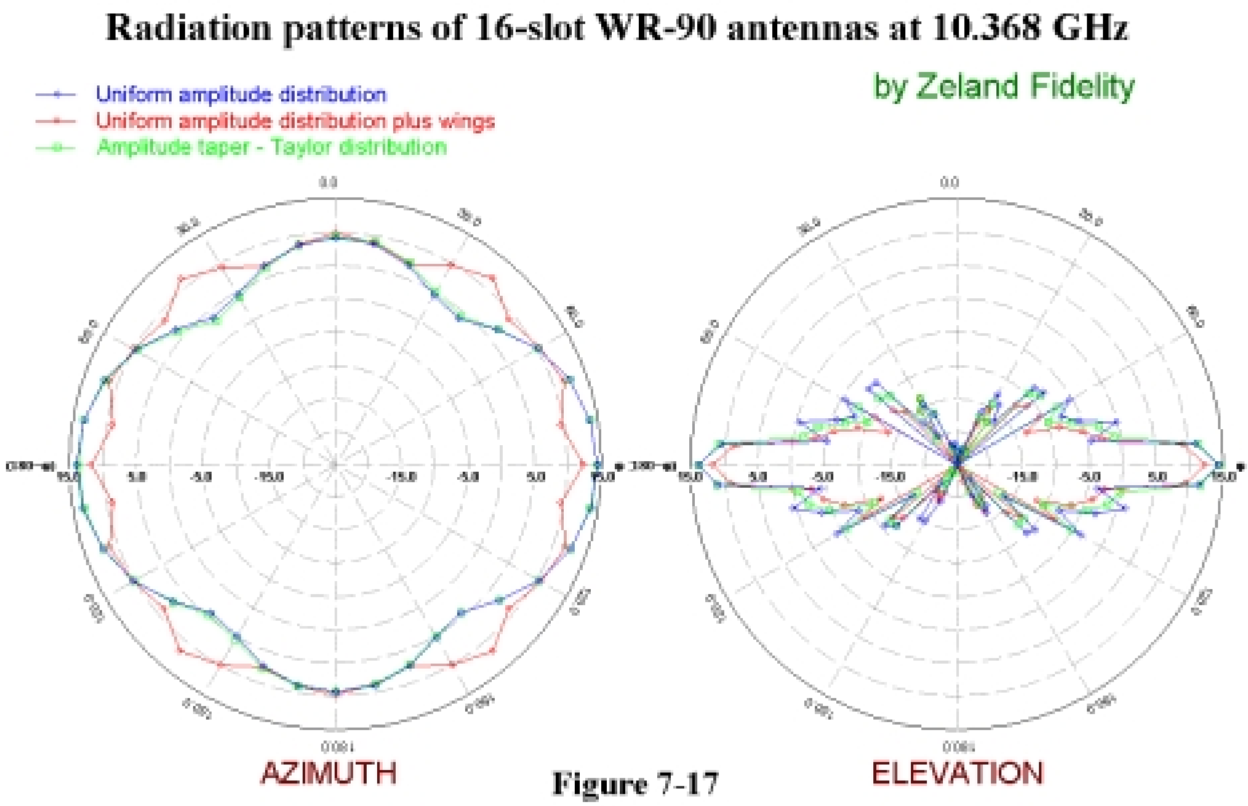


Figure 7-17

The difference in dimensions between the plain and enhanced slot antennas can be seen in dimensioned templates for the two antennas. Figure 7-18 is the template for a plain 16-slot WR-90 antenna for 10.368 GHz, while Figure 7-19 is the template for the same antenna enhanced with amplitude taper using the Taylor distribution. Wings like Figure 7-10 may be added to either version. The dimensions in the second template may be used as to check the calculation procedure before attempting to enhance other slot antennas.

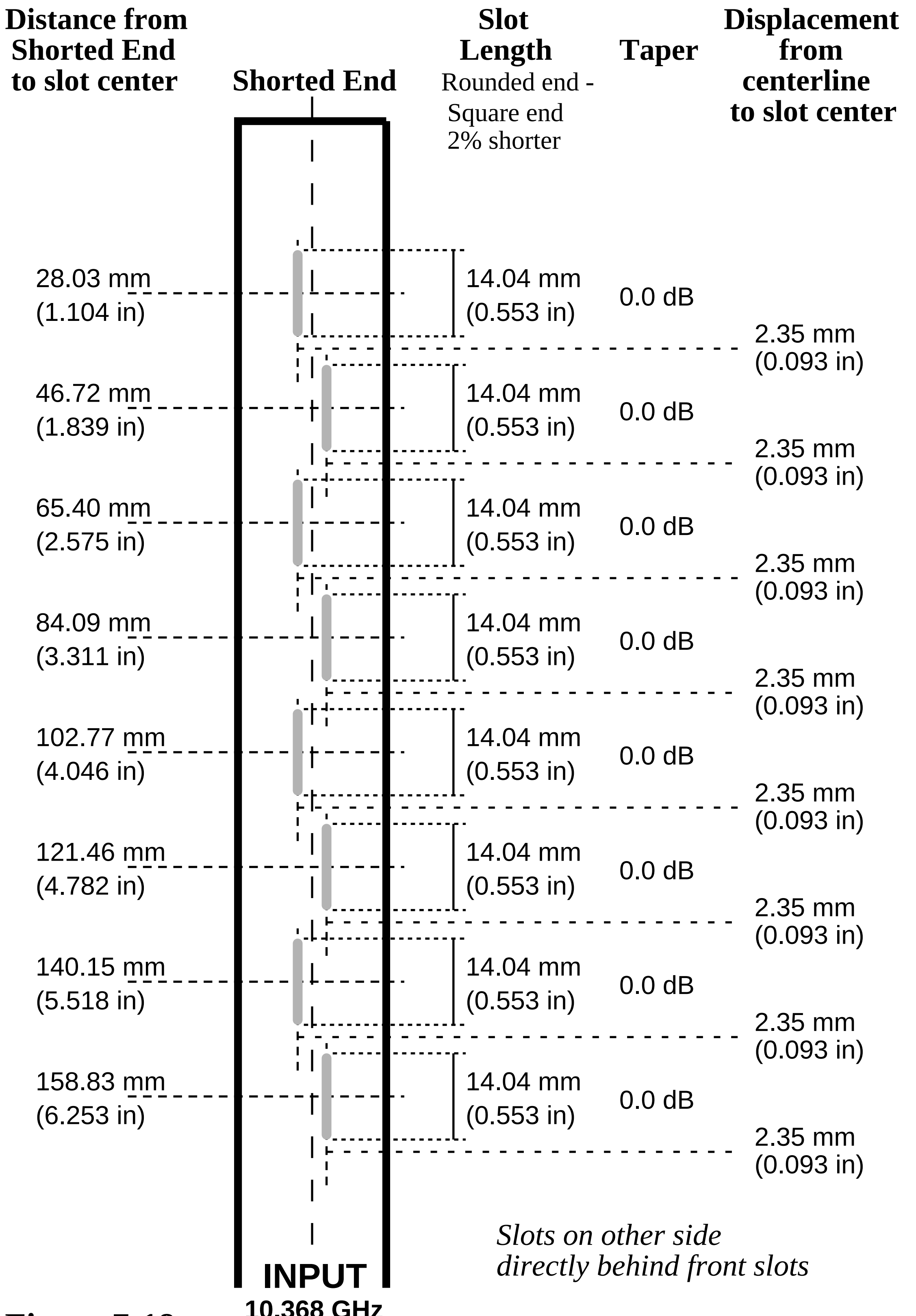


Figure 7-18

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WR-90 Waveguide 16-slot Antenna with Uniform Distribution

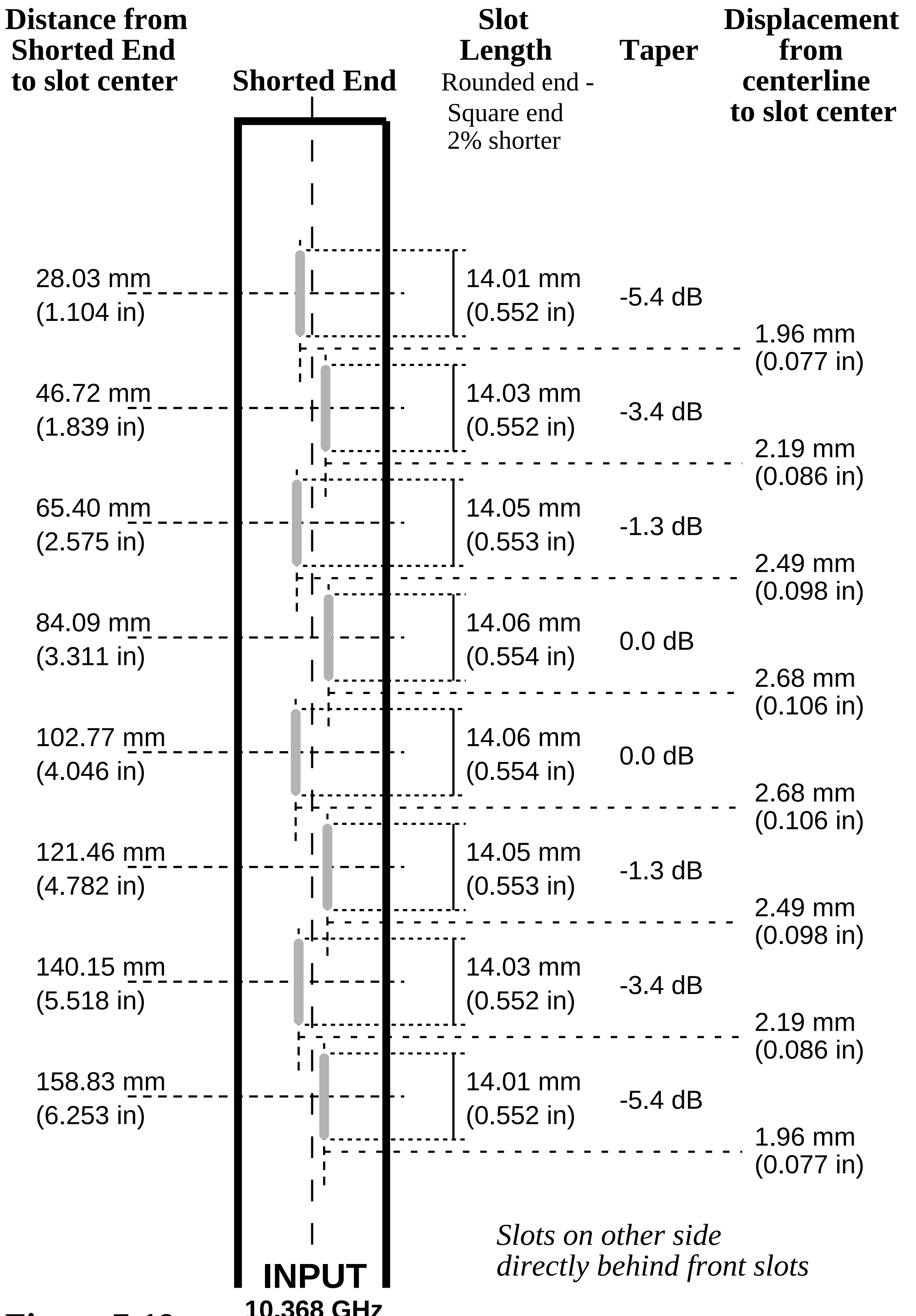

Figure 7-19

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WR-90 Waveguide 16-slot Antenna with Tapered Distribution