7.2.8 Frequency sensitivity

To evaluate the effect of frequency error on the antenna performance, I also calculated the radiation patterns for the 16-slot antenna at 9.0 GHz and 11.736 GHz. The resulting elevation patterns are shown in Figure 7-21: both have a null on the horizon, with the main lobes tilted both upward and downward. Clearly, a frequency error this large makes the antenna nearly useless.

Since the frequency difference is enough that the antenna can no longer be considered resonant, we may analyze it as a phased-array with a traveling-wave feed. Working from Elliott[22], we find that the beam will be tilted at an angle of:

$$\Theta = \arcsin\left[\left(\frac{slotspacing}{\lambda_g} - 0.5\right) \bullet \frac{\lambda_0}{slotspacing}\right]$$

from horizontal. At the resonant frequency, where the *slotspacing* = λ_g, the calculated $\theta = 0^{\circ}$, just as we expect.

The calculated tilt angles for the other frequencies in Figure 7-21 are 12° below horizontal at 9.0 GHz and 8° above horizontal at 11.736, which correlate well with the elevation patterns. The second, slightly weaker, lobe is the beam from the reflected wave traveling in the other direction. Since the slots are no longer resonant, they are not well matched, so a significant amount of the energy in the guide will not be absorbed by the slots and will reach the shorted end, to be reflected back in the other direction. Part of the reflected energy will then be absorbed by the slots to create the downward beam, as the combination of forward and reflected waves at each slot add with different phases. Each slot then radiates with a different phase resulting in a combined elevation pattern with two major lobes.

If the frequency difference were smaller than the ~13% in Figure 7-21, not only would the tilt angle would be smaller, but the slots would be better matched, reducing the reflected power so that the second lobe would be smaller than the main lobe. However, I don’t see any obvious amateur application for beam tilt – we want our beacons to reach the horizon, and beyond. A common use for beam tilt is in TV broadcasting, to provide a very strong signal in the area surrounding a very high antenna.

If a tilted beam were really desired, then the slots and displacement should be calculated for the operating frequency, but the slot spacing adjusted using the above equation to realize the desired tilt angle. The change in spacing from a half-wavelength causes a new impedance mismatch which will generate a smaller second beam, so further calculations might be needed if the tilt angle is significant.

Waveguide Slot Antenna Performance vs. Frequency

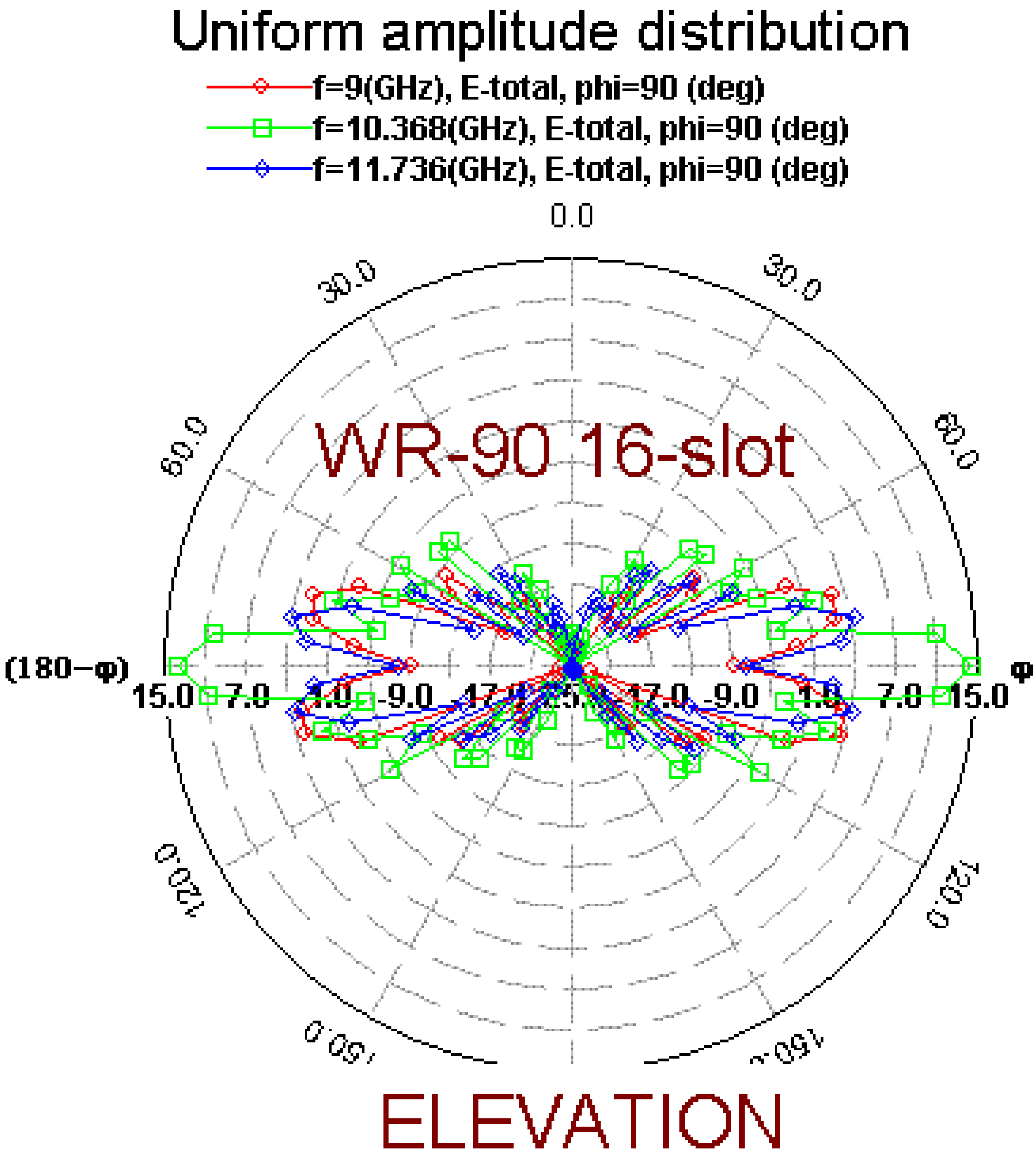


Figure 7-21

7.2.9 Waveguide size

For most amateur bands, there are three usable sizes of standard waveguide: a small one where the ham band is near the low end of the waveguide recommended frequency range, a large one where the ham band is near the high end of the range, and an intermediate one where the ham band is near the center of the range. At 10.368 GHz, these sizes are WR-75, WR-112, and WR-90, respectively.

When we calculated slot dimensions, we found that they were most critical for the smaller size waveguide, so that the larger size would be preferable from a construction standpoint. To make sure this was also true for performance, I made computer models for 16-slot antennas in WR-75 and WR-112 waveguide to compare to the WR-90 results in Figures 7-15 and 7-16. With perfect dimensions, the calculated WR-75 antenna patterns shown in Figure 7-22, with uniform amplitude distribution, are similar to the WR-90 results in Figure 7-16, except for the slightly larger elevation sidelobes that we would expect due to larger slot spacing. Similarly, Figure 7-23, with a Taylor-distribution amplitude taper, compares well with the WR-90 pattern in Figure 7-16.

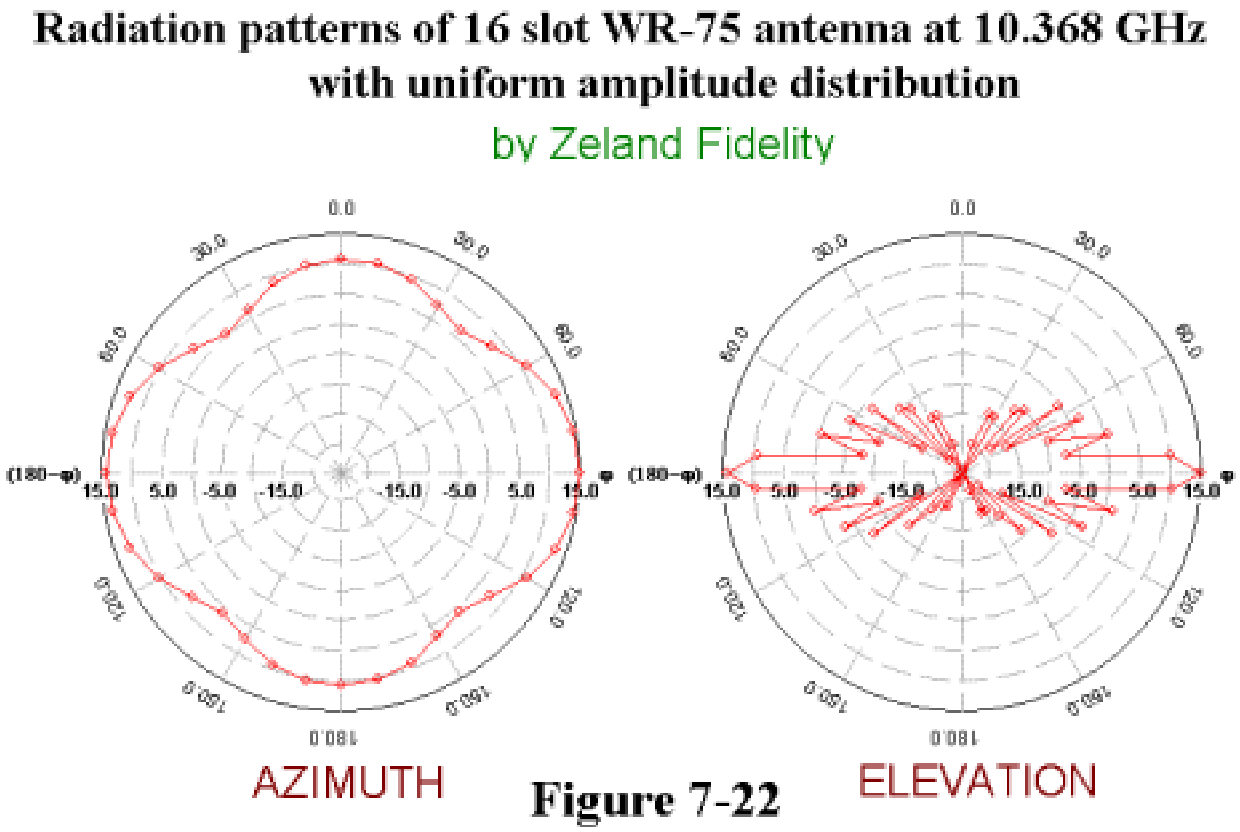
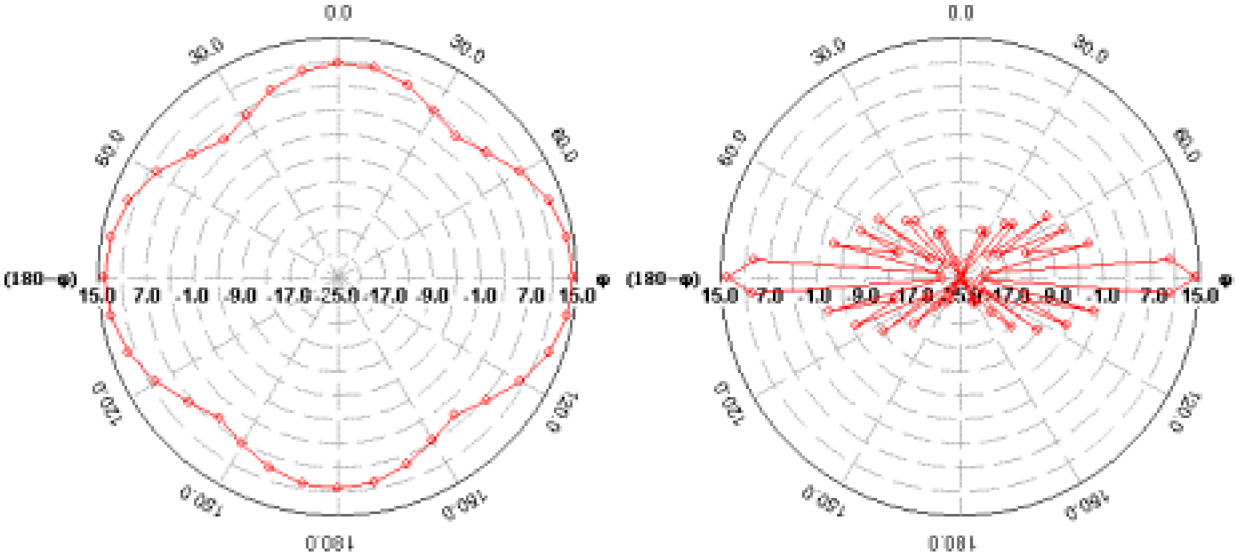

Radiation patterns of 16 slot WR-75 antenna at 10.368 GHz
with uniform amplitude distribution
by Zeland Fidelity

Figure 7-22

Radiation patterns of 16 slot WR-75 antenna at 10.368 GHz with Taylor distribution amplitude taper

by Zeland Fidelity



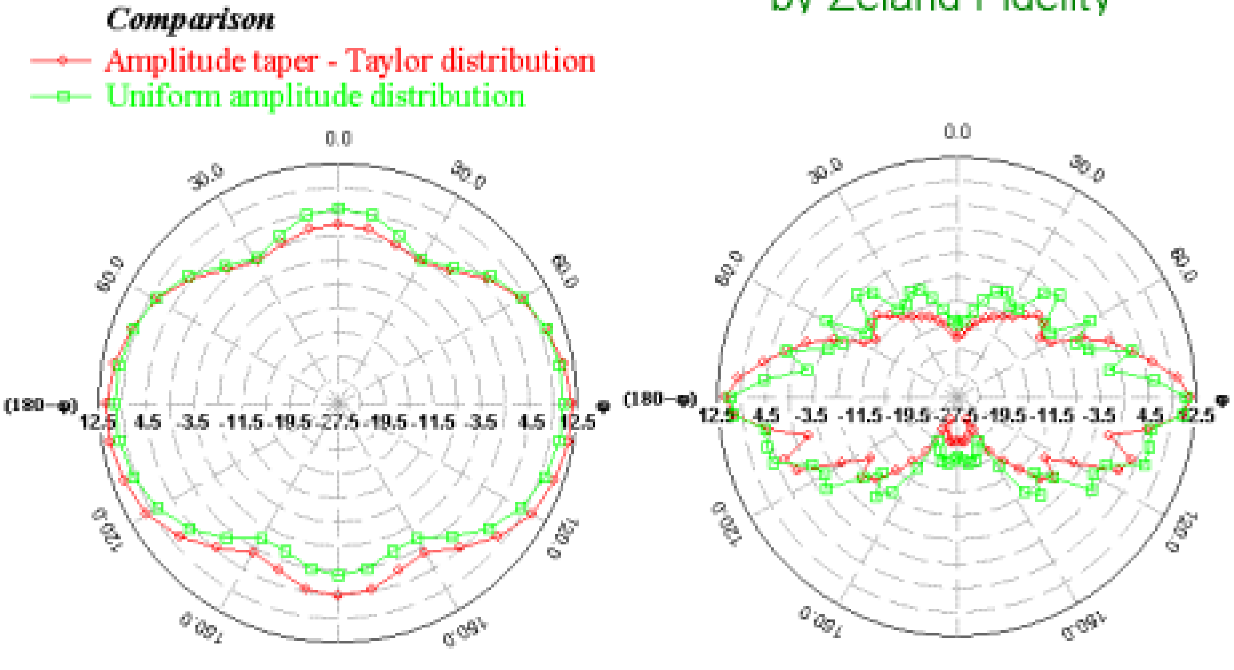
AZIMUTH

ELEVATION

Figure 7-23

Radiation patterns of 16 slot WR-112 antennas at 10.368 GHz

by Zeland Fidelity



AZIMUTH

ELEVATION

Figure 7-24

However, the WR-112 calculated antenna patterns are somewhat distorted, as shown in Figure 7-24. The elevation patterns have large excess sidelobes, particularly below the horizontal plane, while the azimuth pattern also displays some assymetries. The three waveguide sizes are compared in Figure 7-25, showing the radiation patterns for 16-slot antennas with uniform amplitude taper. The WR-75 and WR-90 patterns are very similar, while the poor elevation patterns and unwanted azimuth directivity of the WR-112 patterns suffer in comparison.

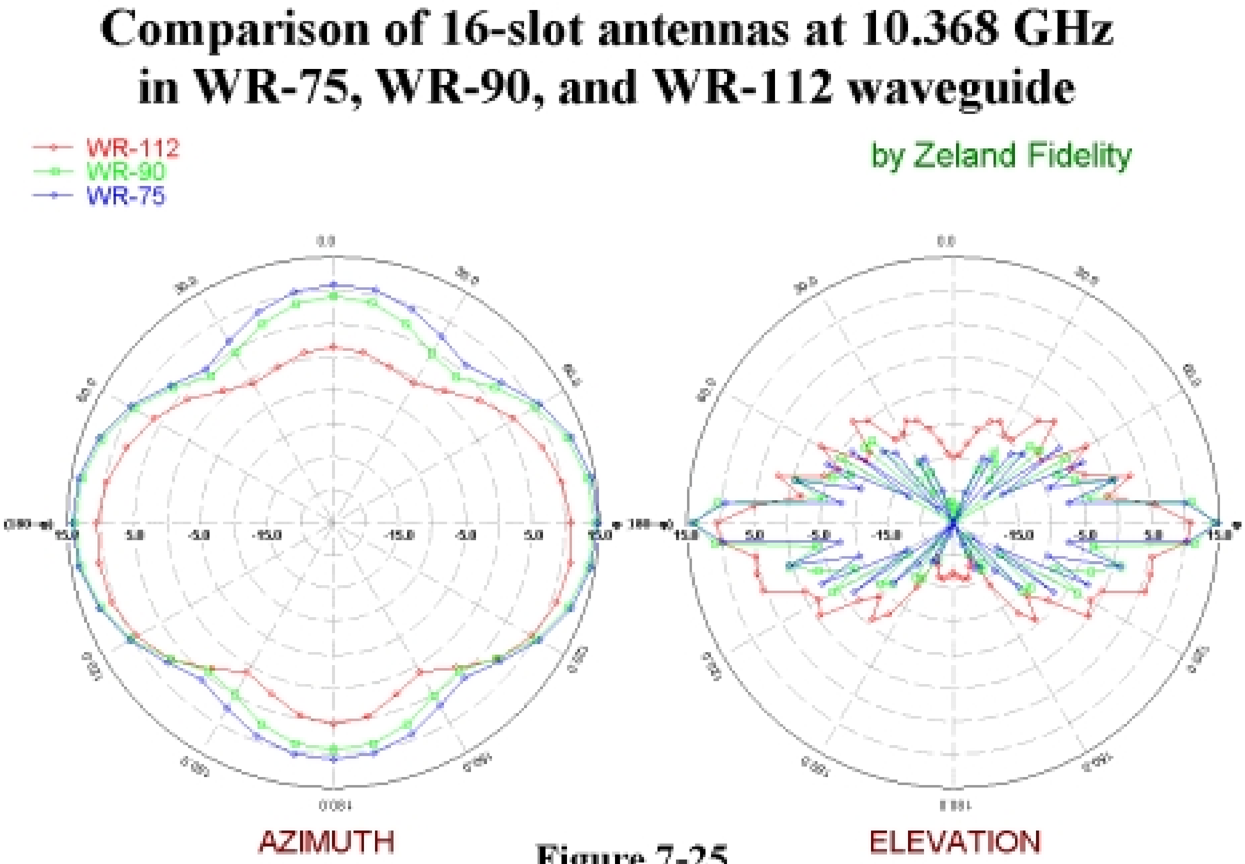


Figure 7-25

My hypothesis for the cause of the distortion in the large waveguide is that higher-order waveguide modes are excited at each slot. In the smaller waveguide, they are well beyond cutoff and so are rapidly attenuated before they reach the next slot. In the large waveguide, on the other hand, the higher-order modes are not attenuated as fast, and the slots are closer together, so some of the energy in the undesired mode may reach the next slot. Since different modes travel at different phase velocities, the undesired energy would have different phase and distort the pattern. A second problem, probably affecting the azimuth pattern, is that the large slot displacement from the centerline is a significant part of a wavelength, so that the array of slots no longer appears as a single vertical column, but rather two columns with a phase difference.

Whatever the cause, the bottom line is that of three usable waveguide sizes for any given frequency, the smaller two are more likely to have predictable performance with perfect dimensions. Since the smallest size will have the most critical dimensional tolerances, we are most likely to get good results by constructing an antenna in the middle size waveguide, or WR-90 for 10 GHz.

The ideal omnidirectional waveguide slot antenna design would include all the elements we have seen thus far:

1. Use the standard waveguide size with the design frequency near the center of the recommended frequency range for the guide.
2. Minimize sidelobes in the elevation pattern with a Taylor distribution, achieved by tapering the slot displacement.
3. Add large wings to make the azimuth pattern more uniform.
4. Calculate dimensions with Elliott's improvements, using **slotantenna.xls** spreadsheet.

At 10.368 GHz, the best waveguide size would be WR-90.

7.210 Construction of waveguide slot antenna

The ideal tool for cutting slots in waveguide is a milling machine — a large, formidable piece of machinery. Most of us don't have one in the basement or garage. A milling machine is probably necessary to produce any quantity of slot antennas. However, if you are making just one or two, it is probably just as fast to do it by hand.

The basic procedure for hand construction is straightforward: mark out the outlines of the slot locations carefully, drill of row of slightly undersize holes in each slot location, and file out the slots to the outline. Small random errors will tend to average out and not affect performance – they might even smooth out the peaks and valleys in the azimuth pattern.

Most waveguide is made of brass or aluminum, materials that are easy to work. Waveguide has also been made from copper, plated steel, and pure silver. All are more difficult to machine or file; the first two might be better put to other uses, and the latter should be sent to W1GHZ.

The final step in construction is to solder on a short-circuit for the closed end and a waveguide flange on the input end. For brass waveguides, flux and a hot torch will do the job. Soldering aluminum is much more difficult, and I have never been happy with the results — special materials and techniques are required, and the water-resistance of the final joint is questionable.

At the lower microwave frequencies, real waveguide is hard to find, but rectangular aluminum extrusions intended for structural purposes may be used. K6LEW used some 4 x 1.5 inch aluminum extrusion stock as waveguide for a 2304 MHz slot antenna. For an even larger version at 23 cm, F4DAY and F9YA[23] sawed off one wall of a rectangular extrusion and taped two pieces together with aluminum tape to form a wider rectangle. The completed antenna, shown in Figure 7-26, is nearly as tall as Gerard. While it appears that he used hand tools, a woodworking router could also be used to quickly cut the large slots in soft aluminum.

Figure 7-26

7.2.11 Weatherproofing

Weatherproofing is a problem for all antennas, but the open slots can easily fill the waveguide with water or insects. One approach that has been used successfully is to cover the slots with a thin tape of low-loss material, like kapton or mylar. The tape must be thin — a thick dielectric will change the resonant frequency of the slots and raise the VSWR, so check the VSWR change when adding tape. Ultraviolet radiation from sunlight will deteriorate the tape over time, so it must be replaced periodically.

Another approach is to enclose the slot antenna in a plastic tube. I can't recommend any particular type, so some experimentation is needed here. Again, if the enclosure changes the VSWR significantly, it is probably affecting the performance as well.

WA5VJB suggested a third approach – mount the antenna upside-down, fed from the top, so that water drains out. This probably works well in climates where water doesn't freeze and ice is only found in a glass! The short circuit, now at the bottom, need not seal the whole waveguide; in Figure 7-4, the very little electric field reaches the side walls, so the short circuit can be a wide strap across the center of the guide. The open corners will make little difference and allow water to drain out.

Of course, we would like a beacon antenna to still work during a gullywasher; heavy rain can provide excellent rain-scatter propagation but could fill the antenna with flowing water. Some sort of open radome over the upside-down slot might be a winning combination.

7.3 Two-dimensional waveguide slot arrays

A two-dimensional array of slots would have a narrowed beam in both azimuth and elevation, so it is a directional antenna. As such, it makes little sense to have slots on both sides of the waveguide. The equivalent dipole antenna is the old "extended-expanded collinear" by Oliver Wright, W6GD[24].

A surplus slot antenna is shown in Figure 7-27, an array of 14 by 14 slots with the corners missing, for a total of 156 slots. From the slot dimensions, I estimate the operating frequency as about 9.2 GHz; the input VSWR is best near this frequency, with fairly narrow bandwidth. As we saw in section 7.2.8, it is likely that the bandwidth for good performance is also narrow. Moving the freqency would require changes to both slot length and spacing, so modification of this surplus antenna to 10 GHz is impractical.

The array is fed by WR-90 waveguide, but the array is constructed of half-height waveguide, which decreases the slot displacement and makes dimensions more critical. The guides are formed by brazing thin walls between two thin sheets of aluminum, with the slots in the top sheet, so that the whole antenna only weighs about 500 grams, or just over a pound. With an automated punch press, it would be possible to make these arrays in volume, but I don't think they could ever be as cheap as the 18 inch DSS offset dishes, which retail for about $13.

The aperture diameter of the array is about 10λ, so it would be reasonable to expect the gain and beamwidth to be similar to a dish of 10λ diameter. The light weight, compact construction, and rear feed would make this an attractive alternative to the dish if one were available for an amateur band.

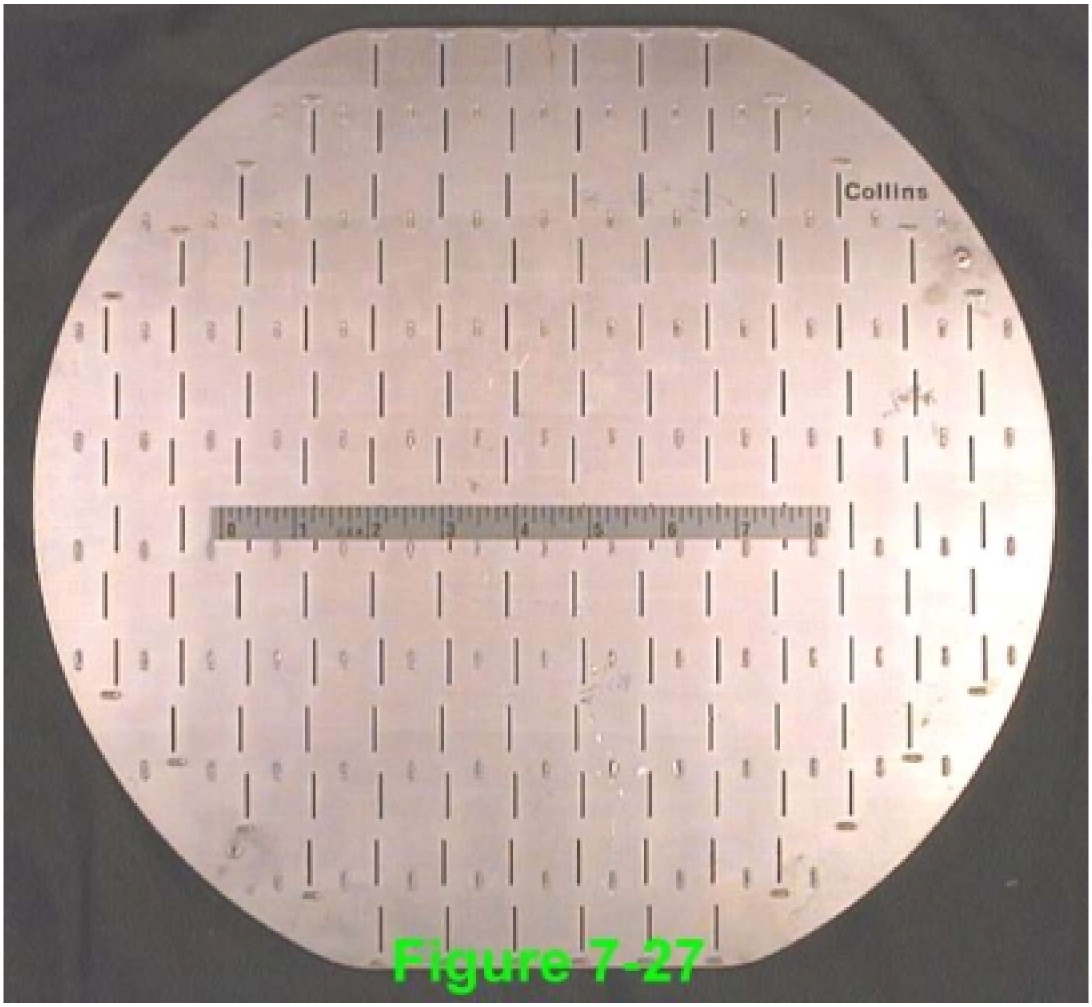


Figure 7-27

The design procedure for a two-dimensional slot array is similar to the linear array above, with the additional complication of mutual coupling between the parallel slots. Elliott[22] has a good analysis for mutual coupling. The waveguide power divider is another issue, and the array in Figure 7-27 had a few tuning bumps brazed into the waveguide — probably at locations found empirically.

Measuring the slot dimensions provided some further insight into the design. The slot displacement was clearly tapered to provide a tapered amplitude distribution as described above, and the slot lengths also varied slightly, as would be necessary to compensate for the different displacements. This design clearly used the enhancement described previously.

This antenna suggests that a tapered amplitude distribution for reduced sidelobes is useful in directional antennas. It could be applied just as well to large arrays of Yagi-Uda antennas — reduced sidelobe levels with only a slight reduction in gain could result in a significant **G/T** improvement. However, the improvement is only significant for a fairly large array, with at least eight antennas in one direction.