Analysis of the OK1DFC Septum Feed

Paul Wade, W1GHZ ©2003

The septum feed[1] was described by Zdenek, OK1DFC, at the 10th International EME Conference 2002 in Prague. On-the-air results were promising, but, like any new antenna, there were questions as to how well it really works. Computer simulations suggest that this feed should work well, and also suggest some variations to allow use over a range of dish f/D. The septum polarizer may also be used to generate circular polarization in other feedhorns.

Description

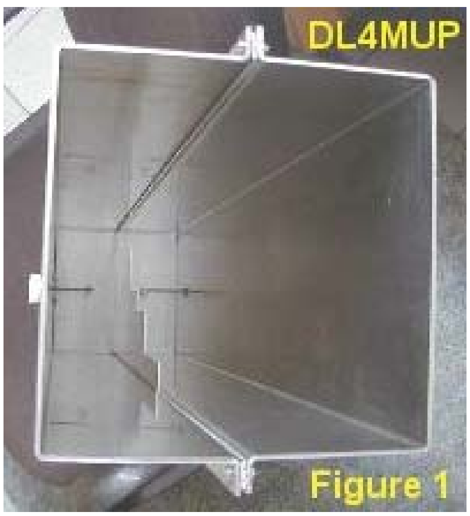


Figure 1

The septum feed as described by OK1DFC is an unflared square horn, or simply a square waveguide, with an internal stepped septum to generate circular polarization. Figure 1 is the view looking into the horn, and Figure 2 is a photo of a partially assembled feed with the septum in place, and Figure 3 is a cartoon of a septum feed with one wall cut away. The horn is excited by inputs on either side of the septum, with the two sides exciting opposite senses of circular polarization. For EME, this provides separate transmit and receive ports of opposite polarization. The excitation may come from two rectangular waveguides, each matching the dimensions of one-half of the square horn, or from a perpendicular probe on each side of the septum acting as an integral transition from coax to the

Figure 2

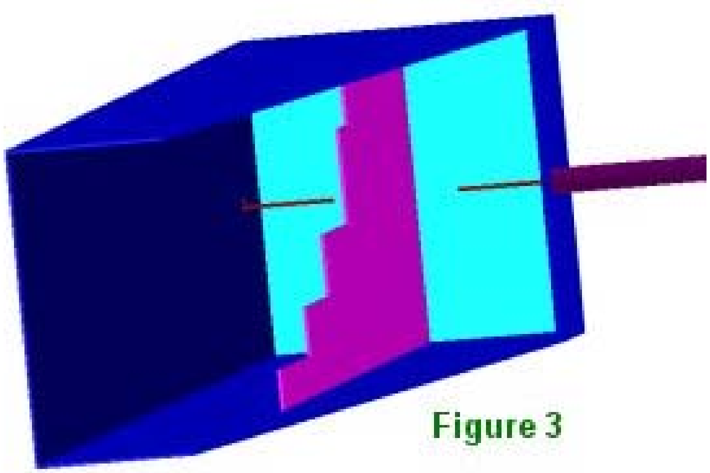


Figure 3

waveguide. The two methods should provide identical results provided that the waveguide section before the septum is long enough to suppress any spurious modes.

The radiating element, at the aperture, is simply a square horn. Rotated 45 degrees, it is identical to a diagonal horn[2]; if the diagonal horn is excited with circular polarization, then the radiated pattern should be identical. N7ART has shown[3] the diagonal horn to be a good feed, so we might expect the septum feed to be also. The version described by N7ART used phased crossed dipoles to generate circular polarization, an arrangement that seems awkward at higher frequencies. The septum could be a better way to generate circular polarization.

The septum is a bit more complicated. A circularly polarized wave entering the aperture may be considered two have two polarization components with a 90º phase difference, one parallel to the septum and one perpendicular. The parallel component is divided equally by the septum and passes to the two rectangular input waveguides. The cutoff frequency for the perpendicular component is changed by the septum, so that the wavelength for the perpendicular component is shorter. Thus, the electrical length of the septum is longer for the perpendicular component than for the parallel component; if the difference in length is ¼ λ, or 90°, then the horizontal and vertical components arrive in phase at the input. The components add together on one side and cancel on the other, depending on the sense of circular polarization, so that the two ports are isolated from each other. In order to achieve the difference in electrical lengths in a reasonable physical distance, the septum polarizer operates near the cutoff wavelength of the waveguides.

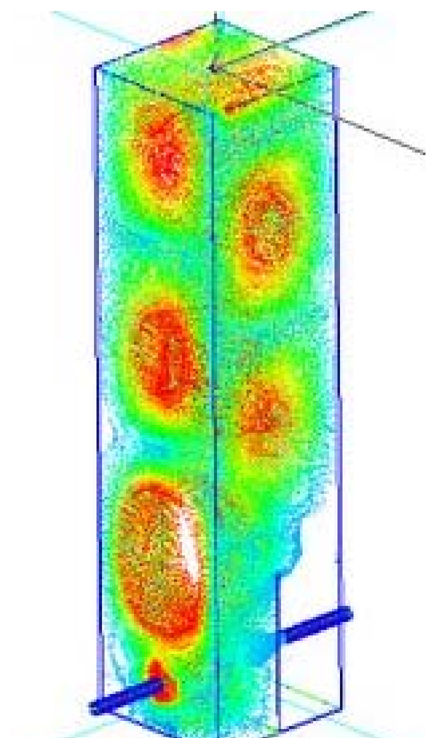


Figure 4

Figure 4 shows the simulated E-field distribution in a transparent septum feed, with the polarization component perpendicular to the septum visible through the left wall and the parallel component visible through the top wall. The red areas of high field intensity are separated by ½ λ_g along each wall, so we can see that the top and side are ¼ λ apart at the aperture end, but go through a more complex difference around the steps in the septum. The cancellation at the input probe on the far side is also clear.

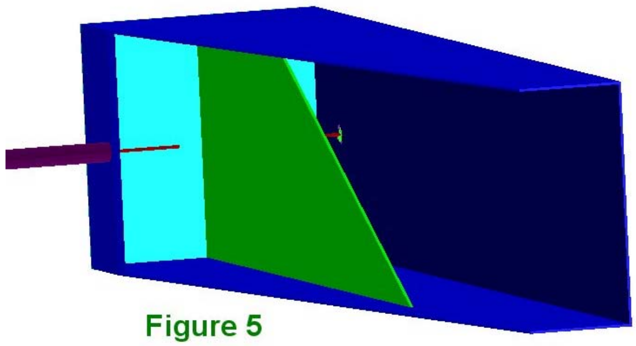


Figure 5

The first septum polarizers[4] used a sloping septum, with a linear taper around 30°, like the cartoon cutaway in Figure 5. This version apparently[5] offered limited bandwidth and isolation, so the stepped septum[6] was developed to improve isolation and bandwidth. All the references state that the field solution around the septum is very difficult so no analytic procedure is available. However, Chen & Tsandoulas[6] show an example with dimensions, which OK1DFC has converted to a spreadsheet which calculates dimensions for other frequencies by scaling the dimensions. Since the example is for a 0.635λ square horn, and we don't know how to calculate septum dimensions for other horn sizes, we are limited to this size horn for the septum section. It should work equally well at all frequencies as long as all the dimensions are scaled.

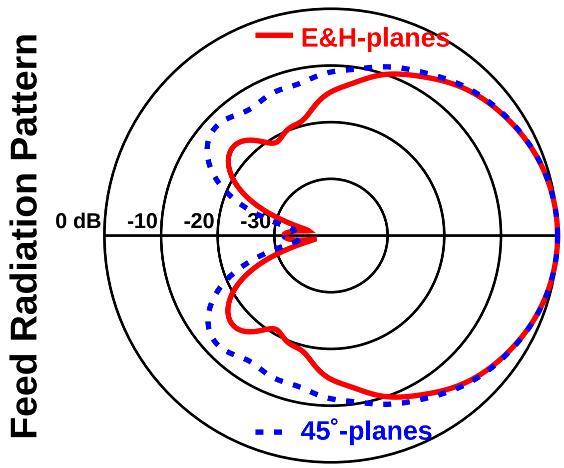
Simulations

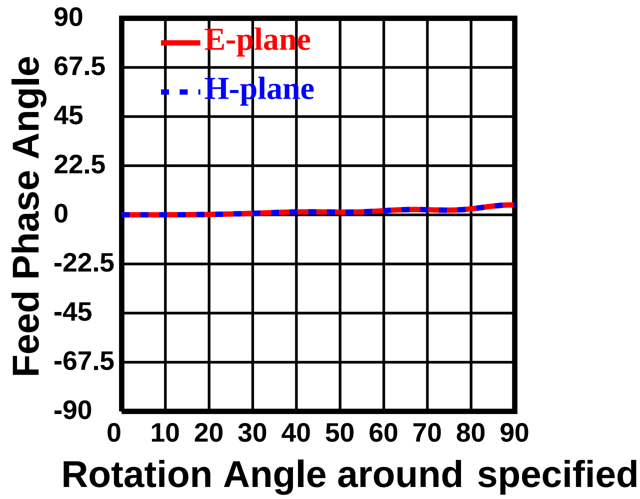
A septum feed for 1296 MHz with dimensions specified by OK1DFC was simulated using Ansoft **HFSS** software[7]. The calculated radiation patterns in Figure 6 show the broad illumination expected of a small horn. Like other open waveguide feeds, the rear lobes are relatively large, only about 12 dB down, reducing the calculated efficiency to about 68% with best ***f*/D** around 0.35 to 0.4. Patterns for right and left hand circular polarization are pretty much identical. Patterns were calculated for both probe excitation and rectangular waveguide excitation; they were very similar, so the distance from the probe to the septum is adequate.

Previous simulations of diagonal feeds[8] with linear polarization showed good radiation patterns, but with efficiency reduced by the large rear sidelobes typical of open waveguide feeds. Square horns[9], with linear polarization parallel to the sides, also show large sidelobes in the E-plane. Since the circular polarization vector is constantly rotating between these two conditions, we might expect the radiation pattern to be a composite of a diagonal horn and a square horn. The circularly polarized pattern of the septum feed, shown in 3D in Figure 7, looks like we might imagine this composite, showing sidelobes on the four corners like the diagonal horn, generated as the polarization vector passes through horizontal and vertical polarization in the square horn. The sidelobes on the corners reduce the calculated efficiency by perhaps four percentage points compared to a calculation using only the traditional horizontal and vertical pattern cuts.

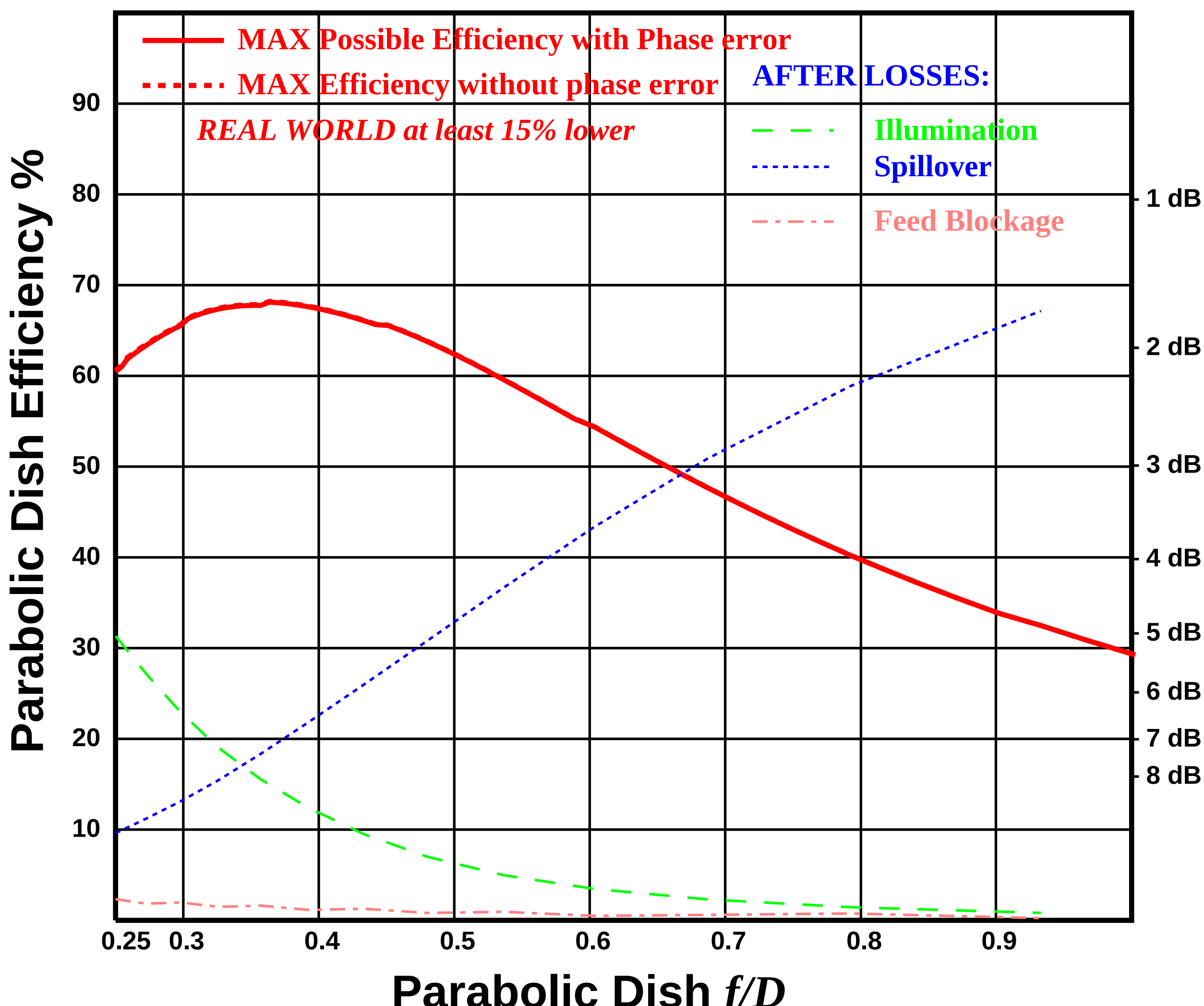
OK1DFC Septum feed for 1296, 0.63λ square, RHCP

Figure 6



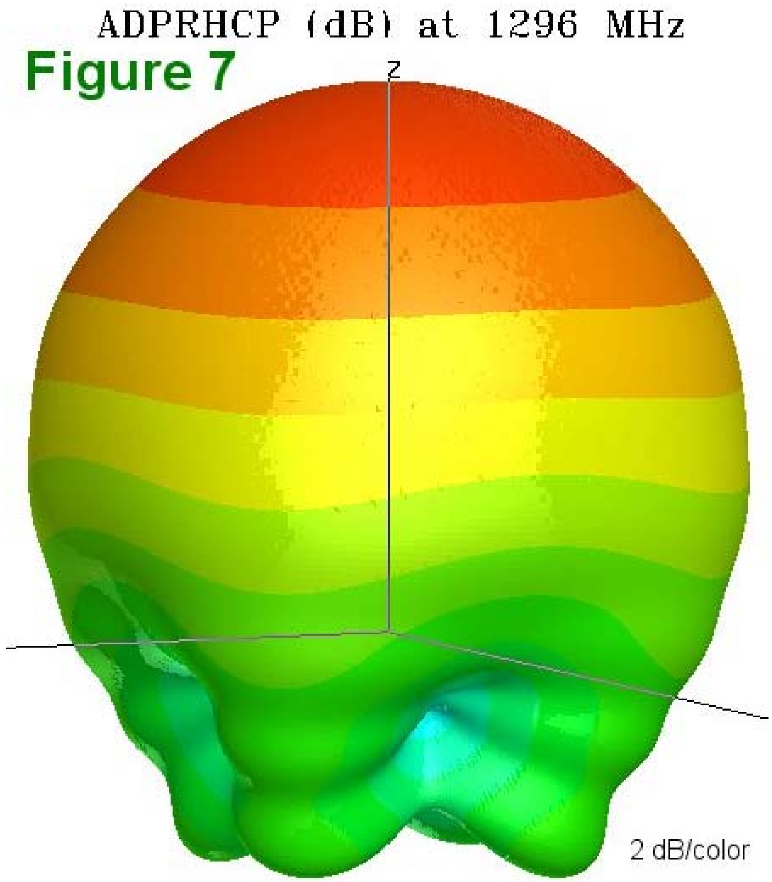


Dish diameter = 10 λ   Feed diameter = 0.63 λ   Phase Center = 0 λ beyond aperture



W1GHZ 1998, 2002

The circular polarization is quite good, with cross polarization about 21 dB down, and the pattern circularity is good. Isolation between the two ports is about 24 dB at 1296 MHz, with reasonable bandwidth, showing good isolation from at least 1.2 to 1.4 GHz. Note that reflection from the parabolic reflector reverses the circular polarization, so that the reflection coming back into the horn will reduce the isolation.



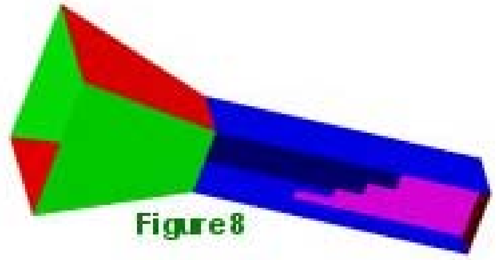
While the calculated efficiency of this feed is not as high as some, the better ones have a larger blockage shadow, so the septum feed may be the best performer on a small dish where circular polarization is required.

Simulation of the version with a simple 30° tapered septum showed very similar performance at 1296 MHz, but the isolation between ports was high over a smaller bandwidth, roughly 100 MHz. This is quite adequate for amateur use, and the sloping septum might be easier to fabricate at higher frequencies.

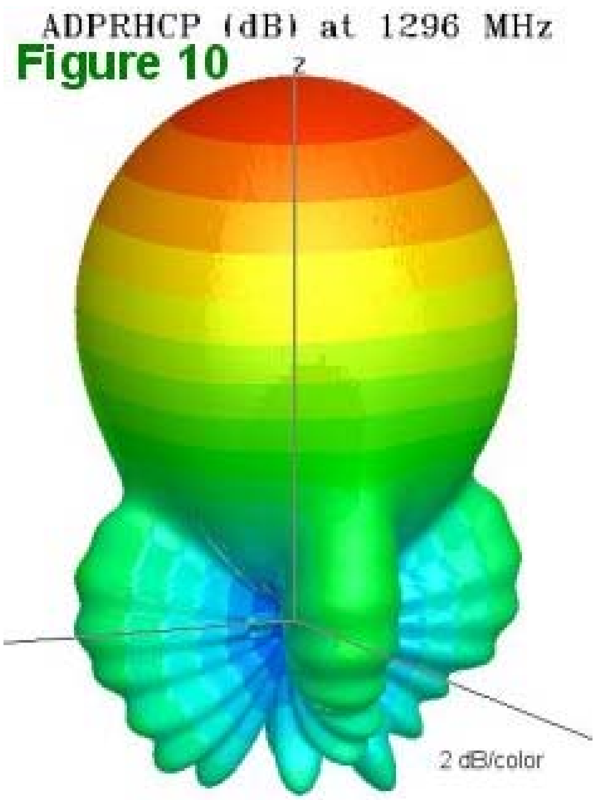
Other *f*/D dishes

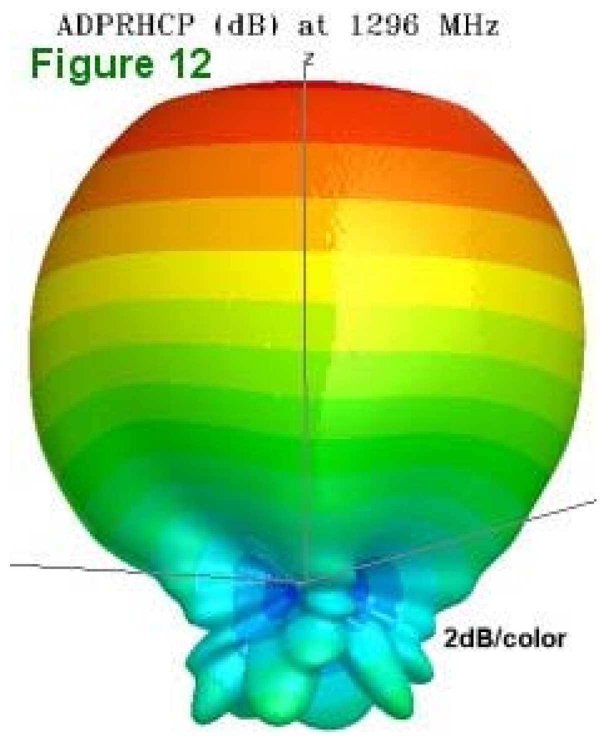
The diagonal horn may be tailored to illuminate a various ***f*/D** by varying the dimensions of the diagonal section, or by adding a flared section for larger ***f*/D**. Since the operation of the septum in generating circular polarization depends on the guide dimensions being close to the cutoff wavelength, the square cross-section is fixed at 0.63λ for a given operating frequency. However, a flare section may be added to increase the aperture size to optimize the horn for any larger ***f*/D**, so that the septum feed may be used for any dish with ***f*/D** > 0.3. Since there are no good feeds for very deep dishes, the septum feed is probably as good as any for deeper dishes.

The flare section is similar to a rectangular waveguide horn, except that it should maintain a square cross-section. Rectangular horns need different aperture dimensions in the E- and H- planes to achieve the same beamwidth, but the circular polarization of the septum feed has no fixed planes – they are constantly rotating in a circle – so the square cross-section should be maintained (an octagonal shape might be even better). The flare should have a gentle taper, like the cartoon in Figure 8, with one wall cut away to reveal the septum.



I first tried a adding a flare section with an aperture 1.4λ square and a flare angle of 30° (15° halfangle on each side of the septum), since this size diagonal horn with linear polarization is a good feed for an offset dish with an equivalent ***f*/D** around 0.7. With the septum feed generating circular polarization, the calculated efficiency in Figure 9 is high with best ***f*/D** is around 0.7 to 0.85, suitable for many offset dishes. This horn also had high rear sidelobes on the corners, so that the 3D pattern in Figure 10 looks like a rocket with fins.

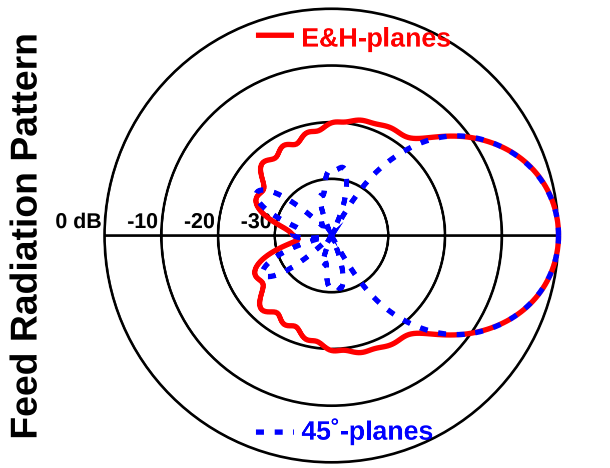


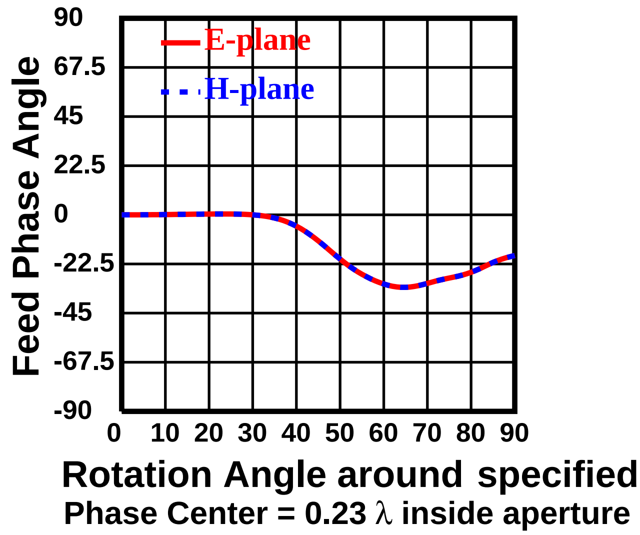


An intermediate size flare, with an aperture 1.1λ square, produces the radiation patterns in Figure 11 with high calculated efficiency at intermediate ***f*/D**, best around 0.5 to 0.6. The corner lobes for this horn are less pronounced in the 3D pattern, Figure 12.

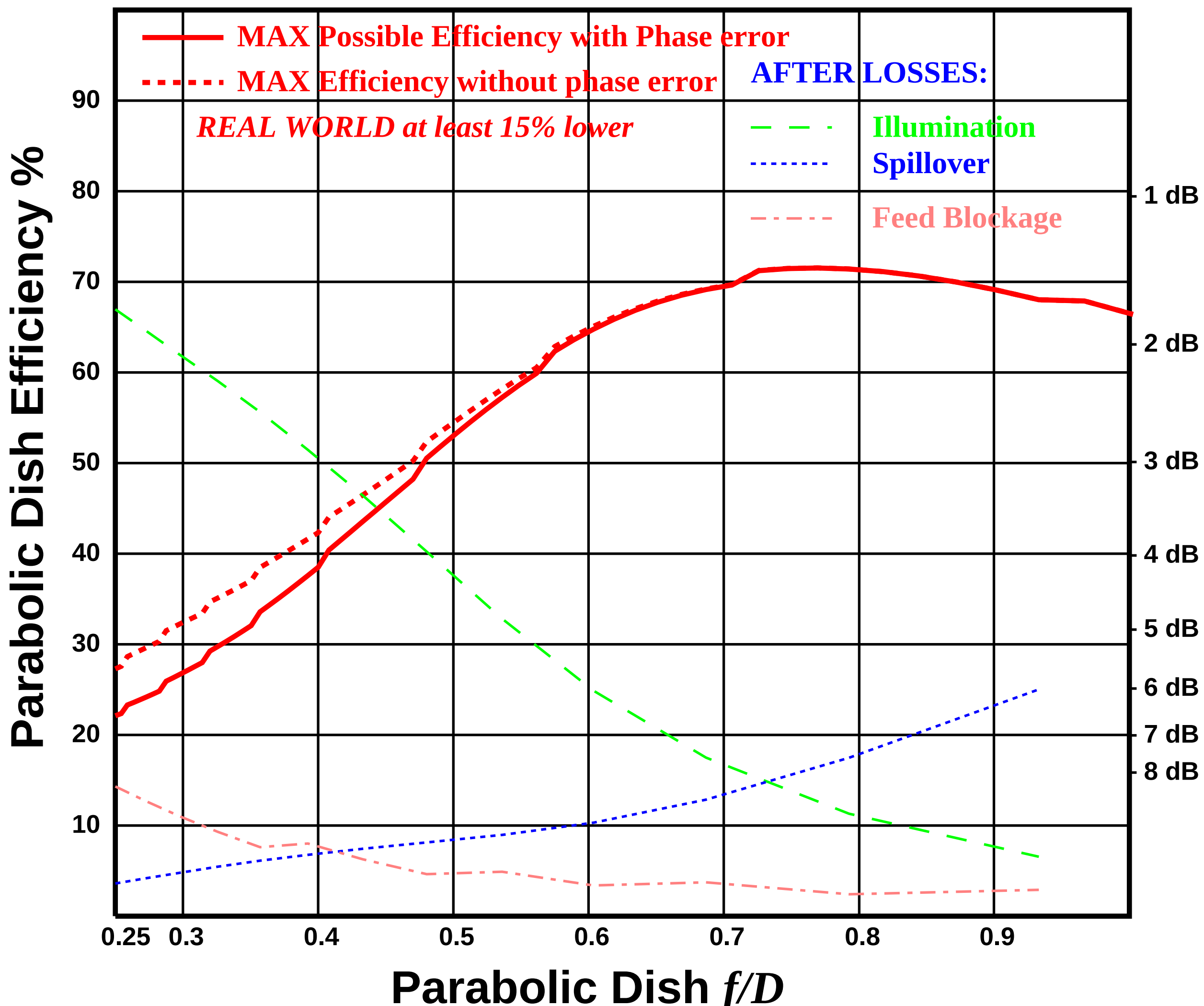
OK1DFC Septum feed with flare to 1.4λ square at 1296, RHCP

Figure 9





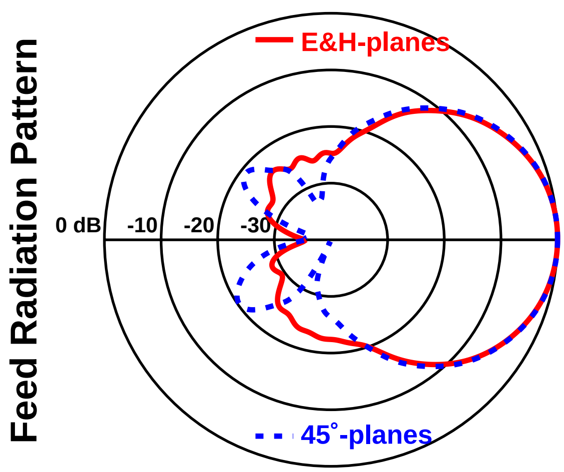
Dish diameter = 14 λ   Feed diameter = 1.4 λ

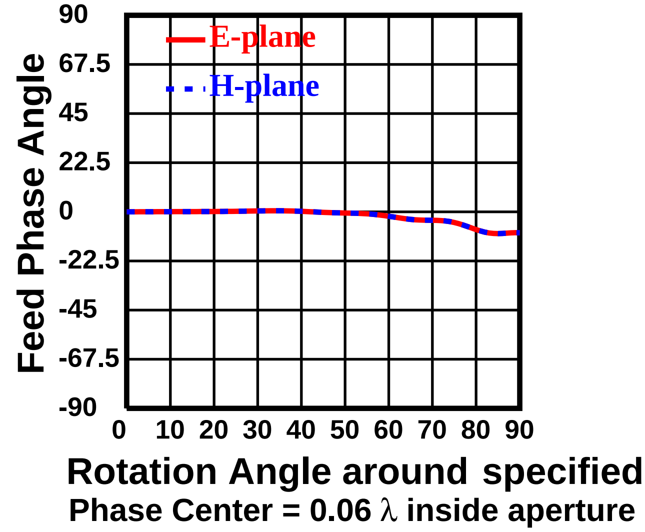


W1GHZ 1998, 2002

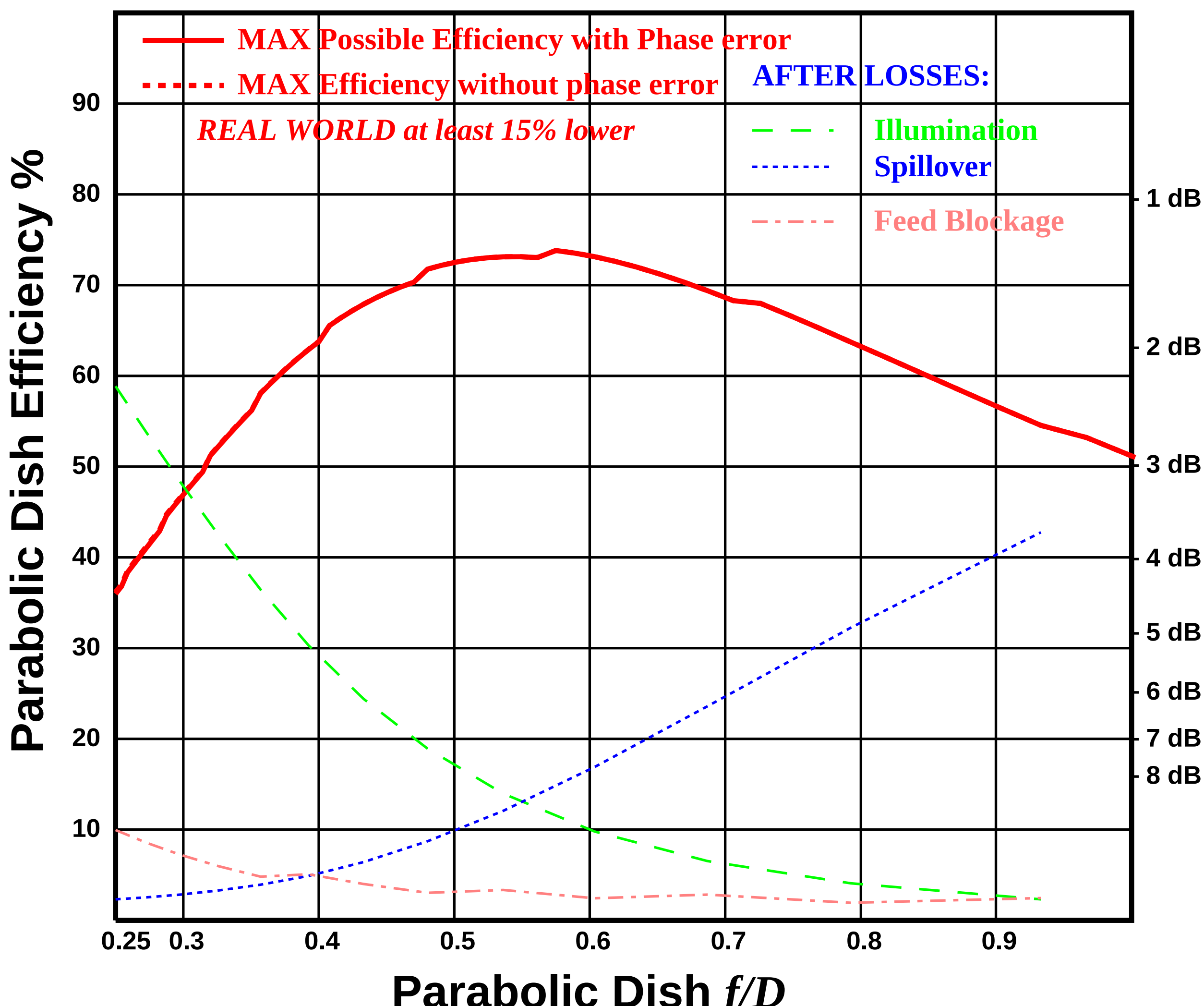
OK1DFC Septum feed with flare to 1.1λ square at 1296, RHCP

Figure 11





Dish diameter = 11 λ   Feed diameter = 1.1 λ



W1GHZ 1998, 2002

Both flared septum horns show good isolation and cross-polarization. Since horn beamwidth is inversely related to aperture size, we can choose an appropriate aperture for the flare for any ***f*/D** by interpolating between the results for the three sizes above, 0.63λ square, 1.1λ square, and 1.4λ square. For smaller apertures, the flare angle should be small so that the flare length is reasonably long.

Chokes

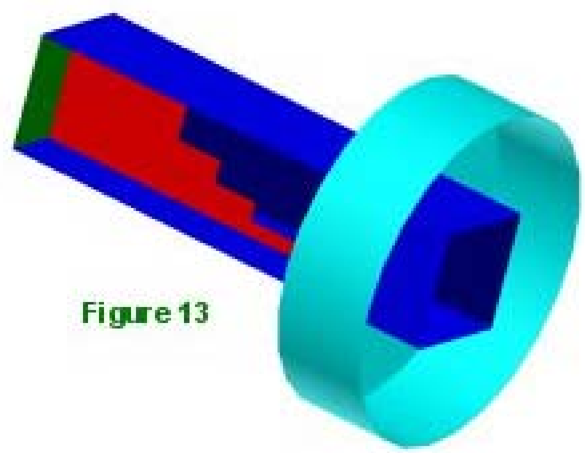


Figure 13

The VE4MA feed[10] adds a choke ring around a circular waveguide feed to reduce side and back lobes, thus increasing feed efficiency by putting more of the energy on the reflector. Since the unflared septum feed has rather large rear lobes, perhaps a choke would improve the septum feed also; the cartoon in Figure 13 shows one with a circular choke and one wall cut away to reveal the septum. Adding a circular choke with the same dimensions as the VE4MA feed, 419 mm in diameter and 121 mm deep at 1296 MHz, resulted in a significant reduction in the back lobes, as shown in Figure14. Calculated efficiency improved to 72% with best ***f*/D** between 0.33 and 0.43. The 3D pattern, Figure 15, shows that the round choke eliminates the corner lobes. Isolation between the ports is still good, but the cross-polarization is slightly lower at about 19 dB. However, the increased efficiency comes at a price: the blockage shadow has increased from 0.63λ square to 1.8λ diameter, a significant difference for a small dish.

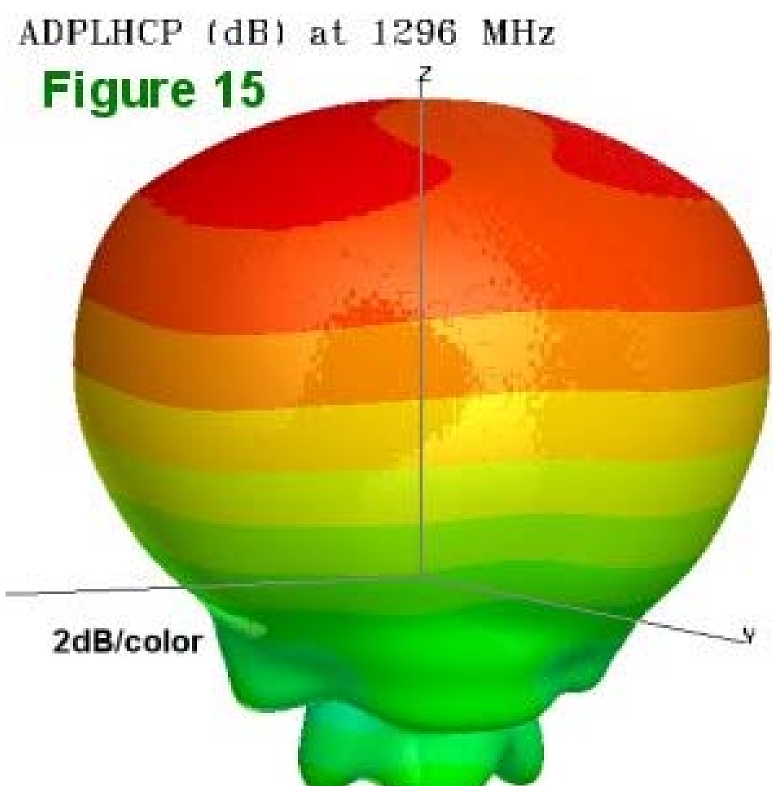
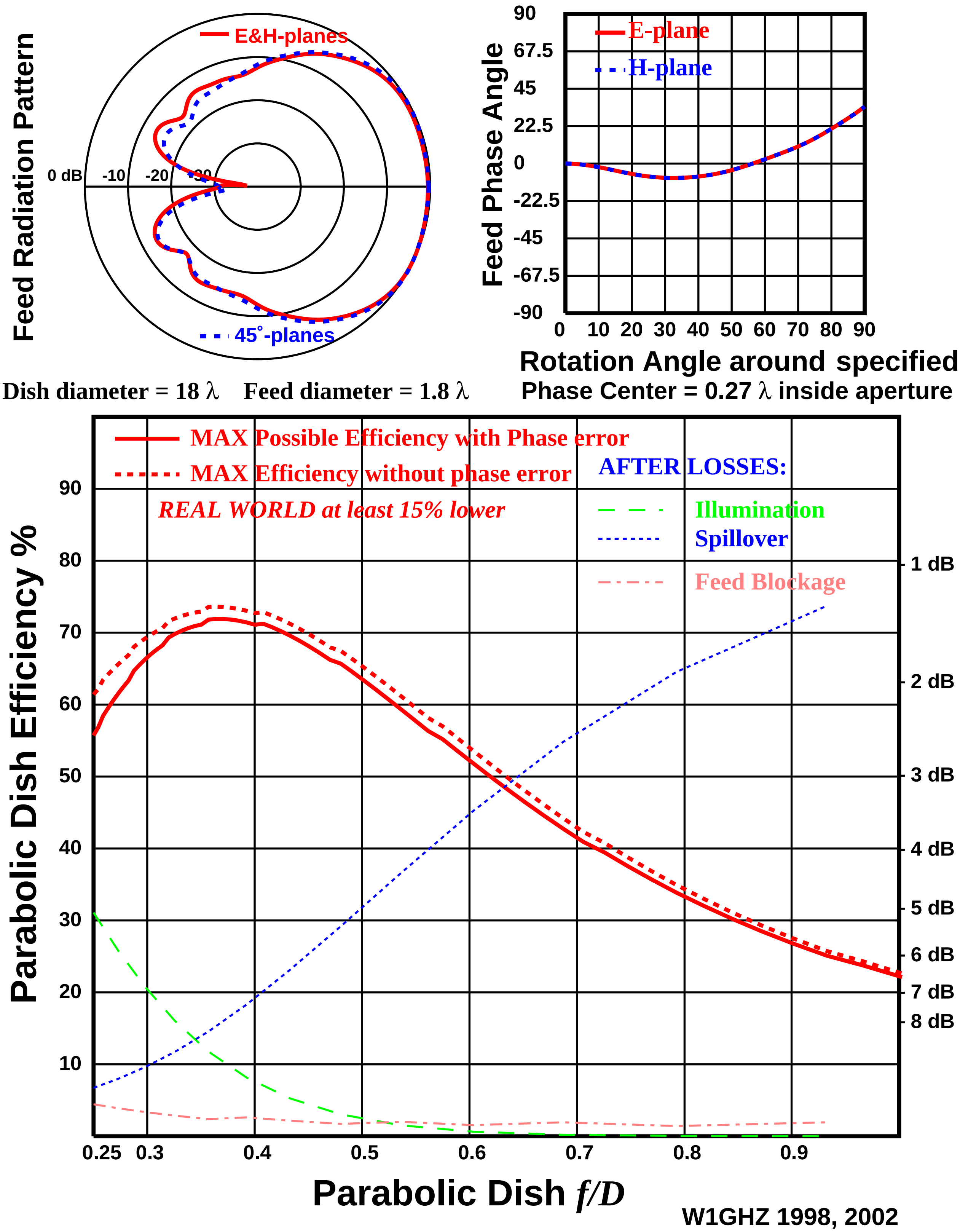


Figure 15

Septum feed with 1.8λ dia round choke, LHCP at 1296 MHz

Figure 14



W1GHZ 1998, 2002

Since the septum feed may be fabricated by cutting and bending sheet metal, it seemed that a square choke like the cartoon in Figure 16 might be easier to fabricate than a round one. From the round choke, I estimated choke dimensions of 1.7λ square and the same 121 mm deep. As shown in Figure 17, the square choke does not work nearly as well as the round one, with lower efficiency and a 3D pattern, in Figure 18, resembling a pepper. I don't know whether it is the shape or the dimensions that reduce the performance, but I'd recommend sticking with the round choke.

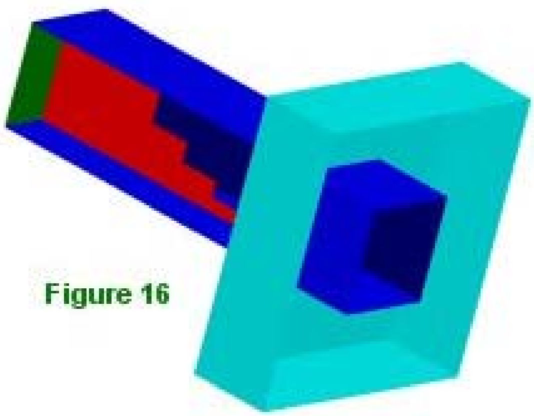


Figure 16

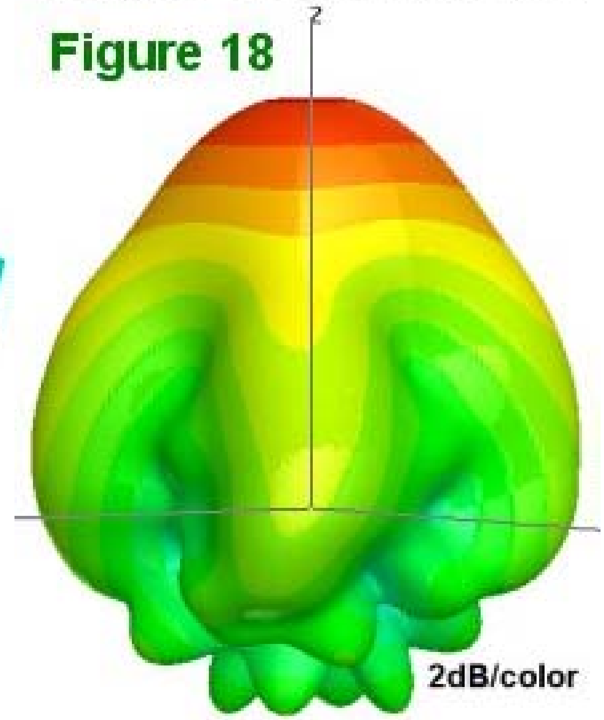


Figure 18

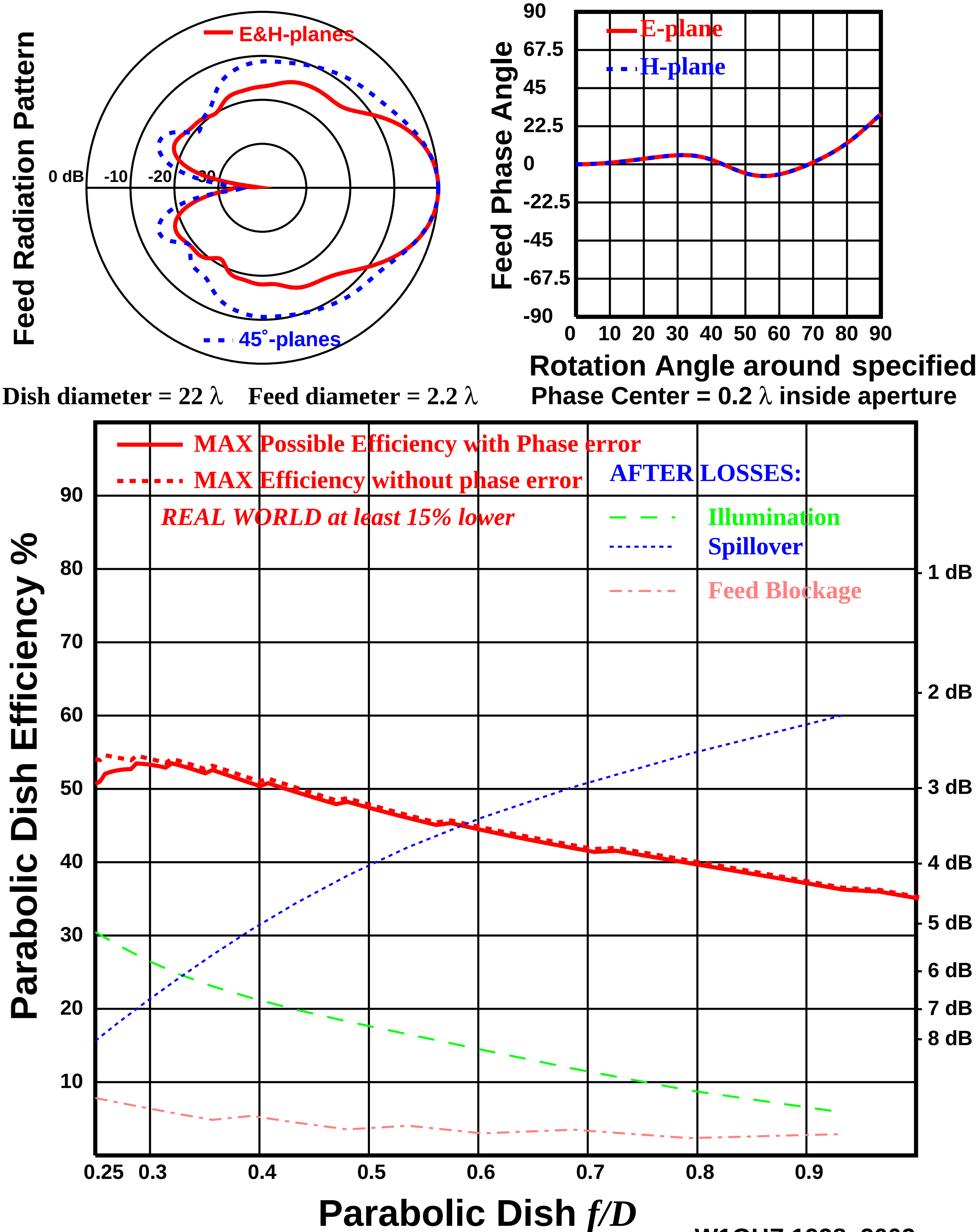
VE4MA feed with septum polarizer

The septum polarizer seems to do a good job of producing circular polarization in a square cross-section, with no adjustment required. Would a septum polarizer work in circular waveguide? One reference[11] described a stepped septum in circular waveguide, talked about using a computer program to solve the wave equation, and plotted the relative cutoff wavelengths of the parallel and perpendicular components vs. step height. Then they said the lengths are adjusted experimentally to achieve 90° phase shift.

The simplest septum polarizer is just a linear taper, and it seems to work well in the square feed. Davis, et. al., suggest[4] 30° as an appropriate taper for a septum polarizer, so I added a 30° septum to a VE4MA feed with relatively small diameter circular waveguide, so that it would be close to cutoff. The resulting radiation patterns were OK, but the polarization ratio (the ratio of desired to undesired polarization) was not: the undesired sense was only about 10 dB down, so that efficiency would be reduced since about 1/10th of the energy is in the wrong polarization.

Septum feed with 1.7λ square choke, LHCP at 1296 MHz

Figure 17



W1GHZ 1998, 2002

The polarization ratio was also sensitive to frequency, so I fiddled with the waveguide diameter. The best I could find with a 30° septum taper was about a 13 dB polarization ratio, at a waveguide diameter of about 0.7λ. Since this is far worse than the stepped taper in a square guide, perhaps the stepped taper might be needed in a circular guide also.

Lacking a spreadsheet for circular guide, I decided to try a quick approximation. I adjusted the frequency in Zdenek's spreadsheet for square guide until the septum height matched the 0.7λ waveguide diameter, then used the calculated step dimensions. A cartoon cutaway of this feed is shown in Figure 19. I don't know whether these are the best dimensions, but they work pretty well: a VE4MA feed with these dimensions has a polarization ratio around 22 dB at 1296 MHz, and good isolation between ports. The calculated radiation patterns and efficiency are shown in Figure 20; best calculated efficiency is about 68% at an ***f*/D** around 0.35 to 0.45. This is similar performance to the original square septum feed, but with a larger blockage shadow. As might be expected, the 3D pattern in Figure 21 has no corner lobes, since all the cross-sections are round.

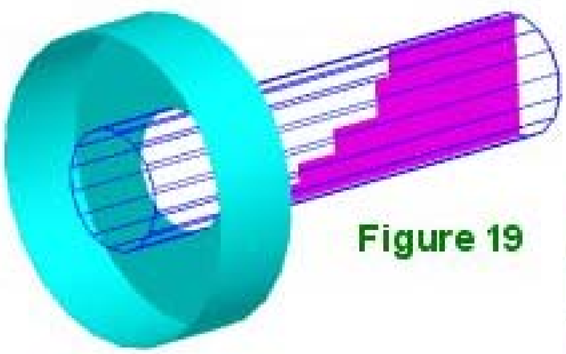


Figure 19

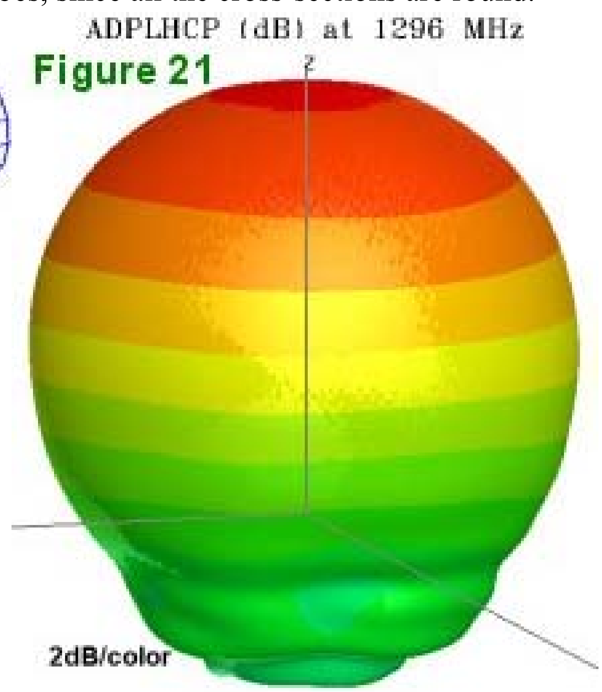


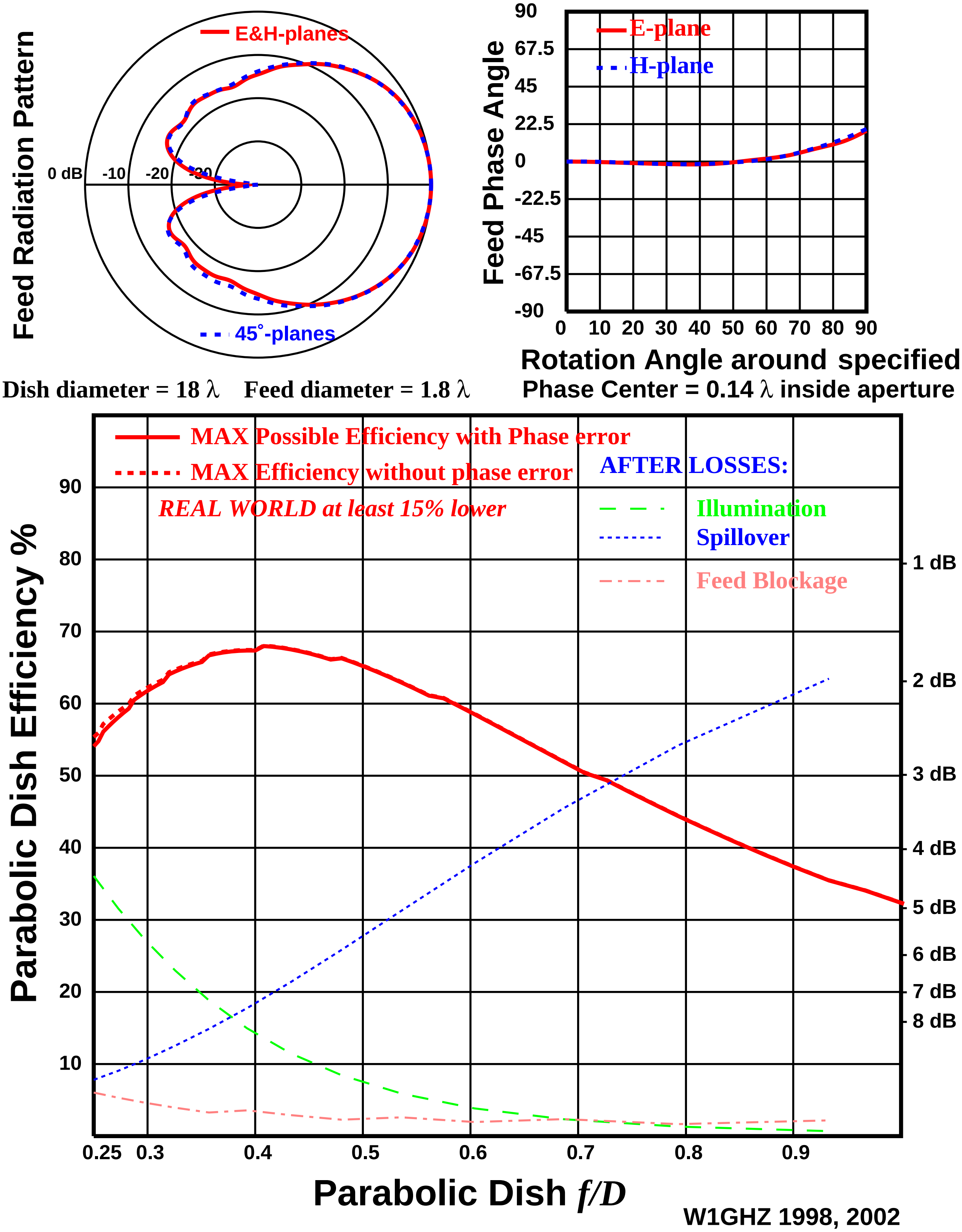
Figure 21

Input probes

Since the intent was to examine feedhorn performance, these simulations were all done with single-mode waveguide excitation. The only exception was one with input probes to The OK1DFC dimensions, to make sure the probes do not affect the basic radiation pattern. The calculated patterns and efficiency were identical, but the probe version had higher isolation, shown in Figure 22. Achieving such high isolation in an actual feed would require careful construction, and then reflections from the dish surface would still reduce the isolation as described above.

VE4MA feed with stepped septum, LHCP at 1296 MHz

Figure 20



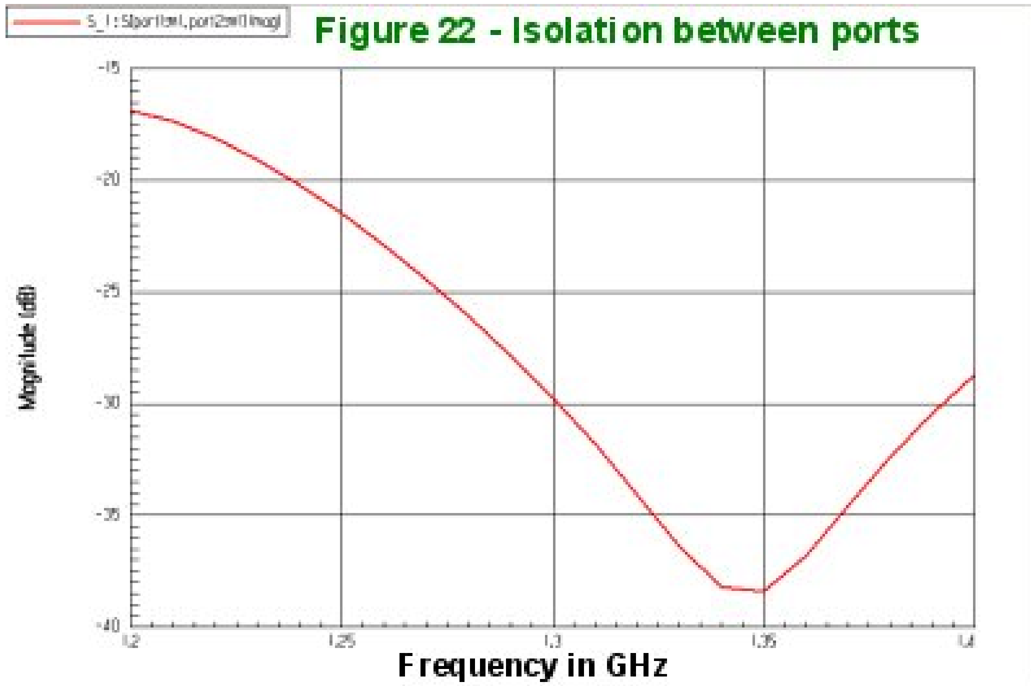


Figure 22 - Isolation between ports

Because the septum cuts the guide in half in the input area, the probe length is limited. The optimum probe length might be very close to the septum, particularly in circular guide, close enough to arc over with high power. For the square guide, Zdenek has shortened the probe length and compensated with a tuning screw to add capacitance, a reasonable solution. Anyone wishing to add a septum polarizer to a VE4MA feed with probe excitation will have to empirically find probe and tuning screw dimensions for the circular guide. Since the polarization and isolation are taken care of by the septum, only the VSWR of each probe must be adjusted.

Summary

The septum feeds are impressive – good circular polarization performance with no adjustments. The other common ways to achieve circular polarization use two orthogonal probes phased by 90°; the phasing is achieved with an external 3-dB hybrid or a phasing section in the guide, often a series of screws to provide a slow-wave structure for one polarization. The screws require careful adjustment to achieve good circularity and good VSWR, while the external hybrid and cabling adds some losses. The septum polarizer offers the possibility of good, low-loss, circular polarization with no adjustments.

The septum polarizer looks like a good way to make a circularly polarized feedhorn with no adjustments required. The simple square cross-section described by OK1DFC is ideal for low blockage on small deep dishes, while a choke may be added for better performance on larger dishes. A flare section to increase the aperture will better illuminate shallow and offset dishes. The septum polarizer can also be used in cylindrical horns like the VE4MA feed.

References

1. Zdenek Samek, OK1DFC, “Feed for Parabolic Dish with Circular Polarization,” *10th International EME Conference 2002*, Prague, 2002. www.qsl.net/ok1dfc
2. A.W. Love, “The Diagonal Horn Antenna,” *Microwave Journal*, March 1962, pp. 117-122. (reprinted in A.W. Love, *Electromagnetic Horn Antennas*, IEEE, 1976, pp. 189-194.)
3. R. Miller, N7ART, “A 23cm Diagonal Waveguide Feed,” ***DUBUS***, 2/1997, pp. 5-14.
4. D. Davis, O. J. Digiondomenico, and J. A. Kempic, "A new type of circularly polarized antenna element," 1967 IEEE Group on Antennas and Propagation Int. Symp. Dig., vol. 5, pp. 26 - 33, October 1967.
5. H. Schrank; Antenna designer's notebook, IEEE Antennas Propagat. Soc. Newsletter, vol. 25, pp. 23 - 24, October 1983.
6. Ming Hui Chen, G. N. Tsandoulas; A wide-band square-waveguide array polarizer, IEEE Trans. Antennas Propagat., vol. 21, pp. 389 - 391, May 1973
7. www.ansoft.com
8. P. Wade, W1GHZ, *The W1GHZ Microwave Antenna Book – Online*, Section 6.5.3, www.w1ghz.org
9. P. Wade, W1GHZ, *The W1GHZ Microwave Antenna Book – Online*, Section 6.4.2, www.w1ghz.org
10. B.W. Malowanchuk,VE4MA, “Selection of an Optimum Dish Feed,” *Proceedings of the 23rd Conference of the Central States VHF Society*, ARRL, 1989, pp. 35-43.
11. R. Behe and P. Brachat, "Compact duplexer-polarizer with semicircular waveguide," IEEE Trans. Antennas Propagat., vol. 39, pp. 1222 - 1224, August 1991.