High-Efficiency Feedhorns for Prime-focus Dishes

VE4MA and Chaparral feeds with Septum Polarizers

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This started out to be a simple project – optimize the VE4MA feedhorn[1] with a septum polarizer[2] for circular polarization. Some unexpected results have led to a larger analysis with conclusions that may differ from the prevailing wisdom, but have been verified by measurements made by WD5AGO. Some improved variations of the VE4MA and Chaparral feedhorns are described which show some of the highest calculated *and measured* efficiencies to date for a prime-focus dish.

What we often call a "feedhorn" includes several separate elements: an antenna which shapes the beam for improved dish illumination, a waveguide section (round, square, or rectangular), perhaps a circular polarizer, and an excitation region (waveguide, probe transition to coax, or other transition). While these elements may interact, each has a separate function and may be analyzed independently. It is not necessary to exactly replicate all the dimensions from end-to-end, but it would be foolhardy to make changes without considering possible interactions.

Thus, we will separate the following elements for examination:

- VE4MA horn
- Chaparral-style horn
- Septum polarizer in circular waveguide
- VE4MA and Chaparral horns with septum polarizer

The excitation is a separate problem; all analysis here, using Ansoft **HFSS** software[3], will use single-mode waveguide excitation. Probe transitions in circular waveguide were studied in a previous paper[4], so probes will not be included here. *The probe is not part of the antenna.* The only complication which might be added by probe excitation would be additional waveguide modes; if the waveguide section preceding the horn is sufficiently long, then the additional modes will not reach the horn and thus not affect the radiation pattern. Single-mode excitation eliminates this potential complication from the analysis.

Dish illumination review

The ideal illumination for a parabolic dish antenna would provide uniform energy over the reflector surface, with no spillover energy missing the dish. Real feed antennas do not provide this ideal distribution. Figure 1, from the *W1GHZ Microwave Antenna Book – Online*[5], shows the desired illumination vs. a typical (idealized) feed pattern. The typical pattern energy decreases from the central peak, while the desired pattern energy *increases* toward the edges to compensate for space attenuation – the edge of the dish is farther from the feed than the center of the dish.

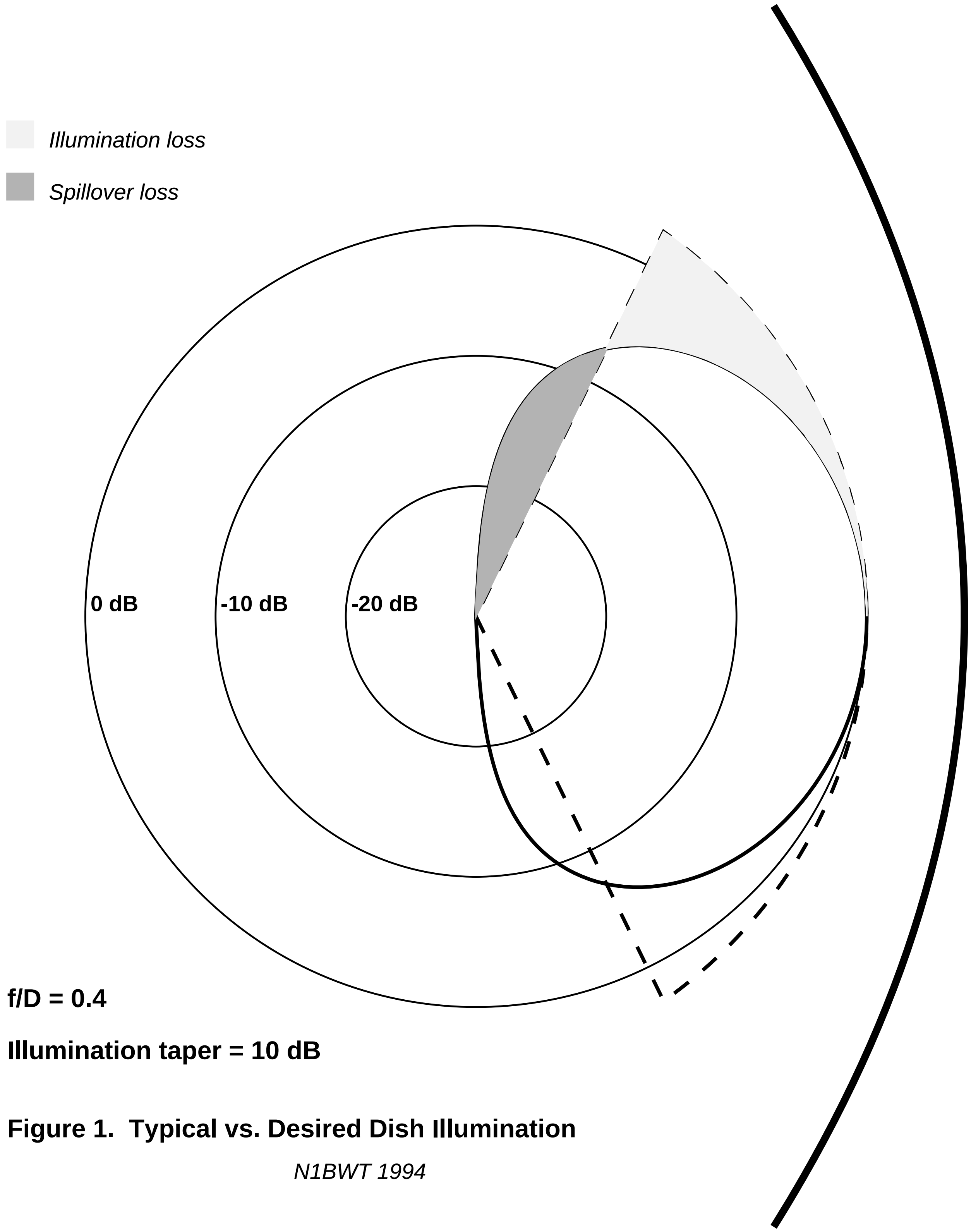


Figure 1. Typical vs. Desired Dish Illumination

N1BWT 1994

The typical feed pattern also has spillover energy which misses the reflector, and real feeds have sidelobes and backlobes which also waste energy. For many feeds, it has been found that the tradeoff between illumination and spillover yielding best efficiency occurs when the illumination (not the feed pattern – we must account for space attenuation) is about 10 dB down at the edge of the dish. This 10 dB feed taper is just a rule-of-thumb; for accurate analysis, we use pattern integration, calculating the efficiency for the full three-dimensional feed pattern (in practice, for well behaved feeds, only a few cuts, typically the **E-** and **H-**plane cuts, through the 3D pattern are necessary).

Note: all efficiency calculations are for an arbitrary 20λ dish diameter and a 1.7λ feed diameter, or a constant blockage ratio of 0.085, so that we are comparing apples to apples. For small dishes, the actual blockage is more significant and efficiency should be recalculated.

VE4MA Feed

The VE4MA feed[1] is based on a paper by Kumar[6]. This horn, which adds a single ring around a circular waveguide (Figure 2), has patterns shown in both papers which are not maximum at the center, but rather increase somewhat like our desired feed before tapering off like a typical feed – see Figure 1. Thus, the pattern, shown in Figure 3, tends to be more like the desired illumination, and provides somewhat better efficiency than a simple feed, for instance, the open circular waveguide ("coffee-can feed") without the ring. The pattern and efficiency plots for open circular waveguide feeds are shown in Figure 4; calculated efficiency is lower than the VE4MA feed for all but the largest diameters, and those larger diameters are large enough to propagate additional modes which will degrade the performance.

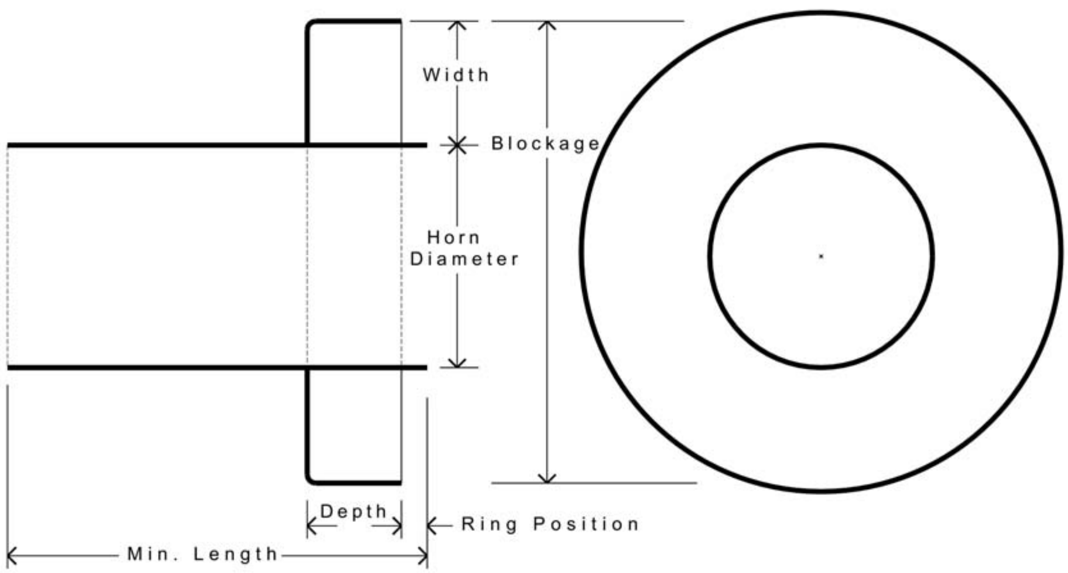
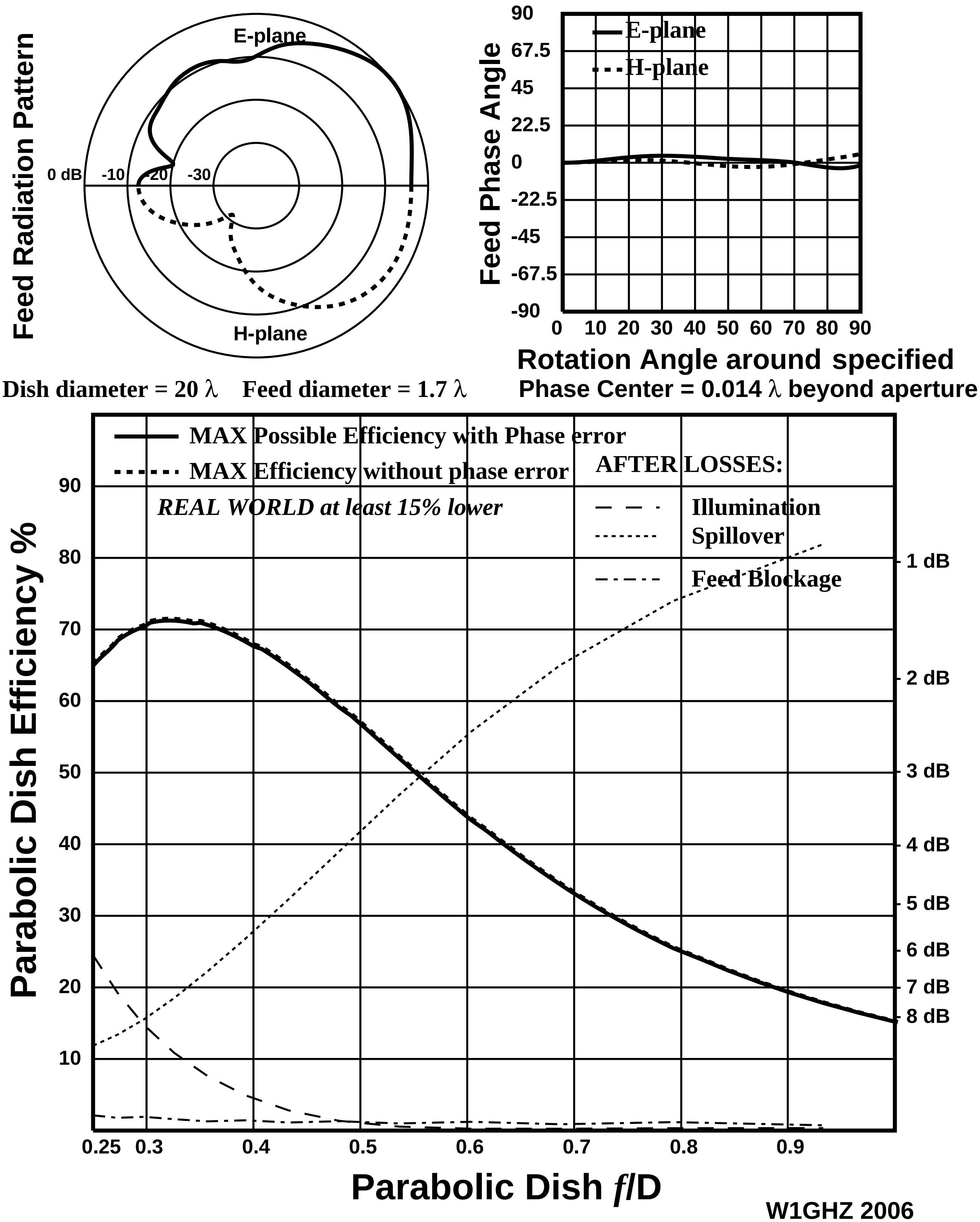


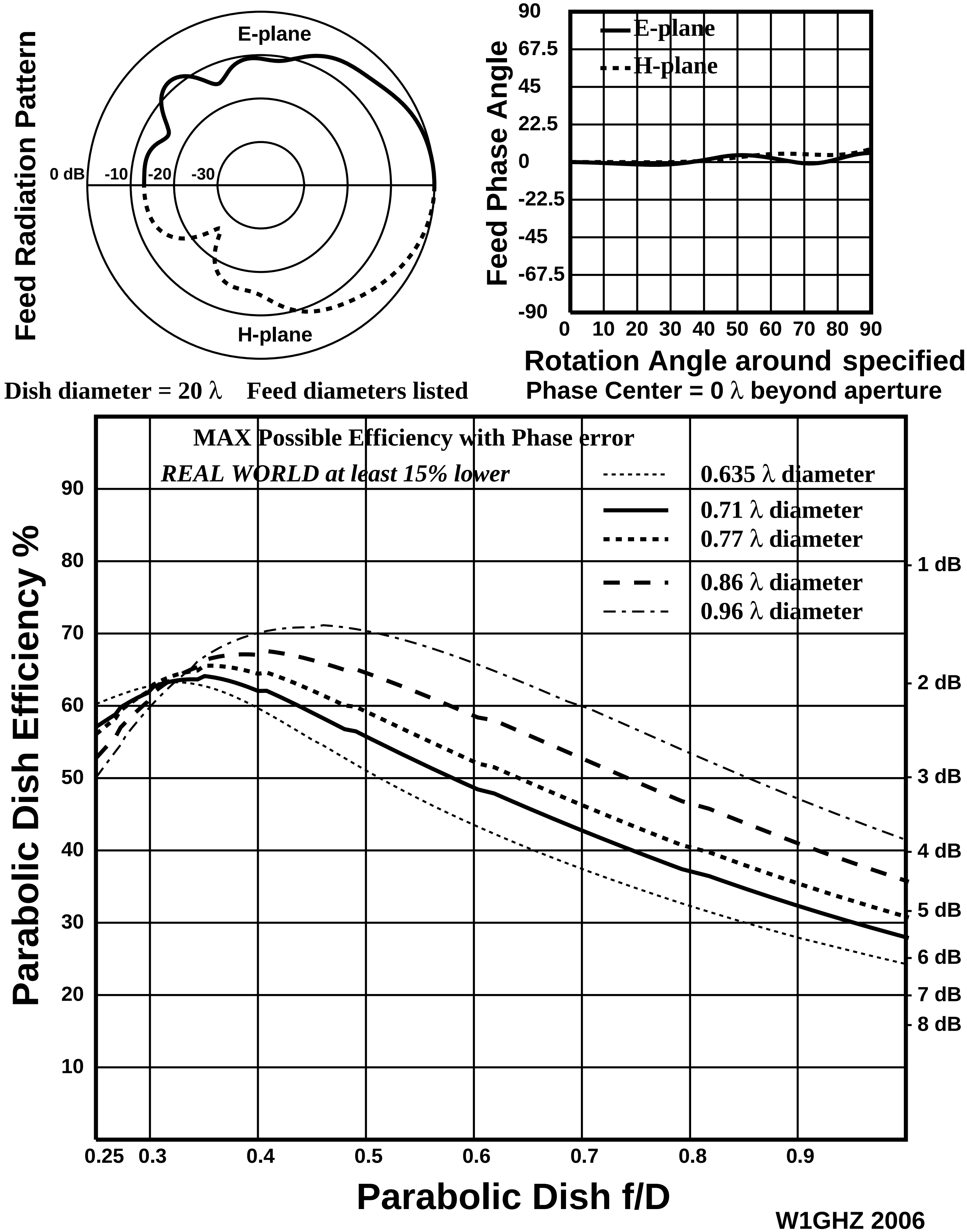
Figure 2. VE4MA (Kumar) Feed

It was suggested by Kumar that a ring dimension, ½λ wide x ½λ deep, forms a resonant structure which creates the improved pattern. Therefore, hams have carefully duplicated the dimensions published by Barry, VE4MA, for this feed, with very good results. One reason for the popularity of this feed is that it works well for conventional dishes over a wide range of ***f*/D**; the feed is optimized by the position of the ring with respect to the rim of the central horn.

Original VE4MA Feed 0.77λ horn diameter
Ring 0.50λ wide x 0.50λ deep, 0.15λ behind rim
Figure 3



Cylindrical waveguide feeds, no ring
"Coffee-can Feed"
Figure 4



If the ring is resonant, there should be a clear peak in performance with dimensions which are resonant. However, when I first varied the dimensions, the only slight peak was with one ring position, with the ring 0.15λ behind the rim of the central horn. Varying the other dimensions, I could find no peak at all – either there is no peak, or it is so sharp that we have no hope of duplicating it. The performance was nearly identical over a broad range of dimensions, suggesting that we could make better use of available materials. Performance was slightly better over a range of smaller ring dimensions, which would have the additional benefit of reduced blockage. The improvement with a smaller ring could be significant for the smaller dishes used by many hams.

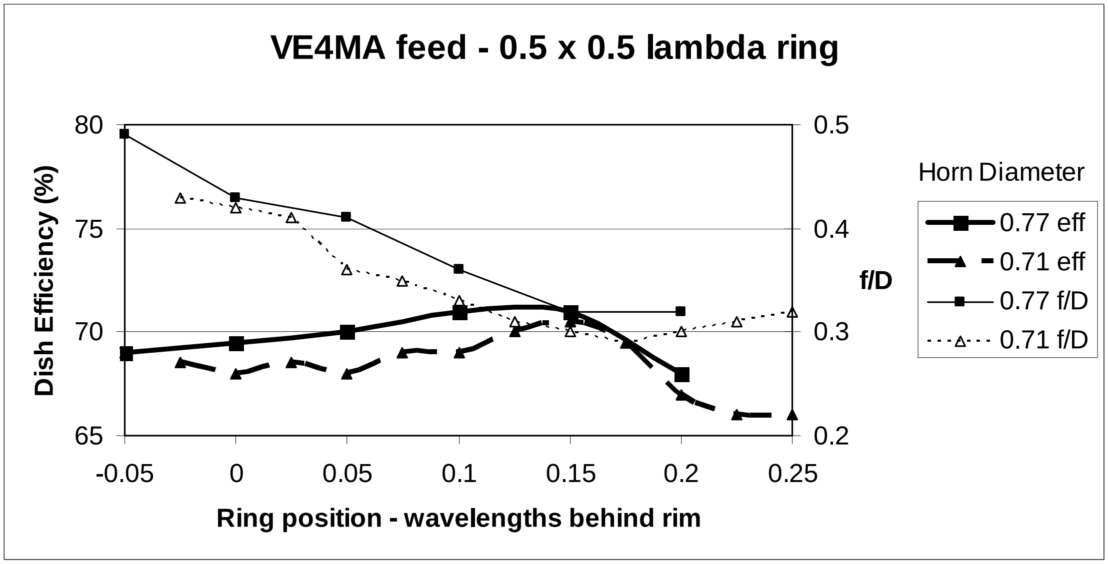


Figure 5. VE4MA feed – horn diameter comparison

The VE4MA dimensions specify a circular waveguide horn diameter of 0.77λ. My previous work with the OK1DFC septum found that the septum worked best with a 0.71λ diameter circular waveguide, so most of the variations in ring dimensions I tried were with the smaller diameter so that they would also work with a septum polarizer. However, comparing feedhorns with the same ring dimensions on the two different diameter horns showed little difference, as illustrated in Figure 5 for the original ring dimensions of 0.5λ wide and 0.5λ deep, and for a smaller ring of 0.35λ wide and 0.35λ deep in Figure 6 below.

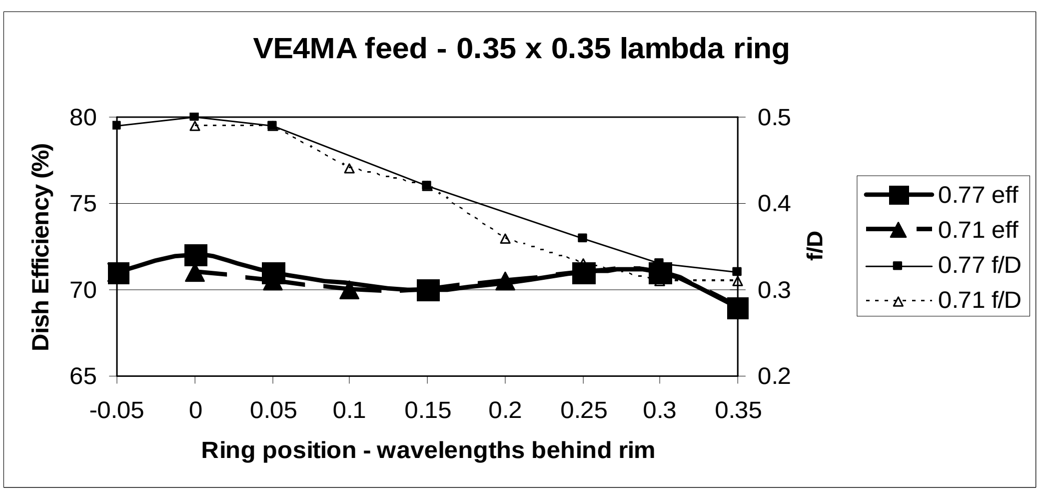
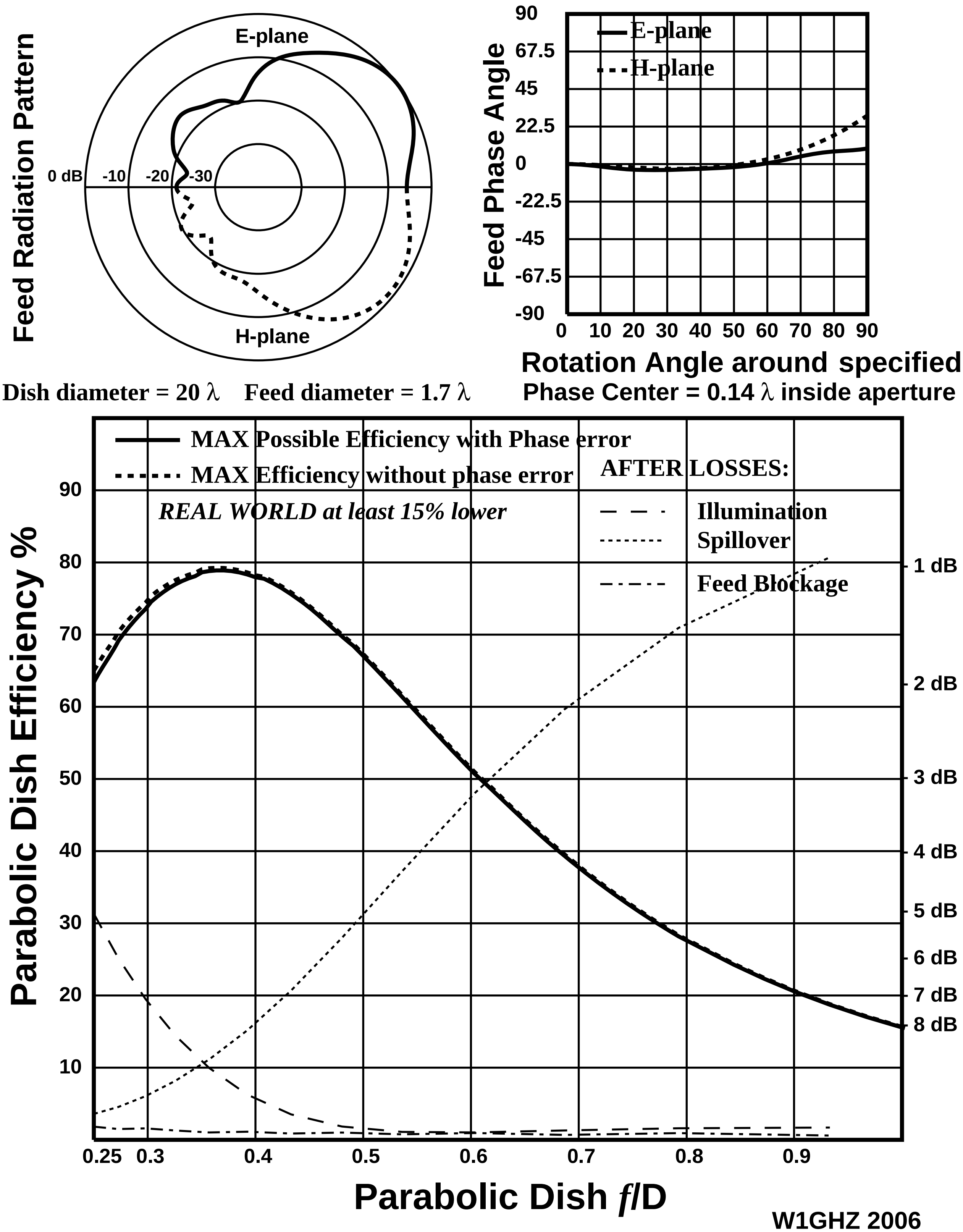


Figure 6

Super-VE4MA feed, 0.71λ horn diameter
Ring 0.60λ wide x 0.45λ deep, 0.15λ behind rim
Figure 7



The original 0.77λ diameter horn might have a slight advantage, but the two diameters give comparable performance, and sizes in between would probably work just as well. So, for linear polarization, any available material is this diameter range would be good.

Later, I tried much larger and deeper rings, and did find a peak with significantly higher efficiency (nearly 80%), for a ring with dimensions around 0.6 to 0.65λ wide and 0.4 to 0.45λ deep. The peak extends to another range of ring dimensions around 0.65 to 0.75λ wide and 0.3 to 0.4λ deep. I chose ring dimensions of 0.6λ wide and 0.45λ deep to be near the center of this peak. Figure 7 is the efficiency plot for this larger horn, which we shall call the "Super-VE4MA." For larger dishes, 20λ and up, this may be a winner. WD5AGO has built and measured a horn with a ring 0.6λ wide and 0.45λ deep, with the predicted improvement in sun noise – see the measurement results in Appendix A.

The improved feedhorn does show the desirable distinctive dip in the center of the radiation pattern, shown in the 3D plot in Figure 8. We might conclude that Kumar was on the right track, but lacked the software to refine the dimensions.

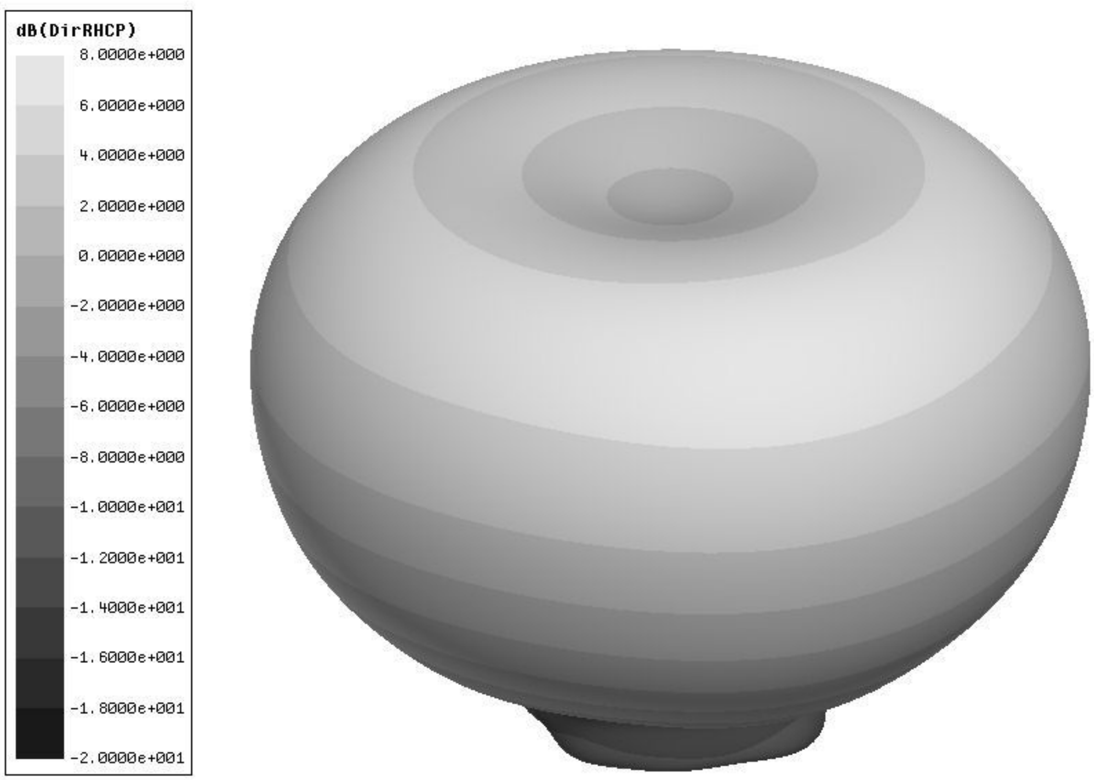


Figure 8. 3D pattern for Super VE4MA feed

The larger ring provides higher efficiency with horns of both 0.71λ and 0.77λ diameter, as shown in Figure 9. The downside of the larger ring is that the improved efficiency is only useful for a limited range of ***f*/D**, roughly 0.35 to 0.45.

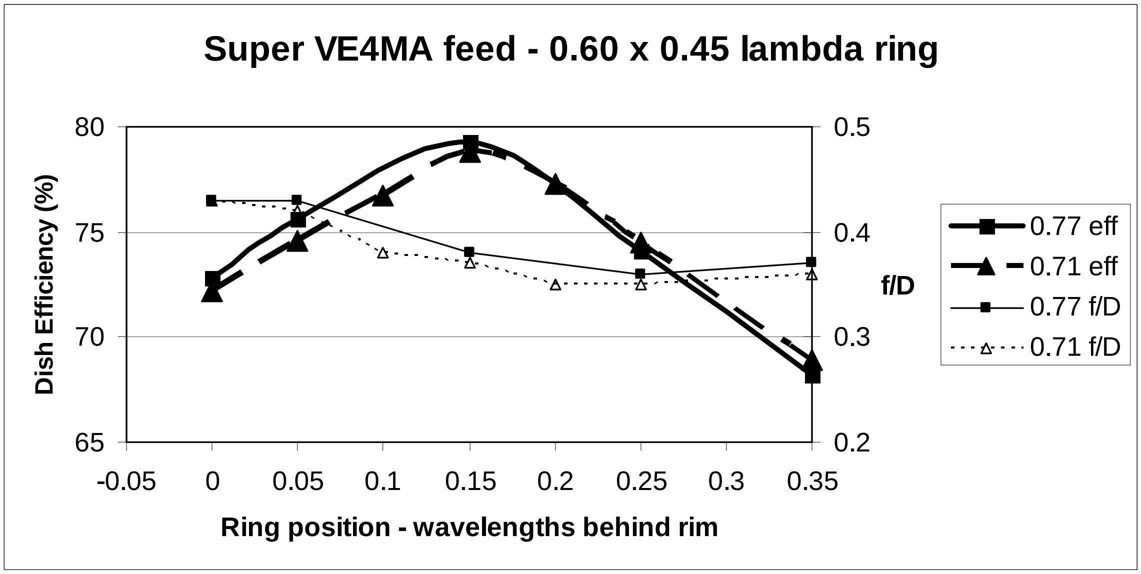


Figure 9. Super VE4MA feed – horn diameter comparison

Some of the smaller versions provide good performance, as good as or better than the original dimensions, over a wider range of ***f*/D**. Some promising combinations include a ring 0.35λ wide and 0.35λ deep in Figure 6 above, a ring 0.4λ wide and 0.3λ deep shown in Figure 10, and a ring 0.25λ wide and 0.25λ deep shown in Figure 11. The last one seems particularly attractive for very small dishes, since the blockage is much less than the original dimensions while the efficiency is as good or better.

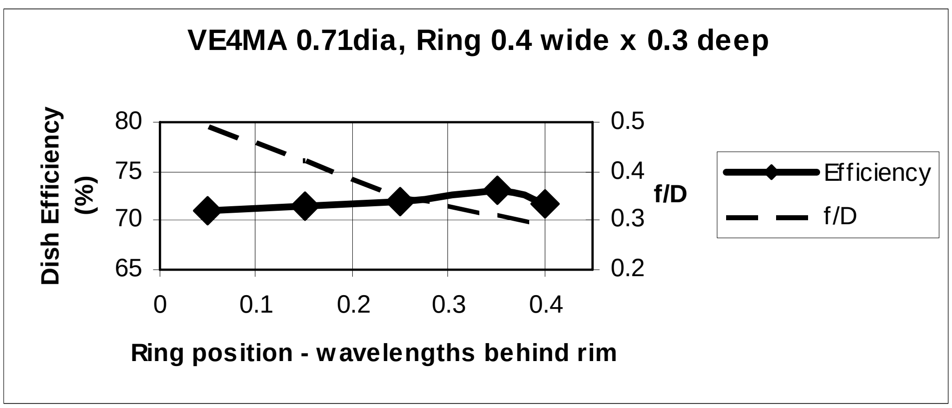


Figure 10

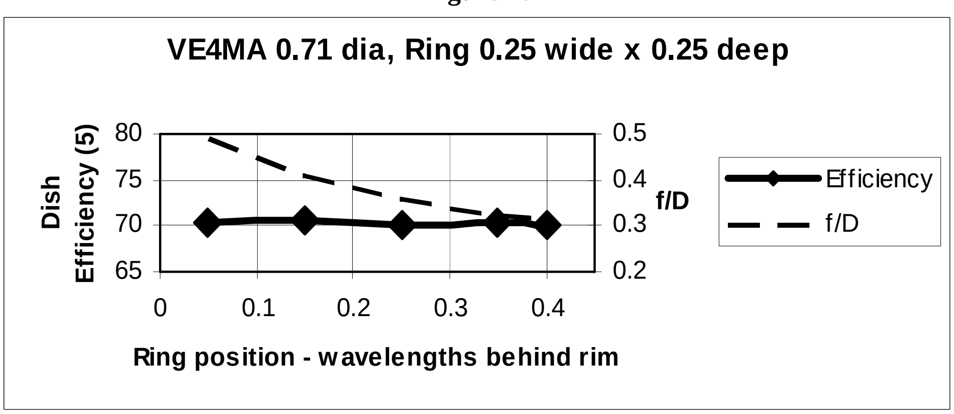


Figure 11

The smallest ring was suggested by CT1DMK, 0.12λ wide and 0.26λ deep. Figure 12 shows that it is not quite as good as the others, but not significantly worse. The blockage of this feed is quite small, since the overall diameter is less than one wavelength.

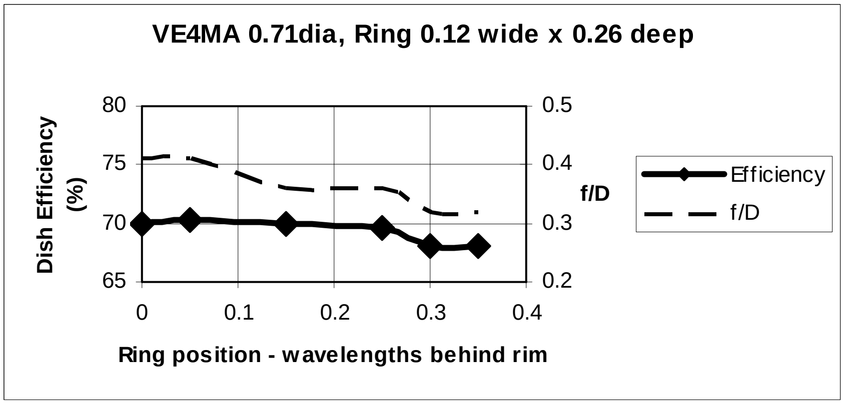


Figure 12

Rather than bury us with numbers at this point, I will include all the simulation data in Appendix B. A few of the most promising versions are compared in Figures 13 and 14, but perusal of the appendix will suggest that most combinations of ring width and depth will work pretty well, so a size that can be made from available materials can be found for most applications.

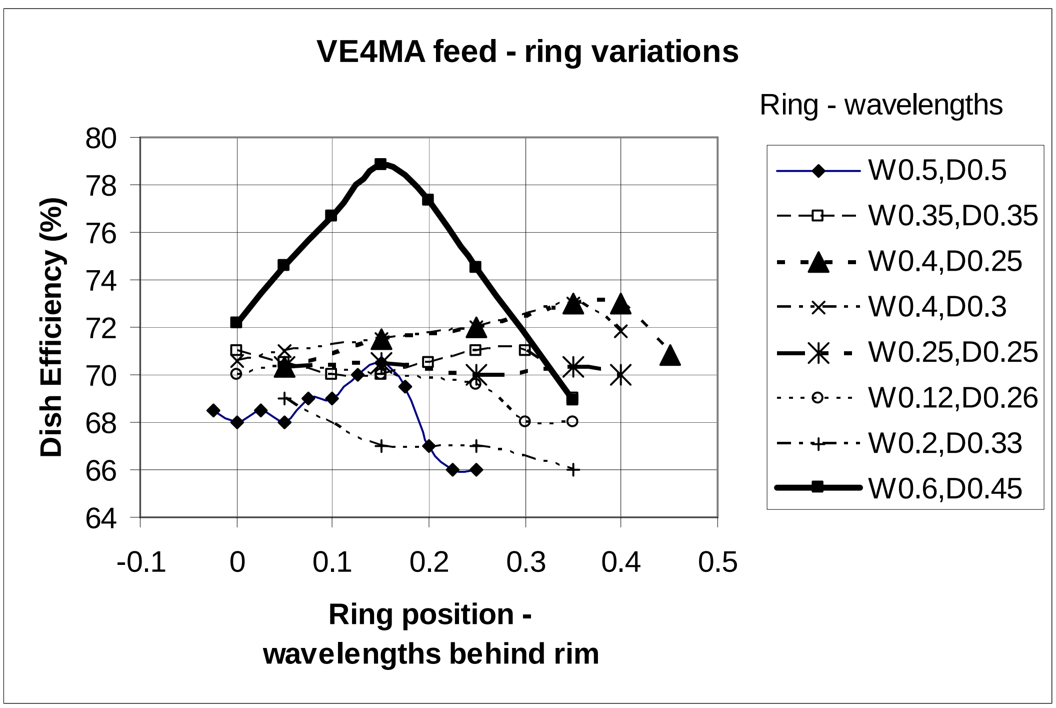


Figure 13

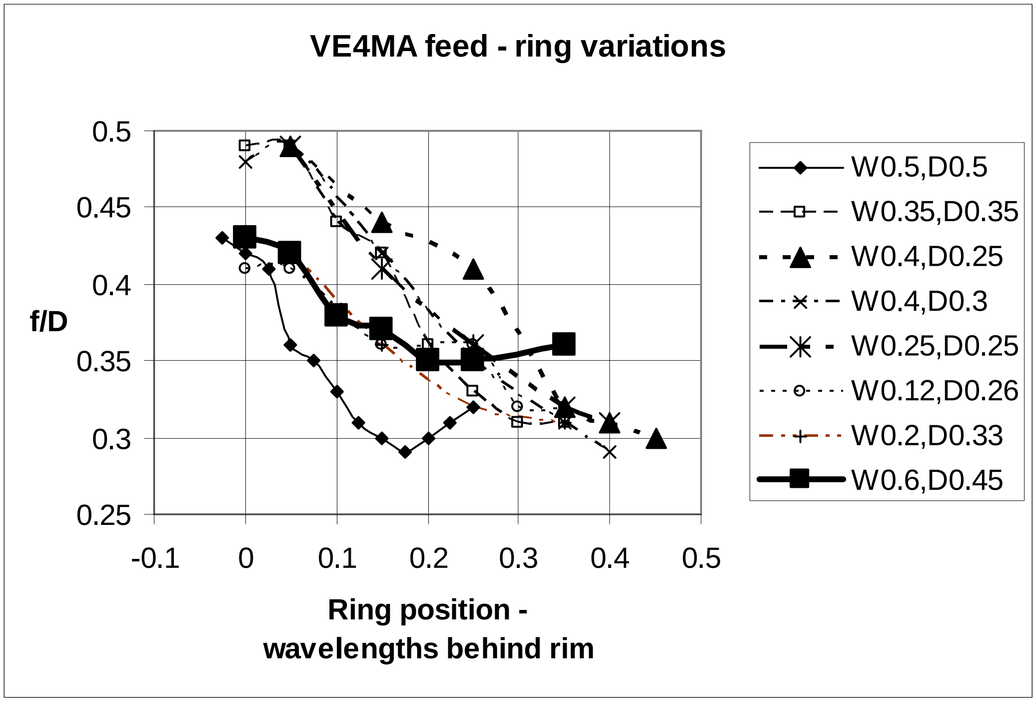


Figure 14

When we look at a wide range of ring sizes in Figure 15, we see that there is a range of ring sizes that does not work well: widths around 0.55λ wide with depths less than about 0.5λ provide low efficiency. This may be the other side of the resonance. Appendix B probably shows all the details more clearly.

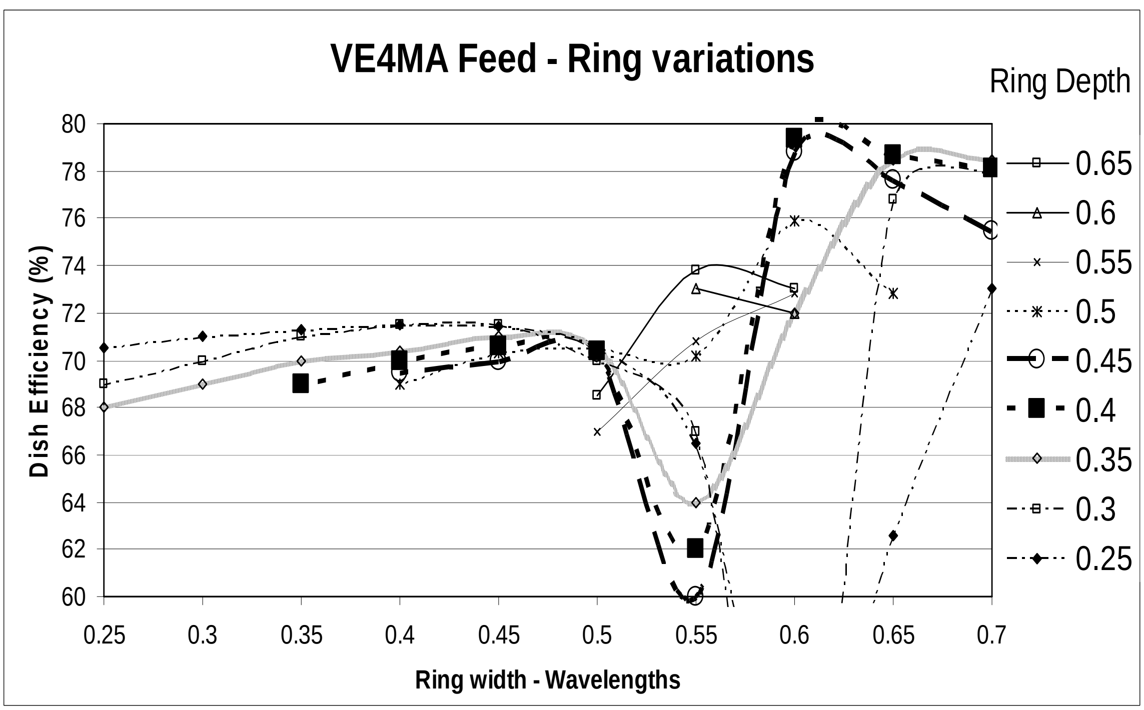


Figure 15

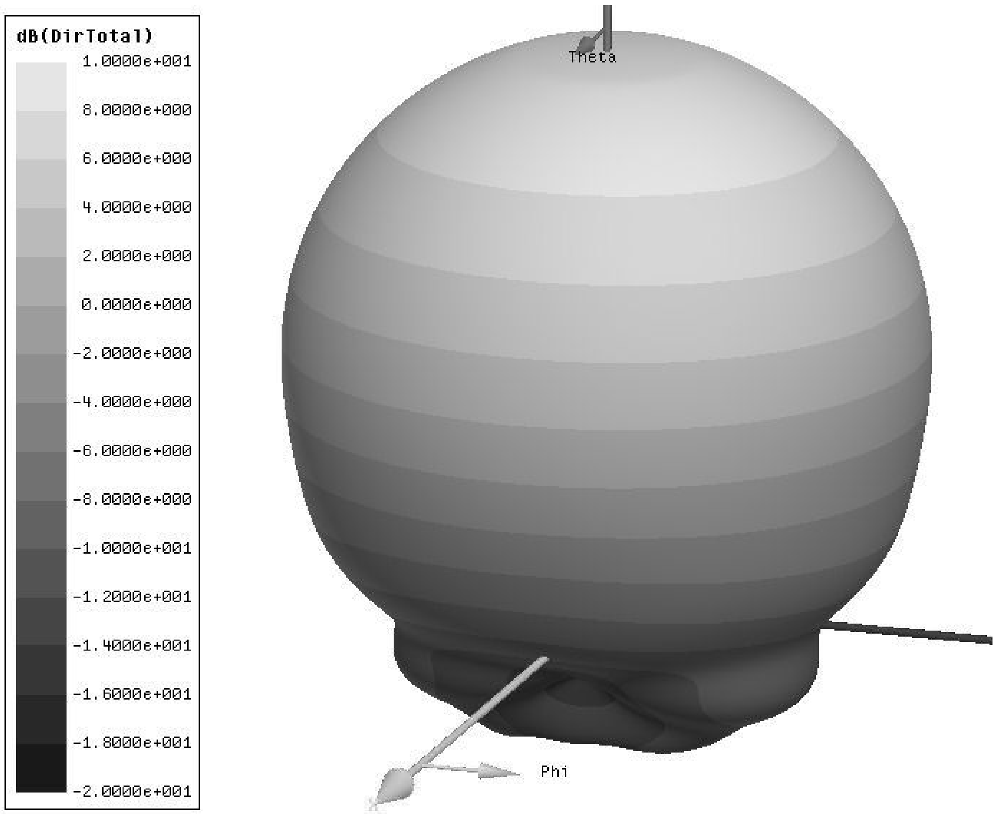


Figure 16 Small VE4MA feed, ring 0.4λ wide x 0.3λ deep, flush with rim

Also worth noting are the radiation patterns produced by these horns as the ring position is varied. With the ring forward, flush with the rim of the circular waveguide at the aperture, the patterns are similar to the typical feed in Figure 1. An example of a 3D pattern with the rim flush is shown in Figure 16, and the efficiency plot, Figure 17, shows that this position is best for a dish with ***f*/D** around 0.45 to 0.5. As the ring is moved back, the pattern broadens with the maximum moving away from the center for improved efficiency – this is more pronounced in the E-plane. Figure 18 is a 3D example of this pattern shape, for the original VE4MA dimensions. The efficiency plot for this pattern in Figure 3 shows that moving the ring back is better for deep dishes, with ***f*/D** as low as 0.3. The Super-VE4MA pattern in Figures 7 and 8 is much more axisymmetrical. As the ring is moved back, the back lobes become stronger, probably reducing efficiency slightly, but the maximum energy moves from the center of the dish toward the edge to provide bether illumination efficiency. Thus, the ring position seems to have a stronger effect on efficiency than on optimum ***f*/D**. Therefore, we may choose the ring dimensions to utilize available materials, and adjust the ring position for best efficiency, starting with the data in Appendix B and optimizing it using sun noise measurements.

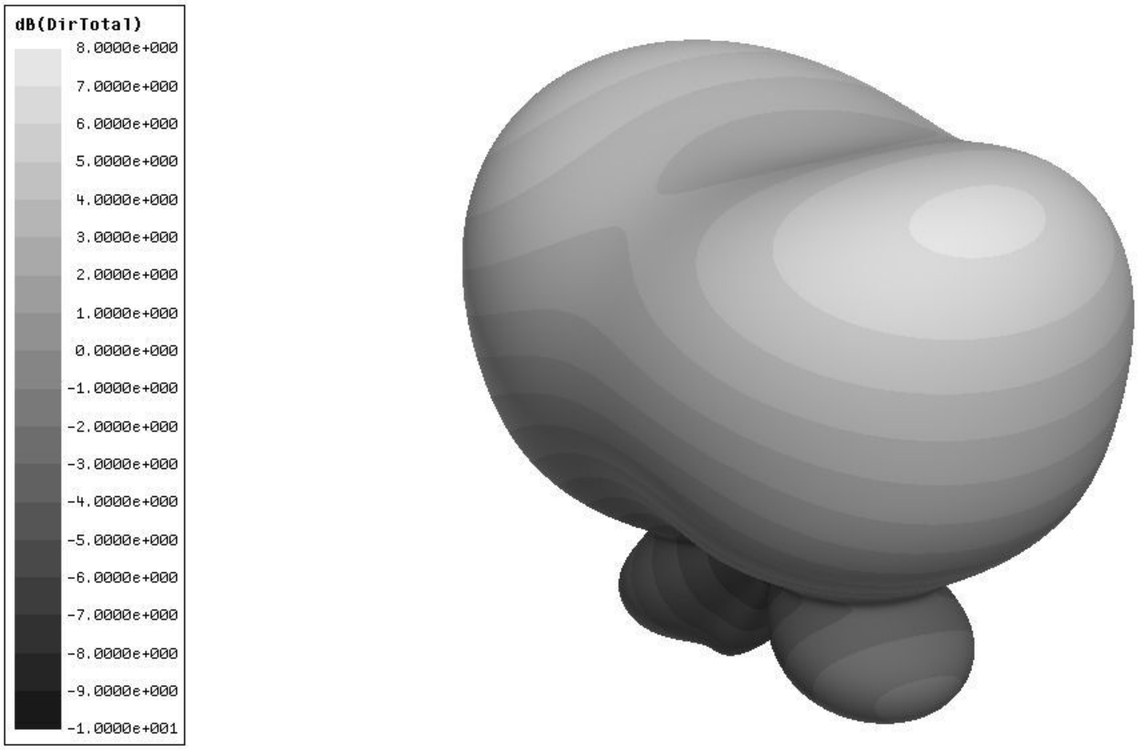


Figure 18 – Original VE4MA dimensions, ring 0.15λ behind rim

Phase Center

The phase center for all variations of the VE4MA feed is roughly at the center of the aperture, but varies a bit with different ring sizes and positions. The total variation is only quarter-wavelength or so, but a ¼λ error in axial position can lose a dB of gain for a deep dish, turning a good feed into a mediocre one. Therefore, we should consult Appendix B for the calculated phase center for each combination, followed by sun noise measurements for final adjustment.

Chaparral-style feeds

The Chaparral-style feed (Chaparral Communications makes them for satellite TV) has multiple smaller rings around the circular waveguide (Figure 19). The original description was a paper by Wohlleben[7], and the late Tay Howard, W6HD, was involved in the commercial development for Chaparral.

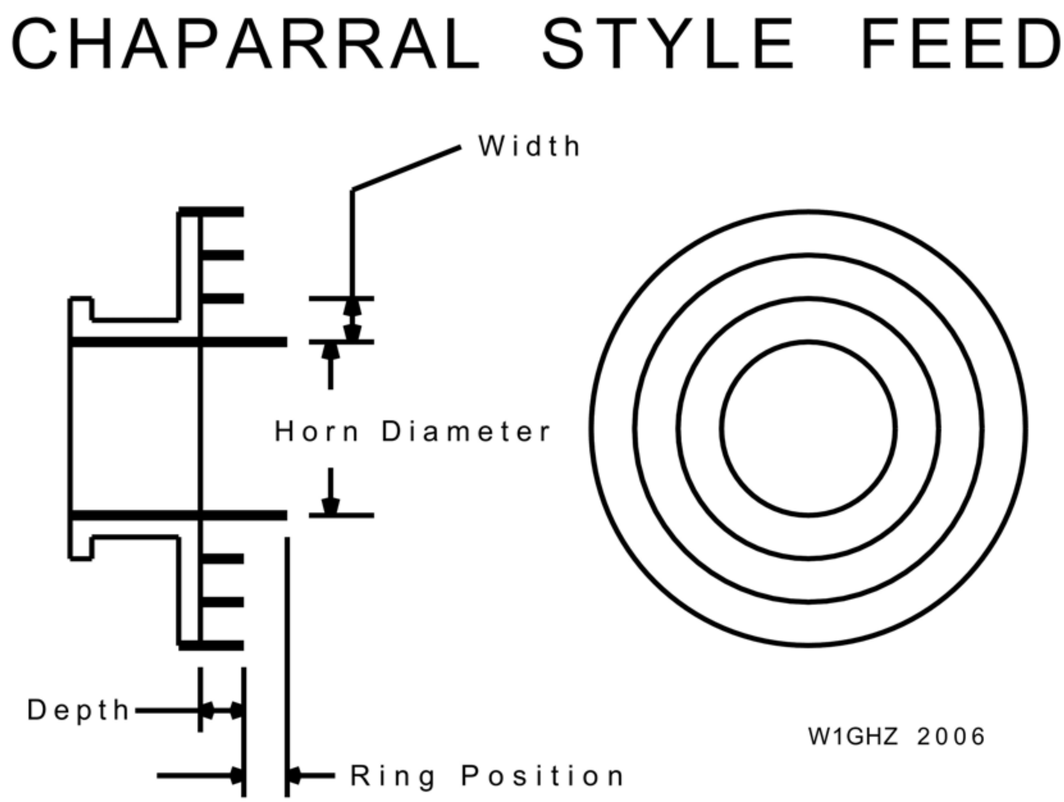


Figure 19

The multiple rings, typically slightly more than ¼λ deep and spaced less than ¼λ, create what electromagnetics professionals call a "soft" surface – one that reflects energy like a surface but does not conduct surface currents, thus reducing the edge currents that generate sidelobes. Adding the additional variable, multiple rings, to the horn makes a search for an optimum combination prohibitively large, so I limited analysis to combinations with uniform rings, so that all rings on each variation have the same width and depth. I started with some dimensions suggested by WD5AGO, then added a few variations to attempt to understand the effect of the multiple rings. Finally, the ring dimensions were varied to improve efficiency.

The first version has three rings, each 0.17λ wide and 0.3λ deep. The total width of the three rings is 0.51λ, almost exactly the same as the original VE4MA ring, so there is no blockage penalty for the additional rings; both feeds have a total shadow 1.7λ in diameter. The performance, summarized in Figure 20, shows higher efficiency than the original VE4MA, particularly for deeper dishes with ***f*/D** in the 0.3 to 0.4 range.

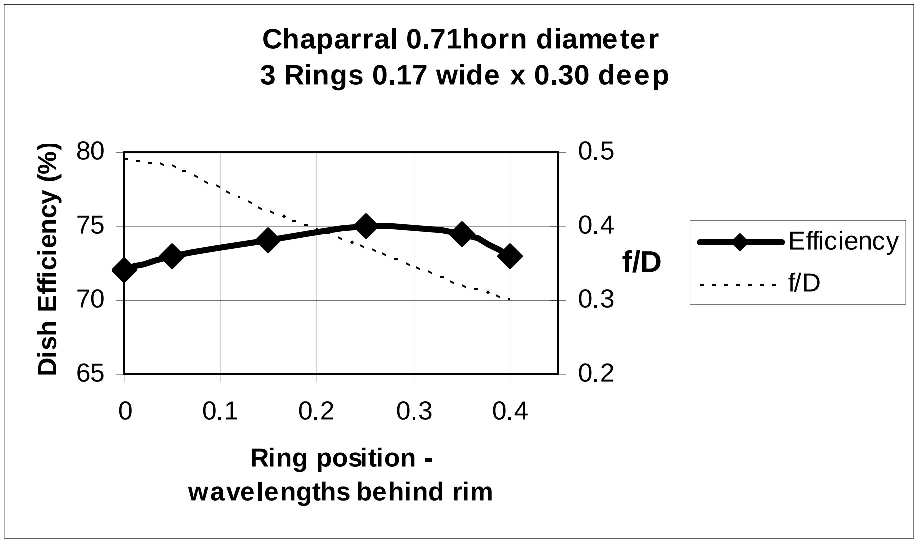


Figure 20

A second version has three rings, each 0.20λ wide and 0.33λ deep. The total width of 0.60λ adds slightly more blockage, 1.9λ in diameter, but the calculated efficiency is a bit higher, so it is worth considering for all but the smallest dishes. The super-VE4MA feed with the same blockage has even higher efficiency, but over a smaller range of ***f*/D**. Figure 21 compares these two Chaparral versions with the two VE4MA versions, original and Super – the improvements should be apparent.

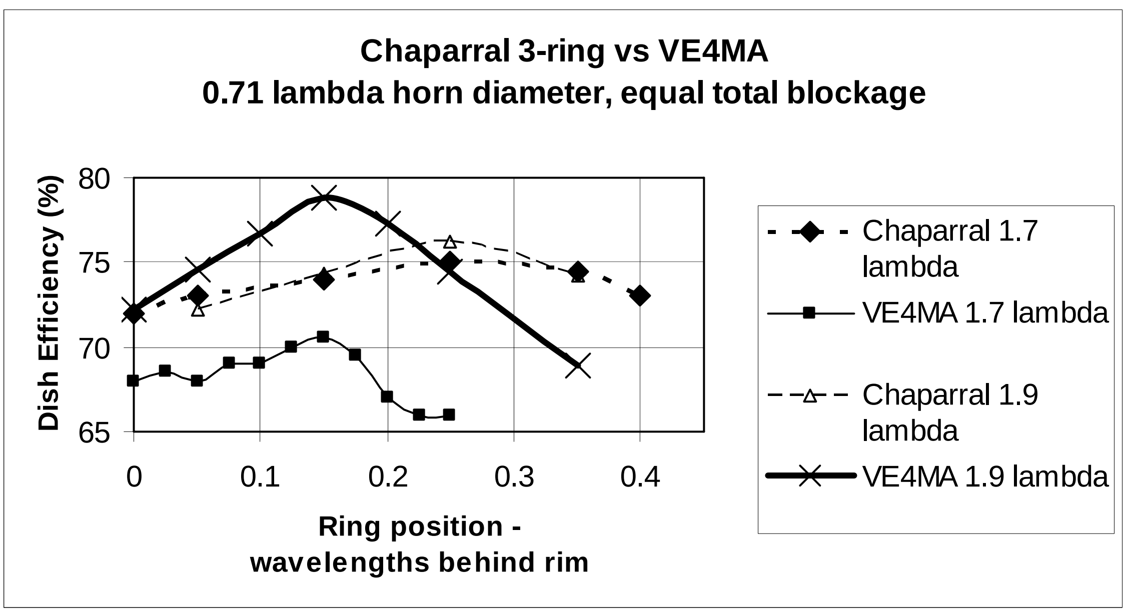


Figure 21

To see if the additional rings were beneficial, I tried versions with one, two, three, and four rings, each ring 0.20λ wide and 0.33λ deep. Figure 22 below shows that each additional ring increases dish efficiency, but it looks like the fourth ring is yielding diminishing returns.

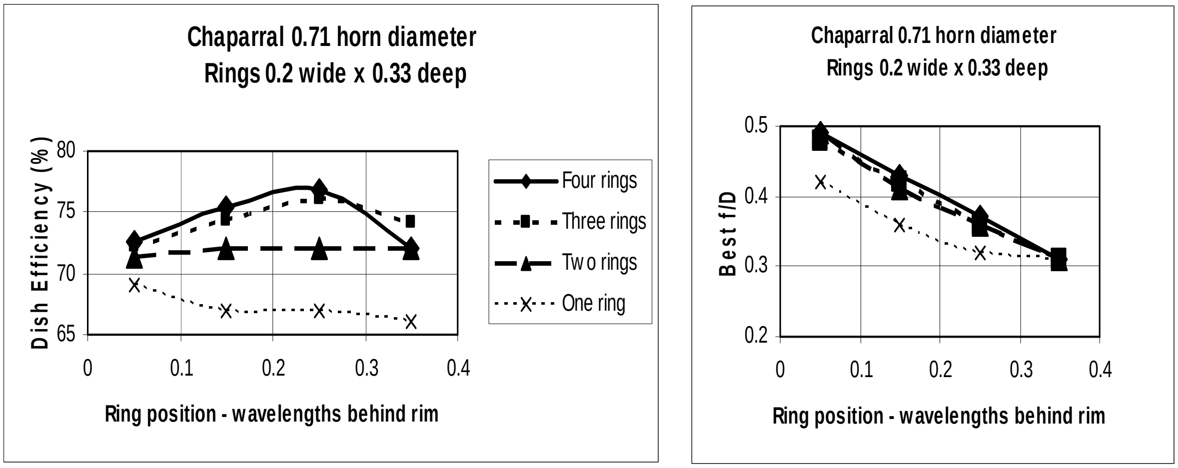


Figure 22

Is the increase in efficiency with more rings due to the number of rings or the larger size? To test this question, I tried two additional variants with the same overall width, 0.60λ, as the three ring version above: two rings, each 0.30λ wide, and four rings, each 0.15λ wide. Figure 23 suggests that that two or three rings are about equal, with excellent efficiency, but adding more rings, closely spaced, has no benefit. Efficiency is not quite as high as the super-VE4MA with the same blockage, but the Chaparral is better for deep dishes.

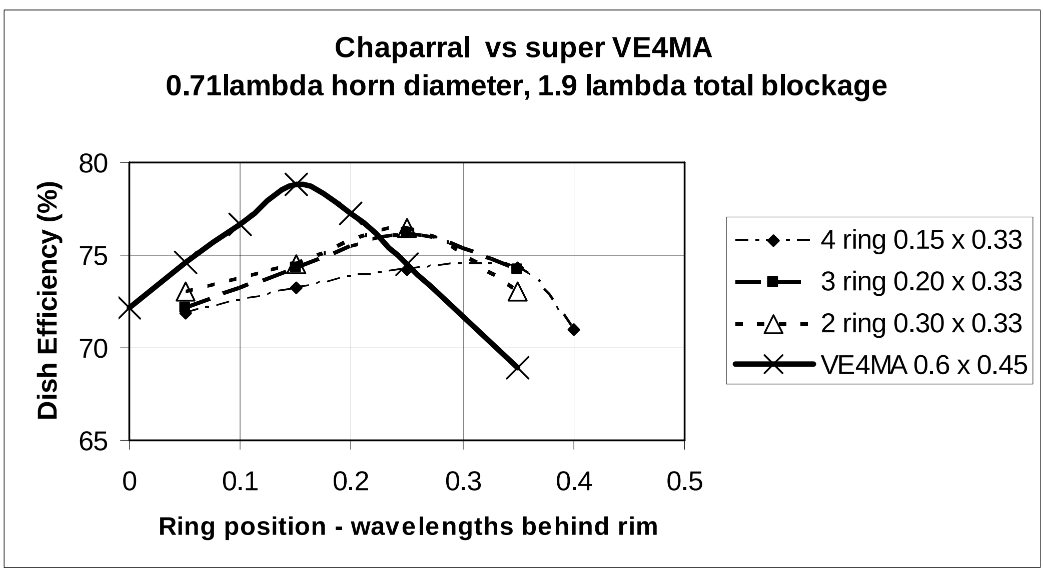


Figure 23

The next experiment was to vary ring width, with three rings. Figure 24 shows only a slight increase in efficiency as the width of each ring is increased from 0.17λ to 0.27λ - the small increase can probably be attributed to the much larger overall diameter of the horn. So neither additional rings nor very wide rings offer enough improvement to justify additional blockage.

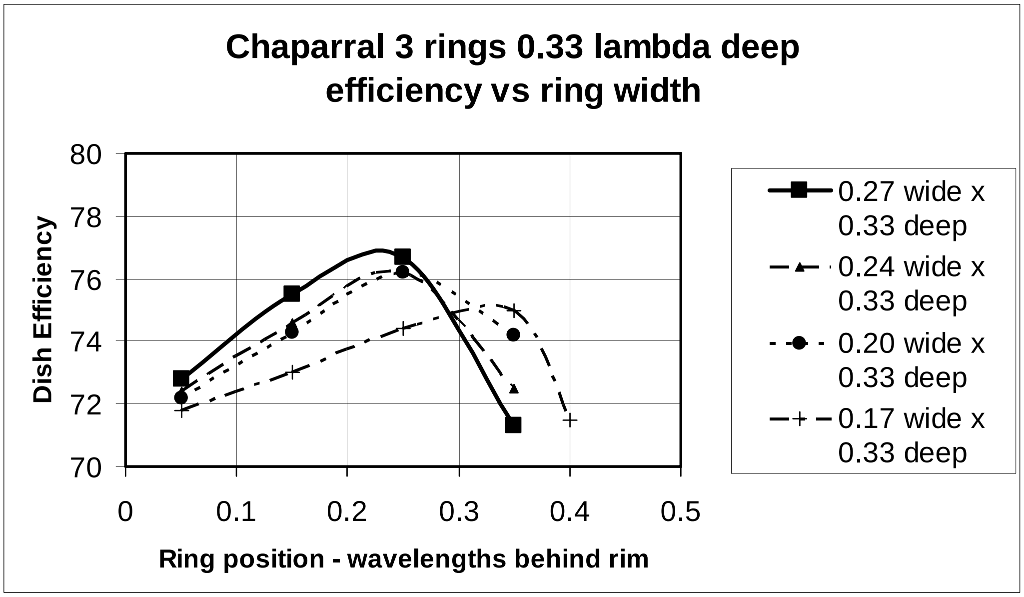


Figure 24

The final variable is ring depth. For large tapered corrugated horns with many rings, depths between ¼ λ and ½ λ have been shown[7] to work well, with performance degradation outside this range. For the three-ring Chaparral-style feed, however, efficiency increases as the ring depth is decreased from 0.33λ down to 0.15λ, then decreases for even shallower depths. For a ring width of 0.20λ, shown in Figure 25, best efficiency is nearly as good as the Super-VE4MA feed.

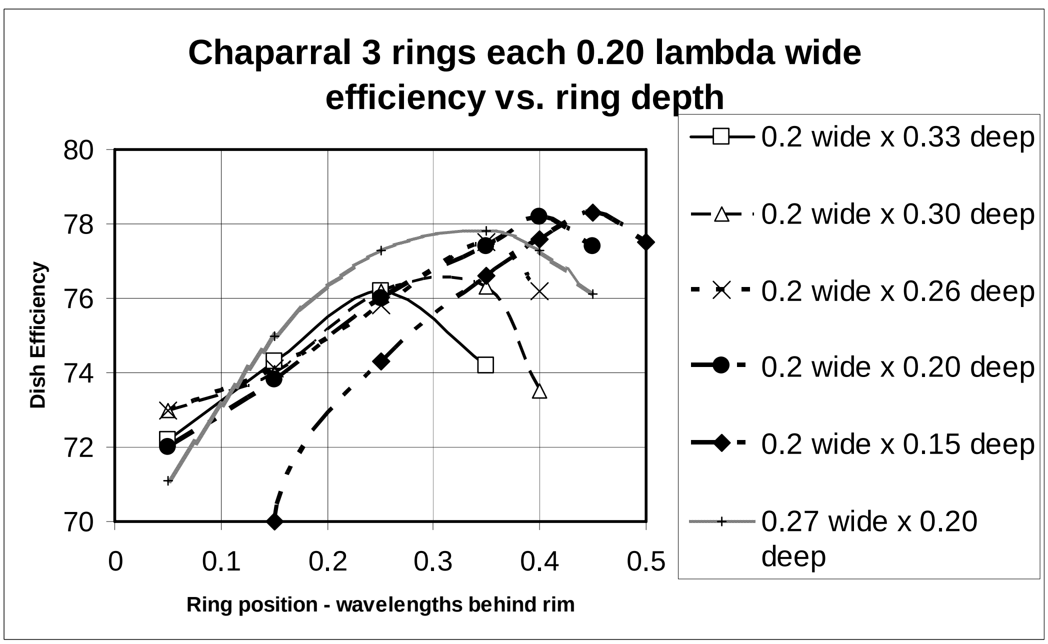


Figure 25

A narrower ring width, 0.17λ, shows similar behavior in Figure 26 as ring depth is decreased. Figure 27, plotting efficiency vs. ***f*/D** for some of the best Chaparral dimensions, suggests that the narrower rings are better for deeper dishes, with ***f*/D** < 0.35, than either the wider ring version or the Super-VE4MA feed. The calculated efficiencies for the best Chaparrals are nearly as high as the Super-VE4MA feed, and over a wider range of ***f*/D.**

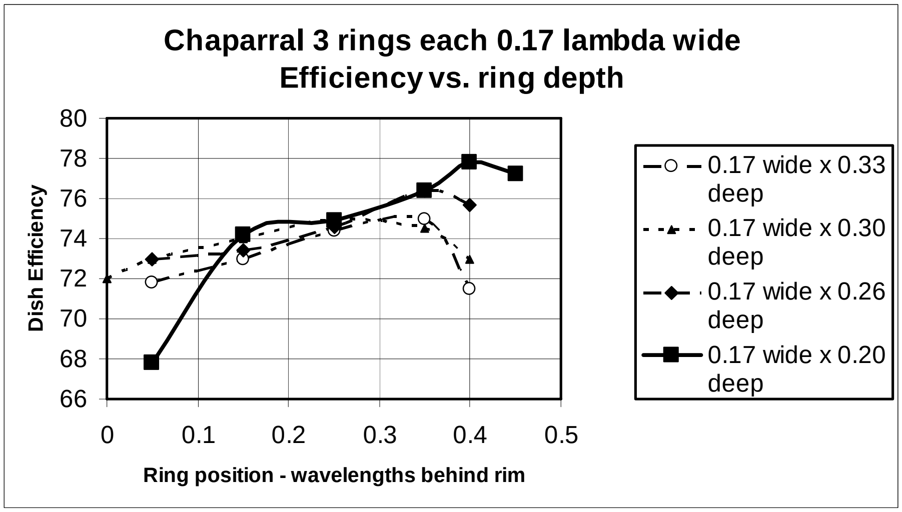


Figure 26

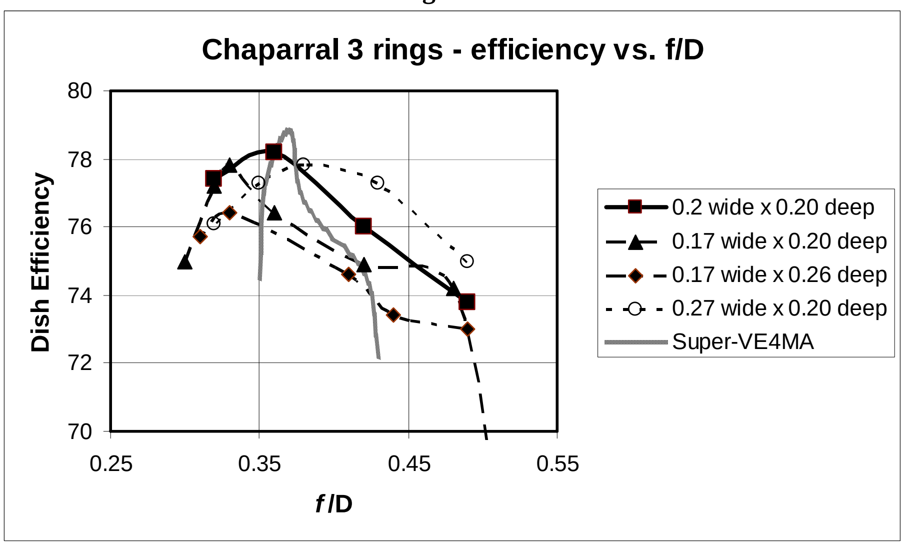


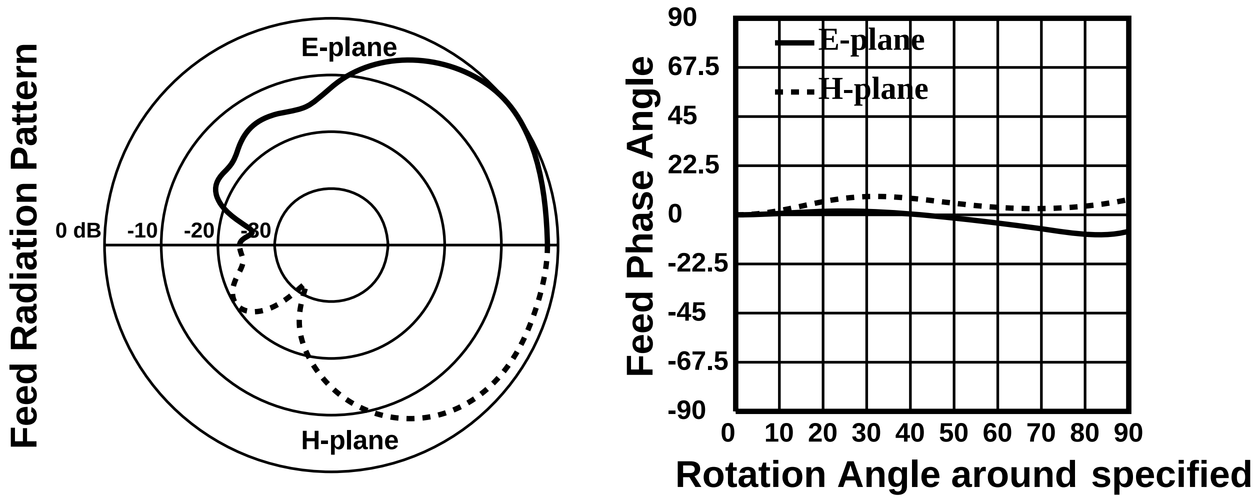
Figure 27

An efficiency plot for the highest efficiency Chaparral-style feed, with 3 rings 0.20λ wide x 0.20λ deep, 0.4λ behind the rim, is shown in Figure 28. Calculated best efficiency is 78.2% for an ***f*/D** around 0.35. A similar feed, with the same rings on a horn 0.76λ in diameter, has a calculated efficiency of 78.7%. Figure 29 shows that the horn diameter only makes a small difference. Sun noise measurements by WD5AGO, in Appendix A, on these two feeds measured 64% efficiency for the 0.76λ horn diameter and 63% for the 0.71λ horn diameter. Thus, both calculated and measured efficiencies are only slightly lower than the Super-VE4MA feed – by 1% and 2% respectively.

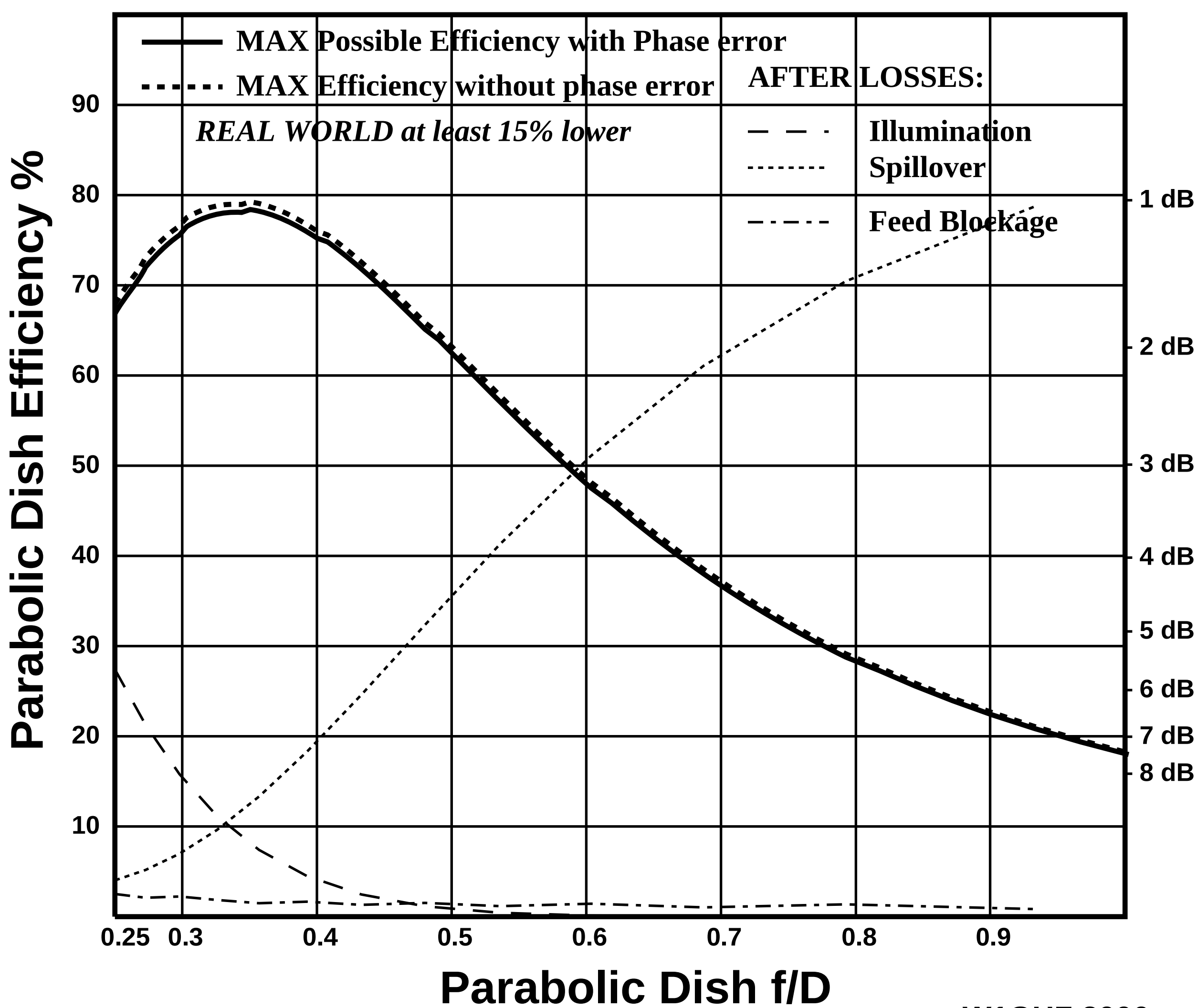
An efficiency plot of the dimensions that looks best for very deep dishes, with 3 rings 0.17λ wide x 0.26λ deep positioned 0.4λ behind the rim in Figure 30 shows pretty good efficiency for ***f*/D** as low as 0.25 – 71%. This is much better than other feed choice for these very deep dishes, as good as the original VE4MA feed on a shallower dish.

All the simulation data for the Chaparral-style feeds is included in Appendix C. Nearly all combinations of dimensions offer quite good performance, making potential conversion of surplus feeds from other frequencies to ham bands attractive.

Chaparral Feed 0.71λ horn diameter
3 Rings 0.20λ wide x 0.20λ deep, 0.40λ behind rim
Figure 28



Dish diameter = 20 λ   Feed diameter = 1.7 λ   Phase Center = 0.04 λ inside aperture



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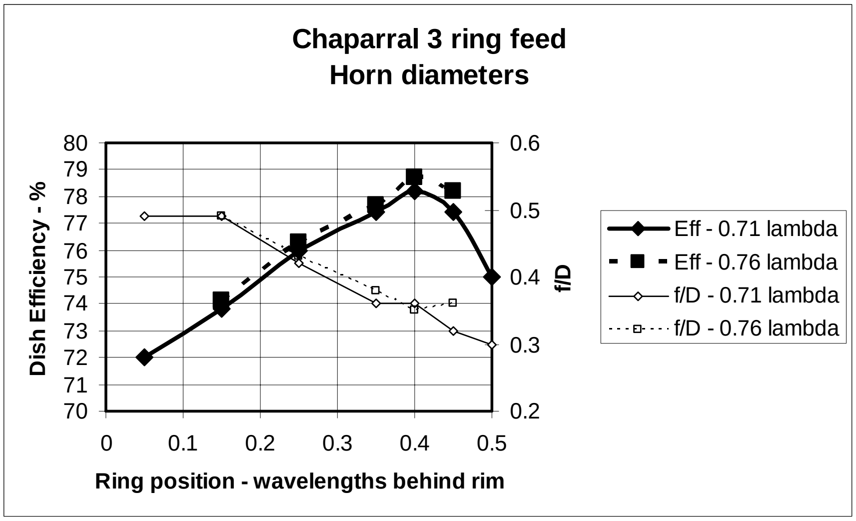


Figure 29

The radiation patterns from the Chaparral-style feeds do not demonstrate the large dip in the center that seems to provide improved illumination efficiency for the best VE4MA variations. The additional rings seem to simply reduce radiation in undesired lobes and put more even energy over a wide angle on the reflector, as seen in Figure 31, a 3D pattern for the feed in Figure 30 with 3 rings 0.17λ wide and 0.26λ deep, 0.4λ behind the rim.

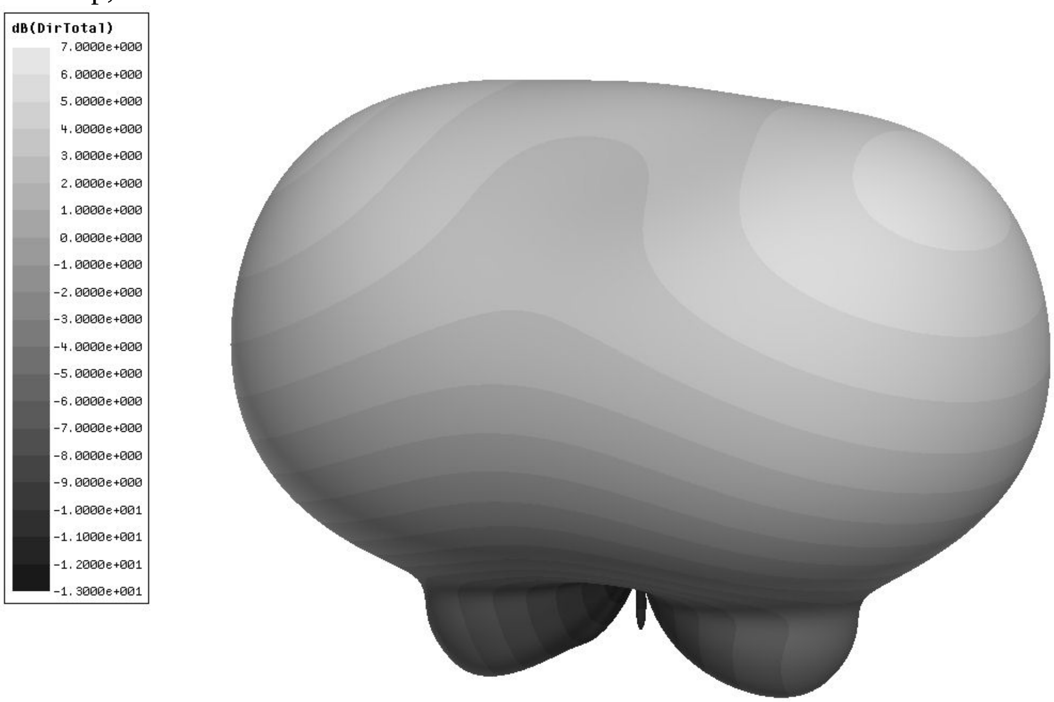
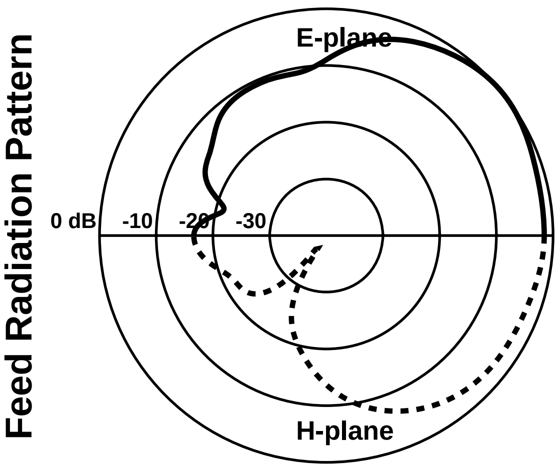
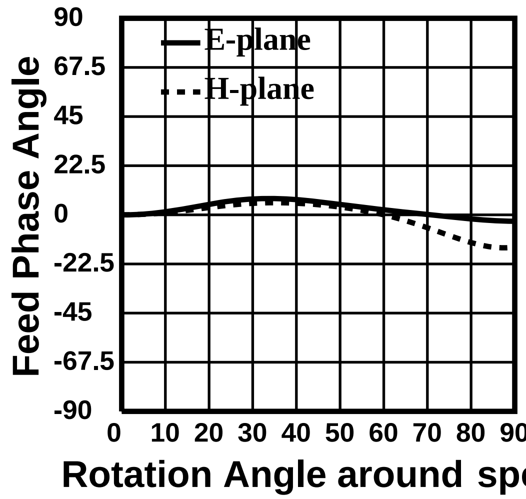


Figure 31. 3D pattern for Chaparral feed with 3 rings 0.17λ wide and 0.26λ deep, back 0.40λ

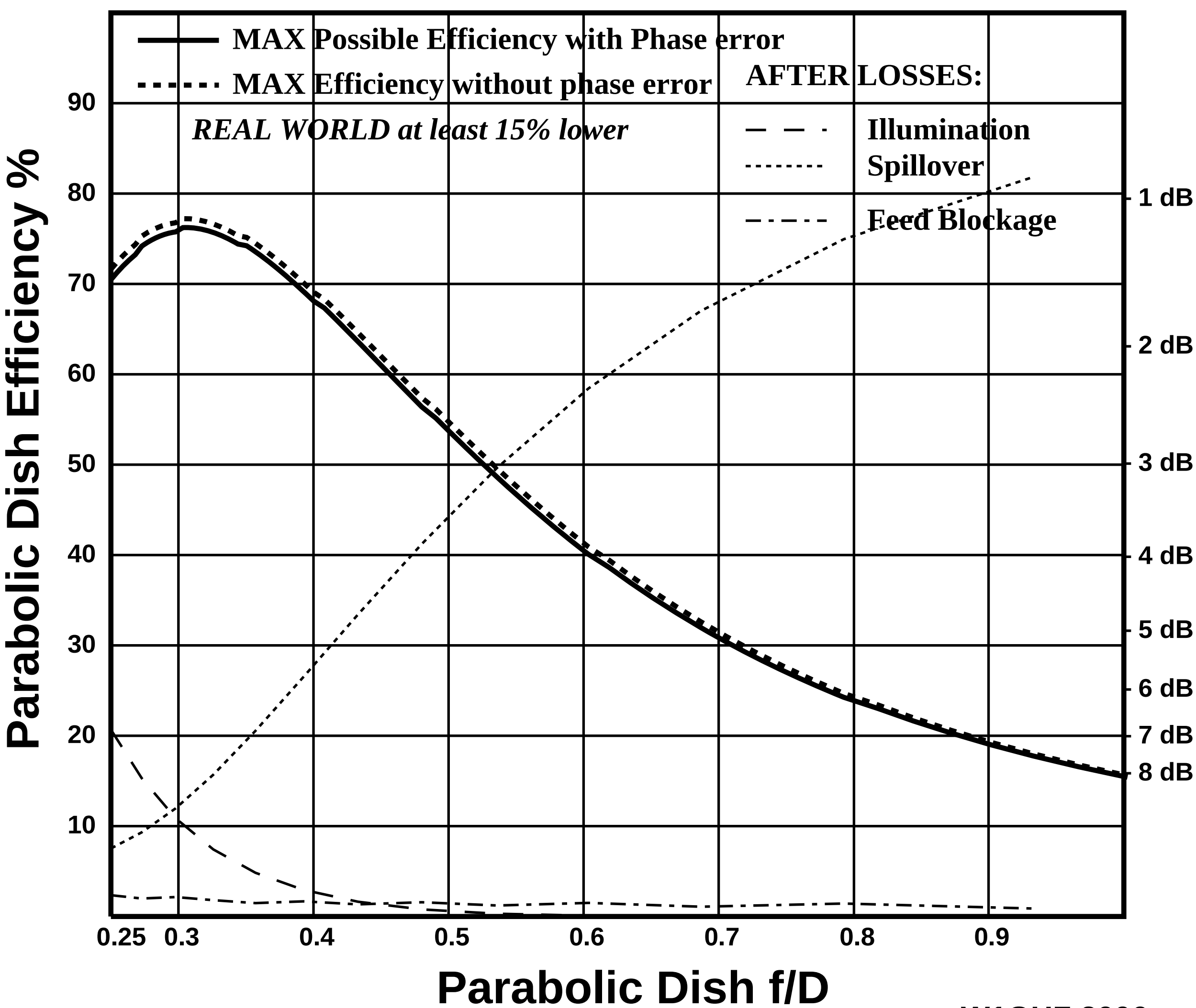
The advantage of the Chaparral-style feeds over the simpler VE4MA is very high efficiency over a wider range of ***f*/D**, and probably over a broader bandwidth. The bandwidth was not investigated explicitly, since all amateur operation is in relatively small bandwidths. However, the dimensions can be recalculated in wavelengths over a range of frequencies and performance at each frequency estimated from the data in Appendix C.

Chaparral Feed 0.71λ horn diameter
3 Rings 0.17λ wide x 0.26λ deep, 0.40λ behind rim
Figure 30





Dish diameter = 20 λ Feed diameter = 1.7 λ



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Septum Polarizer

All septum polarizers to date are based on one set of published dimension in square waveguide, from a paper by Chen and Tsandoulas[9], and adapted for ham use by OK1DFC[2]. Using the open-ended square waveguide as a feed provides reasonably good performance, about 70% efficiency for an ***f*/D** around 0.37, shown in Figure 32, but there is no way to make it adjustable for different ***f*/D.** The heavy lines in the Feed Radiation Pattern are RHCP, while the light broken line is for all polarizations – the rear lobes are not well polarized, but it does not matter since this is all spillover.

I previously[10] found that the same septum dimensions for square waveguide could be scaled to provide good circular polarization in circular waveguide of 0.71λ diameter. With the septum, circularly-polarized performance of an open-ended circular waveguide as a feed, shown in Figure 33, is comparable to linear polarization, in Figure 4, but not as good as the square version. However, the round version of the septum polarizer is compatible with the VE4MA and Chaparral feeds.

I first made some attempts to improve on the septum in circular waveguide, but with confusing results. I finally realized that the isolation is seriously affected by the horn – any mismatch at the aperture (typically 10 to 15 dB return loss), between the horn and free space, is reflected back to the other port as reduced isolation between the two polarizations. Feeding a prime focus dish, the problem is even worse: reflection from the shadowed portion of the reflector, perhaps 15 dB down, has reversed polarity so that isolation is compromised. Therefore, attempts to achieve high isolation in the feed, separate from the dish, are rather futile!

We can demonstrate the effect of any mismatch in software, by placing a "Perfectly Matched Layer" over the aperture, so that there is no reflection. Of course, this layer only exists in software. In Figure 34 below, isolation and return loss of the open-ended waveguide, on the left, is compared with the perfectly-matched aperture on the right. The matched aperture shows better isolation over a wider frequency range. More important, changes to the aperture, by adding rings or horns, will affect the isolation.

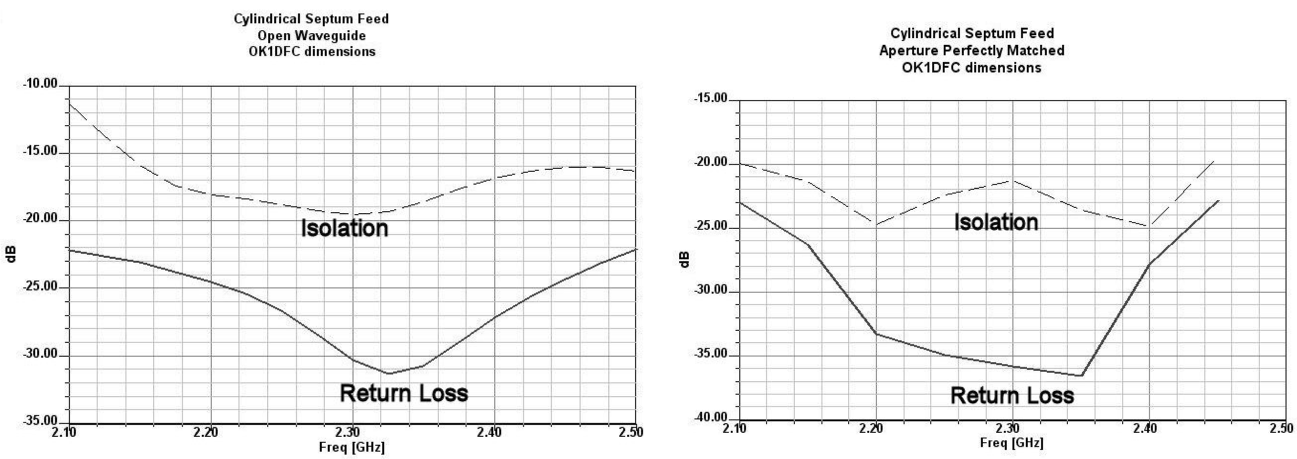
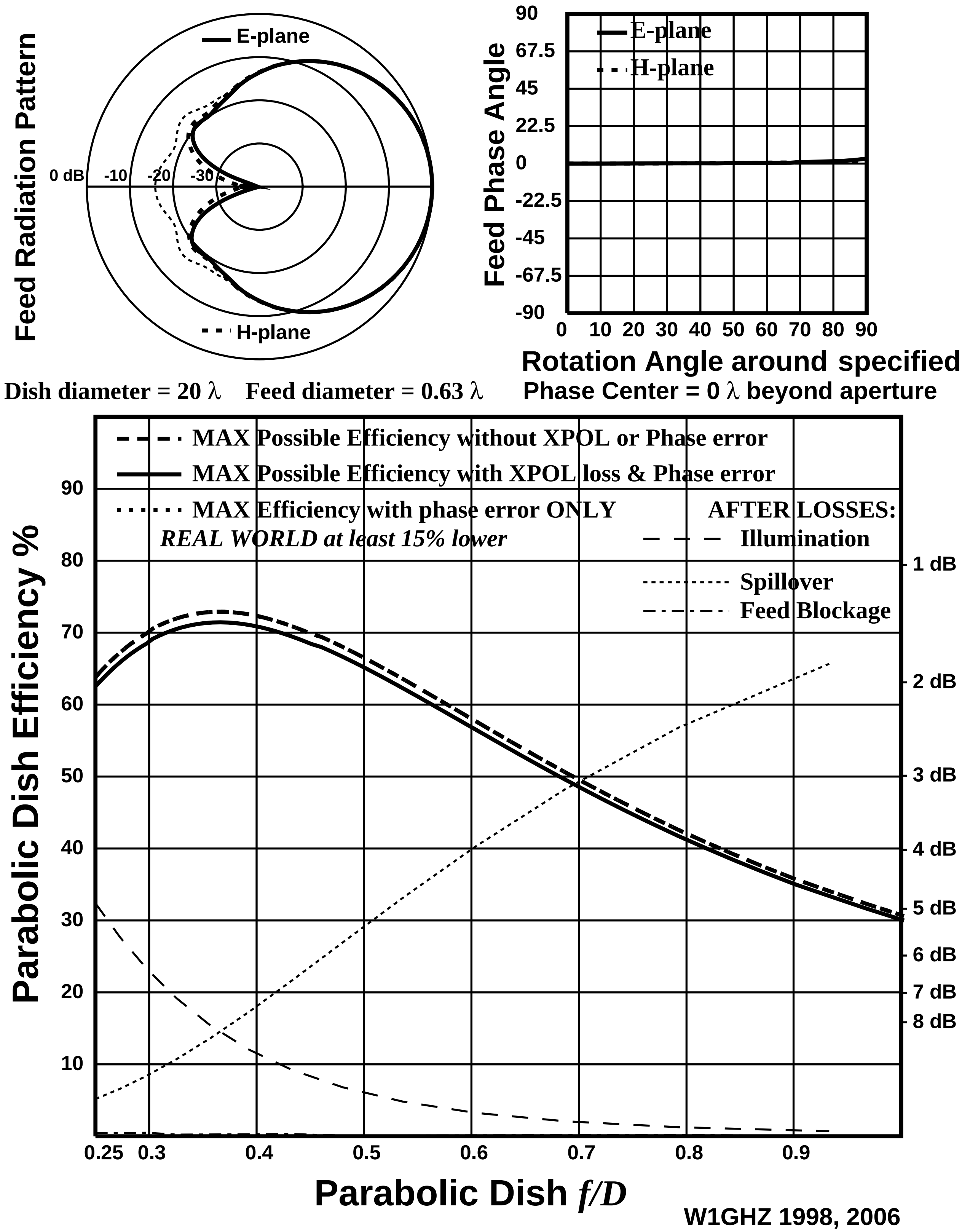


Figure 34

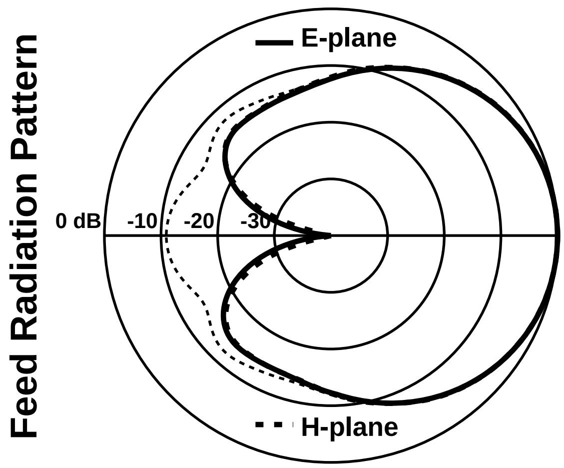
OK1DFC square septum feed

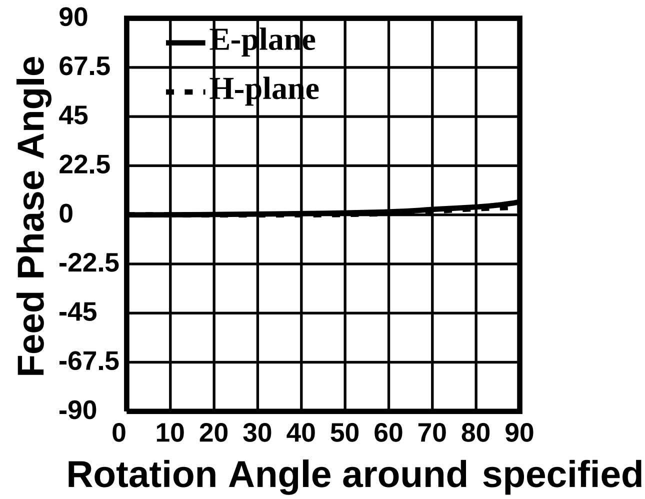
Figure 32



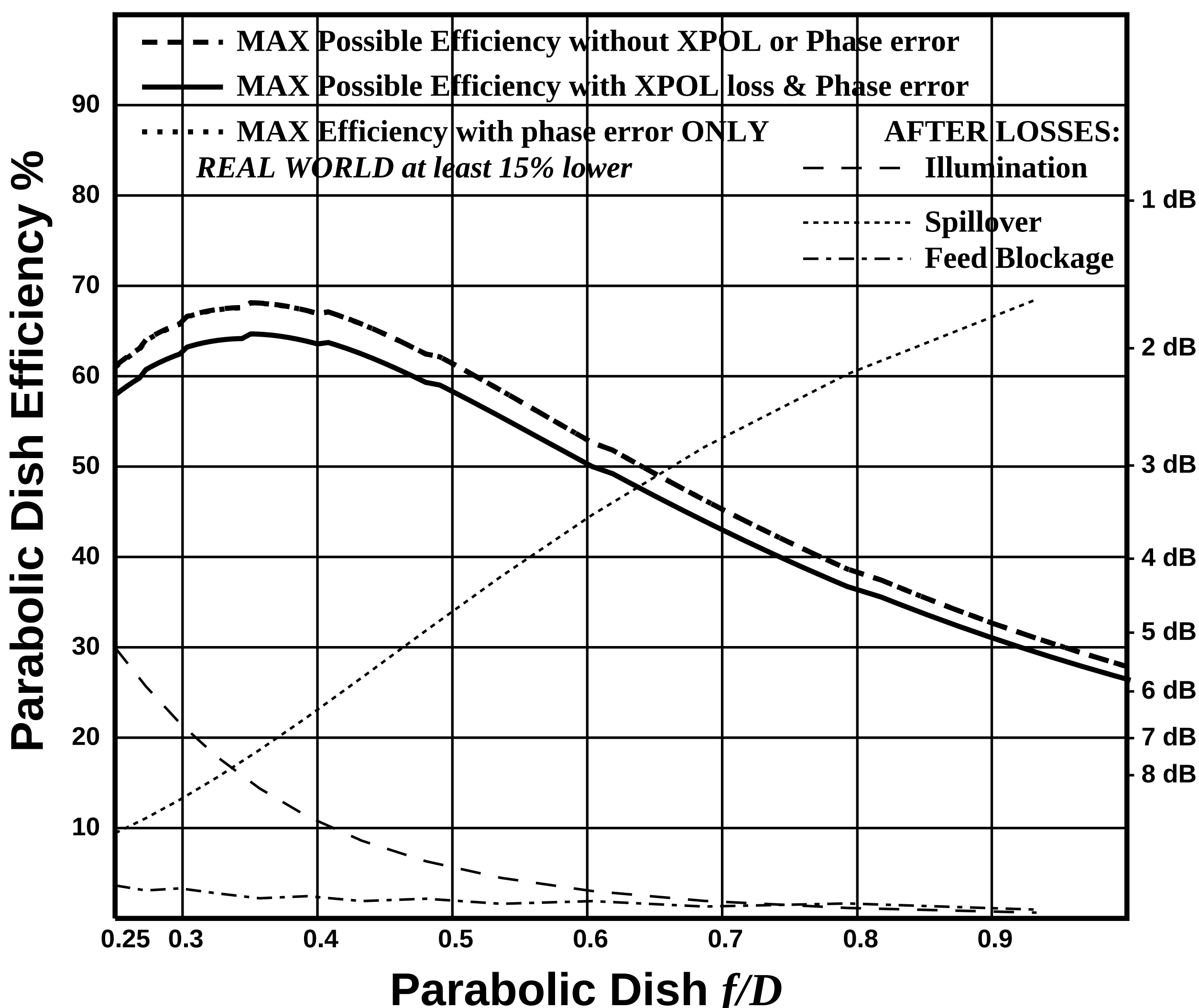
Circular septum feed 0.71λ diameter, no ring

Figure 33





Dish diameter = 20 λ   Feed diameter = 1.7 λ   Phase Center = 0 λ beyond aperture



W1GHZ 1998, 2006

Another paper with septum dimensions, by Bornemann and Labay[11], suggests that a thicker septum may improve isolation. A few quick trials suggest this may be true in square waveguide, which could be useful for higher-frequency septums, where machining the whole polarizer from solid metal might be easier than assembly of small parts. A more important observation was that septum dimensions and thickness had no effect on antenna pattern or performance. This is better demonstrated by simulations of feeds excited by pure circular polarization (easy in software). Comparison of these simulations with the same feed with a septum polarizer shows little difference in antenna performance. Thus, we may conclude that any polarizer providing good circular polarization will also provide good antenna performance. The septum polarizer offers good circular polarization with no adjustment, and with lower loss than some other choices.

VE4MA horn with septum polarizer

Several variations of the VE4MA horn were also simulated with a septum polarizer. The results for the original ring dimensions, 0.5λ wide and 0.5λ deep, are summarized in Figure 35, and compared with linear polarization. Efficiencies are similar, but very slightly lower for circular polarization, and the best ***f*/D** at each ring position is unchanged.

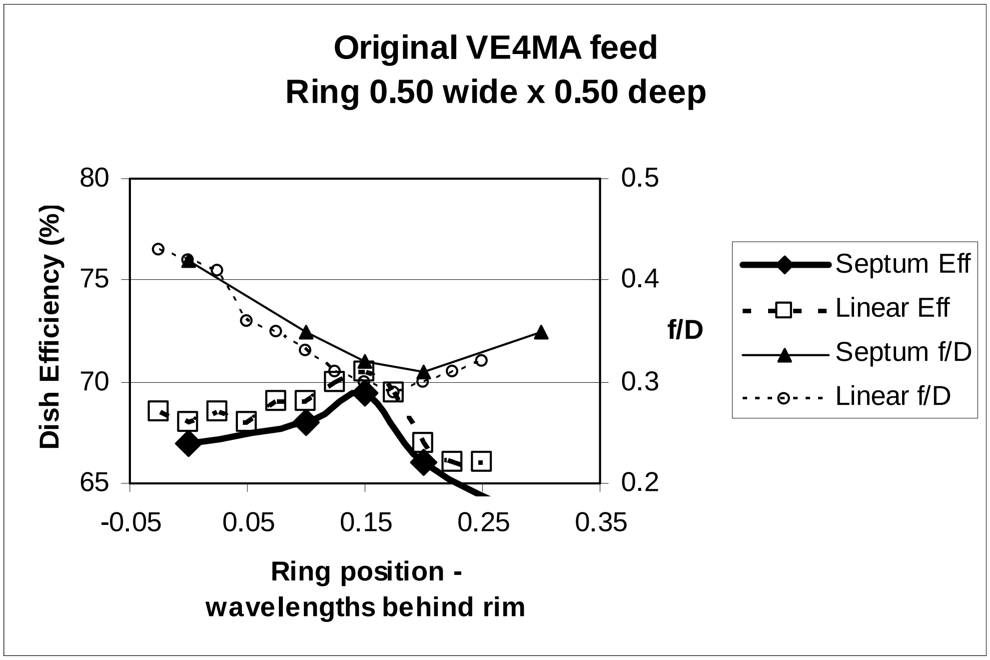


Figure 35. Original VE4MA feed, circular and linear polarization

Two of the versions with smaller rings are compared in Figure 36, with a ring 0.4λ wide and 0.25λ deep, and Figure 37, with a ring 0.35λ wide and 0.35λ deep. For both of these cases, the efficiencies for ***f*/D** greater than about 0.35 for linear and circular polarization are about equal. However, for deep dishes, with ***f*/D** < 0.35, efficiency improves with linear polarization and decreases with circular polarization. Again, the best ***f*/D** at each ring position, as well as the phase center, not shown, do not change with polarization.

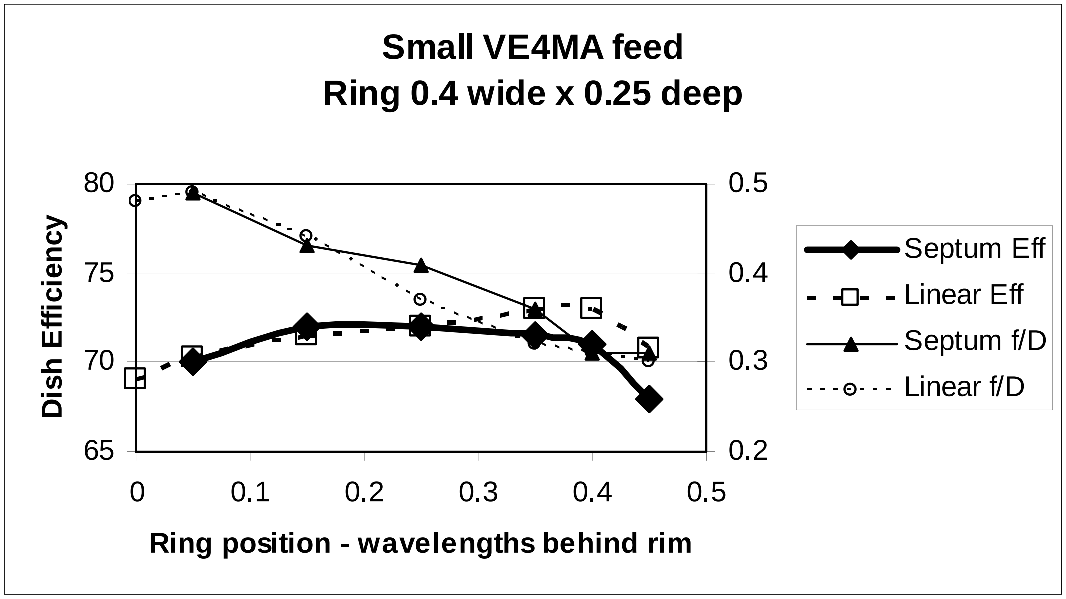


Figure 36

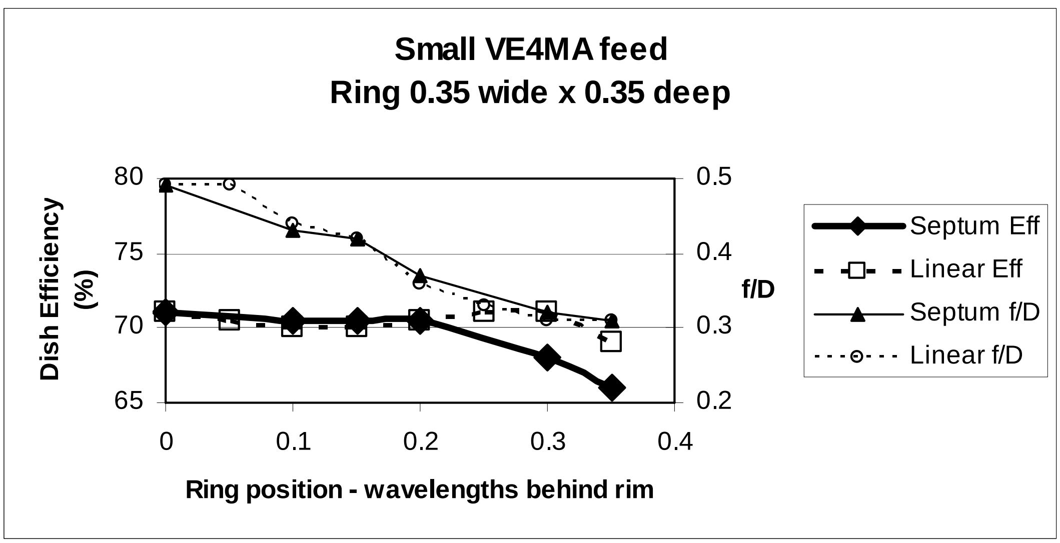


Figure 37

The version with the 0.35λ wide and 0.35λ deep ring was also examined over a range of frequency, summarized in Figure 38. Efficiency was good from 2.3 to 2.6 GHz, better than 10% bandwidth, while isolation peaked at 2.3 GHz.

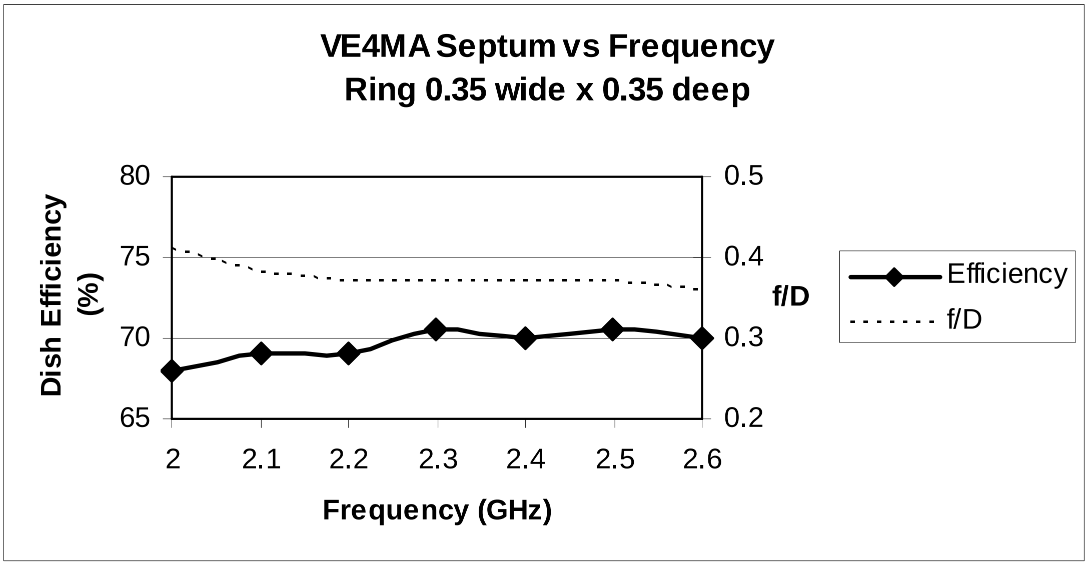


Figure 38

The Super VE4MA works with well with a septum feed, showing efficiency comparable to linear polarization at all ring positions in Figure 39, but the best ***f*/D** range is still fairly limited, around 0.35 to 0.45. The 3D radiation pattern in Figure 40 shows the dip at boresight like our desired illumination in Figure 1.

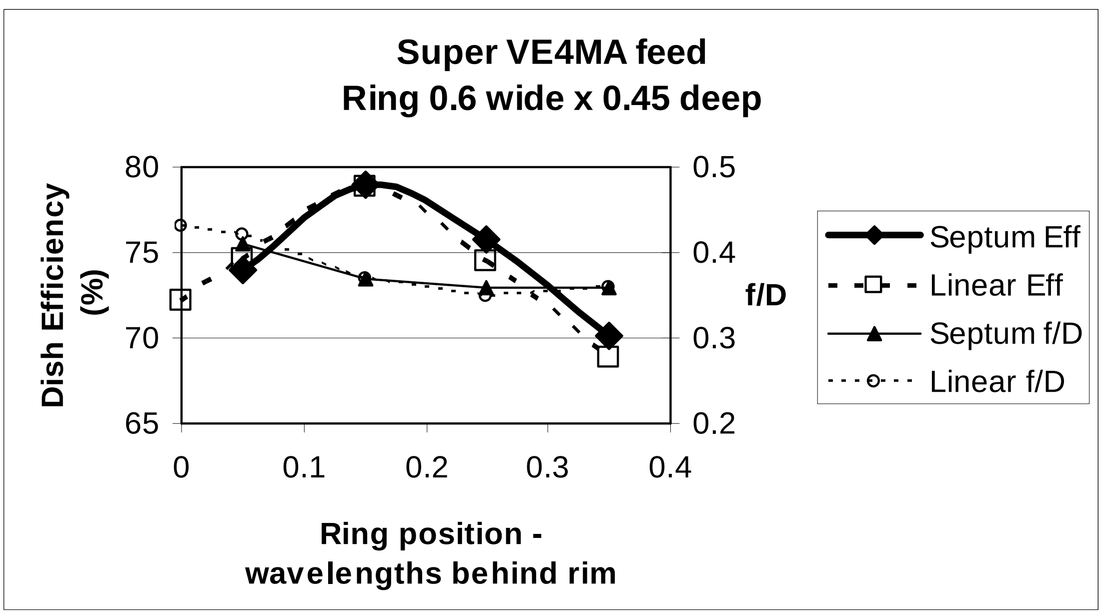


Figure 39

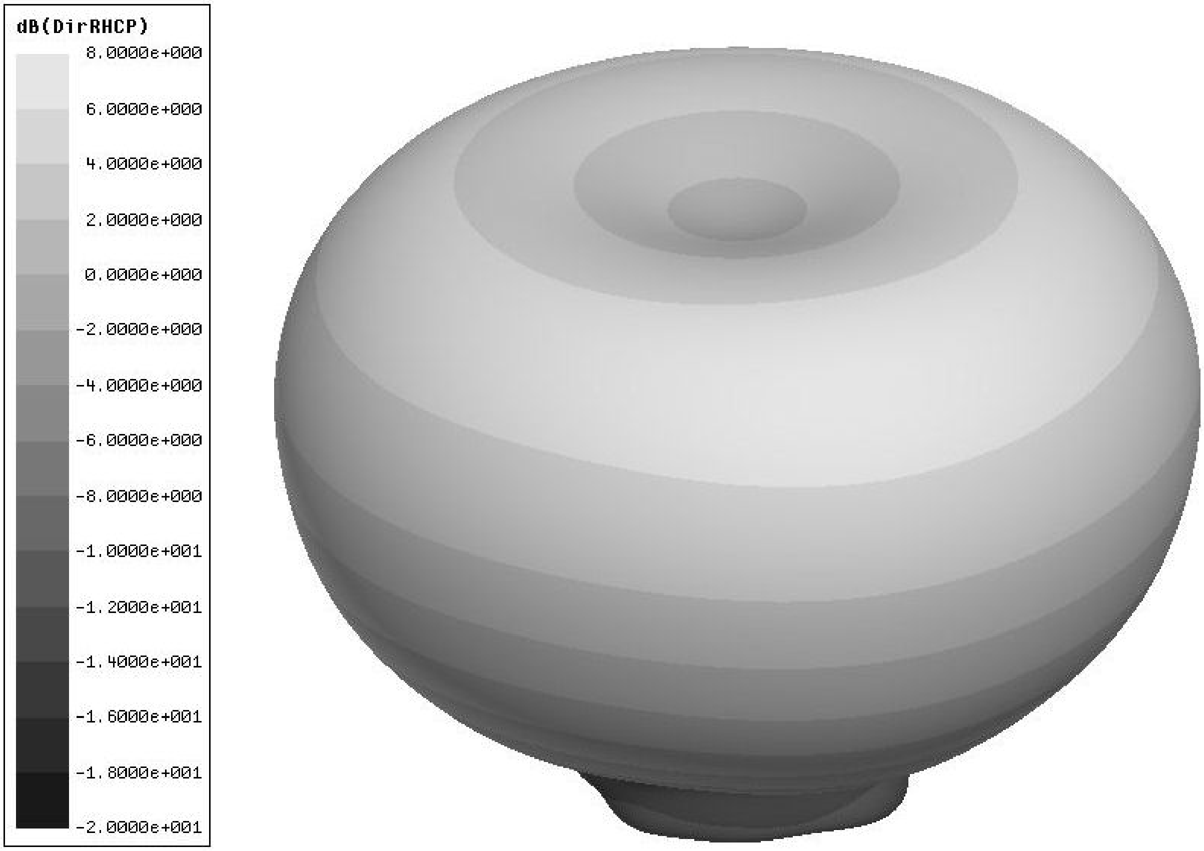


Figure 40. Super VE4MA feed with Septum Polarizer, 3D pattern

The apparent cause of the poorer CP performance at small ***f*/D** is that the circularity is not good at wide illumination angles (theta). Frequently, the circularity of a CP antenna is given for the boresight, but this is not important for a feed – the feed boresight is usually blocked. A CP feed must provide good circular polarization over the whole reflector. Usually, circularity is quantified by the axial ratio, the ratio of the horizontal and vertical components of the circular polarization. For perfect circular polarization, the components are equal and the axial ratio is 0dB. The larger the axial ratio, the more elliptical is the circular polarization. For perfect linear polarization, the axial ratio is infinite.

Measurement of the axial ratio over the whole pattern would be really difficult, but in simulation, it is just more numbers to crunch. For the version in Figure 37, with a ring 0.35λ wide and 0.35λ deep, the axial ratios are plotted in Figure 41 with the ring flush with the rim, providing good linear and CP efficiency for an ***f*/D** of 0.49, and in Figure 42 with the ring pulled back 0.3λ, providing good linear efficiency for an ***f*/D** of 0.31, but a few points lower (68 %, by no means terrible) for CP. In Figure 41, the axial ratio is better than 0.6 dB over an illumination half-angle of 60°, which covers the whole reflector, while in Figure 42, the axial ratio is better than 1 dB over only about 12° and falls off to 5 dB at the edge of the reflector, which subtends an illumination half-angle of 75° for ***f*/D** = 0.31.

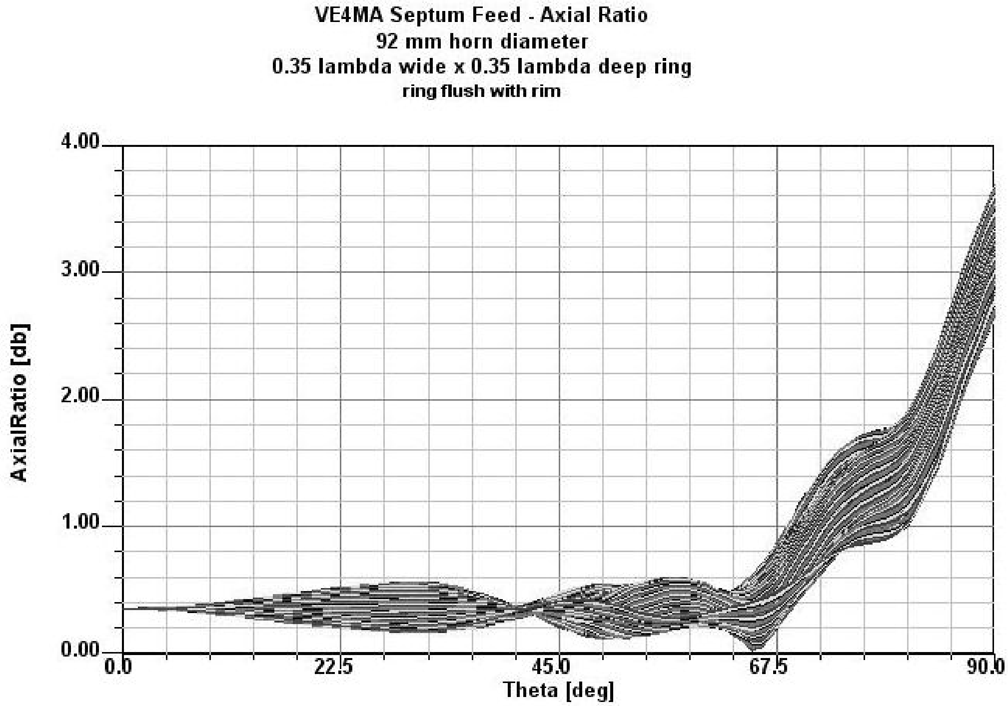


Figure 41

Figures 41 and 42 are plots of axial ratio not just in the **E-** and **H-planes**, but in a large number of planes, at one degree increments of rotation around the feed. Thus we can see how consistent the circular polarization is in three dimensions.

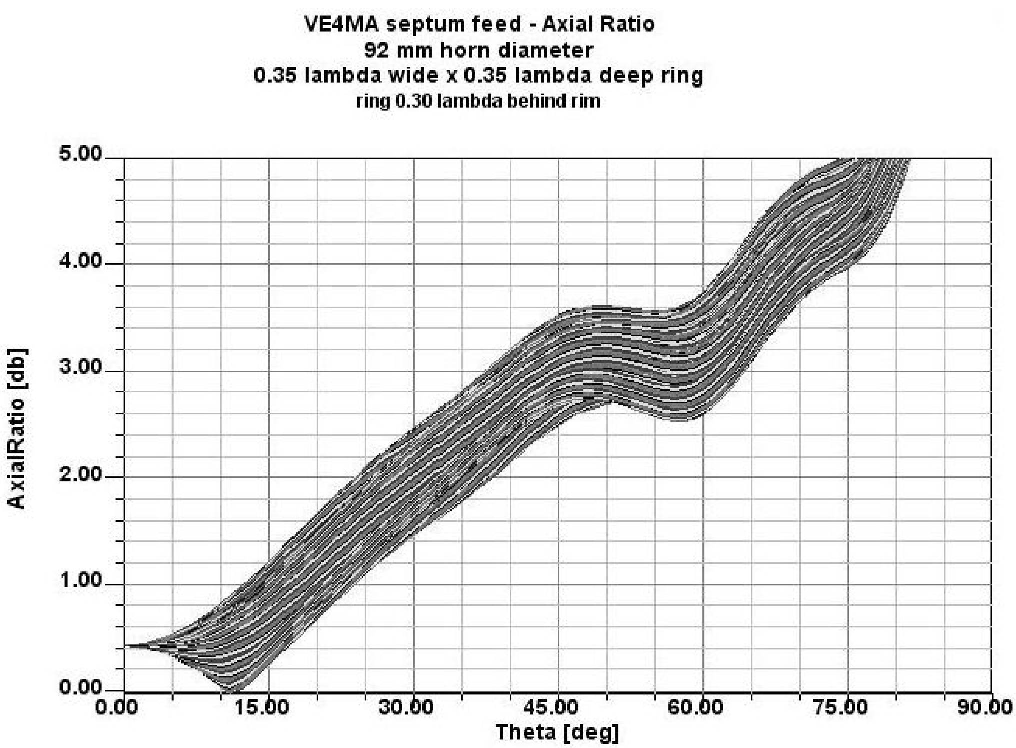


Figure 42

In summary, the VE4MA feed variations with a septum polarizer for circular polarization are better for moderately deep dishes, with ***f*/D** between 0.35 and 0.5.

What about bandwidth – since the septum polarizer is a relatively narrow-band device? In Figures 34, we saw that the septum alone has good isolation and return loss over about 200 MHz at 2.3 GHz. In Figure 43, the performance vs. frequency of a VE4MA feed with septum polarizer is shown. Clearly, it works fine as a circularly-polarized antenna over a wider bandwidth than would be indicated by the isolation and return loss, shown in Figure 44. The bandwidth is limited by the polarizer, not the antenna, but it is adequate to cover the entire 2.3 to 2.45 GHz band.

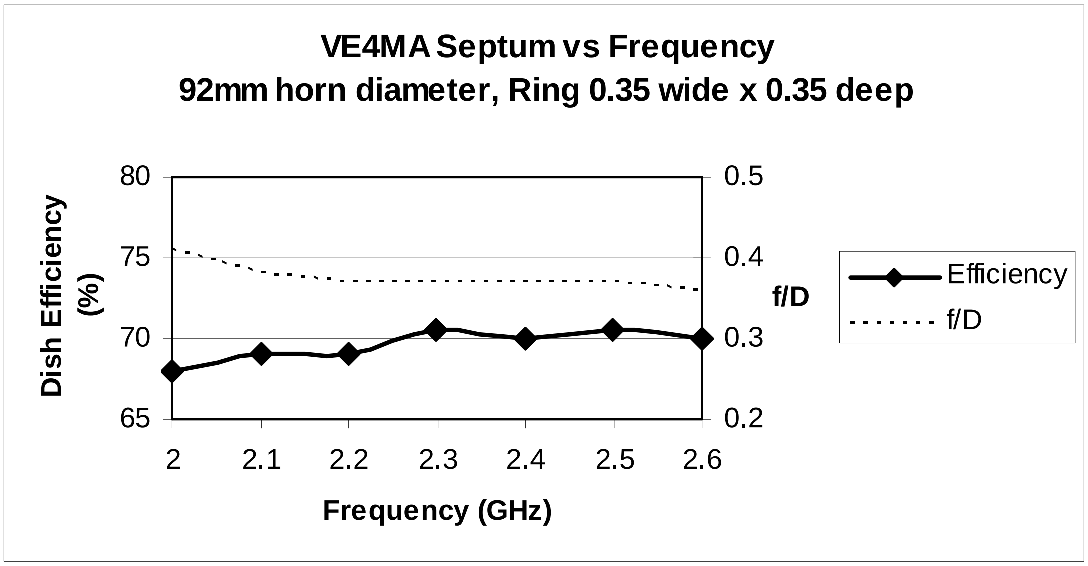


Figure 43

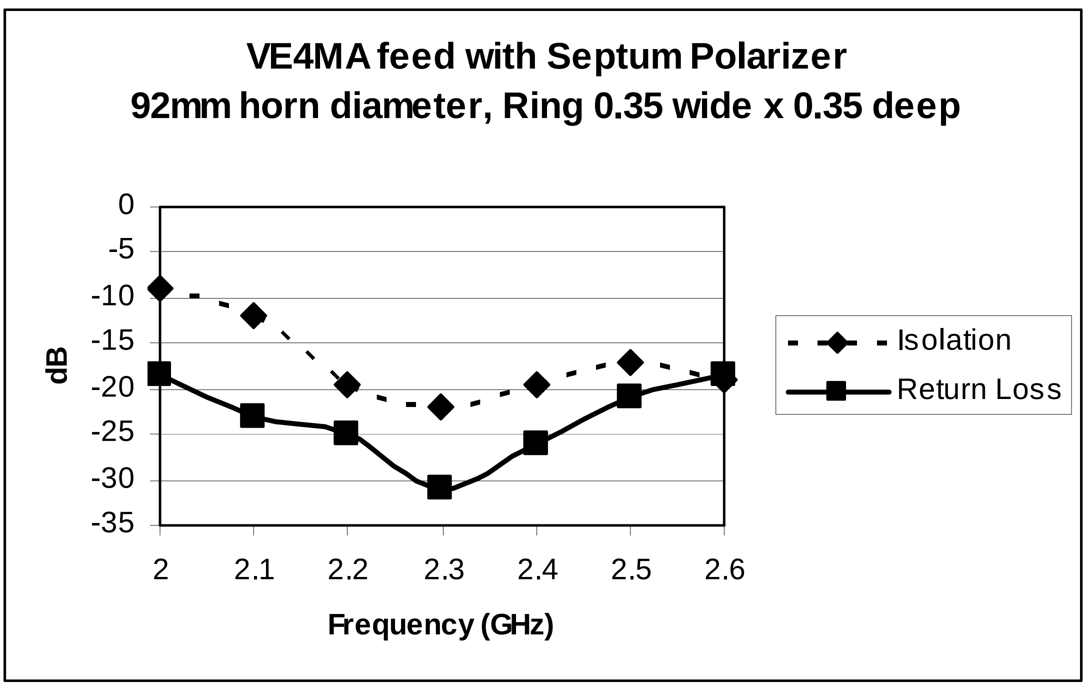


Figure 44

Chaparral horn with septum polarizer

Two of the examples above of a Chaparral horn with three rings were tried with a septum polarizer for circular polarization. The first, with three rings each 0.17λ wide and 0.30λ deep, was simulated over a range of choke positions with the septum polarizer. The results are summarized in Figure 45: efficiency with Circular Polarization is slightly lower for moderately deep dishes, ***f*/D** >0.31, but slightly better for deeper dishes. Note that it is still very good at all positions. The position with best efficiency, 0.35λ behind the rim, provides probably the best CP efficiency available for very deep dishes: 75% for ***f*/D** = 0.32, and still very good at 70% for ***f*/D** = 0.25, as shown in Figure 46. Again, the heavy lines in the Feed Radiation Pattern are RHCP and the light broken line is for all polarizations.

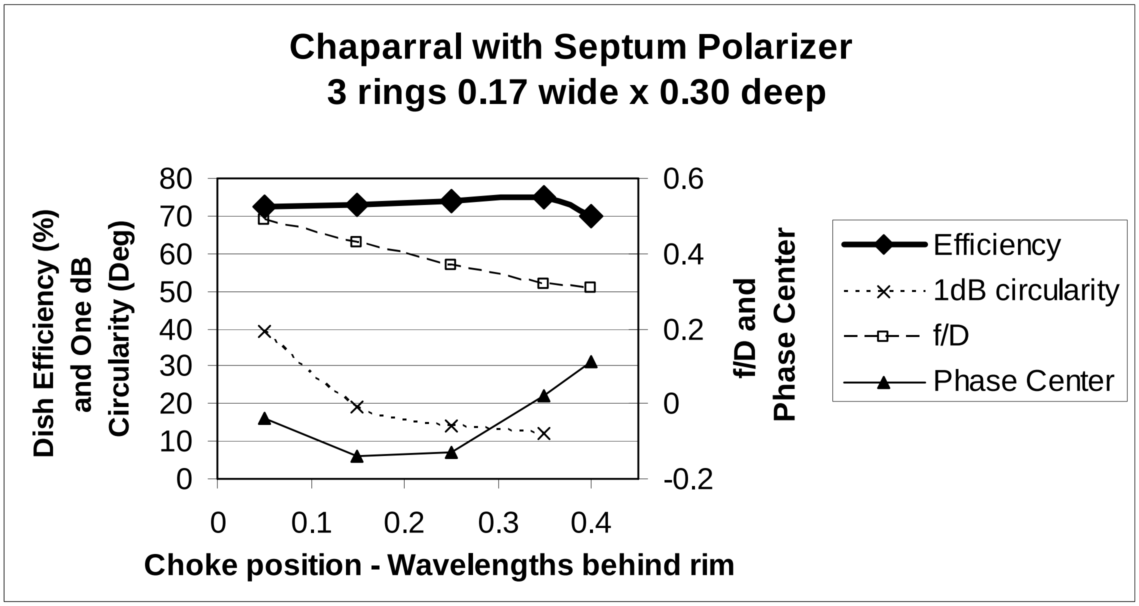


Figure 45

Figure 45 also includes circularity, plotting the maximum illumination angle where the axial ratio is less than one dB. As we saw in Figures 41 and 42 for the VE4MA feed with septum polarizer, the circularity is better with the choke forward, favoring shallower dishes. However, Figure 47 shows that the efficiency for circular polarization is comparable to linear over a much wider range of ***f*/D**.

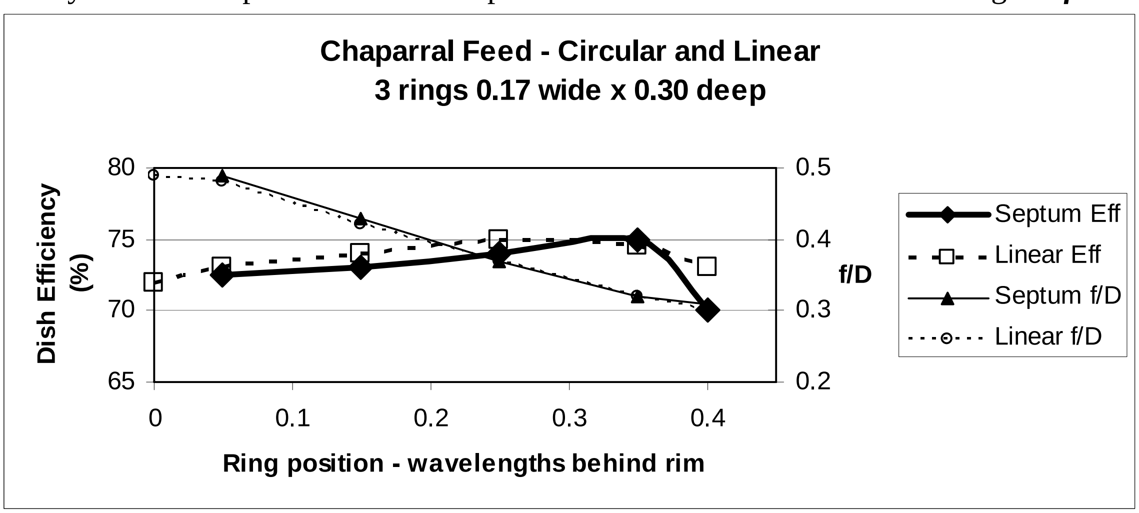
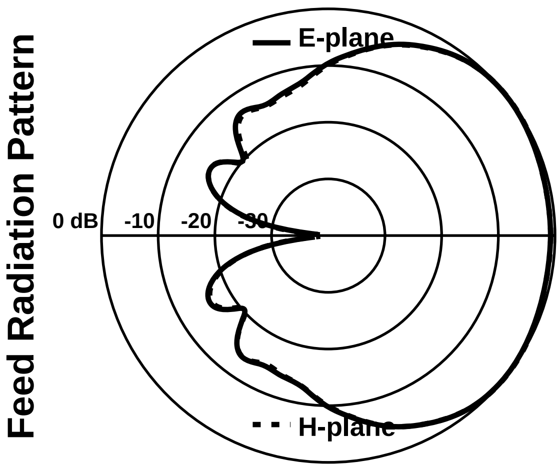
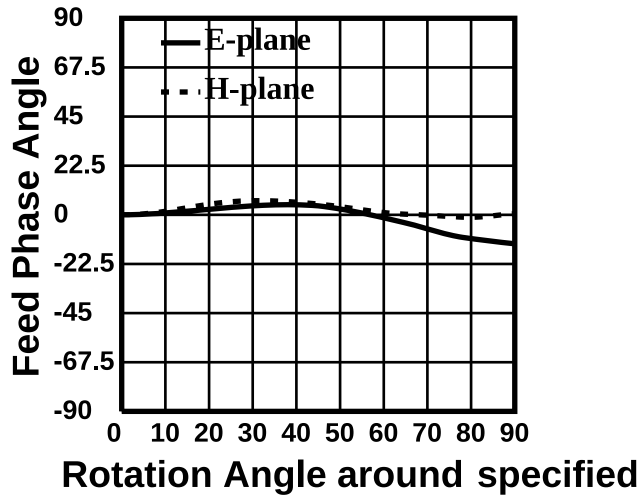


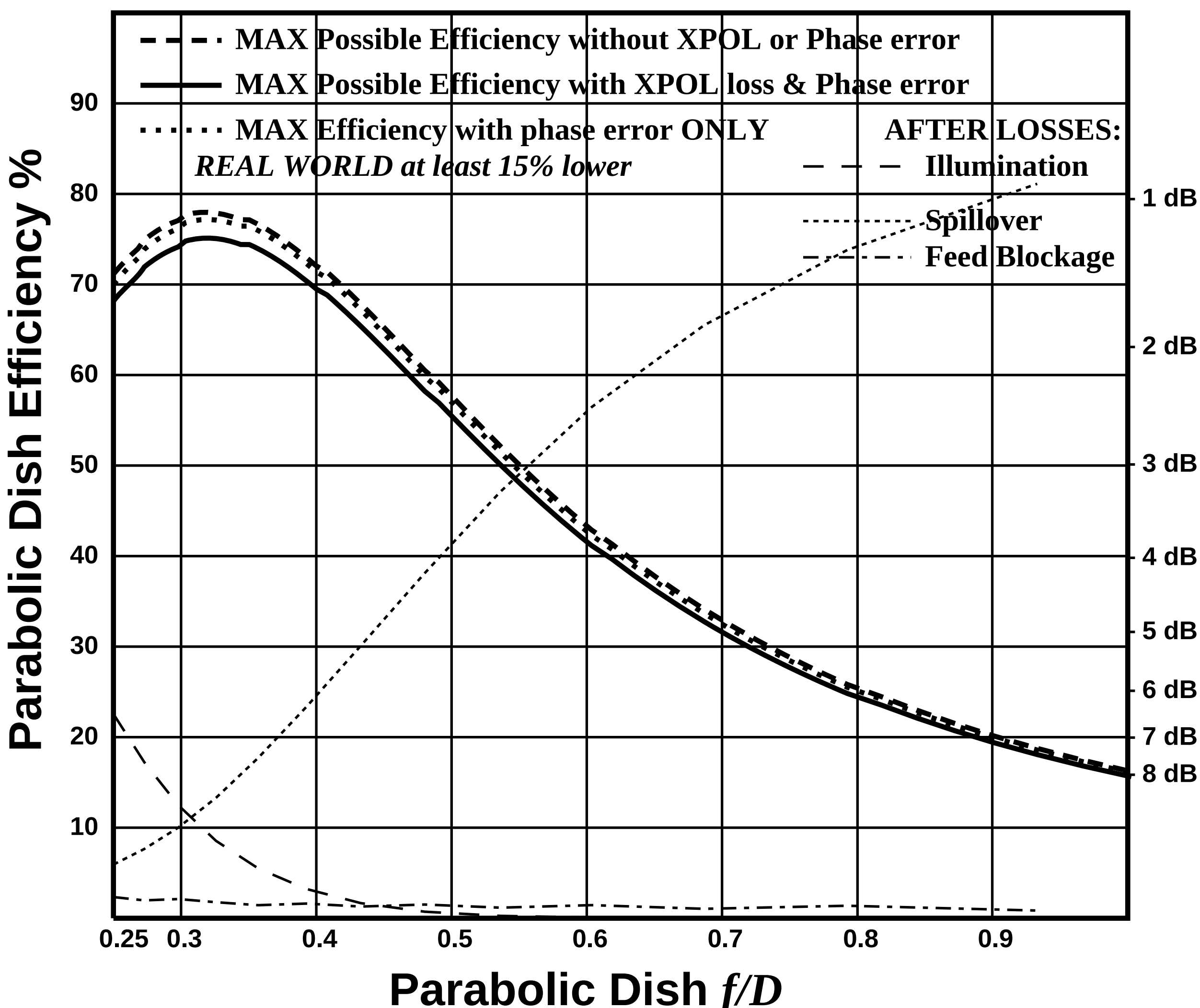
Figure 47

Chaparral Feed with Septum Polarizer, 0.71λ horn diameter
3 Rings 0.17λ wide x 0.30λ deep, 0.35λ behind rim, RHCP
Figure 46





Dish diameter = 20 λ **Feed diameter = 1.7 λ** **Phase Center = 0.03 λ beyond aperture**



W1GHZ 1998, 2006

The second Chaparral horn, with three rings each 0.20λ wide and 0.33λ deep, was also simulated over a range of choke positions with the septum polarizer. This version is not as good with circular polarization, as shown in Figure 48.

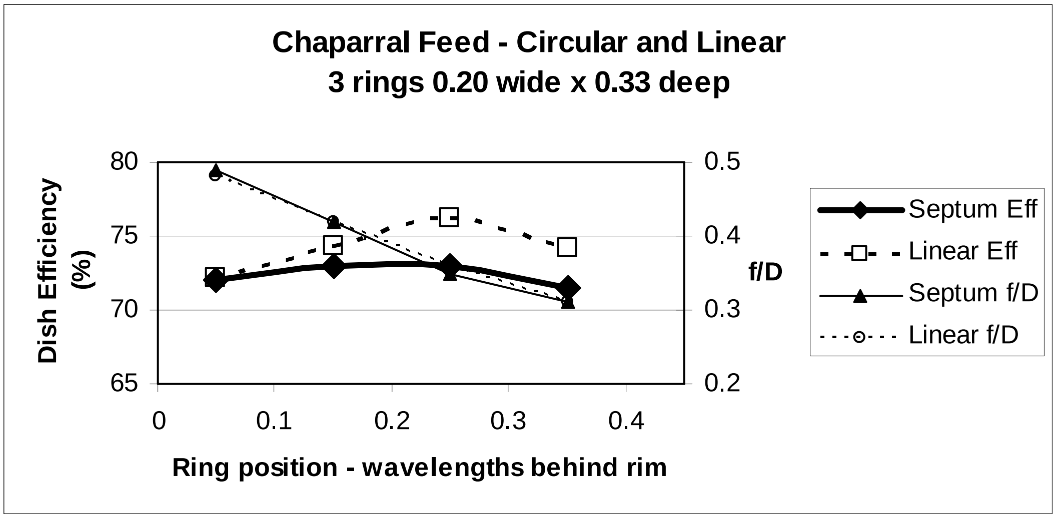


Figure 48

In order to determine why the version with larger and deeper rings did not work as well with a septum polarizer, I tried a few of the best Chaparral variations with circular polarization, exciting them with pure circular polarization rather than a septum. The first of these, with three rings each 0.20λ wide and 0.20λ deep, is shown in Figure 49. The efficiency with circular polarization is identical to the linear performance, at least within calculation error. A few points were also simulated with a septum polarizer, showing slightly lower efficiency, but still excellent at around 75%. This feed provides very high efficiency over a wide range of ***f*/D**, 0.3 to 0.5, with any polarization.

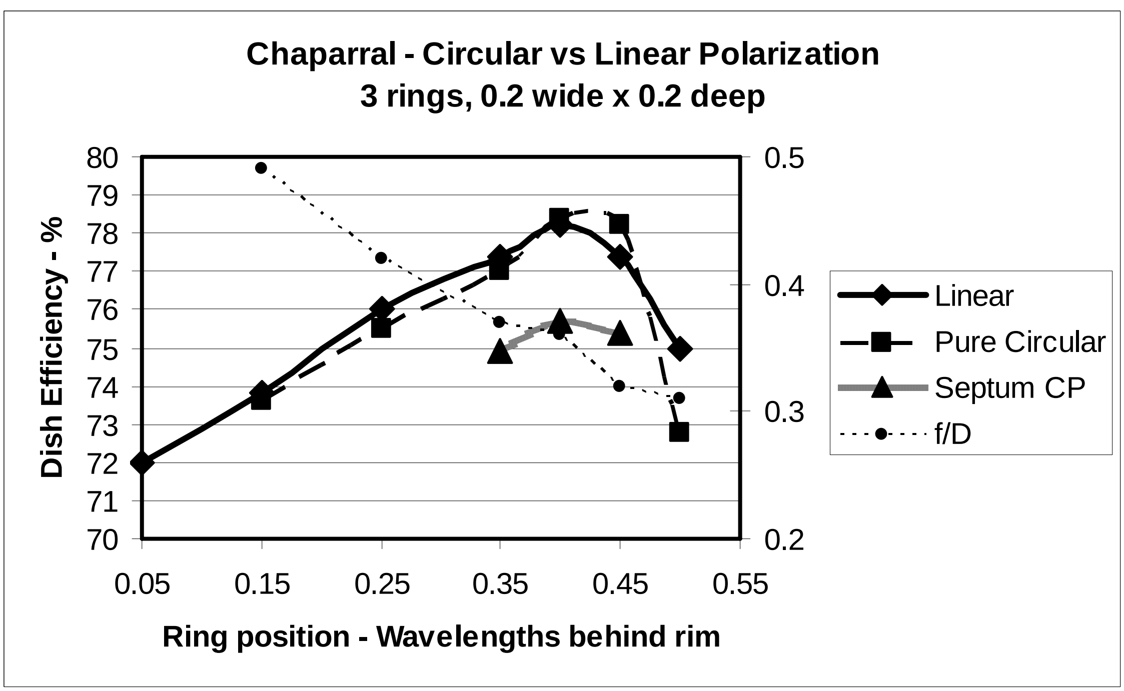


Figure 49

Two other variations had narrower rings, 0.17λ wide like Figures 45 thru 47, but shallower. Figure 50 compares linear and circular polarization for a feed with three rings each 0.17λ wide and 0.20λ deep, while Figure 51 is for larger wider rings, 0.17λ wide and 0.26λ deep. For both versions, the efficiencies are equal for both polarizations except with the ring position furthest behind the rim, favoring a small ***f*/D**.

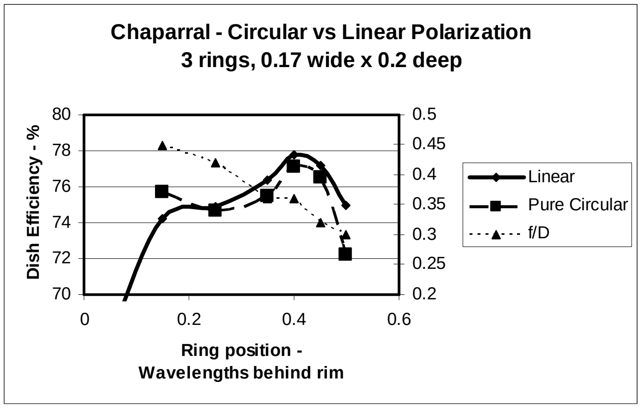


Figure 50

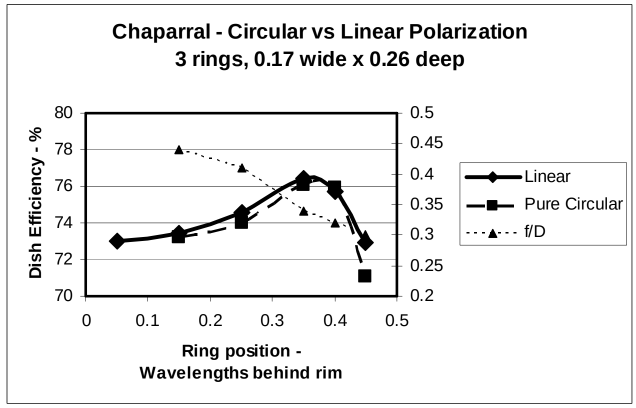


Figure 51

A final variation had larger rings, with three rings each 0.27λ wide and 0.20λ deep. Figure 52 shows very high efficiency over a narrower range of ring positions, with the peak more pronounced for circular polarization. This suggests the smaller rings come closest to being a fully adjustable feed, suitable for nearly all prime-focus dishes.

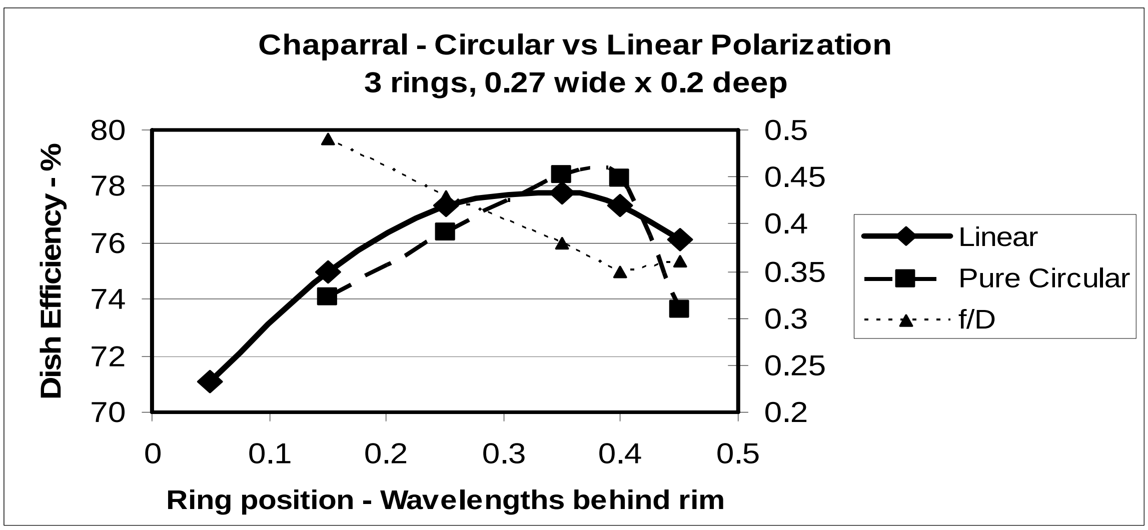


Figure 52

Like the VE4MA horn, the best ***f*/D** at each ring position, as well as the phase center, not shown, does not change with polarization for the Chaparral feeds. Calculated phase center for each combination is listed in Appendix B for the VE4MA feeds and Appendix C for the Chaparral feeds.

All of the above circular polarization dish efficiencies were calculated for the feed only, with no regard for cross-polarization added by the reflector. With linear polarization, deep dishes have significant cross-polarization near the 45° cut planes, because the reflector surface is at an odd angle to the polarization vector. The same effect causes cross-polarization at all angles with circular polarization. This is detrimental in applications requiring high polarization purity, but I believe the efficiency loss for the desired polarization is still small.

Small Dishes

All our comparisons were for a dish 20λ in diameter. Many hams must make do with much smaller dishes, 10λ or smaller diameter. We have seen that the best feeds are 1.9λ in diameter, so the blockage is significant on a small dish. Some of the small VE4MA variations also provide good performance, and would have less blockage. The tradeoff is whether the larger blockage makes the efficiency of the larger feed lower than the smaller feed.

In Figure 53, efficiencies curves for several of the better feeds are plotted for a 10λ diameter dish, using the blockage diameter of each feed. It is clear that the larger super-VE4MA feed is still superior for all but very deep dishes. Even though the calculated efficiency is significantly lower than for larger dishes, it is still higher than the efficiency of other feeds. Similarly, the Chaparral feeds that were best for very deep dishes still have the highest efficiency for these dishes. So the higher efficiency of the best feeds outweighs the higher blockage even in small dishes.

Sun noise measurement and circular polarization

We can evaluate the performance of a dish antenna by sun noise measurements, comparing the noise power received from the sun with the noise power received from cold sky. However, this does not evaluate the quality of circular polarization – noise is randomly polarized in both instances, so we may expect the same results as we measure for linear polarization. There are no celestial sources with well-defined polarization, so far-field polarization measurements for good-sized antennas are difficult unless a large anechoic chamber is available. A ground-reflection range of the type typically used for amateur antenna measurements is unsuitable for circular polarization; according to Hanson[12], “on a ground reflection antenna test range, the antenna under test must be rotated, or tedious calibration procedures must be employed to account for the difference in the reflection coefficients of the range surface for the horizontal and vertical components of the field.”

Without measurements, we must rely on simulation to evaluate circularly-polarized feeds.
We can also simulate pure circular polarization, using two orthogonal modes with equal amplitudes and 90° phase difference. Simulations with pure circular polarization show the same calculated dish efficiencies as pure linear polarization. Therefore, we would expect to measure the same sun noise with either linearly- or circularly-polarized feed, and WD5AGO has confirmed this experimentally.

With a real polarizer, measurement or simulation results may differ from those with pure polarization, because of polarizer losses or imperfect polarization generated by the polarizer. Certain combinations of feedhorn and imperfect polarization might result in slightly better performance than pure polarization. In the absence of good measurements, we must rely on simulation results for polarizers and circular polarization.

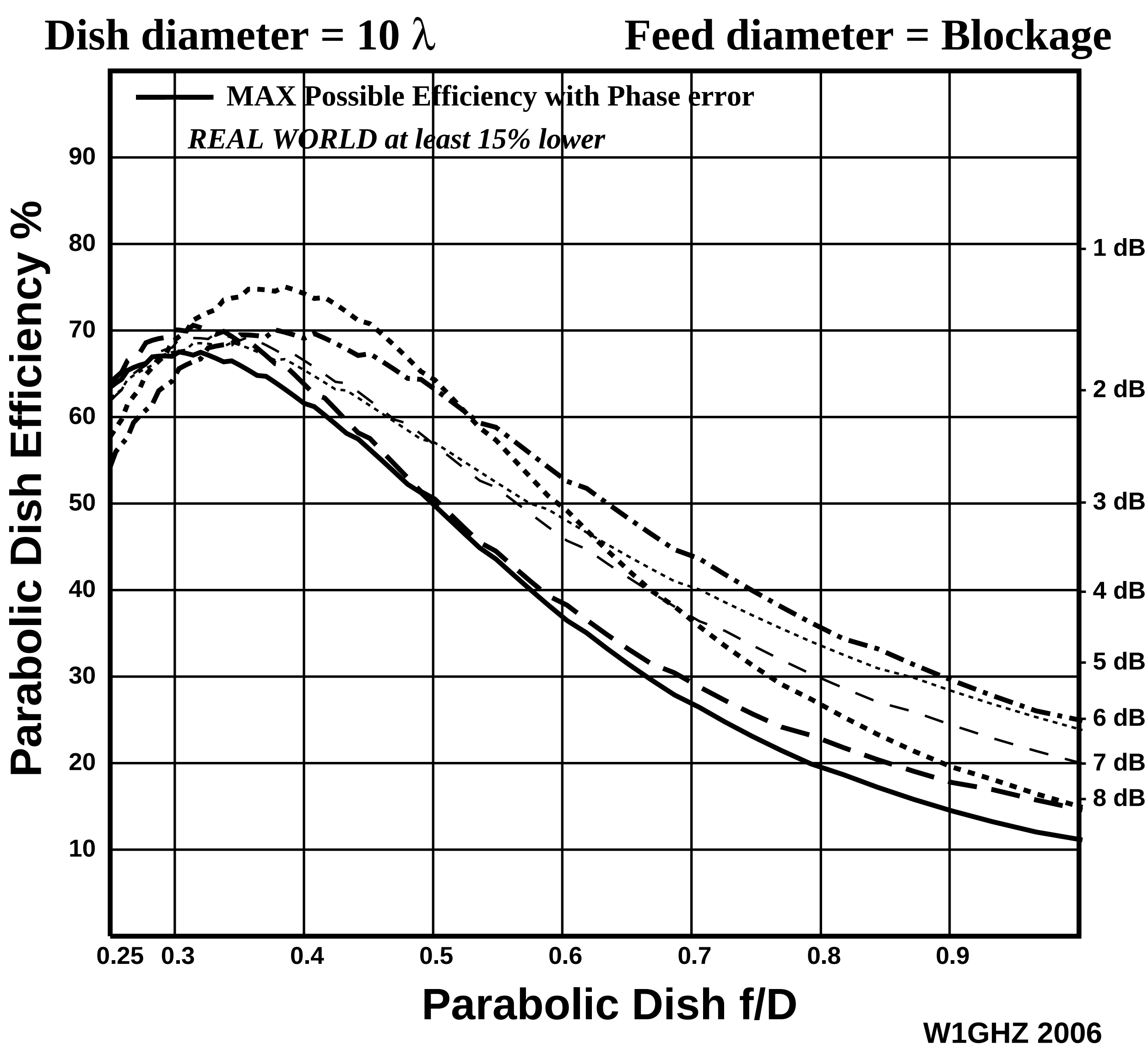
Construction note

Getting the rings in the right position is important for best performance, so making the ring adjustable would be a real advantage. WD5AGO has found that at least six points of good contact around the perimeter are needed for optimum performance.

Feed choices for 10λ diameter Dish

- Original VE4MA 0.50λ wide x 0.50λ deep, back 0.15λ
- Super VE4MA 0.60λ wide x 0.45λ deep, back 0.15λ
- small VE4MA 0.40λ wide x 0.25λ deep, back 0.35λ
- small VE4MA 0.25λ wide x 0.25λ deep, back 0.35λ
- Chaparral 3 rings 0.17λ wide x 0.33λ deep, back 0.25λ
- Chaparral 3 rings 0.17λ wide x 0.26λ deep, back 0.40λ

Figure 53



Summary

The test results in Appendix A are very encouraging. The measurements by WD5AGO are completely independent from the simulations by W1GHZ, yet the comparable results are consistent. The efficiency derived from sun noise measurements is 12 to 14% lower than efficiency calculated from simulations in all cases. Previous tests have shown real world efficiency to be about 15% lower than simulation for small dishes. Therefore, we may believe that the measurements validate the simulation results.

Our results have surpassed the original objective. In addition finding excellent combinations of the VE4MA and Chaparral feedhorns with septum polarizers, we have discovered some improved dimensions for these feedhorns which offer improved performance. Measured efficiencies as high as 65% surpass any previous amateur results for a prime-focus dish, as well as most commercial results. Calculated efficiencies are only about one dB below perfection, so it is hard to imagine that significant further improvements are likely.

From the results, we may draw some conclusions:

- The original VE4MA feedhorn provides good efficiency for a wide range of dish ***f*/D**.
- A larger version of the VE4MA feed, which we call the “Super-VE4MA,” provides excellent efficiency, the highest to date for a prime-focus dish, but over a smaller range of dish ***f*/D**.
- Smaller versions of the VE4MA feed work as well as the original over a broad range of ring dimensions, offering lower blockage for very small dishes.
- The Chaparral feedhorn provides very good efficiency for a wide range of dish ***f*/D**, and the highest to date for very deep dishes, with ***f*/D ~ 0.25**. Variations with shallower rings have higher efficiency than more traditional dimensions.
- The probe is not part of the antenna. It could be 100 meters away, at the far end of the feedline. The loss might reduce the transmitted power, but will not affect the radiation pattern of the antenna.
- The polarizer is not part of the antenna – just like the probe.
- The septum polarizer, or any other polarizer, does not affect the antenna radiation, except to make the polarization circular; any polarizer that excites the antenna with good CP will result in the same pattern. Of course, a poor polarizer will degrade performance.
- All these feedhorns work well (in simulation) with the OK1DFC septum polarizer to provide circular polarization, but the VE4MA feed and variations degrade slightly for ***f*/D < 0.35**.
- For linear polarization, horn diameters of 0.71λ and 0.77λ work equally well, and there is no reason to believe that intermediate diameters will not work as well. The OK1DFC septum polarizer works best with a waveguide diameter of 0.71λ.
- The range of feed dimensions that yields very good performance provides opportunities to use available materials effectively.

If you have a feed that is working well and providing good results, there is no need to change it. However, if you feel that a better feed could help, or if you don’t have a feed yet and are still deciding, then one of the improved feeds described here could be a good choice. For EME, where every dB really matters, these improved feeds should be worth considering. But the most important thing is to put a feed in your dish and get it on the air!

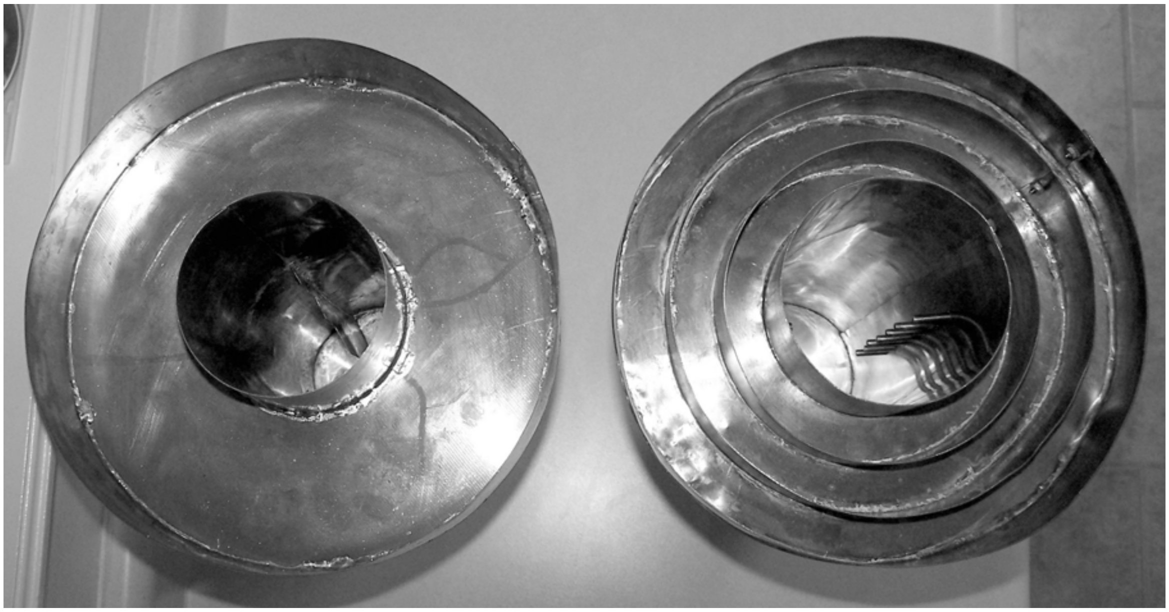
References

1. B.W. Malowanchuk, VE4MA, "VE4MA 3456 MHz circular polarization feed horn," *North Texas Microwave Society Feedpoint*, Nov/Dec 1991.
2. Zdenek Samek, OK1DFC, "Feed for Parabolic Dish with Circular Polarization," CD-ROM for 10th International EME Conference 2002 in Prague. www.ok1dfc.com
3. www.ansoft.com
4. P. Wade, W1GHZ, "Understanding Circular Waveguide – Experimentally," ***QEX***, Jan/Feb 2001, pp. 37-48. www.w1ghz.org/QEX/circular_wg.pdf
5. P. Wade, W1GHZ, *The W1GHZ Microwave Antenna Book – Online*, www.w1ghz.org
6. A. Kumar, "Reduce Cross-Polarization in Reflector-Type Antennas," *Microwaves*, March 1978, pp. 48-51.
7. R. Wohlleben, H. Mattes, O. Lochner, "Simple small primary feed for large opening angles and high aperture efficiency," *Electronics Letters*, 21 Sept. 1972, pp. 181-183. (reprinted in A.W. Love, *Electromagnetic Horn Antennas*, IEEE, 1976, pp. 181-183.)
8. A.J. Terzuoli, Jr., J.H. Richmond, & L. Peters, Jr., "Shielding Effectiveness of Corrugations in Corrugated Horns," *IEEE Transactions on Antennas and Propagation*, September 1978, pp. 654-658.
9. M. Chen & G. Tsandoulas, "A wide-band square-waveguide array polarizer," *IEEE Transactions on Antennas and Propagation*, May 1973, pp. 389-391.
10. P. Wade, W1GHZ, "Analysis of the OK1DFC Septum Feed," DUBUS, 1/2003, pp. 22-38.
11. J. Bornemann & V.A. Labay, "Ridge Waveguide Polarizer with Finite and Stepped-Thickness Septum," *IEEE Transactions on Microwave Theory and Techniques*, August 1995, pp. 1782-1787.
12. J.S. Hollis, T.J. Lyon, & L. Clayton, Jr., "*Microwave Antenna Measurements*," Scientific-Atlanta, July, 1970, p. 10-13.

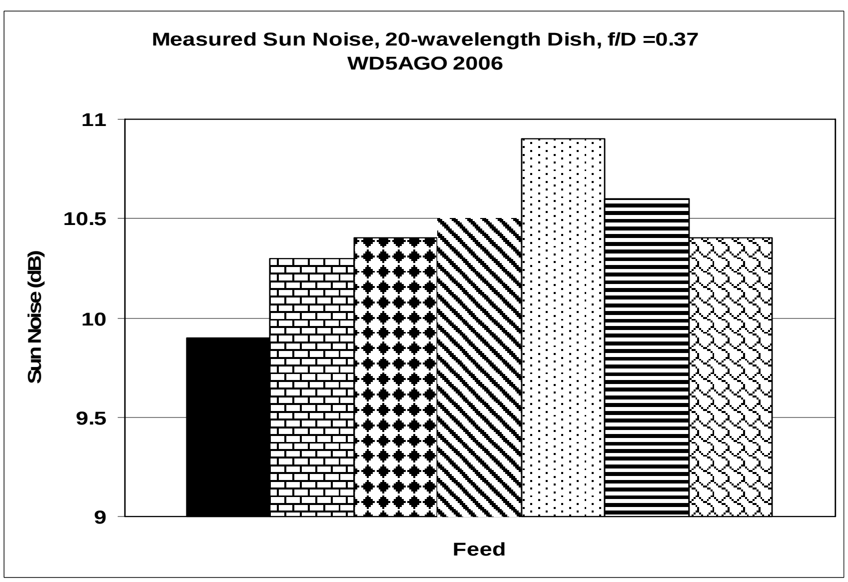
Appendix A

Circularly-polarized Feedhorn Measured Data

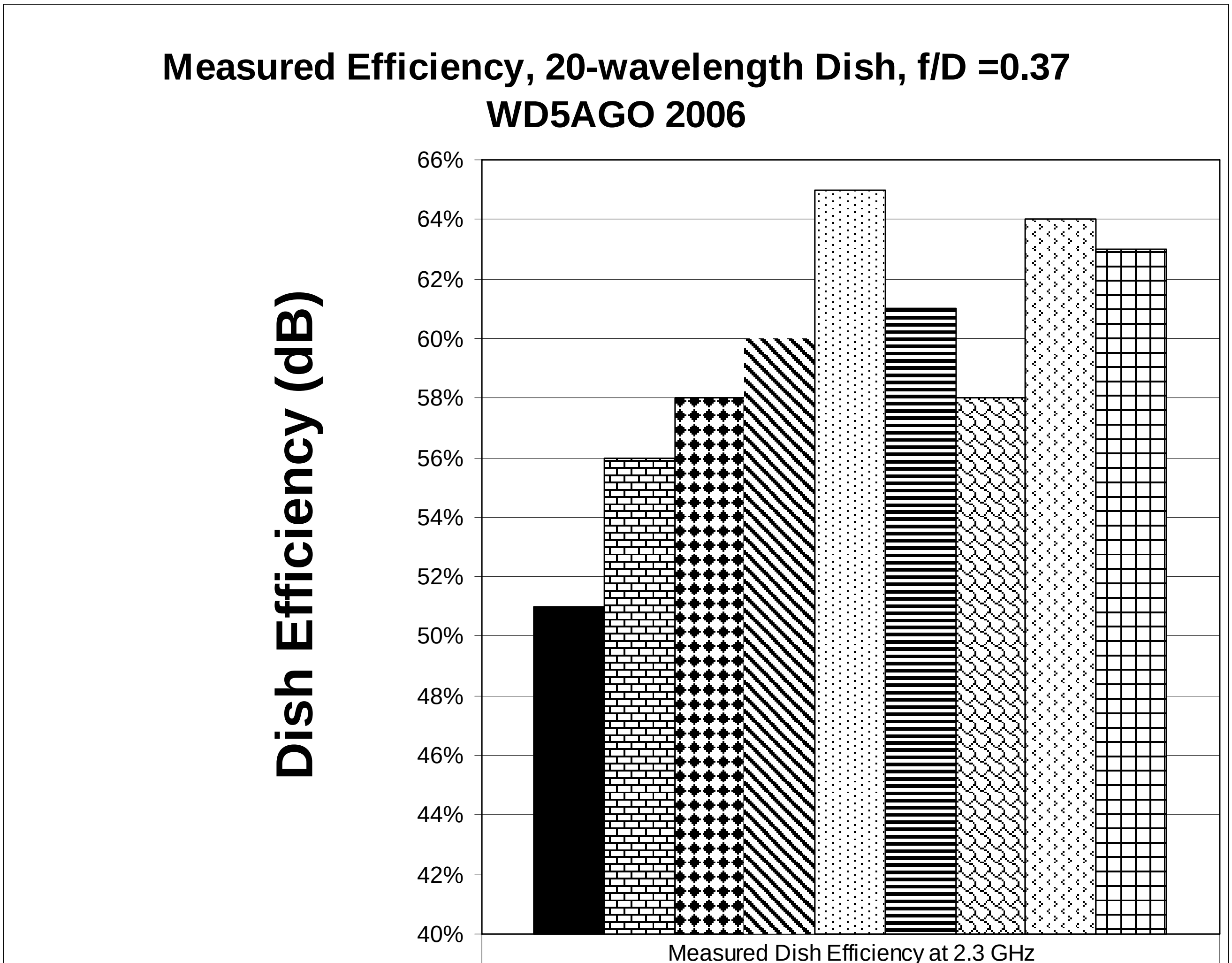
Tommy Henderson WD5AGO



Here we have a comparison of several circularly-polarized feeds for 13cm. All scalar rings are adjusted for best **G/T** for a 2.4 M, 0.37 ***f*/D** Dish (20λ diameter at 13cm). Feed blockage was not as big a factor in **G/T** as seen from the chart. To avoid blockage, which lowers the gain in smaller dishes, a closer spaced 3-ring scalar, with rings spaced 0.15λ was produced. As seen from W1GHZ data, a 0.2λ spacing would have yielded another 1 % efficiency placing it about 62%, still 2% to 3% down from the Super VE4MA with one large ring. All three-ring versions yielded EME echoes 2 to 3 dB out of the noise with a 35° K front end.



Measured Sun Noise at 2.3 GHz (SFU@75)



	Measured Dish Efficiency at 2.3 GHz
Round septum, no rings	51%
1 Ring 0.3 wide x 0.3 deep	56%
2 Rings 0.17 wide x 0.33 deep	58%
3 rings 0.15 wide x 0.33 deep	60%
Super VE4MA, 1 Ring 0.6 wide x 0.45 deep	65%
3 Rings 0.17 wide x 0.33 deep, 7-screw polarizer	61%
VE4MA 0.5 wide x 0.5 deep, 5-screw polarizer	58%
3 rings 0.20 wide and 0.20 deep, 0.76 horn diameter	64%
3 rings 0.20 wide and 0.20 deep, 0.71 horn diameter	63%

Measured dish efficiency from sun noise measurement above

Same data in tabular form. The measured dish efficiency is 12 to 14% lower than simulated. Typical difference for real world is 15% lower than simulation for a small dish.

Feed	**Horn** diameter λ	**Ring** width λ	**Ring** Depth λ	**Polarizer**	**Sun Noise** dB	**Cold Sky** to Ground dB	**Measured** Efficiency	**Simulated** Efficiency
Round	0.71			Septum	9.9	5.2	51%	64%
VE4MA	0.71	0.3	0.3	Septum	10.3	6.6	56%	70%
Chaparral	0.71	2 x 0.17	0.33	Septum	10.4	7	58%	
Chaparral	0.71	3 x 0.15	0.33	Septum	10.5	7	60%	72%
VE4MA	0.71	0.6	0.45	Septum	10.9	6	65%	78%
Chaparral	0.76	3 x 0.17	0.33	7-screw	10.6	6.8	61%	
VE4MA	0.77	0.5	0.5	5-screw	10.4	6.8	58%	
VE4MA	0.71	0.3	0.3	hybrid	9.6	4.5		
Chaparral	0.76	3 x 0.2	0.2	Septum			64%	78%
Chaparral	0.71	3 x 0.2	0.2	Septum			63%	77%
Noise horn						7.8		

Appendix B

Simulation Data from HFSS

VE4MA Feedhorns 0.77λ Horn Diameter

with different ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Original VE4MA								
0.77	0.5	0.5	-0.05	69%	0.49	-0.18	22.5	23
			0	69.5%	0.43	-0.24	24	19
			0.05	70%	0.41	-0.23	24	17
			0.1	71%	0.36	-0.17	21.5	14
			0.15	71%	0.32	0.014	18.5	13
			0.2	68%	0.32	0.11	17.5	12
Small ring								
0.77	0.35	0.35	-0.05	71%	0.49	0.1	18	27
			0	72%	0.5	0	19	26
			0.05	71%	0.49	-0.06	20.5	15
			0.15	70%	0.42	-0.11	24.5	11
			0.25	71%	0.36	-0.1	24.5	16
			0.3	71%	0.33	0	21.5	14
			0.35	69%	0.32	0.08	20	13
Super VE4MA								
0.77	0.6	0.45	0	72.8%	0.43	-0.37	17	23
			0.05	75.6%	0.43	-0.37	18	24
			0.15	79.3%	0.38	-0.07	19.5	23
			0.25	74.1%	0.36	0.2	19	21
			0.35	68.2%	0.37	0.14	20.5	23
1296 published dimensions								
0.77	0.52	0.52	0.1	71.1%	0.34	-0.11	20.5	13
			0.15	70%	0.33	0.1	18	13
2304 published dimensions								
0.77	0.54	0.48	0	68%	0.43	-0.2		18
0.77	0.55	0.55	0.15	67%	0.33	0.11	18.5	12

VE4MA Feedhorns 0.71λ Horn Diameter

with different ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Original VE4MA ring size								
0.71	0.5	0.5	-0.025	68.5%	0.43	-0.21	19	11
			0	68%	0.42	-0.21		18
			0.025	68.5%	0.41	-0.24	21.5	17
			0.05	68%	0.36	-0.24	22	16
			0.075	69%	0.35	-0.21	22	15
			0.1	69%	0.33	-0.18	21.5	14
			0.125	70%	0.31	-0.11	20	13
			0.15	70.5%	0.3	-0.03	18.5	12
			0.175	69.5%	0.29	0.1	17	12
			0.2	67%	0.3	0.18	16	11
			0.225	66%	0.31	0.21	16	12
			0.25	66%	0.32	0.2	15.5	14
Super VE4MA								
0.71	0.6	0.45	0	72.2%	0.43	-0.4	15.5	22
			0.05	74.6%	0.42	-0.37	16.5	23
			0.1	76.7%	0.38	-0.3	17	22
			0.15	78.8%	0.37	-0.14	17	21
			0.2	77.3%	0.35	0.13	17	21
			0.25	74.5%	0.35	0.23	17	19
			0.35	68.9%	0.36	0.17	17	21
Small ring								
0.71	0.35	0.35	0	71%	0.49	0	16	25
			0.05	70.5%	0.49	-0.07	17	14
			0.1	70%	0.44	-0.1	18.5	13
			0.15	70%	0.42	-0.13	20	11
			0.2	70.5%	0.36	-0.13	21.5	18
			0.25	71%	0.33	-0.11	22.5	16
			0.3	71%	0.31	-0.03	21	14
			0.35	69%	0.31	0.086	18.5	12
Small ring								
0.71	0.4	0.25	0	69%	0.48	0.07	14	23
			0.05	70.3%	0.49	0	15	25
			0.15	71.5%	0.44	-0.08	17	25
			0.25	72%	0.37	-0.11	19.5	22
			0.35	73%	0.32	-0.07	23	16
			0.4	73%	0.31	0	21.5	15
			0.45	70.8%	0.3	0.1		13

VE4MA Feedhorns 0.71λ Horn Diameter (cont.)

with different ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Small ring								
0.71	0.4	0.3	0	70.6%	0.48	0.02	15	26
			0.05	71.0%	0.49	-0.04	16	26
			0.15	71.5%	0.42	-0.11	18.5	24
			0.25	72.0%	0.35	-0.11	22	19
			0.35	73.0%	0.31	0	21	14
			0.4	71.8%	0.29	0	19	13
Small ring								
92	0.25	0.25	0.05	70.3%	0.49	0.06	15	26
			0.15	70.5%	0.41	-0.04	17.5	24
			0.25	70.0%	0.36	-0.06	20	21
			0.35	70.3%	0.32	-0.06	21.5	17
			0.4	70.0%	0.31	0	21	15
Smallest ring simulated								
0.71	0.12	0.26	0	70.0%	0.41	0.1	14	24
			0.05	70.3%	0.41	0.06	15.5	22
			0.15	70.0%	0.36	0	16.5	20
			0.25	69.6%	0.36	0	19.5	18
			0.3	68.0%	0.32	0	20	17
			0.35	68.0%	0.32	0	20	16
Single Ring of Chaparral								
0.71	0.2	0.33	0.05	69%	0.42	0	17	21
			0.15	67%	0.36	-0.03	18.5	18
			0.25	67%	0.32	-0.03	21	16
			0.35	66%	0.31	0.014	21	13

VE4MA feed, 0.71λ horn diameter with different ring dimensions, all 0.15λ behind rim

W1GHZ 2006

Dish efficiency

WIDE > / DEEP λ	0.75λ	0.7λ	0.65λ	0.6λ	0.55λ	0.5λ	0.45λ	0.4λ	0.35λ	0.3λ	0.25λ
0.65				73.0%	73.8%	68.5%					
0.6				72.0%	73.0%	68.0%					
0.55				72.8%	70.8%	67.0%					
0.5		70.6%	72.8%	75.9%	70.2%	70.5%	70.3%	69.0%			
0.45	74.3%	75.5%	**77.6%**	**78.8%**	60.0%	70.3%	70.0%	69.5%			
0.4	**77.5%**	**78.1%**	**78.7%**	**79.4%**	62.0%	70.4%	70.6%	70.0%	69.0%		
0.35	**77.8%**	**78.5%**	**78.5%**	72.0%	64.0%	70.5%	71.0%	70.4%	70.0%	69.0%	68.0%
0.3	**77.8%**	**78.0%**	**76.8%**	47.0%	67.0%	70.0%	71.5%	71.5%	71.0%	70.0%	69.0%
0.25	75.2%	73.0%	62.6%	50.0%	66.5%	70.5%	71.4%	71.5%	71.3%	71.0%	70.5%
0.2						70.0%			71.0%		70.7%
0.15						68.0%			68.0%		68.0%
0.1									63.5%		

Best f/D

WIDE > / DEEP λ	0.75λ	0.7λ	0.65λ	0.6λ	0.55λ	0.5λ	0.45λ	0.4λ	0.35λ	0.3λ	0.25λ
0.65				0.41	0.42	0.42					
0.6				0.37	0.42	0.37					
0.55				0.35	0.42	0.31					
0.5		0.38	0.36	0.36	0.31	0.3	0.31	0.31			
0.45	0.38	0.37	0.37	0.37	0.25	0.33	0.33	0.36			
0.4	0.41	0.41	0.39	0.39	0.31	0.36	0.36	0.36	0.36		
0.35	0.42	0.42	0.42	0.41	0.41	0.42	0.41	0.41	0.42	0.42	0.41
0.3	0.43	0.43	0.43	0.49	0.42	0.42	0.43	0.42	0.42	0.42	0.42
0.25	0.45	0.45	0.49	0.25 to 0.5	0.33	0.43	0.43	0.44	0.43	0.43	0.41
0.2						0.44			0.49		0.43
0.15						0.44			0.45		0.44
0.1									0.41		

VE4MA feed, 0.71λ horn diameter with different ring dimensions, all 0.15λ behind rim

W1GHZ 2006

Phase Center, wavelengths in front of aperture

WIDE >	0.75λ	0.7λ	0.65λ	0.6λ	0.55λ	0.5λ	0.45λ	0.4λ	0.35λ	0.3λ	0.25λ
DEEP λ											
0.65				0.17	0	0.08					
0.6				0.24	0.08	0					
0.55				0.26	0.14	0.186					
0.5		0.3	0.26	0.13	-0.03	-0.03	0	-0.04			
0.45	0.17	0.13	-0.01	-0.14	-0.2	-0.19	-0.14	-0.17			
0.4	-0.03	-0.08	-0.17	-0.27	-0.23	-0.2	-0.19	-0.17	-0.14		
0.35	-0.11	-0.18	-0.26	-0.23	-0.14	-0.18	-0.16	-0.13	-0.13	-0.1	-0.07
0.3	-0.16	-0.24	-0.33	-0.53	-0.1	-0.13	-0.11	-0.11	-0.1	-0.086	-0.04
0.25		-0.27	-0.39	-0.06	-0.05	-0.08	-0.08	-0.08	-0.06	-0.04	-0.04
0.2						0			0		0
0.15						0.07			0.086		0.07
0.1									0.14		

VE4MA Feedhorns with Septum Polarizer

0.71λ Horn Diameter, RHCP

with different ring sizes and positions

W1GHZ 2006

Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Isolation dB	1dB Axial Ratio degrees
Original VE4MA ring dimensions								
0.5	0.5	0	67	0.42	-0.21	32	20	20
		0.1	68	0.35	-0.21	32	23	12
		0.15	69.5	0.32	-0.06	31	20	12
		0.2	66	0.31	0.17	31	17	15
		0.3	63	0.35	0.18	32	16	18
Super VE4MA								
0.6	0.45	0.05	74	0.41	-0.37	31.5	17	13
		0.15	79	0.37	-0.186	32	17	9
		0.25	75.8	0.36	0.23	30	17	17
		0.35	70.1	0.36	0.18	31	18	36
Smaller ring variations								
0.35	0.35	0	71	0.49	0	31	16.5	70
		0.1	70.5	0.43	-0.1	34	18.5	24
		0.15	70.5	0.42	-0.13	30	20	19
		0.2	70.5	0.37	-0.13	31	22	18
		0.3	68	0.32	-0.01	31	23	13
		0.35	66	0.31	0.07	32	23	15
0.35	0.25	0.05	70.5	0.49	0.04	31	15	32
		0.15	72	0.43	-0.06	31	17	30
		0.25	71	0.41	-0.1	30.5	20	18
		0.35	70.5	0.35	-0.086	31.5	23	13
		0.4	70	0.32	0	32	23	13
0.4	0.25	0.05	70	0.49	0.03	30.5	15	27
		0.15	72	0.43	-0.07	30	17.5	28
		0.25	72	0.41	-0.13	32	20.5	17
		0.35	71.5	0.36	-0.085	32	24	13
		0.4	71	0.31	0	29.5	23	12.5
		0.45	68	0.31	0.1	31	19.5	15
0.5	0.25	0.15	70.5	0.43	-0.07	31.5	17.5	18
0.25	0.2	0.15	71.5	0.43	0	31	16	33
0.12	0.26	0.3	68	0.36	0	31.5	21	20
0.35	0.25	0.15	72	0.43	-0.06	31	17	30

VE4MA Feedhorns with Septum Polarizer

0.71λ Horn Diameter, RHCP

Performance over Frequency

W1GHZ 2006

Freq	Ring width	Ring depth	behind rim	Dish efficiency	f/D best	Phase center	Return Loss	Isolation
GHz	λ	λ	λ			λ	dB	dB
2.0	0.35	0.35	0.2	68%	0.41	-0.07	18.5	9
2.1				69%	0.38	-0.086	23	12
2.2				69%	0.37	-0.11	25	19.5
2.3				70.5%	0.37	-0.13	31	22
2.4				70%	0.37	-0.11	26	19.5
2.5				70.5%	0.37	-0.11	21	17
2.6				70%	0.36	-0.1	18.5	19

Appendix C

Chaparral-style Feedhorns 0.71λ Horn Diameter

with different ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
One ring (VE4MA), 1.11λ Blockage								
0.71	0.2	0.33	0.05	69%	0.42	0	17	21
			0.15	67%	0.36	-0.03	18.5	18
			0.25	67%	0.32	-0.03	21	16
			0.35	66%	0.31	0.014	21	13
Two rings, 1.51λ Blockage								
0.71	0.2	0.33	0.05	71.3%	0.49	-0.06	17	26
			0.15	72%	0.41	-0.13	19	23
			0.25	72%	0.36	-0.11	22	17
			0.35	72%	0.31	0.11	20	14
Three rings, 1.91λ Blockage								
0.71	0.2	0.33	0.05	72.2%	0.48	-0.11	19	29
			0.15	74.3%	0.42	-0.18	19.5	23
			0.25	76.2%	0.36	-0.11	22	18
			0.35	74.2%	0.31	0.13	19	16
Four rings, 2.31λ Blockage								
0.71	0.2	0.33	0.05	72.6%	0.49	-0.16		33
			0.15	75.4%	0.43	-0.21	19.5	26
			0.25	76.8%	0.37	-0.08	22	21
			0.35	72.0%	0.31	0.1	22	18
Three rings, 1.73λ Blockage								
0.71	0.17	0.3	0	72%	0.49	0	15.5	30
			0.05	73%	0.48	-0.04	16.5	31
			0.15	74%	0.42	-0.14	21	26
			0.25	75%	0.37	-0.14	18	19
			0.35	74.5%	0.32	0.1	21.5	17
			0.4	73%	0.3	0.13	18.5	15
Four rings, 2.07λ Blockage								
0.71	0.17	0.3	0.25	75.3%	0.37	-0.16	21.5	21
Three rings, 2.33λ Blockage								
0.71	0.27	0.3	0.25	76.7%	0.37	-0.09	21.5	21

Chaparral-style Feedhorns 0.71λ Horn Diameter (cont.)

with different ring sizes and positions

and constant blockage

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
One ring (Super VE4MA), 1.91λ Blockage								
0.71	0.6	0.45	0	72.2%	0.43	-0.4	15.5	22
			0.05	74.6%	0.42	-0.37	16.5	23
			0.1	76.7%	0.38	-0.3	17	22
			0.15	78.8%	0.37	-0.14	17	21
			0.2	77.3%	0.353	0.13	17	21
			0.25	74.5%	0.35	0.23	17	19
			0.35	68.9%	0.36	0.17	17	21
Two rings, 1.91λ Blockage								
0.71	0.3	0.33	0.05	73.0%	0.49	-0.13	17	30
			0.15	74.5%	0.42	-0.18	19.5	23
			0.25	76.5%	0.36	-0.1	22	18
			0.35	73.0%	0.31	0.13	18	16
Three rings, 1.91λ Blockage								
0.71	0.2	0.33	0.05	72.2%	0.48	-0.11	19	29
			0.15	74.3%	0.42	-0.18	19.5	23
			0.25	76.2%	0.36	-0.11	22	18
			0.35	74.2%	0.31	0.13	19	16
Four rings, 1.91λ Blockage								
0.71	0.15	0.33	0.05	71.9%	0.48	-0.11	19	28
			0.15	73.2%	0.42	-0.2	19.5	24
			0.25	74.2%	0.35	-0.13	22	19
			0.35	74.3%	0.28	0.1	30	17
			0.4	71.0%	0.27	0.13	17.5	17

Chaparral-style Feedhorns 0.71λ Horn Diameter (cont.)

Variations on ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Three rings, 1.91λ Blockage								
0.71	0.2	0.33	0.05	72.2%	0.48	-0.11	19	29
			0.15	74.3%	0.42	-0.18	19.5	23
			0.25	76.2%	0.36	-0.11	22	18
			0.35	74.2%	0.31	0.13	19	16
Three rings, 1.91λ Blockage								
0.71	0.2	0.3	0.05	73.0%	0.49	-0.07	16	33
			0.15	74.0%	0.43	-0.17	18.5	27
			0.25	76.2%	0.37	-0.16	21.3	30
			0.35	76.3%	0.33	0.07	20.5	17
			0.4	73.5%	0.3	0.14	18.3	16
Three rings, 1.91λ Blockage								
0.71	0.2	0.26	0.05	73.0%	0.49	-0.04	15	35
			0.15	74.1%	0.44	-0.13	17	32
			0.25	75.8%	0.41	-0.14	20.5	25
			0.35	77.5%	0.35	-0.04	22	19
			0.4	76.2%	0.31	0.09		18
Three rings, 1.91λ Blockage								
0.71	0.2	0.2	0.05	72.0%	0.49	0.04	13	30
			0.15	73.8%	0.49	-0.1	16	35
			0.25	76.0%	0.42	-0.16		33
			0.35	77.4%	0.36	-0.11	21	27
			0.4	78.2%	0.36	-0.04	21	24
			0.45	77.4%	0.32	0.07	20.5	22
			0.5	75.0%	0.3	0.11	18.5	17
Four rings, 2.31λ Blockage								
0.71	0.2	0.2	0.4	78.2%	0.35	0	21	27
Three rings, 1.91λ Blockage								
0.71	0.2	0.15	0.05	35.0%	~.65	-0.1	13	9
			0.15	70.0%	0.5	-0.17	15	18
			0.25	74.3%	0.44	-0.17	17	24
			0.35	76.6%	0.41	-0.16	20	27
			0.4	77.6%	0.37	-0.1	21	26
			0.45	78.3%	0.35	-0.02	21	23
			0.5	77.5%	0.33	0.08	20	21

Chaparral-style Feedhorns 0.71λ Horn Diameter (cont.)

Variations on ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Three rings, 1.91λ Blockage								
0.71	0.2	0.1	0.4	68.4%	0.43	-0.23	21.5	16
			0.5	70.7%	0.37	-0.11	21.3	
Three rings, 1.73λ Blockage								
0.71	0.17	0.33	0.05	71.8%	0.48	-0.07	17	28
			0.15	73.0%	0.42	-0.16	19.4	23
			0.25	74.4%	0.36	-0.11	21.5	17
			0.35	75.0%	0.31	0	19.4	14
			0.4	71.5%	0.3	0.14	17.2	15
Three rings, 1.73λ Blockage								
0.71	0.17	0.3	0	72.0%	0.49	0	15.5	30
			0.05	73.0%	0.48	-0.04	16.5	
			0.15	74.0%	0.42	-0.14	21	26
			0.25	75.0%	0.37	-0.14	18	19
			0.35	74.5%	0.32	0.1	21.5	17
			0.4	73.0%	0.3	0.13	18.5	15
Three rings, 1.73λ Blockage								
0.71	0.17	0.26	0.05	73.0%	0.49	-0.01	15.5	35
			0.15	73.4%	0.44	-0.1	17.5	30
			0.25	74.6%	0.41	-0.14	19.5	24
			0.35	76.4%	0.33	-0.04	21.5	18
			0.4	75.7%	0.31	0.04	20.5	17
			0.45	72.9%	0.3	0.13		17
Three rings, 1.73λ Blockage								
0.71	0.17	0.2	0.05	67.8%	0.51	-0.23	16	11
			0.15	74.2%	0.48	-0.11	16	23
			0.25	74.9%	0.42	-0.14	18	33
			0.35	76.4%	0.36	-0.11	21	26
			0.4	77.8%	0.33	-0.06	21.8	23
			0.45	77.2%	0.32	0.03	21	20
			0.5	75.0%	0.3	0.1		17
Three rings, 2.15λ Blockage								
0.71	0.24	0.33	0.05	72.4%	0.48	-0.14	17.3	31
			0.15	74.6%	0.43	-0.21	19.4	24
			0.25	76.2%	0.36	-0.11	22	19
			0.35	72.5%	0.3	0.14	19.3	17

Chaparral-style Feedhorns 0.71λ Horn Diameter (cont.)

Variations on ring sizes and positions

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Three rings, 2.33λ Blockage								
0.71	0.27	0.33	0.05	72.8%	0.49	-0.17	21	33
			0.15	75.5%	0.43	-0.23	19.5	25
			0.25	76.7%	0.37	-0.09	21.5	21
			0.35	71.3%	0.32	0.11	19	17
Three rings, 2.33λ Blockage								
0.71	0.27	0.2	0.05	71.1%	0.48	0	13.5	40
			0.15	75.0%	0.49	-0.14	16	35
			0.25	77.3%	0.43	-0.16	18	35
			0.35	77.8%	0.38	-0.1	21	27
			0.4	77.3%	0.35	0.01	21	24
			0.45	76.1%	0.32	0.07	20	23

Chaparral-style Feedhorns 0.76λ Horn Diameter (cont.)

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ	Return Loss dB	Front to Back dB
Three rings, 1.96λ Blockage								
0.76	0.2	0.2	0.15	74.1%	0.49	-0.09		43
			0.25	76.3%	0.43	-0.13		36
			0.35	77.7%	0.38	-0.1		28
			0.4	78.7%	0.35	-0.04	22.5	26
			0.45	78.2%	0.36	0.07		23

Chaparral-style Feedhorns 0.71λ Horn Diameter (cont.)

Circular Polarization

W1GHZ 2006

Horn Diameter λ	Ring width λ	Ring depth λ	behind rim λ	Dish efficiency	f/D best	Phase center λ
Three rings - Circular (pure)						
0.71	0.2	0.2	0.15	73.6%	0.49	-0.1
			0.25	75.5%	0.42	-0.14
			0.35	77.0%	0.37	-0.1
			0.4	78.4%	0.36	-0.03
			0.45	78.2%	0.32	0.06
			0.5	72.8%	0.31	0.11
Three rings - Septum						
0.71	0.2	0.2	0.35	74.9%	0.37	-0.13
			0.4	75.7%	0.36	-0.09
			0.45	75.4%	0.32	0.04
Three rings - Circular (pure)						
0.71	0.17	0.2	0.15	75.7%	0.45	-0.13
			0.25	74.7%	0.42	-0.14
			0.35	75.5%	0.36	-0.11
			0.4	77.1%	0.36	-0.06
			0.45	76.5%	0.32	0.03
			0.5	72.2%	0.3	0.1
Three rings - Circular (pure)						
0.71	0.17	0.26	0.15	73.2%	0.44	-0.11
			0.25	74.0%	0.41	-0.14
			0.35	76.1%	0.34	-0.07
			0.4	75.9%	0.32	0.04
			0.45	71.1%	0.3	0.11
Three rings - Circular (pure)						
0.71	0.17	0.26	0.15	73.2%	0.44	-0.11
			0.25	74.0%	0.41	-0.14
			0.35	76.1%	0.34	-0.07
			0.4	75.9%	0.32	0.04
			0.45	71.1%	0.3	0.11
				0.0%		
Three rings - Septum				0.0%		
0.71	0.2	0.33	0.05	72.0%	0.49	-0.11
			0.15	73.0%	0.42	-0.2
			0.25	73.0%	0.35	-0.14
			0.35	71.5%	0.31	0.1
Three rings - Circular (pure)						
0.71	0.27	0.2	0.15	74.1%	0.49	-0.11
			0.25	76.4%	0.43	-0.14
			0.35	78.4%	0.38	-0.06
			0.4	78.3%	0.35	0.04
			0.45	73.6%	0.36	0.1