## 6.9.6 Dual-band feed experiments

I was impressed with the performance of the dual-band feeds for 10 and 24 GHz; I hypothesized that the wider frequency separation might provide better results than the more closely spaced frequencies of the W5LUA feeds. A few experiments, at least in computer simulation, could test this hypothesis. Two of the possible pairs of bands with wider separation are 2304 and 5760 MHz, a 2.5:1 frequency ratio, and 3456 and 10368 MHz, a 3:1 frequency ratio.

Since WR-90 waveguide for 10 GHz is readily available, perhaps we could scale the W5ZN feed to 3456 MHz and 10 GHz, by adding a waveguide to the rear of a coffee-can feed. I calculated radiation patterns using the Zeland **Fidelity** 3D-simulation program; performance was just like a coffee-can feed at 3456 MHz, but disastrous at 10 GHz — the patterns are distorted, with a large null around the boresight.

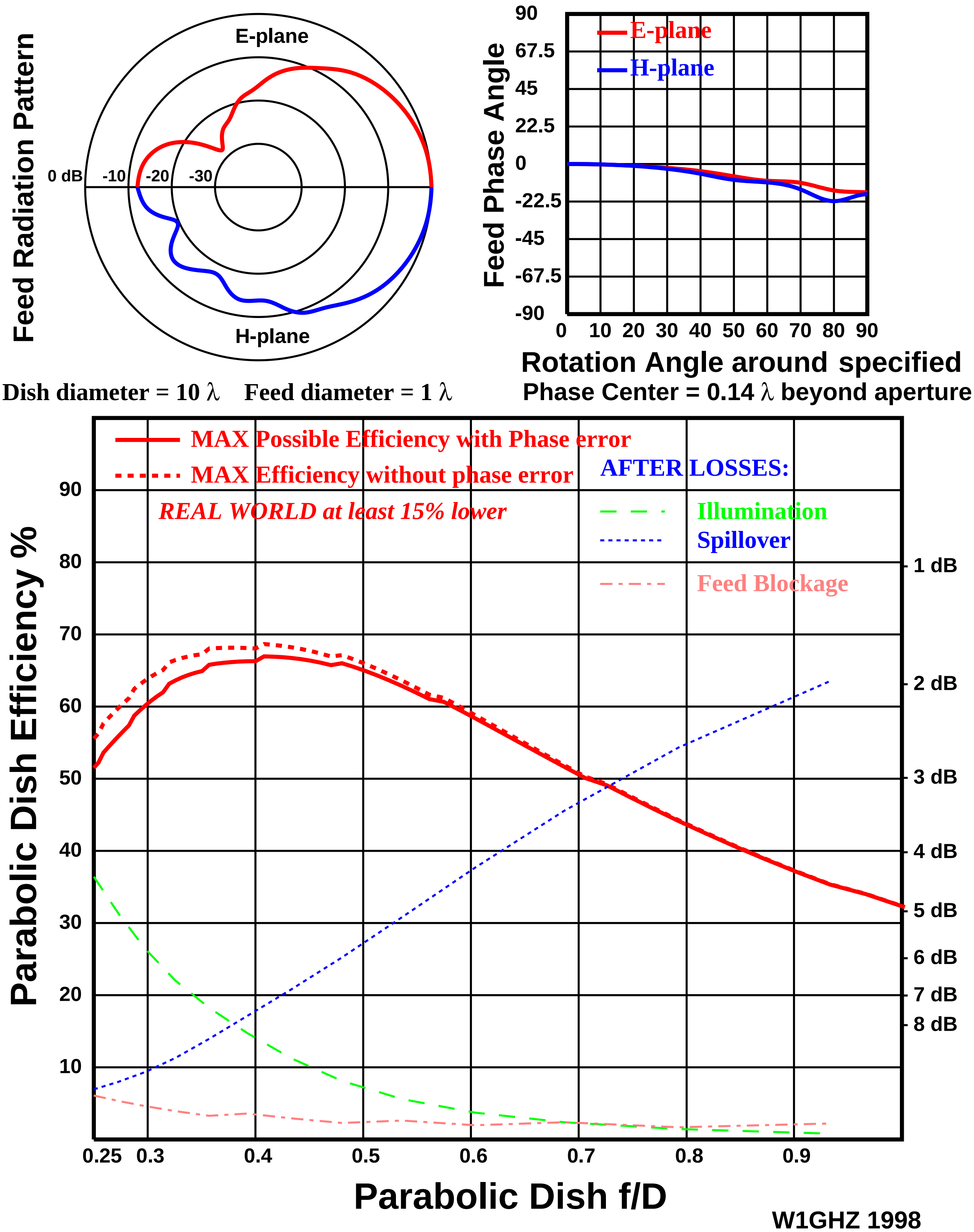
Perhaps the 3:1 frequency difference from 3456 to 10368 MHz is too large, since from 10368 to 24192 MHz is only a 2.33:1 ratio. A closer match is 2304 to 5760 MHz, a 2.5:1 ratio. I modeled this combination by grafting together the dimensions of the 2304 MHz and the 5760 MHz sections of the two W5LUA feeds, joined by a simple step transition. The radiation patterns calculated by the **Fidelity** 3D-simulation program are much more promising for this experiment. At 2304 MHz, the performance shown in Figure 6.9-24 is similar to a coffee-can feed, with good efficiency and best ***f*/D** in the 0.35 to 0.45 range. At 5760 MHz, calculated efficiency in Figure 6.9-25 is also good in spite of slight phase error, with best ***f*/D** is in the 0.45 to 0.55 range. Phase center is at the center of the aperture at 2304 MHz, but about $0.35\lambda$ in front of the aperture, outside the horn, at 5760 MHz. For a compromise ***f*/D** of about 0.45, we might expect up to 50% efficiency on both bands. If a feed for this frequency combination were needed, this second dual-band experiment would be worth trying; a bit of work is required to get the feedpoints matched on both bands.

Why does the second experiment work but not the first one? Perhaps comparison of the fields inside the feeds might provide some insight — the 3D simulator can display these fields. First, we will examine the electric field inside the W5ZN dualband feed at 10 GHz, in Figure 6.9-26, with a cross-section along the E-plane, slicing through the probe, on the left. A cross-section along the H-plane, through the center of the horn perpendicular to the probe, is on the right, and a slice across the aperture is in the middle (the probe is vertical in this orientation). The energy propagates smoothly down the circular waveguide, with only a small amount entering the small rectangular waveguide at the back, so the fields are very similar to a plain coffee-can feed. In the H-plane, the aperture field is concentrated in the center, providing a clear phase center for radiation. On the other hand, in the E-plane, the field extends across the aperture with high field intensity at the rim of the horn, causing the edge currents and sidelobes we previously noted in simple feeds. The field in the aperture clearly shows that we are propagating the dominant **$TE_{11}$** mode: compare the aperture field in Figure 6.9-26 with Figure 6.5-5a. In the former, a high electric field is indicated by red coloring, while in the latter, a high field is indicated by closely-spaced arrows.

# Dual-band feedhorn for 2304 & 5760 at 2304 MHz,

by Zeland Fidelity™

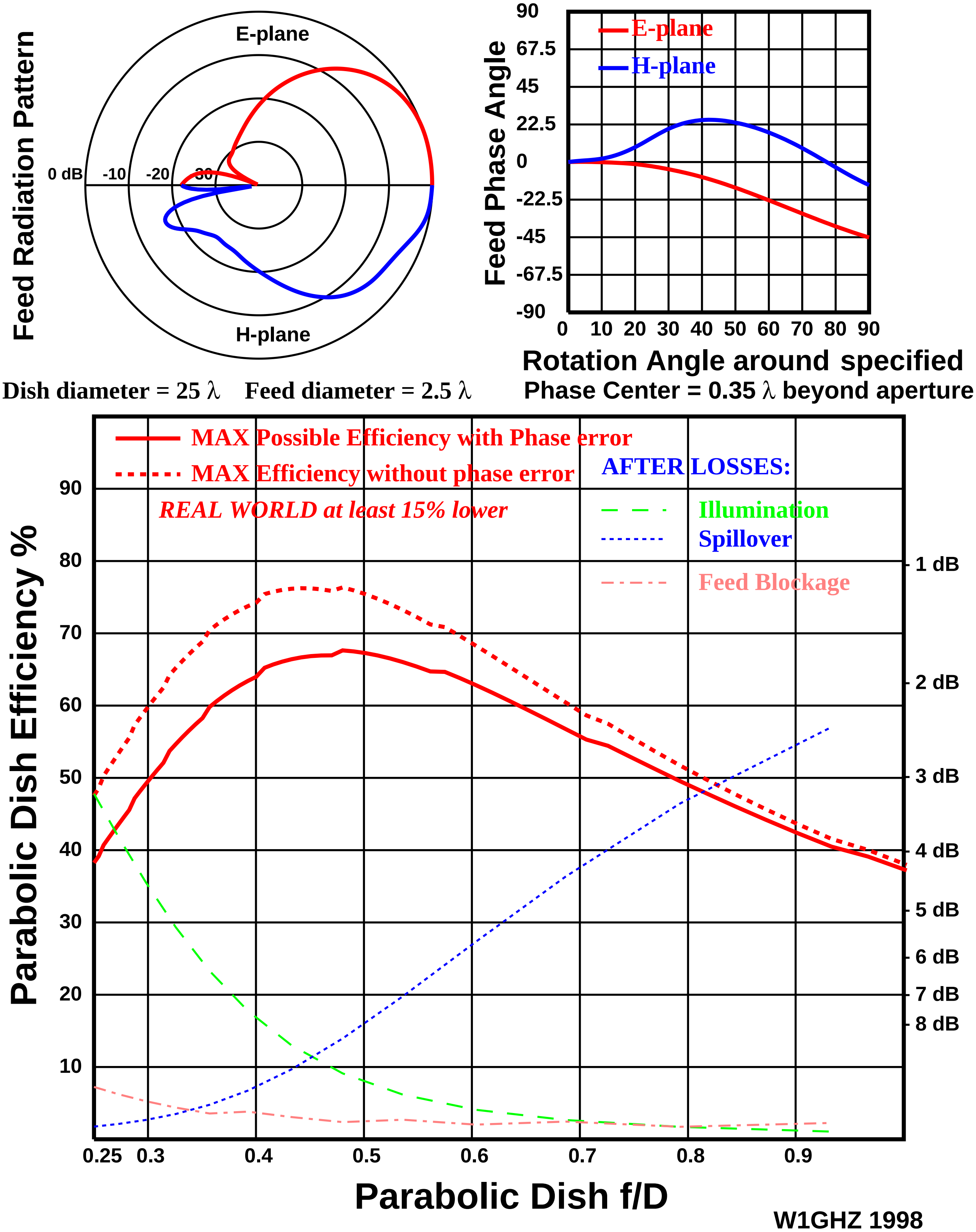
Figure 6.9-24



# Dual-band feedhorn for 2304 & 5760 at 5760 MHz,

by Zeland Fidelity™

## Figure 6.9-25



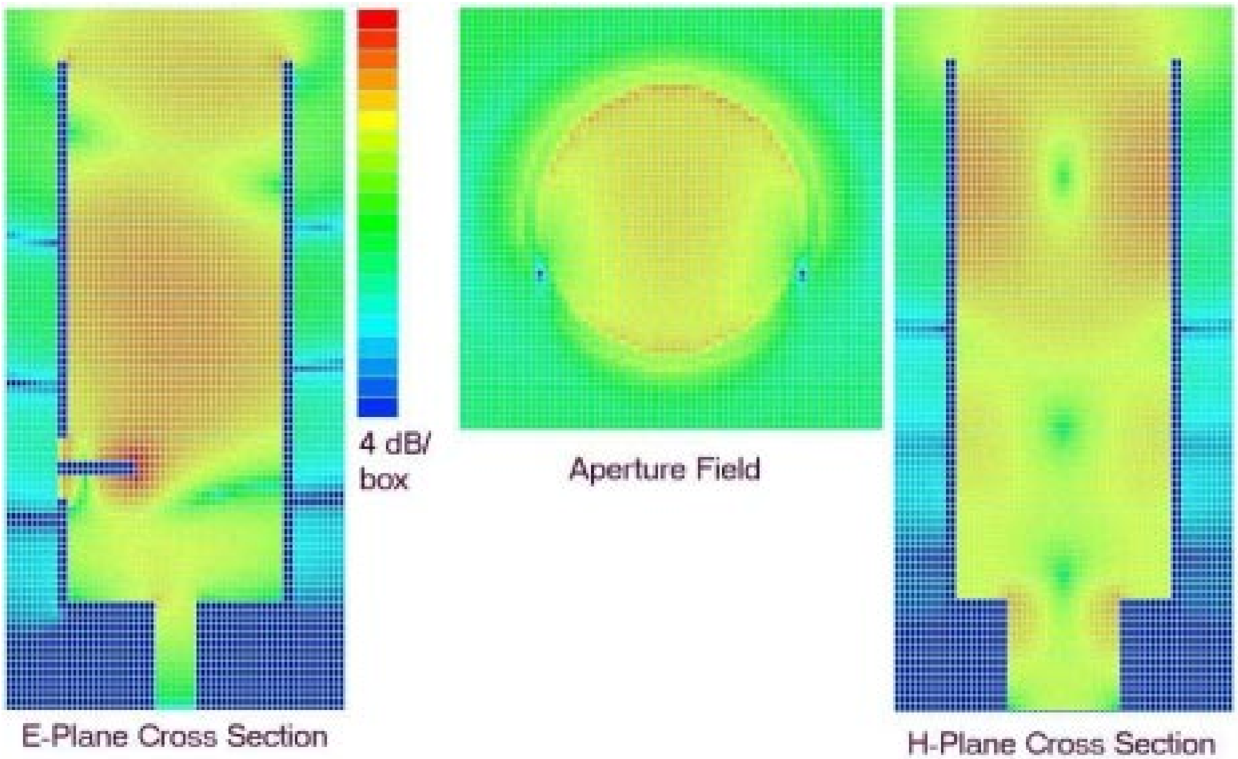



Figure 6.9-26 Dual-band feed experiment for 10 & 24 GHz
Electric Fields at 10.368 GHz **by Zeland Fidelity**

Figure 6.9-27 shows the fields inside the W5ZN dual-band feed at 24 GHz. The fields in the E- and H-plane cross-sections start out in the small waveguide, then show some evidence that additional modes are excited by the step to the larger diameter section. Apparently all the modes arrive in phase at the aperture, since the aperture field is similar to that of a coffee-can feed.

Having examined the fields in a good dual-band feed, we can return to our unsuccessful experiment, the dual-band feed for 3456 MHz and 10 GHz.. The cause of the distorted pattern is apparent from examination of the fields inside the feed, shown at 10 GHz in Figure 6.9-28. Higher-order waveguide modes are being excited by the large step from the smaller rectangular to the larger circular waveguide, and are propagating in the larger section. At the aperture, the field in Figure 6.9-28 looks like the **$TM_{11}$** mode; see Figure 6.5-5b for a sketch of this mode. The field is very small at the center of the waveguide, so there is little energy radiated straight ahead; most goes in unwanted directions.

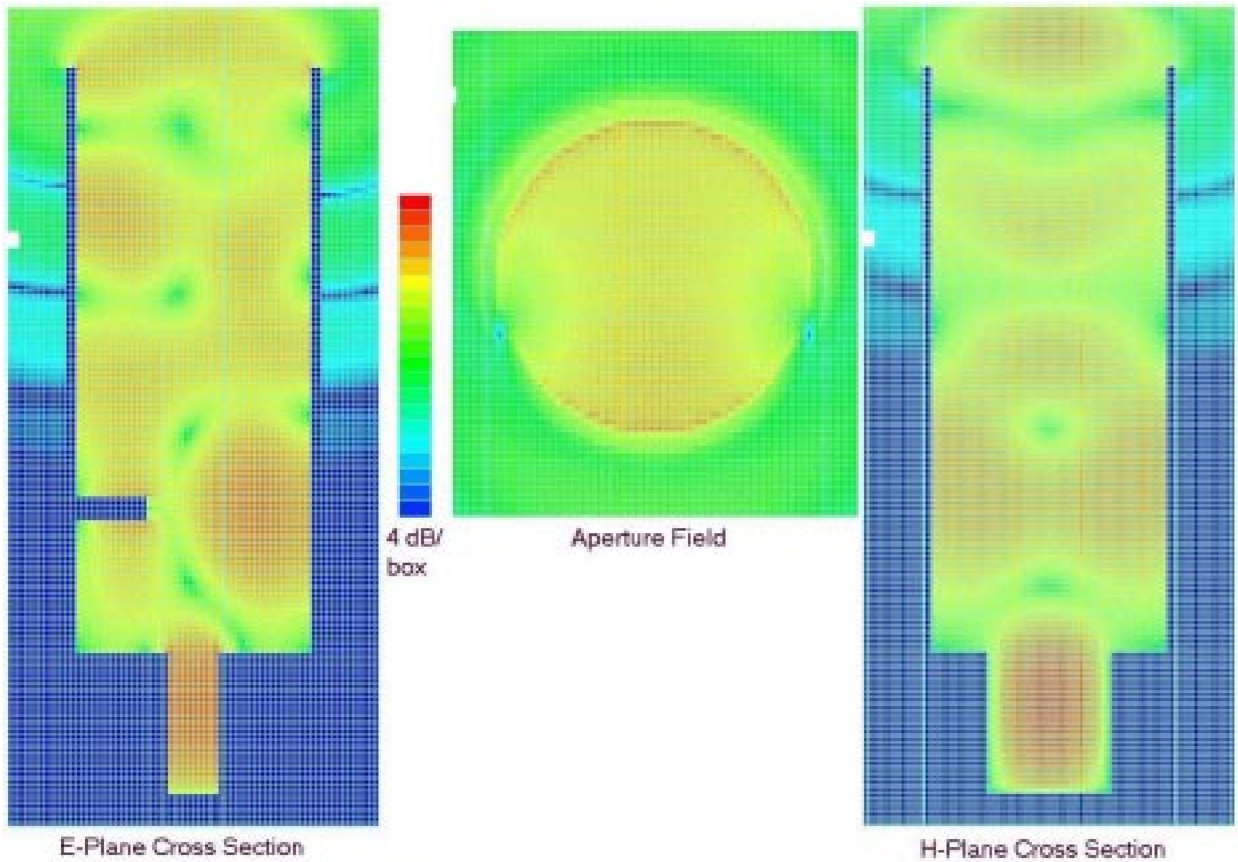



Figure 6.9-27 Dual-band feed experiment for 10 & 24 GHz
Electric Fields at 24.192 GHz by Zeland Fidelity

Our second experimental dual-band feed, for 2304 and 5760 MHz, is better. The fields at 5760 MHz in Figure 6.9-29 show that additional modes are being excited by the step change in diameter and propagated, but they apparently arrive at the aperture in a phase relation with maximum energy at the center, so that the radiation pattern is usable. The aperture field in does show mode irregularities and assymetry between the E- and H-planes that contribute to the phase error we saw in Figure 6.9-25.

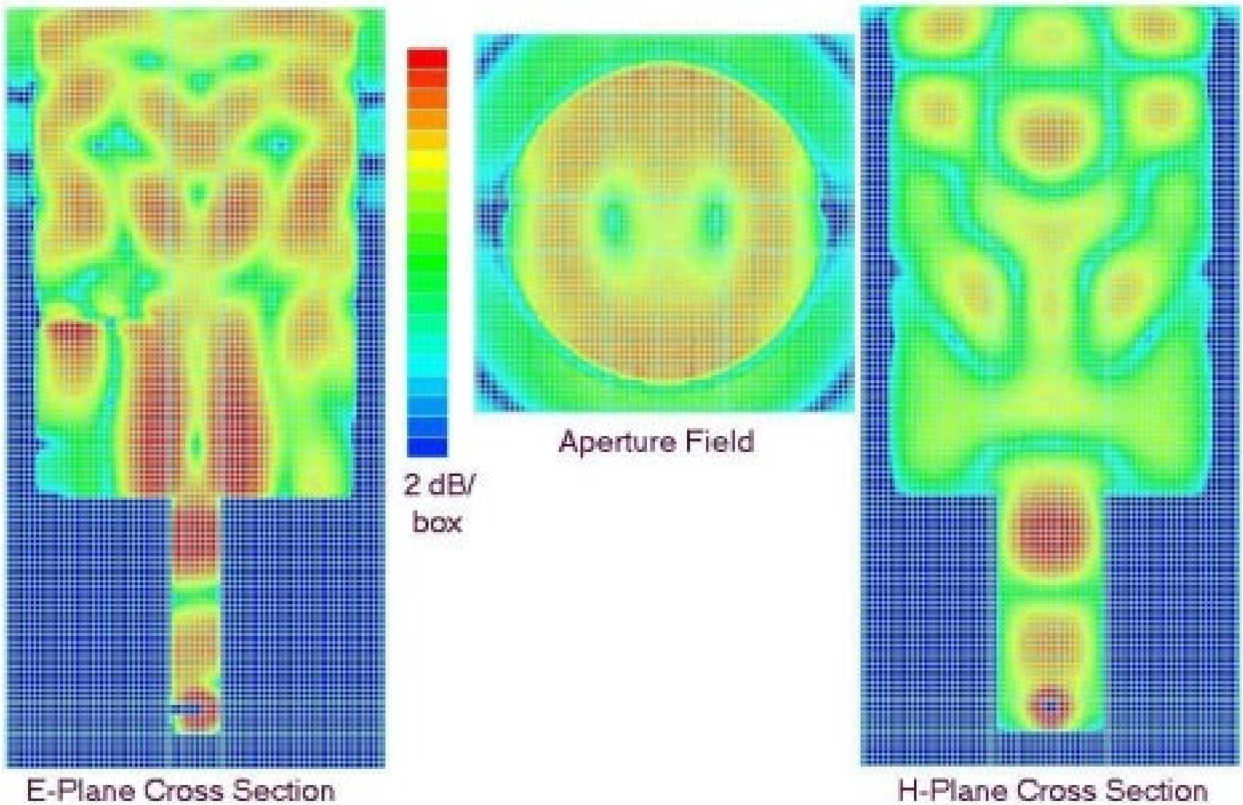



Figure 6.9-28 Dual-band feed experiment for 3.4 & 10 GHz
Electric Fields at 10.368 GHz **by Zeland Fidelity**

Now we can see that we must find a set of dimensions so that any modes that are excited arrive at the aperture with magnitudes and phases that provide a reasonable radiation pattern. I returned to the first experimental feed and tried some modifications. First, a longer large-diameter section to improve 10 GHz phasing showed no significant improvement. Next, I changed the 10 GHz back section to a cylindrical waveguide and added a flared transition section to make it a dual-mode feed at 10 GHz — this one showed some improvement, but higher-order modes were still propagating and distorting the pattern. Finally, I reduced the diameter of the large section to 0.68λ at 3456 MHz, as small as I felt would provide a good pattern at that band, and then used **HDL_ANT** to calculate the best flare dimensions for dual-mode operation at 10 GHz. The final combination works better — the fields at 10.368 GHz in Figure 6.9-30 show that the some undesired modes are excited by the flare but cannot propagate in the reduced diameter of the larger section; note how the fields become well behaved near the aperture. The resulting field at the aperture is reasonably good, but the aperture diameter is quite large in wavelengths, so that the 10 GHz radiation pattern in Figure 6.9-31 is rather narrow, and best ***f*/D** is about 0.8. The dual-band performance is still unsatisfactory, since the radiation pattern at 3456 MHz in Figure 6.9-32 is broad like a coffee-can feed, with best calculated efficiency at an ***f*/D** of about 0.4. No good compromise for ***f*/D** seems likely, due to the difference in patterns at the two frequencies.

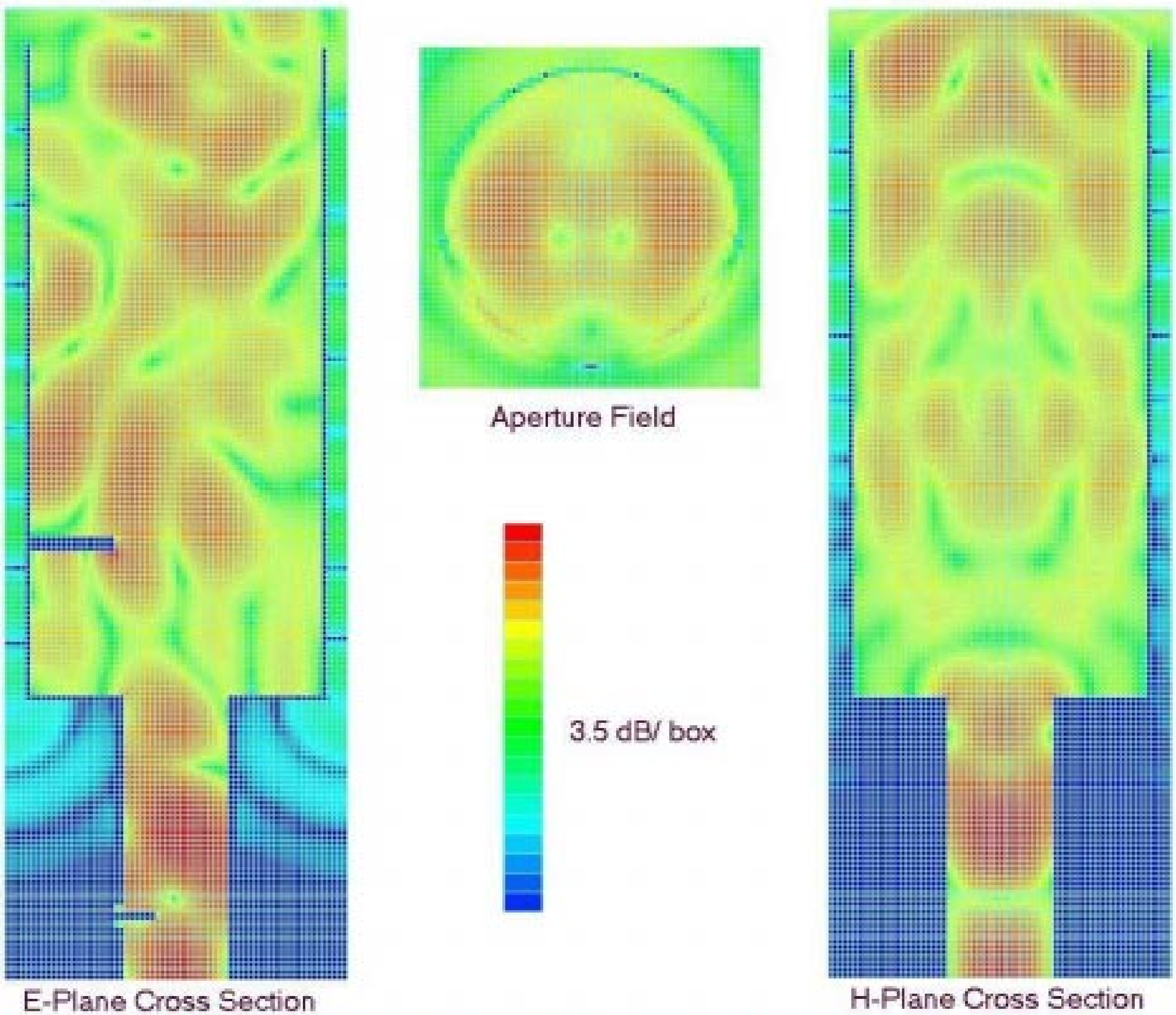



Figure 6.9-29 Dual-band feed experiment for 2304 & 5760 MHz
Electric Fields at 5760 MHz **by Zeland Fidelity**

The lesson we might learn from these dual-band feed experiments is that designing a good dual-band feedhorn is difficult and requires a lot of time, either experimental or computer time. W5LUA and W5ZN should be commended for their efforts.

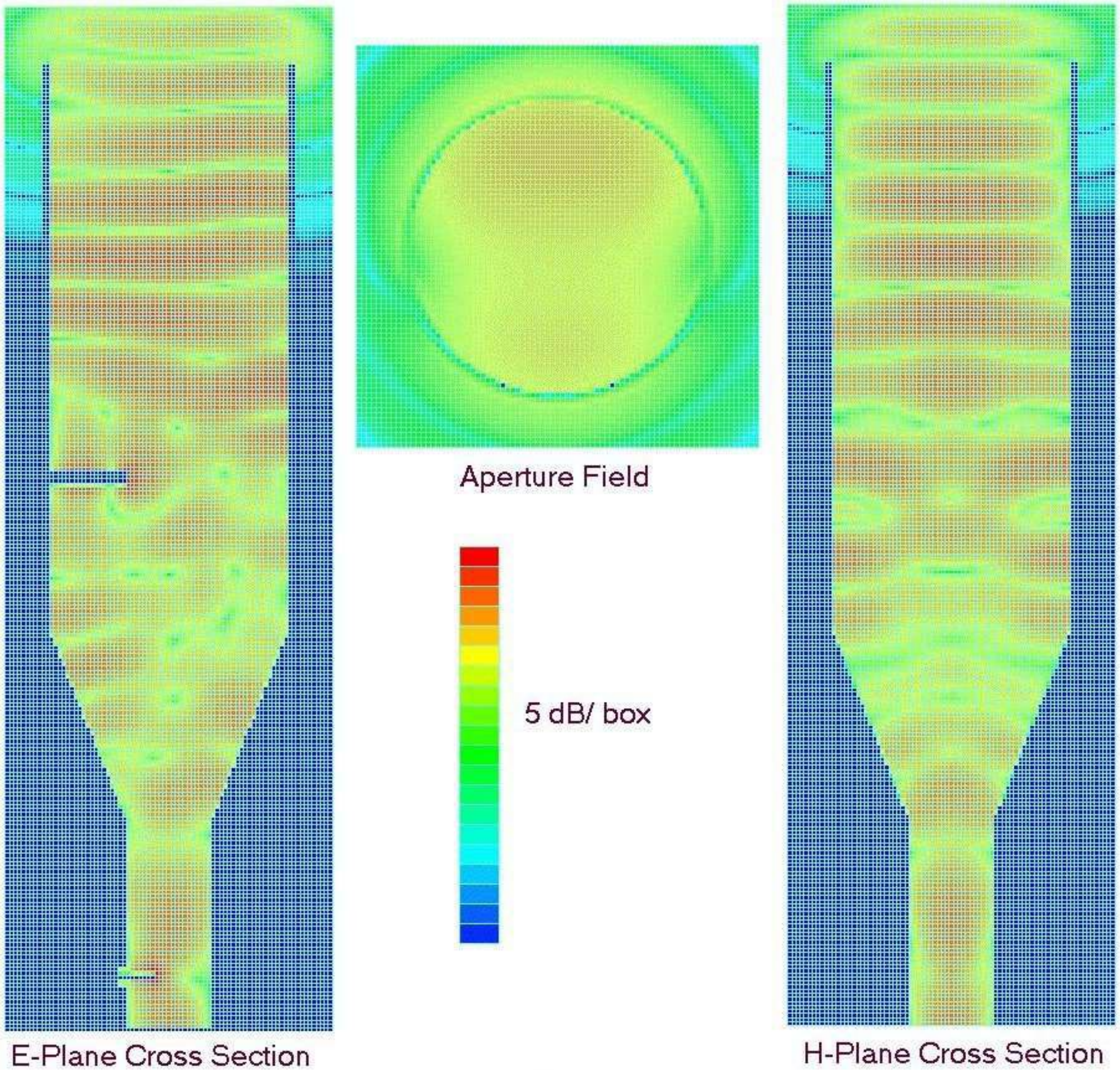
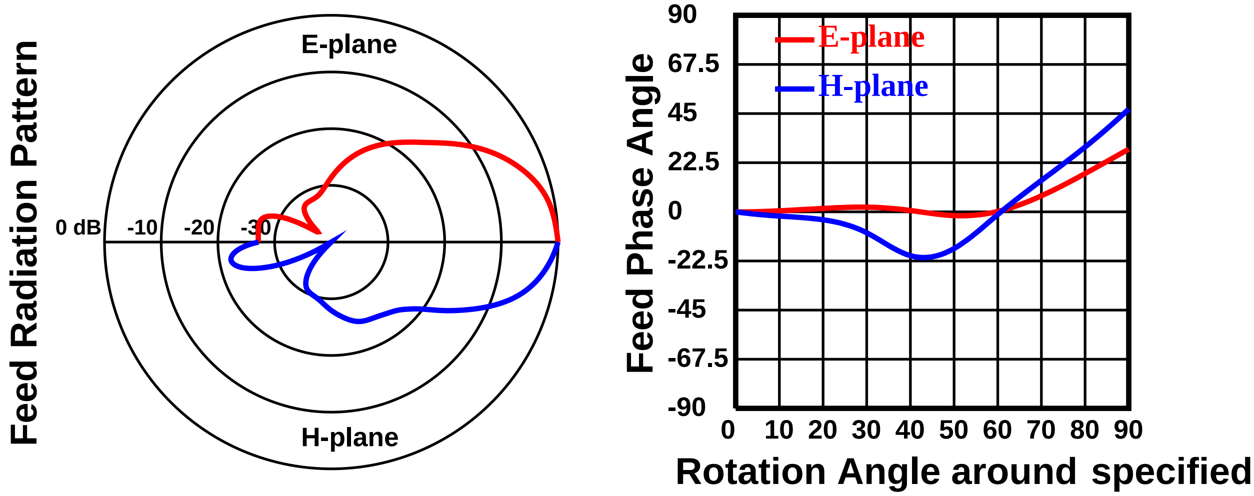



Figure 6.9-30 Dual-band feed --
final dual-mode experiment for 3.4 & 10 GHz
Electric Fields at 10.368 GHz
**by Zeland Fidelity**

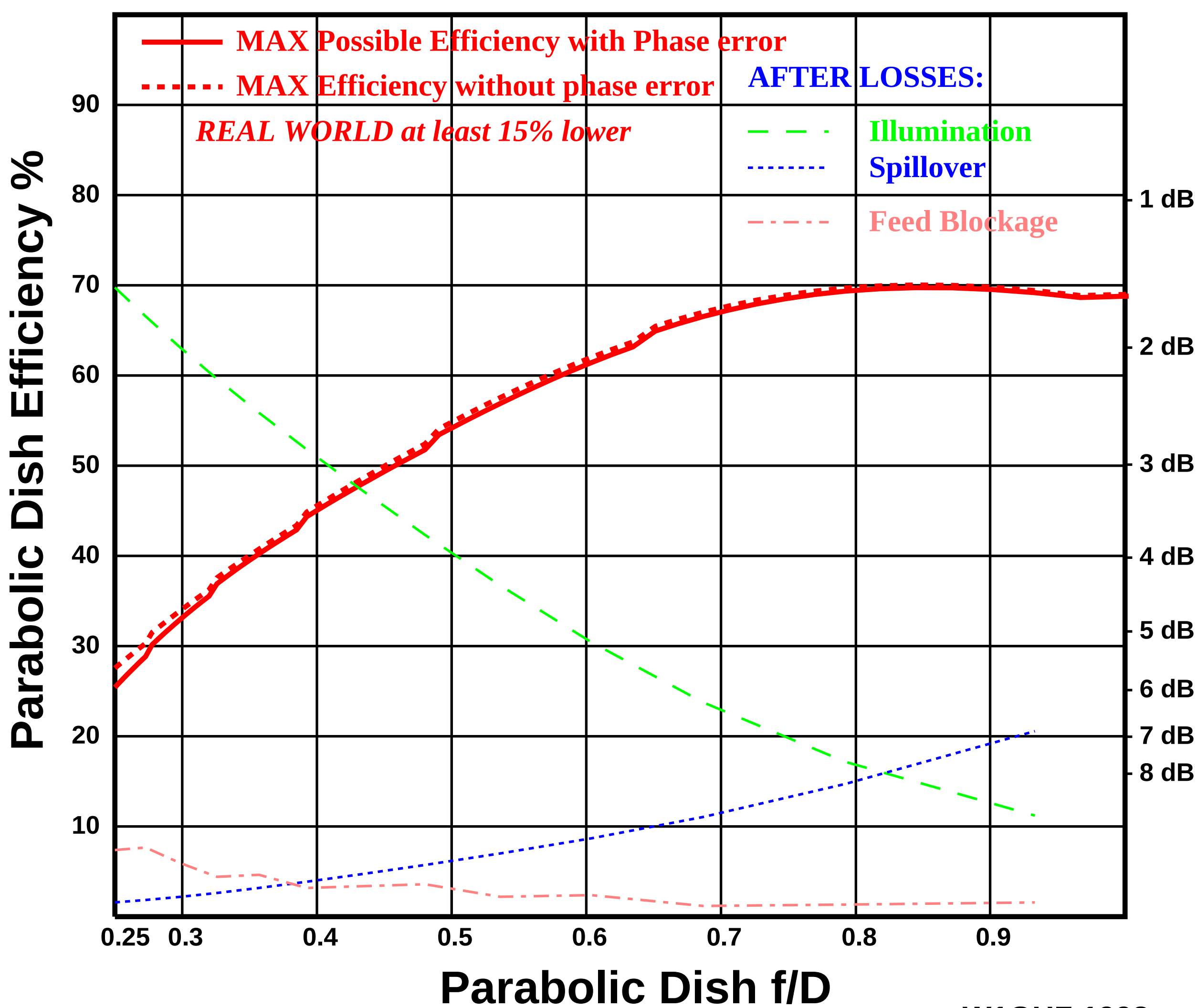
# Dualband 3 & 10 GHz feed with flare at 10.368 GHz,

by Zeland Fidelity™

## Figure 6.9-31




Dish diameter = 30 λ  Feed diameter = 2.04 λ  Phase Center = 0.3 λ inside aperture

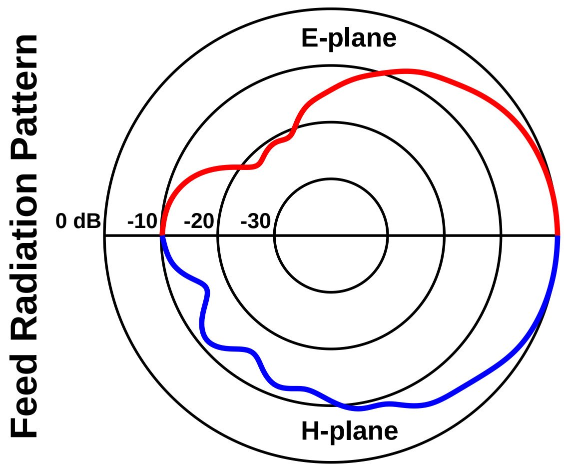


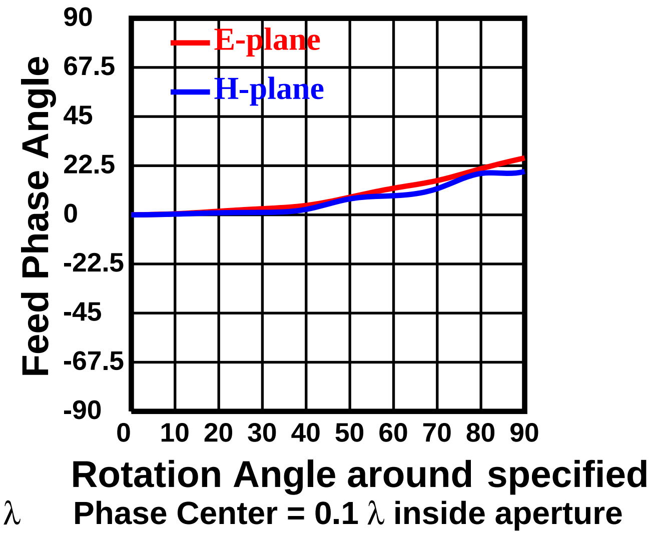

W1GHZ 1998

# Dualband 3 & 10 GHz feedhorn with flare at 3456 MHz,

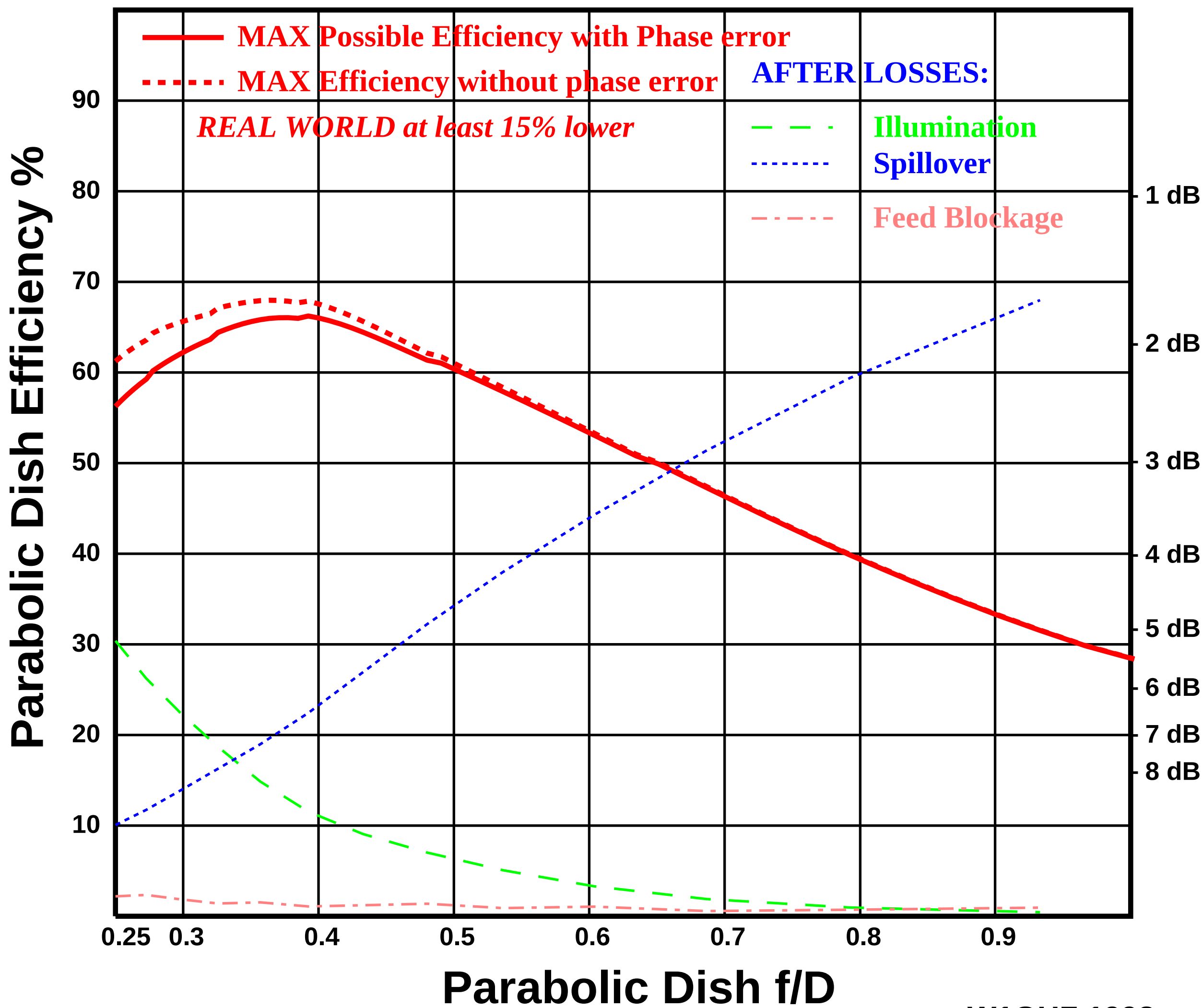
**by Zeland Fidelity™**

## Figure 6.9-32




**Dish diameter = 10 λ  Feed diameter = 0.68 λ**




W1GHZ 1998

### 6.9.7 Broadband feeds

There are two common types of broadband microwave antennas, log-periodic arrays and ridged-waveguide horns.  For both, broadband means having some nominal gain and input match over a range of frequency; it does not necessarily mean have a well-controlled radiation pattern at every frequency in that range.

The log-periodic antenna is a travelling-wave antenna with tapered element lengths, so that a few of the elements are active at each frequency.  Antenna handbooks[14] often describe a microwave version with the elements cut in a flat plate, rather than individual rods, called a “trapezoidal-tooth” log-periodic.  W2IMU once told me that log-periodic arrays have poor phase-center characteristics, and I’ve never seen anything to contradict him.

WA1MBA investigated log-periodic arrays as feed antennas[15] and built some of the trapeziodal-tooth variety to cover the bands from 2304 to 10 GHz.  Figure 6.9-33 is a photograph of one.  When we made gain measurements on a dish with this feed, efficiency at 10 GHz was poor, under 40%.

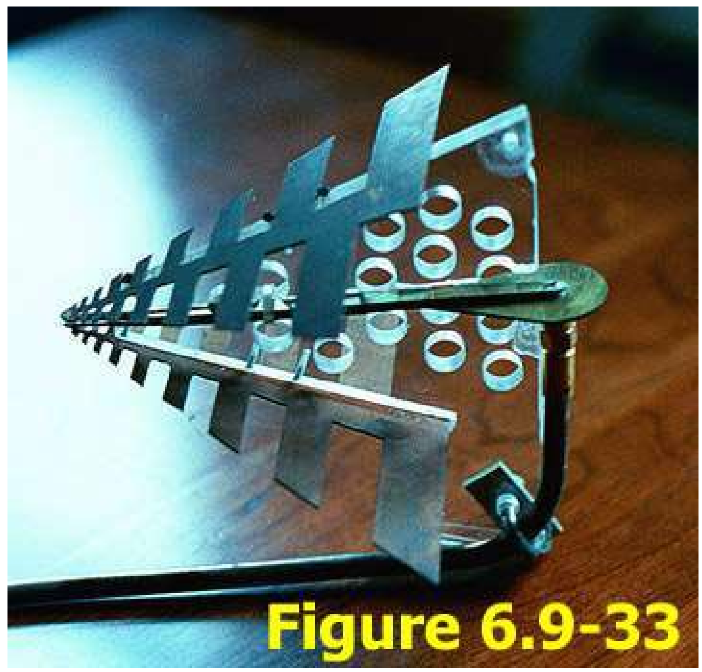


Figure 6.9-33

Ridged-waveguide horns are rectangular or conical horns flared from waveguide of the same cross section.  The ridges are added to waveguide to increase the cutoff frequency for higher-order modes, thus increasing the usable bandwidth of the dominant mode.  If ridges are extended into the flare, the horn may have the same usable bandwidth as the waveguide.

I have seen surplus conical horns with four ridges, every 90° around the perimeter, labeled “2 to 18 GHz.”  A feedhorn using this type of construction claimed[16] to have an octave bandwidth and to provide a constant secondary (dish) beamwidth over the bandwidth — but dish beamwidth should decrease with increasing frequency if the performance is good.  Radiation patterns were only published for the ends of the octave but had much different beamwidths, suggesting that the feed under-illuminated the reflector at the upper end of the band.

Rectangular ridged-waveguide horns can also provide very wide bandwidths.  One paper[17] described versions covering 1 to 12 GHz and 0.2 to 20 GHz with nominal 12 dB gain.  However, sample patterns at several frequencies were very inconsistent, suggesting that this would not be a good broadband feedhorn.

The *Antenna Engineering Handbook*[14] recommends a "planar sinous antenna" as a feed, claiming it provides a constant beamwidth in the E- and H-planes and a frequency independent phase center. Unfortunately, only a sketch is given, with few details and no performance results. I have not found any other references for this antenna.

Although these broadband antennas may not have useful radiation patterns over the whole bandwidth, there are probably smaller frequency ranges where the pattern is acceptable. Someone with a *lot* of excess time on a powerful computer could probably find dimensions to put the better patterns in the microwave ham bands. Since the broadband antennas typically have moderate gain, 10 dB or so, the beamwidth is more suitable for a higher ***f*/D**. Thus, an offset dish might be a better target for broadband feed design.

## 6.9.8 Multi-band feed assemblies

An alternative to a multi-band feed is to have multiple feeds on one parabolic reflector. A good example of this technique is used by VE1ALQ[18] for EME operation on 432 and 1296 MHz. The feed is shown in the photograph of Figure 6.9-34 — a combination of an EIA dual-dipole feed (Section 6.2.2) for 432 MHz and an N7ART diagonal feed (Section 6.5.3) for 1296 MHz. The physically-small diagonal feed in the center should have little effect at 432, while the two dipoles are so widely spaced that they are hardly in the pattern of the 1296 MHz feed. One feature of this combination is that the dimensions of each feed can be adjusted for best illumination over a range of ***f*/D**, and the phase center of each feed can be individually located at the focus of the dish.

Figure 6.9-34 VE1ALQ Dual-band feed assembly for 432 and 1296 MHz

The VE1ALQ feed above is a good example, but it would be difficult to have more than two bands with a common phase center. Perhaps a dual-band feed could be used at the center, for a total of three bands.

On a large dish, several feeds could be mounted side-by-side, requiring rotation of the dish when changing bands to compensate for the off-axis feed. The best focal distance for an off-axis feed is on a curve called a "Petzval surface[19]." A combination of dual-band feeds could add up to a good multi-band antenna, but the operational difficulty of dish movement when changing bands is problematic, particularly with very weak signals (the interesting ones!).

A better alternative might be movable feeds, with a mechanism to move the desired feed into position. Large radiotelescopes often have movable feed arrangements, but they are large enough to tolerate a small room full of equipment behind the feed with little blockage. Most amateurs must get by with much smaller dishes, so a good alternative is the offset-fed dish, where the feed mechanism and unused feeds can be positioned out of the beam.


One such feed mechanism, by WD4MUO[20], is shown in the photograph of Figure 6.9-35, although John's example has feedhorns more suitable for a prime-focus dish. Several waveguides for different bands feed into the lower plate. The upper plate moves the desired horn into position, with a waveguide bend connecting from the horn to the proper location on the upper plate to match the feed waveguide. Obviously, some careful machining is required for everything to line up properly.

A somewhat simpler approach is used by KA1ZE on his latest "rovermobile." The feeds are rotated into position by a standard antenna rotor, which has enough power to rotate both the feeds and a transverter for each band. Figure 6.9-36 shows the assembly; the rotor and all the equipment are out of the beam of the offset dish. One problem that Stan found was that the obliquely-mounted rotor had too much slop to reliably position the feedhorns at the dish focus — rotors are designed for vertical mounting. He added the plastic bearing above the feeds to remove the slop.

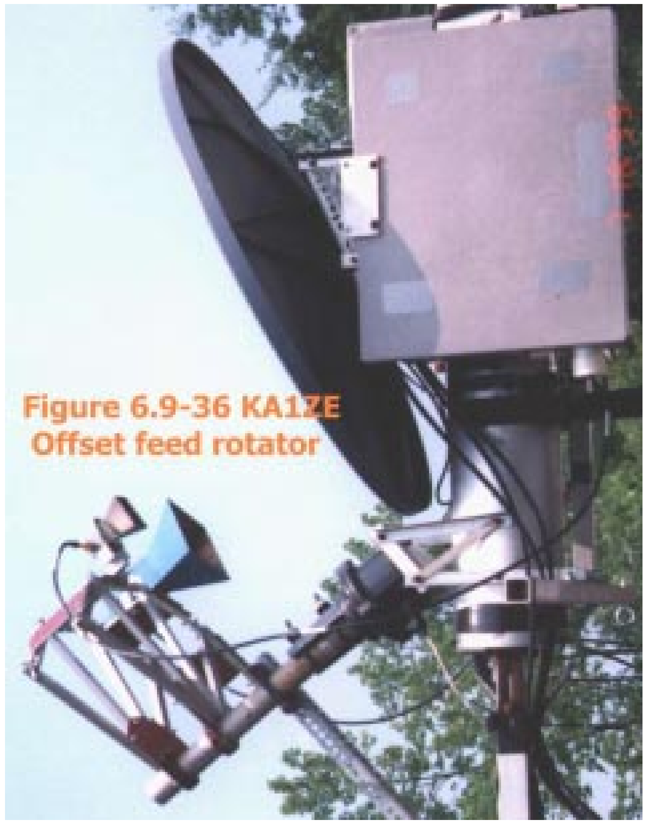


Figure 6.9-36 KA1ZE Offset feed rotator

A final choice, where the dish is accessible, is to make the feeds easily interchangeable. WA5VJB has such a mechanism on his EME dish, fashioned from plastic plumbing fixtures. On EME, there is usually adequate time between schedules for a quick feed change.

## 6.9.9 Summary

Multi-band feeds are never as good as the best single-band feeds, but some two-band feeds can provide performance that is acceptably close. For many amateur installations, having an additional band without requiring an extra dish is a good compromise. Another useful feature is he ability to aim the dish on a lower band, then switch to a higher band without disturbing the dish. However, for EME, where every dB is essential, co-located feeds or interchangeable feeds might be a better choice.

## 6.9 References


1. J. Harrison, W5ZN, "Horns for the Holidays," *Proceedings of Microwave Update '97*, ARRL, 1997, pp. 147-149.

2. J. Harrison, W5ZN, "W5ZN Dual Band 10 GHz / 24 GHz Feedhorn," *Proceedings of Microwave Update '98*, ARRL, 1998, pp. 189-190.

3. J. Harrison, W5ZN, "Further Evaluation of the W5LUA & W5ZN Dual Band Feeds," *Proceedings of Microwave Update '99*, ARRL, 1999, pp. 66-84.

4. T. Hill, WA3RMX, "A Triband Microwave Dish Feed," ***QST***, Aug. 1990, pp. 23-27.

5. Zeland Software, Inc. http://www.zeland.com

6. K. Britain, WA5VJB, "Dual Band Dish Feeds," *Proceedings of Microwave Update '91*, ARRL, 1991, pp. 174-175.

7. G.J.Burke & A.J. Poggio, *Numerical Electromagnetic Code (NEC) — Method of Moments*, Lawrence Livermore Laboratory, 1981.

8. P. Wade, N1BWT, "Dual-band Feedhorn for the DSS Offset Dish, *Proceedings of the 23rd Eastern VHF/UHF Conference*, ARRL, 1997, pp. 107-110.

9. D. Evans, G3RPE, "Pyramidal horn feeds for paraboloidal dishes," *Radio Communications*, March 1975. also in:
10. M.W. Dixon, G3PFR, *Microwave Handbook, Volume 3,* RSGB, 1992, p. 18.85.

11. A. Ward, WB5LUA, "Dual Band Feedhorns for 2304/3456 MHz and 5760/10368 MHz, *Proceedings of Microwave Update '97*, ARRL, 1997 pp. 158-163.

12. W.A. Imbriale, P.G. Ingerson, and W.C. Wong, "Experimental Verification of the Analysis of Umbrella Parabolic Reflectors," *IEEE Transactions on Antennas and Propagation*, September 1973, pp. 705-708.

13. http://www.ntms.org/FeedPatterns.htm

14. R.H. DuHamel & J.P. Scherer, "Frequency-Independent Antennas," in R.C. Johnson, *Antenna Engineering Handbook*, McGraw-Hill, 1993, pp. 14-33 to 14-65.

15. T. Williams, WA1MBA, "A Broadband Dish Feed for Amateur Radio SHF," *Proceedings of Microwave Update '94*, ARRL, 1994, pp. 23-33.

16. J.K. Shimizu, "Octave bandwidth feed horn for paraboloid," *IRE Transactions on Antennas and Propagation*, March 1961, pp. 223-224.

**17.** J.L. Kerr, "Short Axial Length Broad-Band Horns," *IEEE Transactions on Antennas and Propagation*, September 1973, pp. 710-714.

**18.** http://www.ve1alq.bizland.com/downloads/index.htm

**19.** C. Scott, *Modern Methods of Reflector Antenna Analysis and Design*, Artech House, 1990, pp. 70-73.

**20.** J.E. Anderson, WD4MUO/0, "Switched Feeds for Multi-band Parabolic Antennas," *Proceedings of Microwave Update '99*, ARRL, 1999, pp. 100-106.