# Optimized Dual-mode Feedhorns


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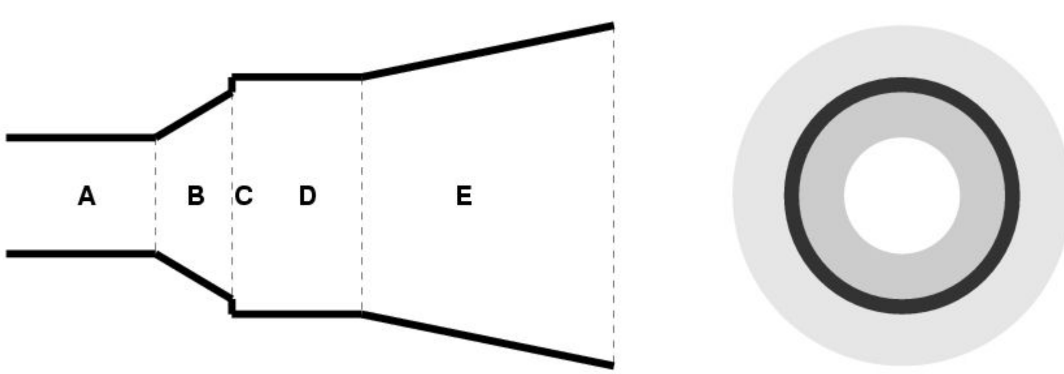
Dual-mode feedhorns for parabolic dishes provide excellent performance over a wide range of microwave bands, especially for offset-fed reflectors. For many commercial applications, the bandwidth of a dual-band horn is too narrow, so corrugated horns are preferred, but bandwidth is rarely a problem for amateur use. While excellent performance is also provided by corrugated horns, they are much more difficult to fabricate with limited machining capabilities, so the dual-band horn is usually preferred when we wish to tailor a feedhorn for a specific dish and frequency.

A recent paper by Skobolev, et al, describes a series of "optimum" geometry dual-mode horns[1]. Simulated performance suggests that these horns can be very high efficiency feeds, and measured results to date confirm this potential. A simple set of design curves makes it easy to find best dimensions for a specific application.

## Dual-mode horn evolution

One of the first dual-mode horns was the Potter[2] type, which uses a step transition in diameter to excite a second mode, TM11, in addition to the normal TE11 mode. The relative amplitudes of the two modes are controlled by the dimensions of the step, shown as **C** in Figure 1. Since the output diameter of the step must be large enough to support both waveguide modes, the input diameter is usually larger than single-mode circular waveguide, **A**, so a gentle flare, **B**, increases the diameter without significant mode conversion. After the step is a phasing section, **D**, to get the two modes to the desired phase relationship, followed by a flare section, **E**, to the aperture diameter needed for the desired beamwidth. Beamwidth is inversely proportional to aperture diameter, while the flare angle affects the beam shape; the right combination can provide high feed efficiency. Once the flare dimensions are chosen, the phase shift of the flare section is calculated and the length of the phasing section adjusted so that the two modes cancel at the rim of the horn. If good cancellation is achieved, there are no edge currents to generate undesired sidelobes. The calculations required to design a Potter horn are fairly complicated.

**Potter dual-mode conical horn**



Dick Turrin, W2IMU, invented a small dual-mode horn[3] which is much simpler than the Potter horn, shown in the sketch in Figure 2. The second mode is excited by a flare section directly from the input waveguide diameter, **A**, to the desired aperture diameter, **B**, followed by a phasing section, **C**, to get the two modes to the desired phase relationship at the aperture. The relative amplitude of the two modes is controlled by the flare angle. Calculation of the required dimensions is significantly easier, and fabrication is also fairly simple[4]. The shortcoming of the W2IMU horn is that it is limited to small aperture diameters before additional unwanted modes can propagate in the phasing section. The result is that it is only good for a small range of ***f*/D**, about 0.5 to 0.8 – perfect for common offset dishes.

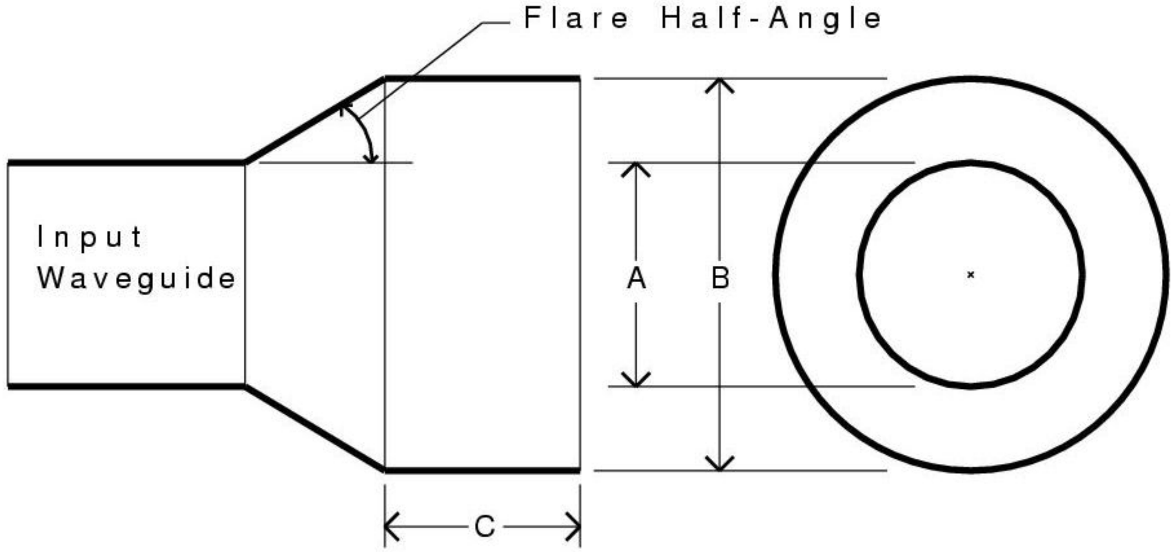



**Figure 2 - W2IMU dual-mode horn**

For multiple-reflector dishes, like the Cassegrain antenna[5], the best combination of parameters might need a feedhorn providing a small illumination angle, equivalent to a large ***f*/D**. This is often the case if we are trying to use an existing subreflector, rather than machining a new one – a large hyperbolic surface is a challenge. One alternative is to design a Potter horn for the large ***f*/D**. Lyle, VK2ALU, found a simpler approach[6]: he added a flare section to the end of a W2IMU dual-mode horn, shown soldered on in Figure 3. Lyle assumed that the two modes have the the desired phase relationship at the end of the W2IMU horn, and used Potter's curves to find a flare length that maintained the desired phase relationship at the larger aperture.

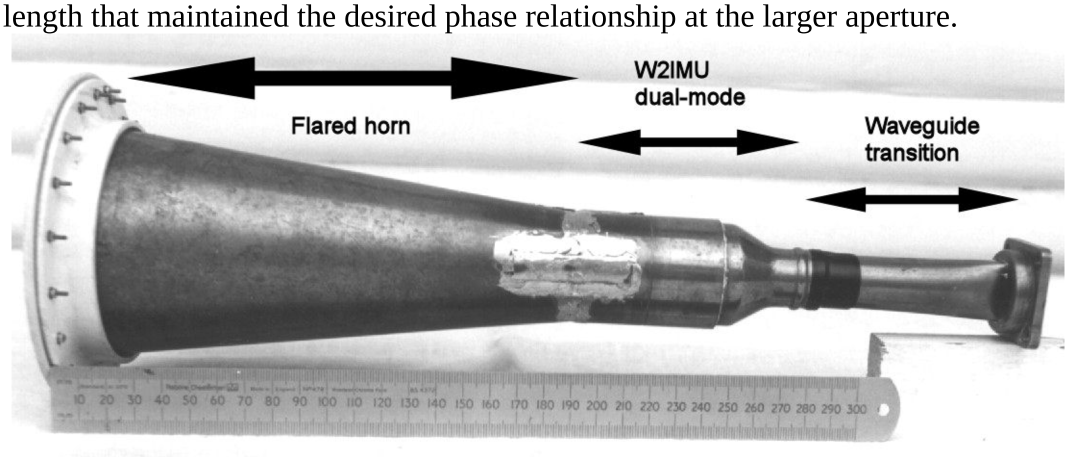



**Figure 3 - VK2ALU extended dual-mode horn**

The “optimum” geometry dual-mode horns described by Skobolev[1] are sketched in Figure 4.

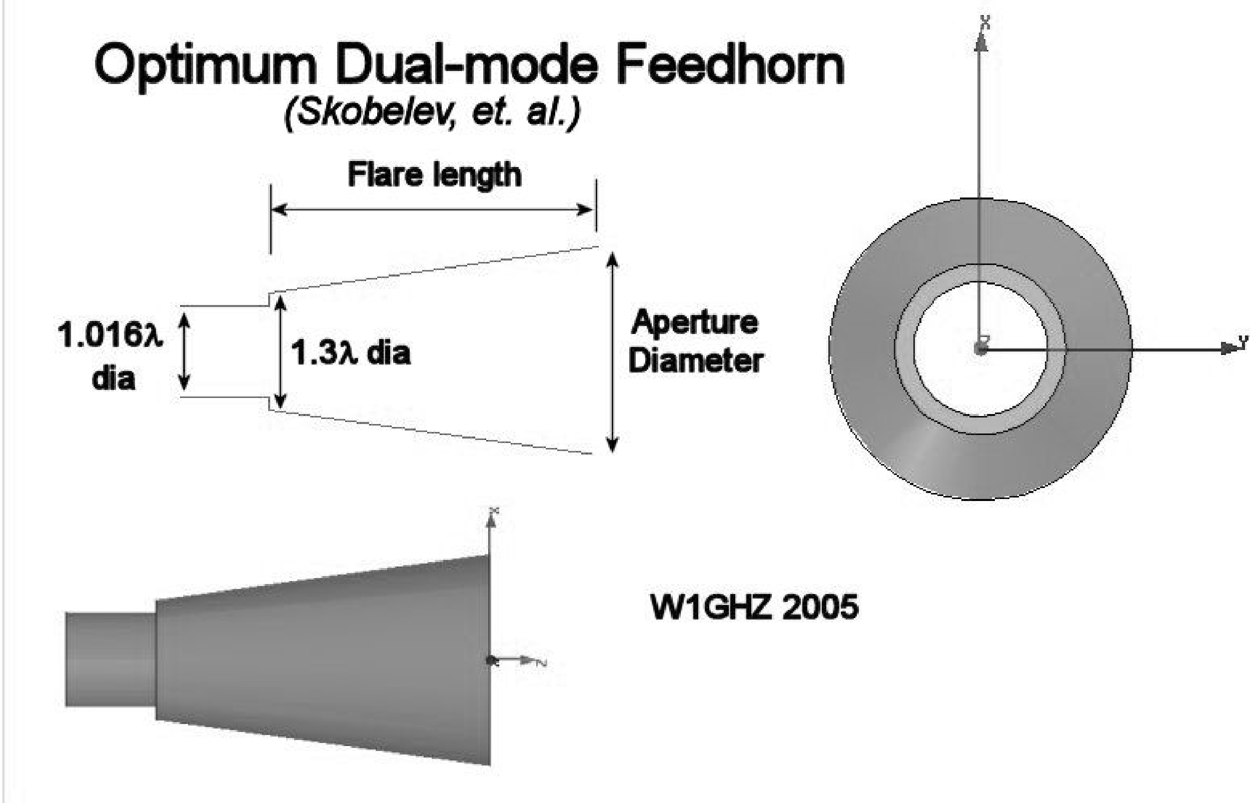



**Figure 4**

These horns have a step transition to excite the second mode, followed immediately by a flare section to the desired aperture diameter, so the total horn length is minimized. The length of the flare is calculated to get the two modes to the desired phase relationship, and a graph is included to find the flare length for aperture diameters between 2 and 6 wavelengths. The graph looks close to a straight line, so I used a simple straight-line approximation:

$$\text{Flarelength (in } \lambda) = 3.45 \cdot r_{\lambda} - 0.35$$ where $r_{\lambda}$ is the radius of the aperture.

Using this approximation, I calculated horn dimensions for aperture diameters of 2, 3, 4, 5 and 6 wavelengths, and calculated radiation patterns for each using Ansoft[7] **HFSS** software. All of the horns had good axisymmetrical radiation patterns with low side and back lobe levels; an example is the 3D plot for the 3λ diameter horn is shown in Figure 5. As a feedhorn, the calculated efficiency is shown in Figure 6 – 79% efficiency for ***f*/D** around 1.2, with very low sidelobe and backlobe levels. This looks like an excellent feed, only 1 dB below

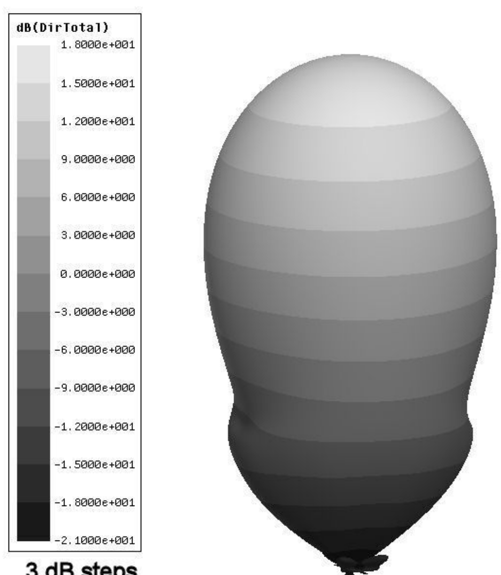
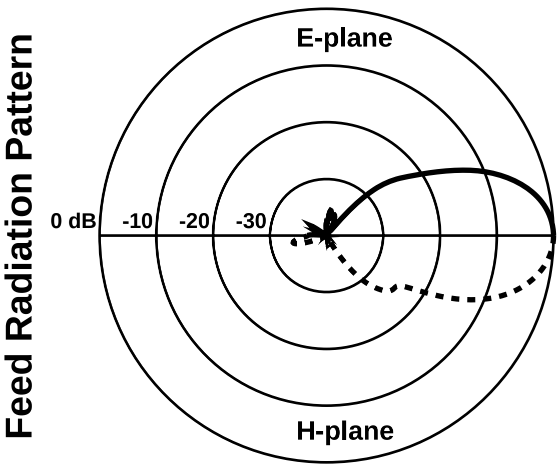
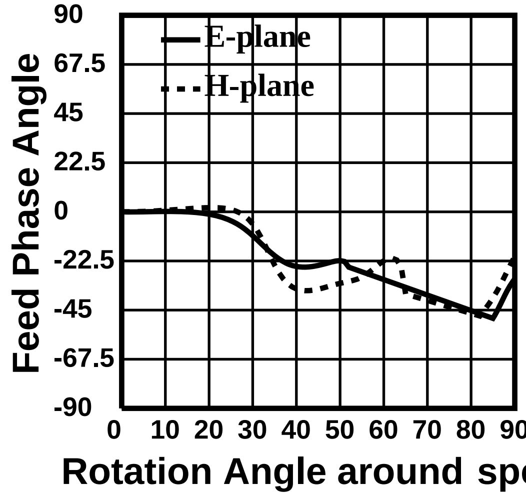



Figure 5

# Optimum dual-mode feed, flare 3λ diameter, 4.85λ long

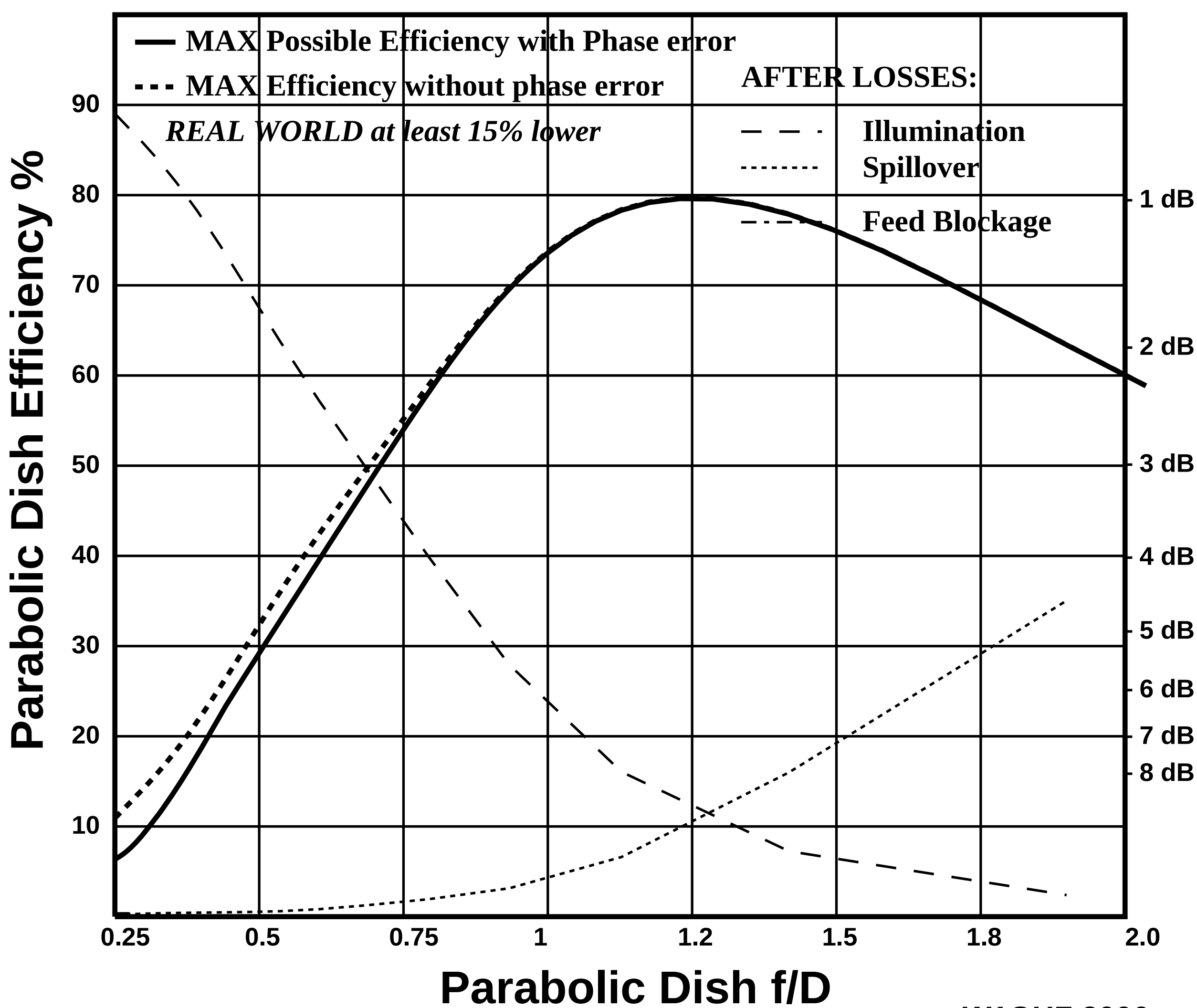
## Figure 6




Dish diameter = 50 λ Feed diameter = 0.5 λ

Phase Center = 0.7 λ inside aperture

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perfection. A near-field plot, Figure 7, demonstrates the dual-mode action: the E-field intensity is high on the H-plane wall of the horn (the top half of the picture) as the wave is launched from the step. As the wave approaches the horn aperture, the electric field near the wall is cancelled by the second mode, resulting in low intensity all around the aperture rim. The result is a pattern with very low sidelobes.

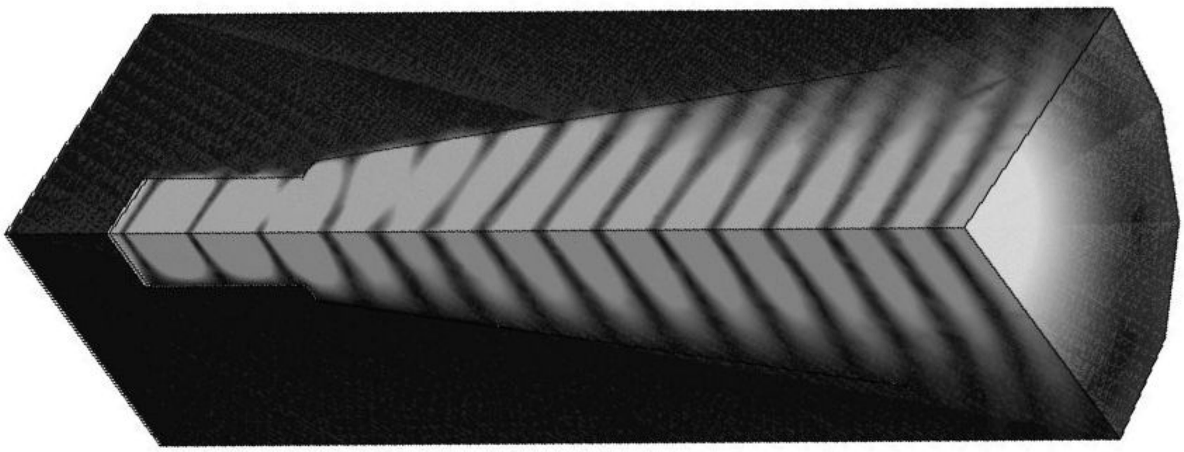


**Figure 7 - E-field**

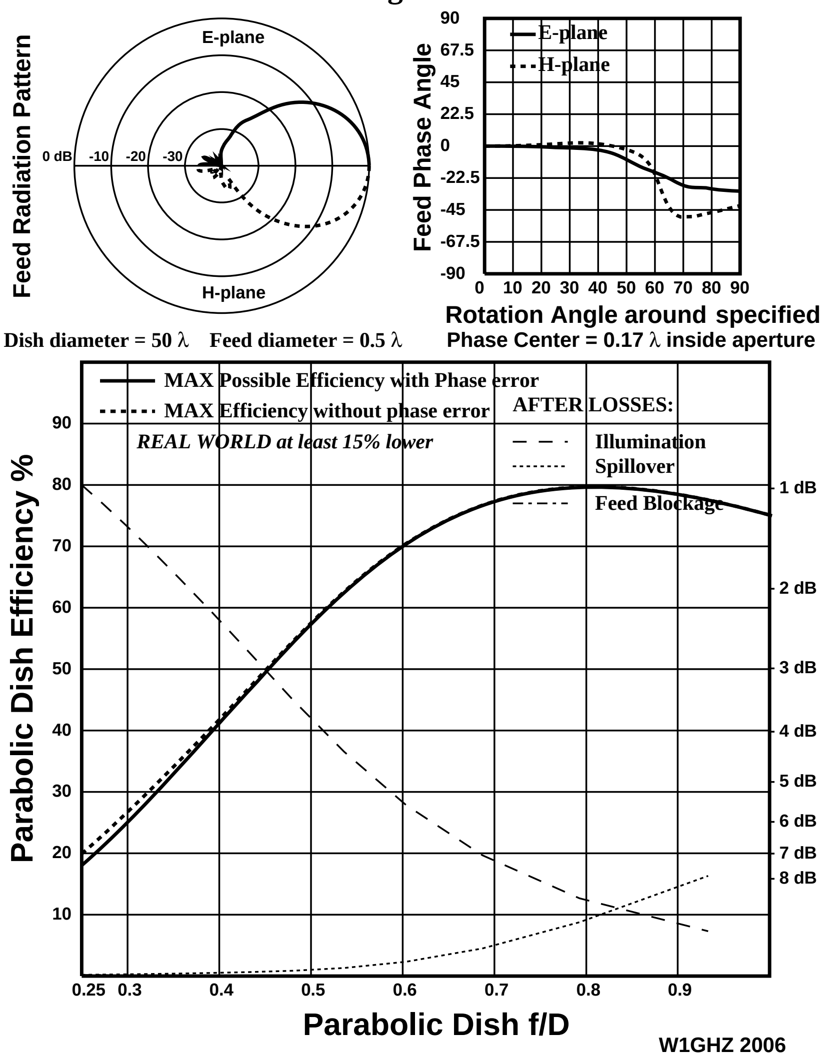
Dish efficiency was calculated for these feedhorns by integrating the patterns using the PHASEPAT program. Dish efficiency plots for the horns are shown in Figures 8 thru 11 for aperture diameters of 2, 4, 5, and 6 $\lambda$ respectively. All show very high calculated efficiency, with optimum ***f*/D** proportional to the aperture diameter, covering a range of ***f*/D** from 0.8 to about 2.0. The patterns are clean with very low sidelobe and backlobe levels. All results are summarized in Table 1.

A horn of the very largest size, 6$\lambda$ in diameter, was contructed for AMSAT use at 10.4 GHz for the Cassegrain antenna of the Bochum Radio Telescope in Germany. Dr. Karl Meinzer DJ4ZC, reported a 1.5 dB improvement in gain and G/T, compared to the previous feed. His sketch of the feed is shown in Figure 12.

**Figure 12 – 10.4 GHz Feedhorn for Bochum Radio Telescope (courtesy Dr. Karl Meinzer, DJ4ZC)**

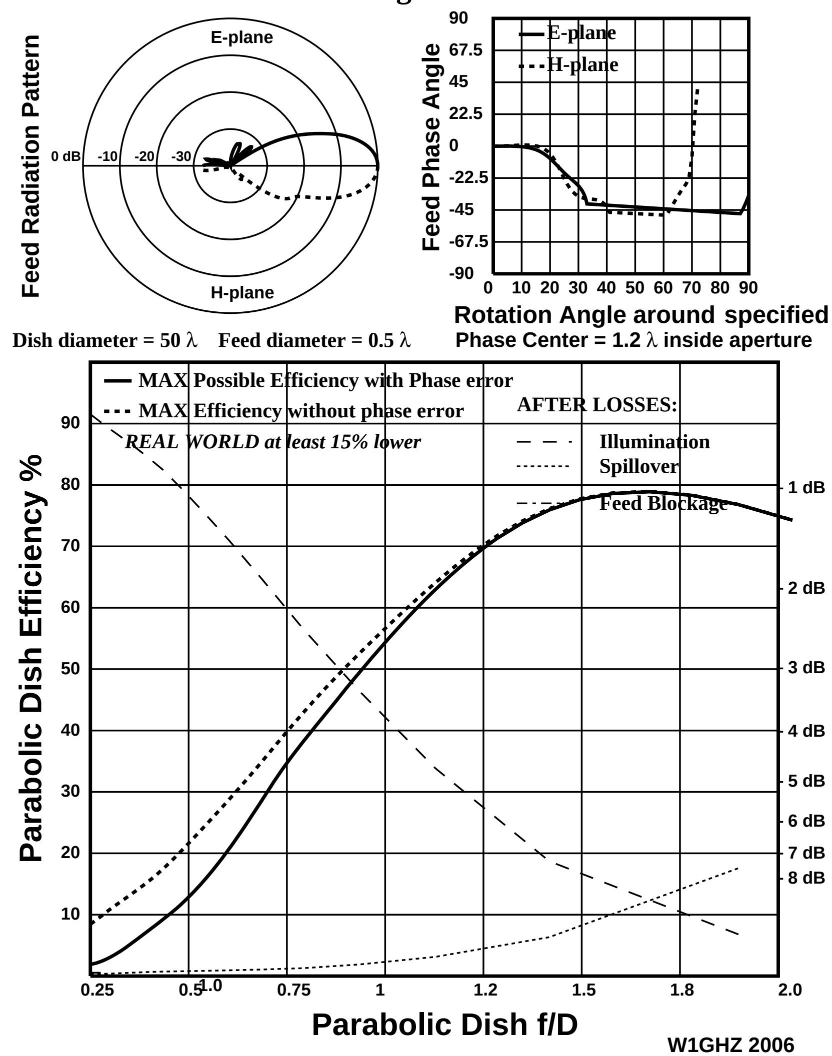
## Optimum dual-mode feed, flare 2λ diameter, 3.1λ long

**Figure 8**



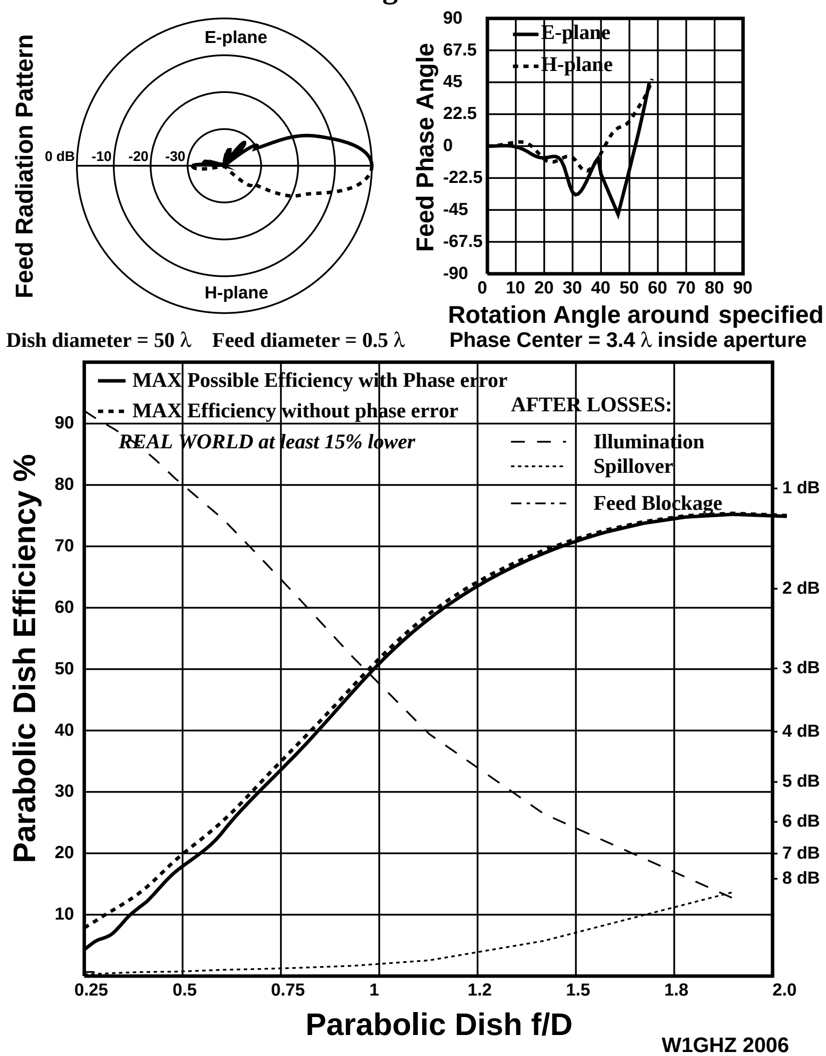

## Optimum dual-mode feed, flare 4λ diameter, 6.55λ long

**Figure 9**



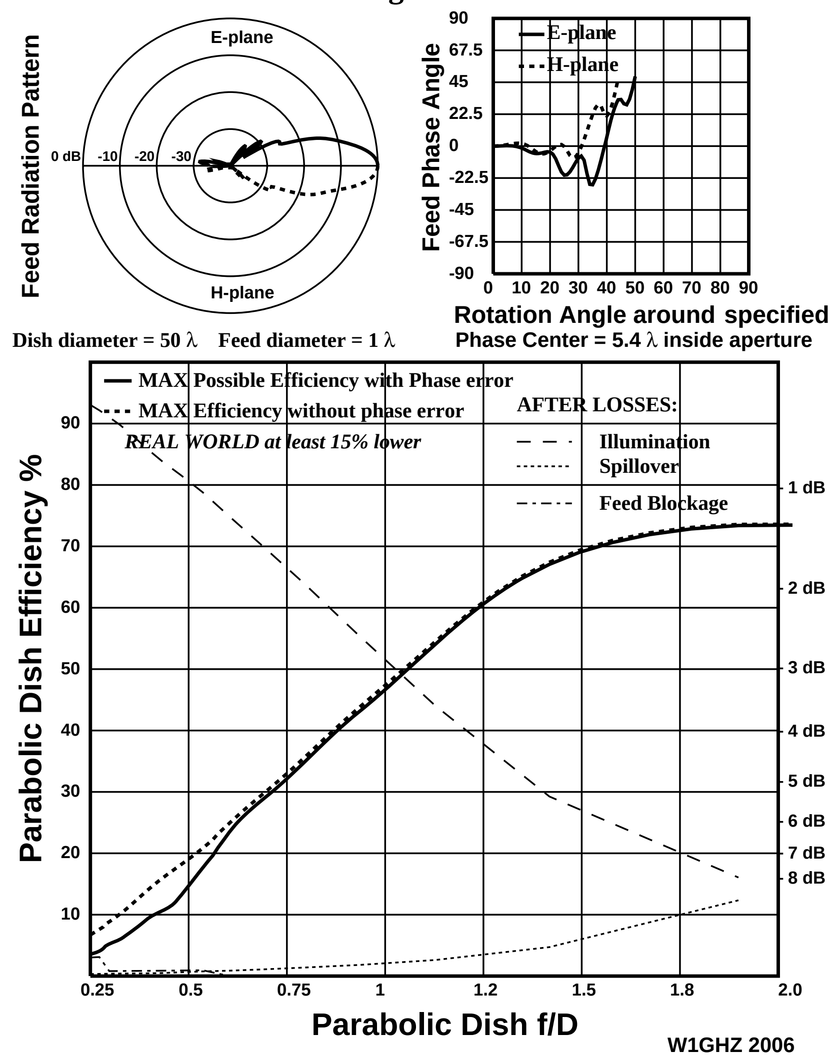
## Optimum dual-mode feed, flare 5λ diameter, 8.25λ long

### Figure 10




## Optimum dual-mode feed, flare 6λ diameter, 10λ long

### Figure 11



Two additional aperture diameters are listed in Table 1. I was asked for a10 GHz optimum feedhorn for an ***f*/D** of 0.935 by GW4DGU for his offset dish. I estimated that the required aperture diameter would be 2.3λ, and this proved to be very close. This horn has an extremely high calculated dish efficiency, 80.2%, less than one dB down from perfect. The dish efficiency plot is shown in Figure 13.

## DSS offset dishes

The smallest optimum dual-mode horn, 2λ diameter, is best suited to an ***f*/D** = 0.83, and the larger ones for larger ***f*/D**. Since most common offset dishes, like the ubiquitous DSS dishes, need an illumination angle equivalent to 0.7 ***f*/D**, I wanted to make a smaller version. Using the straight-line approximation to estimate flare length, I tried several different sizes, from 1.5λ to 1.9λ in diameter and various flare lengths; most were pretty good, as shown in Table 1. An aperture diameter of 1.7λ with a flare length of 2.57λ came closest, but calculated efficiency was not as good as the larger horns. I then tried flare lengths 10% longer and 5%, 10%, and 20% shorter; the 5% and 10% shorter versions, 2.34λ and 2.44λ long respectively, were the winners, both with a calculated dish efficiency of 79.6%. The dish efficiency plots are shown in Figures 14a and 14b for the two flare lengths – the shorter one favors a slightly higher ***f*/D**, while the longer one is better for a slightly higher ***f*/D**. A 3D plot of the very clean radiation pattern for the 2.44λ long version is shown in Figure 15. A photo of a 47 GHz feedhorn 1.7λ in diameter is shown in Figure 16, and one for 10.368 GHz with matching section to WR-90 in Figure 17.

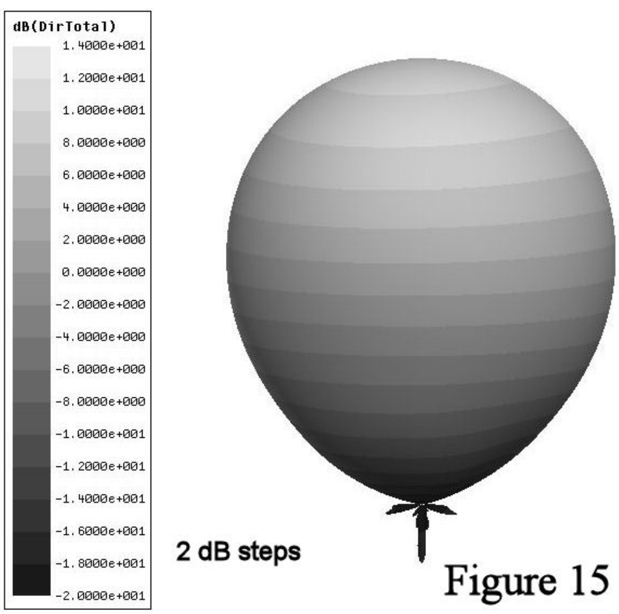



Figure 15

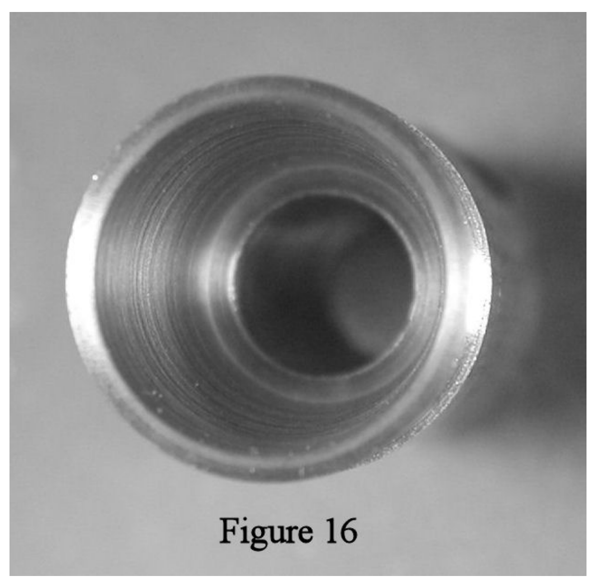
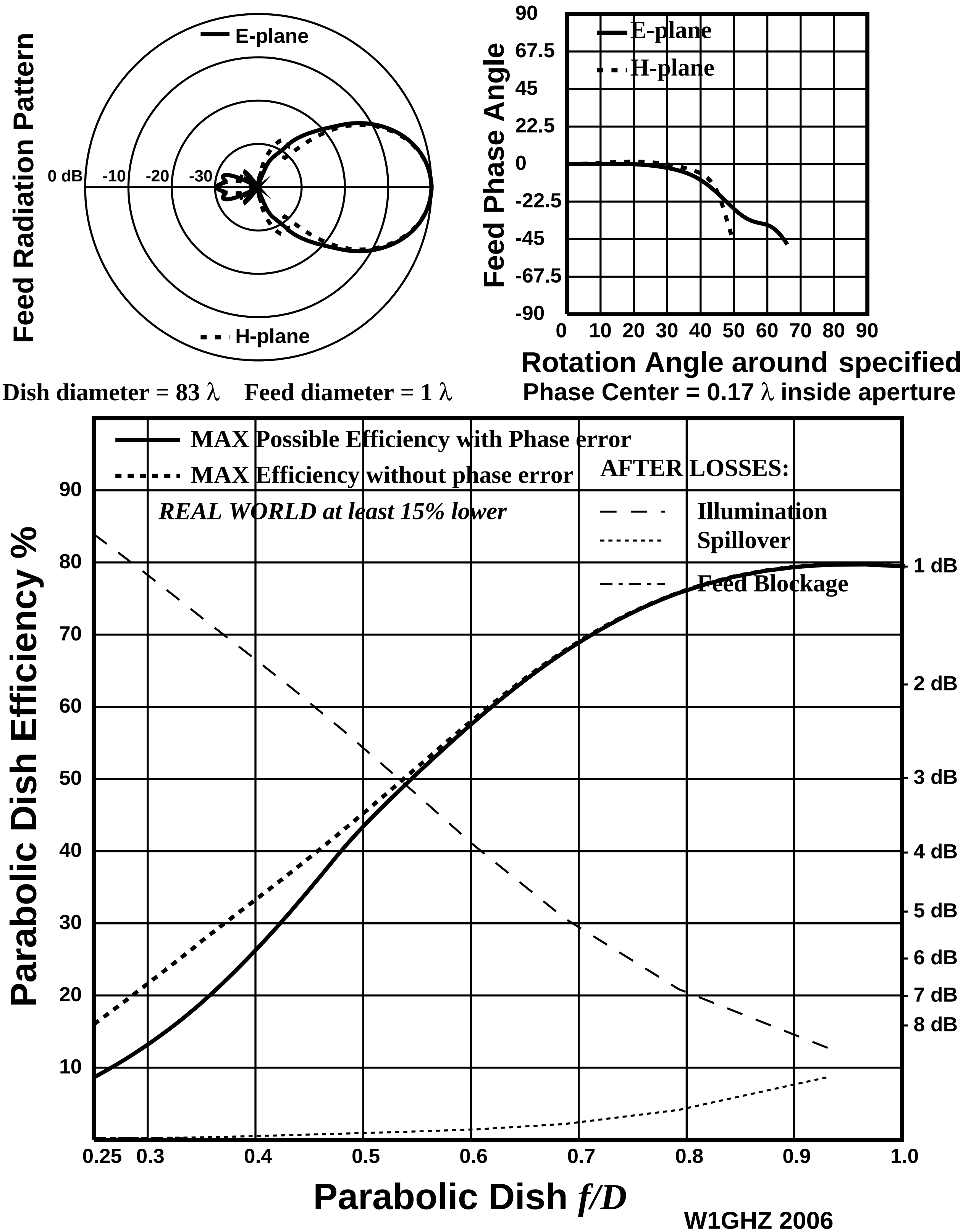


Figure 16

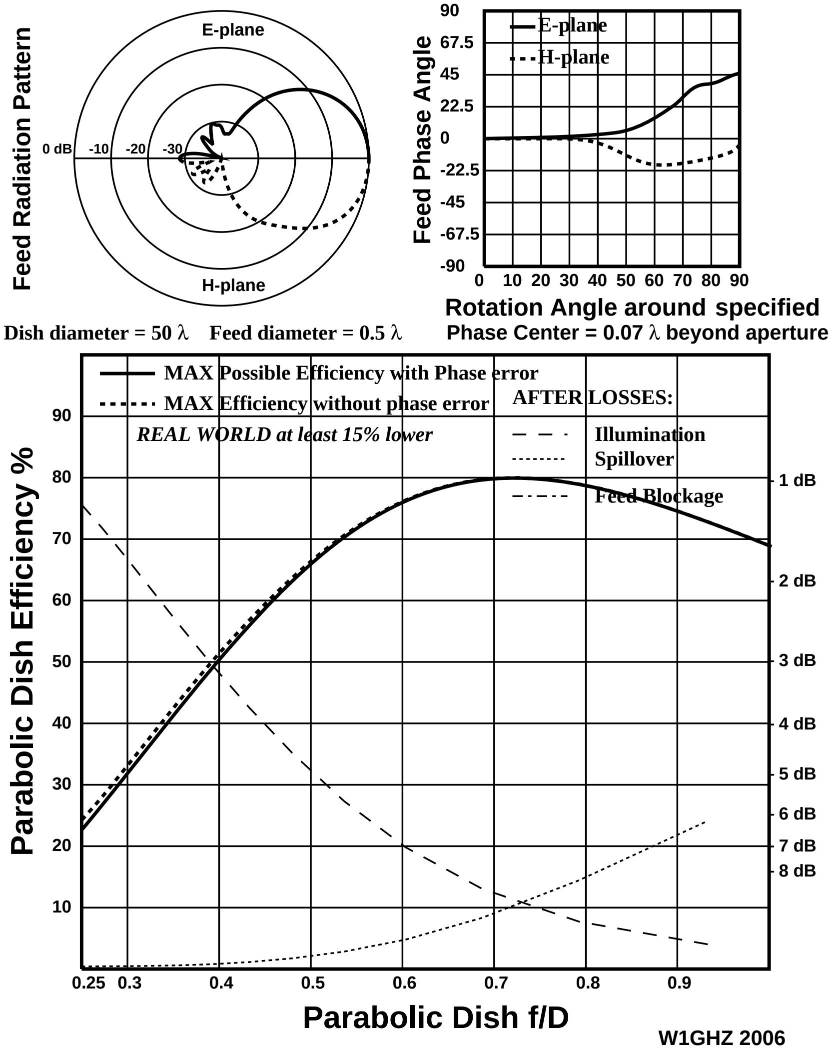
# Optimum dual-mode feed, flare 2.3λ diameter, 3.62λ long

## Figure 13



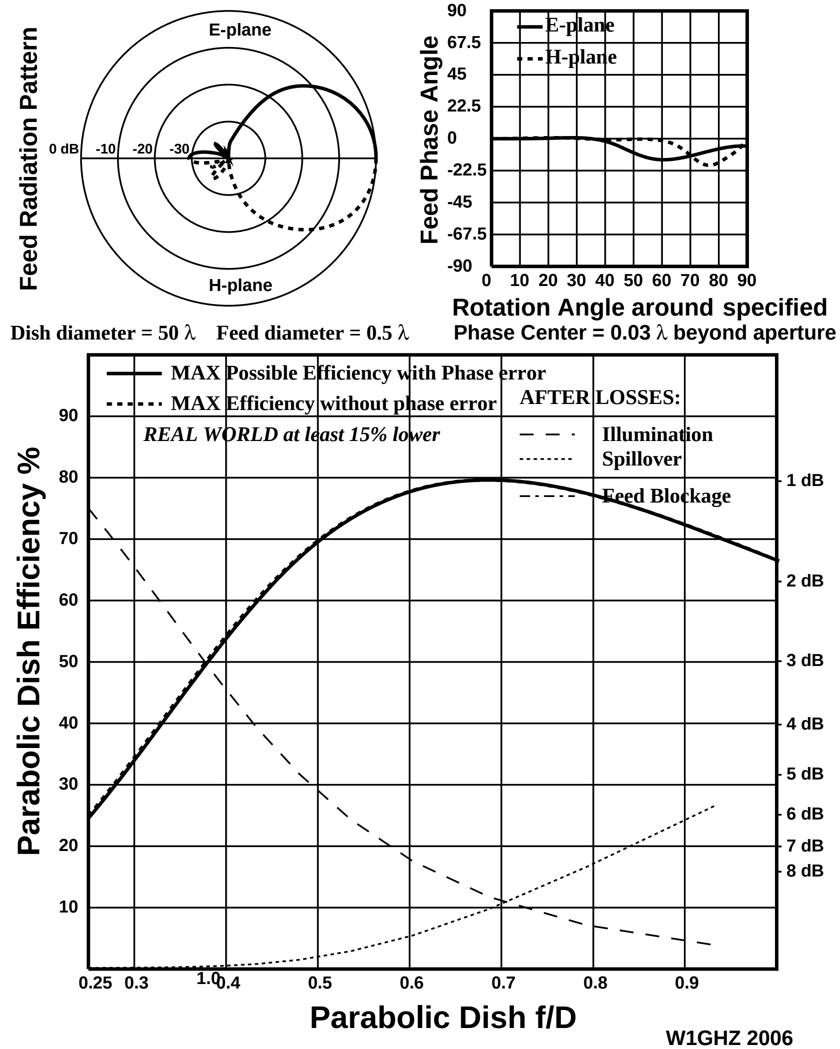
## Optimum dual-mode feed, flare 1.7λ diameter, 2.34λ long

### Figure 14a




## Optimum dual-mode feed, flare 1.7λ diameter, 2.44λ long

### Figure 14b



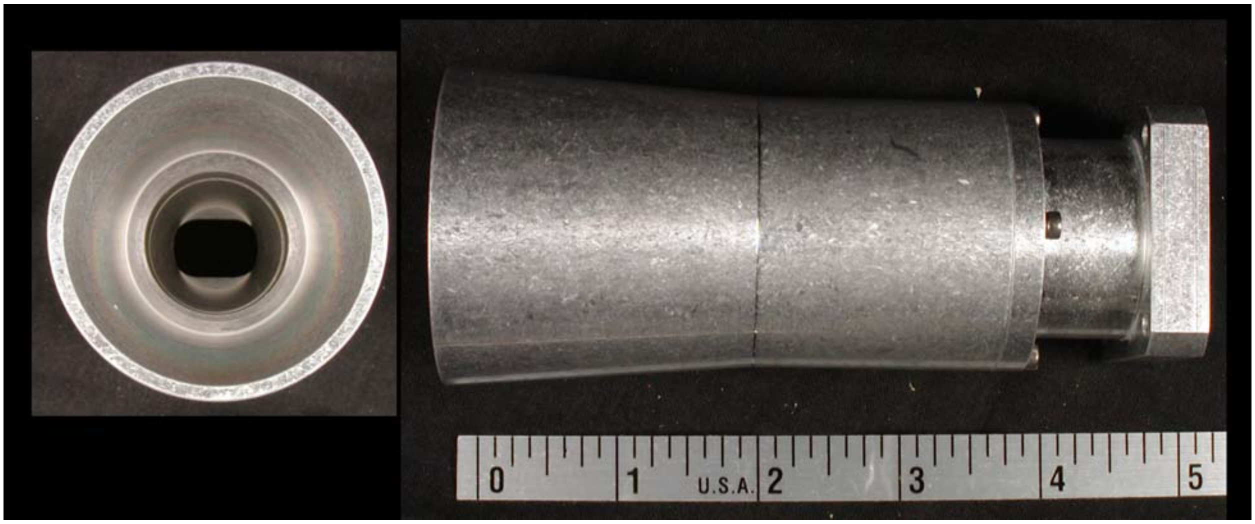


**Figure 17 – Optimum dual-mode feed for 10.368 GHz, 1.7λ Aperture Diameter, 2.4λ Flare length**

## Further Optimization

After seeing how adjusting the length improved efficiency for the small version, I tried length variations on the larger diameters. Most showed some improvement and very high efficiencies were calculated, some over 80%. All the results are listed in Table 1, with calculated efficiencies plotted in Figure 18 and best ***f*/D** in Figure 19. Design curves in Figure 20 summarize the best results and may be used to find dimensions of a feedhorn for any desired ***f*/D**.

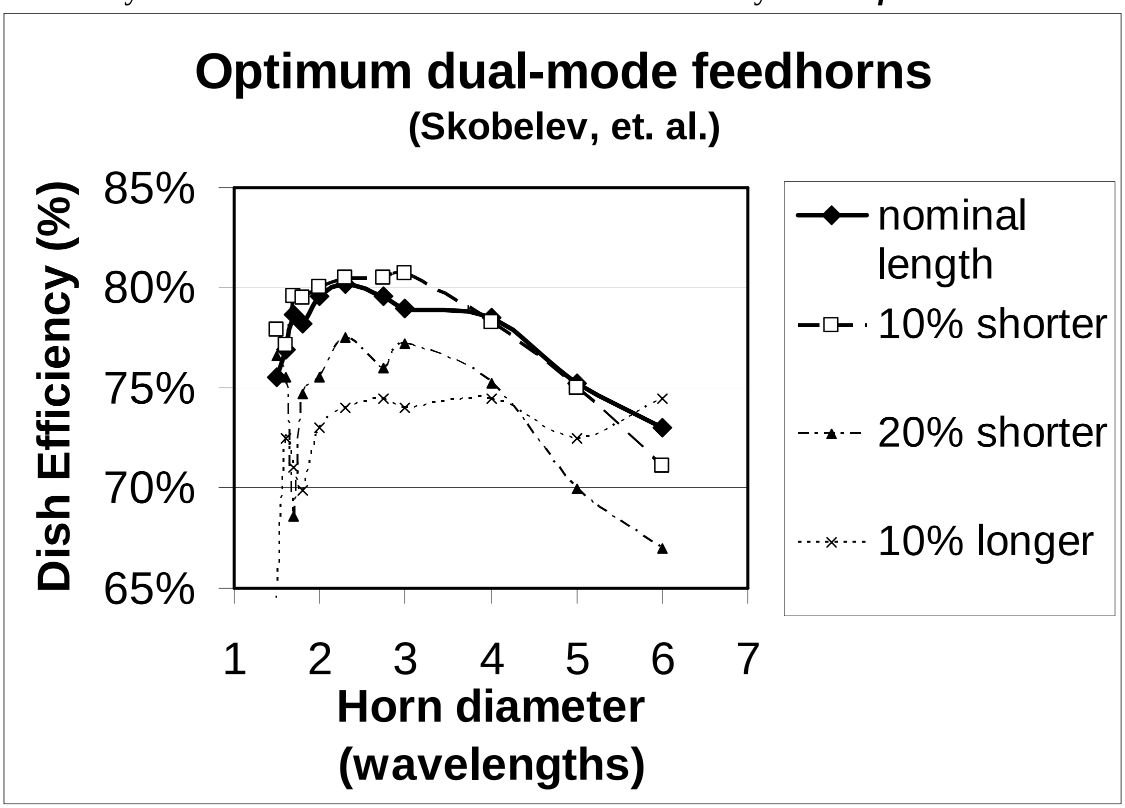


**Figure 18 – Optimum dual-mode feedhorn efficiency**

## Matching

All sizes of the optimum dual-mode horn use the same step diameters, from 1.016λ at the input to 1.3λ at the flare, so the input diameter is larger than single-mode circular waveguide, typically close to 0.7λ in diameter. The calculated return loss for the 1.016λ diameter input waveguide is good, so a matched transition is all that is needed. A gentle flare or multiple steps will work for circular guide, or a rectangular step may be used to transition directly to standard rectangular waveguide.

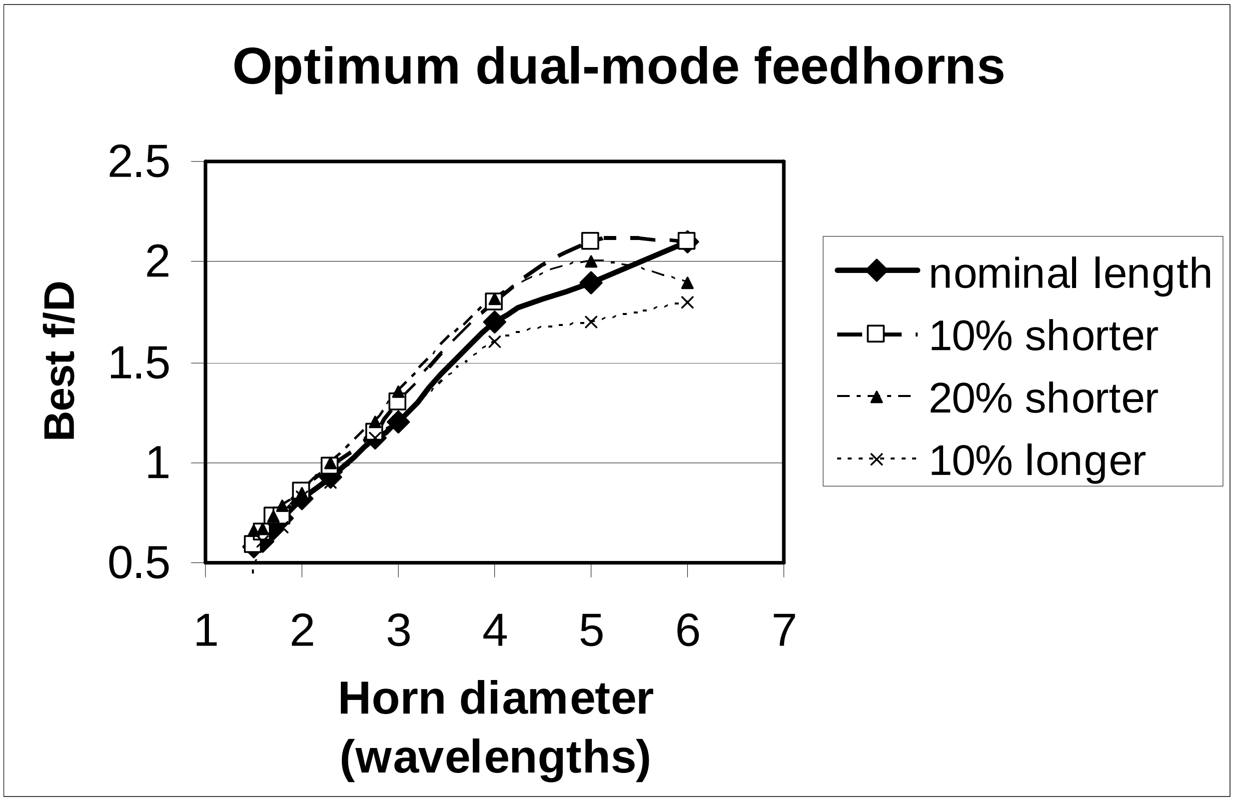



**Figure 19 - Optimum dual-mode feedhorn efficiency**

Summary

A series of "optimum" geometry dual-mode horns originally described by Skobolev and further optimized using HFSS software potentially provide exceptionally high efficiency feeds for offset and multiple-reflector dishes. Preliminary results to date on various sizes at frequencies from 10 to 90 GHz are encouraging. More measurement data will be forthcoming.

Design curves in Figure 20 should be adequate to choose best dimensions for most applications. More measurement data will be forthcoming.

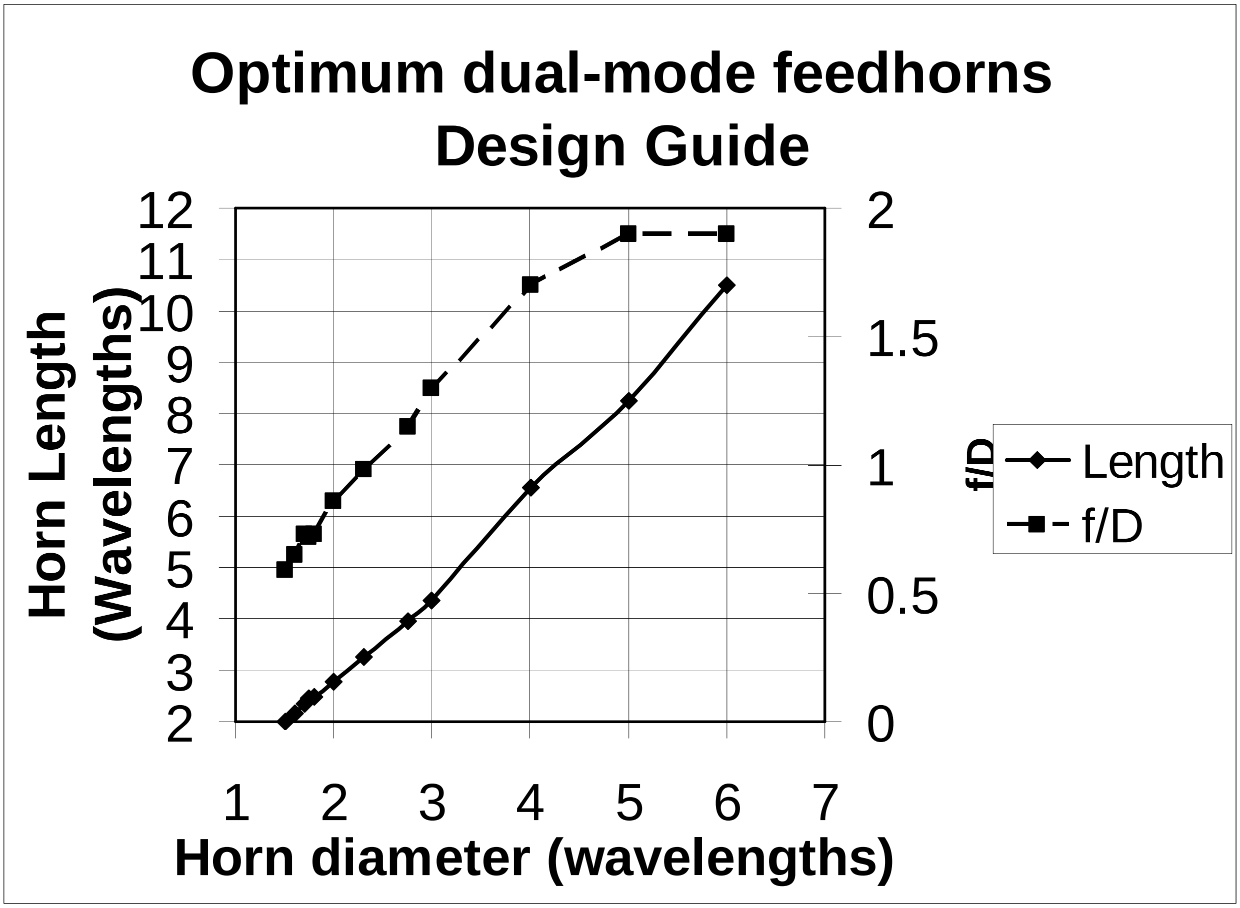



**Figure 20 – Design guide for optimum dual-mode feedhorn dimensions**

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7. www.ansoft.com

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after Skobolev, et al

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| Aperture Diameter λ | Flare Length λ | f/D (best) | Efficiency (dish) | Phase Center λ | Front to Back dB | Sidelobe (worst) dB | Gain (horn) dB | Beamwidth 10 dB degrees |
|---|---|---|---|---|---|---|---|---|
| **Nominal** | | | | | | | | |
| 1.5 | 2.238 | 0.58 | 75.5% | -0.1 | 21 | -10 | 11.5 | 95 |
| 1.6 | 2.41 | 0.61 | 76.9% | -0.07 | 25 | -19 | 11.9 | 91 |
| 1.7 | 2.57 | 0.67 | 78.7% | -0.02 | 27 | -24 | 12.6 | 83 |
| 1.8 | 2.755 | 0.72 | 78.2% | -0.11 | 28 | -31 | 13.5 | 74 |
| 2 | 3.1 | 0.82 | 79.6% | -0.17 | 34 | -33 | 14.3 | 67 |
| 2.3 | 3.62 | 0.93 | 80.2% | -0.23 | 40 | -30 | 15.6 | 58 |
| 2.75 | 4.4 | 1.12 | 79.6% | -0.46 | 35.8 | -25 | 17.0 | 49 |
| 3 | 4.85 | 1.2 | 79.0% | -0.7 | 36 | -24 | 17.9 | 44 |
| 4 | 6.55 | 1.7 | 78.5% | -1.2 | 32 | -32 | 20.2 | 33 |
| 5 | 8.25 | 1.9 | 75.2% | -3.4 | 31 | -29 | 21.7 | 28 |
| 6 | 10 | 2.1 | 73.0% | -6 | 32 | -25 | 22.3 | 25 |
| **10% shorter** | | | | | | | | |
| 1.5 | 2.01 | 0.59 | 77.9% | 0.03 | 31.5 | -27 | 11.5 | 94 |
| 1.6 | 2.17 | 0.65 | 77.1% | 0.13 | 35.8 | -20 | 12.1 | 87 |
| 1.7 | 2.34 | 0.73 | 79.6% | 0.07 | 28.6 | -30 | 12.9 | 77 |
| 1.8 | 2.48 | 0.73 | 79.5% | 0.03 | 45 | -38 | 13.5 | 74 |
| 2 | 2.79 | 0.86 | 80.0% | 0 | 39.5 | -32 | 14.7 | 65 |
| 2.3 | 3.26 | 0.98 | 80.5% | 0 | 30 | -28 | 15.9 | 56 |
| 2.75 | 3.96 | 1.15 | 80.5% | -0.15 | 28 | -25 | 17.4 | 47 |
| 3 | 4.36 | 1.3 | 80.7% | -0.25 | 35 | -25 | 18.2 | 42 |
| 4 | 5.9 | 1.8 | 78.3% | -0.9 | 31 | -27 | 20.6 | 32 |
| 5 | 7.42 | 2.1 | 75.0% | -2.8 | 31.5 | -27 | 22.3 | 26 |
| 6 | 9 | 2.1 | 71.1% | -6 | 29 | -24 | 23.1 | 24 |
| **20% shorter** | | | | | | | | |
| 1.5 | 1.79 | 0.66 | 76.6% | 0.16 | 24 | -19 | 12.0 | 85 |
| 1.6 | 1.93 | 0.67 | 75.5% | 0.18 | 26 | -20 | 12.3 | 84 |
| 1.7 | 2.06 | 0.73 | 68.6% | 0.04 | 22 | -15 | 12.9 | 75 |
| 1.8 | 2.2 | 0.78 | 74.7% | 0.13 | 22 | -19 | 14.0 | 78 |
| 2 | 2.48 | 0.85 | 75.5% | 0.13 | 27 | -18 | 14.7 | 64 |
| 2.3 | 2.9 | 1 | 77.5% | 0.13 | 26 | -21 | 15.9 | 55 |
| 2.75 | 3.52 | 1.2 | 76.0% | 0 | 24 | -19 | 17.7 | 44 |
| 3 | 3.88 | 1.35 | 77.2% | -0.2 | 26 | -22 | 18.4 | 40 |
| 4 | 5.24 | 1.82 | 75.2% | -1 | 26 | -23 | 20.8 | 30 |
| 5 | 6.6 | 2 | 70.0% | -3.5 | 27 | -22 | 22.2 | 25 |
| 6 | 8 | 1.9 | 67.0% | -7 | 29 | -20 | 23.1 | 23 |

## Table 1

# Optimum Dual-Mode Feedhorns (cont.)

after Skobolev, et al

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **10% longer** | | | | | | | | |
| 1.5 | 2.46 | 0.45 | 64.5% | -0.21 | 15 | -7 | 10.7 | 107 |
| 1.6 | 2.65 | 0.61 | 72.5% | -0.14 | 20 | -17 | 11.9 | 92 |
| 1.7 | 2.82 | 0.67 | 71.0% | -0.21 | 21 | -16 | 12.5 | 86 |
| 1.8 | 3.03 | 0.68 | 69.9% | -0.34 | 19 | -15 | 13.0 | 80 |
| 2 | 3.41 | 0.83 | 73.0% | -0.37 | 23 | -16 | 14.3 | 67 |
| 2.3 | 3.98 | 0.9 | 74.0% | -0.5 | 27 | -16 | 15.4 | 59 |
| 2.75 | 4.84 | 1.12 | 74.5% | -0.75 | 25 | -15 | 17.0 | 48 |
| 3 | 5.34 | 1.2 | 74.0% | -1 | 28 | -25 | 17.7 | 45 |
| 4 | 7.2 | 1.6 | 74.5% | -2.25 | 30 | -29 | 19.9 | 35 |
| 5 | 9.08 | 1.7 | 72.5% | -6.5 | 29 | -25 | 21.3 | 30 |
| 6 | 11 | 1.8 | 74.5% | -6 | 30 | -21 | 22.2 | 27 |
| **20% longer** | | | | | | | | |
| 6 | 12 | 1.85 | 73.0% | -8.7 | 27 | -18 | 21.7 | 28 |
| **other** | | | | | | | | |
| 1.7 | 2.44 | 0.68 | 79.6% | 0.03 | 29 | -33 | 12.8 | 80 |
| 6 | 10.5 | 1.9 | 74.9% | -6.5 | 31 | -24 | 22.5 | 26 |
| **BEST** | | | | | | | | |
| 1.5 | 2.01 | 0.59 | 77.9% | 0.03 | 31.5 | -27 | 11.5 | 94 |
| 1.6 | 2.17 | 0.65 | 77.1% | 0.13 | 35.8 | -20 | 12.1 | 87 |
| 1.7 | 2.34 | 0.73 | 79.6% | 0.07 | 28.6 | -30 | 13.0 | 77 |
| 1.75 | 2.46 | 0.72 | 80.0% | 0.08 | 30 | -31 | 13.1 | 77 |
| 1.8 | 2.48 | 0.73 | 79.5% | 0.03 | 45 | -38 | 13.5 | 74 |
| 2 | 2.79 | 0.86 | 80.0% | 0 | 39.5 | -32 | 14.7 | 65 |
| 2.3 | 3.26 | 0.98 | 80.5% | 0 | 30 | -28 | 15.9 | 56 |
| 2.75 | 3.96 | 1.15 | 80.5% | -0.15 | 28 | -25 | 17.4 | 47 |
| 3 | 4.36 | 1.3 | 80.7% | -0.25 | 35 | -25 | 18.2 | 42 |
| 4 | 6.55 | 1.7 | 78.5% | -1.2 | 32 | -32 | 20.2 | 33 |
| 5 | 8.25 | 1.9 | 75.2% | -3.4 | 31 | -29 | 21.7 | 28 |
| 6 | 10.5 | 1.9 | 74.9% | -6.5 | 31 | -24 | 22.5 | 26 |

## Table 1 (cont.)