

Parabolic Dish Focus, Zoom, and Tilt

Paul Wade W1GHZ ©2009

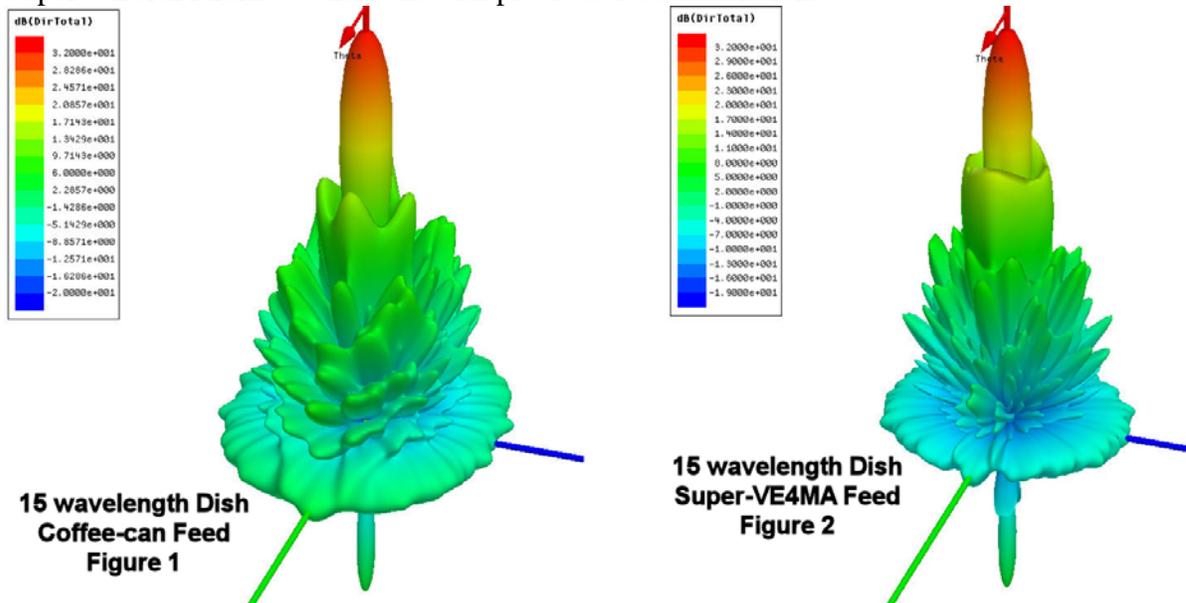
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Only recently has it become affordable to simulate a reasonable size dish antenna with the same accuracy as small horns and wire antennas. For instance, simulation of an 18 inch DSS dish at 10 GHz, 15.5 wavelengths in diameter, requires about 30 GB of RAM and a fast processor to do the calculations in a reasonable amount of time. Advances in PC and software technology have made this possible on a desktop.

Since it would be very difficult to find a large enough antenna range with the necessary dynamic range (>50 dB) and low enough reflections (50 dB down), the simulated antenna patterns are likely the most accurate available, much better than the approximations previously available. Now we can use the improved antenna patterns to re-examine some of the assumptions we have been making and see how we can improve our operating results.

Prime Focus Dish

First, let's look at a moderate size conventional dish, 15λ in diameter – we might use a larger one on 10 GHz or higher, but there aren't too many bigger ones on lower bands. The simulated dish has an $f/D = 0.33$. With the classic “coffee-can” cylindrical waveguide feed, we get the 3D radiation pattern shown in Figure 1. The dish pattern has a nice narrow beam, and a lot of small sidelobes all around. An improved feed, the “Super-VE4MA” horn¹, gives the pattern shown in Figure 2 – not a lot different. When we plot the horizontal patterns with a scale, in Figure 3, we can see the difference: about a dB of gain, with the extra energy coming from reduced sidelobes with the better feed. Calculated efficiencies for the ideal dish, with no feed supports or losses, are 57% with the coffee-can feed and 68% with the Super-VE4MA horn – consistent with previous feed simulations.



Notice that there are relatively large sidelobes at 90 degrees and at 180 degrees, directly off the back. We would expect that a solid dish would not allow much energy to get through, so the front-to-back ratio would be high. What we are seeing in these lobes is diffraction from the edge of the dish – if the dish is nice and symmetrical, it all adds together directly off the back.

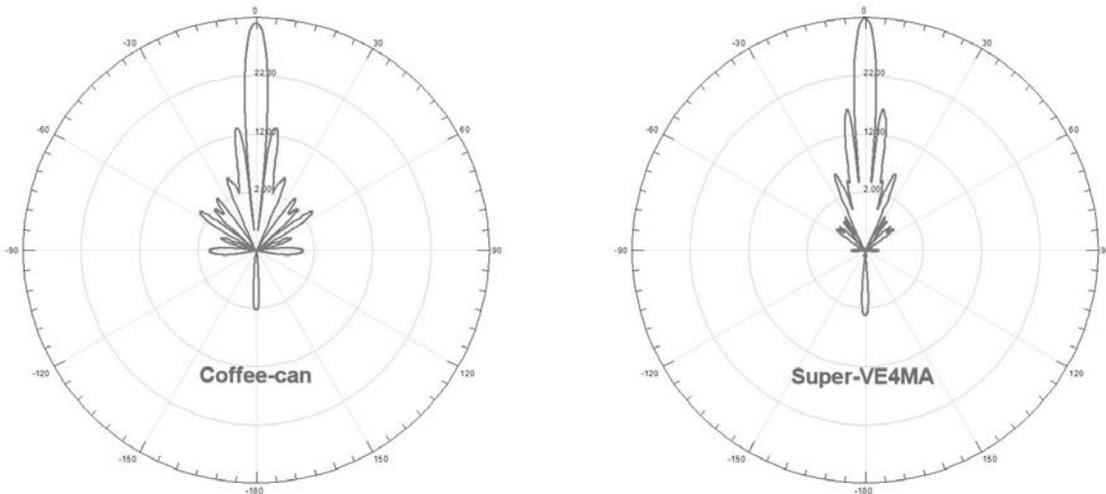


Figure 3

With other feeds, we would expect similar radiation patterns, with differences in sidelobe levels resulting in different efficiency. The pattern of the main beam is controlled by the size of the parabolic reflector; the feed affects the efficiency mostly due to energy wasted in sidelobes.

What about the feed position? I've been telling you for years that the focus of a deep dish is pretty critical², as shown in Figure 4, calculated from various assumptions. But suppose we actually calculate radiation patterns at various feed positions and plot the gain. Figure 5 is the result, showing the same shape with both feeds. A quarter-wavelength error is significant, and a wavelength of error (an inch at 10 GHz) is a disaster – the gain is degraded by ~10 dB. The error is in wavelengths, regardless of the size of the dish; a big dish loses just as much gain as a small one for the same error in feed position. Note that the Super-VE4MA feed is optimum with the aperture slightly closer to the dish – the phase center is slightly inside the horn, as predicted¹.

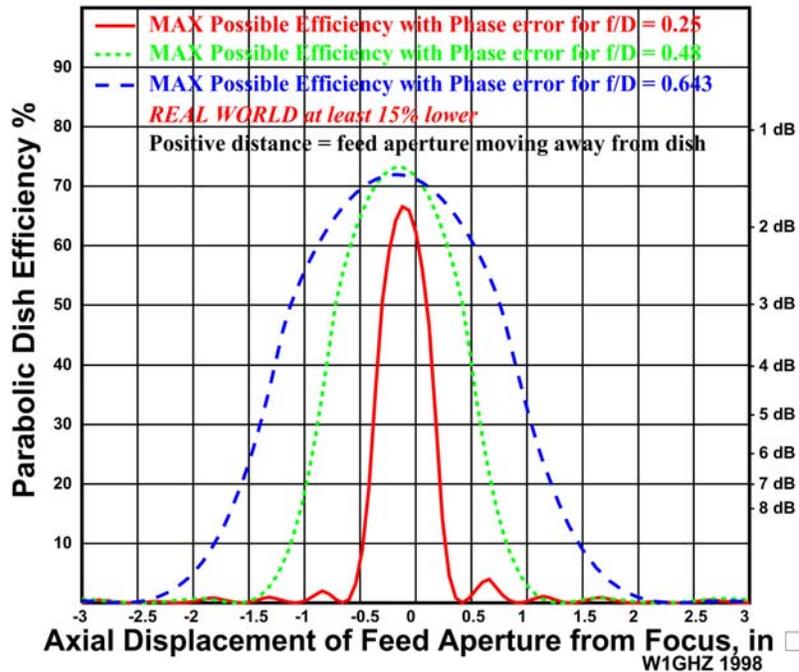


Figure 4

Since focal point is critical, it is probably a good idea to adjust the axial feed location for each dish, rather than depending on the dish shape and measurements to be accurate. To locate the focal point accurately requires a very long test range, greater than fifty times the Rayleigh distance³, so it can easily be a mile or more even for a small dish. Attempting to adjust the feed position across your backyard will always result in an incorrect focus, putting you down the curve in Figure 5. A better choice is to measure sun noise⁴, comparing sun noise to cold sky at various feed positions along the axis and noting the results until you are pretty sure of the best position. For very large dishes, the sun is no longer a point source, but other celestial noise sources⁵ are available.

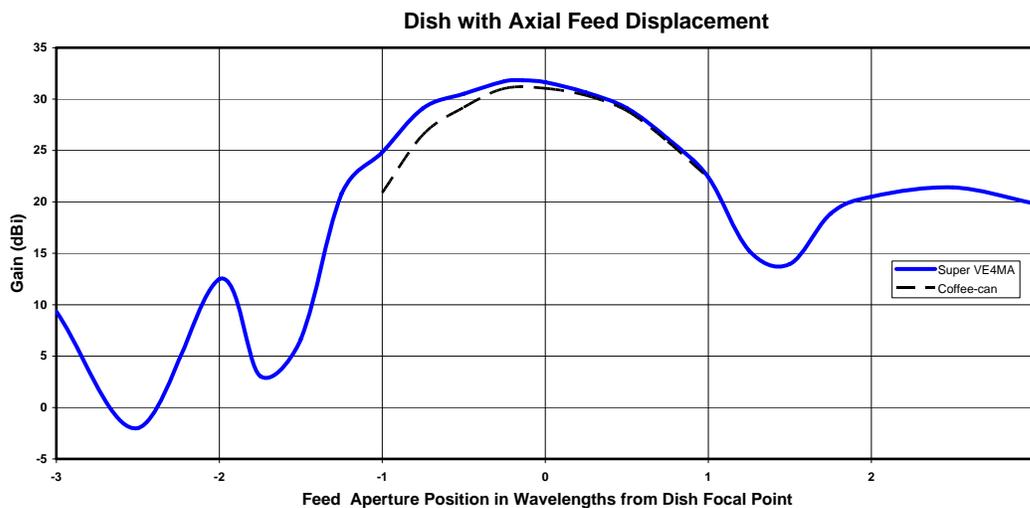


Figure 5 – Axial Feed Displacement, 15λ Dish, $f/D = 0.33$

Polar radiation patterns for all the feed positions in Figure 5 are shown in the Appendix. Scanning through them shows the gain decreasing as the feed is moved, with the lost energy scattered around as increased sidelobes. At extreme positions, the axial gain, on boresight, drops near zero. What we are seeing is phase error – when the feed is at the focal point, all the reflected energy is radiated in phase and adds together to form the beam. At other locations, energy reflected from different parts of the dish surface has traveled different distances, so it is not in phase and doesn't add together.

What happens when the gain drops near zero? Where is the energy going? A 3D pattern with the feed 1.75λ toward the reflector, in Figure 6, shows that the phase errors have created a null on axis, where the dish is pointed, and the energy is going off in many other directions – but there isn't a whole lot of gain anywhere.

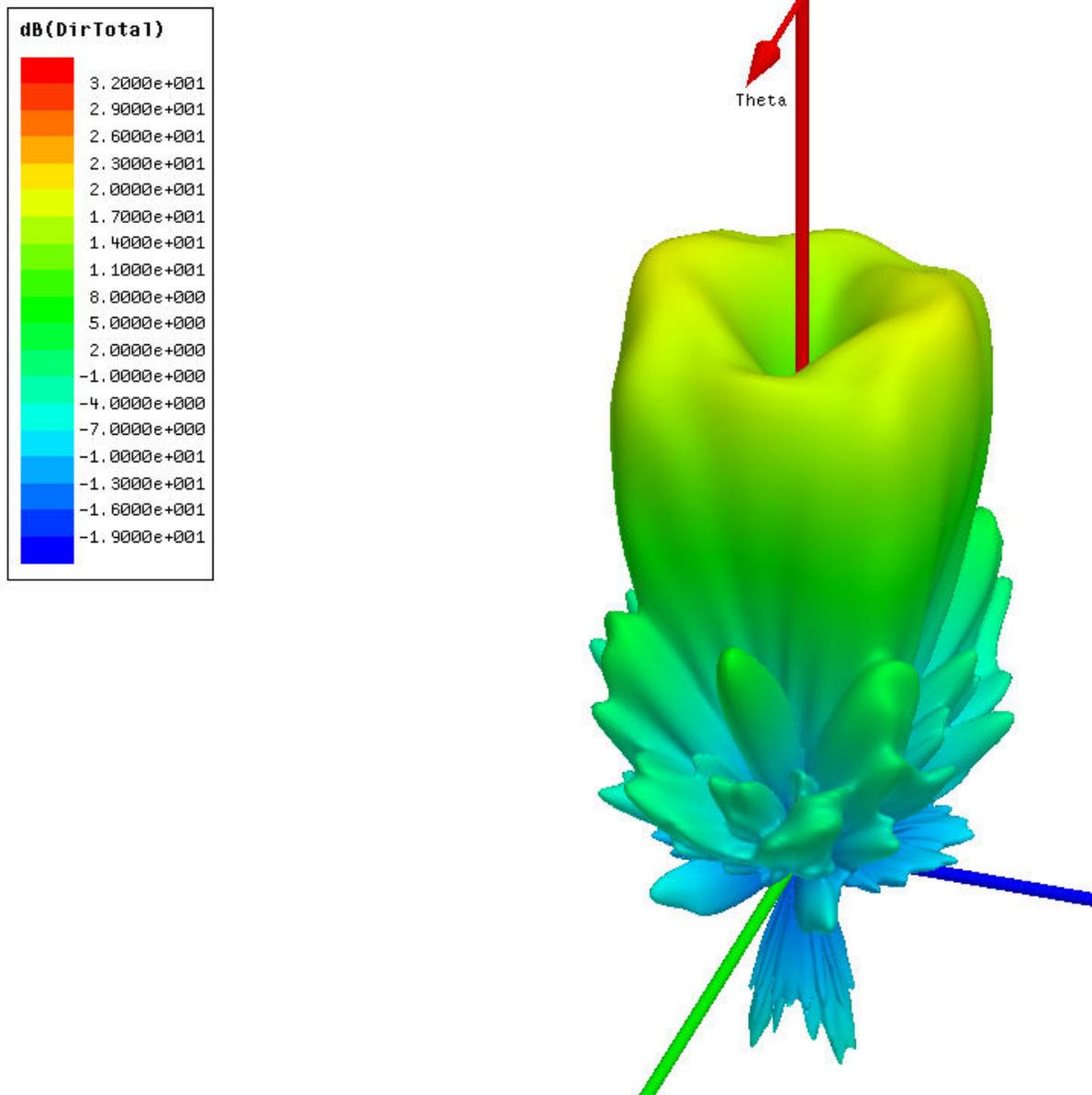
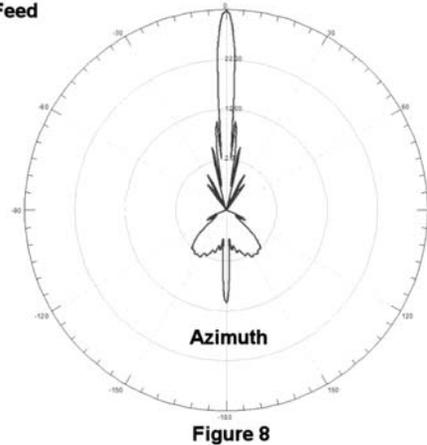
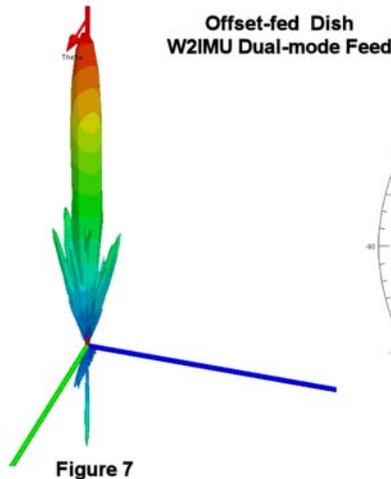


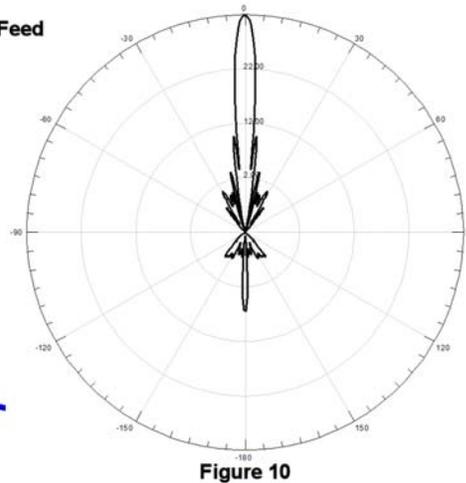
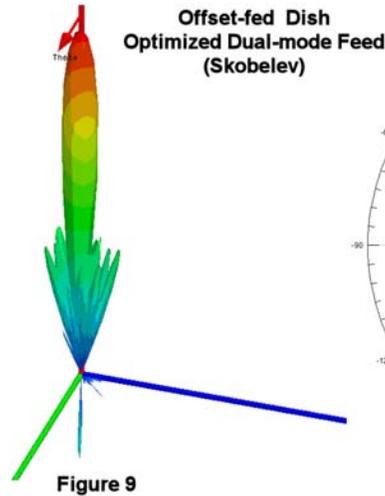
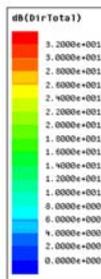
Figure 6 - Dish with Feed 1.75λ toward reflector

Offset-fed Dish

The radiation pattern of an offset dish is probably less intuitive, because of the asymmetry. The 3D radiation pattern for an 18-inch DSS dish, 15.5λ in diameter at 10 GHz, with a W2IMU dual-mode feed⁶, shows a nice narrow beam in Figure 7, with about the same beamwidth, ~ 4 degrees, as a comparable prime-focus dish but with fewer sidelobes. A polar radiation pattern with a scale in Figure 8 confirms that the sidelobes are farther down. The azimuth and elevation patterns are not the same, as we might expect, and the elevation pattern is not symmetrical. An interesting result is that there are fewer sidelobes in the azimuth plane than other directions. The sidelobes in the azimuth pattern are small enough so that they are hardly noticeable when listening to a signal while the dish is rotated.



The W2IMU feed is not optimum for the common offset dishes, because the pattern is a bit too broad, better for a slightly lower f/D . It is still popular because it is simple and offers reasonable performance. A feed optimized for this dish is a Skobelev optimum dual-mode feed^{7,8} with an aperture diameter of 1.7 wavelengths, best for an f/D around 0.7. The radiation pattern for the 18-inch DSS dish with this feed is shown in 3D in Figure 9 and polar plots in Figure 10. The main beam is almost identical, but the sidelobe levels are lower, so less energy is wasted. The calculated efficiency with the Skobelev feed is about 65% compared to 59% with the W2IMU feed.



The feed position for an offset dish should be less critical, because the feed angle is narrower, equivalent to a larger f/D , around 0.7 for the common DSS dishes. These dishes are sections of a full parabola starting at the vertex, so the geometric axis is from the bottom edge of the dish through the focal point. Thus, we should move the feed along this axis, just like a prime-focus dish.

However, when the W2IMU feed is moved along the axis, we find that the axial gain in Figure 11 decreases more quickly than expected from Figure 4. A 3D radiation plot in Figure 12 with the feed moved closer by 25 mm, 0.86 wavelengths at 10.368 GHz, shows us why – the beam is tilted upward 2.75 degrees. The peak gain is only 0.6 dB less than at the focal point. Moving the feed another 25 mm, so it is 50 mm closer to the dish, tilts the beam upward by 5.75 degrees, with 2 dB less gain. Similarly, moving the feed in the other direction, to a position 25 mm away from the dish, tilts the beam downward by 2.75 degrees, with only 0.25 dB decrease in gain. I used much larger increments for the offset dish because I was expecting the position to be less critical – and it is, if we look at maximum gain rather than axial gain. Figure 13 shows the polar radiation patterns in both azimuth and elevation for all 4 positions.

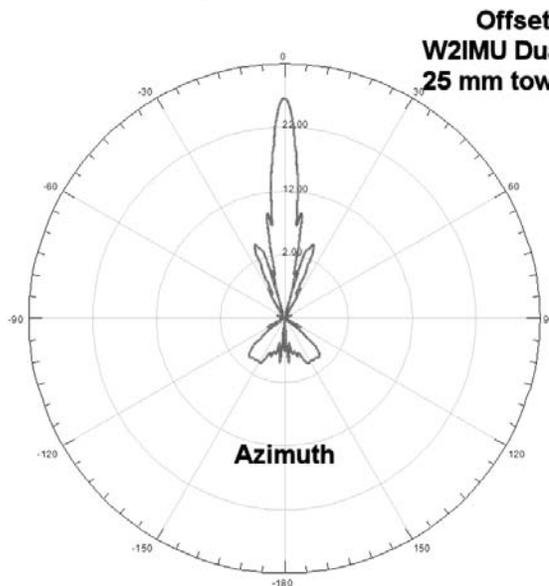


Figure 11

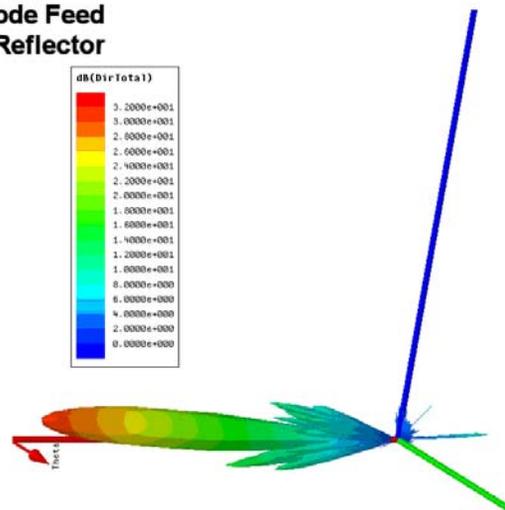


Figure 12

So, how can we adjust the feed position? We would have to move it in three dimensions, not just along the axis. I have seen feed supports with this much flexibility, but I don't think you'd have a snowball's chance in Texas of finding the peak. Since it isn't really critical, just put the feed at the calculated position using the string technique⁹ and bolt it down. If you are a little off in your calculations or placement, the gain won't suffer enough to measure – the beam will just be tilted slightly. Since there is no intuitive beam heading for an offset dish, you'll never know.

Seeing how the beam tilts as the feed is moved helps to understand what happens in the prime-focus dish. With a complete parabola, the beam tilts away from the axis all the way around, so that the beam forms a ring around the axis.

Offset-fed Dish
W2IMU Dual-mode Feed
Axial Feed Displacement

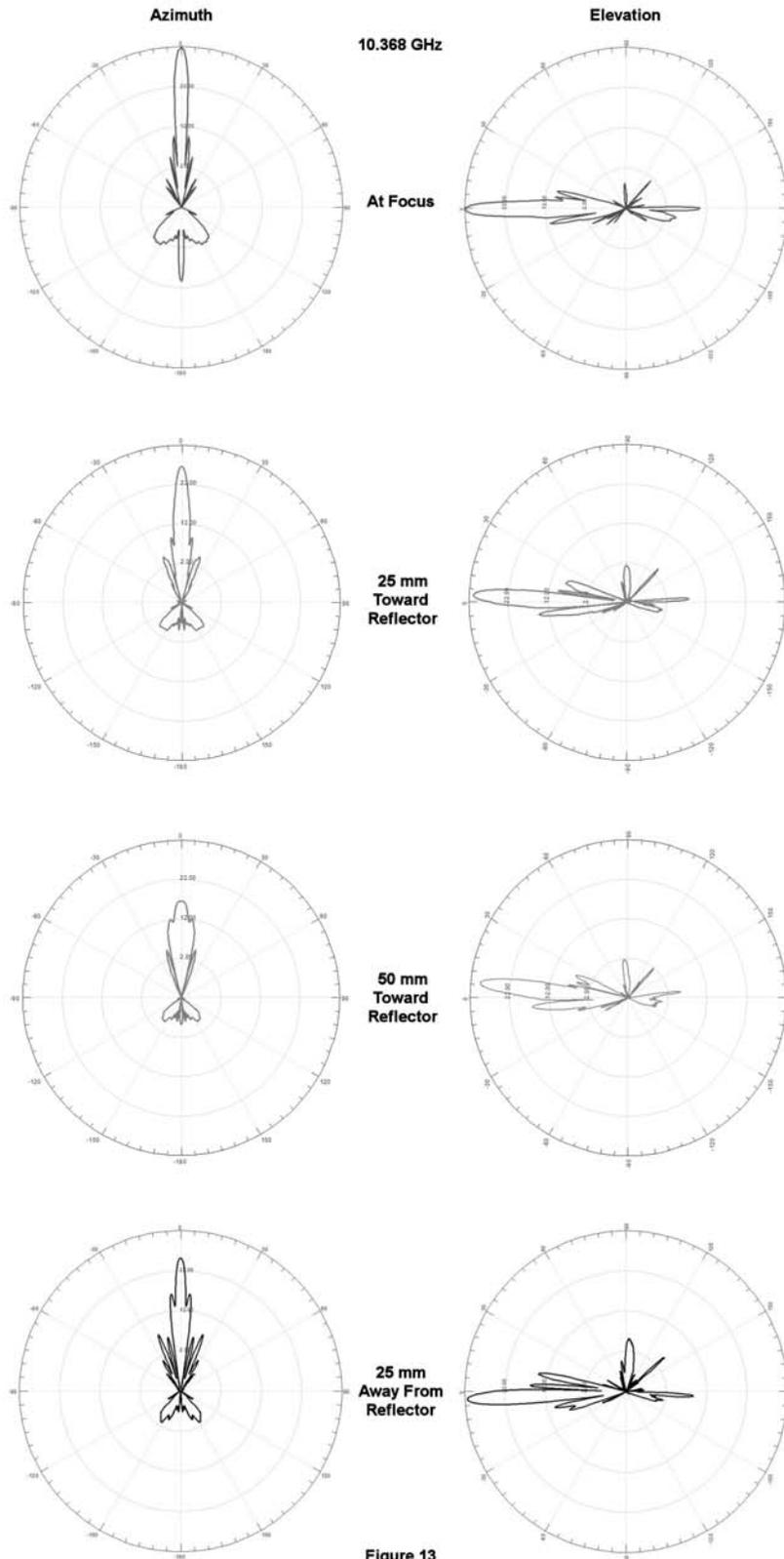


Figure 13

Zoom Control

It is occasionally suggested that one can adjust the beamwidth of a dish by moving the feed in and out, to act like a zoom lens on a camera. This would presumably make it easier to find other stations. One proponent of this idea is Dick Knadle, K2RIW. One successful zoom antenna¹⁰ used an offset Gregorian (elliptical subreflector) feed, a bit complicated for most amateurs.

We would like to use a zoom with a simple prime-focus dish. However, examination of the prime-focus polar radiation patterns in the Appendix, with the gain scale constant, shows that the 3 dB beamwidth does not increase significantly until the feed has moved approximately one wavelength, in either direction. The patterns for both feeds positioned one wavelength closer to the reflector are shown in Figure 14, and one wavelength further away in Figure 15. At these positions, the beam is roughly three times as wide, a decent zoom. But the gain at these positions is down by almost 10 dB. So it is easier to find strong stations, but weak ones will be lost in the noise. And the weak stations are usually the interesting DX.

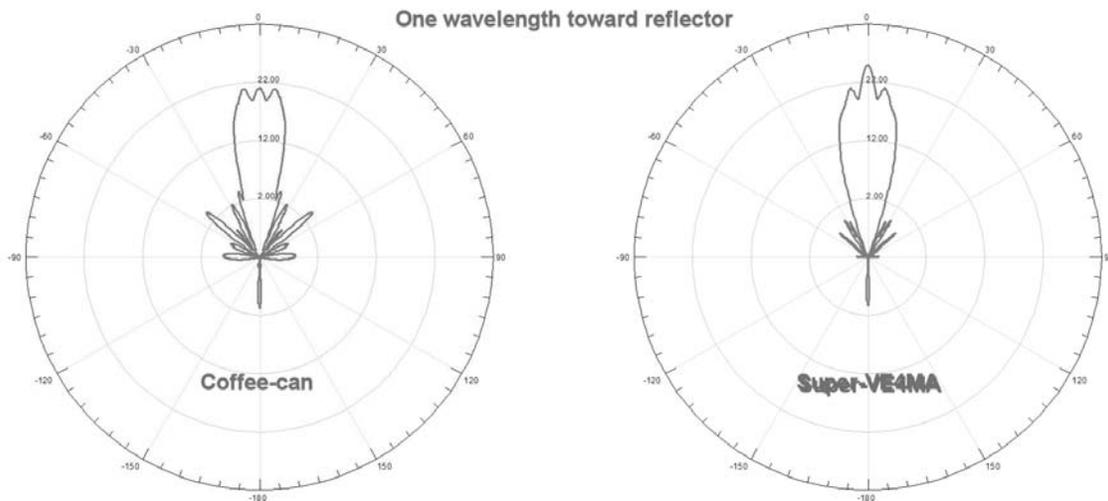


Figure 14

The lower gain at these feed positions should be no surprise. A beam three times as wide makes the beam area 9 times larger, so the energy density is nine times lower, or about 9.5 dB lower. The unpleasant surprise is that there is nothing in between – no gradual zoom. The sharp three-dB beamwidth hardly changes until the feed is moved a full wavelength, but the gain decreases as the feed is moved from the focus. So what we have is not a zoom control, but a gain control.

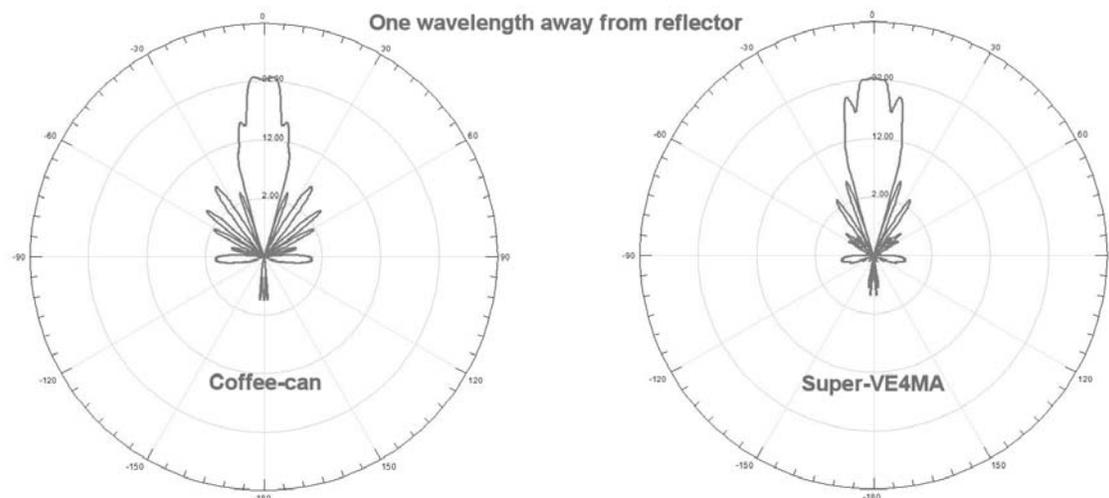


Figure 15

I discussed these findings with K2RIW, and he agreed with the data, but still felt that the zoom is useful. He based this on his experience when both stations were aimed incorrectly, but were perhaps 30 dB out of the noise when finally lined up. In this case, a zoom at each end might have made the contact much easier.

How hard is it to aim a dish correctly? A small dish, like an 18" dish at 10 GHz, has a beamwidth of about 4 degrees, and the gain falls off very quickly to a null about 5 degrees on either side of the peak. An aiming error of more than 2 degrees will significantly reduce signal levels, and a 5 degree error is a disaster, putting the signal in the first null of the pattern. Larger dishes are even more critical.

How hard is it to have a two degree error? That's about as accurately as I can read a hand compass. Many of us line up on the position of the sun, or on a known landmark heading. But I have been in thick fog at locations with magnetic anomalies, so no heading was available until I could find a signal and peak on it. Even in this extreme case, a zoom wouldn't have been much help – I couldn't get close enough to start. (One suggestion I've heard is to walk with a GPS until it reports a direction of travel.)

Rather than a zoom control, I'd suggest being aware of your beamwidth and working with it. If the beamwidth is 4 degrees, moving the dish in increments of 3 degrees will make sure there are no dead spots in the search. Two increments of 3 degrees each will cover the first null in the dish pattern. As a reminder, the pointer on your compass rose could be enhanced to indicate beamwidth.

Tilt Control

On longer paths, elevating the beam a few degrees can often enhance signals significantly. And on one occasion with unusual conditions, several of us found the signal peaking below the horizon. Rain scatter may require even more elevation, to take advantage of high thunderheads. But sometimes it doesn't matter – the recent August weekend of the 10 GHz

contest was very hot and hazy, and changing the elevation by 10 degrees made almost no difference.

We have seen that moving the feed axially on an offset dish will tilt the beam. This could be used as a small tilt control, but I wouldn't recommend it. Of course, if you mount an offset dish sideways, this wouldn't work – and any tilt mechanism becomes difficult.

A good tripod head is preferable for portable stations, and it helps if the dish is somewhat balanced. Some sort of tilt indicator is valuable – a washer on a string will do, but I prefer an inexpensive tilt indicator made for RVs shown in Figure 16. KA1OJ found these at a large discount store whose name begins with “W”.



Figure 16 - RV Level Indicator shows Dish Tilt

If you must have a digital elevation readout, a digital level would suffice and can be found at a moderate price.

Summary

More accurate radiation patterns for dish antennas have confirmed some of our previous suppositions and added a few new insights. These include:

- The focal point of a deep dish is critical – needs careful adjustment
- The focal point of an offset-fed dish is much less critical – use calculated dimensions
- Moving the feed axially in a prime-focus dish reduces the gain but does not make the pattern significantly broader until the gain is reduced by about 10 dB
- Moving the feed axially in an offset dish does not change the beamwidth but rather tilts the beam vertically
- Feed radiation pattern does not affect the beamwidth of the dish antenna, only the sidelobes and efficiency

So my dish recommendations remain: pick a good feed, put it at the focal point, and get on the air!

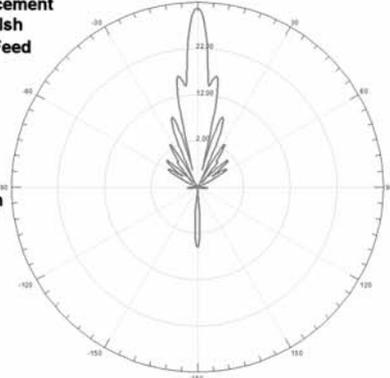
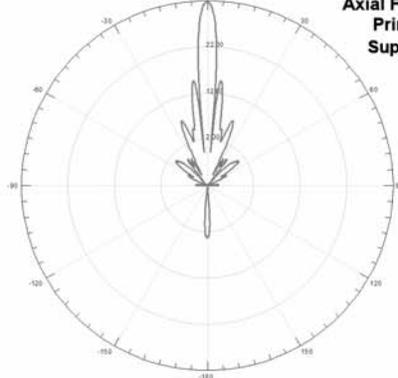
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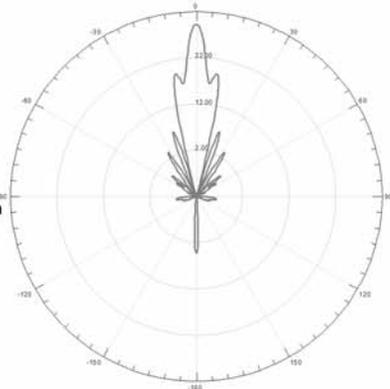
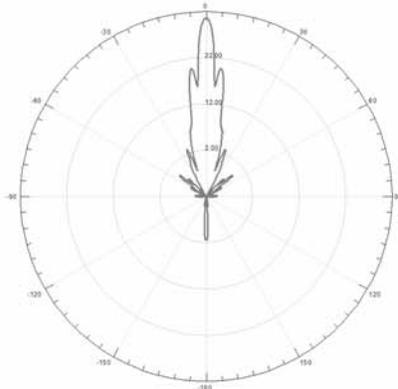
Appendix
Axial Feed Displacement
Prime Focus Dish
Super-VE4MA Feed

Toward Reflector

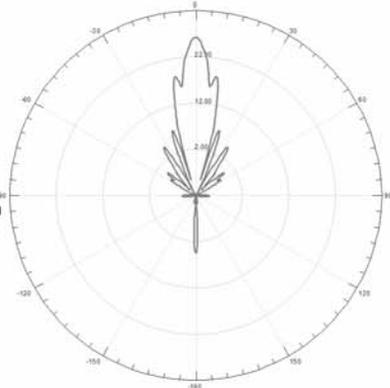
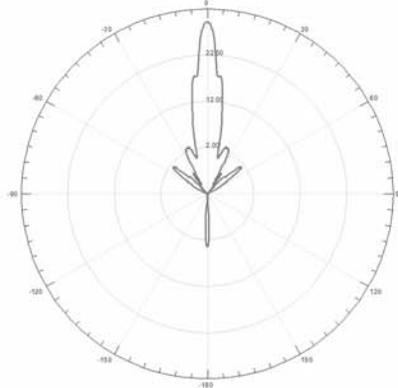
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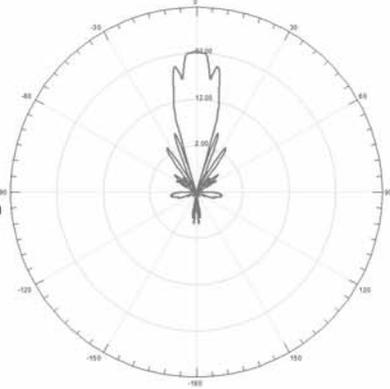
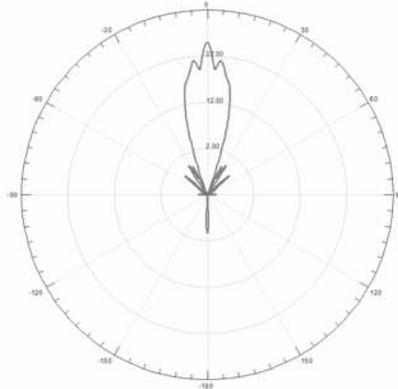
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Wavelength



1/2
Wavelength



3/4
Wavelength

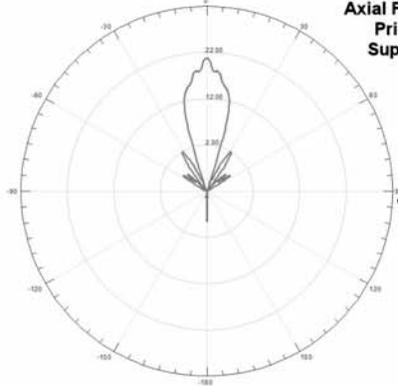


One
Wavelength

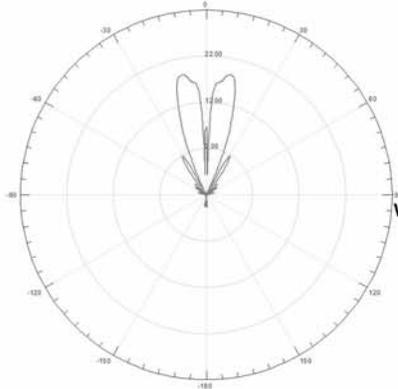
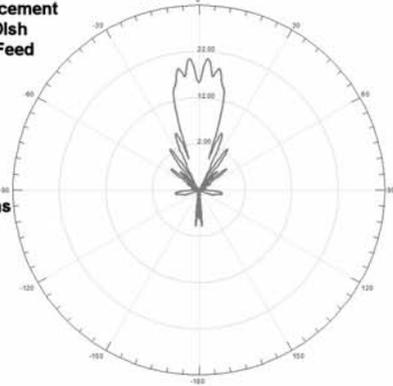
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Super-VE4MA Feed

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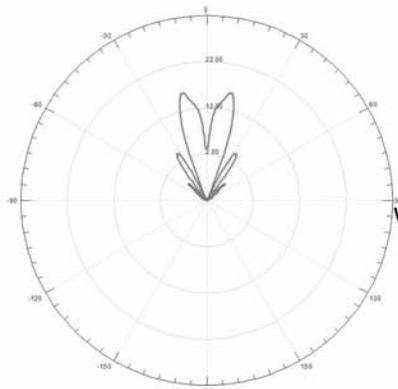
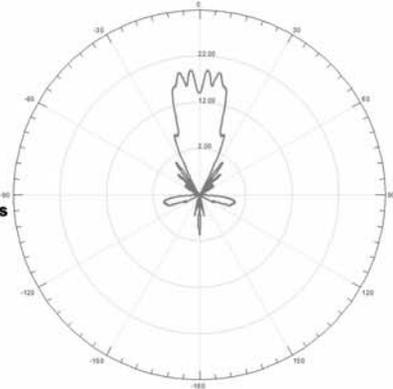
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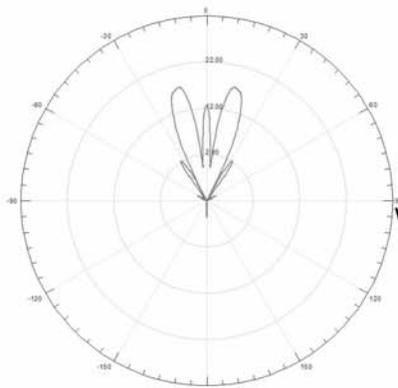
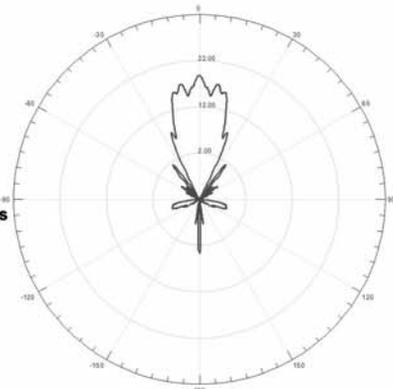
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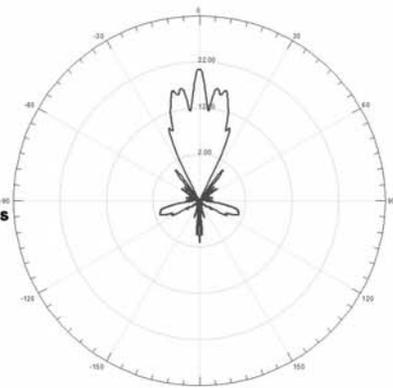
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Wavelengths



1.75
Wavelengths



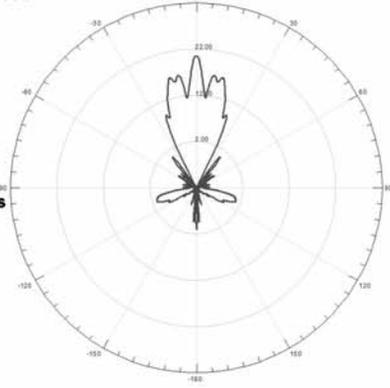
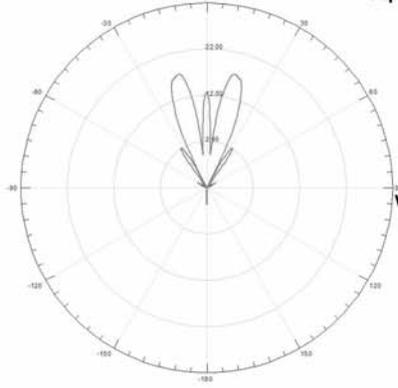
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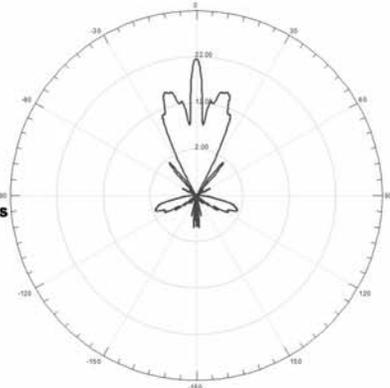
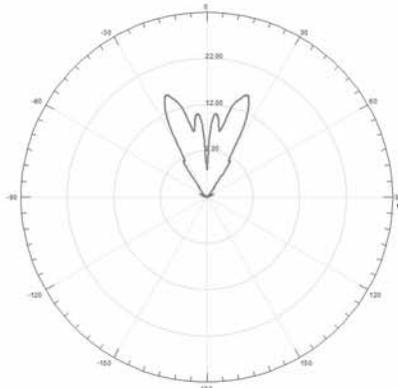
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Super-VE4MA Feed

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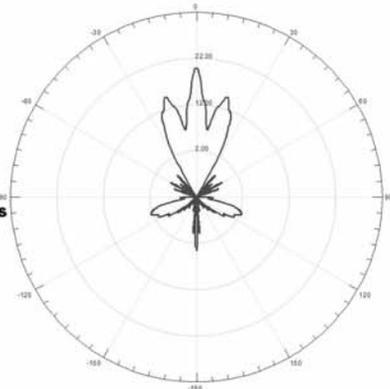
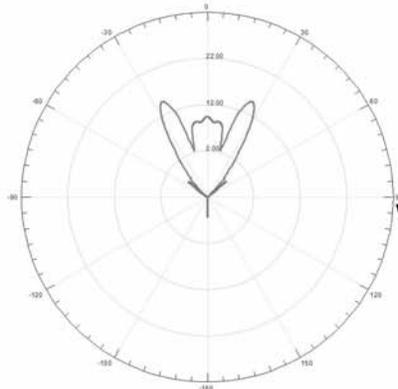
Away From Reflector



Two
Wavelengths



2.5
Wavelengths

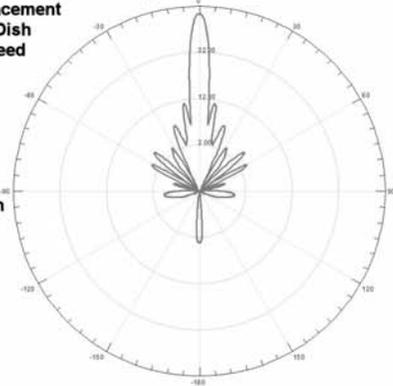
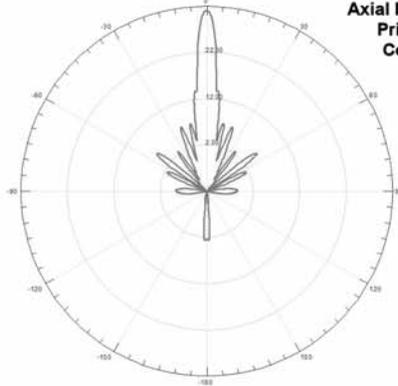


3
Wavelengths

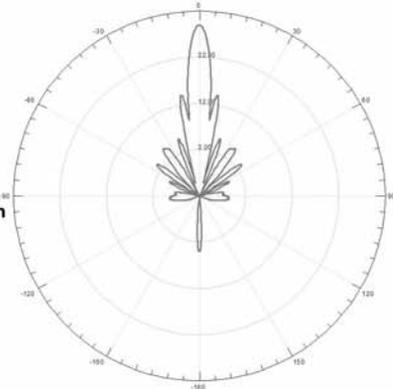
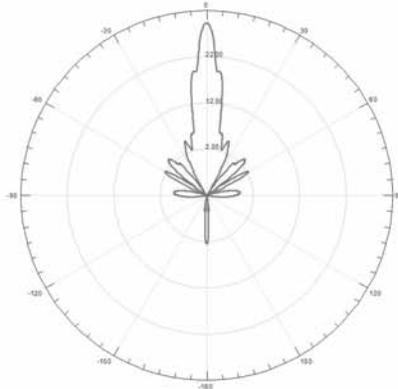
Appendix
Axial Feed Displacement
Prime Focus Dish
Coffee-can Feed

Toward Reflector

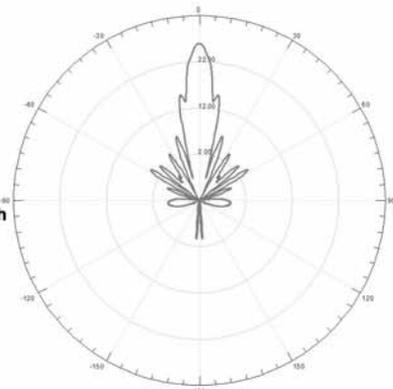
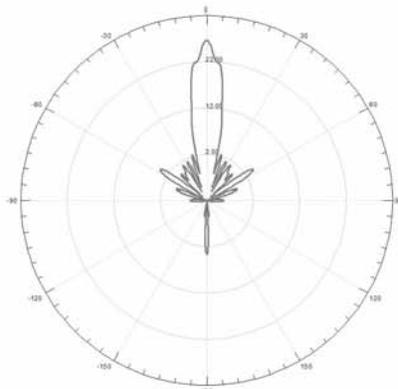
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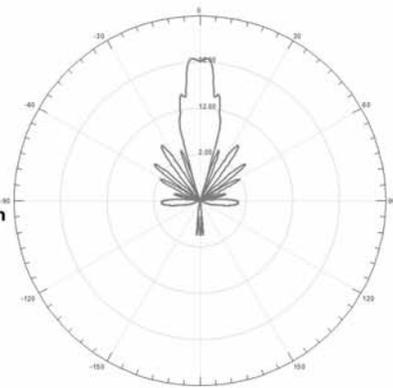
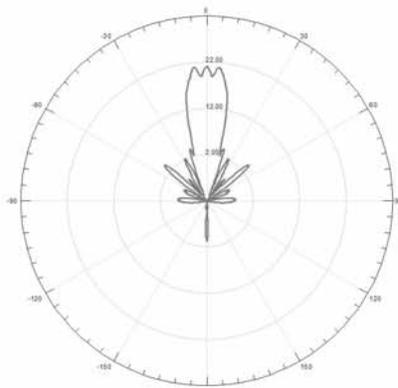
1/4
Wavelength



1/2
Wavelength



3/4
Wavelength



One
Wavelength