Chapter 5
OFFSET-FED PARABOLIC DISH ANTENNAS
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Introduction

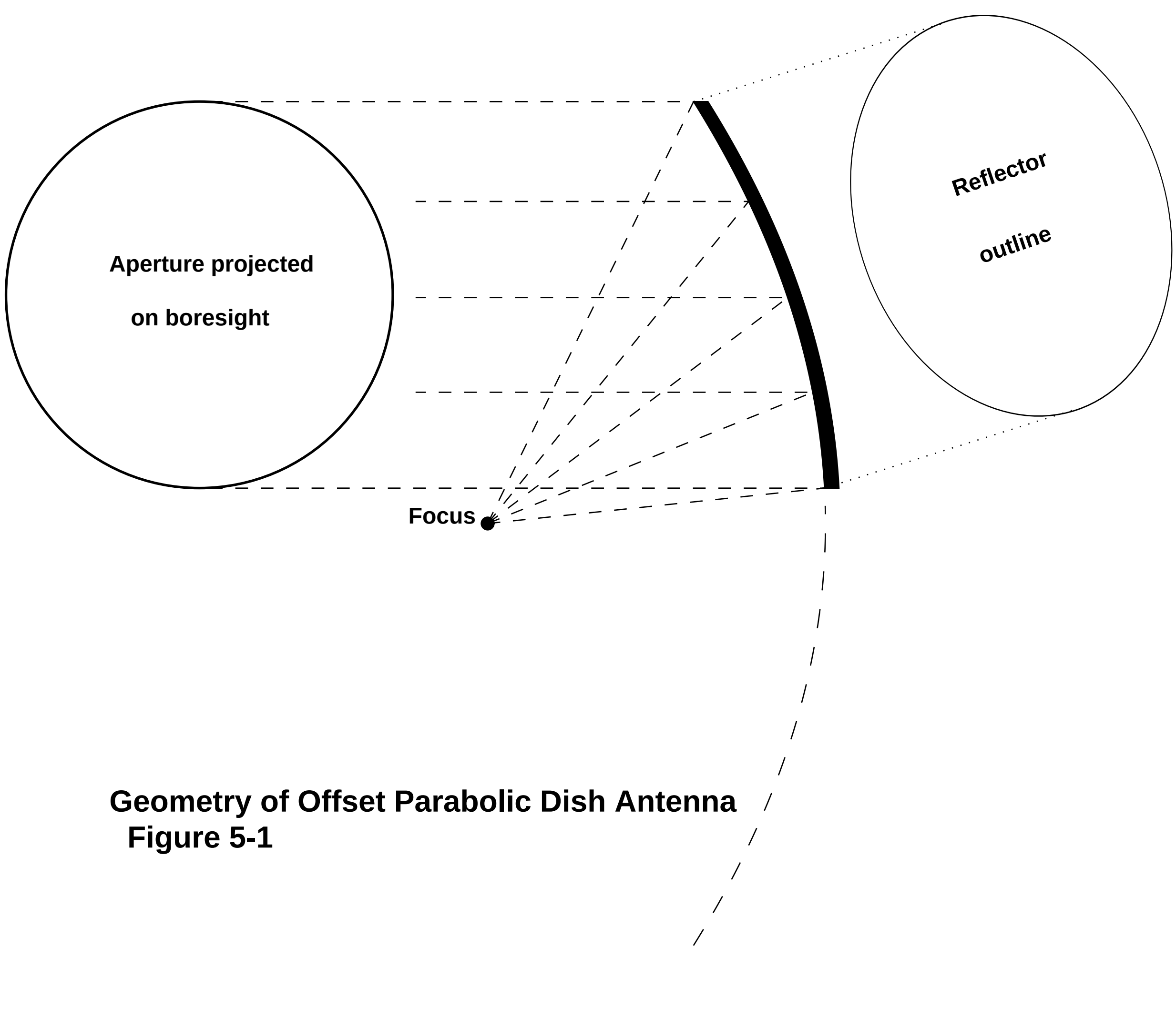
In the past few years, you have probably noticed little grey dish antennas sprouting from rooftops, and appearing for sale in stores as part of satellite TV systems. One common version is the RCA DSS system, which uses an 18-inch offset fed dish. Inexpensive offset-feed dishes are now readily available and offer excellent performance up to at least 10 GHz.

An offset-feed dish antenna has a reflector which is a section of a normal parabolic reflector, as shown in Figure 5-1. If the section does not include the center of the dish, then none of the radiated beam is blocked by the feed antenna and support structure. Otherwise, only a small bit at the edge of the beam is blocked. For small dishes, feed blockage in an axial-feed dish causes a significant loss in efficiency. Thus, we might expect an offset-feed dish to have higher efficiency than a conventional dish of the same aperture.

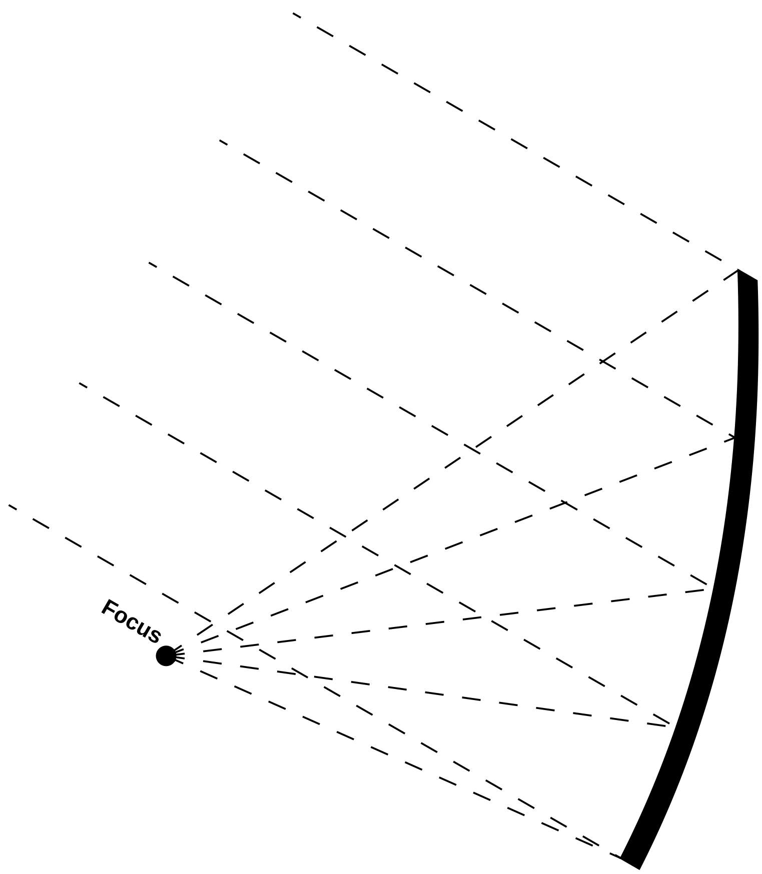
In addition to higher efficiency, an offset-feed dish has another advantage for satellite reception. The dish in Figure 5-2, aimed upward toward a satellite, has its feedhorn pointing toward the sky. A conventional dish would have the feedhorn above it, pointing toward the ground, as shown in Figure 5-3. Any spillover from the feed pattern of the conventional dish would receive noise from the warm earth, while spillover from the offset dish would receive less noise from the cool sky. Since a modern low-noise receiver, such as a satellite TV LNB, has a noise temperature much lower than the earth, the conventional dish will be noisier. This is the **G/T** which is described in Chapter 4; the offset dish offers higher gain, **G**, since the efficiency is higher, plus reduced noise temperature, **T**, so both terms in the **G/T** ratio are improved. The higher gain means more signal may be received from a source, and the lower noise temperature means that less noise accompanies it, so a higher **G/T** offers a higher signal-to-noise ratio.

RCA DSS Dish

The real incentive to use an offset-fed dish was provided by Zack Lau, KH6CP[2] (now W1VT), who pointed out that the 18” RCA DSS dishes are available by mail order for about $13. I ordered[3] a dish and a mounting bracket to see if I could figure out how to use one at 10 GHz. When it arrived, it wasn’t obvious where the feed point should be, so I took a trip to a local discount store to eyeball the system on display.

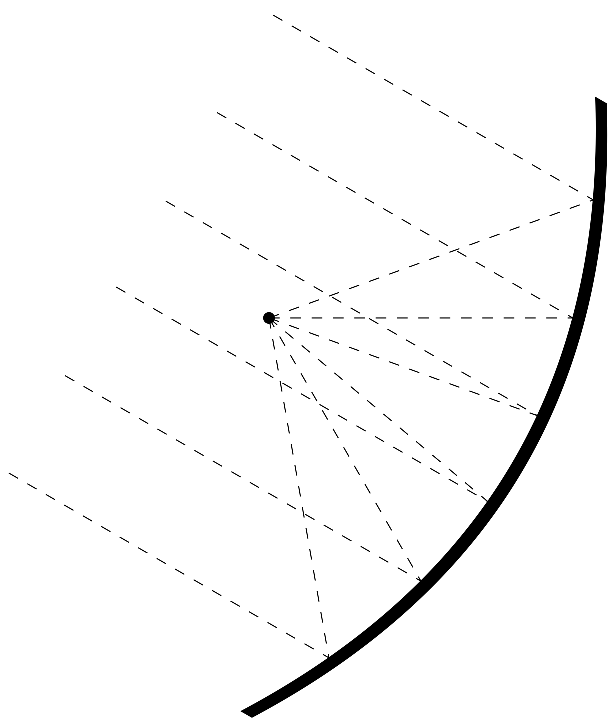


Geometry of Offset Parabolic Dish Antenna
Figure 5-1



Offset Parabolic Dish Antenna Aimed at Satellite

Figure 5-2



Parabolic Dish Antenna Aimed at Satellite

Figure 5-3

Now I had an idea where to put the feed, but not the exact location. The RCA reflector is oval shaped, but Ed, W2TTM, provided the insight that the dish aperture should appear circular when viewed on boresight, as shown in Figure 5-1. Thus the dish must be tilted forward for terrestrial operation. The angle, feedpoint location, and the rest of the dish geometry can be calculated — see Appendix 5-1 for the procedure. Version 3 of the **HDL_ANT** program will do these calculations for you.

The calculations show the focal length of the dish to be 280 mm. If it were a full parabola rather than just an offset section, the diameter would be 929 mm., for an ***f*/D** = 0.31. However, a feedhorn need only illuminate the smaller angle of the offset section, a subtended angle of about 78°. This subtended angle is the same as a conventional dish with an ***f*/D** of 0.69, so a feedhorn designed for a 0.69 ***f*/D** conventional dish should be suitable. I used G3RPE's graph[4,5] for rectangular feedhorns and the **HDL_ANT** computer program to design suitable rectangular horns, then made two of different lengths from flashing copper. The **HDL_ANT** program includes an approximation to G3RPE's curves so that the program can design feedhorns for both offset and conventional dishes as well as generate templates for constructing them.

Since the actual reflector geometry has an ***f*/D** of 0.31, the focal distance should be quite critical. This dimension is the most critical for dish antenna performance — even more critical for reflectors with smaller ***f*/D** — so the phase center of the feed should be positioned within a quarter-wavelength of the focal point. The RCA dish must be tilted forward to an angle of 67.6° from horizontal for terrestrial operation, with the beam on the horizon. In this orientation, the focal point is level with the lower rim of the dish, so the most of the feedhorn and all of the feed mounting structure are out of the beam. To locate the focus accurately, I calculated the distance to both the top and bottom of the rim, tied a knot in a piece of string, and taped the string to the rim so that the knot was at the focus when the string is pulled taut, as demonstrated in Figure 5-4. Then I made a sliding plywood holder for the feedhorn and taped it in place, and adjusted it so that the knot in the string was at the phase center of the horn, as shown in Figure 5-5. Materials aren't critical when they aren't in the antenna beam!

Where should the feedhorn be aimed? On a conventional dish it is obvious — at the center. However, an offset feed is much closer to one edge of the dish, so that edge will be illuminated with much more energy than the opposite edge. I read an article[6] which did a lengthy analysis of the various aiming strategies and concluded that small variations have little effect, so aiming at the center of the reflector is close enough.

After all this analysis, it was time to see if the offset dish really works. We (W1RIL, WB1FKF, N1BAQ, and N1BWT) set up an antenna range and made some of the measurements shown in Chapter 9. The RCA dish with a simple rectangular feedhorn measured 63% efficiency at 10 GHz, significantly higher than we've *ever* measured with on an 18" conventional dish. Varying the focal distance showed that the calculations were correct and that the dimension is critical. Figure 5-6 is a template for the rectangular feed


Figure 5-4

Figure 5-5

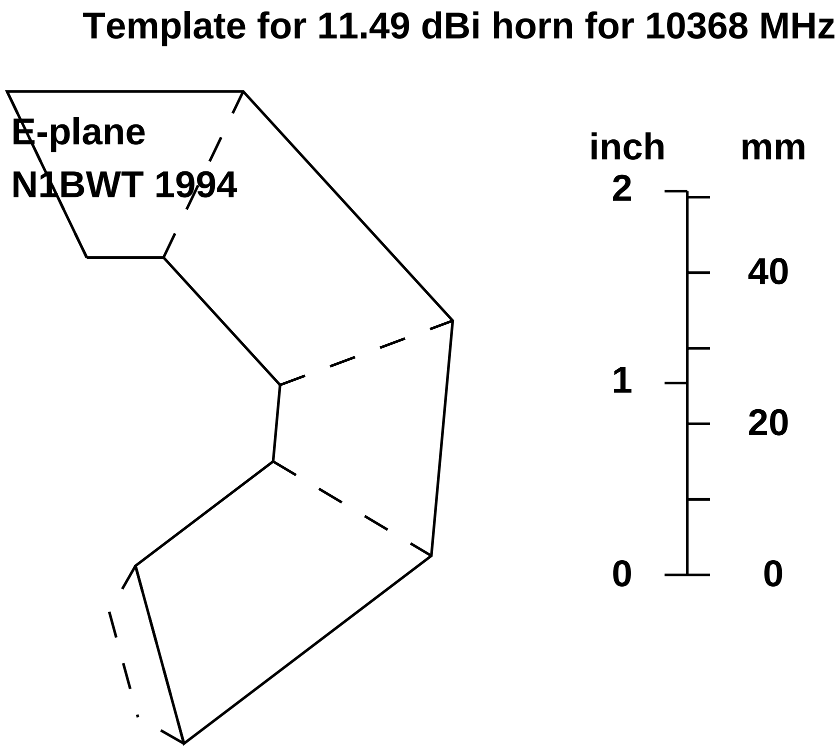


Figure 5-6. Feedhorn Template for RCA DSS Offset Dish
(WR-90 Waveguide)

horn which gave the highest efficiency, and a feed horn I made from flashing copper using the template is shown in Figure 5-7.

The higher efficiency of the offset-feed dish is mainly due to reduced blockage by the feed and supporting structure. Figure 5-8 is a photograph of a conventional dish while measuring sun noise, so that the shadow of the feed demonstrates the actual area blocked — neither light nor RF energy from the sun is reaching the reflector. Figure 5-9 is a photograph of the RCA offset dish peaked on the sun to measure sun noise; note that the shadow of the feed is only a tiny area at the bottom edge. Remember that these feed horns provide a tapered illumination, so the energy illuminating the center of the reflector is typically 10 dB stronger than at the edge. Thus, central blockage in a conventional dish is *ten times* worse than the same area blocked at the edge of an offset dish, and the photographs clearly illustrate how much more blocked area there is in a conventional axial-feed dish.

Improved Offset Reflector Calculations

The curve fitting calculations described above and in Appendix 5-1 are limited by the estimated tilt angle and by the accuracy with which we can measure the deepest point of the reflector. Those calculations show the bottom edge of the offset reflector to be displaced from the center of the original full parabola, which would eliminate feed blockage. Recently, K2RIW was questioning whether the slight efficiency improvement is worth the additional design complexity. He contacted one of the original designers of the RCA DSS dish and learned that the bottom edge of the reflector is at the center of the full parabola.

As a result, I made some calculations, and found that the edge can be centered by a small change in the tilt angle. Our original tilt angle was only an estimate, so there is no reason to believe it was correct. In practice, we have always found that the DSS dishes peaked at a slightly different tilt angle than we had calculated. Notice that the feed shadow in Figure 5-9 places the center of the horn in line with the edge of the dish.

Version 3 of the **HDLANT** *program adjusts the tilt angle until the bottom edge of the offset reflector is at the center of the full parabola, then calculates the focal point. For the RCA DSS dish, the tilt angle changes from the original estimate of 66.9°to 68.3°, and the focal length from 283 mm to 291 mm. A string to set the focal point would have lengths of 291 mm from the bottom edge of the dish and 476 mm from the top edge of the dish. The change in focal length is small enough so that the illumination angle is still approximately 78°, equivalent to an* ***f*/D** *of 0.71.*

UPDATE: ***While measuring additional points for the curve-fitting routine in*** **HDL_ANT version 3,** ***I measured slightly different numbers. I ran the curve-fitting for both metal and plastic (SMC) DSS reflectors and came up with very similar***

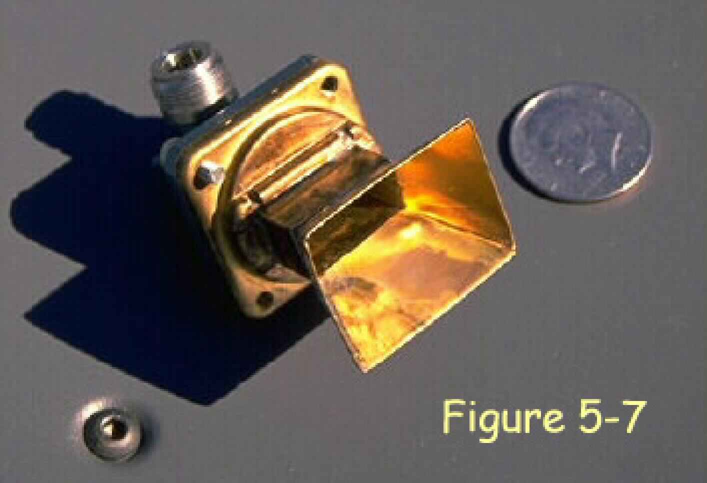


Figure 5-7

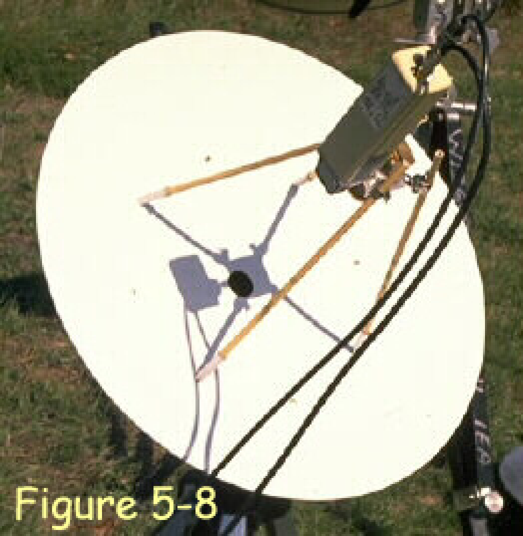


Figure 5-8

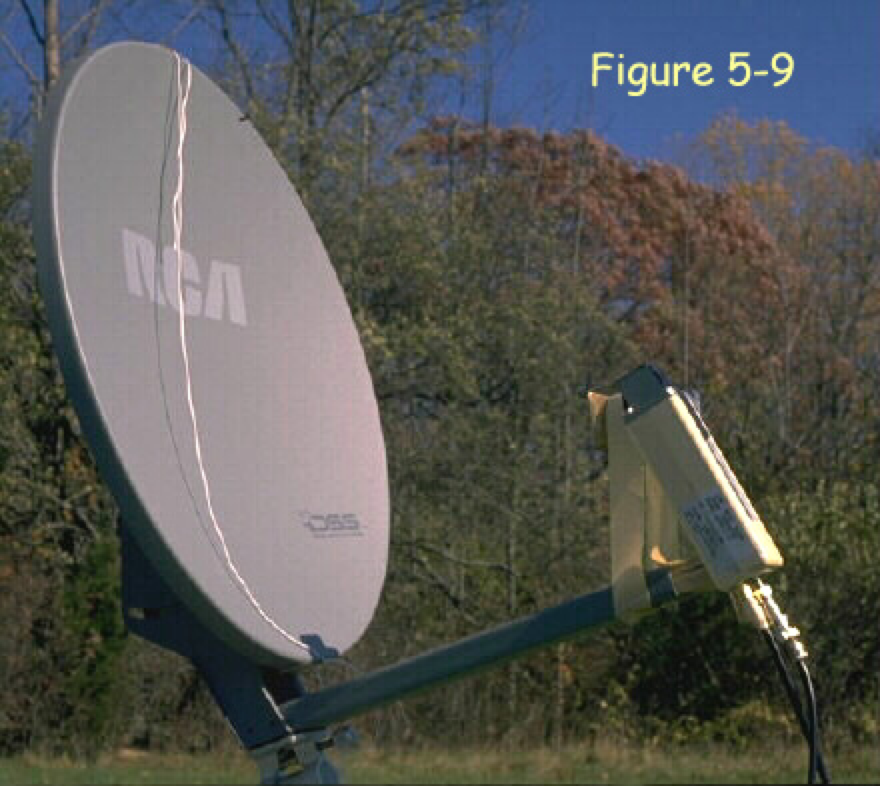


Figure 5-9

numbers for the two reflectors.. My current best estimate (29 April 1998) for the DSS dishes:

> **Focal length = 278 to 281 mm (also bottom string length)**
> **Tilt angle = 67.6°**
> **Top string length = 466 to 468 mm**
> **Feed *f*/D = 0.69**

The previous estimate of focal length for the RCA DSS dish was less than 1/4λ in error; from Chapter 4, this would result a gain reduction of less than 1 dB. The other error is in tilt angle. Both these errors can be corrected by empirical adjustments. However, for larger offset dishes, the focal length error would be much more significant — WB1FKF found that the focal point of a 24-inch offset reflector calculated by version 2 of **HDLANT** *required adjustments to achieve good performance. The improved calculations in version 3 of* **HDLANT** *should be more accurate for larger offset dishes.*

Other Offset Feeds

A rectangular feed horn is fine for linear polarization, but what if we want circular polarization? Chapter 6 provides details for a number of feeds.

Other Offset Dishes

I was given an offset-feed 24 inch plastic dish with a cosmetic defect (and no other information). Measurements showed the geometry to be similar to the RCA dish, so the same feedhorns would work fine. I was not able to support the feed as well on this dish, so the feed location may not have been optimum, but it still measured 61% efficiency at 10 GHz.

Two other types of offset dishes seem to be fairly common, so some will probably wind up in amateur hands eventually. Many automobile dealerships and discount stores have larger offset dishes, four feet or more in diameter, with a reflector which appears circular. The other type is another brand of TVRO system, with an odd shape dish about 3 feet across; the ones I've seen are marked "Primestar." I had a chance to look one over at a county fair, next to the tractor dealer. The reflector appeared to be wider than it was high, requiring a fairly wide feed angle. The feed horn had a curved plastic surface which could possibly be a molded lens.

If I were to acquire one of these reflectors, I would place it flat on the ground with the reflecting surface facing upward and fill it with water. The water should fill an oval area reaching the top and bottom edges of the rim, but not the sides. Measuring this oval as described in Appendix 5-1, and measuring the depth and location where the water is deepest, should be enough to calculate the offset geometry. The feedhorn beamwidth would have to be broader from side-to-side than from top-to-bottom, but a rectangular feedhorn can be designed to provide an assymetrical pattern.

Version 3 of **HDLANT** *assumes that all offset reflectors have a bottom edge coincident with the center of the original full parabola. For a reflector where this is not the case, more complex curve fitting is required: measure the position and depth several points along the center line between top and bottom, and fit them to a parabolic curve. This would be easy if the dish were perfect and the measurements precise. However, with more than three points, there is probably enough error that they will not land exactly on a parabola.*

Therefore, the curve fitting option in Version 3 searches through a range of parabolas with different focal lengths and does a least-squares fit of the measured points. It also checks for offset reflector which do not start at the center of the full parabola. Since it is fitting points along the center line and doesn't care about other dimensions, this routine will work for any shape of dish. It also reports the average error, which should be less than one millimeter for a good 10 GHz reflector.

I had nine different offset reflectors available; on each, I measured three points, the deepest point and two arbitrary ones. Using the curve fitting option, all the reflectors have their bottom edge within 2 mm. of the center of the original parabola. I attribute this small difference to measurement error rather than design, and conclude that small offset dishes are designed to include the center of the full parabola. This makes setting up the antenna much easier — the focus is level with the bottom of the dish. Then the tilt of the reflector may be determined simply by the string length to the upper edge, rather than having to accurately measure an angle.

Mounting an Offset Dish

To aim an offset dish on the horizon with the feed below the dish, the reflector must be tilted forward — 67.6° from horizontal for the RCA dish. One way to accomplish this would be to mount it on a wedge cut at the correct angle, so that the bottom of the wedge can be mounted on a level surface or tripod. An alternative technique is to rotate the dish so that the feed is to the side, level with the center of the dish. In this configuration, the elevation uncertainty is eliminated, but an aiming device must be provided for azimuth. An accurate azimuth readout is a good idea for any dish, since aiming a narrow beam by eye is fraught with error. A settable compass rose with one-degree graduations works well for all rover operations.

I prefer the to have the feed below the dish, to minimize feedline length. For a portable rig, the dish can be mounted directly on top of the transverter, using a wedge to set the tilt angle, as shown in Figure 5-10. This orientation may also have a slight advantage in noise reduction, since the feed is pointed at cold sky as depicted in Figure 5-2. No one I know has found a way to make a comparably compact, robust rover system using a conventional dish.


Figure 5-10

Summary

An small offset-fed parabolic dish can deliver more performance than a conventional dish of the same size. Direct-broadcast TV from satellites has made small offset dishes widely available at very low cost, and they are well suited for integration into a small system. All these advantages should make the offset dish the ham antenna of choice for terrestrial microwave communications.

References

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3. MCM Electronics, 650 Congress Park Drive, Centerville, OH 45459, 800-543-4330. Dish part number 221196-7.

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6. V. Jamnejad-Dailami and Y. Rahmat-Samii, "Some Important Geometrical Features of Conic-Section-Generated Offset Reflector Antennas," *IEEE Transactions on Antennas and Propagation*, AP-28, November 1980, pp. 952-957.

Appendix 5-1
Measurements and Calculation for an Offset Parabolic Reflector

The geometry of an offset-feed dish antenna is a bit more complicated than a conventional dish antenna, but the measurements needed to use one are straightforward. We need to first determine the tilt angle of the reflector, then do some curve fitting calculations for the dish surface, calculate the focal length, and finally determine the focal point in relation to the offset reflector.

One common type of offset parabolic reflector has an oval shape, with a long axis from top to bottom and a shorter axis from side to side. However, if you were in the beam of this antenna, looking down the boresight, it would appear to be circular, with the feed at the bottom. Tilt the top of the reflector forward, until it appears circular from a distance, and it will be in the correct orientation to operate with the beam on the horizon. The approximate tilt can be determined much more accurately with a simple calculation:

Tilt angle (from horizontal) = *arcsin*(short axis / long axis)

[Note: the *arcsin* function is called sin^{-1} on some scientific calculators]

For the RCA 18" dish, the short axis is 460 mm. (about 18") and the long axis is 500 mm. Therefore, the tilt angle = *arcsin*(460/500) = 66.9 degrees above horizontal. At 10 GHz, one millimeter is sufficiently accurate for most dish dimensions, so using millimeters for calculations eliminates a lot of tedious decimals.

If the offset reflector is not oval, we can still use the same calculation by placing it on the ground with the reflecting surface upward and filling it with water. The surface of the water in the dish should be an oval just touching the top and bottom rims, the other axis of the oval of water is the shorter axis.

The other dimension we need is location and depth of the deepest point in the dish. The deepest point is probably not at the center, but somewhere along the long axis. Using a straightedge across the rim for an oval dish, or the water depth for other shapes, locate the deepest point and measure its depth and distance from the bottom edge on the long axis.

For the RCA dish, the deepest point is 43 mm deep at 228 mm from the bottom edge on the long axis.

When the dish is tilted forward to 66.9 degrees above horizontal, the translated coordinates describe the curve of the long axis by three points:

0, 0 mm	(bottom edge)
49.8, 226.6 mm	(deepest point)
196, 460 mm	(top edge)

If we assume that the bottom edge is not at the axial center of a full parabola of rotation (the equivalent conventional dish of which the offset dish is a section), but rather is offset from the center by an amount X_0, Y_0, then all three points must fit the equation:

$$4 * \boldsymbol{f} * (X + X_0) = (Y + Y_0)^{2}$$

The unknowns are X_0, and Y_0, and ***f***, the focal length; plugging in the three points gives us 3 equations and 3 unknowns, a readily soluble 3x3 matrix (actually, the 0,0 point allows reduction to a 2x2 matrix, even easier, followed by a simple calculation for X_0 and Y_0). Version 2 of the **HDL_ANT** program will do the calculations for you.

For the RCA dish, the answers are:

f = 282.8 mm = 11.13"
X_0 = 0.1 mm behind bottom edge
Y_0 = 11 mm below bottom edge, so the feed doesn't block the aperture at all.

However, the bottom edge of the dish should be at the center of the full parabola, so that $X_0 = 0$ *and* $Y_0 = 0$. *We can repeat the calculations above with slightly different tilt angles until* $X_0 = 0$ *and* $Y_0 = 0$; *for the RCA dish, the new tilt angle is 68.3°, a small change from our original estimate of 66.9°. The focal length is then calculated to be 291 mm. Version 3 of the* **HDL_ANT** *program will do the improved calculations.*

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Focal length = 278 to 281 mm (also bottom string length)
Tilt angle = 67.6°
Top string length = 466 to 468 mm
Feed *f*/D = 0.69

So, we tilt the dish to 68.3 degrees from horizontal, and the feed is on a line level with the bottom edge of the dish. To help locate the focal point, it is 291 mm from the bottom edge, and 476 mm from the top edge, both edges on the long axis. I tied a knot in a piece of string and taped it to the top and bottom edges so that the knot locates the focal point.

For the RCA dish, we can also calculate the illumination angle to be 77.2 degrees on the long axis and 78.1 degrees on the short axis, so it is roughly symmetrical. The optimum feed for this illumination angle is equivalent to an axial-feed dish with ***f*/D** ≅ 0.71.

Although the illumination angle is equivalent to an ***f*/D** ≅ 0.71, the surface is a section of a parabola about 36.5 inches in diameter with a focal length of about 11.5 inches. Thus, the real ***f*/D** is 0.31, so the focal distance is quite critical.