Parabolic Dish Antennas

Our previous column [August 2005, page 75] looked at horn antennas—easy to make, and they always work. But sometimes we need more gain, or just have to have a bigger antenna. There are lots of large dishes out there, so they are the obvious choice. A parabolic dish antenna can provide very high gain, but it takes some understanding and attention to detail to achieve good performance.

A large antenna is one with dimensions of many wavelengths. By this measure, all antennas for the 160 meter band are small, but most useful microwave antennas are big antennas. One of the interesting things about large antennas is that we can use optical techniques for analysis. In fact, a dish antenna has a lot in common with a reflecting telescope.

Aperture Gain and Efficiency

The gain of an antenna is proportional to the aperture area—for a dish or horn antenna, this is the cross-sectional area you see when the antenna is pointed at you. The gain of an aperture with area A may be calculated:

$$\mathrm{Gain}_{\mathrm{dBi}} = 10\log_{10}\left(\eta\frac{4\pi}{\lambda^2}A\right)$$

where η is the aperture efficiency and λ is wavelength.

The aperture efficiency is a measure of how well a given antenna works compared to an ideal antenna with the same aperture, which would have 100% efficiency. Typical aperture efficiency for a horn is about 50%, but a dish can have significantly higher efficiency—or much lower, if we don't get it right. The efficiency directly affects the gain, so we get maximum gain from a given antenna size by maximizing efficiency.

The aperture size also controls the beamwidth—increased gain comes from squeezing more energy into a narrower beam, so that high gain antennas require careful pointing. The aperture efficiency has only a small effect on beamwidth, so a large antenna with poor efficiency and thus low gain is just as sharp and hard to point as one with good efficiency. Wind loading is also important—big dishes make great sails—so, for a desired gain, we would rather have a smaller dish with good efficiency than a larger dish with poor efficiency.

If the aperture efficiency is low, where does it go? At low frequencies, small antennas, like a loaded vertical, suffer from low *radiation* efficiency, where energy is dissipated in loading coils and in the ground, so the percentage that is radiated is low. Most microwave antennas have very high radiation efficiency, so that essentially all the energy is radiated, but not all is radiated in the desired direction. Energy radiated in other directions does not contribute to gain, so it reduces *aperture* efficiency. An aperture efficiency of 50% means that ½ of the energy is radiated in desired directions. Where does the rest go? As an example, small sidelobes that are 20 dB (0.01x) down but are 100 times broader in area than the main beam will contain just as much energy as the main beam, so that half is in the main beam and half in the sidelobes.

A parabolic dish is a reflecting lens, a shaped mirror that acts like a lens. Like any lens, it must be focused to work properly.

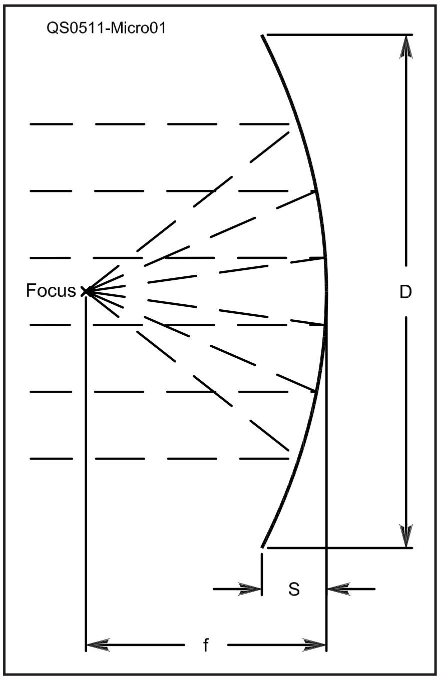

Figure 1—How to find the focus by measuring the depth, s, of the dish, and the diameter, D.

Figure 1 shows how to find the focus, by measuring the depth, s, of the dish, and the diameter, D. Then, because it is a parabola, the focal distance f is easily calculated:

$$f = \frac{D^2}{16s}$$

A parabolic reflector has the unique property that all paths, or rays, originating at the focus and reflecting from the surface form a beam of parallel rays leaving the reflector, as illustrated by dashed lines in Figure 1. For receiving, energy arriving along the beam is reflected to converge at the focus. All rays originating at the focus also have identical path lengths to any plane parallel to the rim, so that the rays are all in phase. Rays originating from a different point would have different path lengths, so they would not be in phase and would not all contribute to gain. This is why it is important for the feed to be positioned at the focus of the dish—an error in the focal distance f of as little as $\lambda/4$ can reduce gain significantly, particularly for deeper dishes.

Illumination

While all dishes have a parabolic curvature, a true parabola extends to infinity, so we only use part of the curve. If a dish uses only a small part of the curve, it will be rather flat, while another may use more of the curvature, so it will have a deeper depth s. We usually characterize curvature by the f/D ratio, so that we can concentrate on the geometry rather than the size—all dishes with the same f/D have the same geometry, regardless of size. The important part of the geometry is the illumination angle, θ, shown in Figure 2, that the feedhorn must illuminate.

To achieve high efficiency, all parts of the aperture must contribute equally—the aperture must be uniformly illuminated. For a dish, the reflector is illuminated by a feed antenna, placed at the focus of the parabola. One common feed antenna is a small horn, like the one we made in the previous column. We would like all of the radiated energy from the feed antenna to illuminate the reflector uniformly, with nothing wasted in other directions. Unfortunately, real antennas fall a bit short. In Figure 2, we

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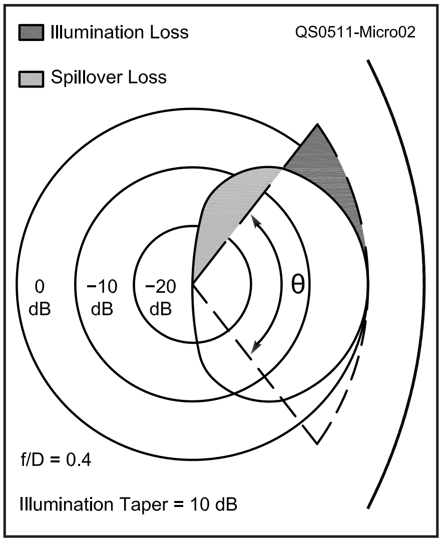

Figure 2—The geometry of the illumination angle, θ.

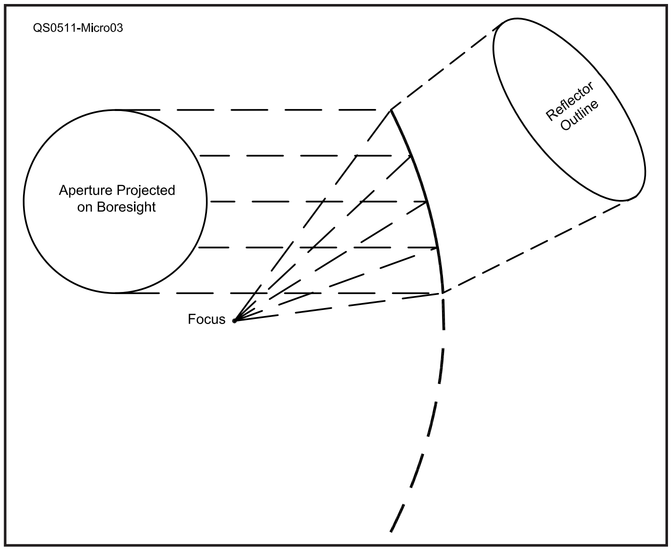

Figure 3—Geometry of the offset parabolic dish antenna. A major advantage of these dishes is that the feedhorn is out of the main beam.

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Figure 4—To locate the feed, I tie a knot in some string, then tape the string to the edges of the dish so the knot is the required distances from the edges.

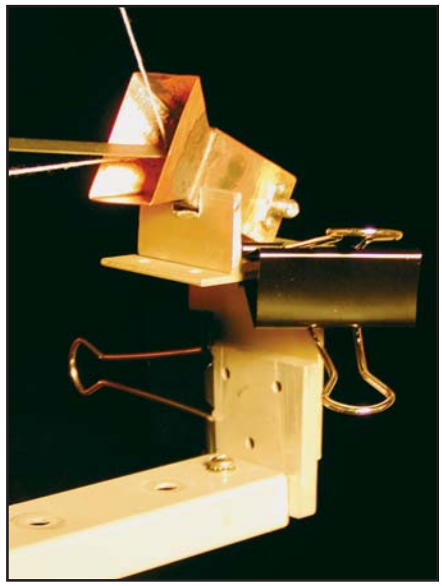

Figure 5—The feedhorn location is adjusted so the knot is at the phase center of the horn.

compare the desired uniform feed radiation pattern, shown as a dashed line, with a realistic one, the solid line. Some of the feed energy, colored in red, misses the reflector entirely and is lost; we call this *spillover* loss. The energy on the reflector is not uniform, so not all parts of the reflector contribute equally; we call this *illumination* loss. Finally, for a conventional dishes of reasonable size for amateur use, the shadow of the feed on the dish blocks a significant part of the beam; we call this *blockage* loss.

For dishes small enough to be manageable for rovers and portable stations, the blockage by the feed and support structure is a large factor in reduced efficiency. One way to avoid this is to use an offset parabola, like the small DSS satellite TV dishes that seem to be on every other house. A major advantage of these dishes is that the feedhorn is out of the main beam, as shown in Figure 3. The offset dish is simply a portion of a larger full parabolic dish—imagine taking a saw, starting at the center of a dish, and cutting out an oval from one side. The DSS dish is that oval. An incoming radio wave, coming down the boresight of the main beam in Figure 3 at an angle to the oval, sees it as a circular cross-section, so the aperture is a circle whose diameter is the smaller dimension of the oval.

The horn we made in the previous "Microwavelengths" column is an excellent feedhorn for the DSS dish. The phase center, a point from which the horn appears to radiate, is about 6 mm inside the aperture of the horn.

Locating the Feedhorn

We must still locate the feedhorn so the phase center is at the focus of the parabola, but the focus of the offset dish is no longer easy to find. An easy way is to measure the location of the original TV feedhorn; otherwise, some curve-fitting arithmetic is necessary. For the common RCA DSS dish, I have calculated that the focus is 468 mm from the center of the top edge and 280 mm from the center of the bottom edge. To locate the feed, I tie a knot in some string, then tape the string to the edges of the dish so the knot is the required distances from the edges, as shown in Figure 4. The feedhorn location is adjusted so the knot is at the phase center of the horn, as shown in Figure 5. The feed support is held together with clamps (binder clips from the stationery supply store) for ease of adjustment. Once everything is in place, the holes are marked and drilled, and the pieces bolted firmly together. We don't want anything to shift, and any attempt to adjust the feed in the field will probably make it worse.

DSS dishes are cheap and readily available, and they work very well. Another, less obvious advantage of offset dishes is the opportunity to reduce feed line loss, which can be significant at microwave frequencies. On a conventional dish, we must either run our feed line from behind the dish out to the feed or place the electronics at the feed and suffer additional blockage loss. The feedhorn of an offset dish, on the other hand, is not in the main beam, so we can mount electronics right at the feedhorn without introducing any shadow. Figure 4 shows a transverter mounted directly under the dish, with only a few inches of coaxial feed line. The dish is mounted so that the feedhorn is level with the bottom of the dish, in this case by a wooden wedge cut to the appropriate angle mounted directly on top of the transverter.

You have probably guessed by now that I prefer offset dishes. If you would rather use a conventional dish, or want to dig deeper for either type, please visit my Web page, **www.w1ghz.org**.