Parabolic Dishes with Flat Subreflectors

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Feedline loss is a difficult problem at the higher microwave frequencies. Even for a portable dish, some feedline is needed to get from the electronics to the feedhorn. For bands above 24 GHz, even waveguide has significant loss. At 10 and 24 GHz, an easy solution is to use an offset-fed dish with the electronics close to the feedpoint, but common offset dishes may not have sufficient surface accuracy for higher bands.

An elegant solution to the feedline problem is to reverse the feed, using a subreflector in a Cassegrain[1]configuration, as sketched in Figure 1, or Gregorian configuration. In these configurations, the feedhorn is near the main parabolic reflector, with the waveguide passing through the center of the dish. The electronics can be right on the back of the dish, with only a very short waveguide.

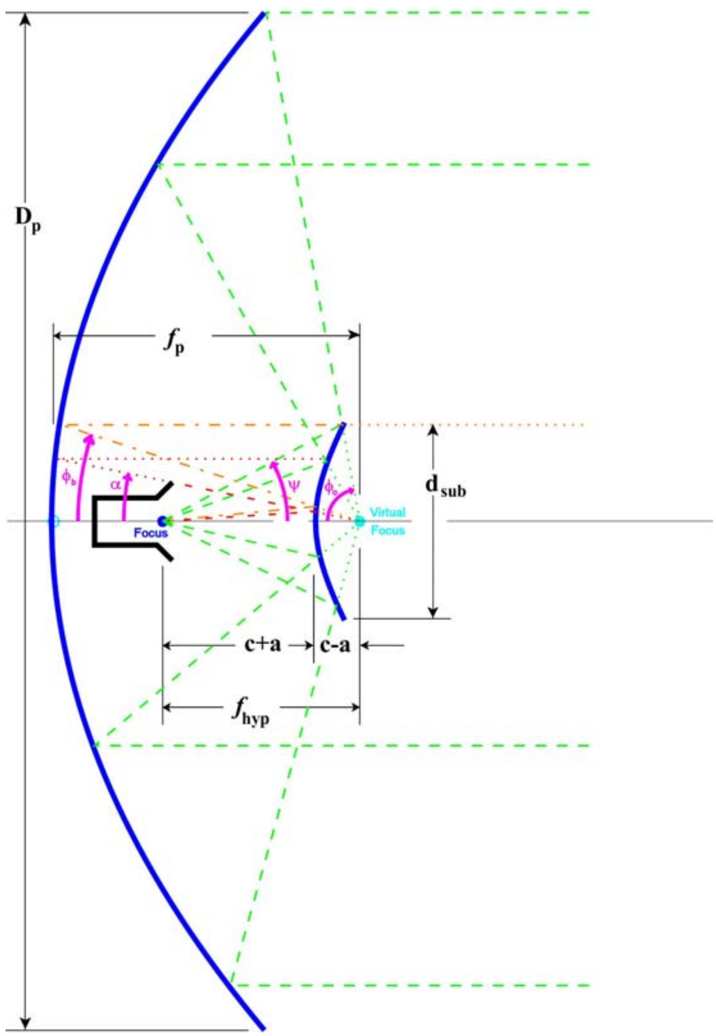

Figure 1 – Geometry of Cassegrain Dish Antenna

However, the subreflector requires an accurate curvature: hyperbolic for the Cassegrain, or elliptical for the Gregorian. Producing the curvature with enough accuracy for the higher microwave bands requires some serious machining skill, unless you have a CNC machine available. A few subreflectors have turned up as surplus – then the problem imvolves fitting the curve and matching it to a dish and feed.

On the other hand, a flat surface is pretty easy to find. A dish with a flat subreflector, or degenerate Cassegrain, is not as good as a Cassegrain with a shaped subreflector, but how bad is it? Can the loss be less than the feedline loss for the prime focus configuration, without a subreflector?

Flat Subreflector

One problem with the flat subreflector scheme is that the geometry is set by main parabolic reflector – deep dishes, with low ***f*/D**, have a short focal length and require a feed with a very broad pattern for full illumination. An ***f*/D** = 0.33 subtends an angle of 149º, while an ***f*/D** = 0.25 subtends a full 180º; no good feeds are available for the latter. Figure 2 shows a sketch of a dish with a flat subreflector, with the original feed at the prime focus feed the subreflector and the new reversed feed below. The focal length is the same as the dish, but is now the distance from the vertex of the parabola to the subreflector and back to the feed. The two feeds are the same distance from the subreflector – one is a mirror image of the other, with the flat subreflector as the mirror. The subreflector must subtend the same angle as the feed illumination, so it tends to be very close to the feedhorn, resulting in the feedhorn blocking a substantial part of the dish. Not only does this prevent part of the energy from reaching the dish surface, it also reflects back into the feedhorn, raising the VSWR.

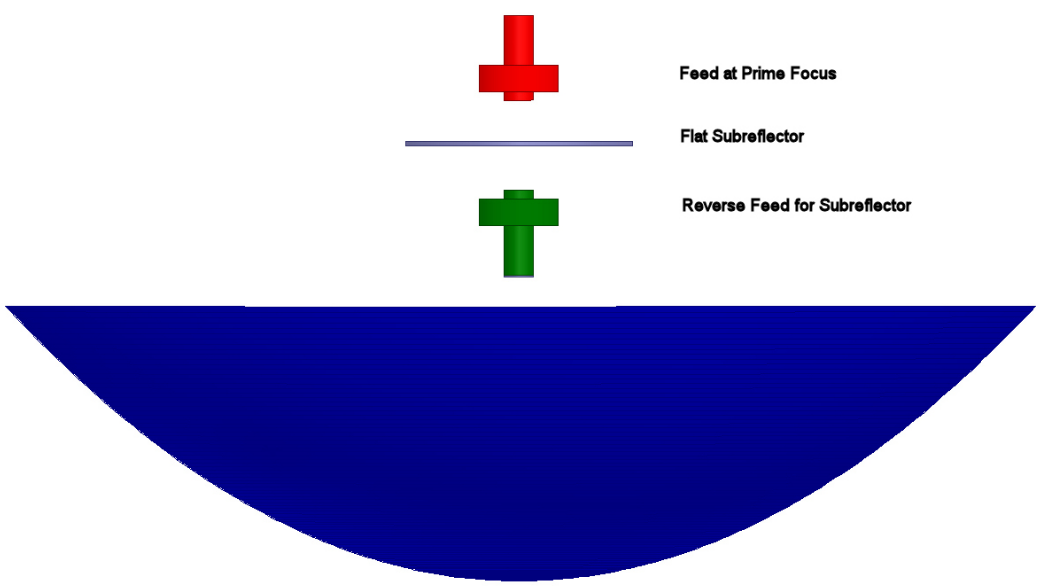

Figure 2 – Dish with Flat Subreflector

In contrast, a Cassegrain or Gregorian configuration has another variable – the curvature of the subreflector. The subreflector has a different focal length than the main reflector, so we may choose the placement and illumination angle of the feedhorn separately. For instance, this allows illumination of a very deep dish, with ***f*/D** ~0.25, with a high efficiency feedhorn that would be appropriate for a shallower dish.

Flat Subreflector Performance

To quantify the performance of a flat subreflector dish, I simulated some examples using Ansoft HFSS software[2]. While it is only possible to simulate modest sized dishes, those are what most hams are using. As a starting point, I modified my Cassegrain design spreadsheet to accommodate the flat subreflector – the calculation attempts to estimate a size where blockage loss and diffraction loss are equal. This should be roughly the optimum size for a flat subreflector as well as for a Cassegrain.

The simulation results for a 15 wavelength diameter dish, ***f*/D** = 0.33, are shown in Figure 3, with two different feedhorns, comparing the dish gain to the gain with the high-performance Super-VE4MA feed at the prime focus. For the flat subreflector configuration and a small open waveguide "Coffee-can" feed, the best performance is with a subreflector diameter of about 3.5λ. Degradation is about 1 dB, with another dB lost to power reflected back into the feed (lower curve) by the subreflector. With a Super-VE4MA feed, the best performance is with a subreflector diameter of about 5λ, giving about 1 dB degradation. The overall gain of the dish is roughly the same with either feed, 1 to 2 dB lower than with the Super-VE4MA feed at the prime focus.

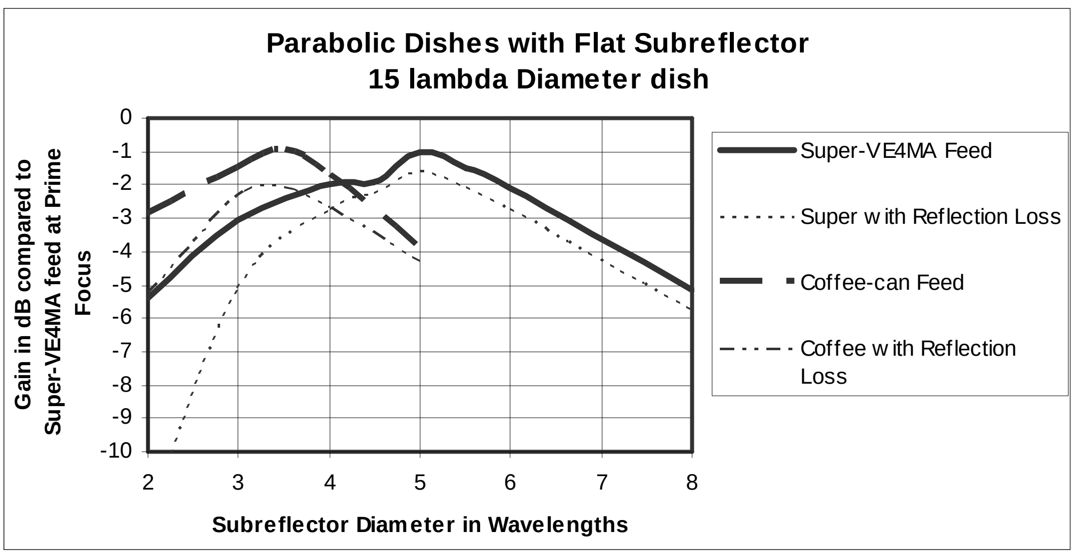

Figure 3

Larger dishes and longer focal lengths have more distance between the feedhorn and the subreflector, so the blockage and reflected power should both be less. A few more examples, in Figure 4, show this. A 20λ diameter dish with ***f*/D** = 0.33, with a Super-VE4MA feed and a flat subreflector, has about ¾ dB degradation for a best subreflector diameter of 5λ, and reflection loss is less than ½ dB. However, a 25λ diameter dish with ***f*/D** = 0.33 has slightly more degradation. The best subreflector diameter is about 5λ for all three dish sizes – it seems to be related to the feedhorn rather than the dish size. Again, we can expect a gain 1 to 2 dB lower than the same dish with the feed at the prime focus.

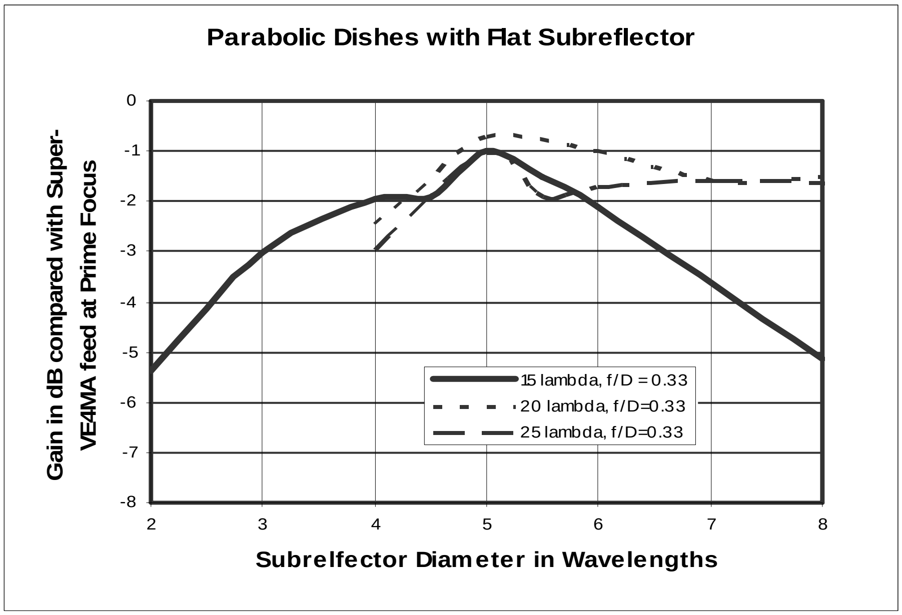

Figure 4

For an ***f*/D** = 0.4, curves for both 15λ and 20λ diameter dishes are shown in Figure 5. These two examples have a variant of the Super-VE4MA feed chosen to match the ***f*/D**, which has very good performance as a prime-focus feed, about 70% simulated efficiency. Both sizes show degradation of less than a dB, and both have reasonable VSWR show reflection loss is is less than ½ dB. What is strange about these curves is that there is not a smooth peak – I suspect an interaction between the horn and subreflector, which is in the near field of the horn.

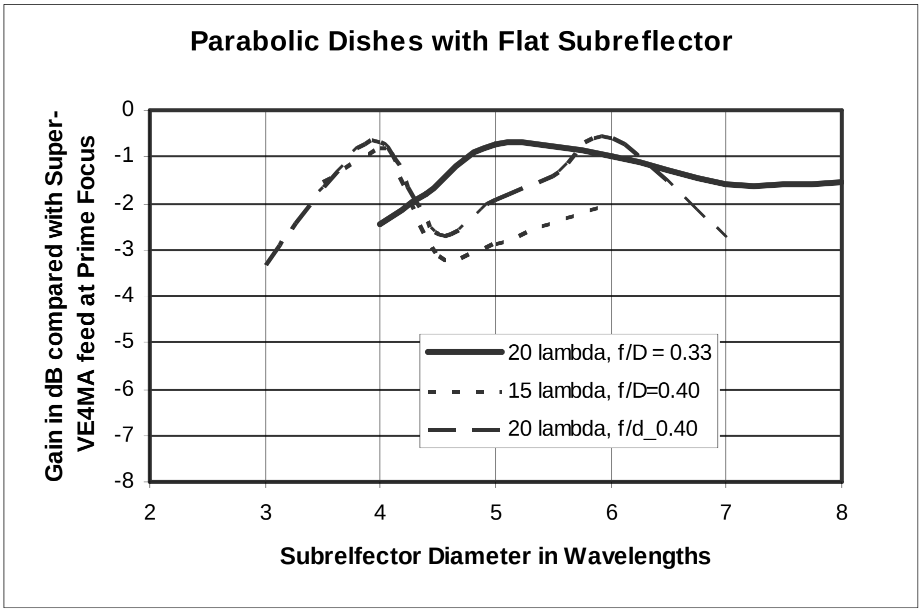

Figure 5

These results are encouraging – the flat subreflector has a penalty of only a dB or two on these small dishes. At higher microwave frequencies, 24 GHz and up, this is probably less than feedline loss even in waveguide, so it is worth considering. Of course, at the higher frequencies, even a physically small dish is probably larger than 20 wavelengths.

Small Cassegrain Dishes

I described the Cassegrain dish in a 2004 paper[3]. The Cassegrain configuration, with a hyperbolic subreflector, works well for large dishes but not as well for small dishes. A small subreflector suffers from diffraction loss since subreflector is not much larger than the feedhorn, so the feedhorn is not a good approximation to a point source. One estimate is that a Cassegrain dish must be at least 50 wavelengths in diameter to offer a performance benefit. Also, a Cassegrain dish is more difficult to adjust, since there are two focal lengths to adjust.

So we don't expect great performance from a small Cassegrain dish, but how bad is it? Is it any better than a flat subreflector; if not, it certainly isn't worth the effort to make an accurate curve. Where it may still be useful is for the pattern reshaping provided by the hyperbolic subreflector – we can match a high-efficiency feedhorn to a very deep dish which no good feedhorn is able to illuminate efficiently.

I simulated a few examples of a small Cassegrain antenna, comparable to the flat subreflector examples. These also have a 20λ diameter main reflector with ***f*/D** = 0.33. Two high-performance feedhorns were used: the popular W2IMU dual-mode horn[4], best for an ***f*/D** around 0.6, and a Skobolev optimized dual-mode feedhorn[5] with dimensions best for an ***f*/D** around 0.7. The hyperbolic curve was generated using parameters calculated by the cass_design.xls spreadsheet[3]. The second horn requires a more curved surface, which increases the diffraction loss.

I also simulated a very deep Cassegrain dish, ***f*/D** = 0.25, fed with the W2IMU dual-mode horn. There is no good prime-focus feed for a dish this deep, so any reasonable performance is good.

The results for the Cassegrain simulation are shown in Figure 6. For the dish with ***f*/D** = 0.33 and a W2IMU feed, the cass_design.xls spreadsheet predicts an optimum subreflector size of 3.8 wavelengths, while best performance is found with a slightly larger one – apparently diffraction loss is more important than blockage with a small reflector. The degradation is slightly less than a dB compared to a Super-VE4MA feed at the prime focus, which is comparable to the same dish with a flat subreflector.

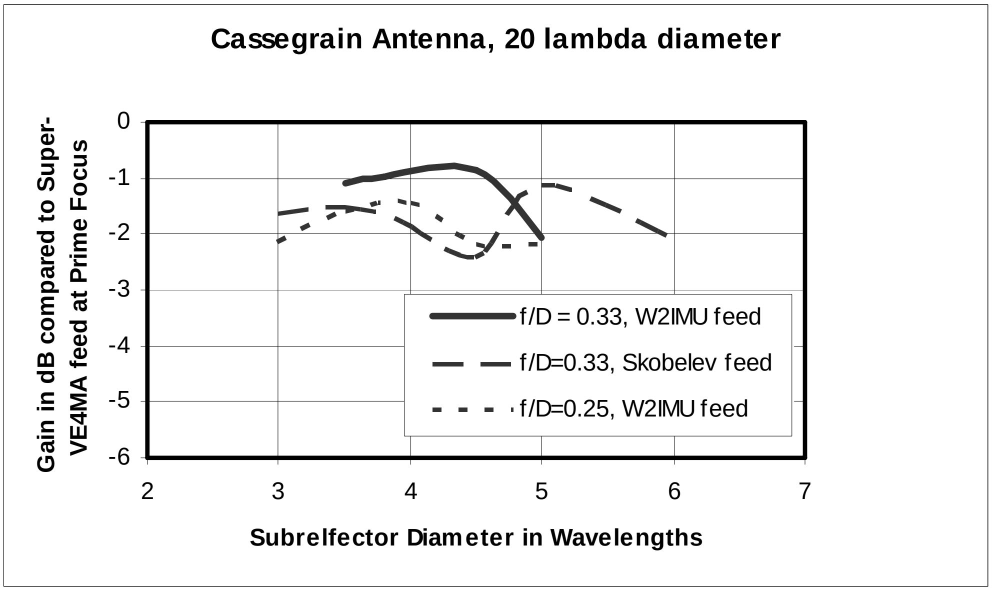

Figure 6

The dish with ***f*/D** = 0.33 and a Skobolev optimized dual-mode feedhorn doesn't do quite as well, even though the feed should provide slightly higher efficiency. The spreadsheet predicts an optimum subreflector size of 3.94λ, but the simulations show two peaks, at about 3.5λ and about 5λ diameter. Both peaks have more than one dB of degradation, not as good as with the W2IMU feed.

Finally, the very deep dish, ***f*/D** = 0.25, fed with the W2IMU dual-mode horn is not quite as good as the other dish with the W2IMU feed. The spreadsheet predicts an optimum subreflector size of 3.51λ, but best performance is with a slightly larger subreflector. The calculated degradation is about 1.5 dB compared to the shallower dish with prime focus feed.

We can conclude that a small dish with a Cassegrain feed is no better than with a flat subreflector. The flat subreflector is much easier to make and to adjust, so there is no advantage to the Cassegrain dish. The only exception is very deep dishes, which are difficult to illuminate with any other feed.

Summary

For modest-sized dishes, perhaps 15 to 25 wavelengths, using a reverse feed with a flat subreflector only costs a dB or two of gain. At high microwave frequencies where any feedline loss is high, this could be a reasonable tradeoff. On the other hand, for EME use on lower bands, where every dB counts, the additional loss would be unacceptable.

Very small dishes, 10λ or less in diameter, would not work well – the feedhorn would be so close to the subreflector that either the horn or the dish would suffer from a large blockage.

Large dishes should also work with a flat subreflector, with only a small degradation compared to a prime-focus feed. However, a true Cassegrain, with a hyperbolic subreflector, could potentially offer more performance than a prime focus feed.

Opinion

An offset-fed dish can provide better performance than a conventional dish, and the equipment can be very near the feedpoint so that feedline loss is minimized. I'd recommend an offset dish whenever it is a choice.

References

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