Chapter 11
PARABOLIC DISH FEEDS — PERFORMANCE ANALYSIS

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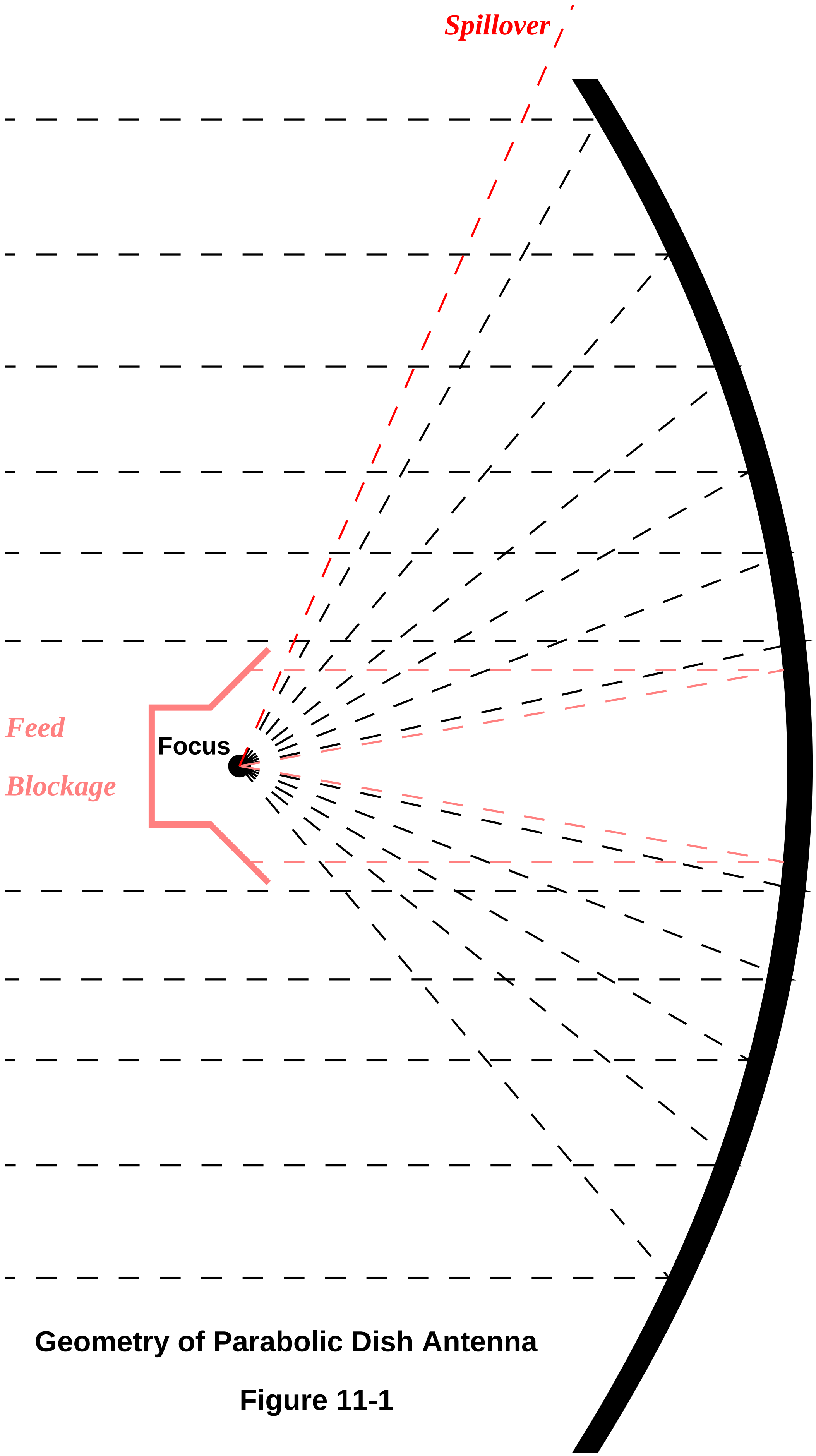
Achieving optimum performance from a microwave dish antenna requires that the feed antenna be matched to the parabolic reflector. Traditionally, we have relied on "rules of thumb" to choose a feed for the dish. Alternatively, a computer program can be used to analyze performance of a feed antenna based on measured or calculated radiation patterns and, more importantly, present the data in a graphical format for easy comprehension. This tool is used to explore a number of published feed designs in an effort to enhance understanding of the performance of dish antennas and feeds.

Parabolic antenna overview

Parabolic dish antenna fundamentals were covered in detail in Chapter 4, but a short review of key points is in order here. Figure 11-1 illustrates the operation of the dish antenna: a feed antenna at the focus of the parabola *illuminates*, or radiates energy toward, the reflector, which reflects it into a narrow beam of energy. Part of the feed antenna radiation misses the reflector; this loss is called *spillover*. Another part of the feed energy is reflected back into the feed antenna and doesn't become part of the main beam; this loss is referred to as *feed blockage*.

Ideally, all areas of the reflector should be illuminated with equal energy from the feed. Figure 11-2 shows this desired feed pattern as a broken line; since the edges of the parabolic curve are farther away from the focus than the center of the curve, more energy is required at the edges than at the center, but with no energy missing the reflector. An additional requirement is that all the feed energy be in phase, so that it appears to be radiated from a single point at the focus. The desired radiation pattern cannot be realized with real feed antennas, so perfectly uniform illumination cannot be achieved. Figure 11-2 also shows an idealized typical feed antenna pattern; the difference between the desired feed pattern and the actual feed radiation pattern results in *illumination loss* because some areas of the reflector are unable to work as effectively as others, as well as the spillover loss of the energy that misses the reflector and continues in an undesired direction.

For each reflector, we try to choose a feed that provides a compromise of illumination loss and spillover loss which yields maximum performance, which we measure by *aperture efficiency*, a comparison of the actual gain to the maximum theoretical gain achievable for the same aperture area. The traditional rule of thumb for this compromise is that best efficiency occurs when the illumination energy is 10 dB down at the edge of the dish, so the feed should be designed for a radiation pattern which is 10 dB down at the edge of the dish. It isn't necessary to do this for each individual dish; all dishes with the same ***f*/D**, the



Geometry of Parabolic Dish Antenna

Figure 11-1

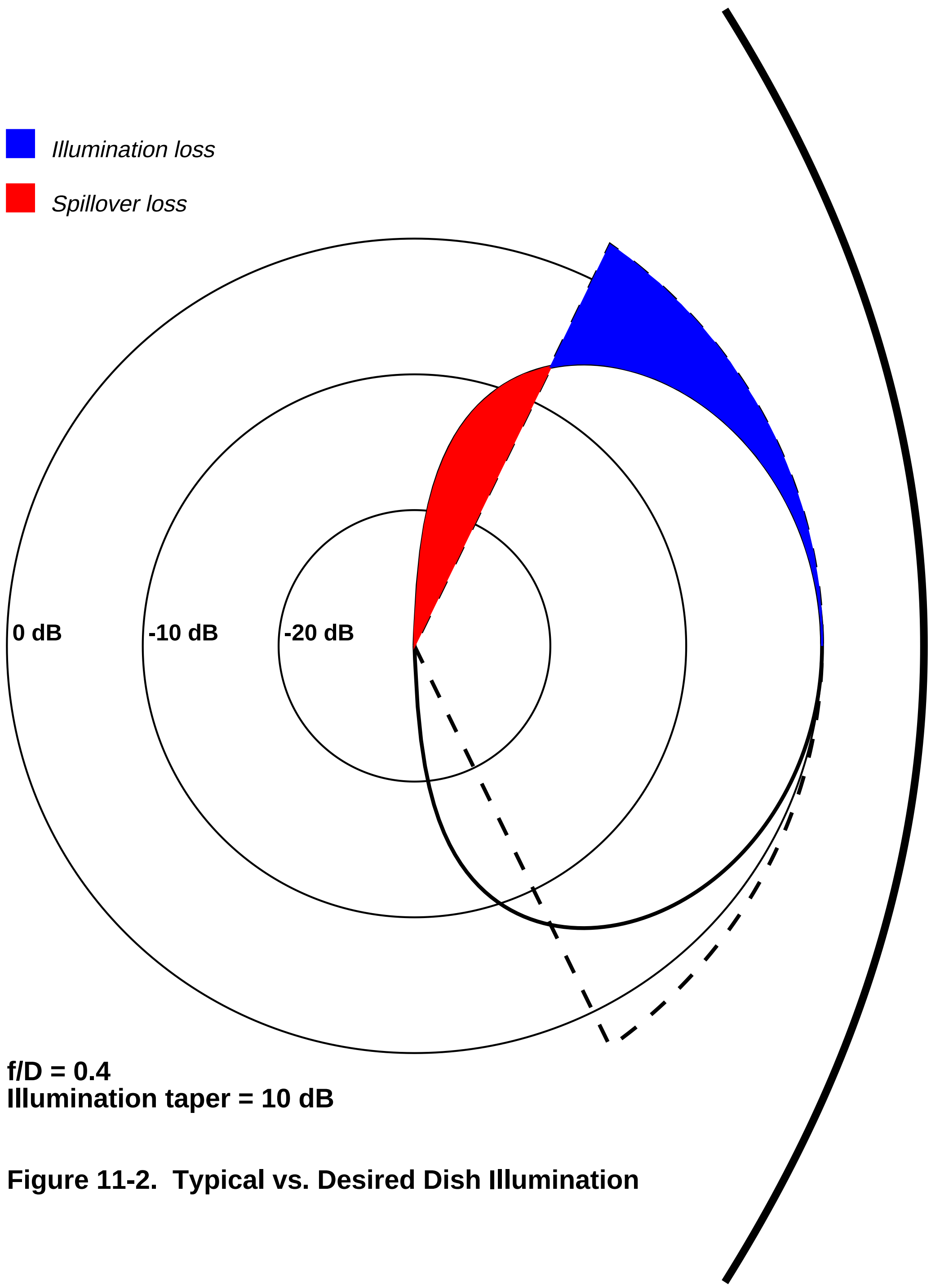


Figure 11-2. Typical vs. Desired Dish Illumination

ratio of focal length to diameter, have the same geometry regardless of reflector diameter. Thus, all dishes with the same ***f*/D** can use the same feed design, and good feed designs are available for several common values of ***f*/D**.

Efficiency calculation

The aperture efficiency of a dish antenna is the amount energy concentrated into the beam divided by the total energy radiated by the feed. The efficiency can calculated by integrating (remember calculus?) the feed pattern radiated over the area of the reflector and dividing the result by the total integrated feed pattern. When this calculation was done by hand, it was usually done by approximating the feed pattern with an idealized $\cos^n$ feed pattern (n = 3 in this example) as shown in Figure 11-3, making the integration much easier. With a computer, we can do numerical integration of actual feed patterns, performing the tedious calculations for many data points.

The numerical integration routine I used is borrowed from a BASIC program by W7PUA[1] which is based on a 1947 paper by Cutler [2]. I translated the routine to **C++**, then added some enhancements:

- the data interpolation is more flexible to use whatever feed pattern data is available,
- feed blockage loss is calculated,
- and the output is graphical for visual comprehension.

I find that a simple curve is easier to understand than tables of numbers or long descriptions. The output format is PostScript™, which can be displayed or printed using the free Ghostscript software [3].

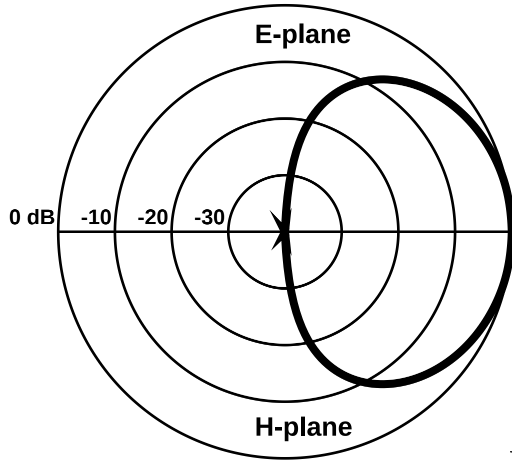
The bottom half of Figure 11-3 is an example of the graphical output, a plot of efficiency vs. ***f*/D** for the $\cos^n$ feed pattern shown as a polar plot in the top half of Figure 11-3. It is obvious at a glance that this feed pattern is best suited for a reflector with an ***f*/D** of 0.4 to 0.5. The calculated efficiency of 80% for this idealized feed pattern provides a benchmark against which real feed antennas may be compared.

The efficiency curve in Figure 11-3 shows decreasing efficiency for ***f*/D** less than 0.4. These are deep dishes, requiring the feed to provide illumination over a very wide angle. For a dish with an ***f*/D** = 0.25, the focus is level with the rim of the dish, so that the feed must provide illumination over 180 degrees, as shown in Figure 11-4a. The polar plot of feed radiation in Figure 11-3 shows almost no energy radiated straight up and down, toward the edges of this dish. So it is not surprising that the illumination loss increases for small values of ***f*/D**.

The other end of the efficiency curve, for ***f*/D** greater than 0.5, also shows a decreasing efficiency. These shallower dishes, like the one illustrated in Figure 11-4b, require a narrower angle of illumination, so more of the energy from the feed in Figure 11-3 misses the dish, and spillover loss increases as the ***f*/D** increases.

Cosine^n Feed Pattern

Figure 11-3



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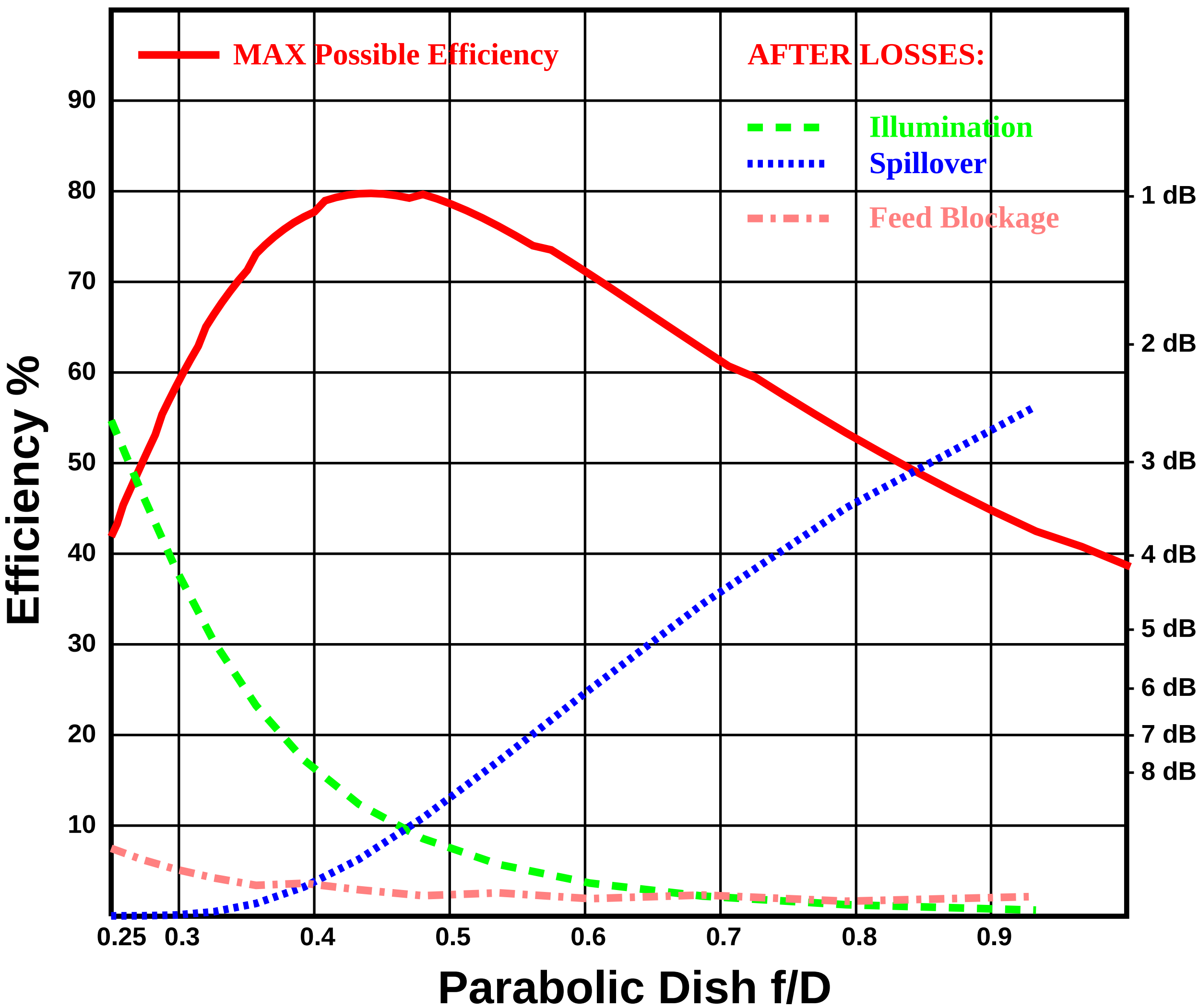
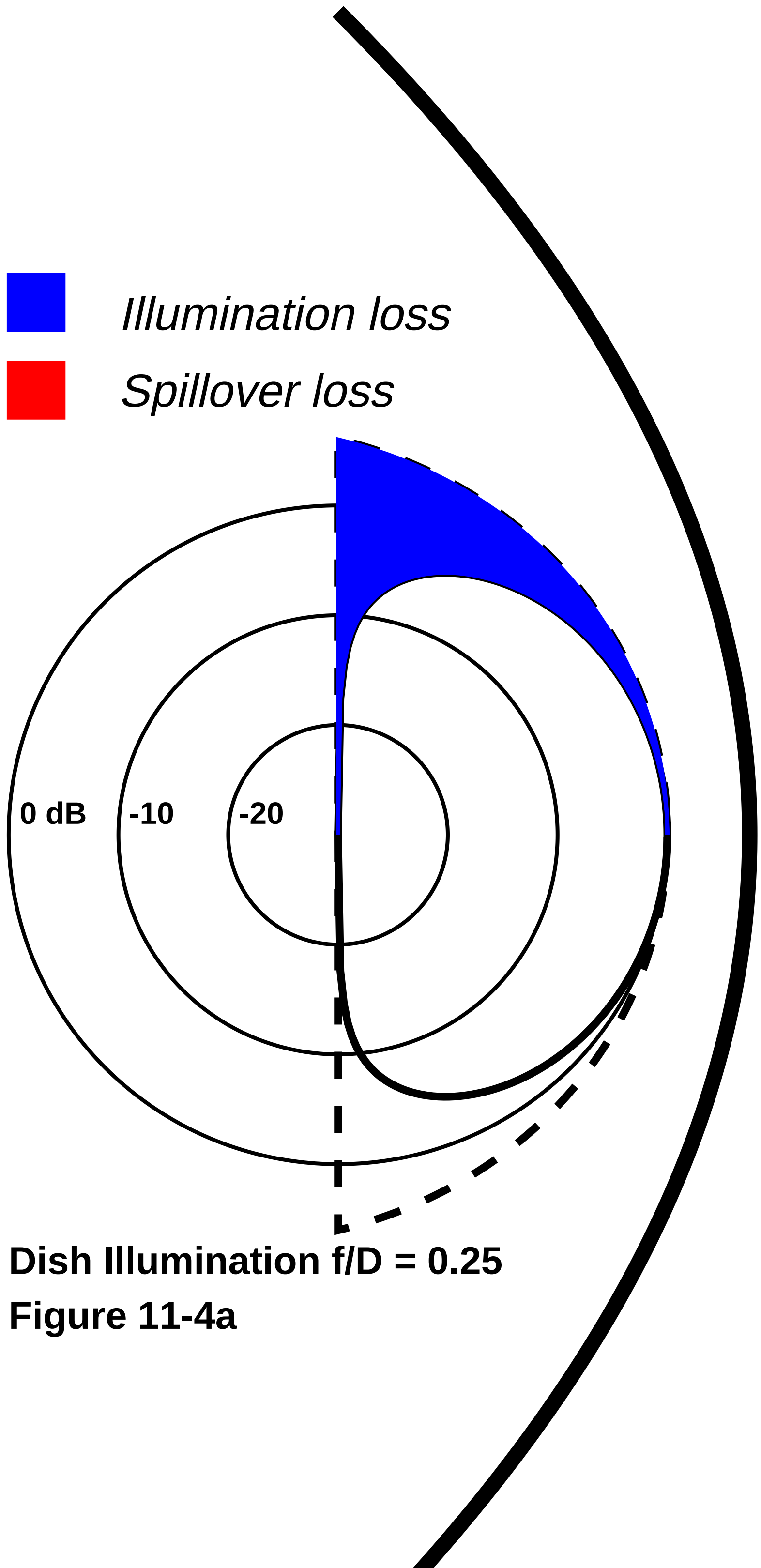
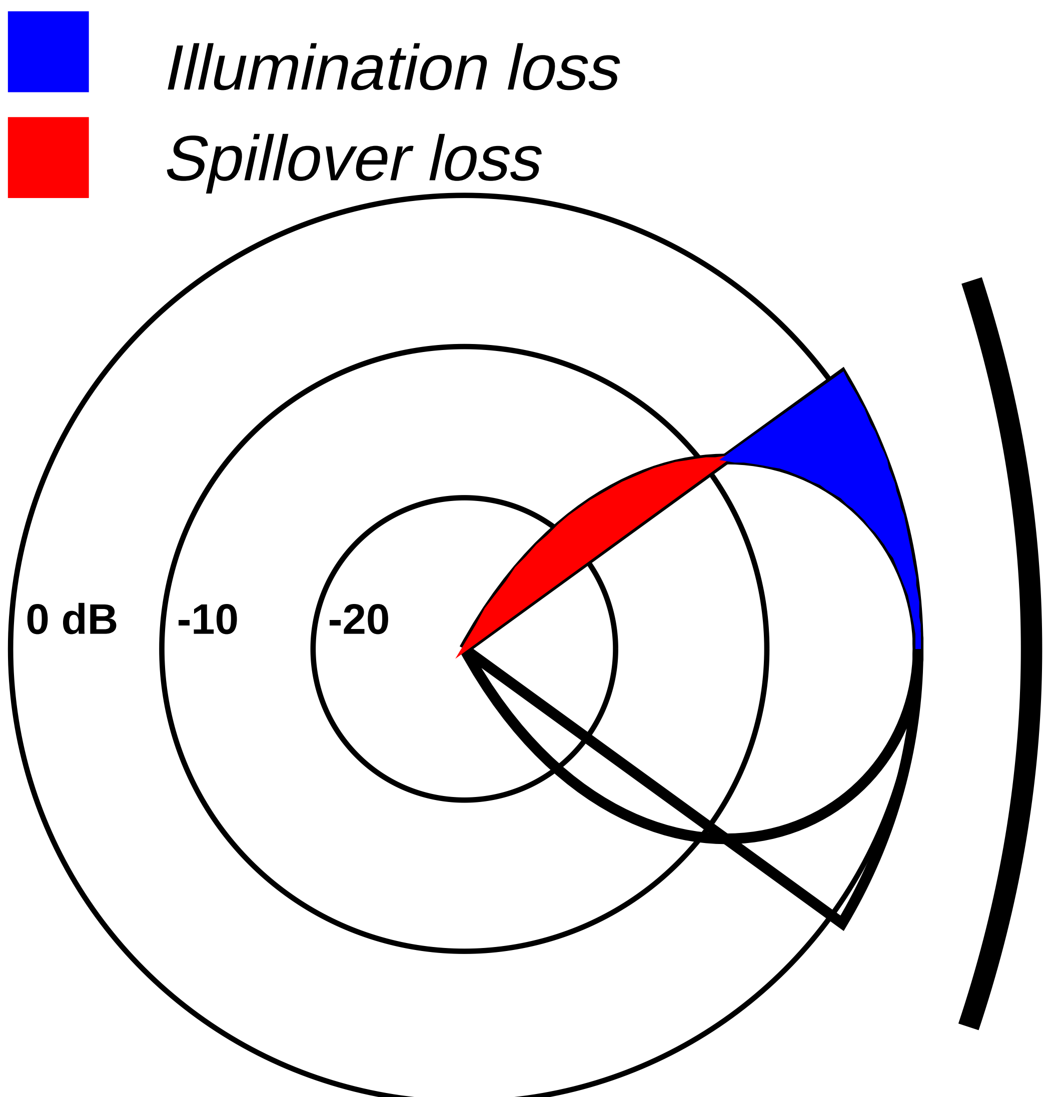
Dish diameter = 10 λ
Feed diameter = 1 λ





Dish Illumination f/D = 0.25
Figure 11-4a



Illumination taper = 10 dB

Figure 11-4b: Dish Illumination f/D = 0.75

Real feed antenna example

Now let's look at an example of a real antenna. There are many big TVRO dishes around which are being replaced by the small DSS systems and becoming available. A 12-foot TVRO dish might be usable for EME operation on 1296 MHz. The dishes typically have an ***f*/D** around 0.35 to 0.45, so we would like to find a suitable feedhorn. Popular feedhorn designs for 1296 MHz have been described by W2IMU [4] and VE4MA[5], so let's look at graphs of the published patterns for these two feeds. The W2IMU dual-mode feedhorn in Figure 11-5 provides good efficiency at an ***f*/D** around 0.6, but is not very good around our target of 0.35 to 0.45. On the other hand, the VE4MA feedhorn in Figure 11-6 provides its best efficiency at an ***f*/D** around 0.4, so it is a much better choice for a TVRO dish. The maximum calculated efficiency is just a bit lower than the 80% for the idealized feed in Figure 11-3. Later we will compare it with other real feeds.

Feed blockage loss

The feed blockage loss shown in Figure 11-6 is under 10% for a twelve foot dish, where the dish diameter is 8.6 times larger than the feedhorn diameter. Since the feed diameter does not change when it is used on larger or smaller dishes, let's look at a few more examples and see what happens. Figure 11-7 shows efficiency curves for the VE4MA feed on a range of dish sizes. At the top is the curve for a 28 foot dish; since the reflector diameter is 20 times as large as the feed diameter, feed blockage is small and efficiency is high. The next curve, for an 8 foot dish, 5.7 times larger than the reflector, shows efficiency a bit lower than the 12 and 28 foot dishes. Going to smaller dishes makes the efficiency much lower: the 4 foot dish, 2.9 times larger than the feed, has significantly reduced efficiency, while the 2 foot dish, only 1.4 times larger than the feed, hardly works at all. Of course, a 2 foot dish at 1296 MHz is a pretty small antenna, but with efficiency this low the gain would be perhaps 11 dB, not much higher than the feedhorn alone. A more important point is that any blockage, whether by the feed or by the structure supporting it, reduces the efficiency of the dish.

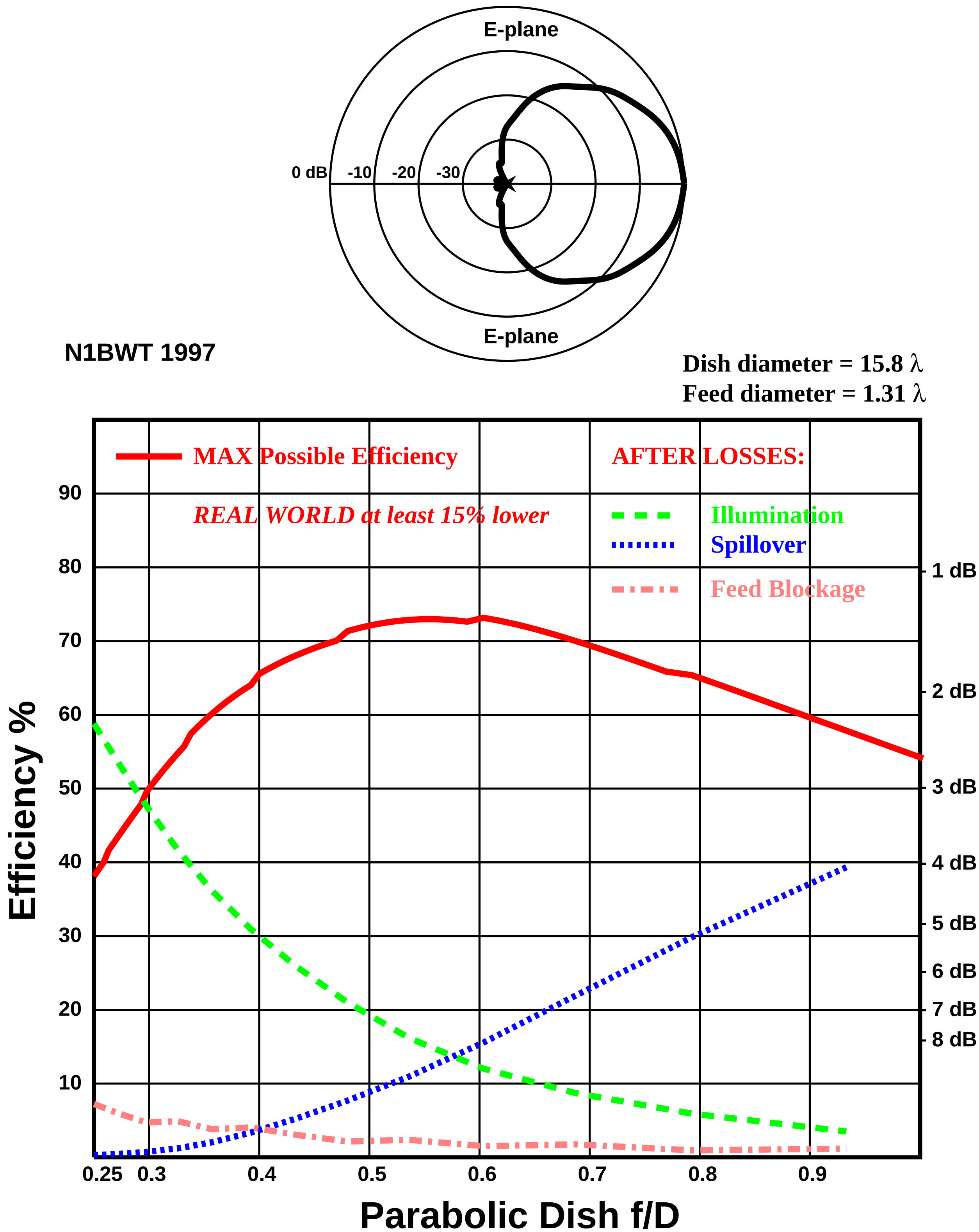
Feed blockage is more significant on small dishes, but small is a relative term; any dish with a diameter less than 10 λ can be considered small. Thus, a 2 foot dish at 10 GHz, about 20 λ in diameter, is a moderately large dish, while a 20 foot dish at 432 MHz, less than 10 λ, is a small dish.

Bad feed example

Occasionally a surplus dish is found with the original feed attached. One example I have seen is a dish fed with WR-90 waveguide, which covers X-band (8-12 GHz). This dish is fed by from the open end of the waveguide pointing at the dish; an open waveguide is known to act as a moderate gain antenna. I located a published radiation pattern for open WR-90 waveguide[6] and graphed it in Figure 11-8. Clearly the efficiency this simple feed provides is far lower than the previous ones. The moral of this story is that just because a

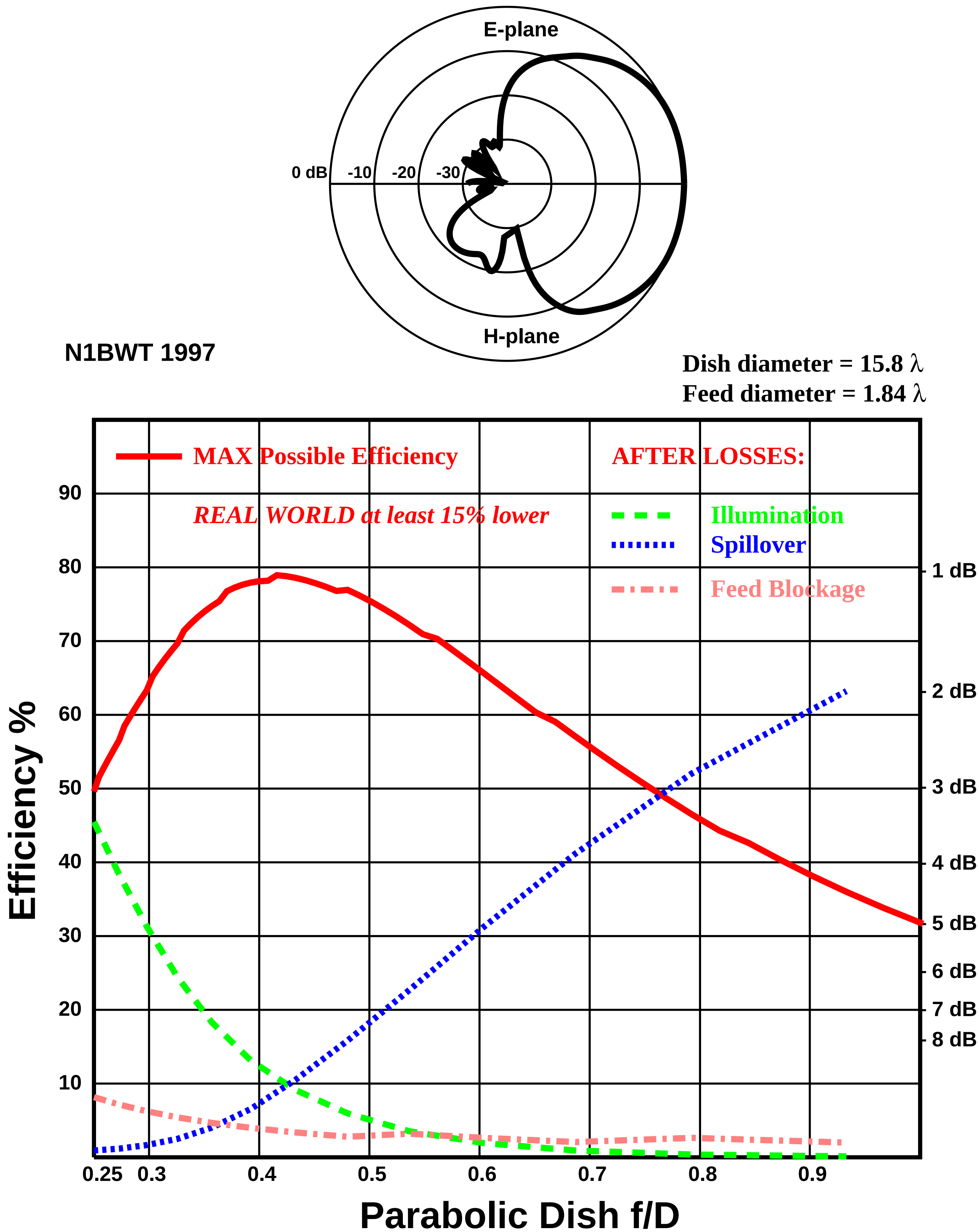
12 foot TVRO dish at 1296 MHz with W2IMU feed

Figure 11-5



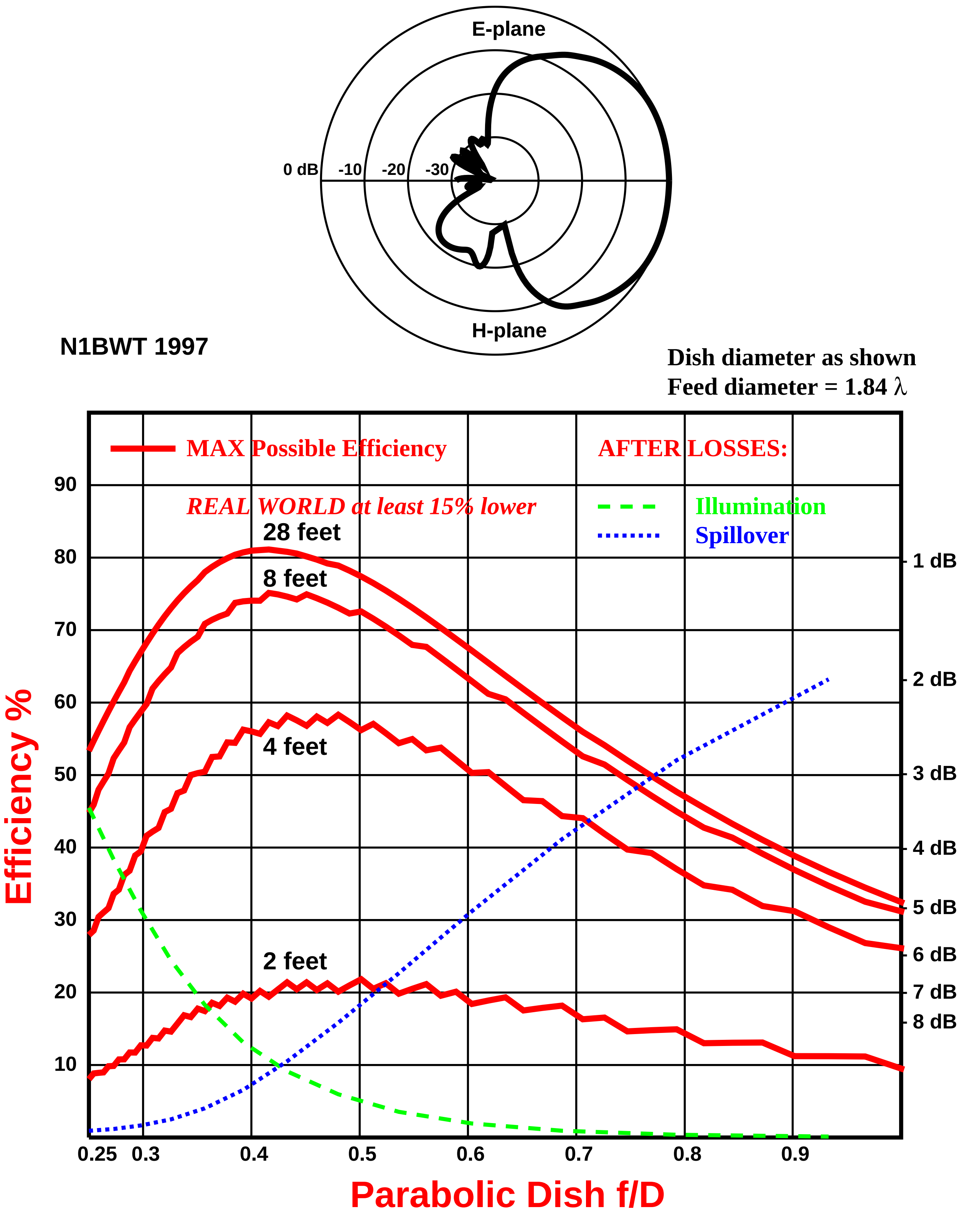
12 foot TVRO dish at 1296 MHz with VE4MA feed

Figure 11-6



VE4MA Feed at 1296 MHz vs. Dish diameter

Figure 11-7



dish already has a feed does not mean it is a good feed — the original design goal may not have been maximum gain.

Understanding the graphs

The purpose of these graphs is to help in visualizing the performance of various dish feeds and comparing them so that the best feed available may be chosen for each application. The underlying assumption is that we wish to obtain the maximum efficiency from a given dish, and thus the maximum gain. After all, a dish doesn't get any lighter or have any less wind resistance if we get less than maximum gain from it. On the right side of each graph is a dB scale, relating the efficiency to a loss in dB from the theoretical gain for that aperture. The ripple in some of the curves is an artifact of the discrete points used in the numerical integration process, and could be removed by integrating at smaller intervals.

The program only accounts for the losses that are unavoidable: illumination loss, spillover loss, and feed blockage loss. There are several other losses found in a real dish:

- phase error
- feed not at focus
- diffraction from the edge of the dish
- polarization shift due to reflector geometry
- blockage by feed supports
- surface error in the parabolic reflector
- feedline loss
- feed VSWR

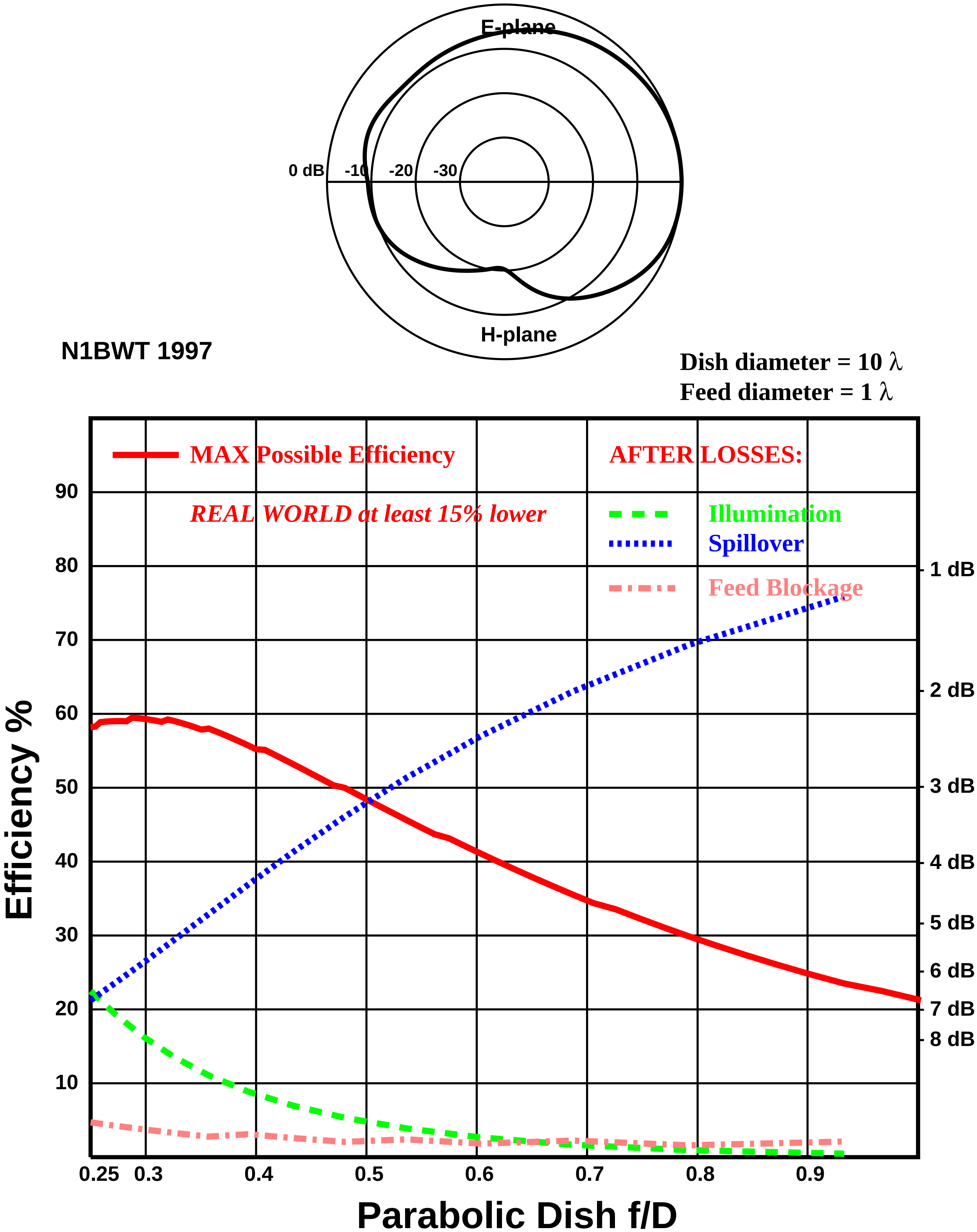
These losses occur in greater or lesser amounts in a given antenna, so that the real efficiency is lower than the maximum possible efficiency shown in the curves. The best antennas I have measured have efficiencies perhaps 15% lower than the curves, while others are significantly worse. A typical efficiency for a moderate-sized dish is about 50%, for a gain 3 dB below the theoretical gain for a given aperture size. A really good dish has an efficiency of 60% or so, about 1 dB better than a typical dish, while a poorly chosen feed or a poor installation can make the gain several dB worse. One dB difference may not seem like much, but it is a huge difference for an EME station that can't squeeze another dB from the preamp or power amplifier.

Another limitation of these curves is the accuracy of the data available for each feed pattern. Many of the published articles only give data for the major part of the pattern, but not the backlobes. This is sufficient to calculate the shape of the efficiency curve, but the whole pattern is required to calculate the maximum efficiency, so I have estimated the rest of the pattern based on similar feeds where data for the whole pattern is available.

Since some of the feeds are physically larger than others and would have more feed blockage loss on a given dish, comparisons on any fixed dish size would make smaller feeds look better. Therefore, most of the graphs for the various feeds described in Chapter 6 use a reflector diameter about ten times larger than the feed diameter. If you

Open WR-90 Waveguide as Dish Feed

Figure 11-8



are comparing these feeds for use on your dish, you can run the program for the actual reflector diameter of your dish.

Phase errors

All of these graphs are based on amplitude patterns only for the feeds, because phase data is *much* more difficult to measure and is rarely available. If the phase of the radiated energy is not uniform over all areas of the reflector, then different parts may reflect energy into the main beam which is not in phase and reduces the total energy in the main beam, lowering the gain. Another common problem is feeds that do not have the same phase center in the E-plane and the H-plane, which has the same effect as not having the phase center at the focal point: reduced gain and pattern distortion.

Phase errors are probably the largest cause for low efficiency, so you should not expect to get efficiencies near the calculated values unless the feed has good phase performance. A feed with small phase error still suffers from all the other losses listed above, so the expected performance of a real dish might be only 15% lower than the calculated efficiency curve.

The only feeds which have published phase data are the Kumar (VE4MA), Chaparral, Chaparral with slots, and the Koch Multi-ring feed discussed, all described in Chapter 6. All of these have excellent phase performance over a wide illumination angle, so the efficiency curves for these feeds are good for any ***f*/D** greater than 0.3. None of these feeds can adequately illuminate an ***f*/D** of 0.25, but the bent-dipole "Handlebar" feeds of W7PUA [1] show promise at the lower frequencies.

Spillover and sidelobes

Perhaps we should take a lesson from the radio astronomers. The radiotelescope feeds described in Chapter 6 all operate at a point on the efficiency curve to the left of the peak, or lower ***f*/D**, for reduced spillover. W7PUA suggests that since spillover increases sidelobes and sidelobes are always bad, we should make any compromise to the left side of the peak.

Computer program

The **FEEDPATT** program does all the calculations and plots graphs like the ones above. For those with access to the Internet, the **FEEDPATT** program and all the data files for feed patterns are available on my 10 GHz Web page:

www.tiac.net/users/wade/feedpatt.zip or ***www.qsl.net/~n1bwt***

See the **README.TXT** file for details of program operation.

The output graphs from the program are files in PostScript™ format, ready for printing on a laser printer or for viewing and printing on a PC using the free Ghostscript [3] software. On my PC running Windows95™ or WindowsNT™, I run the **FEEDPATT** program in one window and Ghostscript **gsview** in another to view the output as I work.

With the data files for the feeds described in Chapter 6, it should be possible to graph the potential performance of any of them on your dish for any frequency of interest. For other feeds, if you can find, calculate, or measure a radiation pattern, you can calculate a graph of estimated efficiency. Please send me a copy of any new feed data.

Summary

Using the **FEEDPATT** computer program, we can accurately analyze the pattern data for various feed antennas. The output is in graphical format for easy visual comparison. We used this tool in Chapter 6 to analyze a wide range of feed designs and followed the evolution from early WWII-vintage designs to modern high-performance feeds. The program and feed pattern data files are available to help further understanding of dish performance.

Notes

1. B. Larkin, W7PUA, "Dipole-Reflector Parabolic Dish Feeds for f/D of 0.2-0.4," ***QEX,*** February 1996, pp. 3-11.

2. C.C. Cutler, "Parabolic-Antenna Design for Microwaves, *Proceedings of the IRE*, Nov. 1947, pp. 1284-1294. (reprinted in A.W. Love, *Reflector Antennas*, IEEE, 1978, pp. 16-26.)

3. Ghostscript by Aladdin is available from *http://www.cs.wisc.edu/~ghost/index.html* hints for using Ghostscript successfully: *http://www.tiac.net/users/wade/gs_hints.htm*

4. D. Turrin, W2IMU, "A Paraboloidal Reflector Antenna for 1296 mc/s," *Crawford Hill Technical Report #5*, 1971.

5. B.W. Malowanchuk, VE4MA, "Selection of an Optimum Dish Feed," *Proceedings of the 23rd Conference of the Central States VHF Society*, ARRL, 1989, pp. 35-43.

6. H. Jasik, *Antenna Engineering Handbook*, First Edition, Mcgraw-Hill, 1961. Fig. 10-14, p. 10-16.