GBT Memo No. 41

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To: GBT Memo Series

From: Roger D. Norrod

Subj: **Spillover Blockage in the GBT Design**

Introduction

This memorandum discusses feed spillover, and its impact, particularly for the GBT subreflector feeds. A brief review of spillover efficiency with numerical examples is first. Then the fact that the GBT feed support arm constitutes blockage of the secondary feed spillover is discussed and the impact estimated. Finally, shields that can be employed to reduce the blockage scattering are described and a couple of possible designs sketched.

Spillover Efficiency

Microwave feed horns, even high quality corrugated horns, have finite slope on the skirts of their power patterns. Figure 1 shows a typical feed pattern cut, out to the -30 dB point. The pattern angular width can be scaled by the feed designer to achieve a particular taper at the edge of the reflector being illuminated. If, for instance, the feed of Figure 1 was illuminating a reflector with subtended half-angle (θ_H) of 15 degrees, the edge taper would be about -12 dB. The feed design could be changed to vary the pattern width to increase or decrease the taper.

Spillover efficiency is the fraction of the total power received that comes from within the reflector subtended angle, and is given by:

$$\eta_S = \frac{\int_0^{2\pi} \int_0^{\theta_H} F_p\ (\theta,\phi)\ \sin\theta\ d\theta\ d\phi}{\int_0^{2\pi} \int_0^{\pi}\ F_p\ (\theta,\phi)\ \sin\theta\ d\theta\ d\phi}$$

where $F_p(\theta,\phi)$ is the feed power pattern. Under the assumption that the feed pattern of Figure 1 is circularly symmetric, and that it tapers from the -30 dB point to -60 dB at 90 degrees, and stays at that level to 180 degrees, the spillover efficiency is plotted as a function of edge taper in Figure 2a. A few representative values are tabulated below.

Taper	Spillover Efficiency
-10	84%
-12	89%
-15	94%
-18	96%
-20	97%
-30	99.3%

At a -12 dB taper, 11% of the power received comes not from the reflector being illuminated, but from sources outside the reflector subtended angle. Suppose for example that this feed is at the prime focus of an antenna, and -12 dB edge taper has been selected. Then the spillover noise would be:

$$T_{SP} = (1-E_{SP})\, T_{GROUND} = 0.11 * 280 = 31 \text{ Kelvin}$$

assuming all the spillover hits the ground, at an equivalent temperature of 280 Kelvin. If the edge taper is increased to -18 dB, the spillover noise is reduced to 11.2 Kelvin. Unfortunately, the edge taper cannot be increased without penalty. Figure 2b shows how the taper efficiency decreases as the edge taper increases. The product of taper and spillover efficiency has a broad peak between edge tapers of -8 and -15 dB. For prime focus use in low noise systems, the optimum edge taper is usually between -15 and -20 dB, and often feeds with steeper pattern slopes are used, such as dual hybrid-mode horns, allowing acceptable noise and reasonable efficiencies.

When the feed is illuminating a subreflector, the feed (or forward) spillover usually falls mostly in the sky, and not the ground. Since most of the forward spillover falls near the main beam, it is often not considered particularly worrisome, and the taper (for unshaped systems) is kept at about -12 dB. (As we have recently been reminded, when the subreflector is relatively small in wavelengths, the subreflector edge taper indirectly affects the rear spillover noise, because of diffraction. Diffraction causes the pattern reflected from the subreflector toward the main reflector to spread, and some of the energy spills over the main reflector edge onto the ground. As the subreflector edge taper is increased, the magnitude of this effect is reduced.) Shaped reflectors, because the taper efficiency loss can be regained in the shaping process, typically use subreflector edge tapers of -15 to -18 dB. This reduces the power in the forward spillover region, and for subreflectors small in wavelengths, the diffraction induced rear spillover.

GBT Feed Arm Blockage

Consider the GBT, with a feed similar to that shown in Figure 1, illuminating the M1 subreflector, and with -12 dB feed taper at the 15 degree subtended half-angle of the subreflector. Figure 3 is a view from the feed toward the subreflector and shows the support structure that extends behind the subreflector. The dashed circles show the extent of θ_H plus 5, 10, and 15 degrees, approximately at the plane of the subreflector. With a -12 dB taper, the +15 degree circle is at about the -30 dB point on the feed pattern, and hence contains all but about 0.7% of the feed power. The feed arm structure within these circles constitute blockage of the forward spillover. Consider the effect of this blockage. The problem can be estimated by assuming that energy striking complicated truss structures will be scattered isotropically. If the support arm intercepts, say, 15% of the spillover energy, then the resulting scattered sidelobe level is:

$$SL = (1 - E_{SP}) * 0.15 = -18 \text{ dBi}$$

If half of this strikes the ground, the resulting noise temperature will be:

$$NT = 0.5 * (1 - 0.89) * 0.15 * 280 = 2.3 \text{ Kelvin}$$

As is discussed in [1] and [2], the best symmetrical antennas exhibit average far sidelobe levels of -10 to -15 dBi. The causes are dominated by scattering by blockage, panel gaps, etc. A somewhat arbitrary, but not unreasonable goal for the GBT is to try to achieve -30 dBi for all the contributing causes so that the net level achieved will be less than about -25 dBi. The spillover efficiencies calculated above show that, if we can control the spillover that would hit the support structure to the -30 dB level on the feed pattern, and the feed arm blocks 15% of spillover, the scattered sidelobe level will be -30 dBi.

M1 and Spillover Shields

Figure 4 shows one scheme for controlling the M1 feed spillover. A shield is shown that intercepts the spillover before it strikes the support arm, directs it to the main reflector, and then to within about 3 degrees of the main beam. The shield need not be attached to the subreflector, and need not move if the subreflector tilts or translates. It could be located behind the subreflector rim as long as it is only a few inches away. The S1, S2, and S3 segments intercept the θ_H +5, +10, and +15 degree portions of the spillover. Each segment can be flat in the cut shown in Figure 4, but should be curved slightly across the width of the arm. It would be possible to omit the S3 segment if the subreflector edge taper was increased to -15 dB or more (e.g. if shaping is used). It may be possible to omit S3 even with the -12 dB taper. The preliminary support arm drawing used for these calculations indicates that the arm covers only about 3% of the area between the θ_H +10 and +15 circles. The spillover efficiency at the +10 circle is about 98%, meaning the resulting sidelobe level with 3% blockage is about -32 dBi. However, if the arm were brought closer to the subreflector than shown in Figure 4, this 3% blockage might increase. We can quickly check a particular structural design using the techniques used above to see if the -30 dBi goal is met.

It is inconvenient to maintain the distance between the edge of the subreflector and the arm required to allow room for the shields shown in Figure 4. Figure 5 shows an alternate design that may be worth exploring. Here part of the intercepted spillover is directed to the subreflector and then to the primary. This double bounce would allow part of the shield to be laid nearly parallel to the arm axis, and the arm could be about where the dashed lines indicate. The two segments shown, S1′ and S2′ could probably be united (this would be desirable to reduce diffraction effects), but the ray-tracing required to work out the details is tedious and time-consuming. However, if the kind of arm change indicated is significant and desired, this possible design should be pursued.

M2 and Spillover Shields

The small M2 subreflector will likely be operated with the M1 subreflector behind. M1 will intercept almost all of the M2 feed spillover, as shown in Figure 6. This energy will be focused (roughly) back toward the primary, but most of it will strike the back of M2 and then will be scattered. It appears that a shield will be required all around the rim of M2 to control the disposition of the feed spillover, out to the -30 dB level on the feed pattern. The shield width again will be roughly equal to the radius of the subreflector, somewhat less if shaping is employed. It can be fabricated with flat or simple curved segments, need not move if the subreflector is tilted or translated, and need not have an accurate surface.

Acknowledgements

Rick Fisher emphasized the importance of the spillover blockage and showed me how to analyze the impact. The memo [1] by James Lamb was very useful and is recommended reading.

References

[1] "Far-Out Sidelobes in Large Reflector Antennas", James Lamb. GBT Memo No. 13.

[2] "Low Sidelobe Antenna Study, Literature Survey and Review to 1977", P. R. Foster and A. W. Rudge. ERA Technology Report No. 81-106.

[3] Antenna Handbook, Y. T. Lo and S. W. Lee, editors. VanNostrad Reinhold Company, 1988.

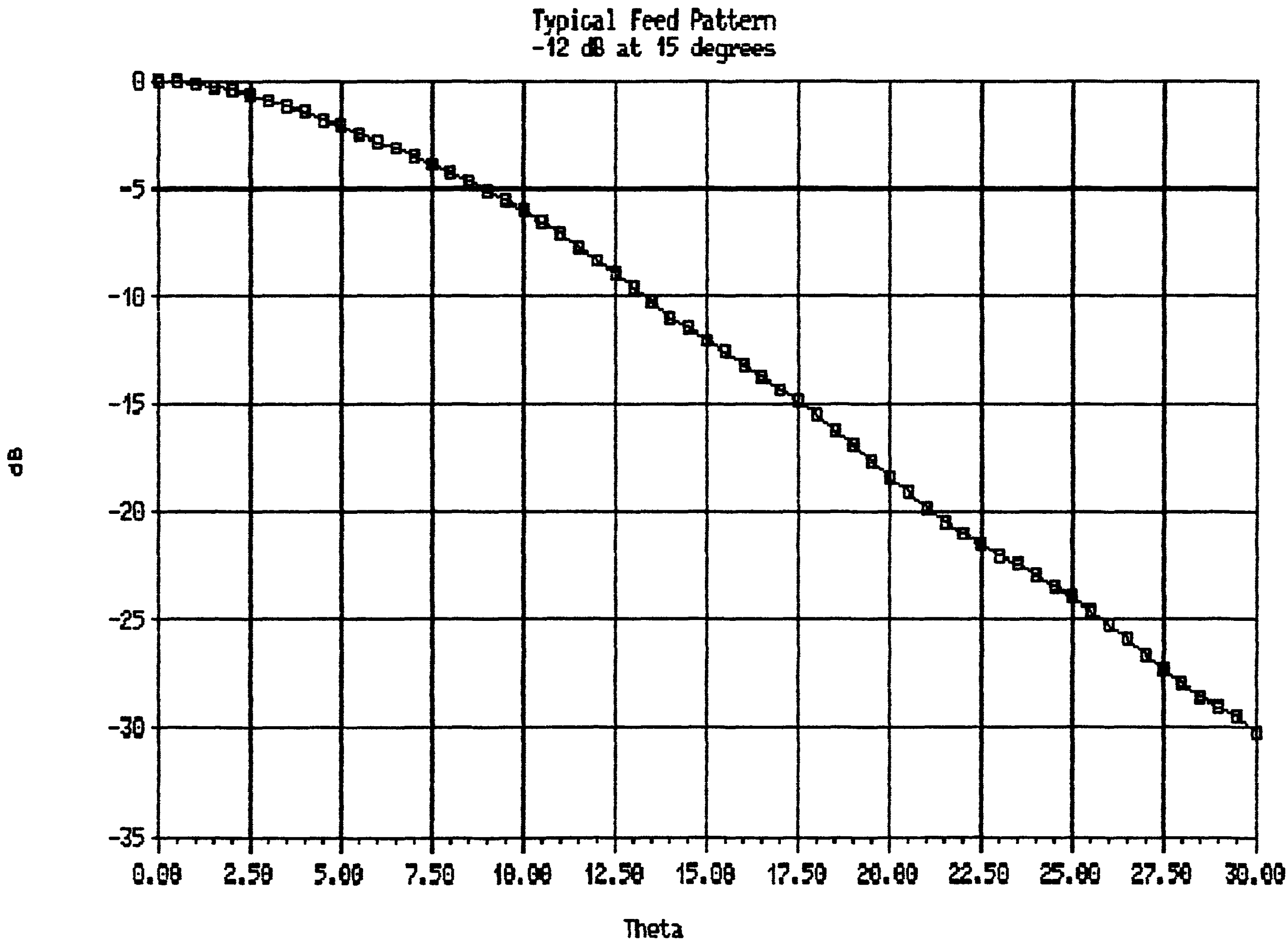

FIGURE 1. Typical Corrugated Horn Power Pattern.

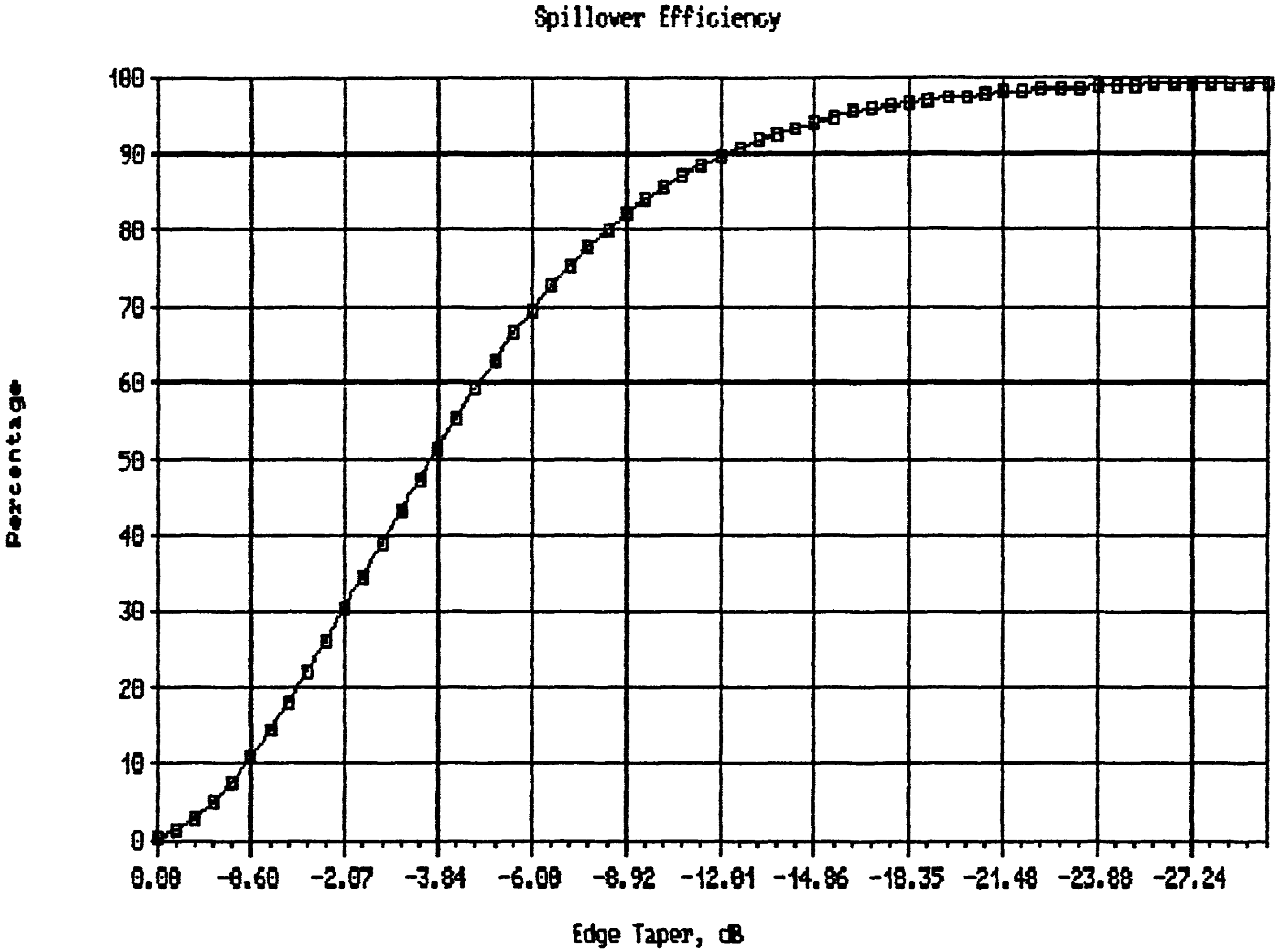

FIGURE 2a. Spillover Efficiency from Pattern of Figure 1.

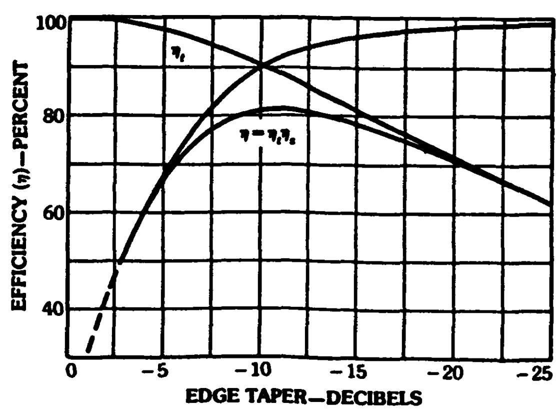

FIGURE 2b. Spillover and Taper Efficiency from [3].

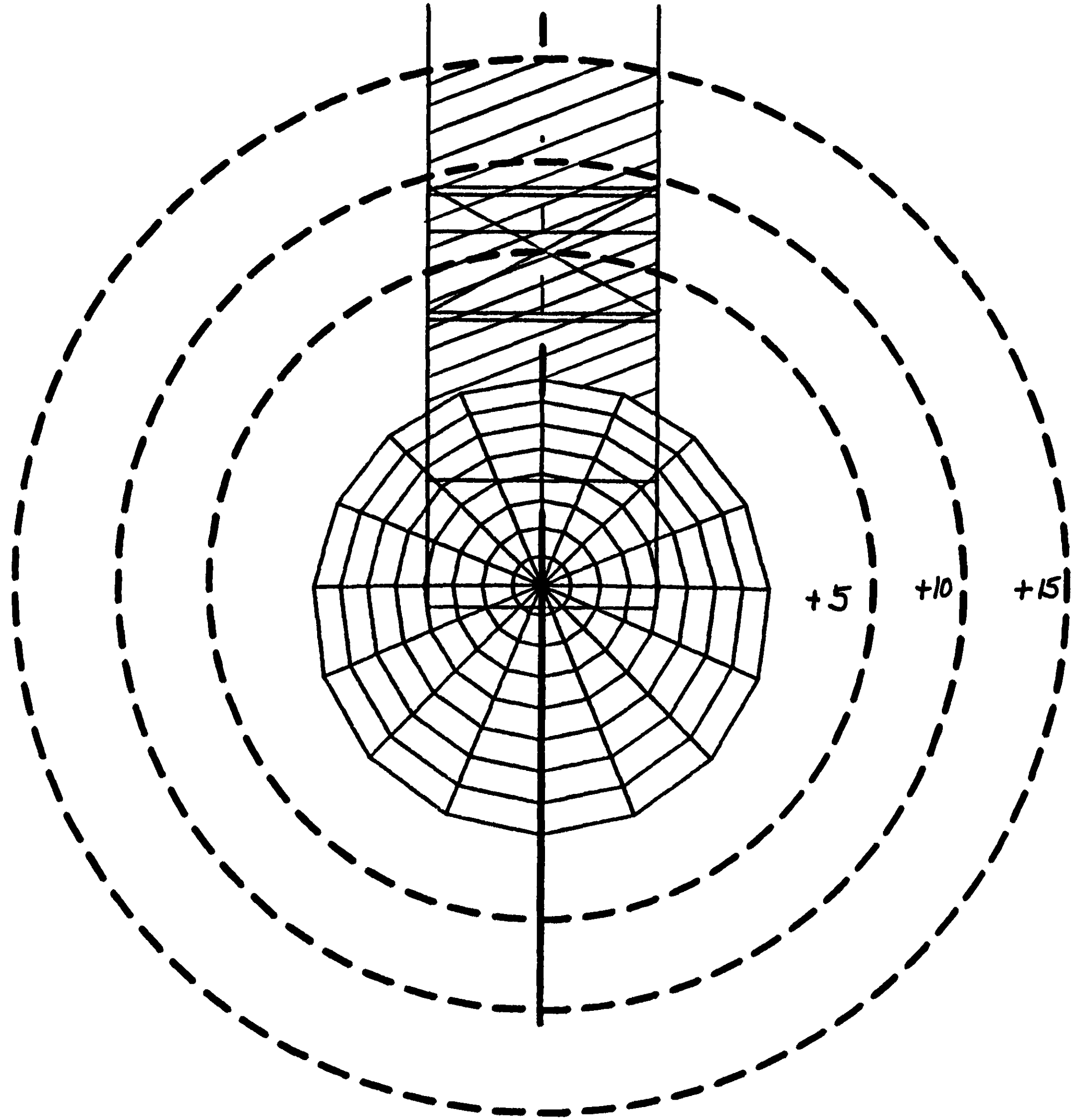

FIGURE 3. View from Feed showing M1 and Support.

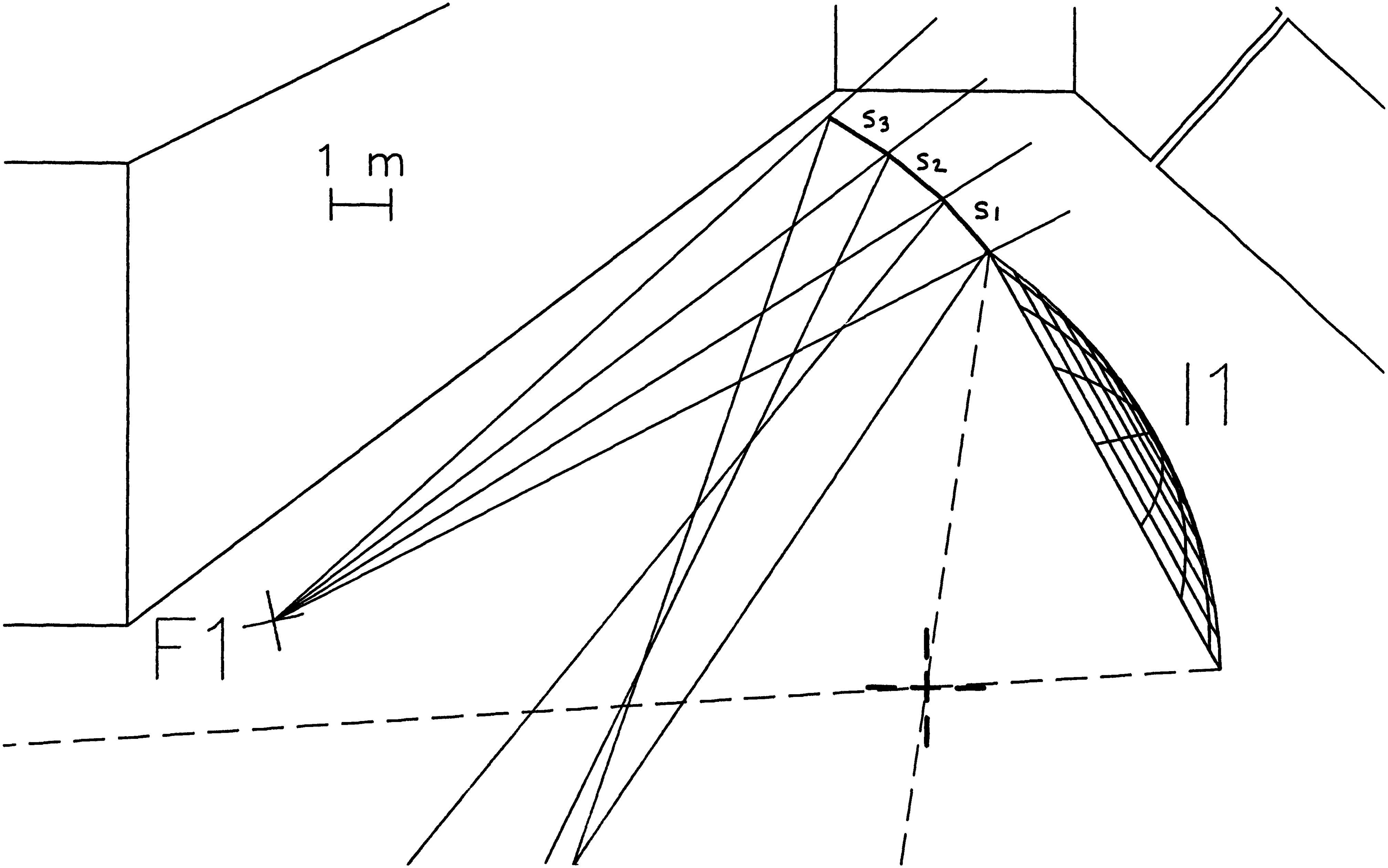

FIGURE 4a. Scheme to Intercept the Feed Spillover out to the -30 dB Level, for a 12 dB Taper.

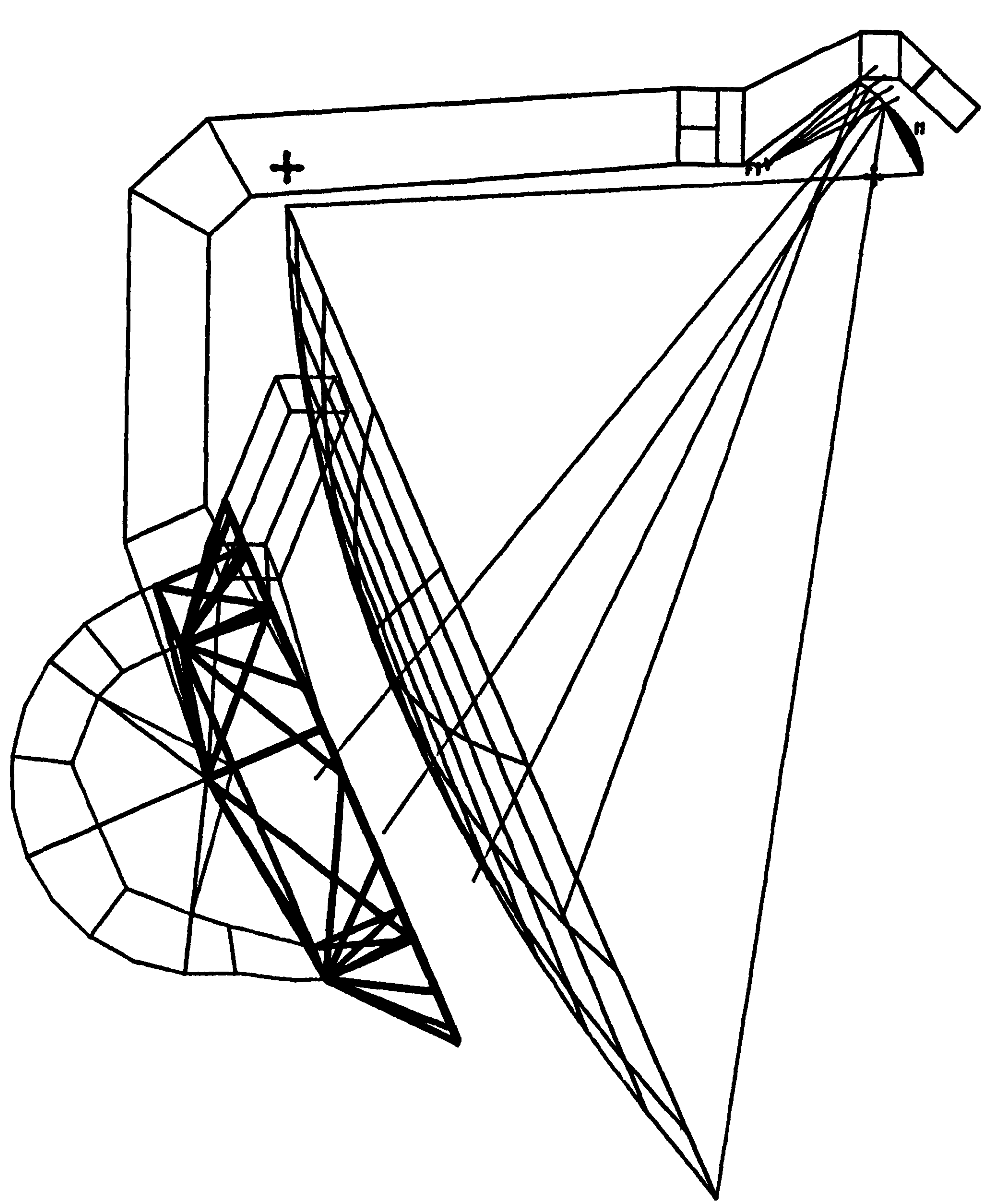

FIGURE 4b. All the Rays Hitting the Shields Reflect to the Main Reflector and Then to Within a Few Degrees of the Main Beam.

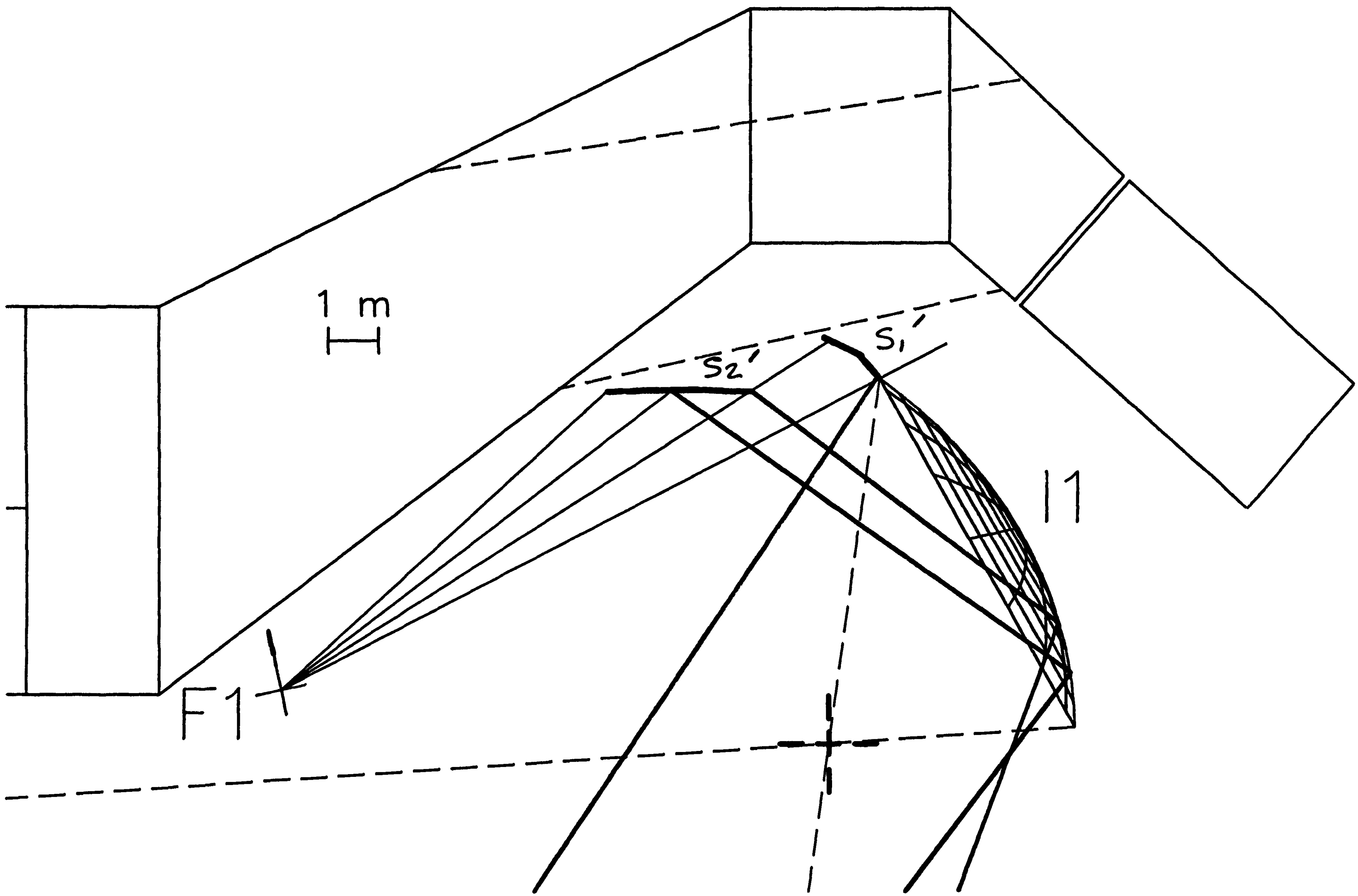

FIGURE 5. An Altern[illegible] Shielding Scheme.

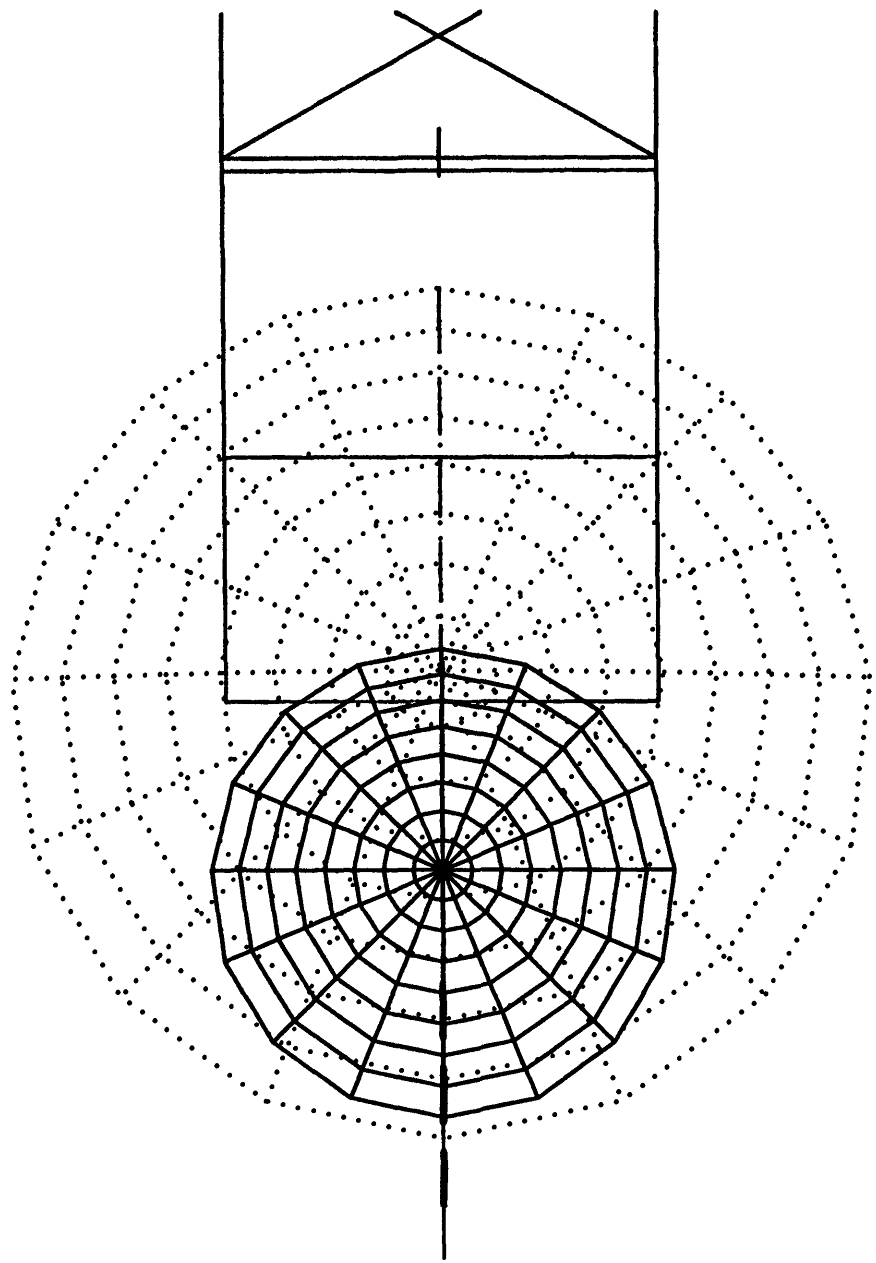

FIGURE 6. M2 Subreflector with M1 (dotted) and Arm Behind.
View from the feed.