# PRIME FOCUS FEEDS FOR THE COMPACT RANGE

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Prime focus fed paraboloidal reflector compact ranges are used to provide plane wave illumination indoors at small range lengths for antenna and radar cross-section measurements. The “quiet zone”, which is the region of space within which a uniform plane wave is created, has previously been limited to a small fraction of the reflector size. A typical quiet zone might be six feet by four feet for a ten foot radius reflector.

Two new feed antennas have been designed which can provide an increase in quiet zone size as defined by the amplitude taper in the quiet zone field. Design details for the feeds are presented and the performance of the feeds in a compact range is discussed.

## INTRODUCTION

Offset paraboloidal reflector-based compact ranges offer many advantages in terms of performance over other, more complicated compact range designs. The single reflector of this design can often be manufactured to a more precise surface tolerance than either reflector of a dual-reflector design. In addition, the extremely flexible optics of the paraboloidal reflector compact range allow the range designer wide latitude in the choice of feed configurations. These designs exhibit an inherent amplitude taper in the quiet zone field. This amplitude taper arises from differential space loss from the feed to different points on the reflector and from the amplitude rolloff of the feed pattern. Although this taper is an inherent feature of this type of range, optimized feed designs can minimize it. In order to understand the basis for the choice of a feed and the design procedure, it is important to understand the sources of the amplitude taper, the effects of the feed design on the quiet zone field, and the tradeoffs involved in the design of the feed.

## SOURCES OF AMPLITUDE TAPER IN THE COMPACT RANGE

Figure 1 illustrates a compact range. The dimensions shown on the figure are the dimensions of the Model 5753 compact range reflector. This reflector consists of a 15' radius semicircular paraboloidal section with a 5' blended rolled edge treatment. The focal length for the Model 5753 is 24 feet. The reflector is shown in a cross-section cut by a vertical plane containing the range axis.

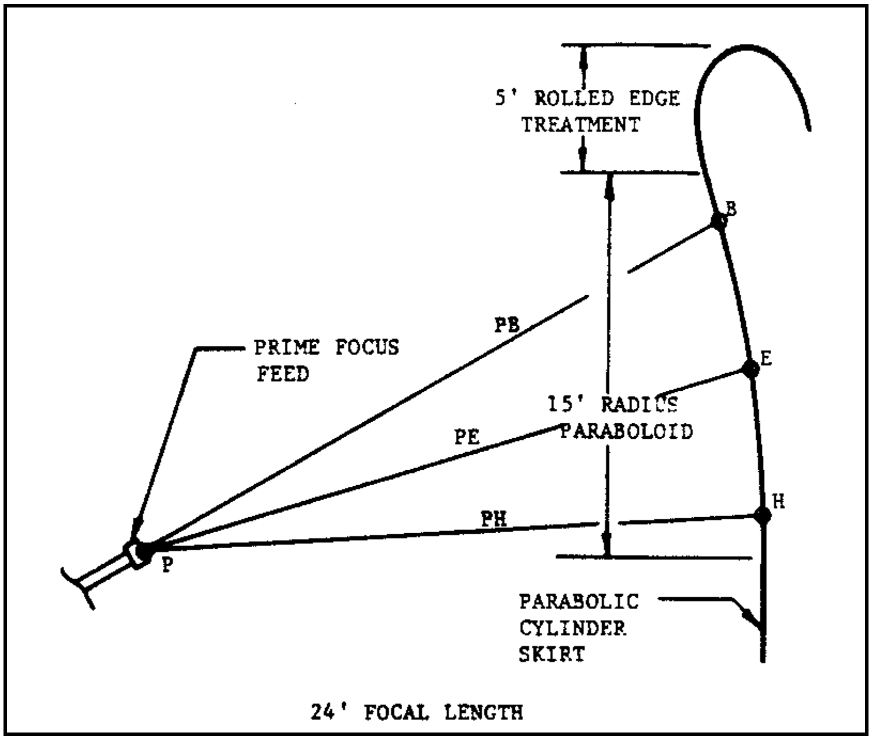


Figure 1. Prime focus-fed paraboloidal reflector compact range. The amplitude taper in the vertical plane is related to the difference in length of the line segments PH and PB.

As the figure indicates, the distance from the feed to the point labeled B, from which the geometrical optics ray from the feed to the top of the quiet zone is reflected, is greater that the distance from the feed to the point labeled E, from which the geometrical optics ray from the feed to the center of the quiet zone is reflected. Also, the distance from the feed to the point labeled H corresponding to the geometrical optics ray to the bottom of the quiet zone is less than the distance from the feed to point E.

The differences in distance from the feed to different points on the reflector give rise to different values of the space loss, or spreading loss, from the feed to different points in the quiet zone. The amplitude (not power) space loss from the feed to a point on the reflector is proportional to 1/R where R is the distance from the feed to the point on the reflector. Thus a greater distance from the feed to a point on the reflector corresponds to a greater space loss from the feed to that point on the reflector. Once the feed energy is reflected from the reflector it is collimated and no further space loss occurs.

The total length of each geometrical optics ray drawn from the feed to the quiet zone via the reflector is the same. This is necessary in order to generate a plane wave in the quiet zone. Space loss only occurs for that part of the path from the feed to the reflector, however, and this part of the length of each geometrical optics ray from the feed to the quiet zone is not the same. It is this aspect of the geometry of the paraboloidal reflector that gives rise to the differential space loss.

Figure 2 shows a cross-section of the reflector cut by a horizontal plane containing the range axis. Again, the distance from the feed to the point labeled D (which is the same as the distance from the feed to point F) which maps onto an edge of the quiet zone, is greater than the distance from the feed to the point labeled E which maps onto the center of the quiet zone. This point (E) is the same in Figures 1 and 2. The differential space loss between points B and E in Figure 1 is greater than the differential space loss between points D and E in Figure 2 because, from the geometry of the reflector, the difference in the distance from the feed to points B and E is greater than the difference in the distance from the feed to points D and E. This means that the amplitude taper caused by differential space loss is greater in the vertical plane than in the horizontal plane.

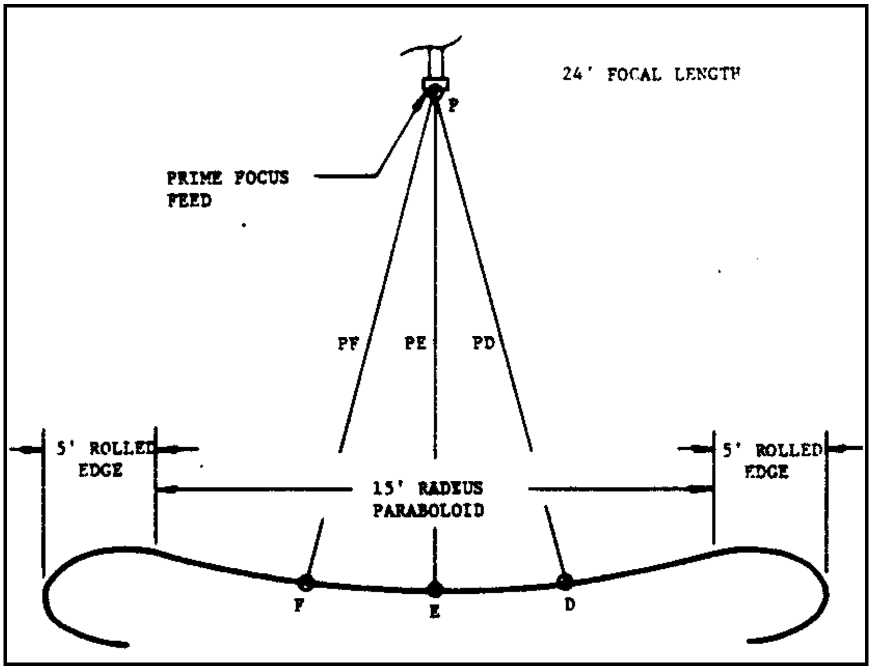


Figure 2. Prime focus-fed paraboloidal reflector compact range. The amplitude taper in the horizontal plane is related to the difference in length of the line segments labeled PF and PE.

Fortunately, the space loss between the top and bottom of the quiet zone can be at least partially compensated by designing a feed with an amplitude pattern which is in some sense the inverse of the differential space loss and tilting it to illuminate the reflector with the peak of the main beam of the feed at the appropriate angle to compensate for the differential space loss. For Series 5750 compact range reflectors, the feed pattern required to optimally illuminate the reflector exhibits a broad main beam and low backlobes. A feed with such a pattern, tilted to the proper angle, will partially compensate the amplitude taper in the vertical quiet zone dimension caused by the differential space loss while introducing minimal additional amplitude taper in the horizontal quiet zone dimension from feed pattern amplitude rolloff.

## DESIGN CONSIDERATIONS FOR COMPACT RANGE FEEDS

A typical pattern for a Scientific-Atlanta standard compact range feed appears in Figure 3. This pattern was taken at the center frequency of the half-octave band of operation of the standard compact range feed. The main beam is azimuthally symmetric to a good approximation, so only the H-plane pattern is shown. The feed, shown in Figure 4, consists of an open-ended round waveguide aperture with a corrugated choke flange. The choke flange improves the pattern stability with frequency and the pattern symmetry. A symmetrical pattern is important if dual-polarized operation is to be obtained by rotating the feed.

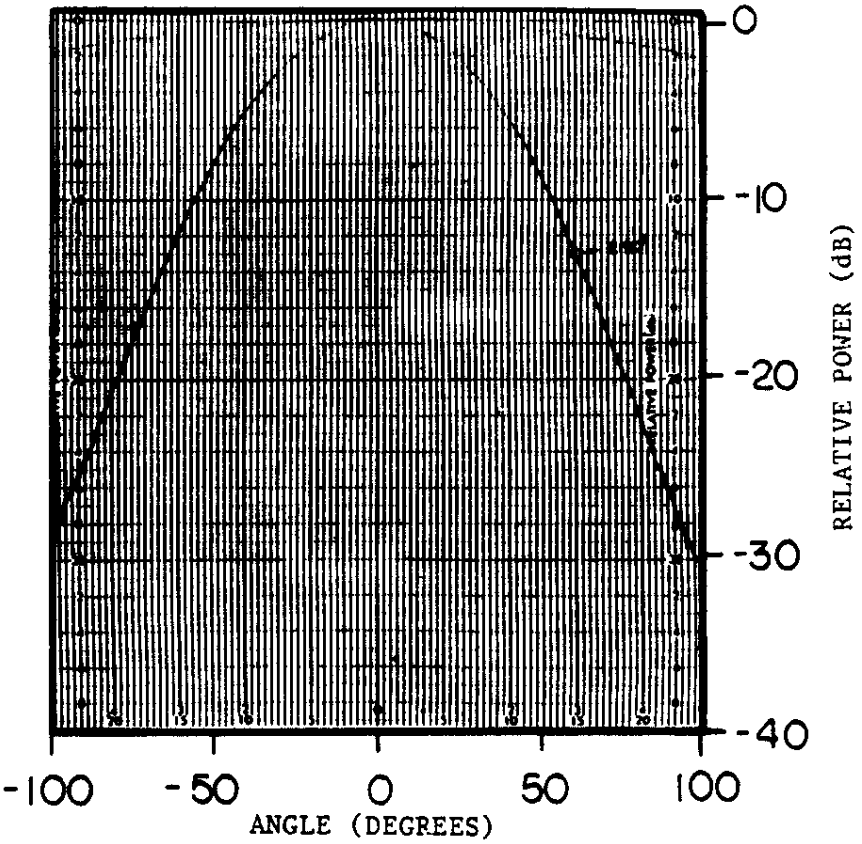


Figure 3. Typical feed pattern for standard compact range feeds.

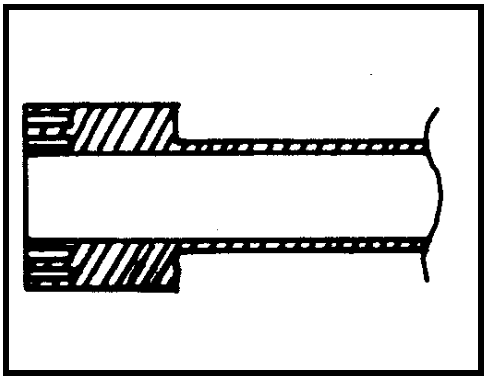


Figure 4. Standard compact range feed. The feed consists of an open-ended empty round waveguide aperture with a corrugated choke flange.

The pattern of the standard feed partially compensates the differential space loss of the Series 5750 compact range reflectors. The standard feeds used with a Model 5753 reflector produce a quiet zone 8 feet high by 12 feet wide with a 1-dB amplitude taper. At all but the lowest frequencies of operation the blended rolled edge treatment limits edge diffraction to a very low value (a few tenths of a dB) over a much larger area than the 8' X 12' quiet zone. In other words, the quiet zone size for the Model 5753 reflector is not limited by edge diffraction. If the amplitude taper could be reduced, the usable quiet zone produced by the Model 5753 compact range reflector could be expanded with no further effort.

Unfortunately, increasing the beamwidth of the compact range feed also necessarily increases the level of direct feed radiation into the quiet zone. This is referred to as backlobe radiation, but the angle from the feed to the quiet zone is such that it is really the far-out skirts of the feed’s main beam which radiate into the quiet zone. For the Model 5753 reflector, the front of the quiet zone (nearest the reflector) is 8 feet behind the feed. Depending on the angle from the horizontal to which the feed is tilted (which is approximately 25°), the angle from the feed to the front top center point of the quiet zone is approximately 100°. At the high end of the band of operation of the standard feed, the feed pattern level at this angle is well below -40 dB referred to the peak of the feed’s main beam. At the low end of the band where the main beam of the feed pattern is broader, the pattern level at this angle is approximately -30 dB. An increase in the feed beamwidth is always accompanied by an increase in the level of direct feed radiation into the quiet zone. This is a fundamental tradeoff associated with the design of compact range feeds.

The design of a compact range feed is essentially an attempt to find an optimum operating point on the amplitude taper vs. direct feed radiation characteristic subject to some other constraints on the design. A much more ideal feed pattern can be synthesized , for example, if the feed is allowed to be electrically large and/or narrowband. This is not usually acceptable since a large feed causes unacceptably large mutual coupling (multiple reflections between the feed and the test antenna or target in the quiet zone) and diffraction off the feed structure and feed support into the quiet zone. Also, narrowband feeds are unacceptable for testing broadband antennas and for high resolution (which implies broad bandwidth) RCS measurements. Small, broadband, broad-beam antennas do exist. Examples are the planar spiral and the planar log-periodic antenna. These antennas are currently being evaluated. This paper reports only the results of investigations performed on compact range feed designs based on round open-ended waveguide.

## REDUCED-APERTURE FEED COMPACT RANGE FEED

The two feed designs reported in this paper are illustrated in Figure 5. They are the reduced-aperture empty round waveguide feed operated near its cutoff frequency (abbreviated RAF) and the ridged round waveguide feed operated below the cutoff frequency for the $TE_{11}$ mode in empty round waveguide (abbreviated RWGF).

The RAF operates in the $TE_{11}$ mode of the empty round waveguide just as the standard feed does. The difference is that the lowest design frequency of operation for the standard feed is 1.35 times the cutoff frequency for the $TE_{11}$ mode, whereas the lowest design frequency of operation for the RAF is only 1.01 times the cutoff frequency for this mode. The RAF thus exhibits high dispersion and a poor match at the aperture. In addition, the frequency coverage over which a broader illumination can be achieved is limited to approximately a 1.25:1 band. None of these limitations are important in testing antennas of moderate bandwidth and the RAF is a promising feed design for these applications.

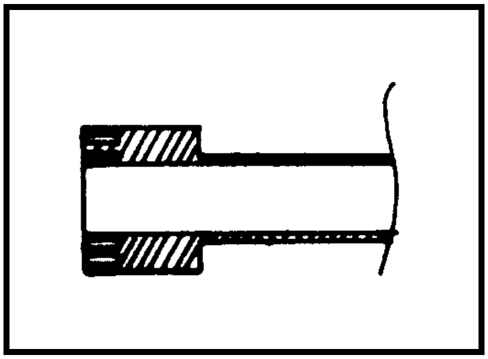


Figure 5(a). Reduced aperture compact range feed. The aperture size for this feed is approximately 25% smaller than the standard compact range feeds.

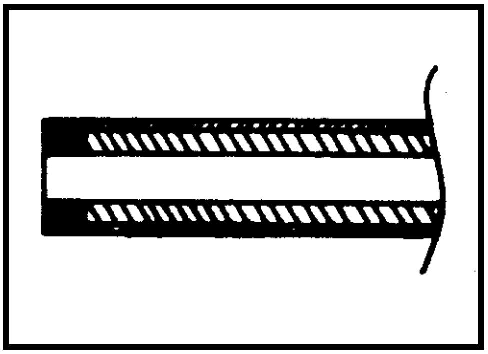


Figure 5(b). Ridged waveguide compact range feed. The aperture size for this feed is approximately 33% smaller than the standard compact range feed.

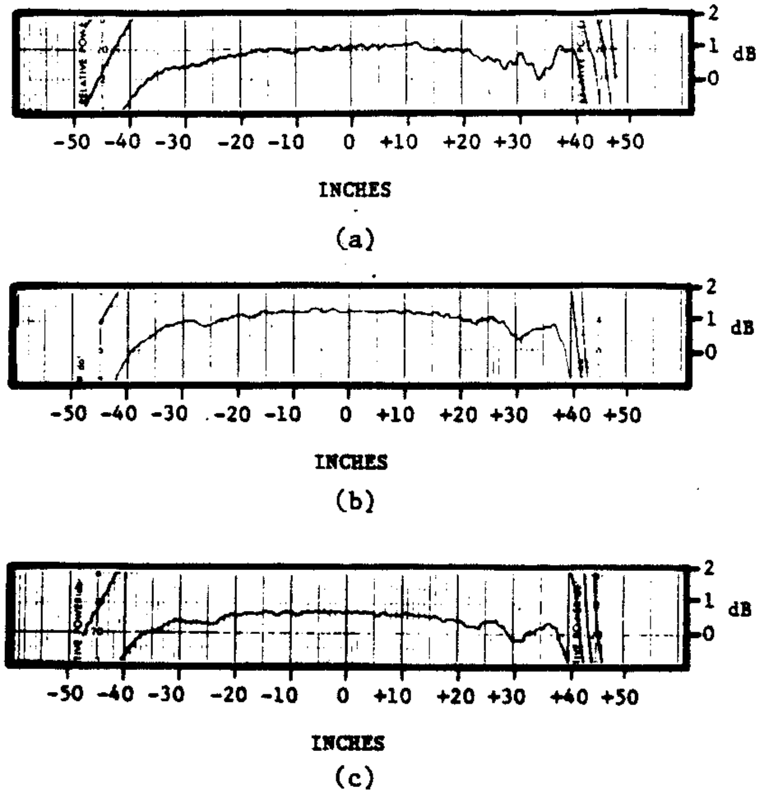


Figure 6. Vertical field probe amplitude cuts on a Model 5754 compact range reflector fed with (a) the standard compact range feed, (b) the RAF with chokes, and (c) the RAF without chokes.

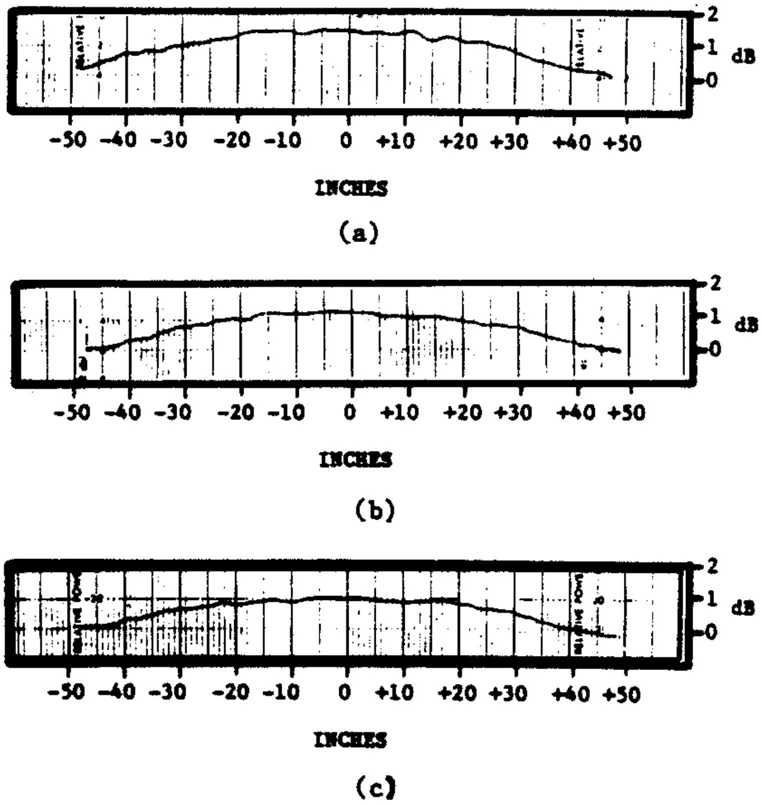


Figure 7. Horizontal field probe amplitude cuts on a Model 5754 compact range reflector fed with (a) the standard compact range feed, (b) the RAF with chokes, and (c) the RAF without chokes.

Figure 6 illustrates the comparison of the RAF with the corrugated choke flange and without the corrugated choke flange to the standard compact range feed for vertical field probe cuts with vertical polarization. Figure 7 illustrates the same comparison for horizontal field probe cuts. All data is taken at the mid-band frequency of operation of the standard feed.

All the field probe data shown in this paper was obtained using a Model 5754 compact range reflector. This reflector is an exact half-scale model of the Model 5753 reflector, so the eight-foot field probe data shown in this paper is equivalent to sixteen-foot field probe data for the Model 5753. Data for the different feeds evaluated are shown side-by-side for a single frequency to facilitate comparisons between the performance of the feeds. The criterion used for comparison is the performance of the feed in illuminating the reflector to produce a six-foot diameter quiet zone which corresponds to a twelve-foot diameter quiet zone for the Model 5753.

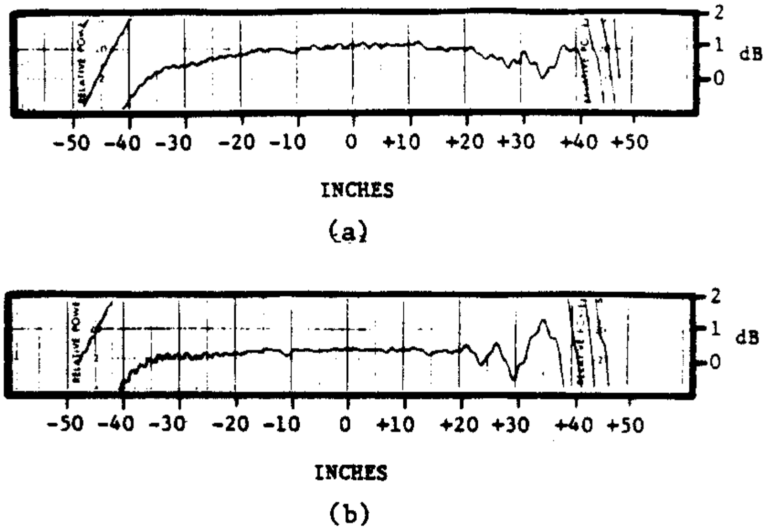
Comparison of the field probes in Figure 6 shows that the amplitude taper across the six-foot vertical quiet zone dimension is approximately 1-dB for the standard compact range feed. With the chokes, the amplitude taper across the same six-foot vertical quiet zone dimension is approximately 0.8-0.9 dB. It is difficult in all field probe data to separate the effects of amplitude taper from the effects of amplitude ripple. This field probe data, however, seems to indicate that the RAF with the choke flange produces almost the same amplitude taper in the quiet zone as the standard compact range feed. When the choke flange is removed as in Figure 6 (c) the amplitude taper across the six-foot quiet zone is reduced to approximately 0.7 dB.

Comparison of the field probe data shown in Figure 7 indicates that the standard compact range feed produces approximately 1 dB of taper across the six-foot horizontal dimension of the quiet zone as well. For the RAF with the choke flange, the taper is reduced to about 0.8 dB. For the RAF without the choke flange, the taper is approximately 0.5-0.6 dB in the horizontal quiet zone dimension.

These figures indicate that the RAF produces about the same amplitude taper as the standard feed when used with the corrugated choke flange. Without the flange the amplitude taper is decreased. This is caused by the fact that a corrugated choke flange narrows the beam of an open-ended waveguide feed. The decay of surface currents on a corrugated flange is fairly gradual with distance along the corrugated surface [2]. The corrugated flange therefore radiates and increases the effective aperture of the feed. Without the corrugated flange the pattern symmetry and stability versus frequency suffer and the feed radiates more strongly in the direction of the quiet zone. Therefore, use of a corrugated flange and the number of corrugations and size of the flange if it is used are other tradeoffs to be considered in the design of a compact range feed. As the figures indicate, the effects of the feed on the compact range quiet zone are small. Feed pattern optimization is a correction for a small imperfection in the quiet zone field, the amplitude taper. It is not yet clear how much amplitude taper affects the accuracy of measurements made using the compact range. It has been shown that in some cases, amplitude taper is much less important than amplitude ripple, especially for radar cross-section (RCS) measurements [1]. What this means to the feed designer is that the tradeoff between direct feed radiation into the quiet zone, which contributes to amplitude ripple, and feed beamwidth, which affects the amplitude taper, must be considered carefully. The price for correcting a small amount of amplitude taper may be a large increase in the amplitude ripple. For some applications this is a good tradeoff, but not for all.

## RIDGED WAVEGUIDE FEED DESIGN

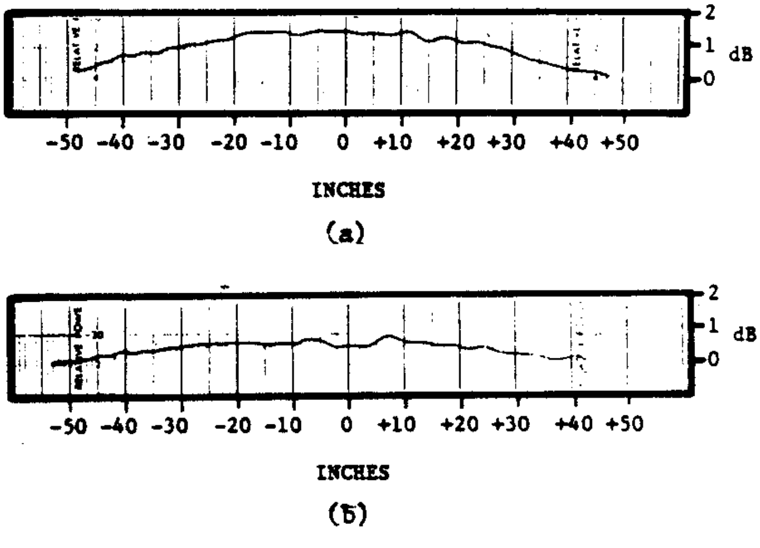
Figure 8 shows a comparison of field probes taken using the standard feed and the RWGF at the mid-band frequency of the standard feed. The field probe cuts shown are vertical cuts for vertical polarization. Figure 9 shows a comparison of the same two feeds in horizontal cuts for vertical polarization. The choke slots cut into the end of the ridges in this feed were not perfectly symmetrical, with the result that the feed pattern varied somewhat with frequency, introducing an overall amplitude tilt in the field probe cuts at some frequencies. This tilt is normalized out in the data presented in the figures.



(a)

(b)

Figure 8. Vertical field probe amplitude cuts on a Model 5754 compact range reflector fed with (a) the standard compact range feed, and (b) the RWGF.



(a)

(b)

Figure 9. Horizontal field probe amplitude cuts on a Model 5754 compact range reflector fed with (a) the standard compact range feed, and (b) the RWGF.

Comparison of the field probes shown in Figure 8 demonstrates the dramatic effect on the amplitude taper in the quiet zone achievable with the RWGF. The standard compact range feed produces approximately 1 dB taper across the six-foot vertical quiet zone dimension. The RWGF produces less than 0.5 dB taper across the same quiet zone dimension. In the horizontal quiet zone dimension the standard feed again produces approximately 1 dB taper. The RWGF produces approximately 0.5 dB taper across the six-foot horizontal quiet zone dimension.

The RWGF used for these measurements was operated at X-band (8.2 - 12.4 GHz). The round waveguide in which the ridge was constructed, however, was of the same diameter as the standard Ku-band (12.4 - 18 GHz) compact range feed. The ridges capacitively load the fundamental $TE_{11}$ mode [5] and lower the cutoff frequency of this mode. This allows propagation through a smaller diameter waveguide and radiation from a smaller aperture. The pattern is therefore broader than the pattern of a larger radiating aperture. In addition, if the $TE_{11}$ mode is properly excited in the ridged waveguide so that asymmetrical higher order modes are not excited, the bandwidth of the ridged waveguide feed is potentially greater than that of an open-ended empty round waveguide radiator. For the RWGF used in these measurements, the cutoff frequency of the next higher mode with the same symmetry as the $TE_{11}$ mode was computed to be approximately 16 GHz, indicating that the RWGF could possibly be used to illuminate the reflector not only in X-band, but over much of Ku-band as well. Extended frequency coverage would require extremely precise fabrication techniques in order to avoid asymmetries which could excite undesired higher order modes at the top end of the band. It is not yet known how much frequency coverage could be obtained with the RWGF.

The same probe horn was used for both of these data sets so the ripple magnitudes may be compared directly. The ripples near the top of the quiet zone in the vertical cuts with a period of approximately 1.5 inches in the RWGF field probe cuts are caused by the backlobes of the feed. We can compute the increase in the extraneous signal level due to the feed backlobe from the following equation [3]

$$20 \log_{10} \frac{E_{ex}}{E_{pr}} = 20 \log_{10} \left( \frac{1-10^{-\Delta/20}}{2} \right) \tag{1}$$

where

$E_{ex}$ = extraneous signal level
$E_{pr}$ = primary signal level

and

$\Delta$ = peak-to-peak amplitude ripple in dB.

A modified form of this equation and a nomogram from which extraneous signal levels may be read is found in Microwave Antenna Measurements (Hollis, Lyon, and Clayton, eds.) [4].

This equation does not take into account the effect of the probe horn's pattern, but the effect is the same for both feeds and only the difference in level is considered here, so the probe horn pattern cancels out. The computed difference in direct feed radiation amplitude into the quiet zone between the RWGF and the standard feed is approximately 6 dB. That is, the amplitude of the direct feed radiation into the quiet zone compared to the amplitude of the collimated wave from the reflector is approximately 6 dB higher for the RWGF than for the standard feed. The absolute levels (which are corrupted by the effect of the probe horn's pattern) are on the order of -40 dB.

## CONCLUSION

We have demonstrated that it is possible to improve the amplitude taper performance of the paraboloidal reflector compact range by optimizing the feed design. We have evaluated two approaches to reduce the aperture size and broaden the beamwidth of open-ended waveguide radiators. Each reduces the amplitude taper of the quiet zone field to some extent at the cost of increased direct feed radiation into the quiet zone and a higher VSWR. The RAF has an inherently moderate bandwidth, while the bandwidth of the RWGF is potentially higher than that of the standard feeds.

Both of the feed configurations reported in this paper show promise for antenna measurement applications where feed VSWR is not a problem and only moderate bandwidths are required. Work is in progress to evaluate other approaches which may not be so costly in terms of VSWR and bandwidth.

## ACKNOWLEDGEMENT

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