Compact Range Phase Taper Effects Due to Phase Center Shift in Wide-Band Quad-Ridge Feeds

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Abstract

Wide frequency bandwidth feeds are used in compact ranges when multi-octave bandwidth operation of the range is desired. Dual-ridge or quad-ridge horns have been widely used in RCS applications as well as in antenna measurement applications to achieve wide band operation. This selection is made to take advantage of the lower cost of quad-ridge horns vs. other options.

In designing a compact range, one primary concern is the beamwidth of the feed over the operating band. This affects the amplitude taper across the quiet zone of the range. Another primary concern is the movement of the phase center vs. frequency of the feed. This directly affects the phase taper across the quiet zone as a result of de-focusing of the reflector.

Here we present measured data of the beamwidth and phase center movement vs. frequency of a wide-band quad-ridge feed designed to operate from 2.0-18.0 GHz. Measured and predicted quiet zone performance data over this bandwidth are presented with the feed installed in a Model 5751 compact antenna test range having a 4-foot quiet zone.

Key Words: Compact Range, Feed, Phase Taper

1. Introduction:

Traveling about the world and touring a number of antenna and RCS ranges has clearly shown to the authors that there is no one feed or type of feed that is ideal for all compact range applications. Ever since Richard C. Johnson addressed the relationship of the size of the quiet zone to the beamwidth of the compact range feed and to the focal length of the reflector [5], feed designers have employed many different feeds and techniques to optimize their particular application. A quick review of published papers will reveal a wide variety of compact range feeds in use such as; circular waveguides with corrugated apertures [3, 6,10], sinuous antennas used as feeds [1], feed clusters consisting of several closely spaced apertures [4], and a variety of dual-ridged flared horns in various configurations [2,7,8].

All of these various feeds are useful in some respect in that they satisfy some number of general requirements placed upon the feed design. Borrowings from Lewis and Cook [1] general requirements for Compact Range Feeds are:

- Minimum amplitude taper across the reflector
- Stable beamwidth patterns
- Constant phase center
- Low cross-polarization
- Low side and back lobes
- Broadband to reduce fabrication, mounting, and operational cost. Broadband measurements are also required for high spatial resolution measurements.
- Have low resistive loss to improve dynamic range
- Small physical size to reduce mutual coupling and diffraction effects
- Absence of modal resonances and energy storage

The intent of this paper is to provide compact range users and designers with some measured data on a wideband dual-ridged and a quad-ridged horn used as a feed. Of particular interest is data presented here on the beamwidth and phase center changes vs. frequency of one antenna of this type with the corresponding quiet zone performance when this antenna was installed as a compact range feed. Armed with this information and in reviewing the above requirements, one can see the advantages and disadvantages of this type of feed.

2. Hardware Description and Test Setup

Data from two different ranges is presented in this article.

The first set of data was acquired using a Model 1795 Microwave receiver on an SA Model 5751 compact range reflector with a 12 foot focal length and a 4 foot quiet zone fed by a BAE Systems Model AHO-2036 quad-ridged horn with the lens cover removed. Data presented on this system consists of the quiet zone performance from 4-18 GHz. The quiet zone data was acquired with a 6-foot phase probe using a quad-ridged, conical horn as the sampling antenna. Additional data presented here depicts phase center location vs. frequency of this feed obtained from far-field antenna pattern measurements.

The second set of data was acquired using a Model 1795 Microwave Receiver on an SA Model 5706 compact range reflector with a 12 foot focal length and a 6 foot quiet zone fed by an AEL Model 1498 Dual-Ridged Horn. Data presented on this system consists of the quiet zone performance from 4-18 GHz. The quiet zone data was acquired using a 6-foot phase probe and a quad-ridged, conical horn as the sampling antenna. Unfortunately, phase center data is unavailable for this antenna.

3. Phase Center and Beamwidth Variations

For the quad-ridged feed, far-field pattern data was obtained using the same Model 5751 for which quiet zone performance was obtained. Patterns were taken from 4-18 GHz in 0.5 GHz increments. Care was taken to ensure that both the amplitude and phase were accurately recorded in order to determine the lateral and translation phase center shift with respect to the feed axis. Once the far-field phase patterns were measured and stored, a Matlab™ routine was written to extract the phase center parallel to the axis of the feed using the method outlined in [9]. The phase center movement normal to the axis of the feed was determined by this method as well. The equations for determining lateral and translation offsets are given below.

$$lateral offset = m_l \, l \quad (1)$$

$$translation offset = m_t \, l \quad (2)$$

where m_l and m_t represent the slopes of fitted lines through the phase data versus sin(azimuth) and 1-cos(azimuth) for lateral and translation offsets respectively. Multiplying the wavelength (l) by the slope gives the distance between the phase center and the axis of rotation. In computing the location of the phase center, the portion of the far-field pattern lying between the 10 dB beamwidth was used.

Figure 1 shows the axial phase center offset vs. frequency for one port of the feed in the E-plane and H-plane of the feed. The other port of the 2-port feed exhibited essentially the same behavior. In this figure the phase center offset is measured from the front of the feed aperture. This figure shows the total variation of the apparent phase center along the feed axis to be approximately 3.5 inches.

The lateral phase center offset vs. frequency was insignificant (less than 0.1 inches total variation across the entire frequency band) for both the E-plane and H-plane of the feed and so will not be presented here.

Figure 2 shows the 1 dB beamwidth of one port of the quad-ridged feed in both the E- and H-planes. As shown in this figure the 1 dB beamwidth does vary quite a bit over the bandwidth of the feed. The beamwidth varies from a max of nearly 60 degrees down to a minimum of 9 degrees at the highest frequency. As shown in the next section this will result in large variations in the quiet zone taper as the subtended angle of the quiet zone as viewed from the feed is approximately 20 degrees.

4. Compact Range Quiet Zone Performance

Both data sets were analyzed for amplitude and phase variations. Phase variation is presented both as total variation and as phase taper only. Phase taper is computed using a least-squares fit to the data. Figures 3 and 4 show the total phase variation and phase taper of the 5751 illuminated by the quad-ridge feed. Comparison of Figures 1 and 4 show the strong correlation between the phase taper and the movement of the feed phase center as expected.

Amplitude variations in the quiet zone are presented as amplitude ripple and amplitude taper using a least squares fit to the data to separate the two components from the total amplitude variation. Amplitude ripple shown in Figure 5 is determined by subtracting the least squares fit curve from the total variation. Amplitude taper is presented in Figure 6 for the quiet zone when using the quad-ridged feed. Comparisons of Figures 2 and 6 show the strong correlation between 1 dB beamwidth and the amplitude taper of the quiet zone.

The 5706 system with the dual-ridged feed, although designed to perform at 2 GHz over a 6 foot quiet zone, was evaluated here from 4 to 18 GHz over a 4 foot quiet zone for comparison purposes to the 5751 and quad-ridged feed system. Figures 7 through 10 show the performance of this system. Unfortunately, time did not permit measurement of the far-field performance of the dual-ridged feed. Comparisons between the two sets of quiet zone data show similar phase taper performance and better amplitude performance for the dual-ridged feed.

5. Summary

Data is presented in this article on compact range quiet zone quality when illuminated by dual-ridge and quad-ridged feeds. These feeds have acceptable performance for some of the general requirements listed in the introduction. Primarily these feeds are useful when extremely wide-band performance is desired without having to swap out compact range feeds. However, these feeds are not suitable for applications that require high quality phase and amplitude taper over a waveguide bandwidth or less. In this application feeds consisting of circular waveguides with corrugated apertures such as those presented by Hess in [11] are a better choice.

6. Acknowledgement

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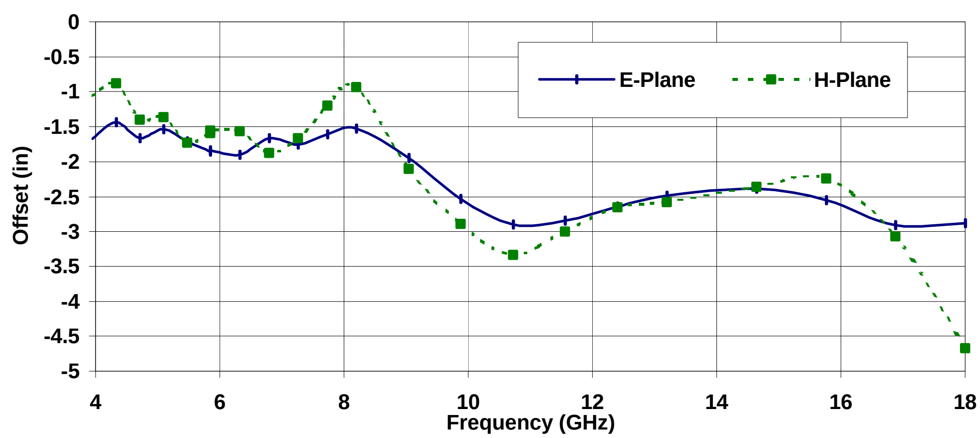

Figure 1: Quad-Ridged Feed Phase Center Translation Offset

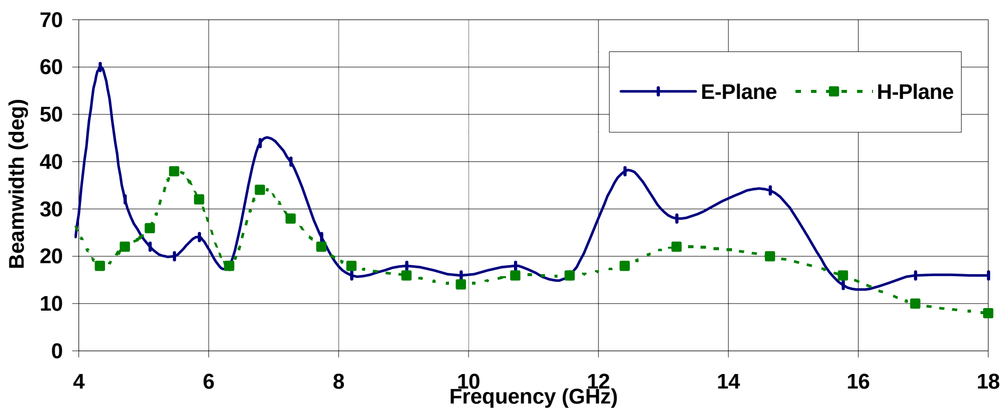

Figure 2: Quad-Ridged Feed 1 dB Beamwidth

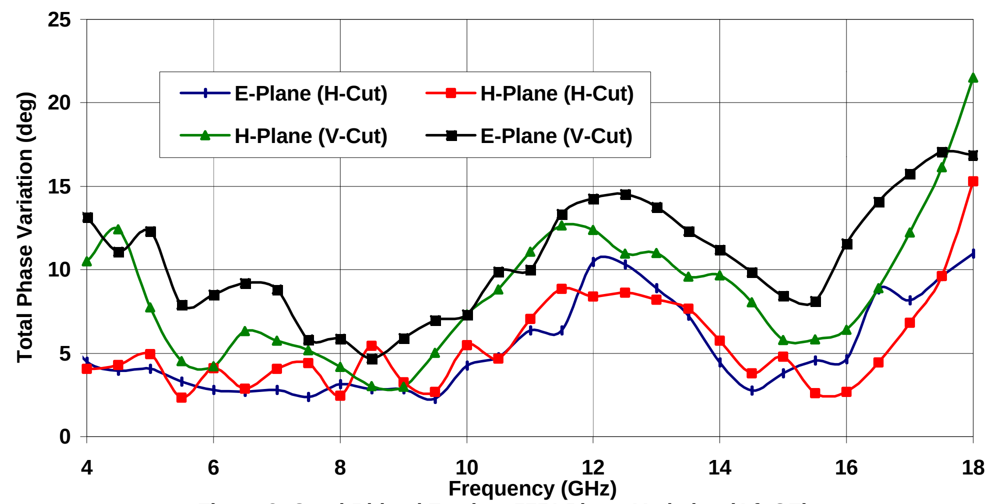

Figure 3: Quad-Ridged Feed on 5751 Phase Variation (4 ft QZ)

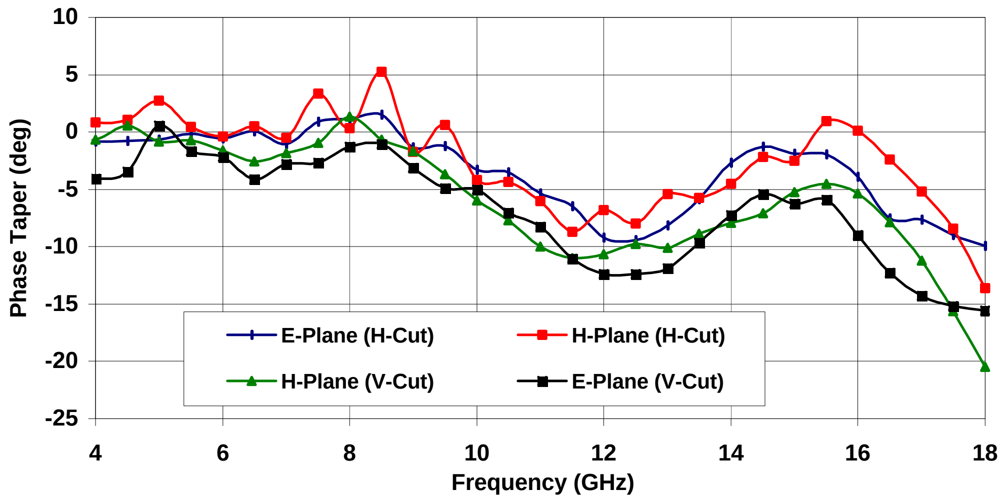

Figure 4: Quad-Ridged Feed on 5751 Phase Taper (4 ft QZ)

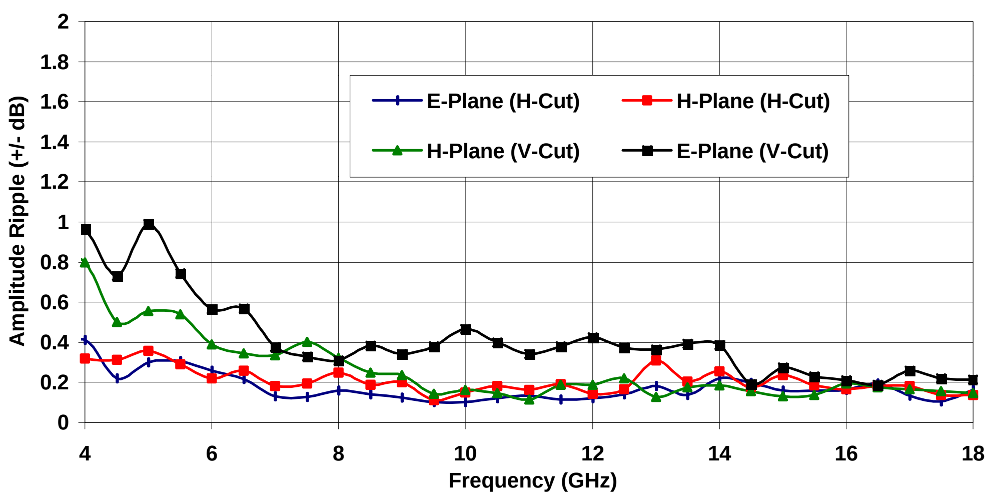

Figure 5: Quad-Ridged Feed on 5751 Amplitude Ripple (4 ft QZ)

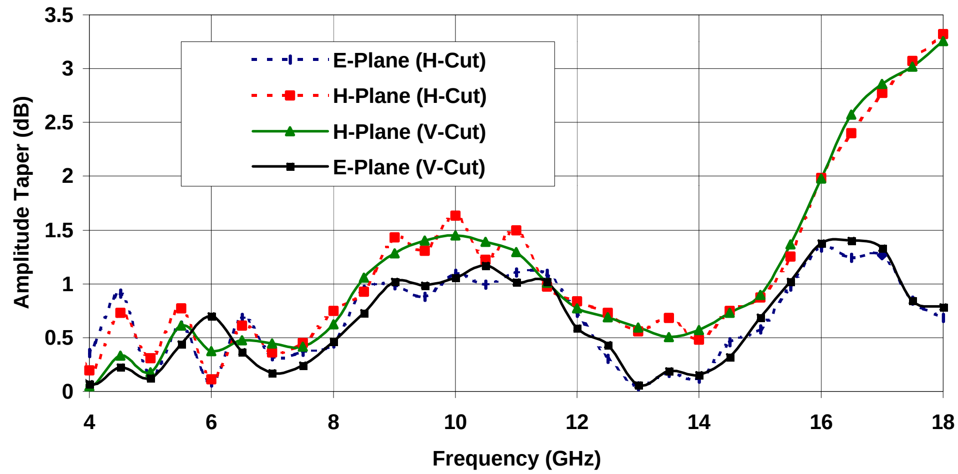

Figure 6: Quad-Ridged Feed on 5751 Amplitude Taper (4 ft QZ)

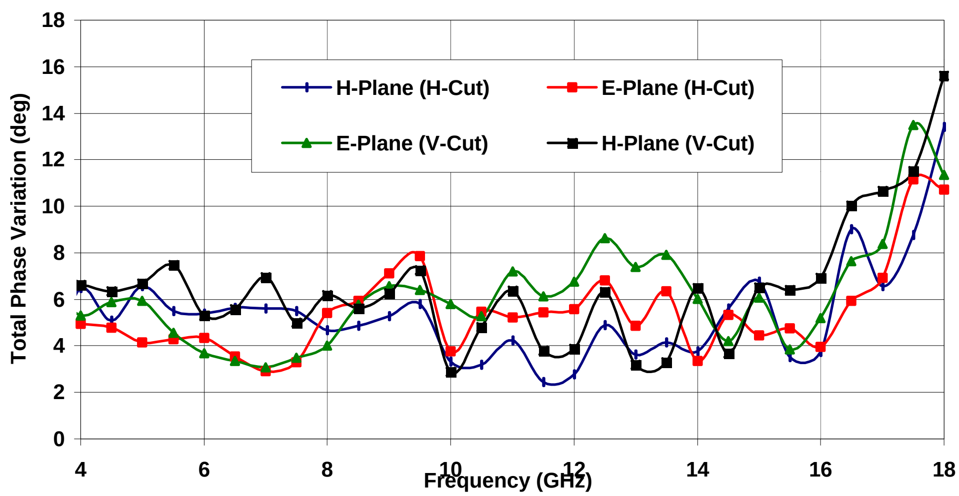

Figure 7: Dual-Ridged Feed on 5706 Phase Variation (4 ft QZ)

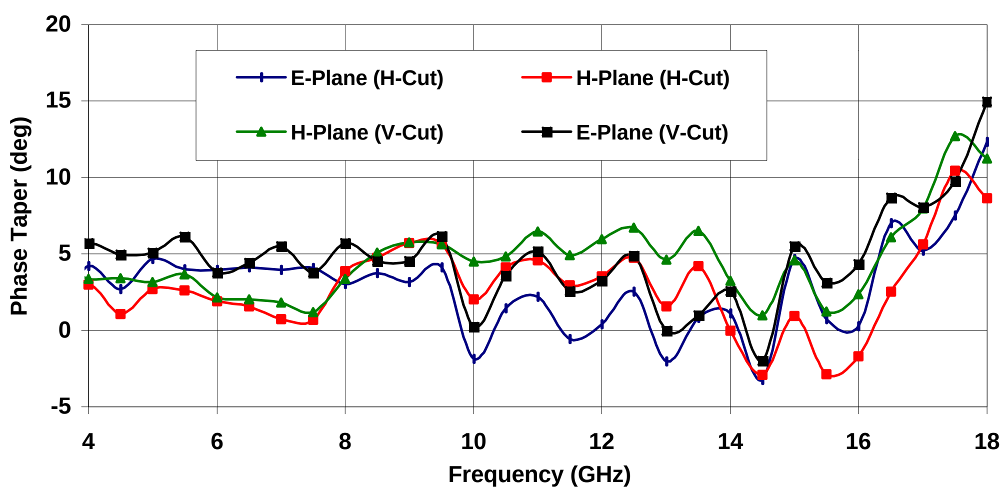

Figure 8: Dual-Ridged Feed on 5706 Phase Taper (4 ft QZ)

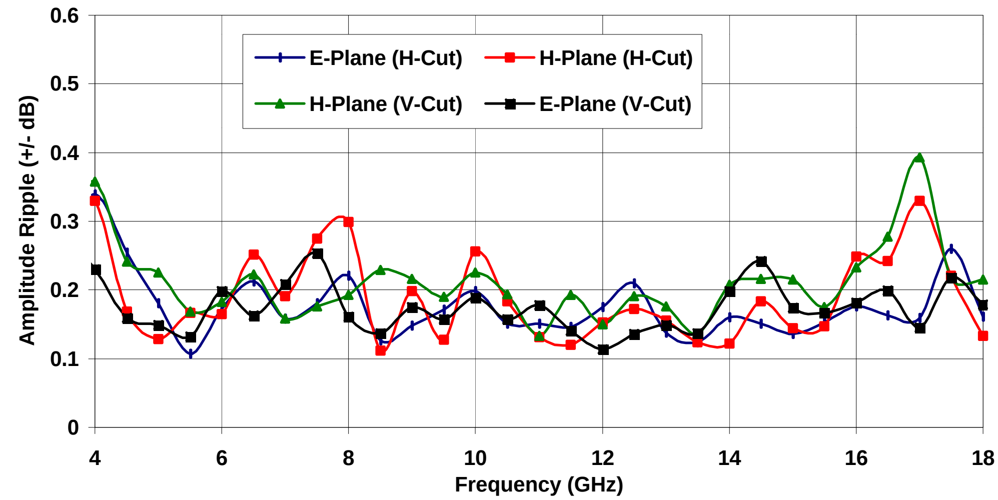

Figure 9: Dual-Ridged Feed on 5706 Amplitude Ripple (4 ft QZ)

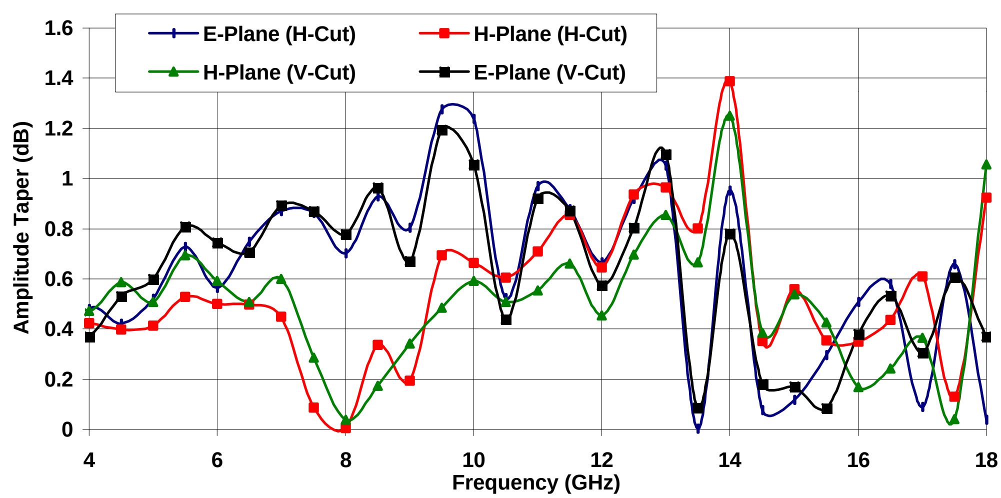

Figure 10: Dual-Ridged Feed on 5706 Amplitude Taper (4 ft QZ)