Design and Measurement of VLBA C-Band Feed Horn

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Abstract:

A secondary focus wideband feed horn to cover the 4-8 GHz frequency range on the VLBA has been designed, fabricated, and tested. The feed horn is a compact corrugated horn with an aperture diameter of 7.0λ and a length of 18.0λ at 6 GHz. There are 68 corrugations out of which the first eight are the ring-loaded type, which provides the broadband match for the feed horn. Measured patterns give an average taper of -13.7 dB at 13.1°, the half-angle subtended by the subreflector. Cross-polarization is lower than -26.1 dB up to 7.7 GHz. Measured return loss is better than 18.5 dB.

Introduction:

The scientific goal for the new wideband C-band receiver project on the VLBA is to facilitate access of important spectral lines for measuring galactic structure and kinematics. The major components of this upgrade include new low-noise amplifiers, new feed, new down-converter, and upgrades on monitor and control systems. The original C-band feed (4.6-5.1 GHz) is a linear taper horn with a taper angle of 9.11° and has an aperture diameter of 14.646" and length of 41.368". For the new feed, the target illumination taper at the edge of the subreflector (13.1°) is -14 dB over the 4-8 GHz frequency range. The new feed should roughly be the same size as the feed that it replaces in order to fit in the existing slot on the feed cone assembly of the VLBA antenna. This memo presents the design of the feed, construction details, and far-field range measurements on the prototype feed.

Design:

The size limit on the feed necessitated the choice of a compact or a profile horn design [1], [2]. The compact horn uses a cosine taper from the throat to the aperture of the horn. This design is about 28% shorter in length and about 35% smaller in aperture size compared to a linear taper horn for a comparable illumination taper. The input diameter of the feed is 1.875" to match the diameter of the quad-ridge orthomode transducer. The first corrugation starts at a diameter of 1.876". The mode converter, where the TE_{11} in the circular waveguide is converted to HE_{11} mode in the corrugated section, has a linear taper of 8° and has eight ring-loaded corrugations [3]. There are a total of 68 corrugations with a pitch of 0.462", yielding more than three corrugations per wavelength at 8 GHz. The taper of the profile section is 8° at the output of the mode converter, increases to a maximum of 15° at about three-fifths of the length from the mode converter output, and ends at 0° taper at the aperture. The aperture diameter of the feed is

13.779” and the length is 35.416”, including the input waveguide. The aperture is 7.0λ and length is 18.0λ at 6 GHz. The EVLA C-band feed is 11.2λ at the aperture and is 33.5λ long at 6 GHz. The EVLA feed is larger because of the higher directivity required to illuminate the 9.25° half-angle subreflector.

Mechanical Details:

The feed is machined out of aluminum casting and the main body of the feed has four corrugated sections. Eight aluminum disks machined on both sides are stacked to form the ring-loaded corrugations in the mode converter. The smallest of the four sections has 10 corrugations on one side and a cylindrical bore on the other side, into which the aluminum disks slide in and are held in place by the input waveguide section as seen in Figure 1. The second and third sections have 15 corrugations each and the fourth section has 20 corrugations. Each section is attached to the next section with eight ¼-20 UNC screws. A 3/32” O-ring sits in a groove between the sections. A Gore Tenara 3T20 fabric is used as radome at the aperture of the feed and is held in place by a 4-section retainer ring. The total weight of the feed is about 55 lbs.

Range Measurements:

Far-field patterns of the feed were measured on the Green Bank outdoor range (Figure 2) starting March 1, 2011. The measurements were done in two bands: 3.95-5.85 GHz and 5.85-8.0 GHz. Two standard gain horns were used for the two bands. Circular-to-rectangular stepped transitions (1.875” circular to WR187 & WR137 rectangular waveguides) fabricated for the EVLA project, were used in the two measurements. Patterns were recorded between 4.0 and 8.0 GHz, one frequency at a time, in 300 MHz steps. Measurements were carried out in the ±120° angular range at 1° step. Co-polarized patterns were measured in E-, H-, and 45°-planes. At each frequency, the phase pattern was measured in the ±30° range for different axial positions of the feed on the turntable in order to locate the phase center. The position that yielded nearly flat phase response was noted. The corresponding distance of the aperture of the feed from the center of rotation gives the phase center distance. Amplitude and phase patterns were recorded at this position of the feed on the turntable. Cross-polarized patterns were measured only in the 45°-plane. The following procedure was adopted while measuring the cross-polarization. After completion of the co-polarized pattern measurement in the 45˚-plane, the feed was returned to boresight. The power meter (measuring the amplitude) was set to zero and the source horn was rotated by 90°. The source horn was further rotated by small amounts in either direction until the reading on the power meter dropped to a minimum. With the source horn at this position, amplitude and phase were recorded yielding cross-polarized pattern.

Results of Range Measurements:

Measured far-field patterns are compared to theoretical patterns in H- and E-planes in Figures 3, 4, and 5 at 4.0, 6.0, and 8.0 GHz, respectively. Theoretical patterns are calculated using mode-matching technique. There is excellent agreement between measurement and theory at all the measured frequencies except at 8 GHz in the E-plane. The receiver may have been locked on one of the upper harmonics during this measurement. Figures 6-9 show measured H- and E-plane patterns superimposed at 4.0, 6.0, 7.7, and 8.0 GHz, respectively. The agreement between the two patterns is not good at 8.0 GHz because of the error in the E-plane measurement. The beam is circularly symmetric at other frequencies as well. Measured amplitude and phase patterns in H-plane are shown in Figures 10 and 11. E-plane patterns are shown in Figures 12 and 13. The beamwidth decreases monotonically with frequency up to 7.3 GHz as seen in the amplitude plots. The changing profile of the horn generates the HE_{12} mode which affects the pattern above about 7.6 GHz. Table 1 shows the illumination taper at the edge of the subreflector in the principal planes.

The phase patterns essentially remain within ±10° of the boresight value. Table 1 shows the phase center distance inside the horn from the aperture plane. The feed horn could not be moved any further forward to the phase center locations above 7.0 GHz. The patterns at 7.3 GHz and above were recorded with the aperture of the horn 25.3" in front of the center of rotation. The cross-polar peak measured in the 45°-plane, with respect to the co-polar peak, is below -26 dB except at 8.0 GHz where the cross-polarization is -19.7 dB. Figure 14 shows the co-polarized and cross-polarized patterns measured in the 45°-plane.

Table 1

Frequency (GHz)	**Taper at 13.1° (dB)**		**Cross-polarization (dB)**	**Phase center (ins)**
	H-plane	**E-plane**		
4.0	-10.6	-9.6	-27.6	9.4
4.3	-12.1	-11.6	-31.3	12.2
4.6	-12.9	-13.6	-31.2	15.0
5.0	-13.7	-14.7	-37.9	17.6
5.3	-13.8	-14.5	-35.4	18.8
5.7	-13.5	-14.0	-35.0	20.0
6.0	-13.3	-13.9	-34.8	21.1
6.3	-13.4	-13.6	-40.8	22.3
6.7	-14.1	-13.6	-42.0	23.8
7.0	-14.5	-14.4	-37.2	25.3
7.3	-15.2	-15.3	-35.1	
7.7	-16.5	-14.6	-26.1	
8.0	-16.2		-19.7	

Return Loss Measurements:

Return loss of the feed was measured with a vector network analyzer in two bands: 3.8-5.8 GHz and 5.7-8.2 GHz. Calibration was done for each band at the circular waveguide end of the circular-to-rectangular transition. The combined results of the measurements are shown in Figure 15. At 4 GHz, return loss is 18.5 dB and is better than 20 dB above 4.08 GHz.

Conclusion:

The average illumination taper is -13.8 dB in the H-plane in the 4-8 GHz band and -13.6 dB in the E-plane in the 4-7.7 GHz band. The measured taper of the feed is close to the target value of -14 dB at 13.1°. Measured far-field patterns in both E- and H- planes, agree well with simulation. The cross-polarized sidelobes are lower than -26.1 dB up to 7.7 GHz. The phase center at 4 GHz is 9.4" from the aperture plane and moves inside the horn to 25.3" (from the aperture) at 7.0 GHz. Measured return loss is better than 18.5 dB. The aperture of the feed is smaller than the earlier narrow band feed by about 0.8" and shorter by about 6".

Acknowledgements:

J. Ruff and H. Dinwiddie did the mechanical design of the feed. H. Sipe and R. Dickenson at the Green Bank machine shop carried out the machining and assembly of the feed. G. Anderson and J. Bauserman assisted in the range measurements. Special thanks go to M. Mayo and P. Ward for proofreading the draft version of this memo.

References:

[1] B. K. Watson, A. W. Rudge, R. Dang and A. D. Olver, "Compact Low Cross-Polar Corrugated Feed for E.C.S., " *IEEE Antennas and Propagat. Conf. Digest,* Quebec, vol. 1, pp. 209-212, June 1980.

[2] G. L. James, "Design of Wide-Band Compact Corrugated Horns," *IEEE Trans. Antennas Propagat.,* vol. AP-32, pp. 1134-1138, Oct. 1984.

[3] Y. Takeichi, T. Hashimoto and F. Takeda, "The Ring-Loaded Corrugated Waveguide," *IEEE Trans. Microwave Theory Tech.,* vol. MTT-19, pp. 947-950, Dec. 1971.

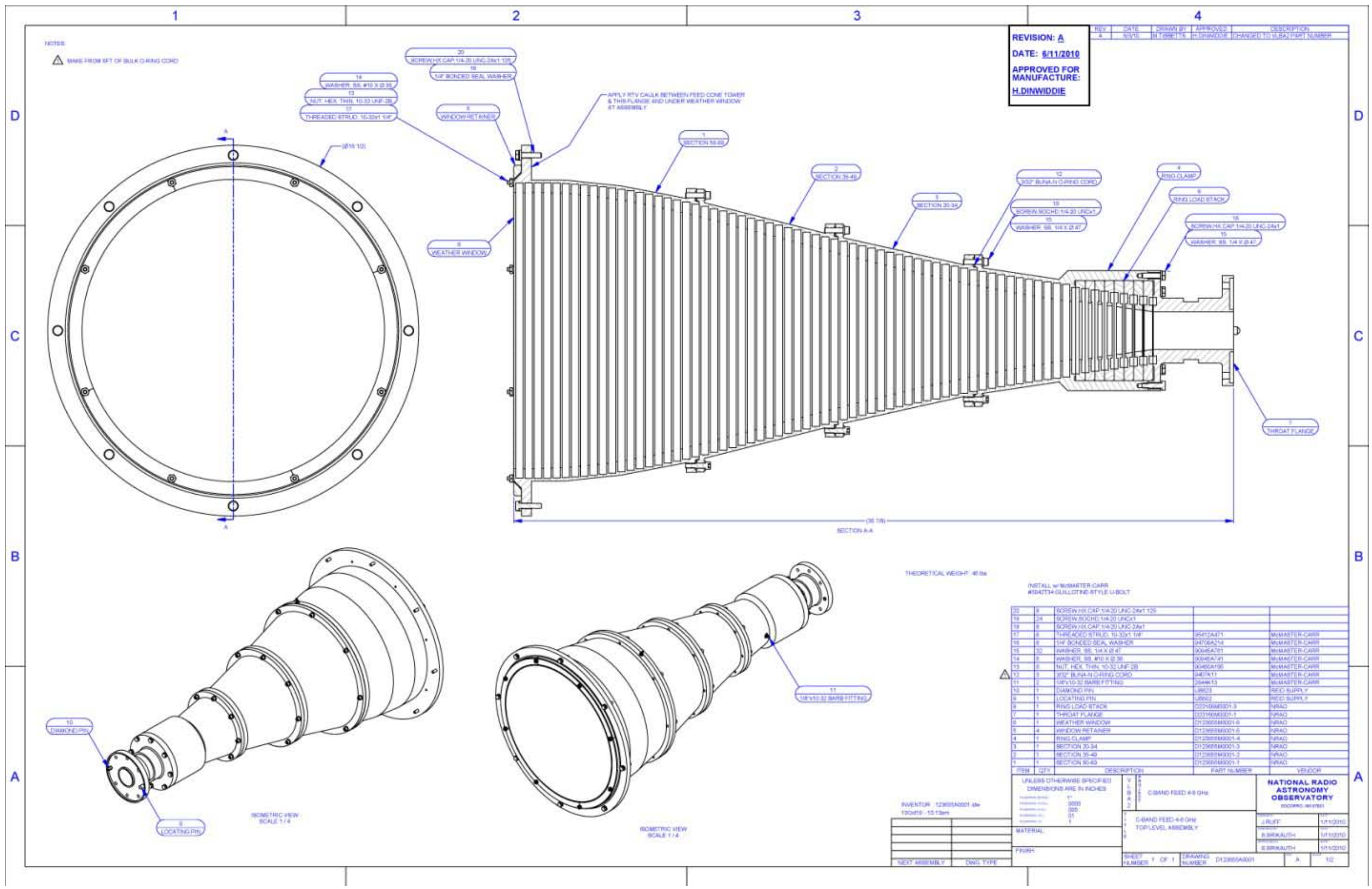
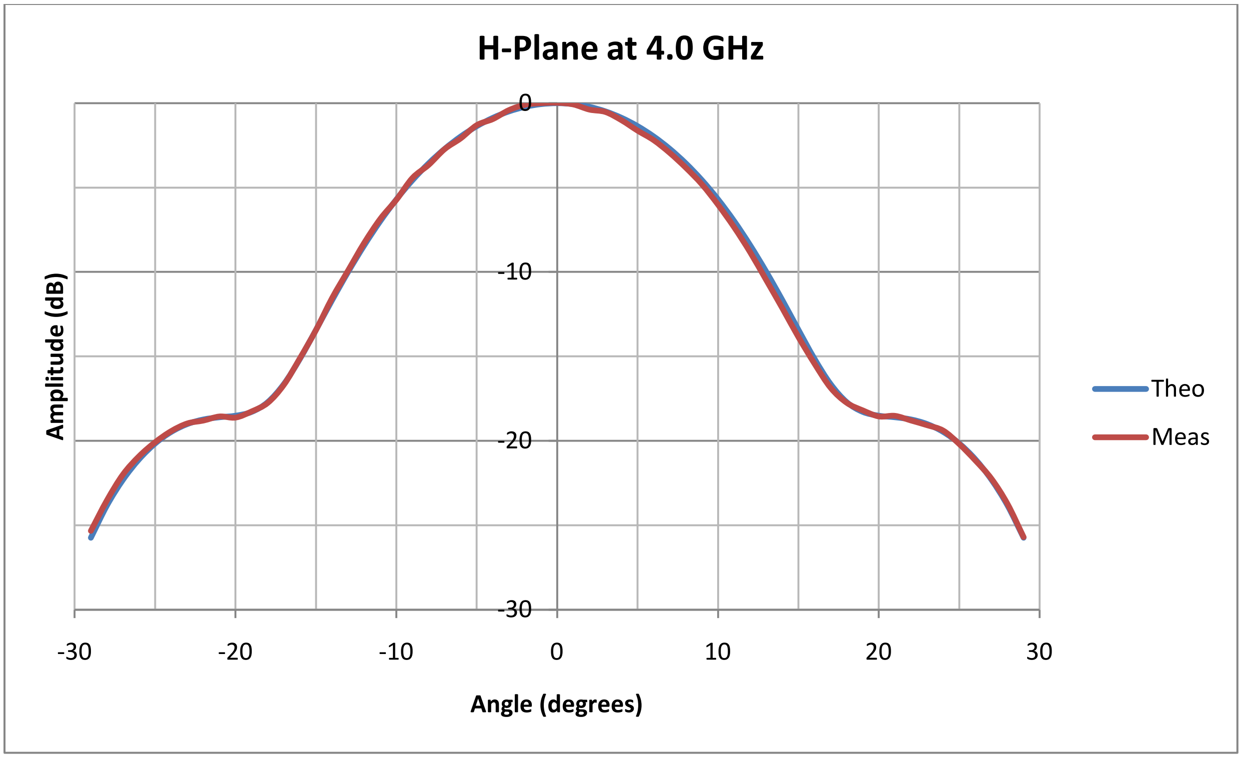
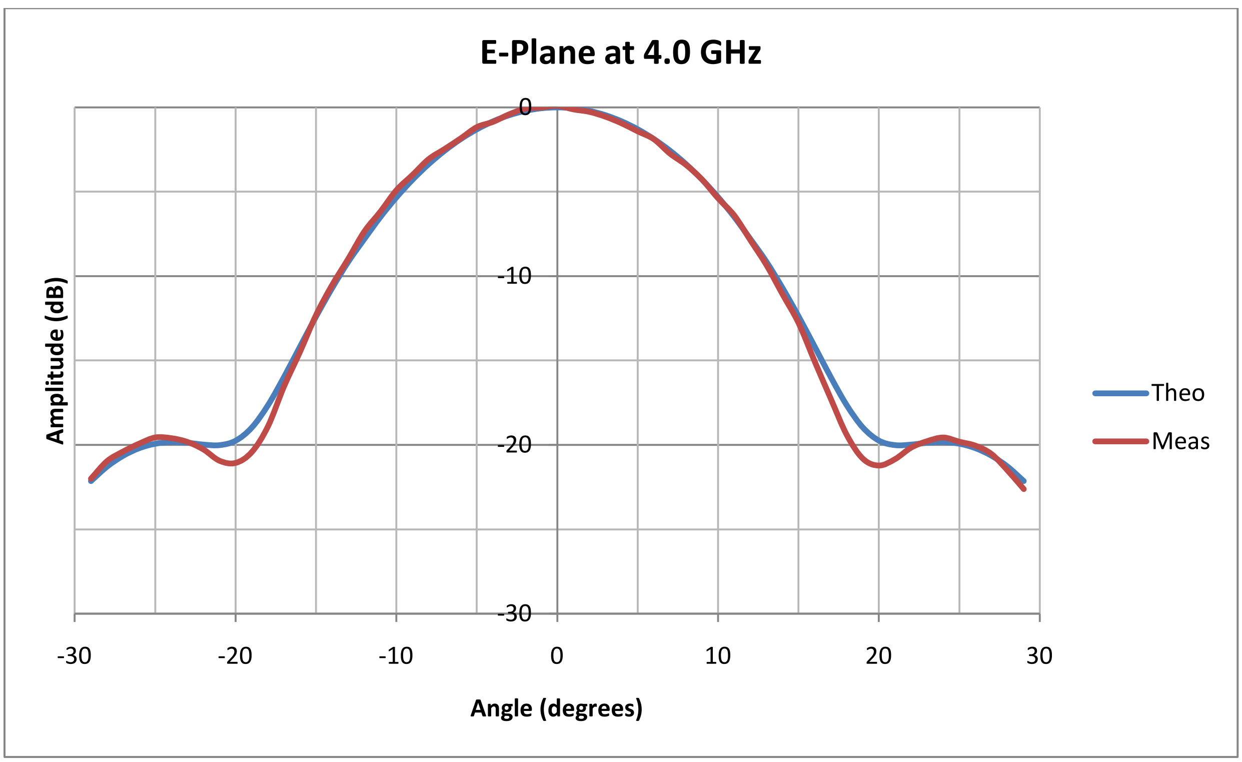


Figure 1. Feed horn assembly.

Figure 2. Feed horn on the Green Bank outdoor range tower.

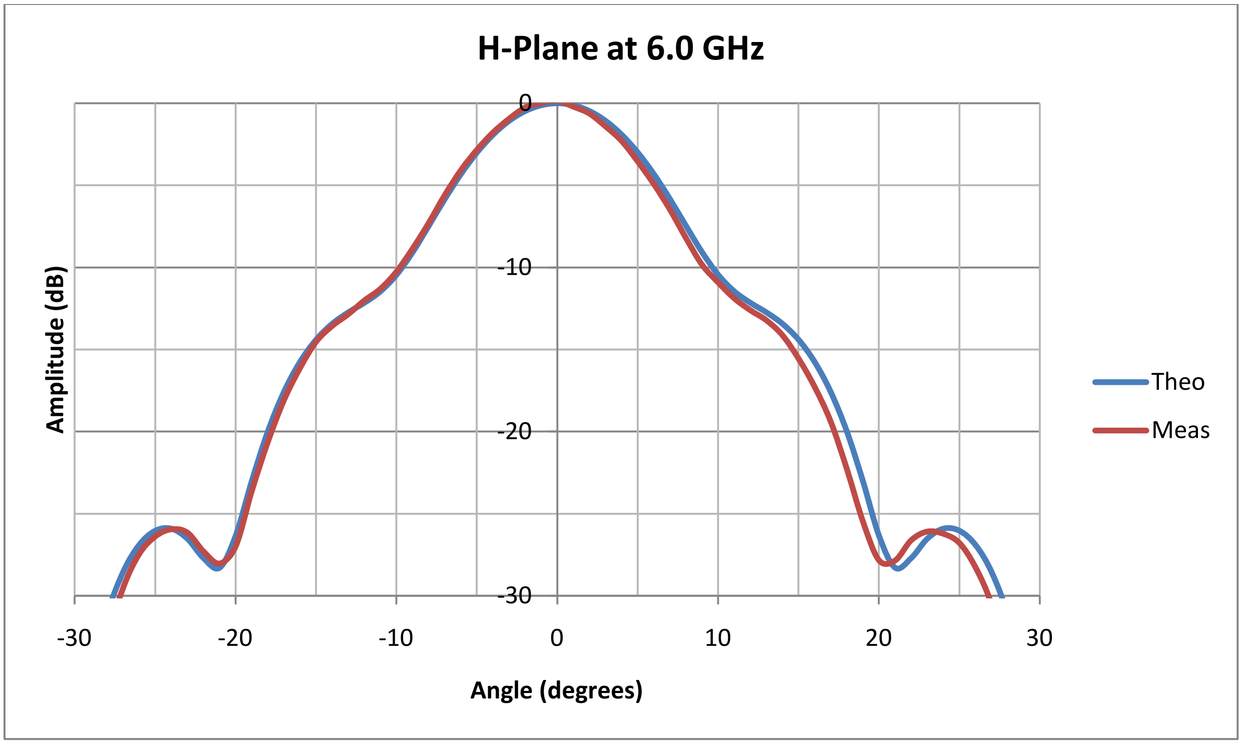


a) H-plane

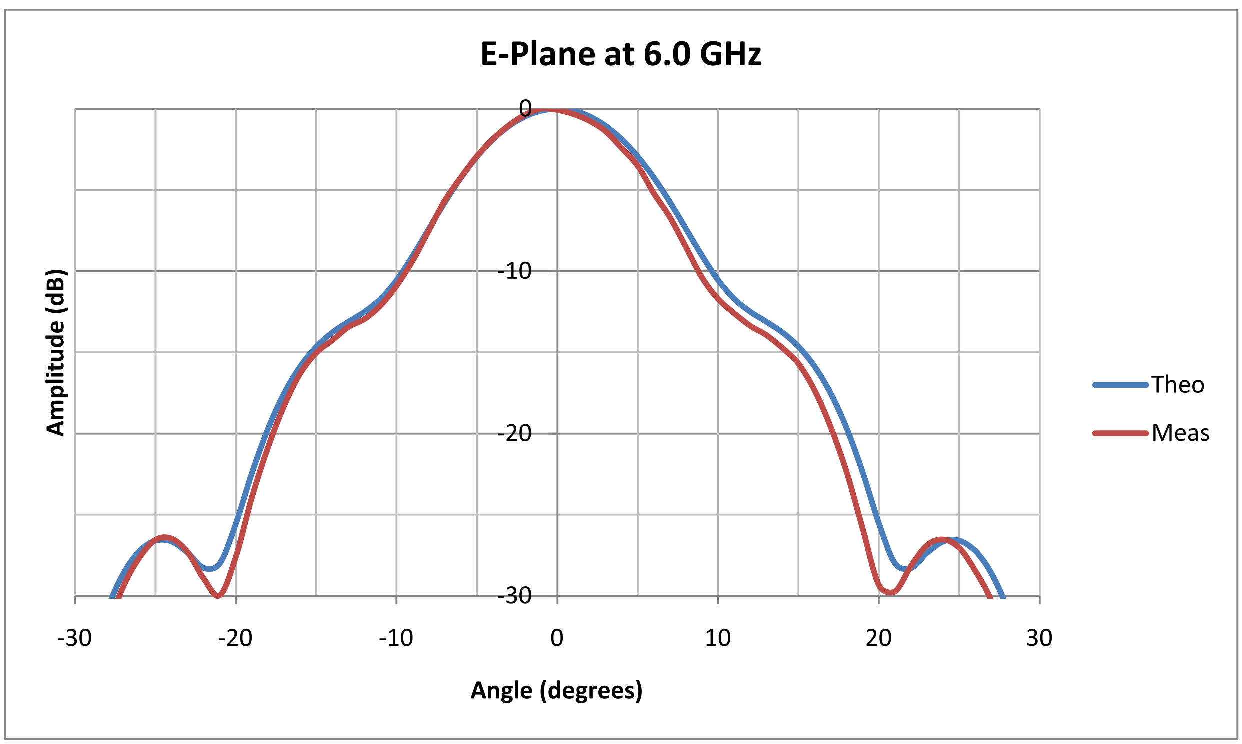


b) E-plane

Figure 3. Far-field patterns at 4.0 GHz; theory and measurement.

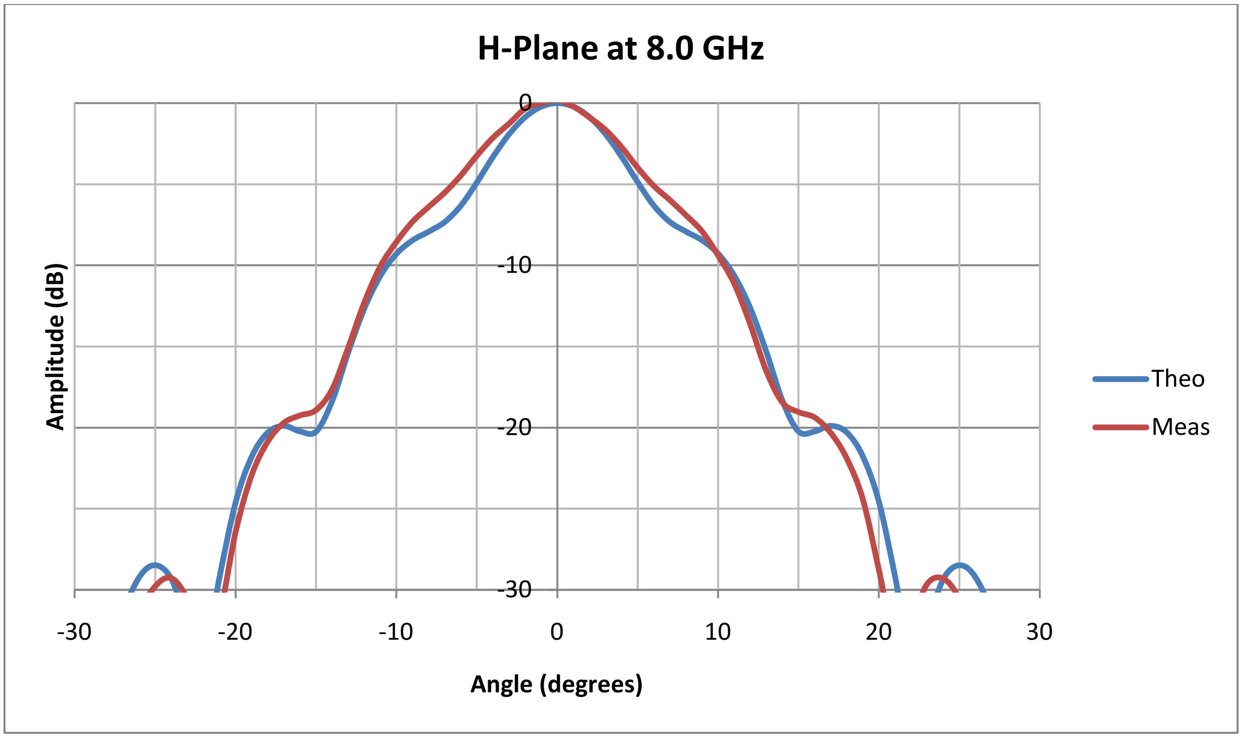


a) H-plane

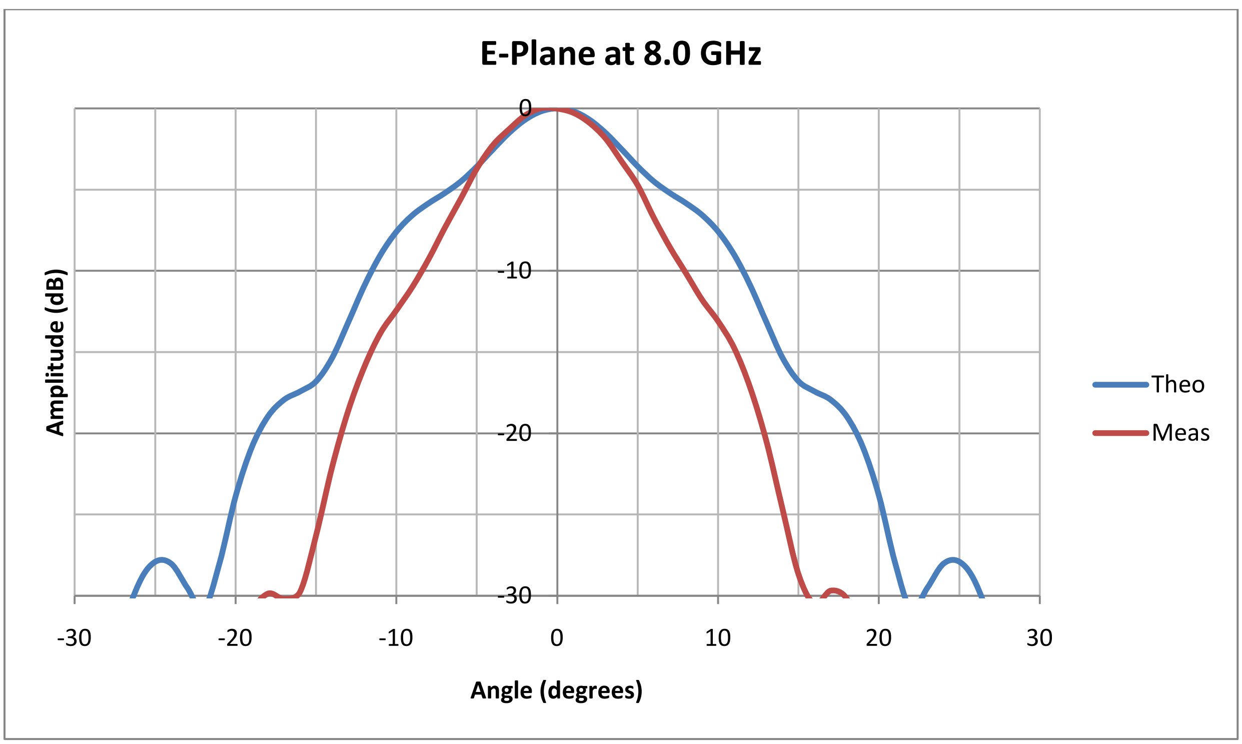


b) E-plane

Figure 4. Far-field patterns at 6.0 GHz; theory and measurement.



a) H-plane



b) E-plane

Figure 5. Far-field patterns at 8.0 GHz; theory and measurement.

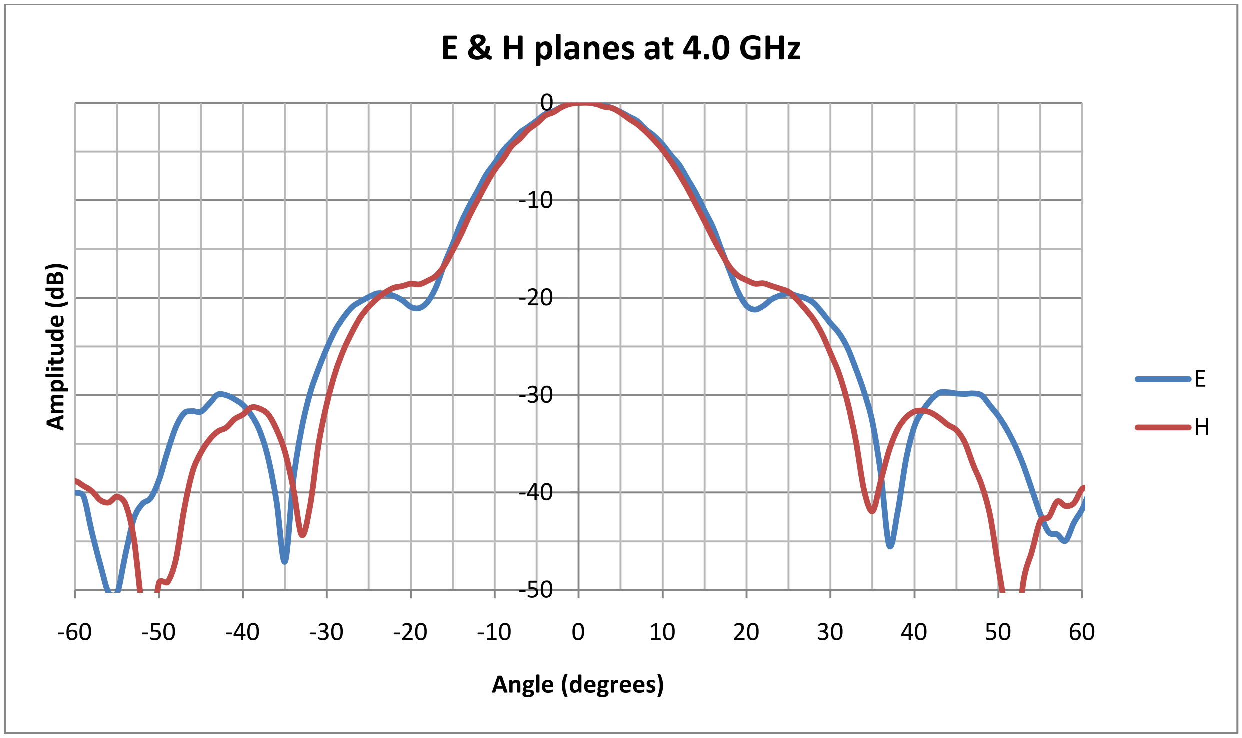


Figure 6. Measured far-field patterns at 4.0 GHz; E- and H-planes.

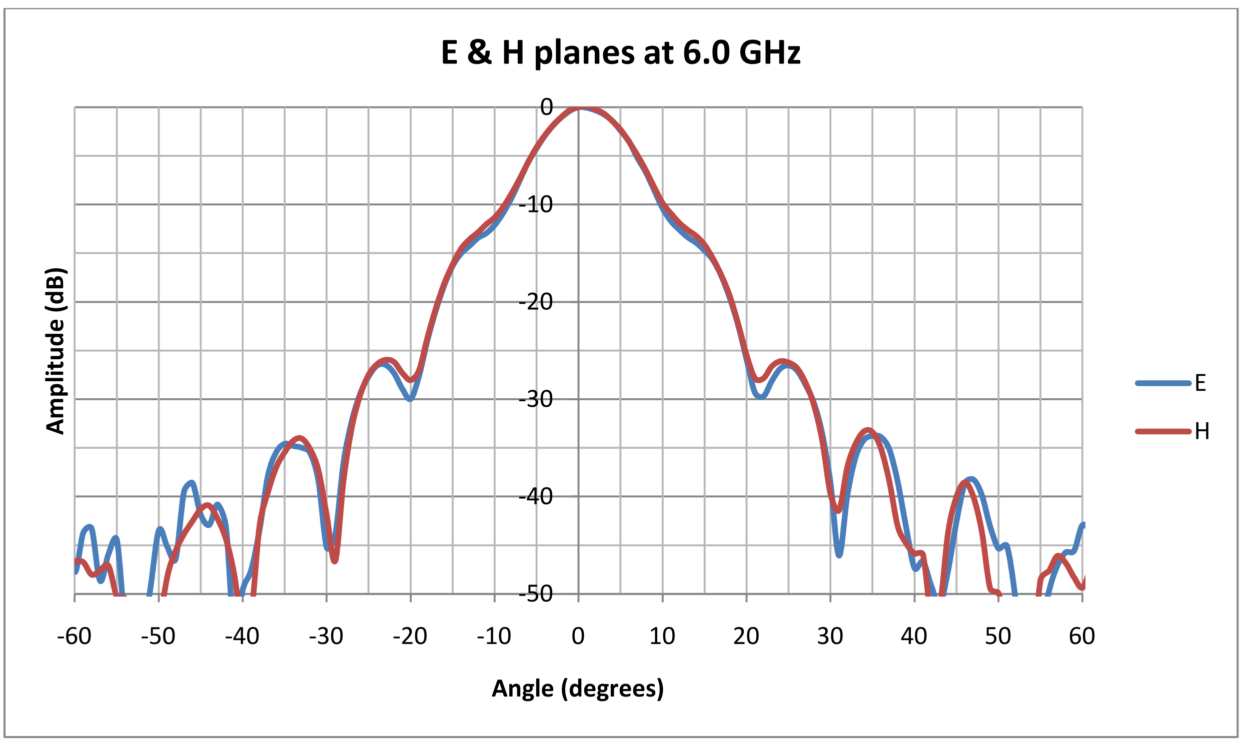


Figure 7. Measured far-field patterns at 6.0 GHz; E- and H-planes.

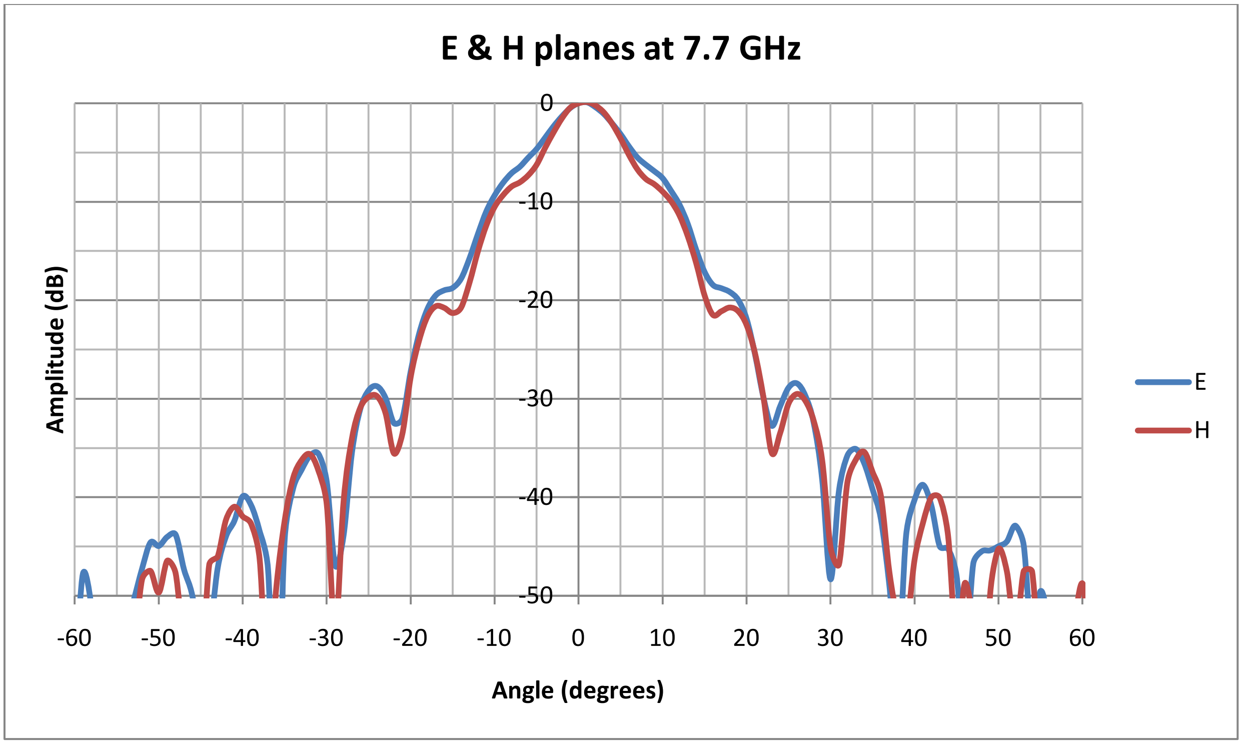


Figure 8. Measured far-field patterns at 7.7 GHz; E- and H-planes.

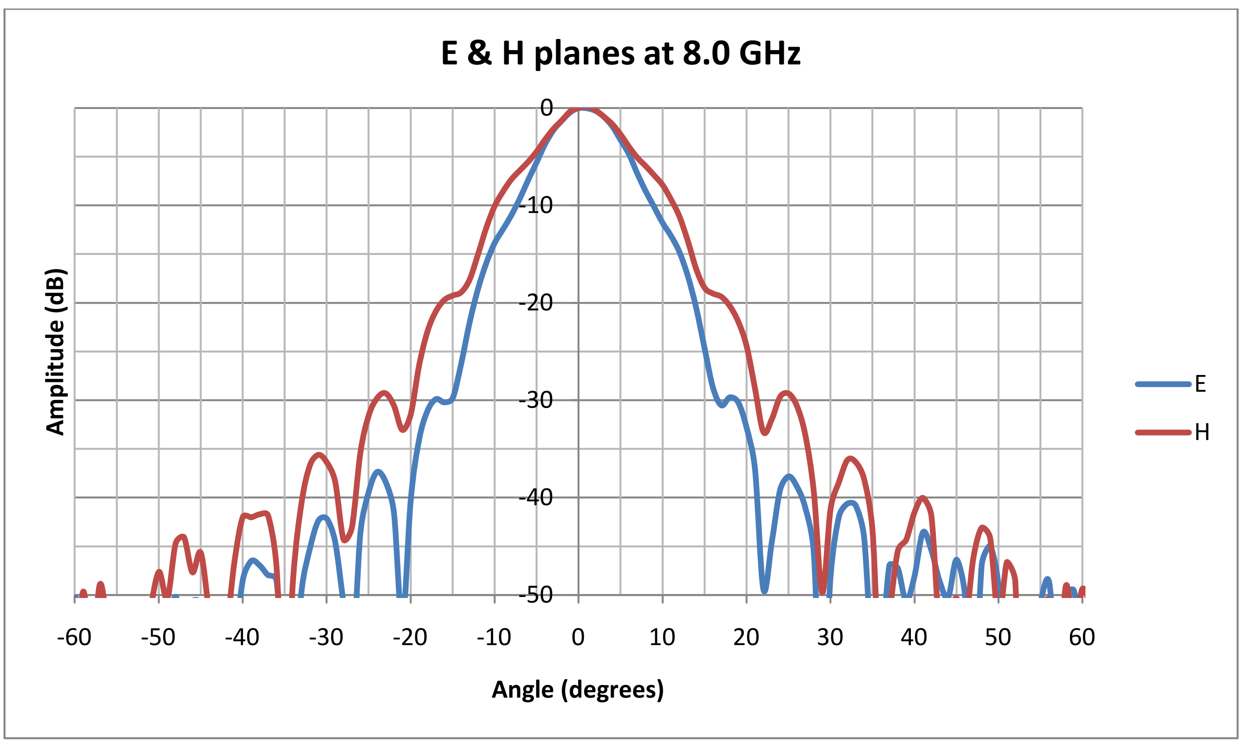
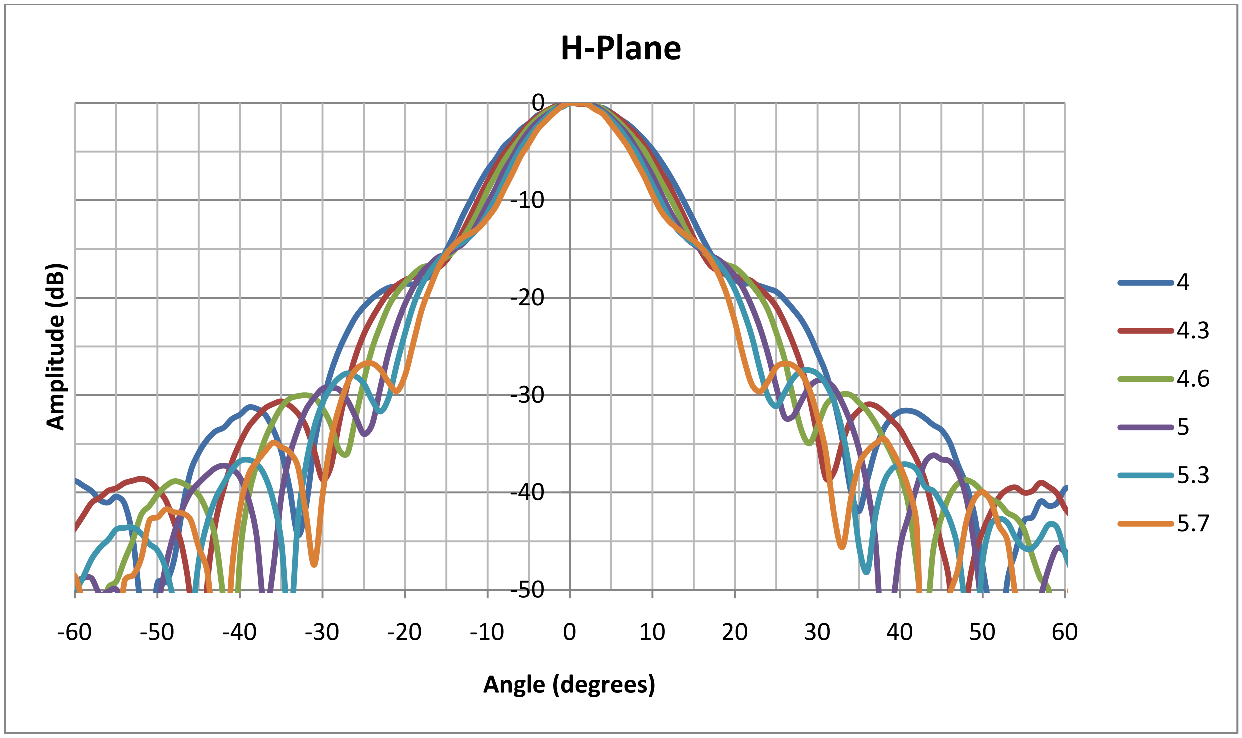
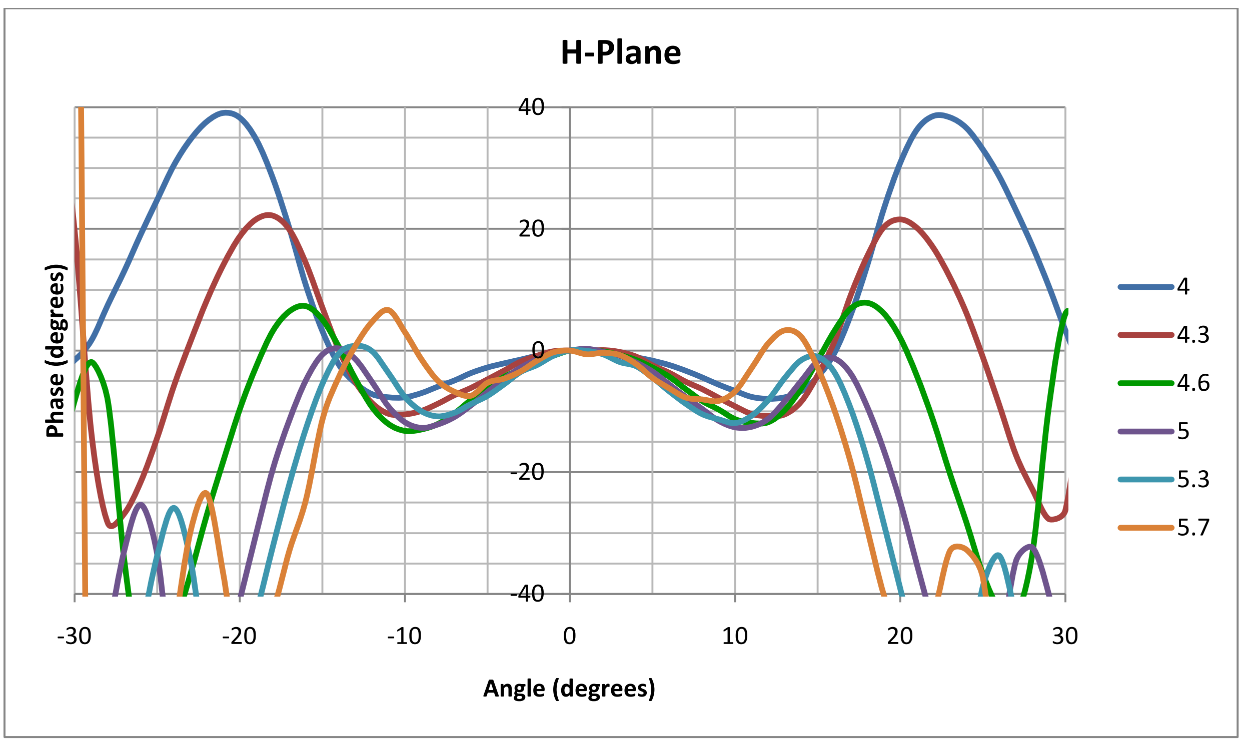


Figure 9. Measured far-field patterns at 8.0 GHz; E- and H-planes.

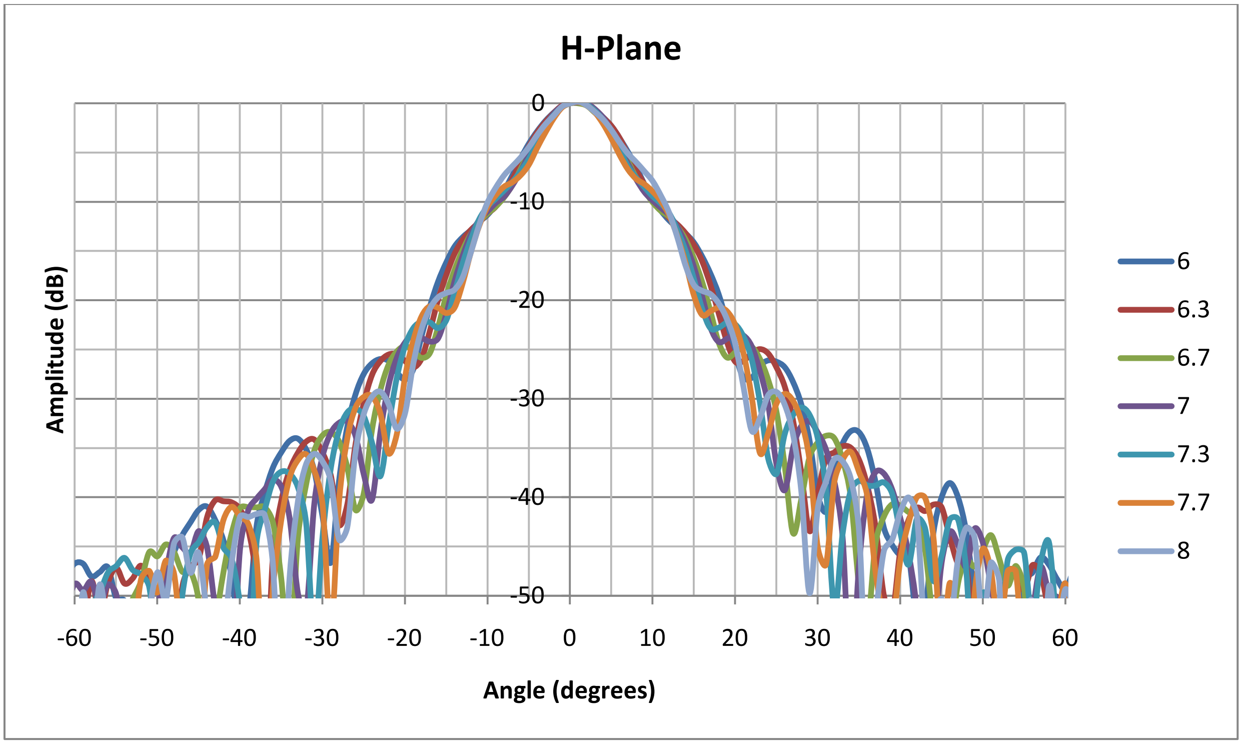


a) Amplitude

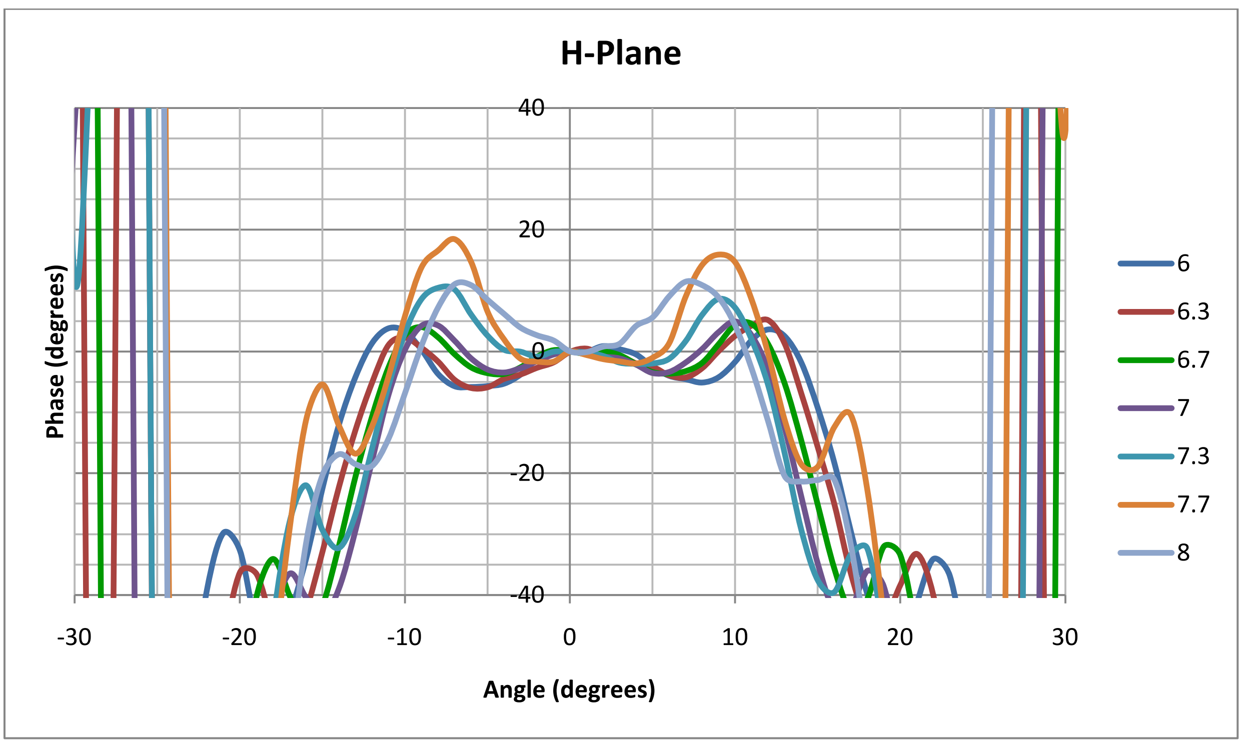


b) Phase

Figure 10. Measured far-field patterns; 4.0-5.7 GHz in H-plane.

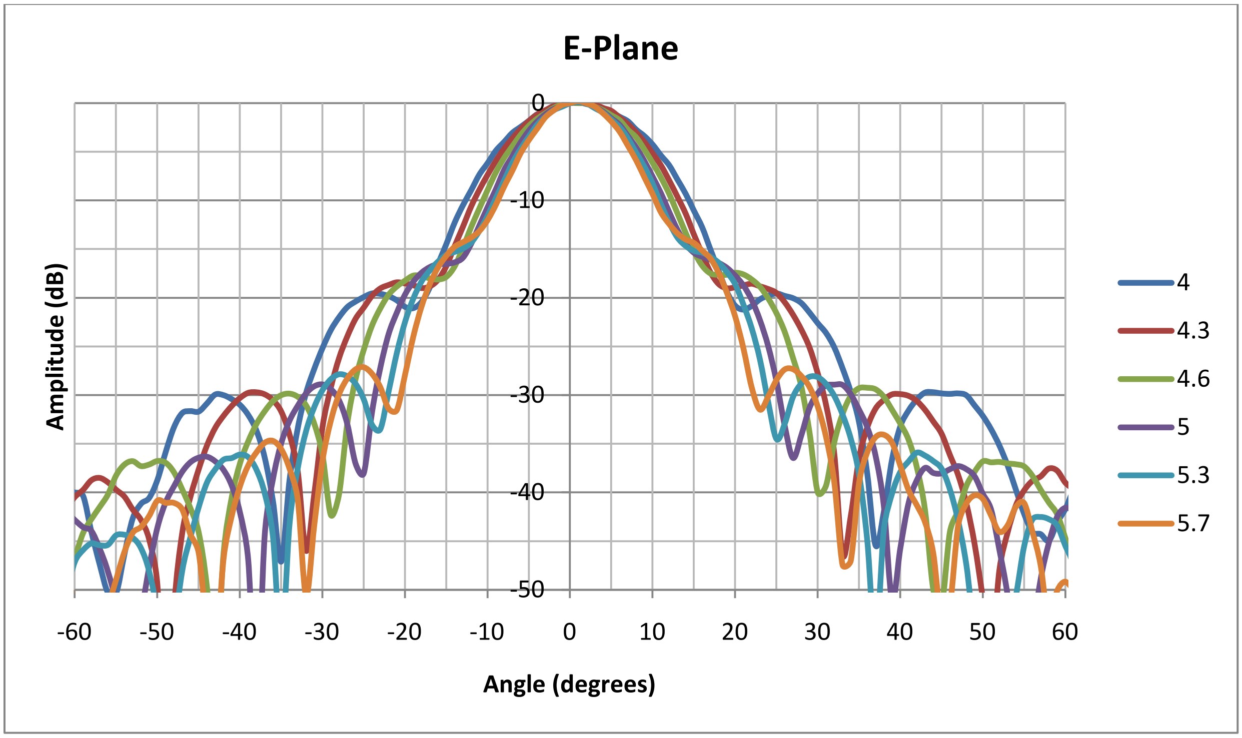


a) Amplitude

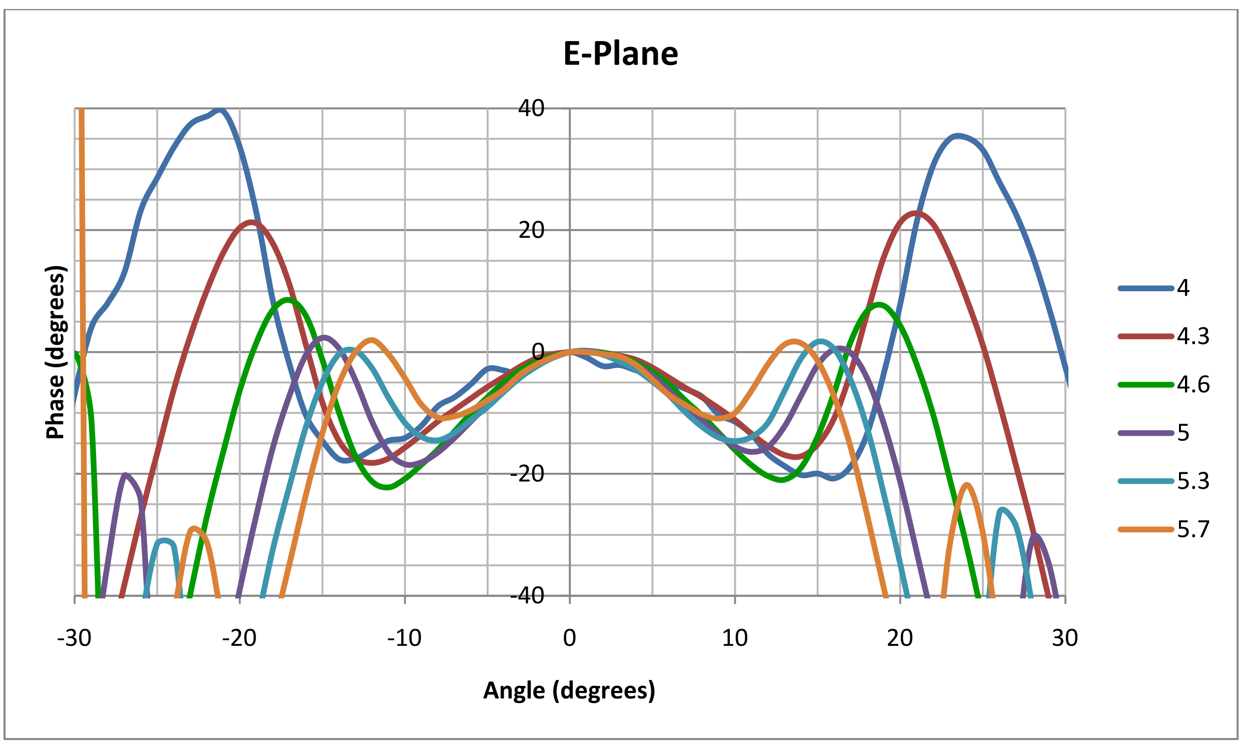


b) Phase

Figure 11. Measured far-field patterns; 6.0-8.0 GHz in H-plane.

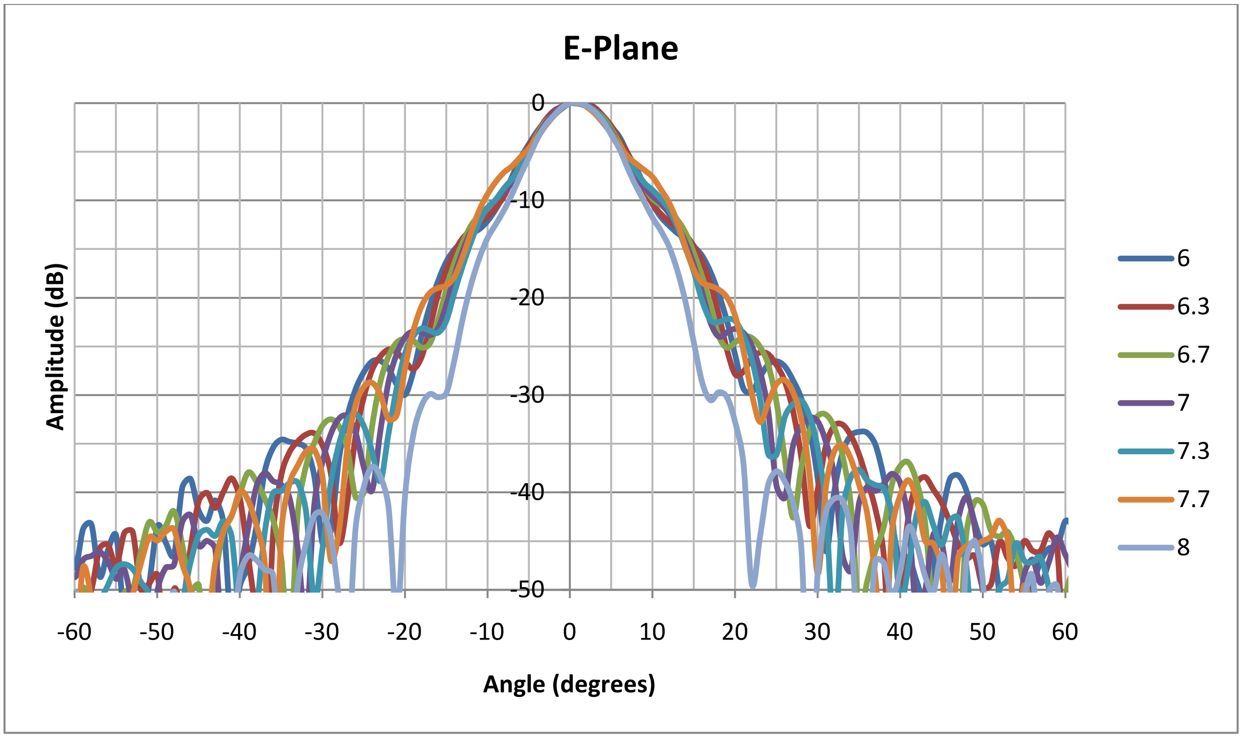


a) Amplitude

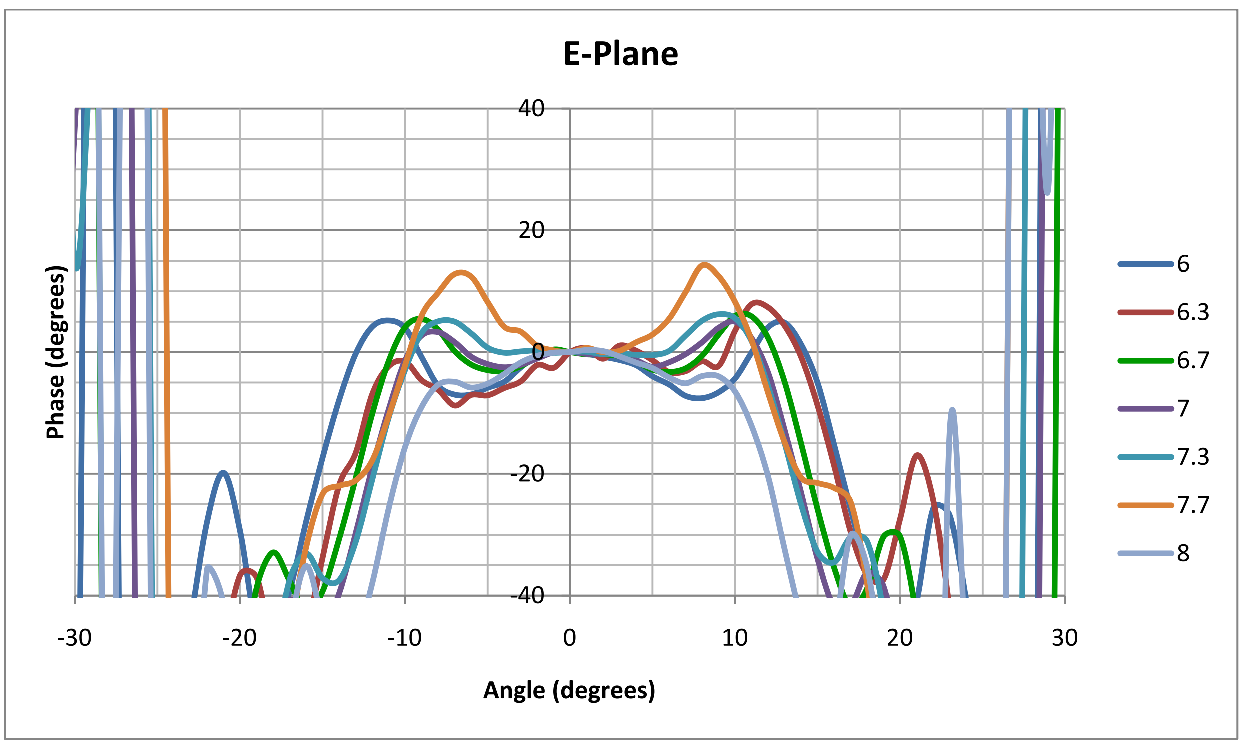


b) Phase

Figure 12. Measured far-field patterns; 4.0-5.7 GHz in E-plane.

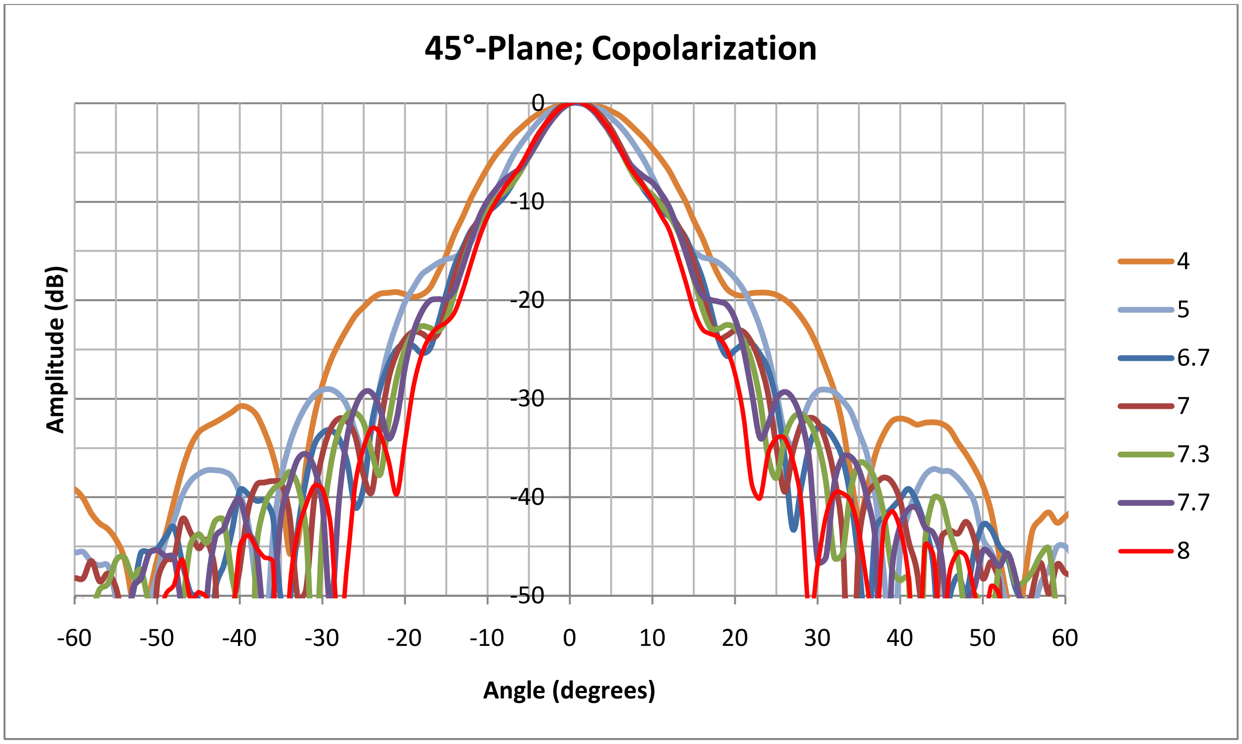


a) Amplitude

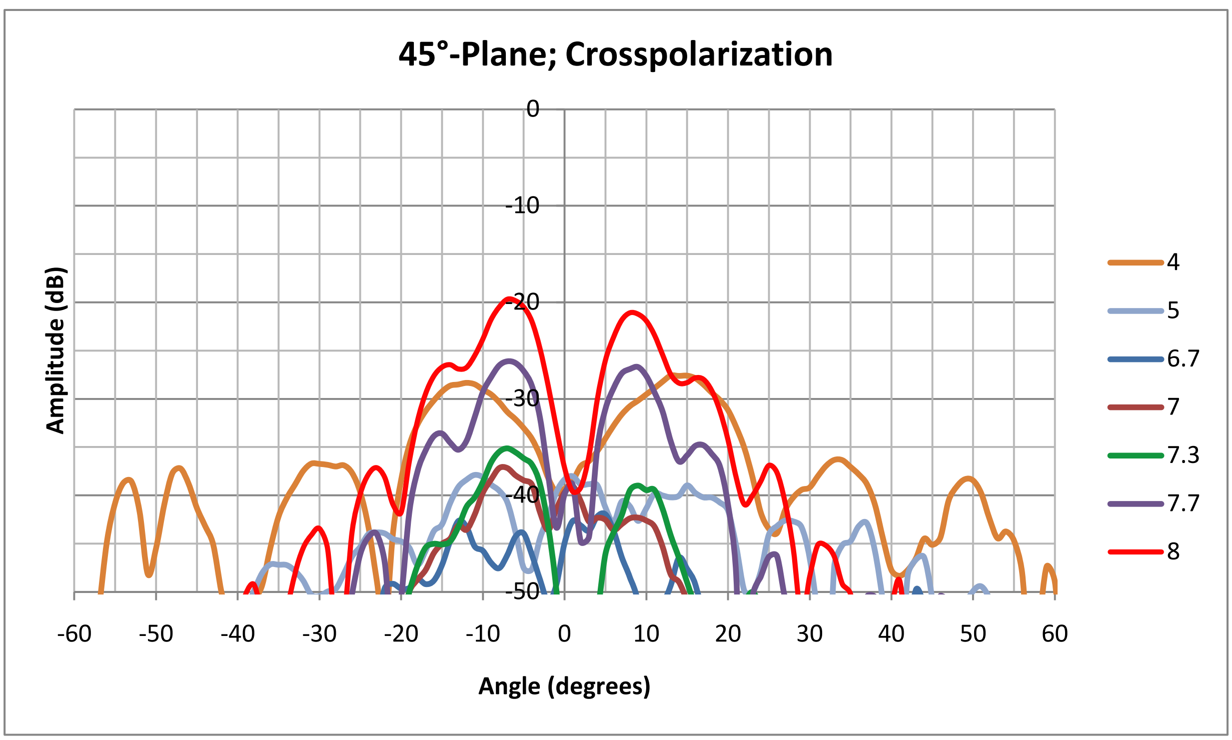


b) Phase

Figure 13. Measured far-field patterns; 6.0-8.0 GHz in E-plane.



a) Co-polarized patterns



b) Cross-polarized patterns

Figure 14. Measured far-field patterns in the 45°-plane.

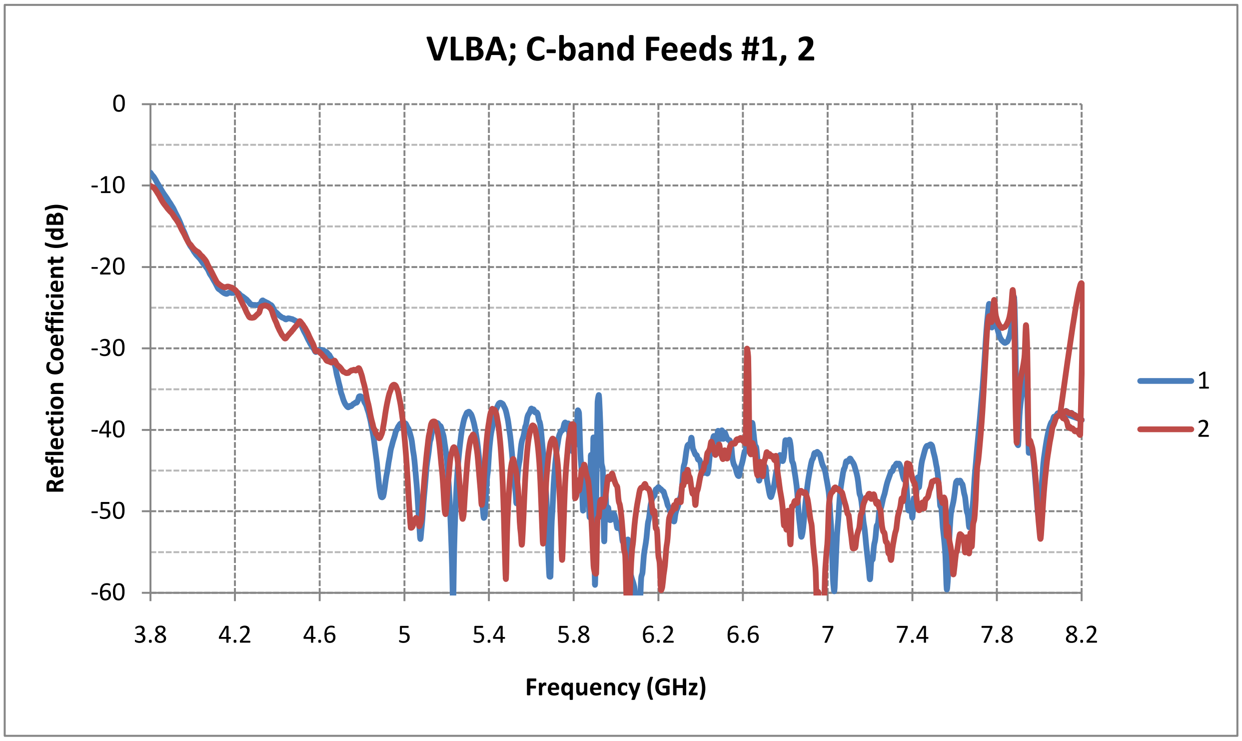


Figure 15. Measured return loss of Feeds serial #s 1 and 2.