EVLA Memo 112

Design, Prototyping and Measurement of EVLA S-Band Feed Horn

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Abstract:

A prototype of the S-band (2-4 GHz) feed horn for the EVLA was measured at the Outdoor Antenna Test Range (OATR) in Socorro in June 2007. In May 2006, a half-scale (C-band) version of this feed was measured at the same test range and was found to meet the design specifications. The S-band feed has an inside aperture diameter of 41.945” and a length of 129.75”. The average illumination taper at the edge of the subreflector (9.3°) is -13 dB and the cross-polarized sidelobes are below -28 dB.

Introduction:

The space limitation on the EVLA feed cone precluded the use of a feed large enough to yield the optimum -17 dB taper at the edge of the subreflector. A taper of -13 dB was chosen for the EVLA C- and S-band feeds. The S-band feed uses a profile/compact horn design with a cosine inside taper. In order to obtain a good impedance match over the 2:1 band, ring-loaded corrugations are used in the mode converter section of the horn. This memo presents the design details, measurement results of the half-scale and full-size prototype feeds, and calculated efficiency and spillover temperature on the EVLA antenna.

Design:

The S-band feed uses a compact or profile horn design [1], [2], where the transition from the output of the mode converter to the aperture of the horn uses a cosine taper. The feed has an input diameter of 3.750” and the first corrugation (ring-loaded) starts at a diameter of 3.754”. There are eight ring-loaded corrugations in the mode converter which has a linear taper of 8°. The pitch of the corrugations is 0.945”, which gives more than three corrugations per wavelength at 4 GHz. The flange thickness is 0.090”. Scaling the EVLA C-band design [3] would result in an aperture inside diameter of 44.245” and length of 131” for the S-band feed. The outside diameter of this feed is 48” and such a feed will not fit in the assigned slot on the feed cone. Hence, an alternate design with a smaller aperture is used. In this design, the profile section starts with an 8° taper at the output of the mode converter, goes through a maximum angle of 11.7° and ends with 0° taper at the aperture. The aperture inside diameter is 41.945” (10.7λ at 3 GHz) and the length of the feed horn is 129.75” (33λ at 3 GHz). The illumination taper of this new design is nearly the same as that of a scaled version of the C-band feed. The return loss at 2 GHz is about 1 dB worse than that of the scaled version. Figure 1 shows the general arrangement of the S-band feed.

Prototype Feeds:

First, a prototype feed at C-band (4-8 GHz) was built to evaluate performance characteristics. This feed has five machined sections. The ring-loaded corrugations are formed by stacked aluminum disks in a machined housing and held by a throat flange that also has the input waveguide. In addition, the first fifteen conventional corrugations are machined into the housing. The outside diameter at the aperture is 23.5" and the length of the feed is 65". After successful testing of this feed, a full-size S-band feed was fabricated. The ring-loaded section is made just like the C-band prototype feed. The conventional corrugations are made using sheet metal rings and bands, following the same technique used in the L-band feed [4]. Figure 2 shows the S-band prototype feed on the foam tower at the OATR.

Range Measurement of the Half-Scale Prototype Feed:

In May 2006, the C-band prototype feed was measured at the OATR, located at the New Mexico Tech Campus. The feed was positioned on a 12-foot tower and was fastened to the azimuth turntable with straps. The distance between the transmit tower and the feed tower is 28.5'. Measurements were carried out in two sub-bands: (i) 3.5-5.8 GHz and (ii) 5.6-8.3 GHz. Circular-to-rectangular transitions used in the EVLA C-band feed measurements were used. The frequency interval was set at 0.1 GHz and the azimuth angular range was ±90° with 0.5° spacing. In the low band, measurements were carried out for three axial positions (aperture at 16.0", 25.5", and 31.1" in front of the center of rotation (COR)) of the feed. A single axial position (43.25") was used in the upper band measurements. Co-polarized patterns were measured in H-, E-, and 45°- planes. Cross-polarized patterns were measured only in the 45°-plane and normalized with respect to the peak of the co-polar patterns. The measurement distance of 28.5' is in the far-field at the low end of 4-8 GHz band. Above 2.6 GHz, the measurement distance is between D^2/λ and $2D^2/\lambda$ and hence the measurements are mostly far-field measurements.

Figures 3 and 4 show measured patterns superimposed on theoretical patterns calculated by a mode-matching software at 4.8 GHz and 8.0 GHz, respectively. Minor differences between the patterns are attributed to reflections present in the measurements. Figures 5 and 6 show measured H-plane pattern overlaid on E-plane pattern at 4.8 GHz and 8.0 GHz, respectively. There is excellent match between the patterns in the two planes. Figure 7 shows phase patterns measured with the aperture of the feed 31.5" in front of the COR. The phase center at about 4.8 GHz is at the COR in this measurement. Figure 8 shows cross-polar patterns measured in the 45°-plane. The peaks of the cross-polar lobes are below -28 dB with respect to the co-polar peaks. Table 1 shows the taper at 9.3° for the measured patterns in the principal planes. Theoretical values are also shown for comparison.

TABLE 1				
Freq. (GHz)	Taper at 9.3° (dB)			
	Measured		Theory	
	H-plane	E-plane	H-plane	E-plane
4.0	-11.7	-11.4	-10.5	-9.0
4.4	-11.7	-12.8	-11.9	-11.9
4.8	-11.2	-12.0	-12.2	-14.0
5.2	-10.9	-11.3	-11.9	-13.5
5.6	-10.7	-10.9	-12.7	-13.2
6.0	-13.1	-13.1	-12.1	-13.1
6.4	-13.8	-14.2	-13.0	-12.6
6.8	-13.9	-14.8	-13.9	-12.7
7.2	-14.7	-13.8	-15.0	-13.9
7.6	-13.1	-12.1	-15.0	-13.8
8.0	-11.3	-12.6	-12.9	-15.5

Near-field Measurement of the S-band Prototype Feed:

The size of the S-band feed prohibited shipping the feed to Green Bank for far-field range measurements. The S-band feed was measured at the OATR during June 25-28, 2007. Since the distance to the transmit tower at the OATR is about 29’, all the measurements are in the near-field. Two circular-to-rectangular stepped transitions were designed and fabricated for the measurements. The low band (1.9-2.6 GHz) transition has ten steps and the high band (2.6-3.95 GHz) transition has nine steps. Each section was fabricated using EDM technology. The azimuth range was ±120° with 0.5° step. In the low band, patterns were recorded between 1.9 GHz and 2.6 GHz with 0.1 GHz spacing. In the high band, measurements were carried out from 2.5 to 4.1 GHz. Figure 9 shows the measured pattern at 2.4 GHz along with calculated far-field pattern. Also shown, is the near-field pattern calculated at a distance of about 29’. From the theoretical far-field, the coefficients of expansion in terms of transverse electric and transverse magnetic spherical waves are calculated. Backing up into the near field, the spherical wave expansion accurately calculates the transverse and radial components of the electric field. It is seen that the measured pattern follows the near-field pattern more closely compared to the far-field pattern. In Figures 10 and 11, which show patterns at 3 and 4 GHz, respectively, the match between the measured and calculated near-field patterns is again good. Figure 12 shows cross-polar patterns measured in the 45°-plane and the sidelobes are below -24.5 dB.

Return Loss Measurements:

The measurement of return loss of the C-band prototype feed was done in two bands: (i) 3.8-5.8 GHz and (ii) 5.7-8.2 GHz, with two calibrations of the vector network analyzer. Return loss of this feed is better than -22 dB over the 4-8 GHz band. At S-band, two different calibrations were performed using the two circular-to-rectangular transitions in the 1.9-2.6 GHz and 2.6-4.1 GHz ranges. Figure 13 shows the measured return loss of the S-band feed. At 2.0 GHz, the return loss is -18.8 dB. Return loss is better than -25 dB above 2.12 GHz. The blue trace in Figure 13 is the return loss of the feed with the radome installed. The S-band feed uses Esscolam10 radome from L-3 Communications ESSCO.

Aperture Efficiency and Spillover Temperature:

Using the measured far-field patterns of the half-scale feed, aperture efficiency and spillover temperature on the EVLA antenna were calculated. Aperture efficiency varies between 62% and 69.5% as indicated by the pink trace in Figure 14. It is assumed in this calculation that the feed phase center at each frequency is located at the secondary focus. Figure 15(a) shows spillover temperature as a function of elevation angle at different frequencies. At 2 GHz, the spillover temperature at 20º elevation is 23K. The S-band feed is located at the twelve o'clock position on the feed cone, when the antenna is pointed at horizon. At low elevation angles, the feed is pointed towards the ground and the feed spillover hits the ground resulting in elevated system temperature. Aperture efficiency and spillover of a linear taper horn, of about the same size as the profile horn, were calculated for comparison. The linear taper horn has broader beam at the low end of the band but at higher frequencies, the beam is narrower. Figure 15(b) shows the spillover of the linear taper horn. At 2 GHz, spillover temperature is about 15K for elevation angles above 30º. At the high end of the band, the linear taper horn has lower spillover temperatures. Aperture efficiency of the linear taper horn (blue trace in Figure 14) is marginally higher over most of the band.

Conclusion:

Measured patterns of the fabricated horns match well with theoretical patterns as indicated by the comparison of the far-field patterns of the half-size feed and the near-field patterns of the S-band feed. The feed has an average illumination taper of -12.5 dB at 9.3º. It also has excellent return loss characteristics over the entire 2-4 GHz band. Calculated aperture efficiency is higher than 62%. The linear taper horn compares favorably at the high end of the band while at lower frequencies, the profile horn has better performance. However, the profile horn has more uniform taper over the 2-4 GHz band and hence the decision to go with that design.

Acknowledgements:

The throat section of the half-scale prototype feed was fabricated at Standard Machine Shop, in Albuquerque, NM and the rest of the feed was machined at Johnson Brass and Machine Foundry, in Saukville, WI. The throat section of the S-band prototype feed was fabricated at Johnson Brass and Machine Foundry. The aluminum rings and bands making up the conventional corrugations of this feed were fabricated in the VLA machine shop. The laminating of the feed was carried out at LTC Corporation in Albuquerque, NM. D. Mertely and H. Dinwiddie arranged and assisted in measurements of both the prototype feeds. J. Wall operated the crane hoisting the feed up and down. T. Oakes, C. Dunlap, R. Davis, D. Monroy, T. Parsons, and J. Pomeroy performed the pattern measurements.

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 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. 19.

[3] S. Srikanth and J. Ruff, “Design, Prototyping and Measurement of EVLA C-Band Feed Horn,” NRAO EVLA Memo #95, August 9, 2005.

[4] J. Ruff, “Fiberglass Laminating EVLA C-, S- and L-band Feed Horns,” NRAO EVLA Project Specification No. 23665S001, Jan. 4, 2005.

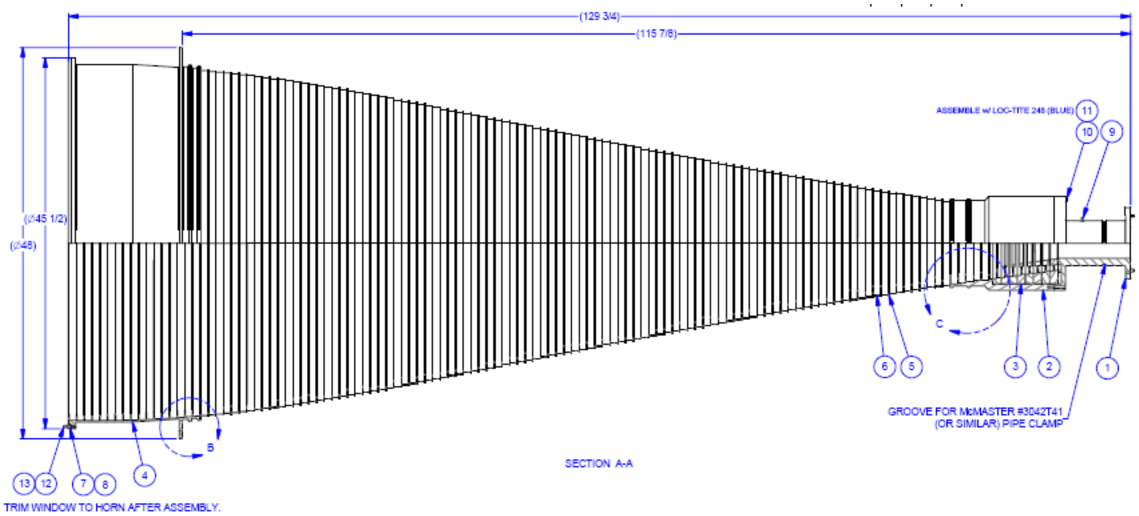
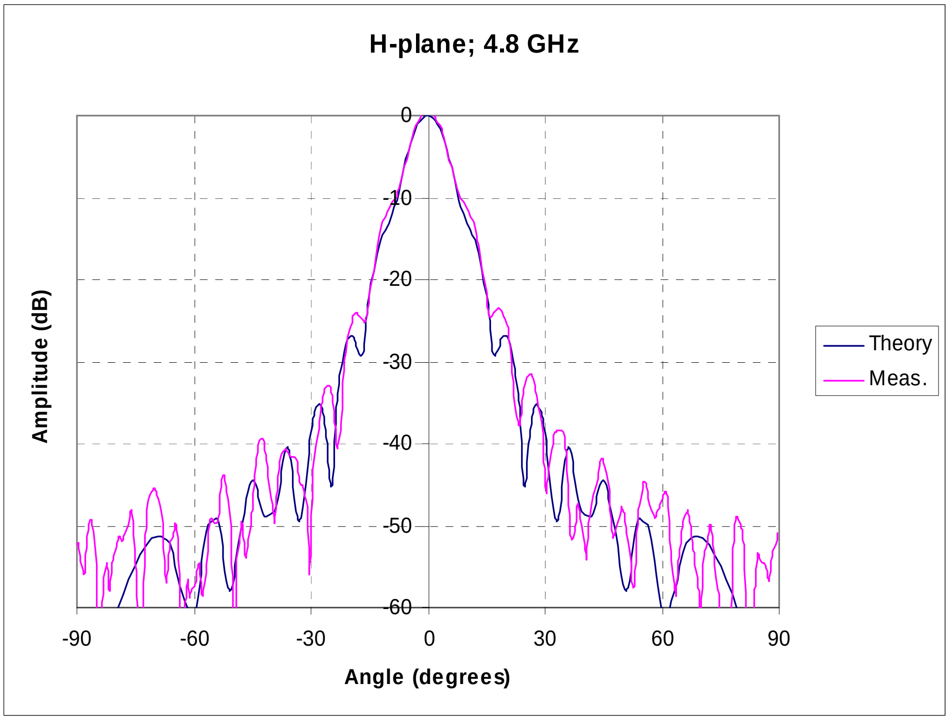
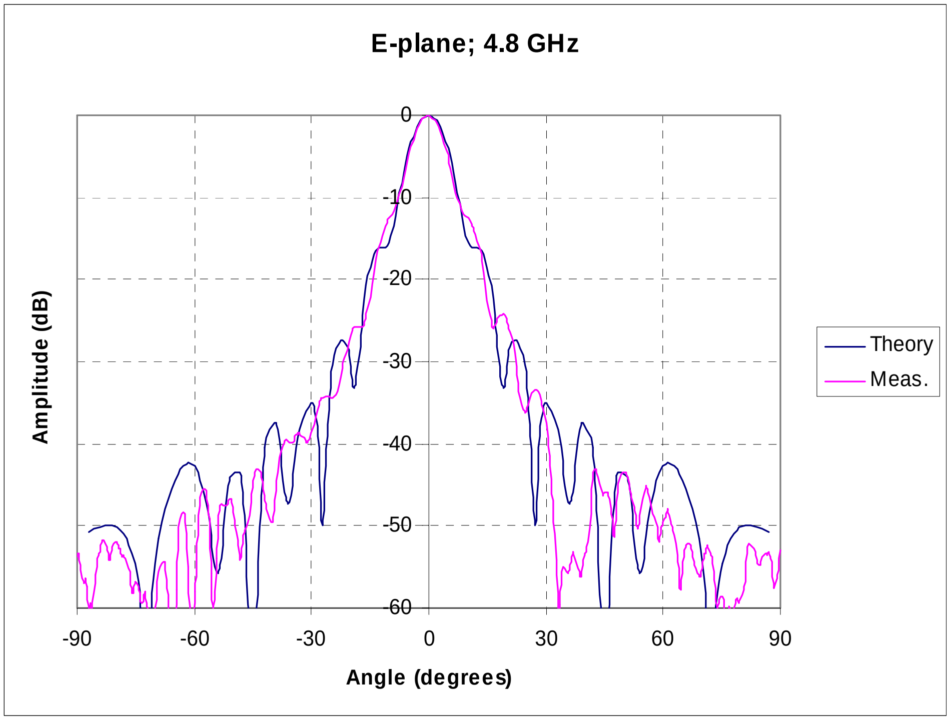


Figure 1. S-band feed horn

Figure 2. Range testing of S-band feed horn at OATR

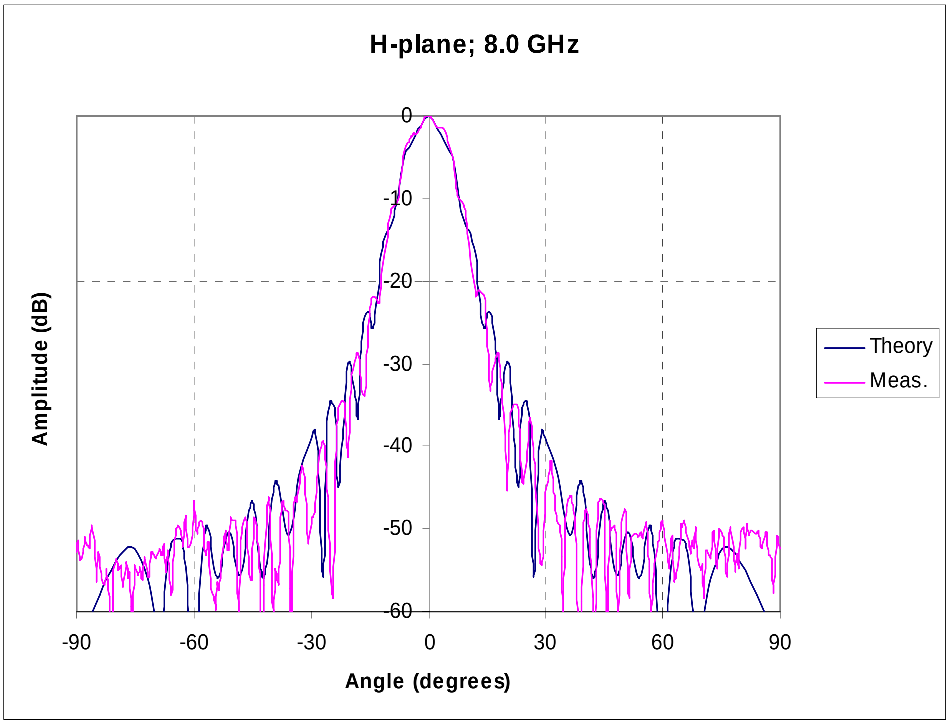


(a) H-plane

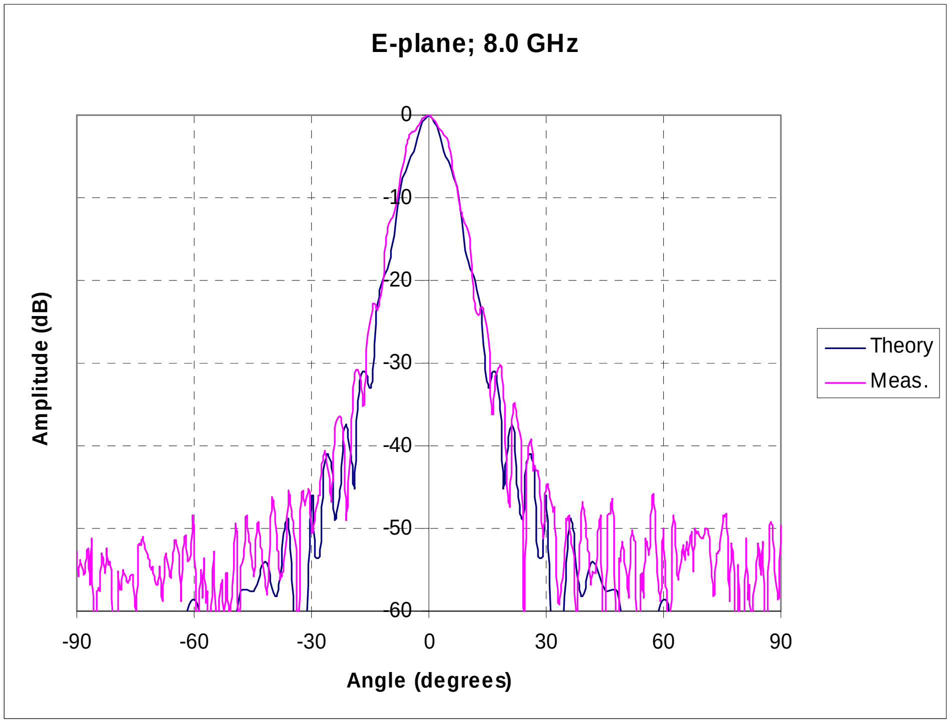


(b) E-plane

Figure 3. Far-field patterns: theory & measurement at 4.8 GHz



(a) H-plane



(b) E-plane

Figure 4. Far-field patterns: theory & measurement at 8.0 GHz

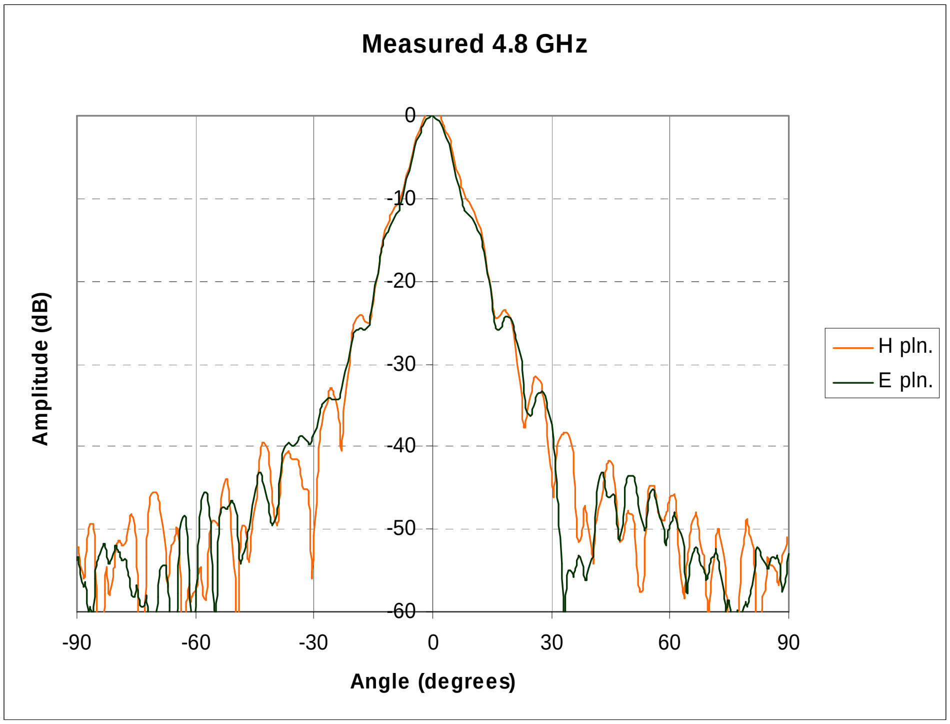


Figure 5. Far-field measured patterns at 4.8 GHz

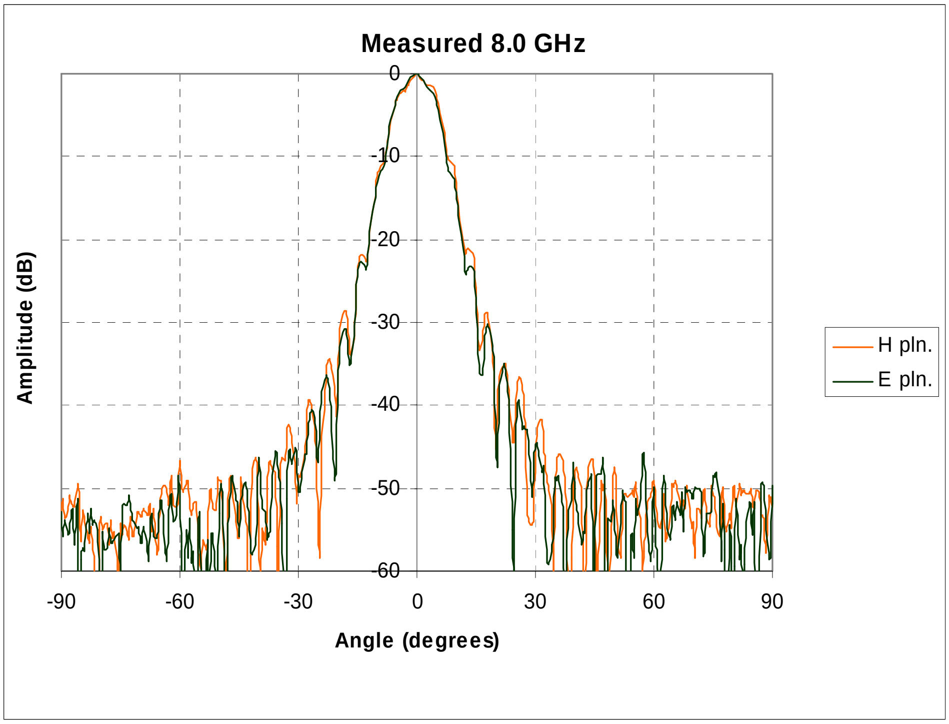
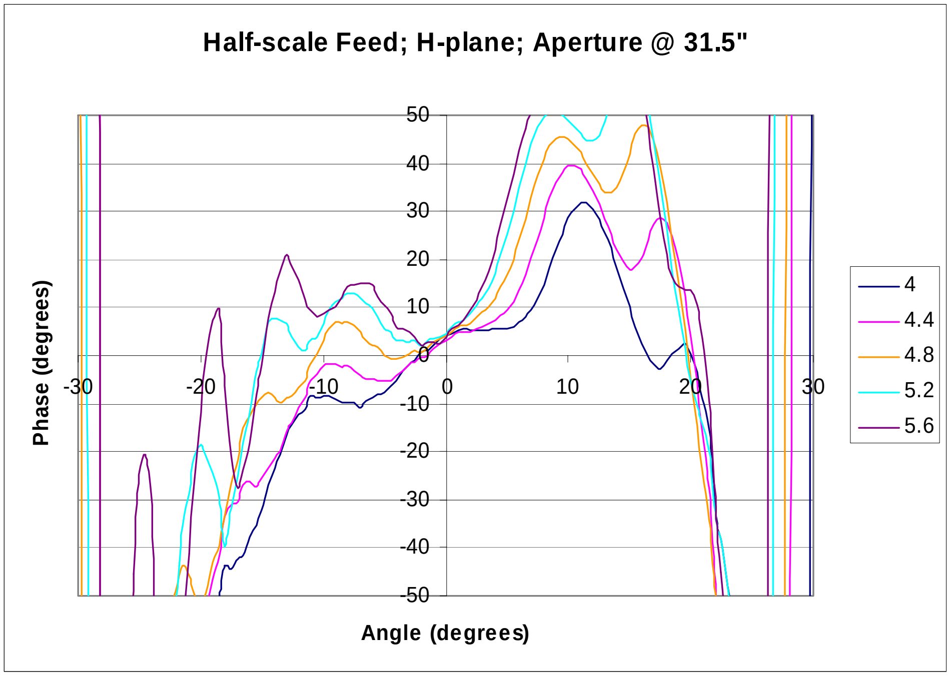
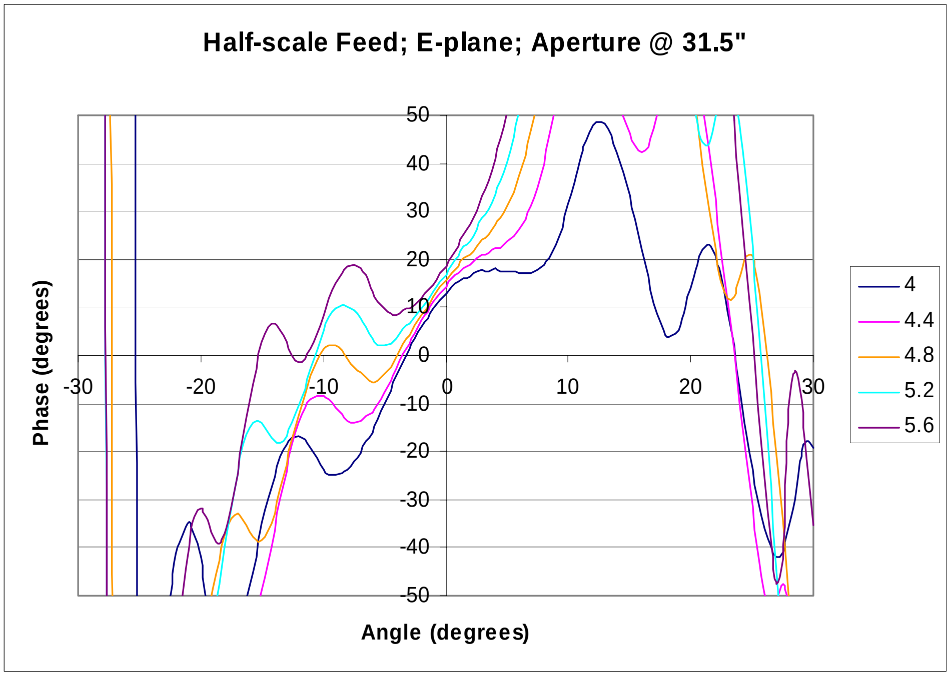


Figure 6. Far-field measured patterns at 8.0 GHz



(a) H-plane



(b) E-plane

Figure 7. Measured phase patterns with aperture 31.5” in front of the COR

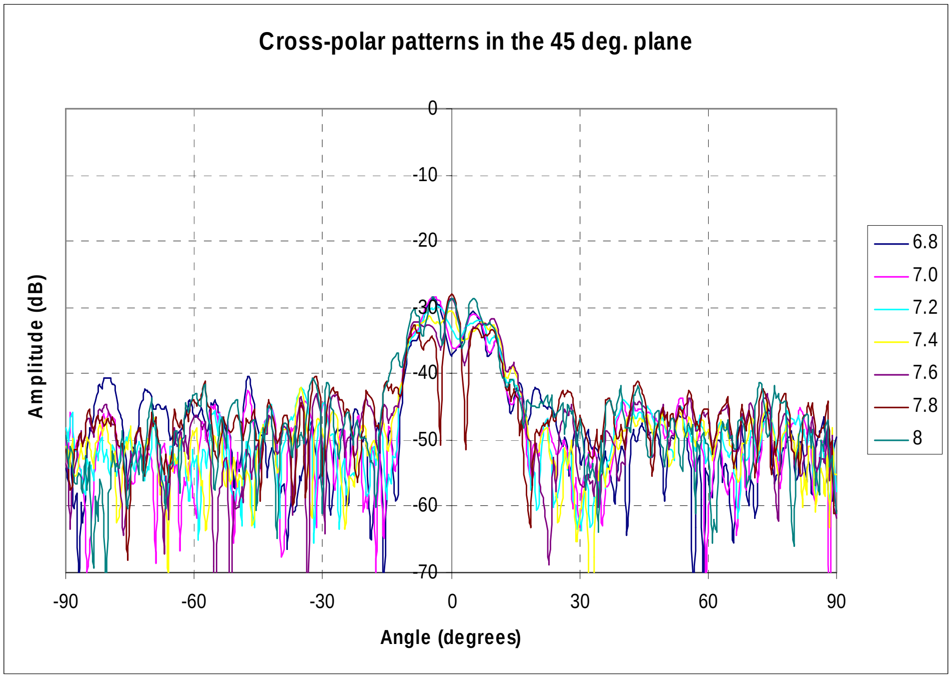
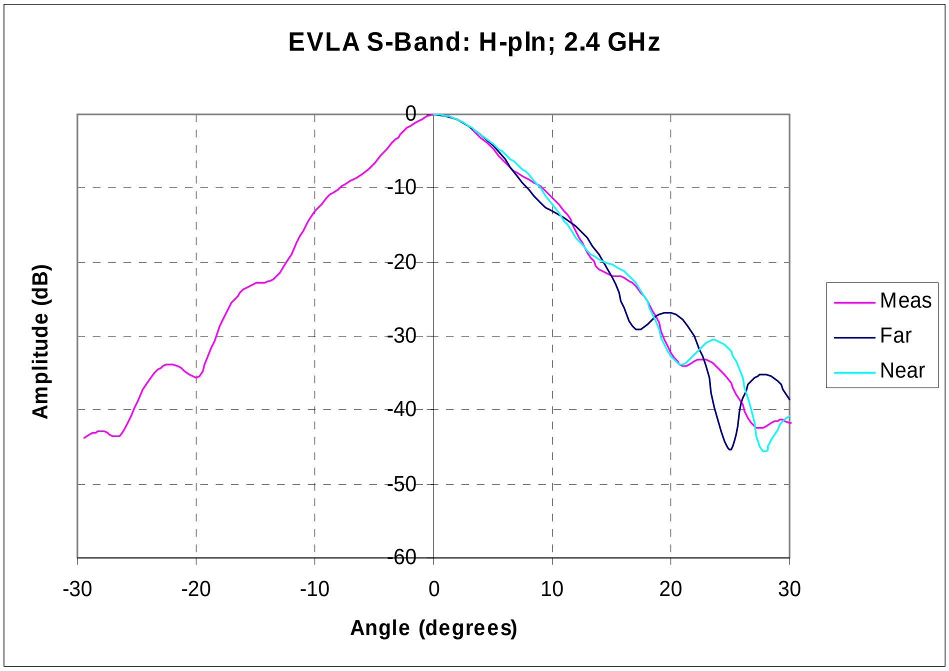


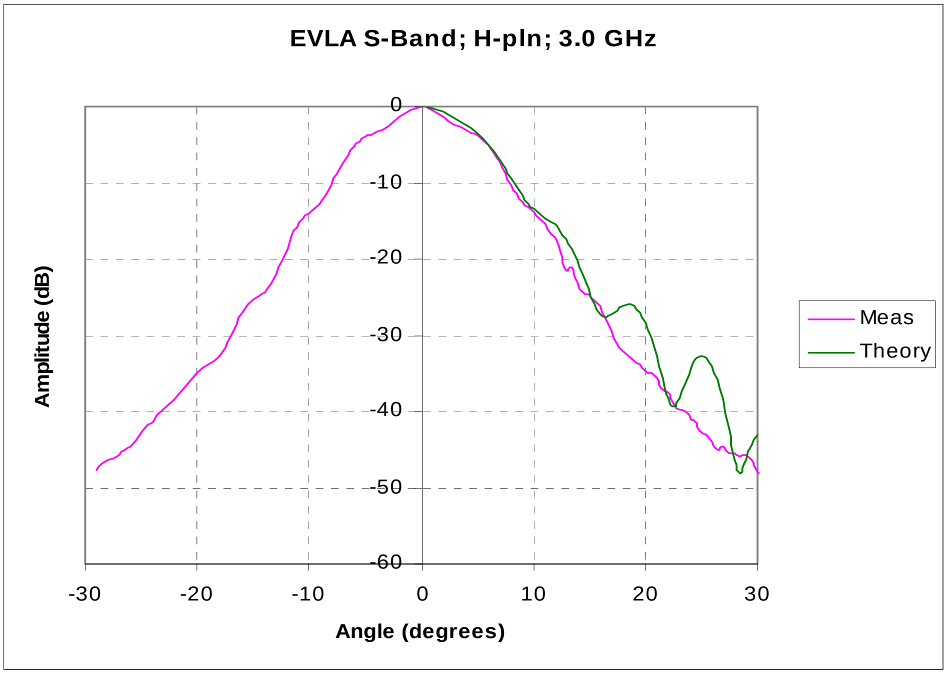
Figure 8. Cross-polar patterns in the 45°-plane



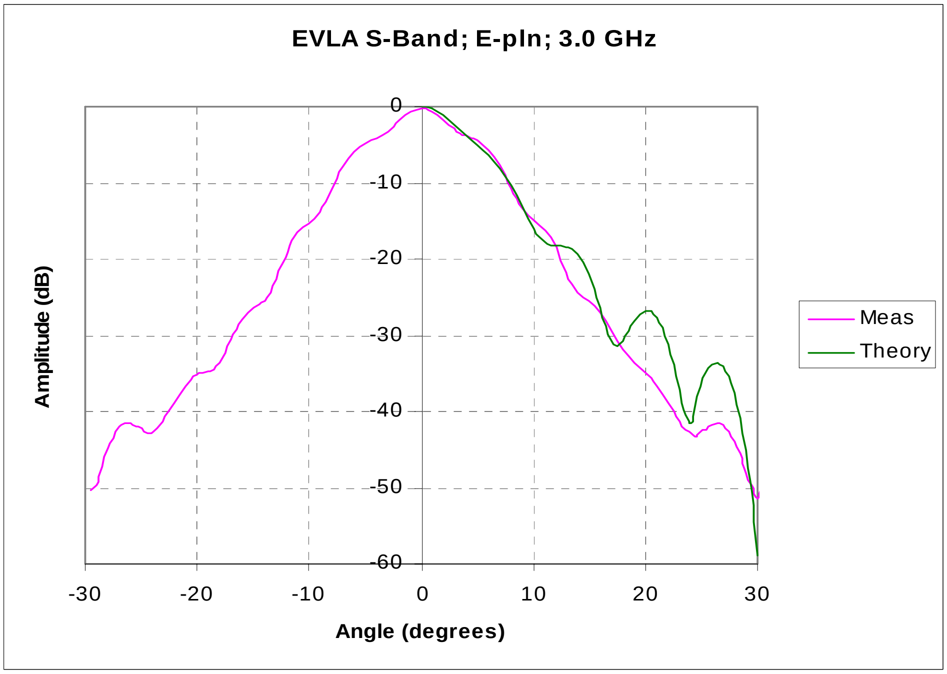
(a) H-plane

(b) E-plane

Figure 9. Far and near-field patterns at 2.4 GHz

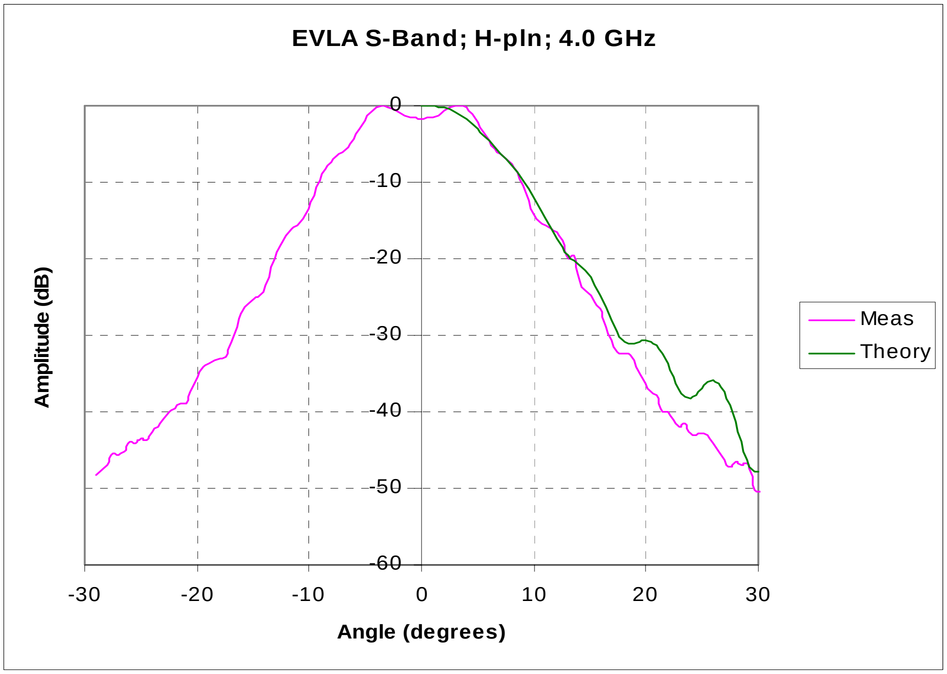


(a) H-plane

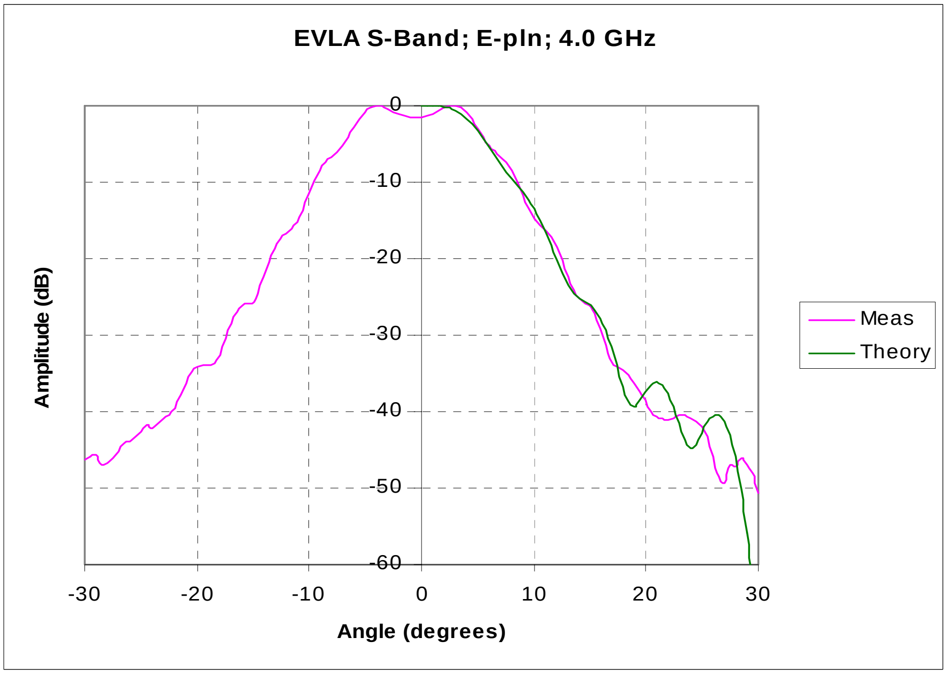


(b) E-plane

Figure 10. Near-field patterns at 3.0 GHz: measured and theory



(a) H-plane



(b) E-plane

Figure 11. Near-field patterns at 4.0 GHz: measured and theory

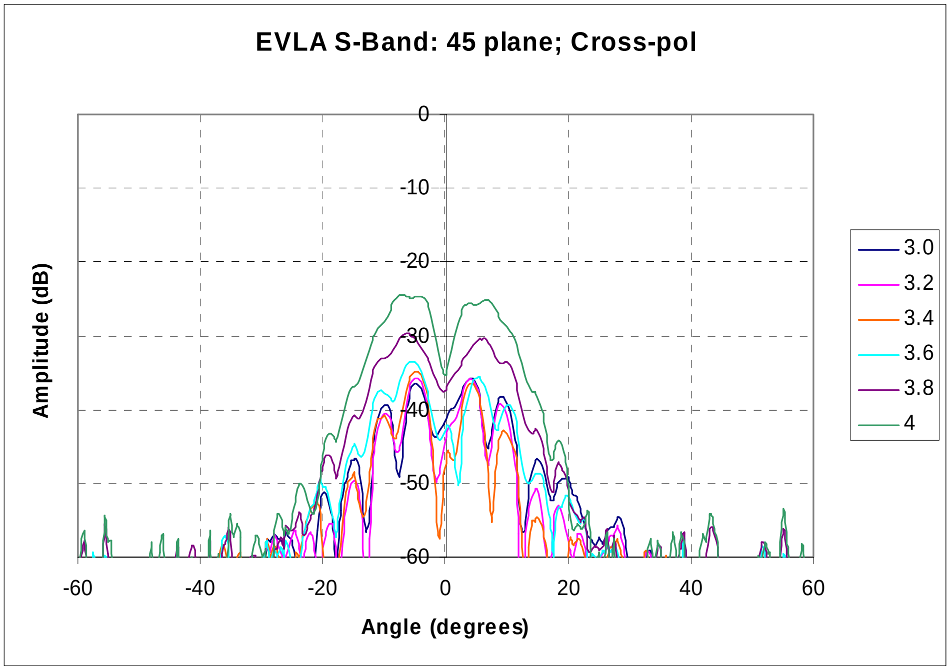


Figure 12. Cross-polar patterns in the 45º-plane

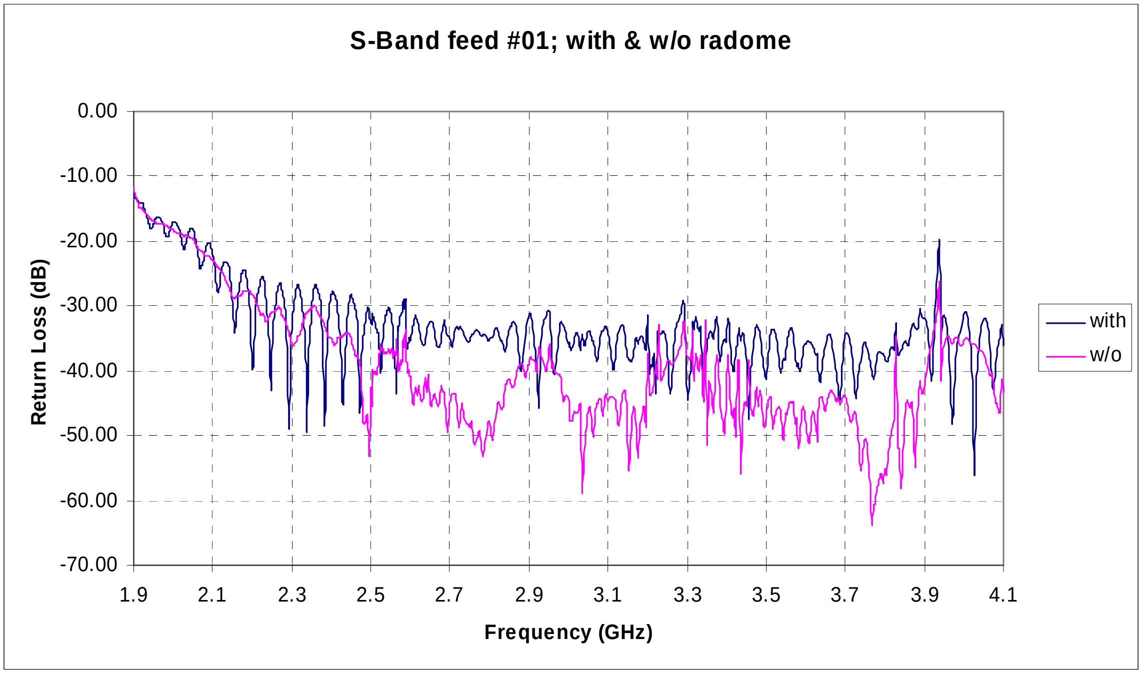


Figure 13. Measured return loss of S-band feed with and without radome

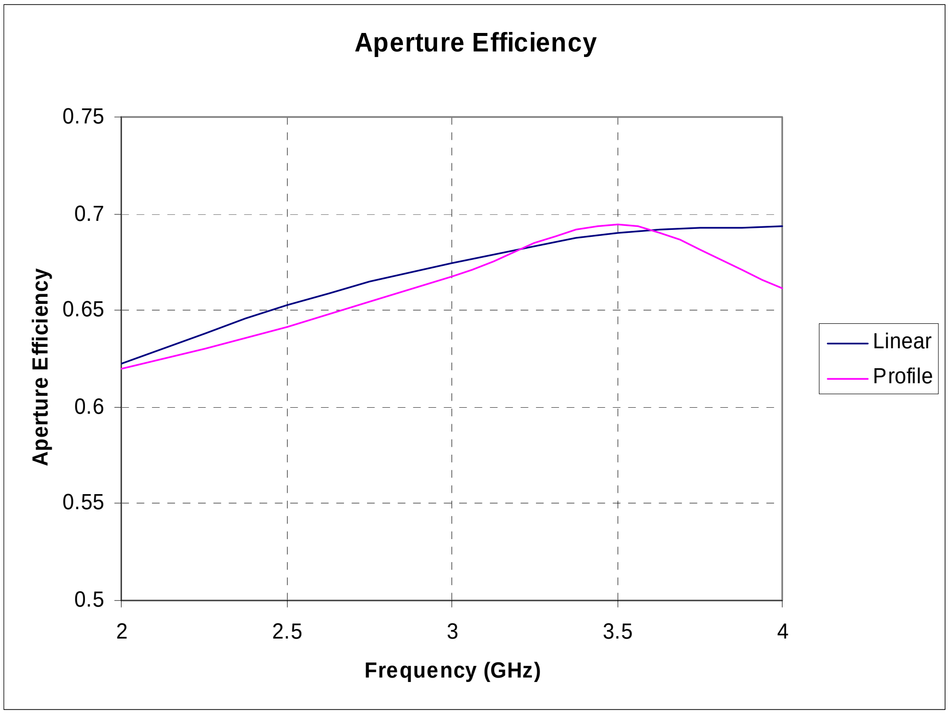
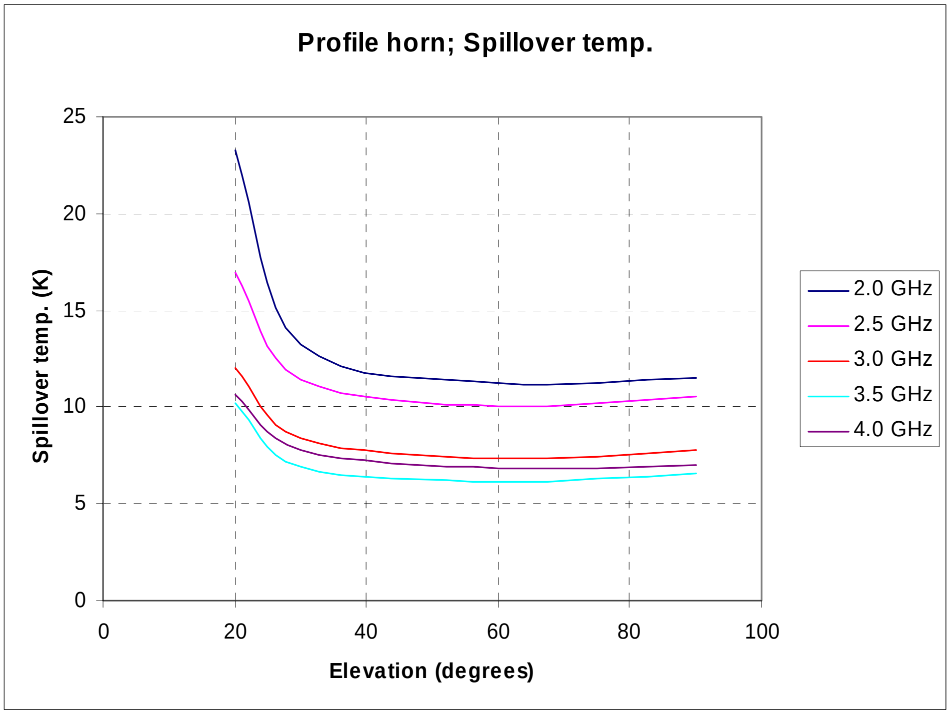
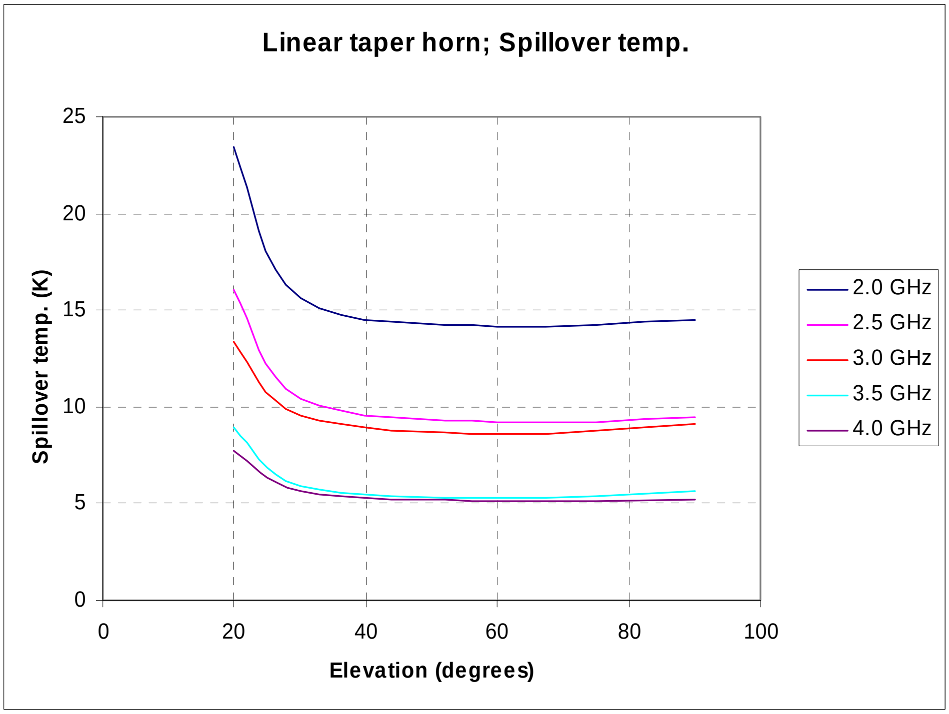


Figure 14. Calculated aperture efficiency of profile & linear taper horn



(a) Profile horn



(b) Linear taper horn

Figure 15. Spillover temperature vs. elevation angle