GBT MEMO 262

COMPARISON OF GBT K-BAND FEEDS
LINEAR TAPER HORNS AND PROFILE HORN

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The first generation K-band receiver on the GBT uses two sub-bands to cover the 18-26.5 GHz band. The sub-bands are 18-22 GHz and 22-26.5 GHz. The reason for dividing the band into two sub-bands was that there was no broad band polarizer available at that time to cover the full frequency range. Two linear taper horns centered at 20 GHz and 24.25 GHz, respectively, were designed to cover the two sub-bands. The illumination taper at the edge of the subreflector was specified at -13 dB. The receiver uses septum polarizers which are relatively narrow in bandwidth. The lower band horn (20 GHz) has an inside diameter (ID) of 5.55" (10.34λ), outside diameter (OD) of almost 6" at the horn aperture and is 9.76" long. The upper band horn (24 GHz) has an ID of 4.54" (9.32λ), OD of 4.93" and length of 8". The horn flare angle is 17.5˚ and each horn has a total of 80 corrugations. The mode converter has 8 corrugations where the taper angle is 8˚. In the mode converter, the depth of the corrugations changes from about 0.5λ at the input to 0.25λ at the output of the converter.

The development of full waveguide band phase shifters and orthomode transducers in the mid 90s had made it possible to build broad band receivers for the EVLA. The 18-26.5 GHz and 26-40 GHz receivers are typical examples. The K-band components used on the EVLA receiver have been instrumental in the development of the K-band Focal Plane Array (KFPA) receiver for the GBT. If wide band linear taper horns are used on the KFPA receiver, the element spacing would be 6". This would have resulted in a beam spacing of 4.1 half-power beam widths (HPBW) at 18 GHz and 5.7 HPBWs at 26.5 GHz. In order to keep the beam spacing smaller, profile taper (compact) horn was chosen as the feed element. The ID of this horn is 2.93" at the aperture and the OD is 3.4". This horn is 6.7" long and has a total of 86 corrugations. In order to achieve a wider bandwidth (1.47:1), ring-loaded corrugations are used in the mode converter. The beam spacing varies between 2.3 and 3.2 HPBWs in the 18 to 26.5 GHz range.

Measured far-field patterns of the profile horn are overlaid on that of the 20 GHz linear taper horn in Figures 1, 2 and 3 at 18 GHz, 22 GHz and 26.5 GHz, respectively. The measured patterns of the 24 GHz horn are compared with those of the profile horn at 22 GHz, 24 GHz and 26.5 GHz in figures 4 through 6. The linear taper horns were measured in the outdoor antenna range at Green Bank. The dynamic range of this antenna range is only about 50 dB. The profile horn was measured in the Green Bank Anechoic Chamber antenna range. This range has better than 70 dB dynamic range.

Beam patterns of the GBT were calculated using the measured patterns of the linear taper horns and the profile horn. A dual-reflector analysis program was used in the computations. The subreflector scattered pattern is calculated using geometric theory of diffraction (GTD) and the secondary beam of the telescope is calculated by aperture integration (AI). Feed patterns measured in the two principal planes were used. The beams of the GBT in the symmetric plane for the 20 GHz linear taper horn and the profile horn are shown in figures 7, 8 and 9. At 18 GHz, the peaks of the two beams are nearly equal. At 20 GHz and 22 GHz, the linear taper horn yields higher gain. Figures 10, 11 and 12 show the GBT beams calculated at 22 GHz, 24 GHz and 26.5 GHz, respectively, for the 24 GHz linear taper horn and the profile horn. Aperture efficiency and HPBW for the linear taper horns and the profile horn are listed in Tables 1 and 2. The illumination taper at the edge of the subreflector is also shown. The last column in the two tables shows the difference in efficiencies between the two horns. At 18 GHz, aperture efficiency for the two cases is about the same. However, at higher frequencies the linear taper horns result in higher aperture efficiency in the range of 9-10%.

Another parameter used in this memo to compare the linear taper horn and profile horn, is the beam efficiency.

The beam efficiency (η_b) of an antenna is defined as

$$\text{Beam efficiency} = \frac{\text{Power radiated in cone angle of } \theta_1}{\text{Power radiated in } 4\pi \text{ sr}}$$

The angle θ_1 is arbitrary, and can be the angle at the -3 dB level of the beam or the angle at the first null, as the case may be. Table 3 shows the beam efficiencies of the horns at an angle of 15˚, which is the half-angle subtended by the subreflector from the secondary focus. Measured feed patterns in the principal planes were used in this calculation. Feed patterns were available only in the ±120˚. The error in not integrating up to π radians is negligible. The 20 GHz horn has about 3-4% higher efficiency, while the 24 GHz horn has about 1% higher efficiency compared to the profile horn.

The telescope beam efficiency for the two types of horns was also calculated. Here the integration was carried out on the computed beam of the GBT. The angle θ_1 used in the calculation is the angle at which the first null occurs. The angle of the first null for the linear taper horn is greater than that for the profile horn at 18 GHz (Figure 7). For all the other cases (figures 8-12), the first null for the linear taper horn is at a smaller angle. Table 4 shows the beam efficiency of the GBT beam for the 20 GHz horn and the profile horn. The angle θ_1 used in all the cases is the angle of the null for the linear taper case. Beam efficiency at the angle of the null for the profile horn case is also listed. At 18 GHz, the beam for the linear taper horn has higher η_b (0.42%) while at 20 and 22 GHz, η_b is smaller for the linear taper beam. At 18 GHz (Figure 7), the beam for the linear taper horn has a lower average side lobe level, which results in the higher $\eta_{b.}$ Table 5 shows the GBT beam efficiency for the 24 GHz horn and the profile horn. Here the difference between the two cases varies between -1.2% and 0.6%.

Table 1. Aperture Efficiency (η_{ap}) and HPBW; 20 GHz Horn vs. Profile Horn

Frequency (GHz)	Linear taper			Profile			$\frac{\eta_{apl} - \eta_{app}}{\eta_{apl}}$ (%)
	Edge Taper (dB)	HPBW (“)	η_{apl}	Edge Taper (dB)	HPBW (“)	η_{app}	
18	-12.64	40.9	0.6995	-11.45	40.4	0.6965	0.43
20	-12.23	36.7	0.7284	-13.41	37.4	0.6560	9.94

22	-14.07	34.0	0.6888	-13.95	34.6	0.6189	10.15

Table 2. Aperture Efficiency (η_{ap}) and HPBW; 24 GHz Horn vs. Profile Horn

Frequency (GHz)	Linear taper			Profile			$\frac{\eta_{apl} - \eta_{app}}{\eta_{apl}}$ (%)
	Edge Taper (dB)	HPBW (“)	η_{apl}	Edge Taper (dB)	HPBW (“)	η_{app}	
22	-12.10	33.3	0.6770	-13.95	34.6	0.6189	8.58
24	-12.58	30.7	0.6669	-13.48	31.8	0.6050	9.28
26.5	-12.46	28.1	0.6456	-14.32	29.2	0.5864	9.17

Table 3. Horn Beam Efficiency (η_b) at 15˚

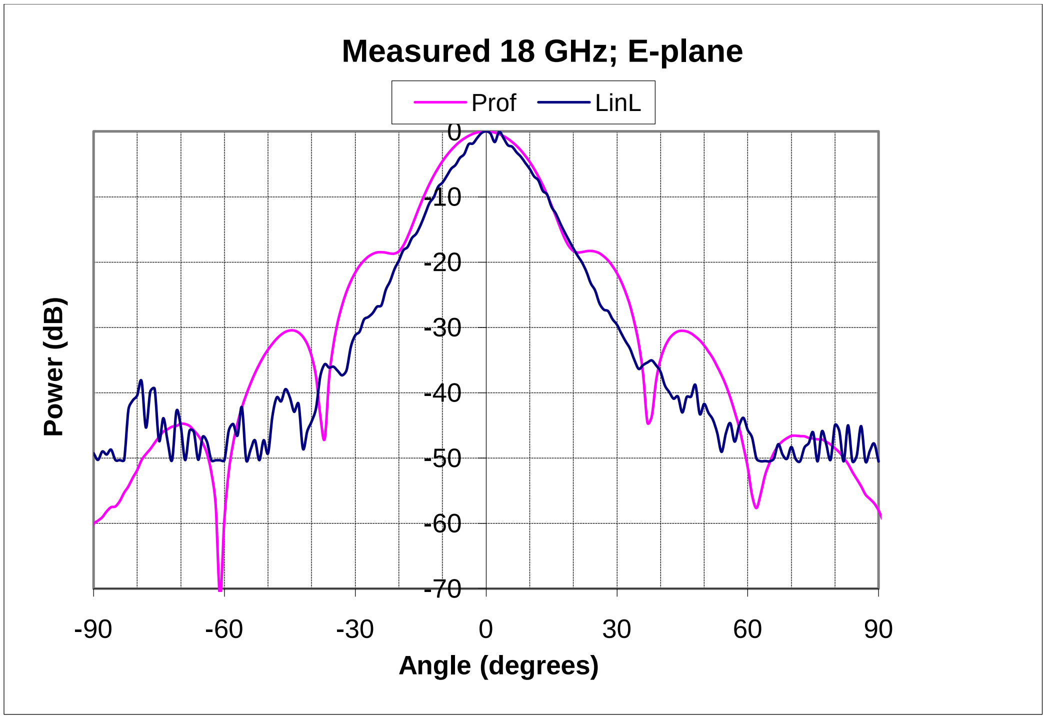
Lower band			Upper band		
Frequency (GHz)	Linear taper Horn (η_b)	Profile horn (η_b)	Frequency (GHz)	Linear taper Horn (η_b)	Profile horn (η_b)
18	0.9081	0.8749	22	0.8966	0.8802
20	0.9161	0.8777	24	0.8994	0.8897
22	0.9407	0.8802	26.5	0.9198	0.9210

Table 4. GBT Beam Efficiency (η_b) **at the first null**

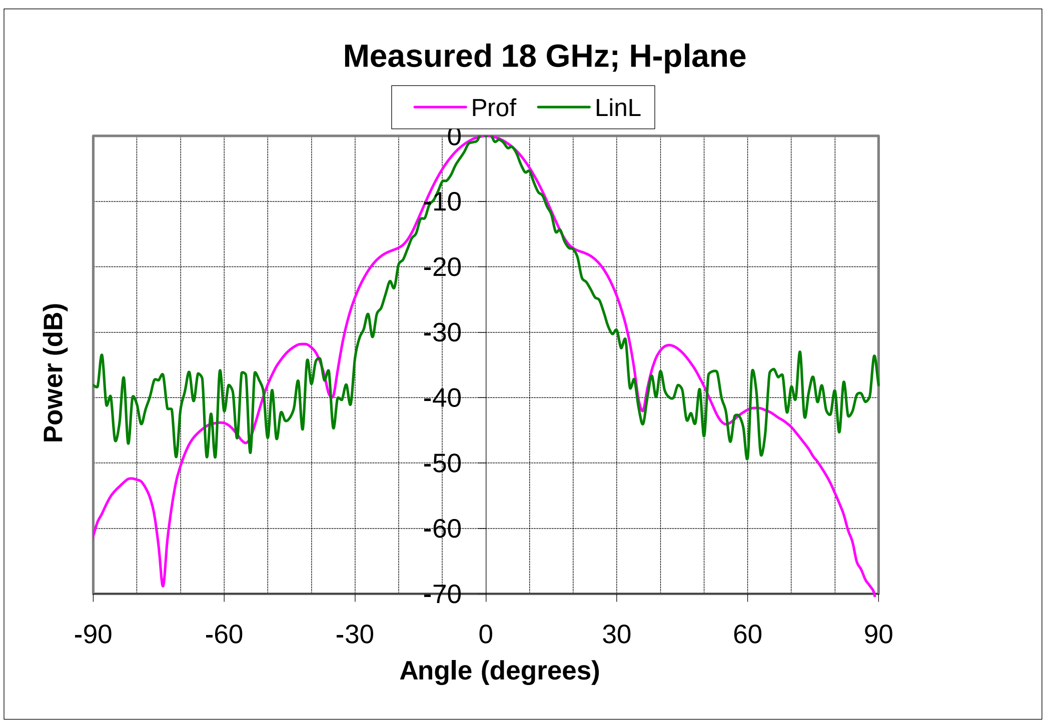
Frequency (GHz)	Linear taper horn (20 GHz)		Profile horn	
	Angle of null (degrees)	(η_b)	Angle (degrees)	(η_b)
18	0.0150	0.9807	0.0144 (null) 0.0150	0.9766 0.9767
20	0.0138	0.9800	0.0138 (null)	0.9864
22	0.0130	0.9859	0.0130 0.0132 (null)	0.9907 0.9907

Table 5. GBT Beam Efficiency (η_b) **at the first null**

Frequency (GHz)	Linear taper horn (24 GHz)		Profile horn	
	Angle of null (degrees)	(η_b)	Angle (degrees)	(η_b)
22	0.0124	0.9793	0.0124 0.0132 (null)	0.9906 0.9767
24	0.0116	0.9811	0.0116 0.0126 (null)	0.9878 0.9880
26.5	0.0106	0.9849	0.0106 0.0118 (null)	0.9794 0.9812

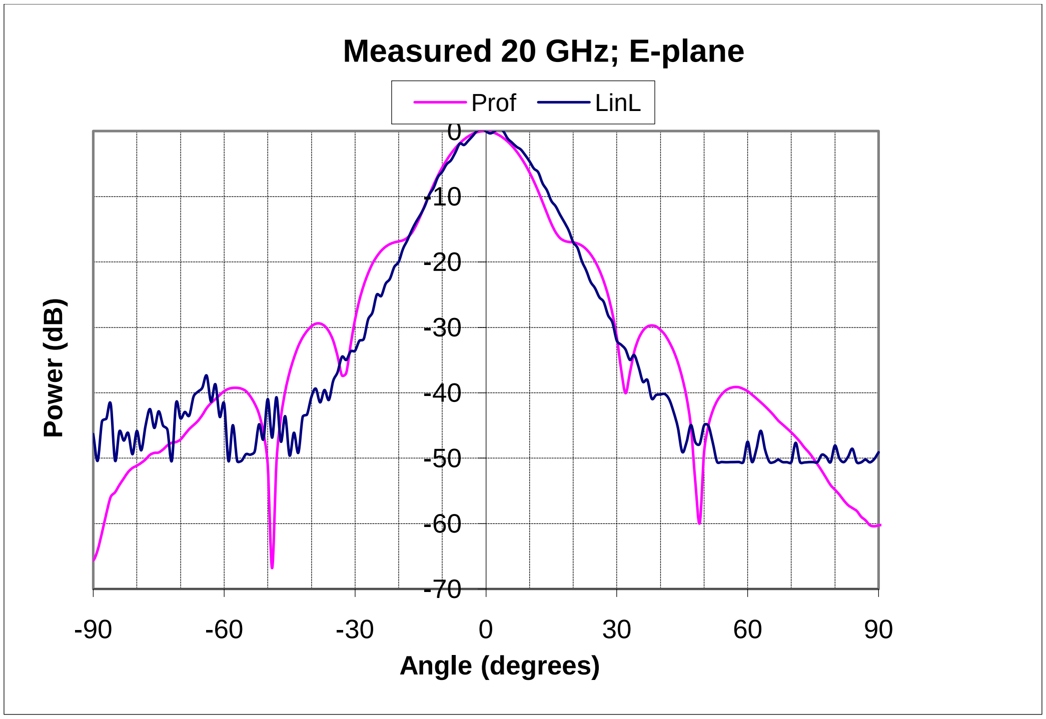


(a) E-plane

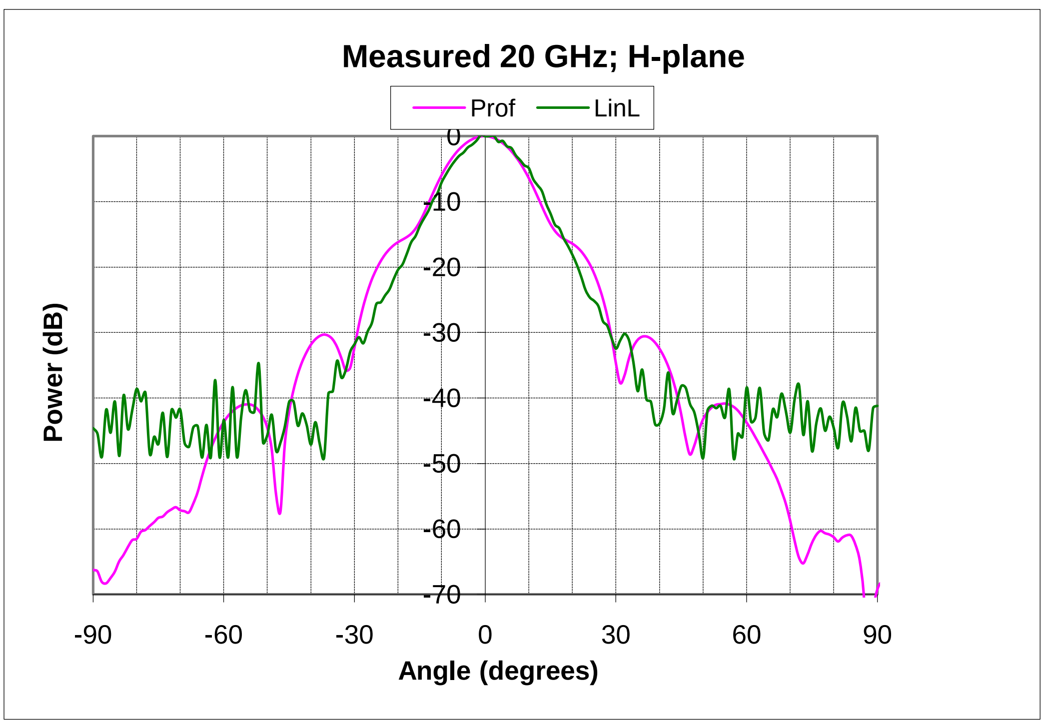


(b) H-plane

Figure 1. Far-field patterns at 18 GHz of Profile horn and 20 GHz linear taper horn

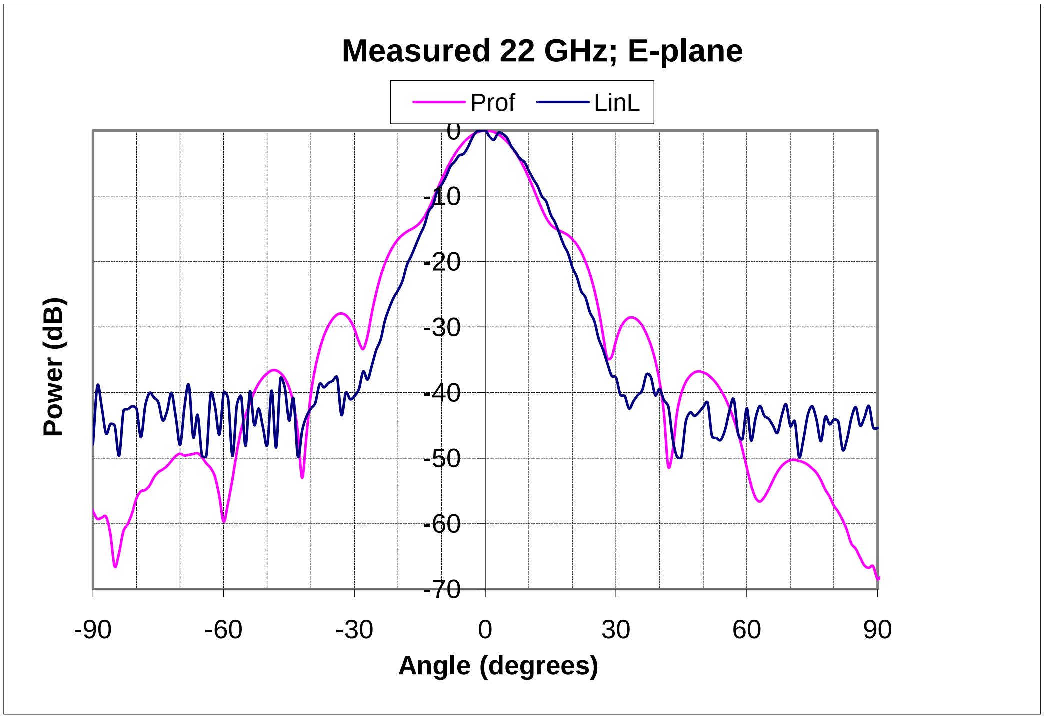


(a) E-plane



(b) H-plane

Figure 2. Far-field patterns at 20 GHz of Profile horn and 20 GHz linear taper horn



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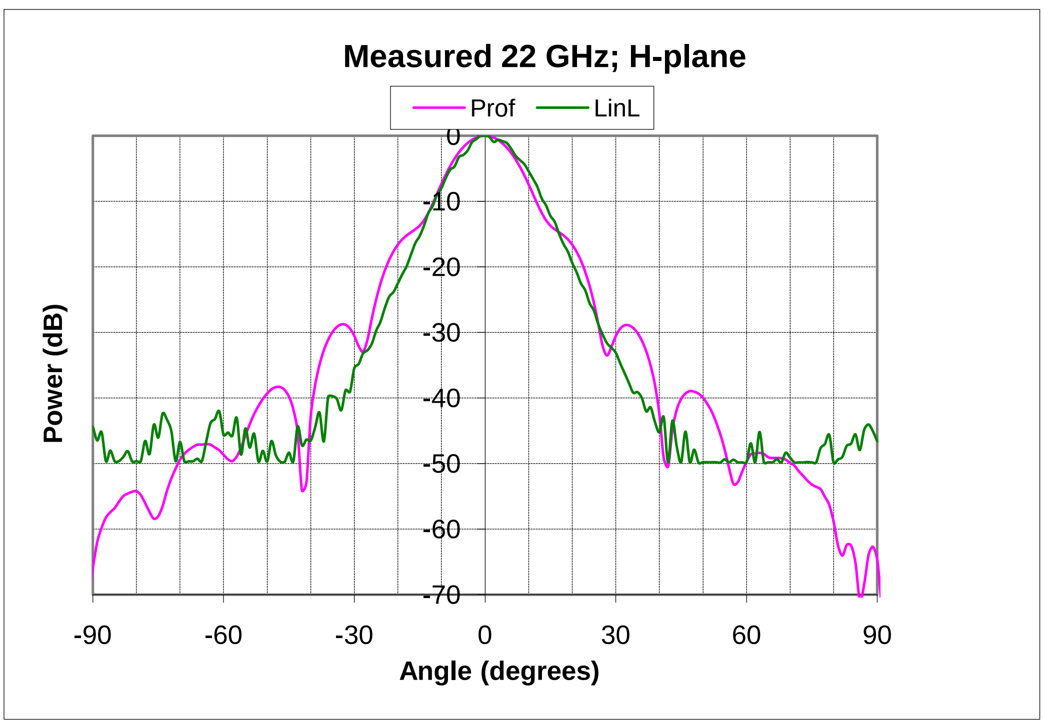
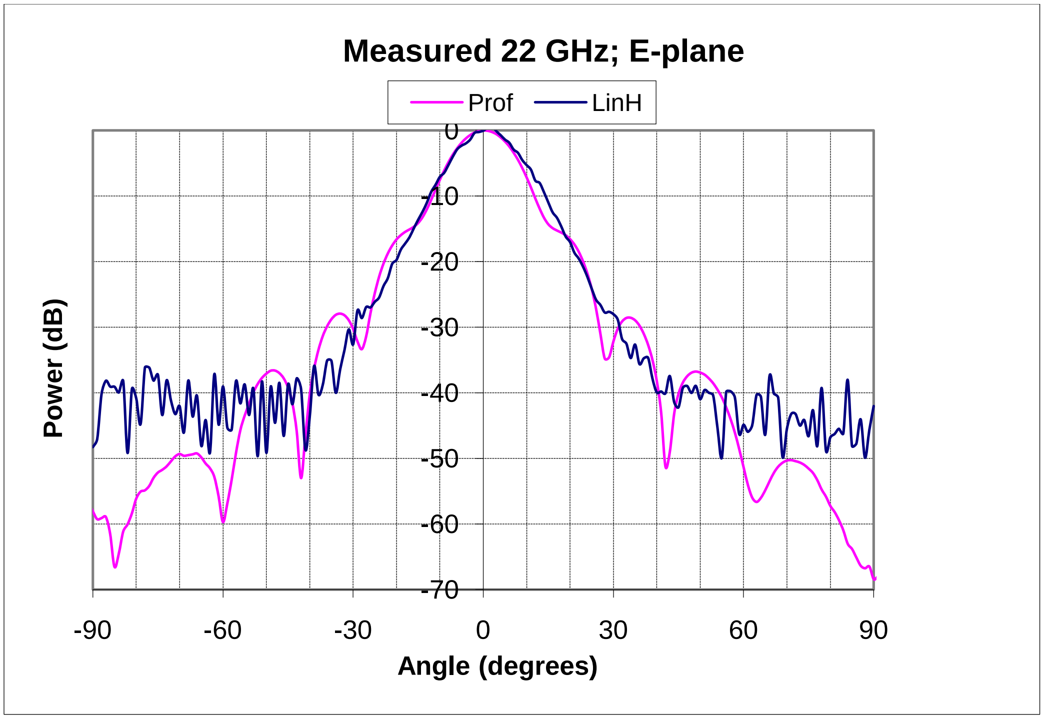
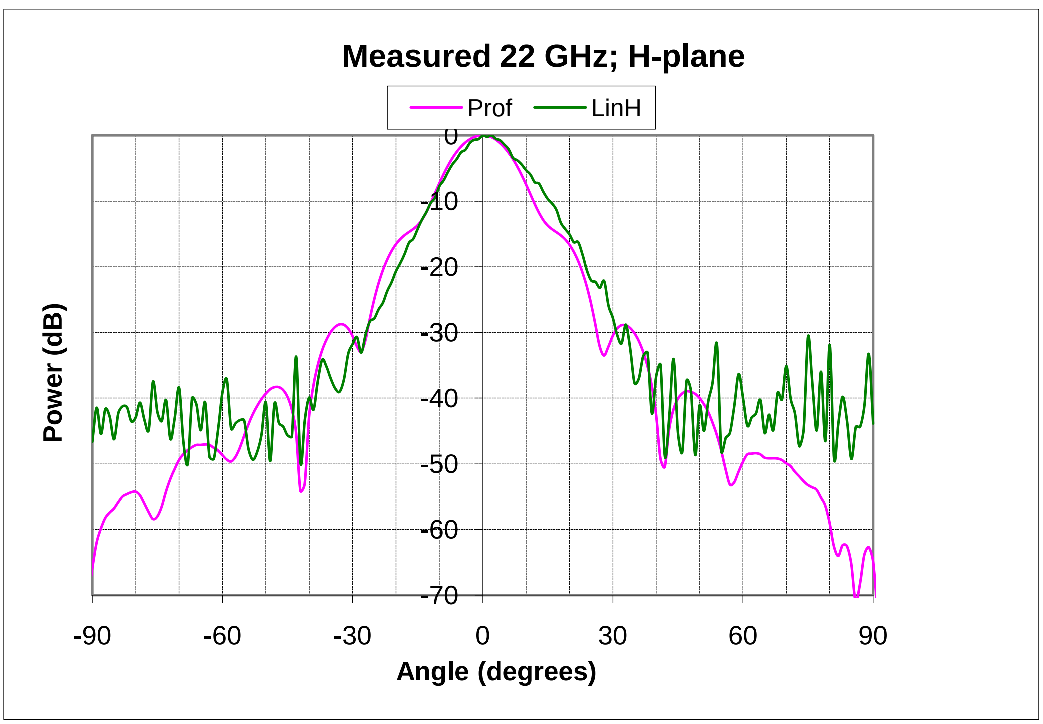


(b) H-plane

Figure 3. Far-field patterns at 22 GHz of Profile horn and 20 GHz linear taper horn

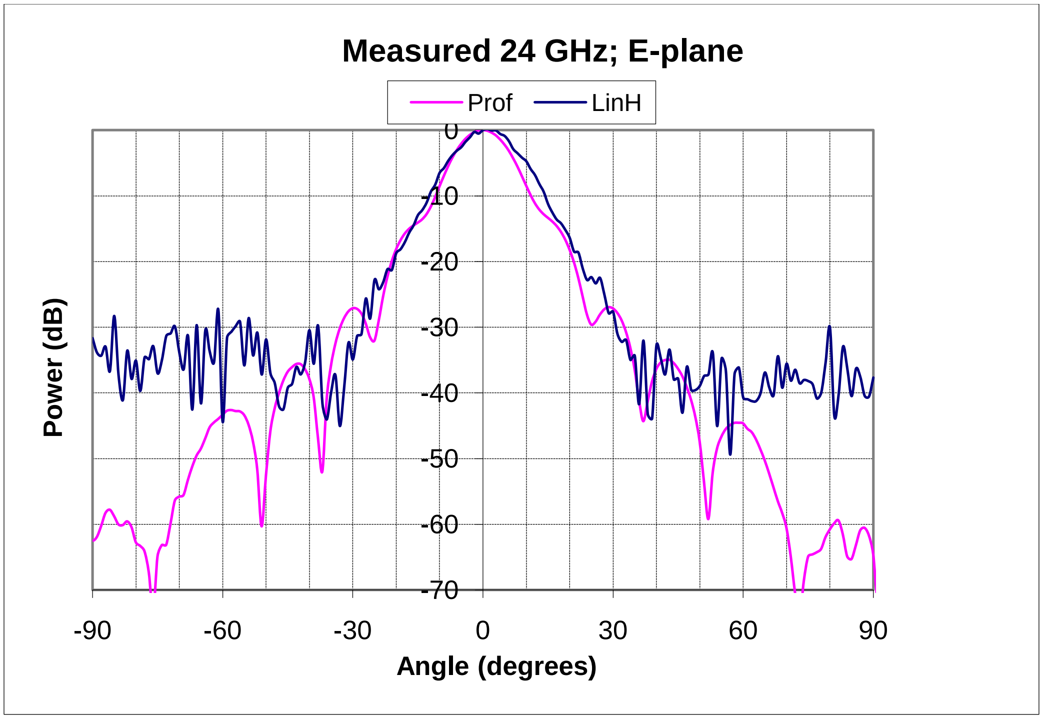


(a) E-plane

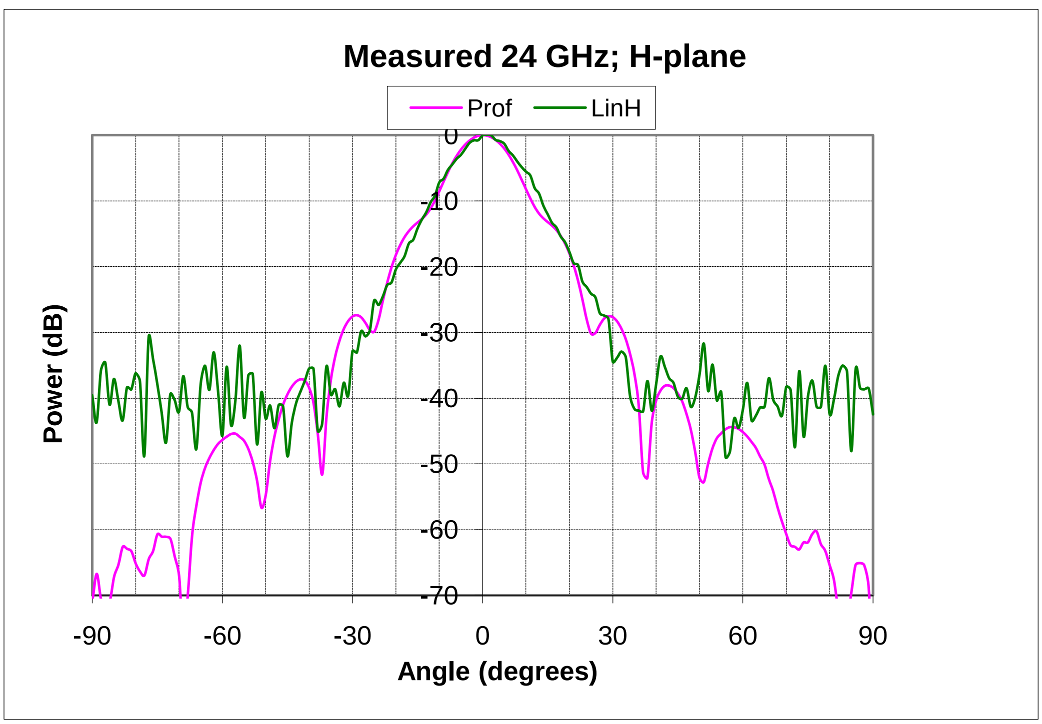


(b) H-plane

Figure 4. Far-field patterns at 22 GHz of Profile horn and 24 GHz linear taper horn

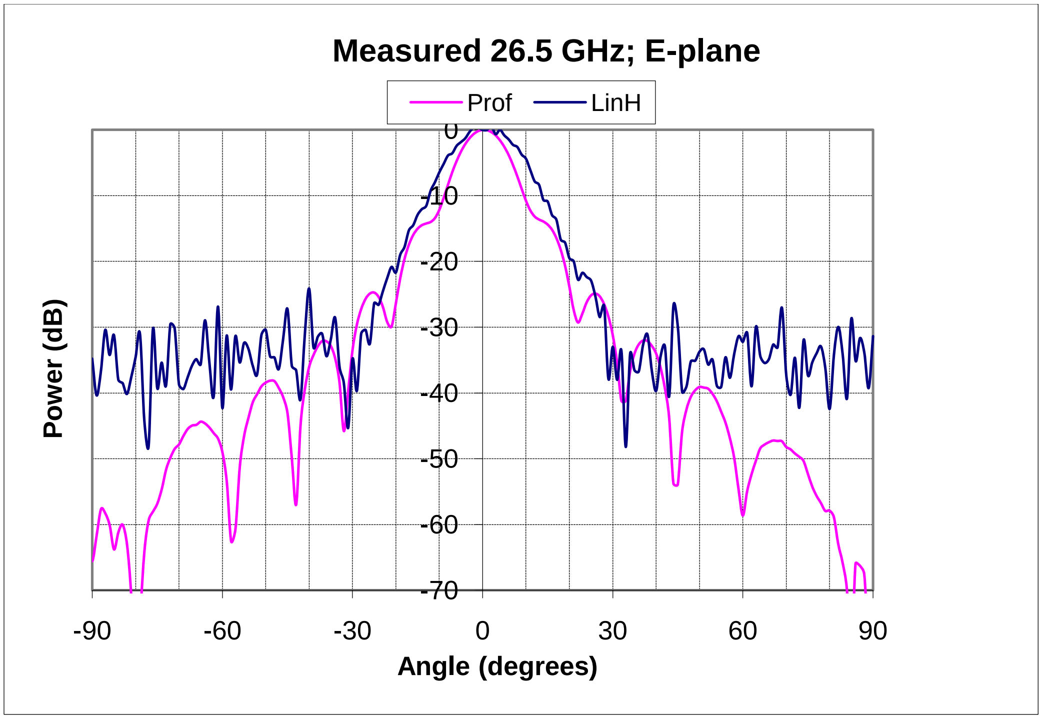


(a) E-plane

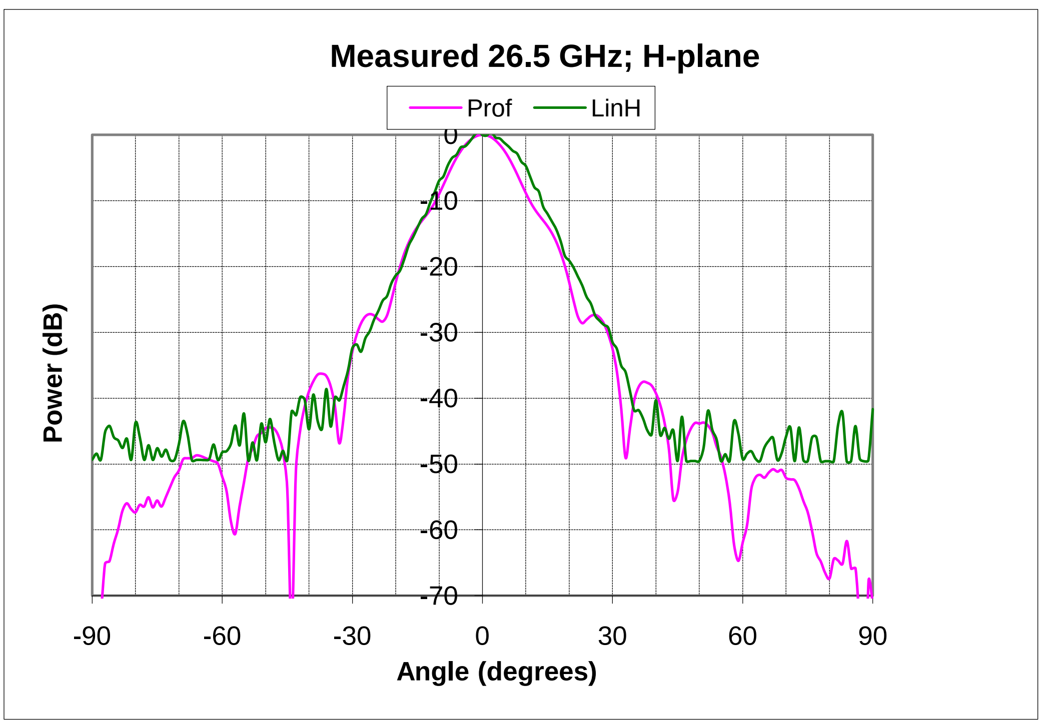


(b) H-plane

Figure 5. Far-field patterns at 24 GHz of Profile horn and 24 GHz linear taper horn



(a) E-plane



(b) H-plane

Figure 6. Far-field patterns at 26.5 GHz of Profile horn and 24 GHz linear taper horn

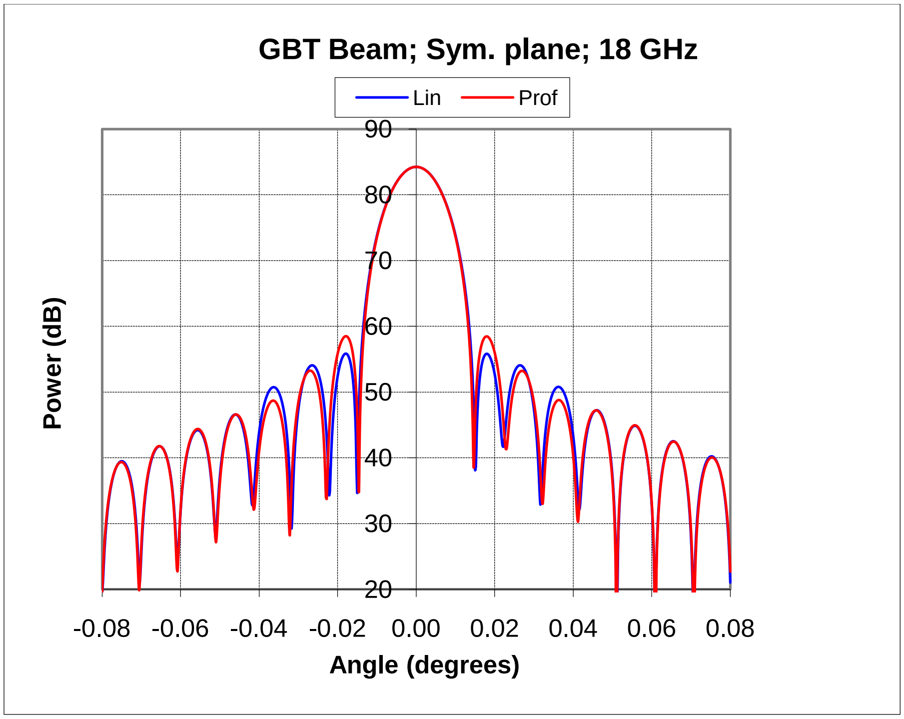


Figure 7. GBT beams at 18 GHz; Profile horn, 20 GHz horn

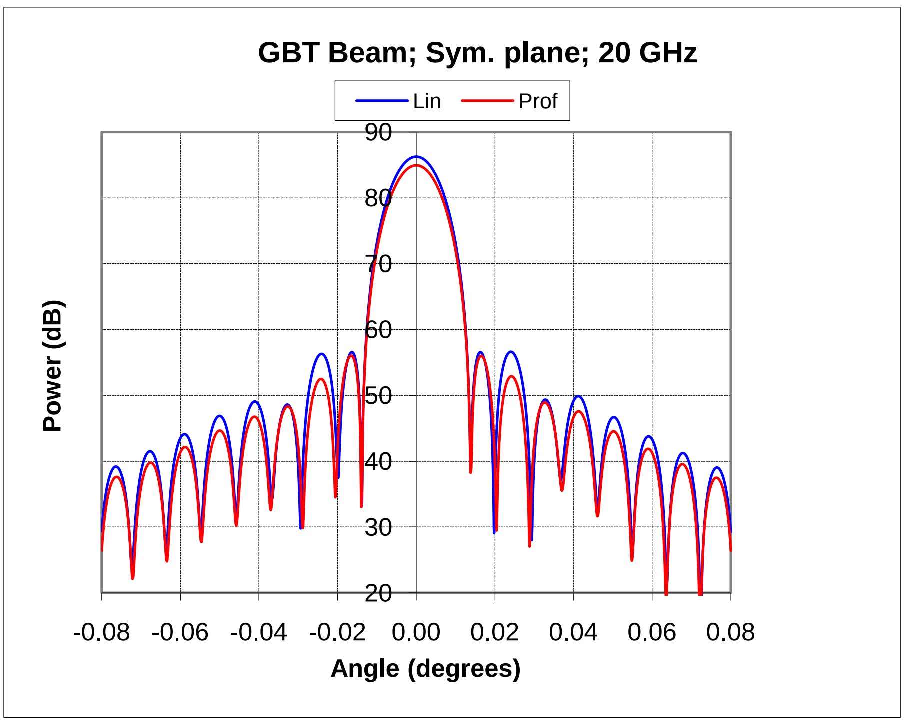


Figure 8. GBT beams at 20 GHz; Profile horn, 20 GHz horn

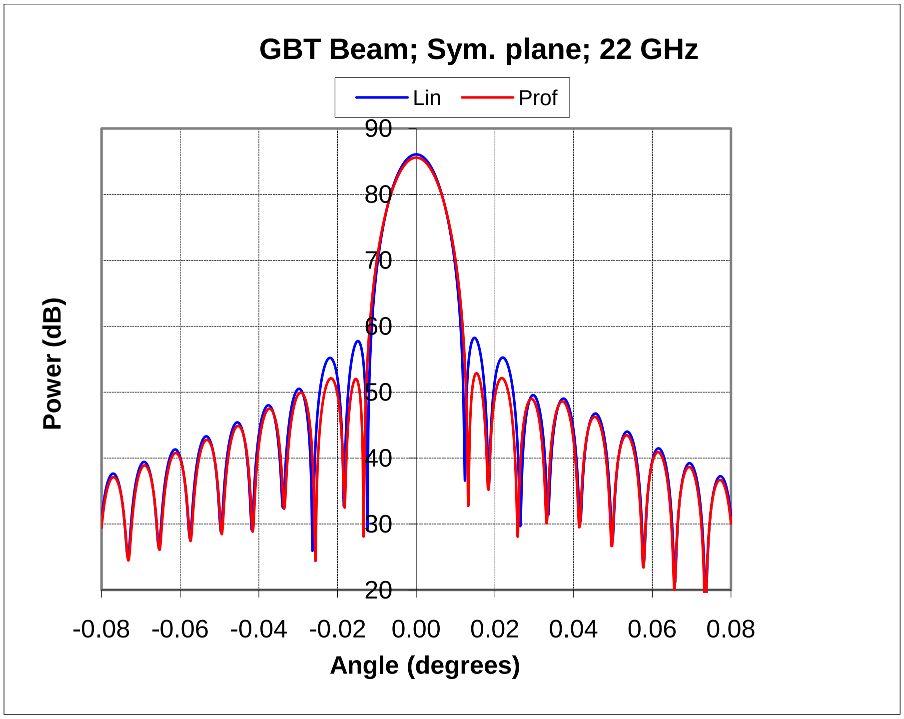


Figure 9. GBT beams at 22 GHz; Profile horn, 20 GHz horn

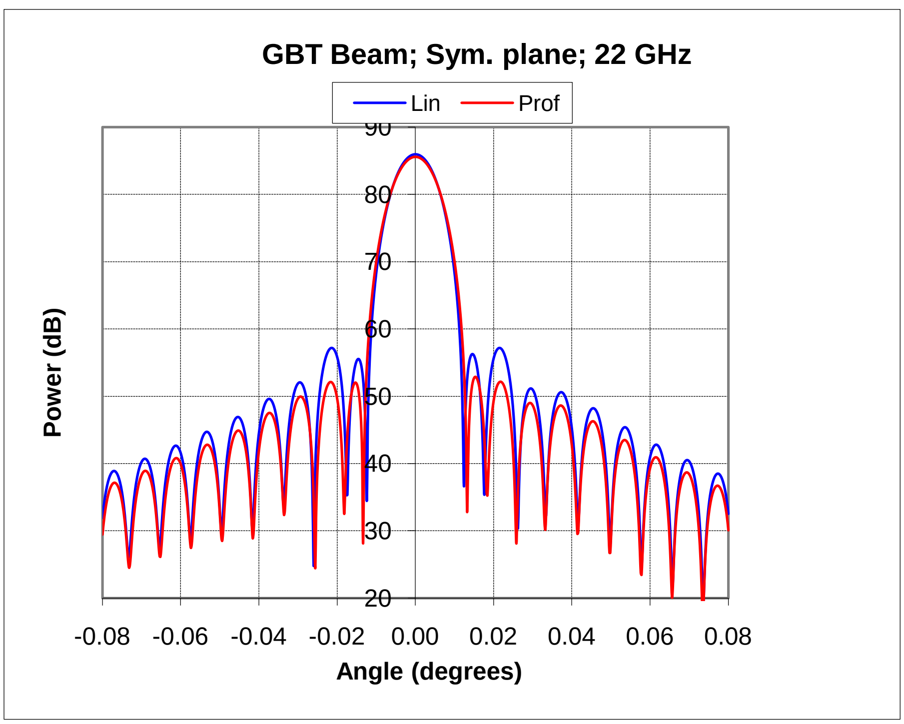


Figure 10. GBT beams at 22 GHz; Profile horn, 24 GHz horn

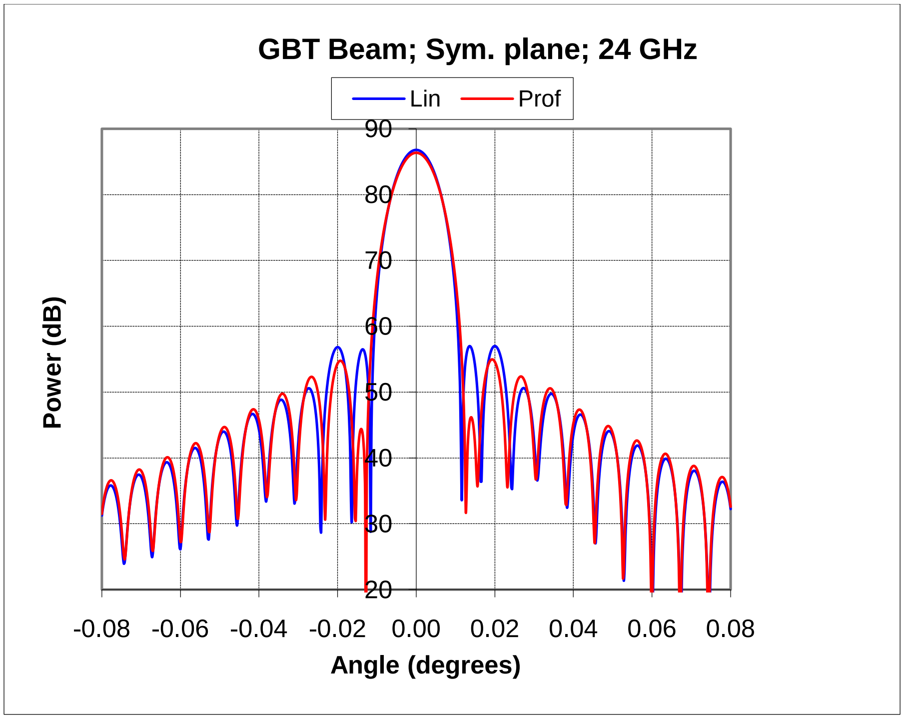


Figure 11. GBT beams at 24 GHz; Profile horn, 24 GHz horn

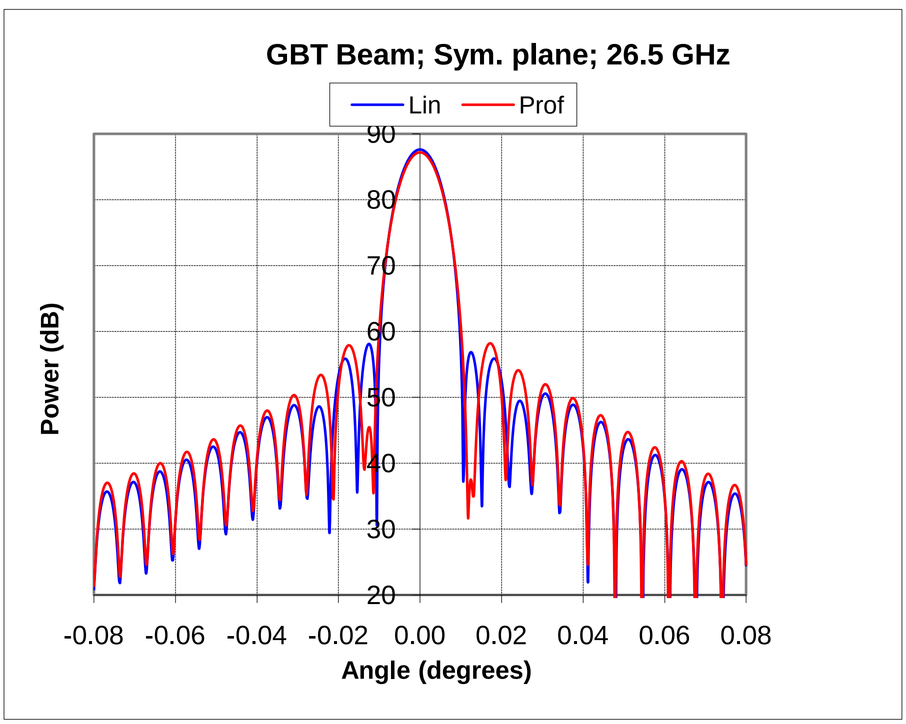


Figure 12. GBT beams at 26.5 GHz; Profile horn, 24 GHz horn