Electromagnetic Analysis of the VLA Antennas at L-Band

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The Ultrasensitive Array has been under development for the past few years. As a part of this upgrade, it has been proposed to retrofit the VLA with receivers providing complete frequency coverage from $\sim$ 50 MHz to 50 GHz. The receiver bands have been defined to be consistent with developing technology and observing needs. Two main factors in the selection of receiver bandwidths are the number of receivers that are required to cover the frequency range and the performance on the telescope at the band edges. In order to keep the number of receivers small, it has been proposed to build secondary focus receivers with octave bandwidths in the following bands: 1–2 GHz, 2–4 GHz, and 4–8 GHz. Components such as amplifiers, isolators, polarizers, windows, feeds, etc. can be built to these required bandwidths with existing technology. This plan, which uses the existing subreflector on the VLA antenna, requires the use of feeds that are very large both in length and in diameter at the aperture. Hence, it is critical to determine the trade-offs between the physical size of the L-band feed and its performance at the low end of the band.

In order to keep the system temperature low, the use of feeds with a phase correcting lens has been precluded, since the lens is suspected as being the cause of the VLA's elevated system temperature at low elevations. Limited space in the feed ring of the antenna forces the use of compact horns for the above-mentioned bands. Compact horns have a plane phase front in the aperture. These horns are shorter in length than linear taper horns. The reduction in length is achieved by the use of a profiled section between the throat and the aperture of the horn. By loading the corrugations in the throat section with rings, a good input match is obtained over an octave bandwidth. Two designs of profile horns, one with a length of 230" and maximum diameter of 85" and the other with a length of 186" and diameter of 76", were considered for the 1–2 GHz band. At the center of the band, the former has an illumination taper of -12 dB at the edge of the subreflector, while the latter has a -11 dB taper. Diffraction and scattering effects are strong at low frequencies. In order to assess the performance of the antenna at L-band, a full-scale diffraction analysis is required. Analysis of a prime focus feed is also required in order to determine the frequency below which a prime focus system has superior performance.

A computer program based on the technique of 'Physical Optics' (PO) was written to analyze the performance of the shaped reflectors of the VLA antenna, as well as the asymmetry in the subreflector. The analysis was done from 0.80 GHz to 2.0 GHz. The subreflector scattered pattern was calculated first using the theoretical feed pattern. This calculated subreflector pattern was then used as the input for the main reflector, from which the beam of the telescope is calculated. The program accounts for near-field effects by calculating the fields at the reflector surface distances. The accuracy of the program has been checked by comparing the fields calculated for the VLBA antenna with those calculated by an independent program. The blockage due to the subreflector is included in the calculations, while scattering due to the quadrupod legs is not present.

For the two sample Cassegrain feeds considered, the aperture efficiency (ϵ), system temperature T_{sys} and figure of merit (K/ T_{sys}) at frequencies between 1 and 2 GHz were calculated. T_{sys} includes the spillover contribution from the ground, plus a receiver and sky contribution and an estimated contribution due to the quadrupod legs. These calculations were performed for a range of elevations. The figure of merit, K/T_{sys}, in units of Jy^{-1} is given by:

$$K/T_{sys} = A_p\epsilon/(2760T_{sys})$$

where A_p is the physical aperture (m^2). (K is the antenna sensitivity, $K = \epsilon A_p/2k$). At frequencies below 1.4 GHz, the ratio K/T_{sys} is about the same for the two Cassegrain feeds. However, at frequencies above 1.4 GHz, the performance improvement with the bigger feed can be as great as 15%. It is clear that subreflector diffraction is the limiting factor at frequencies below 1.4 GHz. The longer feed, when installed, would protrude through the floor of the vertex room by 40 inches, while the other feed would fit inside the vertex room.

The complexity of the antenna modifications to accommodate the larger feed has led to a preference for the smaller feed for the 1.5 GHz band. The calculated aperture efficiency and T_{sys} are listed in Table 1. The figure of merit K/T_{sys} is plotted for four different elevation angles from 0.80 GHz to 2.00 GHz in Figure 1. T_{sys} increases by 8 K at 900 MHz from zenith to 20 degrees in elevation, and by about 6 K at 2.0 GHz. However, below 900 MHz, the performance of this Cassegrain system degrades rapidly due to overillumination of the subreflector by the feed. This diffraction effect both lowers the efficiency, and increases ground pickup at low elevations.

Table 1: **The results of an EM model for the 1.5 GHz Cassegrain System**

Freq	ϵ	T_{sys} (K)			
(GHz)	(%)	$E = 90°$	$E = 60°$	$E = 30°$	$E = 20°$
0.80	.23	46	52	71	80
0.85	.32	41	42	55	60
0.90	.46	31	33	38	39
0.95	.46	31	32	37	38
1.0	.49	31	32	36	37
1.1	.53	29	29	32	33
1.2	.50	27	29	32	33
1.4	.57	27	29	34	34
1.6	.61	25	25	28	28
1.8	.62	23	25	28	29
2.0	.64	24	25	29	29

It is expected that a prime focus system will be superior to a Cassegrain system below some frequency near 1.1 GHz. The efficiency and antenna temperatures were calculated for a wideflare corrugated horn at the prime focus and are shown in Table 2. This feed has a taper at the outside edge of the main reflector of −11.5 dB at 800 MHz and −19 dB at 1.00 GHz. The calculated aperture efficiency is 50% at 800 MHz and 35% at 1.00 GHz. Figure 1 shows the plot of K/Tsys vs. frequency for this system. Below 1.00 GHz, Tsys increases faster than the aperture efficiency due to over-illumination of the reflector, and, hence, there is a net drop in G/T_{sys}. Above 1 GHz, the loss in efficiency is higher than the decrease in system temperature because of phase errors introduced by the non-parabolic shape of the main reflector surface. From the results presented here, it appears that the switchover from secondary focus to prime focus should be done around 1.1 GHz. These results for the PF system are preliminary — little optimization has been attempted.

Figure 2 shows the calculated far-field pattern at 900 MHz when fed from the prime focus, and Figure 3 shows the pattern at 1.4 GHz when fed from secondary focus. The smoothness of the former figure is a result of underillumination of the reflector. The sharp nulls in the latter figure are due to the shaping of the subreflector and main reflector – which directs power from the feed preferentially to the outer parts of the main reflector.

Table 2: **The Performance of a Prime Focus 1.0 GHz Feed**

Freq (GHz)	ϵ (%)	T_{sys} 90	60	30	20
0.70	.54	31	32	37	38
0.75	.52	27	28	32	33
0.80	.49	23	25	28	29
0.85	.46	20	22	25	25
0.90	.43	18	19	22	22
0.95	.40	15	17	19	19
1.00	.34	13	15	16	17
1.05	.34	13	14	16	17
1.10	.33	14	15	17	17
1.15	.31	15	16	18	18
1.20	.30	15	16	19	19

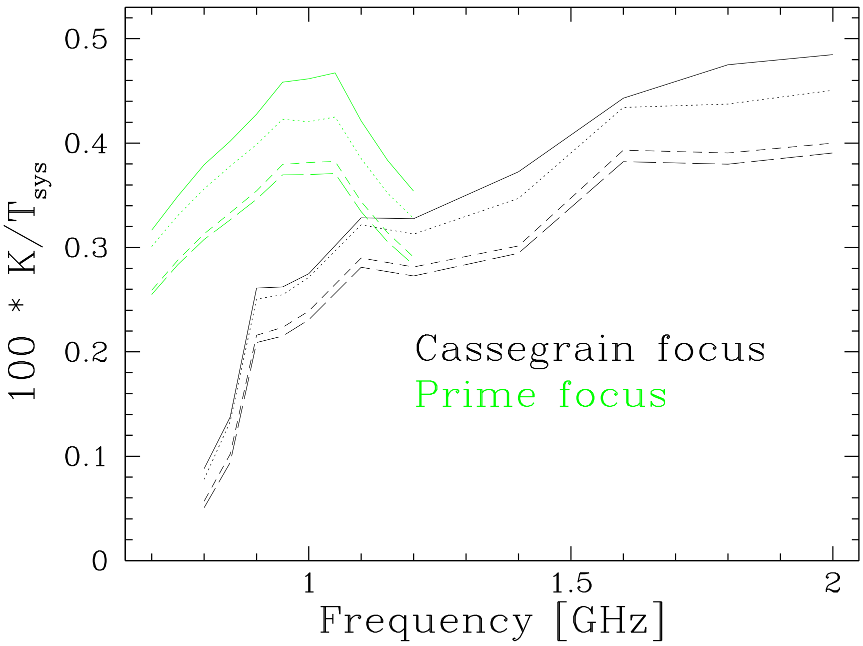

Figure 1: K/Tsys calculated for the Cassegrain (black lines extending to 2 GHz) and prime focus (green lines, 0.7–1.2 GHz) feeds. Solid lines: elevation=90°; dotted lines: 60°; short dashes: 30°; long dashes: 20°.

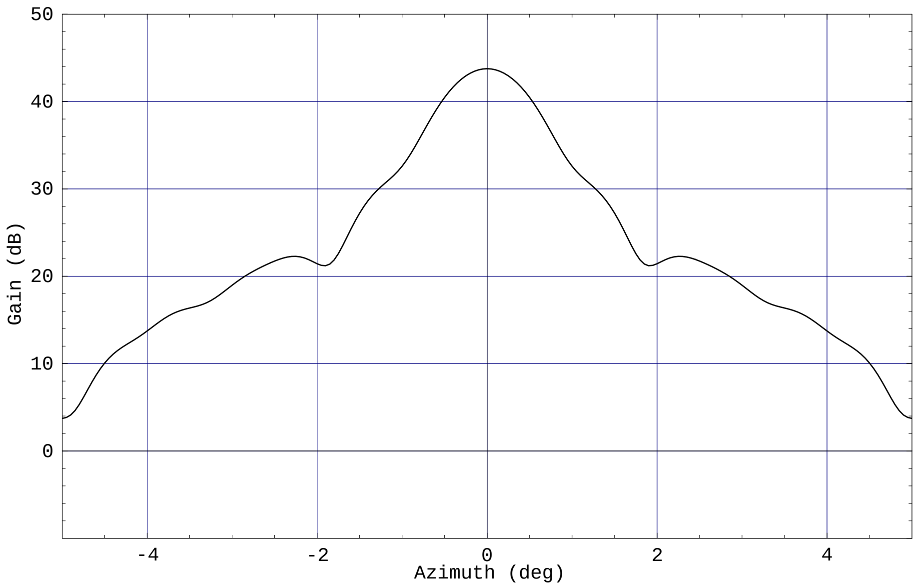

Figure 2: The calculated antenna power response at 900 MHz with a Prime Focus feed

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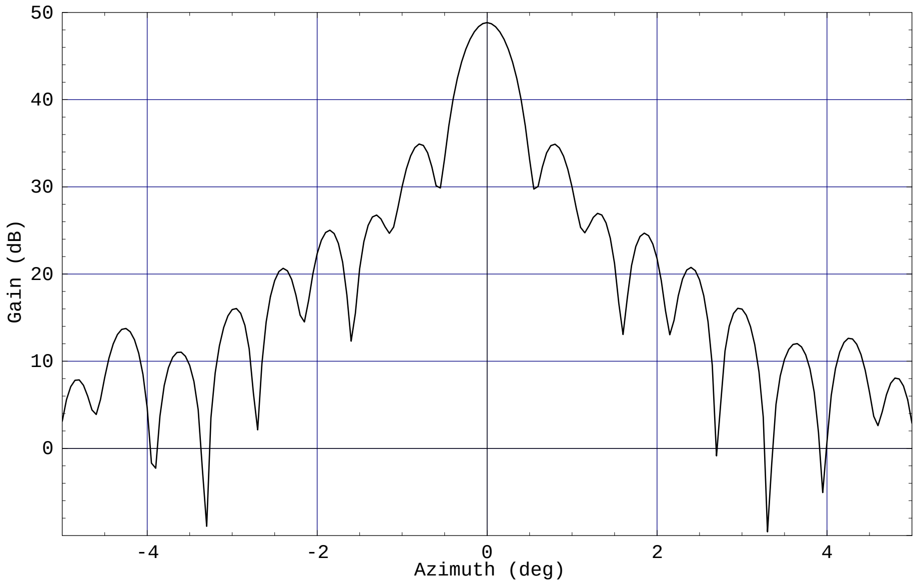

Figure 3: The calculated antenna power response at 1400 MHz with the improved Cassegrain feed

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