GBT Memo No. 4

PERFORMANCE COMPARISON OF SYMMETRICAL AND CLEAR APERTURE ANTENNAS

Attached is a group of six short reports prepared by members of a NRAO committee formed to study possible optics configurations for the GBT.

The reports summarize our current understanding of the relative performance of symmetrical and clear aperture (offset-fed) large antennas.

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The six subjects considered are:

Gain and Noise Temperature Polarization Sidelobes Baselines Field-of-View Possible Configurations of Feeds and Receivers

GAIN AND NOISE TEMPERATURE: COMPARISON OF SYMMETRIC AND CLEAR APERTURE ANTENNAS

R. Norrod and S. Srikanth July 25, 1989

1.1 Introduction

For the purpose of this comparison, we reviewed and revised the estimates previously presented in NLSRT memos 54 and 66. The details of the data presented here differ slightly from the previous estimates, but the conclusions we reach are similar. A symmetrical antenna with relatively low blockage (about 3% geometrical), and a clear aperture (doubly offset) antenna were considered.

<u>1.2 Aperture Efficiency</u>

In order to compare the aperture efficiencies for the two antenna types with cassegrain configurations, Srikanth introduced the preliminary feed-suport tripod structure designed by L. King into his pattern calculation programs, along with a representative corrugated horn feed pattern. The estimated aperture efficiencies resulting from these calculations are:

	<u>Symmetrical</u>	<u>Clear aperture</u>
Illumination	0.80	0.77
Spillover	0.93	0.93
Blockage	0.94	1.00
Miscellaneous	0.95	0.955
Total	0.66	0.68

The calculations were performed at 1.4 and 4.8 GHz, and the totals varied by less than 0.5% at these two frequencies. The illumination efficiency of the clear aperture antenna is lower, due to the increased space attenuation to the far edge of the main reflector. (We assumed a 0.6 F/D for the clear aperture antenna. The penalty in the illumination efficiency would be greater for a shorter F/D, or from the prime focus. We estimate that the illumination efficiency for a prime focus fed clear aperture antenna

because of this effect.) The clear aperture antenna would have fewer reflections in the structure; hence the higher miscellaneous term.

1.3 Antenna Temperature

In order to estimate the antenna temperatures, the spillover was calculated by numerically integrating the subreflector pattern from the edge of the main reflector to the horizon (assuming a ground temperature of 250 Kelvin), and the feed pattern from the edge of the subreflector to the horizon (assuming a sky temperature as tabulated in NLSRT No. 54 versus frequency). The scattered temperature was estimated for the symmetrical antenna by assuming isotropic scattering from the aperture blockage for both the plane and spherical waves. A rough estimate for the clear aperture antenna scattered temperature was obtained by assuming a solid support tower (located below the main reflector), and isotropic scattering from the tower for the spherical wave from the feed.

Antenna	Frequency	Spillover	Scatter			
			Zenith	30 Deg.El.		
Symm.	1.4 4.8	3.3 2.1	2.5 3.0	5.0 5.5		
Unbl.	1.4 4.8	3.3 2.1	0.2			

These efficiency and temperature estimates were extrapolated to frequencies, combined with estimates higher of receiver temperatures, sky temperatures, and surface efficiencies as described in NLSRT No. 54, and are tabulated in the attached table for zenith and 30 degrees elevation. For the two lower frequencies, prime focus feeding was assumed so the illumination efficiency effect discussed above was included. The ratio of the antenna gain to system temperature for equal projected apertures are plotted in Figures 1-1 and 1-2.

It has been noted that since a clear aperture antenna will likely cost more to construct than a symmetrical antenna, we could build a larger symmetrical antenna for a fixed budget. Figures 1-3 and 1-4 show the corresponding sensitivities if the diameter of the symmetrical antenna were increased to 110 meters.

1.4 Summary

If we can really achieve the low-blockage being proposed for the symmetrical antenna, the degradation in aperture efficiency compared with a totally clear aperture antenna is quite low, probably less than our ability to estimate or even measure. The real difference expected is in lower system temperatures, which are of more relative importance under conditions where the antenna scattered temperature is a significant fraction of the total system temperature. That is, when receiver and sky temperatures are low, and when low spillover temperatures are being achieved. For instance, at low frequencies where spillover temperatures tend to be higher and the galactic background adds significant noise, and at high frequencies where the atmosphere and receiver noises are higher, a smaller clear aperture antenna will likely sacrifice some sensitivity. It should also be noted that the improvement of the clear aperture case will be more pronounced at lower elevations, where a larger fraction of the scattered sidelobes are illuminating the earth.

Because of the short time allowed to produce this report, there are some effects that have not been fully considered. For instance, the analysis of the clear aperture spillover and scatter temperatures needs more work to correctly account for the feed and reflector angles with respect to the earth. Once more detailed monopod and tripod designs are available, their effect on the scatter and spillover must be considered. Under the assumptions made, we feel that the comparison produced above is accurate to within a few percent, but if it is felt that the selection of clear aperture versus symmetric hinges on this comparison, then a detailed analysis of specific antenna designs should be made. 25-Jul-89 FILE: ANT-DATA WK1

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COMPARISON OF SYMMETRIC AND CLEAR APERTURE ANTENNA SENSITIVIT(ZENITH)

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(GHz)		(K) Ť	×		(K/Jy)	(K)	(10e-3/J	×(۲		(K/Jy)) (K)	(10e~3/Jy)×
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0.61	1.000	30	×	0.660	1.8	86	52.2	2 ×	0.660	1.6	38 4	55.2 ×
1.5	1.000	13	×	0.660	1.8	86	98.0	X E	0.680	1.9	93 4	113.8 ×
4.8	0.996	16	×	0.657	1.8	75	89.3	1 ×	0.677	1.9	99 2	107.1 ×
8.4	0.988	19	×	0.652	1.8	6 5	77.3	3 ×	0.672	1.9	91 2	91.1 ×
15	0.963	29	×	0.636	1.8	1 6	51.3	7 ×	0.655	1.8	36 3	58.2 ×
22	0.929	46	×	0.609	1.7	Э 7	32.3	7 ×	0.627	1.7	79 3	96.4 ×

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0.33	1.000	72	×	0.660	1.88	8	23.5	×	0.660	1.88	4	24.7	7 ×
0.61	1.000	32	×	0.660	1.88	8	47.0	×	0.660	1.88	4	52.2	2 ×
1.5	1.000	15	×	0.660	1.88	8	81.6	×	0.680	1.93	4	101.6	3 ×
4.8	0.996	18	×	0.657	1.87	8	72.0	×	0.677	1.93	3	91.8	×
8.4	0.988	23	×	0.652	1.86	8	59.9	×	0.672	1.91	4	70.8	э ж
15	0.963	35	×	0.636	1.81	8	42.1	×	0.655	1.86	4	47.8	× 6
22	0,923	59	×	0.609	1.73	9	25.5	×	0.627	1.79	4	28.3	× E
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Kt (1/Jy)

POLARIZATION EFFECTS IN SYMMETRICAL AND CLEAR APERTURE ANTENNAS

A. R. Thompson July 25, 1989

2.1 Clear Aperture Antenna with Prime-Focus Feed

2.1.1 Linear polarization

Cross polarized sidelobes occur centered close to the -6 dB level of the main beam, see, e.g., Rudge and Adatia Fig. 8. The phase of the cross-polar sidelobes is in quadrature with that of the main beam, and the phase of the sidelobes changes by 180° and their level goes through zero on the main-beam axis. Thus, the cross-polar sidelobe amplitude is zero on the main beam axis. but the rate of change of amplitude with angle is not zero at that point as it is for a symmetrical antenna. Instead, the cross-polar amplitude has the form of a cusp at the main-beam axis. This means that the cross polarization varies continuously over the main beam. The peak cross-polar sidelobe level depends strongly upon the f/D ratio, and for a value of 0.6 (as defined in NLSRT Memo 44) the peak is approximately 22 dB below the main beam response. The crosspolar level does not vary much with the illumination taper, or with small transverse offsets of the primary feed (see Rudge and Adatia Figs. 9 and 11). Three methods of greatly reducing the cross polarization are known. First, it is possible to design a horn-type feed that is matched to the field at the prime focus when the antenna is illuminated by a linearly-polarized plane wave. Prototype feeds of this type produce an additional suppression of cross polarization of between 10 and 20 dB, but only over a bandwidth of 4-5% (see R. and A. Fig. 27 and associated text). This type of feed is only a partial answer for the GBT because of the restricted bandwidth and the fact that at the lowest frequencies dipole feeds are likely to be the more convenient than horns. The second method of reducing the cross-polar sidelobes is by use of a Cassegrain system with a suitable transverse offset of the feed. This is the method that is most readily applicable to the GBT. A third method that has been proposed is to use a dual reflector system with special shaping of the main reflector and subreflector: see R. and A., p. 1615.

2.1.2 Circular polarization

With circularly polarized feeds the effect that causes the cross-polar sidelobes now appears as a beam offset (squint). This offset is normal to the plane of symmetry of the antenna (i.e. the plane containing the center of the main reflector aperture and the axis of the parent paraboloid). However, no cross polarized component is generated, and the polarization remains circular across the beam. The degree of offset varies in much the same manner as the peak value of the cross-polar sidelobes in the linear case, i.e., it depends largely upon the f/D value: see Chu and Turrin Fig.5 (reproduced by R. and A. as Fig. 14). For f/D = 0.6 and the reflector offset angles discussed in NLSRT 44, the

beam offset is 0.11 half-power beamwidths, i.e., the separation of the oppositely polarized beams is 0.22 beamwidths. In the nominal boresight direction the response of each beam is 0.967 of the maximum response. In comparison, in the VLA antennas, which also have beam squint, the offset of each beam is approximately .033 beamwidths, and the relative response in the boresight direction is 0.997. The same beam offset would occur for an offset feed antenna with f/D approximately equal to 0.88 ($\theta_0 = 20^\circ$, $\theta_c = 25^\circ$ in the symbols of NLSRT Memo 44).

2.2 Clear Aperture Antenna with Cassegrain Feed

With a Cassegrain system the feed can be offset in such a way that the polarization introduced by this offset cancels the polarization resulting from the lack of symmetry of the main reflector. This scheme is often referred to as a double offset reflector system (see R. and A. p. 1613). According to R. and A. (p. 1613) the match between the two cancelling polarization effects is close to exact within the limits of geometrical optics. However, they note that in practice diffraction effects require that the subreflector be no less than 25 wavelengths in diameter to achieve 40 dB suppression of (linear) cross-polar sidelobes below the main beam. One would expect that polarization resulting from imperfections in feeds or blockage in symmetrical antennas would appear in the -30 to -40 dB range of sidelobe levels, so to avoid being limited by diffraction, 25 wavelengths is a good preliminary number to use for the minimum size of the subreflector. However, this number should be verified part of the final design procedure. For 1 GHz, for example, the 25-wavelength subreflector size is 7.5 m. The -40 dB (linear) cross polarization level corresponds to a circular polarization beam shift of about 0.002 beamwidths.

P. Napier has pointed out that circular polarization measurements with high precision are important for study of Zeeman splitting of the hydrogen line. The 7.5 m diameter subreflector should accommodate such measurements down to 1 GHz. Astronomers should consider whether high precision measurements of circular polarization are required below about 1 GHz, because these would probably require the use of the polarization-compensating horn feeds mentioned in section 2.1.1 above. For continuum observations the narrow tuning range permitted by these feeds may be acceptable. R. Fisher estimates that the diameters of such feeds is intermediate between those of single-mode and dual-mode hybrid feeds.

2.3 Comparison of Clear Aperture and Symmetrical Antennas

With a symmetrical reflector and an on-axis feed there is no beam offset, and it is possible to design feeds with no cross-polar sidelobes. However, some low-level cross-polar responses are generated by scattering and blockage by the feed support legs. These statements apply for both prime-focus and Cassegrain feeds, and for all frequencies for which it is possible to make horns with controlled excitation of the various modes, i.e., all frequencies except those for which horns become too big, and dipoles must be used. At such low frequencies the polarization purity is often limited by the performance of the feed. In the case of a double-offset Cassegrain clear aperture reflector antenna the polarization performance is essentially the same as that of a symmetrical antenna. The only important difference between the two types of antennas occurs in the case of an clear aperture antenna with a prime-focus feed, i.e., when the frequency is too low to allow the use of a subreflector of sufficient size.

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COMPARISON OF SIDELOBE LEVELS OF SYMMETRIC AND CLEAR APERTURE ANTENNAS

S. Srikanth and J. Coe July 26, 1989

3.1 General

The near-in sidelobes of an axially symmetric system depend mainly on the central blockage and the amplitude taper at the edge of the main reflector [1]. The spherical wave scattering by the feed/subreflector support struts also contributes to the near-in sidelobes [2]. The far-out sidelobes and the backlobes in a two reflector symmetric system are caused by (i) spillover and edge diffraction from the subreflector, (ii) spillover and edge diffraction from the main reflector (iii) plane wave scattering from support struts, and (iv) scattering of the plane wave by the feed system. The reflector surface errors and gaps between the panels also contribute to the sidelobes which depend on the statistical nature of the errors [3].

From the above, it is conceivable that a clear aperture system should eliminate the sidelobes caused by central blockage and the support struts. In order to estimate how much improvement could be achieved, it is necessary to determine the contribution to the sidelobes by these two sources. Results from measurements and numerical computations are presented below for the symmetric and clear aperture designs.

3.2 Experimental Data

Figure 3-1 from [4] compares the sidelobe levels of a 600 λ symmetric antenna with a 750 λ clear aperture antenna. For the clear aperture design, the sidelobe level falls to the isotropic level as close as 4° from the beam maximum. Whereas for the symmetric antenna, the sidelobes remain above the isotropic level up to about 20° from the main beam. In the region between 3° to 30° the sidelobes of the clear aperture antenna are between 10 and 18 dB below that of the symmetric antenna. Measured radiation pattern of an offsetfed dual reflector system [5] is shown in Figure 3-2. This antenna has a 7.6 meter main reflector and a concave gregorian subreflector. Absorber-lined shields were placed in strategic locations while measurements were done. The sidelobe envelope is about 20 dB below the CCIR [32dBi - $(25dBi) \times \log(\theta)$] curve (A in Figure 3-2). Figure 3-3 gives the measured patterns of an offset-fed dual reflector cassegrain antenna designed by M. Mizusawa et al. [6]. Figure 3-4 shows the measured patterns of a 34-m symmetric cassegrain antenna with improved struts designed to suppress certain sidelobe peaks [7]. The sidelobe envelope is about 10 dB below the CCIR curve.

The quantity (1 - Beam Efficiency) gives an indication of the power in the sidelobes of an antenna. For the symmetric Effelsberg antenna, the beam efficiency is 0.7 at 1.7 HPBW (Half Power Beam Width). For the Crawford Hill clear aperture antenna, it is 0.97 at 1.7 HPBW [8]. Lockman in [8] also lists measured beam efficiencies for other antennas. Figure 3-5 shows the measured radiation pattern of the Dwingeloo 25-m telescope with three feed support legs. The ring sidelobes caused by the legs contain 4.1% of the telescope's total response [9,10]. An experiment on the 300-foot telescope demonstrated how a clear aperture can keep the sidelobes low and thereby reduce the pick-up of ground radiation. A special feed which illuminated a patch on the telescope, offset from the center and away from the feed support legs and central blockage, was used to measure the antenna temperature as a function of feed rotation angle. The difference in system temperature was as high as 12° when the feed was pointed directly into one of the legs as compared to when pointed between the legs (Figure 3-6).

3.3 Numerical Results

From computed data, the first sidelobe level increases by about 0.15 dB when the blockage ratio increases from 0 to 0.1, for -10 dB edge taper and by 2.5 dB for an increase from 0.1 to 0.2 of the blockage ratio [1,11]. Here the blockage ratio is the fraction of the central blockage to the main aperture area.

Analyses were done using a Reflector Antenna Code [12,13] for computing the sidelobe levels of the two antennas in the comparison. A dual reflector system was used for both antennas. For the symmetric antenna f/D is 0.4, main reflector is 100 m in diameter, and the subreflector is 7 m in diameter. A tripod feed support system of L. King is used for support legs blockage. Α dual offset geometry is used for the clear aperture antenna with f/D of 0.615. main reflector diameter of 90 m, and subreflector diameter of about 7 m. The support tower holding the subreflector is not included in the analysis. The Reflector Antenna Code does not compute the spherical wave scattering from the feed support legs. This is likely to underestimate the near-in sidelobe level of the symmetric antenna. The subreflector edge diffraction is not accounted for which again underestimates the far-out sidelobes of the symmetric antenna. A quantification of this error needs to be carried out.

Far-field patterns have been computed at 1.4 and 4.8 GHz [14]. Patterns at 1.4 GHz have been attached. For the symmetric antenna in the strut plane, the sidelobes, up to 40° from the beam maximum in Figure 3-7a, are barely below the CCIR curve (broken lines). In a plane 30° from the strut plane, the sidelobes lie between 1 and 8 dB below the CCIR curve. For the clear aperture antenna, the patterns in the asymmetric plane of the antenna and 80° from this plane are shown in Figure 3-8. In these planes the sidelobes are about 25 dB below the reference curve.

3.4 Summary

Results from measured and computed data of the preceding sections are summarized in Table 3-1. θ_{iso} is the angle from the beam maximum where the level of the pattern falls to the isotropic level. G_{sl} is the gain of the dominant sidelobe with reference to isotropic in the region 30° to 60° from the beam maximum. Measured results reveal that the far-out sidelobes of a 100 λ clear aperture antenna (Figure 3-2) is at least 10 dB lower than a 680 λ symmetric antenna (Figure 3-4). Based on the numerical results, the sidelobe level of the 90-m clear aperture antenna is, on the average, 24 dB lower at 1.4 GHz and about 28 dB lower at 4.8 GHz compared to the 100-m symmetric antenna.

Computations accounting for scattering from the support tower, in the case of the clear aperture antenna, are to be carried out, though this effect is expected to be minor. Also, spherical wave scattering from the feed support struts/tower and subreflector diffraction are to be included for more precise comparisons. The far-out sidelobe pattern, predicted by the Reflector Code [12,13] used here, has been compared with the measured pattern of an 8-ft. antenna at X-band and has been found to be in good agreement. However, comparisons should be done with measurements on a large telescope, for instance, the 140-foot telescope.

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	Antenna	Туре	D (meters)	D/X	θ iso (degrees)	G _{sl} Between θ = 30° and 60° (db)
	CCIR [4]	Offset Cassegrain	11.5	750	4.2	-14
	CCIR [4]	Symmetric Cassegrain	-	600	20.0	- 4
MEASURED	GTE [5]	Offset Gregorian	7.6	100	4.5	-22
	Mitsubishi [6]	Dual Offset Cassegrain	1	72	5.3	-13.7
	Yamaguchi Earth Station [7]	Symmetric Cassegrain	34	680	5.0	-13
	GBT	Symmetric Cassegrain	100	473	6.7	- 5.8
CALCULATED	GBT	Symmetric Cassegrain	100	1600	11.0	- 5.0
	GBT	Clear Aperture Cassegrain	90	426	2.6	-31.0
	GBT	Clear Aperture Cassegrain	90	1440	1.5	- 34 . 0

TABLE 3-1





A: offset Gregorian antenna ($D/\lambda = 66$, 25 GHz, D = 0.8 m) B: offset Cassegrain antenna ($D/\lambda = 750$, 19.5 GHz, D = 11.5 m)

C: symmetrical Cassegrain antenna ($D/\lambda = 600$)



Measured peak envelope pattern of an assimmetric Gregorian antenna (D = 7.6 m), j = 6175 MHz, D A = 100 (Azimuth plane) A reference diagram of Recommendation 465

Fig. 3-2. Typical measured azimuth pattern of GTE antenna (D/ λ = 100).



Fig. 3-3. Measured azimuth patterns of low sidelobe cassegrain antenna $(D/\lambda = 72)$.



Fig. 3-4. Radiation pattern of 34-m antenna with improved strut. (a) Co-polarization. (b) Cross-polarization. $(D/\lambda = 680)$.



Fig. 3.5. Radiation pattern plot for the Dwingeloo 25 m radiotelescope at 1.415 GHz. The dashed circles show the expected positions for strut blockage sidelobes. Contours are in dB. Those not marked are -60 dB. See reference [15].



Fig. 3-6. Variation in the 300-foot system temperature with feed rotation at two elevations. The telescope's two feed support legs are located North and South.



Fig. 3-7. Pattern of 100-meter symmetric antenna at 1.4 GHz.



(a) Asymmetric (0°) Plane



Fig. 3-8. Pattern of 90-meter clear aperture antenna at 1.4 GHz.

COMPARISON OF SPECTROSCOPIC BASELINE PURITY OF SYMMETRIC AND CLEAR APERTURE ANTENNAS

J. R. Fisher and C. J. Brockway July 20, 1989

Spectroscopic baseline ripples are produced by multi-path interference of broadband noise. Within a reflector antenna structure there are two modes of multi-path interference: far sidelobes which are the vector sum of radiation scattered from any points in the antenna structure, and standing waves in the feed-reflector system.

Far sidelobe frequency sensitivity is important below a few GHz where the quiet sun is strong enough to add noise greater than the system sensitivity, typically 10 to 500 mK at 21 cm. This noise is nearly fully modulated in the frequency domain by the sidelobe response. Reduction of this type of baseline ripple requires a reduction in the far sidelobe response of the antenna. A 10 dB improvement in far sidelobes will reduce the baseline ripple by a factor of 10.

The baseline ripple amplitude due to feed-reflector standing waves is proportional to the continuum source strength and the voltage reflection coefficients of the feed-reflector system. The absolute amplitude of the antenna gain modulation as a function of frequency depends on too many factors to calculate accurately, but a useful comparison between various reflector geometries can be made because many of the factors can be assumed to be nearly the same. The reflection coefficient (as seen from the feed) of the antenna reflector(s) is the comparison variable.

A cassegrain antenna contains all of the reflection sources of a prime focus system but the specular reflection from the subreflector is the dominant component. Figures 1, 2, and 3 from Dragone and Hogg [1974, IEEE AP-22, page 472] show a comparison of reflection coefficients for symmetrical and nearly unblocked configurations. The difference is roughly 30 dB (a factor of 30 in voltage reflection coefficient, hence, baseline ripple due to the subreflector) over the range of useful reflector sizes and focal lengths. The variables in Figure 3 are $k = 2\pi/\lambda$, a_2 = subreflector radius, and f_2 = subreflector vertex to focus distance. Since the stationary phase point is at the edge of the subreflector in Figure 2(c), Figure 3 gives a <u>lower limit</u> to the difference between the symmetrical and offset designs. Notice, too, that the reflection coefficient is very nearly independent of the size and focal length of the subreflector and dependent on wavelength to the first power (6 dB/octave).

At prime focus the best reflection coefficient information probably comes from 3 GHz reflectometry measurements on the 140-ft and 300-ft. The table below summarizes the coefficients for the various components observed. Unfortunately, we do not have similar measurements for an offset prime focus system. Some calculations may be in order. Spoilers on subreflectors have been tried, e.g., Morris and Thum, 1981, MPIfR Tech. Rpt. 57, and reductions in reflection coefficients have been in the neighborhood of 10 to 15 dB for the strongest reflection. Wideband spoiler designs are considerably more difficult on a subreflector than on the main reflector because there are fewer Fresnel zones over which to taper the spoiler before significantly reducing the aperture efficiency. The practical limit seems to be about 15 dB (factor of about 5 in the reflection coefficient), even for a narrowband spoiler.

Baseline perturbations are also introduced in the receiving system independent of antenna characteristics. The combination of a non-uniform receiver spectral noise temperature over bandwidths of several tens of MHz and significant continuum temperature has been especially problematic because the baseline structure is usually non-periodic and more difficult to recognize and remove in data reduction. In this circumstance, the overall baseline improvement factor would be <u>less</u> than that expected of the offset to symmetric design. On the other hand, there are many times when a receiver operates in a region of very uniform spectral noise temperature and/or with negligible continuum noise so that the dominant component of baseline structure is due to antenna properties.

Firm conclusions are difficult to draw in a subject that is so complex, but here are some general statements that seem reasonable.

- 1. The biggest improvement by going to a clear aperture design, in baselines due to feed-reflector standing waves, will come at the cassegrain focus. A factor of 30 improvement in the primary reflection is the minimum to be expected.
- 2. Improvements in daytime baselines below a few GHz, particularly 1.4 GHz and below will be in direct proportion to the far sidelobe power reduction.
- 3. Any baseline improvements at prime focus and improvements greater than about a factor of 20 at secondary focus will require close attention to reflections from feed and subreflector support structures and discontinuities running along lines of constant phase such as panel gaps.
- 4. As receiver development progresses, most baseline perturbations are expected to be due to antenna characteristics and the improvement factor of the clear aperture to symmetric design will be most fully realized.

Prime Focus Reflection Coefficients

	<u>140-ft</u>	<u>300-ft</u>	<u>Est, Error</u>
Before adding spoilers:			
Center of main reflector	-60 dB*	-60 dB	3 dB
Cassegrain house and feeds	- 55		3
Inter circumferential panel gaps	-65	- 80	5
Outer circumferential panel gaps	-70	<-88	3
Reflector edge	-91	<-85	3
*Partially obscured by cassegrain house.			
After adding spoilers:			
Center of main reflector		-73 dB	3 dB
Cassegrain house and feeds	-76		3

Outer circumferential panel gaps -73 -- 3



Figure 4-1



(C) BISECTED CASSEGRAIN

(a) Cassegrainian configuration without blockage. (b) Gregorian configuration without blockage. (c) Bisected Cassegrainian configuration with some blockage.

Figure 4-2



Reflection coefficients for cases of Figs. 1 and 2(c), assuming an illumination taper of 13 dB at edge of subreflector.

Figure 4-3

COMPARISON OF FIELD-OF-VIEW PROPERTIES OF CLEAR APERTURE AND SYMMETRICAL ANTENNA DESIGNS FOR THE GBT

P.J. Napier and J. Lamb July 26, 1989

5.1 Summary

Clear aperture and symmetrical antenna designs for the GBT are compared with respect to the amount of space needed to scan the beam by feed translation and the loss of gain/sidelobe performance due to scan induced phase aberrations. At the prime focus the clear aperture design is likely to have somewhat poorer scan performance than the symmetrical design. A possible advantage of the clear aperture design may be that at both the primary and secondary focus more space is available to locate feeds off axis because blockage is not a concern. Also, lower magnification Cassegrain geometries may be possible in the clear aperture case because the monopod can support feeds close to the subreflector, allowing more compact secondary focus focal plane arrays. Detailed calculations of secondary focus scan performance should be made before selecting a very low magnification Cassegrain geometry for an clear aperture antenna.

5.2 Introduction

For a number of reasons it is desirable to have the capabilty of scanning the beam of the GBT off axis by moving the feed transversly in the focal plane. The amount of scan may be a few to many beamwidths (NLRST memo 51). The maximum amount of scan available is limited by two principal effects: the space available to locate the feed off-axis and the gain/sidelobe degradation caused by phase aberrations. We compare clear aperture and symmetrical antennas with respect to these two effects. Data for the clear aperture case is taken from the thorough treatment of offset antennas in section 3.3 of Rudge et.al.(1982) and for the symmetrical case from Ruze (1965).

5.3 Space Needed For Feed Translation

The distance, d, that a feed must be translated to produce a beamscan of N beamwidths is given approximately by:

$$d=(1.2*N*lamda/BDF)*(Fe/D)$$
 (1)

where lambda is the wavelength, BDF is the beam deviation factor (see Rudge et.al. pg 140 and 228 for values), D is the diameter of the circular aperture and the factor 1.2 is appropriate for a -10dB illumination taper at the aperture edge. For a prime focus symmetrical antenna Fe is the actual focal length, F. For the prime focus clear aperture case Fe is larger than F, the focal

length of the parent paraboloid, and is a function of THETAS, the reflector semiangle and THETAO, the offset angle (see pg 231, Rudge et.al.). For a case close to the GBT, say F/D=0.6, THETAS=38deg and THETAO=46deg, Fe=1.21*F. Using expression (1) to compare the value of d needed for N=1 for this clear aperture case and a with F/D=0.42symmetrical case we obtain d=0.9 wavelengths/beamwidth for the clear aperture and 0.6 wavelengths/beamwidth for the symmetrical case. Thus for a given amount of scan at the prime focus the clear aperture design requires approximately 50% more space than the symmetrical design. This does not appear to be a significant limitation, however, because in the clear aperture case blockage is not a problem and so the additional space can be made available. To give a specific example consider a compact 7 feed array at 600MHz which would be useful for pulsar searches. In such an array the outer beams are 2.8 beamwidths off axis which for the symmetrical case means a feed displacement of 84cm and for the clear aperture case 126cm.

At the secondary focus Fe is increased by the magnification, M, of the Cassegrain geometry. For the longer effective focal lengths at the secondary focus BDF=1.0 so that (1) gives d=0.8*M wavelengths/beamwidth and 0.5*M wavelengths/beamwidth for the clear aperture and symmetrical cases discussed above. For the symmetrical geometry presented in the GBT Proposal M= 12 giving d=6 wavelengths/beamwidth. A likely range of values of M for the offset geometry is a minumum of M=3 for a secondary focus high on the monopod to a maximum of M=10 at the base of the monopod. Thus the likely range for d in the clear aperture case is between 2.5 and 8 wavelengths/beamwidth. Smaller values of d are obviously desirable from the point of view of keeping arrays of feeds as compact as possible and it seems that the offset geometry may offer a slight advantage in this regard because the monopod can be used to support the secondary focus receiver cabin reasonably close to the subreflector (as suggested by A. Thompson). Also, as at the prime focus, more space is potentially available in the clear aperture case because blockage is not a problem.

As a specific example, for the symmetrical and clear aperture cases considered in the previous paragraph, consider a 1.4GHz 7 feed compact array which would be useful for wide field hydrogen mapping. For the symmetrical design the outer feeds would be 3.5m off axis and in the clear aperture case between 1.5m and 4.7m depending on magnification.

5.4 Loss of Performance Due to Phase Aberrations

As the beam is scanned by translating the feed, phase aberrations in the aperture cause loss of aperture efficiency and increased coma sidelobe level. For the symmetrical case, with -10dB edge illumination, the number of beamwidths, K, that can be scanned for 1dB loss in gain is given by:

$$K= 0.44+22(Fe/D)**2$$
 (2)

where for both prime and secondary focus Fe is the same as in (1) There is no simple corresponding expression for clear above. aperture reflectors. It is to be expected that an offset reflector with a given F/D will have somewhat worse gain loss than a symmetrical reflector with the same F/D because aperture phase aberrations increase with increasing radial distance measured from the axis of rotation of the paraboloid. In the clear aperture case the maximum value of this radial distance is at least twice the maximum value in the symmetrical case. An estimate of the significance of this effect in the prime focus case can be made using the computed examples presented in fig 3.59 of Rudge et.al. and reproduced below as fig 5.1. In fig 5.1 additional points for the symmetrical case, computed from (2) above, have been added for comparison. From fig 5.1 we see that the clear aperture cases with F/D=0.5 and 0.9 have comparable scan gain loss performance to symmetrical cases with F/D = 0.31 and 0.36 respectively. Inspection of fig 5.1 suggests that a GBT clear aperture design with F/D=0.6 will lose -1dB gain at about 2.7 beamwidths scan, compared to 4.3 beamwidths for a symmetrical design with F/D=0.42. Thus the prime focus scan performance of an clear aperture design is likely to be somewhat worse than a symmetrical design. As a specific example consider the 600MHz seven feed array mentioned above. In the symmetrical case the outer beams would suffer a gain reduction of 8% and the clear aperture case about 22%.

For the secondary focus case fig 5.1, expression (2) and the computations presented by Mrstik (1979) suggest that the long effective focal length for both the symmetrical and clear aperture designs will almost certainly mean that available space rather than aberrations will limit the field of view, so we will not consider this case further here. This may not be true if a very small magnification (say M=3) design is chosen and detailed calculations should be made before this geometry is selected for the clear aperture case.

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Mrstik, A.V., 1979, Scan Limits of Off-Axis Fed Parabolic Reflectors", IEEE Trans., vol AP-27, 647-651.

Rudge, A.W., Milne, K., Olver, A.D. and Knight, P., 1982, "The Handbook of Antenna Design, vol I", Peter Peregrinus pub.

Ruze, J., 1965, "Lateral-Feed Displacement in a Paraboloid", IEEE Tran., vol AP-13, pp 660-665.



Fig. 3.59 Beam-scanning gain loss an Rudge et.al I and -10dB (column III a $\theta^* = 30^\circ, \theta_0 = 0$ b $\theta^* = 45^\circ, \theta_0 = 0$ c $\theta^* = 30^\circ, \theta_0 = 45^\circ$ d $\theta^* = 45^\circ, \theta_0 = 45^\circ$ Beam-scanning gain loss and coma-lobe levels. illumination tapers of -6dB (column

Figure 5-1.

POSSIBLE CONFIGURATIONS OF FEEDS AND RECEIVERS

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6.1 General Considerations.

In considering the possible arrangements for mounting feeds and receiving equipment on the antennas, the primary concerns are the ability to change between different frequency bands rapidly, and the accessibility of equipment for maintenance. One would like to be able to change bands under computer control without the need for manual intervention. Use of both the prime and secondary foci is desirable, so the ability to change rapidly between equipment at these two locations is an important factor. The size of the subreflector is one of the critical factors involved because for ease of change-over the subreflector should be small. On the other hand, to avoid unwanted diffraction effects the diameter of the subreflector needs to be at least 10 wavelengths (to preserve aperture efficiency), and for the clear aperture antenna not less than 25 wavelengths (for effective polarization compensation), at the lowest frequency for which the Cassegrain system is used. Also the angle subtended by the subreflector at the secondary focus must not be too small or the feeds would have to be very large.

6.2 The Symmetrical Antenna

Consider a main reflector with diameter 100 m and focal length 42 m, and a subreflector of diameter 10 m. These are reasonable, non-extreme values for an example to start with. They are used in NLSRT Memo 67 (see Figs. 9 and 10), in which the secondary focus is 3 m above the vertex, which is helpful in accomodating long The diameter of the 21 cm feed turns out to be 3.49 m, feeds. which is large, possibly too large to be feasible, and certainly too large if an array of feeds is required. Thus, the 21 cm band is best accomodated at the prime focus, but higher frequency bands can use the secondary focus. One could consider increasing the size of the subreflector to decrease the size of the feeds, but 10 m is already so large that moving it out of the way (but not dismounting it from the antenna) when prime focus operation is required is not easv. Also, it is too large to vibrate for beam switching. Some possible ways to modify the system so as to avoid some of these problems are considered below.

(a) Another way to increase the angle subtended by the subreflector is to increase the height of the secondary focus above the vertex. A feed tower is then required; the 70 m DSN dish at Goldstone provides a good example of this approach. A problem for

us is that, unlike the DSN, we need to operate also at prime focus, and the secondary feed tower then causes scattering of the primary feed radiation. Keeping the top of the feed tower small would restrict the number of secondary feeds that could be accomodated. The tower would have to be 20 m high for a factor-of-two reduction in the subreflector diameter, so stability of the tower presents a potential problem, and a retractable tower to avoid scattering of prime focus radiation is hardly feasible.

(b) A large service tower could be located on the north side of the antenna so that the prime focus comes to the top of the tower when the antenna is pointed to the northern horizon. A large subreflector could then be used. For prime focus operation it would be dismounted and parked on the tower. However, manual intervention would probably be necessary in such an operation.

(c) The focal length of the main reflector could be reduced to 30 m, so that the feed apertures could be decreased by a factor of approximately 0.7. Then 21 cm and all higher frequency bands would be done from the Cassegrain focus. The disadvantage of this approach is that a 21 cm feed array is still rather cumbersome, and for lower frequencies that must be accomodated at the prime focus the aperture efficiency is decreased by a factor of about 0.87 because of the low f/D value of 0.3. This approach would be attractive if one could say that frequencies below 1 GHz are relatively unimportant.

(d) All feeds could be mounted at the prime focus, using a large prime focus cabin (say, 6 m on a side). A disadvantage of this scheme is that the aperture efficiency for prime focus operation with f/D = 0.42 is approximately 0.93 relative to that for Cassegrain operation with effective f/D > 1. A small subreflector of 1 to 2 m diameter could be used for frequencies greater than 20 GHz, with dielectric lenses on the feeds to keep them from being too long.

(e) A large subreflector of diameter, say, 15 m could be used, made in two parts so that the central 5 m diameter part could be moved to one side to allow prime focus operation. Problems are the difficulty of keeping the two parts of the subreflector accurately aligned, and increased aperture blockage.

Unfortunately, none of the above schemes is without at least one serious drawback. The only one that does not compromise the performance at some frequency is to use a fairly large (10-12 m) subreflector and park it off the antenna when not in use. The basic problem is that as we go to a large antenna, the distance of the secondary focus from the subreflector increases, and the size of the subreflector increases up to the point that becomes hard to handle for moving out of the way or for beam switching.

6.3 The Offset Feed Antenna

In the clear aperture antenna there is no particular reason to put the secondary focus close to the vertex, as there is in the case for the symmetrical antenna. Instead, the possibility exists of putting the secondary focus at a point on the large prime-focus support arm, where it can be relatively close to the subreflector. Thus, the constraints on the size of the subreflector are greatly reduced. A minimum size of 7.5 m has been derived from considerations of polarization compensation, and this is taken as the basis for a design shown in Fig. 6.1. The secondary focus is approximately 16 m from the subreflector, and the subreflector subtends a full-angle of 27.8° at the secondary focus. In this configuration the subreflector has an elliptical outer edge, and axes 7.2 x 10 m. A corrugated horn to match the subreflector would have a diameter of 5 to 10 wavelengths, i.e., about 1 to 2 m at 20 cm wavelength. Without a lens the corresponding length would be about 3 to 4.5 m. Thus, it should be possible to accommodate feeds for L-band and higher frequencies at the secondary focus. A feed box or cabin would contain the front ends, the feeds being mounted The box would be mounted so that it could be moved on one side. across or along the arm to place the appropriate feed at the focus. Figure 6.1 also shows a smaller subreflector of dimensions 1.2 x 1.4 m, which could be used for the highest frequencies. If both subreflectors are available on the antenna, then the requirements for the accuracy of the larger one are relaxed, and the smaller one allows faster beam switching at the higher frequencies. The two subreflectors could have secondary foci at the same position or different positions along the arm, depending on whether one or two boxes or cabins were preferred. Equipment mounted at the prime focus would include the two subreflectors and two or more primary These could be on a revolving turret, or a frame with feeds. motion in two directions, to allow the required unit to be positioned for use. With the clear aperture feed antenna, moving a large subreflector out of the way of a prime-focus feed presents less of a problem than with the symmetrical antenna because the subreflector need not block the aperture. Access for maintenance should present no great problems so long as the arm is on the lower side of the antenna.



FIGURE 6-1