National Radio Astronomy Observatory
Charlottesville, Virginia

GAIN/SYSTEM TEMPERATURE OPTIMIZATION AT SECONDARY FOCUS

S. Srikanth

October 6, 1992

The receiver plan for the GBT calls for continuous frequency coverage from 290 MHz to 52.0 GHz [1], [2]. The lowest frequency available at the secondary focus is 1.15 GHz. The secondary focus bands vary in bandwidth from 1.5:1 to about 1.2:1 in the L to Ka bands [1]. The limitation at the higher frequencies is the polarizer which has a narrower bandwidth with existing technology. Table 1 gives the frequency breakup. The lowest three bands at the secondary focus will use compact wideband horns (profile horns) in place of conical horns. Compact horns have extra losses due to the generation of unwanted higher order modes in the nonlinear section. The size of this type of horn is the driving force for using it at lower frequencies. These horns will make use of ring-loaded slots in the converter section [3]-[5] to achieve bandwidths greater than 1.5 to 1. The two bands in the 3.95-8.20 GHz range will use linear taper horns also with ring-loaded slots. All the higher frequency bands will have linear taper horns with varying depth slots. Hence, there are at least three different designs of corrugated horns at the secondary focus. This memo presents the first step in the design of these horns, which is optimization of Gain/System temperature (G/T_{syst} - sensitivity) as a function of feed taper at the edge of the subreflector.

The optimization is done at 1.42 GHz, 5.00 GHz and 15.00 GHz, and at two elevations of the GBT, zenith and 30°. Theoretical feed patterns with tapers ranging from -8 dB to -19 dB at 15° from boresight, which is the semi-angle of the subreflector from the secondary focus, are used. A figure of merit for sensitivity is given by:

$$K_f = G/T_{syst} \qquad (Jy^{-1})$$

where

$$G = Ap*\eta/2760 \qquad (K/Jy)$$

$$Ap = \text{Projected aperture area} \qquad (m^2)$$

$$\eta = \text{Aperture efficiency}$$

$$T_{syst} = T_{rx} + T_{ant} + T_{sky}$$

Table 2 lists the receiver temperature (T_{rx}) and the sky temperature (T_{sky}) at the three frequencies.

The aperture efficiency (η) is calculated using a dual reflector analysis program with theoretical feed patterns. The program uses the Jacobi-Bessel expansion technique to evaluate the physical optics radiation integral of the main reflector and the Uniform Geometric Theory of Diffraction for computing the subreflector scattered fields. For phase efficiency, a surface rms value of 1.25 mm is used for frequencies below 15 GHz and 0.44 mm at 15 GHz. Figure 1 shows the plot of aperture efficiency vs. feed taper, and the peak is at -12 dB feed taper at all three frequencies. The antenna temperature (T_{ant}) is comprised of scattered (T_{sc}) and spillover temperatures ($T_{spillover}$). Scattering is ignored in these calculations. $T_{spillover}$ is the sum of rear (T_{rear}) and forward (T_{for}) spillover. Feed pattern is integrated to obtain the forward spillover. For rear spillover, subreflector scattered patterns in 15 planes are used. Tables 3, 4 and 5 list the efficiencies, spillover temperatures and sensitivity K_f at 1.42, 5.00 and 15.00 GHz, respectively. Figure 2 shows the plot of T_{syst} vs. feed taper and Figure 3 shows G/T_{syst} vs. feed taper.

At 1.42 GHz, K_f is increasing monotonically all the way up to -18 dB feed taper. At long wavelengths diffraction causes increased rear spillover. The spillover temperature is comparable to the receiver and sky temperatures at this frequency and, hence, has a large effect on K_f. The increase in K_f going from -12 dB to -15 dB taper is about 10% and from -15 dB to -18 dB taper is only 4%. The feed phase pattern is nearly constant only over the range of amplitudes up to about -15 dB. The above facts, plus the size of the feed, have forced the choice of -15 dB taper for the compact horns. At 5.00 GHz, K_f peaks at -15 dB taper and varies by less than 1% at -14 dB and -17 dB tapers. Hence, a choice of taper anywhere between -14 dB and -16 dB at 5.00 GHz seems appropriate. At 15.00 GHz the peak of K_f occurs at -13 dB feed taper. At higher frequencies the spillover temperature is low due to reduced diffraction. $T_{spillover}$ forms a small fraction of T_{syst} and is the reason for the peaks of K_f and aperture efficiency to be nearly coincident. In order to keep the number of different designs small, the horns in the 3.95 to 8.20 GHz range (bandwidth ratio 1.5 to 1) will have -15 dB taper, and all the horns above 8.20 GHz (bandwidth 1.2:1) will have -13 dB taper.

[1] G. Behrens, "Proposed Plan to Implementing Prime Focus Receiver Requirements for the GBT," GBT Memo No. 69, October 14, 1991.

[2] M. Balister, R. Norrod and S. Srikanth, "Gregorian Receivers for the GBT," GBT Memo No. 66, Sept. 10, 1991.

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

[4] F. Takeda and T. Hashimoto, "Broadbanding of Corrugated Conical Horns by Means of Ring-Loaded Corrugated Waveguide Structure," IEEE *Trans. Antennas Propagat.*, vol. AP-24, p. 786, 1976.

[5] G. L. James, "TE_{11} to HE_{11} Mode Converters for Small Angle Corrugated Horns," *IEEE Trans. Antennas Propagat.*, vol. AP-30, pp. 1057-1062, Nov. 1982.

TABLE 1

GBT RECEIVER PLAN

	BAND	FEED								RECEIVER			POLARIZATION
RX NR.		GHz LOW	GHz HIGH	TYPE	BW RATIO	WG DIA Inches	Flo/Fco	Fco GHz	Fhom GHz	GHz LOW	GHz HIGH	BW RATIO	
1	L	1.15	1.73	Profile	1.50	6.628	1.10	1.04	1.73	1.15	1.73	1.50	Dual Linear
2		1.73	2.60	Profile	1.50	4.406	1.10	1.57	2.60	1.73	2.60	1.50	Dual Linear
3	S	2.60	3.95	Profile	1.52	2.932	1.10	2.36	3.91	2.60	3.95	1.52	Dual Linear
4		3.95	5.85	Lin.Taper	1.48	1.930	1.10	3.58	5.95	3.95	5.85	1.48	Dual Linear
5	C	5.85	8.20	Lin.Taper	1.40	1.303	1.10	5.31	8.81	5.85	8.20	1.40	Dual Linear
6	X	8.00	10.00	Lin.Taper	1.25	1.024	1.18	6.76	11.20	8.00	10.00	1.25	Dual Circular
7		10.00	12.40	Lin.Taper	1.24	0.769	1.11	9.00	14.92	10.00	12.40	1.24	Dual Circular
8	Ku	12.00	15.40	Lin.Taper	1.28	0.700	1.21	9.88	16.39	12.00	15.40	1.28	Dual Circular
9		15.40	18.00	Lin.Taper	1.17	0.499	1.11	13.86	22.98	15.40	18.00	1.17	Dual Circular
10	K	18.00	22.00	Lin.Taper	1.22	0.427	1.11	16.20	26.86	18.00	22.00	1.22	Dual Circular
11		22.00	26.50	Lin.Taper	1.20	0.349	1.11	19.79	32.83	22.00	26.50	1.20	Dual Circular
12	Ka	26.50	33.00	Lin.Taper	1.25	0.290	1.11	23.84	39.55	26.50	33.00	1.25	Dual Circular
13		33.00	40.00	Lin.Taper	1.21	0.233	1.11	29.69	49.25	33.00	40.00	1.21	Dual Circular
14	Q	40.00	45.50	Lin.Taper	1.14	0.192	1.11	35.99	59.70	40.00	45.50	1.14	Dual Circular
15		45.50	52.00	Lin.Taper	1.14	0.169	1.11	40.94	67.90	45.50	52.00	1.14	Dual Circular

TABLE 2

FREQUENCY (GHz)	T_{rx} (K)	T_{sky} (K)	
		Zenith	30° Elevation
1.42	7	6	9
5.00	10	6	9
15.00	12	9	15

TABLE 3. G/T_{syst} at 1.42 GHz

Feed Taper (dB)	Aperture Eff. η	90° Elevation				30° Elevation			
		$T_{spillover}$ (K)		T_{syst} (K)	K_f (Jy^{-1})	$T_{spillover}$ (K)		T_{syst} (K)	K_f (Jy^{-1})
		T_{rear}	T_{for}			T_{rear}	T_{for}		
-12	0.7272	6.22	0.44	19.66	0.1052	6.64	0.56	23.20	0.0892
-13	0.7265	5.50	0.40	18.90	0.1094	5.86	0.55	22.41	0.0922
-14	0.7219	4.83	0.38	18.21	0.1128	5.15	0.54	21.68	0.0947
-15	0.7142	4.22	0.26	17.48	0.1163	4.48	0.37	20.85	0.0975
-16	0.7042	3.60	0.22	16.82	0.1191	3.82	0.31	20.13	0.0996
-17	0.6930	3.21	0.18	16.39	0.1203	3.42	0.22	19.64	0.1004
-18	0.6802	2.81	0.15	15.96	0.1213	2.98	0.19	19.17	0.1009

TABLE 4. G/T_{syst} at 5.00 GHz

Feed Taper (dB)	Aperture Eff. η	90° Elevation				30° Elevation			
		$T_{spillover}$ (K)		T_{syst} (K)	K_f (Jy^{-1})	$T_{spillover}$ (K)		T_{syst} (K)	K_f (Jy^{-1})
		T_{rear}	T_{for}			T_{rear}	T_{for}		
-12	0.7006	2.55	0.44	18.99	0.1050	2.66	0.56	22.22	0.0897
-13	0.6986	2.18	0.40	18.58	0.1070	2.28	0.55	21.83	0.0910
-14	0.6928	1.87	0.38	18.25	0.1080	1.95	0.54	21.49	0.0917
-15	0.6840	1.63	0.26	17.89	0.1088	1.69	0.37	21.06	0.0924
-16	0.6728	1.45	0.22	17.67	0.1083	1.51	0.31	20.82	0.0920
-17	0.6608	1.25	0.18	17.43	0.1079	1.30	0.22	20.52	0.0916

TABLE 5. G/T_{syst} at 15.00 GHz

Feed Taper (dB)	Aperture Eff. η	90° Elevation				30° Elevation			
		$T_{spillover}$ (K)		T_{syst} (K)	K_f (Jy^{-1})	$T_{spillover}$ (K)		T_{syst} (K)	K_f (Jy^{-1})
		T_{rear}	T_{for}			T_{rear}	T_{for}		
-10	0.6943	1.86	0.88	23.74	0.0832	1.91	1.13	30.04	0.0658
-11	0.7016	1.60	0.45	23.05	0.0866	1.64	0.57	29.21	0.0684
-12	0.7035	1.40	0.44	22.84	0.0876	1.44	0.56	29.00	0.0690
-13	0.7008	1.21	0.40	22.61	0.0882	1.24	0.55	28.79	0.0693
-14	0.6942	1.04	0.38	22.42	0.0881	1.07	0.54	28.61	0.0691
-15	0.6847	0.92	0.26	22.18	0.0879	0.93	0.37	28.30	0.0688
-16	0.6728	0.80	0.22	22.02	0.0870	0.81	0.31	28.12	0.0681

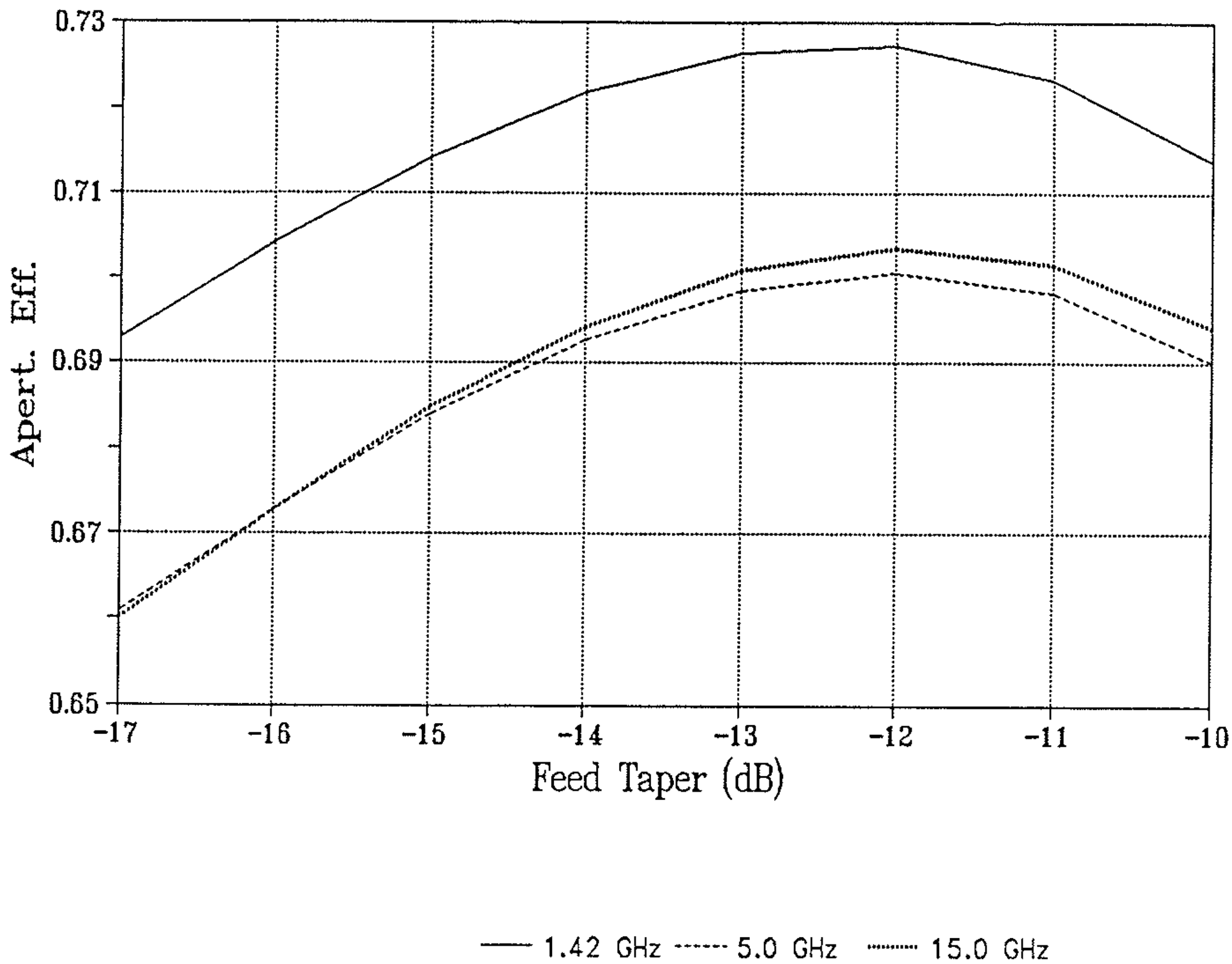
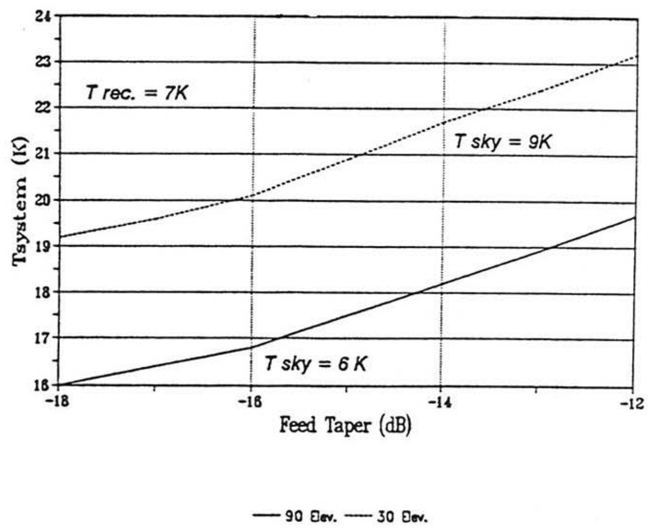
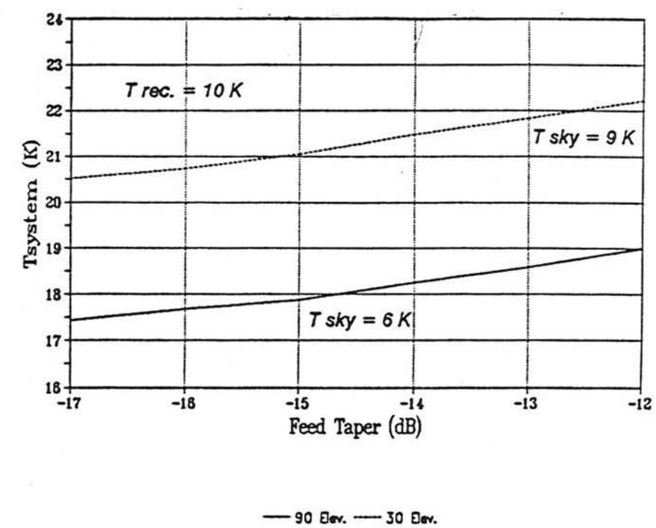


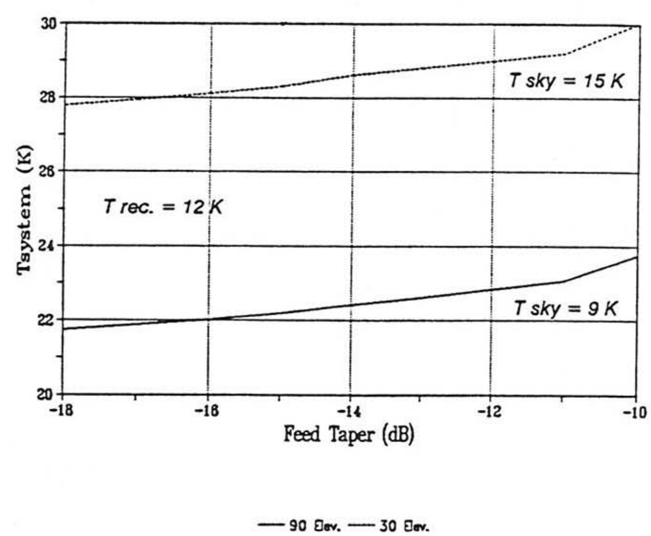
Fig. 1. Aperture efficiency vs. feed taper.



(a) 1.42 GHz

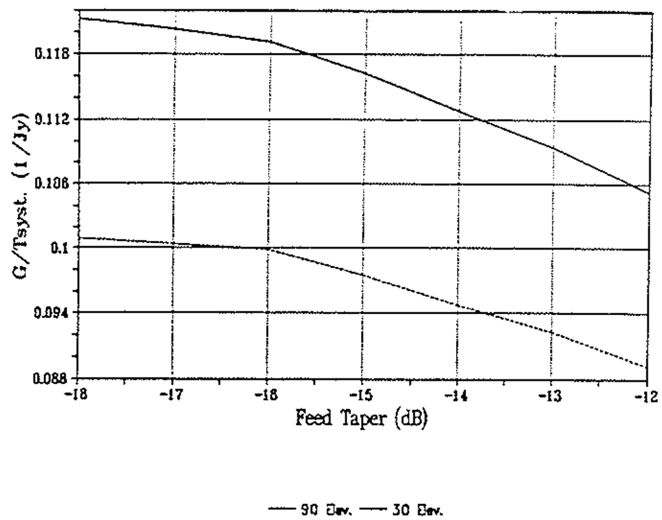


(b) 5.00 GHz

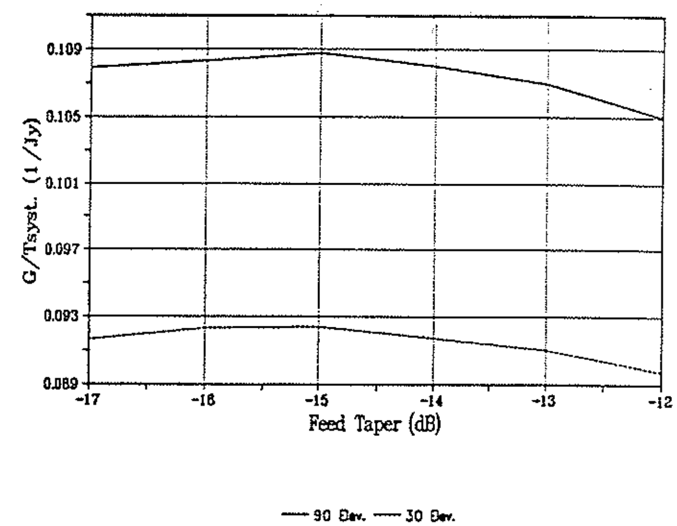


(c) 15.00 GHz

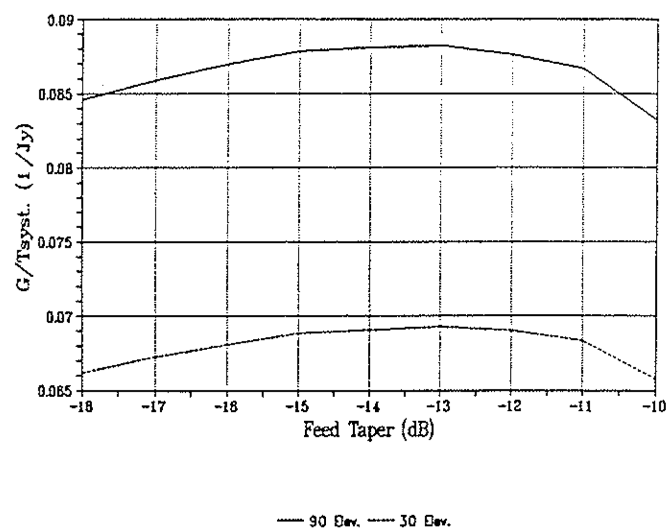
Fig. 2. System temperature vs. feed taper.



(a) 1.42 GHz



(b) 5.00 GHz



(c) 15.00 GHz

Fig. 3. G/T_{syst} vs. feed taper.