NATIONAL RADIO ASTRONOMY OBSERVATORY
Socorro, NM

VLA TEST MEMO. 170

SYSTEM TEMPERATURE AND NOISE CAL MEASUREMENTS USING MOON

D. S. Bagri and P. Lilie
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ABSTRACT

Simultaneous measurements of system temperatures on and off moon, and using hot and cold loads and sky on three antennas were used to determine contribution from moon to the system temperature at different bands. Assuming the same contribution to system temperature due to moon for all antennas (i.e. same beam efficiency for all antennas over the moon) we determine system temperature for other antennas. These system temperature values and synchroneous detector outputs are used to determine values of the noise calibration signals. Tipping curves were used to correct for different atmospheric absorption at different elevations for sky measurements during hot and cold load tests and measurements on moon. Average value of the system temperature at zenith (for default observing frequency settings) is about 31° K at L-band, 44 ° K at C-band, 30 ° K at X-band, 115° K at U-band (including 6° K due to atmosphere), and 160° K (including 34° K due to atmosphere) at K-band.

INTRODUCTION

It is hard to get reasonable estimates of the system temperatures for various antennas. Estimates of the system temperatures using laboratory determined T_{cal} values have been unreliable when compared with those using hot/cold load tests on antennas. Measurements of the system temperatures using hot/cold load tests are too laboreous and time consuming. In past we have used moon in a different way for measuring T_{cal} values. We used to assume that although individual noise calibration signal may change the average value over all the antennas at any band still remained same as determined during measurements in the laboratory. This average was used to scale system temperature on moon for individual antenna. This was in turn used to determine T_{cal} value for each antenna. It is not clear whether the assumption, that the average value remains unchanged, is valid. Further, in general the lab T_{cal} values refer to the receiver inputs whereas the values estimated on the antennas correspond to inputs of the feed horns. Also it has been somewhat of a problem keeping track of updating the values of the noise calibration signals (when maintainance is done in concerned parts of the system, T_{cal} values need to be updated, which does not happen many times). It seems a reasonable assumption to use same beam efficiency for different antennas over half a degree (size of moon), atleast at C-band and higher frequencies where the antenna beam is much smaller than moon, to determine the system temperature. Therefore we decided to try this out at all frequency bands above 1 GHz.

APPROACH USED

At each band we made hot/cold load measurements on three antennas to determine system temperature when we made system temperature measurements ON and OFF moon. The hot/cold load measurements are used to determine contribution of moon to the system temperature of these three antennas at each band. Assuming that contribution to system temperature due to moon is same for all antennas, we estimate system temperature for all antennas at various bands. The system temperatures and the synchroneous detector values are used to estimate T_{cal} values for all antennas at different frequencies. Antenna tipping measurements were made while making system temperature measurements using hot/cold load tests as well as while making measurements on and off moon. The tipping measurements provide estimates of atmospheric contribution to the system temperature values.

DATA

1) Hot/cold load measurements at L, C, X, U, and K bands, and antenna tipping results for the antennas #8, 9, and 10 (Table 1)
2) OFF/ON moon and antenna tipping measurements for the antennas # 8, 9, and 10, and contribution from moon to system temperature at different bands (Table 2)

RESULTS

1) T_{sys} (Table 3) and T_{cal} (Table 4) at L, C, X, U and K bands for all antennas
2) Average values of T_{sys} and T_{cal} at L, C, X, U and K bands (Table 5)
3) We can compare the average T_{sys} at L-band with measurements made during December 1992-february 1993 on Virgo/Crab for upgraded L-band antennas. For upgraded antennas the system equivalent flux density (SEFD) for zenith was about 310 Jy during these tests (VLA Test Memo No. 167). Assuming antenna efficiency of 52% (Napier et al, 1983, Proc. IEEE, 71, 1295) this gives T_{sys} of about 30°K, which is not too far off from the present estimate.

CONCLUSIONS

The method is essentially transferring the the hot/cold load measurements through measurements on moon. It seems a practical way to determine system temperature (T_{sys}) and noise cal (T_{cal}) values for all antennas. The beam efficiency and effective temperature of moon are not likely to vary with frequency appreciably over a given band. Therefore this may be a practical way to determine system temperature and noise cal values at various frequencies. Also it may not be necessary to make hot/cold load tests every time moon-measurements are made. We may instead use (1) model of moon's temperature variations with phase of the moon (e.g. Krotikov and Pelyushenko, 1987, Sov. Astron. 31, 216), (2) beam efficiency measurements over the area of the moon which need to be made only once, and (3) tipping curves to account for atmospheric attenuation, to determine the contribution of moon to the system temperature. This (contribution

from moon) can then be used to estimate T_{sys} and T_{cal} values using synchroneous detector measurements off and on moon.

TABLE 1: HOT/COLD LOAD TESTS AND TIPPING MEASUREMENTS FOR ANTENNA Nos. 8, 9, AND 10

T(amb)= 26
T(H)=273+T(amb)
T(c)= 77
T(spill) L 18
C 13
X 13

ANTENNA	BAND	T(SYS) A	T(SYS) B	T(SYS) C	T(SYS) D	T(atm)	T(cal) A	T(cal) B	T(cal) C	T(cal) D
8	L	30.2	29.6	28.2	27.8		4.65	4.4	4.29	4.23
	C	43.9	42.8	44.2	43		3.37	3.18	3.12	3.05
	X	29.9	29.1	31.4	31		4.12	3.87	4.08	4.02
	U	99.1	98.3	114.3	115	4.3	10.59	10.16	11.9	12.08
	K	141.4	142	123.1	123.1	26	12.72	12.31	11.79	11.79
	T(sys)-T(atm)@U	94.8	94	110	110.7					
	T(sys)-T(atm)@K	115.4	116	97.1	97.1					
9	L	31.2	30.7	30.8	32		2.84	2.88	2.98	3.03
	C	47.3	47.7	43.6	43.5		3.66	3.77	3.96	3.95
	X	26.8	27	29.3	30.1		3.53	3.64	3.74	3.85
	U	88.9	89.5	109.6	111.1	3.8	13.1	13.5	11.45	11.6
	K	170.6	170.9	193	185.5	21.2	9.89	10.17	10.94	10.55
	T(sys)-T(atm)@U	85.1	85.7	105.8	107.3					
	T(sys)-T(atm)@K	149.4	149.7	171.8	164.3					
10	L	37.3	37.1	34.5	37.6		3.69	3.55	3.35	3.77
	C	52.4	52.2	36.8	36.9		3.24	3.132	2.94	3.06
	X	29.8	29.5	29.9	30.1		4.64	4.42	4.62	4.84
	U	92.1	92.7	116.5	114.9	3.9	13.9	13.5	12	12.5
	K	110	105.7	118.5	127.6	14.2	11.02	10.59	10.45	10.8
	T(sys)-T(atm)@U	88.2	88.8	112.6	111					
	T(sys)-T(atm)@K	95.8	91.5	104.3	113.4					

TABLE 2: OFF/ON MOON AND ANTENNA TIPPING MEASUREMENTS AND CONTRIBUTION OF MOON TO SYSTEM TEMPERATURE
FOR ANTENNAS Nos. 8, 9, AND 10 AT L, C, X, U, AND K BANDS

Ant-IF DESCRIPT.	8a	8b	8c	8d	9a	9b	9c	9d	10a	10b	10c	10d	T(a)*EFF *(1-ATT)
L-V(OFF)	7.58	7.175	7.35	7.11	4.93	5.65	5.41	5.59	5.38	5.28	5.03	5.16	
L-V(ON)	2.17	2.09	2.015	2	1.36	1.63	1.44	1.6	1.77	1.75	1.63	1.73	
L-T(CAL)	4.65	4.4	4.29	4.23	2.84	2.88	2.98	3.03	3.69	3.55	3.35	3.77	
L-T(OFF)	27.60554	27.59582	26.26531	26.77215	25.92292	22.93805	24.78743	24.39177	30.86431	30.25568	29.97018	32.87791	
L-T(ON)	96.42857	94.73684	95.80645	95.175	93.97059	79.5092	93.125	85.21875	93.81356	91.28571	92.48466	98.06358	
L-Ton-off	68.82303	67.14102	69.54115	68.40285	68.04767	56.57115	68.33757	60.82698	62.94925	61.03003	62.51448	65.18568	67.94757
C-V(OFF)	3.54	3.28	3.31	3.245	3.53	3.64	4.2	4.185	2.85	2.75	3.7	3.55	
C-V(ON)	0.76	0.67	0.715	0.7	0.81	0.805	0.885	0.89	0.71	0.675	0.695	0.68	
C-T(CAL)	3.37	3.18	3.12	3.05	3.66	3.77	3.96	3.95	3.24	3.132	2.94	3.06	
C-T(OFF)	42.83898	43.62805	42.41692	42.29584	46.65722	46.60714	42.42857	42.47312	51.15789	51.25091	35.75676	38.78873	
C-T(ON)	199.5395	213.5821	196.3636	196.0714	203.3333	210.7453	201.3559	199.7191	205.3521	208.8	190.3597	202.5	
C-Ton-off	156.7005	169.954	153.9467	153.7756	156.6761	164.1382	158.9274	157.246	154.1942	157.5491	154.603	163.7113	161.4518
X-V(OFF)	6.19	5.87	5.86	5.78	6.02	6.46	5.84	6.13	6.97	6.67	6.96	7	
X-V(ON)	0.97	0.89	0.94	0.91	0.85	0.92	0.92	0.94	1.065	1.015	1.07	1.08	
X-T(CAL)	4.12	3.87	4.08	4.02	3.53	3.64	3.74	3.85	4.64	4.42	4.62	4.84	
X-T(OFF)	29.95153	29.6678	31.33106	31.29758	26.38704	25.35604	28.81849	28.26264	29.95696	29.82009	29.87069	31.11429	
X-T(ON)	191.134	195.6742	195.3191	198.7912	186.8824	178.0435	182.9348	184.3085	196.0563	195.9606	194.2991	201.6667	
X-Ton-off	161.1825	166.0064	163.9881	167.4936	160.4953	152.6874	154.1163	156.0459	166.0994	166.1405	164.4284	170.5524	165.4363
X-T(atm) at MOON'S ELEVATION = 4K, GIVING ATTENUATION=0.013													
U-V(OFF)	4.76	4.67	4.855	4.855	6.58	6.82	4.63	4.74	6.68	6.21	4.63	4.77	
U-V(ON)	1.825	1.81	2.03	2.03	2.4	2.51	1.91	1.965	2.41	2.26	1.94	1.98	
U-T(CAL)	10.59	10.16	11.9	12.08	13.1	13.5	11.45	11.6	13.9	13.5	12	12.5	
U-T(OFF)	100.1155	97.9015	110.2987	111.967	89.58967	89.07625	111.2851	110.1266	93.63772	97.82609	116.6307	117.9245	
U-T(ON)	261.1233	252.5967	263.7931	267.7833	245.625	242.0319	269.7644	265.6489	259.5436	268.8053	278.3505	284.0909	
U-Ton-off	161.0077	154.6952	153.4944	155.8162	156.0353	152.9556	158.4793	155.5223	165.9058	170.9792	161.7198	166.1664	162.3981
U-T(atm) at MOON'S ELEVATION = 6K, GIVING ATMOSPHERIC ATTENUATION = 0.017													
K-V(OFF)	3.9	3.81	4.07	3.93	2.47	2.55	2.43	2.43	3.71	3.625	3.32	3.625	
K-V(ON)	2.09	2.02	2.06	1.99	1.46	1.52	1.495	1.5	1.92	1.855	1.76	1.8	
K-T(CAL)	12.72	12.31	11.79	11.79	9.89	10.17	10.94	10.55	11.02	10.59	10.45	10.8	
K-T(OFF)	146.7692	145.3937	130.3563	135	180.1822	179.4706	202.5926	195.3704	133.6658	131.4621	141.6416	134.069	
K-T(ON)	273.8756	274.2327	257.5485	266.608	304.8288	301.0855	329.2977	316.5	258.2813	256.9003	267.1875	270	
K-Ton-off	127.1064	128.839	127.1923	131.608	124.6466	121.6149	126.7051	121.1296	124.6155	125.4382	125.5459	135.931	129.6977
K-T(atm) at MOON'S ELEVATION = 1.22*28=34K, GIVING ATMOSPHERIC ATTENUATION = 0.12													

TABLE 3: System Temperature using measurements on moon

DATE930528 TMOON-TBG
LUNAR TRANSFER L 65.25
C 158.8
X 162.7
U 159.7
K 127

Tsys:

FREQ	AC:	1465	BD:	1385	AC:	4885	BD:	4835	AC:	8415	BD:	8465	AC:	14985	BD:	15035	AC:	22485	BD:	22435
AVG:	AC:	32.56	BD:	35.05	AC:	43.93	BD:	44.50	AC:	31.37	BD:	31.64	AC:	116.2	BD:	113.2	AC:	159.8	BD:	159.7
ANT#	LA	LC	LB	LD	CA	CC	CB	CD	XA	XC	XB	XD	UA	UC	UB	UD	KA	KC	KB	KD
1	32.1	31.7	31.2	29.6	49.9	49.4	49.5	50.2	33.4	33.9	34.1	34.5	122	175	122	176	189	177	190	175
2																				
3	37.2	33.6	36.7	36.2	44.8	38.4	44.1	39.0	29.2	32.7	29.6	33.3	113	116	117	113	150	154	150	152
4	31.1	33.4	31.3	33.1	60.0	54.1	62.3	53.1	31.9	32.2	31.8	32.5	111	114	109	115	191	186	186	192
5	27.3	26.8	28.8	27.9	42.3	57.4	43.0	60.1	26.3	26.4	26.5	26.3	115	146	114	140	135	129	137	126
6	35.4	35.7	37.9	35.4	57.4	55.1	58.5	57.7	33.4	33.2	33.9	34.0	159	159	159	161	153	163	152	164
7	30.8	31.3	36.7	37.0	43.3	47.2	43.1	46.9	31.2	29.6	31.1	29.4	125	105	127	106	161	151	161	152
8	28.3	26.3	29.5	28.1	43.4	43.4	42.5	43.0	29.7	30.8	29.7	31.0	99	316	102	115	147	130	146	130
9	27.9	26.9	28.5	28.9	48.0	42.8	46.0	43.1	27.0	29.8	27.1	29.9	92	113	93	114	184	202	187	204
10	34.1	34.2	35.8	37.2	52.8	36.7	52.1	38.4	29.5	29.6	29.4	29.8	90	116	91	114	134	141	135	144
11	33.2	38.5	38.8	44.8	41.5	37.3	42.5	38.2	30.3	29.0	31.3	29.6	149	128	153	126	154	178	155	183
12					52.5	43.4	54.3	44.9	35.8	33.3	35.3	32.8	102	89	103	91	129	143	128	143
13	34.9	35.4	34.8	34.1	40.0	44.2	41.9	44.8	25.7	29.2	26.0	28.9	106	166	105	169	142	153	144	152
14	34.6	32.9	37.2	35.8	42.1	39.1	41.9	39.0	37.9	39.0	39.4	39.4	121	114	122	114	176	172	173	169
15	29.5	30.7	33.9	40.7	48.9	39.0	54.1	42.6	31.5	37.6	31.6	39.7	114	76	120	75	130	154	128	149
16					39.0	39.5	39.8	39.7	35.5	34.3	36.9	34.5	129	108	130	112	167	159	173	163
17	26.8	26.5	28.5	28.9	44.3	39.2	43.0	38.7	32.6	33.4	31.7	33.5	108	93	107	95	156	187	160	184
18	29.0	28.9	32.7	31.6	47.8	46.7	47.0	45.7	30.3	30.4	30.2	30.6	106	100	108	101	135	181	131	184
19	42.9	34.7	38.6	35.2	39.8	38.9	39.4	38.6	26.3	27.7	26.3	27.6	95	100	97	97	162	152	162	151
20	36.1	35.1	45.1	45.0	48.0	37.9	48.7	37.6	35.1	33.1	35.7	33.7	100	156	101	158	253	147	231	147
21	35.6	35.4	35.4	34.0	45.4	50.0	47.0	59.1	31.5	33.8	31.8	34.2	111	113	110	114	137	148	139	147
22	33.0	31.6	32.3	31.7	36.6	36.8	36.6	35.6	35.6	35.8	36.2	36.7	97	99	98	98	142	133	141	134
23	35.0	36.0	39.7	43.1	40.5	34.8	39.9	34.4	26.3	25.0	29.1	24.5	67	70	67	70	137	151	140	152
24	32.2	30.0	32.5	31.0	39.2	42.8	38.5	41.1	30.9	32.8	30.9	32.1	122	103	123	99	151	138	150	141
25	36.7	29.6	35.4	32.0	37.5	37.4	38.0	38.2	27.1	28.5	27.5	28.5	94	101	96	102	163	137	164	136
26	34.2	34.3	37.2	38.6	56.2	39.8	61.9	39.3	33.1	33.5	32.9	33.5	88	97	90	98	187	176	186	177
27	25.6	24.8	29.0	27.8	43.5	31.6	41.6	31.0	34.3	33.2	34.8	33.5	103	108	105	112	161	154	161	154
28	38.1	42.2	44.1	53.1	47.6	37.0	48.7	36.6	27.1	27.7	26.6	27.8	118	144	117	141	216	196	213	196

TABLE 4: Noise calibration signal (T-cal) using measurements on moon

DATE930528 TMOON-TBG
LUNAR TRANSFER L 65.25
C 158.8
X 162.7
U 159.7
K 127

Tcal:

FREQ	AC:	1465	BD:	1385	AC:	4885	BD:	4835	AC:	8415	BD:	8465	AC:	14985	BD:	15035	AC:	22485	BD:	22435
AVG.	AC:	3.54	BD:	3.55	AC:	4.71	BD:	4.58	AC:	4.16	BD:	4.10	AC:	12.1	BD:	12.0	AC:	12.9	BD:	12.6
ANT#		LA		LC		LB		LD		CA		CC		CB		CD		XA		XC
1	5.17	4.53	5.12	4.85	5.03	4.12	4.70	4.12	4.60	4.01	4.26	3.92	15.3	16.8	14.7	16.4	21.6	21.1	22.1	22.1
2																				
3	3.05	3.00	2.86	2.78	6.01	5.74	5.92	5.67	3.74	3.57	3.71	3.59	15.4	14.0	15.8	14.7	11.6	10.6	11.5	10.6
4	3.06	3.13	3.16	3.06	4.87	4.02	4.81	3.85	4.60	4.45	4.33	4.20	9.5	8.4	9.3	8.1	8.1	7.8	8.3	8.0
5	3.33	4.36	4.07	3.84	3.62	3.74	3.56	3.61	4.19	4.11	4.01	3.95	10.4	14.7	11.8	13.3	11.5	8.3	11.7	8.2
6	2.66	2.61	3.00	2.78	6.02	4.90	6.01	4.51	4.28	4.79	4.02	4.32	9.3	10.0	9.3	9.4	10.2	8.8	10.1	7.9
7	3.09	3.05	3.10	2.92	4.61	5.20	4.80	5.18	5.12	4.67	5.12	4.65	10.8	12.0	12.4	13.5	7.5	10.0	8.0	10.2
8	4.53	4.08	4.42	4.16	3.41	3.19	3.11	3.11	4.09	4.02	3.89	3.97	10.5	20.3	10.6	12.4	12.7	11.7	12.4	11.4
9	2.91	3.04	3.38	3.40	3.77	4.00	3.72	4.01	3.62	3.86	3.89	4.07	13.5	11.6	14.1	12.0	10.1	11.0	10.7	11.0
10	3.88	3.64	3.94	3.98	3.35	3.02	3.21	3.03	4.57	4.58	4.37	4.66	13.4	11.9	12.7	12.1	11.1	10.5	10.9	10.8
11	3.26	3.49	3.18	2.98	4.37	4.48	4.25	4.34	3.41	3.53	3.26	3.37	12.5	13.2	11.5	11.9	10.6	12.7	9.8	12.2
12					6.80	6.60	7.28	5.69	3.97	4.03	3.84	3.91	15.6	13.8	16.4	14.3	17.6	18.7	14.6	15.4
13	4.61	4.36	4.23	4.08	4.70	5.39	4.59	5.35	4.22	4.21	3.93	4.17	9.5	14.2	9.4	15.2	13.1	13.5	12.5	13.9
14	4.90	4.86	4.99	5.14	7.29	6.64	6.56	6.32	4.49	4.34	4.34	4.35	13.2	13.6	12.8	13.5	14.0	13.9	13.5	13.7
15	4.03	4.17	4.22	4.14	3.19	4.17	3.50	4.16	4.14	4.27	4.46	4.32	10.4	11.5	11.6	11.6	13.1	12.5	13.8	12.2
16					4.48	4.63	4.40	4.45	3.95	4.17	4.05	4.01	10.8	12.8	9.9	11.2	15.8	15.4	15.9	15.2
17	4.62	4.37	4.73	4.00	5.33	4.49	5.07	3.98	4.01	3.92	4.06	3.61	12.2	10.7	12.5	9.0	14.3	12.9	14.9	11.9
18	2.52	2.72	2.52	2.70	4.92	5.11	4.98	5.08	5.00	4.51	4.77	4.47	12.5	13.0	12.6	13.5	16.9	18.4	14.9	16.5
19	2.94	2.62	3.09	2.89	4.95	4.97	4.85	4.64	4.06	4.05	4.21	4.19	13.4	12.2	13.0	11.6	10.4	12.5	10.6	12.2
20	3.53	3.14	3.56	3.08	3.99	3.74	3.93	3.86	3.60	3.72	3.76	3.89	11.9	11.0	12.6	11.3	11.8	11.8	11.7	12.3
21	3.85	4.48	3.68	3.02	5.08	4.35	4.82	4.47	5.07	4.95	4.84	5.09	12.7	12.1	11.8	11.6	12.9	13.9	12.6	14.1
22	4.84	4.89	5.14	5.21	4.44	4.46	4.09	4.09	3.95	4.10	3.62	3.81	9.8	10.7	9.8	10.6	16.2	16.1	15.3	15.3
22	3.21	3.41	3.19	3.45	4.53	5.26	4.43	5.01	4.13	4.96	4.15	4.72	9.1	9.6	8.8	9.3	12.4	14.1	12.3	13.9
24	2.58	2.52	2.83	2.67	5.28	6.27	5.49	5.95	3.92	4.49	3.96	4.23	12.8	14.1	12.2	13.2	10.2	8.3	10.4	8.0
25	2.18	2.72	2.51	2.58	4.70	4.18	4.49	4.12	3.50	3.24	3.41	3.30	11.9	11.3	11.9	11.5	15.6	13.8	15.5	14.1
26	3.45	2.85	2.94	2.90	4.35	3.95	4.03	4.15	4.34	4.24	4.23	4.55	9.8	10.6	9.2	11.1	14.4	10.9	13.4	11.3
27	3.64	3.69	3.38	3.46	4.00	3.08	3.82	3.01	4.33	4.03	4.35	4.16	6.3	7.2	6.2	7.1	8.1	9.9	7.6	9.7
28	2.70	2.73	2.98	2.99	5.55	6.22	5.51	5.90	3.26	3.65	3.23	3.66	12.6	18.8	13.6	21.5	18.5	16.1	18.9	17.0

TABLE 5: Average system temperature and cal values for all antennas at various bands

BAND	SYSTEM TEMP. AC	SYSTEM TEMP. BD	T(cal) PRESENT AC	T(cal) PRESENT BD	Ave. T(cal) from old files
L	29.5*	32*	3.54	3.55	4.15
C	44	44.5	4.71	4.58	4.725
X	31	31	4.16	4.1	3.998
U	116**	113**	12.1	12	12.02
K	160#	160#	12.9	12.6	14.38

* Zenith value-- corrected for system temperature changes with elevation (VLA TEST MEMO 167)
** Includes T(atm) = 6K
# Includes T(atm) = 34K