G. Nelson

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THE AUSTRALIA TELESCOPE NATIONAL FACILITY

RECEIVER SYSTEM TEMPERATURES

Russell Gough

1. INTRODUCTION.

The system temperature is a fundamental measure of telescope sensitivity. By itself it is a measurement of receiver performance and, in conjunction with antenna efficiency, it is used to scale correlations to give fringe amplitudes. This report summarizes the system temperatures in the AT bands.

The AT conversion and local oscillator systems are very flexible. If an astronomer wishes to observe outside the designated AT band, I would encourage him/her to first check the extent to which the system performance is degraded at their frequency of interest. For example, we routinely observe the 6668 MHz methanol line although it is well above the upper frequency of the 6 cm band and the system temperature at this frequency is of the order of 100 K. One of the objectives of this report is to document the system temperature penalty resulting from observing outside the designated AT bands.

Sections 2 and 3 describe the nature of the limitations of the AT bands and the way the "astronomical" system temperature measurements were made. The results are presented in Section 4, and in Section 5 the system temperatures are corrected for antenna efficiency and for changes in the acceped flux density of the calibrator used for the measurements.

The "astronomical" system temperature is a measure of system sensitivity which includes the receiver system temperature, but also depends on
- antenna efficiency,
- calibrator flux density and
- the effect of decorrelation due to local oscillator phase noise.

The "astronomical" system temperature increases as the antenna points towards the horizon[1] and includes the noise from the radio source being observed.

The "astronomical" system temperature is the system temperature which is displayed by CAOBS and CAMON, is used by CACOR to scale the correlations and is written to the RPFITS file.

The "hot box" system temperature, which is system temperature measured with an ambient temperature load as described in [1], is independent of antenna efficiency and decorrelation effects.

2. AT OBSERVING BANDS.

The AT fully supports observing bands which are wholly contained within the advertised AT bands, but will allow observing at any centre frequency within the current band limits. The band limits are software limits which restrict range of centre frequencies for which CAOBS will set up the conversion system and local oscillators. It may be possible to change the band limits to enable observations to be made at centre frequencies outside the current band limits. The AT band, the current band limits and the frequency ranges used for the system temperature measurements reported here are given in Table 1.

Band	AT Band (MHz)	Current Band Limits (MHz)	Range of Centre Frequencies for Tsys Measurement (MHz)
20 cm	1250 – 1750	1200 – 1807	1216 – 1728
13 cm	2200 – 2500	2223 – 2632	2240 – 2624
6 cm	4400 – 6100	3900 – 6860	4288 – 6720
3 cm	8000 – 9200	8000 – 10117	8000 – 9152

Note: The band over which the system temperature was measured was Centre Frequency ± 64 MHz.

Table 1.

At the low frequency end of the 20 cm band the system temperature increases as the ring-loaded-slot waveguide section becomes cutoff and the horn becomes reflective; the high frequency end of the band is limited by the attenuation of the bandsplitter[2]. Operation is not recommended at frequencies below 1200 MHz.

The low frequency end of the 13 cm band is limited by the attenuation of the bandsplitter; at the high frequency end of the band the system temperature increases as the gain of the cooled LNA drops and the attenuation of the bandsplitter increases. The current lower band limit for the 13 cm band seems high, but observations below 2223 MHz (with 128 MHz bandwidth) would require that some local oscillators operate at frequencies not normally used.

At the low frequency end of the 6 cm band the system temperature increases as the ring-loaded-slot waveguide section and the orthomode transducer[2] become cutoff; the high frequency end of the band is limited by the attenuation of the bandsplitter. Operation is not recommended at frequencies below 4200 MHz in the 6 cm band.

As for the 13 cm band, the low frequency end of the 3 cm band is limited by the attenuation of the bandsplitter and at the high frequency end of the band the system temperature increases as the gain of the cooled LNA drops and the attenuation of the bandsplitter increases. In the 3 cm band the gain variation across the band is 8 to 12 dB. The gain of the receiver is adjusted so that, with the 14 dB attenuator range, optimum IF power can be delivered to the samplers for observing frequencies between 8000 MHz and 9200 MHz.

As stated above, *if an astronomer wishes to observe outside the designated AT band, I would encourage him/her to first check the extent to which the system performance is degraded at their frequency of interest.*

3. SYSTEM TEMPERATURE MEASUREMENT

Between October 1 and October 15, 1993, tests were carried out on the compact array to determine the system temperature across all the AT bands. The measurements were made using 128 MHz wide bands, centred on odd multiples of 64 MHz to give contiguous bands between possible interference from harmonics of the 128 MHz sampler clock. The frequency ranges used for the system temperature measurements are given in Table 1. For the 20 cm and 13 cm bands, the centre frequencies were restricted to those within the current band limits; for the 6 cm band, the lowest centre frequency used was 4288 MHz as the system temperature was already three times higher than at the band centre; for the 3 cm band, the highest centre frequency used was 9152 MHz as the gain of the receiver system was getting low.

I tracked 1934-638, the AT primary flux calibrator, with the compact array. At each frequency, delays were adjusted to maximize the correlation, and the "astronomical" system temperatures of the receivers (receiver gains)[1] were adjusted to give a fringe amplitude equal to the flux density of the calibrator. The flux densities used for 1934-638 were interpolated from Appendix D of the ATCA User's Guide.

The serial numbers of the receivers installed on the compact array antennas when the system temperatures were measured are listed in Table A-1.

When the system temperatures were measured, the subreflector position was fixed, and it is my understanding that it is at an optimum position for observations in the 6/3 cm bands.

4. RESULTS.

Fig. 1 shows the "astronomical" system temperatures of both polarizations for all six antennas for observing frequencies of 1472 MHz, 2368 MHz, 4800 MHz and 8640 MHz.

The XA receiver on CA04 stands out as having a poor system temperature: the A- and B-polarization "astronomical" system temperatures on CA04 at 8640 MHz are 66 K and 38 K respectively. The system temperatures were checked with a "hot box" and were found to be 42 K and 43 K respectively. These results are consistent with system temperature measurements made in the lab. prior to receiver installation. The high system temperature is not apparent in total power; it is only apparent when the receiver is used in a correlation mode. The CB receiver on CA01 also exhibits a similar problem: a "hot box" measurement shows that the system temperature CB is 40% higher than that of CA (in itself not good), but the "astronomical" system temperature CB is 70% higher than that of CA. The faulty HEMT amplifiers in the C/X receivers on CA01 and CA04 were repaired in December, 1993.

Figs. 2, 3 and 4 show the "astronomical" system temperatures of both polarizations for all six antennas for the 20 cm/13 cm, 6 cm and 3 cm bands respectively.

Fig. 5 shows T_{SYS_1}, the average of the "astronomical" system temperatures of both polarizations over all six antennas at each frequency. For the 3 cm band, the average is of eleven system temperatures, excluding XA on CA04.

5. ANALYSIS OF SYSTEM TEMPERATURE MEASUREMENTS

As noted in Section 1, the "astronomical" system temperature depends on antenna efficiency and the assumed flux density of the calibrator. The gain calibration assumes a fixed efficiency, η_0, of 0.726 (S/T = 10) and the flux densities used for 1934-638 were interpolated from Appendix D of the ATCA User's Guide.

Table A-2 shows revised values for the flux density of 1934-638 as suggested by John Reynolds[3]. As the correction factor varied significantly between the 6 cm and 3 cm bands, I fitted a second order polonomial to the correction factor, C, for frequencies from 1665 MHz to 8420 MHz.

$$C = 7.5418 \cdot 10^{-9} f^2 - 4.1677 \cdot 10^{-5} f + 0.96431 \quad (1)$$

where f is the frequency in MHz. The correction factors given in Table A-2, and the second order approximation, are plotted in Fig. 6.

The estimate of system temperature can be corrected for the revised flux density estimates for 1934-638 using

$$T_{SYS_2} = C \cdot T_{SYS_1} \quad (2)$$

where C is calculated using eqn. (1).

Fig. 7 shows the average of the "astronomical" system temperatures over the central portion of each band using both the currently used (old) and revised (new) flux density estimates for 1934-638.

If we use the theoretical dish efficiencies, η_1, given by James[4] and subtract the noise contribution from the calibration source we can obtain a more realistic estimate of the system temperature, off source at an elevation of 40°.

$$T_{SYS_3} = T_{SYS_2} \cdot \frac{\eta_1}{\eta_0} - T_{source} \quad (3)$$

where

$$T_{source} = S_{1934-63} \cdot \frac{\eta_1}{7.26} \quad (4)$$

and $S_{1934-63}$ is flux density of 1934-638 in Jansky. The results are summarized in Table 2. Fig. 8 shows the typical system temperature, T_{SYS_3}, over the AT bands.

Note that T_{SYS_3} includes noise contributions of about 1 K from the calibration noise source and 1 – 2 K from the longer path through the atmosphere at an elevation of 40°[1].

Frequency (MHz)	T_{SYS_1} (K)	T_{SYS_2} (K)	η_1	T_{source} (K)	T_{SYS_3} (K)
1472	39.4	36.2	0.69	1.4	33.0
2368	51.1	46.4	0.51	0.8	31.3
4800	46.0	43.2	0.67	0.6	38.4
8640	35.9	41.9	0.64	0.3	34.7

η_1 Theoretical antenna efficiency (James[4]).
T_{source} Contribution from the calibtatior 1934-638 (see eqn. (4))
T_{SYS_1} Average "astronomical" system temperature, on source and at an elevation of 40°, assuming antenna efficiency η_0.
T_{SYS_2} Average "astronomical" system temperature, on source and at an elevation of 40°, assuming antenna efficiency η_0 (T_{SYS_1}), but corrected for the revised flux density estimates for 1934-638.
T_{SYS_3} Typical system temperature. T_{SYS_3} is the system temperature, off source at an elevation of 40°, calculated with revised flux density estimates for 1934-638, estimated from T_{SYS_1} assuming antenna efficiency η_1 .

Table 2.

6. REFERENCES.

[1] Sinclair, M.W. and Gough, R.G., "System Temperature Calibration of the Australia Telescope Receiver Systems", IREECON'91 International Proceedings, pp. 381-384, 1991.

[2] Sinclair, M.W., Graves, G.R., Gough, R.G. and Moorey, G.G., "The Receiver System", JEEEA, Vol. 12, No 2, pp. 147-160, June 1992.

[3] J. Reynolds, Private communication.

[4] James, J.L., "The Feed System", JEEEA, Vol. 12, No 2, pp. 137-145, June 1992.

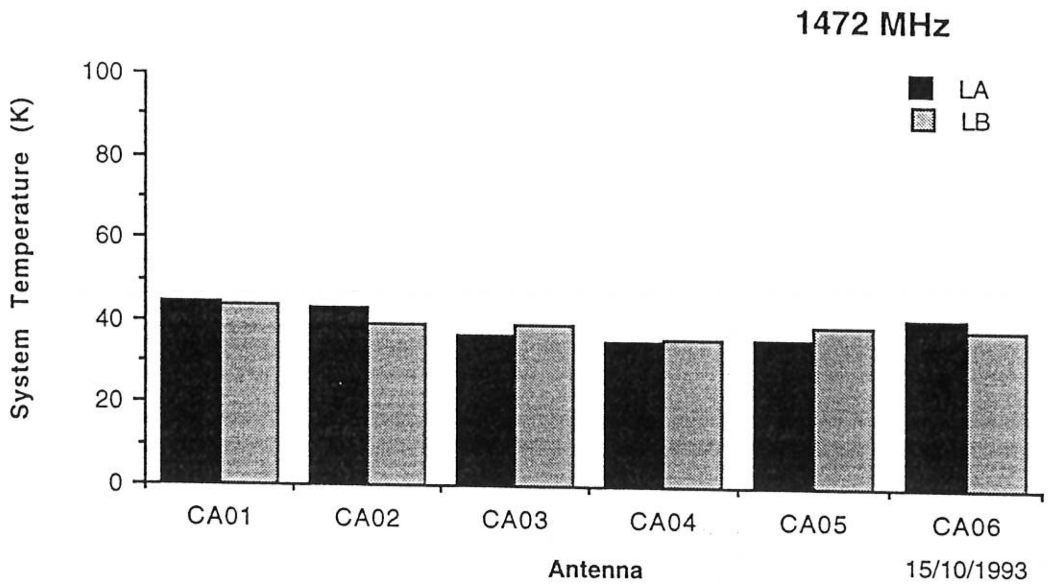
APPENDIX.

Antenna	20/13 cm receiver serial number	6/3 cm receiver serial number
CA01	05	04
CA02	01	01
CA03	03	03
CA04	04	02
CA05	06	06
CA06	07	08

Table A-1. Serial numbers of the receivers installed on the compact array antennas when the system temperatures were measured.

Frequency (MHz)	Currently used 1934-638 flux density (Jy)	Revised 1934-638 flux density (Jy)	Correction factor (revised flux/ current flux)
408	6.26	6.24	0.997
843	14.39	13.65	0.949
1612	15.80	14.57	0.922
1665	15.65	14.32	0.915
2295	13.37	12.16	0.909
4850	6.25	5.87	0.939
8420	2.70	3.10	1.148

Table A-2. Revised values for the flux density of 1934-638 as suggested by John Reynolds[3].



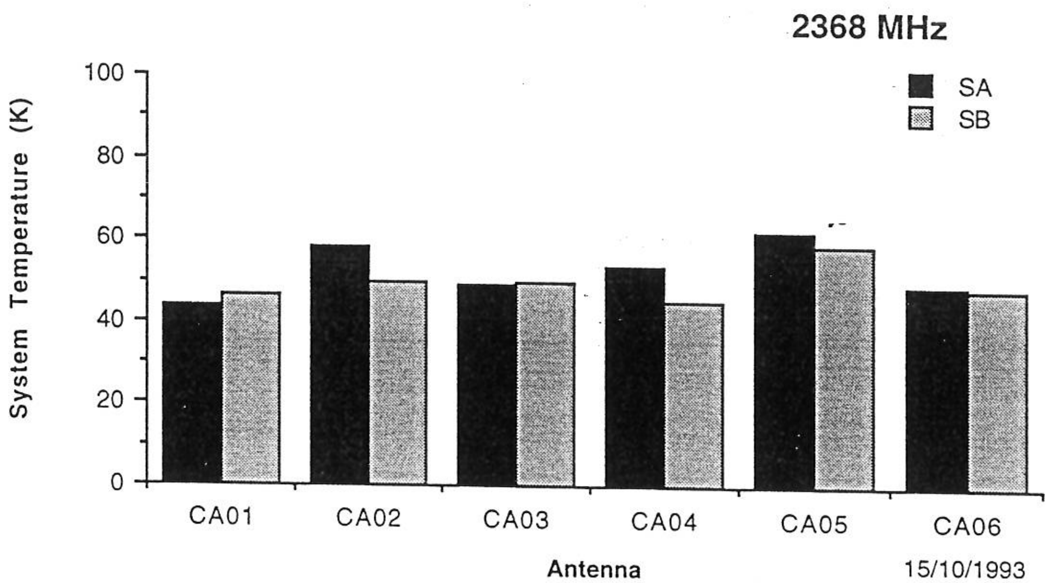
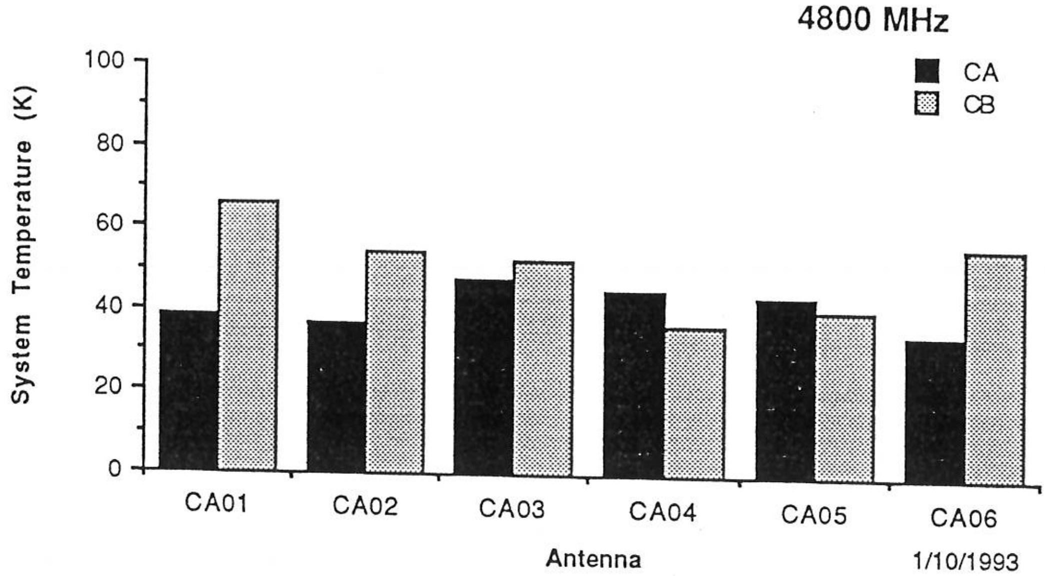


Fig. 1. "Astronomical" system temperatures of both polarizations for all six antennas for observing frequencies of 1472 MHz, 2368 MHz, 4800 MHz and 8640 MHz.



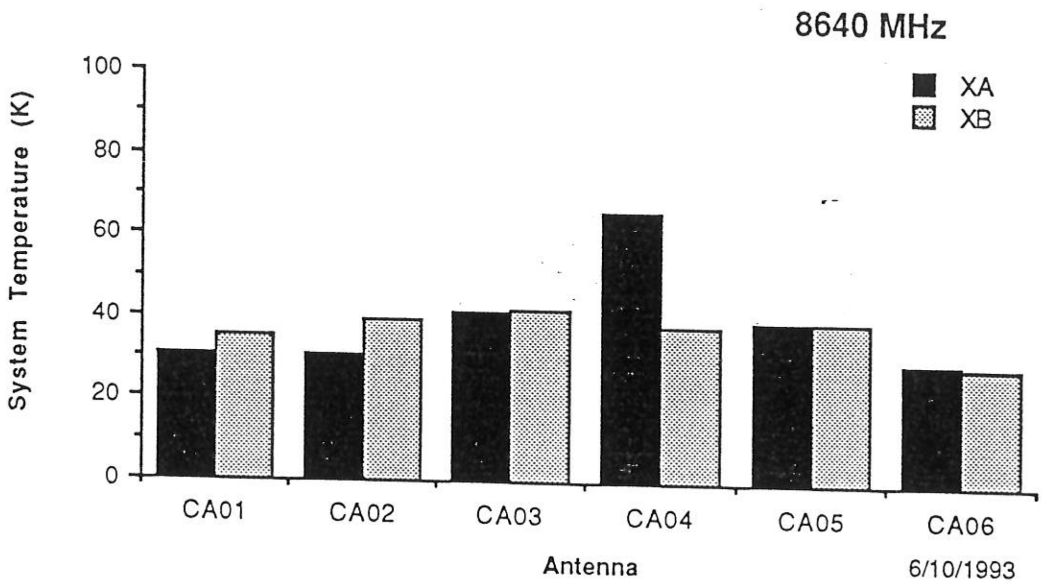


Fig. 1.(cont) "Astronomical" system temperatures of both polarizations for all six antennas for observing frequencies of 1472 MHz, 2368 MHz, 4800 MHz and 8640 MHz.

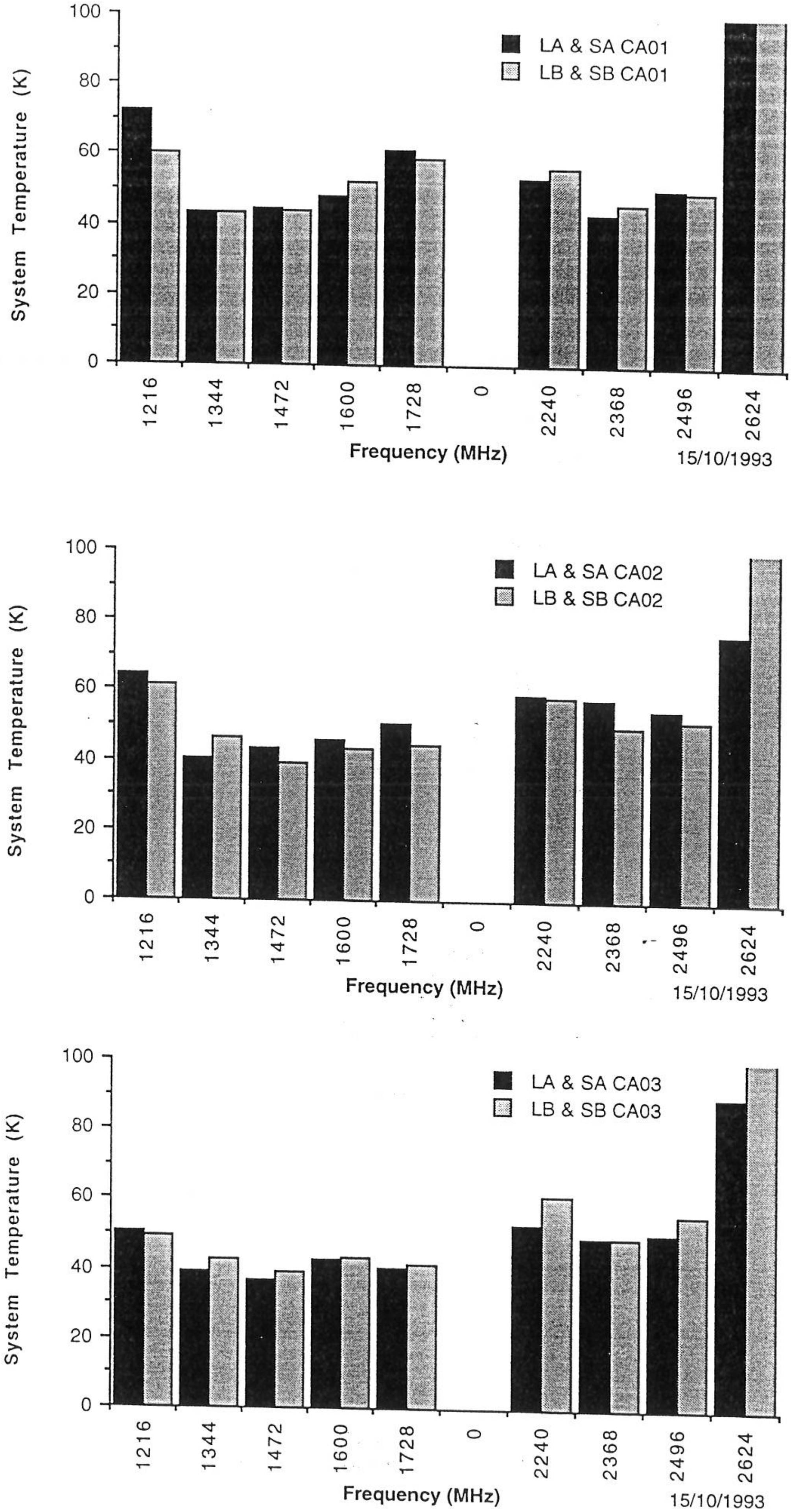
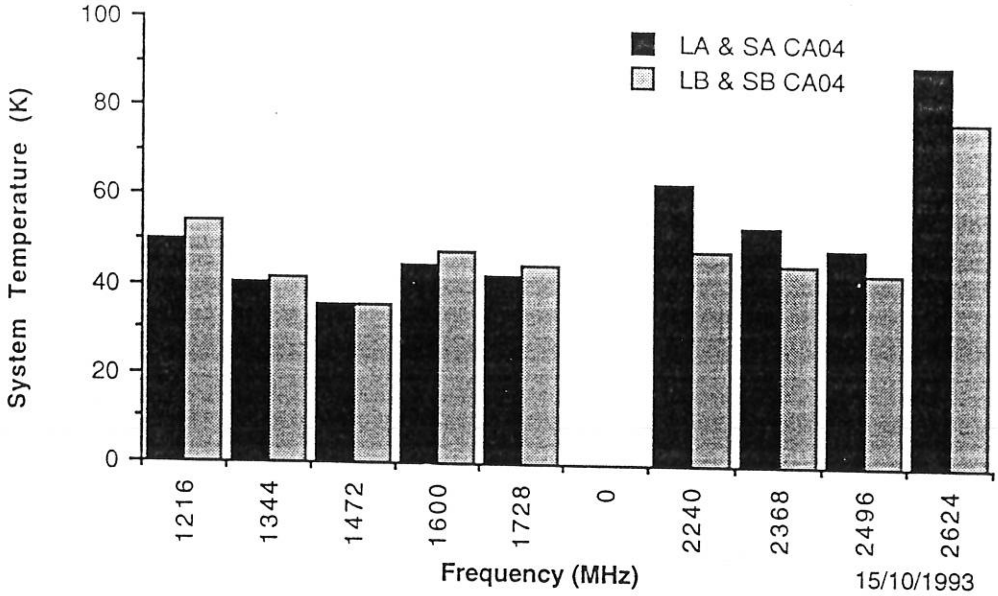
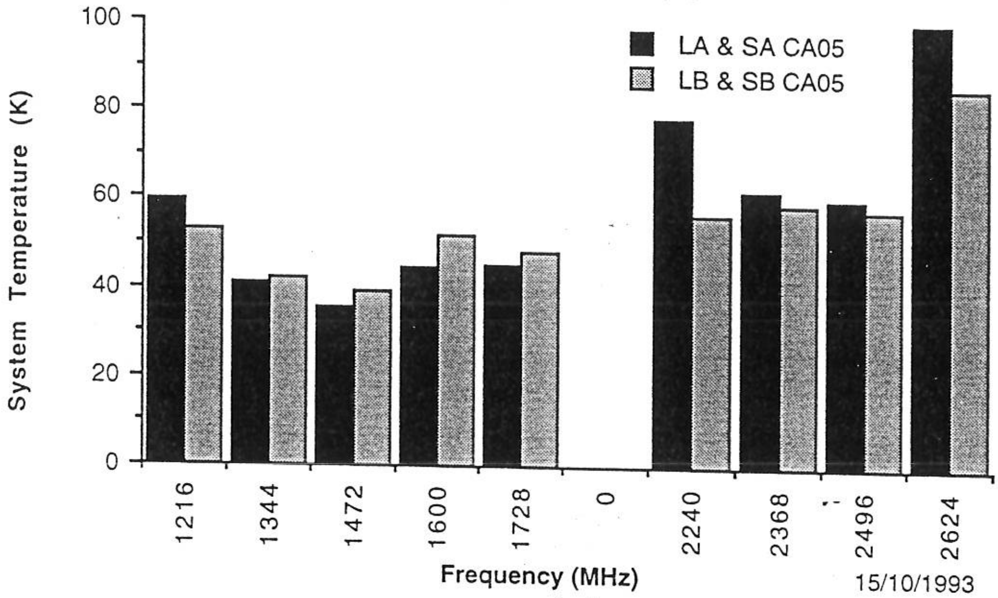


Fig. 2. "Astronomical" system temperatures of both polarizations for all six antennas for the 20 cm/13 cm bands.





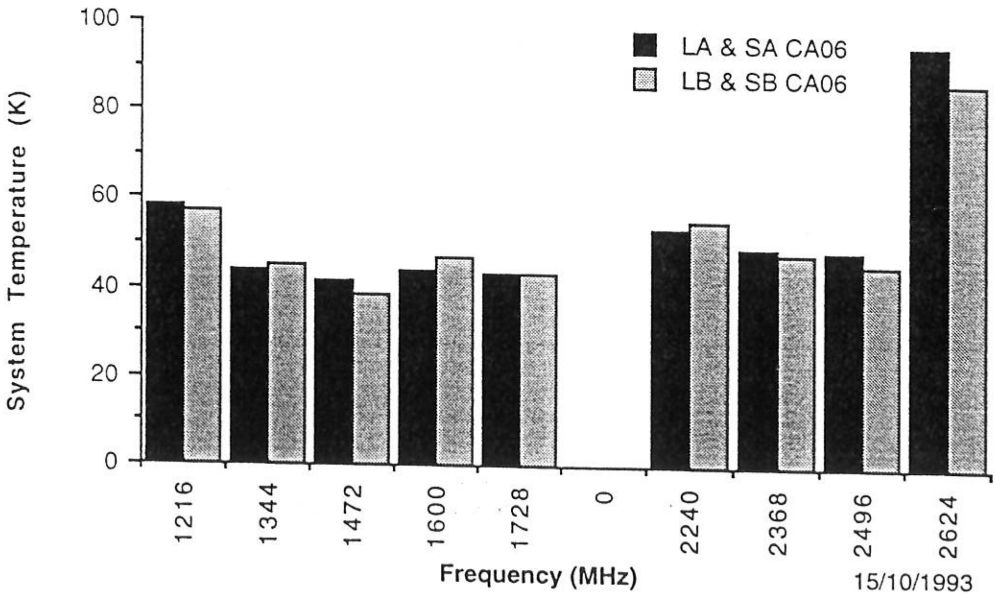


Fig. 2.(cont) "Astronomical" system temperatures of both polarizations for all six antennas for the 20 cm/13 cm bands.

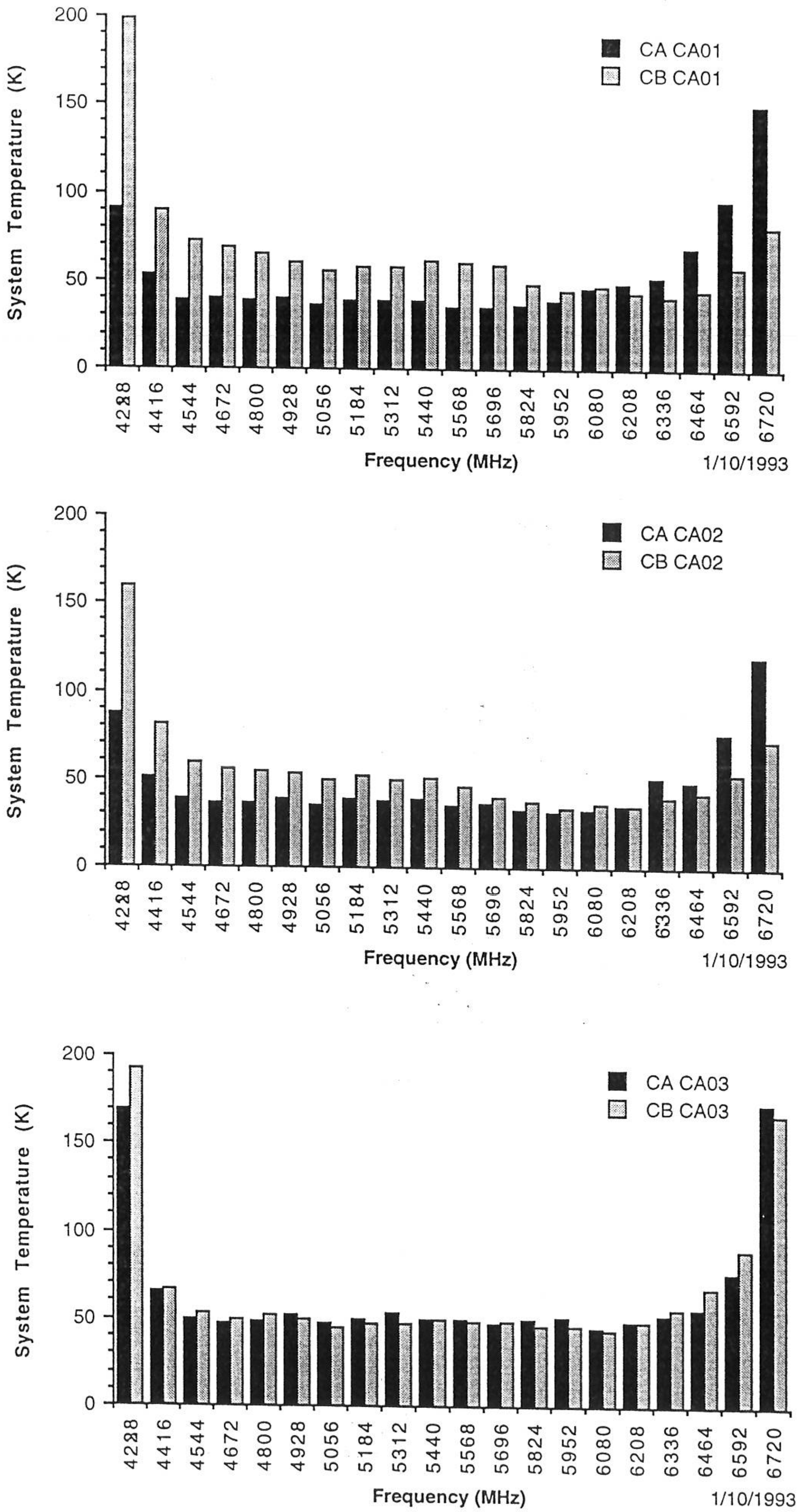
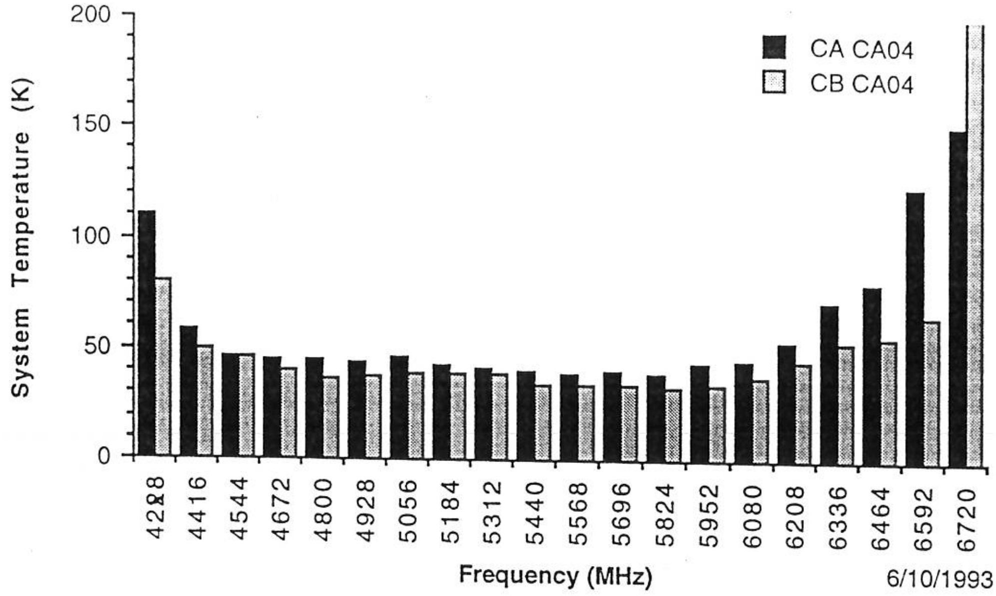
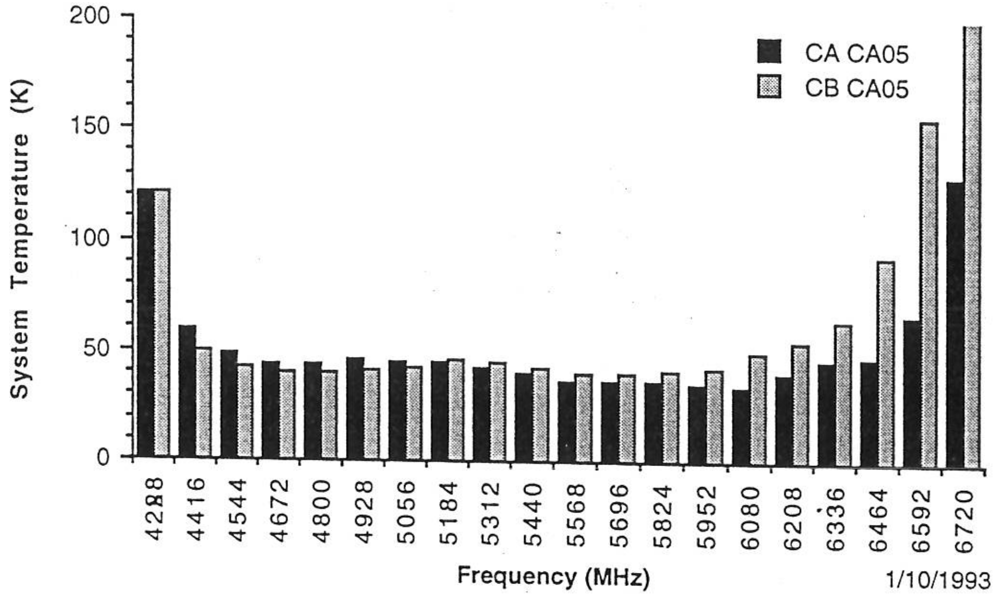


Fig. 3. "Astronomical" system temperatures of both polarizations for all six antennas for the 6 cm bands.





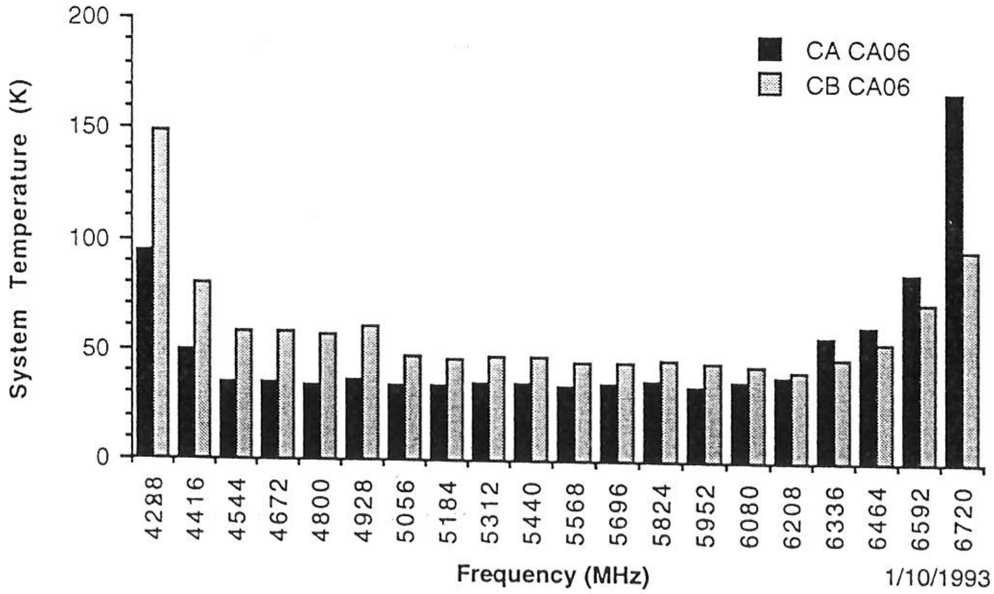


Fig. 3.(cont) "Astronomical" system temperatures of both polarizations for all six antennas for the 6 cm bands.

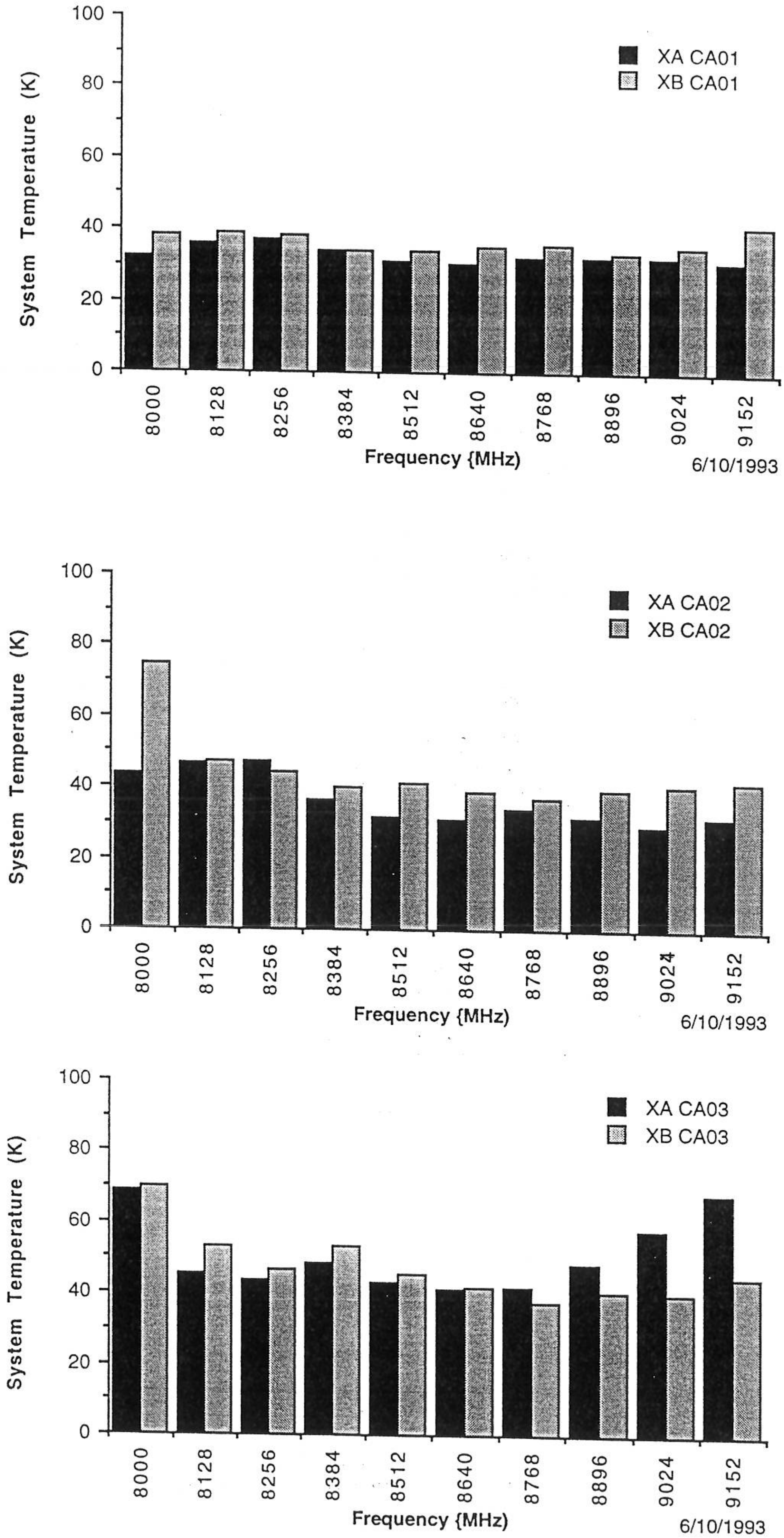
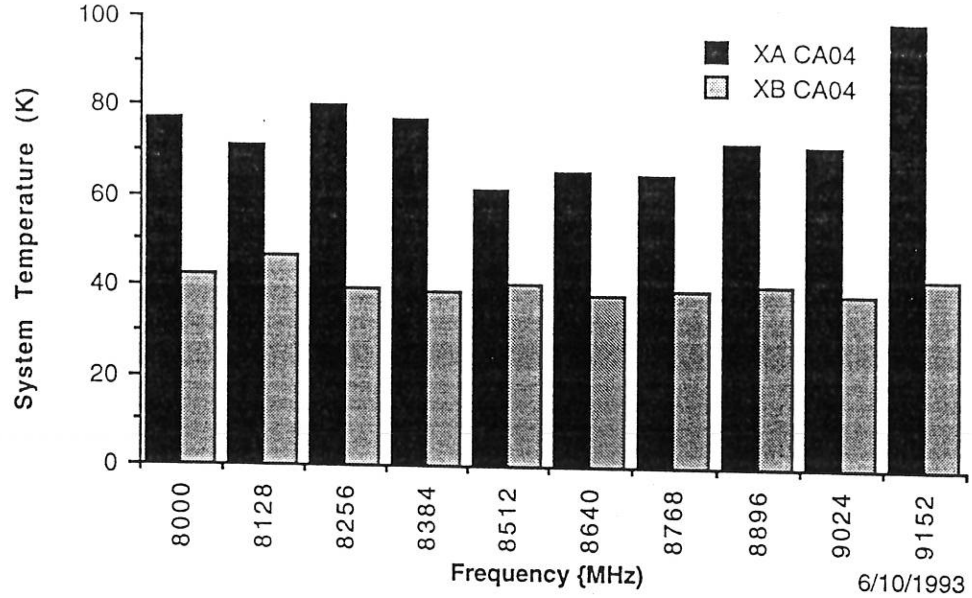
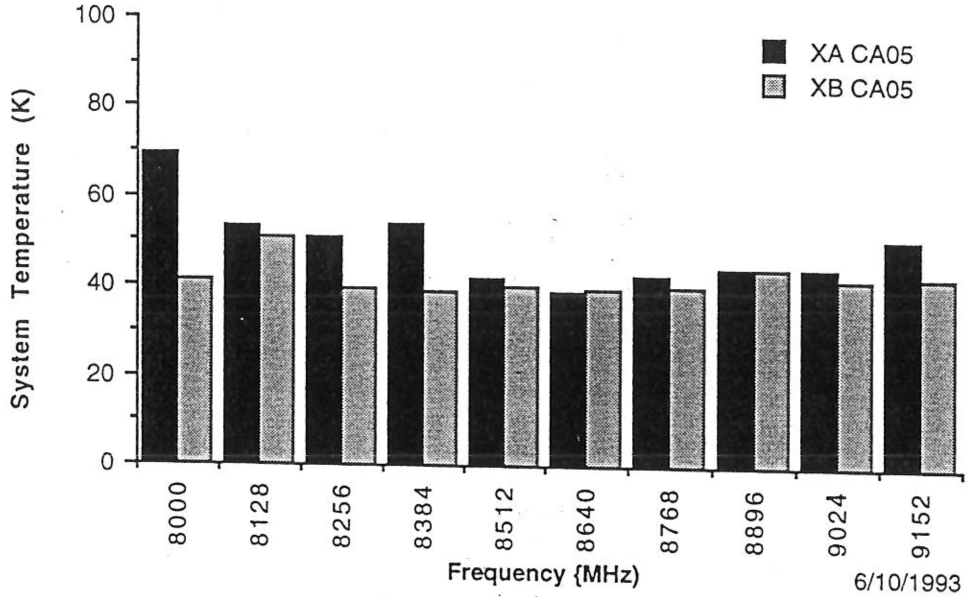


Fig. 4. "Astronomical" system temperatures of both polarizations for all six antennas for the 3 cm bands.





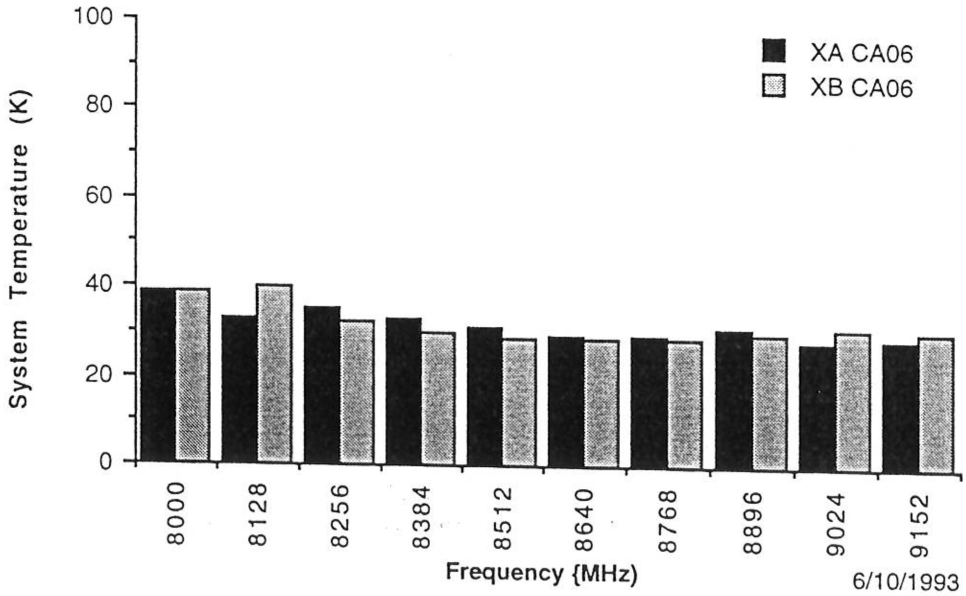


Fig. 4.(cont) "Astronomical" system temperatures of both polarizations for all six antennas for the 3 cm bands.

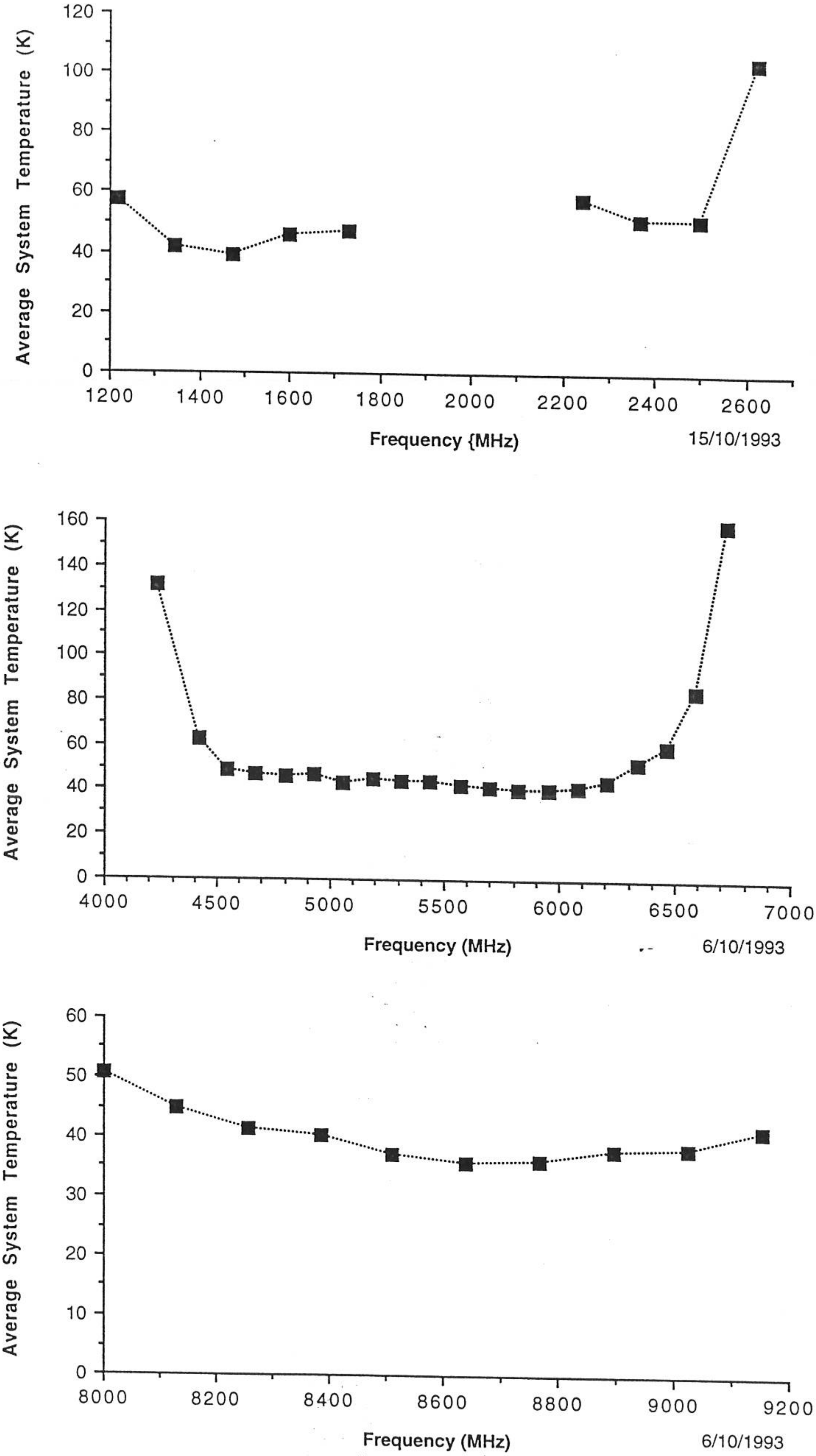


Fig. 5. Average of the "astronomical" system temperatures, T_{SYS_1}, of both polarizations for all six antennas at each frequency. For the 3 cm band, the average is of eleven system temperatures, excluding XA on CA04.

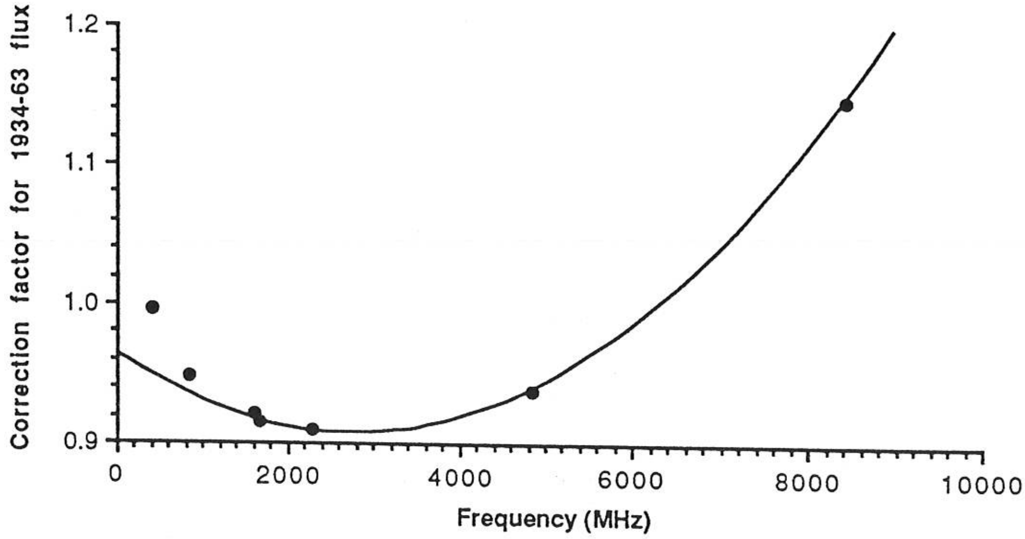


Fig. 6. Correction factors for the flux density estimates for 1934-638 given in Table A-2 and the second order approximation, eqn(1).

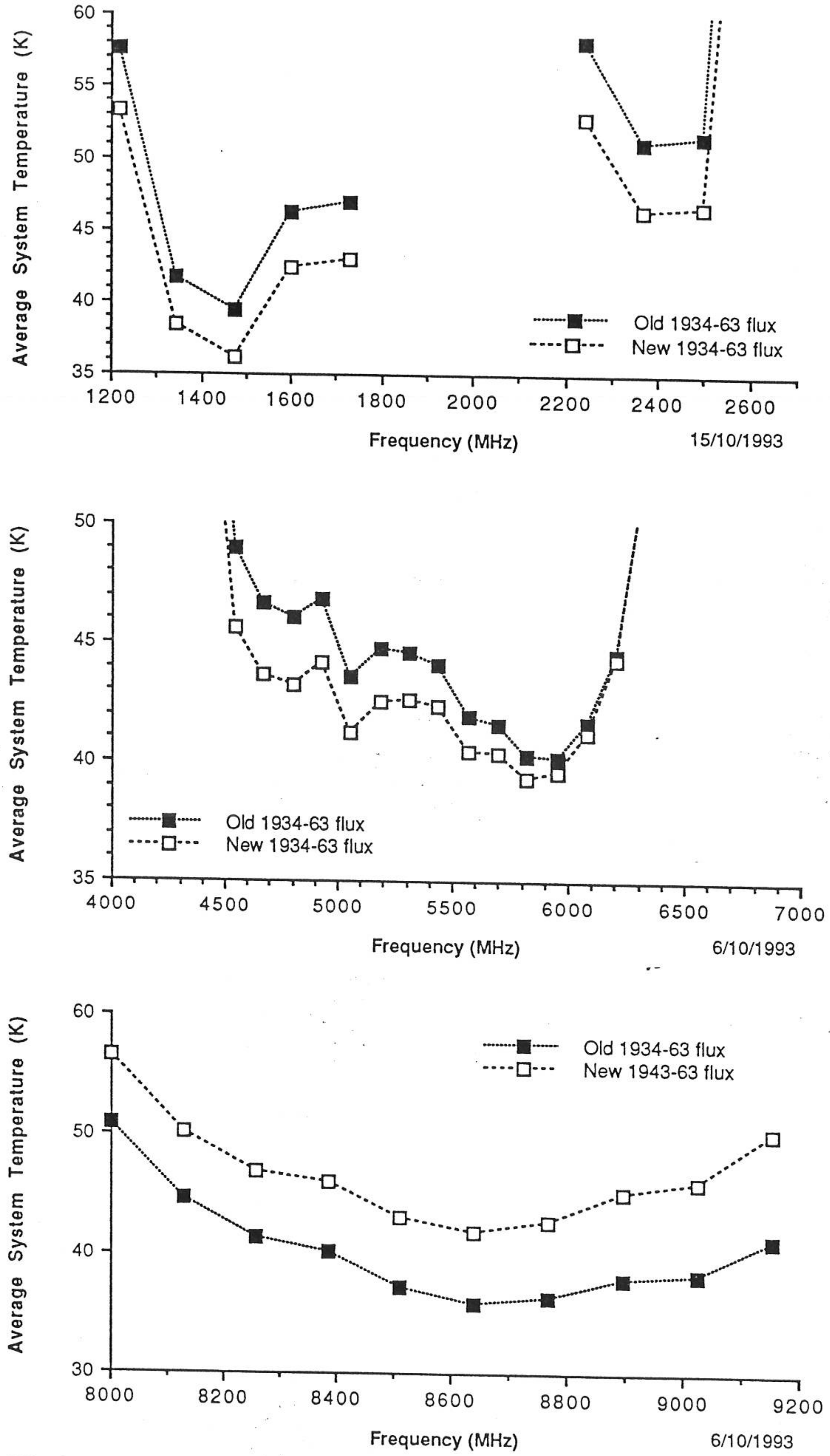


Fig. 7. Average of the "astronomical" system temperatures, T_{SYS_1} and T_{SYS_2}, using both the currently used (old) and revised (new) flux density estimates for 1934-638 respectively, plotted over the central portion of each band .

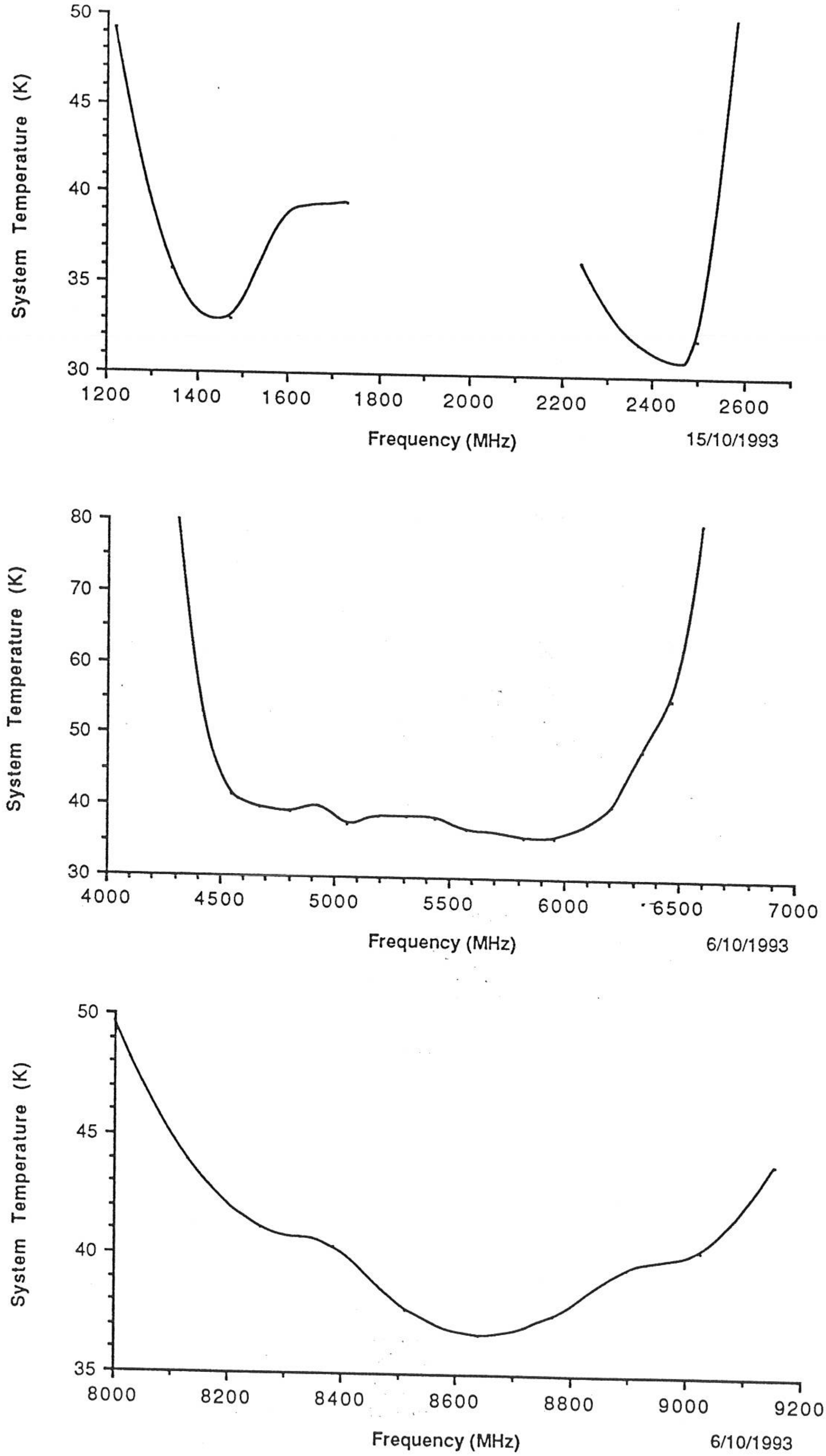


Fig. 8. Typical system temperature, T_{SYS_3}, of the AT receiver systems.