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"HOT BOX" MEASUREMENT OF COMPACT ARRAY RECEIVER SYSTEM TEMPERATURES

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1. INTRODUCTION.

The receiver system temperature measured with a "hot box" is a measure of receiver sensitivity which, in conjunction with antenna sensitivity can be used to estimate antenna efficiency. This report summarizes the receiver system temperatures of the compact array antennas in the AT bands measured with a "hot box". Antenna efficiency is estimated from previous measurements of "astronomical" system temperature.

The term "hot box system temperature", which will be used to describe the system temperature measured with a "hot box"[1] is independent of antenna efficiency and decorrelation effects.

The "hot box" system temperature is normally measured at zenith, and includes contributions from

- the receiver system,
- horn loss,
- spillover and scattering of ground radiation off the antenna structure,
- the cosmic background and
- loss in the atmosphere at zenith.

The "astronomical" system temperature, reported previously in [2], is a measure of system sensitivity which, in addition to the "hot box" system temperature, includes contributions from

- calibrator flux density and
- the increase in system temperature which occurs as the antenna points towards the horizon[1].

The measured "astronomical" system temperature will be higher

- if the value assumed for antenna efficiency, $\eta_0 = 0.726$ (S/T = 10 Jansky/Kelvin), is too high, or
- if there is decorrelation due to local oscillator phase noise or
- if the value assumed for the flux density of the calibrator is too high.

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.

2. "HOT BOX" SYSTEM TEMPERATURE MEASUREMENTS

Between April 13 and April 18, 1994, Graham Baines and I measured the system temperatures of the receivers on the compact array using a "hot box". The measurements were made using the program TSYS written by Robin Wark. With the "hot box" placed over the feed, the output power of the receiver was measured for a range of frequencies. The "hot box" was then removed and the receiver output power was measured at the same frequencies. Attenuator settings were chosen to optimize the output power with the "hot box" placed over the feed; the same attenuator settings were used when the hot box" was removed. The system temperature was calculated from the ratio of the receiver output powers measured with and without the "hot box"[1]. The program also measures the injected calibration noise signal.

The system temperatures measurements were made using 128 MHz wide bands, centred on odd multiples of 64 MHz. The bands were the same as those used for the system temperature measurements made in October, 1993[2]. The AT bands and the frequency ranges used for the system temperature measurements are given in Table 1.

Band	AT Band (MHz)	Range of Centre Frequencies for Tsys Measurement (MHz)
20 cm	1250 – 1750	1216 – 1728
13 cm	2200 – 2500	2240 – 2624
6 cm	4400 – 6100	4288 – 6720
3 cm	8000 – 9200	8000 – 9152

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

Table 1.

The serial numbers of the receivers installed on the compact array antennas when the "hot box" system temperatures were measured are listed in Table A-1. Between the measurement of the "astronomical" and "hot box" system temperatures in October, 1993, and April 1994, respectively, the 3/6 cm receivers on CA01 and CA02 and the XA HEMT amplifier on CA04 were changed.

The subreflector positions are listed in Table A-2. The positions of the sub-reflectors was not changed between the measurements of the "astronomical" and "hot box" system temperatures in October, 1993, and April 1994, respectively. As the subreflector position monitoring circuitry was not completed in April, 1994, both the distance between reference points marked on structure and the distance above the centre of subreflector travel are given. The centre of subreflector travel will be the reference point (0 mm) for the subreflector position monitor. Note that as the subreflector is moved *up* (away from the dish surface) the distance between reference points marked on structure *decreases* and the distance above the centre of subreflector travel *increases*.

3. COMPARISON OF "HOT BOX" AND "ASTRONOMICAL" SYSTEM TEMPERATURES

Figs. 1, 2 and 3 show the "hot box" system temperatures of both polarizations for all six antennas for the 20 cm/13 cm, 6 cm and 3 cm bands respectively. Fig. 4 shows the average "astronomical" and "hot box" system temperatures, where the averages at each frequency are of both polarizations and all six antennas. For the 3 cm band, the "astronomical" average is of eleven system temperatures, excluding XA on CA04.

As noted in Section 1, the "astronomical" system temperatures depend on the assumed antenna efficiency but the "hot box" system temperatures are independent of antena efficency. From the "astronomical" system temperatures reported in [2] and the "hot box" system temperatures reported here we can estimate the efficiency using

$$\eta = \eta_0 \cdot \frac{T_{SYS_B} + \Delta T_{ATM}}{C \cdot T_{SYS_A} - S_{1934-638} \cdot \frac{\eta_0}{7.26}} \tag{1}$$

where

C (= revised flux/current flux) is the correction factor used to obtain the revised values for the flux density of 1934-638 suggested by John Reynolds[3]. Equation (A-7) is the polynomial approximation used to calculate C.

η is the antenna efficiency,

$\eta_0 = 0.726$ is the assumed efficiency (S/T = 10 Jansky/Kelvin),

T_{SYS_A} is the ""astronomical" system temperature,

T_{SYS_B} is the "hot box" system temperature,

ΔT_{ATM} is the estimated increase in system temperature (from zenith to an elevation of 40°) due to increased loss in the atmosphere for typical site conditions of 25°C ambient temperature and a relative humidity of 0.6, and

$S_{1934\text{-}638}$ is the flux density of the calibrator 1934-638 in Jansky.

Equation (1), which is derived in the Appendix, assumes that the receiver system temperature did not change between the "astronomical" and "hot box" system temperature measurements. As the 6/3 cm receivers were changed on antennas CA01 and CA02 between the "astronomical" system temperature measurements made in October, 1993, and the "hot box" system temperature measurements made in April, 1994, efficiencies could not be calculated for these antennas for the 6 cm and 3 cm bands. In addition, the 3 cm HEMT low-noise amplifier in the XA channel on CA04 was changed between October, 1993, and April, 1994, so efficiencies could not be calculated for this channel.

Note that the efficiency calculated using eqn. (1) is based on interferometer measurements of the "astronomical" system temperature. If there are effects which reduce the fringe amplitude by decorrelating the signals from the antennas, this estimate of efficiency will be less than the (single dish) antenna efficiency.

Efficiencies have been calculated, using eqn. (1), for the four AT bands. Figs. 5, 6 and 7 show the efficiencies for the 20 cm/13 cm, 6 cm and 3 cm bands respectively. The average of the efficiencies has also been plotted.

In Figs. 5 and 7, CA05 stands out as having a poor efficiency in both the 13 cm and 3 cm bands. The efficiency of only CA05 in the 20cm/13 cm bands is shown in Fig. 8. Focus tests carried out on CA01 to CA05 by Mike Kesteven in October, 1990, showed that the optimum subreflector position for CA05 at 8400 MHz was -12 mm, lower than that for most of the other antennas. The poor efficiency of CA05 in the 20cm/13 cm bands was probably because the antenna was poorly focussed when the subreflector was at +13 mm.

Also in Fig. 7, XA of CA03 stands out as having a poor efficiency in the 3 cm band. The 3 cm band efficiency of only CA03 is shown in Fig. 9, and the "astronomical" and "hot box" system temperatures are shown in Fig. 10. While the "hot box" system temperatures are relatively independent of frequency, the "astronomical" system temperature of XA increases more rapidly with frequency than the system temperature of XB. The fact that XB on CA03 has good efficiency indicates that the antenna is focussed in the 3 cm band, but there may be subtle processes which are causing decorrelation of the XA channel. The exact cause of the problem has yet to be identified, but I could speculate that the decorrelation may be due to a low level, out-of-band, oscillation in the XA low noise amplifier.

Fig. 11 shows the average and theoretical efficiencies in the AT bands. The corresponding S/T ratios are show in Fig. 12. Average system temperatures and efficiencies for the compact array are summarized in Table 2.

Freq. (MHz)	T_{SYS_A} (K)¶	C	$C \cdot T_{SYS_A}$ (K)¶	$S_{1934-638} \cdot \frac{\eta_0}{7.26}$ (K)	T_{SYS_B} (K)¶	ΔT_{ATM} (K)	η¶	η‡
1472	39.4	0.919	36.2	1.4	31.0	1.2	0.68	0.69
2368	51.1	0.908	46.4	0.8	33.6	1.3	0.56	0.51
4800	46.0	0.938	43.2	0.6	36.0	1.5	0.65*	0.67
8640	35.9**	1.167	41.9**	0.3	40.6	2.2	0.73***	0.64

¶ Average for the compact array.
‡ Theoretical efficiency[4].
* Average for the compact array excluding CA01 and CA02.
** Average for the compact array excluding XA on CA04.
*** Average for the compact array excluding CA01, CA02 and XA on CA04.

Table 2. Summary of average system temperatures and efficiencies for the compact array.

While the average efficiencies in the 20 cm and 6 cm bands are close to the theoretical efficiencies predicted by James[4], the 13 cm and 3 cm bands have higher efficiencies than predicted. The predicted efficiency for the 13 cm band may be low because the theory over estimates the loss of efficiency which occurs when the 13 cm band horn is not focussed. For the 3 cm band, the high measured efficiency may be because the revised estimates for the flux density of 1934-638 still too low.

5. 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] Gough, R.G., "Receiver System Temperatures", AT/39.2/022, January 19, 1994.

[3] Reynolds, J., Private communication.

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

APPENDIX.

A1. Receiver serial numbers

Antenna	20/13 cm receiver serial number	6/3 cm receiver serial number
CA01	05	05
CA02	01	04
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, in April, 1994, when the system temperatures were measured using a "hot box".

A2. Subreflector positions

Antenna	Distance between reference points marked on structure (mm)	Distance above the centre of subreflector travel (mm)
CA01	72.5	-1.0
CA02	81.5	-4.5
CA03	79.0	-3.5
CA04	47.0	+19.0
CA05	60.0	+13.0
CA06	69.0	+5.5

Table A-2. Position of the subreflectors on the compact array antennas, in April, 1994. The position of the subreflectors was not changed between the measurements of the "astronomical" and "hot box" system temperatures in October, 1993, and April 1994, respectively.

Note that as the subreflector is moved *up* (away from the main reflector surface) the "distance between reference points marked on structure" *decreases* and the "distance above the centre of subreflector travel" *increases*.

A3. Derivation of the expression for calculating antenna efficiency from "hot box" and "astronomical" system temperatures.

When pointing at the calibrator, 1934-638, the system temperature includes a contribution, T_{SOURCE} , from the calibrator flux density

$$T_{SOURCE} = \eta \frac{S_{1934-638}}{7.26} \tag{A-1}$$

where $S_{1934\text{-}638}$ is the flux density of the calibrator, 1934-638, in Jansky and η is the antenna efficiency.

As the calibrator was at an elevation of 40°, the system temperature also included a contribution, T_{ATM} , from loss in the atmosphere

$$T_{ATM}(Elevation) = \frac{T_{ATM}(zenith)}{\cos(Elevation)} \tag{A-2}$$

where T_{ATM} depends on frequency and the column density of water vapour[1].

The "hot box" system temperature which we measured, T_{SYS_B}, included T_{ATM} *(zenith)*, so the system temperature when pointing at the calibrator was

$$T_{SYS} = T_{SYS_B} + \Delta T_{ATM} + \eta \frac{S_{1934-638}}{7.26} \tag{A-3}$$

where ΔT_{ATM} is the increase in system temperature (from zenith to an elevation of 40°) due to increased loss in the atmosphere

$$\Delta T_{ATM} = T_{ATM}(Elevation = 40°) - T_{ATM}(zenith) = T_{ATM}(zenith)\left(\frac{1}{\cos(40°)} - 1\right) \tag{A-4}$$

The "astronomical" system temperature, which was reported in [2], assumes an efficiency $\eta = \eta_0 = 0.726$ (that is S/T = 10 Jansky/Kelvin) and used the current values for the flux density of 1934-638. We can calculate the expected "astronomical" system temperature, T_{SYS_A}, from the "hot box" system temperature, T_{SYS_B}, using

$$T_{SYS_A} = \frac{1}{C}\frac{\eta_0}{\eta} T_{SYS} \tag{A-5}$$

that is

$$T_{SYS_A} = \frac{1}{C}\frac{\eta_0}{\eta}\left[T_{SYS_B} + \Delta T_{ATM} + \eta \frac{S_{1934-638}}{7.26}\right] \tag{A-6}$$

where C is the correction factor used to obtain the revised values for the flux density of 1934-638 suggested by John Reynolds[3]. The second order polynomial used to calculate C is

$$C = 7.5418 \cdot 10^{-9} f^2 - 4.1677 \cdot 10^{-5} f + 0.96413 \qquad \text{(A-7)}$$

where f is the frequency in MHz. The correction factors and the polynomial approximation are shown in [2]

Equation (A-6) can be rewritten as

$$\eta = \eta_0 \cdot \frac{T_{SYS_B} + \Delta T_{ATM}}{C \cdot T_{SYS_A} - S_{1934-638} \cdot \frac{\eta_0}{7.26}} \qquad \text{(A-8)}$$

From the "astronomical" system temperatures reported in [2] and the "hot box" system temperatures reported here we can estimate the efficiency using equation (A-8). Note that this efficiency is based on interferometer measurements of the "astronomical" system temperature. If there are effects which reduce the fringe amplitude by decorrelating the signals from the antennas, this estimate of efficiency will be lower than the (single dish) antenna efficiency.

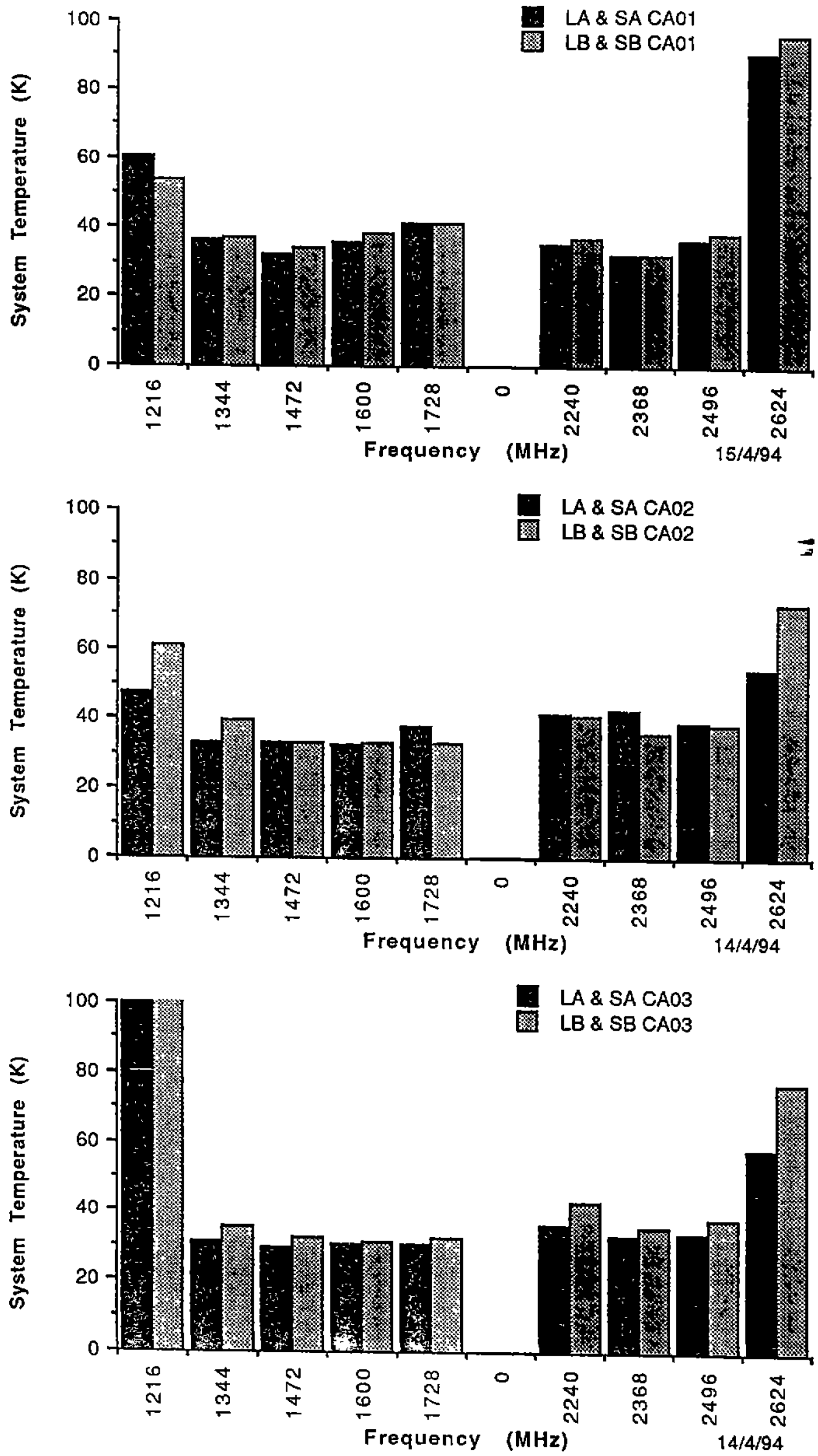
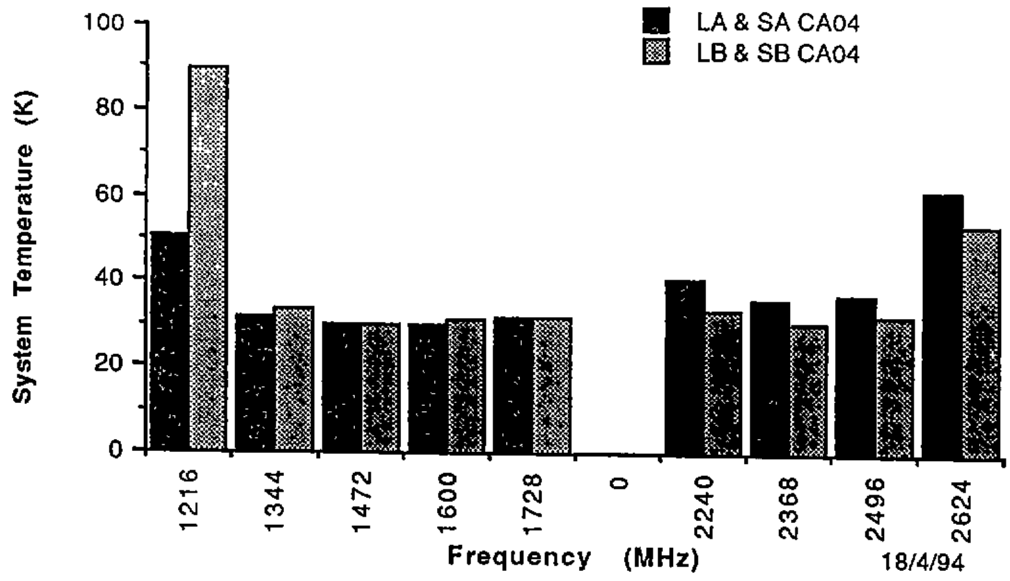
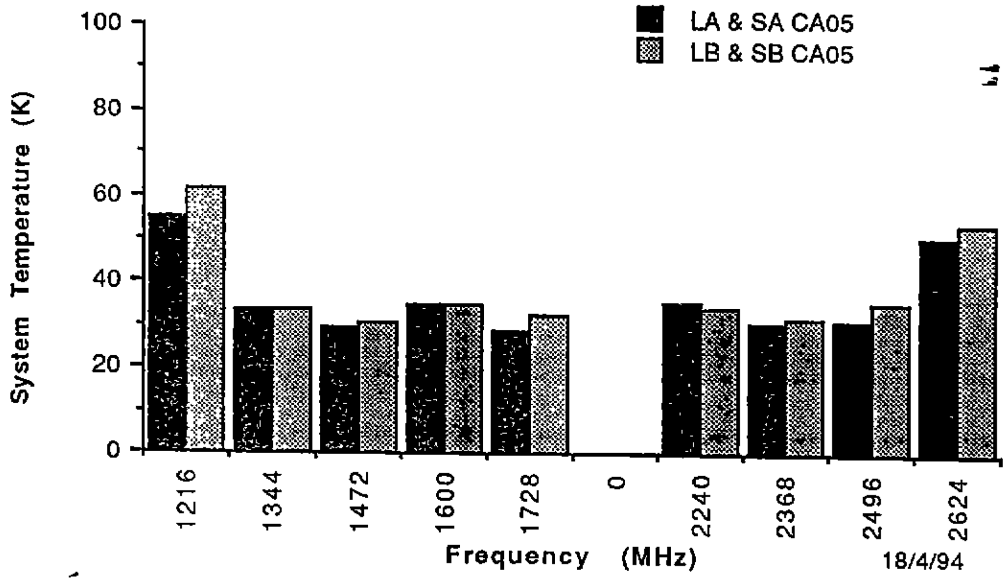


Fig. 1. "Hot box" system temperatures of both polarizations for all six antennas for the 20 cm/13 cm bands.





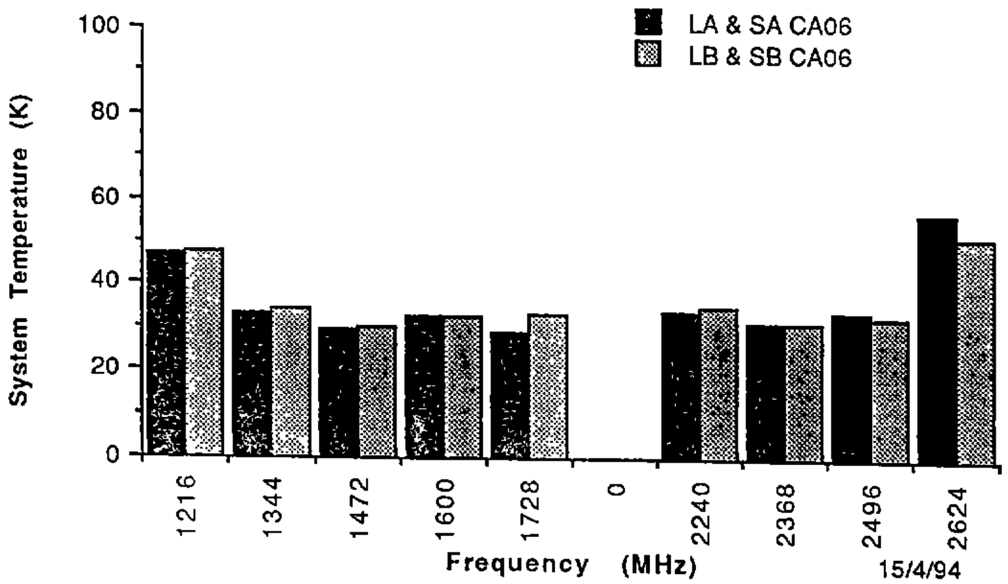


Fig. 1.(cont) "Hot box" system temperatures of both polarizations for all six antennas for the 20 cm/13 cm bands.

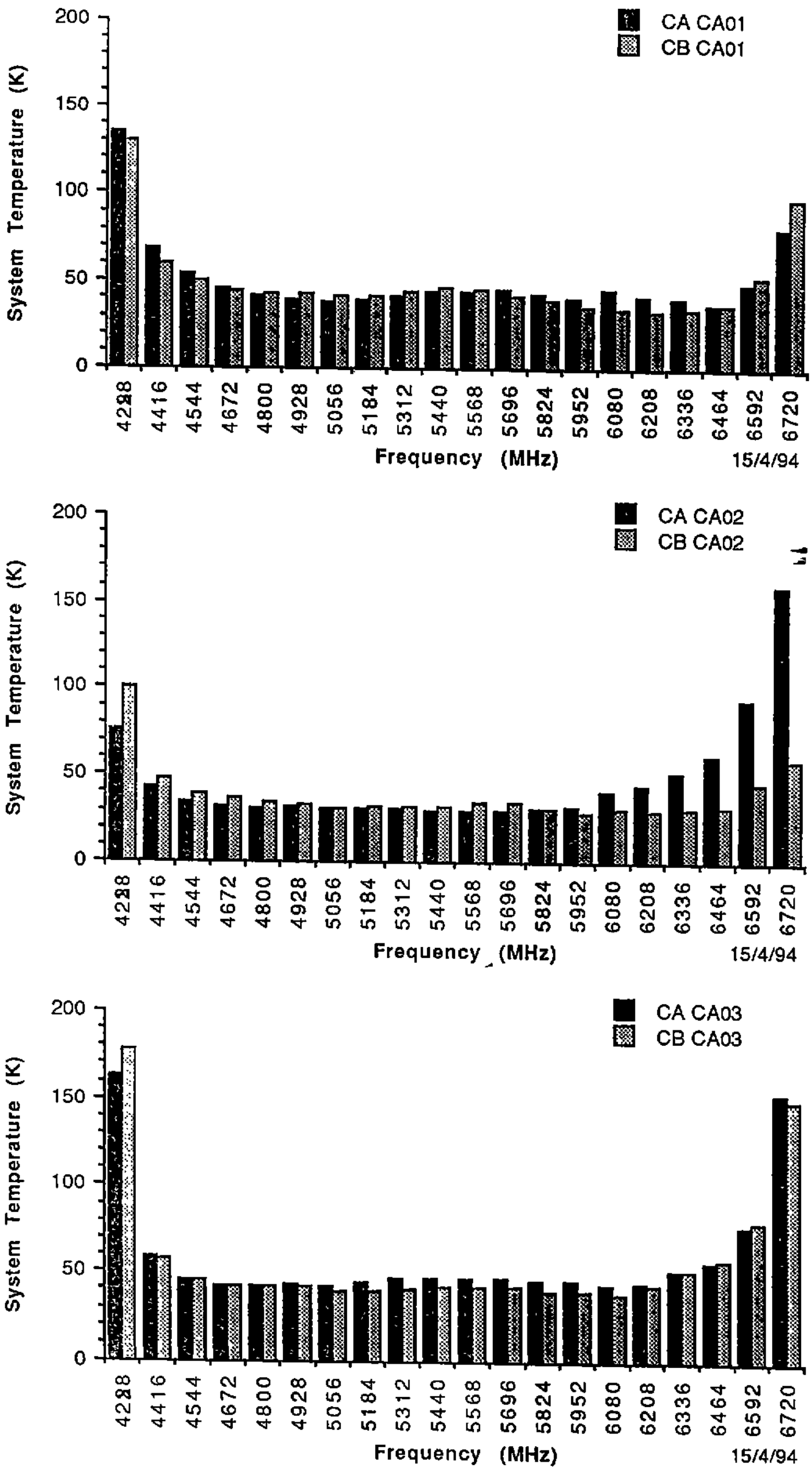


Fig. 2. "Hot box" system temperatures of both polarizations for all six antennas for the 6 cm band.

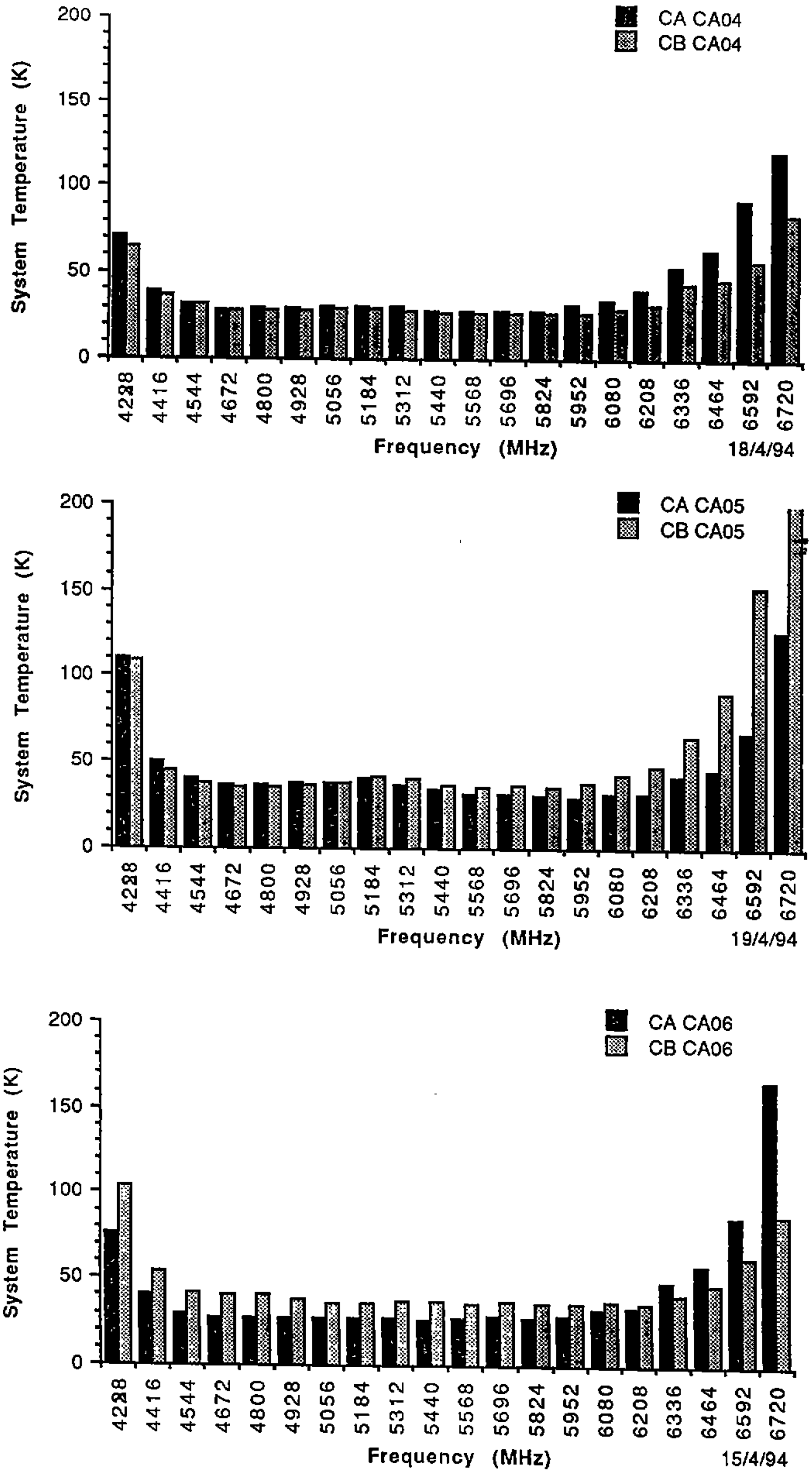


Fig. 2.(cont) "Hot box" system temperatures of both polarizations for all six antennas for the 6 cm band.

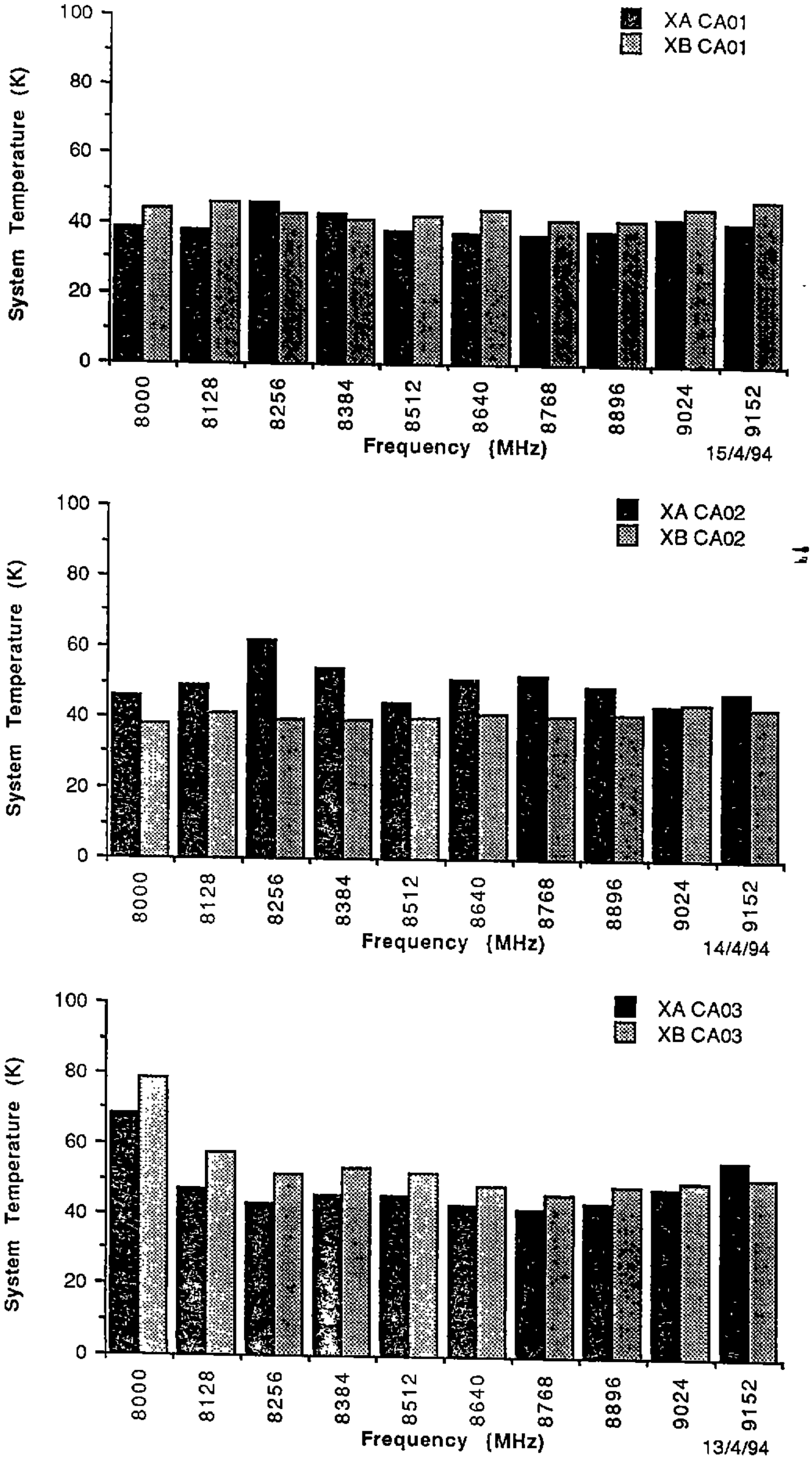
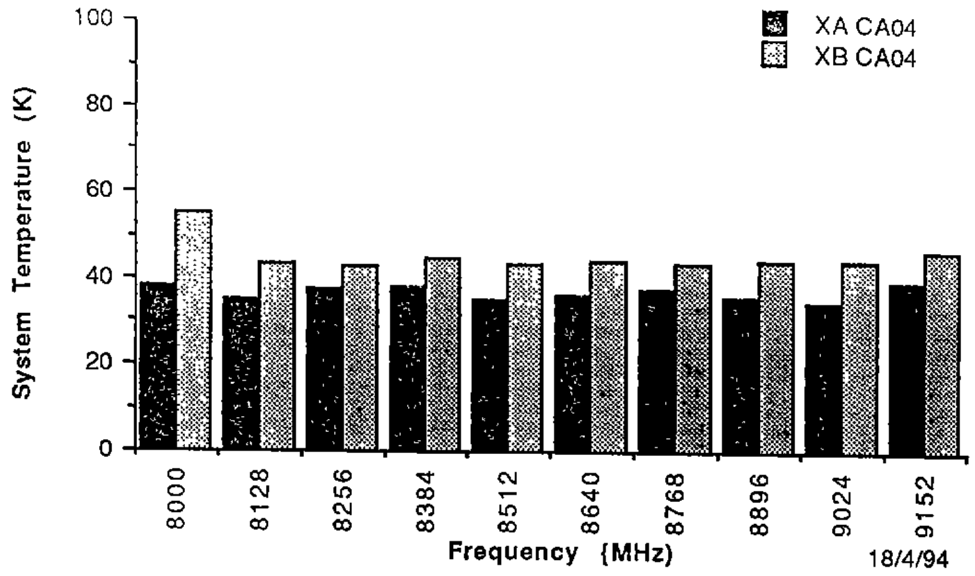
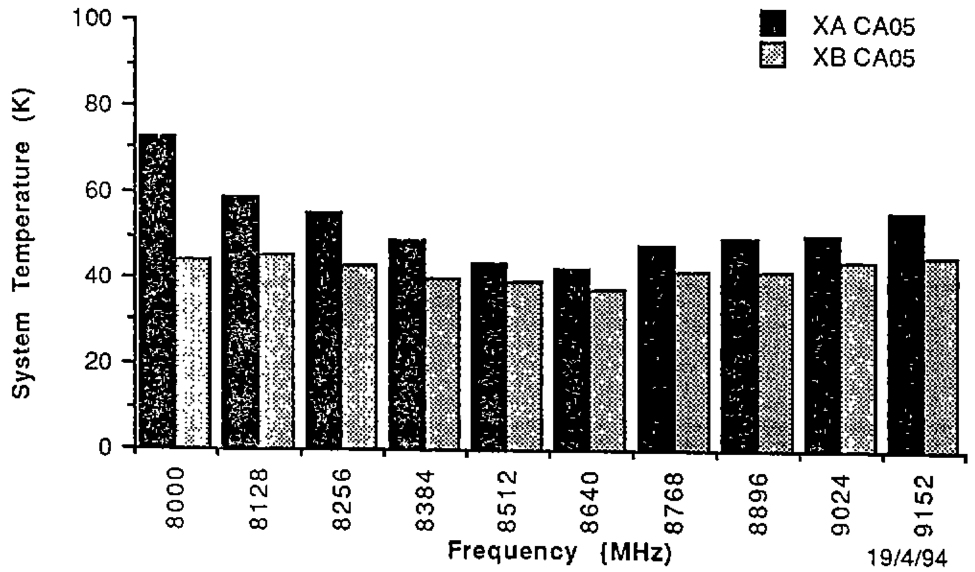


Fig. 3. "Hot box" system temperatures of both polarizations for all six antennas for the 3 cm band.





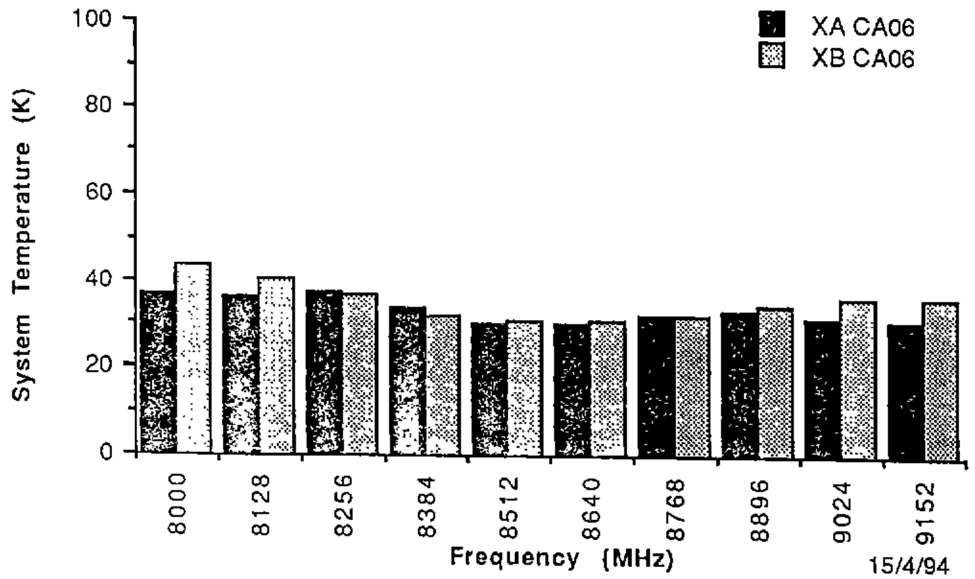


Fig. 3.(cont) "Hot box" system temperatures of both polarizations for all six antennas for the 3 cm band.

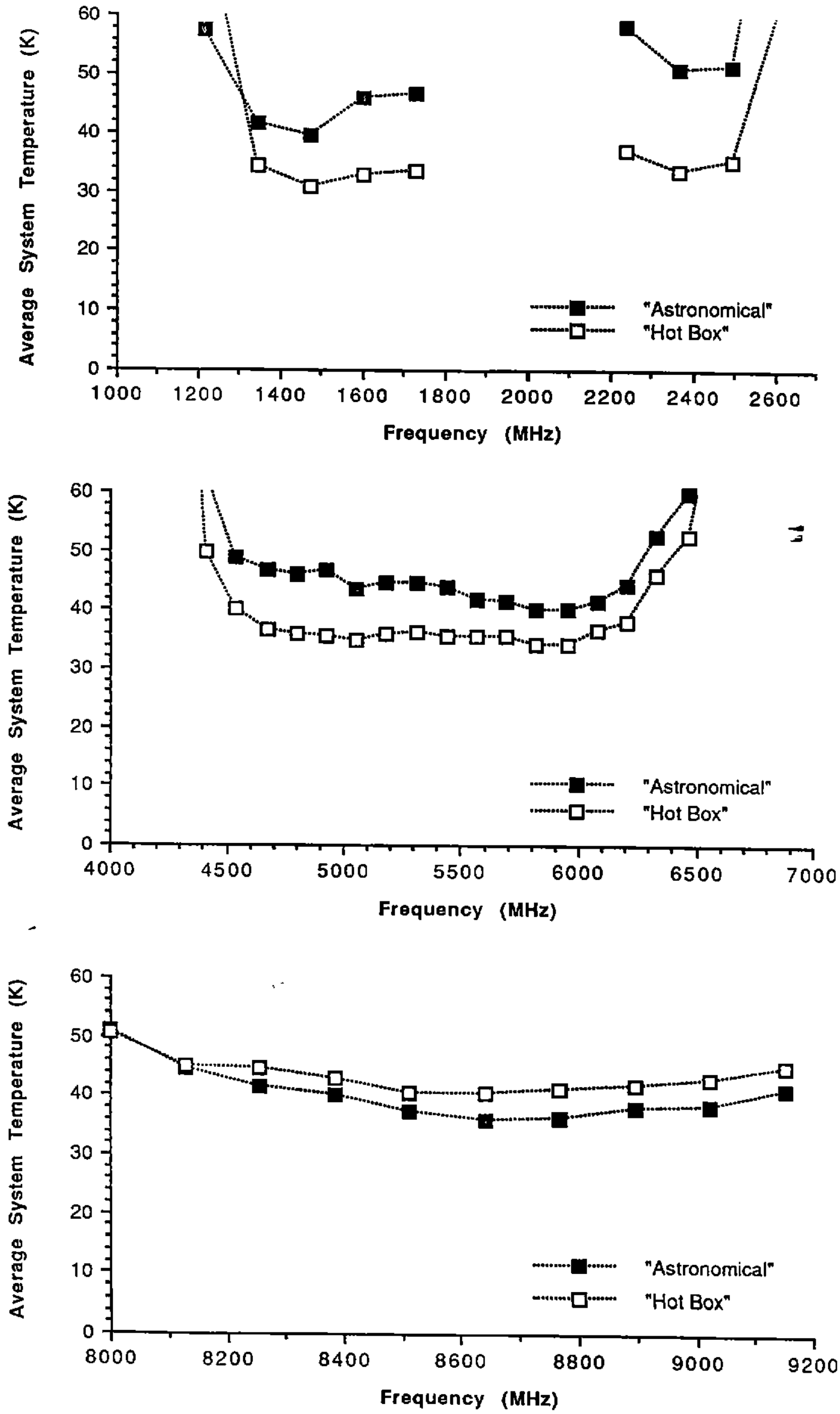


Fig. 4. Average "astronomical" and "hot box" system temperatures, where the averages at each frequency are of both polarizations and all six antennas.

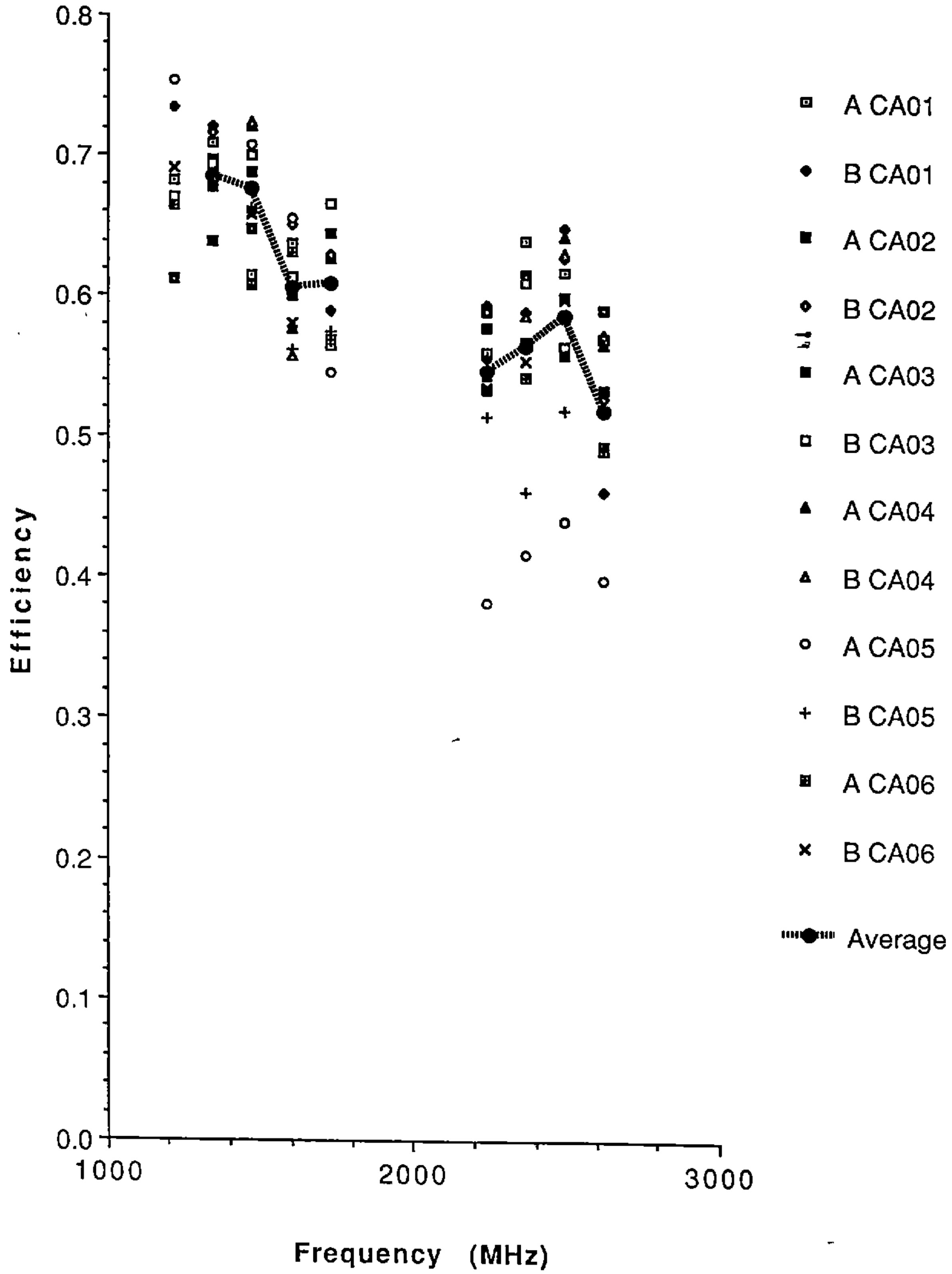


Fig. 5. Efficiencies for the 20 cm/13 cm bands.

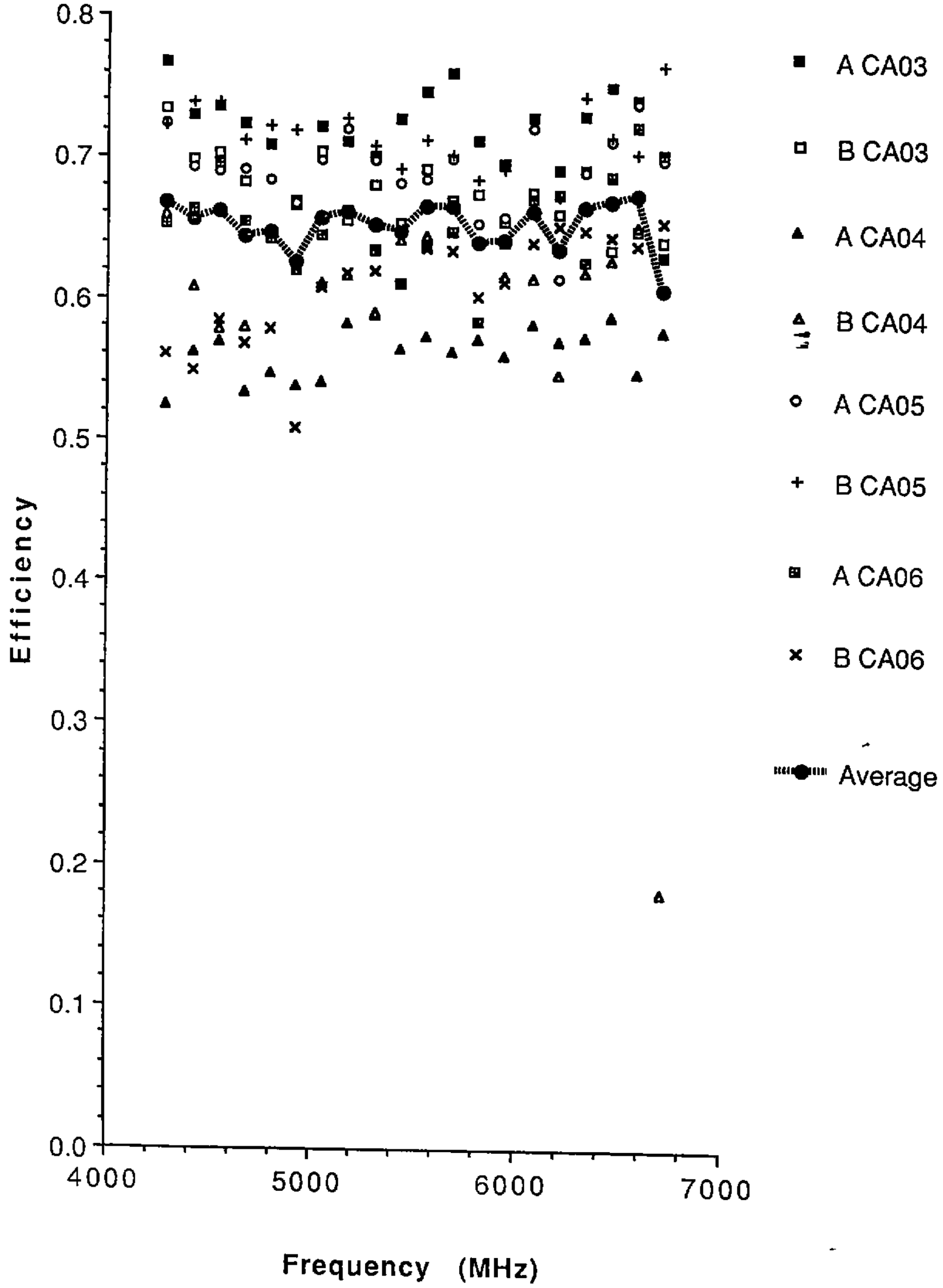


Fig. 6. Efficiencies for the 6 cm band. Note that efficiencies for the 6 cm band could not be calculated for CA01 and CA02 as the 6/3 cm receivers were changed on these antennas between the "astronomical" and "hot box" system temperature measurements.

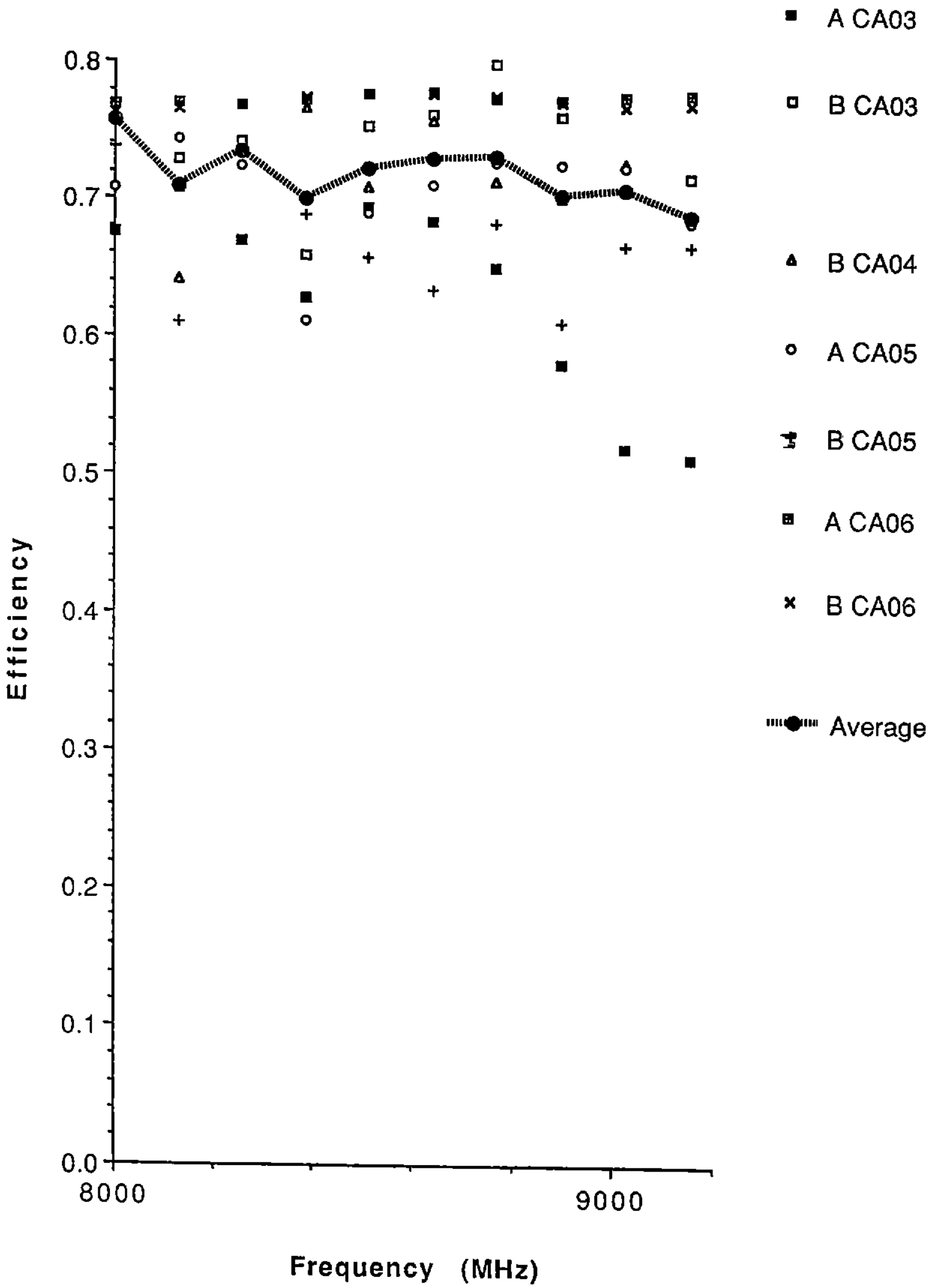


Fig. 7. Efficiencies for the 3 cm band. Note that efficiencies for the 3 cm band could not be calculated for CA01 and CA02 as the 6/3 cm receivers were changed on these antennas between the "astronomical" and "hot box" system temperature measurements. In addition, the 3 cm HEMT low-noise amplifier in the XA channel on CA04 was changed so efficiencies could not be calculated for this channel.

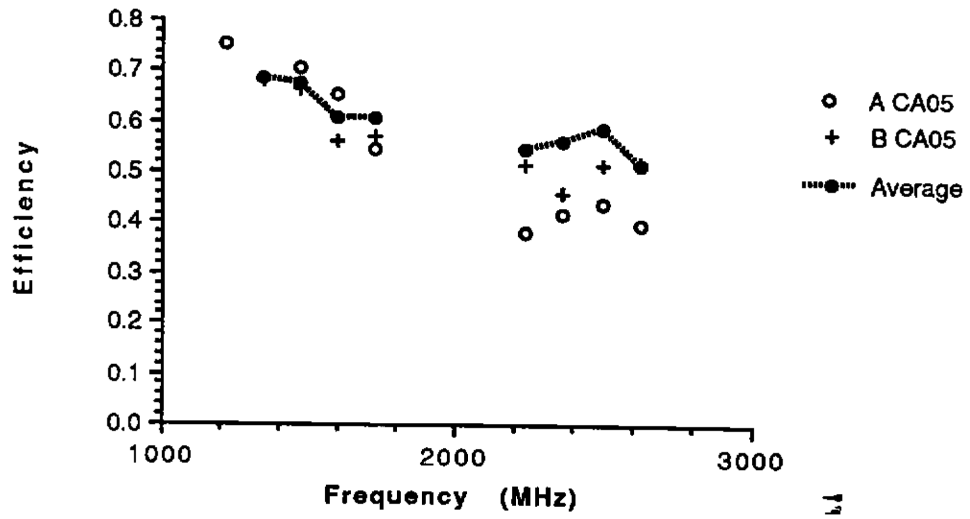


Fig. 8. Efficiency of CA05 in the 20cm/13 cm bands.

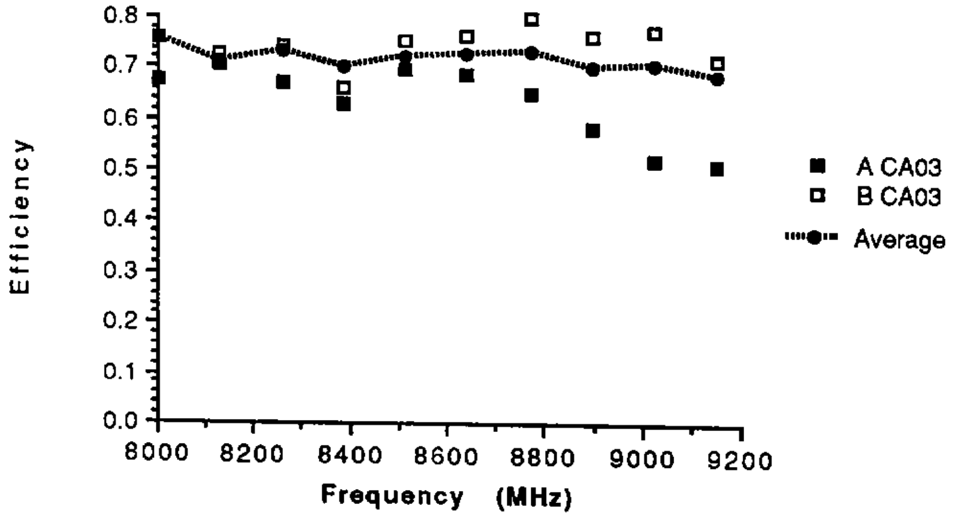
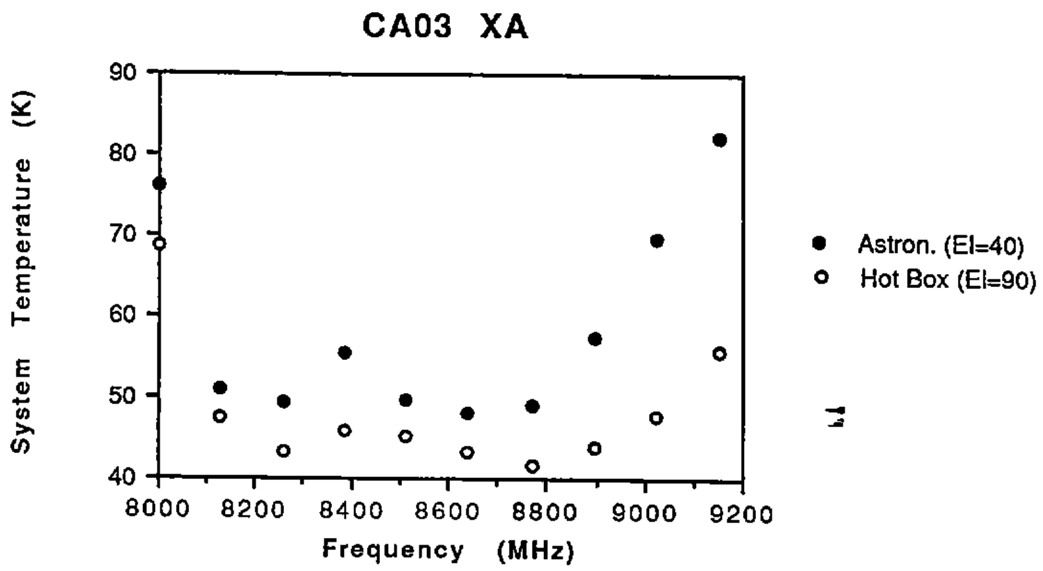
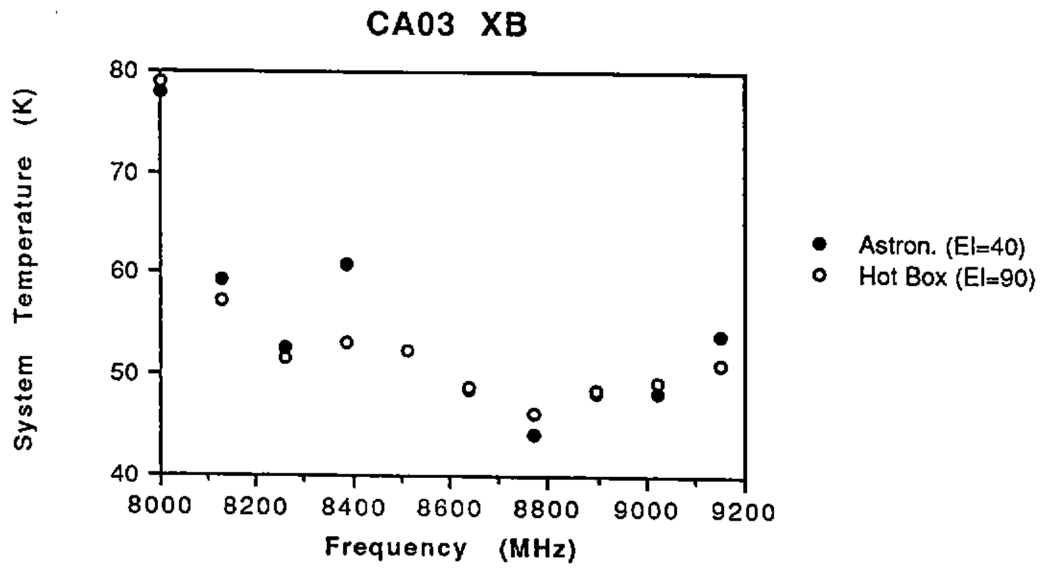


Fig. 9. Efficiency of CA03 in the 3 cm band.



(a)



(b)

<u>Fig. 10.</u> CA03 "astronomical" and "hot box" system temperatures in the 3 cm band.
(a) XA
(b) XB

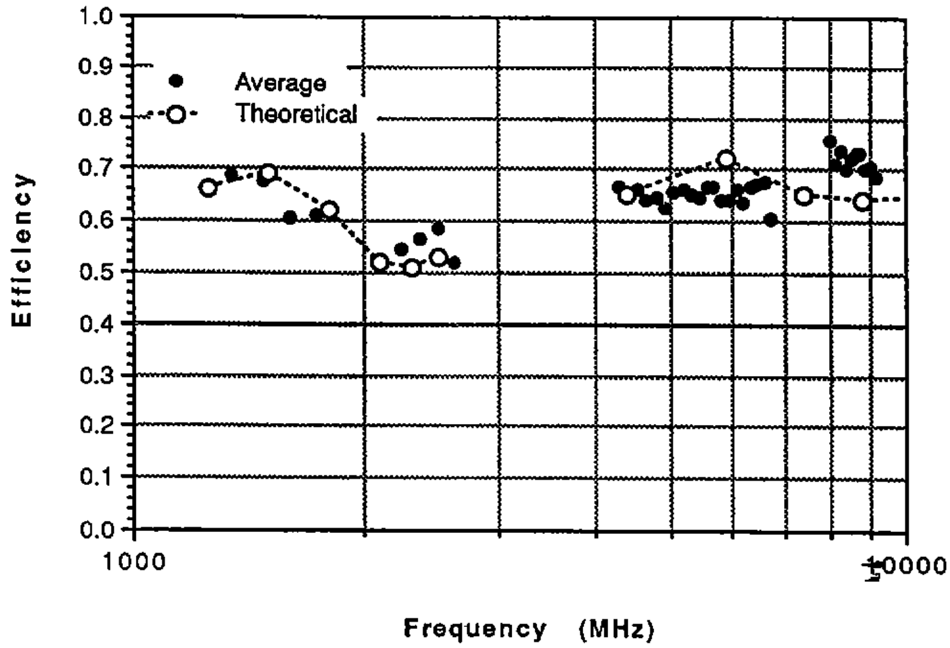


Fig. 11. Average and theoretical efficiencies in the AT bands. Note that average efficiencies for the 6 cm and 3 cm band do not include CA01 and CA02 as the 6/3 cm receivers were changed on these antennas between the "astronomical" and "hot box" system temperature measurements. In addition, the average efficiencies for the 3 cm band do not include the XA channel on CA04 as the HEMT low-noise amplifier in this channel was also changed.

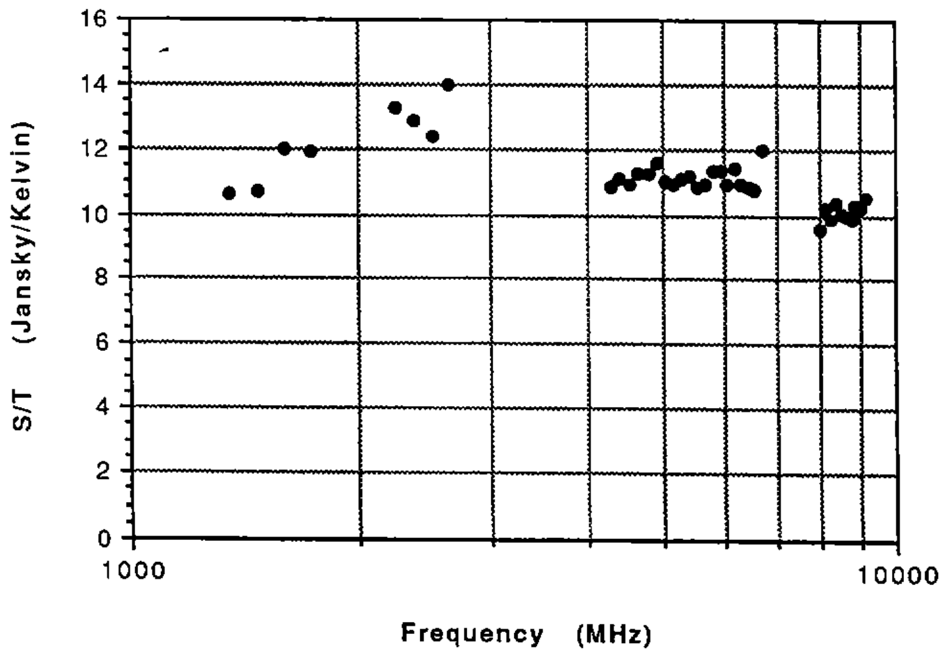


Fig. 12. S/T in the AT bands, calculated from the average efficiencies shown in Fig. 11.