NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA TEST MEMORANDUM NO. 126

PRELIMINARY INVESTIGATION OF TEMPERATURE DIFFERENCE EFFECTS ON VLA ANTENNA POINTING

Steven R. Spangler

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1.0 INTRODUCTION

A persistent problem of the VLA has been the existence of significant (of order one arcminute) and apparently variable single-dish pointing errors. These pointing errors are of concern due to their potentially adverse effects on flux density measurements and total power mapping at the highest frequencies, and on polarization mapping of extended sources at any frequency. Previous observations have indicated that the errors are worse in day than at night, and that large errors are encountered at sunrise. These two pieces of information suggest an origin in temperature differences across the antenna structure.

In the September, 1978 Test/Operations Coordination Meeting, a discussion was held regarding the location on the antenna structure where a temperature gradient would most drastically affect the pointing. The most critical location appeared to be from the front-to-back faces of the yoke arm.

In this memo, I will describe measurements I have undertaken (on antenna 3) to determine the yoke arm temperature gradient, and its relationship to the single-dish pointing of this antenna. The experiments undertaken were by no means definitive, and were designed with the intention of seeing if evidence for a temperature difference dependence of pointing existed, and thus if additional work was justified.

2.0 INSTRUMENTATION

The instrumentation used was developed around the Analog Devices AD590 temperature transducer. This device acts as a high impedance, temperature-dependent current source with a highly linear temperature-output current relationship. Thus the device used is not a conventional thermistor; the output current is very insensitive to the power supply voltage (see Figure 2 of Product Description/Technical Data Sheet).

A highly stylized block diagram of the equipment used is shown in Figure 1. Each of two units containing a temperature transducer was installed on a different part of the antenna, and produced current proportional to the steel temperature at that point. The currents were passed through resistors, and the potential drop across the resistors were input to a difference amplifier, the output of which was recorded by a digital voltmeter or chart recorder. For convenience, the section labeled "difference amplifier" and the recording instruments were located in the pedestal room of antenna 3. A schematic of the instrument is shown in Figure 2. The design was determined by my desire to conduct these preliminary measurements with analog equipment such as digital voltmeters and chart recorders. Since the experiments consisted of measuring a small difference between two large numbers, the use of a difference amplifier was dictated.

The obvious required calibration for this instrument was the difference amplifier output voltage versus temperature difference. This calibration was carried out using the temperature-controlled oven in the IF lab. Calibration measurements were made twice, in August, 1978 prior to early tests of the equipment, and in October, 1978 prior to the measurements described later in this memo. Good agreement was obtained between the results of the two sessions, and the calibration curve resulting from the October measurements is shown in Figure 3.

Here we see that the device produces 0.117 volts per degree centigrade of temperature difference.

The characteristics of each transducer unit were also measured by placing both units in the oven and measuring the voltage across the 10 kΩ resistors in Figure 2. The values for $\Delta V/\Delta T$ for the two devices were the same to 0.6%.

I believe that the largest source of error in this instrument is due to the dc offset of the operational amplifier. As may be seen in Figure 2, this offset was nulled, but dc offset drift would produce a spurious signal. A rough estimate of the magnitude of this effect may be determined from measurements made when the units were placed next to each other on the antenna structure. Over a change of a few hours, a change of .013 V was measured (probably due to offset drift), corresponding to a temperature difference of 0.11°C. Therefore I feel that systematic errors of order 0.1°C may be present in the measured temperature differences.

3.0 MEASUREMENTS ON ANTENNA 3

In this section, I will present results of three experiments related to temperature difference effects on pointing error. The first experiment took place on October 25, 1978, and the temperature difference measuring equipment was operated during a standard SYSPOINT pointing run. The pointing data were reduced by standard pointing programs and gave the elevation pointing error for RR and LL correlators roughly every two minutes. Temperature differences at these times were measured and reduced from chart records. For data presentation and further analysis, the RR and LL pointing errors were averaged, and the mean pointing error and temperature difference were summed over ten-minute intervals. The result is shown in Figure 4.

It is immediately seen that a relationship between temperature difference and pointing error exists (note prominent, correlated features at 17:50 and 19:30 IAT).

To quantify this result, and to investigate the possibility of time delays between the temperature difference and pointing error, a program was written for the DEC-10 computer which would calculate the cross-correlation function for the data shown in Figure 4. The cross-correlation function (CCF) was defined as:

$$C(D) = \frac{\sum_{i=1}^{N-D} T_{i+D} P_i}{\left[\sum_{i=1}^{N-D} T_{i+D}^2\right]^{\frac{1}{2}} \left[\sum_{i=1}^{N-D} P_i^2\right]^{\frac{1}{2}}} , \qquad (1)$$

where T_j is the j^{th} temperature difference reading, and P_i is the i^{th} pointing error reading. The CCF of the data shown in Figure 4 is presented in Figure 5. Three results are obtained from Figure 5:

(1) The shape of the CCF demonstrates that a correlation exists between temperature difference and pointing error. A distinct maximum is seen which continuously decreases with lag offset. If no correlation existed, the CCF would fluctuate about the estimation error.

(2) The correlation is quite strong, the maximum being 0.84.

(3) A distinct lag is seen, the maximum correlation occurs when the temperature difference leads the pointing error by 20-30 minutes. This is the only sense that is consistent with causality.

When the data in Figure 4 is adjusted by the lag indicated in Figure 5, and a plot of pointing error versus temperature difference is made, a slope of ~0.5 arcminutes/^{o}C is obtained. This is considerably greater than both the value expected from theoretical analyses and subsequent investigations. This value must therefore await confirmation in repeated experiments of this kind.

A second pointing run (on November 5, 1978) in which a single source was tracked was unfortunately compromised due to malfunctioning of my apparatus. Only a very short segment (1.5 hours) of useful data were obtained. Cross-correlation analysis once again yielded a large (0.82) value for the maximum CCF, only this time the maximum occurred at zero lag. Due to the small amount of data, however, the estimation error of the CCF was large, and this value for the maximum lag may not be in strong disagreement with that given above.

The second experiment (conducted from October 25-27, 1978) consisted simply of measuring the observed temperature difference over a significant time base, and observing the extrema and dependence of temperature difference on time of day.

Measurements from the charts were made each ten minutes and then averaged to produce 1 hr sums. The two days worth of data are shown in Figure 6, where I have plotted temperature difference versus IAT. Contiguous points are joined by dashed lines, and the times of sunrise and sunset are indicated. We notice that the total temperature excursion exceeds 3.5^{o}C, and that large temperature excursions occur shortly after sunrise. This last observation would seem to suggest that the dawn pointing errors referred to in the introduction are due to temperature differences.

The last experiment was perhaps the most direct, and is the most significant in relation to the effect of temperature differences on pointing error. In late November, Talyvel electronic levels arrived from Green Bank and were installed on antenna 3. These devices are capable of measuring tilt with precision of order of arcseconds. Two of these levels were installed on antenna 3, one on each yoke arm top. During a period in which the antenna was stationary, John Dreher turned on my apparatus, and collected and reduced the tilt and temperature difference data. The results are shown in Figure 7. Here the correlation between temperature difference and yoke arm tilt is dramatically illustrated. The data in Figure 7 was processed through the cross-correlation analysis program, and the resulting CCF's are shown in Figure 8. A very strong correlation (maximum

CCF = 0.95) and marked time lag are seen. For the A level, this lag was one to two hours, and was even longer for the B level. This time lag is, of course, considerably greater than that obtained from the pointing runs described above. As may be seen from Figure 7, the coefficient relating yoke arm tilt to temperature difference is of order 10 arcseconds per degree centigrade. This is substantially less than that obtained from the pointing analysis described above.

4.0 CONCLUSIONS

Two principal results are obtained from this investigation.

(1) A strong dependence of single-dish pointing error on yoke arm temperature gradient has been established. This result is obtained both from comparison of yoke arm temperature difference with total pointing error as determined from astronomical observations, and with direct measurement of yoke arm tilt. The correlation is sufficiently strong as to hold out hope that the pointing errors could be effectively eliminated by corrections employing thermal measurements. This approach is additionally attractive because of the nominal cost of the necessary electronics. The effective control of pointing errors through thermal measurements would require, however, that a stationary and functionally well-behaved dependence of pointing error on temperature exist. The measurements described in this memo are inadequate to determine if this is the case.

(2) There appears to be evidence for a lag time between the occurrence of a surface temperature difference and the associated pointing error or yoke arm deflection. Different experiments have returned different values for this lag time. Clearly, the use of thermal measurements will require the discovery of a constant time lag.

5.0 ACKNOWLEDGEMENTS

I would like to thank Chuck Broadwell for loaning me materials used in the construction of the instrument, and Bob Sefcovic for helping me install the devices and wiring on the antenna 3. John Dreher deserves credit for the carrying out of the important measurements when the temperature difference apparatus and electronic levels were operated simultaneously.

BLOCK DIAGRAM OF TEMPERATURE DIFFERENCE MEASURING EQUIPMENT

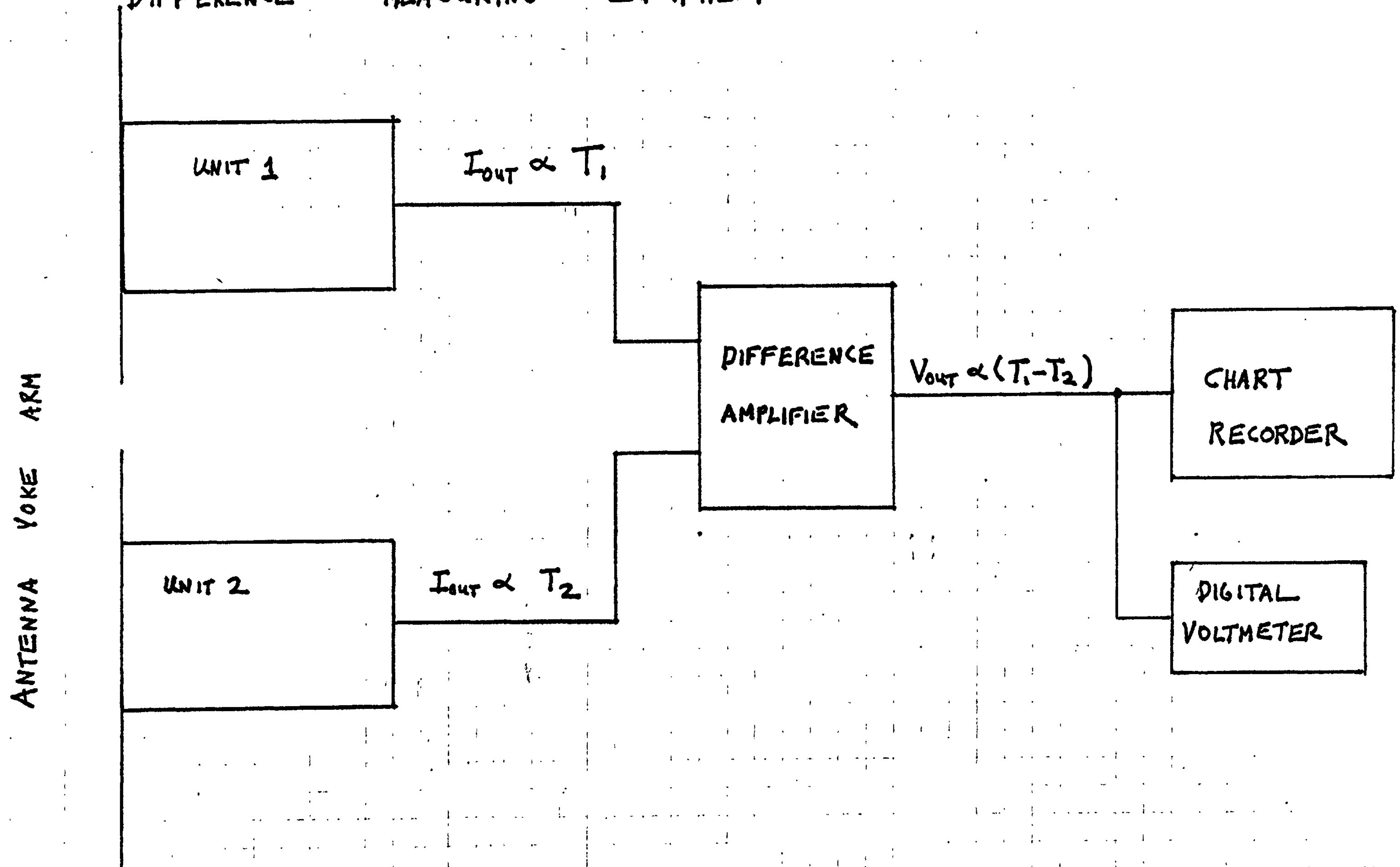
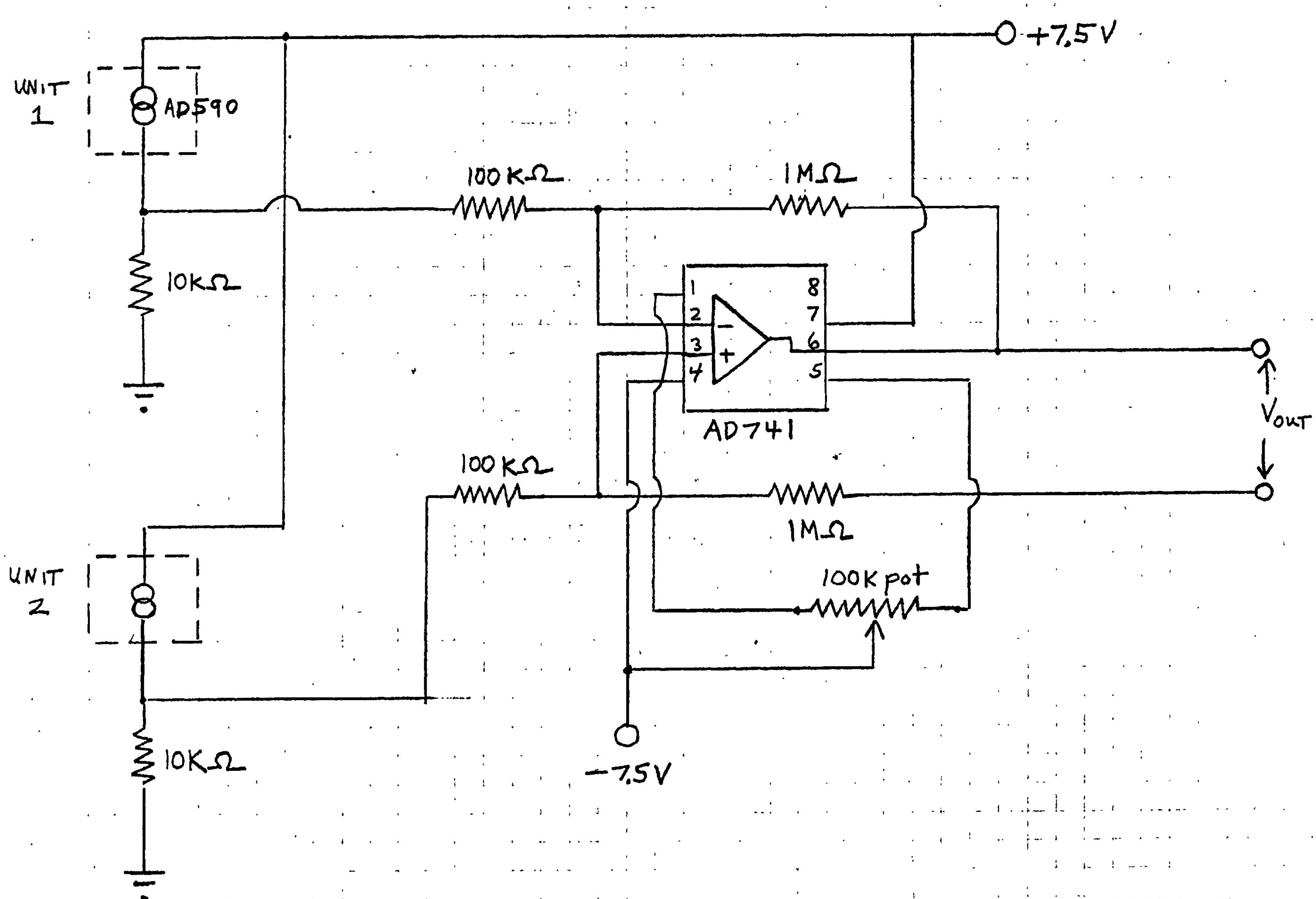


FIGURE 1

TEMPERATURE DIFFERENCE INSTRUMENTATION — SCHEMATIC DIAGRAM



NOTE: TRANSDUCERS ARE ANALOG DEVICES AD590J

FIGURE 2

DIFFERENCE AMPLIFIER CALIBRATION — OCTOBER 1978

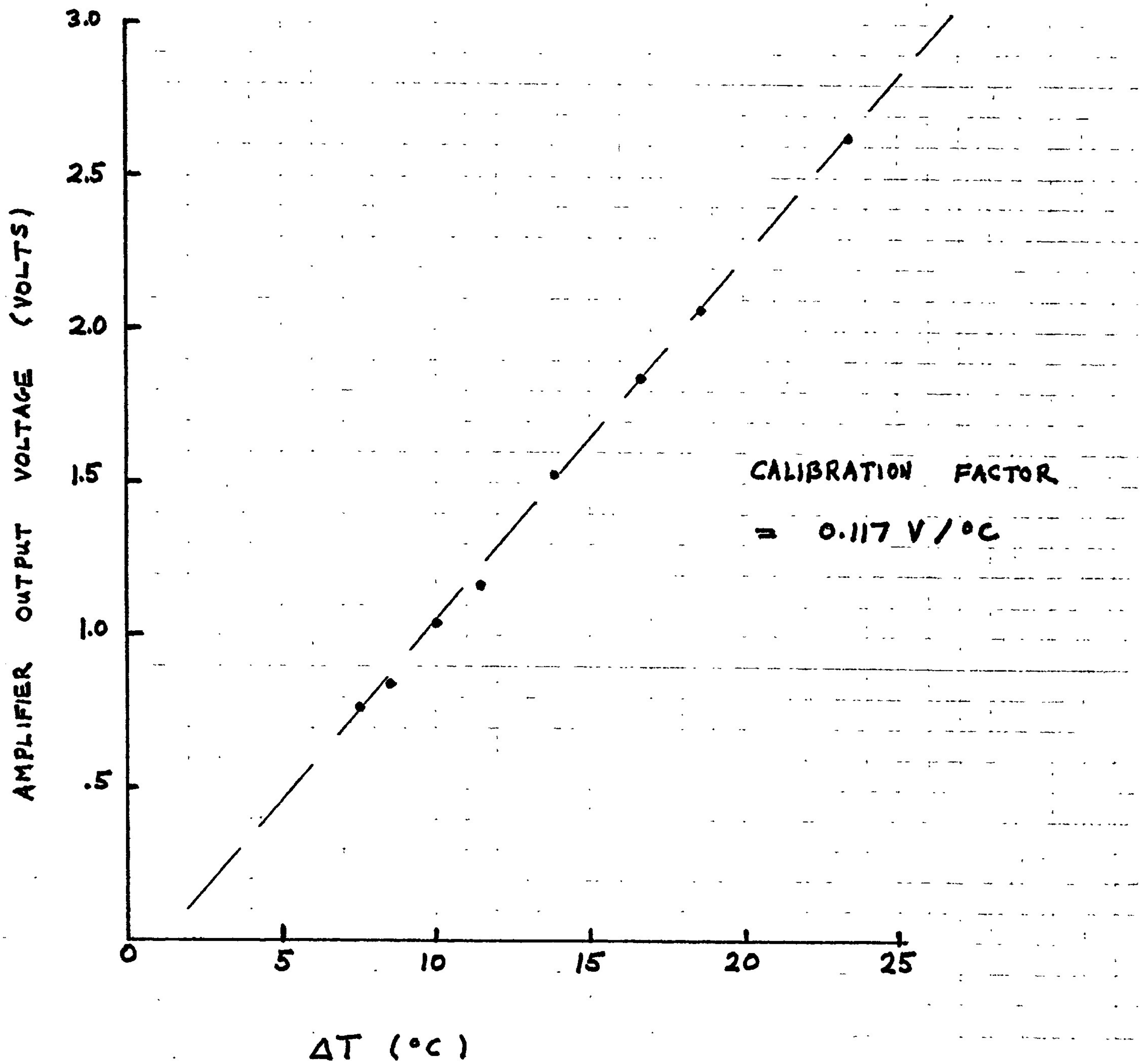


FIGURE 3

FIGURE 4 — TEMPERATURE DIFFERENCE VS. POINTING ERROR : OCTOBER 25, 1978

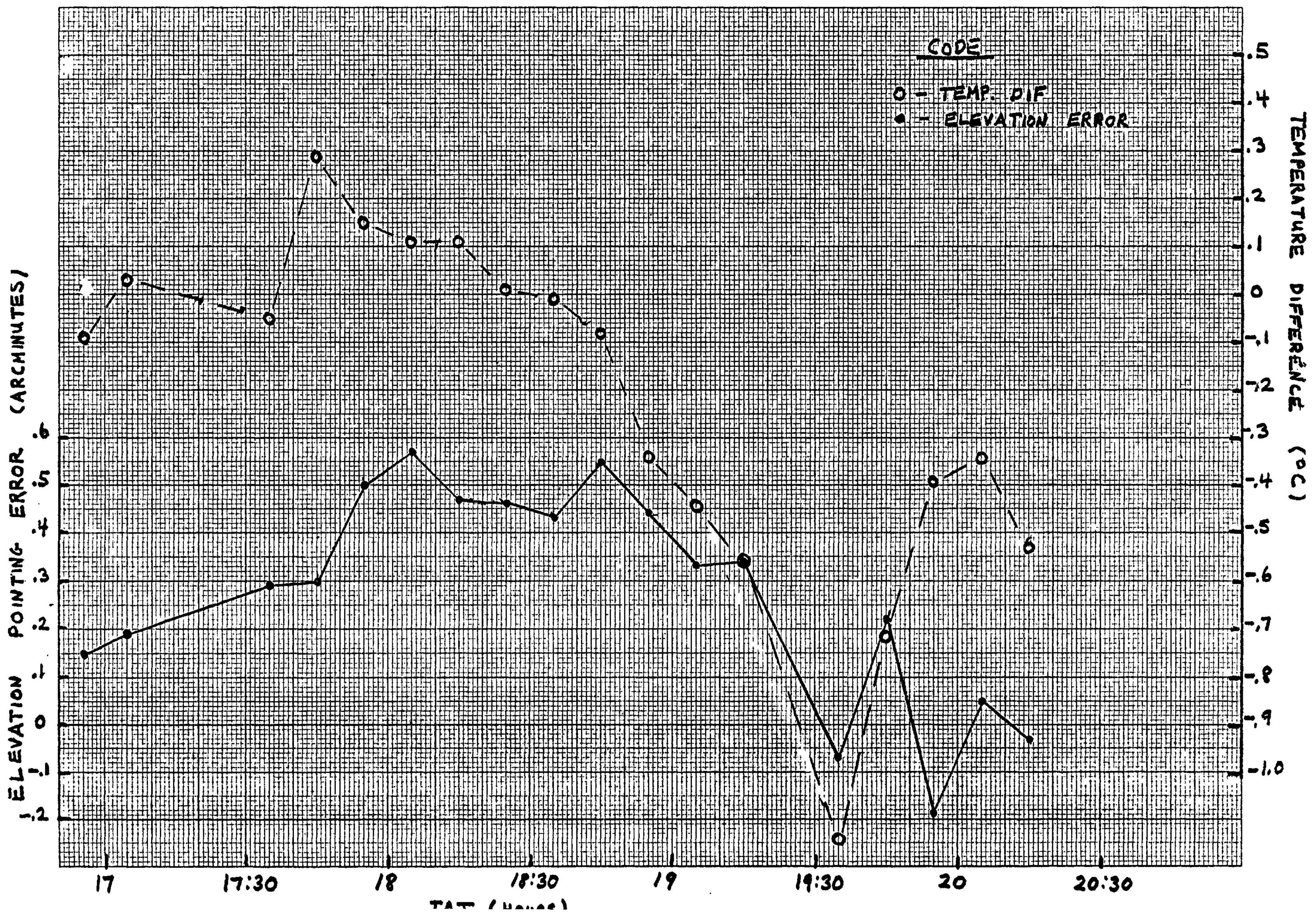


FIGURE 5 - CROSS CORRELATION FUNCTION

TEMPERATURE DIFFERENCE VS. POINTING ERROR: OCT. 25, 1978

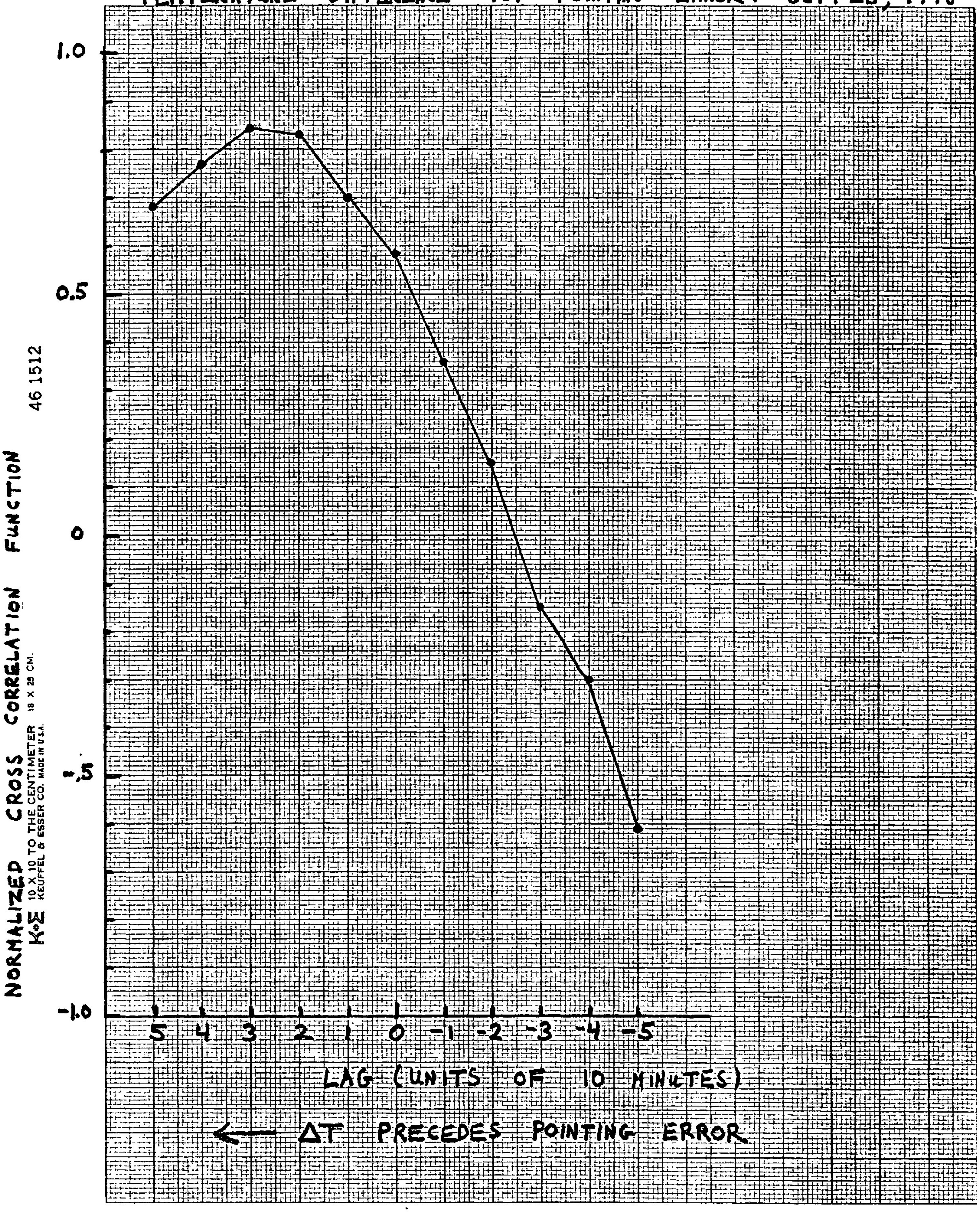


FIGURE 6 - TEMPERATURE DIFFERENCES MEASURED, OCT. 25-27, 1978

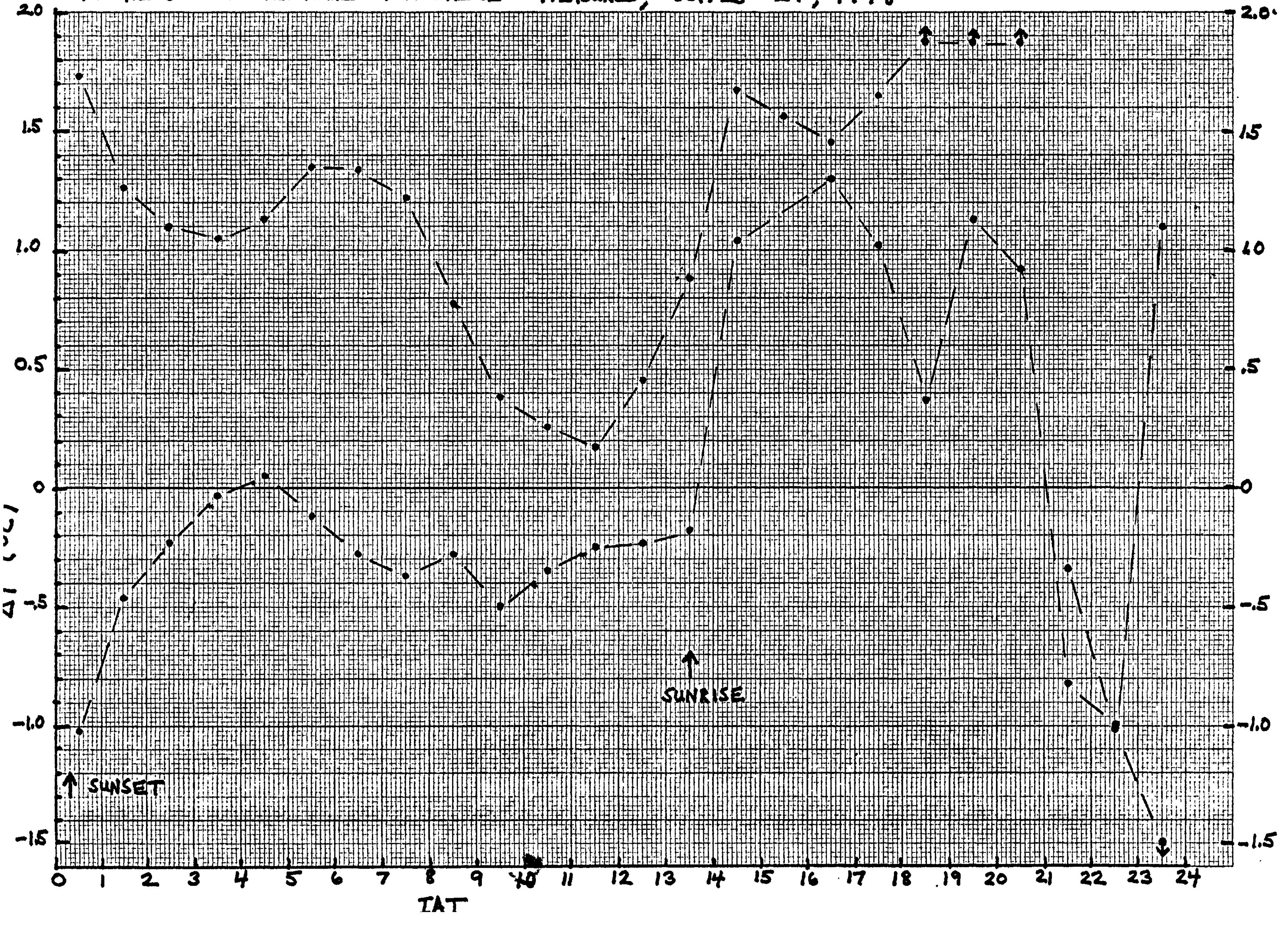
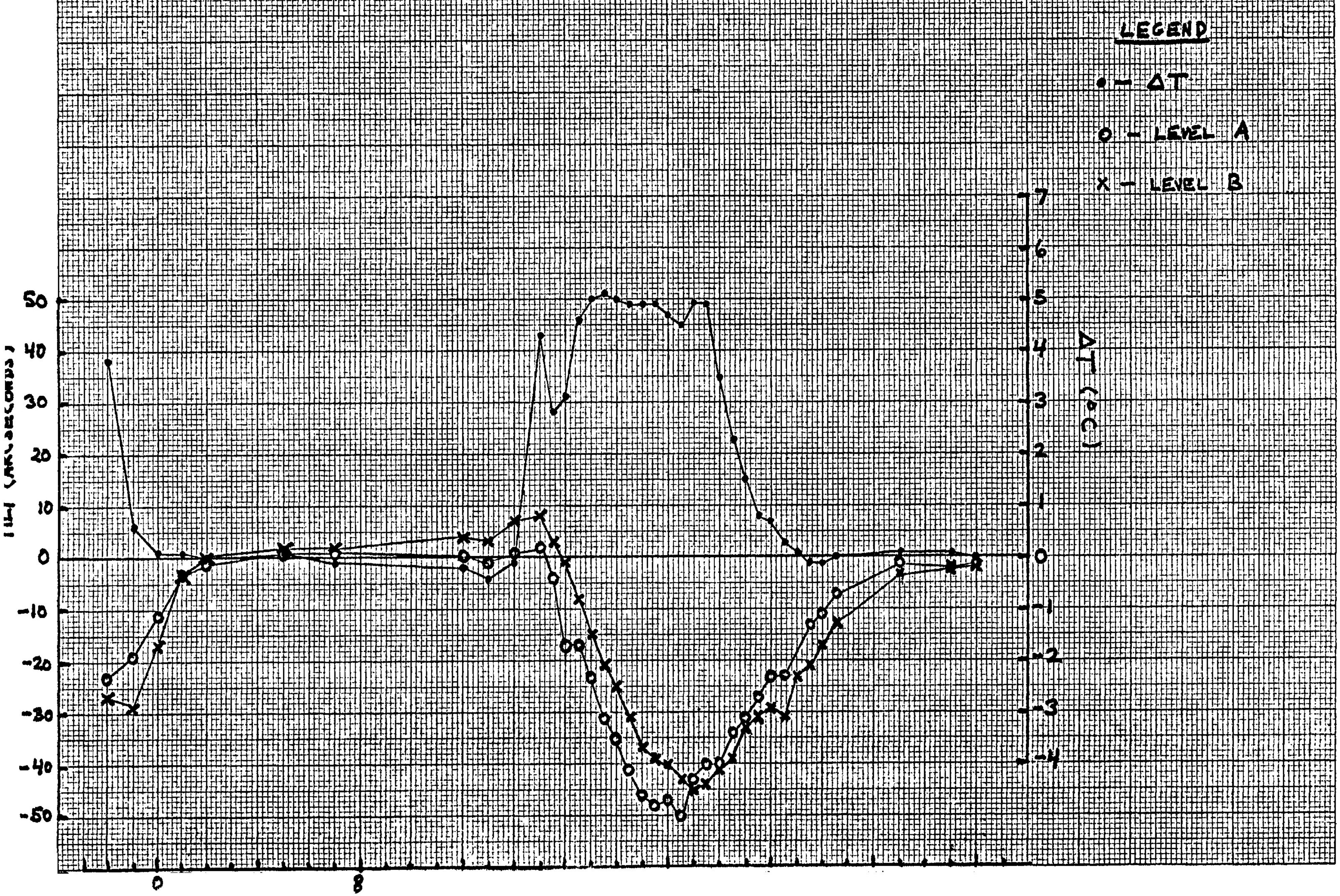


FIGURE 7 — CORRELATION OF TEMPERATURE DIFFERENCE WITH YOKE ARM LEVEL READINGS



CROSS CORRELATION OF TEMPERATURE DIFFERENCE WITH YOKE ARM TILT

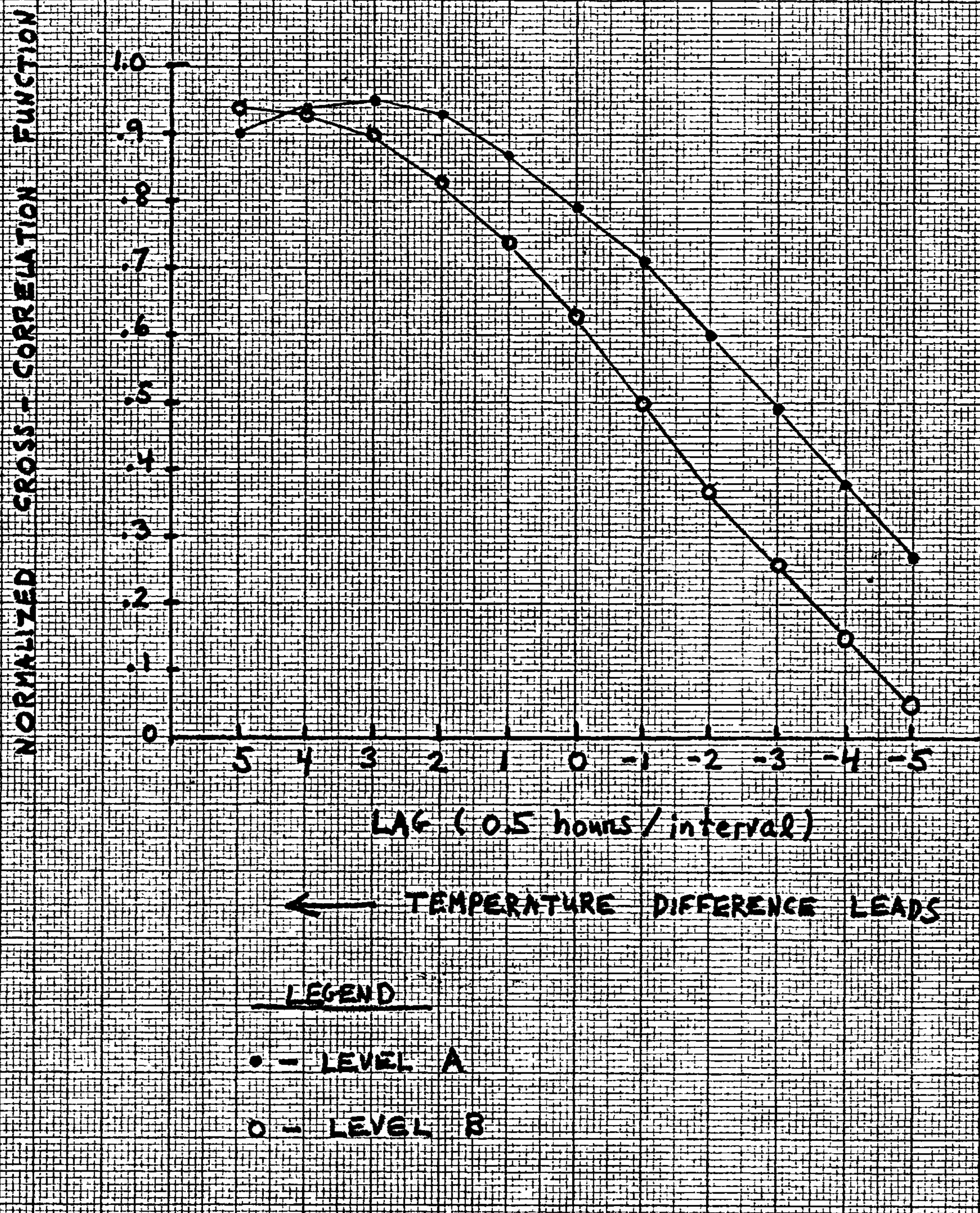


FIGURE 8