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Joseph Arlauskas, 733

NAS5-11215

AUTOMATED SOLAR SEEING MEASUREMENTS

Final Report.

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August 11, 1970

New Mexico Tech, in conjunction with the Solar Physics Branch at Goddard Space Flight Center of the National Aeronautics Space Administration, has undertaken a series of continuous measurements of solar seeing along the ridge just south of the summit of the Magdalena Mountains west of Socorro in New Mexico.

The method used in the survey was an automation of that proposed by Bray and Loughhead (1965) and also Bray et al. (1959). The important difference in the present survey was that an absolute angular calibration of the photo-electronic fluctuations was made. The AC (alternating current) component of the sum of the optical signal through each of two slits on opposite limbs of the solar image was used to monitor the solar seeing. The telescope was mounted both on a 30-foot tower and on the ground in the woods at the southern end of the ridge and on the ground at a saddle just (200 feet) below the summit peak (Figure 1). Within the statistical fluctuations, all three sites gave roughly the same results with negligible deterioration as a function of time during the day. "Good" correlation was observed between the electronic signal and human visual estimate of the "quality" of the seeing--although the electronic signal, in general, showed 1/3 the temporal fluctuation corresponding to the total visual defocusing. The peak of the fluctuating spectrum occurred in the band 1 to 10 Hz.

Description of The Apparatus

Figure 2 shows a schematic drawing of the "Celestron 10" telescope with an Erfle eyepiece resulting in a 20-inch diameter image 50 cm behind the primary mirror. The corrector plate which also serves as the support of the secondary was given a partially reflecting coating so that roughly 1% of the solar flux was transmitted into the telescope proper. This eliminated the problem of component and/or internal atmosphere heating. The image formed by the Erfle eyepiece was close enough to the primary so that the tube support of slits and phototransistors could be made short and lightweight--sufficiently so to be carried by the telescope yoke. The declination drive had to be strengthened as shown in Figure 3 by the addition of a secondary yoke, clamps and drive. Figure 4 shows the extension tube housing (Figure 5) the phototransistors and first stage electronics. The effective "slits" correspond to the aperture of the phototransistors used, FPO-100, manufactured by "Fairchild Semiconductor, Inc." with an effective aperture of 1 mm. For the focal length of the telescope of 2×10^4 cm, this corresponds to 10 arc seconds. Four phototransistors were used, two in right ascension and two in declination. The right ascension ones maintained tracking of the sun by using the right ascension difference to control a voltage-controlled oscillator which, in turn, was amplified and varied the speed of a sychronous drive motor. The tracking in right ascension could be held to 1 arc second if desired, but generally was adjusted to a wider latitude of several arc seconds. A lag of 30 arc seconds was barely sufficient to affect the declination signal.

The declination phototransistor signals after amplification are both differenced and summed. The difference signal is used as a correction or tracking signal in declination and in low wind conditions $\leq$ 10 mph, will keep the telescope pointed to within 1/2 second of arc. This is a factor of x10 better than required for obtaining the seeing signal. The sum of the declination signals cancels out to first order the motion of the telescope and/or that part of the seeing that results in a correlated or unidirectional motion of the whole image. The correlated fluctuation or common mode rejection was usually adjusted to be better than 10 to 1 so that wind vibration of the telescope and mount was unimportant in measurements up to 20 mph. The AC component of the sum signal was observed in three frequency bands roughly a factor of 10 wide centered at 0.3, 3 and 30 Hz. The response of these channels is shown in Figure 6. In practise, six channels of information were recorded, the sum, both difference signals and the 3-filter channels.

Set-up And Calibration

Provision was made for oscillating the telescope in declination at 1 Hz by a small amplitude of 5 to 10 arc seconds peak to peak. Generally, an oscillation of 7 arc seconds was used that maintained the response of the phototransistors within their linear aperture range. The oscillation was superimposed on the declination tracking signal (declination difference) so that normal tracking of the sun was maintained. The amplitude of the oscillation was observed with a machinist dial indicator on the yoke arm of the telescope and an oscillating deflection of 0.0004 $\pm$ 0.00005 inches at a radius arm of 11 inches was measured. Figure 7 shows a composite of the resulting signals.

When both north and south declination phototransistors are properly balanced, and spacially adjusted, the sum signal oscillation is less than 10% of that occurring when either north or south phototransistor is removed from the sum by a switch and the corresponding sum input grounded. The resulting sum signal is that from one phototransistor alone, and the AC component at 1 Hz is primarily due to the movement of the solar disc by a 7.5 arc second motion. The response in each of the 3-filter channels is as if there would be a 7.5 arc second solar limb motion on one side of the sun only, while the opposite side remained stationary and constant intensity. In actual practise, we expect the signal at each limb to be randomly correlated

(The light paths diverge from the telescope at 0.01 radians.) so that a real seeing signal of 7.5 arc second fluctuation would be larger by $\sqrt{2}$ than the calibration oscillation in one channel. In Figure 7, the sum signal is shown for each phototransistor separately as well as both together and the common mode rejection is seen to be better than 10 to 1. The calibration must also include a correction for the frequency response of each filter channel (Figure 6) as well as the absolute value of the sum signal at the time of the calibration versus at the time of a measurement. The variation in average sum signal is of course due to time of day, other absorption factors and the separation spacing of the phototransistors compared to the size of the solar disc. The later changes as a function of time of year as well as due to refraction in the early and late hours of the day. The daily variation during the first 1/2 hour was ignored. The spacing otherwise was adjusted in the following manner. The automatic declination tracking was disconnected and the telescope was slewed (electrically) in declination by a relatively large mount 200 arc seconds or 1/10 the solar disc. As the limb of the sun approaches one phototransistor (the opposite is off the disc), the sum signal decreases to roughly 1/2 the peak value when the same phototransistor is on the center of the solar image. (This is due to the usual limb darkening.) If now the second phototransistor enters the limb as the first is leaving, then the sum signal will remain constant for 10 arc seconds as the second phototransistor balances the decrease from the first. If the phototransistors are too close together, there will be a period when both are contributing too much signal and a sharp peak shows upon limb crossing. Conversely, if the phototransistors are too far apart, a null occurs in limb crossing. In practise, an adjustment sufficient to give a common mode rejection of 10:1 was easily achieved as shown in calibration 2 of Figure 7.

Results

Figure 8 shows a power versus frequency spectrum of the sum signal; an example of the sum signal is shown at the bottom of Figure 7. The data was taken at different days and different times, and accordingly, under different seeing conditions. The few high points at high frequency can be discarded as being correlated with wind vibrations $\geq$ 20 mph of the tower. The tower could be struck a hard blow, and the high frequency power would appear. Exclusive of these few points, there exists a general peak in the observed seeing signal at 3 to 5 Hz. This is in agreement with other measurements of intensity fluctuation, e.g. see Ellison and Seddon (1952).

The reason for this peak in the power spectrum is that for typical wind shear and resulting turbulence in the upper atmosphere the period of the minimum size eddy before viscous dissipation is roughly 1/3 to 1/5 second. Figure 9 gives the statistical results of a series of visual versus electronic measurements of seeing. The measurements were made under various conditions of seeing--some exceptionally good and some exceptionally poor, and the data has a 30% spread.

Figures 10 through 17 show respectively the electronic seeing as a function of hours after sunrise, for the three filter channels overlaid, the number of hours of seeing quality better than a given value and the total hours of sun, clouds and non-observing for each of the three sites--tower in woods, on the ground in woods, and at open saddle--for the respective dates shown.

In general, there is no consistent trend in the data--either as to location or time of day. Although not shown in these statistical analyses, the usually accepted deterioration with time of day definitely does apply to those few days of exceptional seeing. In those few cases, the seeing may start in the early morning at less than a recordable value of 1/4 to 1/2 arc second and increase throughout the day.

An example of the extracted data for the saddle site is shown in Figure 18. The exceptional day, July 9, when the electronic seeing showed a barely detectable signal is included. Visual observation confirmed the exceptional seeing as in Figure 9.

THEORY

"Seeing" includes the three general descriptions of image behavior--scintillation, static defocusing, and image motion. Chandrasekhar (1952) discusses the relationship between the statistical fluctuations observed and the nature of the index of refraction changes in the atmosphere implied. Reiger (1962) relates the refractive index changes to modern theories and measurements of atmospheric fluctuations.

In brief summary, the scintillation phenomenon depends upon the fourth spacial derivative of the correlation function of the refractive index fluctuation. That is, there must exist a finite second spacial derivative of the index of refraction within the aperture "beam" of the telescope in order to focus more or less light onto the telescope. As a consequence, since the effective lens is "weak", i.e., long focal length, the primary contribution occurs roughly one atmospheric scale height (10 km away). This contribution to electronic seeing depends upon atmospheric conditions at high altitude and is aperture dependent. The fourth spacial derivative emphasizes high frequency and therefore the smallest size eddies. For a Reynolds number of 16 at the viscous dissipation limit, this implies a minimum size eddy of 3 cm, which has been verified by by Protheroe and Chen (1960). Consequently, the relative large aperture of 25 cm of the present telescope is expected to reduce the scintillation fluctuation by roughly a factor of x1/4. The theory is in agreement with the measurements of Ellison and Seddon (1952).

Static defocusing requires the same refractive index behavior as scintillation with the added difficulty that since a refractive index fluctuation is caused by turbulent eddies, several eddies must act coherently in order that the apparent index of refractive fluctuation remains static. As a consequence, the low frequency component of seeing is less important in the seeing power spectrum.

The largest contribution to seeing is a result of the random shift in the image due to a finite first derivative of the refractive index. If the electronic measurement of seeing had been made upon a point source, then the shift in image due to this mode of "seeing" would not register in the "seeing" signal within the limits of the common mode rejection. However, by monitoring opposite limbs of the sun two separate light paths are established in the atmosphere separated by the angular size of the sun, $\Delta\theta = 0.01$ radians. Thus at a distance of $\langle D \rangle / \Delta\theta \simeq 20$ meters the rays for each limb of the sun separate and uncorrelated behavior is expected. As a consequence, seeing associated with average angle of arrival fluctuations is suppressed in the first 10 to 20 meters from the telescope. This is the most likely explanation of the lack of sensitivity to tower or ground location. On the other hand, the worst seeing was usually associated with edges of clouds at far greater heights and in all cases the visual seeing correlated with the electronic signal.

CONCLUSION

The electronic seeing measurements quantify the actual refractive index fluctuations for two light paths diverging at 0.01 radians and indicate for the mountain site chosen a very higher percentage, 30 %, of the solar time is available for measurements in which time and spacial measurements of the sun can be made with high precision $\leq$ 2 arc seconds.

This work was encouraged and planned with frequent consultations with Stephen Maran and John Brandt of Goddard Space Flight Center, Greenbelt, Maryland. Charles Goshey, Dennis Osantowski, Roy Wagoner, and David Craft, as students, have operated the apparatus on the mountain. John Colburn and Richard Carlson have designed much of the electronics. The work was supported under NASA Contract No. 5-11215.

References

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Ellison, M. A., and Seddon, H. 1952, "Some Experiments on the Scintillation of Stars and Planets", Monthly Not. Roy. Astr. Soc., **112**, No. 1, pp. 73-87.

Protheroe, W. M., and Chen, K. 1960, "The Correlation of Stellar Shadow Band Patterns with Upper Air Winds and Turbulence", Final Report, Contract AF 19(604)-1570, Dept. of Astron., U. of Pa., Philadelphia, Pa.

Reiger, S. H. 1962, "Atmospheric Turbulence and the Scintillation of Starlight", Report, U. S. Air Force Project Rand, R-406-PR, The Rand Corporation, Santa Monica, California.

LIST OF FIGURES

Figure 7: Is a composite of the two calibrations and the seeing signal. In the first calibration, a 10 arc second oscillation of the declination yoke is initiated; when phototransistor 1, i.e, diode No. 1, is sensitive "only" and/or when phototransistor 3 is sensitive "only" the sum oscillation signal is large, otherwise, the fluctuation of the sum signal shown in the negative direction on the print, shows an oscillation less than roughly 10% of that with either phototransistor alone. The declination difference signal, on the other hand, shows the full oscillation of the declination mount during the period when the declination motor is being oscillated. As one can see, there is negligible difference in the sum signal whether the declination is oscillated or not oscillated when both phototransistors are on. This indicates at least a 10 to 1 common mode rejection. In calibration 2, the telescope is slewed in declination roughly 100 arc seconds in a period of roughly 2 to 3 seconds in time. When the diodes cross the limb of the sun, the sum signal goes in the direction toward zero but only part way. Neither a secondary peak at the time of crossing nor a null occurs indicating that the phototransistor separation is properly adjusted. The declination sum signal for normal seeing conditions is shown at the bottom of the figure along with the declination difference. The AC component of the sum signal is what is read in the 3-filter channels. (Note: diode No. 1 equals north phototransistor, diode No. 3 equals south phototransistor.)

Figure 8: Shows the result of many measurements of the AC power of the sum signal versus frequency measured by a spectrum analyzer with a 20% bandwidth. This data were taken at different days at different times and accordingly under different seeing conditions. The few high points at high frequency are correlated with wind vibrations of the tower.

Figure 9: Gives a correlation between visual and electronic seeing. The data were taken over various conditions--some good, some poor seeing--and the data indicate roughly twice the visual versus electronic seeing at 0.3 Hz and roughly three times the visual seeing versus electronic at 3.0 Hz.

Figure 10: Shows the number of hours of electronic seeing falling within the angular range 1 to 2, 2 to 3, 3 to 4 and +4 arc seconds for the various filter channels at the tower site in the woods. In addition, the number of hours of cloudy, fair, and down time are shown for the period November 1, 1969 to April 1, 1970.

Figure 11: Shows the same information for the ground site, April 2, 1970 to June 11, 1970.

Figure 12: Shows the similar information for the saddle site, June 20, 1970 to July 9, 1970.

Figure 13: Shows the total of all data averaged for the three sites in the full period.

Figure 14: Shows the seeing as a function of hours past sunrise in the 0.3 Hz channel for the three sites in the periods quoted. The dotted curve corresponds to the tower in the woods; the dashed curve to the "on ground" in the woods and the solid curve to the saddle site.

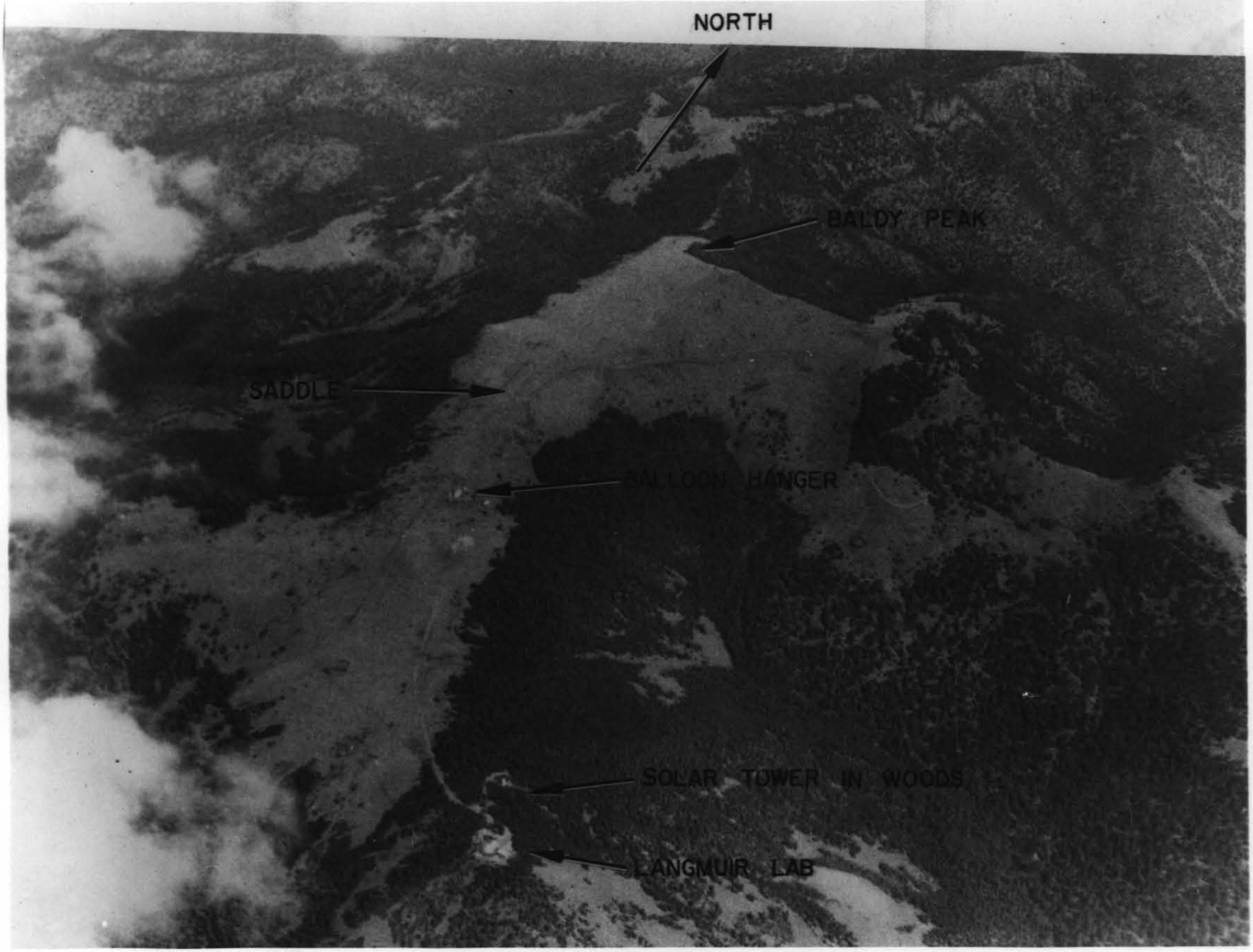
Figure 15: Shows the similar information as Figure 14 but for the 3 Hz channel: again, dotted equals tower in woods, dashed equals ground in woods, and solid equals saddle site.

Figure 16: Shows the similar information as Figure 14 but for the 30 Hz channel.

Figure 17: Shows the seeing averaged for all three sites at the 3 frequencies as a function of hours past sunrise.

Figure 18: Is the example of the daily seeing record. It includes the truly exceptional day, July 9, when a barely detectable seeing fluctuation was observed. There was a modest increase in seeing signal from a small fraction of a second of arc on all three channels to 1 second of arc by 1300 when clouds obscured the site.

Figure 19: Shows the control panel of the electronics as well as the 6-channel recorder.


NORTH
BALDY PEAK
SADDLE
BALLOON HANGER
SOLAR TOWER IN WOODS
LANGMUIR LAB

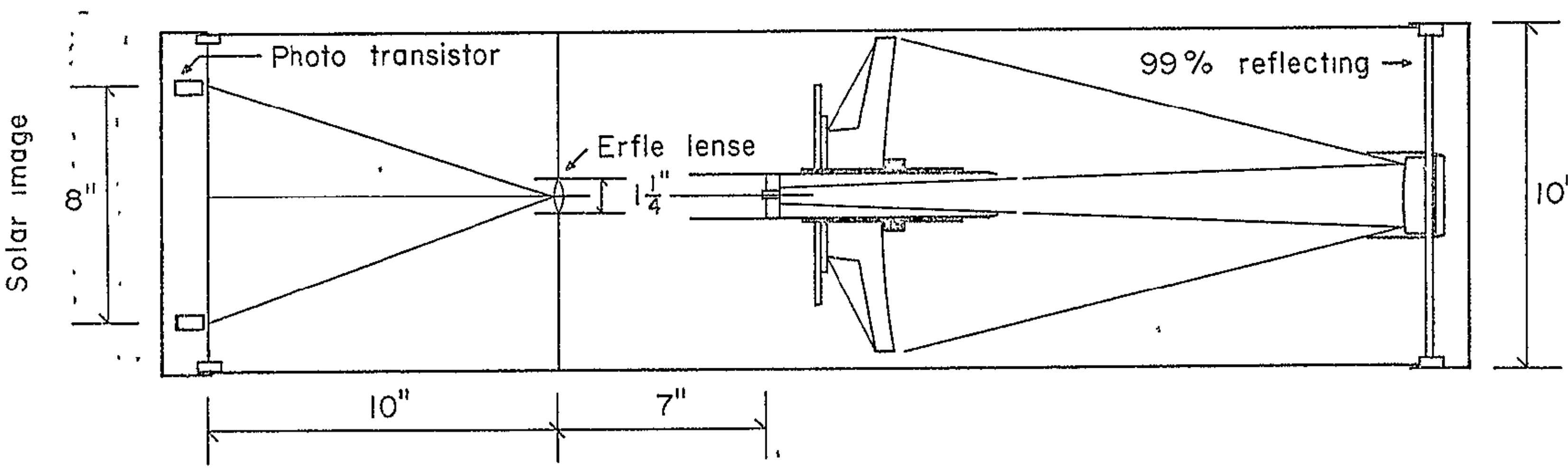
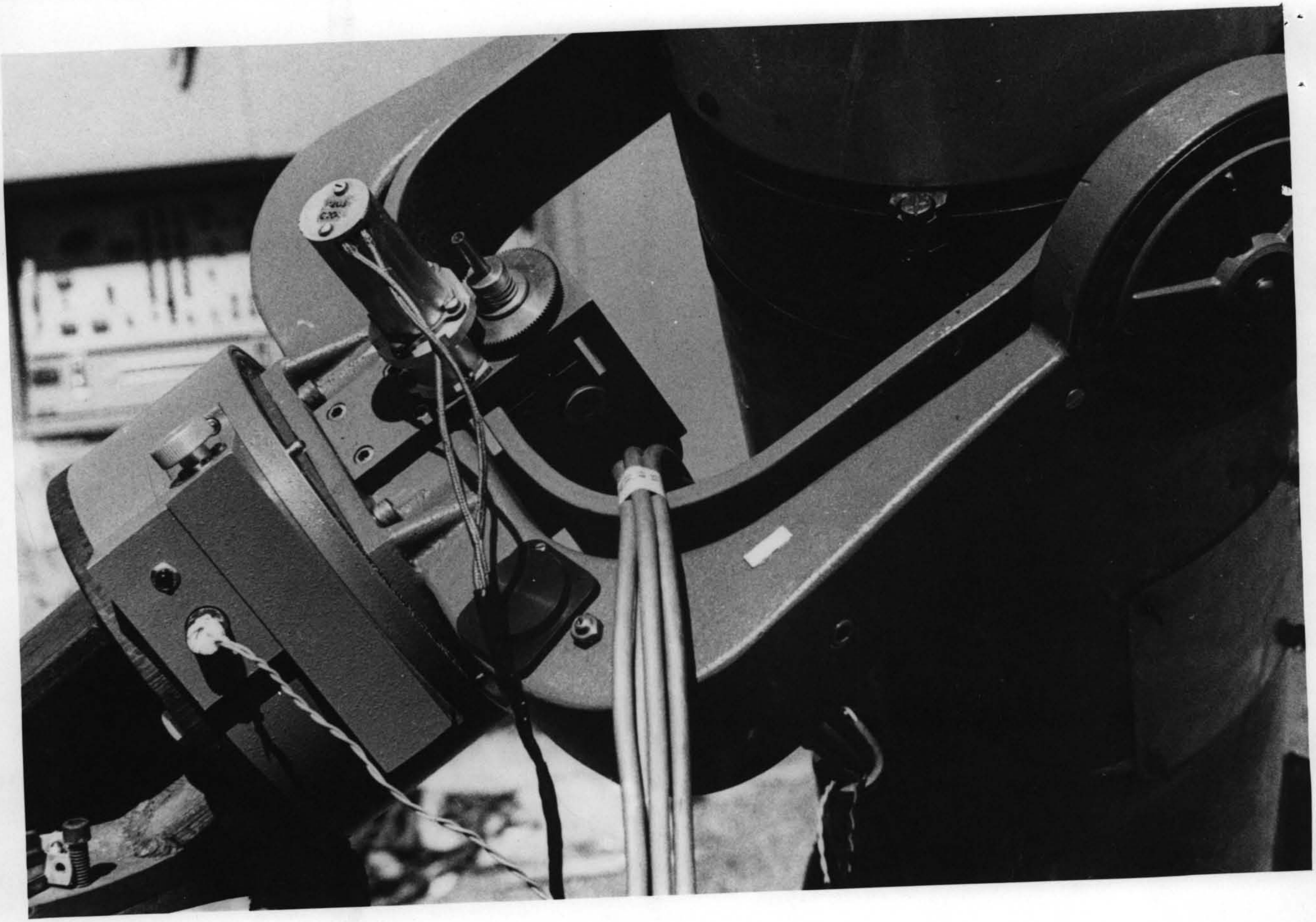
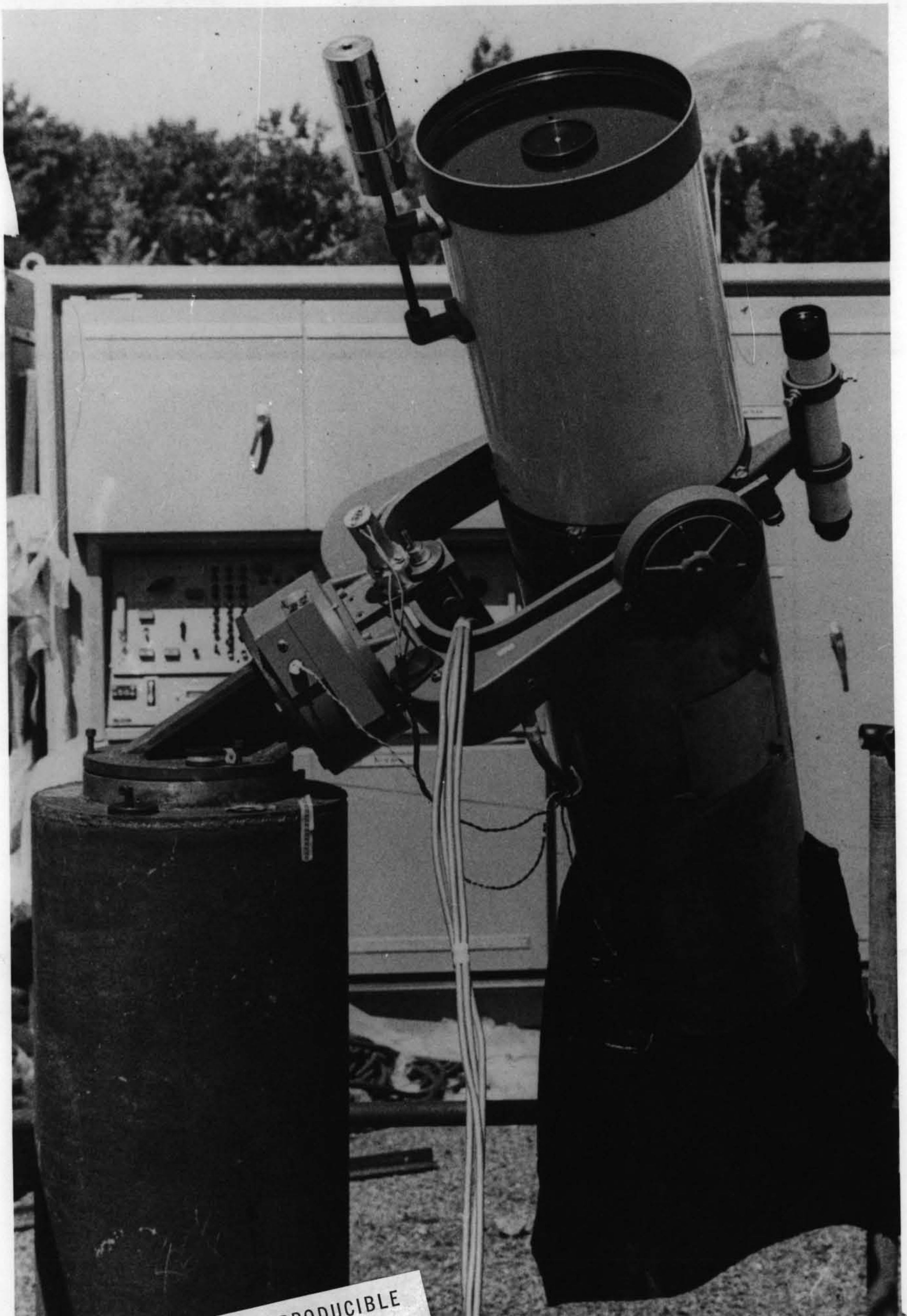
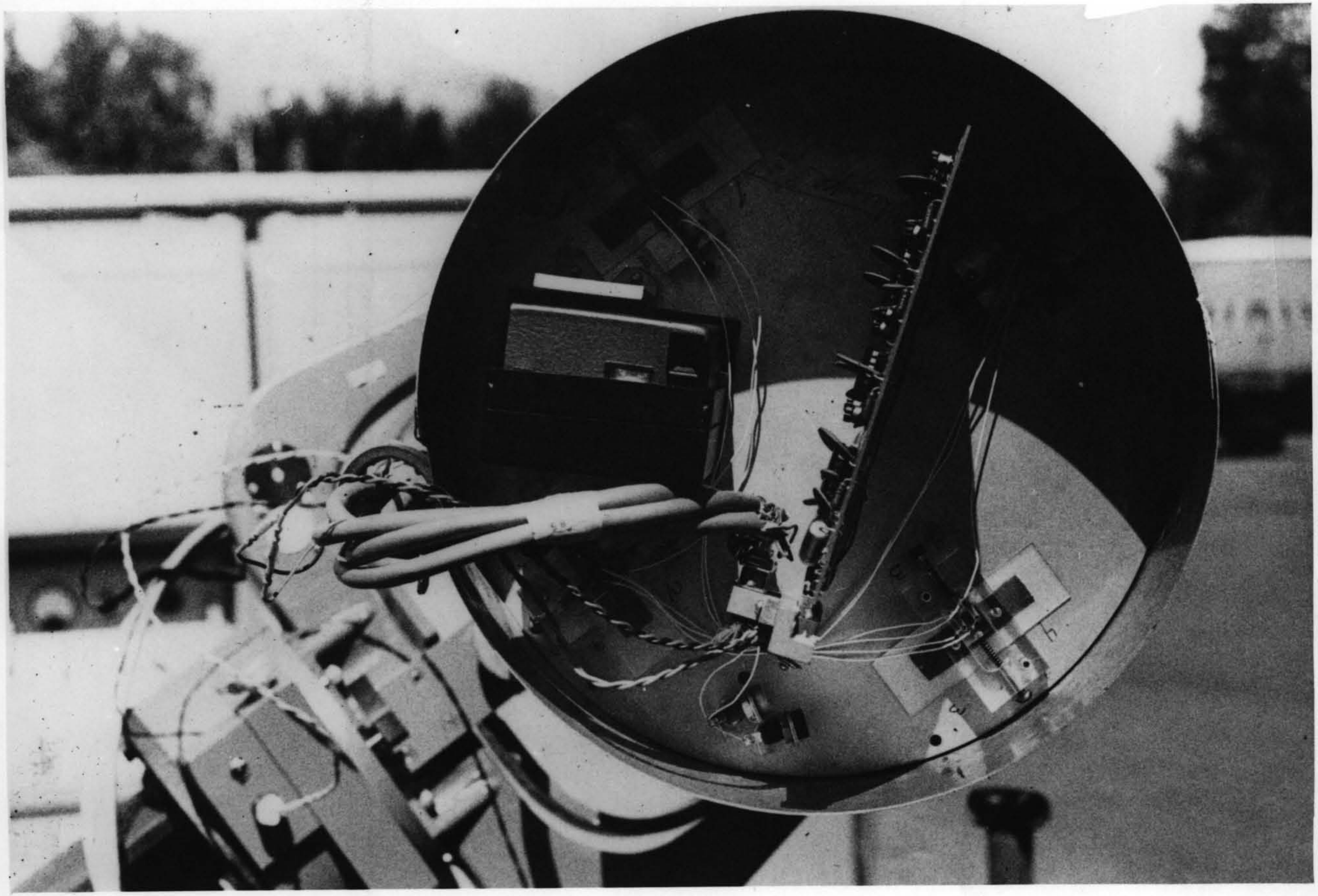
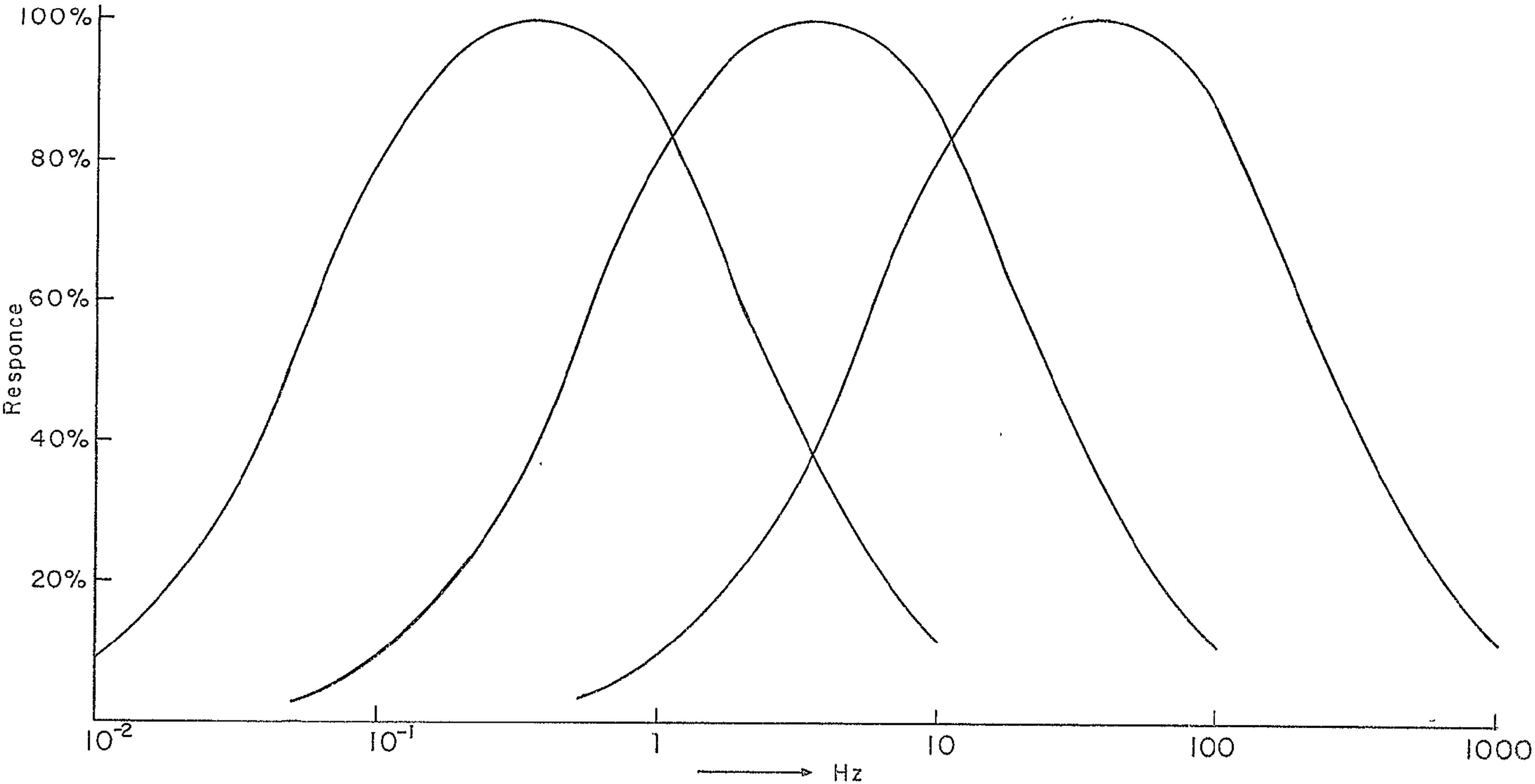


Photo transistor
99% reflecting
Erfle lense
Solar image
8"
$1\frac{1}{4}$"
10"
10"
7"





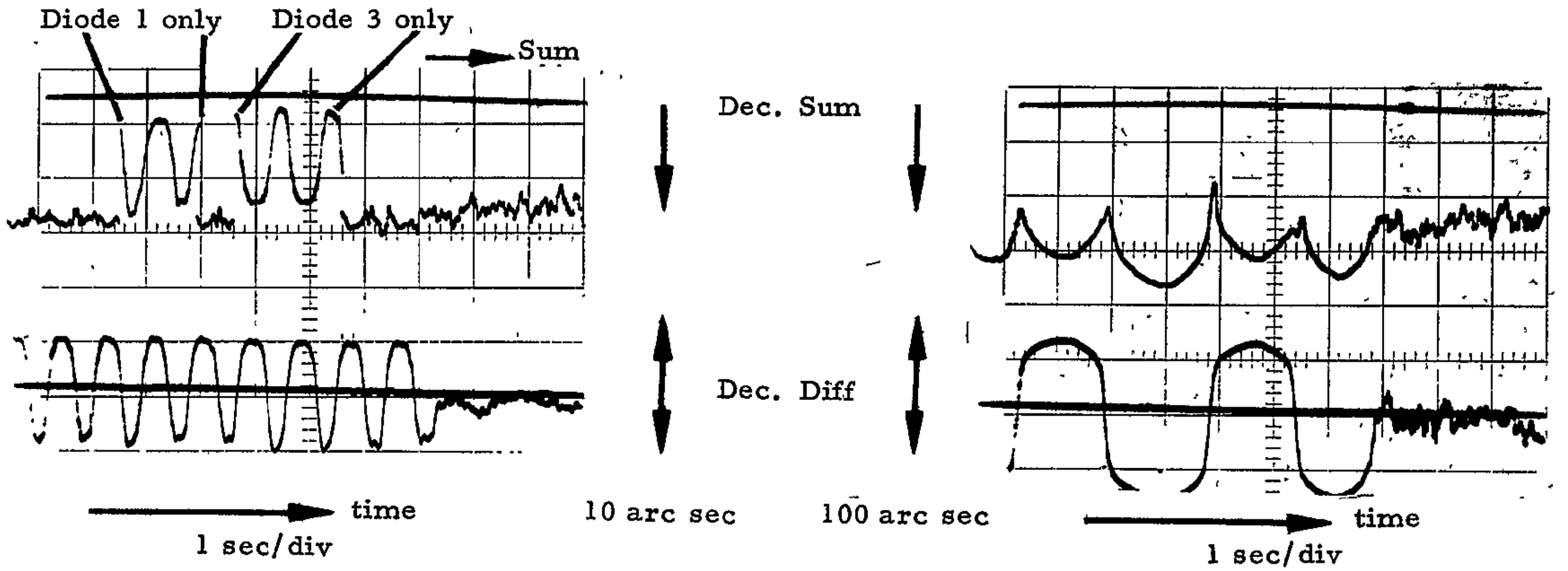




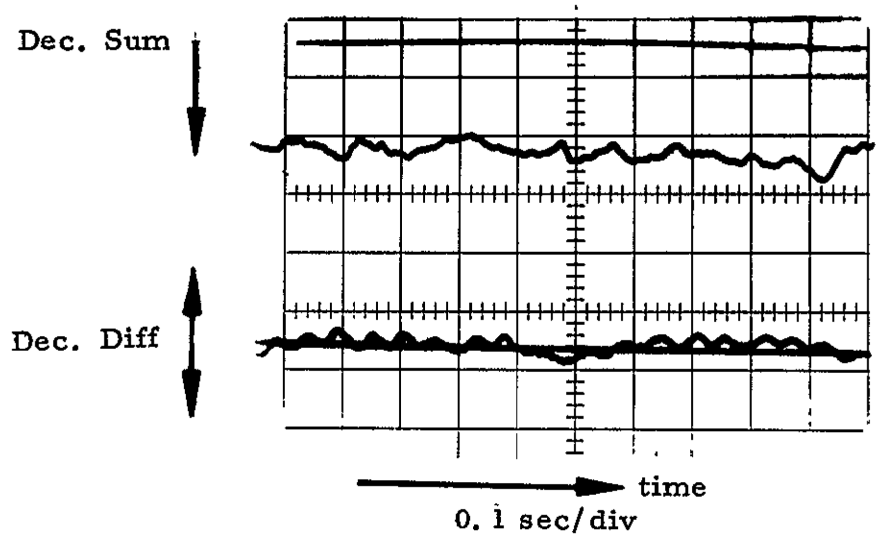
6

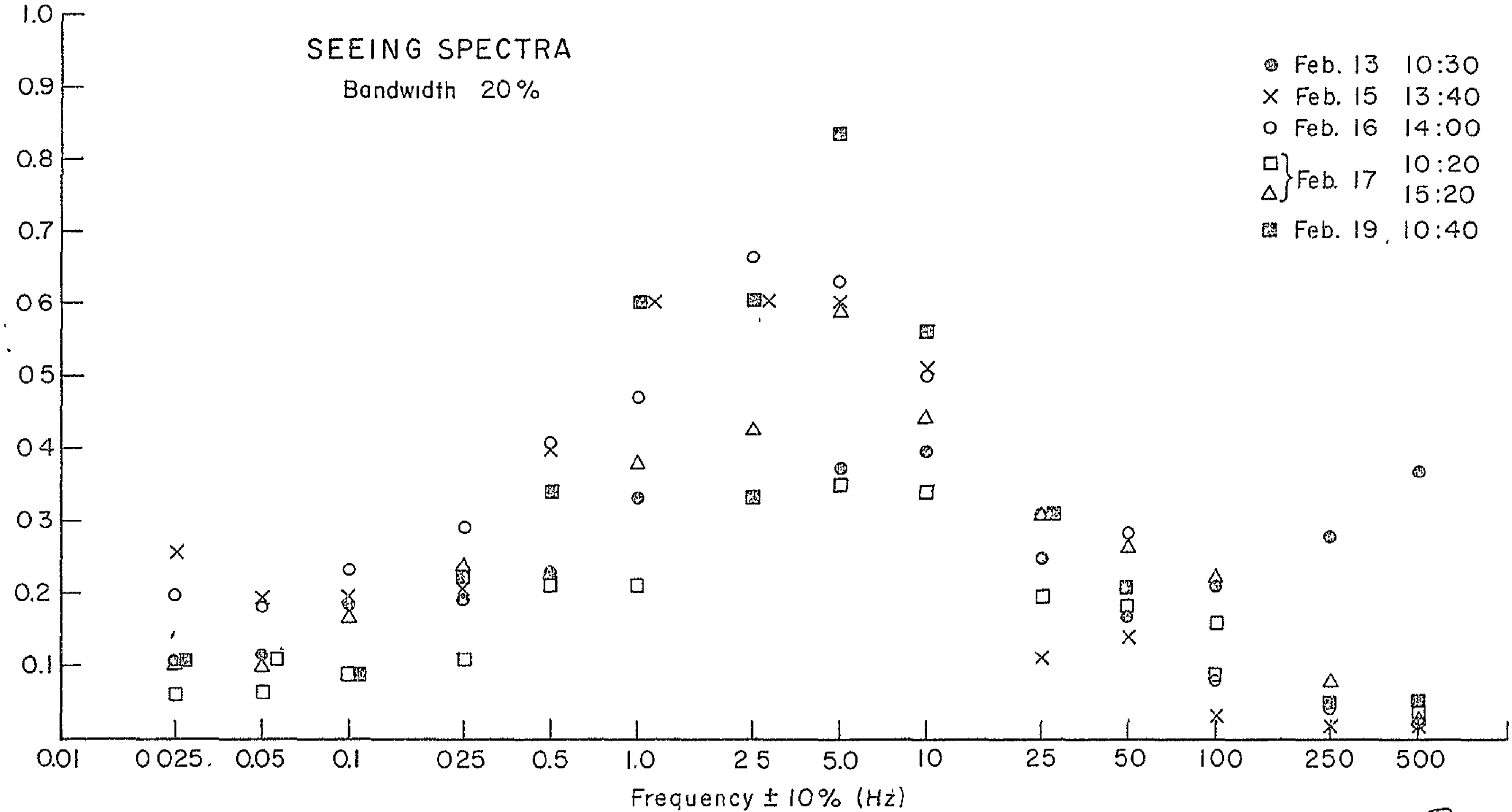
Calibration 1
Dec. Oscillation

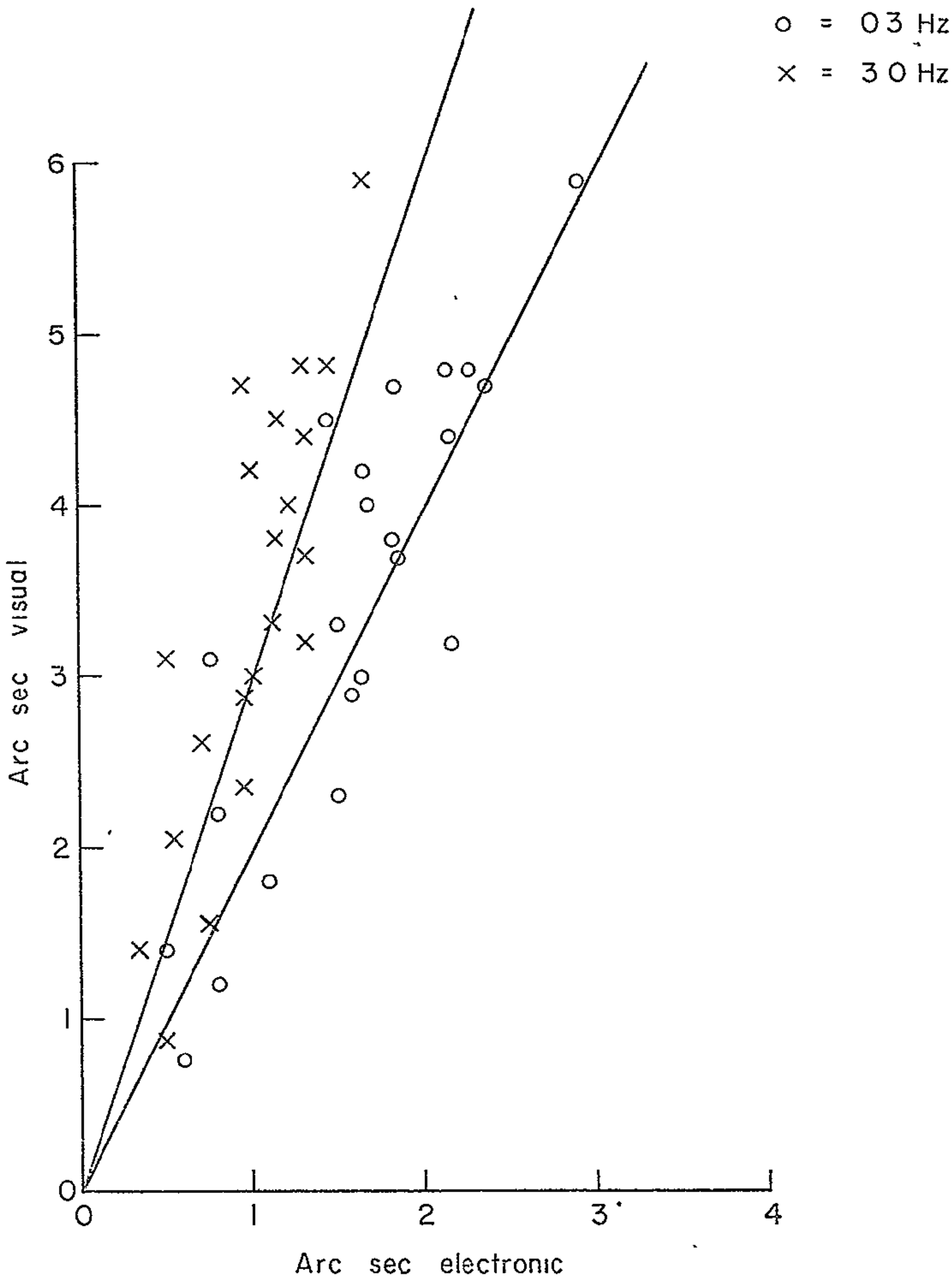
Calibration 2



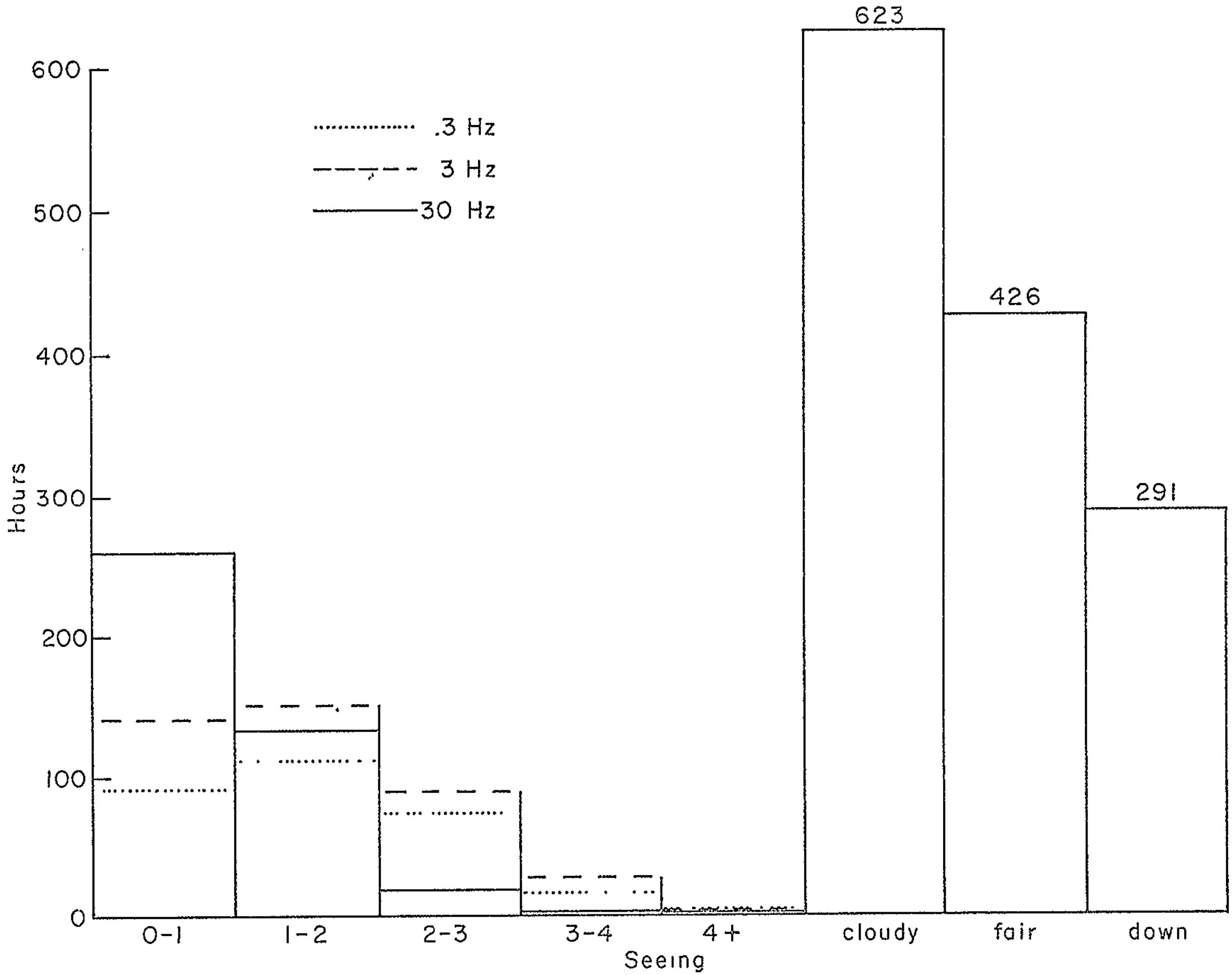
Seeing Signal




SEEING SPECTRA
Bandwidth 20%
Feb. 13 10:30
Feb. 15 13:40
Feb. 16 14:00
Feb. 17 10:20
15:20
Feb. 19 10:40
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01
0.025
0.05
0.1
0.25
0.5
1.0
2.5
5.0
10
25
50
100
250
500
Frequency ± 10% (Hz)

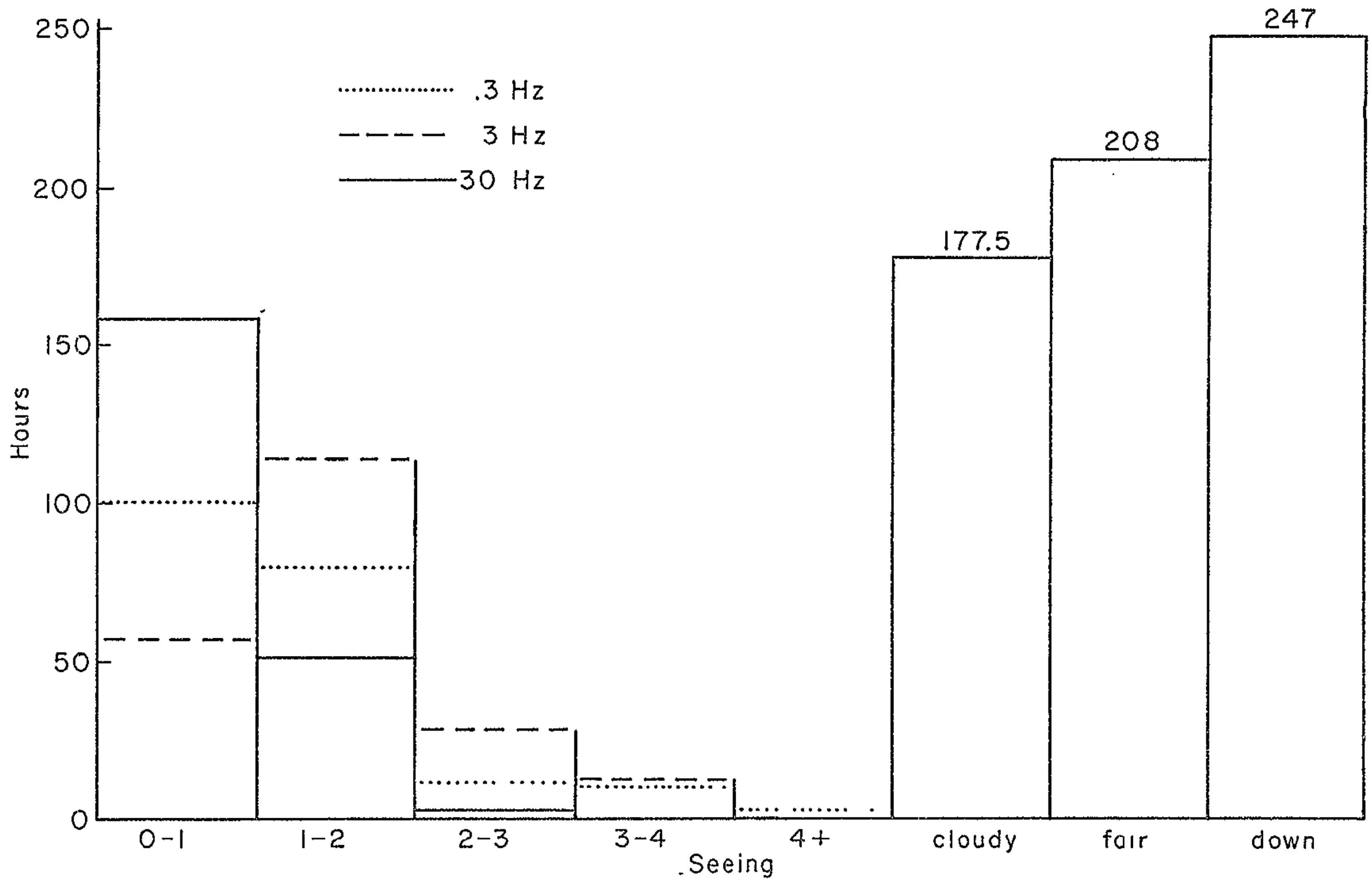


o = 0 3 Hz
× = 3 0 Hz
Arc sec visual
Arc sec electronic
0
1
2
3
4
5
6



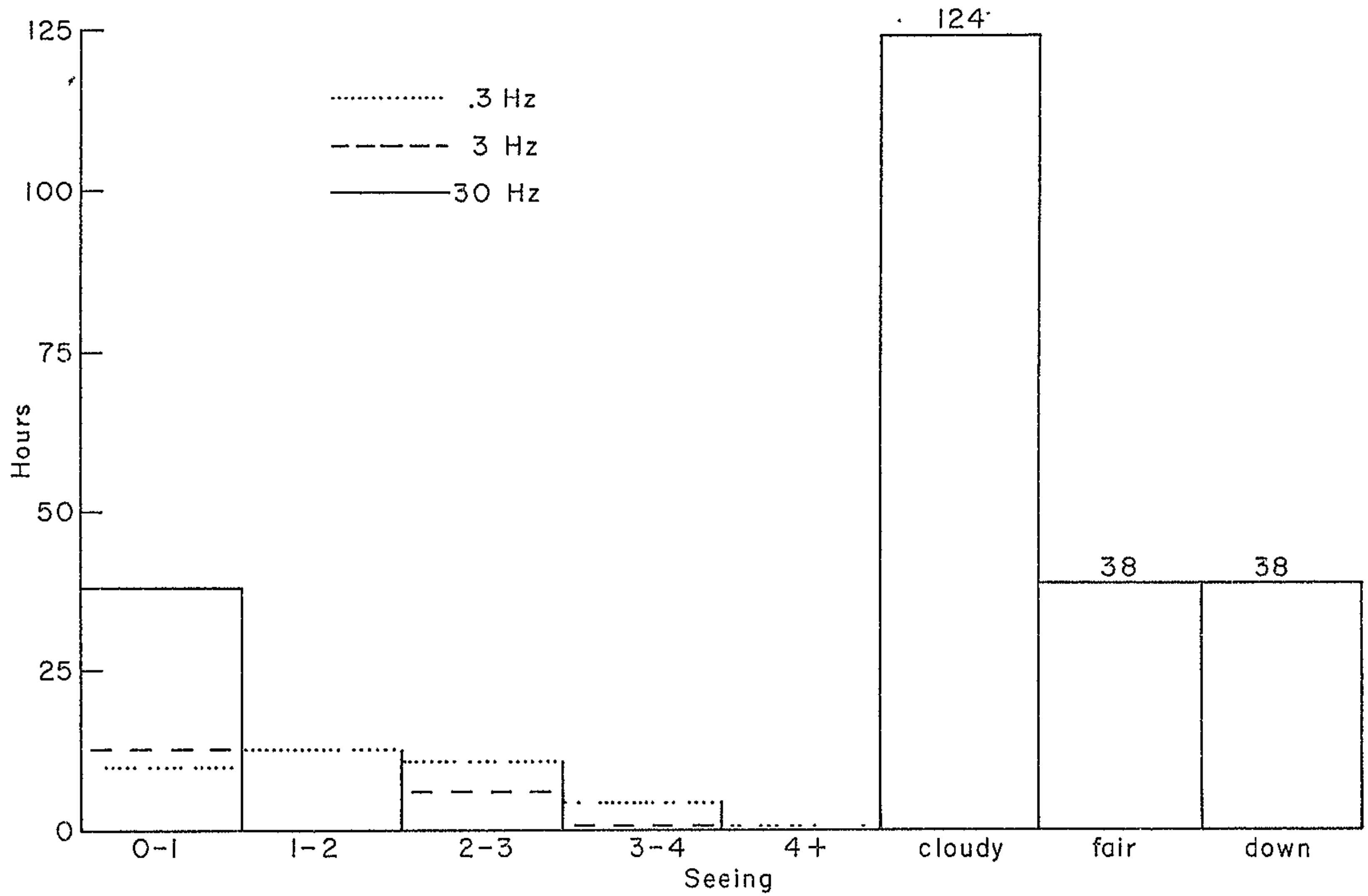
.3 Hz
3 Hz
30 Hz
Hours
600
500
400
300
200
100
0
623
426
291
0-1
1-2
2-3
3-4
4+
cloudy
fair
down
Seeing

1.0"

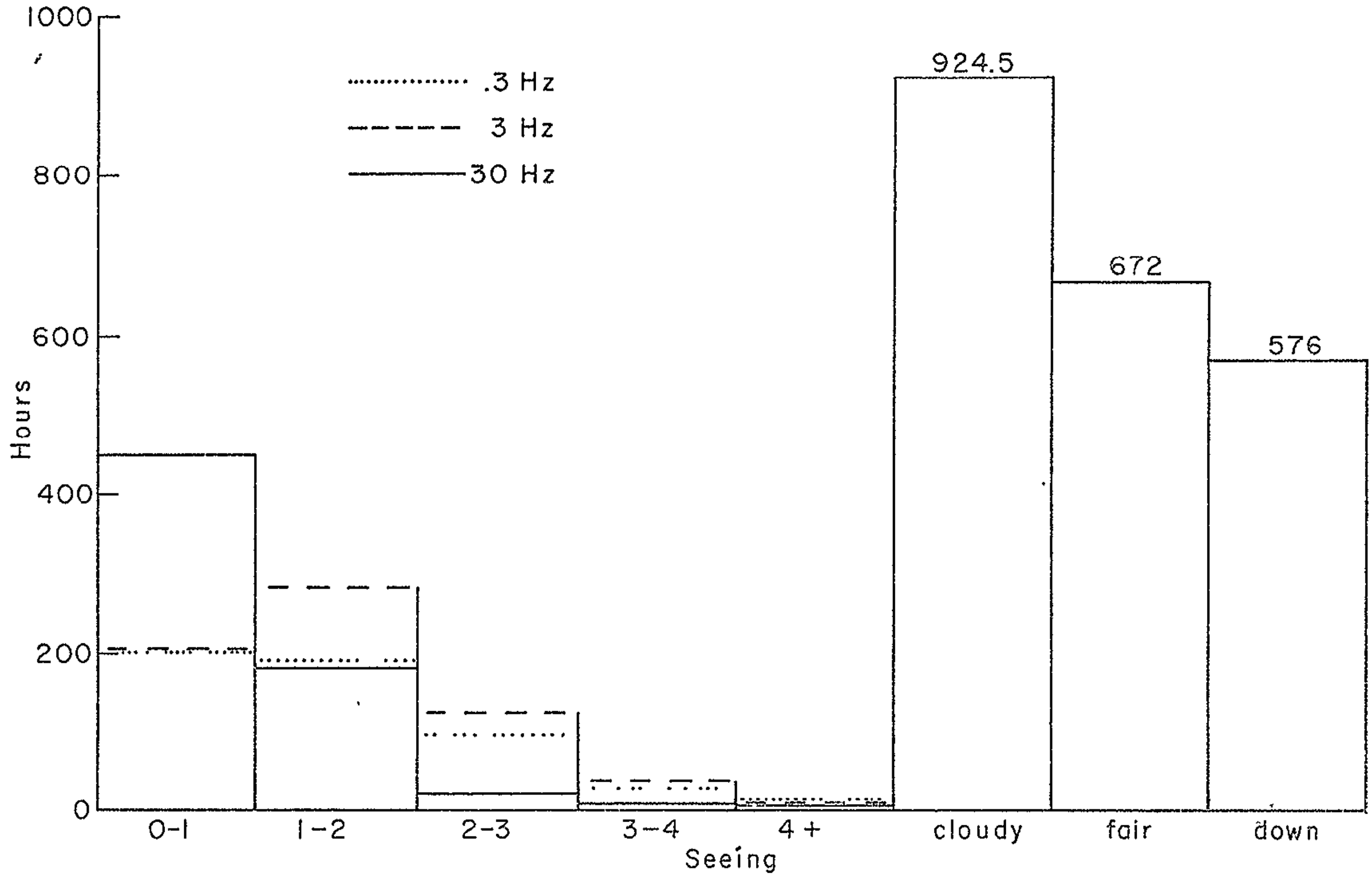


.3 Hz
3 Hz
30 Hz
Hours
250
200
150
100
50
0
177.5
208
247
0-1
1-2
2-3
3-4
4+
cloudy
fair
down
Seeing

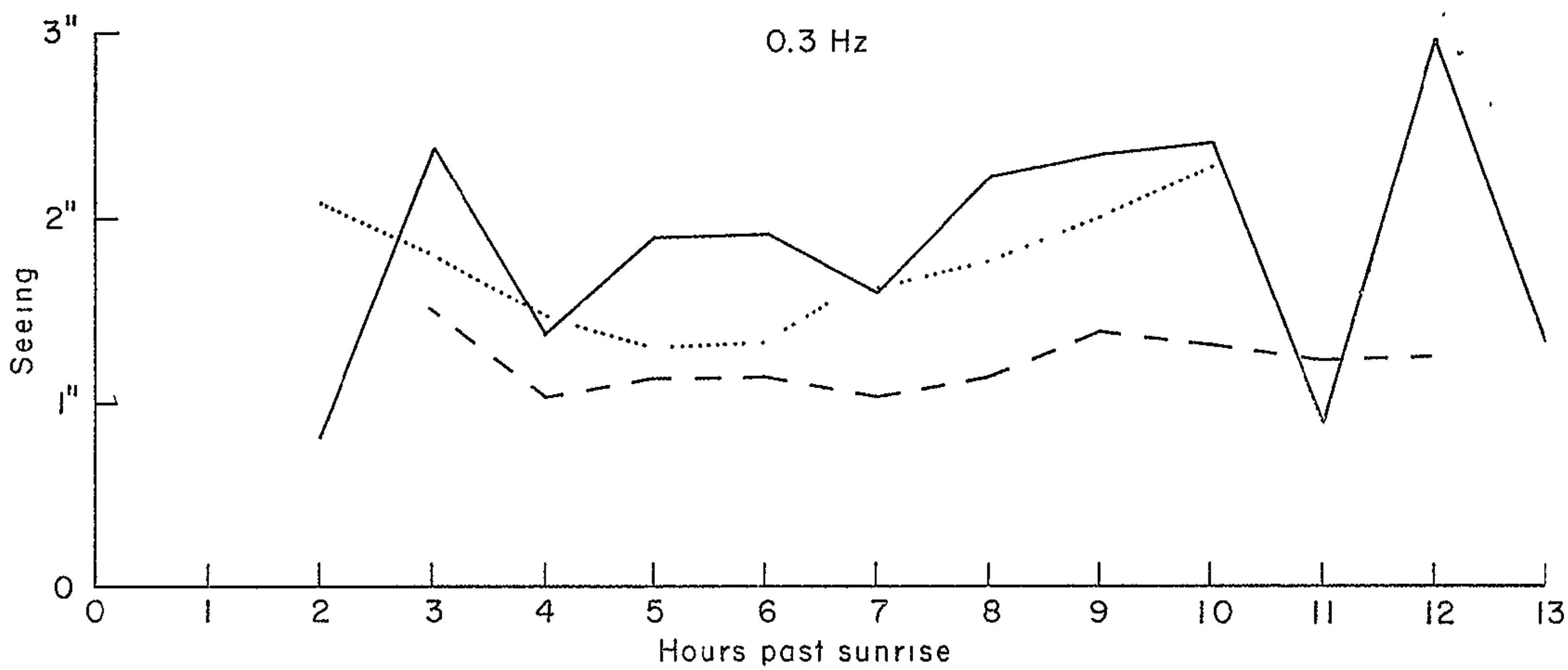
11

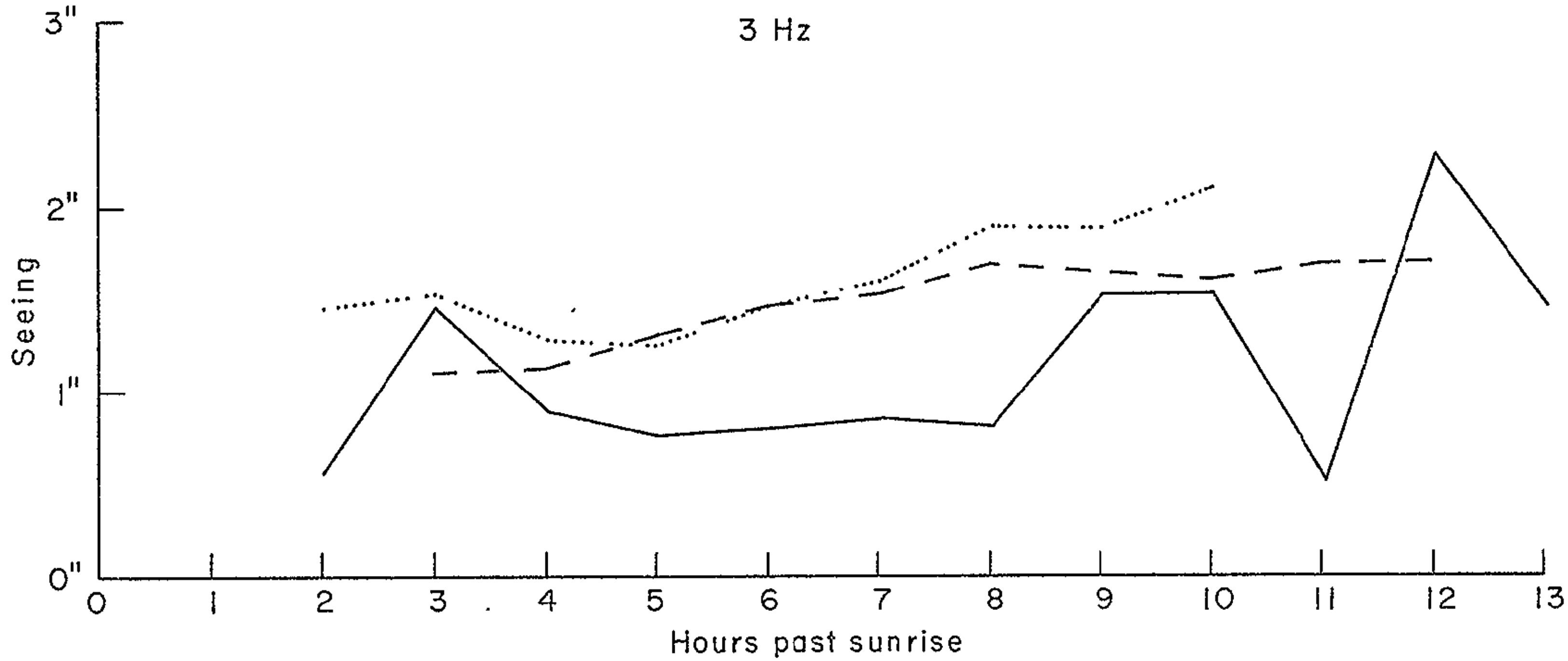


125
100
75
50
25
0
Hours
.3 Hz
3 Hz
30 Hz
124
38
38
0-1
1-2
2-3
3-4
4+
cloudy
fair
down
Seeing

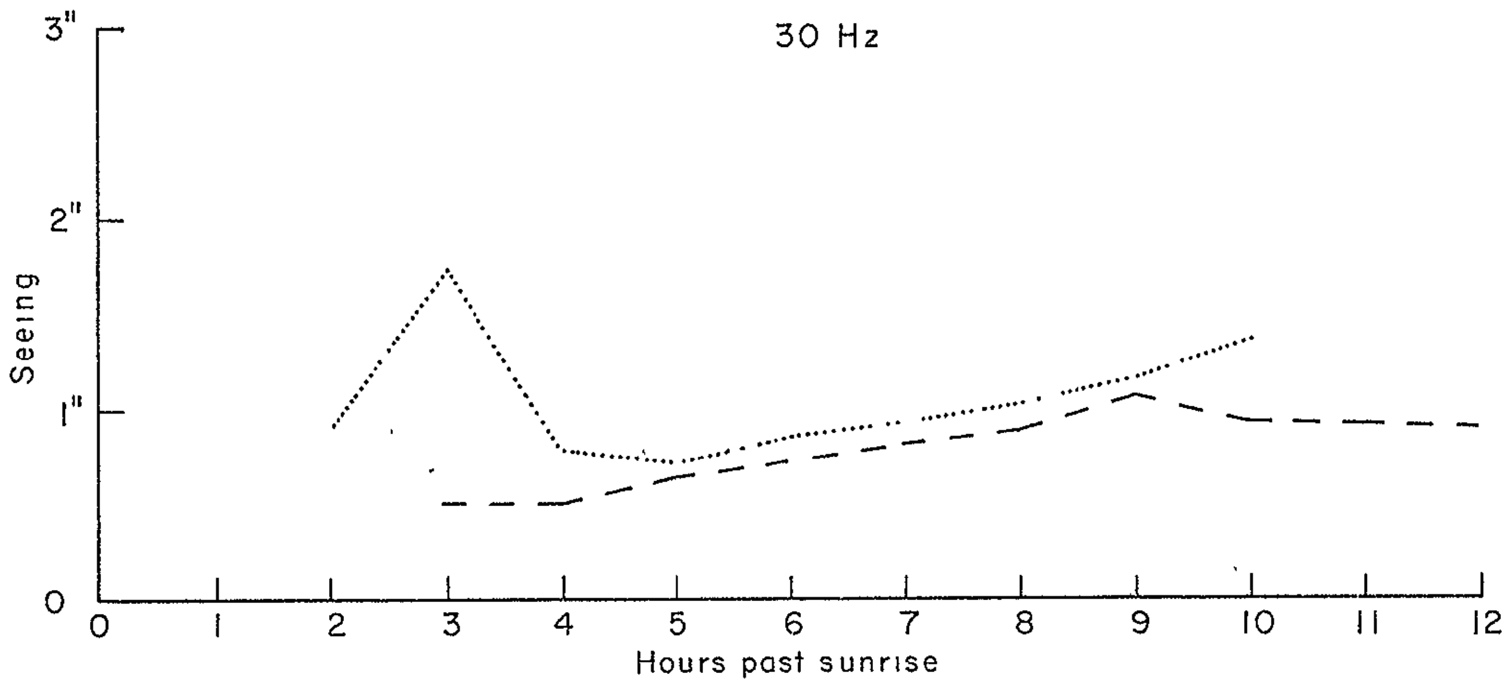


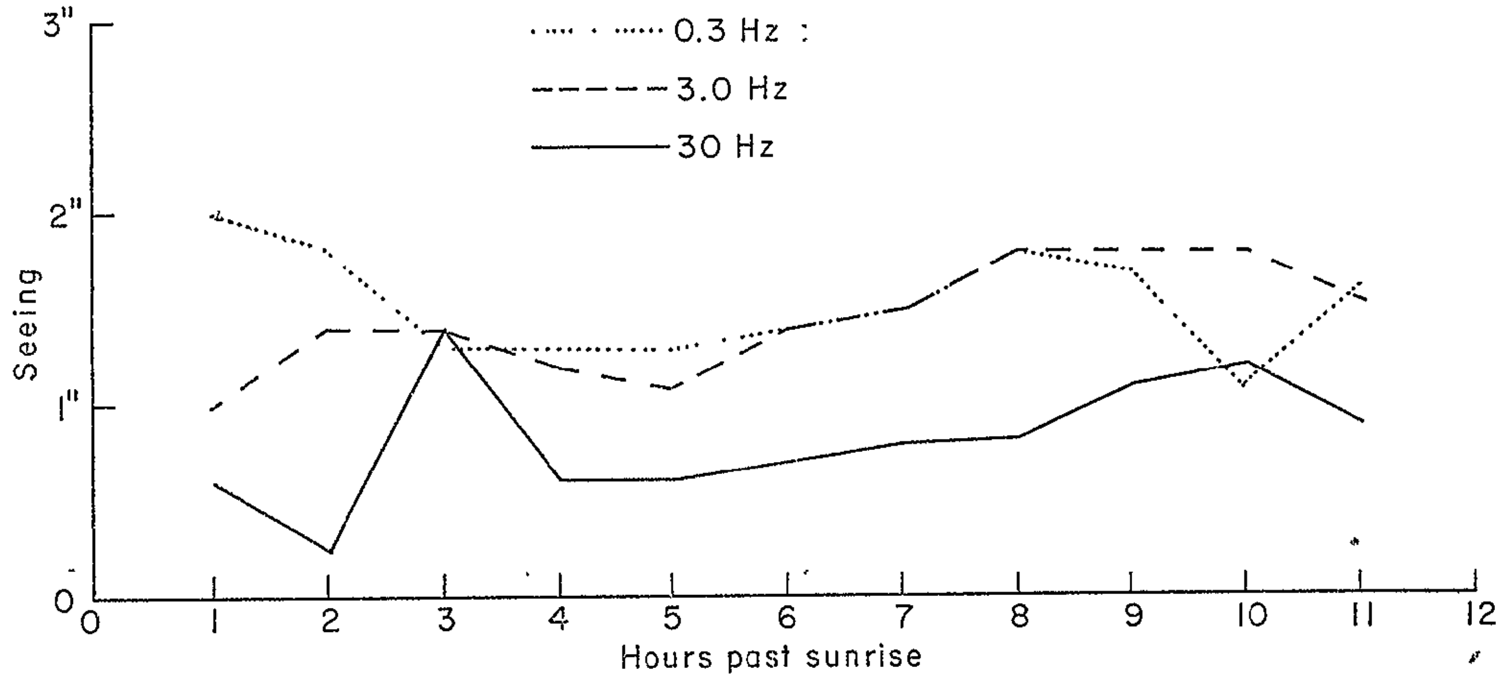
1000
800
600
400
200
0
Hours
.3 Hz
3 Hz
30 Hz
924.5
672
576
0-1
1-2
2-3
3-4
4 +
cloudy
fair
down
Seeing


0.3 Hz
3"
2"
1"
0
Seeing
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Hours past sunrise



15."


30 Hz
3"
2"
1"
0
Seeing
0 1 2 3 4 5 6 7 8 9 10 11 12
Hours past sunrise


0.3 Hz
3.0 Hz
30 Hz
3"
2"
1"
0
Seeing
0
1
2
3
4
5
6
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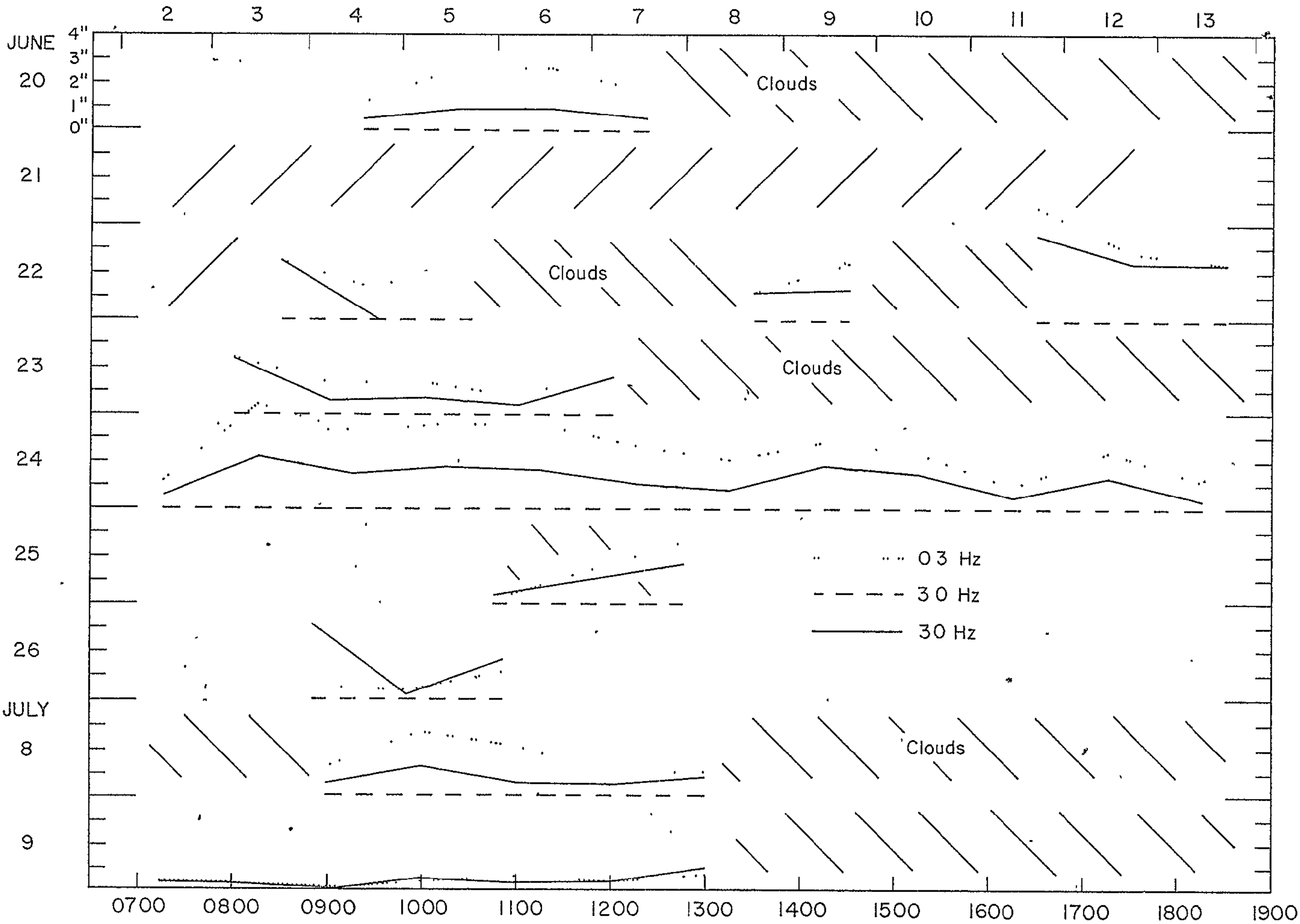
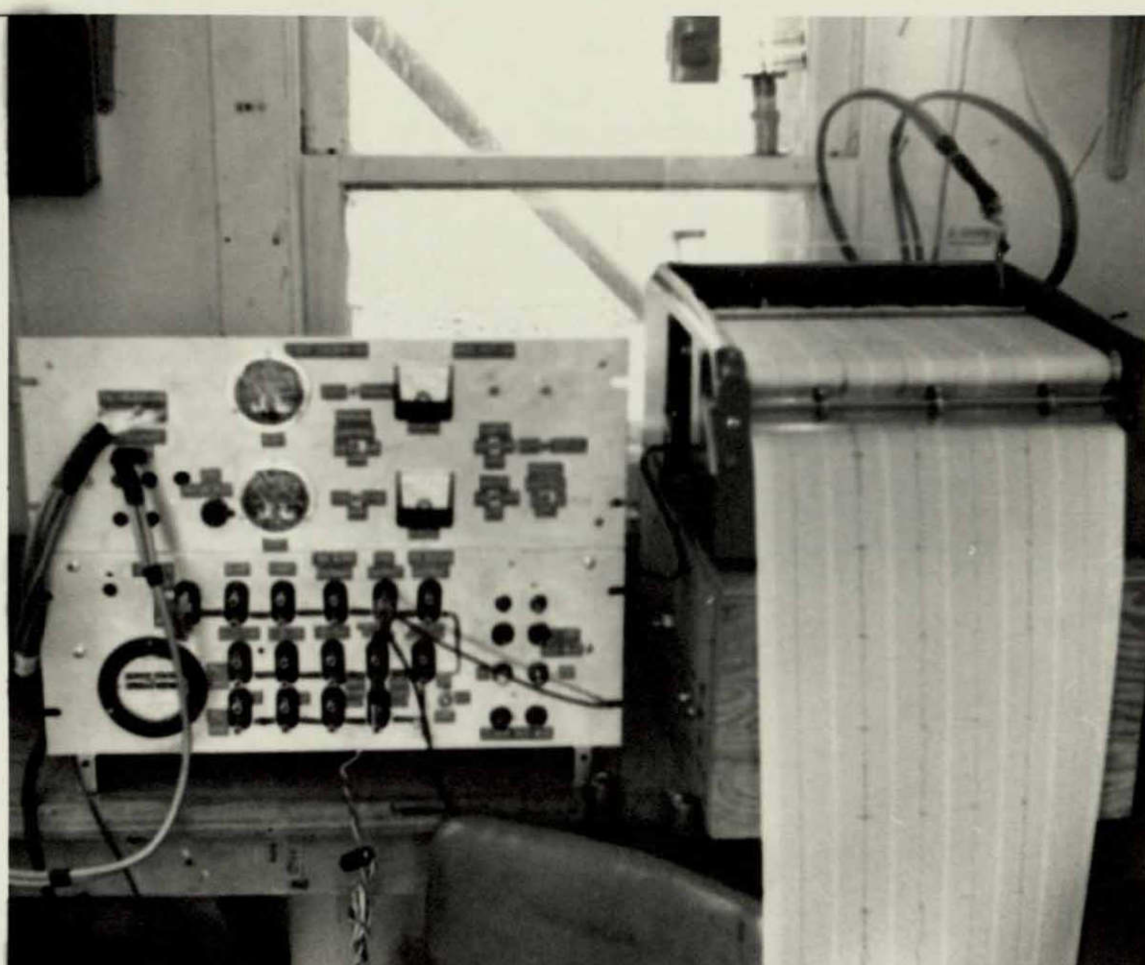
8
9
10
11
12
Hours past sunrise



2
3
4
5
6
7
8
9
10
11
12
13
JUNE
4"
3"
2"
1"
0"
20
21
22
23
24
25
26
JULY
8
9
Clouds
Clouds
Clouds
Clouds
03 Hz
30 Hz
30 Hz
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900

Fig 18



Appendix I

TELESCOPE ALIGNMENT

Solar Telescope Optical Collimation and Adjustment

There are three possible items which can tilt in the telescope's optical path, the secondary mirror, primary mirror, and the tube containing the electronics. Preferred method of collimation is:

1. Remove 4" tube, holding eyepiece, from telescope (do not twist eyepiece itself) adjust tilt of tube containing electronics. There is a transparent piece of glass with crosshairs in center of disk at rear. Move head so crosshairs are centered in eyepiece tube opening. Check if secondary appears centered, and adjust with push-pull screws on this tube, located at ring near telescope mounting. In later, finer adjustment look for reflection of cross hairs and eye back on itself.
2. Adjust secondary mirror tilt. There are 3 set screws at secondary end of telescope. These tilt the secondary with respect to the optical axis. They are to be adjusted so that the reflection of the eyepiece tube is centered. It may be helpful to take a white piece of paper or card, punch a 1/16-inch round hole in the center, and put over center of eyepiece tube. Adjust the 3 screws at secondary to get reflection of hole back on itself in a "targetlike" fashion.

3. Adjust primary tilt. Adjust the 3 pairs of push-pull screws behind primary so that the reflections appear symmetric in eyepiece tube. It may not be necessary to repeat adjustments of electronics tube (fine adjustment) and secondary. Then return eyepiece to eyepiece tube to its place.
4. Star check. At night look through rear of telescope with an eyepiece at the image of a very bright star, far enough out of focus to look "like a tennis ball a foot away". If collimation is good there will be a central black spot in image (made by secondary mirror obscuration). If not central, adjust secondary or primary to make black spot central. This is an extremely sensitive test, so small adjustments only are usually required. If rough adjustments have not been carried out with great care there will be no black spot and these steps should be repeated.
5. Solar size adjustment. Set diodes 8" apart and near center of their travel on the disk. The eyepiece itself screws in and out along its mount (which will defocus the image) and the primary mirror focussing knob can be used to refocus the image. Sun will change size--continue until image of

sun's "edge" touches all four diodes. Then move diodes for a slightly less crude adjustment. Final adjustment of diode spacing is discussed in a section on setting up and calibrating the electronics.

Appendix I

TELESCOPE POLE ALIGNMENT

Basic principle of alignment is that the telescope will be properly rotated in 3 dimensions when 3 stars have their declination circle telescope declinations equal to the stars' true declinations. When indicated and true do not agree, the telescope's polar axis must be moved toward agreement; the north end of the axis must be moved either east or west (azimuthal rotation on mounting) or up or down (altitude adjustment by 3 screws on base plate). Iteration is required for good adjustment.

1. Point telescope roughly (within 30°) toward north pole. Use guide scope crosshairs for all settings.

2. Point telescope toward "meridian" star on list accompanying these instructions. Loosen declination indicating circle and reclamp to declination of meridian star.

3. Point guide scope to "East" star. Read declination circle (do not reset). Note whether telescope's indicated declination is north (more positive) or south (more negative) than star's true declination given on list.

4. Point guide scope to "West" star. Read declination circle (do not reset). Note again whether telescope's indicated declination is north or south of star's true declination.

5. Go to table on accompanying list of 4 possibilities for east and west stars. Adjust polar axis accordingly, and return to instruction (2) above--that is, point telescope to meridian star and reset declination circle. Stop when indicated declination and true declination of all three stars (not just two) agree to within $0.^{\circ}1$, the reading error of the circle. This will usually require 6-12 adjustments.

SOLAR TELESCOPE ALIGNMENT

July - August

Morning

MERIDIAN STAR

β CET	$0^h 41.6^m$	$-18° 12'$	2.02^m

E (EAST) STAR

α TAU	$4^h 33.6^m$	$+16° 26'$	0.86^m

W (WEST) STAR

α AQL	$19^h 48.8^m$	$+8° 46'$	0.77^m

STAR E	STAR W	MOVE POLAR AXIS
South	South	Raise
North	North	Lower
North	South	West
South	North	East

Evening

MERIDIAN STAR

α OPH	$17^h 33.1^m$	$+12° 35'$	2.09^m

E (EAST) STAR

ε PEG A	$21^h 42.2^m$	$+09° 41'$	2.31^m

W (WEST) STAR

α VIR	$13^h 23.1^m$	$-10° 57'$	0.91^m

STAR E	STAR W	MOVE POLAR AXIS
South	South	Raise
North	North	Lower
North	South	West
South	North	East

Appendix II

VISUAL CALIBRATION OF SOLAR SEEING

Appendix II

VISUAL CALIBRATION OF SOLAR SEEING

The solar seeing apparatus measures a fluctuation in intensity of light received from the solar limb. A measurement of such intensity fluctuations is necessary for the design of the apparatus proposed for this site. Measurements of this type are not necessarily closely related to seeing as customarily defined and used by an astronomer. The electronic apparatus results are a composite of seeing and scintillation; the human eye is more sensitive to seeing than scintillation. It is of some interest to try to correlate the electronically recorded seeing with visual seeing more commonly used by astronomers.

A modification made to the telescope allows a diagonal mirror to be inserted into a portion of the optical path not utilized by the diodes; a small section of the optical image of the sun's limb is diverted outside the instrument to an eyepiece having a net magnification of 800. In the eyepiece there is both a dense filter and a reticle with markings 2.5 seconds of arc apart. Visual seeing measurements are made by estimating both the excursions and blurring of the image relative to an absolute scale given by the reticle spacings. Estimates were made simultaneously with the electronic measurements, 8 times per hour, during one day in May and one day in July by the same observer.

The results are shown graphically in Figures and Both figures display visual seeing versus electronic seeing, for frequencies of 0.3 and 3.0 Hz. The two different symbols represent different days. The line in each graph is a least squares fit to the points, forced to go through the origin. The equations of the lines and standard errors of estimates are:

f = 0.3 Hz visual seeing = 2.2 x electronic seeing S.E. = 0.7"

f = 3.0 Hz visual seeing = 3.5 x electronic seeing S.E. = 0.7".

The scatter is small relative to the range of the variables and there appears to be little systematic trend, hence, there is a good linear relationship between visual seeing and electronic seeing. Visual seeing is systematically larger for each frequency filter, presumably because the eye is sensitive to all frequencies and each filter selects only one portion of the seeing frequency spectrum. In addition, visual seeing includes both the defocusing of the image as well as the time dependent correlated and uncorrelated distortion. The uncorrelated time dependent distortion is the primary contribution to the electronic signal. The relationship of these quantities to the theory of fluctuations is discussed in the section on theory. The greater slope for the higher frequency illustrates the well known roll-off of seeing with increasing frequency.

There is a well defined linear relationship between the visual seeing customarily used by astronomers and the seeing measured by the apparatus described in this report.

Appendix III

SET-UP PROCEDURE

SOLAR SEEING ELECTRONICS

The electronics for measuring solar seeing is designed to measure the uncorrelated AC component of the light from two phototransistors at opposite limbs (edges) of the solar image. If the telescope and/or whole solar image is shifted, the resulting combined phototransistor signal is called correlated and the electronics is designed to reject this signal. Since the correlated signal corresponds to the increasing one phototransistor signal while the opposite is decreasing, the sum of the two signals cancels the correlated change. On the other hand, the difference of the two signals exaggerates the correlated change. The difference corresponds to the tracking error, i.e., how well the solar image is centered between the phototransistors and is, therefore, used to correct the telescope pointing. Since the pointing correction will be smallest in the declination direction, the declination phototransistors are used for the seeing signal. The uncorrelated north-south declination phototransistors are summed and the AC component is fed to 3 filters of center frequency 0.3, 3, and 30 Hz. The outputsof these are recorded as the seeing signals at the respective frequencies. The sum signal monitors the total light, and the difference signals north-south in declination, east-west in right ascension monitors the tracking of the telescope. The same signals drive correction motorsto change the telescope position. The declination motor is a DC motor driven through the amplifier by the positive or negative polarity of the declination difference signal. The right ascension motor is a synchronous clock motor normally driven by 110 volts 60 cycles AC, but in this case, the AC is frequency controlled by the right ascension difference signal. This is accomplished by a voltage-controlled oscillator and amplifier.

CALIBRATION PROCEDURES FOR SOLAR-SEEING EQUIPMENT

1. Zero the declination difference signal (Dec. Diff.). When both input declination meters read zero either because
   a. no light on the phototransistors
   b. the cable to the telescope is disconnected
   c. jumper wires short the declination input jacks on the front panel.

   Then the out put of the Dec. Diff. amplifier should read zero. This zero can be read either on the recorder or by means of a voltmeter across the output terminal on the front panel of the Dec. Diff. amplifier.

   Zero Dec. Diff. signal using the offset potentiometer "pot" on board 16.

2. Introduce a difference signal of 5 microamps between the north and south phototransistor inputs. This may be accomplished either
   a. by setting the telescope slightly off the sun
   b. with no light using the plug-in battery and adjustable resistor on either north or south phototransistor and grounding the other
   c. using the test audio-oscillator input to north or south phototransistor.

   With an input difference of 5 microamps the Dec. Diff. output should read approximately full-scale, 10 volts on both the recorder and/or on a voltmeter across the Dec. Diff. output. This output should change sign only when the difference is introduced on the north or south input. When both inputs, north and south, are grounded or shorted together at an arbitrarily higher signal $\leq$ 25 microamps the Dec. Diff. should continue to read zero. If the total gain of the Dec. Diff. is low, i.e., when the 5 microamp difference signal is introduced, adjust the gain of the Dec. Diff. amplifier by the output pot on board 16. If the output of the Dec. Diff. does not remain zero when the two inputs are shorted together either at ground or an arbitrary signal $\leq$ 25 microamps then adjust the relative gain of the two inputs by the north and south pots on board 16. These sets of adjustments assure that a difference signal is delivered by the declination difference amplifier if the appropriate difference signal appears on the phototransistors and assures that no difference occurs when the signals on the two are equal.

3. The output of the Dec. Diff. goes both to the recording pen and to the declination motor amplifier that drives the declination motor on the telescope mount. By clipping a voltmeter to the swinger of the variable resistor pot on the front panel that controls the declination motor current one should observe $\pm$ 5 to 6 volts depending whether the declination difference amplifier is positive or negative. If the cable to the declination motor is anywhere disconnected then the voltage read at the declination motor pot at the front panel will be plus or minus 7 to 8 volts when the Dec. Diff. is greater than plus or minus 1 volt. The current to the declination motor when the declination motor amplifier is saturated is controlled by two potentiometers.

a. The potentiometer on the front panel that is in series with the output of the declination motor drive amplifier, and

b. By the potentiometer on the declination motor amplifier. The potentiometer on the declination motor amplifier governs the current input to the amplifier, and when this potentiometer is in the position of high resistance, it limits the input current to the amplifier transistors so that the output stage of the amplifier is not saturated. Under these circumstances, more of the voltage drop occurs across the transistors than the output 25 ohm resistors, (two 50-ohm resistors in parallel). Consequently, the heat dissipation is shared by both the output resistors as well as the output transistors of the declination motor amplifier.

4. Repeat the same series of set-up measurements for the right ascension difference amplifier (R. A. Diff.); zero the amplifier (board 1) and then introducing a finite signal on the east or west phototransistor input jack on the front panel. In the case of the right ascension amplifier a 10-microamp difference between east and west phototransistor input signals should cause a full-scale deflection of the output of the R. A. Diff. In other words, the R. A. Diff. is set up with half the gain of the Dec. Diff. The output of the R. A. Diff. is recorded on the pen-recorder and can be read by a voltmeter clipped to the appropriate jack on the front panel.

No. page 4 in original document

5. The output of the R.A. Diff. leads in addition to the voltage controlled oscillator (V.C.O.). The frequency of the V.C.O. should be 60 hz when the input voltage from the R. A. Diff. amplifier is zero. This frequency can be observed either on the frequency meter on the front panel if the V.C.O. amplifier is in operation or it can be observed on an oscilloscope connected to the output jack of the V.C.O. If this frequency is not 60 cycles for an input of zero volts, then the offset potentiometer on the voltage controlled oscillator board #2 can be adjusted to change the zero frequency. The gain of the voltage controlled oscillator is governed by the input potentiometer on the same board and should be adjusted such that a 10-volt input signal; namely, full-scale deflection of the R.A. Diff. amplifier corresponds to $\pm$ 7 or 8 cycles per second. This change in frequency is beyond the range of the frequency meter but a linear relationship may be assumed and so a $\pm$ 5-volt input signal to the V.C.O. should lead to a plus or minus 3 or 4 cps change in the V.C.O. frequency. This change in frequency can be read on the frequency meter on the front panel, provided the V.C.O. amplifier is in operation.

6. The output voltage of the V.C.O. amplifier leads directly to the alternating current synchronous motor on the telescope mount. This voltage can be read with a meter by clipping on to the appropriate jack on the front panel. That should be roughly 120 volts AC. The gain on the voltage controlled oscillator board

No Page 4 in original Document

controls the amplitude not the frequency of the V. C. O. output. This amplitude should be just sufficient such that the output AC voltage from the V. C. O. amplifier just saturates (about 120 volts AC). Further gain draws excess current from the power supply and overheats the power transistors. This can be determined by reducing the gain on the V. C. O. board such that the output voltage of the amplifier is reduced and then, in turn, increasing the gain until the output just saturates. This current drain can be so large as to blow the fuse on the positive 25-volt supply voltage. The possibility of blowing the positive supply voltage fuse in this fashion should be remembered in case this fuse is blown.

7. Both the declination and right ascension have manual override controls so that the telescope can be slewed without the respective difference amplifiers in operation. The declination manual drive is operated by switching in $\pm$ 8 volts through a 25-ohm dropping resistor direct to the current limiting potentiometer on the front panel and then to the declination motor. The right ascension manual drive has two modes. One mode switches a positive or negative supply voltage into the input of the V. C. O. and hense increases or decreases the frequency from the V. C. O. amplifier to the synchronous motor of the right ascension drive. In addition, an override switch can disconnect the V. C. O. amplifier output from the right ascension synchronous motor drive and connect instead the 110 volts direct from the line, through an isolation

transformer to the right ascension synchronous motor. The isolation transformer allows one side of the line to be grounded. The 60 cycles from the line should show as 60 cycles on the frequency meter on the front panel. These controls allow the operator to manually slew the telescope faster or slower than sidereal rate and north and south in declination.

8. The sum signal board # 15 of the declination phototransistors (north and south) should first be zeroed by the use of the front panel switches that disconnect the declination phototransistors from the input to the sum amplifier only, and, in turn, shorts these inputs to ground. This assures that the inputs to the Dec. sum amplifier are grounded yet at the same time insures that the same signals are still delivered to the Dec. Diff. amplifier in order to maintain tracking of the sun. Once the sum signal is zeroed, then using 1.5 volts on the input to either the declination north or south phototransistor should result in 27 to 30 microamps on the north or south panel meters and result in a sum signal of 5 volts. This sum signal can be read either on the chart recorder or using a voltmeter on the appropriate jack on the front panel. Again, the overall gain of the Dec. sum signal can be adjusted by the output pot, whereas the relative gain on the inputs can be adjusted by the north and south input pots. When the Dec. inputs both north and south are shorted together and both raised 1.5 volts above ground, the sum signal should be near saturation of 10 volts,

roughly two division on the chart recorder. This corresponds to the maximum phototransistor input signals with either one phototransistor all the way on the sun or the two phototransistors divided on the limb.

9. The output of the Dec. sum amplifier goes to the 3 filter boards each of which have a decade bandwidth centered at respectively 0.3, 3 and 30 Hz. An oscillating input signal can be introduced to either the north or south phototransistor input jacks on the front panel and the response of the respective filter channels observed. Again, each channel should be zeroed with a zero input signal, achieved by the Dec. sum switches on the front panel. The sensitivity of these channels should be set up such that a $\pm$ 10 microamp oscillation of one phototransistor input at the center frequency of the respective channel corresponds to full-scale 10-volt deflection on the output of that channel. In turn, if an equal signal is introduced to both the north and south declination phototransistor inputs simultaneously then the output in each channel should be zero. The system is now ready to receive the phototransistor signals from the telescope and interpret these as both seeing signals and for tracking the sun.

10. Set up of the telescope. The sensitivity of the difference amplifiers in conjunction with the expected phototransistor signals is

sufficiently high in gain such that the telescope should track the sun in right ascension to within an error of a second of arc and in declination within an error of 1/2 second of arc. Therefore, the declination axis can be established very crudely with up to 10 degrees of error without significantly inhibiting the measurements. A larger error than 10 degrees of the declination axis limits the time that the telescope will continue to slew along the solar track when a cloud obscures the sun. When a cloud does obscure the sun, the input signals to right ascension and declination become zero and the telescope then follows at the frequency of zero input voltage to the voltage controlled oscillator which should be 60 cycles and should be solar rate, but the cumulative error is such that whenever a cloud obscures the sun for more than ten minutes there is little likelihood of the telescope acquiring the sun automatically by itself thereafter. The focus and alignment of the telescope should be accomplished according to a seperate discussion.

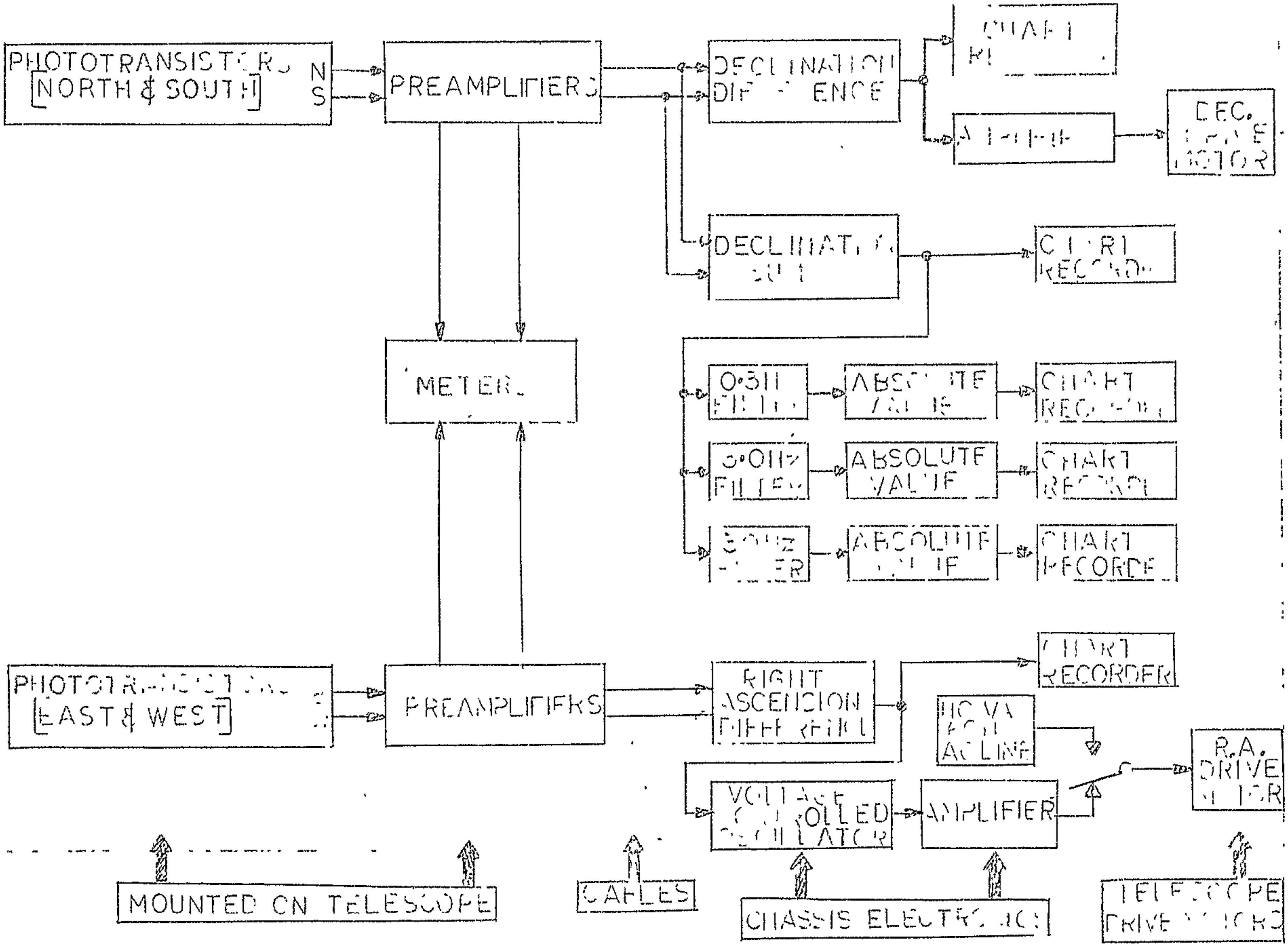
With a solar disk in focus on the phototransistor plane, the phototransistor spacing should be adjusted approximately so that the limb of the sun falls on each phototransistor. A more accurate alignment procedure follows:

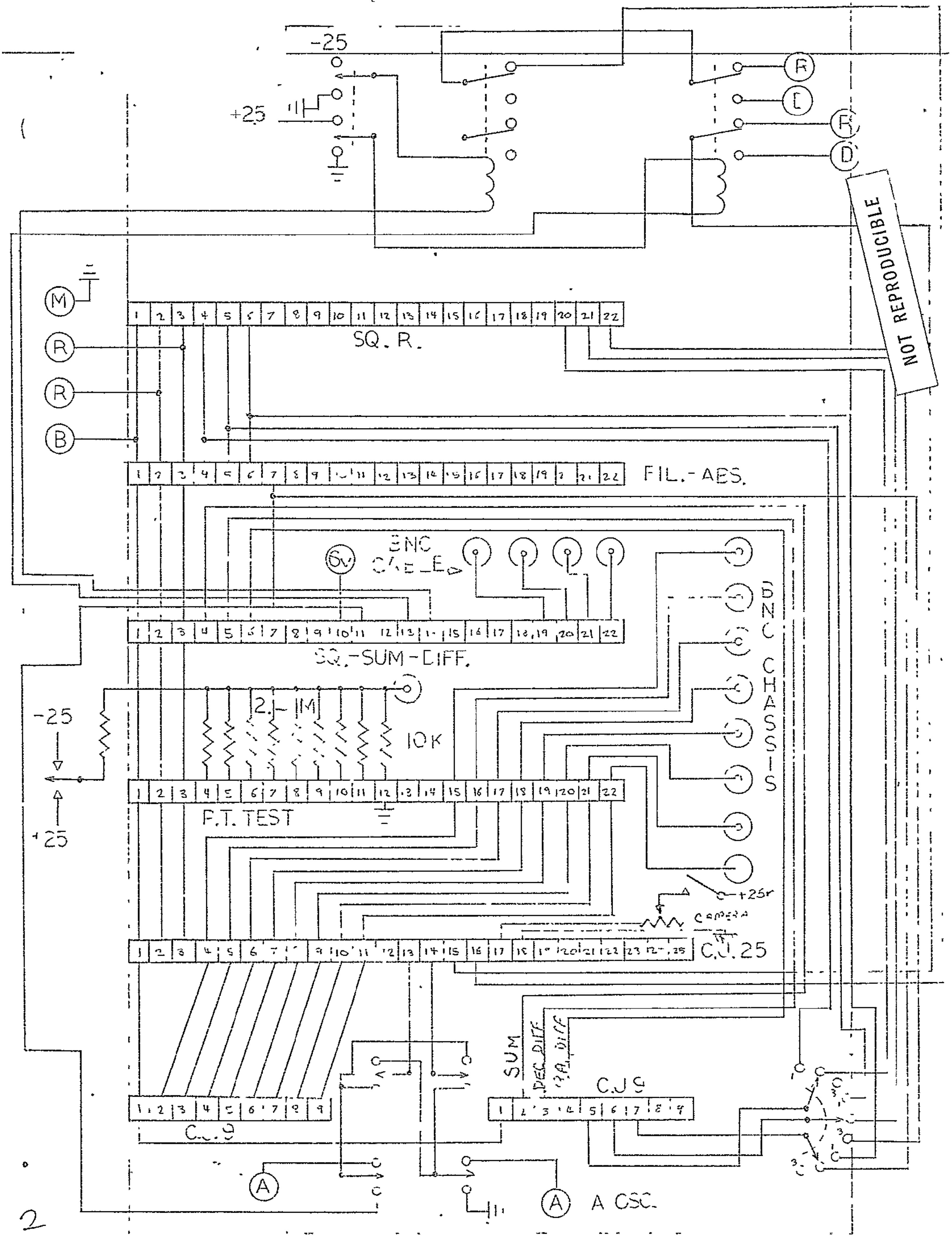
First, manually slew the telescope so that when a given phototransistor is roughly in the center of the solar disk and adjust the gain of the appropriate phototransistor preamp on the board on the telescope such that the output signal corresponds to 40 microamps at noon time with a clear sky. After the gain of each phototransistor amplifier is adjusted to give 40 microamps in this fashion, then the solar disk should be adjusted so that it straddles the phototransistors. Then the automatic guiding should take over and the telescope track the sun. The phototransistors should now be adjusted closer or further apart until their signal currents are roughly 1/3 of the peak signal current when that phototransistor was centered in the middle of the sun. This means in the early morning, if the centered sun signal of the phototransistors are 30 microamps (instead of 40 at noon time) then the phototransistor signal should be 10 microamps when the telescope is tracking automatically and when that phototransistor is straddling the limb of the sun. The automatic tracking will automatically center the sun between both the right ascension and declination diodes so that the phototransistor position adjustment can be accomplished while automatic tracking. The phototransistors are approximately 1 millimeter in aperture corresponding to 10 arc seconds at the 900-inch focal length of the telescope. Consequently, an oscillation of total amplitude of 5 arc seconds will result in a 50% change in the signal of any one phototransistor. Therefore, the correlated change of 5 arc second oscillation results in a 10-13 microamp fluctuation in the Dec. sum signal. A random correlation of the same oscillation at opposite edges of the limb will therefore be smaller by $\sqrt{2}$ giving 7 to 8 microamps oscillation.

Appendix IV

ELECTRONIC DRAWINGS

ELECTRONICS BLOCK DIAGRAMS

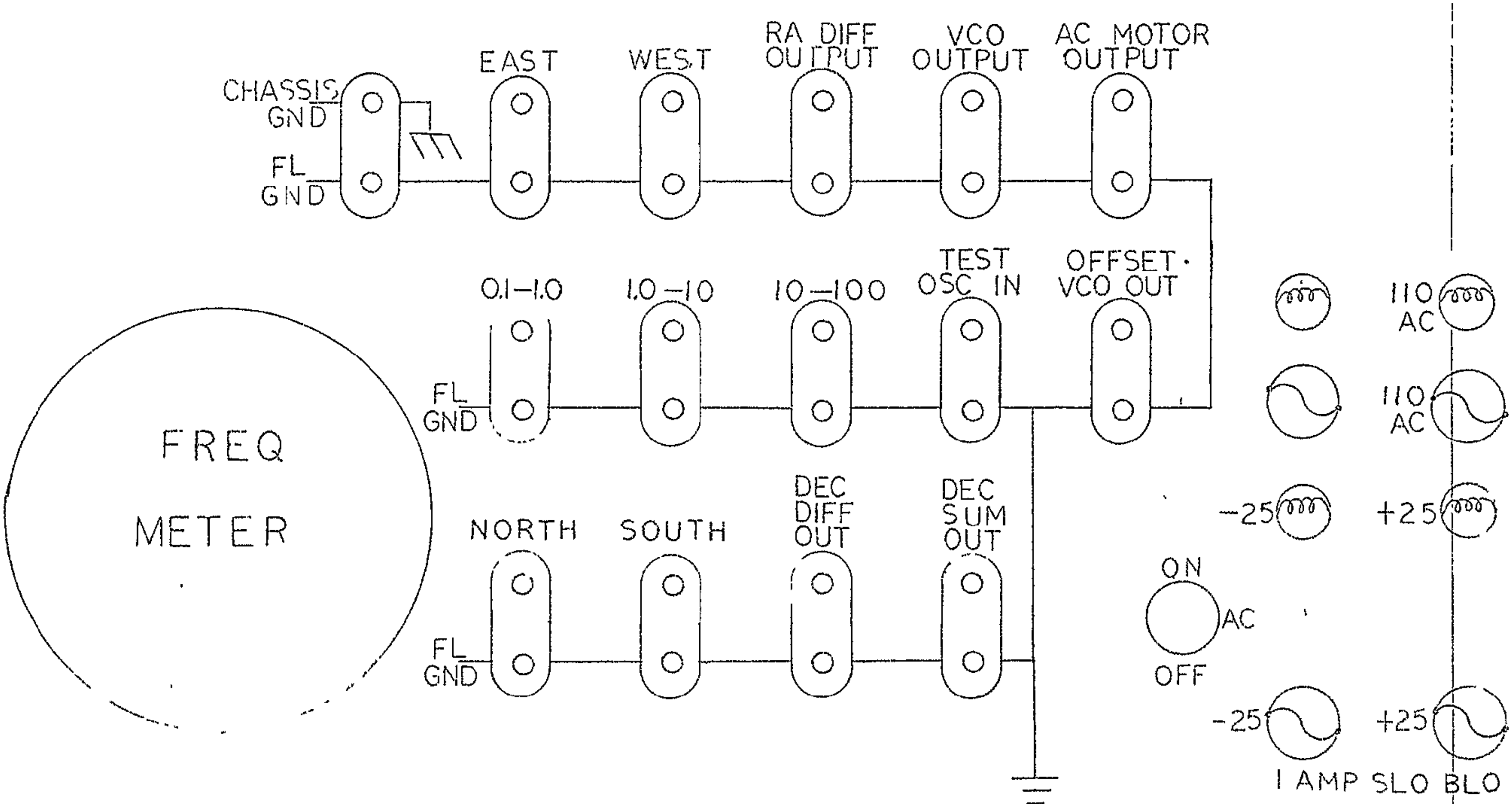




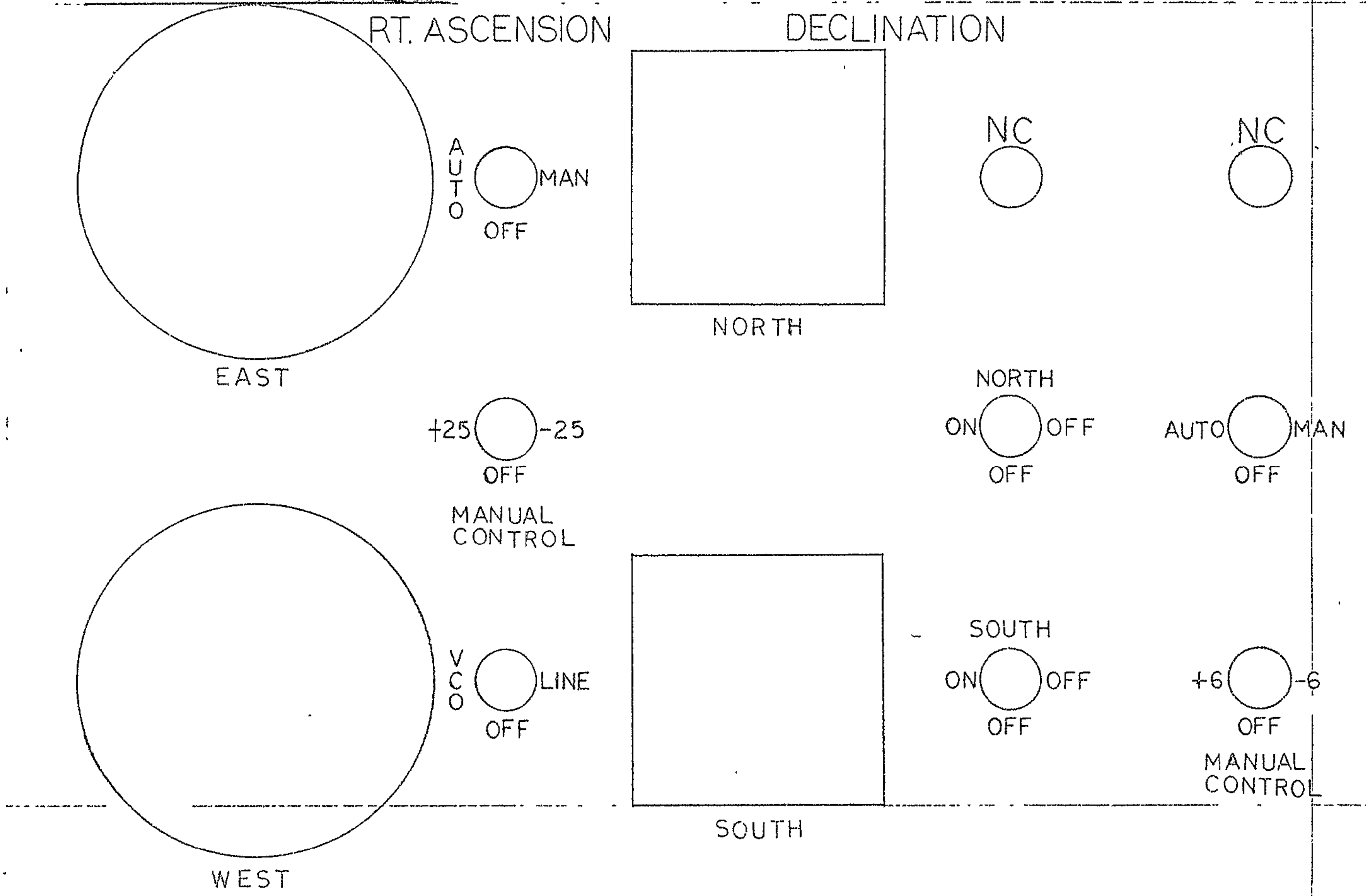
-25
+25
SQ. R.
FIL.-ABS.
BNC CABLES
SQ.-SUM-DIFF.
2.2M
10K
F.T. TEST
BNC CHASSIS
+25r
CAMERA
C.J. 25
SUM
DEC DIFF
R.A. DIFF
C.J 9
C.J. 9
A CSC.

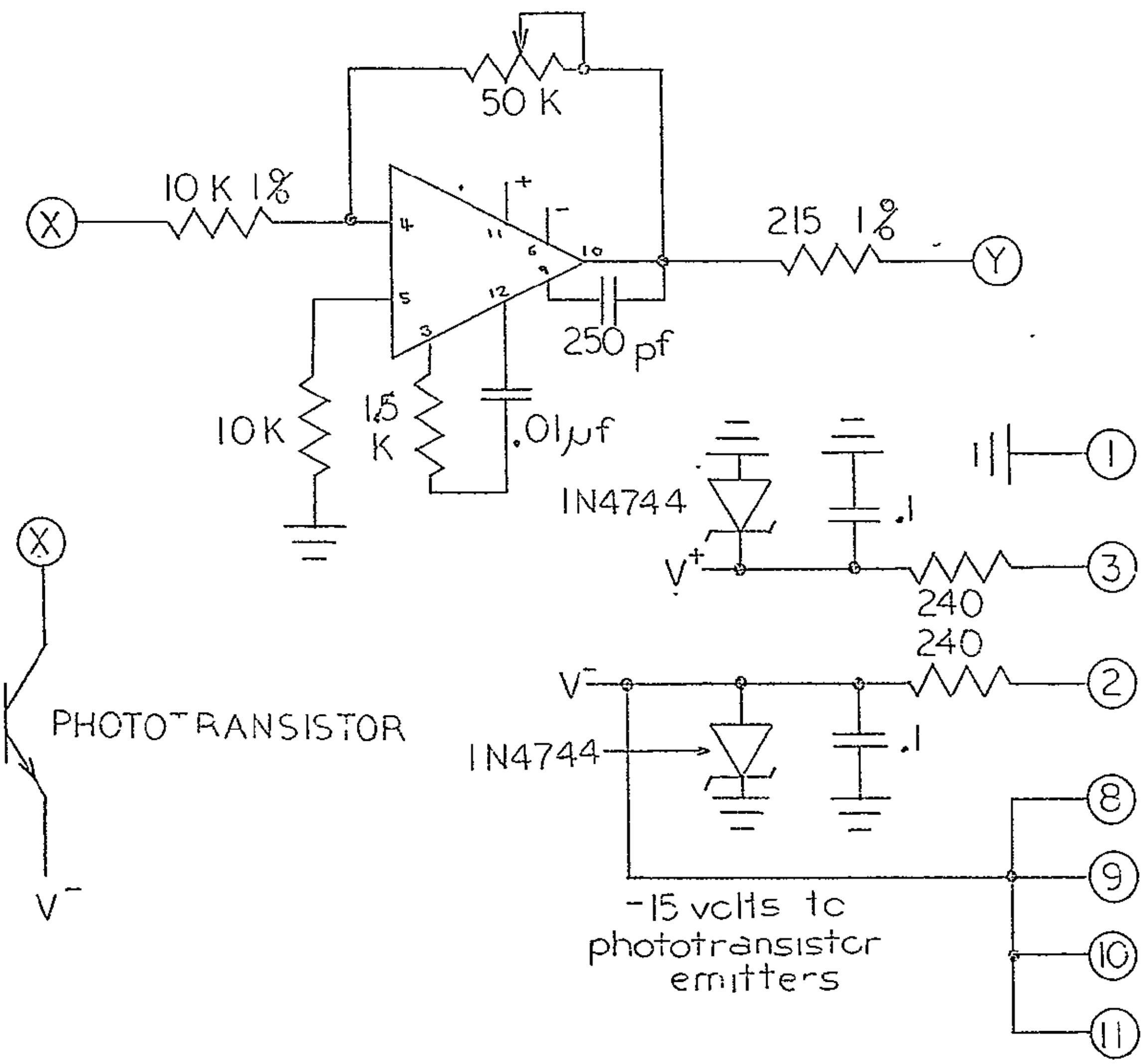
2

TEST JACK PANEL



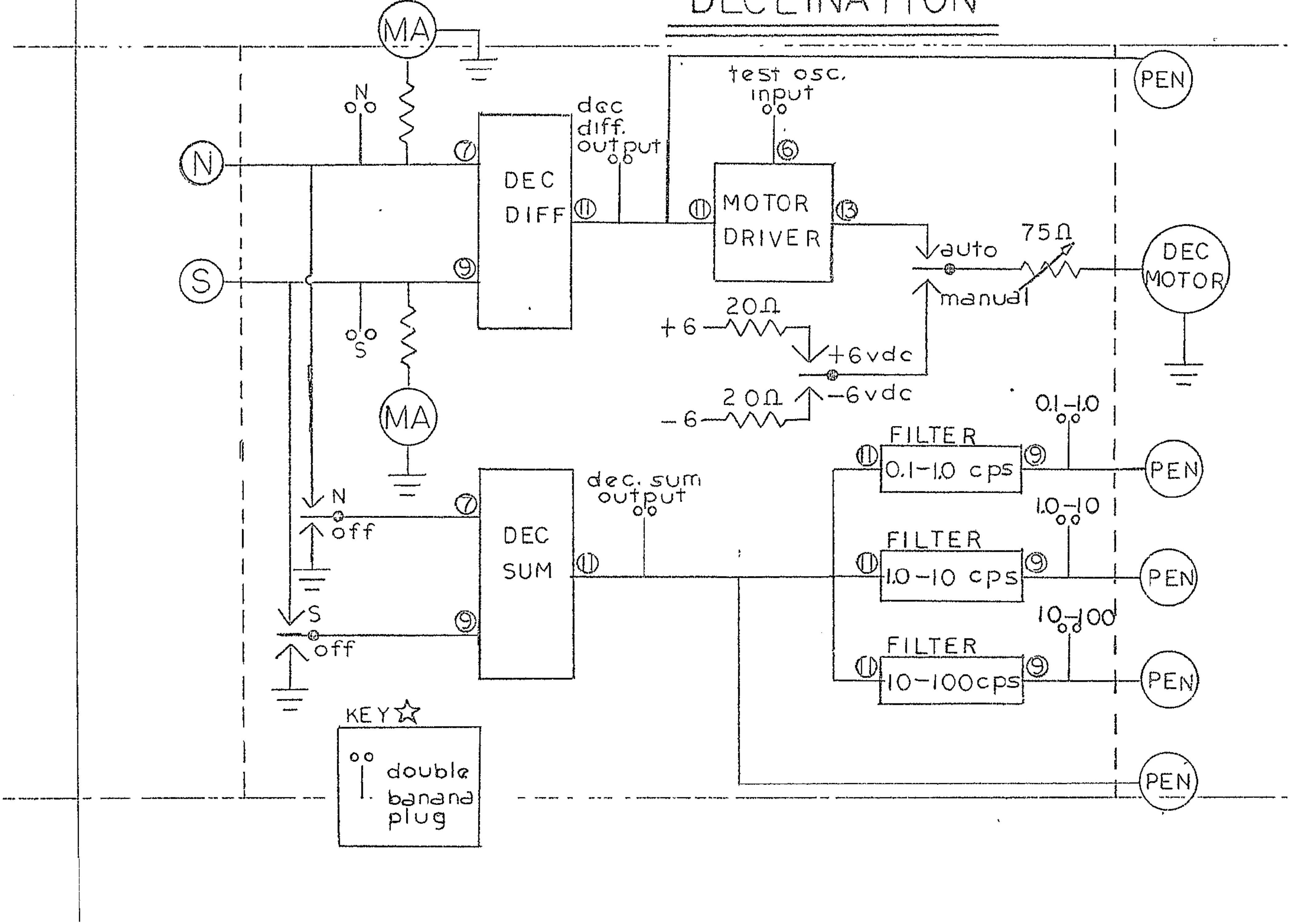
METER PANEL


RT. ASCENSION
DECLINATION
AUTO
MAN
OFF
EAST
+25
-25
OFF
MANUAL CONTROL
VCO
LINE
OFF
WEST
NORTH
SOUTH
NC
NC
NORTH
ON
OFF
OFF
AUTO
MAN
OFF
SOUTH
ON
OFF
OFF
+6
-6
OFF
MANUAL CONTROL

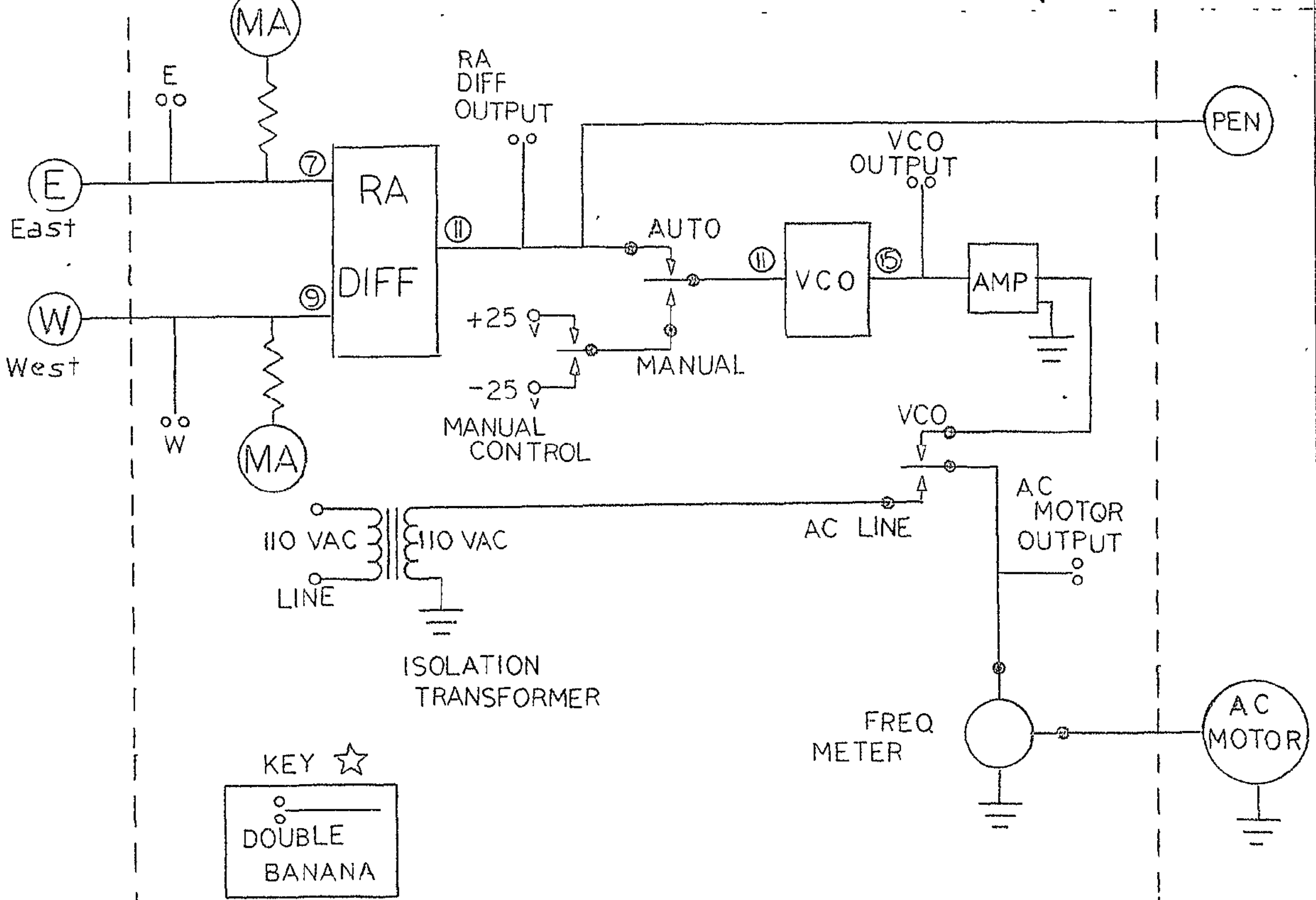


AMP	X	Y
1	4	12
2	5	13
3	6	14
4	7	15

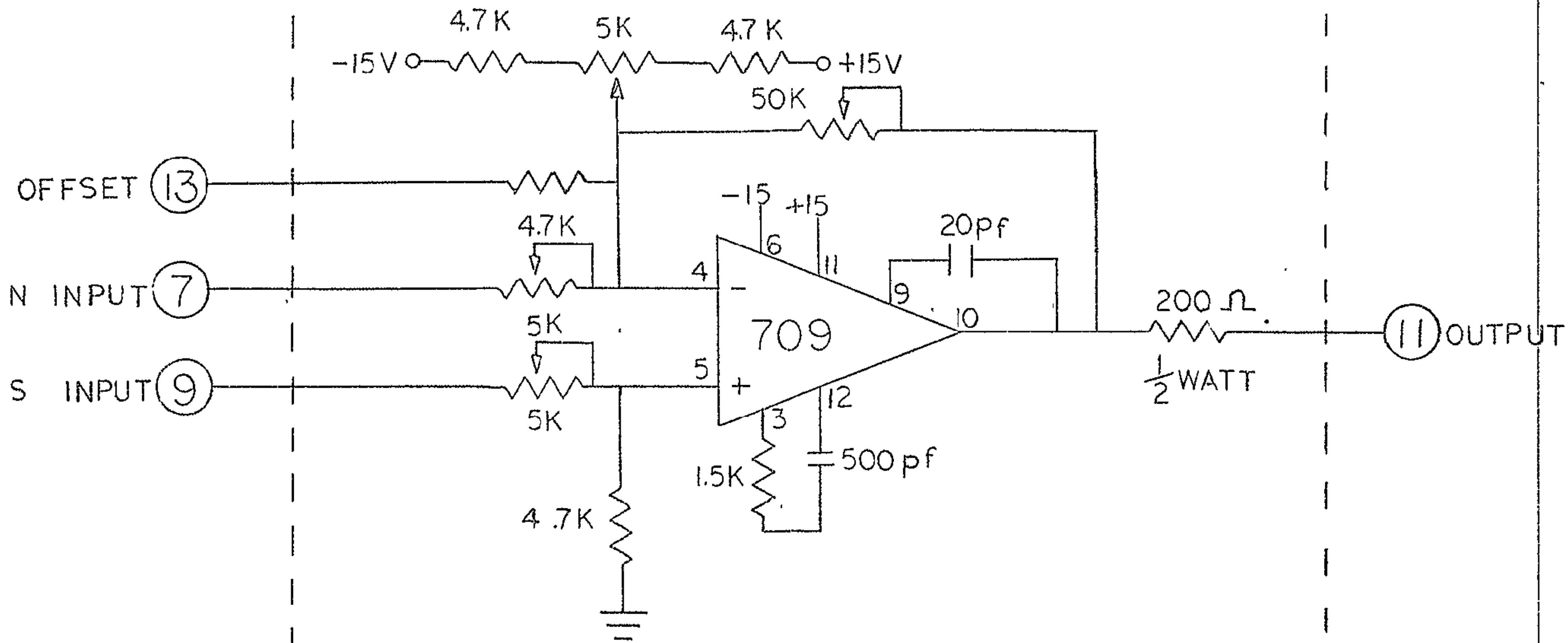
DECLINATION



RIGHT ASCENSION



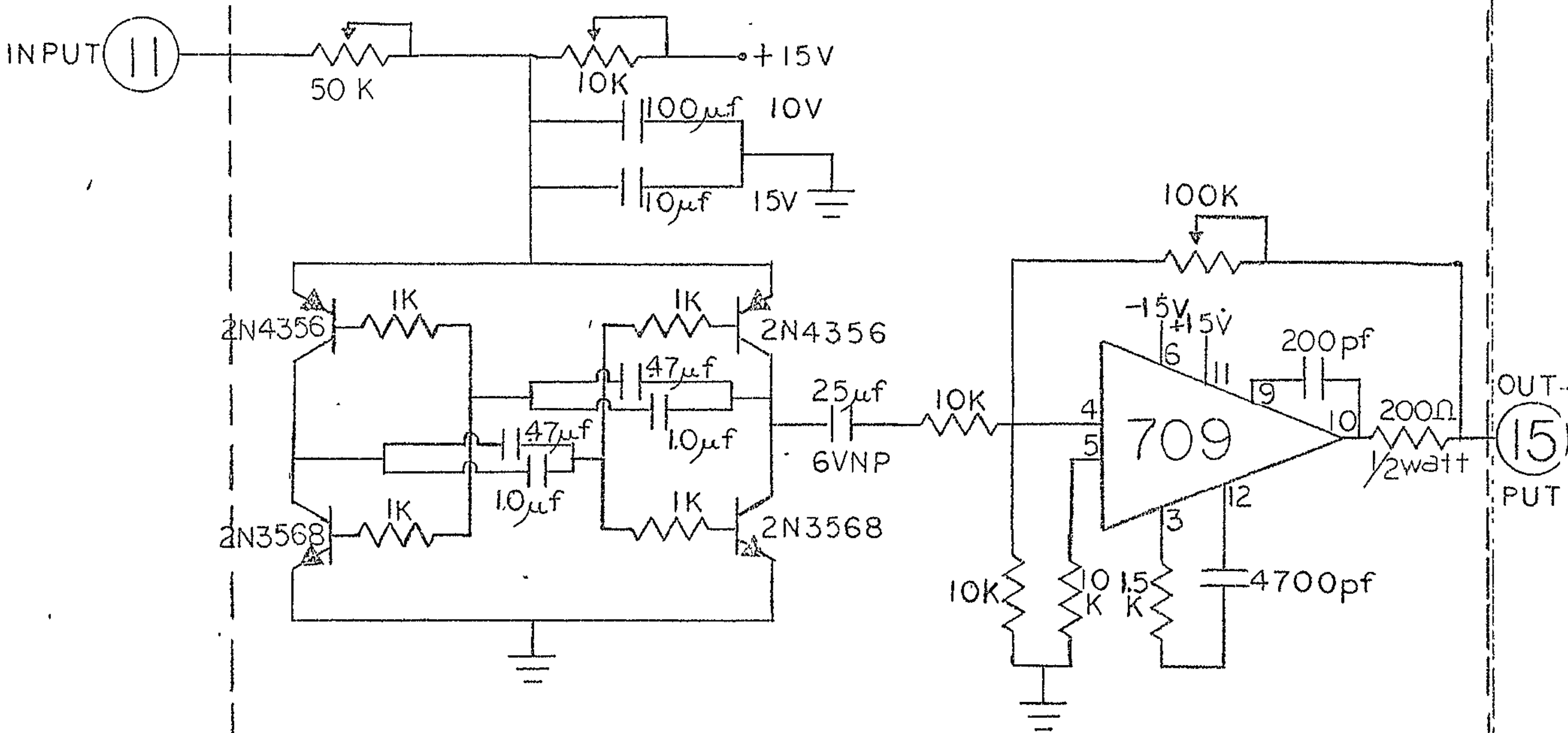
RA AND DEC. DIFFERENCE



ALL RESISTORS 1/4 WATT UNLESS OTHERWISE SPECIFIED

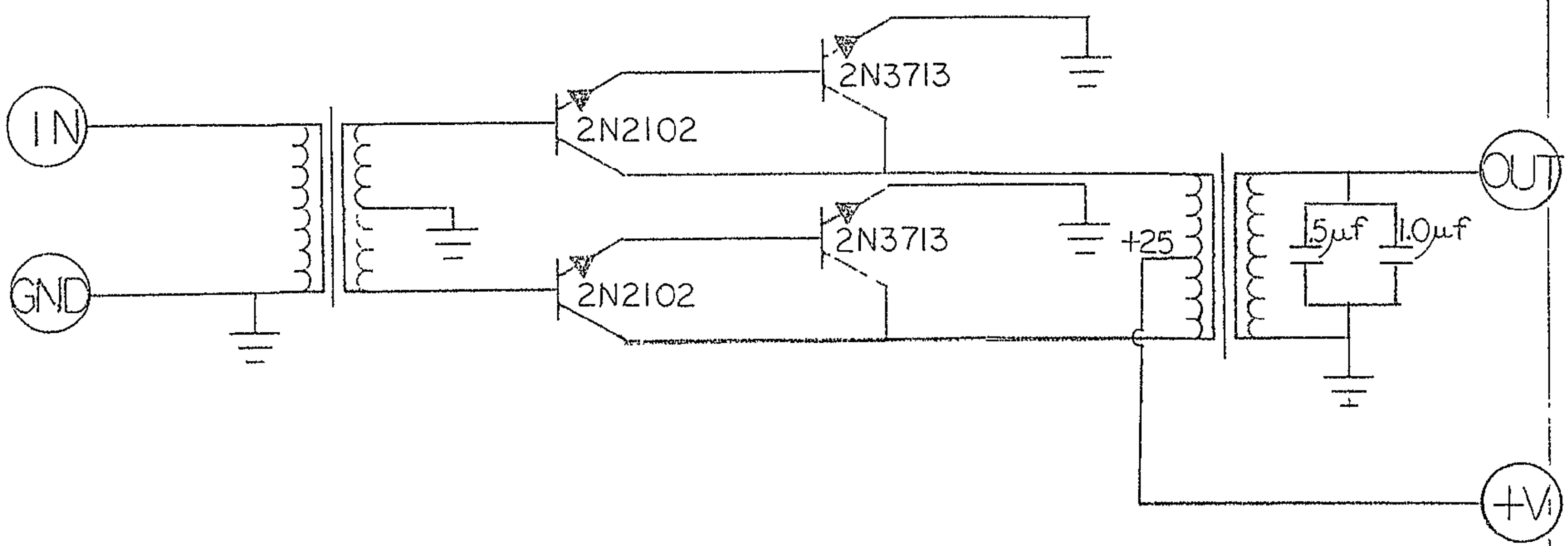
INCLUDE ZENER SUPPLY

VOLTAGE-CONTROLLED OSCILLATOR

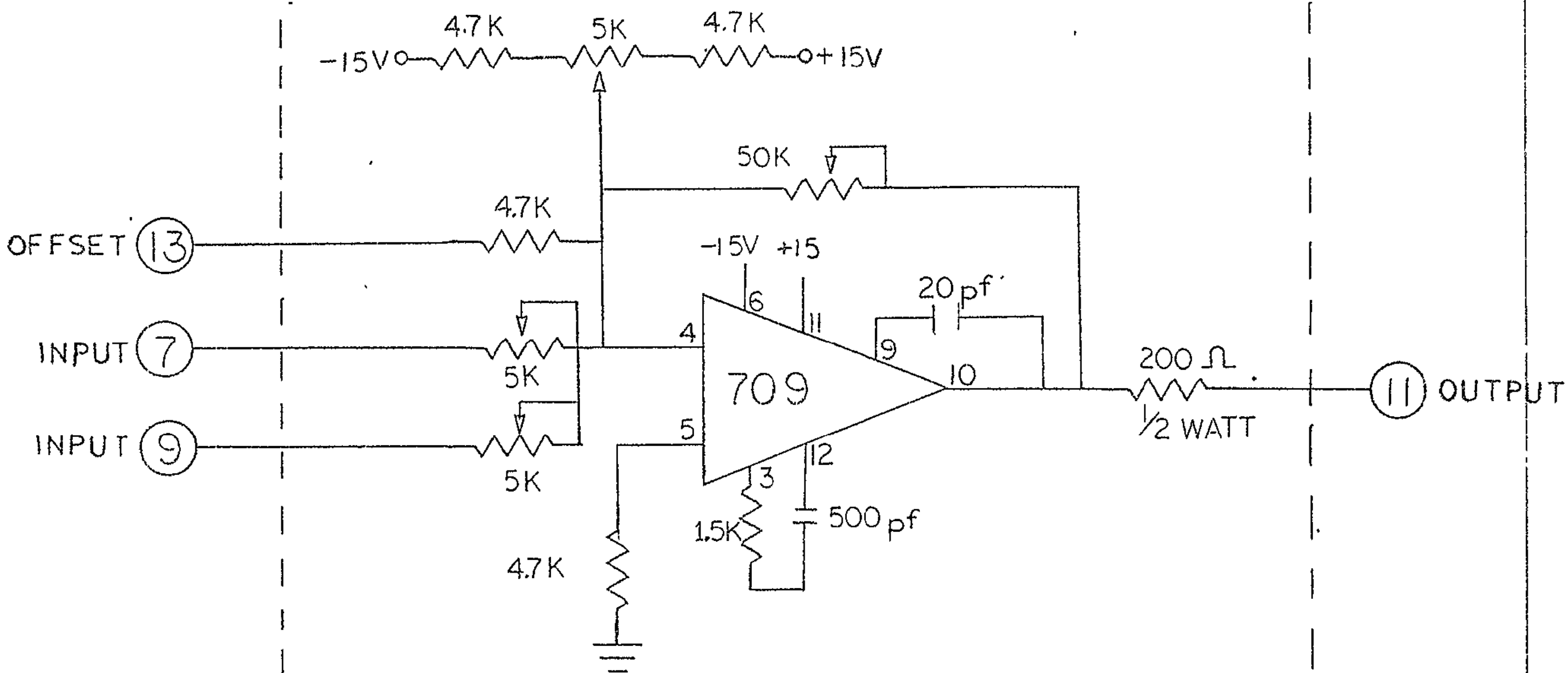


INCLUDE ZENER SUPPLY

AMPLIFIER



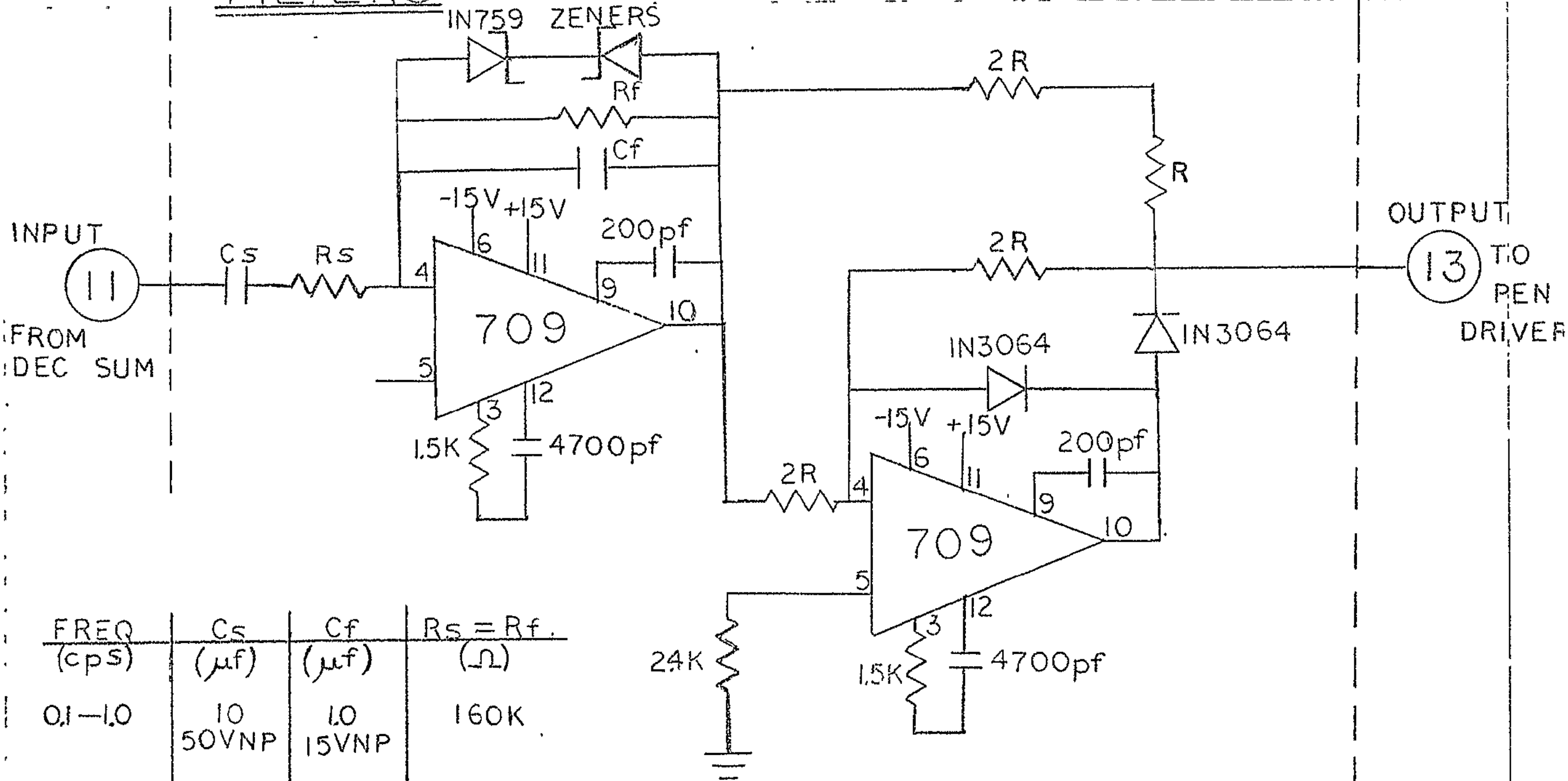
DEC SUM



ALL RESISTERS 1/4 WATT UNLESS OTHERWISE SPECIFIED

INCLUDE ZENER SUPPLY

FILTERS

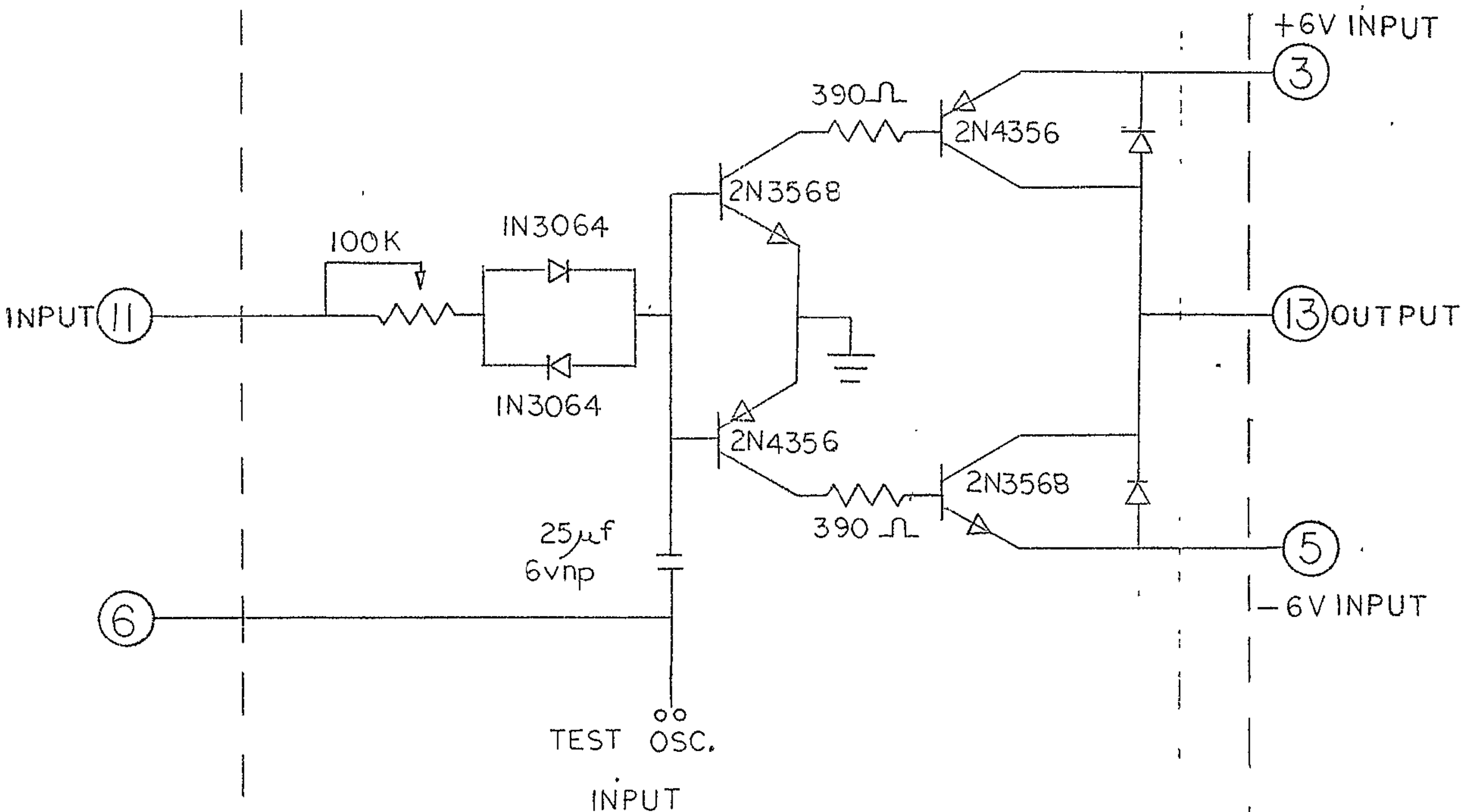


FREQ (cps)	Cs (µf)	Cf (µf)	Rs = Rf. (Ω)
0.1—1.0	10 50VNP	1.0 15VNP	160K
1.0—10	1.0 15VNP	0.1 20V	160K
10—100	0.1	0.01	160K

R = 4.42K, 1%
2R = 8.87K, 1%

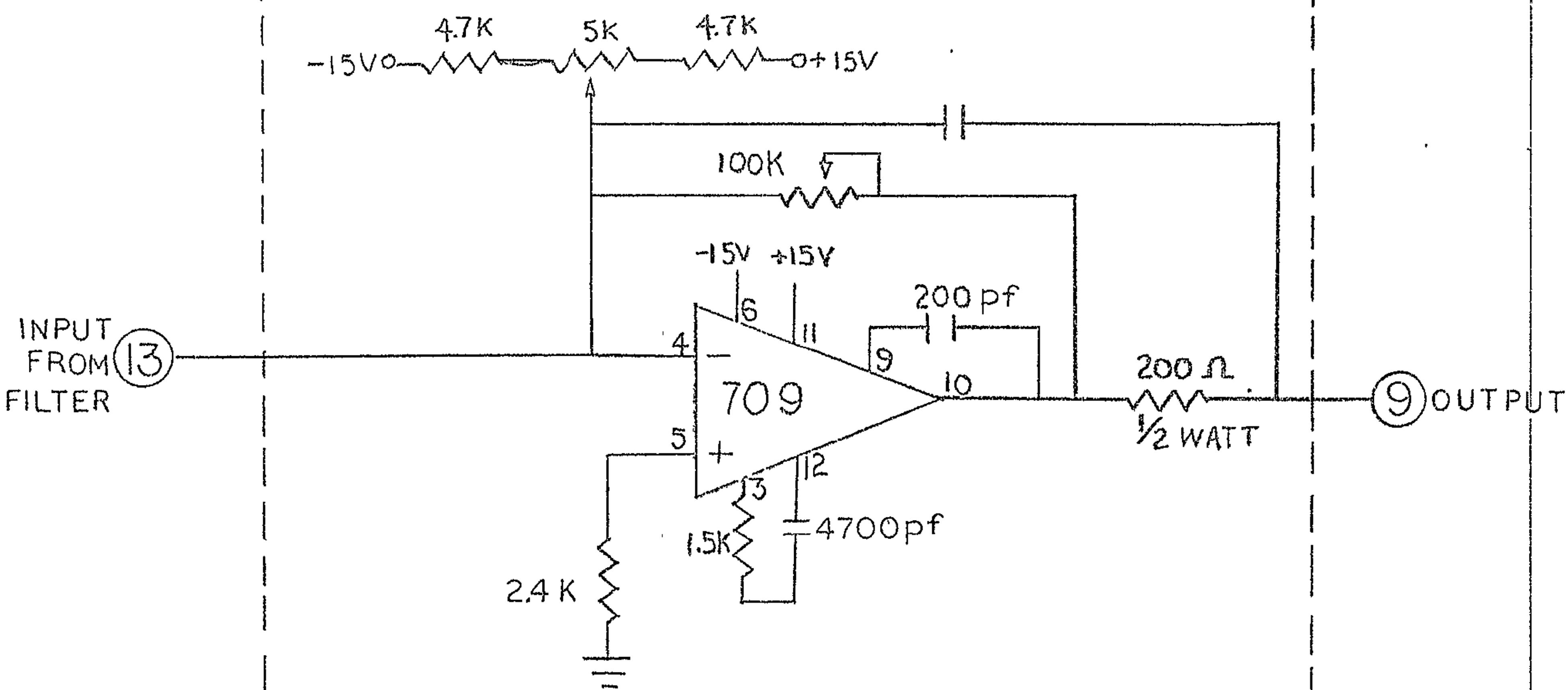
INCLUDE ZENER SUPPLY

MOTOR DRIVER



ALL RESISTORS 1/4 WATT UNLESS OTHERWISE SPECIFIED

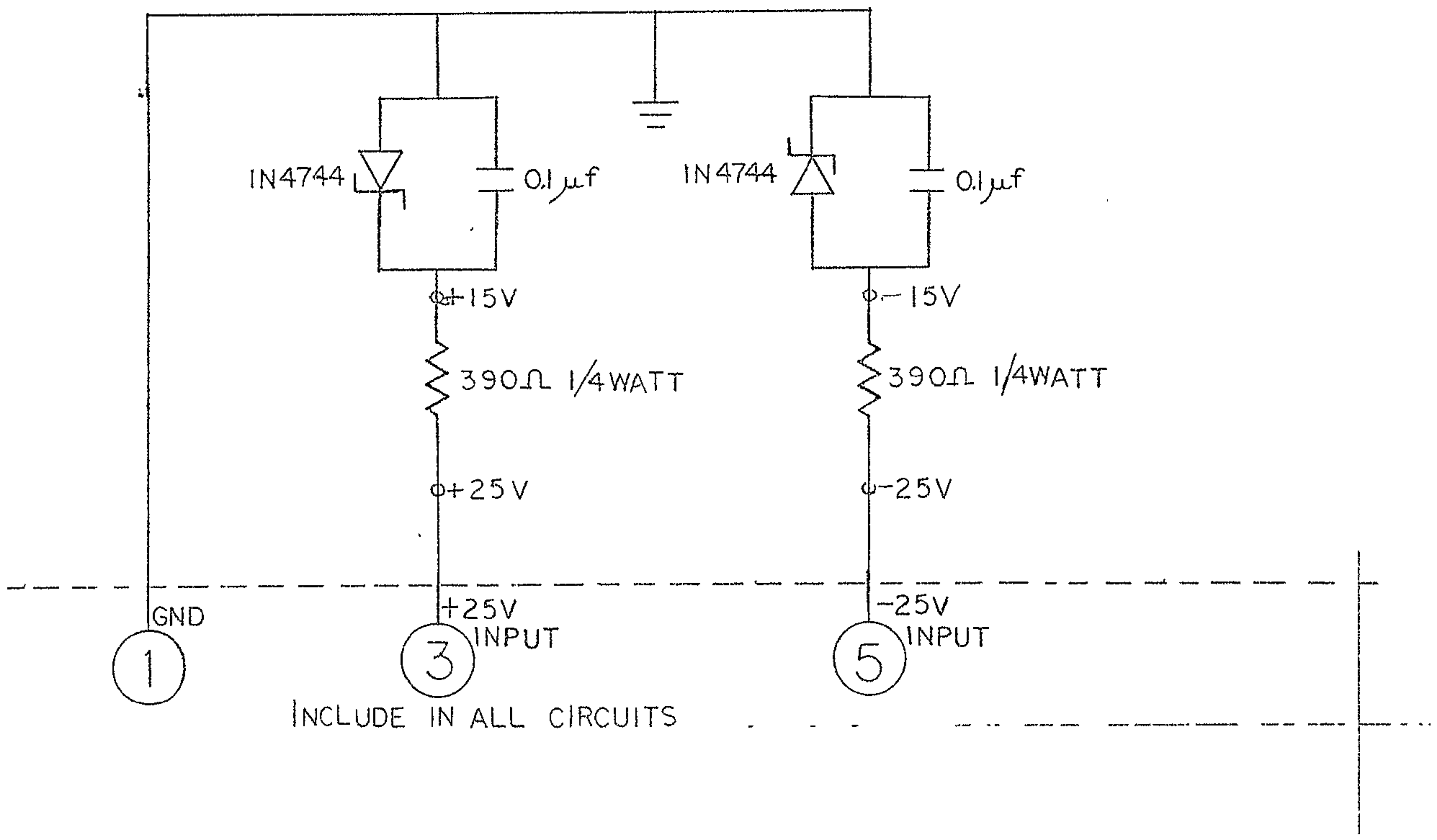
PEN DRIVER



ALL RESISTORS 1/4 WATT UNLESS OTHERWISE SPECIFIED

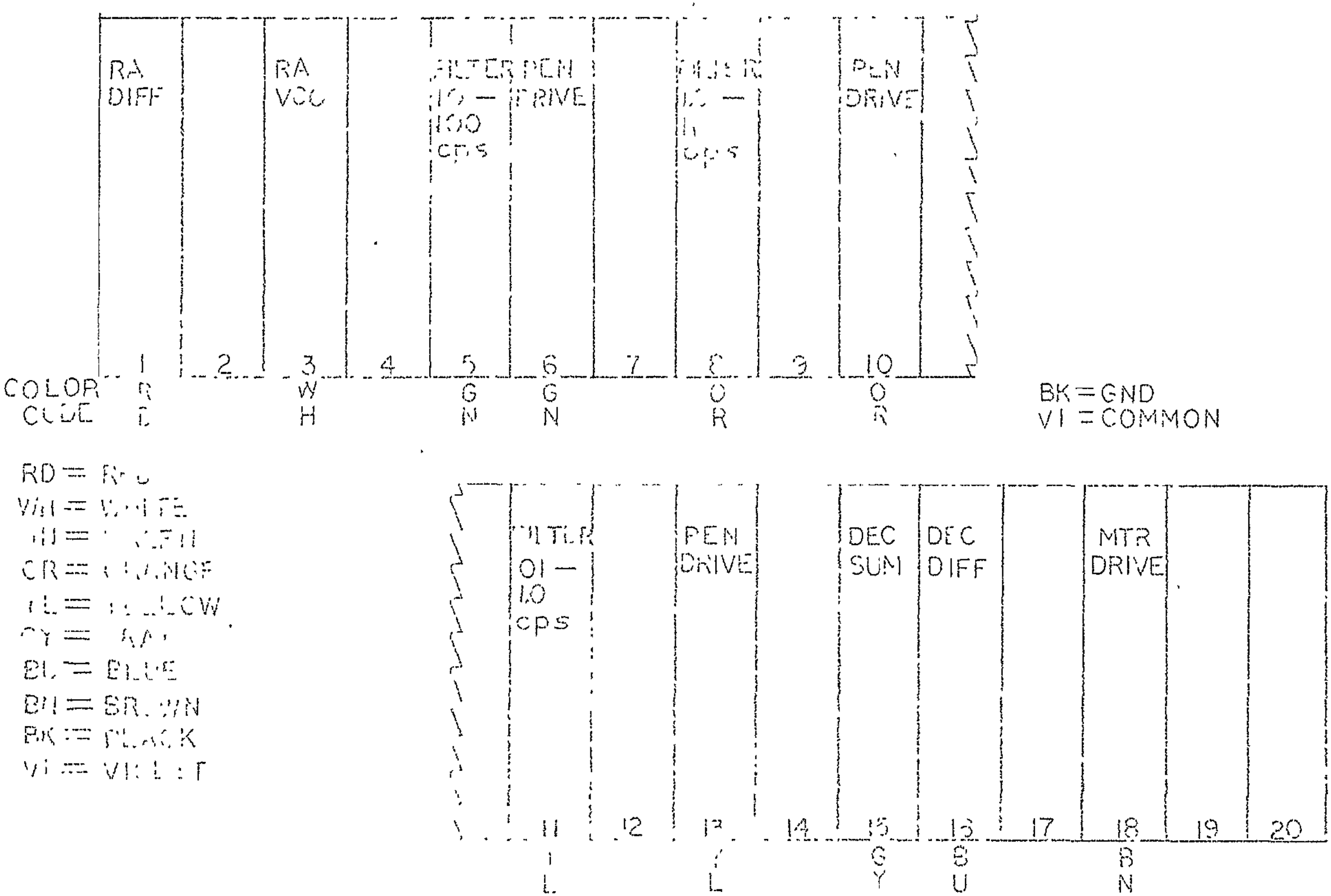
INCLUDE ZENER SUPPLY

ZENER SUPPLY CIRCUIT



INCLUDE IN ALL CIRCUITS

PRINTED CIRCUIT BOARD CHASSIS



Appendix V

PROCEDURE FOR DATA REDUCTION

Appendix V

SOLAR SEEING

Procedure for data reduction:

1. Determine arc sec of oscillation

Δx = oscillation amplitude of yoke

r = radius arm (11 inches)

$$\Delta\theta = \frac{\Delta x}{r} \text{ radians}$$

$$= \frac{\Delta x}{r} \times 2.16 \times 10^5 \text{ arc seconds}$$

2. Determine effective $\Delta\theta$ eff in each channel. This requires two corrections

   1. ϵ(freq) = fractional response of maximum response of that channel to a frequence (freq).

   2. Assume an uncorrelated "seeing" on opposite limbs of the sum. Therefore, the seeing signal from 2 diodes will be $\sqrt{2}$ larger than from one. Then $\Delta\theta$ eff (freq) $= \frac{\Delta\theta\epsilon(\text{freq})}{\sqrt{2}}$.

   3. The seeing sensitivity (ss) of each channel then becomes

   $$ss = \frac{\Delta\theta \text{ eff (freq)}}{\text{calibration signal}} \text{ arc sec per division.}$$

   4. Early in the morning and late in the afternoon, the solar flux is reduced. The AC component of the sumsignal will also be reduced proportionately. Therefore, the final data will have to be corrected for the change in the "sum" signal. Therefore seeing = observed signal x ss $\frac{\text{sum cal}}{\text{sum at observation}}$.
   where sum cal is the sum signal at the time of calibration.

Appendix VI

SUMMARY OF SOLAR RADIATION DATA

Langmuir Lab - 1964-1968

Appendix VI

SOLAR RADIATION (Solar Seeing)

Number of days with full sun

(a) no interuption
(b) 6 hours or more
(c) 4 hours or more
(d) 2 hours or more

1964

(a) 83 days
(b) 163
(c) 199
(d) 228

13 no data days

1965

(a) 47 days
(b) 116
(c) 148
(d) 210

2 no data days

1966

(a) 56 days
(b) 118
(c) 167
(d) 242

11 no data days

1967

(a) 38 days
(b) 105
(c) 150
(d) 206

33 no data days

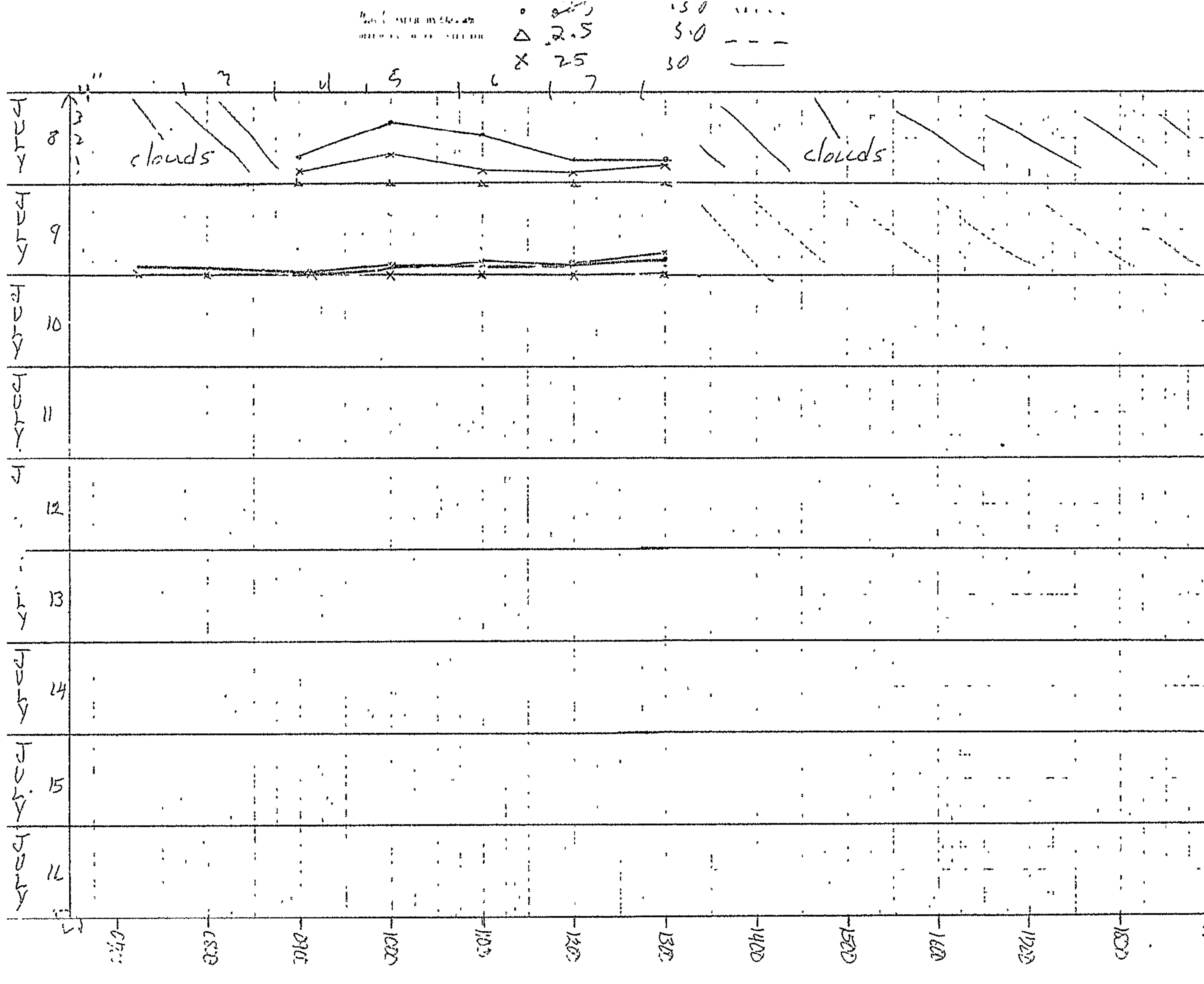
1968

(a) 2 days
(b) 53
(c) 70
(d) 92

170 no data days

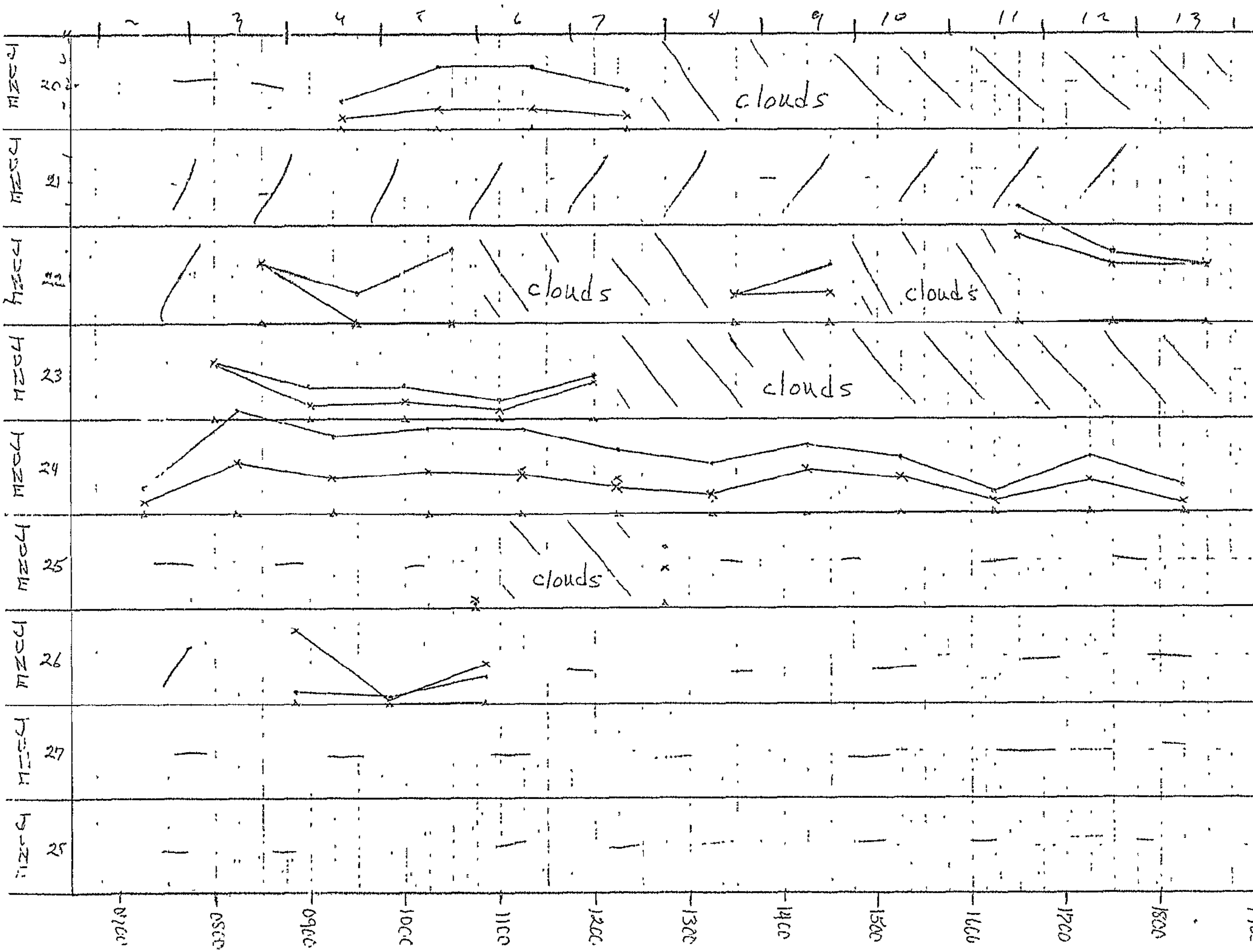
Appendix VII

REDUCED DATA



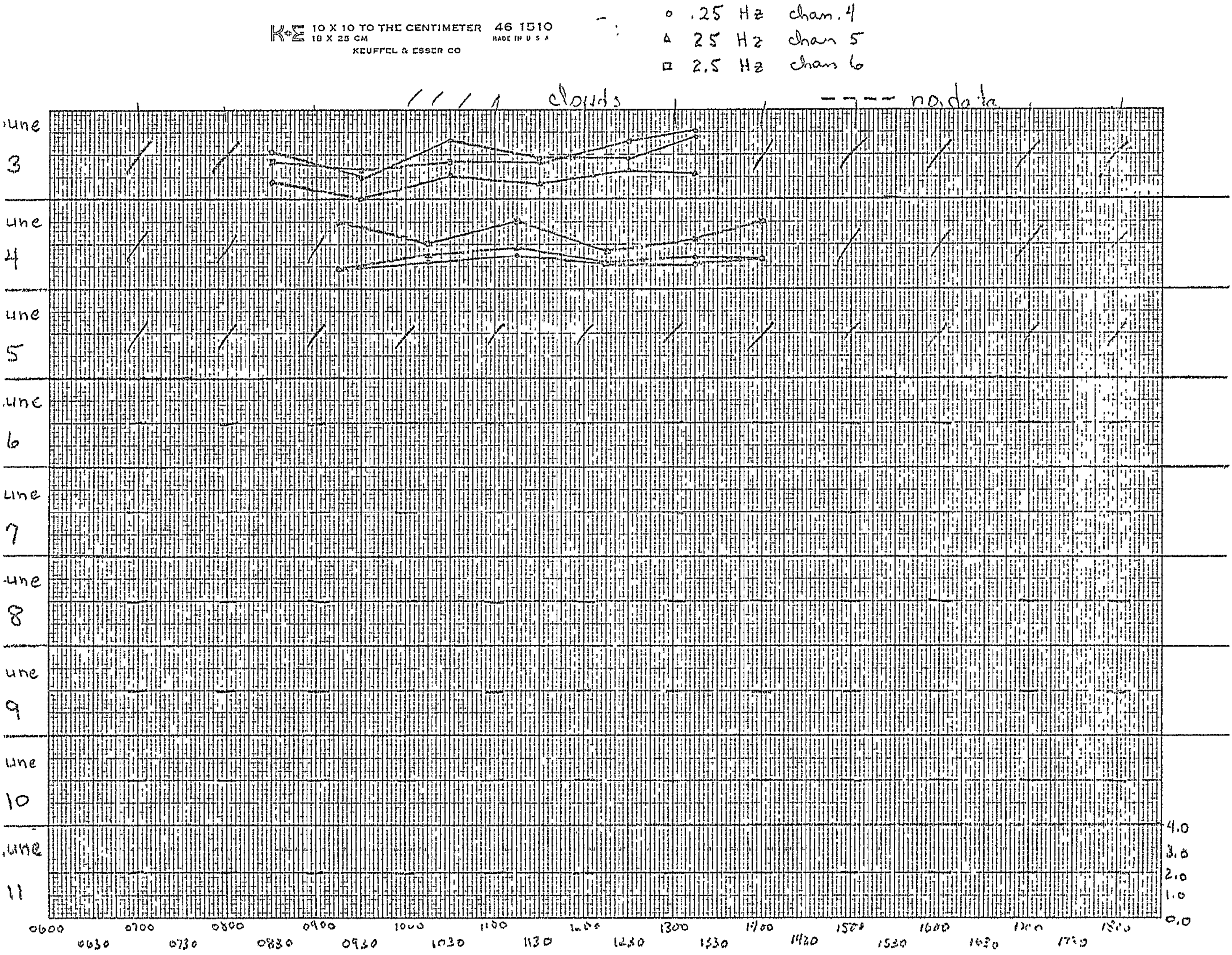
2.5
25
5.0
30
clouds
clouds
JULY 8
JULY 9
JULY 10
JULY 11
12
13
JULY 14
JULY 15
JULY 16
1000
1400
1500
1600
1800
1900


2
3
4
5
6
7
8
9
10
11
12
13
JUNE 29
JUNE 30
JULY 1
JULY 2
JULY 3
JULY 4
JULY 5
JULY 6
JULY 7
clouds
clouds
clouds
clouds
clouds
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900



JUNE 20
JUNE 21
JUNE 22
JUNE 23
JUNE 24
JUNE 25
JUNE 26
JUNE 27
clouds
clouds
clouds
clouds
clouds
1000
1100
1200
1300
1400
1500
1700
1900

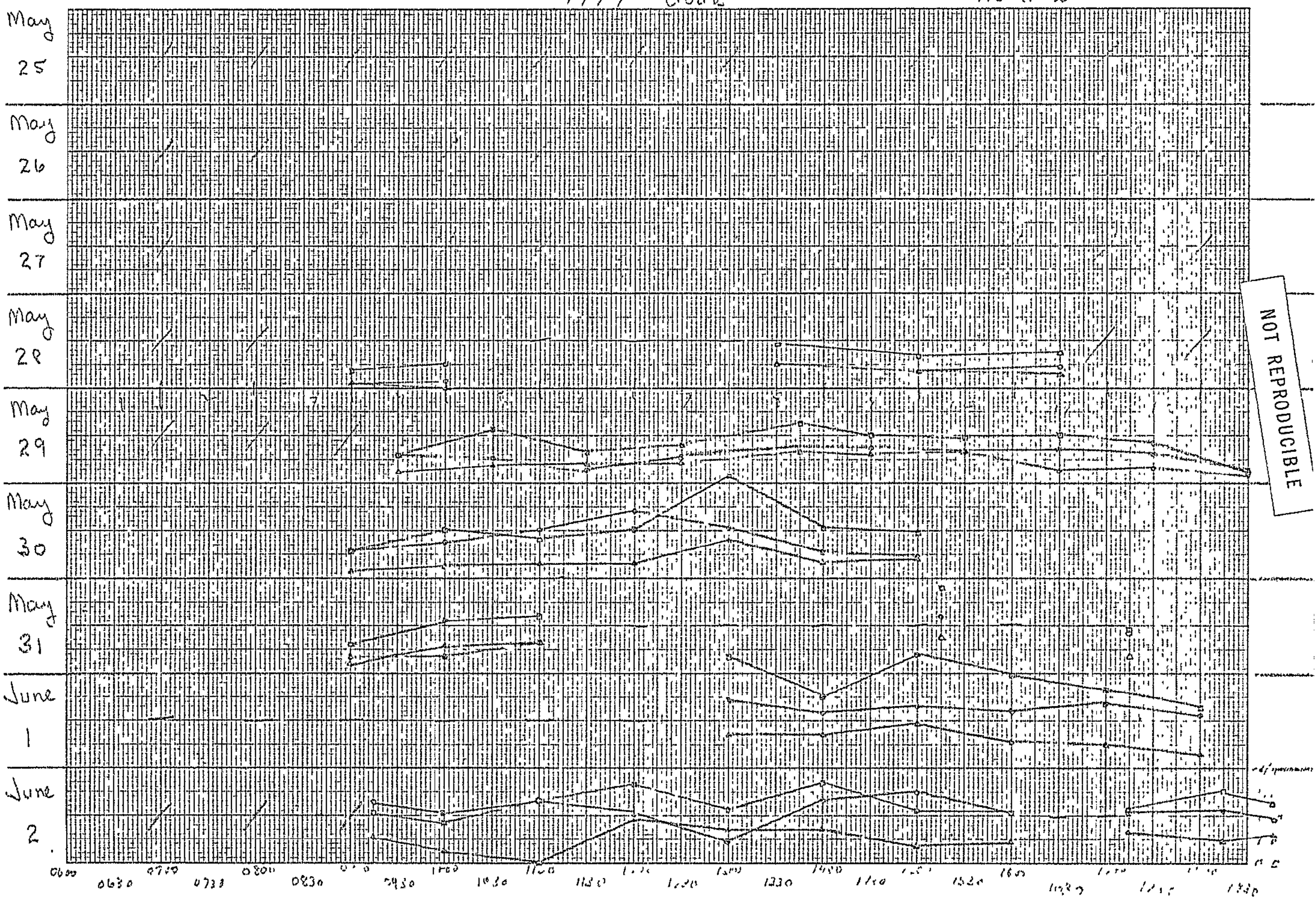
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM 46 1510 MADE IN U.S.A. KEUFFEL & ESSER CO

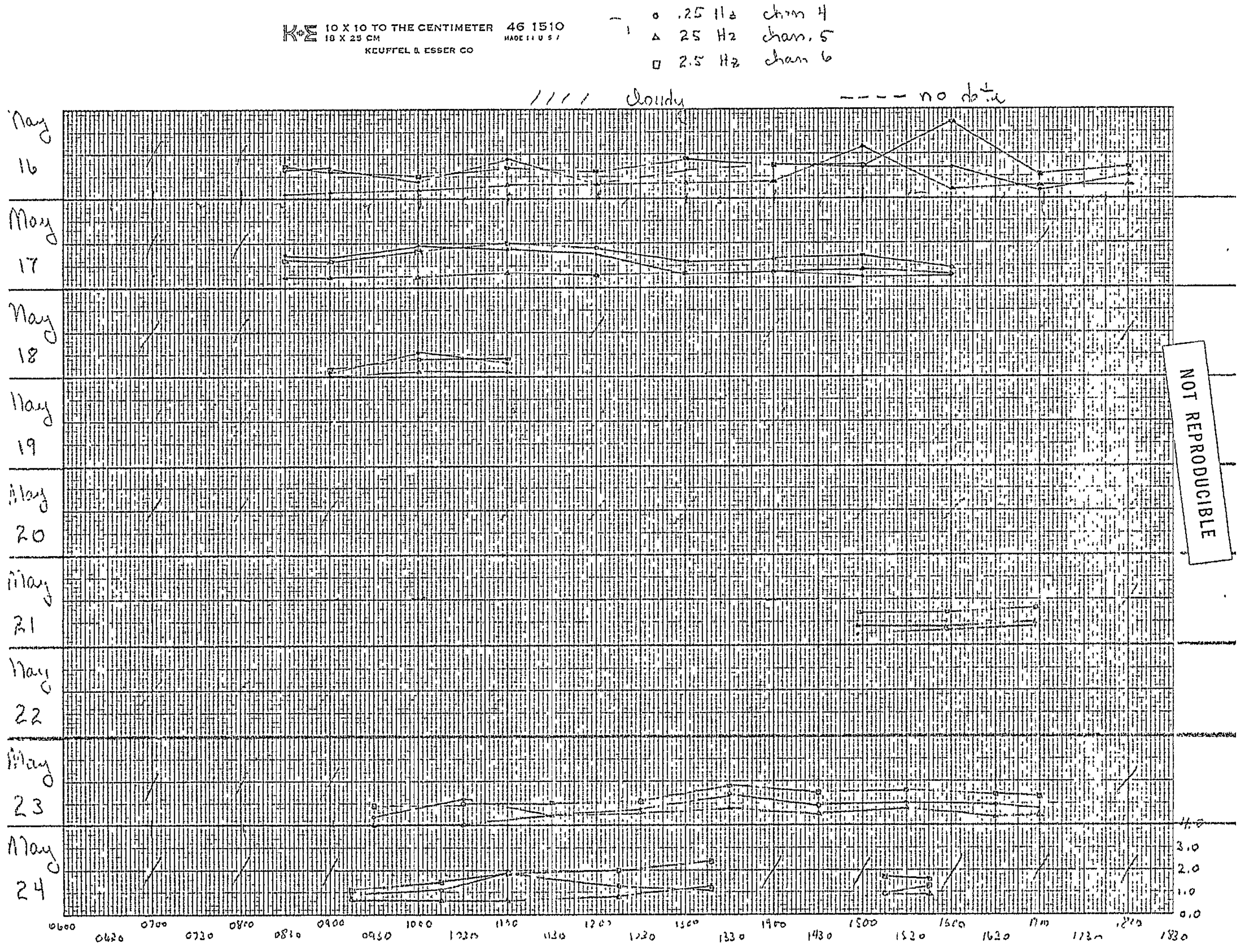


K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM 46 1510 MADE IN U.S.A.
KEUFFEL & ESSER CO

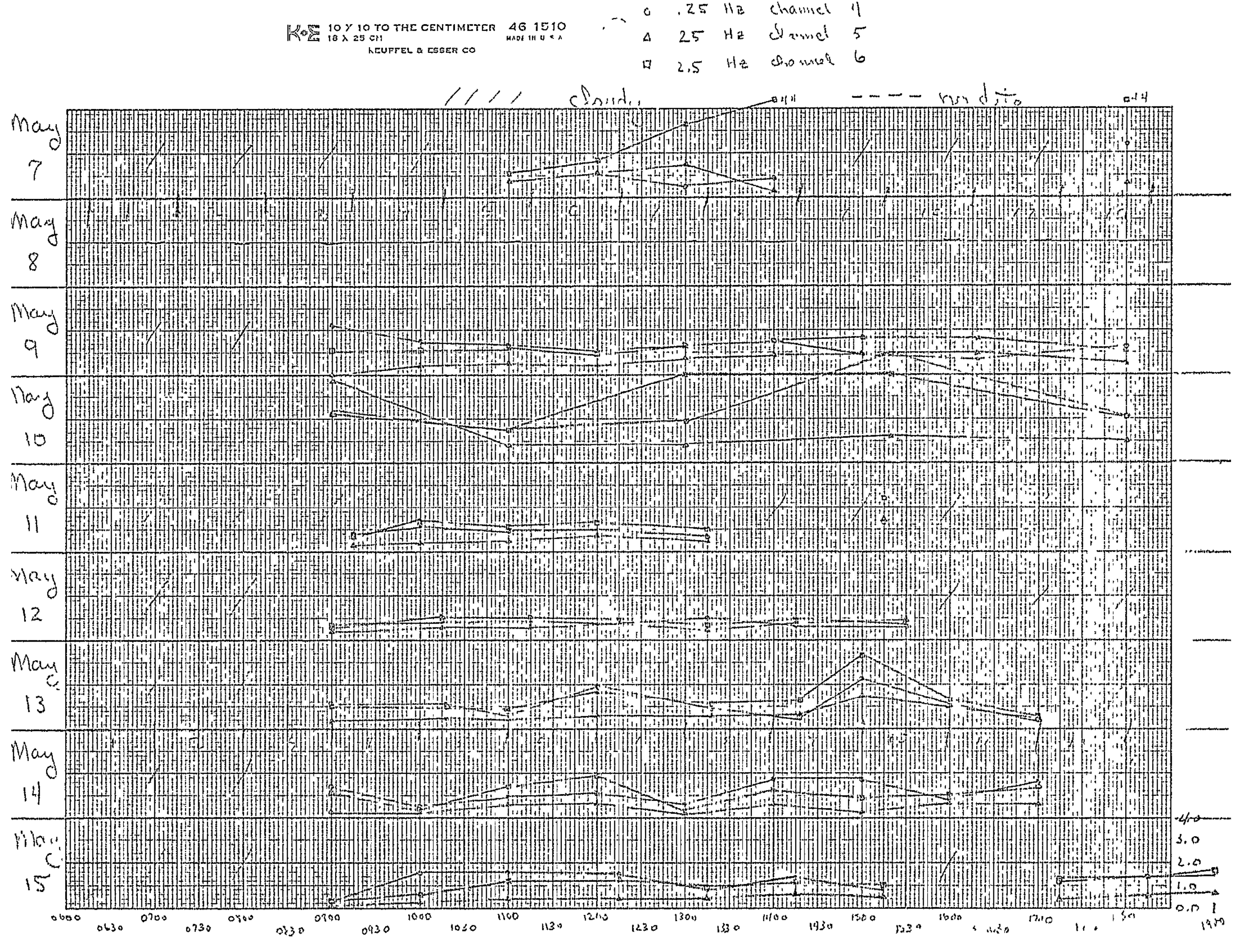
○ .25 Hz chan. 4
△ 25 Hz chan 5
□ 2.5 Hz chan. 6

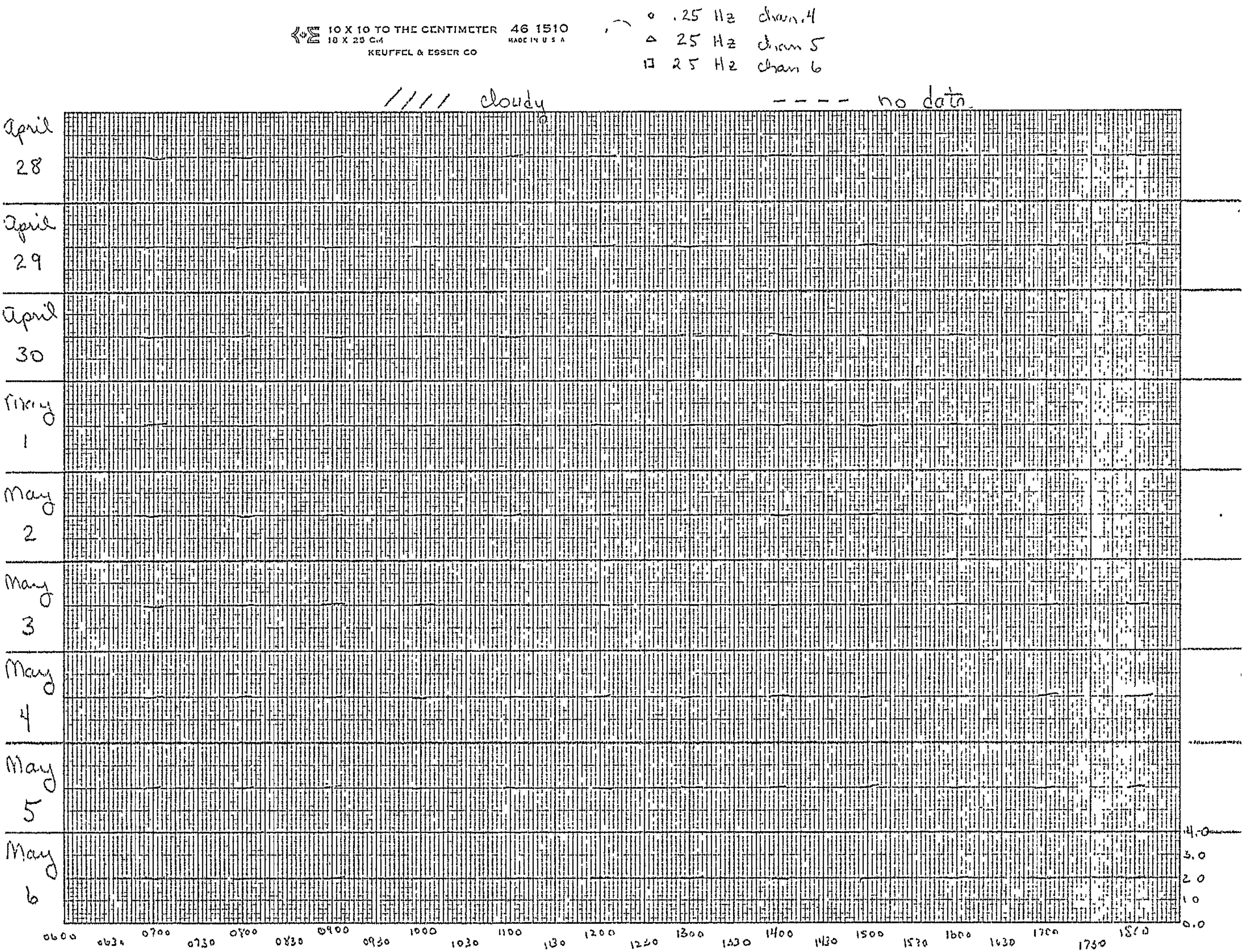
//// clouds ---- no data

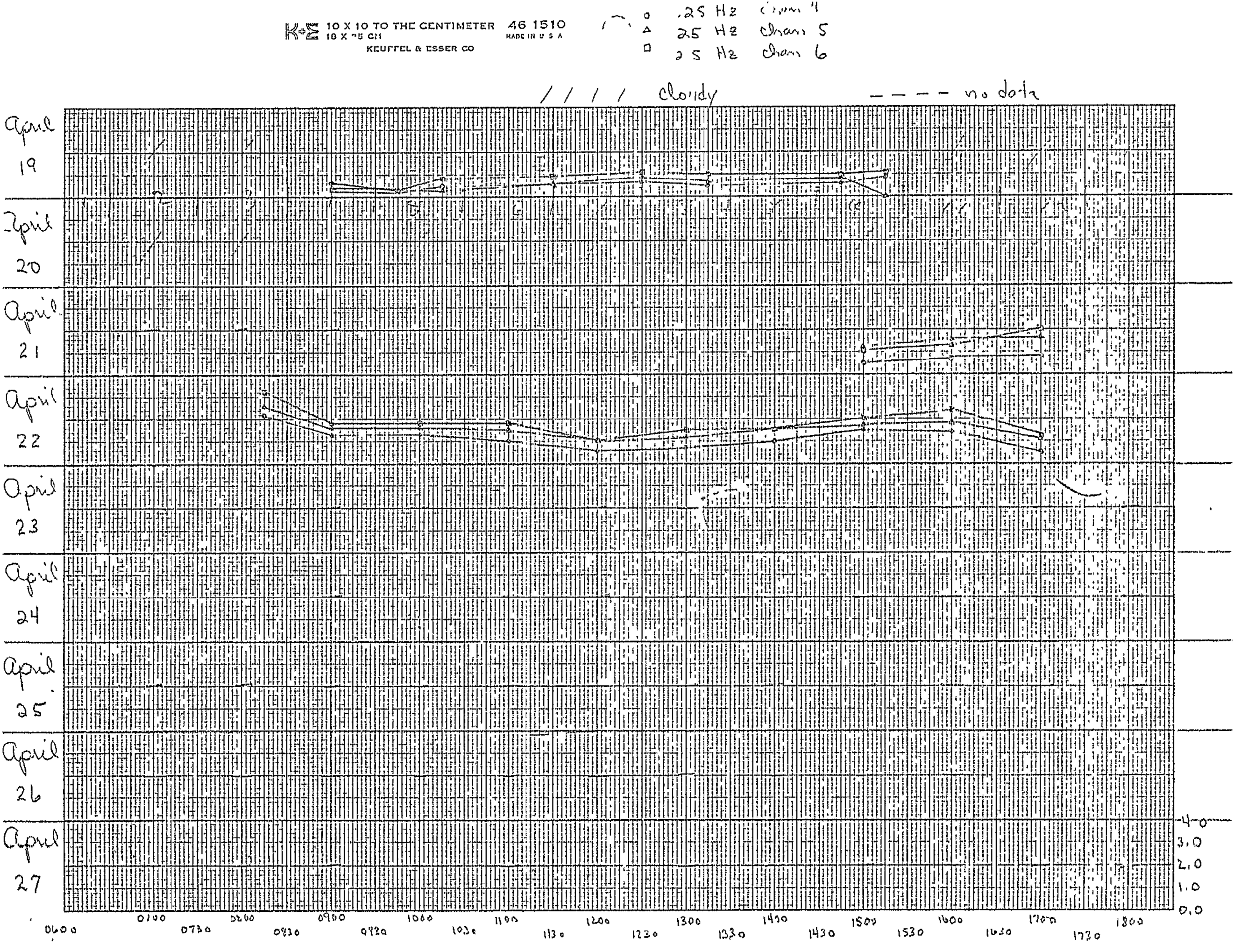




K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM 46 1510 MADE IN U.S.A.
KEUFFEL & ESSER CO
○ .25 Hz chan 4
△ 25 Hz chan. 5
□ 2.5 Hz chan 6
//// cloudy
---- no data
May 16
May 17
May 18
May 19
May 20
May 21
May 22
May 23
May 24
NOT REPRODUCIBLE
4.0
3.0
2.0
1.0
0.0
0600
0630
0700
0730
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1300
1330
1400
1430
1500
1530
1600
1630
1700
1730
1800
1830

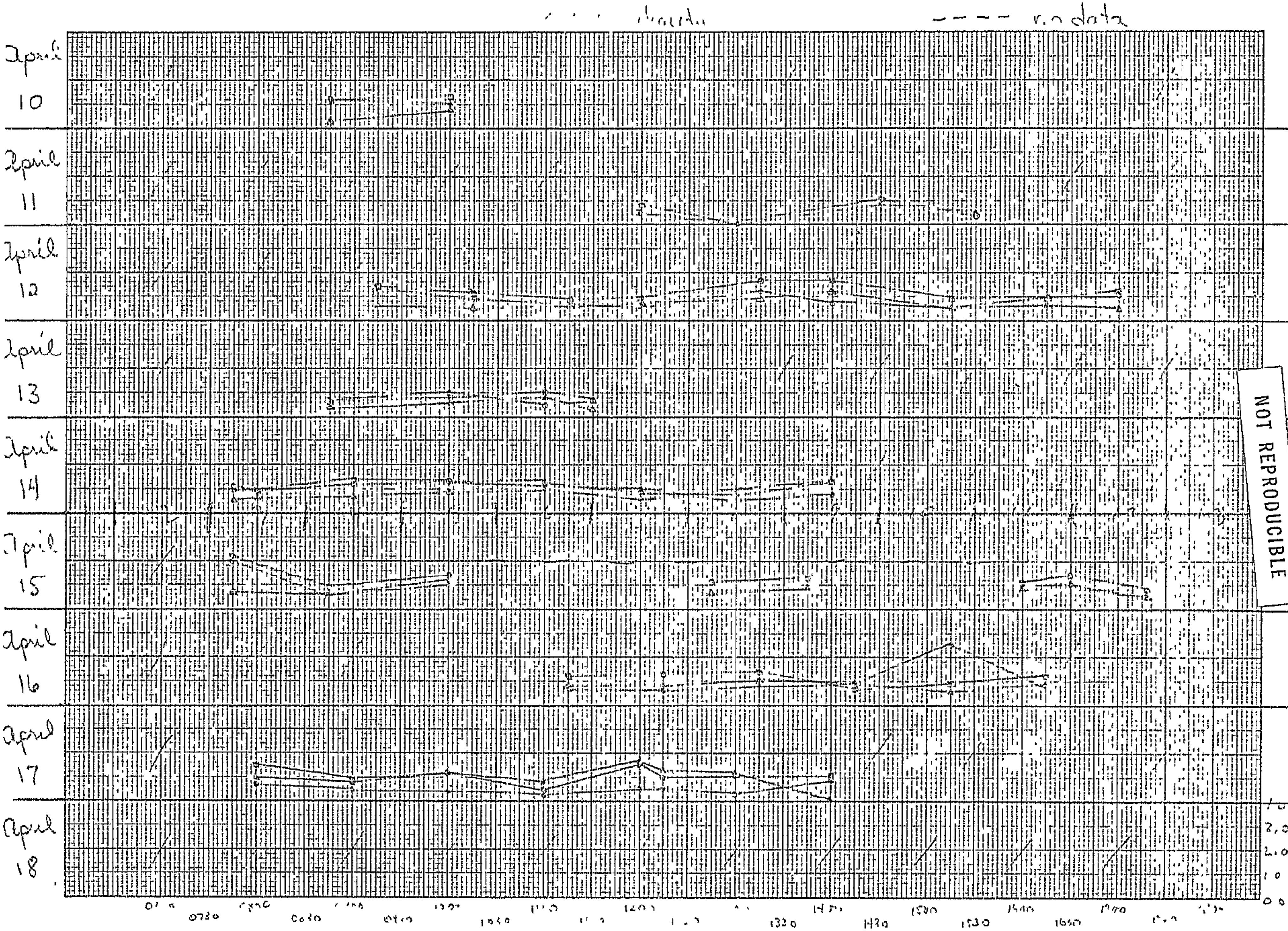

K+E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO
o .25 Hz channel 4
Δ 25 Hz channel 5
□ 2.5 Hz channel 6
//// cloudy
---- no data
May 7
May 8
May 9
May 10
May 11
May 12
May 13
May 14
May 15
4.0
3.0
2.0
1.0
0.0
0600
0630
0700
0730
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1300
1330
1400
1430
1500
1530
1600
1700


○ .25 Hz chan. 4
△ 25 Hz chan 5
□ 25 Hz chan 6
//// cloudy
---- no data
April 28
April 29
April 30
May 1
May 2
May 3
May 4
May 5
May 6
4.0
3.0
2.0
1.0
0.0
0600
0630
0700
0730
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1300
1330
1400
1430
1500
1530
1600
1630
1700
1730
1800

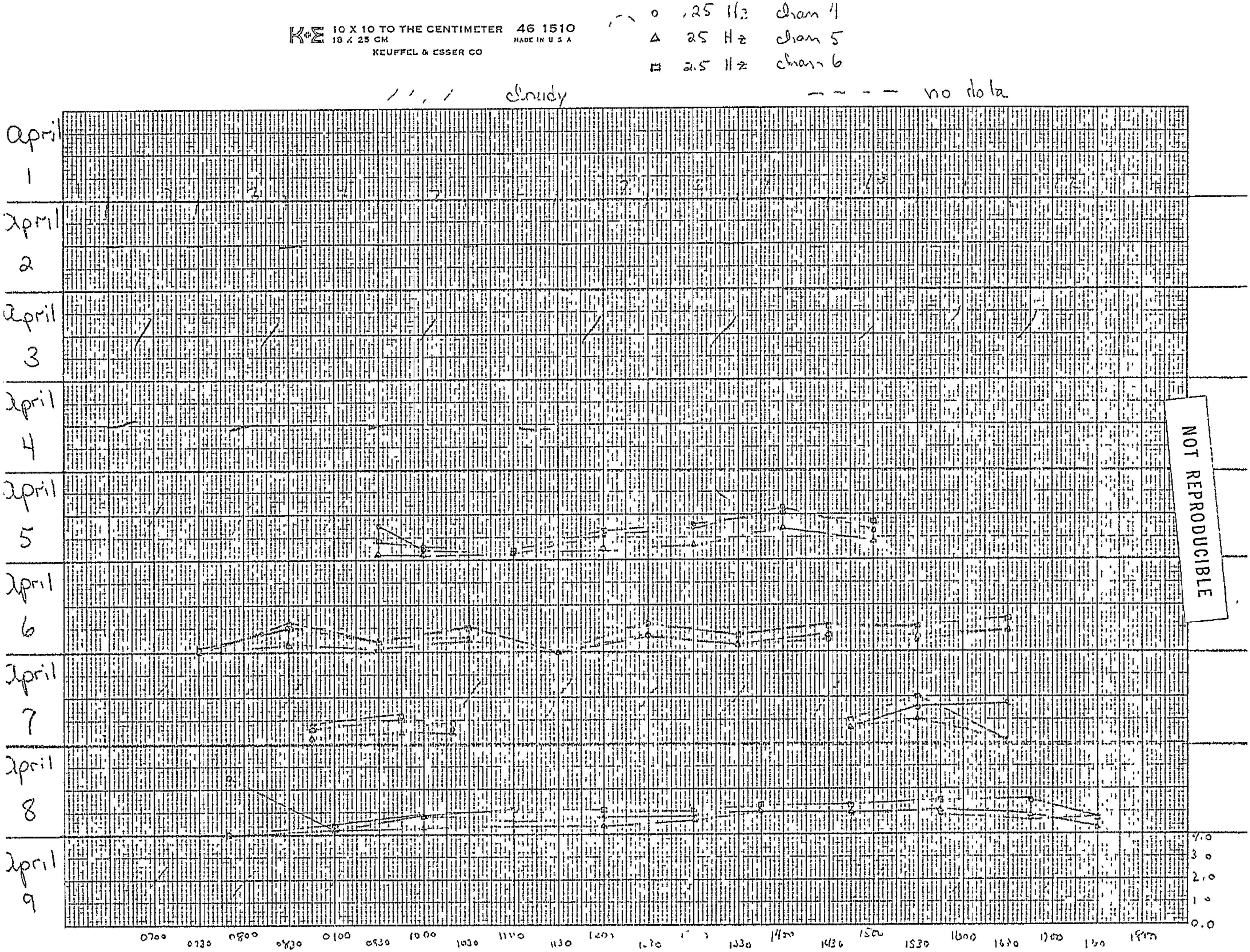

K+E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO
○ .25 Hz Chan 4
△ 25 Hz Chan 5
□ 25 Hz Chan 6
//// Cloudy
- - - - no data
April 19
April 20
April 21
April 22
April 23
April 24
April 25
April 26
April 27
4.0
3.0
2.0
1.0
0.0
0600
0700
0730
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1300
1330
1400
1430
1500
1530
1600
1630
1700
1730
1800

K+E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO

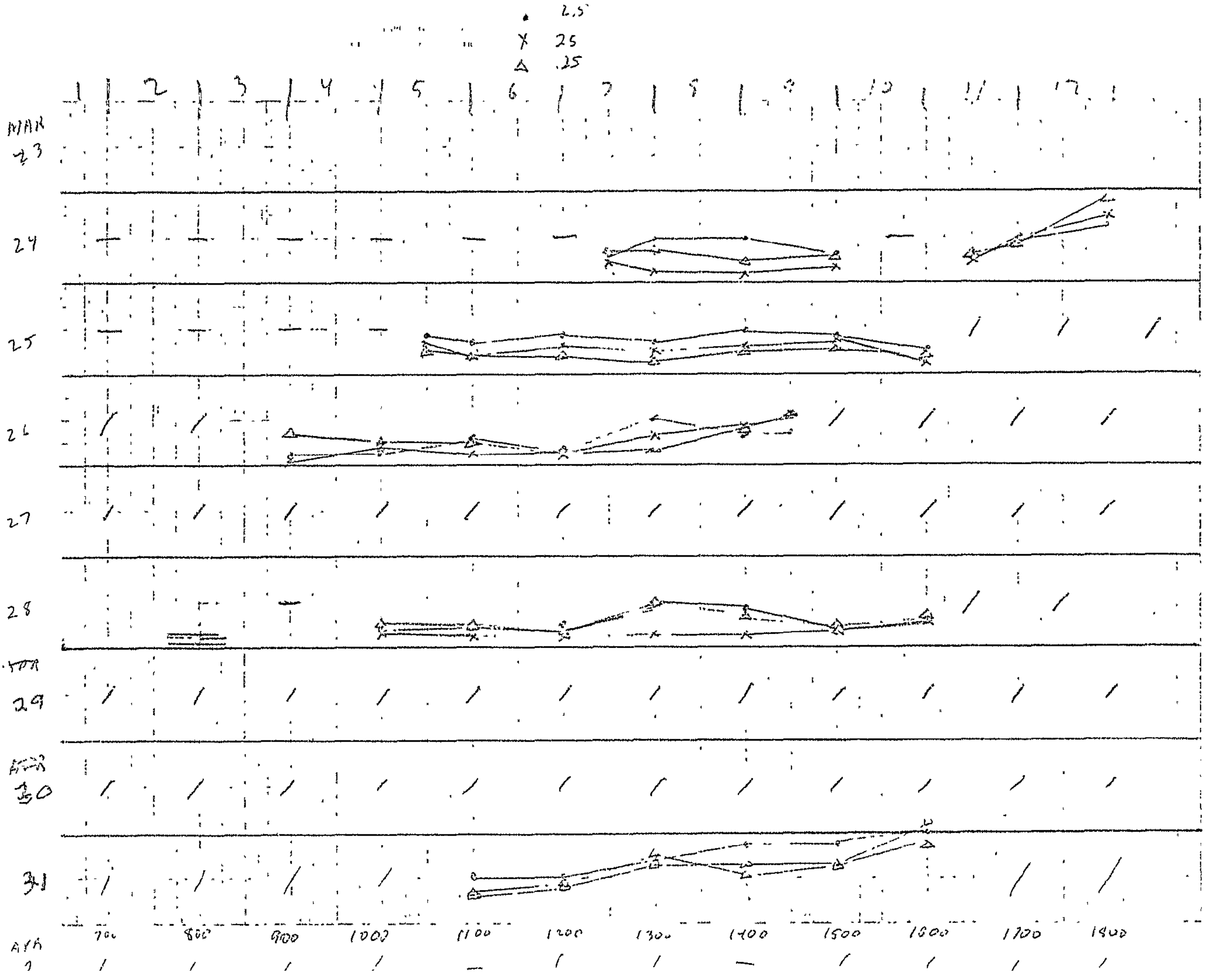
○ .26 Hz chan 4
△ 25 Hz chan 5
□ 2.5 Hz chan 6



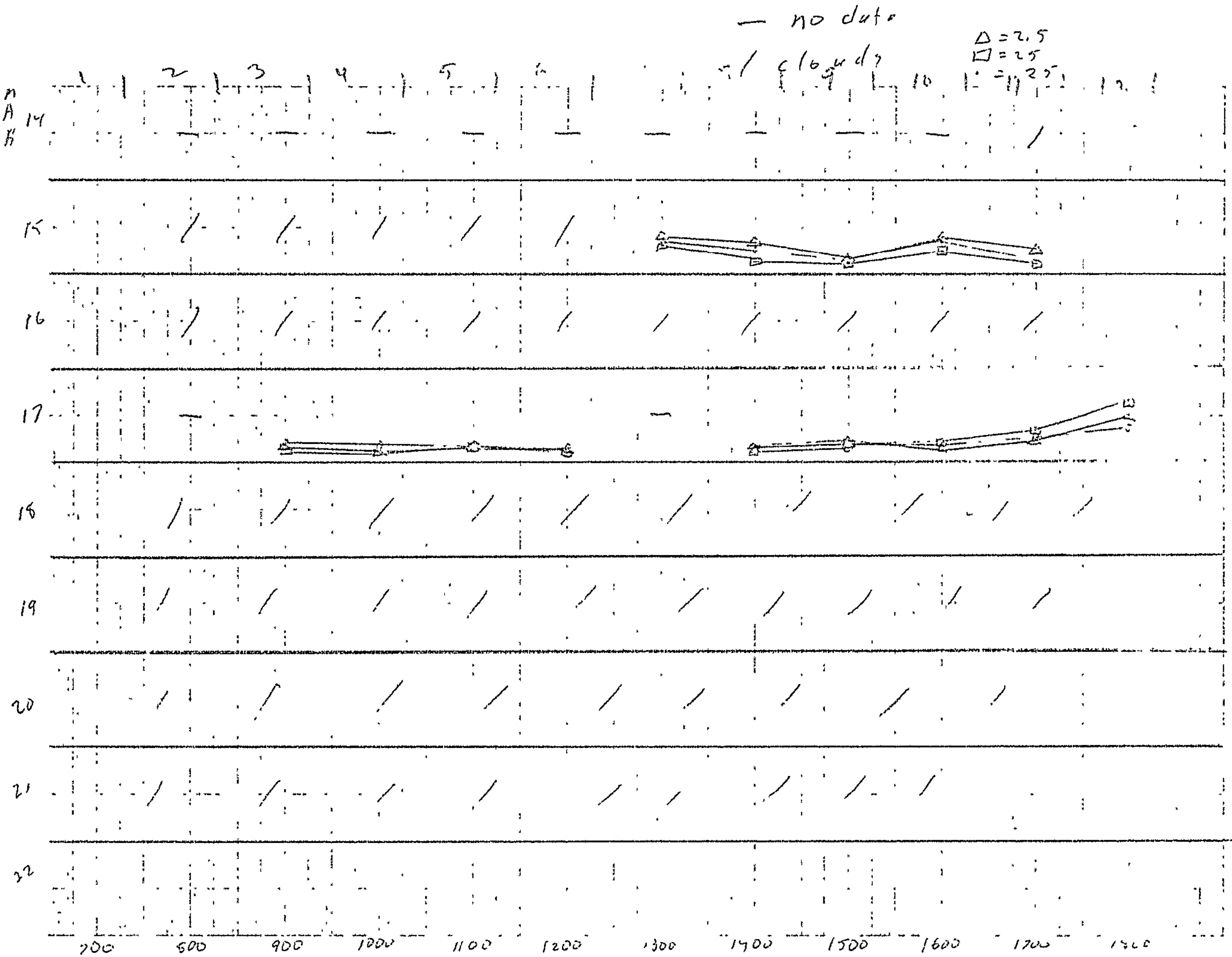
NOT REPRODUCIBLE

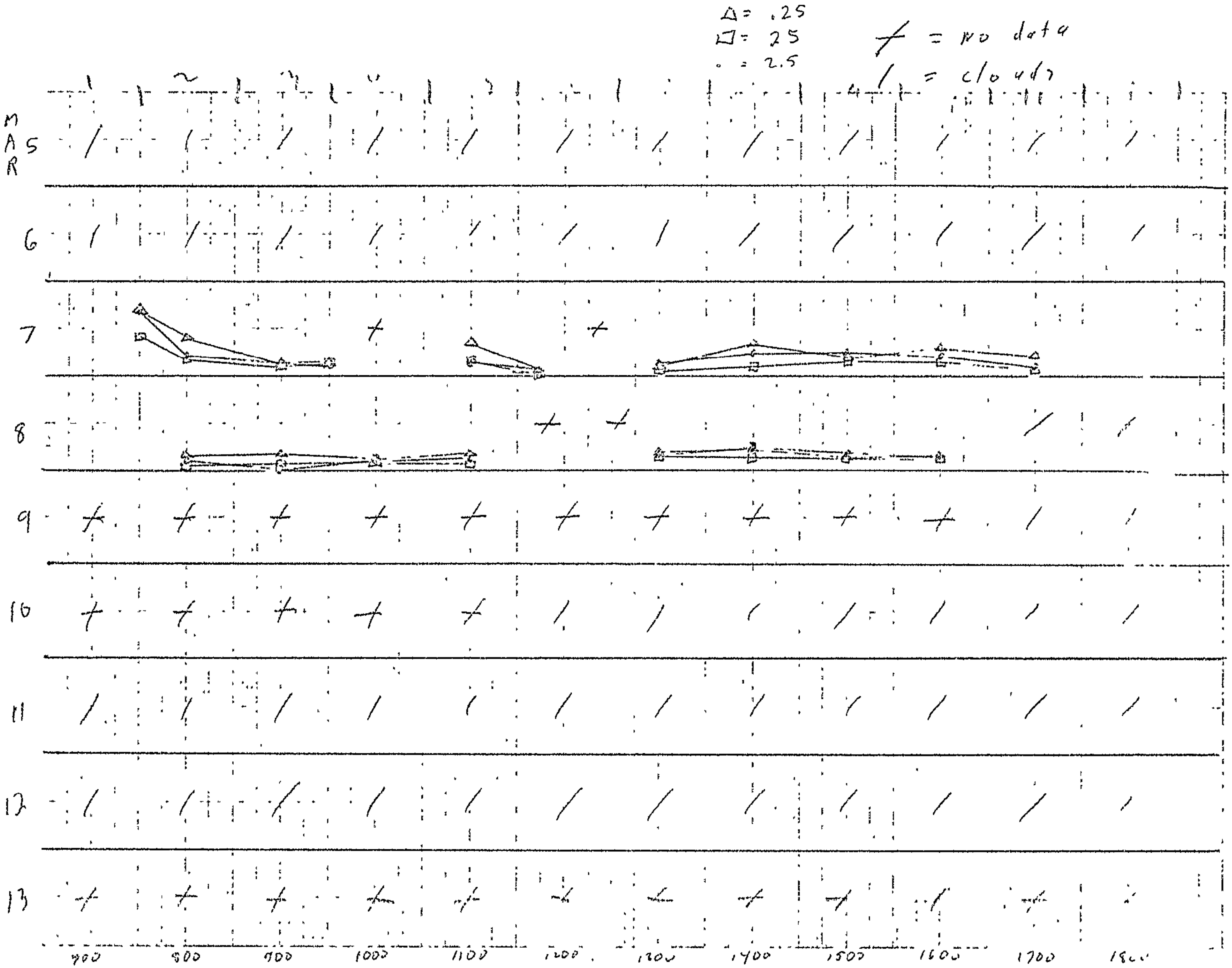


K+E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO
o .25 Hz chan 4
Δ 25 Hz chan 5
□ 2.5 Hz chan 6
/ / , / cloudy
— — — — no data
April 1
April 2
April 3
April 4
April 5
April 6
April 7
April 8
April 9
NOT REPRODUCIBLE
4.0
3.0
2.0
1.0
0.0
0700
0730
0800
0830
0900
0930
1000
1030
1100
1130
1200
1230
1330
1400
1430
1500
1530
1600
1630
1700



• 2.5
X 25
△ .25
1 2 3 4 5 6 7 8 9 10 11 12
MAR 23
24
25
26
27
28
29
30
31
700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800

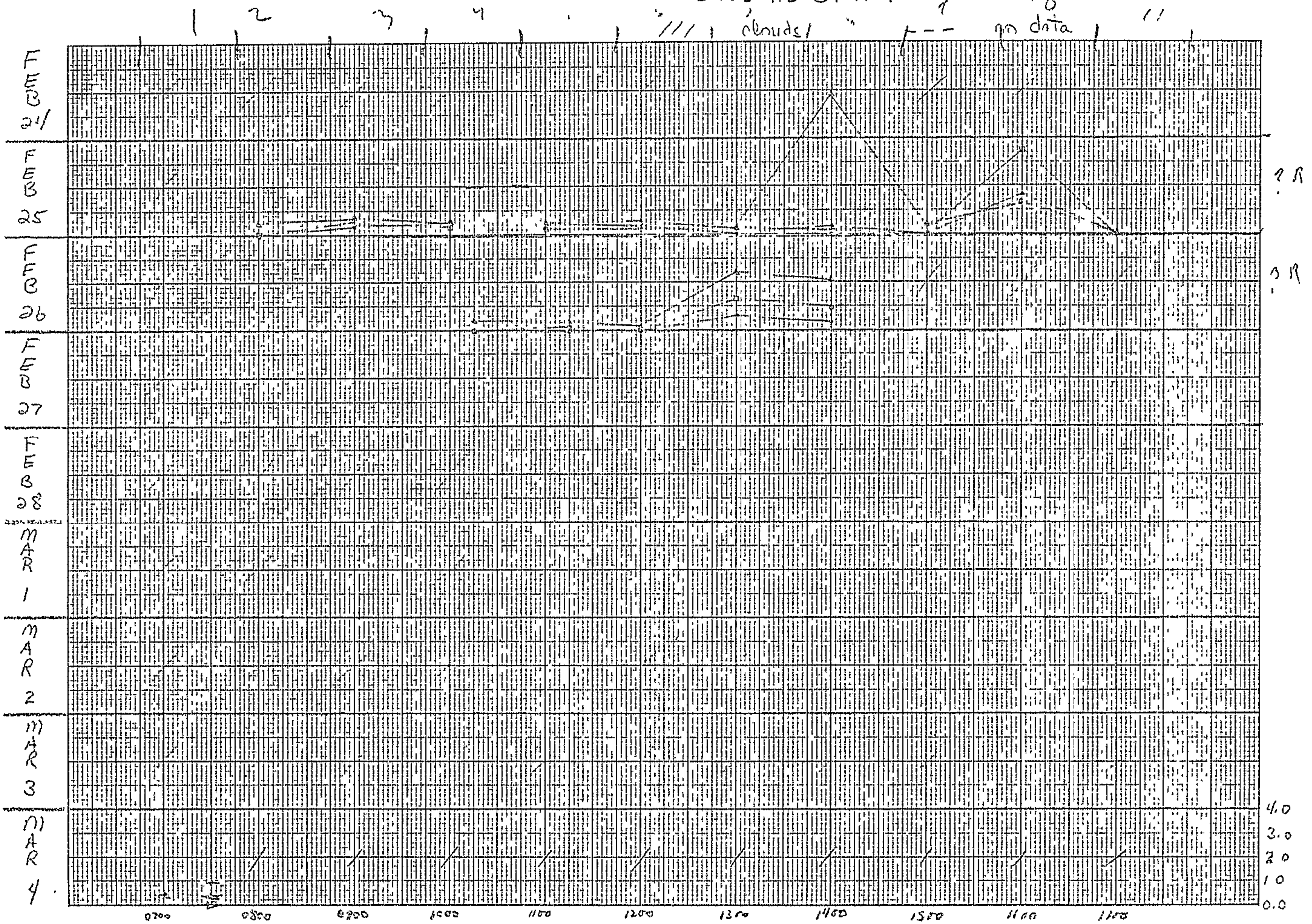

— no data
/ cloudy
Δ = 2.5
□ = 25
1 2 3 4 5 6 7 8 9 10 11 12
14
15
16
17
18
19
20
21
22
700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800

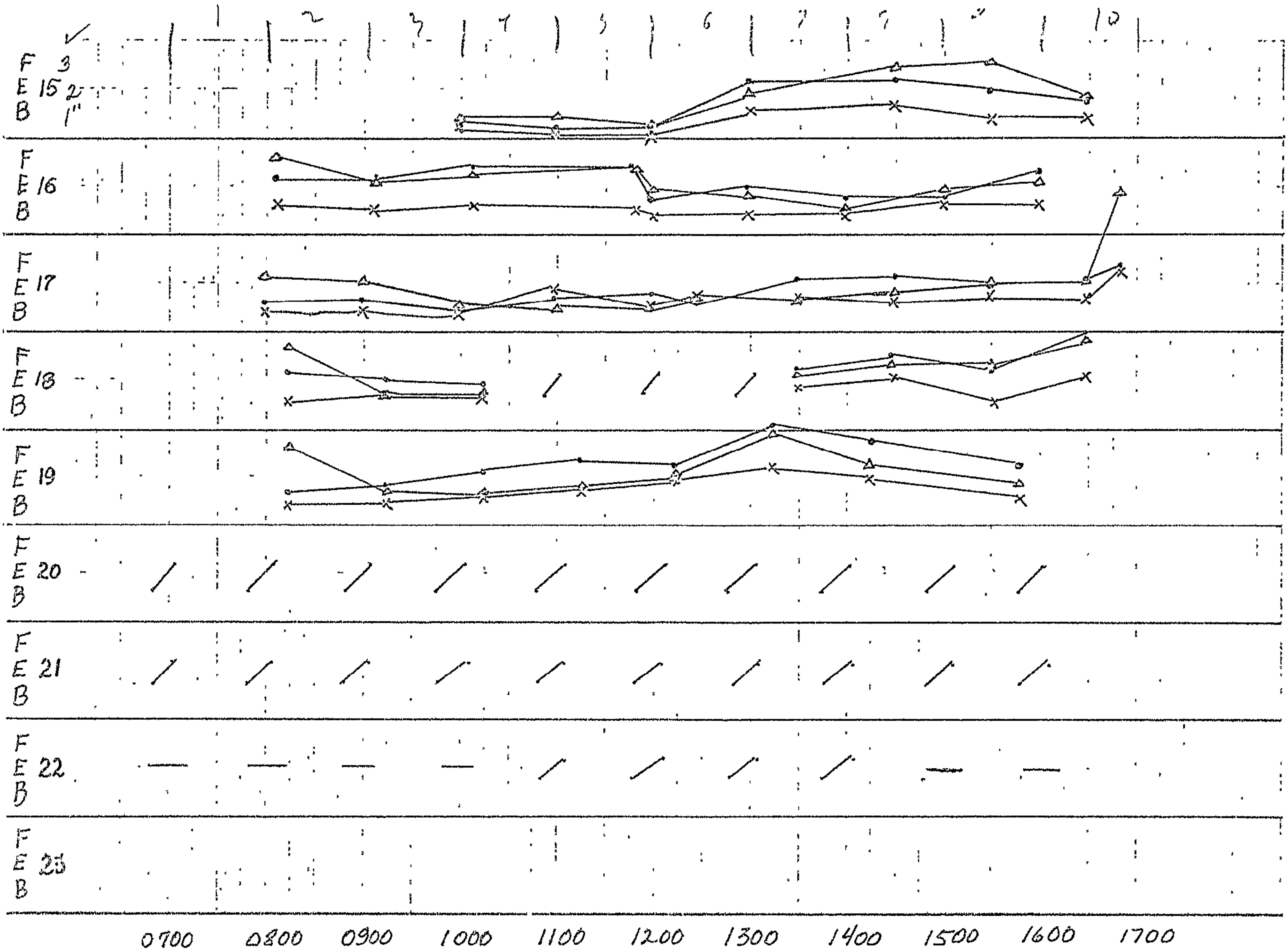


△ = .25
□ = 25
. = 2.5
+ = no data
/ = clouds
MAR
5
6
7
8
9
10
11
12
13
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

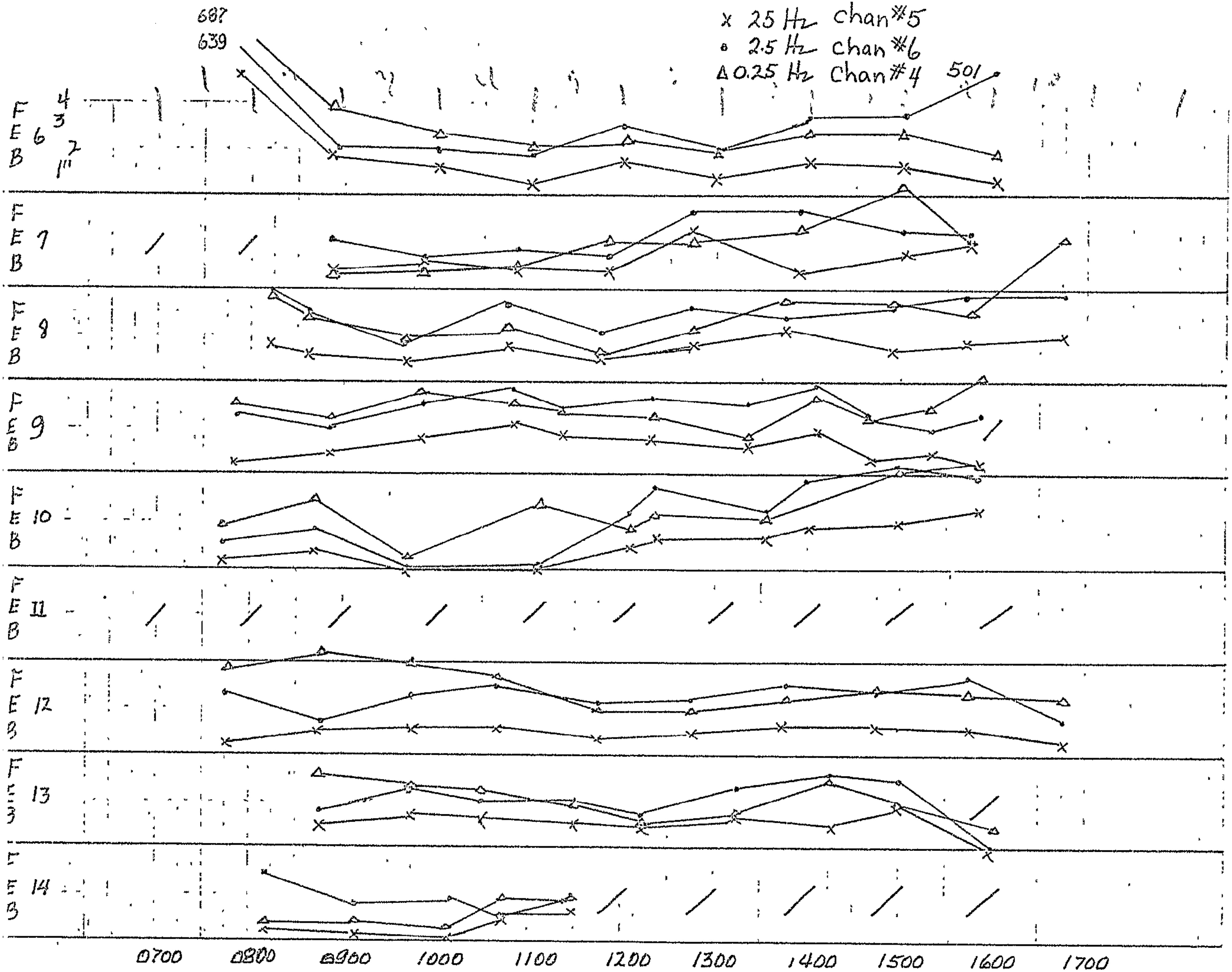
K+E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO

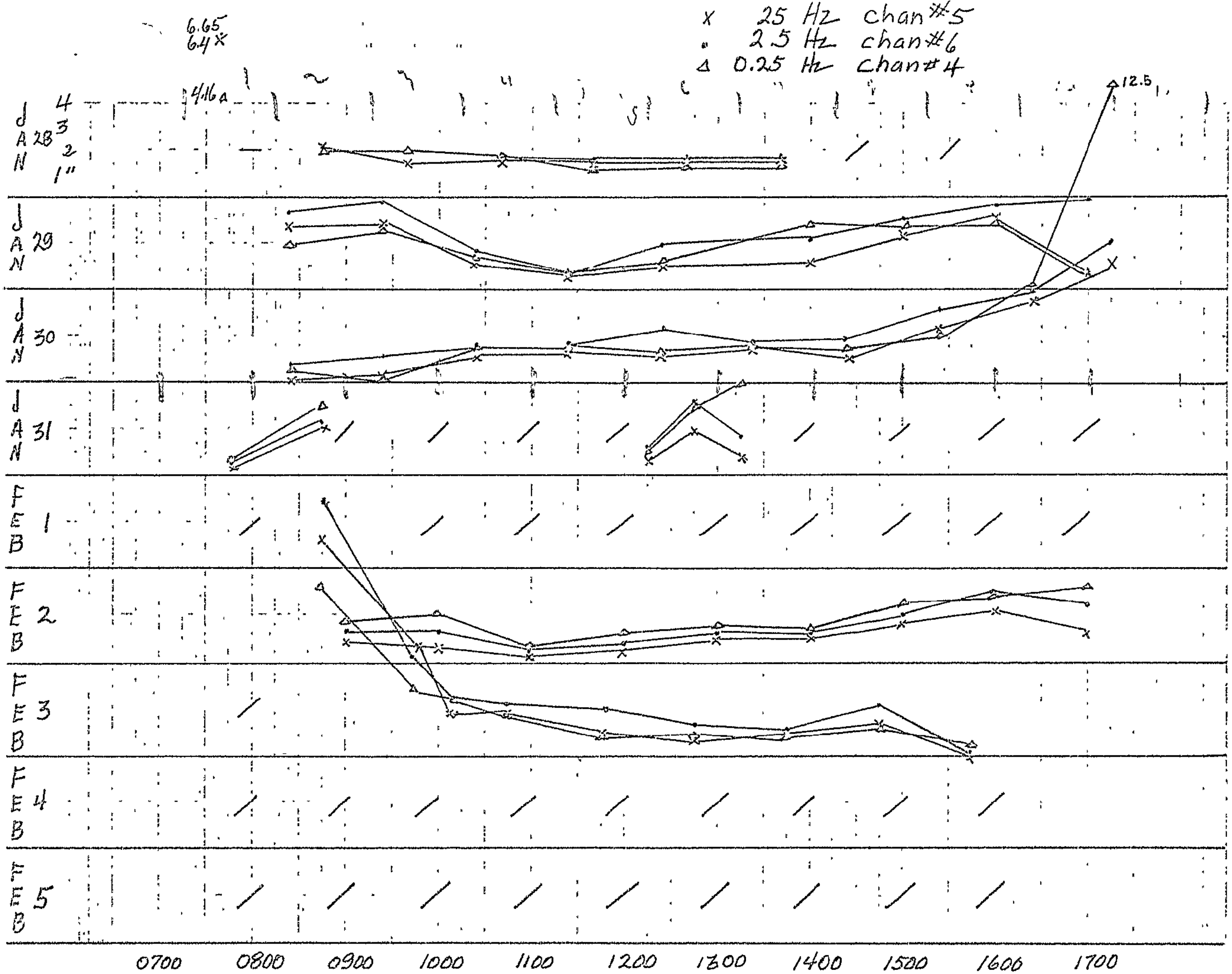
• 2.5 Hz chan 6
□ 25 Hz chan 5
Δ .25 Hz chan 4



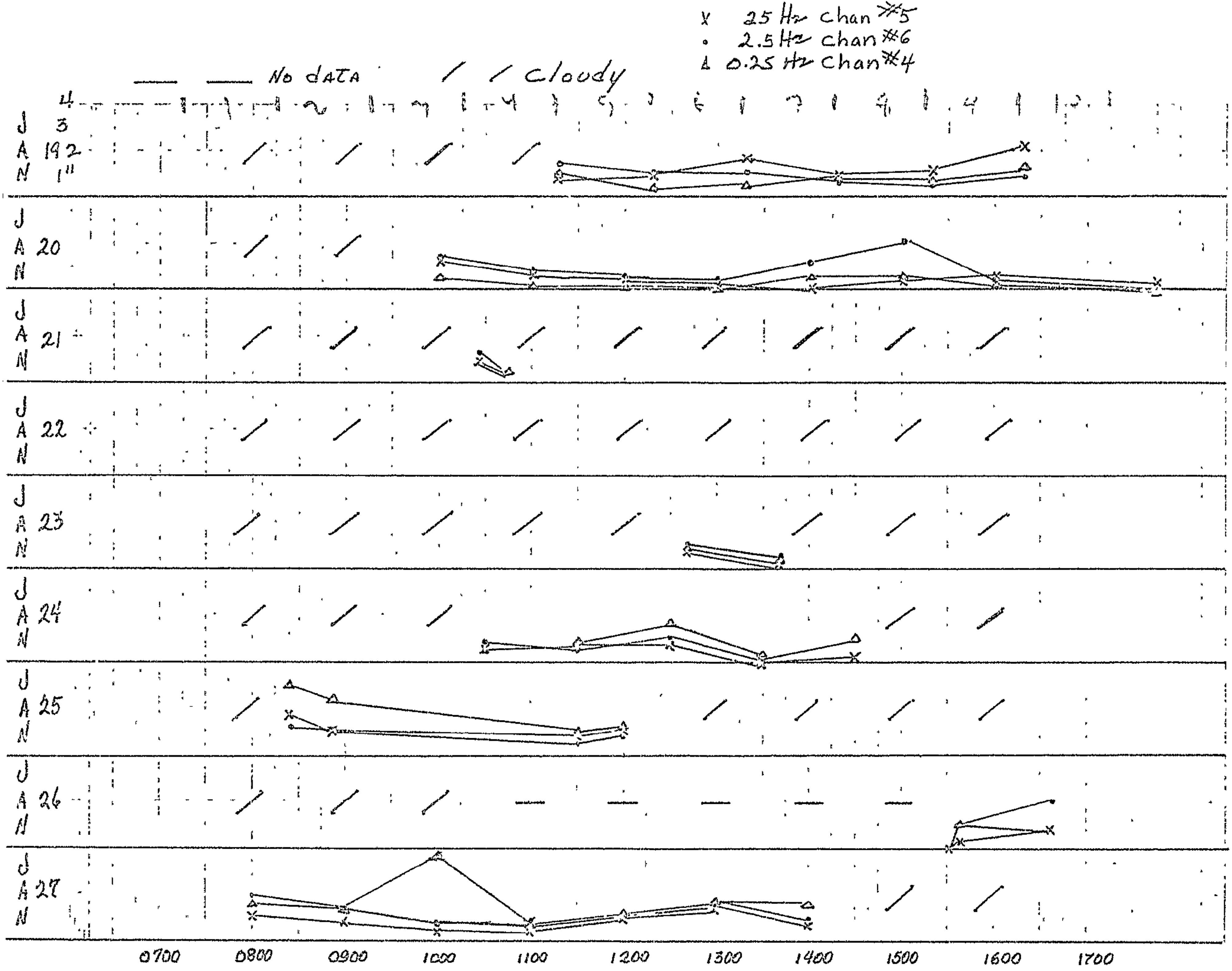


FEB 15
FEB 16
FEB 17
FEB 18
FEB 19
FEB 20
FEB 21
FEB 22
FEB 23
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700

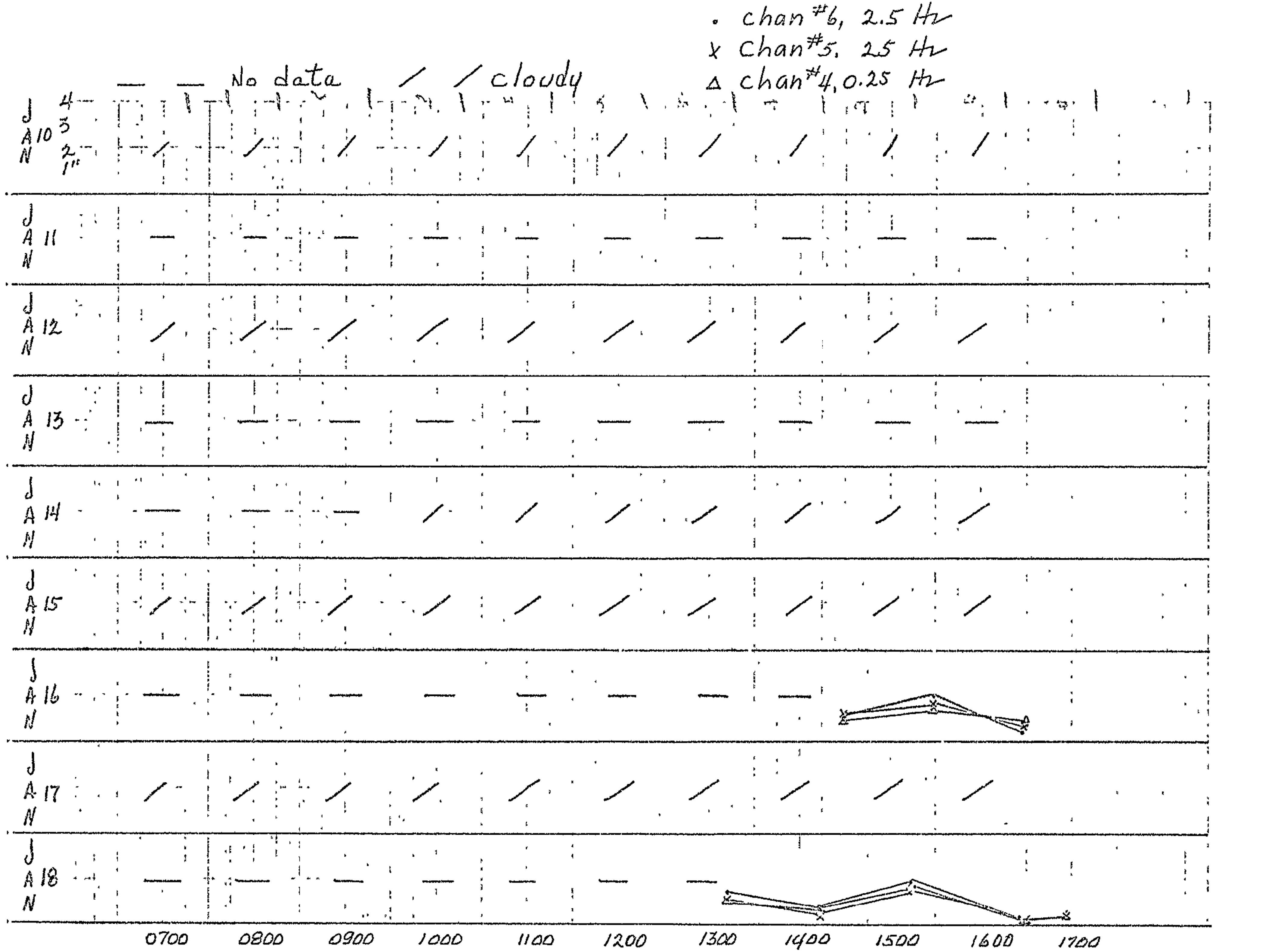

x 25 Hz chan #5
• 2.5 Hz chan #6
Δ 0.25 Hz Chan #4
687
639
501
F E B 6
F E B 7
F E B 8
F E B 9
F E B 10
F E B 11
F E B 12
F E B 13
F E B 14
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700



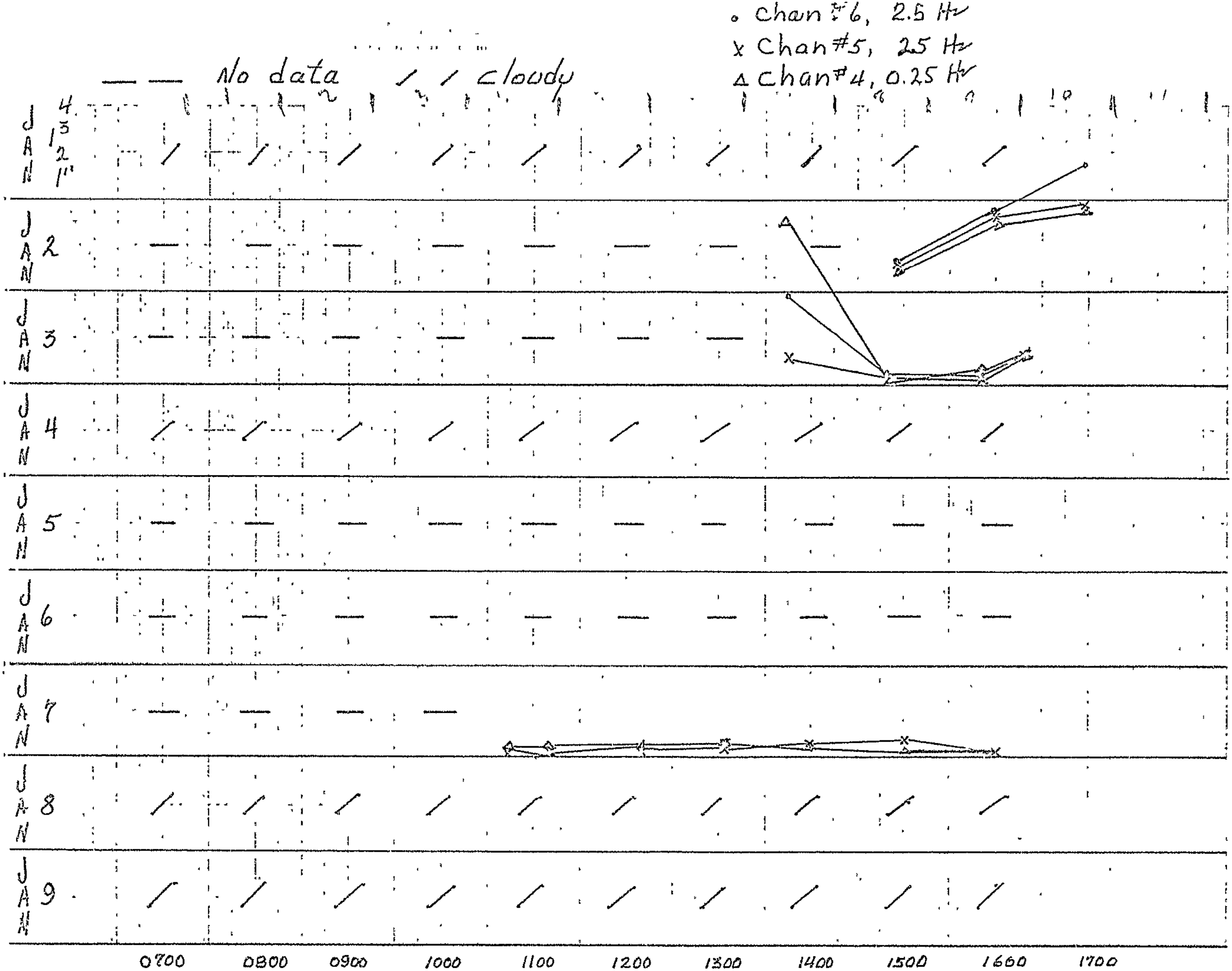
X 25 Hz chan #5
• 2.5 Hz chan #6
Δ 0.25 Hz chan #4
6.65
6.4 X
4.16 Δ
12.5
JAN 28
4
3
2
1"
JAN 29
JAN 30
JAN 31
FEB 1
FEB 2
FEB 3
FEB 4
FEB 5
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700



x 25 Hz chan #5
• 2.5 Hz chan #6
Δ 0.25 Hz chan #4
No DATA
Cloudy
JAN 19
JAN 20
JAN 21
JAN 22
JAN 23
JAN 24
JAN 25
JAN 26
JAN 27
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700

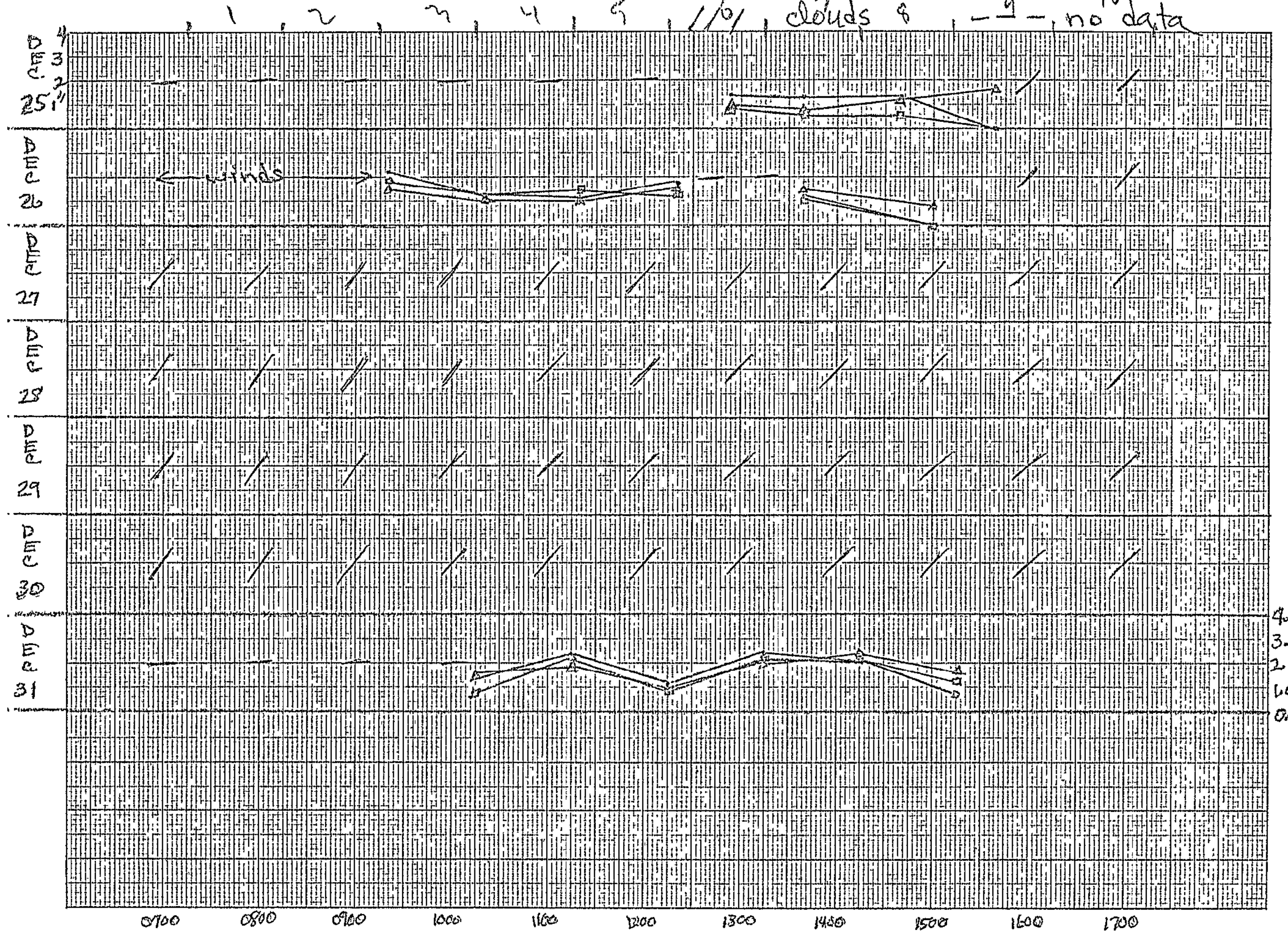


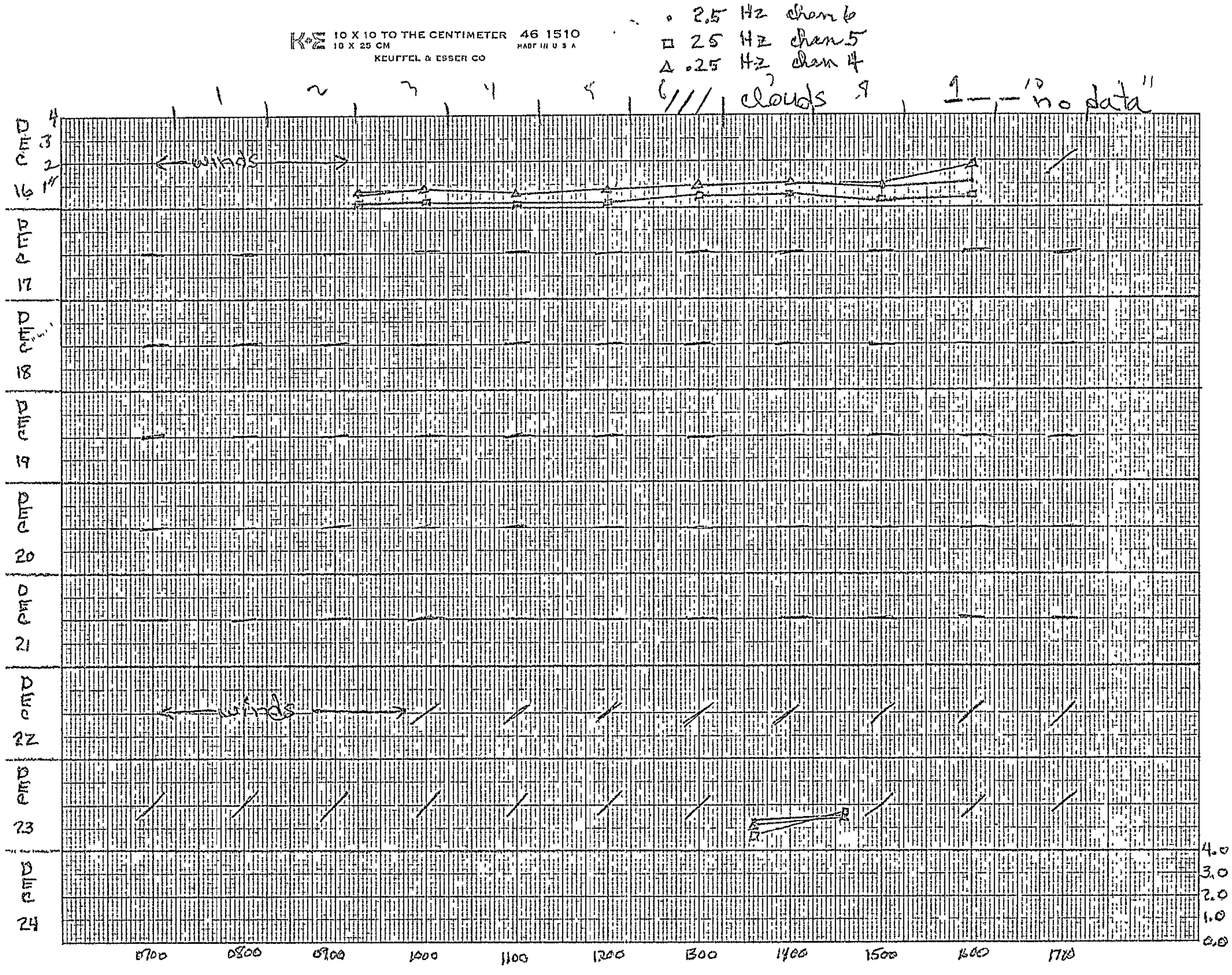
· chan #6, 2.5 Hz
x Chan #5, 2.5 Hz
Δ chan #4, 0.25 Hz
No data
cloudy
JAN 10
4
3
2
1"
JAN 11
JAN 12
JAN 13
JAN 14
JAN 15
JAN 16
JAN 17
JAN 18
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700

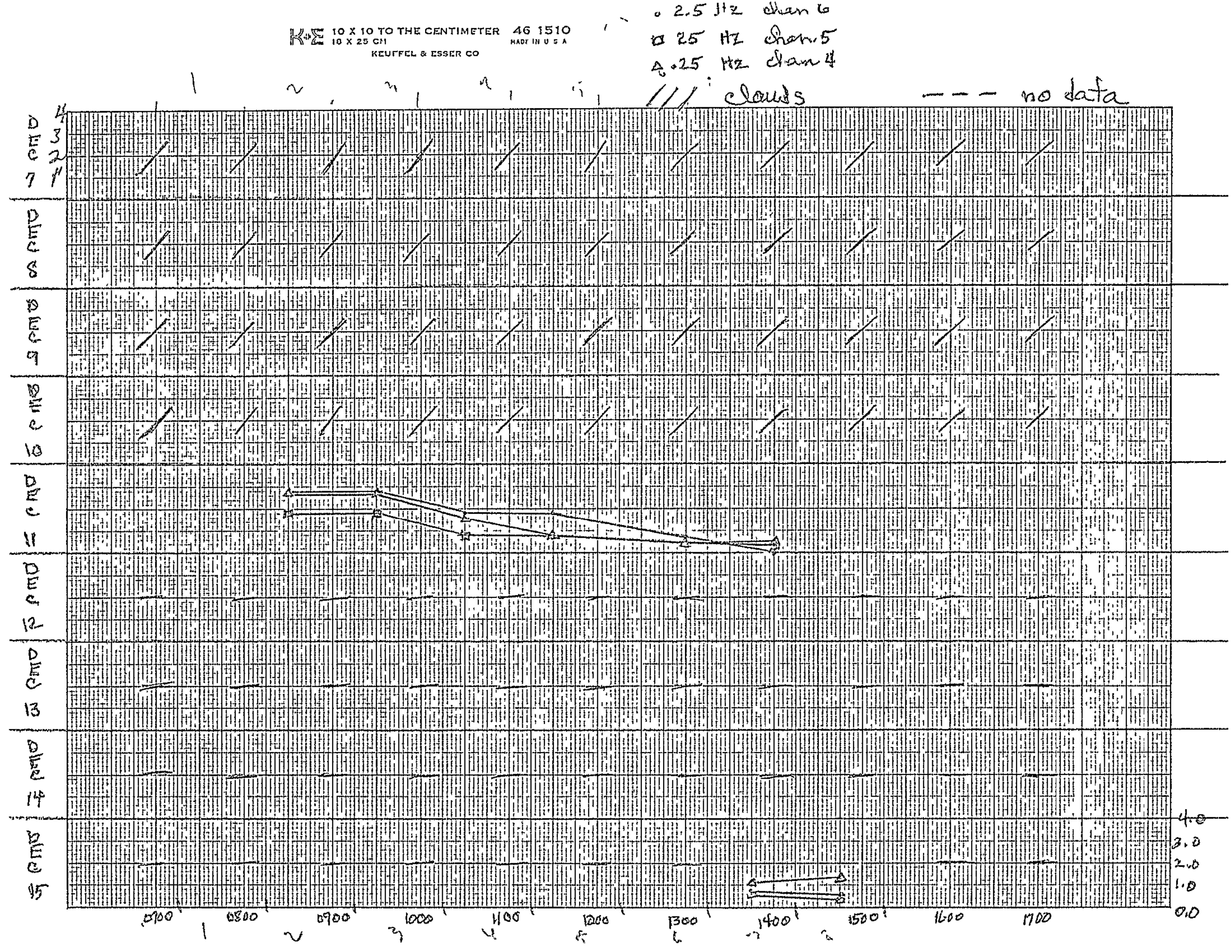


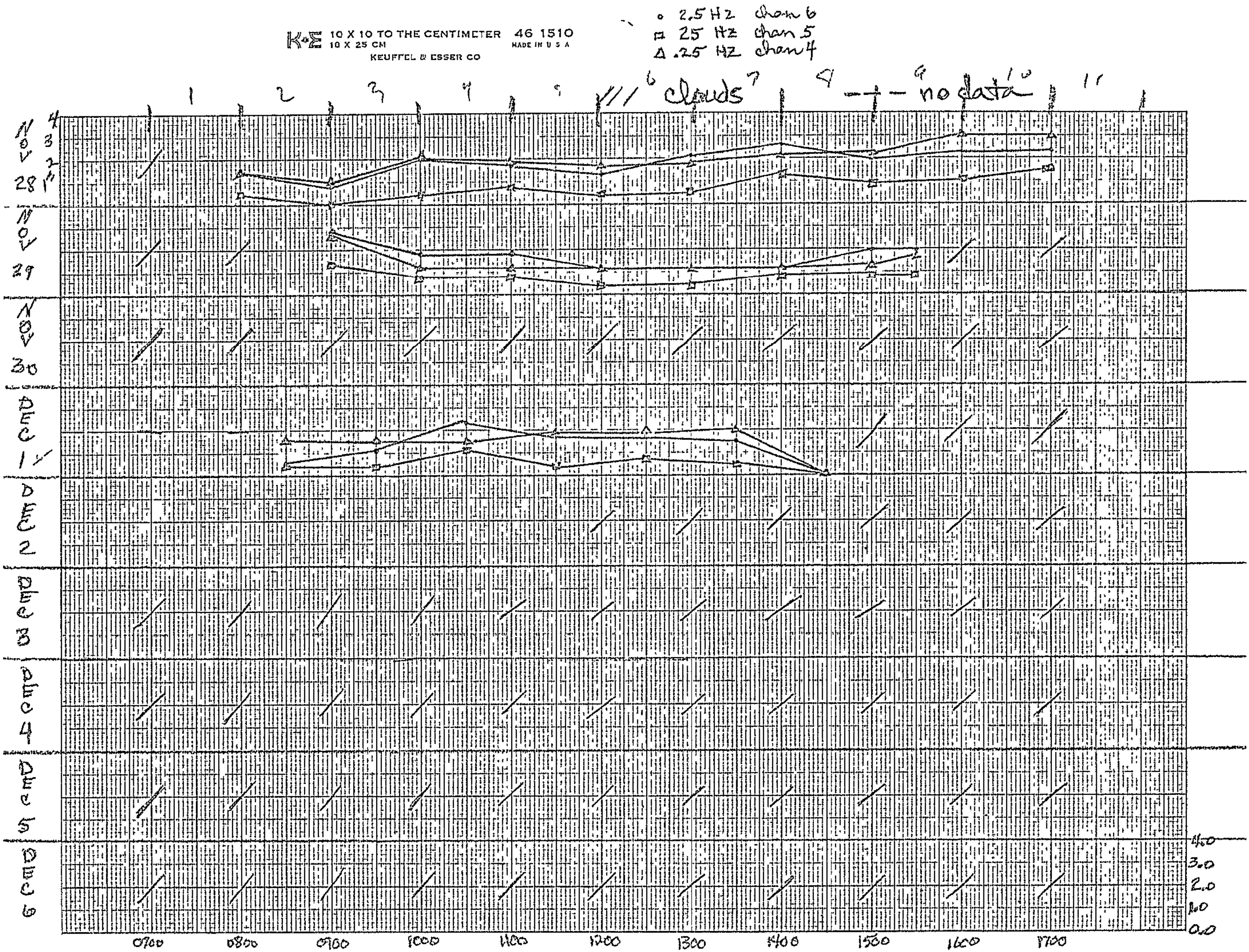
∘ Chan #6, 2.5 Hz
x Chan #5, 2.5 Hz
Δ Chan #4, 0.25 Hz
—— No data
/ / cloudy
JAN 1
JAN 2
JAN 3
JAN 4
JAN 5
JAN 6
JAN 7
JAN 8
JAN 9
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700

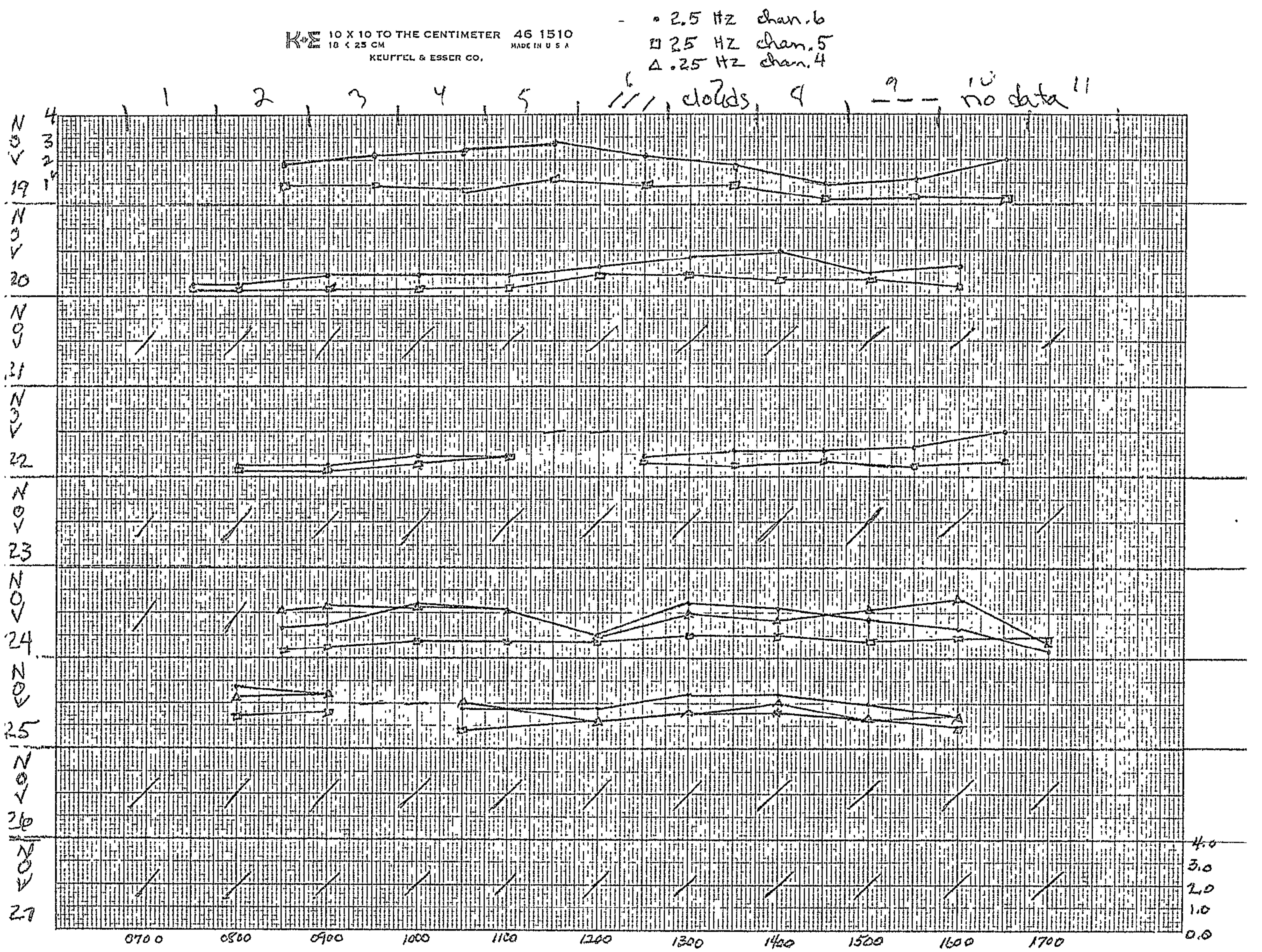
○ 2.5 Hz chan 6
□ 25 Hz chan 5
△ .25 Hz chan 4

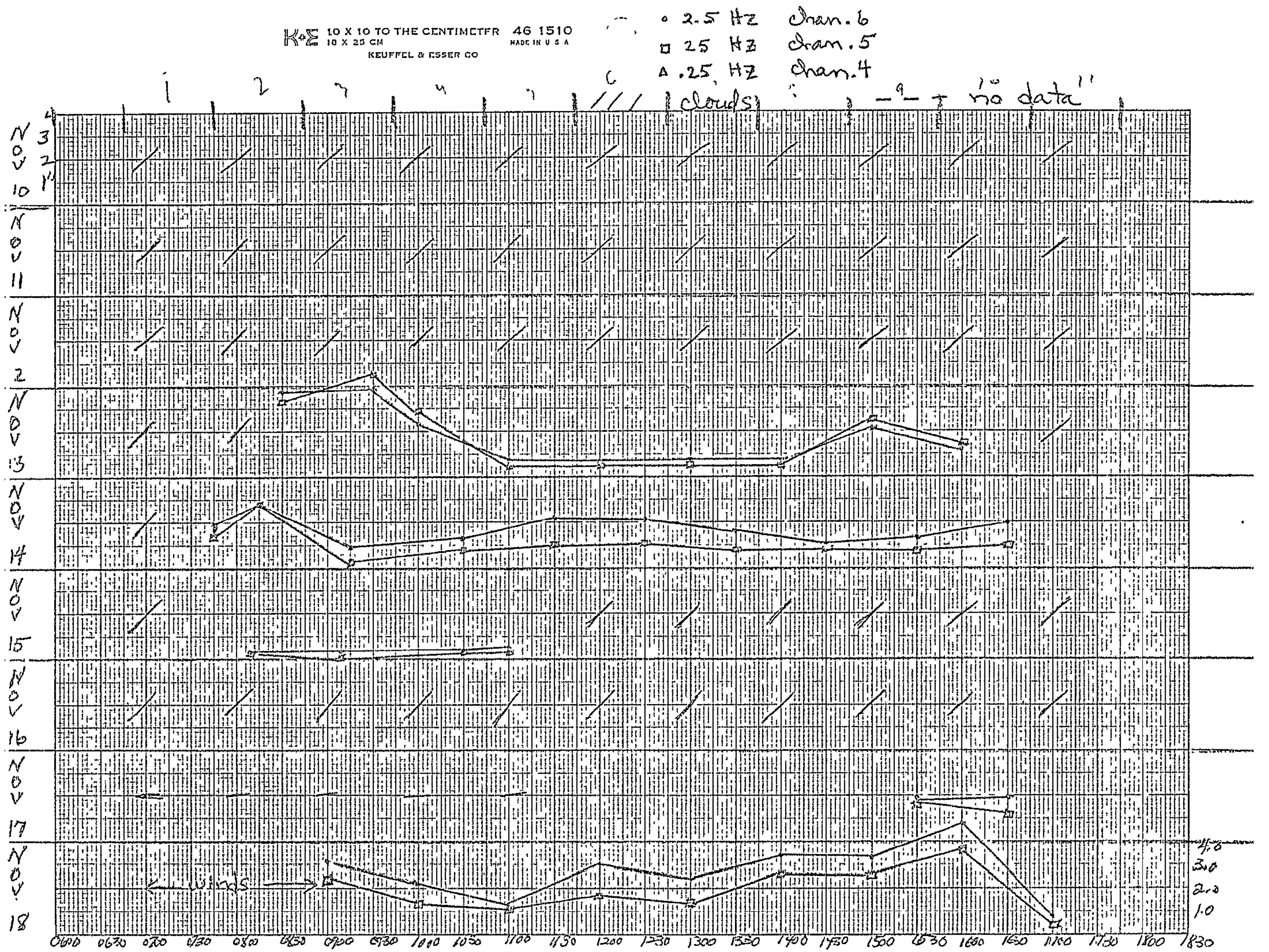


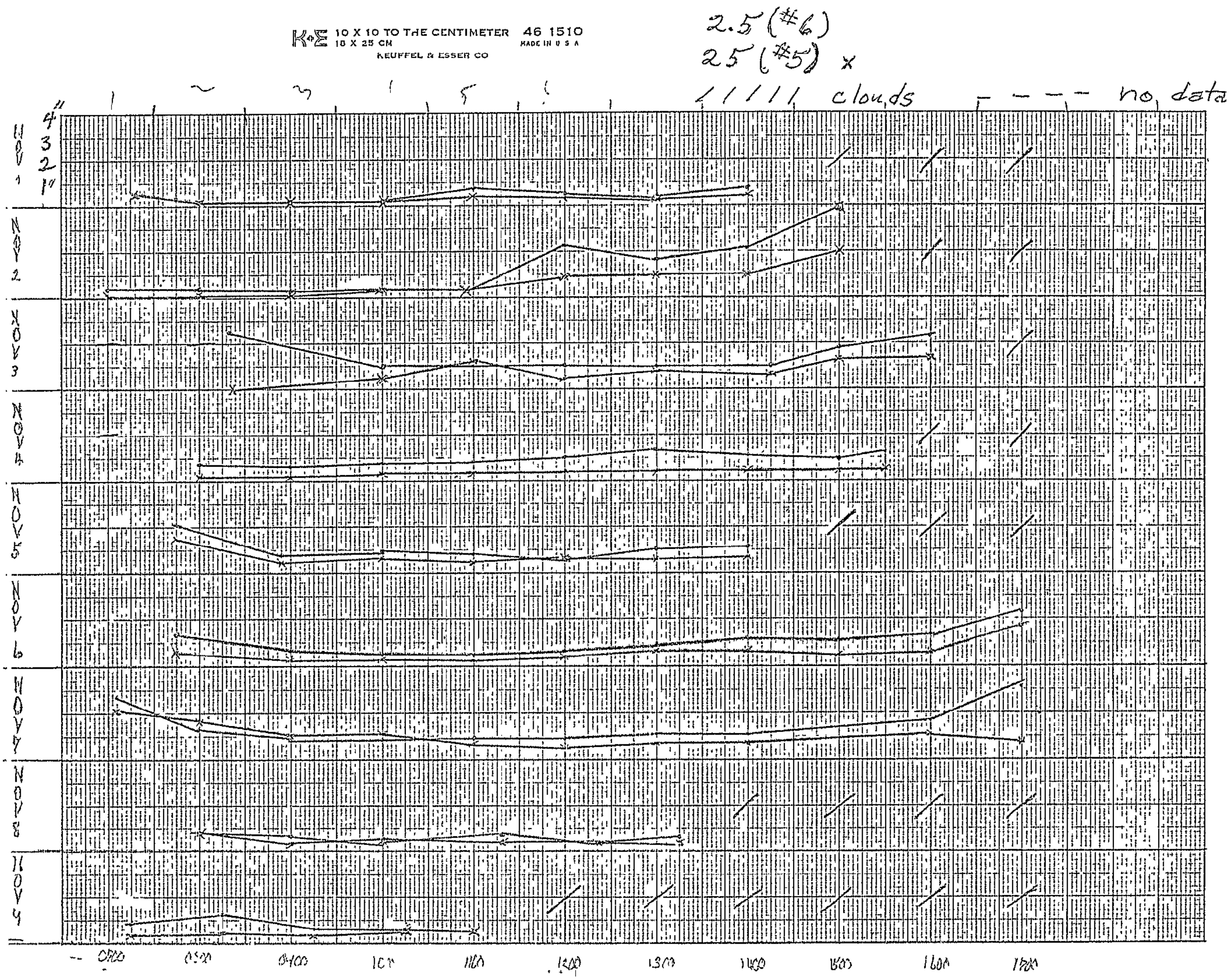

∘ 2.5 Hz chan 6
□ 25 Hz chan 5
△ .25 Hz chan 4
1 2 3 4 5 6 7 8 9 10 11
//// clouds
—— "no data"
← winds →
DEC 16
DEC 17
DEC 18
DEC 19
DEC 20
DEC 21
DEC 22
DEC 23
DEC 24
4.0
3.0
2.0
1.0
0.0
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700


K+E 10 X 10 TO THE CENTIMETER 46 1510
10 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO
○ 2.5 Hz chan 6
□ 25 Hz chan 5
△ .25 Hz chan 4
/// clouds
--- no data
DEC 7
DEC 8
DEC 9
DEC 10
DEC 11
DEC 12
DEC 13
DEC 14
DEC 15
4.0
3.0
2.0
1.0
0.0
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700


K+E 10 X 10 TO THE CENTIMETER 46 1510
10 X 25 CM
MADE IN U S A
KEUFFEL & ESSER CO
∘ 2.5 Hz chan 6
□ 25 Hz chan 5
Δ .25 Hz chan 4
clouds
no data
Nov 28
Nov 29
Nov 30
Dec 1
Dec 2
Dec 3
Dec 4
Dec 5
Dec 6
4.0
3.0
2.0
1.0
0.0
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700


K+E 10 X 10 TO THE CENTIMETER 46 1510
18 X 25 CM MADE IN U.S.A.
KEUFFEL & ESSER CO.
• 2.5 Hz chan. 6
□ 2.5 Hz chan. 5
Δ .25 Hz chan. 4
1 2 3 4 5 6 clouds 9 no data 11
NOV 19
NOV 20
NOV 21
NOV 22
NOV 23
NOV 24
NOV 25
NOV 26
NOV 27
4.0
3.0
2.0
1.0
0.0
0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700


○ 2.5 Hz chan. 6
□ 25 Hz chan. 5
△ .25 Hz chan. 4
clouds
no data
NOV 10
NOV 11
NOV 12
NOV 13
NOV 14
NOV 15
NOV 16
NOV 17
NOV 18
winds
4.0
3.0
2.0
1.0
0600 0630 0700 0730 0800 0830 0900 0930 1000 1030 1100 1130 1200 1230 1300 1330 1400 1430 1500 1530 1600 1630 1700 1730 1800 1830


2.5 (#6)
25 (#5) x
///// clouds
---- no data
4"
3
2
1"
NOV 1
NOV 2
NOV 3
NOV 4
NOV 5
NOV 6
NOV 7
NOV 8
NOV 9
0900
1100
1300