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THE GERMAN LEAD SULFIDE CELL AS A DETECTOR OF SURFACE VESSELS

by

H. L. Clark

FR-2936

Report H-2936

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ABSTRACT

Data available at this Laboratory indicates that the German lead sulfide detector (Elac) gave the same operating ranges during ideal midwinter conditions as the smaller German bolometer detector (Donau): A consideration of the optical parameters of the two systems shows that the lead sulfide system has only one sixth the sensitivity to low temperature radiation as an equivalent bolometer system. The Germans reported an increase of 60% in the operating range of an equivalent bolometer system over the smaller Donau.

Laboratory and field measurements on a lead sulfide detector, constructed by this Laboratory and employing a captured German cell, show that the lead sulfide system when operating under the best conditions electronically is only one seventh as sensitive to low temperature radiation as an equivalent thermister - bolometer system. Also, the lead sulfide system's ranges on surface vessels decrease much faster with increasing atmospheric water vapor than do the ranges of the conventional thermal detection system.

It appears as though the lead sulfide cell makes a relatively poor detector of surface ships.

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CHAPTER I

INTRODUCTION

Authorization: The Director, Naval Research Laboratory.

Information[1,2,3] available at this Laboratory indicates that the German Navy had sponsored the development of two types of surface ship detectors. One type known as the Warmepeilgerat Zeiss, Donaugerat 60 employed a conventional compensated bolometer. The other type known as the Warmepeilgerat Elac, WPG EST, Seeziehl employed a single uncompensated lead sulfide cell. According to Dr. Gaertner, who was in charge of these developments, the lead sulfide detection equipment was not well designed and was continually breaking down, hence never saw action in the field. This unit consequently was never produced on a scale with the bolometer detection equipment. Perhaps that is why such a unit was never available for testing by this Laboratory. Comparative tests between the lead sulfide and bolometer detector were made by the Germans during the winter of 1943-1944 under ideal weather conditions. Both devices gave the same ranges on the same targets. They are: (1) 10 km on U boats, (2) 20 km on the German test vessel "Strahl", and (3) greater than 20 km on a destroyer, hull down. It was stated that because of the greater resolving power of the bolometer detector, it was very difficult to locate targets with it at extreme ranges. With the exception of this operational difficulty, it appears as though the lead sulfide and bolometer systems are equivalent. However, this is not the case for the lead sulfide detector employed a 150-cm diameter collecting mirror with a 64.2 cm focal length, whereas the bolometer detector employed a 60-cm diameter collecting mirror with a 65-cm focal length. The minimum detectable signal in watts per cm^2 which a system with a given sensitive element can detect is given by the expression

$$\text{Min. detectable signal in watts/cm}^2 = K\,\frac{F\sqrt{\alpha\beta}}{D}$$

where
F = f - number of system (focal length/diameter),
$\alpha\beta$ = vertical and horizontal field of view (degrees),
D = diameter of collecting mirror (cm),
K = constant of proportionality (value depends on type of system).
Noise level of cell is assumed to be constant and independent of cell's configuration or area.

Thus, if a bolometer of the correct size were placed in the 150-cm lead sulfide system, the sensitivity of this new system would be more than six times the sensitivity of the 60-cm bolometer unit (α and β are the same in both cases). This would more than double the threshold range in a vacuum (no atmospheric absorption). The Germans did just this and found that the new 150-cm bolometer unit gave a 60 per cent greater range than the old 60-cm bolometer unit. The fact that the range was not increased more is due, of course, to atmospheric abosrption. In other words, then, the conventional bolometer detector has six times the sensitivity of an identical lead sulfide detector. Dr. Gaertner, however, stated that he believed the lead sulfide system would soon be superior to the bolometer system provided that the Germans could get the bugs out of it and that the response of the

[redacted]

cell could be extended to longer wavelengths.

In view of the fact that the above information is based on reports of the interrogation of prisoners, it seemed advisable for this Laboratory to verify the results experimentally. In addition, the fact that the lead sulfide cell can be operated at frequencies much higher than possible with conventional thermal elements, thus making it possible to reduce the effects of shipboard vibration (microphonics) and at the same time increase the rate of search, made it even more imperative that the potentialities of the cell be investigated here. Consequently, this Laboratory undertook the experimental investigation of the lead sulfide cell as a detector of surface vessels.

The investigation consisted of developing and constructing a detection system which took full advantage of the lead sulfide's potentialities and still represented a practical device for shipboard use. This system was then compared experimentally, both in the laboratory and in the field, with a standardized thermal detection system of known sensitivity and characteristics. The relationship of this standardized detector to that now being considered for shipboard use is known, hence a comparison between the lead sulfide unit and the best available shipboard thermal unit can be made.

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CHAPTER II

THE DETECTOR

The detection system employing the lead sulfide cell is shown in Plate 1. It consists of an optical system in which is mounted the lead sulfide cell and preamplifier all of which are mounted on a scanning table. This scanning table is coupled mechanically to a helix recorder upon which appear signals from the preamplifier after they have been amplified by a power amplifier. The power amplifier, together with its power supply, are mounted in the same cabinet which houses the recorder. Recorder and scanning table run in synchronism with respect to each other. Radiation from any target within the optical system's field of view is focused upon the cell momentarily as the optical system sweeps across the target. The resulting voltage pulse from the cell after being amplified by the preamplifier is fed via the slip rings in the scanner base to the final power amplifier which, after additional amplification, feeds it to the recorder. There it appears as a dark spot on the paper, the intensity of the spot being roughly proportional to the strength of the signal. The position of the spot on the paper along a horizontal line corresponds to the bearing of the target. Since the paper is continually advancing through the recorder, repeated sweeps by the optical system across the target produce repeated dark spots, one below the other, on the paper at the instantaneous bearing of the target. A record similar to that shown in Plate 2 is thus produced. The use of this type of recording permits recognition of signals whose amplitudes are as low as one quarter that of the noise simply because the signals line up and the noise does not.

The cell, Plate 3, chosen for this work was a captured German unit[4] with a sensitive area measuring 3 mm wide by 3 mm high. The name plate on the cell gives the following information: Baumuster ST-Z3, Anforderz D, Work - Nr. 137613, bbw. This cell was chosen because it has the smallest sensitive area of those available and hence, when used in combination with a suitable optical system to provide a given optical field of view, yields the greatest sensitivity. The optical system, in which the cell is mounted, consists of a 12-inch diameter, f/2.5, first surface, parabolic mirror of optical quality. Mounted on the optic axis at 45° to it is an optical flat which brings the focal plane at the base of the system. The optical system was constructed by the Farrand Optical Co., Inc. of New York, New York. The optical parameters of the system with the cell mounted in the focal plane symmetric with the optic axis are shown in Plate 4. The horizontal and vertical dimensions of the optical field of view are both 0.22 degrees. For shipboard application the horizontal dimension should be 0.1° to give the necessary bearing accuracy and the horizontal dimension should be at least 0.5° to compensate for errors in shipboard stabilization. However, there was no choice with respect to shape in this case. The parameters of Plate 4 represent a fair compromise.

The sluing speed chosen was 10 RPM or 60 degrees per second. This is considerably faster than the scanning speed of the present shipboard units. However, the latter scanning speed is much too slow. The 10 RPM speed is an estimate, based on experience with other units, of what is acceptable. The sluing motion is one of continuous rotation in one direction and is not a

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sector scan. Micro switches, which are placed at 120° degree intervals on the base of the scanning table, through the action of interlocking relays permit the printing of signals from only one 120° degree at any one predetermined setting. The recorder is geared to the scanning table so that it travels three times faster than the scanner, thus allowing the full width of the paper to represent 120° rather than 360°. The 120° sector, which is to be printed, is chosen with a selector switch. The electrical circuit, which provides this, is shown in Plate 5. The actual switching is done at the output of the power amplifier and consists of throwing the recorder across the output of the amplifier for one 120° sector and then a dummy load resistor for the remaining two 120° sectors.

Since the scanning speed is 60 degrees per second and the horizontal component of the optical field of view is 0.22 degrees, a point source of radiation will cause the cell to generate an approximately rectangular shaped unipolar pulse once per complete revolution of the scanner. The duration of the pulse is $^{0.22}/_{60}$ or approximately $^1/_{270}$th of a second. However, few targets are point sources at the ranges at which the present equipment now works, hence, the above may be considered as a minimum time duration for irradiation. For this work a pulse duration of approximately $^1/_{260}$th of a second was assumed. Unfortunately, the generated pulse is unipolar since the cell is of the uncompensated type. It has been shown[5] that an increase in signal-to-noise ratio of more than two times could be realized if the cell were of the compensated type. (This applies to cells or elements of any type.)

Since the signal is an isolated pulse, a straight pulse amplifier was first employed. This amplifier was tuned to 130 c.p.s. with a bandwidth of 130 c.p.s. This tuning was done in the preamplifier, the wiring diagram of which is shown in Plate 6. The tuning was accomplished by the plate load shunting and under coupling of three pentode stages. It can be shown that

$$f_o = \frac{1}{2\pi(R_L C_L R_g C)^{1/2}}$$

provided that
$$\begin{cases} R_g = 10\,R \\ R_L C_L = R_g C \end{cases}$$

where
f_o = peaking frequency in c.p.s.,
π = 3.1416,
R_L = pentode plate load in ohms,
C_L = plate load shunt in farads,
R_g = grid leak of following stage in ohms,
C = coupling capacitor in farads.

The above applies to pentode stages only and gives a symmetrical tuning curve. It takes three such stages of tuning to give a fractional bandwidth between the half power points of approximate unity. The tuning curve thus obtained is shown in Plate 7. The preamplifier was designed to work down to the thermal agitation noise level of a wire wound input load of 100,000 ohms. This necessitated wire-wound resistors in the first stages and for simplicity batteries for filaments and B+. However, it was found that the current noise in the cell, when cooled with dry ice, was six times the thermal agitation

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noise level of a 100,000 ohm wire-wound resistor. The cell's load was a 500,000 ohm wire-wound resistor with a 90 volt supply. The voltage on the cell (cooled) itself as measured with a 10 megohm meter was 15 volts. This gives a resistance of 100,000 ohms for the cell.

The output of the preamplifier was fed via a cathode follower to the power amplifier. The wiring diagram of the power amplifier and its power supply are shown in Plates 8 and 9. It consists of a balanced modulator whose carrier frequency, supplied by a local oscillator, is 2000 c.p.s. The entire amplifier is of the push-pull type. For the amplification of pulses push-pull is considerably easier on the power supply than single ended stages. This power amplifier is a standardized unit developed by this Laboratory for general detection work. A number of these units have been constructed by the Navy Underwater Sound Laboratory at New London for this purpose. The power handling capabilities of this amplifier are shown in Plate 10. With a properly designed input transformer this amplifier can handle pulses of any duration down to one millisecond.

The output of the power amplifier is rectified before being applied to the helix recorder. Since the recorder is of the chemical type wherein marks are produced as a result of chemical deposition, it is obvious that a pulse-modulated carrier, whose frequency is high compared to the speed of the recorder, will produce a chemical deposit during one half of a cycle and then remove it during the next half before the recorder has had a chance to move appreciably. Hence, rectification of the carrier is necessary before the pulse is applied to the recorder.

The recorder employed here is one supplied by the Alden Products Co. of Brockton, Mass. It is the same type as employed for facsimilie transmission. The printer bar is platinum-iridium and the helix wire is Monel metal. The printer bar is maintained negative with respect to the helix. The paper employed is supplied by Radio Inventions Inc. of New York City. It is eight inches wide. This corresponds to 120° or 15° per inch and permits the resolution of two spots not less than 1/4° apart. The resolving power of the optical system and amplifiers is better than this. However, it is good enough for experimental purposes.

The above detection system was given a number of laboratory tests and then in March, 1946, was taken to the Bureau of Ships Test Station at Lewes, Delaware for a field test employing the U.S.S. Callao as a surface target. The results of this test are described in another section of this report.

The results of both laboratory and field tests seem to check the reported German results of the inferiority of the lead sulfide system. However, it was still possible that something was being overlooked so it was therefore decided to investigated more thoroughly the possibility of employing the lead sulfide cell more advantageously. The particular cell being employed was subjected to a series of measurements, the results of the most important of which are shown in Plate 11. The measured frequency response curve is shown in this plate. Also shown is the measured cell noise as a function of frequency as observed with a constant unit bandwidth. It will be noted that below 100 c.p.s., the cell noise varies with frequency in

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accordance with semi-conductor theory[6], namely, it falls off with increaseing frequency as the reciprocal of the frequency (noise $\propto {}^1/f$). At 100 c.p.s., where the cell noise is six times the normal thermal agitation noise level of a 100,000 ohm were wound resistor, the noise ceases to fall as rapidly as at lower frequencies and appears to be approaching a field value of noise assymtstically. At 1000 c.p.s. the measured cell noise is only twice the measured noise from a 100,000 ohm resistor. Thus, the cell noise gradually approaches the thermal agitation noise level with increasing frequency. This is exactly as predicted by semi-conductor theory for it should be expected that at higher frequencies semi-conductor noise would cease to predominate and that the cell noise would be strictly of a thermal agitation nature. Also plotted in Plate 11 is the cell noise spectrum for constant percentage bandwidth as calculated from the measured spectrum for constant unit bandwidth. In Plate 12 are plotted in arbitrary units, the signal-to-noise ratios for this cell for both constant unit bandwidth and constant percentage bandwidth.

It will be noted that the constant percentage bandwidth curve shows the best signal-to-noise ratio to be in the vicinity of 100 c.p.s. It will be recalled that any detection system which scans over a target once per resolution of its optical system and in so doing irradiates its receiving element with a single isolated pulse of radiation, must employ a pulse amplifier tuned to a frequency determined by the duration of the pulse with a percentage bandwidth (between half power points) of not less than and usually equal to 100 per cent. The faster an optical system scans with a given cell, the shorter the duration of the pulse and the greater the necessary peak frequency and bandwidth. Referring again to figure 12, it is obvious that since the best signal-to-noise ratio for constant percentage bandwidth occurs around 100 c.p.s. and since the bandwidth must be 100 per cent, the peak frequency must also be in the vicinity of 100 c.p.s. The peak frequency chosen for the detector mentioned above was 130 c.p.s. or an optimum. Thus nothing more can be gained from the cell by employing it in this manner. However, reference to the constant unit bandwidth curve of figure 12 shows that the best signal-to-noise ratio occurs at 400 c.p.s. This is true no matter what the numerical value of the bandwidth is. Thus, if the radiation falling on the cell could be chopped at or near 400 c.p.s., then a scanning speed and hence a bandwidth for a maximum signal-to-noise ratio could be chosen. It is obvious that the narrower the bandwidth at or near 400 c.p.s., the greater would be the signal-to-noise ratio. However, too narrow a bandwidth means a high Q, which would make the system unstable and difficult to keep lined up electronically. For example, if it were decided to employ a scanning speed of 1 RPM, which is what the present shipboard detectors employ, a bandwidth of about 15 c.p.s. at say 400 c.p.s. could be used. This would mean an increase in the signal-to-noise ratio of approximately 3.5 times over that obtainable with the 130 c.p.s. pulse system. The Q of such a system is a little too high to be practical. Hence, it would be better to employ the 15 c.p.s. bandwidth at say 150 c.p.s. whence an improvement of approximately three times in the signal-to-noise ratio could be realized. Such a system would, of course, have to scan at 1 RPM and would be inferior in sensitivity to the present shipboard units. (See Chapter 3). In view of the fact that it would be necessary to modify the detection system extensively to take advantage of this possible increase in signal-to-noise ratio, which would not improve its performance sufficiently to put it on a par with the shipboard units, it was decided to abandon the project.

[redacted]

However, an experimental check on the above deductions was made. The performance of the system was observed at 1000 c.p.s. The amplifier bandwidth employed was 130 c.p.s. so as to facilitate correlations of these results with those obtained with the 130 c.p.s. pulse system. To do this, a multi-bladed shutter was installed in the optical system as shown in Plate 13. The shutter chops the radiation at 1000 c.p.s. before it falls on the cell. A second preamplifier was employed. Its wiring diagram is shown in Plate 14. Its frequency response is shown in Plate 15. The bandwidth was obtained at 1000 c.p.s. by adjusting the amount of negative feedback from a parallel-T RC filter network[7] over a single stage comprising a 6SJ7. The signal from a target as observed at the output of the preamplifier is a pulse modulated 1000 c.p.s. carrier. This pulse is demodulated at the output of the preamplifier by a full wave copper oxide rectifier and is then fed to the power amplifier. This procedure would, of course, not be necessary if the carrier frequency in the power amplifier were higher. The results of laboratory tests on this 1000 c.p.s. system verified the calculations that an improvement of only 20 per cent or 30 per cent in the signal-to-noise ratio was possible under these conditions and that the system was not appreciably better than the 130 c.p.s. one. In July 1946, a second field test was also made at the Bureau of Ships Test Station at Lewes, Delaware employing the U.S.S. Callao as target. The results of this test are described in the next section of this report.

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CHAPTER III

LABORATORY AND FIELD TESTS

The standardized thermal detection system with which the subject lead sulfide system was compared is described in another report[8]. Briefly, it consists of a 24-inch diameter, f/2.5, parabolic collecting mirror at the focal point of which is mounted an 1/16" x 1/8" Eppley wire thermopile. The associated pulse amplifier peaks at 5 c.p.s. and has an equivalent input noise level of four times the thermal agitation noise level of the thermopile. The system is similar to the subject one with the signals being presented on a chemical recorder. The minimum detectable signal for the entire system is 7 or 8 x 10^{-11} watts per cm^2 which is approximately two times greater than that of the shipboard models. In other words, the shipboard models are more sensitive. Their threshold or maximum detection ranges on a given vessel are approximately 20 per cent greater than those of the above standardized thermopile unit. Additional details concerning the shipboard detector may be found in an NDRC report[9]. Theoretically, the standardized thermopile detector should be about 5 times more sensitive than the shipboard unit. The fact that it is a factor of ten off may be accounted for by the unduly high noise level of the associated amplifiers and the poor frequency response of the thermopile. Thus, if a sensitive element of the type employed in the shipboard units (a thermister bolometer) were employed in the thermopile system, whose scanning speed were increased to 1 RPM, and had the same shape and area as that of the thermopile, the above factor of ten could be realized,(provided, of course, that the noise level in this new thermister were the same as that of the shipboard thermister, which is possible). In other words an equivalent standardized thermister system, which scans at 1 RPM, would be capable of detecting 8 x 10^{-12} watts per cm^2 whereas the present standardized thermopile detector, which scans at 1/6 RPM, is capable of detecting only 8 x 10^{-11} watts per cm^2. This should be born in mind when a comparison between the subject lead sulfide system and the standardized thermopile detector is made.

The above expressions for radiation density apply to the power radiated by low temperature sources, such as, surface vessels. The sensitivity of a conventional thermal detector is always expressed in terms of the total power density from a black body source at a few degrees above room temperature without specific regard to the wave length of the radiation. Surface vessels may be considered black bodies parts of which rarely exceed 100° C. The spectral distribution of the output radiation is, therefore, very similar to the calibrating sources employed in the laboratory. The peak of such curves occurs in the vapor window between 8 and 13 microns.

The spectral sensitivity of a cooled lead sulfide cell is considerably different. It is sensitive to wave lengths between approximately 1 micron and 3 microns with the peak sensitivity occurring at about 2.5 microns. The power output from a surface vessel is much smaller in this region than in the vapor window. Then too, the transmission of the atmosphere may be different in this region than in the vapor window[10]. However, the sensitivity of the cooled cell in this short wave length region is considerably greater than the sensitivity of any thermal element, hence, this partially compensates for lack of target radiation and any difference in atmospheric abosrption. Since

[redacted]

in this problem, the cell is employed against low temperature targets, the sensitivity of the cell will be expressed in terms of total black body radiation from such targets in the same manner as for thermal elements. This will facilitate comparisons of the effective merit of the lead sulfide cell with that of conventional thermal elements.

Upon completion of the 130 c.p.s. pulse amplifier for use with the lead sulfide cell, the cell-amplifier combination was compared in the laboratory with the thermopile-amplifier combination from the standardized detector. The procedure involved consisted of setting up a black body source of radiation of known temperature in front of which was placed a large shield with a small circular hole of known diameter. A motor driven shutter blade was then placed in front of the hole so that it chopped the radiation emanating therefrom at 130 c.p.s. for the lead sulfide cell and 5 c.p.s. for the thermopile. The chopped wave was a square wave with equal on and off periods. A second shield was placed in front of the shutter. It had a slighter larger hole in it so as to expose only the effective portion of the shutter. With the black body source held at a fixed temperature and the shutter held as closely to air temperature as possible, the two cells, one at a time, were placed in front of the shuttered hole and then backed off until the signal-to-noise ratio became unity (noise plus signal = $\sqrt{2}$ x noise). The distance from the source of radiation was then measured. From the data available, the power density for a given threshold distance was calculated. The power density was also measured with a calibrated thermopile. The results are shown below:

Source Temperature (Degrees C) (Ambient = 25° C)	PbS Cell (watts/cm^2 for $^S/_N = 1$) (130 c.p.s. square chop)	Thermopile (watts/cm^2 for $^S/_N = 1$) (5 c.p.s. square chop)
30°	$\sigma(T_1^4 - T_2^4) =$ 1.8×10^{-6}	0.50×10^{-6}
60°	1.7×10^{-6}	0.50×10^{-6}
100°	1.4×10^{-6}	0.50×10^{-6}

Had the cells been irradiated with single isolated pulses of correct duration and shape to simulate the action of an image of a ship sweeping across them, the power density figures above would be about 35 per cent greater. This is due to the difference in the steady-state response and pulse response of the associated amplifiers (pulse response/steady-state response ≅ 0.75). The sensitive areas of both cells are not the same, lead sulfide cell-9 mm^2, thermopile-5 mm^2. However, it will be assumed that both are the same for the sake of simplicity even though such an assumption does favor the lead sulfide cell. On the basis of the above figures, (assuming identical cell areas), the calculated sensitivities for the complete detection systems are:

Source Temperature (Degrees C) (Ambient = 25° C)	PbS System (12" mirror) (watts/cm^2 for $^S/_N = 1$)	Thermopile System (24" mirror) (watts/cm^2 for $^S/_N = 1$)
30°	1.4×10^{-9}	1.0×10^{-10}
60°	1.3×10^{-9}	1.0×10^{-10}
100°	1.1×10^{-9}	1.0×10^{-10}

[redacted]

The entire lead sulfide system, including the recorder, was also calibrated. This was done by placing a black body source at 100° C at a sufficiently great distance from the optical system, so that, when the system was focused properly, the image of the source was smaller than the sensitive area of the cell. The optical system was then made to scan across the black body source. The optical system's aperture was then completely covered with a piece of cardboard. A small hole in the cardboard was then gradually reduced in size until the trace produced by the black body source was just visible on the recorder (mixed in with the cell noise). The effective power density at the aperture of the optical system was then calculated. The ratio of the area of the hole in the cardboard to the area of the system's mirror gave the reduction in density provided by the cardboard stop. In this manner the minimum detectable signal from a 100° C source set against a 30° C background was found to be 6×10^{-10} watts/cm^2. The value for the thermopile system is 7 or 8×10^{-11} watts/cm^2. Of course, a factor of four can be attributed to the difference in the size of the collecting mirrors - 24" diameter for the thermopile vs. 12" diameter for the lead sulfide cell. Had the optical systems been identical, the sensitivity of the thermopile system would still be slightly more than twice that of the lead sulfide system. As stated previously, the thermopile system is a factor of ten less sensitive than an equivalent thermister-bolometer system. Thus, the 130 c.p.s. lead sulfide system would be a factor of twenty less sensitive than an equivalent thermister-bolometer system. Had the lead sulfide system been designed for a slower scanning speed with the associated amplifiers tuned to 150 c.p.s. with a 15 c.p.s. bandwidth as mentioned in Chapter II and the improvement of three times in the signal-to-noise ratio realized, the lead sulfide system would still be a factor of seven less sensitive than an equivalent thermister bolometer system. It will be recalled that the factor based on the German's experience was six times. Thus, the results check rather well.

The lead sulfide system was given a field test in March 1946 and again in July 1946. The target was the U.S.S. Callao. The test vessel proceeded with all lights off. The threshold ranges are tabulated in Plate 1 together with those for the standardized thermopile system. All ranges are for the stern aspect only. The lead sulfide unit was unable to detect the Callao at the ranges at which the vessel could operate safely - 3500 yds. or greater from shore. The bow thresholds for the thermopile system are roughly one half the stern thresholds. It will be noted that the threshold ranges for July are considerably less than for March. Other measurements[11] have shown that the midsummer ranges for a conventional thermal detector are only one third the midwinter ranges. It appears from the data of Table 1 that the reduction is considerably greater for a lead sulfide system. Note in March how much faster the threshold ranges for the lead sulfide system decrease with increasing water vapor compared to the thermopile system. The German claims are based on work carried out under ideal midwinter conditions. Under such conditions the stern threshold for the U.S.S. Callao as observed with the thermopile system is 18000 yards!

In general then, the present German lead sulfide cells do not make good surface ship detectors. In addition, the cells are microphonic as has been reported by the Germans[12] and great care has to be exercised when using them. Also the noise level and the sensitivity of the cell is greatly influenced by

[redacted]

the particle size of the crushed dry ice employed. Only a carefully powdered snow of dry ice will do. Larger chunks raise the noise level and reduce the sensitivity. The cells are not suitable for shipboard detection work.

TABLE 1

Threshold Ranges for Lead Sulfide and Thermopile Systems

Target - U. S. S. Callao, stern aspect.

PbS System	'Pile System	Date	Time	PPT H O Cm/Sea Mi	Remarks
5,500 yds.	11,500 yds.	3/6/46	2000	1.4	Visibility 12 mi
4,100 yds.	10,900 yds.	3/6/46	2100	1.5	
less than 3500 yds.	9,000 yds.	3/6/46	2300	1.8	Foggy
less than 3500 yds.	5,000 yds.	7/10/46	2200	3.4	Very Foggy
less than 3500 yds.	5,600 yds.	7/11/46	2200	3.3	Light Rain
less than 3500 yds.	7,000 yds.	7/11/46	2300	3.3	Very Hazy

[redacted]

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[redacted]

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11. H. L. Clark - "A Survey of Thermal Radiation from Surface Vessels, Part II (April 1946 to August 1946) Report H-2954

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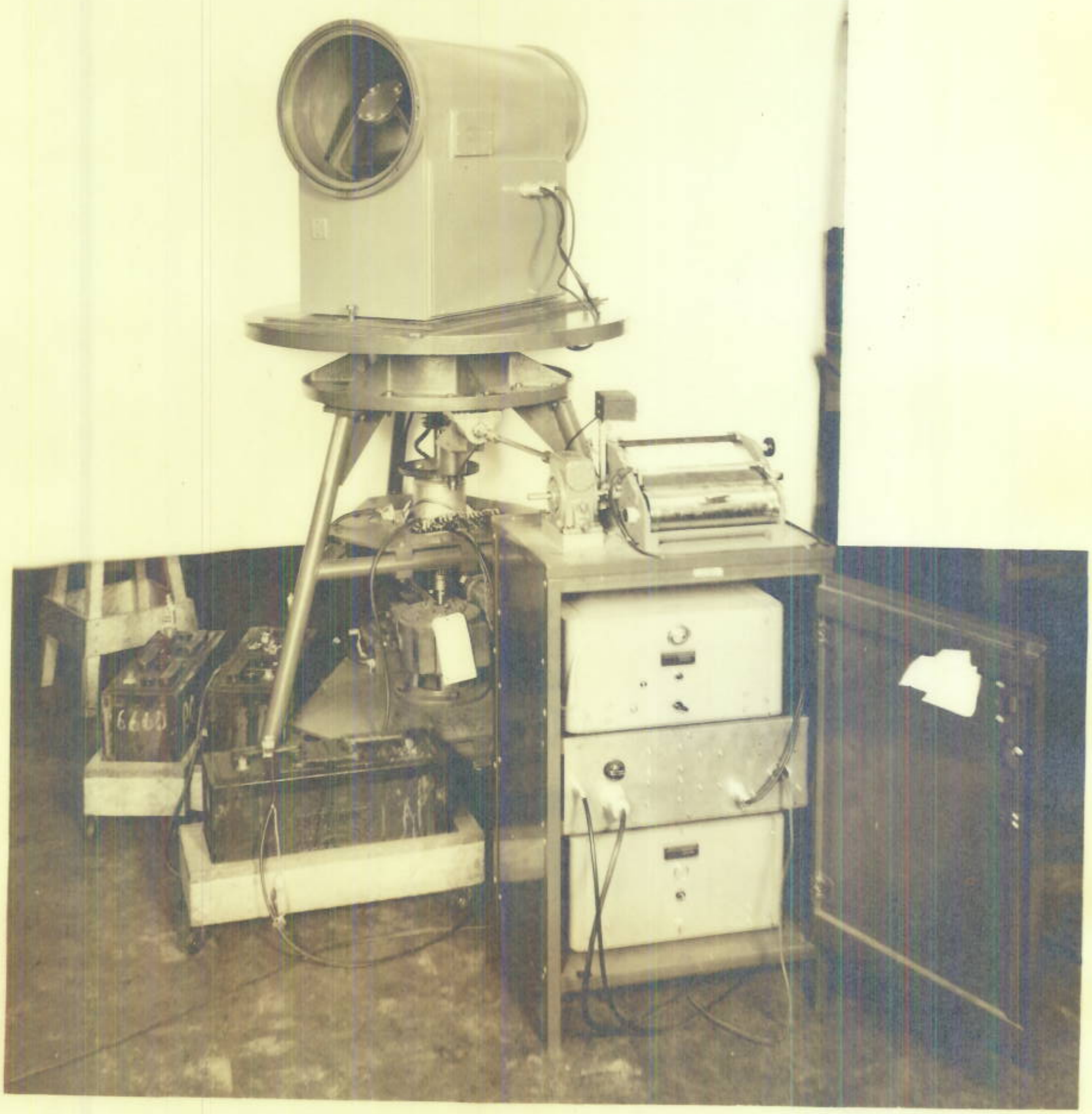

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PLATE I

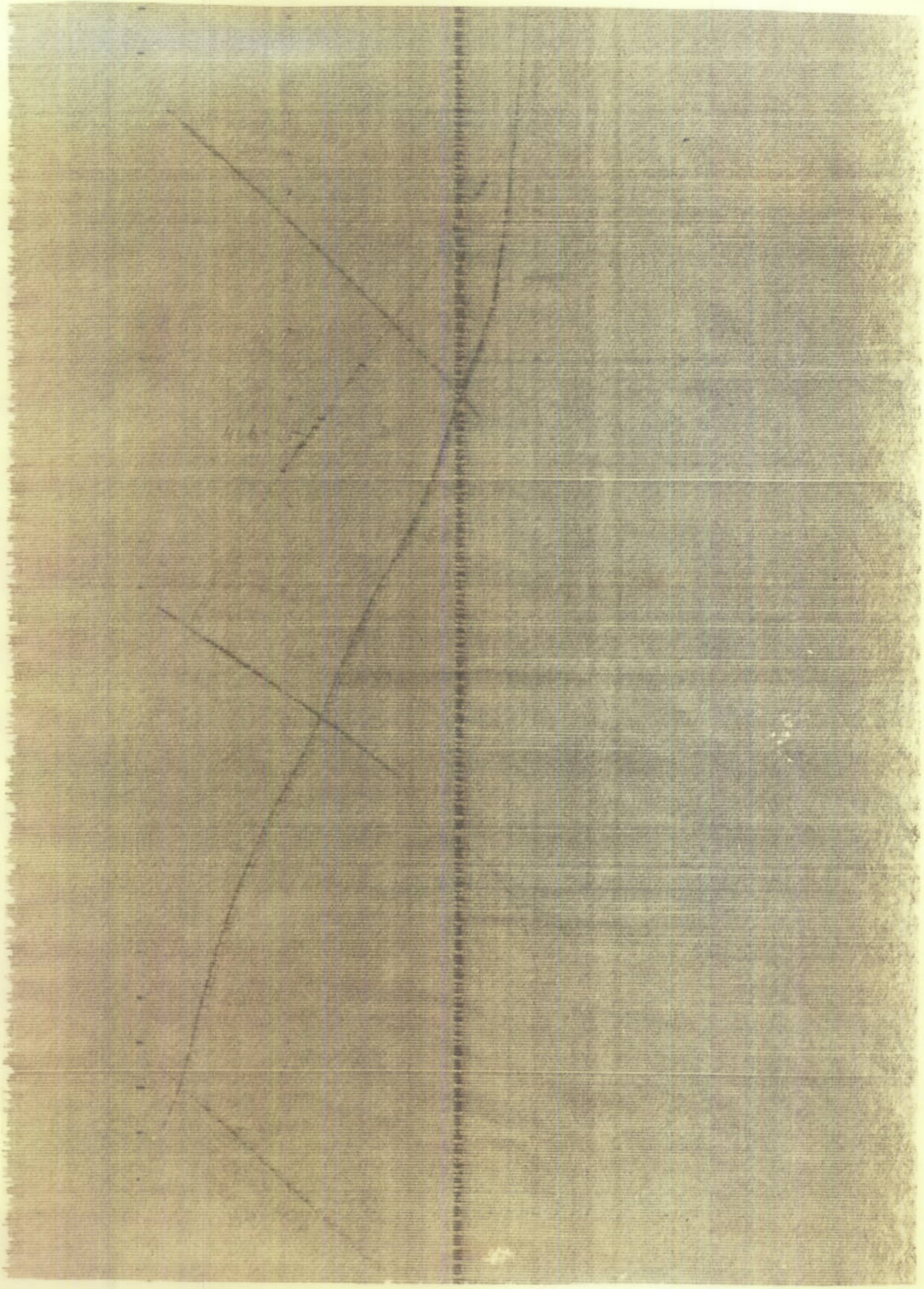

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PLATE 2

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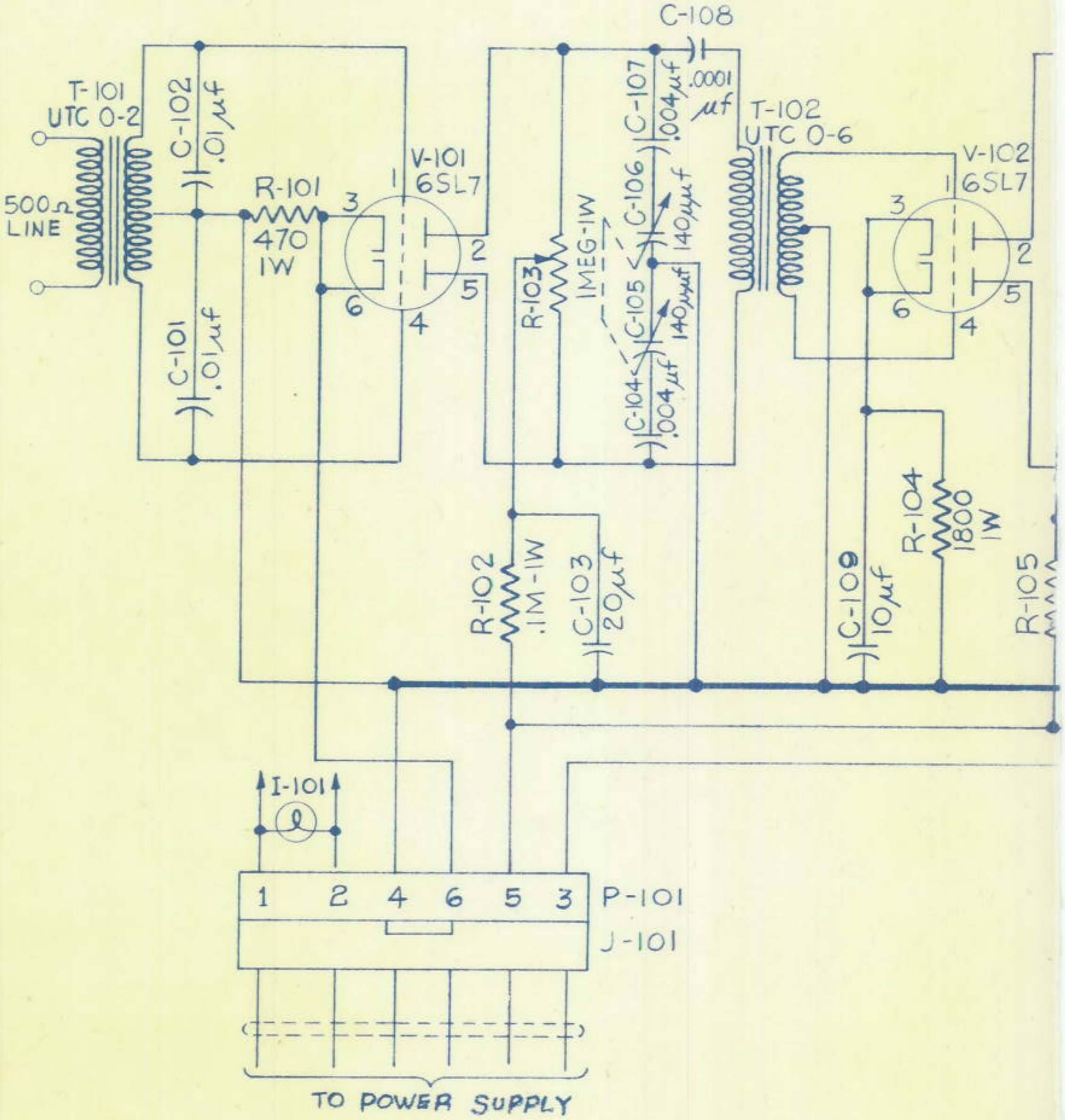
PLATE 3



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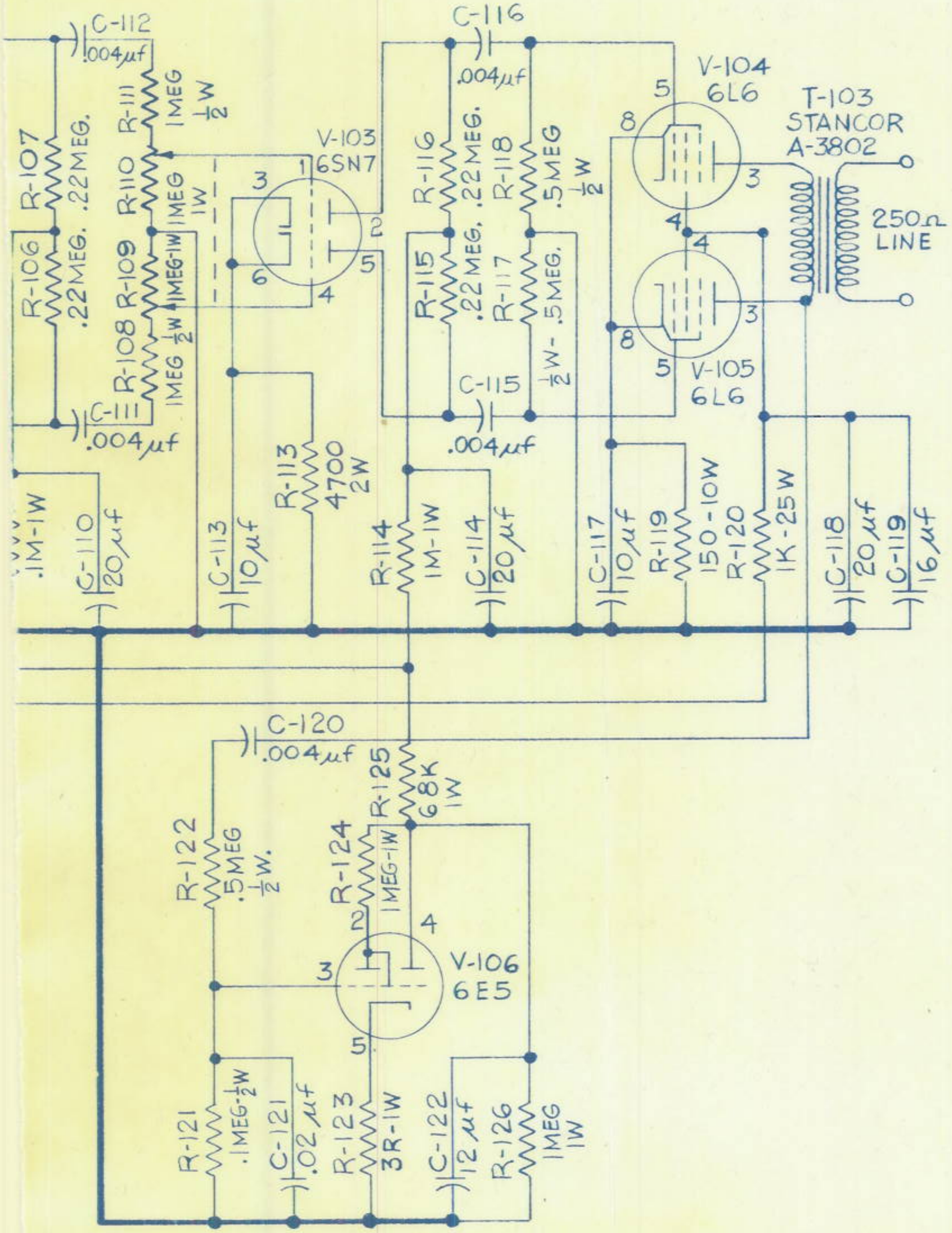

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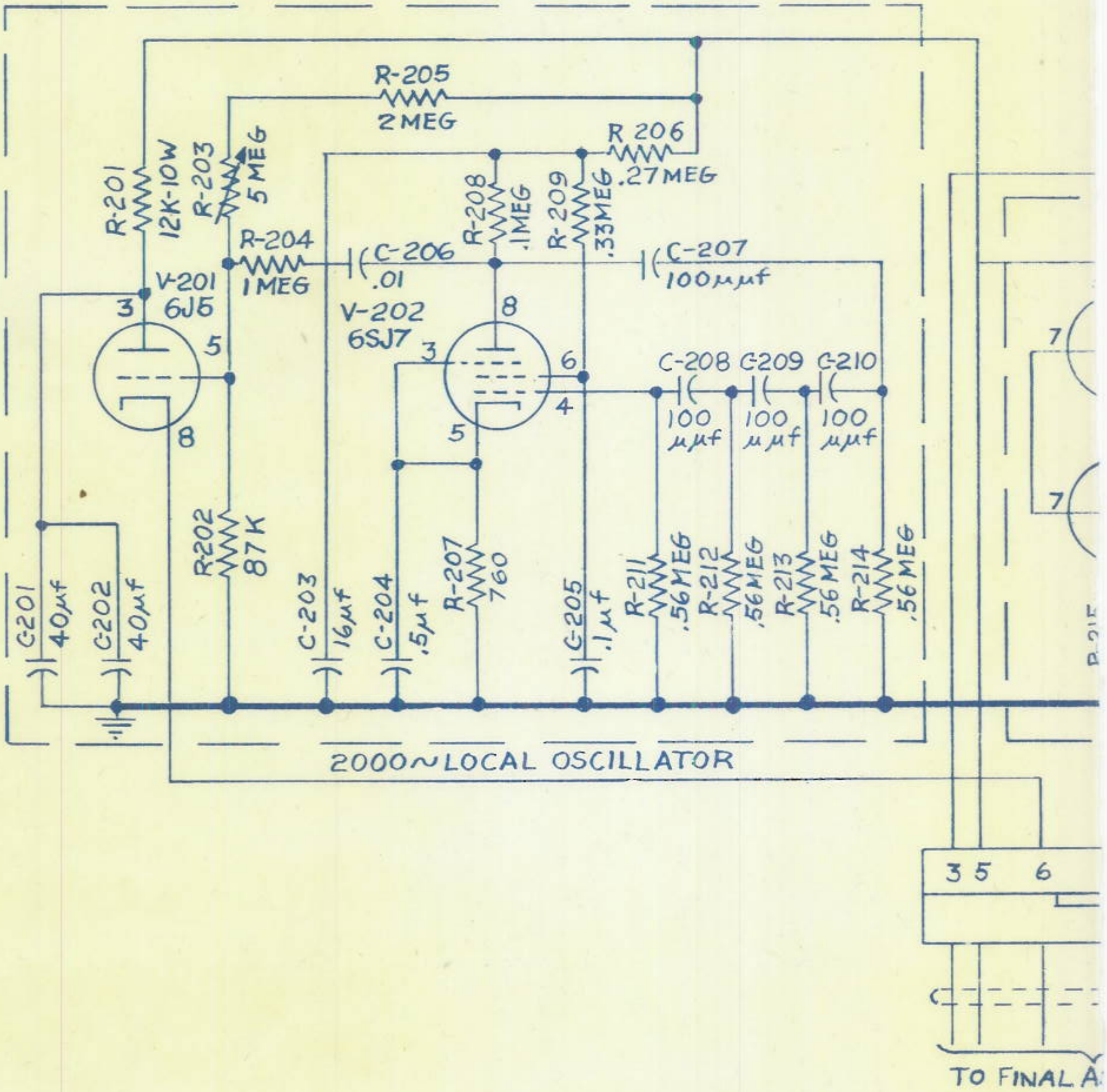
PLATE 8



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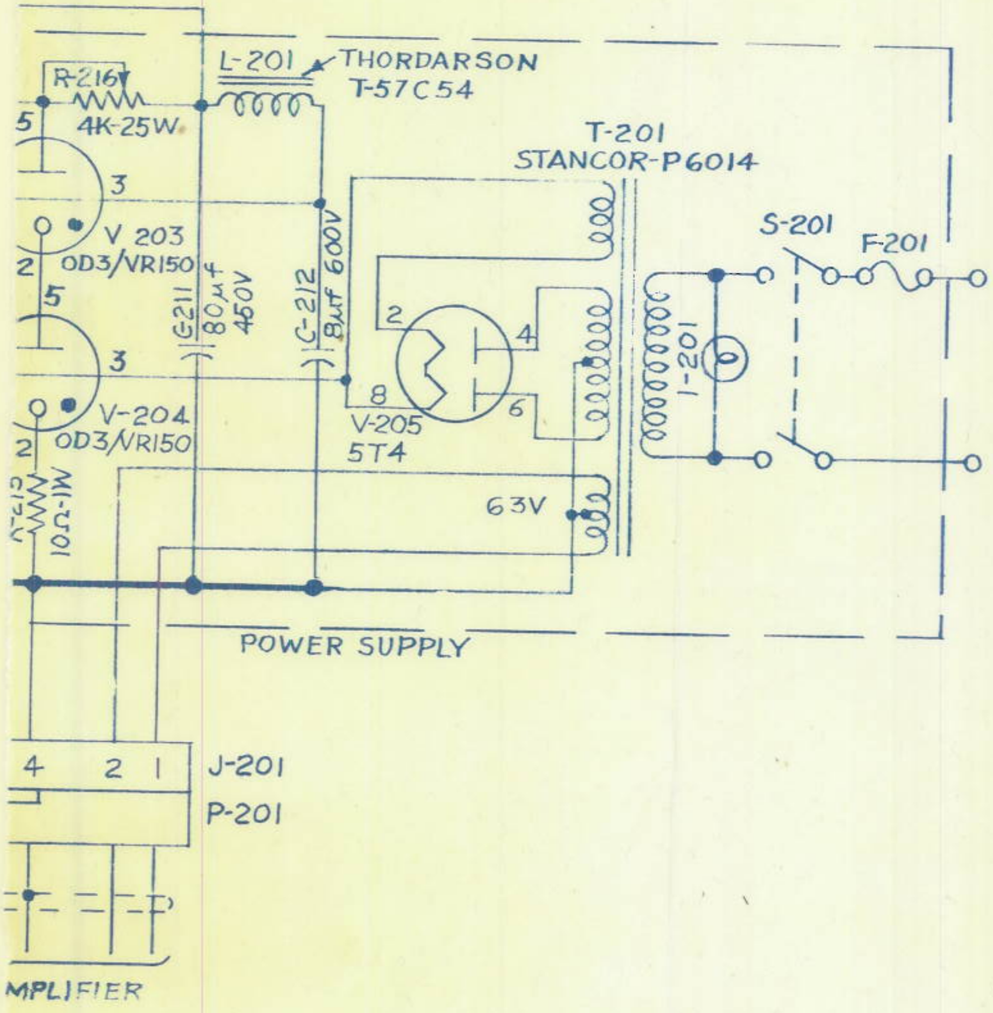
R-216
4K-25W
L-201
THORDARSON
T-57C54
T-201
STANCOR-P6014
5
3
2
V 203
OD3/VR150
5
3
2
V-204
OD3/VR150
C211
80µf
450V
C-212
8µf 600V
2
4
8
6
V-205
5T4
S-201
F-201
I-201
63V
10K-1W
POWER SUPPLY
4
2
1
J-201
P-201
MPLIFIER

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PLATE 9

OPTICAL PARAMETERS

(Not to scale)

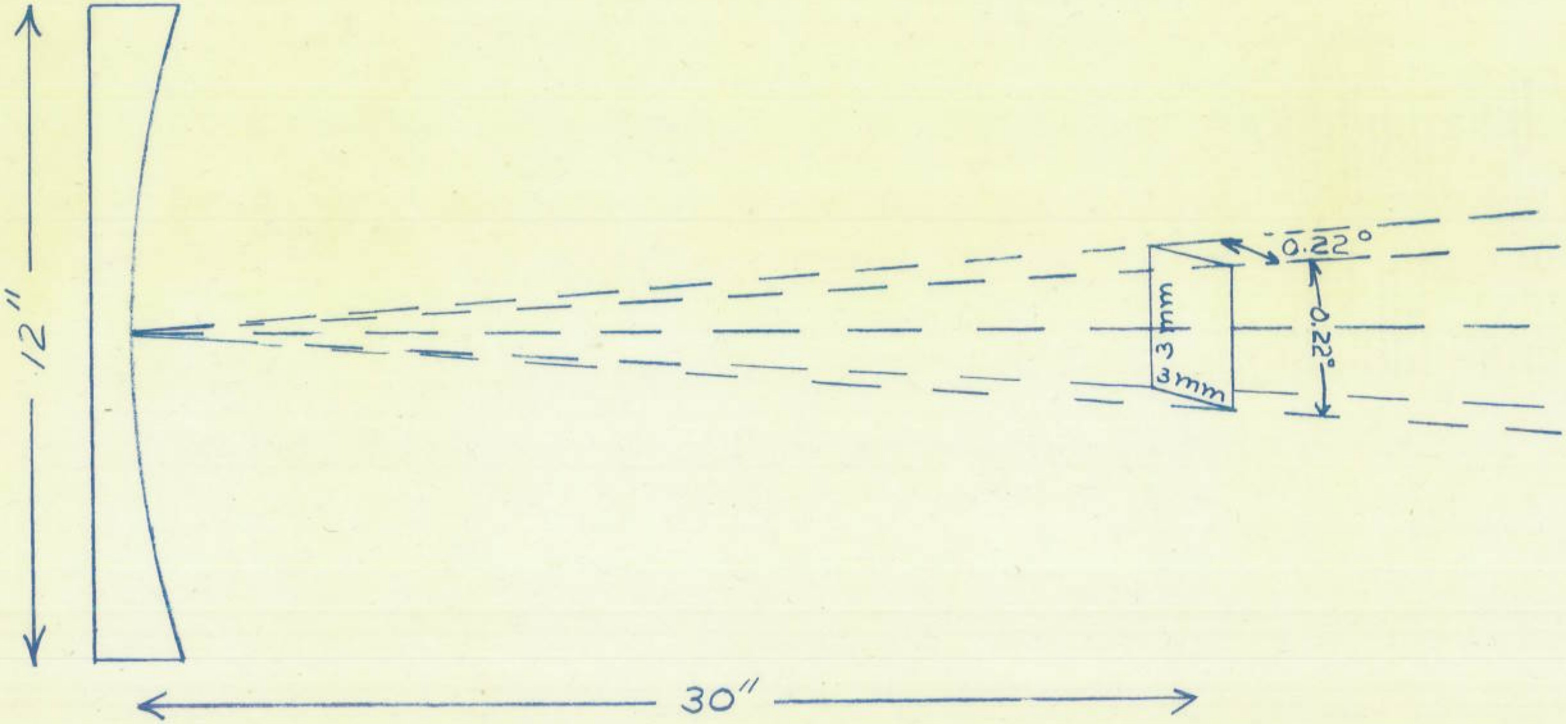

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PLATE 4

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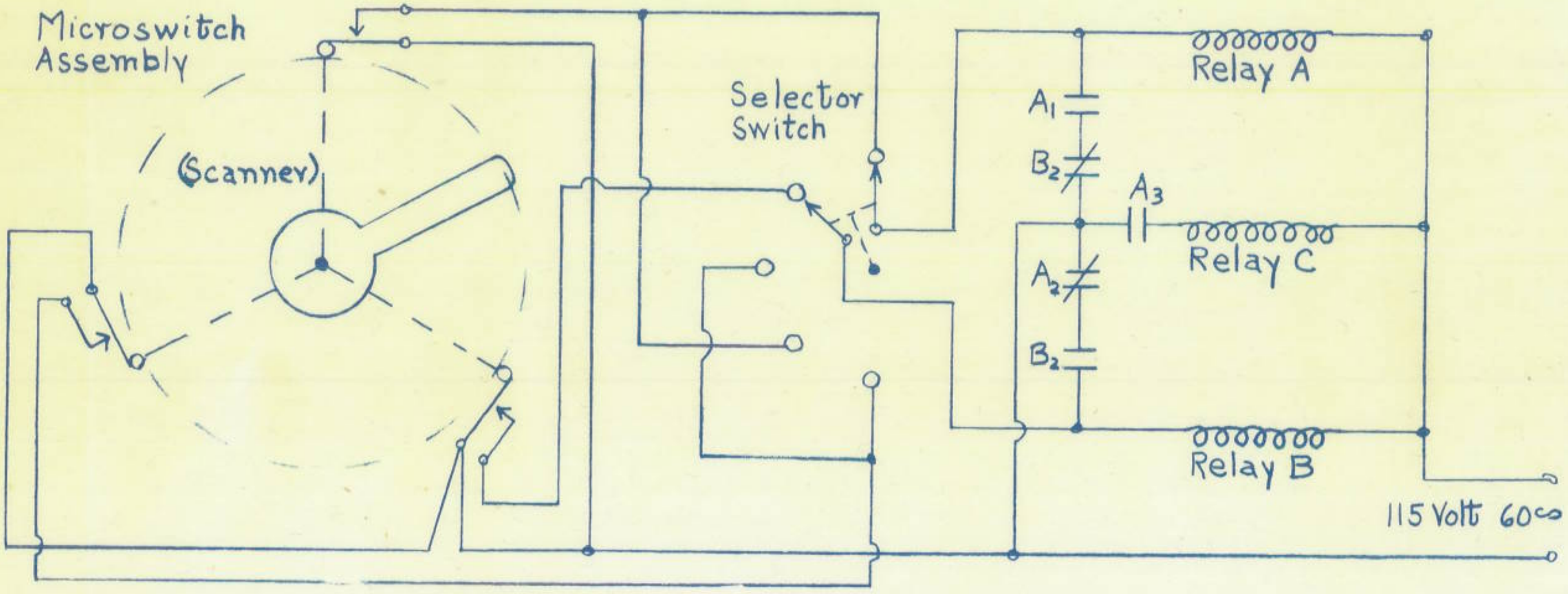
SECTOR SELECTOR



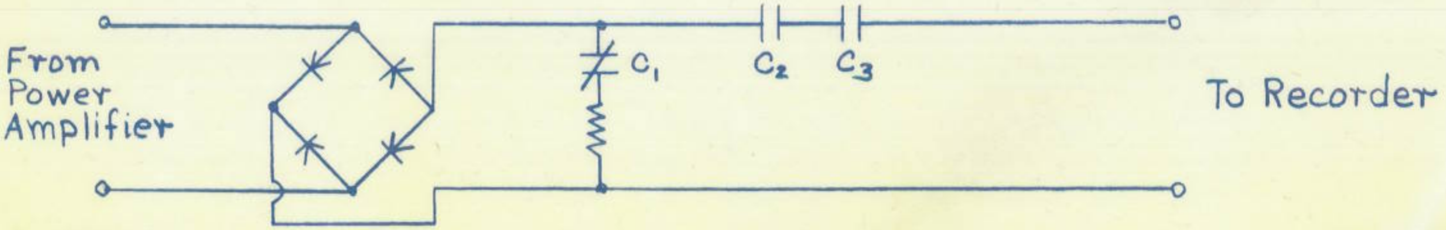


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PLATE 5

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[redacted]

130 CPS PRE-AMPLIFIER

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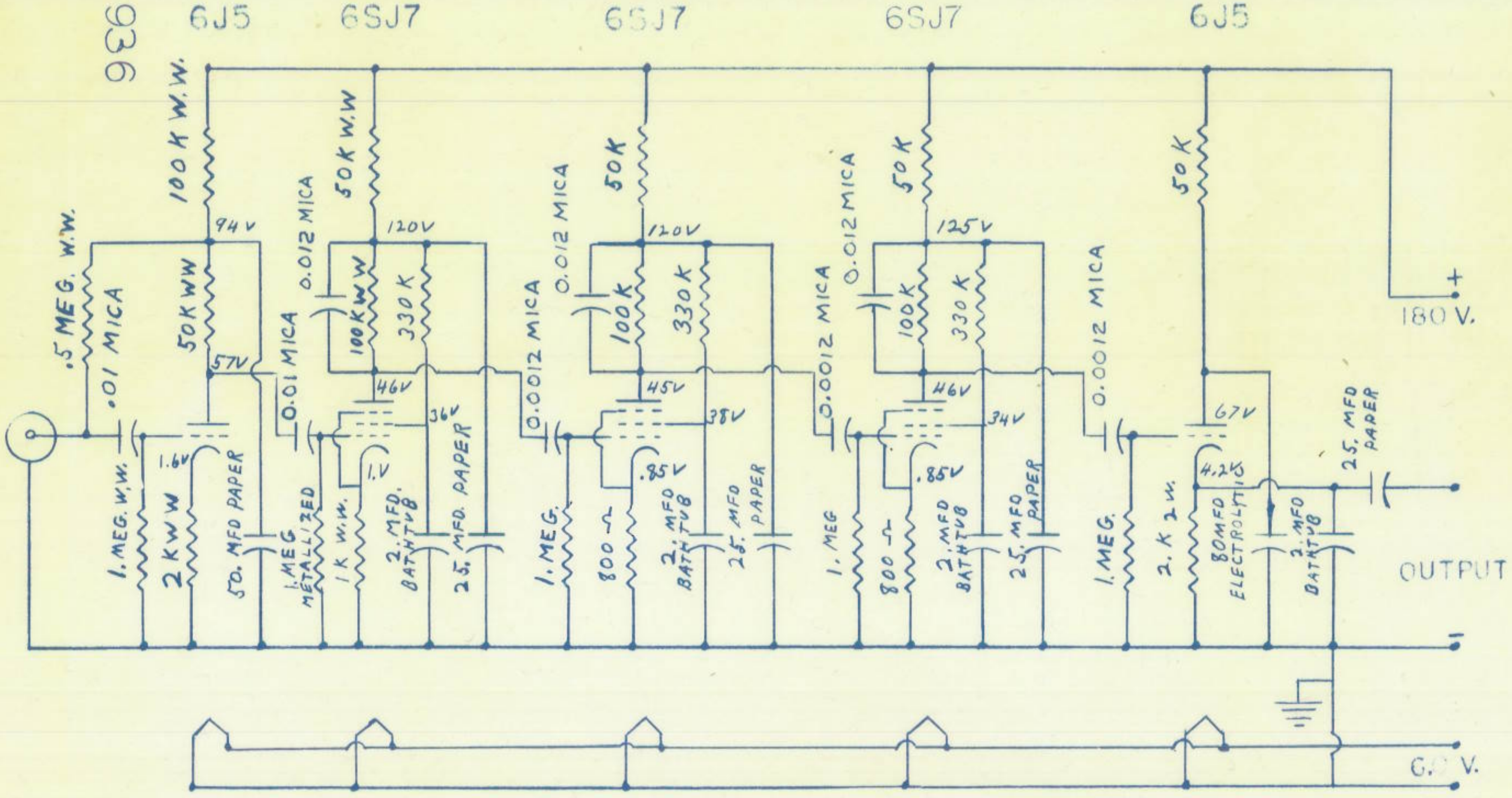
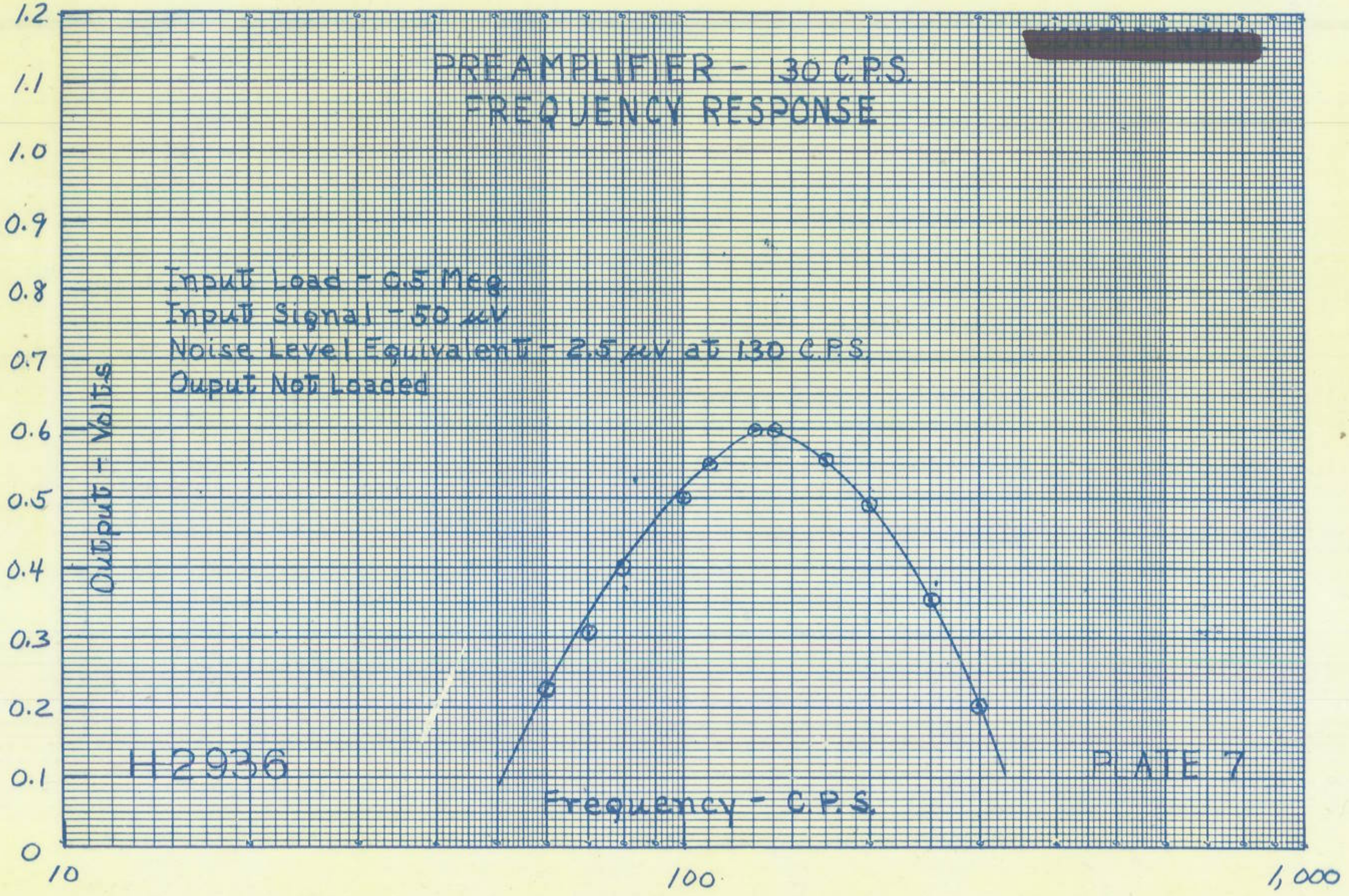


WW = WIRE WOUND

PLATE 6

[redacted]



PREAMPLIFIER - 130 C.P.S.
FREQUENCY RESPONSE

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PLATE 7

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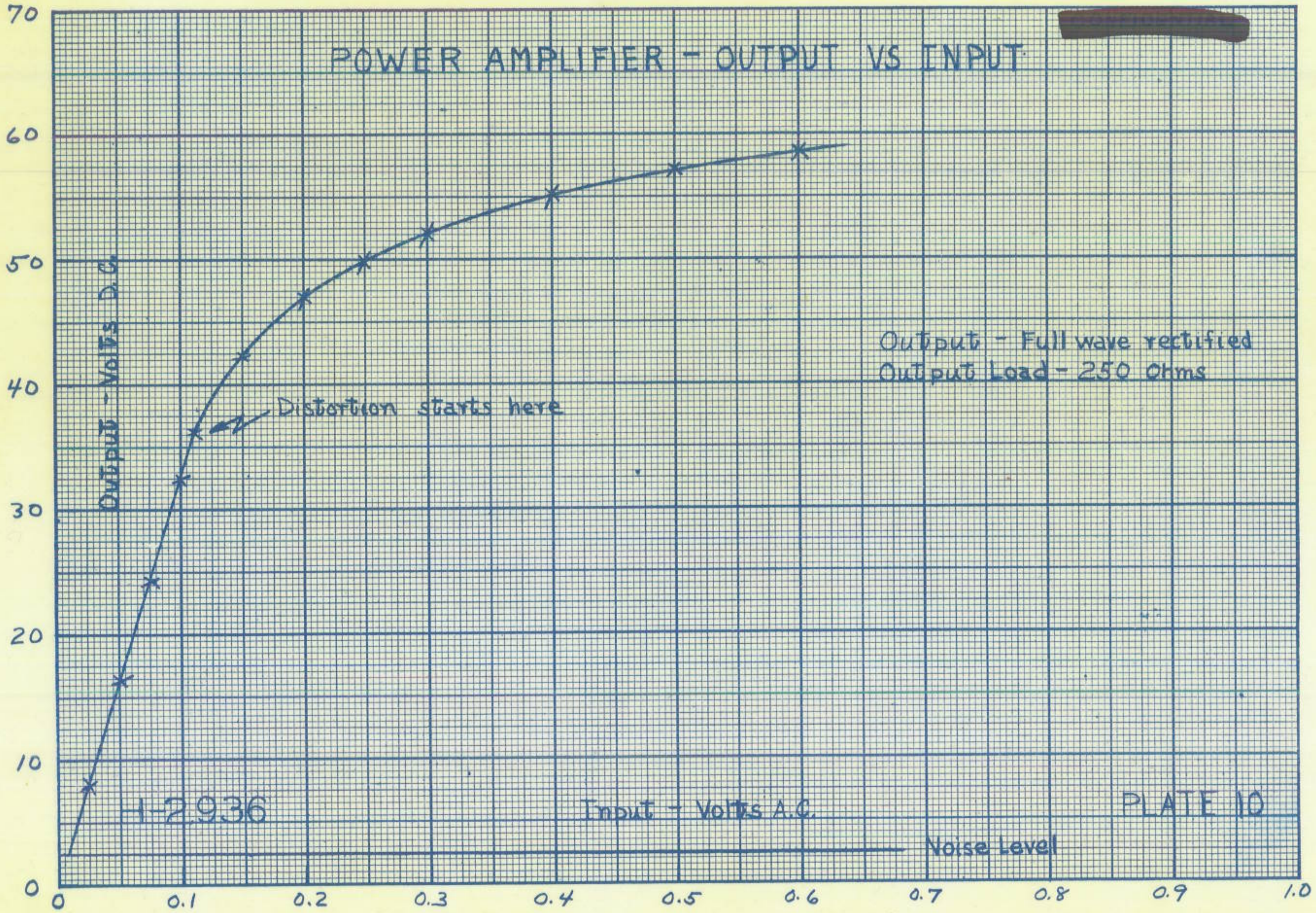
[redacted]



POWER AMPLIFIER - OUTPUT VS INPUT

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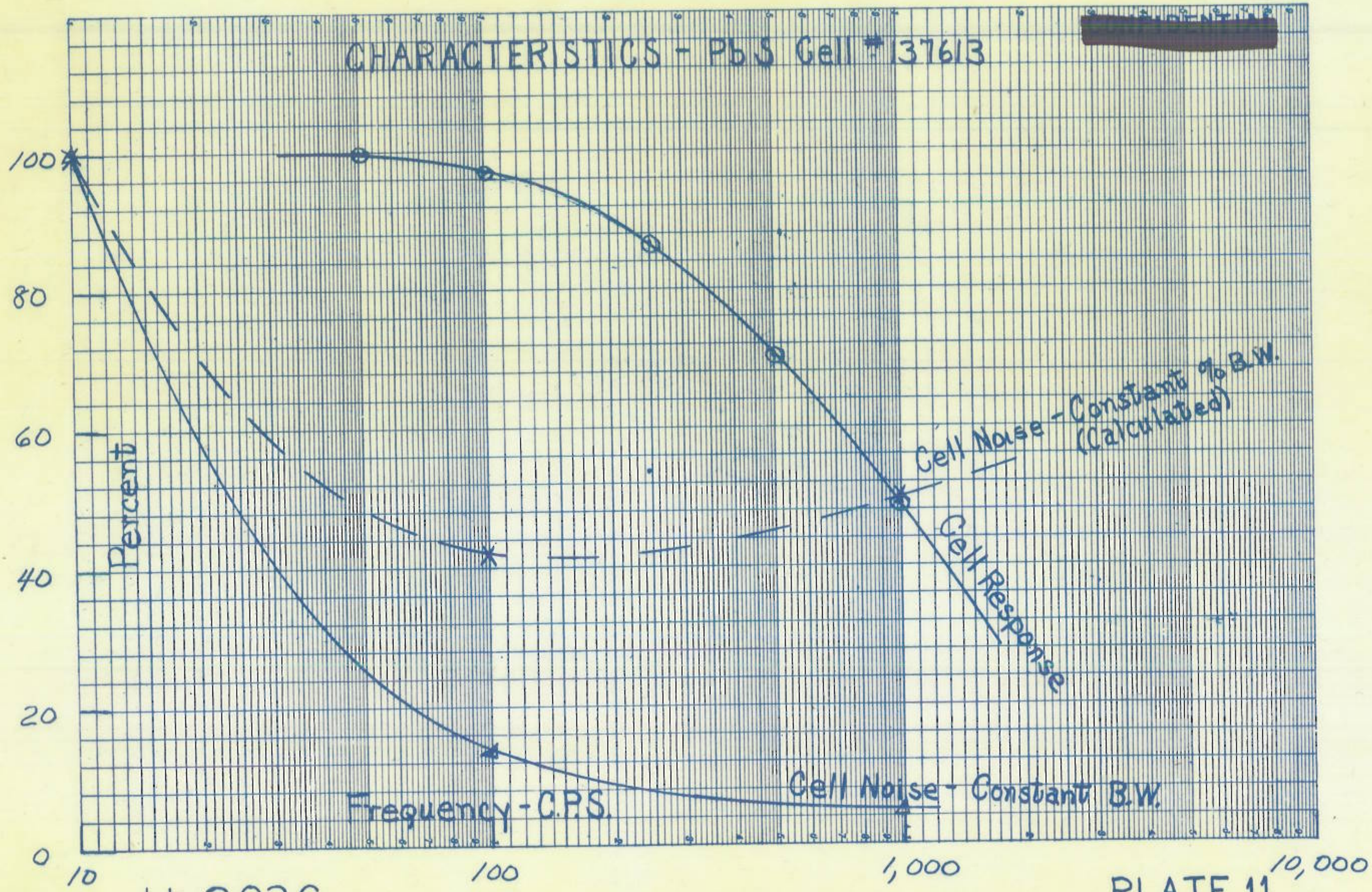
PLATE 10

[redacted]



CHARACTERISTICS - PbS Cell #137613

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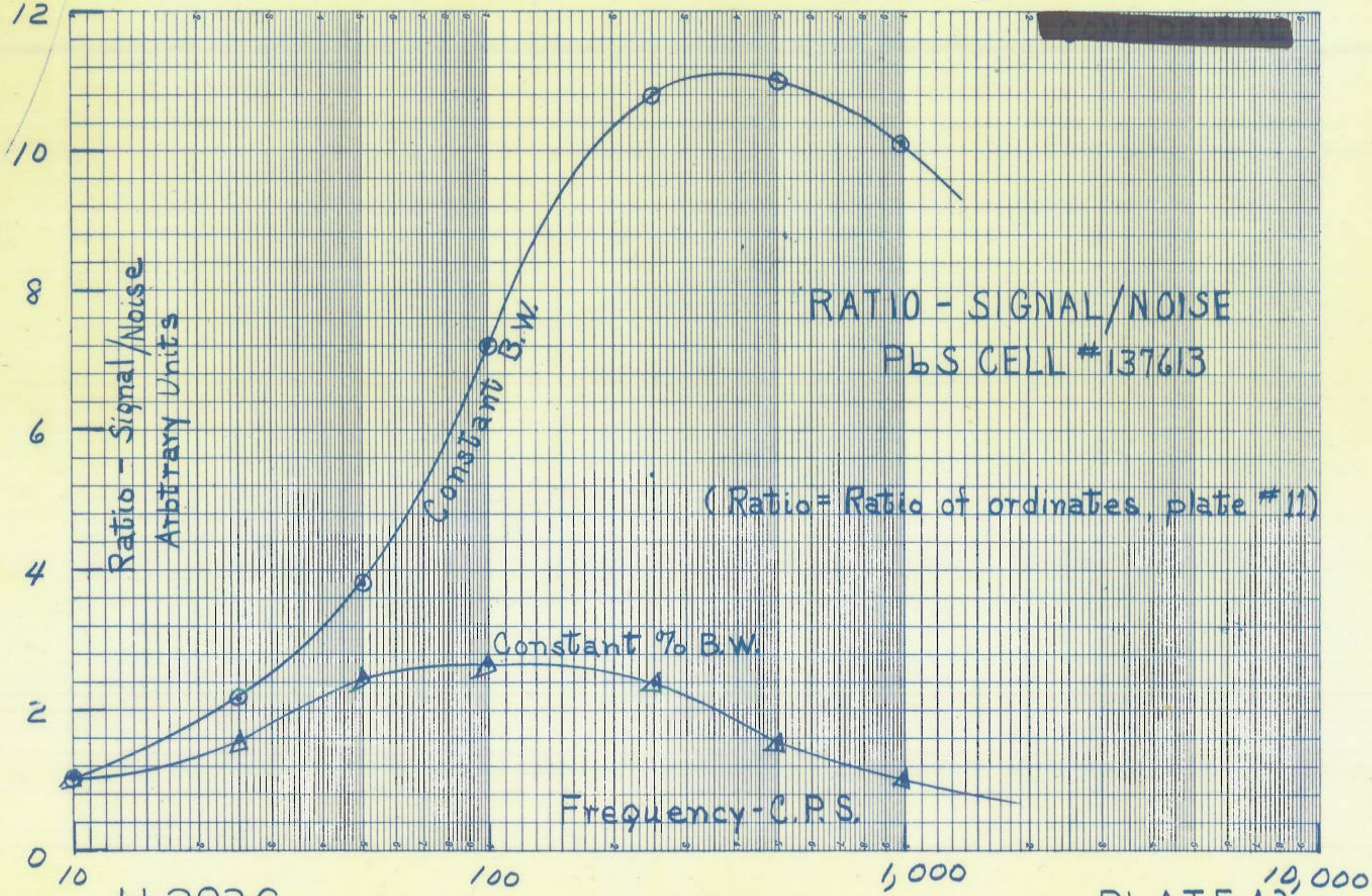
PLATE 11

[redacted]



RATIO - SIGNAL/NOISE
PbS CELL #137613

(Ratio = Ratio of ordinates, plate #11)

H-2936

PLATE 12

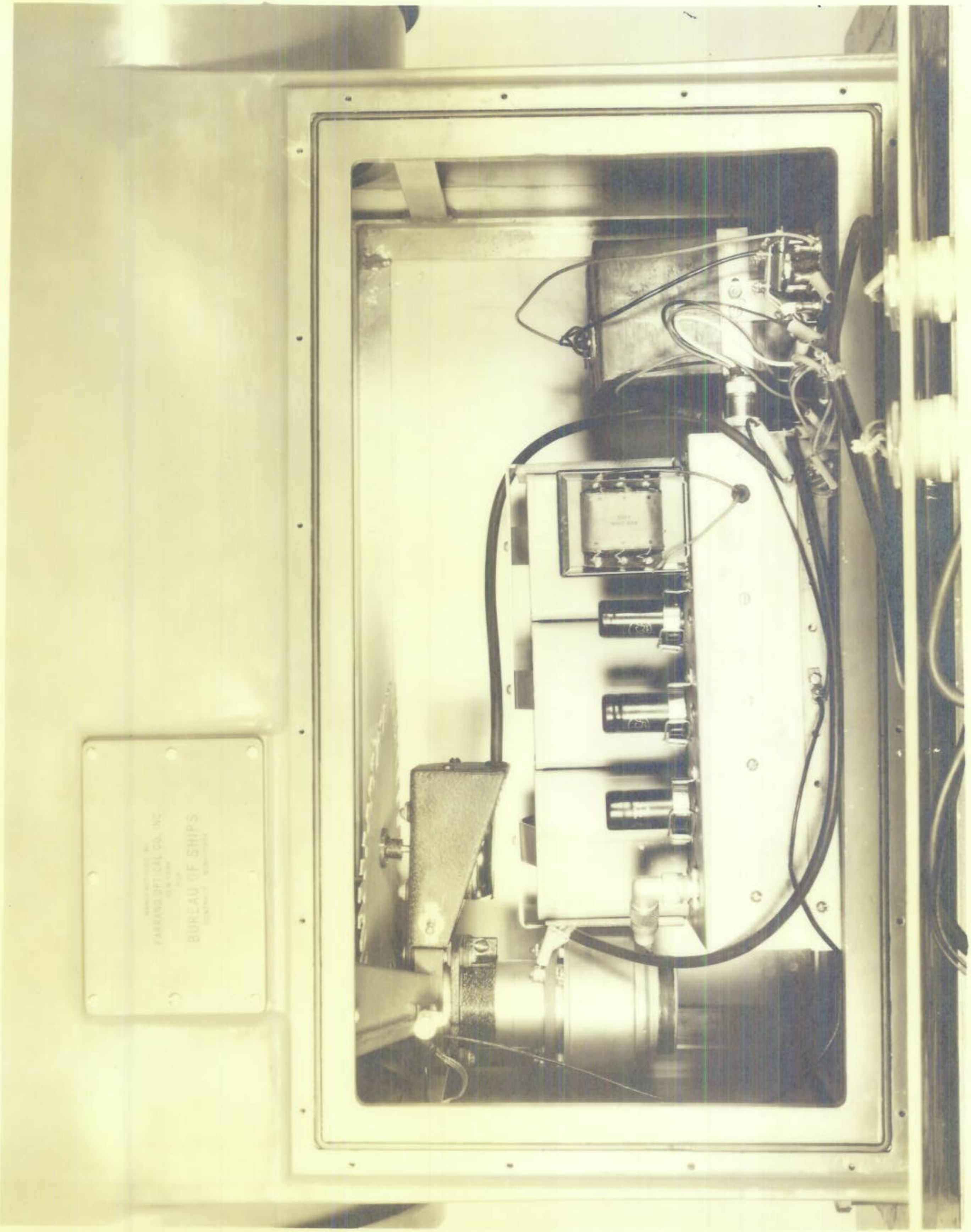


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PLATE 13

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1000 C.P.S. PREAMPLIFIER

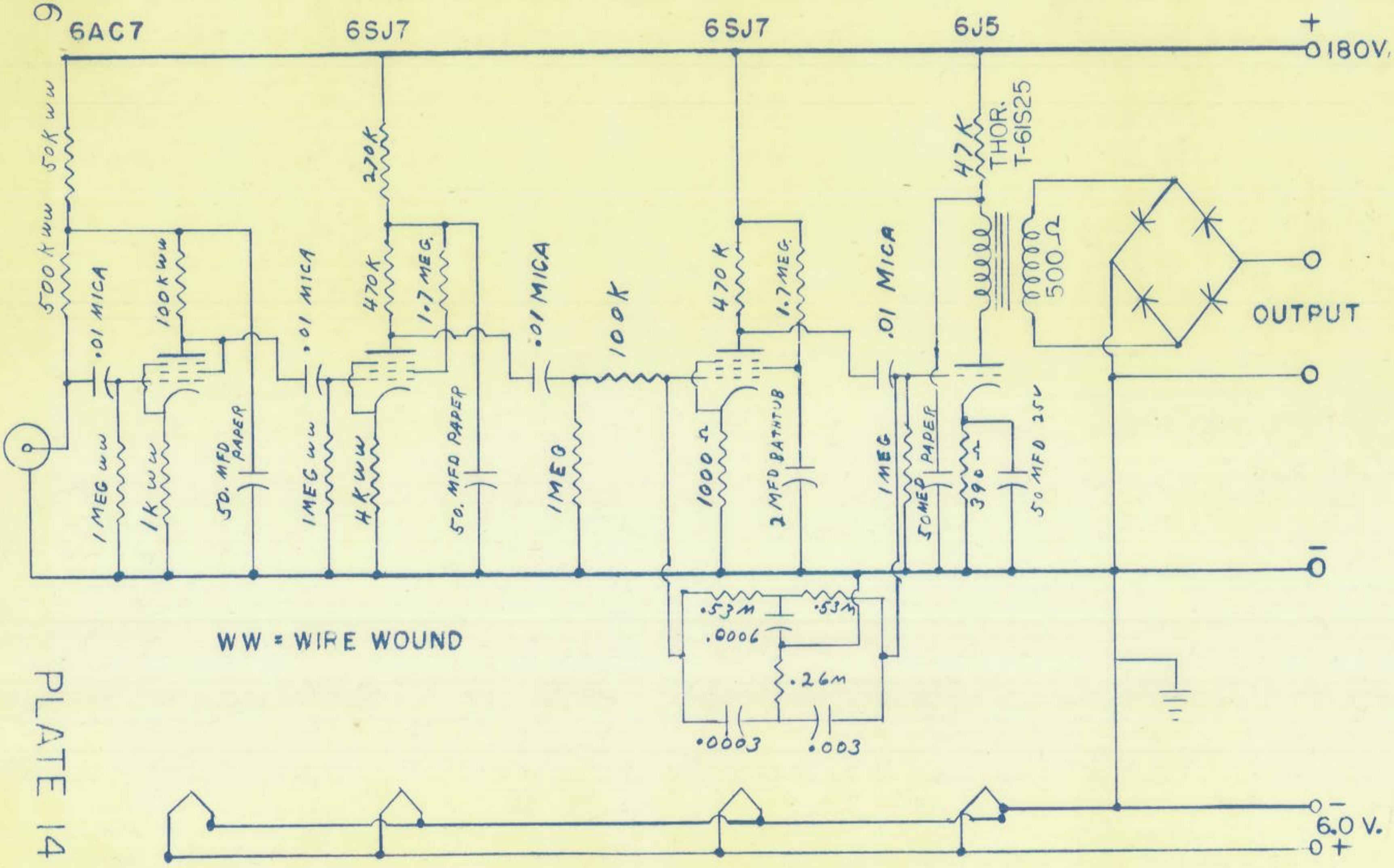

PLATE 14

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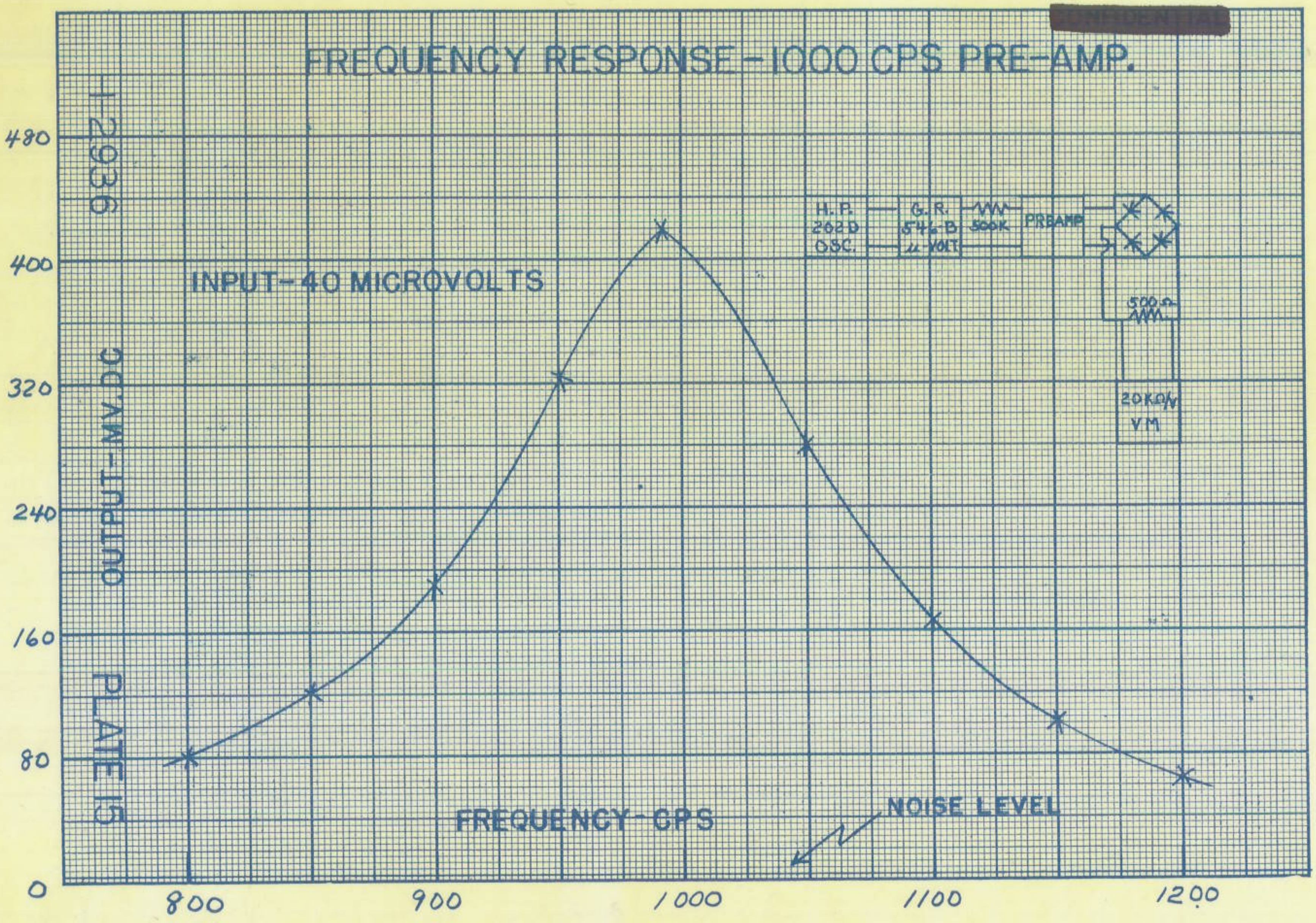
[redacted]



FREQUENCY RESPONSE-1000 CPS PRE-AMP.

I-2936

PLATE 15