

DECLASSIFIED

COPY NO. 29

Navy Department - Office of Research and Inventions

NAVAL RESEARCH LABORATORY
Washington, D. C.

* * *

PHYSICAL OPTICS DIVISION - ENGINEERING DEVELOPMENT SECTION

12 July 1946

DECLASSIFIED by NRL Contract

Declassification Team

Date: 18 Nov 2014

Reviewer's name: A. THOMPSON,

P. HANNA

Declassification authority: NAVY DECLASS

GUIDE, 11 DEC 2012; NAVY DECLASS MANUAL,

11 DEC 2012; DS SERIES

FR-2895

A 5 C.P.S. AMPLIFIER FOR USE
WITH THE PASSIVE BEARING FINDER
(FINAL REPORT)

By H. L. Clark

Report H-2895

UNCLASSIFIED

DECLASSIFIED: By authority of

000 DIR 5200.10
Date

Entered by
* * *

NRL Code

Approved by:

Dr. E. O. Hulburt
Supt., Physical Optics Division

Commodore Henry A. Schade, USN
Director, Naval Research Laboratory

Preliminary Pages ...a-e
Numbered Pages 10
Plates 15
Distribution List ... f

DISTRIBUTION STATEMENT A APPLIES

Further distribution authorized by _____

UNLIMITED only.

DECLASSIFIED

- a -

[REDACTED]

Navy Department - Office of Research and Inventions

NAVAL RESEARCH LABORATORY
Washington, D. C.

* * *

PHYSICAL OPTICS DIVISION - ENGINEERING DEVELOPMENT SECTION

12 July 1946

A 5 C.P.S. AMPLIFIER FOR USE
WITH THE PASSIVE BEARING FINDER
(FINAL REPORT)

By H. L. Clark
Report H-2895

* * *

Approved by:

Dr. E. O. Hulburt
Supt., Physical Optics Division

Commodore Henry A. Schade, USN
Director, Naval Research Laboratory

Preliminary Pages ...	a-e
Numbered Pages	10
Plates	15
Distribution List ...	f

[REDACTED]

DECLASSIFIED

ABSTRACT

A 5-cycle amplifier for use with the Passive Bearing, a thermal detector for use by submarines, was developed by this Laboratory and is now in production by the Raytheon Mfg. Co. The amplifier, which peaks at 5 c.p.s., has an equivalent rectangular band width of 1.9 cycles, an input impedance of 5 ohms, a noise level equivalent to an input signal of 7×10^{-10} volts, and a relaxation time of 0.4 seconds. Signals are presented aurally as the frequency modulated output of a local oscillator. An input signal of 2×10^{-9} volts is easily recognizable. The entire amplifier operates from a 115-volt, 60-cycle supply.

DECLASSIFIED

- b -

TABLE OF CONTENTS

	Page
Abstract.....	b
Chapter 1 - Introduction.....	1
Chapter 2 - The Preamplifier.....	3
Chapter 3 - The Input Transformer.....	4
Chapter 4 - The Input Tube.....	5
Chapter 5 - The Parallel-T Filter.....	6
Chapter 6 - The Final Amplifier.....	8
Chapter 7 - The Power Supply.....	9
Chapter 8 - The Overall Performance.....	10

Plates

Photo of Complete Amplifier.....	1
Wiring Diagram of Preamplifier.....	2
Wiring Diagram of Low Pass Filter.....	3
Frequency Response of Low Pass Filter.....	4
Frequency Response of Preamplifier.....	5
Photo of Thor and U.T.C. X-former.....	6
Frequency Response of X-former.....	7
D.C. Saturation of X-former.....	8
Sketch of Tube for Minimum Flicker Noise.....	9
Wiring Diagram of Parallel-T Filter.....	10
Wiring Diagram of Final Amplifier.....	11
Frequency Response of Final Amplifier.....	12
Wiring Diagram of Power Supply.....	13
Frequency Response of Entire Amplifier.....	14
Build Up and Decay Traces for Entire Amplifier.....	15

CHAPTER 1

INTRODUCTION

Authorization: BuShips ltr S-S67-12(660E-330), Serial 003822 dated 2 Oct. 1945.

The Passive Bearing Finder is a periscope mounted thermal detector for use on submarines against surface ships. As originally developed by the Research Laboratories Division of the General Motors Corporation, it consisted of a wire thermopile mounted in an oscillating optical system. The thermopile was of the compensated type manufactured by the Eppley Laboratories and so mounted in the optical system as to have first one receiver then the other receiver irradiated through the motion of the optical system.

The rate of irradiation was five times per second. The output voltage from the thermopile, of course, varied at the same rate. This signal was then fed into a standard General Motors breaker type D. C. amplifier, the filtered output of which frequency modulated a local oscillator whose signal was presented aurally.

There were a number of objections to this system most of which centered around the amplifier. The three basic ones were:

(a) The internal noise level of the amplifier was greater than the thermal agitation noise level in the thermopile with which it was employed and hence prevented complete realization of the full sensitivity of the entire system.

(b) The D. C. compensating circuit in the input of the amplifier had to be readjusted continually to compensate for thermal drift and to prevent saturation of the input transformer.

(c) The amplifier's breaker contacts became noisy after prolonged periods of operation.

Under these circumstances, it was advisable to investigate the possibilities of a straight A. C. amplifier tuned for 5 cycles per second.

Accordingly, this Laboratory was requested by the Bureau of Ships to undertake the development of such an amplifier. The general requirements were as follows:

- (a) Amplifier must be tuned at 5 c.p.s.
- (b) Input impedance should be 5 ohms.
- (c) Signal presentation should be similar to that employed in the General Motors system - the aural presentation of the output of a frequency modulated local oscillator.
- (d) The internal noise level of the amplifier should be low enough to permit recognition of a signal level of 2×10^{-9} volts from a 5 ohm input load.
- (e) An auxiliary source of D. C. power rated at 6.0 volts, 0.25 amperes should be incorporated into the amplifier's power supply to drive the oscillating optical system.

(f) The entire unit should operate from a 115-volt, 60 cs, power bus.

Such an amplifier was developed by this Laboratory and is now being manufactured for the Bureau of Ships by the Raytheon Manufacturing Co. of Waltham, Mass.

The complete amplifier is shown in Plate 1. It consists of a preamplifier and final amplifier mounted in a single cabinet; a power supply in a second cabinet; and a voltage regulating power transformer.

DECLASSIFIED

CHAPTER 2

THE PREAMPLIFIER

The preamplifier, whose wiring diagram is shown in Plate 2, is designed to work from a 150-volt regulated B-supply and a rectified filament supply. Each stage is heavily decoupled with the decouplers acting both as filters and isolators. R-C networks are employed for this purpose. The condensers are special 150-volt paper units. Electrolytics could not be employed because their leakage currents are rich in low frequency harmonics. They have consequently been omitted entirely in the preamplifier. Because of the prohibitive physical size of paper cathode by-pass condensers, they likewise have been omitted and all cathode resistors remain unby-passed. In the first and second stages, where the signal level is extremely low, wire wound resistors are used thus eliminating current noise.

The input transformer, which is described later, is multiply shielded. However, despite such precautions, there is considerable magnetic pickup both in the transformer and in the input leads. This is predominately 60 cycle and its higher harmonics. To eliminate these, the low-pass filter shown in Plate 3 is employed. The frequency response of this filter is shown in Plate 4. It will be noted from this curve, that the frequencies below 5 c.p.s. are accentuated. This means an increase in flicker noise since it varies as one over the frequency squared. To compensate for this and give partial peaking at 5 c.p.s., the last two stages are under coupled.

The main tuning at 5 c.p.s. is accomplished with a parallel-T network employed degeneratively. This type of filter is described in another chapter of this report. The frequency response of the preamplifier so obtained is shown in Plate 5.

DECLASSIFIED

CHAPTER 3

THE INPUT TRANSFORMER

The specifications for this amplifier called for an input impedance of 5 ohm at 5 c.p.s. which necessitated the use of a special input transformer. Since a transformer of this type was not commercially available, a development contract was entered into by the Bureau of Ships with the Thordarson Electric Manufacturing Co. of Chicago, Illinois for a transformer with the following characteristics:

- (a) Primary impedance - 5 ohms.
- (b) Secondary impedance - 450,000 ohms.
- (c) Turns ratio - 300.
- (d) Operating frequency - 5 c.p.s.
- (e) Primary current - 0 to 1 Ma. D. C.
 10^{-6} Ma. A. C.
- (f) Electrostatic shield between primary and secondary windings.
- (g) Magnetic shielding around entire assembly consisting of four high permeability shields arranged so that magnetic pickup is down 90 decibels.
- (h) Unit to be hermetically sealed.

The Thordarson Company delivered a few such units similar to the one shown in Plate 6 but was forced to discontinue work on the problem because of higher priority commitments. The work was then turned over to the United Transformer Corporation of New York, New York who made some improvements in the design and came out with the unit also shown in Plate 6.

The frequency response of both transformers is shown in Plate 7. These curves were obtained with a Hewlett-Packard 202-D oscillator and a Dumont 208-B oscilloscope both of which operate down to 2 cycles per second. A special amplifier was constructed to measure the voltage, E_2 . It is obvious from these curves that the U. T. C. transformer is slightly better than the Thordarson unit.

Measurements were also made of the D. C. saturability of these transformers. The results are shown in Plate 8. Here again the superiority of the U. T. C. unit is apparent.

As a result of these and other tests the U. T. C. transformers were accepted for use in the subject amplifier. These same transformers in a slightly modified form have subsequently found uses elsewhere¹.

DECLASSIFIED

CHAPTER 4

THE INPUT TUBE

The effective gain of the input transformer is determined to a considerable extent by the secondary loading - the greater the impedance of the secondary load; the greater the effective gain of the transformer. Therefore, for optimum conditions, the grid input impedance of the input tube should be as high as possible. To obtain this in the conventional manner would mean employing cathode bias of some critical value or battery bias which is impractical for shipboard use. Measurements² show, however, that the internal low frequency noise in vacuum tubes, which is known as flicker (not shot), increases rapidly with the size of the cathode bias resistor. These same measurements² and others^{3,4} show, however, that a high grid input impedance can be obtained with minimum flicker noise by operating the vacuum tube as shown in Plate 9. Here a cathode resistance value of zero together with no grid leak resistance are employed. The condenser in series with the grid circuit assumes a charge which provides an optimum bias which in turn provides both high input impedance and minimum flicker noise. Input impedance of from 10 to 15 megohms have been measured on a 6J5 (triode). Some pentodes provide up to 30 or 40 megohms. The resistance across the series condenser in Plate 9 keeps the condenser discharged. Measurements² also indicate that the flicker noise can be reduced considerably by employing very small values of plate supply voltage. Several thousand hours of operation have verified these results.

Full advantage is taken of these facts in this preamplifier as can be seen from Plate 2. The input tube is operated without a grid leak and zero cathode resistance. The series condenser in the grid circuit is a 1.0 microfarad bathtub condenser shunted by a twenty megohm discharge resistor. Because of the high impedance involved, the secondary terminals of the transformer, the series condenser and its shunting resistor, and the input tube socket are coated with coil dope to prevent moisture, which forms on these units in the field from shunting them and thus introducing noise into the amplifier. Experience has shown that this is necessary. The plate voltage on the input tube is very low being 17 volts. Under these conditions the maximum possible gain of the tube is not realized. However, the internal flicker noise is very low. The gain of this tube is just high enough so that the noise contributed by the second tube is only a fraction of the output of the first tube.

Despite all these precautions, the inherent noise level in the amplifier arises in the input tube. It is between one and two times greater than the thermal agitation noise level in the 5 ohm input load.

DECLASSIFIED

CHAPTER 5

THE PARALLEL-T FILTER

Considerable⁵ has been written about the parallel-T filter. However, the most complete information can be found in an unpublished Bell Telephone Laboratory memorandum⁶.

The parallel-T filter is a modified Wien Bridge. It consists of a low pass filter and a high pass filter in parallel. Plate 10 shows the conventional filter. Theoretically, when the resistive and capacitive parameters bear the algebraic relationship to each other shown in Plate 10, then there is a null frequency, f_0 , which the filter will not pass where

$$f_0 = \frac{1}{2\pi RC} \quad D = 3.1416$$

In practice the R's and C's have to be closely matched otherwise the balance or nullpoint will not be sharp. Usually the C's are matched within 1%. The R's are rheostats which are set up with an ohmmeter as closely as possible with the final adjustment or balance being made with an oscillator and high impedance voltmeter or oscilloscope. At the null frequency, f_0 , the input impedance, Z_0 , of the filter is

$$Z_0 = \frac{R}{\sqrt{2}}$$

At lower frequencies it is higher; at higher frequencies, lower.

In the subject amplifier, the filter is employed degeneratively as shown in Plate 2. Under these conditions all frequencies but the null frequency are fed back degeneratively. This results in only the null frequency, f_0 , being amplified. Sharpest tuning is obtained when the filter works out of a relatively low impedance into a relatively high impedance. In practice, the input impedance, Z_0 , is usually made at least twice as large as the plate load resistance of the tube with which the filter is employed. Since a tube usually precedes the stage in question it will overload the filter and must be isolated from it by a series resistor in the grid circuit. The size of this series resistor determines the sharpness of tuning of the filter-tube combination. If conditions are such as to provide maximum sharpness of tuning, then the fractional band width of the filter-tube combination is

$$\frac{\Delta f}{f_0} = \frac{1/\sqrt{3}}{G}, \quad \frac{\Delta f}{f_0} \ll 1$$

where G = gain of tube without feedback,
 Δf = band width between half voltage points
 f_0 = resonant frequency

Referring to Plate 10, the values chosen for R and C for a null at 5 c.p.s. are 0.02 microfarads and 1.6 megohms. At the null frequency, $f_0 = 5$ c.p.s., the input impedance is

$$Z_0 = \frac{1.6}{\sqrt{2}} = 1.1 \text{ megohms.}$$

From Plate 2, it can be seen that the section of the 6SL7 with which the filter is employed has a load resistance of 0.47 megohms. Hence, the filter does not load down the tube appreciably at the resonant frequency. The load on the filter is provided by the 5 megohm resistance in the grid circuit (assuming that the grid input impedance is much greater) which isolates the filter from the preceding stage and prevents that stage from overloading same.

Assuming that the conditions for maximum sharpness of tuning are therefore met, the fractional band width of the filter-tube combination is (measured gain of tube = 28)

$$\frac{\Delta f}{f_0} = \frac{4\sqrt{3}}{28} \approx \frac{1}{4}$$

which gives a band width between the half voltage points of 1.3 c.p.s. ($f_0 = 5$ c.p.s.). From Plate 5, it can be seen that the band width for the entire preamplifier is 1.7 c.p.s. This is determined somewhat by the low pass filter and under coupling. However, if this is ignored, the agreement between calculated and measured results can be considered fair.

DECLASSIFIED

CHAPTER 6

THE FINAL AMPLIFIER

The wiring diagram of the final amplifier is shown in Plate 11. It is a conventional RC coupled unit. Broad tuning at 5 c.p.s. is obtained with a low pass filter (Plate 3 and 4) and slight under coupling between stages. The frequency response of the final amplifier as observed at the grid of the local oscillator is shown in Plate 12.

The local oscillator (884) is of the relaxation type. The variable cathode resistor, which is a screw driver adjustment, is set to provide a normal 800 c.p.s. output from the oscillator. Any signal applied to the grid of the oscillator causes its frequency to swing about the 800 c.p.s. point. A signal is, therefore, heard as a change of pitch in the earphones. Unfortunately, the signal causes the amplitude of the aural note to vary also.

The eye tube is employed as an indication of the noise level of the entire system. Since most signals are down in the noise, it is imperative that the noise level be maintained as constantly low as possible. It is difficult to determine the output level with the earphones, hence, the eye is employed.

DECLASSIFIED

CHAPTER 7

THE POWER SUPPLY

The wiring diagram of the power supply is shown in Plate 13. It supplies 6.3 volts A. C. for filaments and 300 volts unregulated D. C. for plates to the final amplifier; 31.5 volts D. C. for the filaments in series and 150 volts regulated D. C. for the plates to the preamplifier; and 6 volts at 250 milliamps to the oscillating motor in the optical system.

Experience has shown that the power supply for the oscillating motor should be isolated from the rest of the power supply because of the cyclic nature of the load. For this reason, two separate low voltage supplies are provided - one for the preamplifier filaments, the other for the oscillating motor. Combining these two channels results in feedback from the oscillating load which causes the entire amplifier to oscillate.

The voltmeter with selector switch is provided for servicing purposes. As can be seen from Plate 13, it provides a check on line voltage, plate voltage for the final amplifier, plate voltage for the preamplifier, filament voltage for the preamplifier, and oscillating motor voltage. A check on the oscillating motor voltage is almost a necessity for the commutator segments of the motor tend to get dirty and short against each other. The result is a current drain in excess of 0.25 amperes which drops the supply voltage and hence, causes the motor to slow down. This means, of course, that the optical system is wobbled at a frequency lower than 5 c.p.s. which reduces the sensitivity of the entire system. Although it is not a part of this project, it is suggested that another type of oscillator motor be employed, preferably a 400 c.p.s. synchronous aircraft unit. A 60 c.p.s. unit would only introduce additional hum pickup into the system.

The regulating transformer provides a constant line voltage. It does not remove line transients such as the closing or opening of power switches produces. A recent test at the Bureau of Ships Test Station, Lewes, Delaware, showed that the line transients produced by a coded beacon (Navy Type X2A) upset the power supply sufficiently to make the amplifier system inoperable. The line dip in this case was 4 volts. If the amplifier system must operate under such conditions on shipboard, an electronically regulated power supply is necessary. The Raytheon Mfg. Corp., who are manufacturing this unit, are providing such a regulated power supply.

DECLASSIFIED

CHAPTER 8

THE OVERALL PERFORMANCE

The overall frequency response of the preamplifier plus final amplifier is shown in Plate 14. The equivalent rectangular band width is also plotted in Plate 14. It is 1.9 cycles.

The expression for thermal agitation noise is

$$N^2 = 4 k T R \Delta f$$

where N = Effective noise in microvolts,
 k = Boltzman's constant,
= 1.374×10^{-23} joules per $^{\circ}K$,
 T = Degrees Kelvin ($^{\circ}K$),
 R = Resistive component in ohms
 Δf = Rectangular band width.

The resistance of the input load is five ohms. The temperature can be assumed to be $300^{\circ}K$. Then

$$\begin{aligned} N^2 &= 4(1.374 \times 10^{-23})(300)(5)(1.9) \\ &= 15.7 \times 10^{-20} \\ N &\approx 4 \times 10^{-10} \text{ volts.} \end{aligned}$$

The measured noise level was found to be 7×10^{-10} or less than two times greater than the thermal agitation noise. To further check this, the noise level was observed with a five ohm input load and then with the input shorted. The noise dropped 30% in the latter case indicating that the amplifier noise was between 1 and 2 times that of the 5 ohm load. Thus, because of flicker noise, the amplifier is not capable of working down to the thermal agitation noise level of the input load. Under these conditions a signal of 2×10^{-9} volts is easily recognizable in the earphones. A lower noise level and hence greater sensitivity for the entire system could be obtained by decreasing the band width of the amplifier. However, this would slow down the speed of response of the system to an impractical value.

Figure 15 shows the response of the entire amplifier to a suddenly applied and suddenly removed 5 c.p.s. signal as observed at the grid of the local oscillator. The relaxation time (time to decay to $1-1/e$ of peak value where $e = 2.718$ or 37% of peak value) is shown to be 0.4 seconds. A relaxation time greater than this value would spoil the quality of the entire detection system as a search device by making it impractically slow.

Field tests of this amplifier in the complete detection system have shown that the increased sensitivity which it provides cannot be utilized because of "optical noise". Elimination of th "optical noise" can be achieved by the redesign of the optical system which is not part of this project.

DECLASSIFIED

ACKNOWLEDGMENT

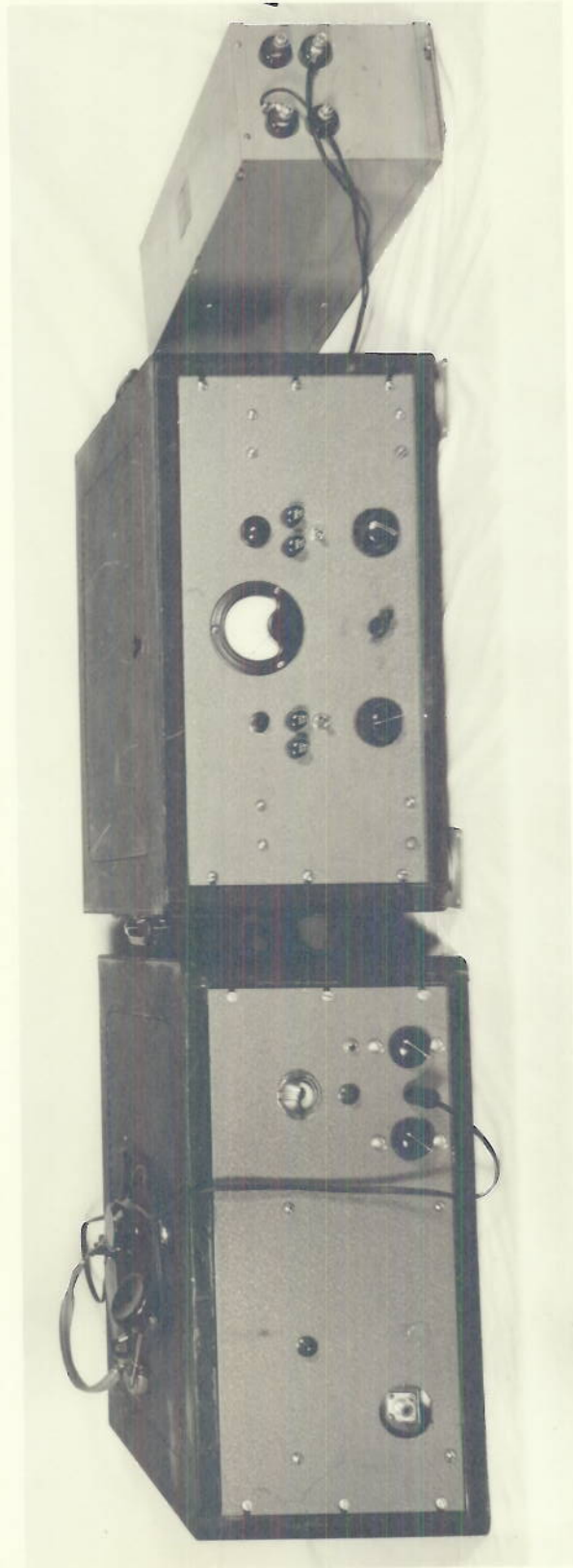
The author wishes to acknowledge the invaluable assistance of Mr. M. H. Bester who constructed much of the equipment and made many of the measurements and the assistance of Mr. M. Handegard who also aided in the construction of the equipment.

DECLASSIFIED

REFERENCES

1. L. C. Roess - "Vacuum Tube Amplifier for Measuring Very Small Alternating Voltages" Rev. Scientific Instruments, Vol. 16, p. 172, July 1945.
2. H. L. Clark - "Flicker Noise in Vacuum Tubes", NRL Report # 2894.
3. Markus and Zeluff - "Electronics for Engineers", p. 358, McGraw-Hill, 1945.
4. E. L. Chaffee - "Stabilized Ship Detector (S.S.D.)", OSRD Report 5985, 31 December 1945.
5. A. E. Hastings - "Analysis of a Resistance-Capacitance Parallel-T Network and Applications", Proc., I.R.E., Vol. 34, p. 126p - 137p, March 1946, and bibliography thereto.
6. R. W. Ketchledge - "Parallel-T Network - Case 23244", Bell Telephone Laboratories, Inc. memorandum, 3 June 1943 - 3510 - R.W.K. - K.I.

DECLASSIFIED

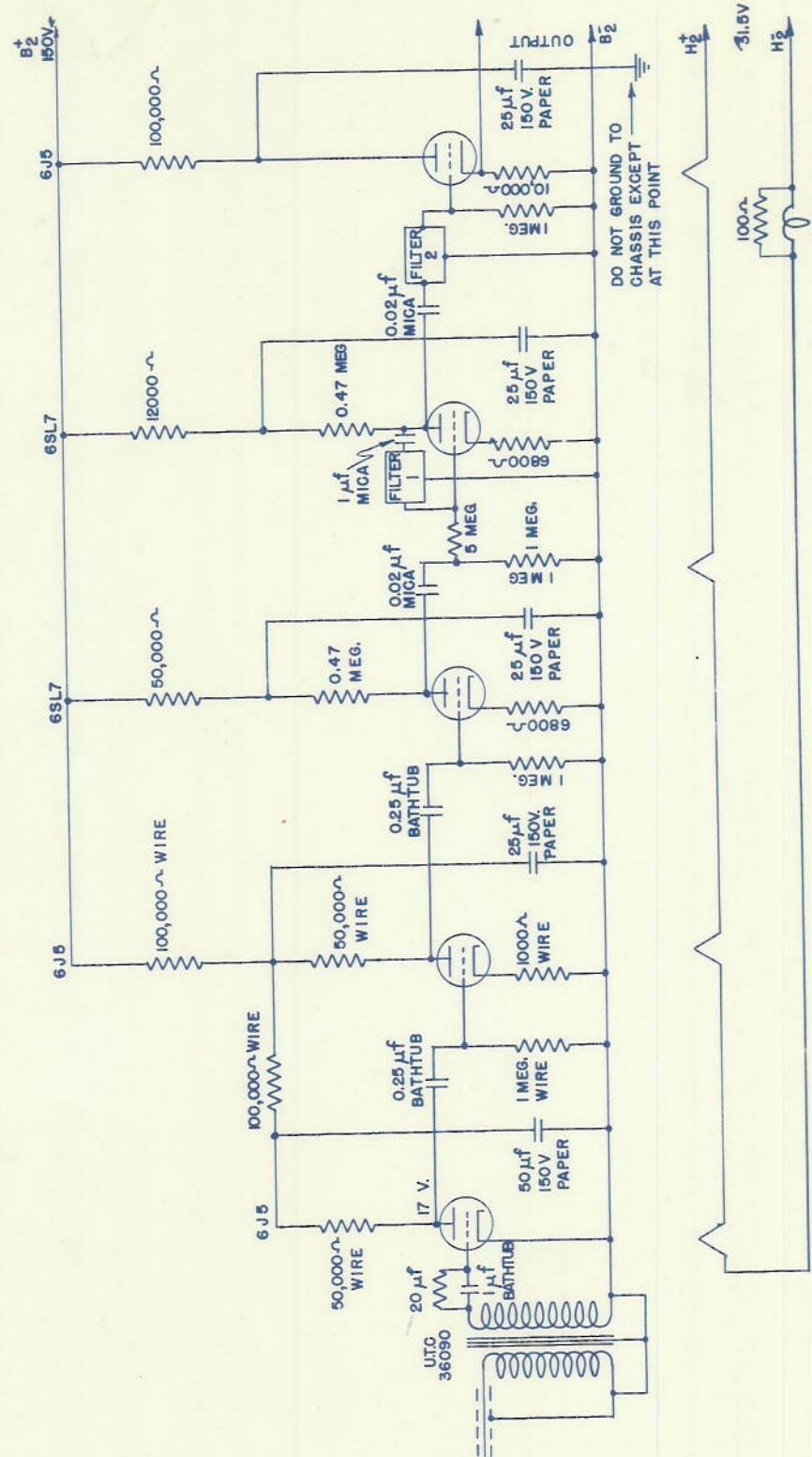


~~CONFIDENTIAL~~

DECLASSIFIED

PLATE 1

5 CPS PREAMPLIFIER



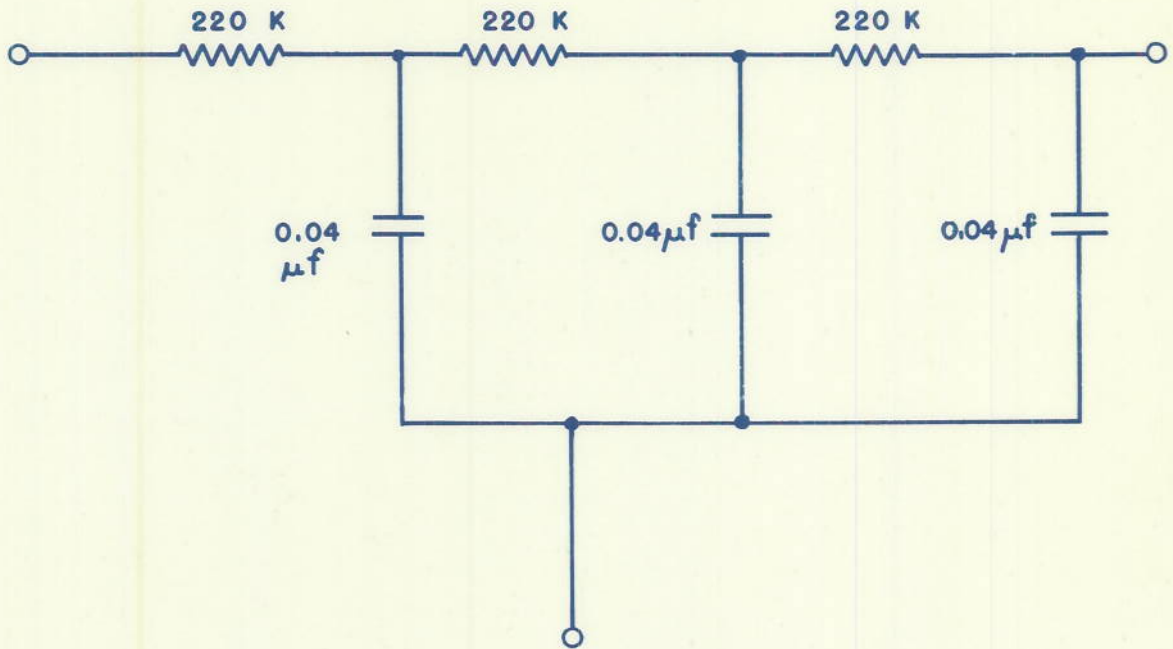
- 1-ALL RESISTORS ARE ONE WATT
- 2-ALL RESISTORS ARE COMPOSITION UNLESS OTHERWISE SPECIFIED
- 3-NO ELECTROLYTIC CONDENSERS ARE PERMITTED

H-2895

PLATE 2

DECLASSIFIED

LOW PASS FILTER
(FILTERS #2 & #3)

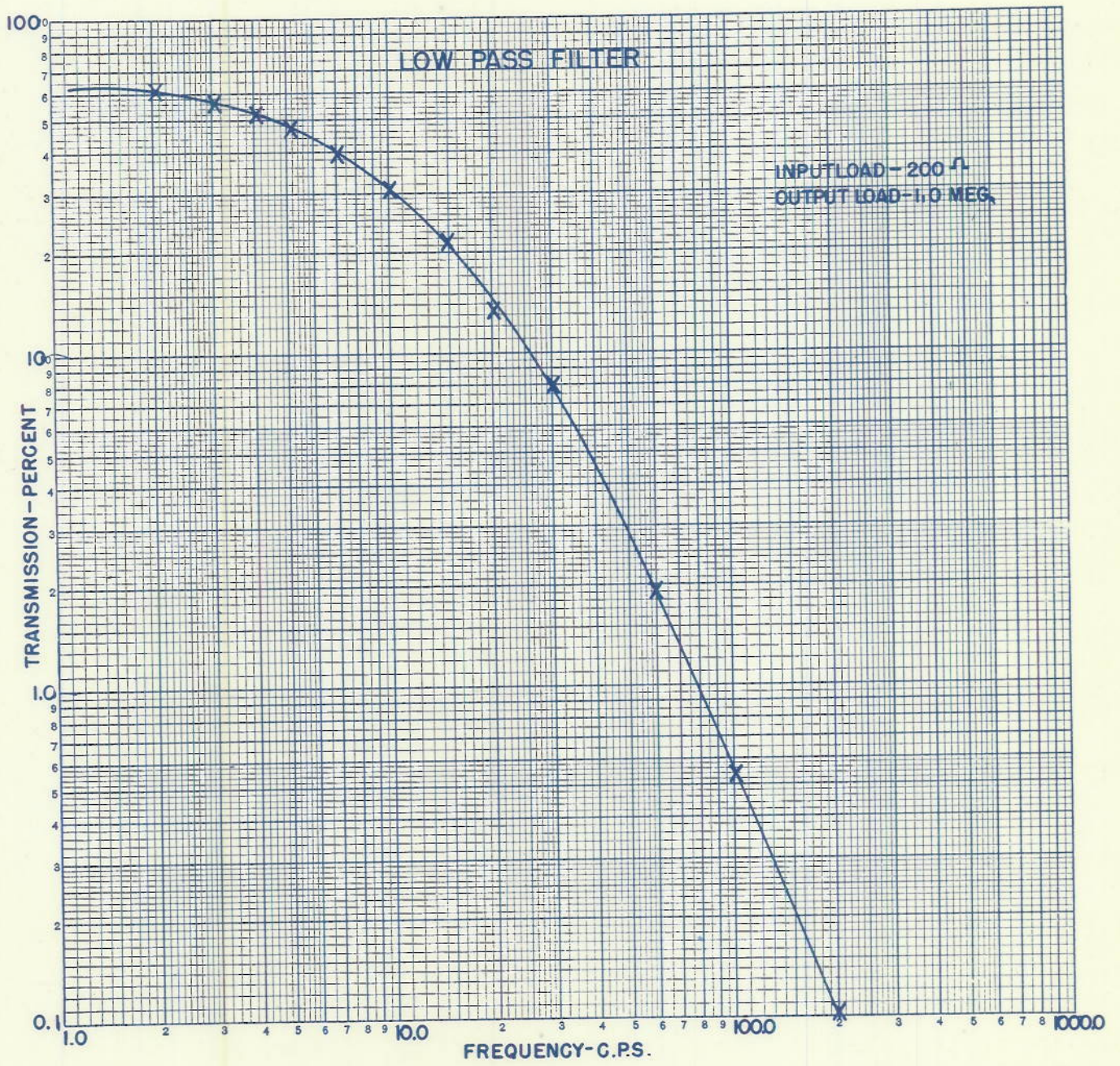


~~CONFIDENTIAL~~

H-2895

PLATE 3

DECLASSIFIED



~~CONFIDENTIAL~~

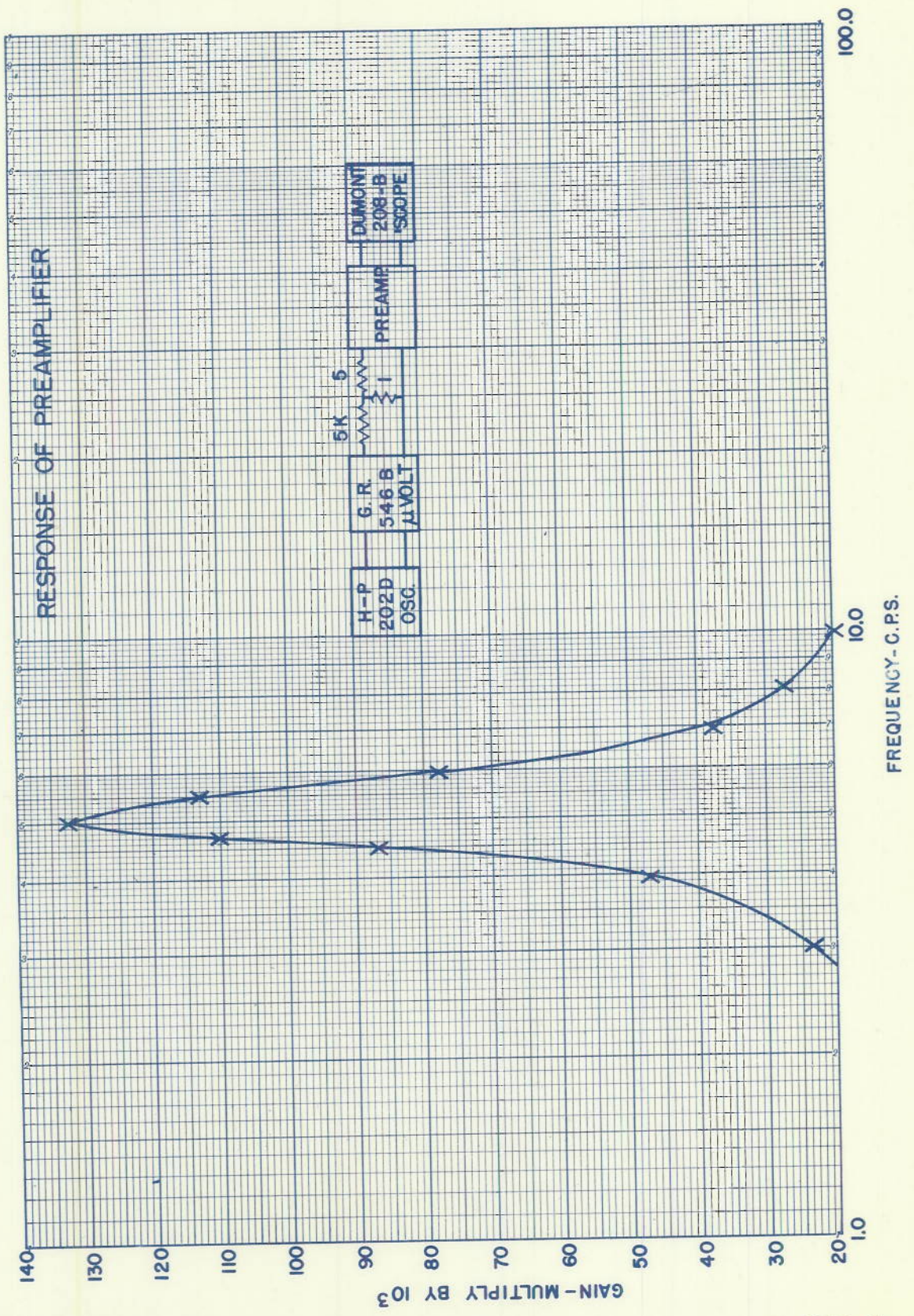
H-2895

PLATE 4

DECLASSIFIED

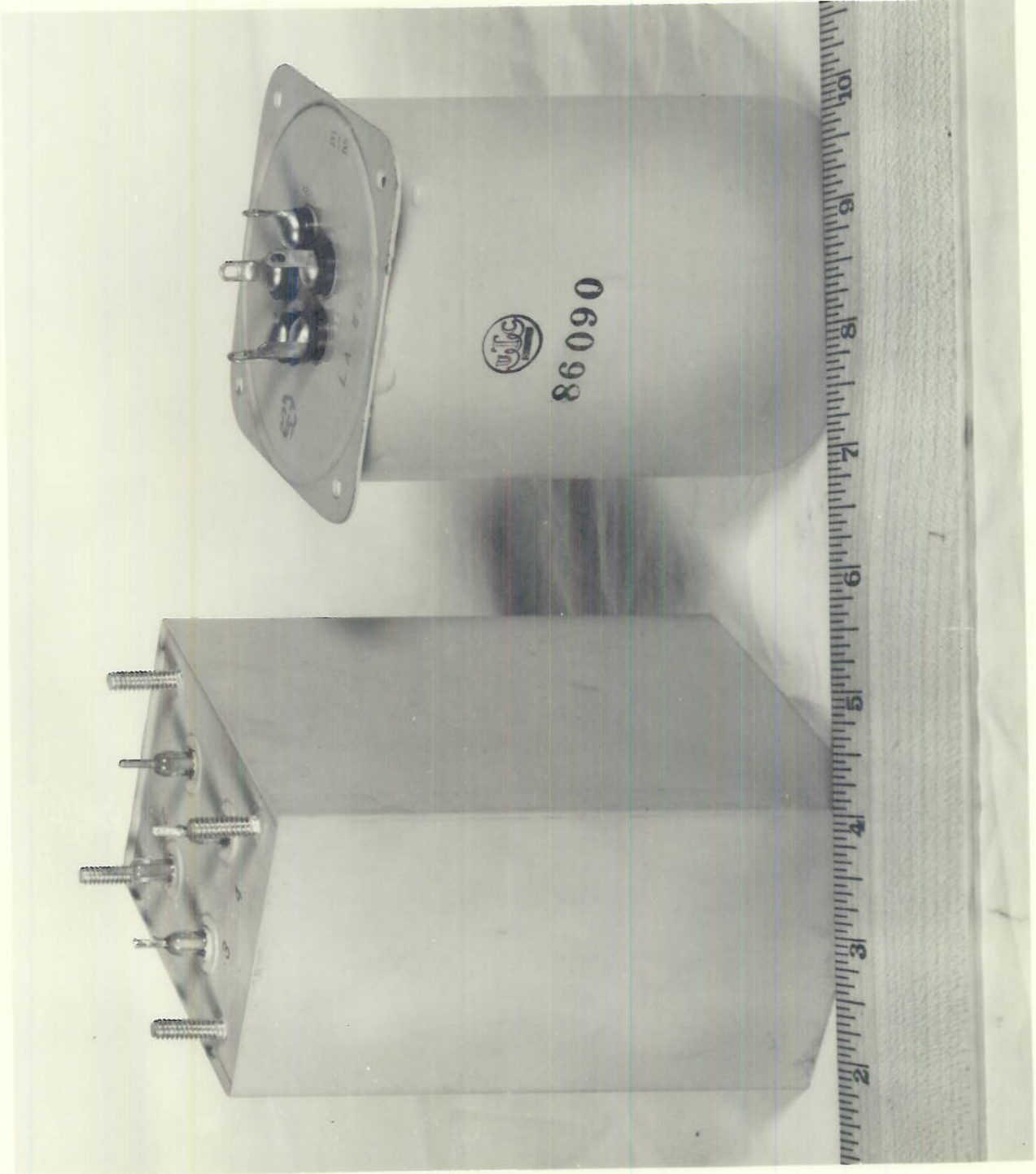
CONFIDENTIAL

DECLASSIFIED



H-2895

PLATE 5



DECLASSIFIED

PLATE 6

CONFIDENTIAL

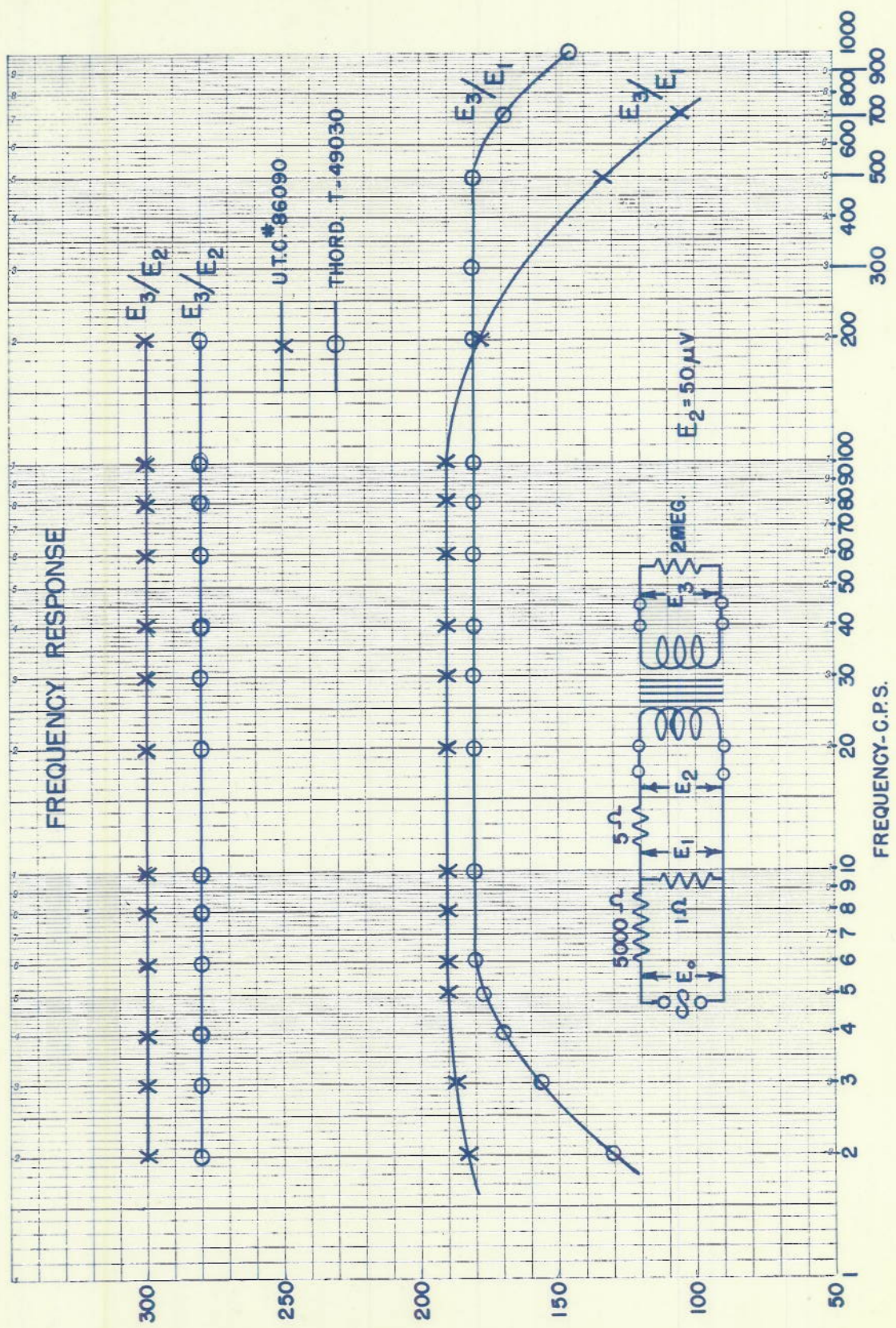
CONFIDENTIAL

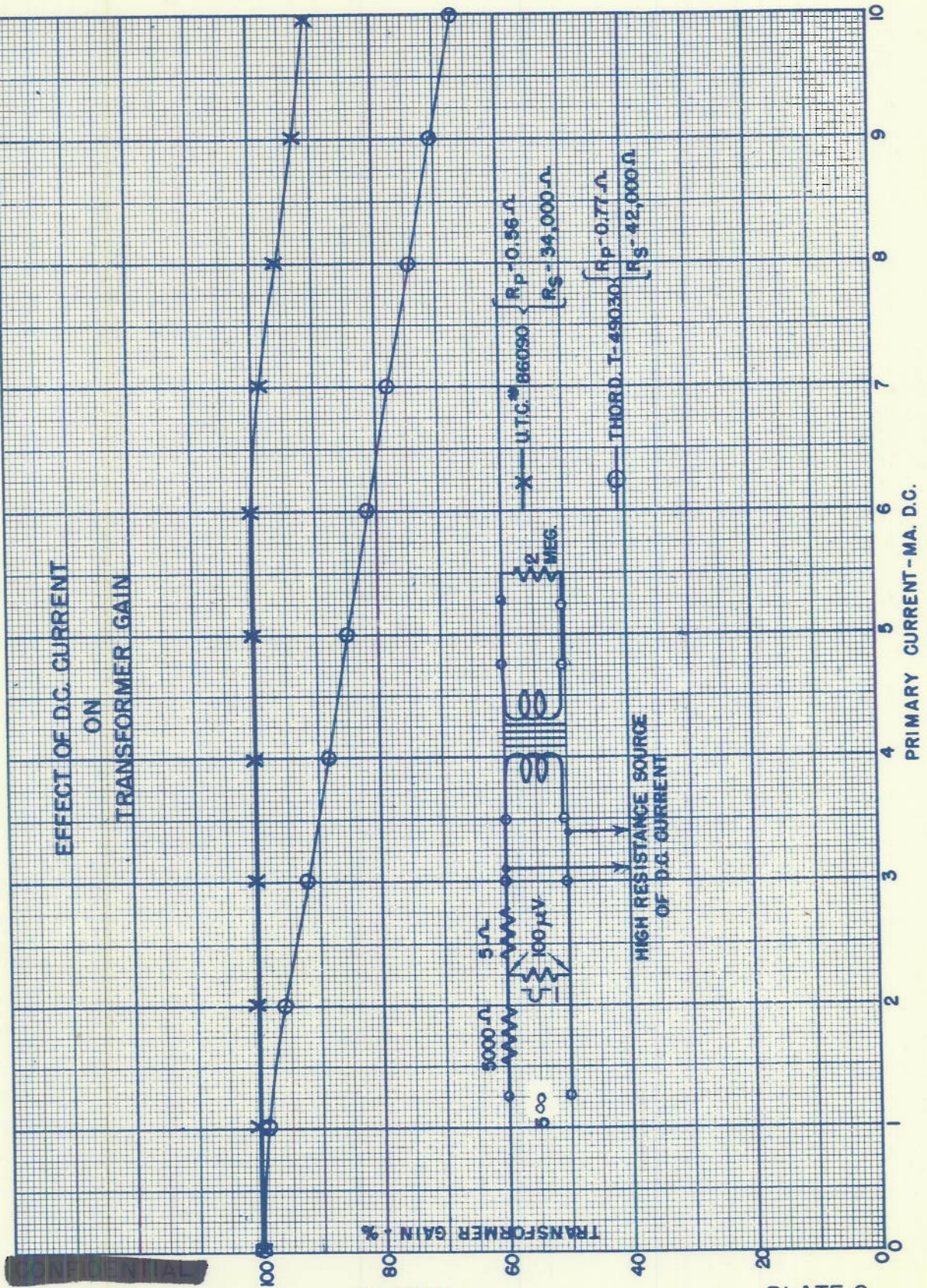
H-2895

RATIO

PLATE 7

DECLASSIFIED



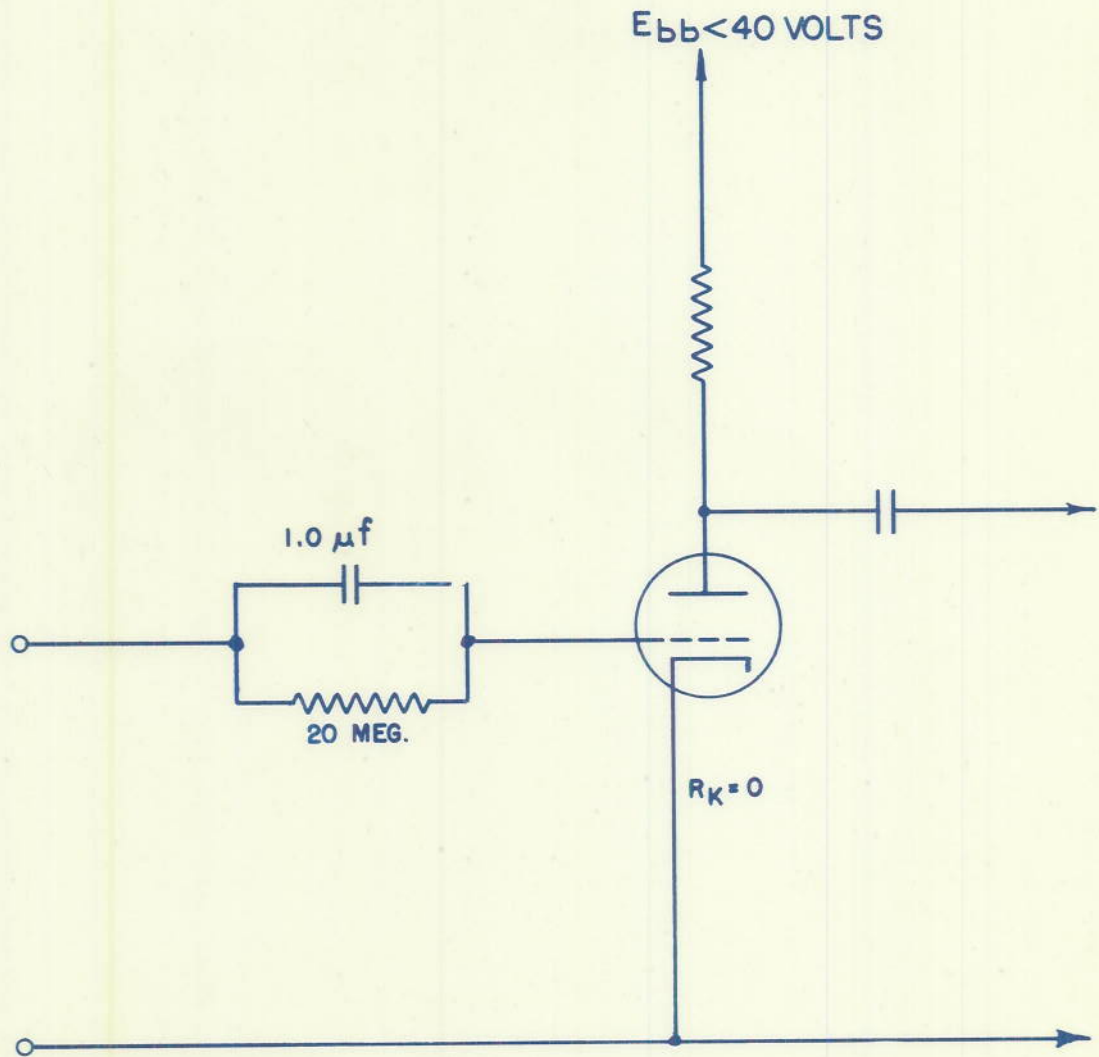


H-2895

PLATE 8

DECLASSIFIED

CIRCUIT ARRANGEMENT FOR
LOW FLICKER NOISE



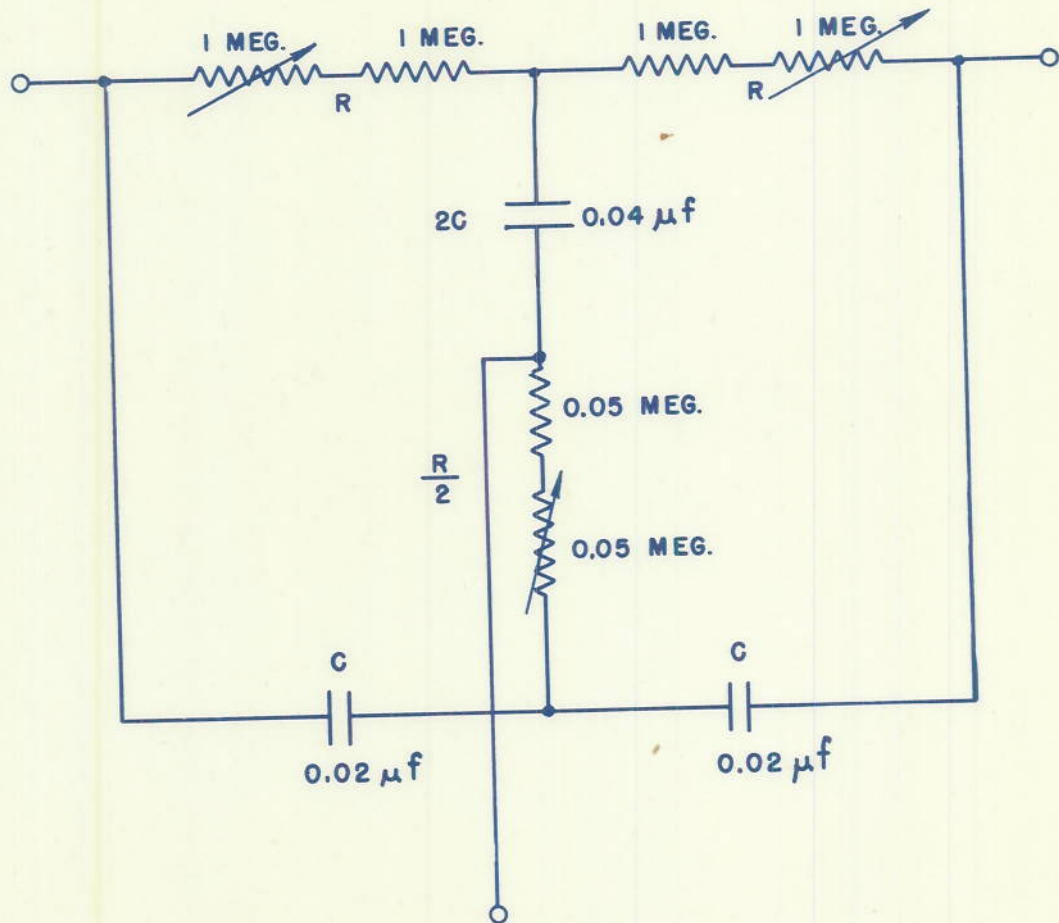
[REDACTED]

H - 2895

PLATE 9

DECLASSIFIED

PARALLEL-T FILTER
(FILTER #1)

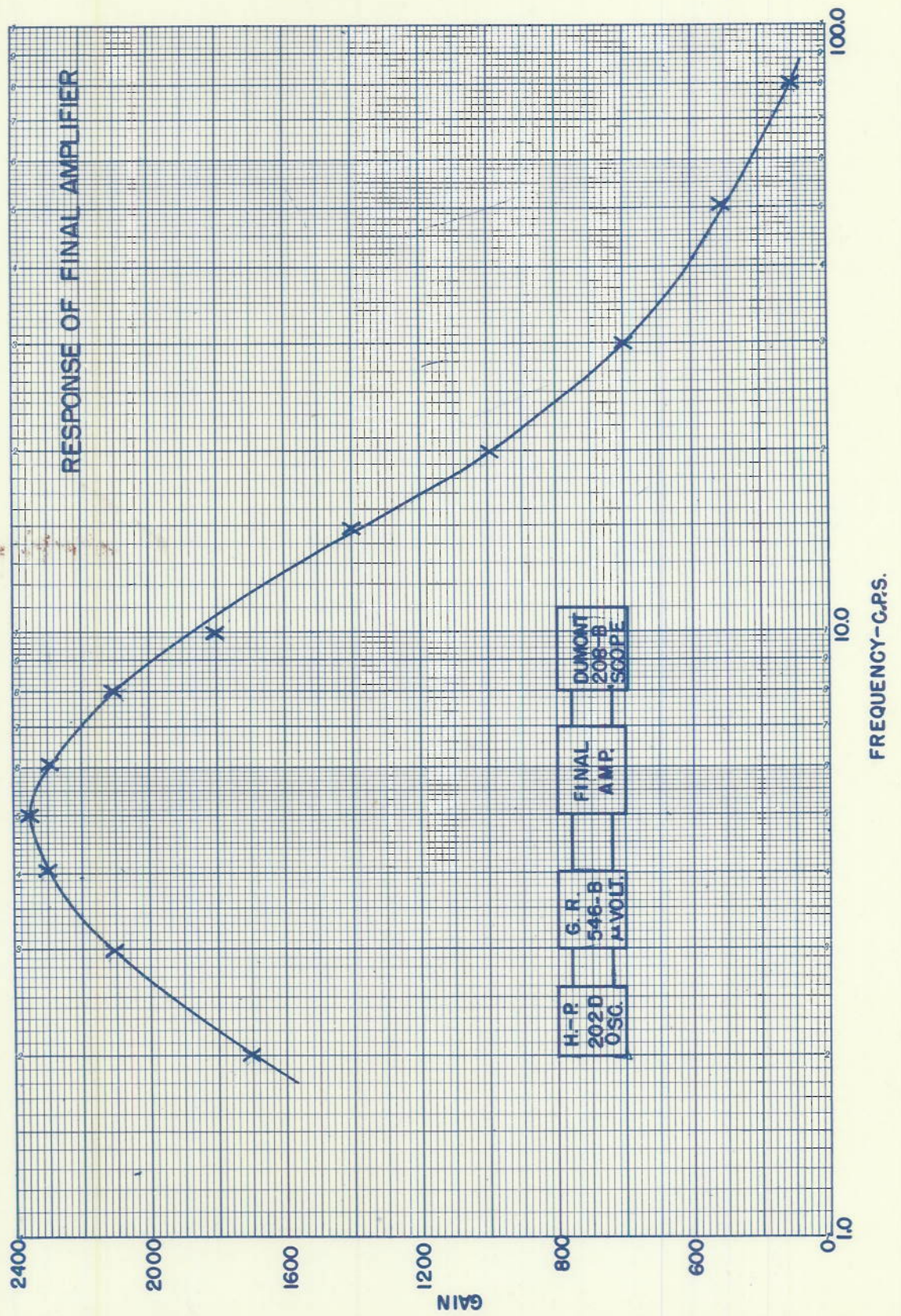


FOR 5 C.P.S.: $R = 1.6 \text{ MEG.}$, $\frac{R}{2} = 0.8 \text{ MEG.}$

H-2895

PLATE 10

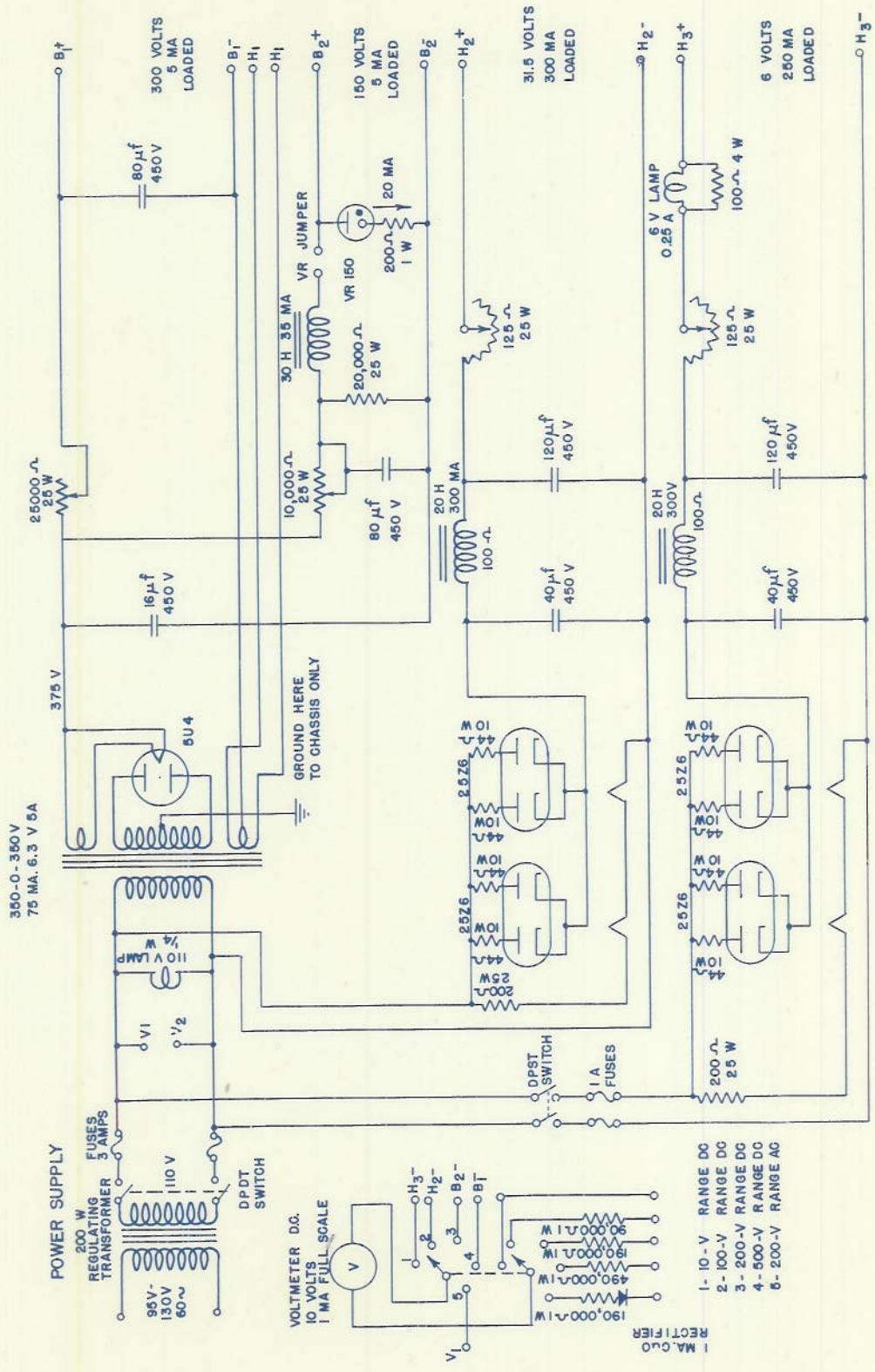
DECLASSIFIED



H-2895

PLATE 12

DECLASSIFIED



350-0-350 V
75 MA. 6.3 V 5A

POWER SUPPLY

200 W REGULATING TRANSFORMER

FUSES 3 AMPS

110 V

DPDT SWITCH

95V-130V-60V

5U4

375 V

25000-ohm 25 W

16 microfarad 450 V

30 H 35 MA

VR 150

200-ohm 1 W

10,000-ohm 25 W

80 microfarad 450 V

20 H 300 MA

40 microfarad 450 V

120 microfarad 450 V

20 H 300V

40 microfarad 450 V

120 microfarad 450 V

6 V LAMP 0.25 A

100-ohm 4 W

125-ohm 25 W

125-ohm 25 W

200-ohm 25 W

1 A FUSES

DPDT SWITCH

300 VOLT, 5 MA LOADED

150 VOLT, 5 MA LOADED

31.5 VOLT, 300 MA LOADED

6 VOLT, 250 MA LOADED

VOLTMETER D.C.

10 VOLTS 1 MA FULL SCALE

190,000-ohm 1 W

450,000-ohm 1 W

1,000,000-ohm 1 W

150,000-ohm 1 W

50,000-ohm 1 W

10,000-ohm 1 W

1,000-ohm 1 W

100-ohm 1 W

10-ohm 1 W

1-ohm 1 W

1 MA. C.U.O RECTIFIER

1-10-V RANGE DC

2-100-V RANGE DC

3-200-V RANGE DC

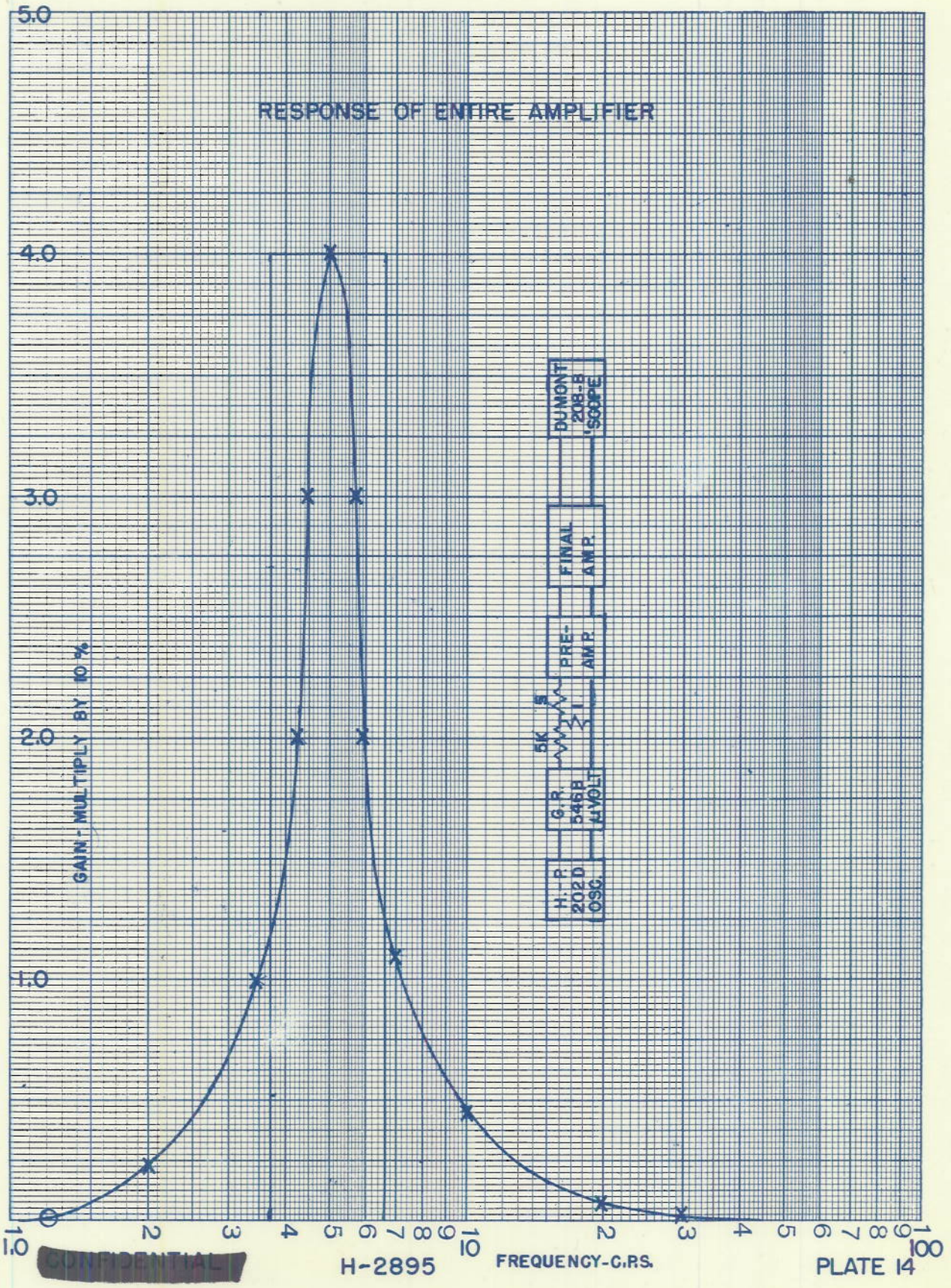
4-500-V RANGE DC

5-200-V RANGE AC

H-2895

PLATE 13

DECLASSIFIED



~~CONFIDENTIAL~~

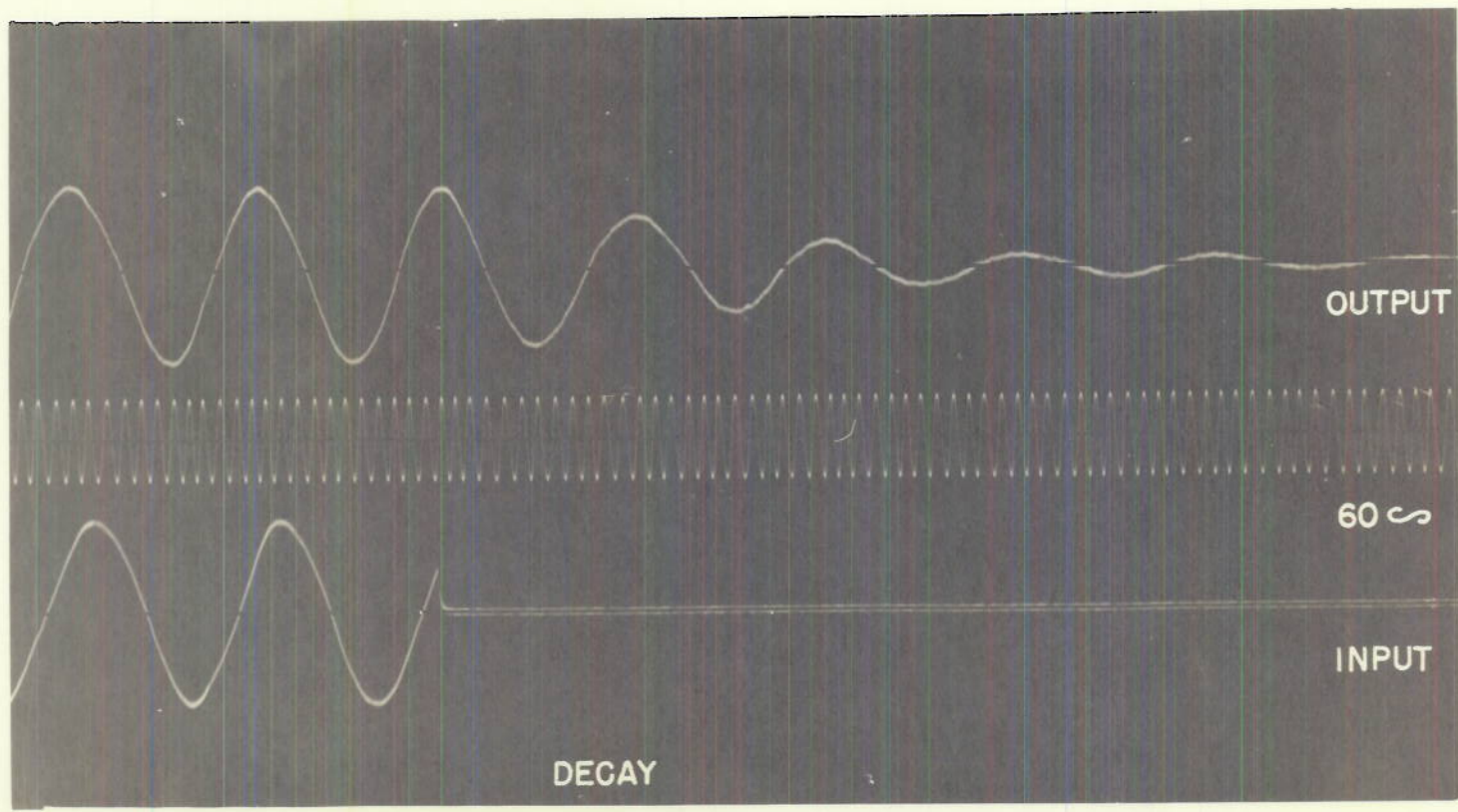
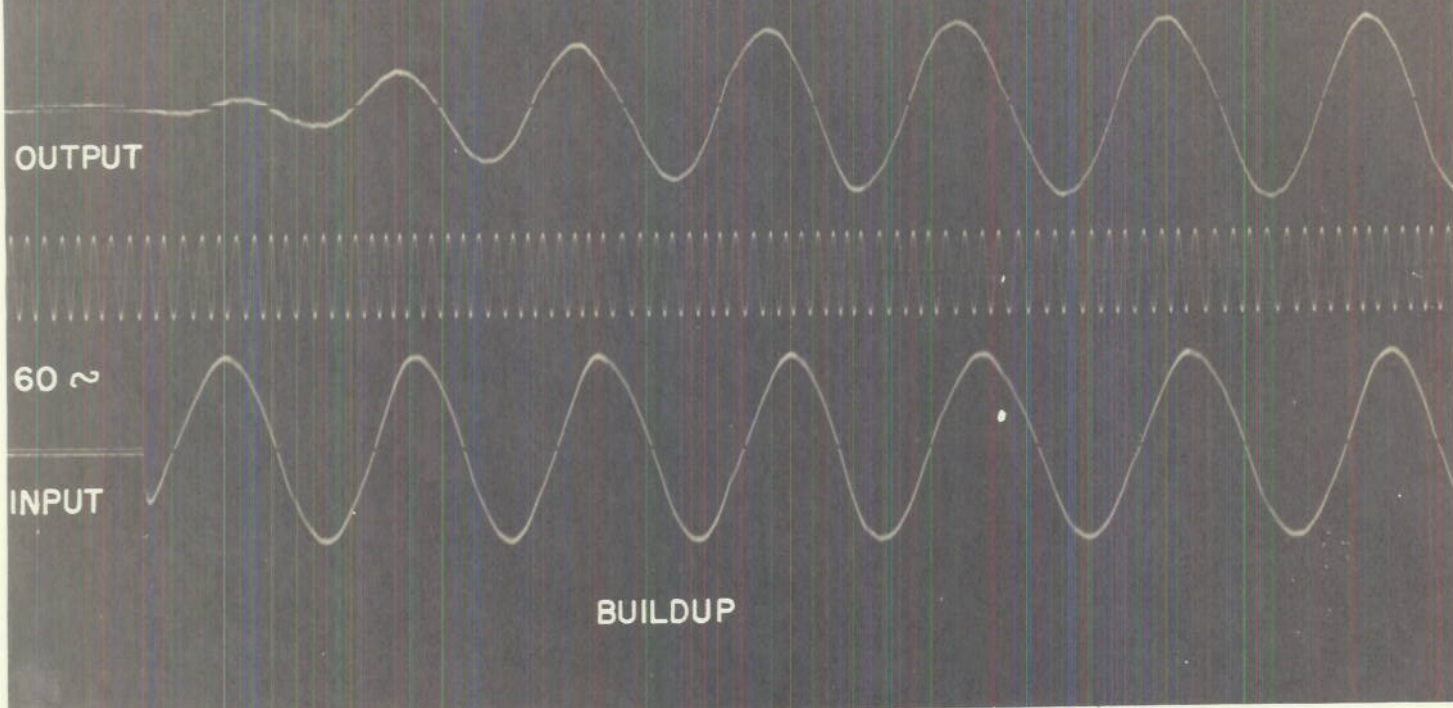
H-2895

FREQUENCY-C.R.S.

PLATE 14

DECLASSIFIED

RESPONSE OF ENTIRE AMPLIFIER



~~CONFIDENTIAL~~

DECLASSIFIED