MODULATION INDICATOR FOR BROADCAST TRANSMITTERS

By

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MODULATION INDICATOR

The need of a means of measuring the ratio of modulation and carrier voltages in present-day broadcast transmitters is obvious, but a few of the more important reasons why such an indicator is necessary will be reviewed here. With the growing tendency which now exists toward higher percentages of modulation the importance of such an instrument is increasing and makes a means of measuring this ratio indispensable in transmitters of any importance. High modulation is undoubtedly desirable. Recent tests made on a 380 meter 50 K W transmitter show that a 20 K W carrier modulated 52 % or a 10 K W carrier modulated 78 % is the equivalent of a 50 K W carrier modulated 31 % for producing a given output from the average receiving set. In adjusting the transmitter it is imperative that a means of measuring percentage modulation be available, so that the capability of the transmitters to handle high modulation and the capability of the modulators to produce the audio voltage be checked. In operation of the transmitter a percentage modulation indication is necessary to adjust the input to the speech amplifier.

At present oscilloscopes are used in these measurements. A coil is coupled to the tank of the transmitter, the picked-up current rectified by means of a two-element vacuum tube and fed into the vibrator coil of the oscilloscope. The beam is adjusted so that with no pickup it strikes on 100 %, and the amount of pickup is varied until with normal carrier and no modulation the beam strikes on 0 modulation. When the carrier is modulated the beam oscillated back and forth across the screen, producing an image which appears to be a solid straight line. The length of this line is proportional to carrier voltage and therefore indicates percentage of modulation.

The object of this paper is to present a new method of measuring modulation percentage, give a general explanation of how it works, list its advantages over the oscilloscope and give full practical data on the test indicator built.

For laboratory use the oscillograph is indispensible. It has many applications and is quite accurate but there are several objections to its use in broadcasting stations and field work. So the modulation indicator was developed for the specific purpose of measuring the characteristics of the rectified antenna current. There are four characteristics that are ordinarily taken in operating and adjusting a transmitter. Monitoring or measuring the per cent modulation is the most important, but the overall frequency characteristic and amplitude characteristic are just as important and the carrier change during modulation is also taken and is important in making the proper adjustment on the transmitter. The oscillograph can not be used for taking frequency characteristics as the vibration will not respond to the high frequency. For monitoring there are several objections to the oscillograph. First, it is hard to read during rapid modulation and experienced operators seldom read the modulation correctly without special effort. It cannot be read except in one position of the head. The instrument is delicate and if the vibrator becomes defective it requires considerable experience to repair it. Next the oscillograph is not similar to any of the standard equipment and is difficult to mount. For amplitude characteristics it can only be used at low frequency (1000 cycles or below.)

All of these objects are met in the modulation indicator, it being well suited for measuring the per cent modulation, frequency characteristics, amplitude characteristics and changes in the carrier during modulation. For monitoring it works exactly like the volume indicator in the studio control room. In fact it is calibrated in TU so that it agrees exactly with the control room measuring devices. For amplitude and frequency characteristics the one can be plotted directly against the other. For per cent modulation a correction curve is used or a dial can be calibrated both in percentage and TU. This calibration is determined by the constants of the device and so need not be calibrated in a laboratory.

The indicator consists of a pick-up coil tuned to the carrier frequency by means of a variable condenser and feeding thru a UX-281 rectifier tube in one lead and a variable resistor and tuned RF choke in the other into a pair of circuits one of which passes the D. C. component while the other passes the audio component. It is evident that with 100 % modulation the peak values of DC and audio voltages will be equal, thus the effective audio current as indicated on a DC ammeter will be $\frac{2}{2}$ of the direct current. If the two currents are known percentage modulation can easily be computed by multiplying the audio current by 2 and dividing the result by the direct current. If the direct current is held constant the percentage modulation is directly proportional to the current in the audio branch. The separation of DC and audio components is effected by means of a suitable choke and condenser. The choke blocks the audio, passing the DC while the condenser blocks the DC and passes the audio component. The current in the DC branch is measured by means of a 0-15 milliampere ammeter and the current in the audio branch is measured, after calibration, by means of a tube voltmeter. Binding posts are provided so that a thermo milliammeter can be connected for checking the calibration. The current in the DC branch is proportional to carrier voltage, therefore the milliammeter in this circuit can be used to indicate whether modulation is more positive than negative. Thus it will serve as a distortion meter. In contrast to the 50 mils required by the oscilloscope only 10 are necessary for the indicator. The indicator, having only meters, switches, and dials on its panel could be made to match up with any station control apparatus. The indicator can be built into a fairly compact unit, while the oscilloscope with its lamp is a bulky, awkward piece of apparatus. In contrast to the rectifier tube and large amount of pick-up apparatus required by the oscillograph, the only external part of the new instrument is a small pick-up coil. Taken as a whole, the indicator is cheaper, more accurate for monitoring smaller and more practical means of measuring percentage modulation than is the oscilloscope.

On K-4308514 is shown a schematic diagram of the complete indicator. The detector circuit will be taken up first. Voltage from the transmitter tank is induced in coil L10 and tank L10-Clo is tuned to the frequency of the transmitter. The voltage across this tank is impressed thru a UX-281 rectifier tube on the condenser C_1. On K-4308515, a graphic analysis of the detector, are shown the voltages and currents present in the circuits. The first curve, labeled carrier voltage, also represents the voltage across the tuned input tank. The current thru the 281 is shown on the next curve. If this tube were feeding into a circuit of pure resistance, the current thru it would look like the positive half of the carrier voltage. But since the condenser C_1 becomes charged on the peak current and sustains its charge throughout the negative half cycle, when the carrier voltage drops to a certain point the condenser charges the filament of the rectifier tube positively with respect to its plate and thus current thru the 281 suddenly drops the zero. The voltage across this condenser C_1 is shown on the next curve. This voltage is impressed thru the 5000-ohm resistor and tuned trap L11 - C11 across the points Q-N of the schematic diagram. The circuit L11 - C11 is tuned to the carrier frequency and effectively traps all of the remaining radio frequency, shown as the high frequency ripple on the third curve of the graphical analysis. The points Q-N include two circuits, one of which passes the d-c component. The total current thru the two circuits is shown, as C on the bottom curve of K-4308515, the current thru L, is shown as A, and the current thru C_2, and R as B.

The static characteristic of the UX-281 is given on H-4308516A, with no external resistance, and B, with a resistance of 5000 ohms. It is seen that with 5000 ohms in series with the load the curve is very nearly linear, so that the tube is well adapted for use as the detector. The output is then proportional to the carrier voltage directly. On

H-4308517, the solid line curve is the B of the preceeding sheet plotted with a larger ordinate scale. The other curve is the dynamic characteristic of the UV 281. To obtain it the pick-up coil was coupled to the tank of a 250 W tube type UV 849, the circuits L_{10}- C_{11} and L_{11} - C_{11} tuned and the current thru the choke L_1 read as the plate voltage was reduced. The pick-up current was assumed proportional to the plate voltage on the UV 849, which should be approximately true. In this curve the dynamic characteristic was then arbitrarily plotted so that it corresponded to the static characteristic at its maximum current. The dynamic characteristic is not as nearly straight as the static, but is not at all bad, especially around ten milliamperes, the point where it is used in the indicator.

The first frequency characteristic taken of the detector is shown on H-4308523 as can be seen the curve has a very bad droop on high frequencies. This condenser was reduced from .002 mfd. to .0005 mfd. and the frequency characteristic was much improved, as shown on H-4308524. This last characteristic was very good, being down only 2% of 1000 cycles at 5000 cycles, and the same amount at 40 cycles.

The choice in selecting the type of tube to be used as detector lay between UX-281, UX-280, UX-866, and a three-element tube such as the 201-A operated either with or without a grid condenser. The prime consideration governing selection is the straightness of the voltage current characteristics. If a 3-element tube were used a constant plate potential would be necessary to bring the tube up to the point where it would operate on the linear portion of its curve. That is, it would have current flowing in its plate circuit at all times and the modulated carrier voltage impressed on the grid would cause merely a variation in plate current, rather than being the complete governor of plate current. If a grid condenser were used all variations in plate current caused by the AC grid swing would be down, and if a condenser were not used the plate current variations would be up. It is obvious that if the three-element tube were used the constant value of plate current would be objectionable due to the fact that all the direct ratios would be destroyed and calibration would be very much more complicated than in the case of the two-element tube. The UX-281 seemed to have the straightest voltage current characteristic under the imposed conditions and was consequently selected as the detector, though the UX-280 or UX-216B would serve almost as well.

The resistance of the AC circuit between Q and N is made to equal the resistance of choke L_1 so that the ratio of the currents, in each branch will also be the ratio of the voltage across the two points (ac and dc). Measuring the direct current is very simple, as a milliammeter of appropriate maximum current is all that is required. Measuring the current in the audio branch is more complicated, however, as ac milliammeters are too sluggish in their action to follow the variations in audio amplitude. A resistor was placed in the audio branch and the drop across it impressed on the grid of a UX-841, which also had a constant bias of about 4 volts. The current in the ac branch was then measured by means of a dc milliammeter in the pate circuit of the UX-841. The 841 was selected because of its high amplification constant and consequent large plate current variation for small grid swing.

Naturally this tube voltmeter must be calibrated before it can be used.

The static grid characteristic of the UV-841 is shown on H-4308517, taken with filament and plate voltages to be used on the indicator. As shown on the schematic diagram a constant bias is supplied to its grid from a drop in the 25 ohm potentiometer. The amount of this bias is such that it will cause a plate current of just enough to bring the indicator to its first mark. On K-4308519 which should be referred to, the curve A-B is the first part of the static grid characteristic of the preceeding page plotted to an enlarged scale. The mark on the indicator to which the pointer is adjusted with no modulation (no ac grid swing on the 841) corresponds, to 0.2 milliamps of plate current. This is point R on the curve and requires four volts of bias to be reached. The line N-N' is drawn thru this point and represents the point about which the grid swings when the set is modulated. A 60 cycle ac voltage was impressed on the grid in addition to the dc bias and adjusted until it caused the plate current to rise from .2 to 1.1 milliamps. This was measured and found to have a root mean square value of four volts. This corresponds to a peak value of 5.64 volts. A curve of this peak value $E_o = 5.64$ is plotted around N - N' as a zero axis. This wave is produced on the current axis as a current of maximum value. I_o is read on the curve as 3.5 milliamps. If these were the positive loops of a pure sine wave the average voltage would be $\frac{1}{2}$ x .636 of the peak value or .318 I_o. That is, for a peak value of 3.5 milliamperes the average value of current, as is read on dc ammeters, would be 1.113 milliamperes. The current for indication in the plate circuit is 1.10 mils, thus the static and constructed dynamic characteristics agree remarkably well, showing that the voltmeter should be independent of frequency, even though the frequency be carried very high. The slight difference in results is probably due to the divergence from true sine wave loops of the plate current curve.

Two courses were open in arranging the tube voltmeter. One was to tap the grid lead from a fixed point of the resistor R and read audio current on the plate current meter. The other was to make this point variable and hold the plate current of the UV 841 constant. The latter method seemed the best, as it allowed the plate current meter to be worked on only the more accurate part of its scale. In this method since the grid voltage is always adjusted for the same plate current, the grid swing will be the same at all percentages of modulation within the range, of the indicator when the tapped resistor is properly adjusted. The RI drop in the part of B between the grid and ground thus being constant, the current will vary inversely as the resistance included by the tap. The resistances to be included between each tap were calculated in the following manner. The currents in the audio branch at each even T.U. between -12 and + 2, assuming ten milliamps in the dc circuit, were computed. These values of current were then divided into the ac voltage required to raise the current in the 841 plate to 1.1 milliamps which had been measured and found to be four volts. These values of resistance were tapped off a wirewound tubular resistor. In operation, then, the tap switch will be adjusted until the plate current of the 841 is its required tap switch. This switch could be arranged to read percentage modulation directly in say ten percent steps, but it seemed more advantageous to have it operate on integral TU's so that it would be similar to audio control apparatus. A curve for converting TU up or down to percentage modulation or vice versa is shown on H-4308520. From this curve it can be seen that the range covered by the nine taps from -12 TU to +2 TU corresponds to a percentage modulations range of from 25 % to 125 %.

To compare the completed indicator with the oscillograph both were used to measure modulation simultaneously, the pick-up for each being obtained from the tank of the IPA in a broadcast transmitter, of known excellence. A tabulation of the results is given on the data sheet. The indicator showed up much better than the oscillograph on this test, as it read 0 TU(100 % modulation) with a 22.9 % rise in tank current. This rise in tank current corresponds to a rise in power of 51 %. If the power rise had been 50 % when the indicator read 0.T.U. the calibration of the indicator would have been perfect. The oscillograph read low throughout the test.

An overall frequency characteristic of the indicator was taken and is shown on H-4308525. It is rather surprisingly bad in view of the good frequency characteristic of the detector and the agreement of the static and dynamic characteristics of the 841. The overall characteristics had a dip at 2000 cycles and the cause of this is not obvious.

The indicator has one disadvantage in monitoring and that is the inertia of the indicating needle prevents it from responding to modulation of very short duration. However the light on the oscillograph lasts for such a short period that it would not be seen except by close observation.

SUMMARY:

The modulation indicator can be built of standard parts and mounted in the control racks as one of these units. The cost would be less than that of the oscilloscope. Repairs could be made as on any of the remote control equipment whereas it requires considerable skill to repair the vibrator of an oscilloscope. The indicator serves five purposes of monitoring, indicating percentage modulation, taking frequency and amplitude characteristics, and indicating variation in carrier during modulation (that is unsymmetrical modulation.) The oscilloscope is just as good for measuring percentage modulation, can not be used for frequency characteristic, and is only partially satisfactory for amplitude characteristics and detecting unsymmetrical modulation. However, the wave shape can be seen and analyzed with the oscilloscope which is very desirable in the laboratory, but in the field the indicator permits sufficiently accurate measurements so that wave shape can be fairly well estimated.

Comparison of modulation indicator and oscillograph.

5 KW amplifier feeding dummy resistor, 1000 N tone used for modulation.

Input TU	Oscillograph -		AV	Mod. D. C.	Ind. T. U.	% Mod. per T. U.
0	6	6	0	10	Tap 0 VI	0
-20	22	18	14%	10	-12-2.5	18 %
-18	30	26	22	10	-12-0	25.2
-16	37	36	30.5	10.1	-10-0	31.2
-14	45	41	37.	10.2	-8-0	40.0
-12	57	48	46.5	10.3	-6-0	51.0
-10	70	57	59.5	10.4	-4-0	63.5
-8	80	70	69.	10.5	-2-0	80.0
-6	94	88	85.	10.9	-0-0	100. *
-4	95	90	86.5	11.	* 2-2	100 **

* Note: The tank current rose from 22 amps. at no modulation to 27 amps. at this setting. The rise was 5 amperes or 22.9 %. This is the correct amount for 100 modulation as the indicator indicated. Undoubtedly the indicator was more accurate than the oscillograph.

** Note: The transmitter saturated and so would not modulate over a 100 %.

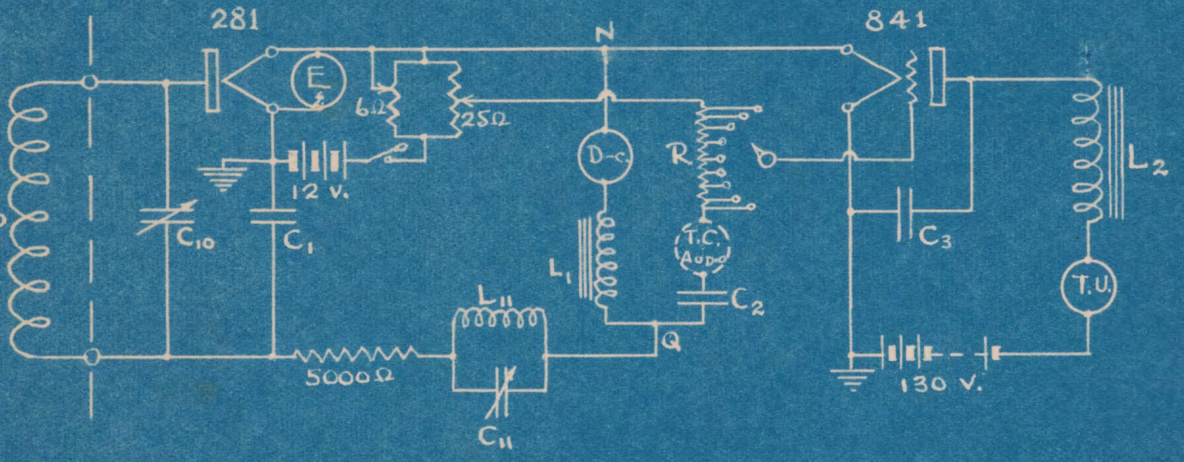
APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Chas A Perkins.

Professor of Electrical Engineering.

SCHEMATIC DIAGRAM
MODULATION INDICATOR



DRAWN BY B. W. Robins INSPECTED BY A. D. Ring

K4308514

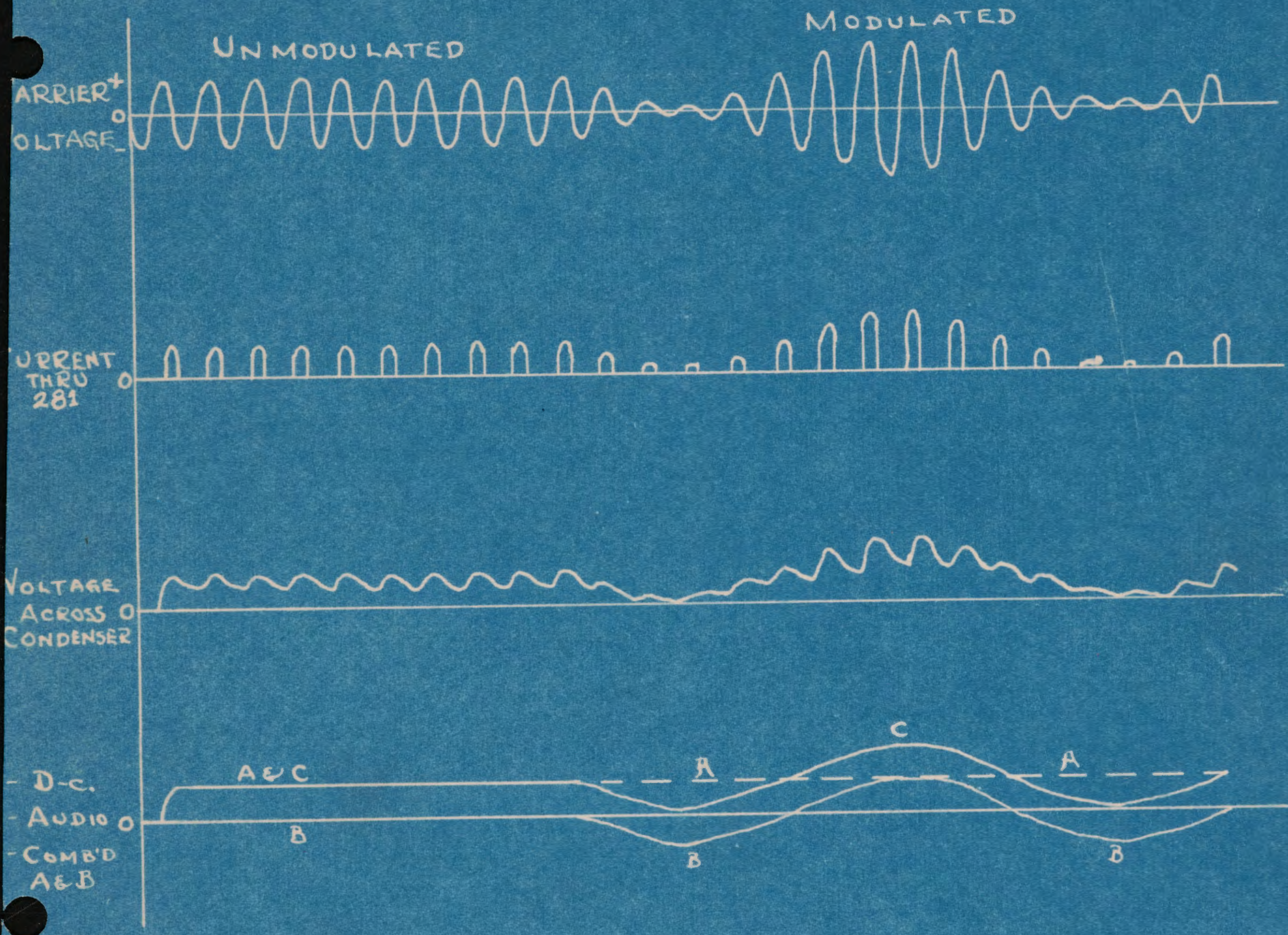
[redacted] Apr. 24, 1929

FF-440-A 15m 2-5-29

GRAPHIC ANALYSIS

MODULATION INDICATOR

Detector



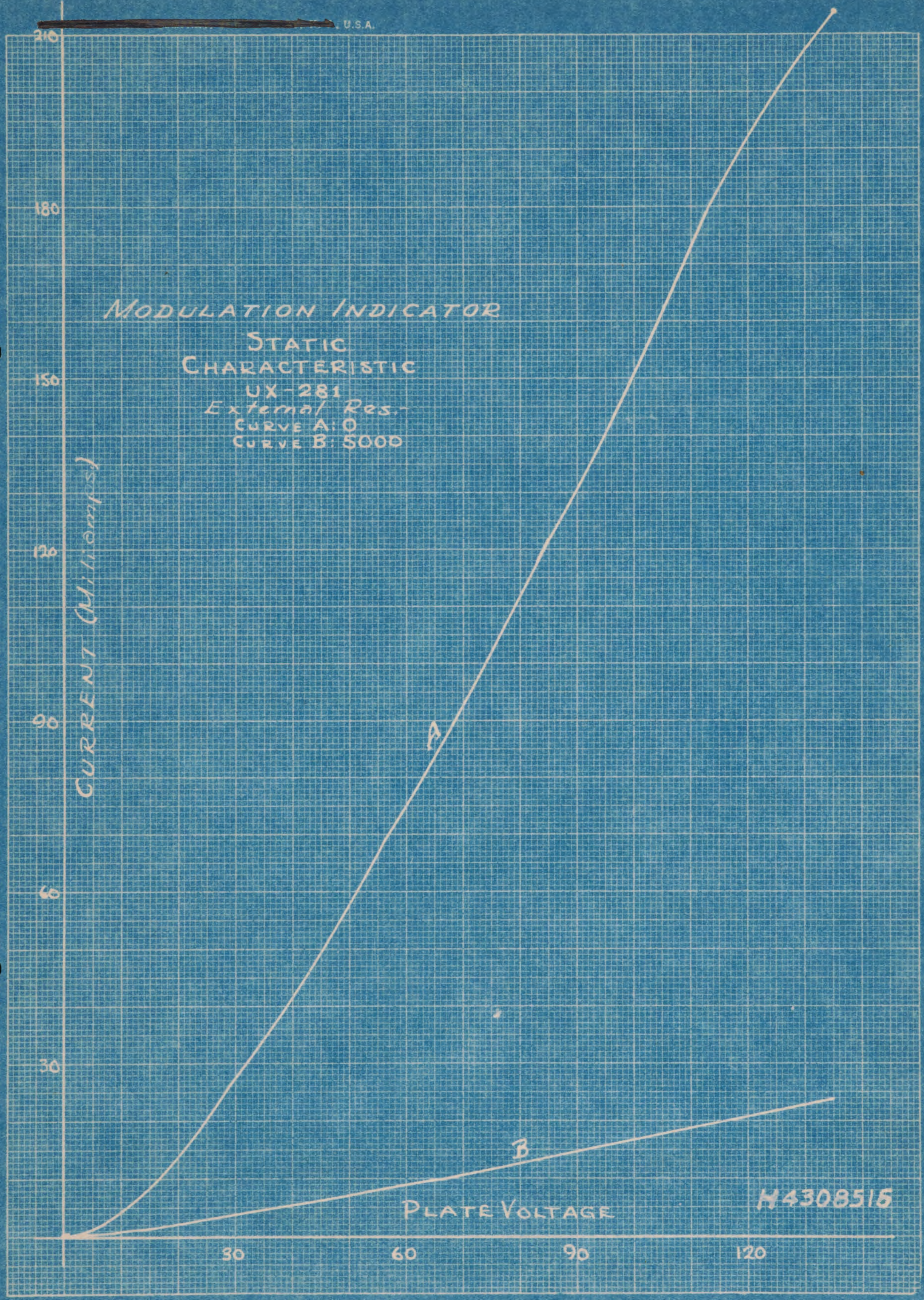
ALL ABSCISSAS ARE TIME

DRAWN BY B. W. Robins INSPECTED BY A.D. Ring

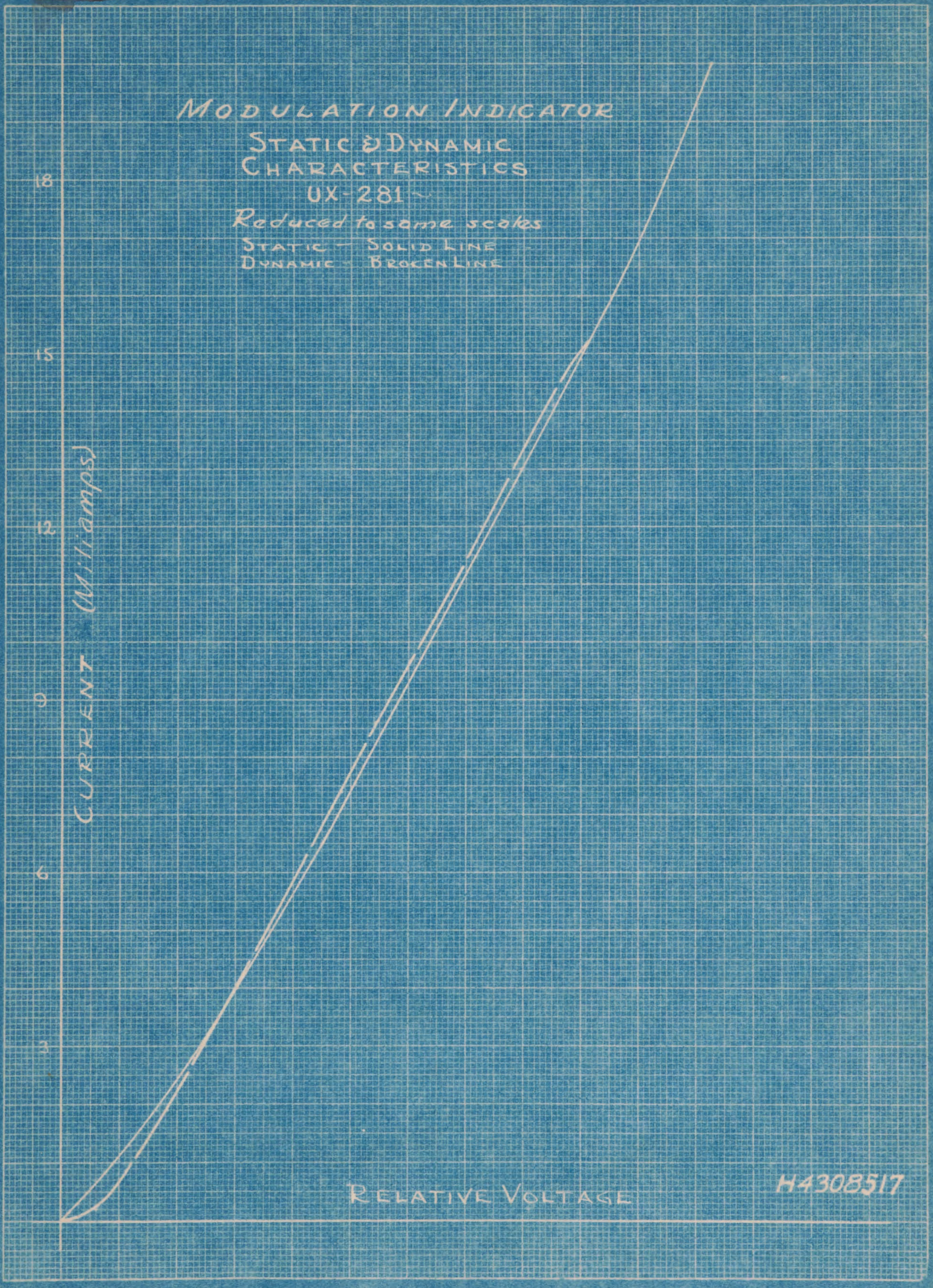
K 4308515

[redacted] Apr. 24, 1929

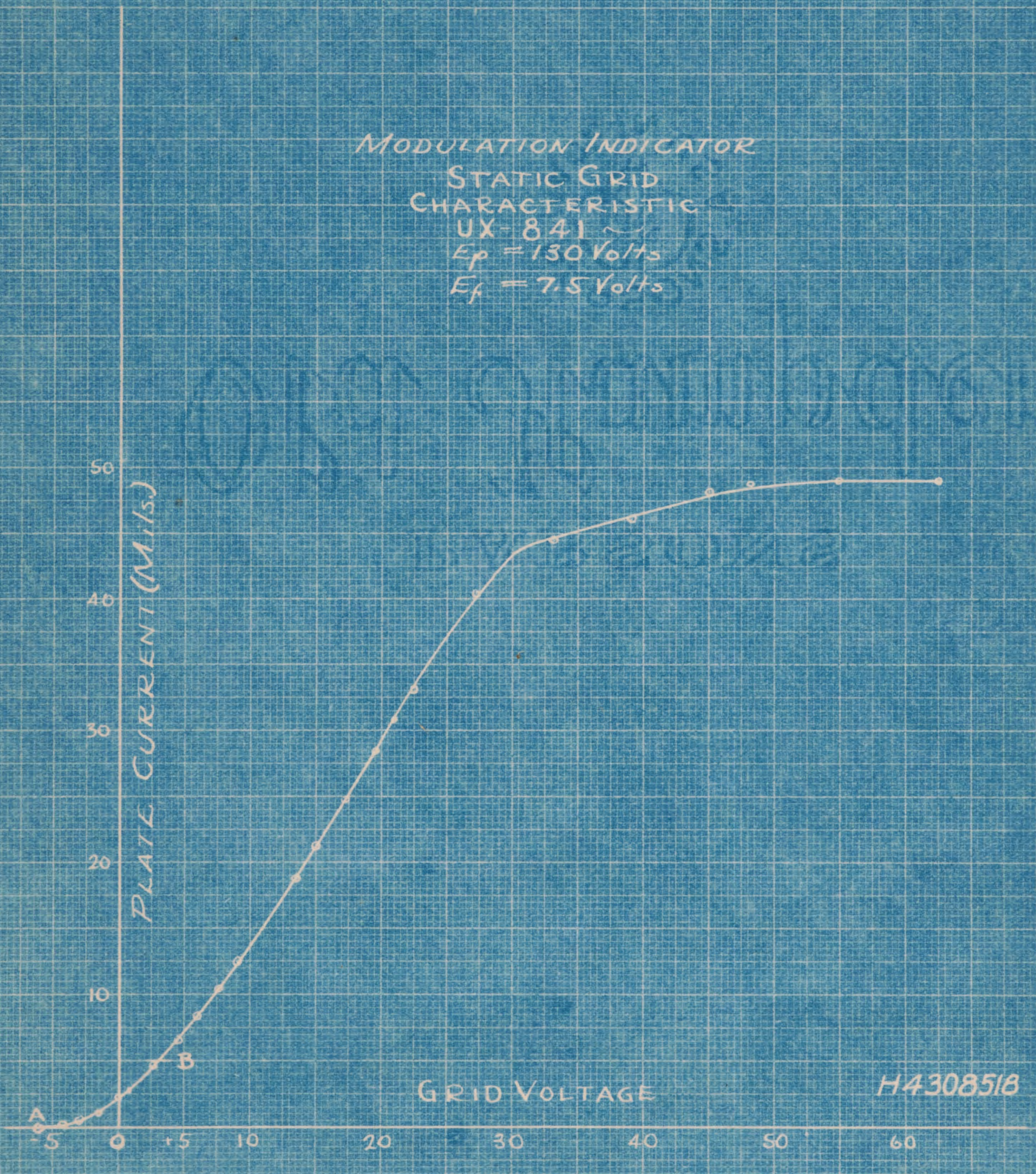
FF-449-A 15m 2-5-29



MODULATION INDICATOR
STATIC
CHARACTERISTIC
UX-281
External Res.-
CURVE A: 0
CURVE B: 5000
CURRENT (Milliamps)
PLATE VOLTAGE
A
B
210
180
150
120
90
60
30
30
60
90
120
H4308515


MODULATION INDICATOR
STATIC & DYNAMIC
CHARACTERISTICS
UX-281
Reduced to same scales
STATIC — SOLID LINE
DYNAMIC — BROKEN LINE
18
15
12
9
6
3
CURRENT (Milliamps)
RELATIVE VOLTAGE
H4308517

[redacted]., U.S.A.

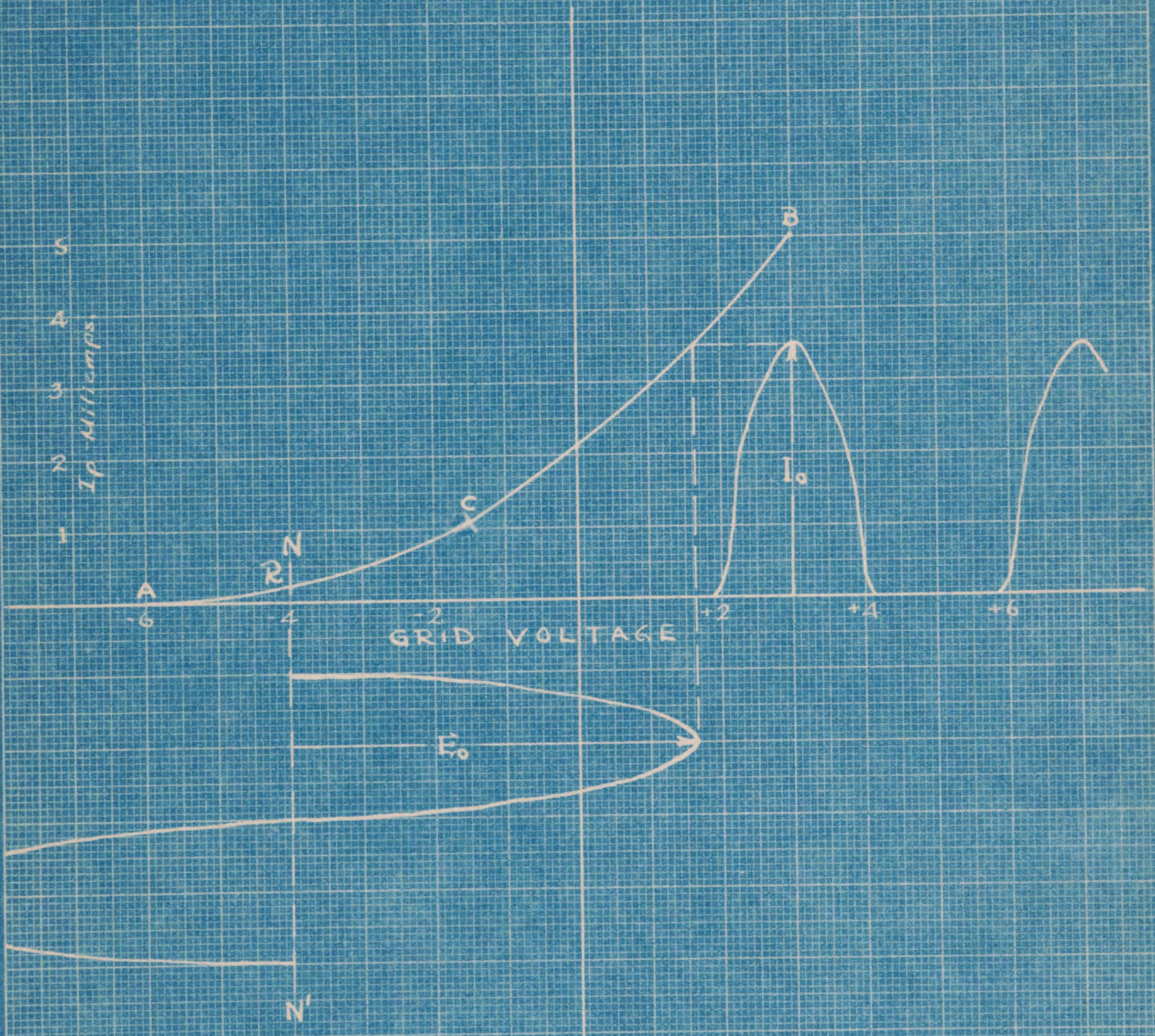


FN-155 40m 2-6-26

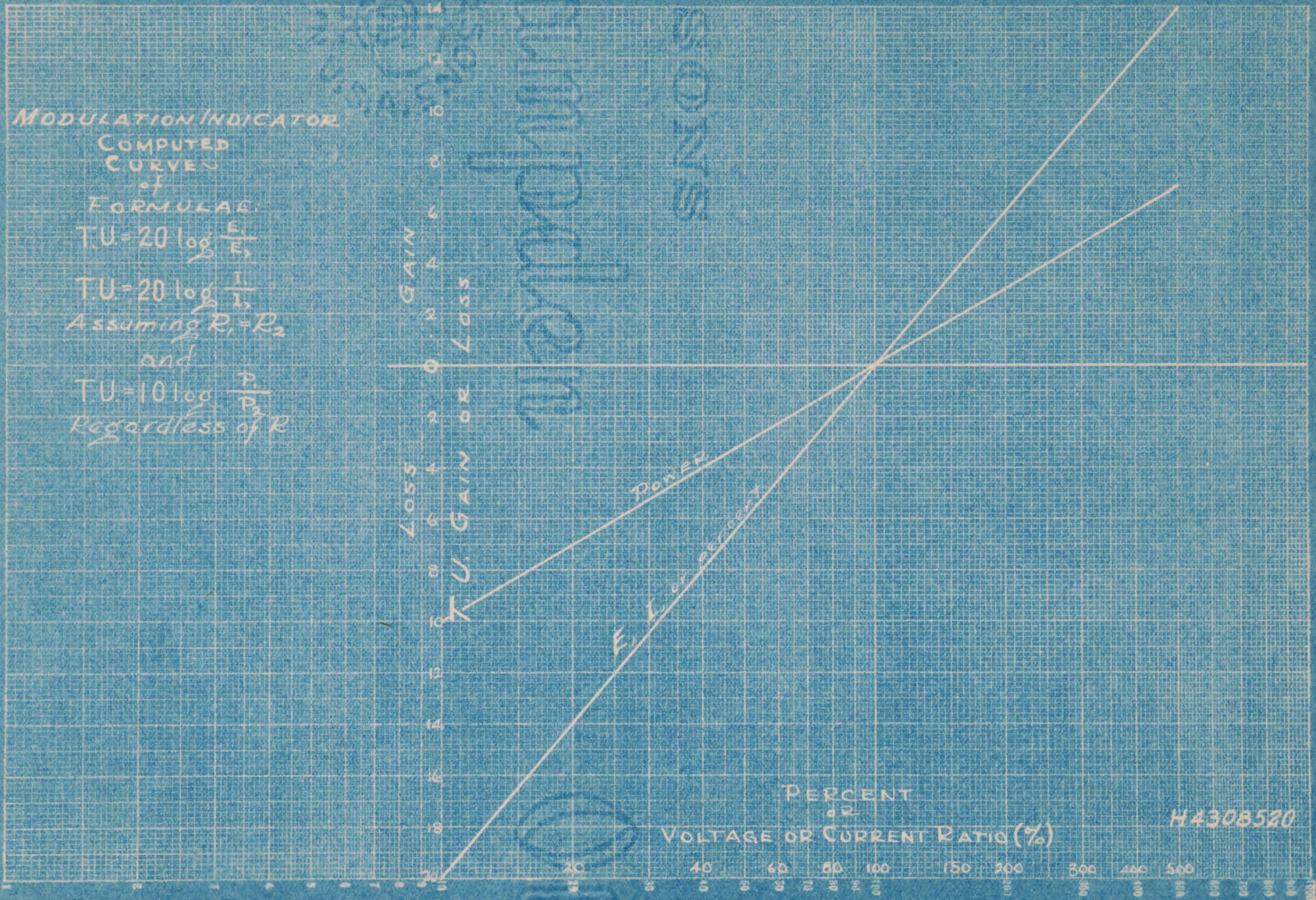
20/84 Inch Divisions

MODULATION INDICATOR

CONSTRUCTED
DYNAMIC
CHARACTERISTIC
~ UX-841

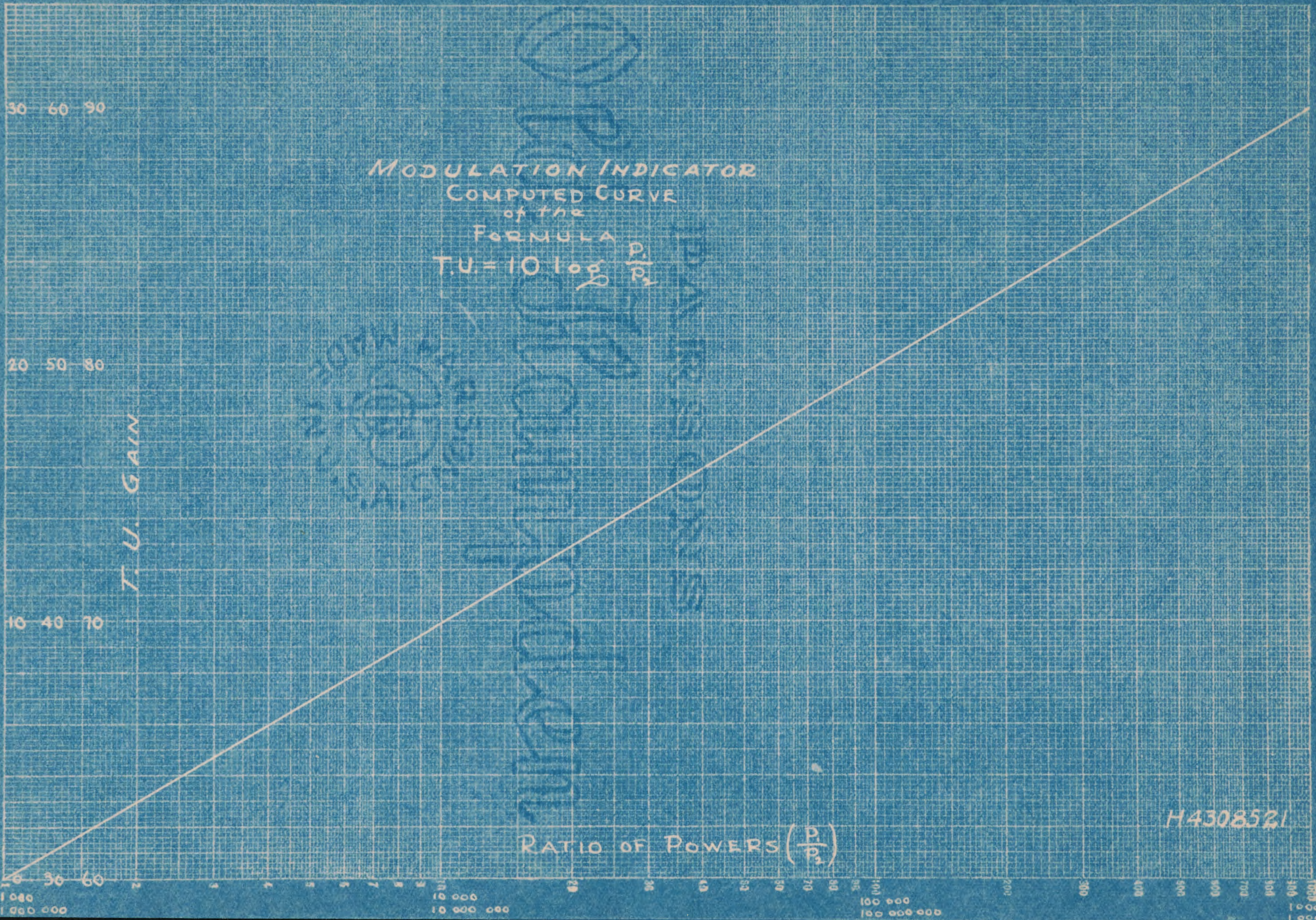


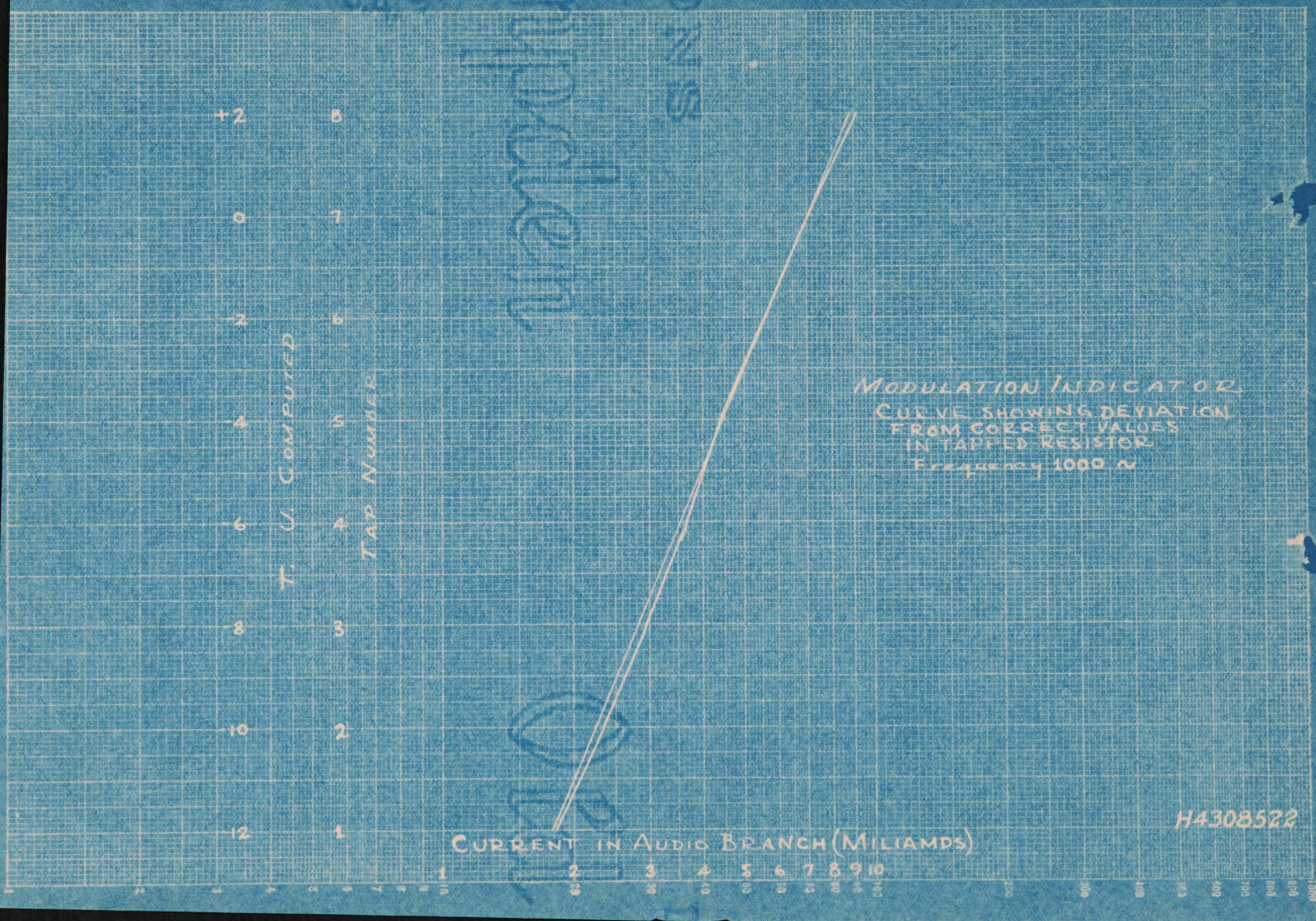
H4308519

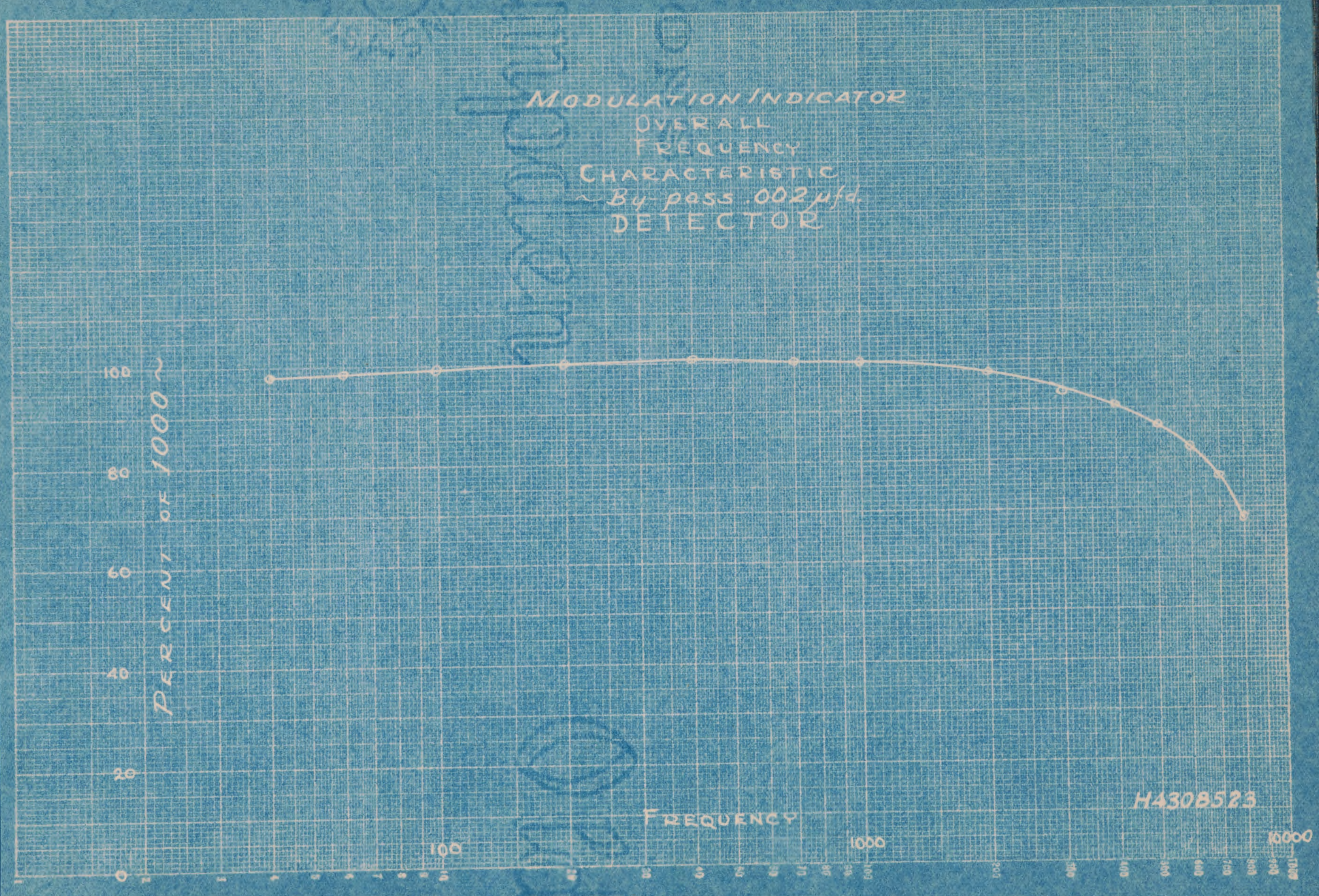

MODULATION INDICATOR
COMPUTED
CURVE
of
FORMULAE
T.U. = 20 log $\frac{E}{E_1}$
T.U. = 20 log $\frac{I}{I_1}$
Assuming $R_1 = R_2$
and
T.U. = 10 log $\frac{P}{P_2}$
Regardless of R
GAIN
LOSS
T.U. GAIN OR LOSS
POWER
E. I. or percent
PERCENT
OR
VOLTAGE OR CURRENT RATIO (%)
20
40
60
80
100
150
200
300
400
500
H4308520

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THE OTHER WAY (VERTICALLY) ... MUST BE LEFT-HAND SIDE.




MODULATION INDICATOR
CURVE SHOWING DEVIATION
FROM CORRECT VALUES
IN TAPPED RESISTOR
Frequency 1000 ~
T. U. COMPUTED
TAP NUMBER
+2
0
-2
-4
-6
-8
-10
-12
8
7
6
5
4
3
2
1
CURRENT IN AUDIO BRANCH (MILIAMPS)
1
2
3
4
5
6
7
8
9
10
H4308522


MODULATION INDICATOR
OVERALL
FREQUENCY
CHARACTERISTIC
~ By-pass .002 μfd.
DETECTOR
PERCENT OF 1000~
100
80
60
40
20
0
FREQUENCY
100
1000
10000
H430B523

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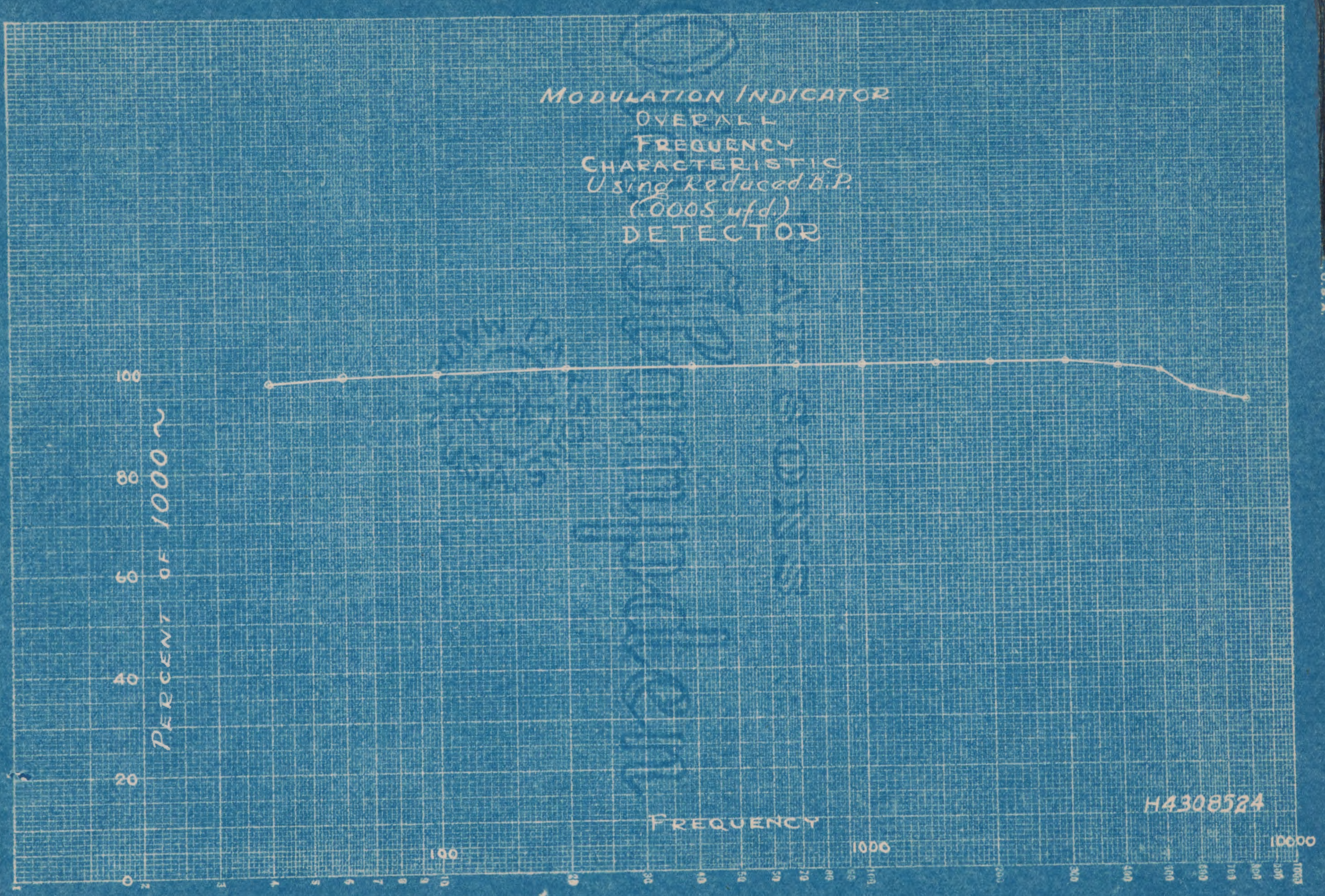

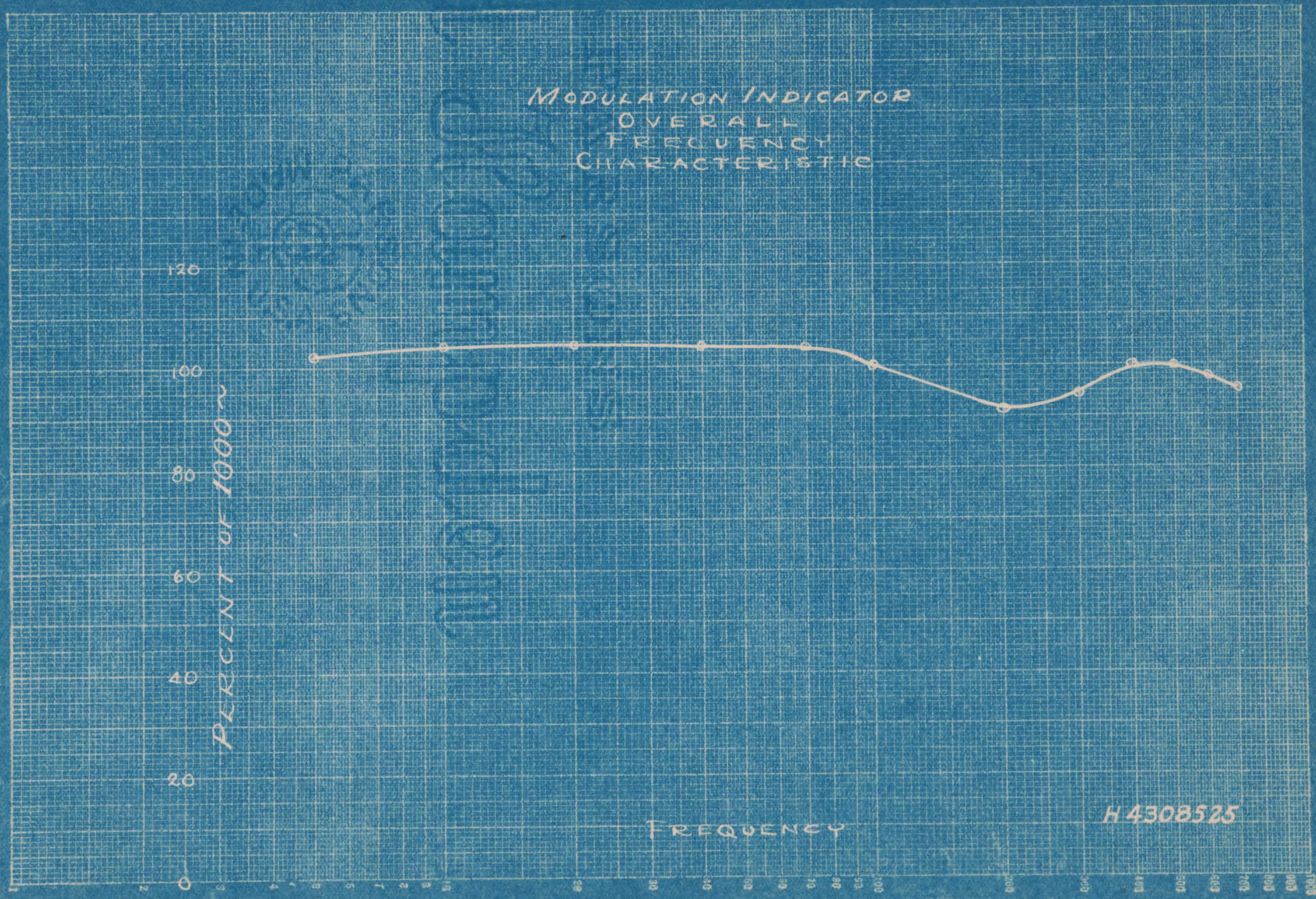
MODULATION INDICATOR
OVERALL
FREQUENCY
CHARACTERISTIC
120
100
80
60
40
20
0
PERCENT OF 1000~
FREQUENCY
H 4308525