Investigation of the transfer characteristics of the degaussing power amplifier on MCB 159 and class canadian minesweepers

Petersons, O.

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INVESTIGATION OF THE TRANSFER CHARACTERISTICS OF THE DEGAUSSING POWER AMPLIFIER ON MCB 159 AND CLASS CANADIAN MINESWEEPERS

O. PETERSONS

OTTAWA

SEPTEMBER 1959

ABSTRACT

The results of performance tests on degaussing power amplifiers used on MCB 159 and class Canadian minesweepers are reported. The tests were performed to obtain data required for adaptation of the existing power amplifiers to a closed-loop degaussing system now under development. The test results consist of static and dynamic transfer characteristics of the "A", "L", and "M" power amplifiers and of the magnetic amplifier stages and d-c generators comprising these amplifiers. The d-c characteristics obtained in the test agree with those published by the manufacturer except in the case of the first stage magnetic amplifier. Transfer functions for the power amplifier stages are derived. The gain of the amplifiers is sufficient for use in the closed-loop degaussing system. The closed loop can be stabilized by addition of a simple stabilizing network. In the existing open-loop degaussing system undesirable transient oscillations were observed. Means of reducing these are suggested.

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INVESTIGATION OF THE TRANSFER CHARACTERISTICS OF THE DEGAUSSING POWER AMPLIFIER ON MCB 159 AND CLASS CANADIAN MINESWEEPERS

- O. Petersons -

INTRODUCTION

In a previous report [1] a possible closed-loop ship's degaussing system was proposed. The power amplifiers used in the existing open-loop degaussing system on MCB 159 and class Canadian minesweepers are suitable for use in the proposed closed-loop system. A unit containing control and power supply equipment for the open-loop degaussing system was brought into the laboratory, and tests were performed on the power amplifier section of the unit in order to obtain the information on characteristics pertaining to its adaptation to the closed-loop system.

DESCRIPTION OF EQUIPMENT

In the existing open-loop system currents to the "A", "L", and "M" degaussing coils are supplied by three power amplifiers in accordance with preset d-c levels and varying signals received from the ship's gyro compass and vertical gyro stabilizer. Except for gain, all power amplifiers are similar, each consisting of a d-c generator, the field of which is excited by a three-stage push-pull magnetic amplifier. To obtain good linearity feedback is provided around the whole power amplifier. In order to make the amplifier stable, local feedback loops are placed around the second and third stage magnetic amplifiers. For protection of equipment each power amplifier is equipped with a current-limiting magnetic amplifier which does not permit the output current to reach an excessive value. The current-limiting amplifier is stabilized by a rate feedback from the generator output.

A schematic diagram of the degaussing power amplifier is shown on Fig. 1. A more detailed description and circuit diagrams are found in the maintenance manual [2].

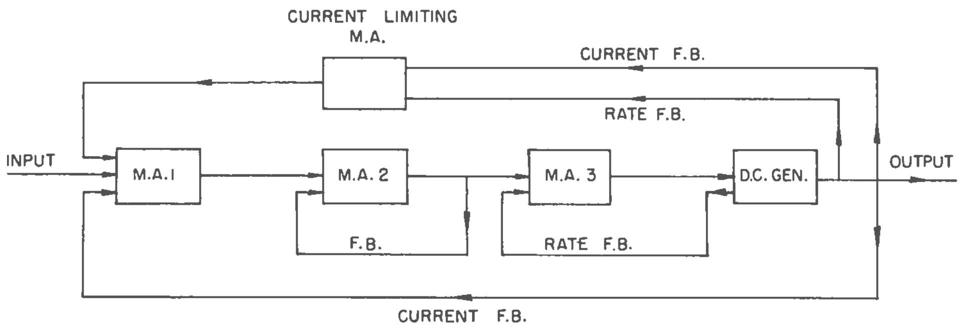

FIG. 1 SCHEMATIC DIAGRAM OF OPEN-LOOP DEGAUSSING POWER AMPLIFIER

TEST METHODS AND PROCEDURE

In the test, static and dynamic characteristics of the three power amplifiers and individual amplifier stages were investigated by obtaining the d-c transfer characteristics, and frequency and step responses.

The method of obtaining the d-c transfer characteristics was that outlined in Ref. 2, unless otherwise stated. During the test amplifiers were loaded as in normal operation.

In frequency response tests the signal to the amplifiers was provided by a low-frequency function generator. Magnitude and phase measurements were made either with a Brush recorder or a transfer function analyzer. Step responses were recorded by a Brush recorder. In the above dynamic tests the amplifiers were connected as in the corresponding d-c tests.

TEST RESULTS

1) Transfer Curves of Power Amplifiers

The d-c transfer curves of the "A", "L", and "M" coil amplifiers are shown on Figs. 2, 3, and 4, respectively. The curves agree with those presented in Figs. 7-10, 7-11, and 7-12 of Ref. 2. The linearity of amplifiers is good.

2) Transfer Curves of Magnetic Amplifiers and D-C Generator

An attempt was made to obtain the d-c transfer characteristics of each amplifying stage of a degaussing power amplifier. Since all three degaussing

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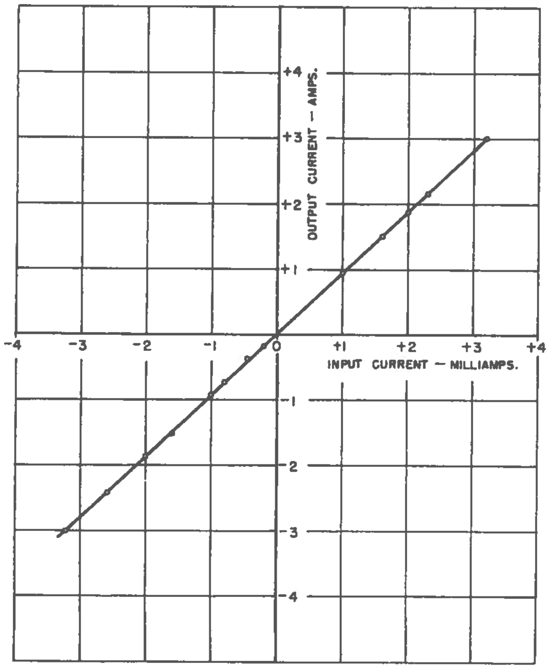

FIG. 2 "A" COIL POWER AMPLIFIER
TRANSFER CURVE

LOAD RESISTANCE: 40 OHMS

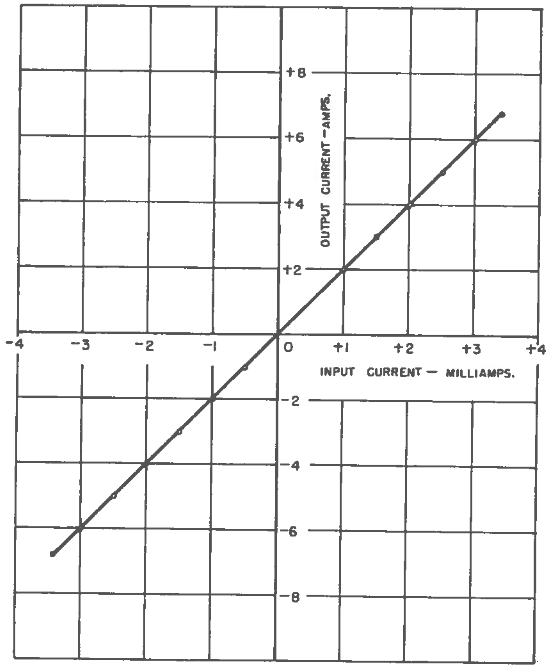

FIG. 3 "L" COIL POWER AMPLIFIER
TRANSFER CURVE

LOAD RESISTANCE: 28 OHMS

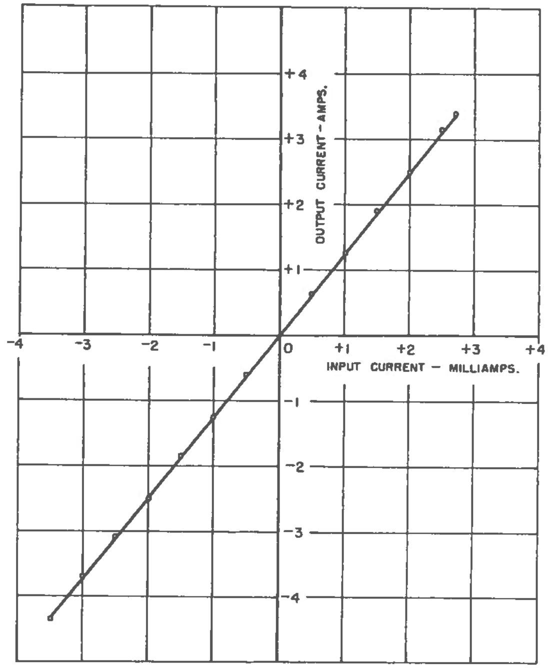

FIG. 4 "M" COIL POWER AMPLIFIER
TRANSFER CURVE

LOAD RESISTANCE: 58 OHMS

power amplifiers are similar, only the "A" coil amplifier was tested.

The transfer characteristics of the first stage magnetic amplifier could not be obtained directly because the amplifier by itself tended to drift towards saturation. Approximate characteristics of this stage are given later in this report.

The transfer curves of the second stage magnetic amplifier are shown on Fig. 5. Two transfer characteristics were obtained: one with the amplifier connected as in the original system, the other with the feedback disconnected at the winding terminal 10 (terminal designations as in circuit diagram, Fig. 9-18, Ref. 2). The input current was supplied to the windings between the terminals 16 and 19 as it is done in normal operation of the amplifier stage, instead of supplying it to the windings between terminals 13 and 15 as suggested in the manual.

Transfer curves of the third stage magnetic amplifier are shown on Fig. 6. During the test the amplifier was connected as in its normal operation. The time constant and rate field windings were left closed. The input signal was supplied to the windings between terminals 20 and 23.

The third stage magnetic amplifier actually consists of two simple polarity-sensitive magnetic amplifiers, each supplying current to separate field windings of the generator. The polarities of the two field windings are opposite so that, if the outputs of the two amplifiers are equal, the resultant generator excitation is zero. On the graph, currents to both field windings, F_1-F_2 and F_3-F_4 (see Fig. 9-17, Ref. 2), are shown. The sum of the two currents is also shown since the excitation of the generator depends on it.

The curves obtained for the second stage magnetic amplifier without feedback and for the third stage magnetic amplifier are similar to the corresponding curves in Ref. 2.

The plot of generator armature current versus field current is shown on Fig. 7. The generator was working into a load resistance of 40 ohms.

3) Dynamic Characteristics of the Power Amplifier and its Individual Stages

The dynamic characteristics of the "A" coil amplifier were investigated by frequency and step response tests. In general, the results of these tests depended somewhat on the amplitude of the applied input signal so that some variation from the results presented in this report is possible.

The frequency response of the whole power amplifier is shown on Fig. 8. Two tests were performed: one with an input signal of ±1 milliampere peak-to-peak and the other with ±0.3 milliampere peak-to-peak. Undistorted outputs for

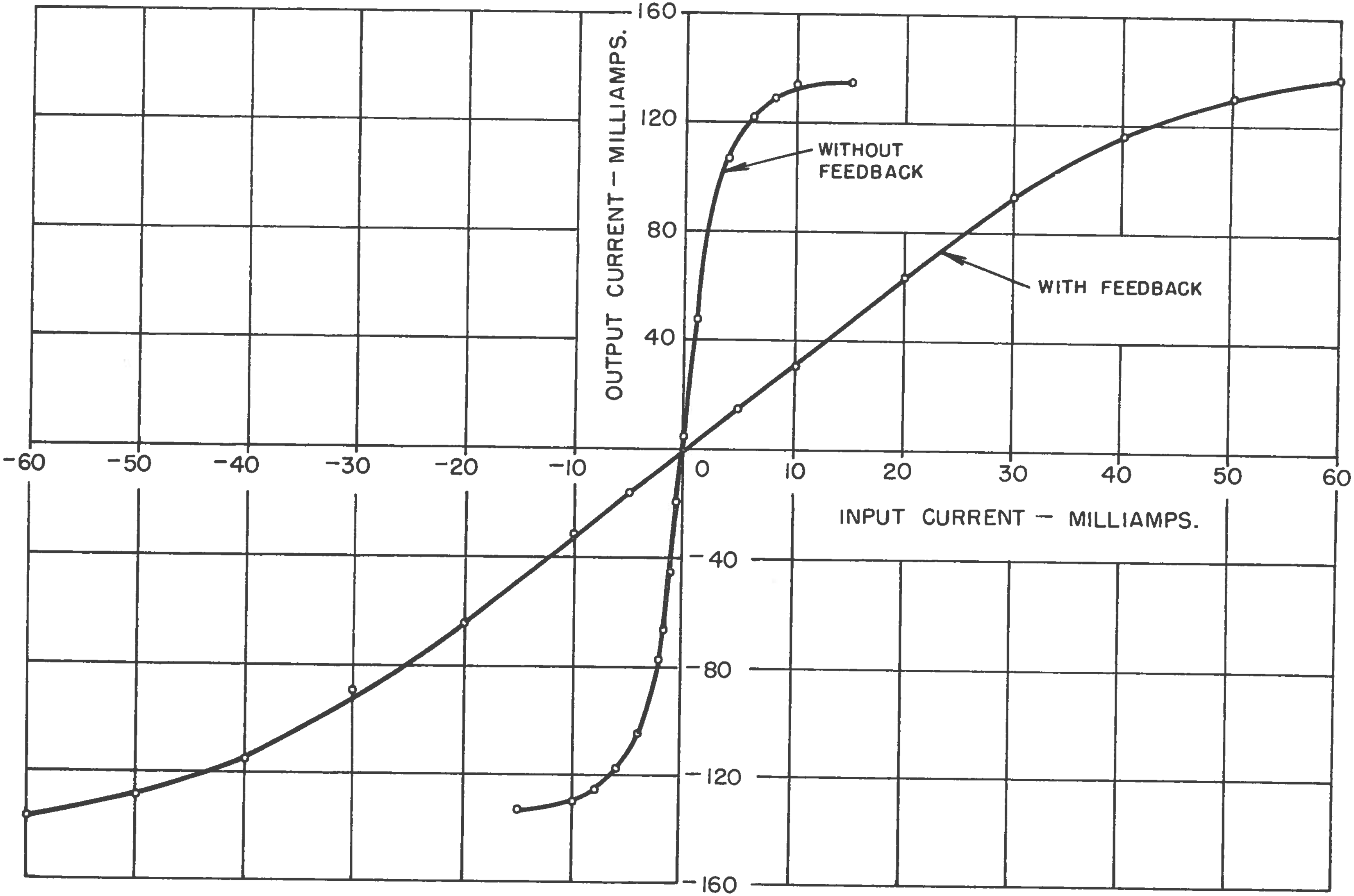

FIG. 5 SECOND STAGE MAGNETIC AMPLIFIER TRANSFER CURVES

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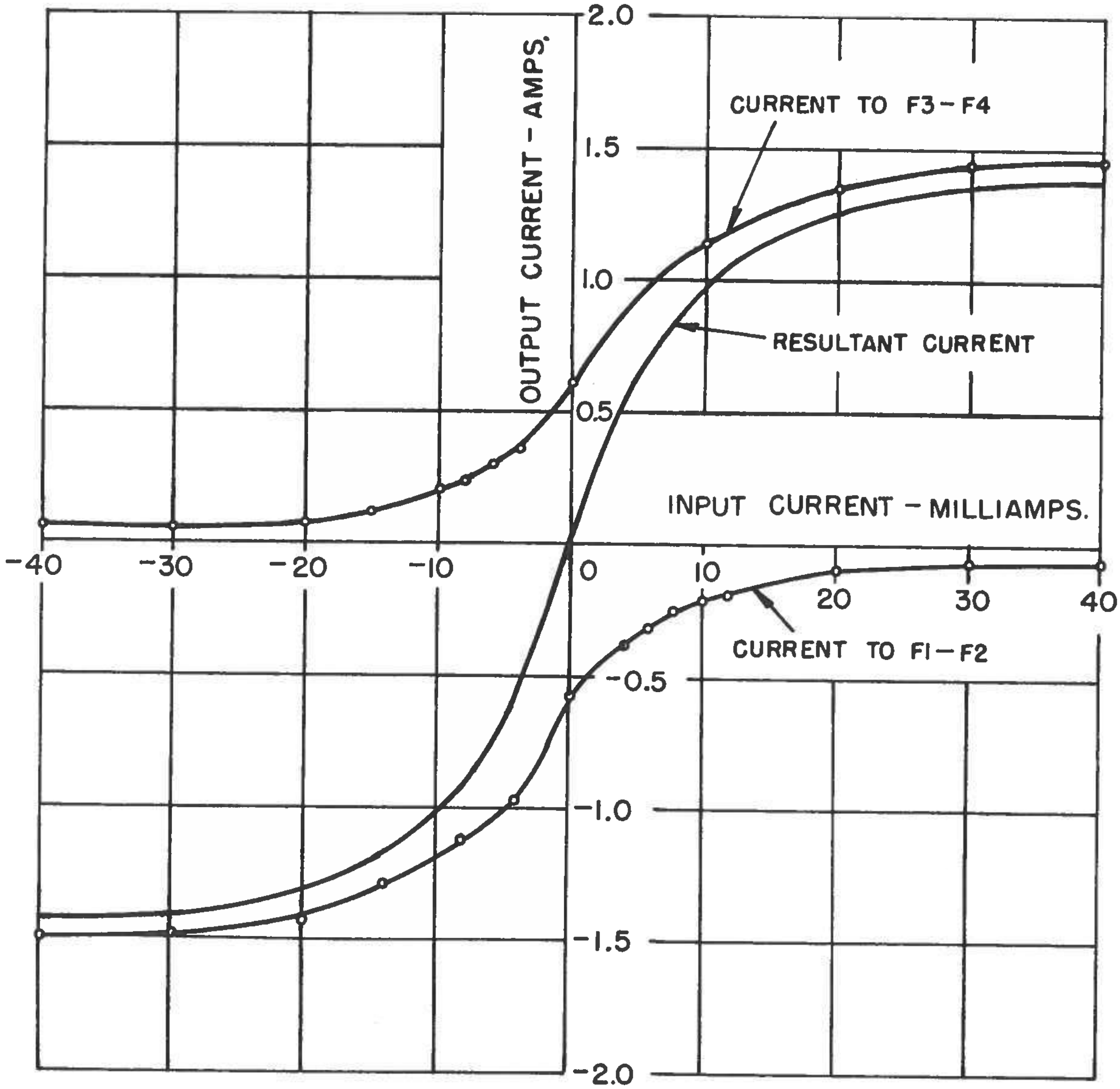

FIG. 6 THIRD STAGE MAGNETIC AMPLIFIER TRANSFER CURVES

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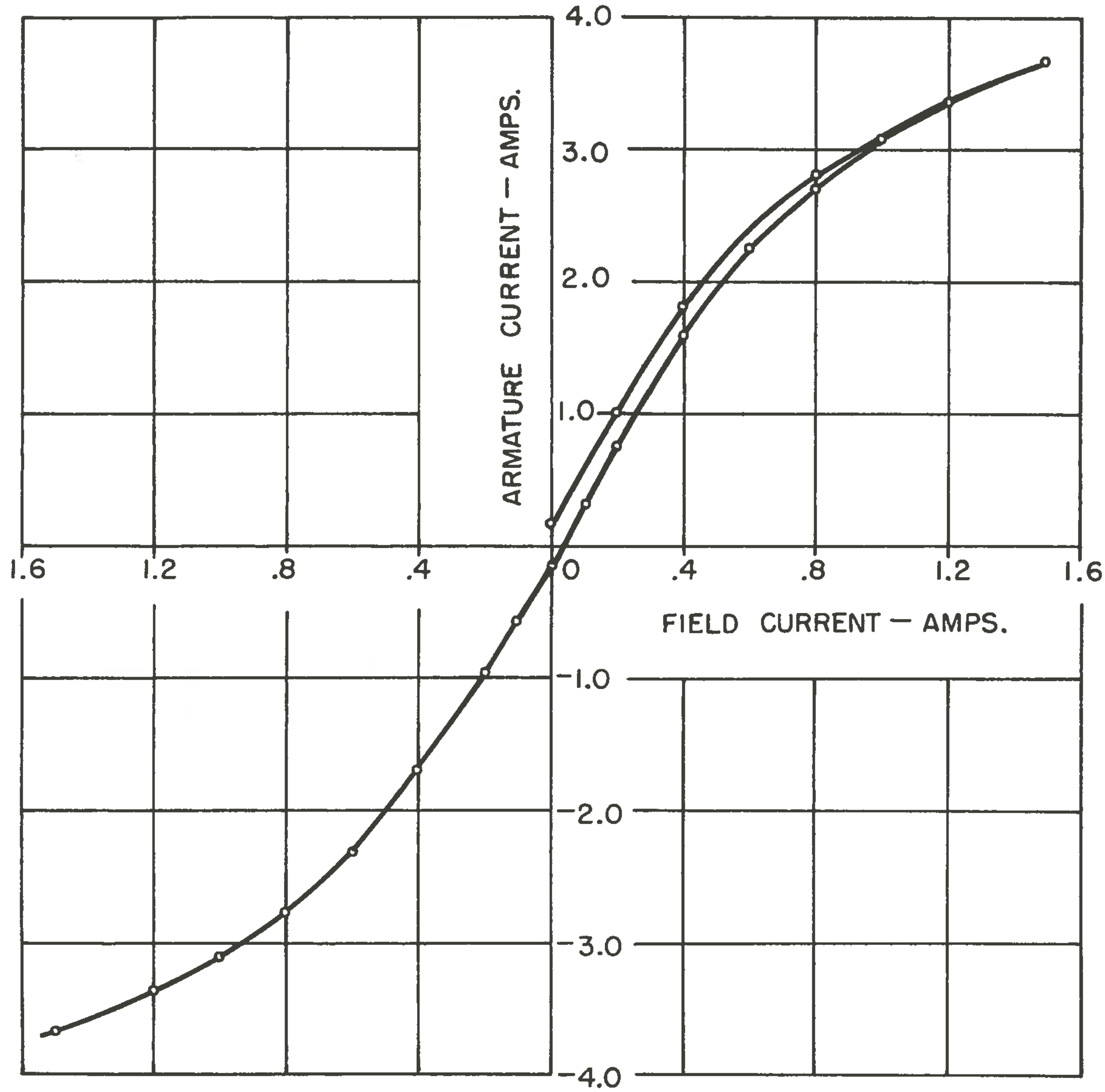

FIG. 7 ARMATURE VS. FIELD CURRENT OF D-C GENERATOR SUPPLYING "A" DEGAUSSING COIL

LOAD RESISTANCE: 40 OHMS

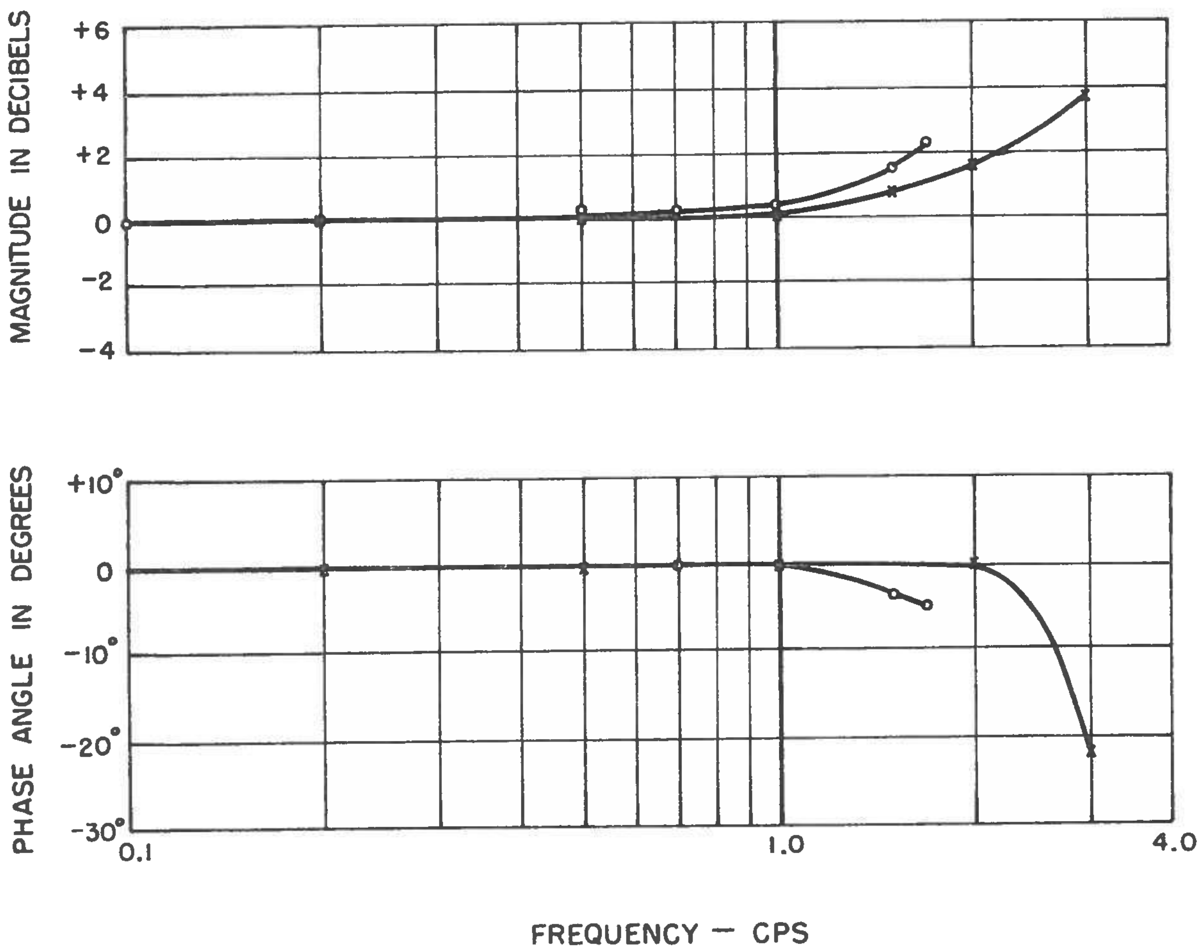

FIG. 8 "A" COIL POWER AMPLIFIER FREQUENCY RESPONSE

LEGEND

o—o—o INPUT SIGNAL AMPLITUDE: ± 1 MA. Peak to Peak
x—x—x INPUT SIGNAL AMPLITUDE: ± 0.3 MA. Peak to Peak

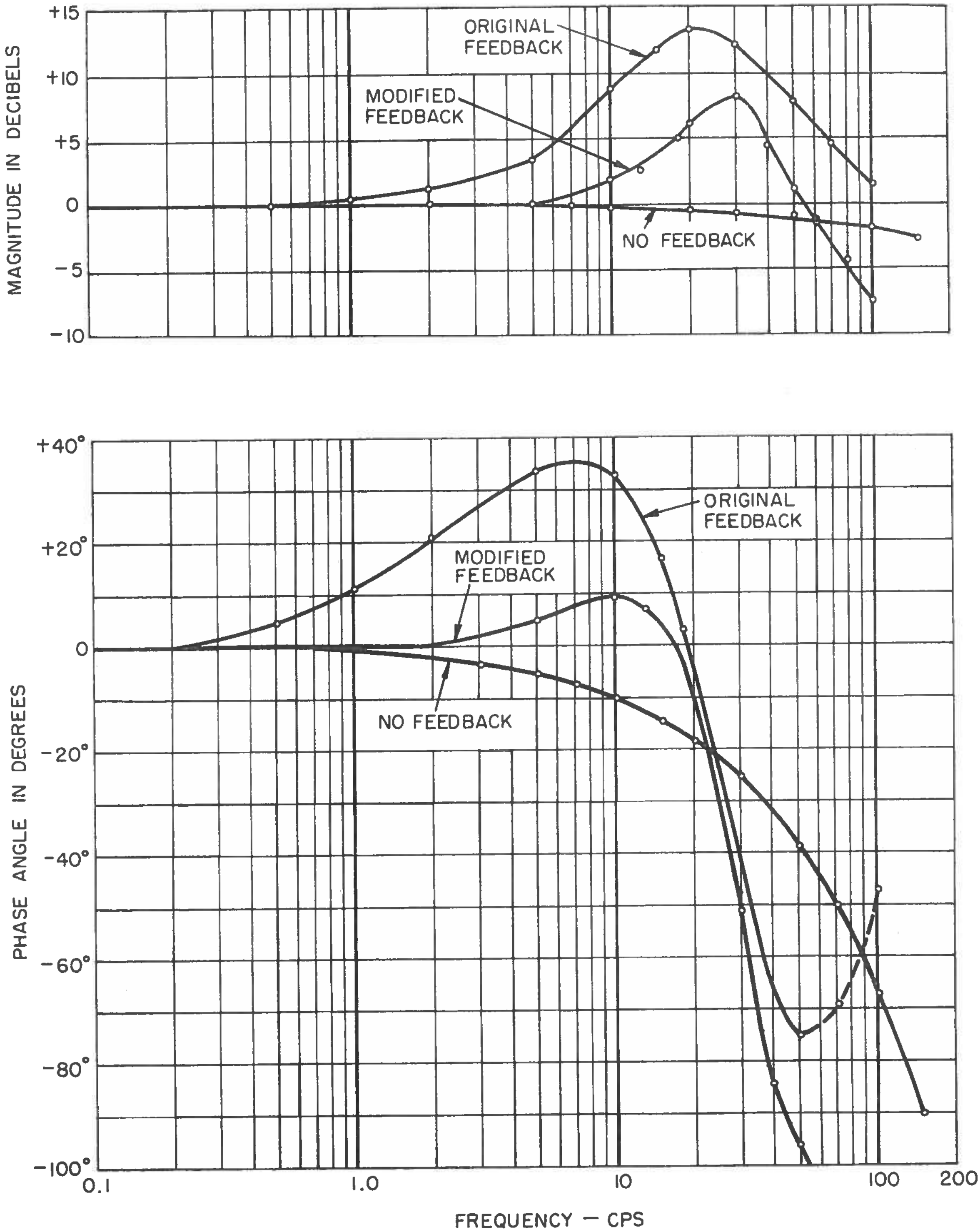

FIG. 9 SECOND STAGE MAGNETIC AMPLIFIER FREQUENCY RESPONSES

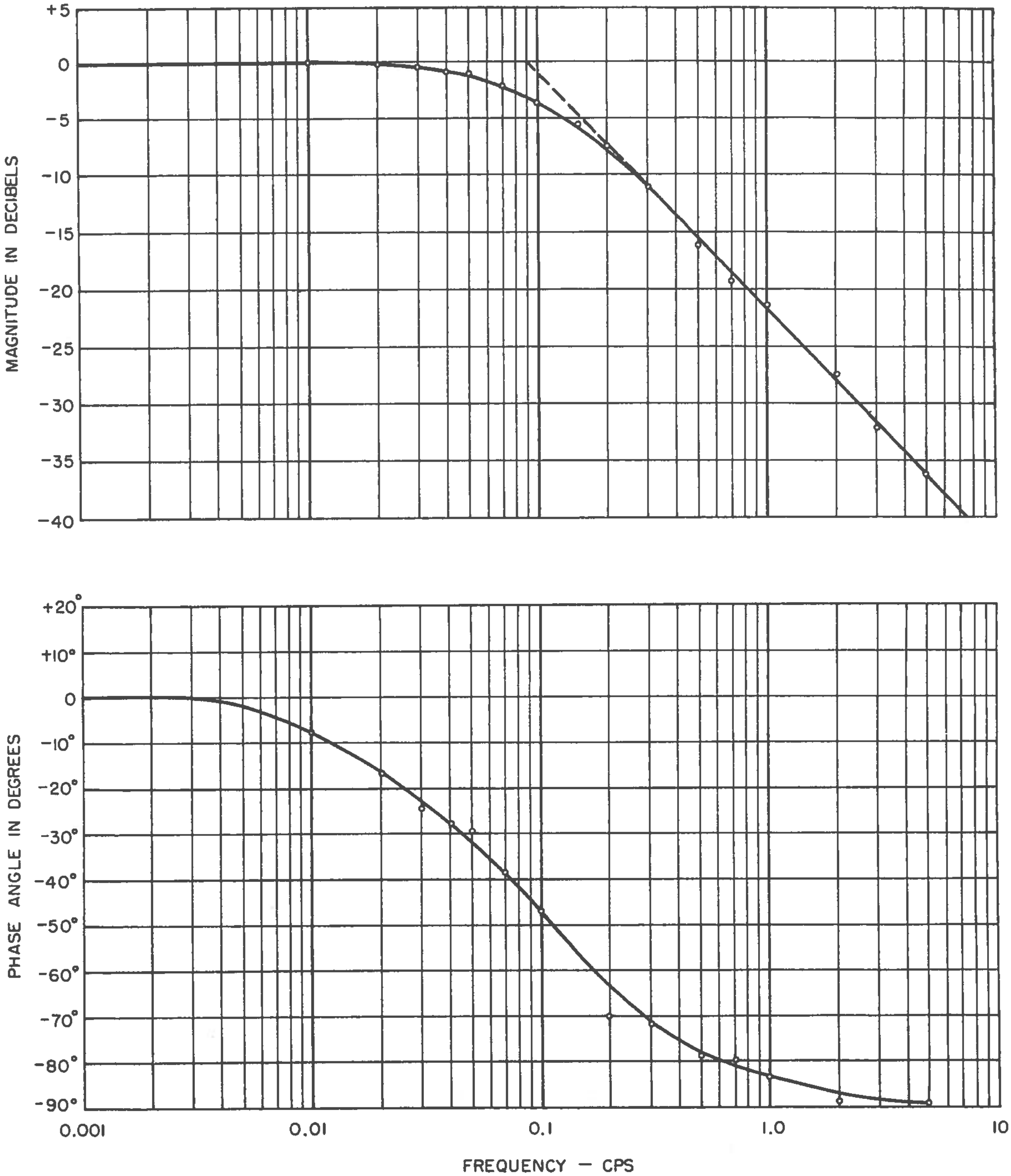

FIG. 10 FREQUENCY RESPONSE OF COMBINED THIRD STAGE MAGNETIC AMPLIFIER AND D-C GENERATOR

these input signal amplitudes could be obtained up to frequencies indicated on the graph. As observed from the graph, the useful frequency range of the amplifier is greater for smaller input signals. The small-signal response was similar when the small sinusoidal input signal was superposed on a relatively large d-c signal.

The frequency response of the first stage magnetic amplifier could not be obtained because of the instability mentioned earlier. Three sets of frequency response curves (Fig. 9) were obtained for the second stage magnetic amplifier: (1) with the amplifier connected as in the original system, (2) with the local feedback disconnected, (3) with the feedback network modified by increasing the value of the resistor R45 (see Fig. 9-17, Ref. 2) from 1.5 kilohms to 10 kilohms and by decreasing the value of the capacitor C16 from 50 μf to 6 μf. The frequency response of the combined third stage magnetic amplifier and d-c generator is shown on Fig. 10.

The response of the "A" coil amplifier to the square wave is shown on Fig. 11.

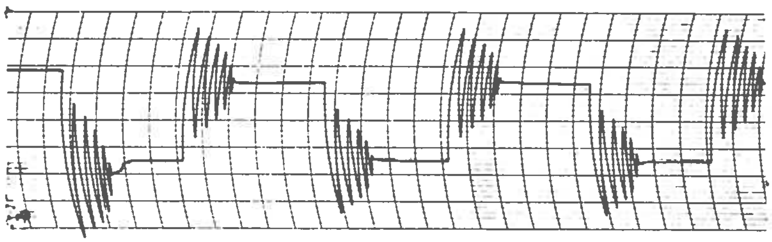

FIG. II RESPONSE OF "A" COIL POWER AMPLIFIER TO SQUARE WAVE

INPUT SIGNAL: ±1 MA.
CHART SPEED: 1 DIV./SEC.

4) Characteristics of the First Stage Magnetic Amplifier

Characteristics of the first stage magnetic amplifier were obtained by stabilizing it for the tests with local negative feedback. The circuit diagram of the stabilized first stage magnetic amplifier is shown on Fig. 12. The amount of feedback is varied by adjusting the variable resistor R_F. The transfer curves for three settings of R_F were obtained (Fig. 13). The frequency response of the amplifier with R_F = 2700 ohms is plotted on Fig. 14.

The gain of an amplifier with negative feedback is given by:

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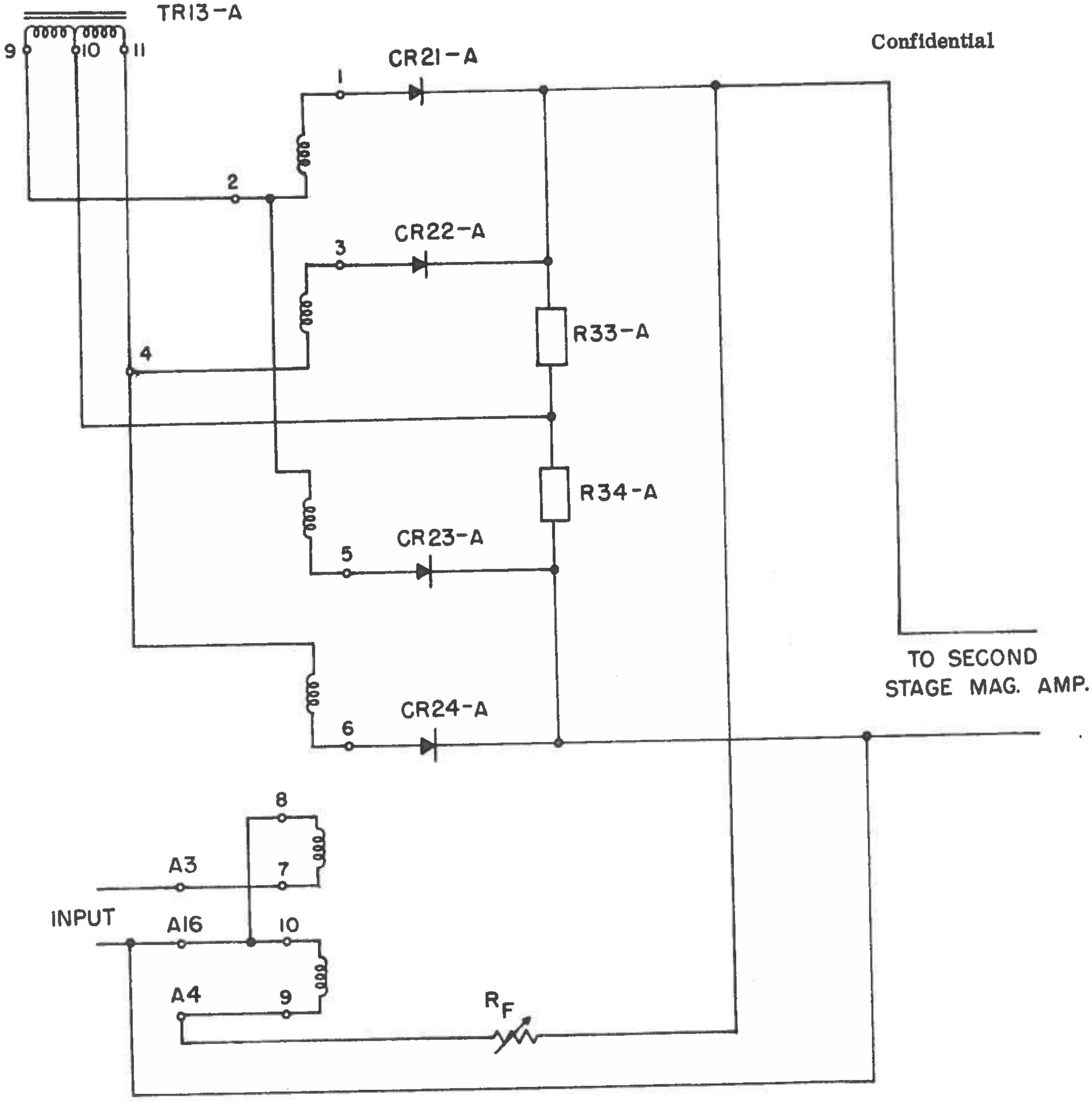
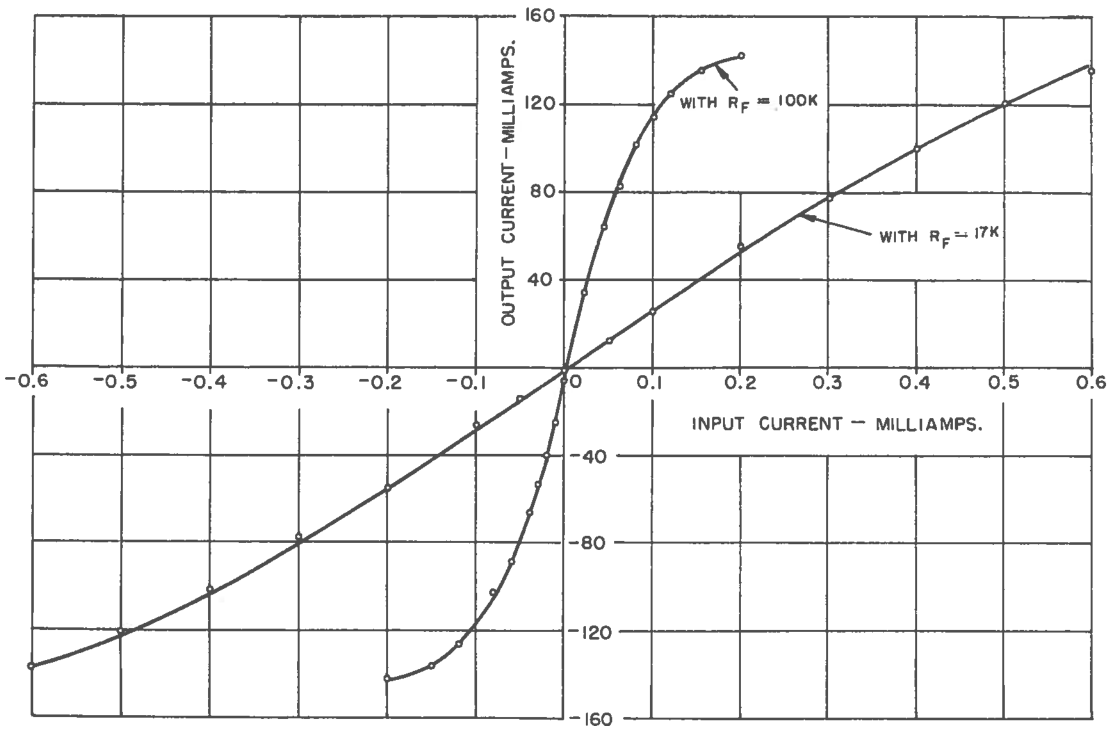


FIG. 12 DIAGRAM OF FIRST STAGE MAGNETIC AMPLIFIER MODIFIED WITH STABILIZING FEEDBACK



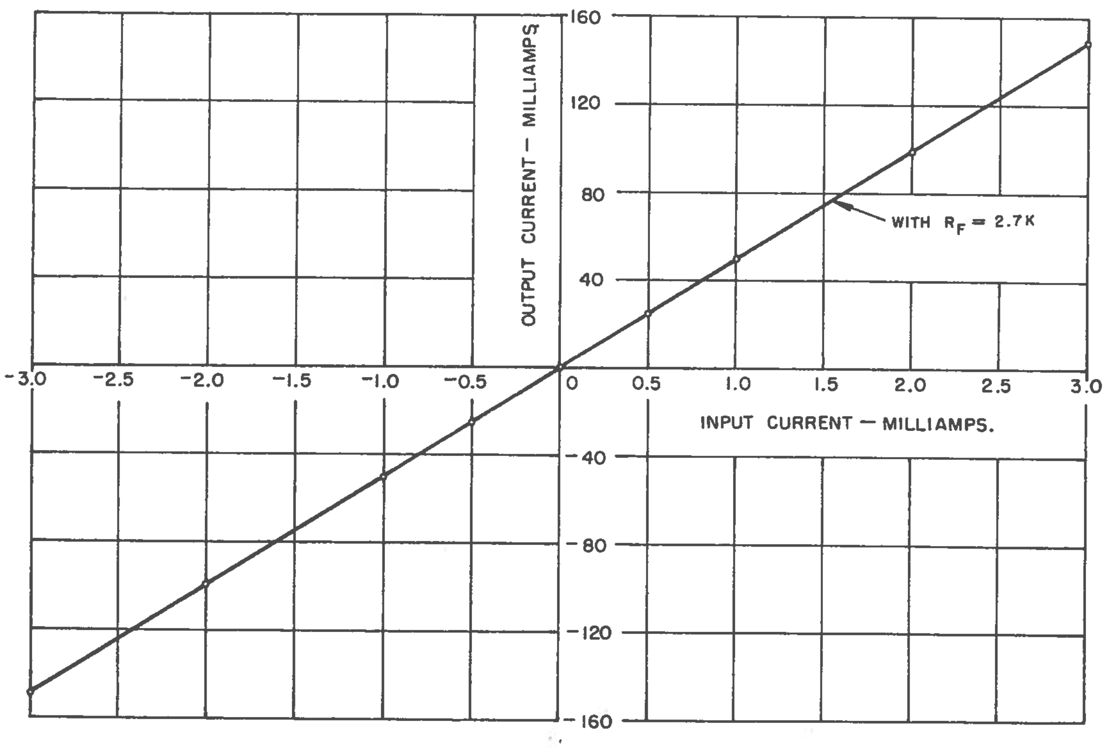


FIG. 13 TRANSFER CURVES OF MODIFIED FIRST STAGE MAGNETIC AMPLIFIER

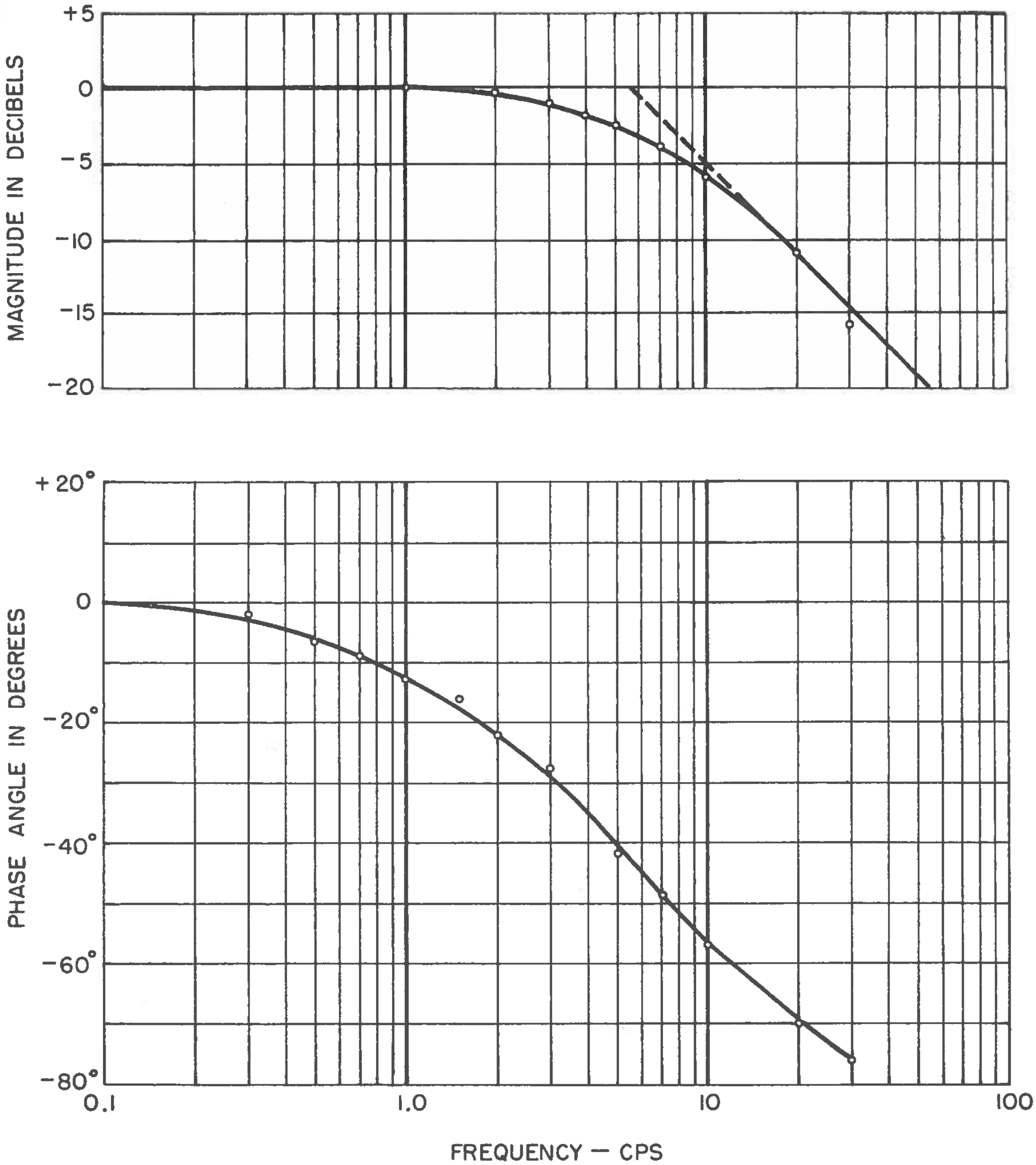


FIG. 14 FREQUENCY RESPONSE OF MODIFIED FIRST STAGE MAGNETIC AMPLIFIER

$$\frac{I_0}{I_1} = \frac{G}{1 + GH} ,$$

where I_0 is the output current,
I_1 is the input current,
G is the gain of the amplifier without feedback,
H is the gain of the feedback circuit.

If the loop gain (GH) of a feedback amplifier is not very large as compared with unity, G can be calculated if I_0/I_1 and H are known. This was applicable to the modified first stage magnetic amplifier with R_F = 100 kilohms. The gain (G) of the amplifier was calculated to be 16,500.

The first stage magnetic amplifier with feedback, as observed from the frequency response curve on Fig. 14, is a simple lag system. Since the feedback circuit does not contain any energy storage elements the amplifier itself is a simple lag system. The gain times bandwidth product of an amplifier without feedback is the same as with feedback. By applying this principle to the data on Fig. 13 and Fig. 14 the cutoff frequency of the first stage magnetic amplifier without feedback was calculated to be 0.018 cps.

BLOCK DIAGRAM OF POWER AMPLIFIER

From the information obtained in the previous tests a block diagram of the whole power amplifier can be established.

The first stage magnetic amplifier and combined third stage magnetic amplifier and d-c generator are approximated by simple lag systems. The second stage magnetic amplifier can be represented by a quadratic lag system. The transfer functions of the current feedback and the local feedback around the second stage magnetic amplifier can be readily determined from the circuit parameters. The block diagram is shown on Fig. 15.

The current-limiting magnetic amplifier is not included in the block diagram, since it does not affect the operation of the system within the rated load. This amplifier performed its current-limiting function satisfactorily.

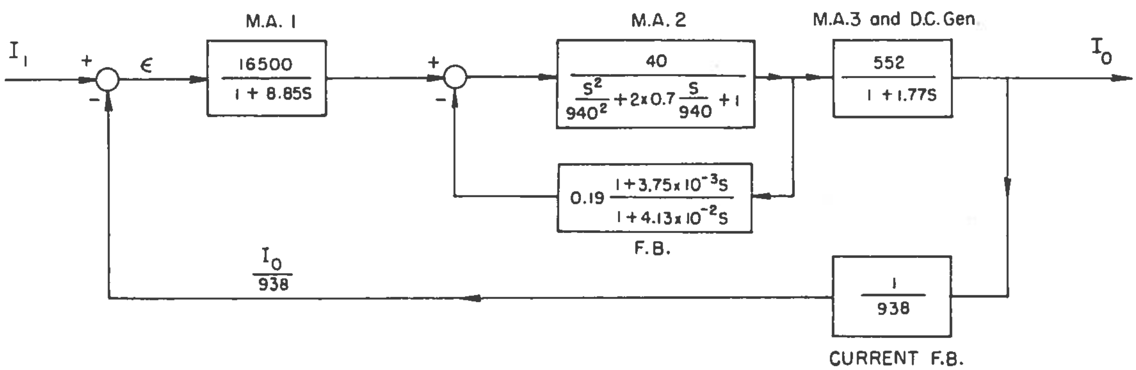


FIG. 15 APPROXIMATE BLOCK DIAGRAM OF DEGAUSSING POWER AMPLIFIER

IMPROVING THE STABILITY OF THE POWER AMPLIFIER

In the power amplifier large oscillations were observed in the response to the square wave. In order to get an indication of the stability of the system and to find possible means of improving it, the loop gain of the original system is plotted on the Nyquist diagram, Fig. 16. The loop gain was obtained by taking the experimental transfer characteristics of amplifiers and the theoretical gain of the principal feedback loop. As observed from the diagram the locus is well away from the critical $(-1 + j0)$ point.

The excessive oscillations are believed to be due to incidental non-linearities in the system, major sources of these being the first stage magnetic amplifier because of its inherent instability and the second stage magnetic amplifier because of the high resonant peak in the frequency response.

In order to improve the step response the system was modified as follows: (1) a local feedback, as shown on Fig. 12 with R_F = 2.7 kilohms, was added to the first stage magnetic amplifier, (2) in the network of the local feedback around the second stage the value of the resistor R45 was increased to 10 kilohms and the value of the capacitor C16 was reduced to 6 μf, giving the amplifier frequency response with reduced peak shown on Fig. 9. This modification of the power amplifier results in considerably better step response (Fig. 17). The frequency response of the modified power amplifier is shown on Fig. 18. The d-c transfer characteristic is the same as in the original system.

The loop gain of the modified system is also plotted on the Nyquist diagram Fig. 16.

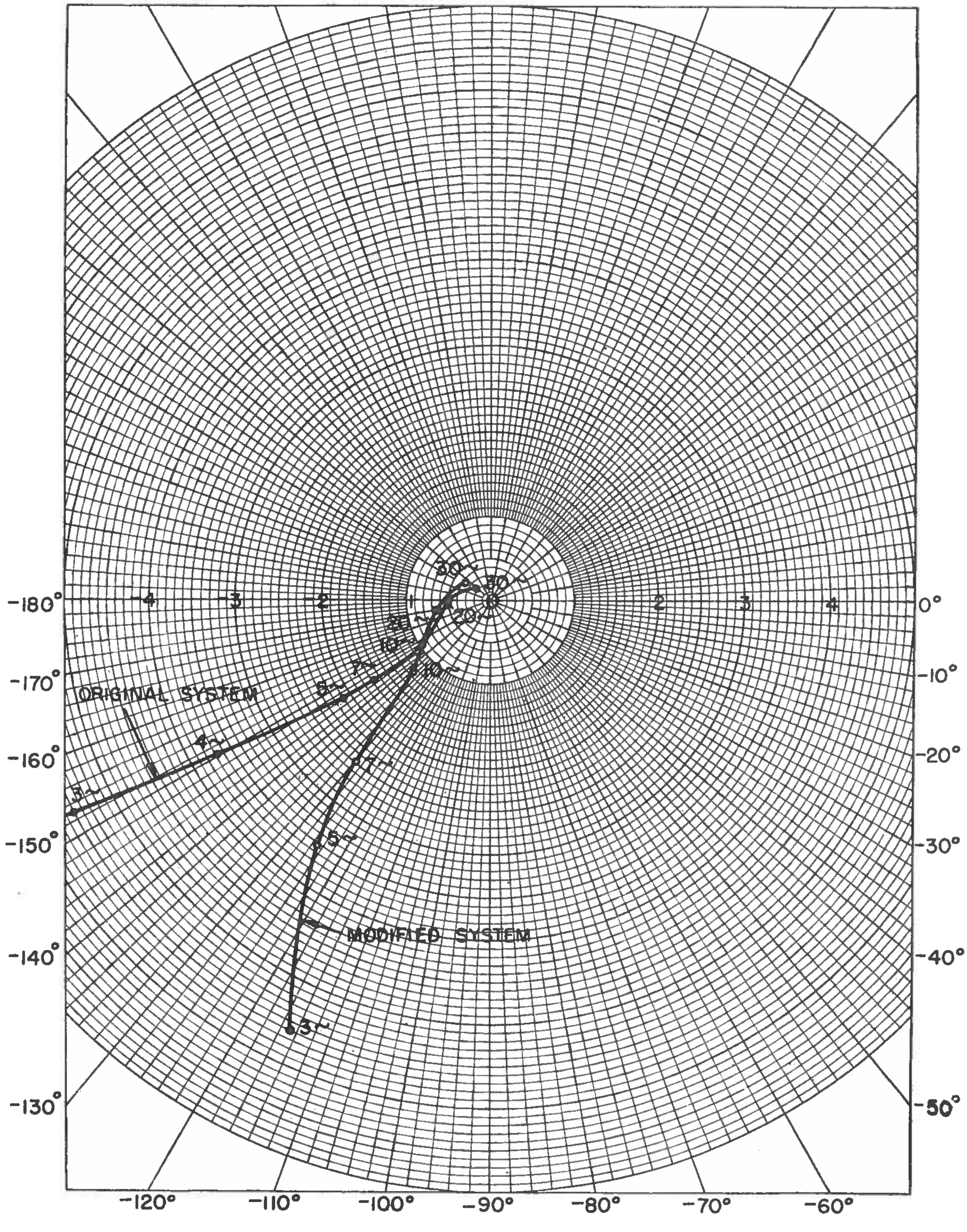


FIG. 16 LOCI OF OPEN LOOP TRANSFER FUNCTIONS $\left(\frac{I_0}{938}/\epsilon\right)$

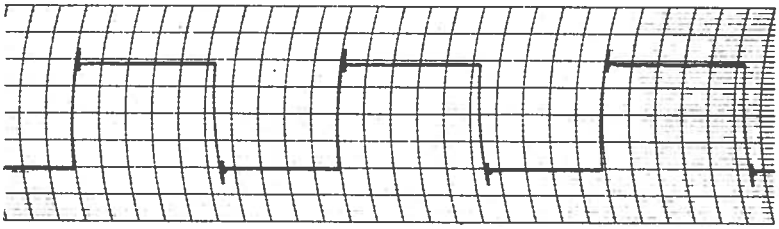


FIG. 17 RESPONSE TO SQUARE WAVE OF MODIFIED "A" COIL POWER AMPLIFIER

INPUT SIGNAL: ±1 MA.
CHART SPEED: 1 DIV./SEC.

In addition to the instability in the step response, further oscillations were observed when the amplifier was switched on by the individual degaussing coil control switch S8 (see Fig. 9-17, Ref. 2). These oscillations have been found to cause large magnetic fields under the ship (see Fig. 36, Ref. 3). Closing of switch S8 connects the degaussing coil to the d-c generator and the magnetic amplifiers to the 400-cps power supply. The signal to be amplified is already supplied to the input of the first stage magnetic amplifier. The transient observed in the output after closing the switch is shown on Brush recorder charts (Fig. 19). As observed from this figure, the instability in the output of the modified system is reduced but not to a satisfactory degree. However, by making the input signal zero at the time of closing this switch, the disturbance in the output is eliminated. Therefore it is recommended that an additional switch be provided for each power amplifier. This switch should be placed before the input of the first stage magnetic amplifier and should be closed after closing the degaussing coil control switch. The resultant transient is then as shown in the step response (Fig. 17).

ADAPTATION OF POWER AMPLIFIER FOR CLOSED-LOOP DEGAUSSING SYSTEM

The requirements of an amplifier in an open-loop degaussing system are good linearity and gain stability, both of which are achieved in the existing system by the use of feedback around the whole amplifier. The gain of the amplifier is very nearly a function of feedback alone.

In a closed-loop system, where the difference between the magnetic field of the ship and the applied degaussing field is detected in the form of an error, the principal requirement is that the gain of the amplifier be large enough to keep the error sufficiently small. The gain of the existing magnetic amplifier stages

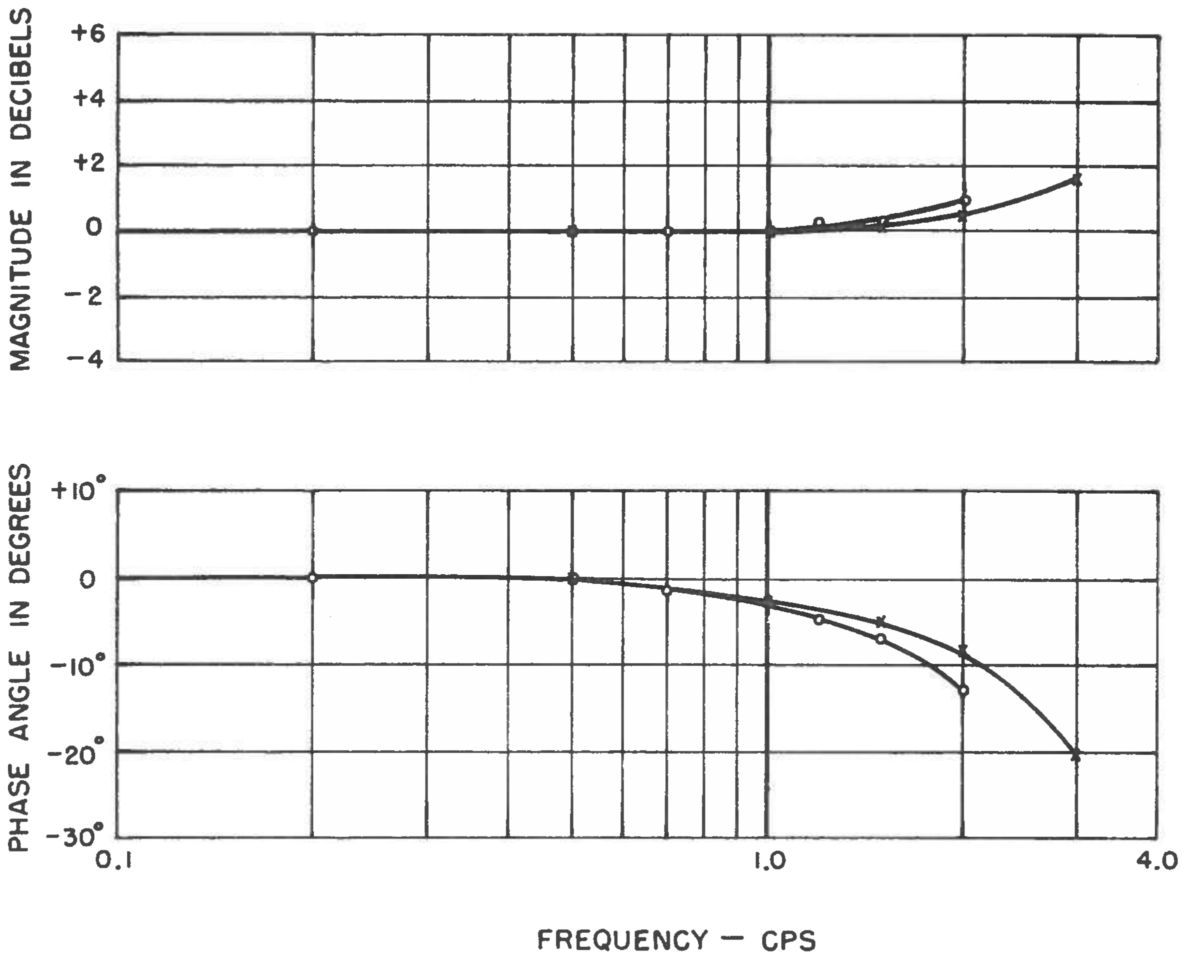
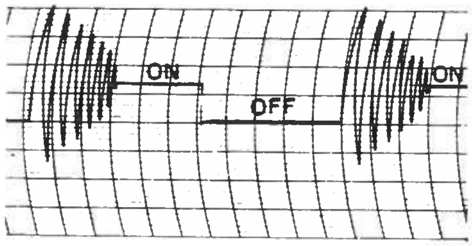


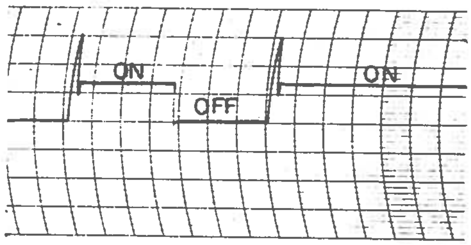
FIG. 18 FREQUENCY RESPONSE OF MODIFIED "A" COIL POWER AMPLIFIER

LEGEND
o—o—o INPUT SIGNAL AMPLITUDE: ± 1.0 MA. Peak to Peak
x—x—x INPUT SIGNAL AMPLITUDE: ± 0.3 MA. Peak to Peak

and rotary amplifier is adequate for use in the closed-loop system.



ORIGINAL SYSTEM



MODIFIED SYSTEM

FIG. 19 TRANSIENT IN "A" COIL POWER AMPLIFIER OUTPUT AFTER SWITCHING AMPLIFIER ON

INPUT SIGNAL: 1 MA
CHART SPEED: 1 DIV./SEC.

The block diagram of the proposed closed-loop degaussing system is shown on page 5, Ref. 1. This system was tested on a laboratory model and was found to be satisfactory. Provided the characteristics of the gradiometer amplifier are known, the power amplifier can be readily incorporated in the full-scale closed-loop degaussing system.

CONCLUSIONS

The power amplifiers used in the open-loop degaussing system on MCB 159 and class Canadian minesweepers can be readily adapted for the closed-loop degaussing system.

The performance of the present degaussing power amplifier equipment was found to be satisfactory, except that large transient oscillations were observed in the degaussing current when a step input was applied to the power amplifier or when the amplifier was switched on. These oscillations can be reduced by simple modifications to the circuit.

The transfer characteristics of the first stage magnetic amplifier could not be obtained by the method outlined in the manufacturer's maintenance manual. The transfer curves of the other magnetic amplifier stages and of the entire degaussing power amplifiers correspond to those given in the manual.

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3. "Magnetic Signature of HMCS "Cowichan" (MCB 162), Esquimalt, B.C., March 1958", R.M. Morris and B.O. Pedersen. National Research Council Report ERA-338, July 1958 (Confidential)