ms-1

FACILITY FORM 602

N65 23063 (ACCESSION NUMBER) — (THRU)

29 (PAGES) — 1 (CODE)

CR 62469 (NASA CR OR TMX OR AD NUMBER) — 03 (CATEGORY)

GPO PRICE $

OTS PRICE(S) $

Hard copy (HC) 2.00

Microfiche (MF) .50

FINAL REPORT
JUNE 12,1964

DIRECT CURRENT TORQUE AMPLIFIER FOR DRIVING A GYRO-STABILIZED PLATFORM

PREPARED FOR

NATIONAL AERONAUTICS and SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

SUBMITTED BY

ORDNANCE DEPARTMENT
OF THE DEFENSE ELECTRONICS DIVISION
GENERAL ELECTRIC
100 PLASTICS AVENUE, PITTSFIELD, MASSACHUSETTS

Contract NAS 8-5421

DIRECT CURRENT TORQUE AMPLIFIER FOR DRIVING A GYRO-STABILIZED PLATFORM

Prepared by
H.L. Broverman
June 12, 1964

FINAL REPORT Contract NAS 8-5421

Prepared for:
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

Submitted by:
The General Electric Company
Ordnance Department
Pittsfield, Massachusetts

FDU 64-7

CONTENTS

Section I
INTRODUCTION

Section II
CIRCUITS AND PACKAGING

Section III
PROJECTED IMPROVEMENTS

Section IV
CONCLUSIONS

LIST OF ILLUSTRATIONS

Section I
INTRODUCTION

1-1 OBJECTIVES AND APPROACH

The objective of this program was to design a d-c amplifier with high power efficiency, small enough to consider gimbal mounting, and with performance characteristics which meet the required specifications. To achieve these objectives an approach was taken which used integrated circuit differential amplifiers for low level gain, a thin-film assembly for high voltage low power components, and a pulse width modulated power discrete output stage. Feedback around the complete amplifier provides linearity and gain stability. All components, including the integrated circuits, thin film assembly, and discrete components, are mounted on a double-sided printed circuit board. The result is a small, compact hybrid module capable of being operated unpotted or potted in epoxy.

Design specifications in brief are as follows:

1. Use state of the art thin film or integrated circuitry.

2. Linearity: ±5 percent 0.1 - 1.0 amp
   Load = 40 ohm + 13 mh

3. Source: 56 ± 2 volt battery supply, with filtering such that the 10-volt peak-to-peak square wave produces less effect than 1.0 mv at input.

4. Input impedance: 50 K, with 0-200 cps response.

5. Gain adjustable from 6.25 amp/volt to 25 amp/volt.

6. Offset: ± 5 mv maximum reference to input.

7. Deadband: ± 1.5 mv maximum.

1-2 ACCOMPLISHMENTS

Four objectives of the program have been accomplished as follows:

1. Six operating modules have been constructed and delivered which meet the intent of all specifications.

2. The complete assembly (unpotted) has dimensions of 1.6 by 1.85 by 0.47 inches. The 0.47-inch dimension does not include terminal pin height or heat sink thickness.

3. An integrated circuit differential amplifier circuit has been developed, in parallel with development work sponsored by the General Electric Company.

4. Practical application of pulse width modulation to an inductive d-c servo motor from a bridge circuit has been demonstrated.

1-3 PROJECTIONS

There are several possible directions in which this work could be extended:

1. The existing functional design could be repackaged, using approved components for life tests, environmental evaluation, and any other pre-production tests deemed necessary before incorporation into flight vehicles.

2. A package could be developed using discrete components in place of the integrated circuits and thin film assembly, to permit immediate usage of the circuit concept where there might be prejudice against the newness of micro-circuitry.

3. A circuit and package could be designed using a new technique of pulse width modulation developed by the General Electric Ordnance Department. This new technique presents significant advantages over the old approach in performance, reliability, and circuit simplicity. A description of the new concept is included in Section III, Projected Improvements, in this report.

Of the three courses of action, the last is the one recommended. Design could be implemented with or without integrated circuits.

1-4 RESULTS

As previously indicated, delivered units met performance specifications. However, it should be noted that some difficulty was encountered in making all units work in all respects, with a certain amount of selecting necessary to achieve desired results. Replacement of the integrated circuits with discrete component circuits would help the situation, but the proposed new approach to Pulse Width Modulation (PWM) is still recommended for best producibility.

Section II
CIRCUITS AND PACKAGING

2-1 CIRCUIT AND PACKAGE DESCRIPTION

2-1.1 CIRCUIT DESCRIPTION. Figure 3 shows the circuitry in the complete assembly. Figure 4 outlines the circuitry contained in each of the integrated circuit differential amplifiers. Operation is as follows: The d-c input signal ($\sim$30K source resistance) is applied to the input of Differential Amplifier No. 1, the output of which is applied to a PNP transistor (Q12) output stage to provide the required voltage swing. The output of Q12 is added to a 4800-cps sine wave reference with a series transformer and applied to the switching bridge circuit. The amplitude and polarity of the d-c voltage out of Q12 determines the duty cycle of applied 4800-cps power pulses to the motor load.

Current feedback is sensed across R7 and R8, and added in Differential Amplifier No. 2. The output of Differential Amplifier No. 2 is compared to the d-c input signal at opposing base inputs of Differential Amplifier No. 1. The result of this current feedback is to linearize and add precision to the transfer function of average current in the motor to the d-c input signal.

Gain is set by adjusting the amount of feedback with an attenuating resistor. Time constants are contained in the loop to prevent loop oscillation while providing noise filtering and the desired loop bandwidth. A balance adjusting resistor on external pins sets zero motor current for zero input signal. An external drift adjust resistor is selected to give minimum drift with temperature due to changing current gains of the two input transistors of Differential Amplifier No. 1.

2-1.2 OPERATION. The Bode plot (figure 5, Appendix A) included shows loop gain, stability and compliance with the required bandwidth.

An input-output curve (figure 6, Appendix A) on unit No. 1 shows the excellent linearity achieved. Temperature drift checks have indicated that requirements of the 100μ V/°C specification have been met.

2-1.3 PACKAGING. Figures 7 through 12 in Appendix A show the construction of the complete unit. The units may be operated with the indicated heat sink plate without potting; or, the units could be potted giving a module approximately 0.0625 inch larger in each dimension. Maximum ambient temperature operation may require the potting for proper component cooling.

2-2 PERFORMANCE DATA

Data from module No. 3 is given in Appendix B as typical of what can be achieved with the existing design.

Section III
PROJECTED IMPROVEMENTS

3-1 EXISTING DESIGN

If a production design of the present concept were to be implemented, the following changes would be recommended:

1. Go either to improved integrated circuit differential amplifiers with lower input base currents, or to discrete component differential amplifiers.

2. Eliminate the thin film assembly. It is generally agreed that this does not significantly reduce package size as compared to what could be achieved with discrete components.

3. Repackage to give more sturdy construction, capable of meeting all environmental requirements of flight vehicles.

3-2 NEW APPROACH

The heart of the new approach to PWM is a switching power amplifier configuration which provides a linear relationship between output d-c current into an inductive load and the d-c voltage signal into the power amplifier. If a triangular switching wave is then used in place of the present sine wave, linear response to a d-c error signal is achieved without the use of feedback around the power amplifier. The complete function of this project can be implemented with a single d-c differential amplifier, a triangle generating circuit, and a switching power amplifier of less complexity than that used on the existing circuit concept. A block diagram of this system is shown in figure 1.

Advantages of this approach over the one previously used are as follows:

1. The d-c gain of the switching power amplifier is independent of load inductance or switching frequency. Therefore, a high switching frequency may be used which eliminates phase lag effects of the sampling process.

2. Direct current linearity is as good as the linearity of the triangular reference wave, without feedback. Complications of loop stability requirements are eliminated through elimination of the loop feedback. A linearity curve of a breadboard design using this approach for another project is shown in figure 2.

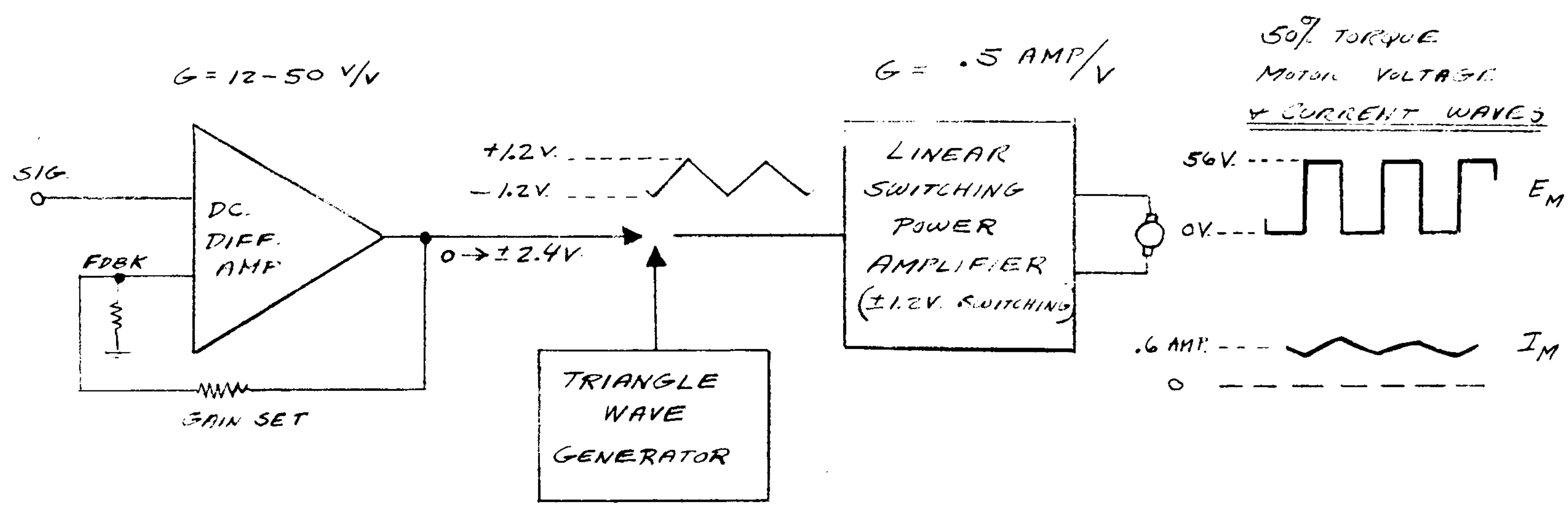

Figure 1. Proposed New PWM Scheme.

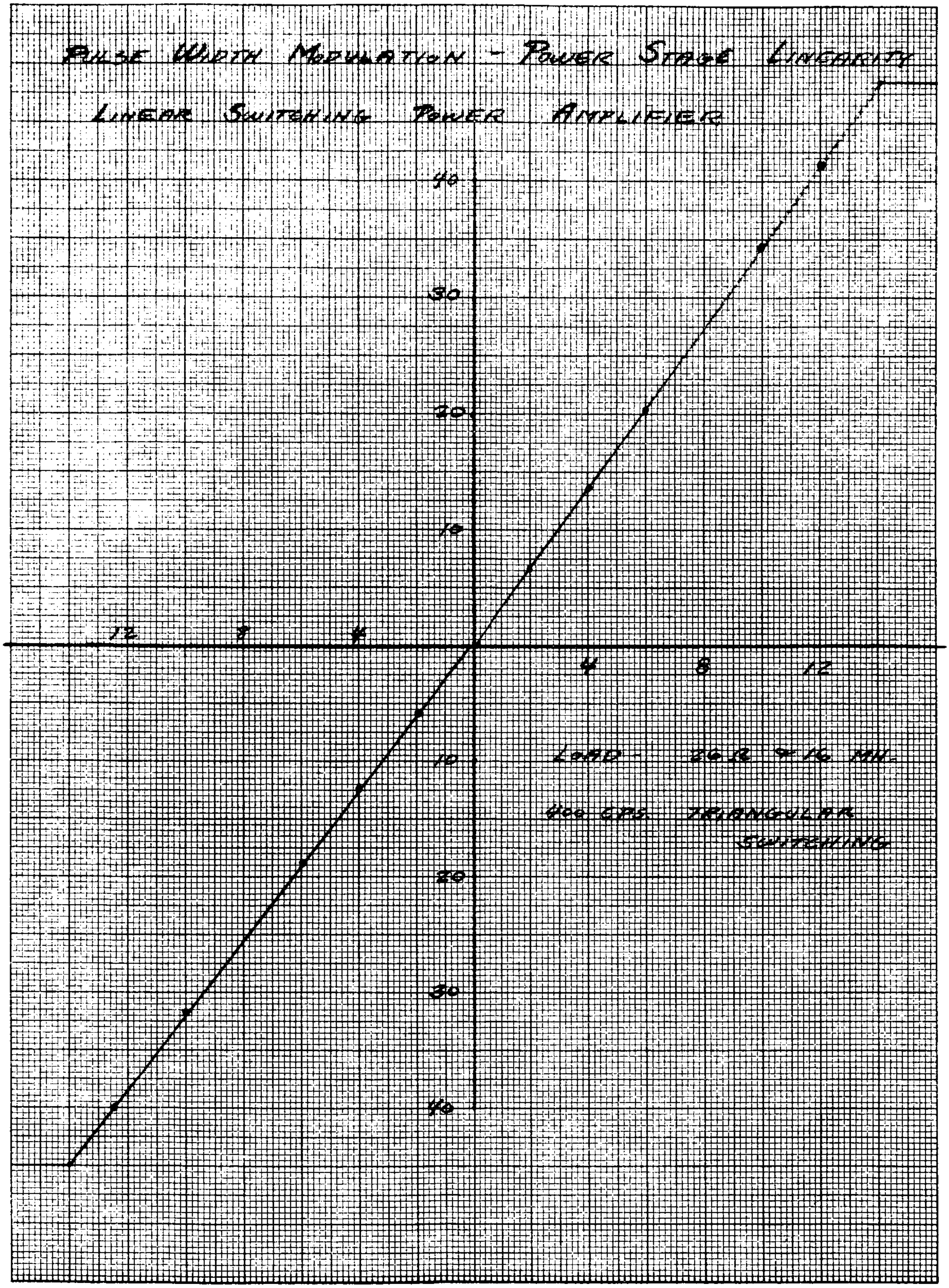

Figure 2. New PWM Scheme Linearity.

3. Maximum a-c heating of the servo motor is reduced by a factor greater than 4. Maximum ripple current is reduced by a factor of 2, giving smoother torque and less of a noise problem on the power source as well. This is a result of allowing continuous current to flow in the load instead of driving it to zero between pulses.

4. An additional plus factor is that no high voltage PNP transistors are required in power amplifier.

5. The power supply does not have to absorb power kick-back from the inductive load after every cycle of reference. A power kick-back pulse only occurs when the direction of applied current is reversed. This tends to minimize the requirements for energy absorption or storage in the power supply.

Section IV
CONCLUSIONS

4-1 CONCLUSIONS AND RECOMMENDATIONS

The amplifier designed for this program is a useful device which meets all specifications stated in the initial contract. The only reservation regarding the design is possible producibility difficulty. As previously stated, this could be helped by replacing the integrated circuits with discrete amplifiers, or with improved quality integrated differential amplifiers. However, the prime recommendation for flight units is to incorporate the new concept of pusle width modulation as described in this report. The new design could use discrete or integrated circuits, as the application of the differential amplifier in the new approach is much less demanding in performance. Redesign effort should be of much lesser magnitude than that of the completed program with a much shorter time cycle to implement. This is the result of having already proven the basic concept on another program at the Ordnance Department, as well as the fact that the state of the art regarding integrated circuits has progressed vastly since one year ago.

APPENDIX A

Appendix A which follows comprises illustrations showing circuit schematics, Bode diagrams, linearity curves and packaging concepts. Also, module layout and printed circuit sketches.

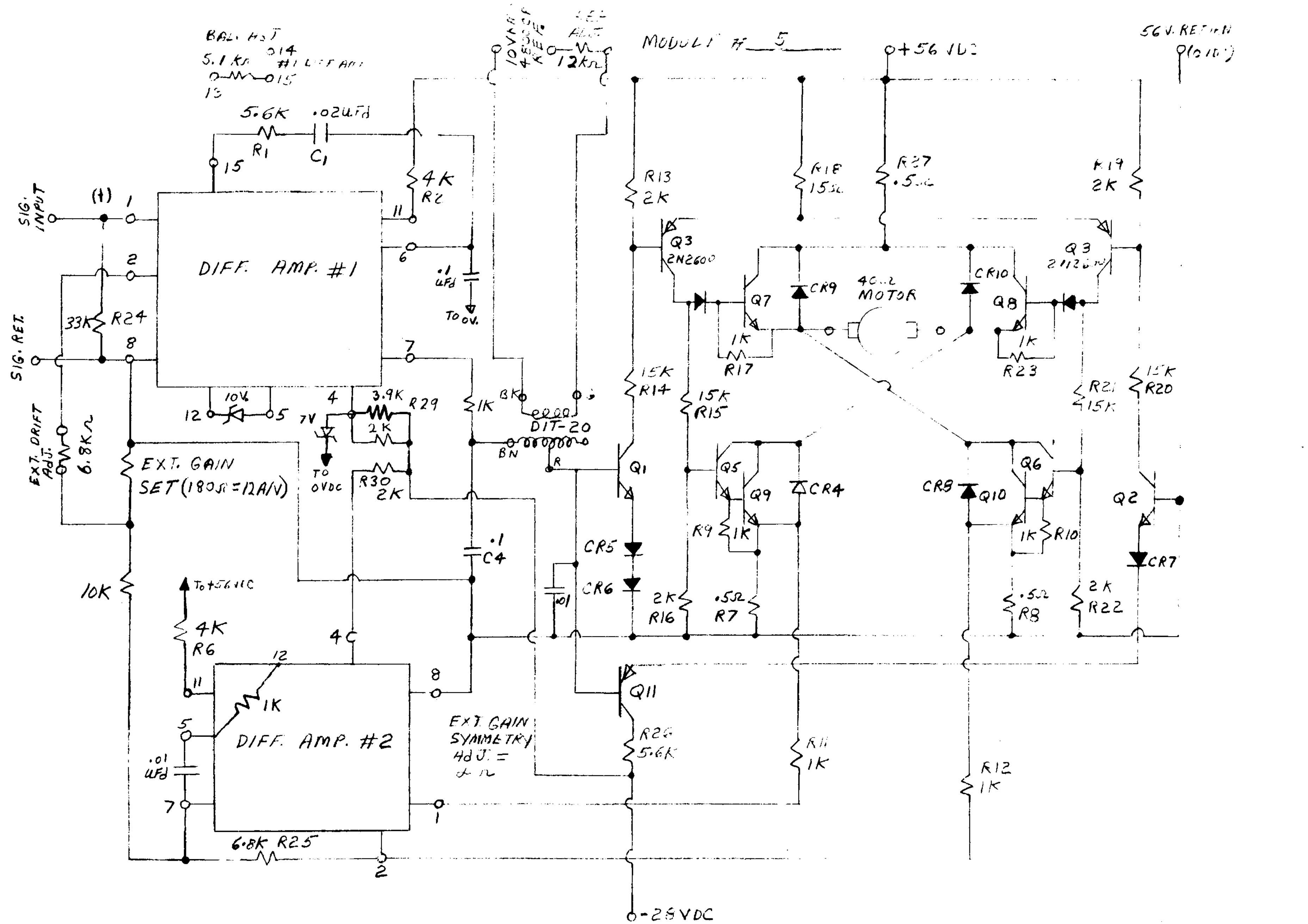

Figure 3. NAS 8-5421 Circuit Schematic.

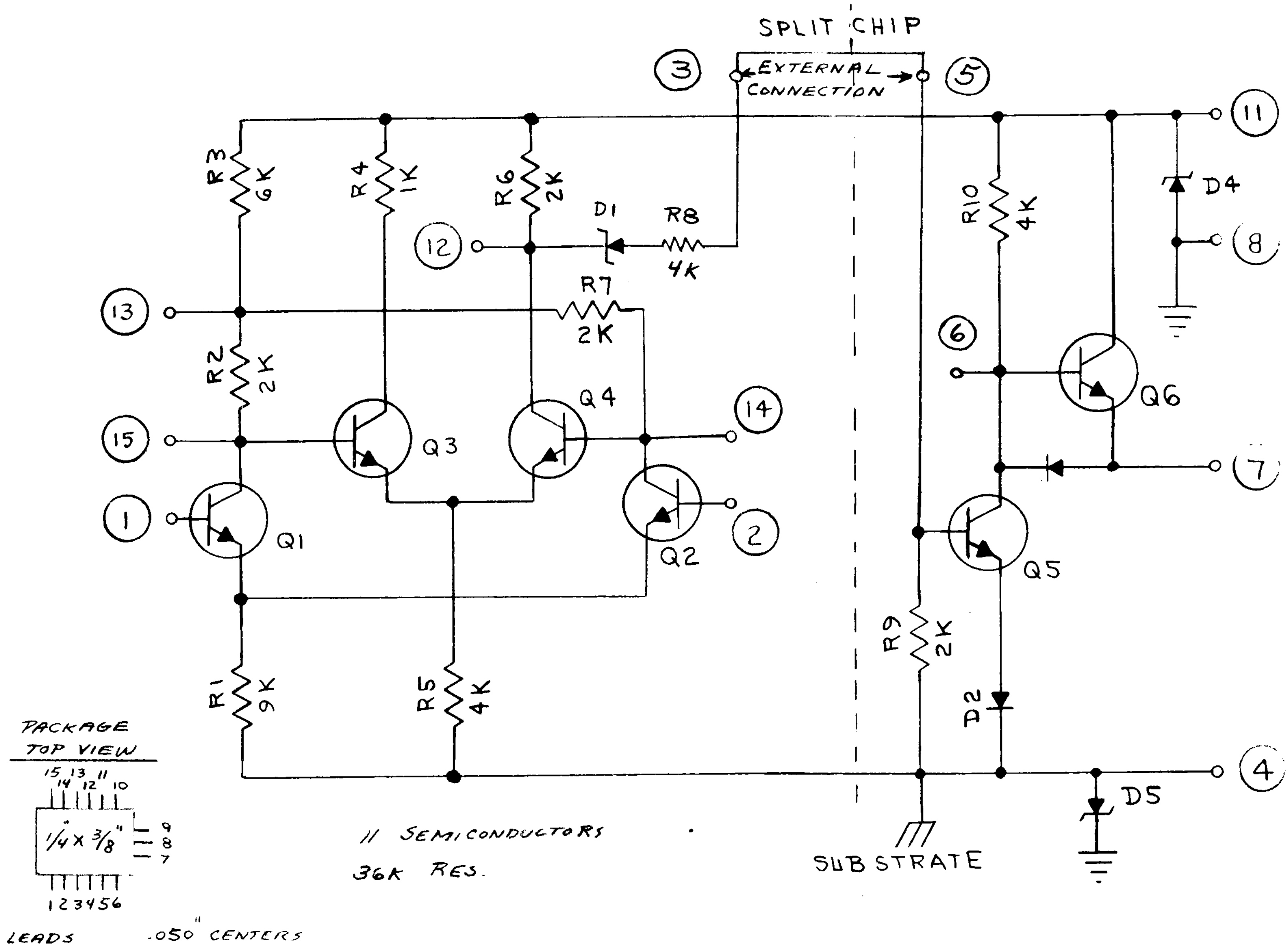

Figure 4. Integrated Differential Amplifier Schematic.

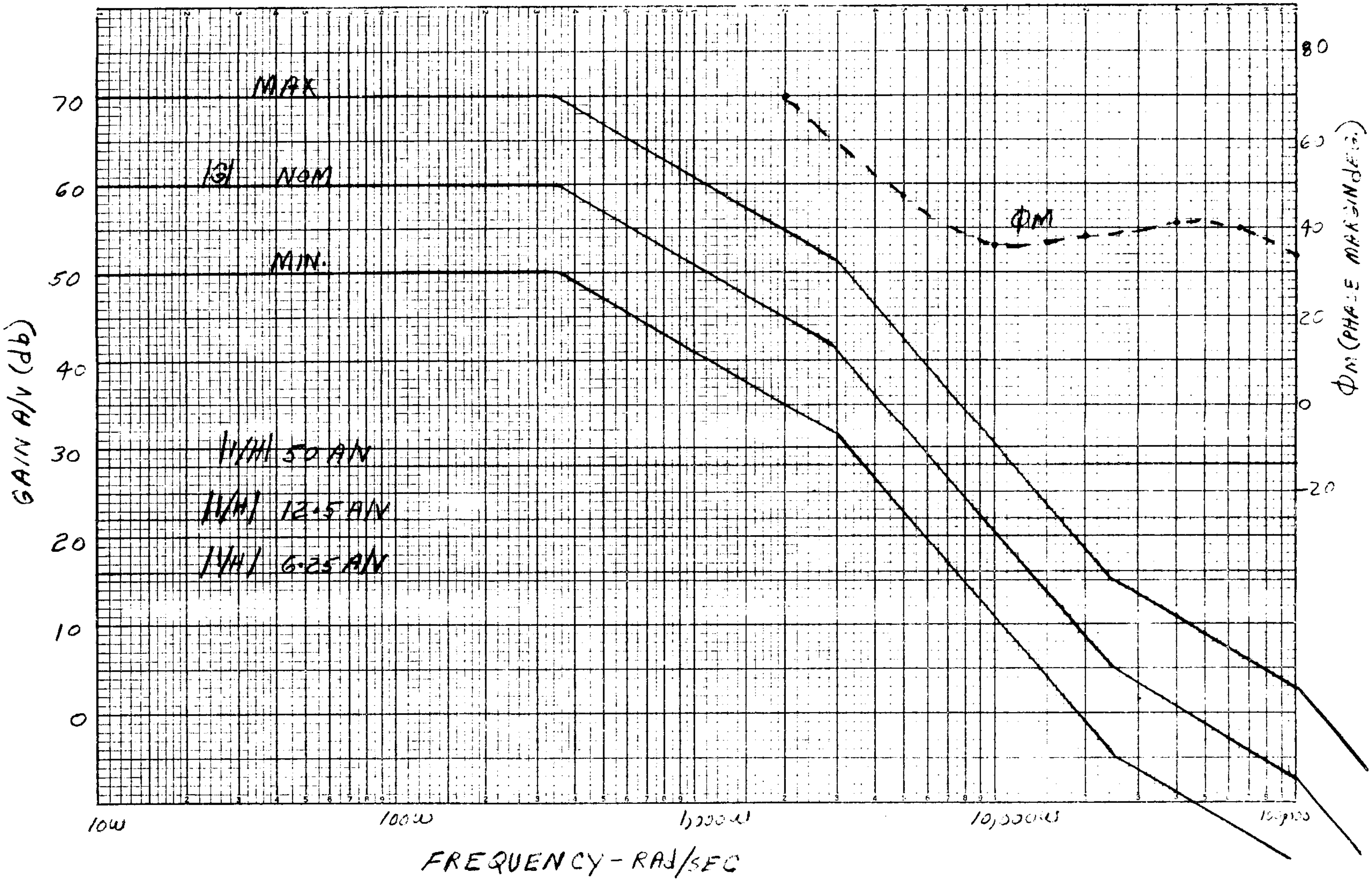

Figure 5. NAS 8-5421 Bode Diagram.

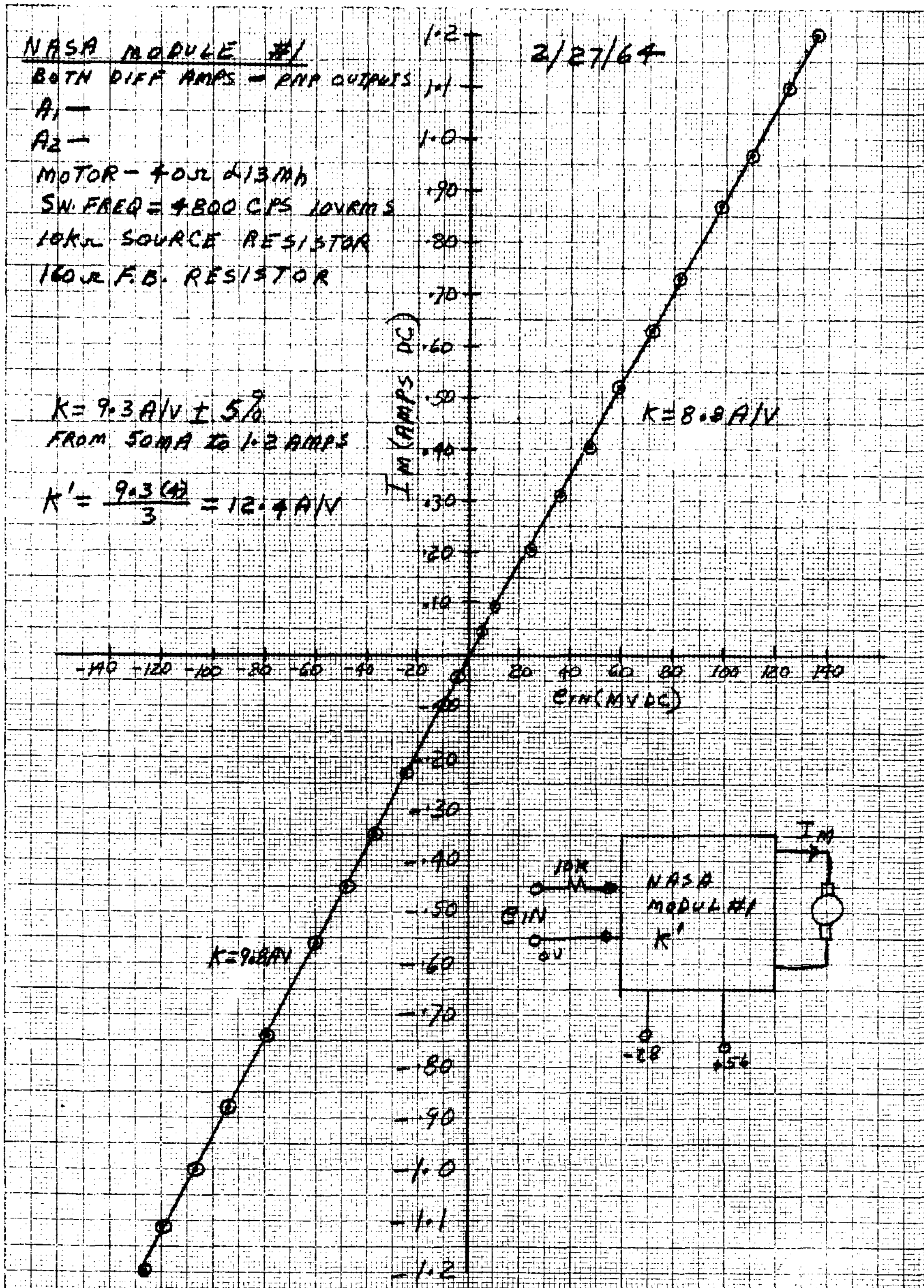

Figure 6. Module No. 1 Linearity Curve.

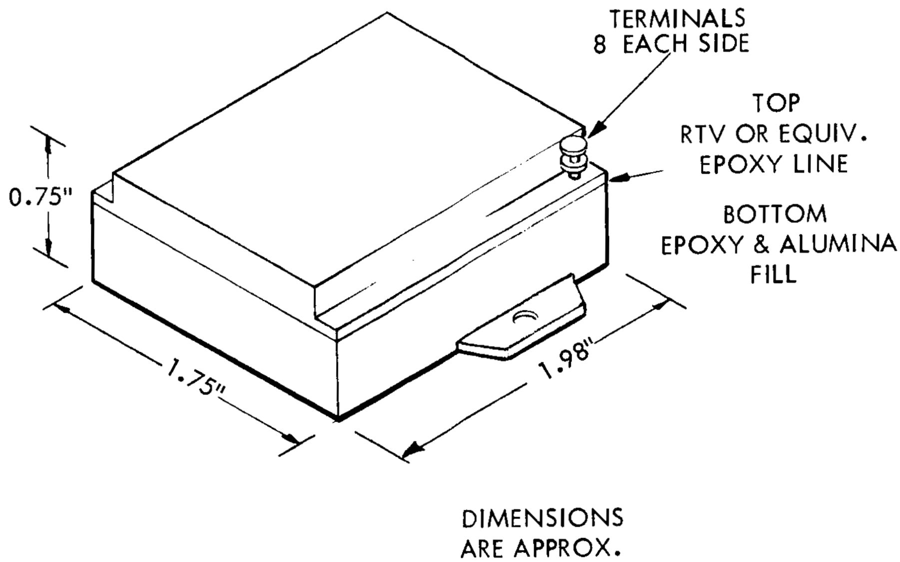

Figure 7. Packaging Concept Sketch.

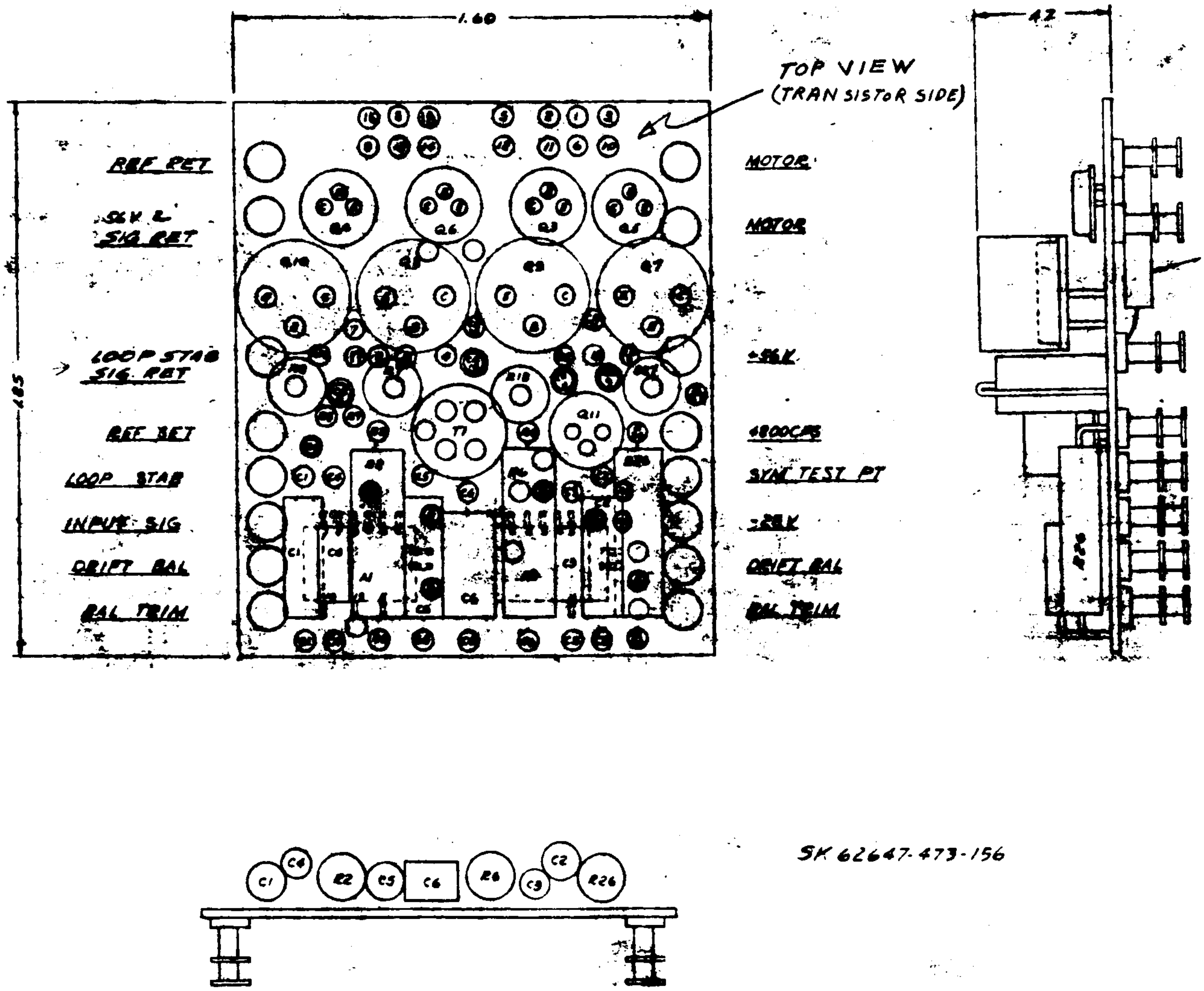

Figure 8. Module Layout.

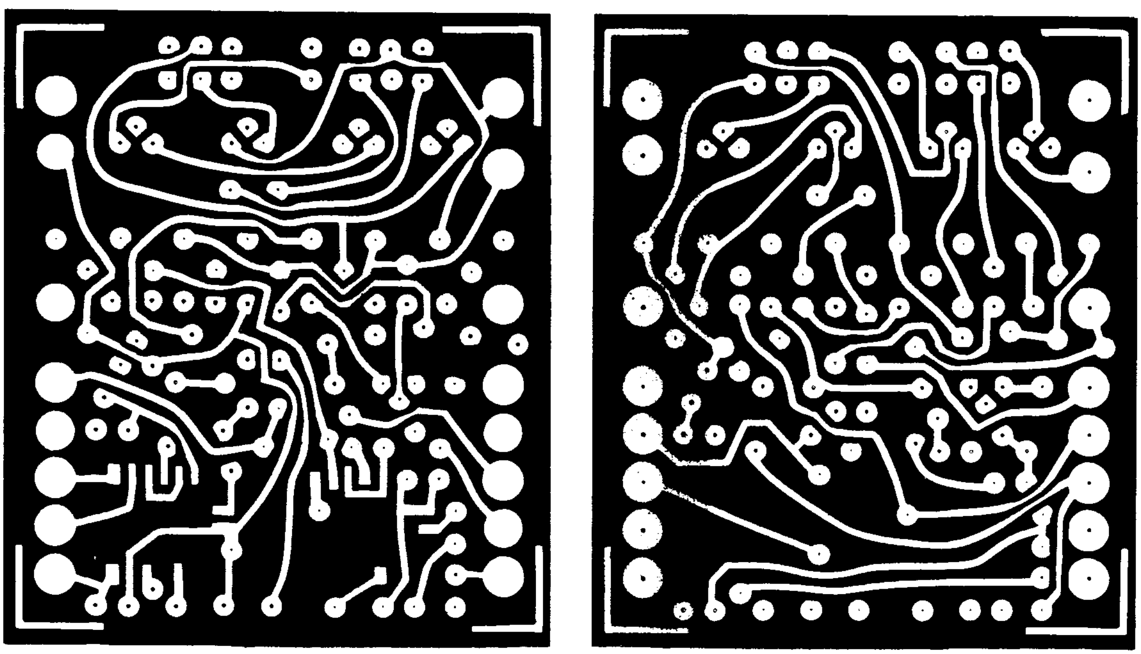

Figure 9. Printed Board Detail.

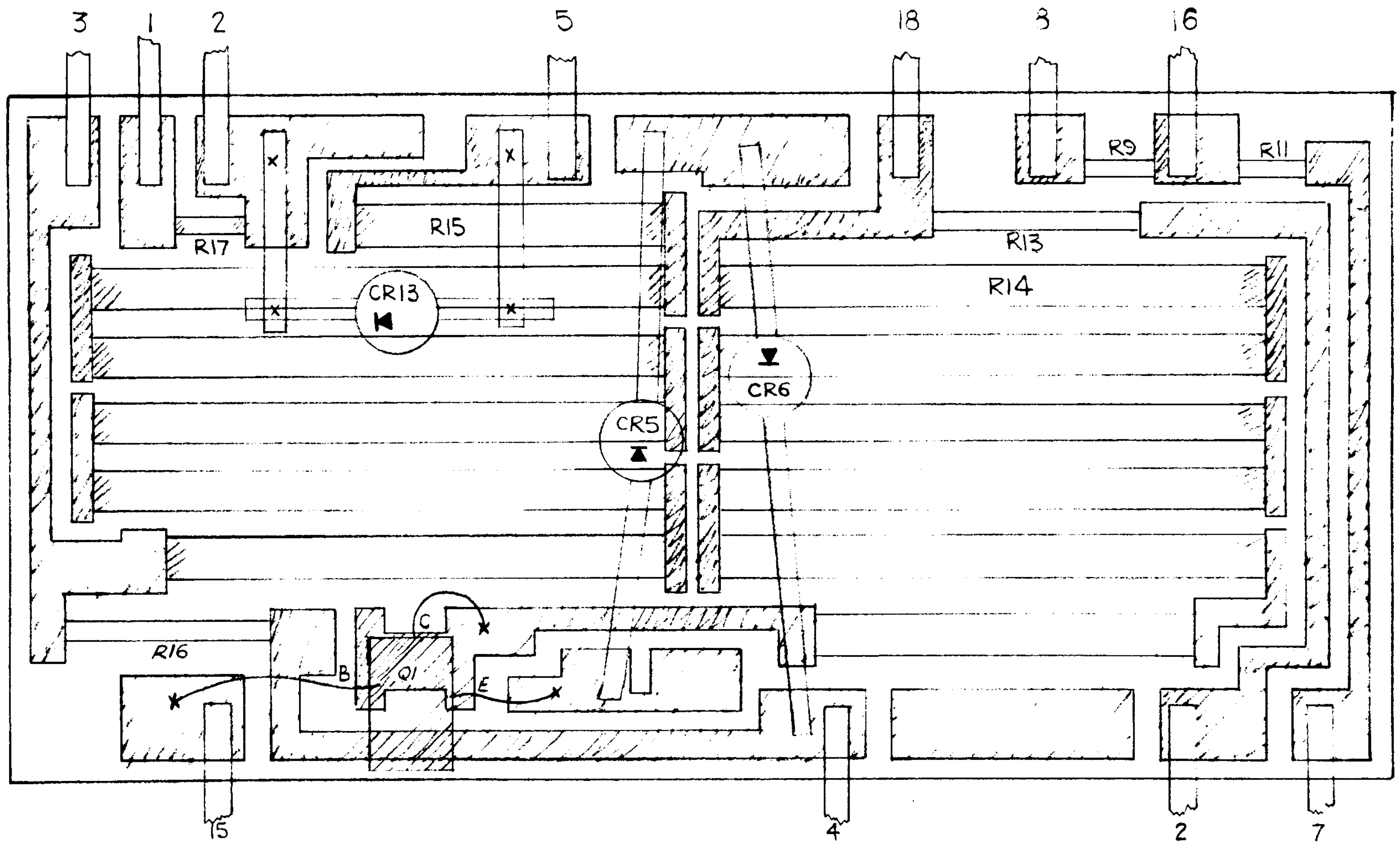

Figure 10. Thin Film Assembly No. 1 Detail.

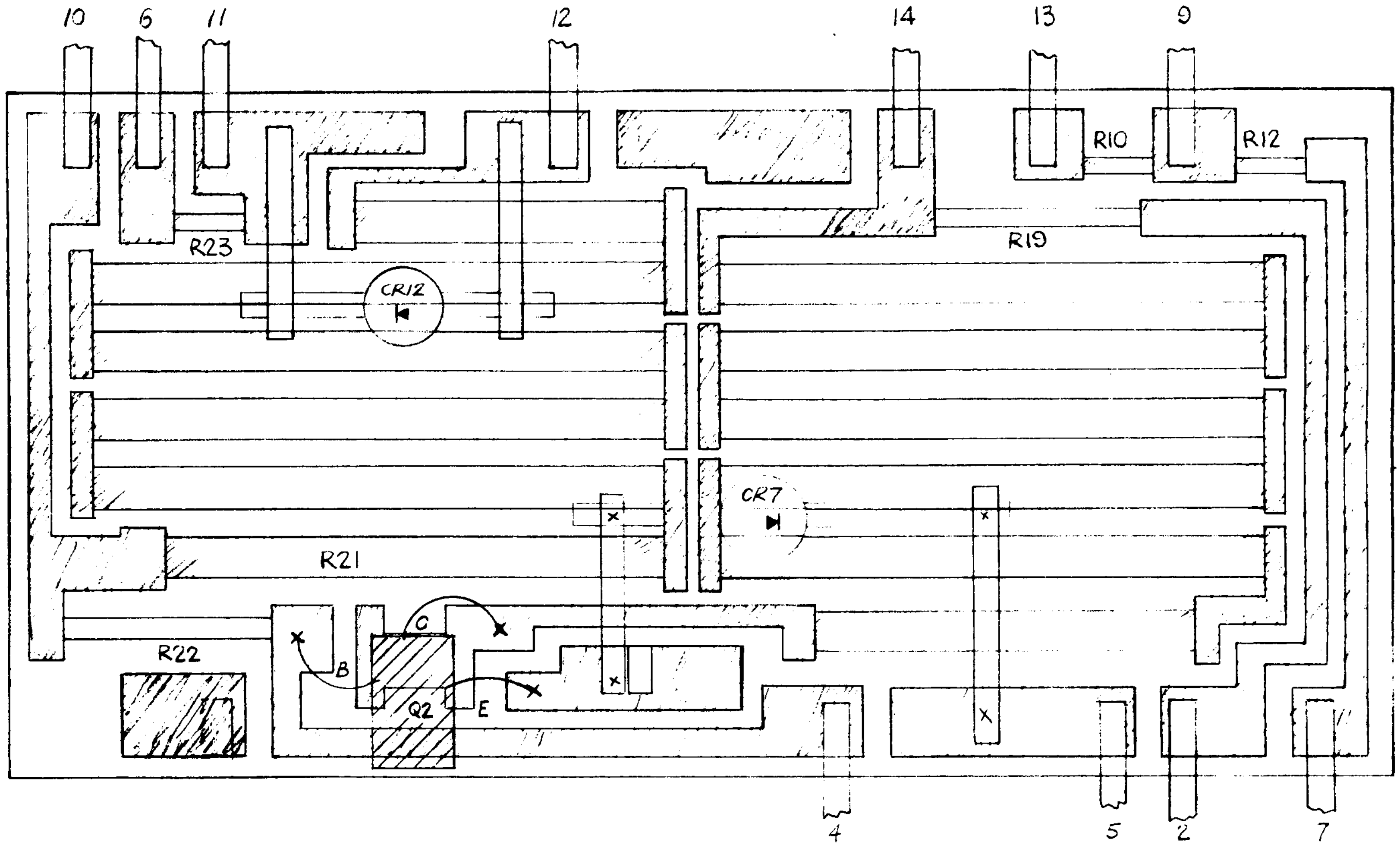

Figure 11. Thin Film Assembly No. 2 Detail.

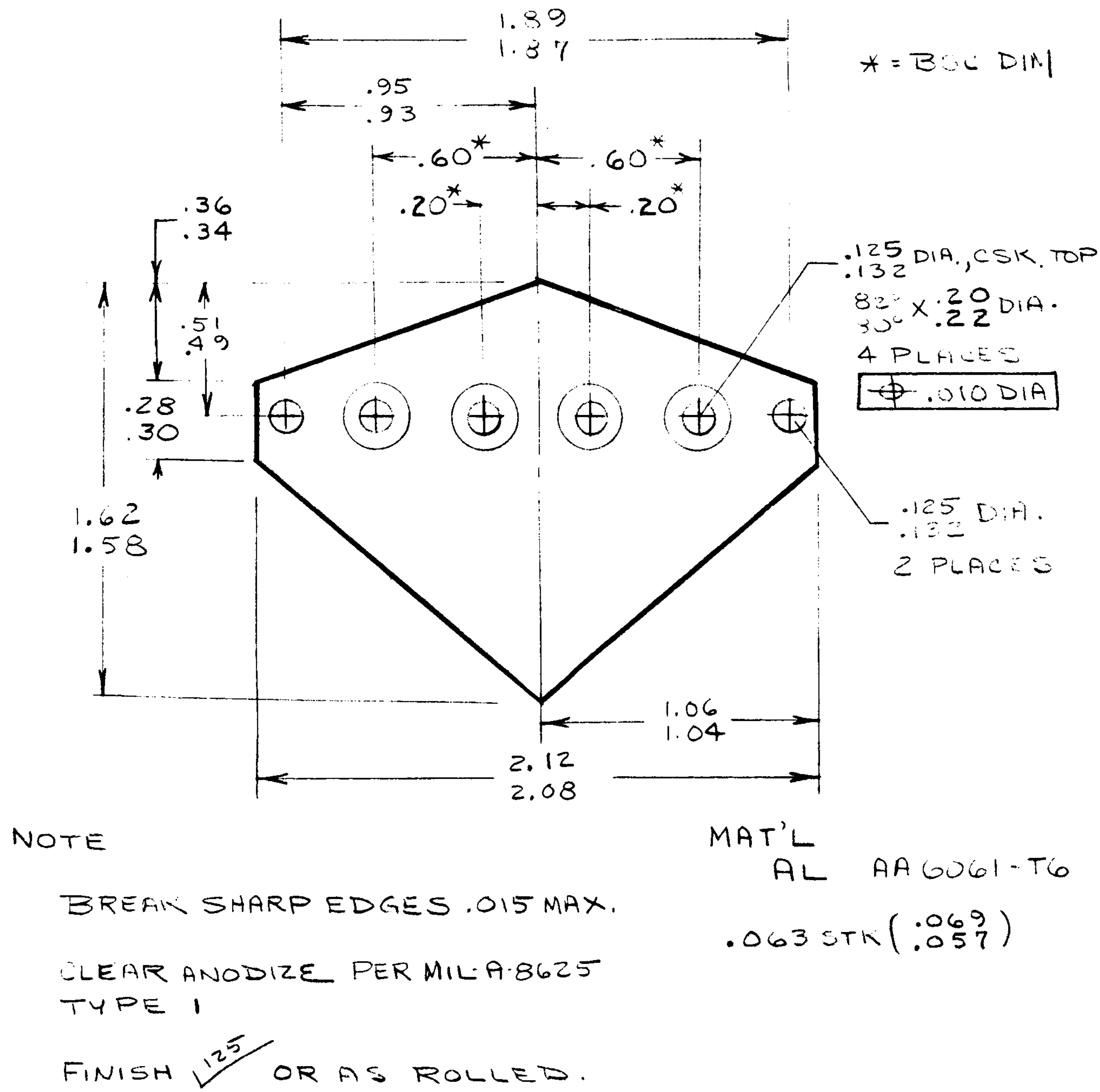

Figure 12. Module Heat Sink Plate.

APPENDIX B

Following is data obtained from Module No. 3, considered to represent typical performance for this design.

1. Gain (150-ohm F.B. resistor)

   K = 10.5 A/V ± 10 percent from zero to 100 ma
   K = 11 A/V ± 5 percent 0.2 to 1.1 amps

2. D-c offset = -2 mv dc

3. D-c drift < 30 μV/°C from 0 degrees C to 100 degrees C (9.09K source)

4. Deadband < 1 mv dc

5. Closed loop phase shift < -15 degrees at 60 cps

Circuit Details are as follows:

1. PNP transistors are not used on differential amplifiers.

2. 10-volt zener diode is used in place of internal coupling network in Differential Amplifier No. 1 for increased gain.

3. Internal differential amplifier zener diodes are used for B+ and B- decoupling.

4. Drift balance resistor = 8.2K
   Balance adjust resistor = 9.1K
   Gain symmetry resistor = 18K
   Reference set resistor = 12K
   150-ohm gain adjust = 11 amp/volt

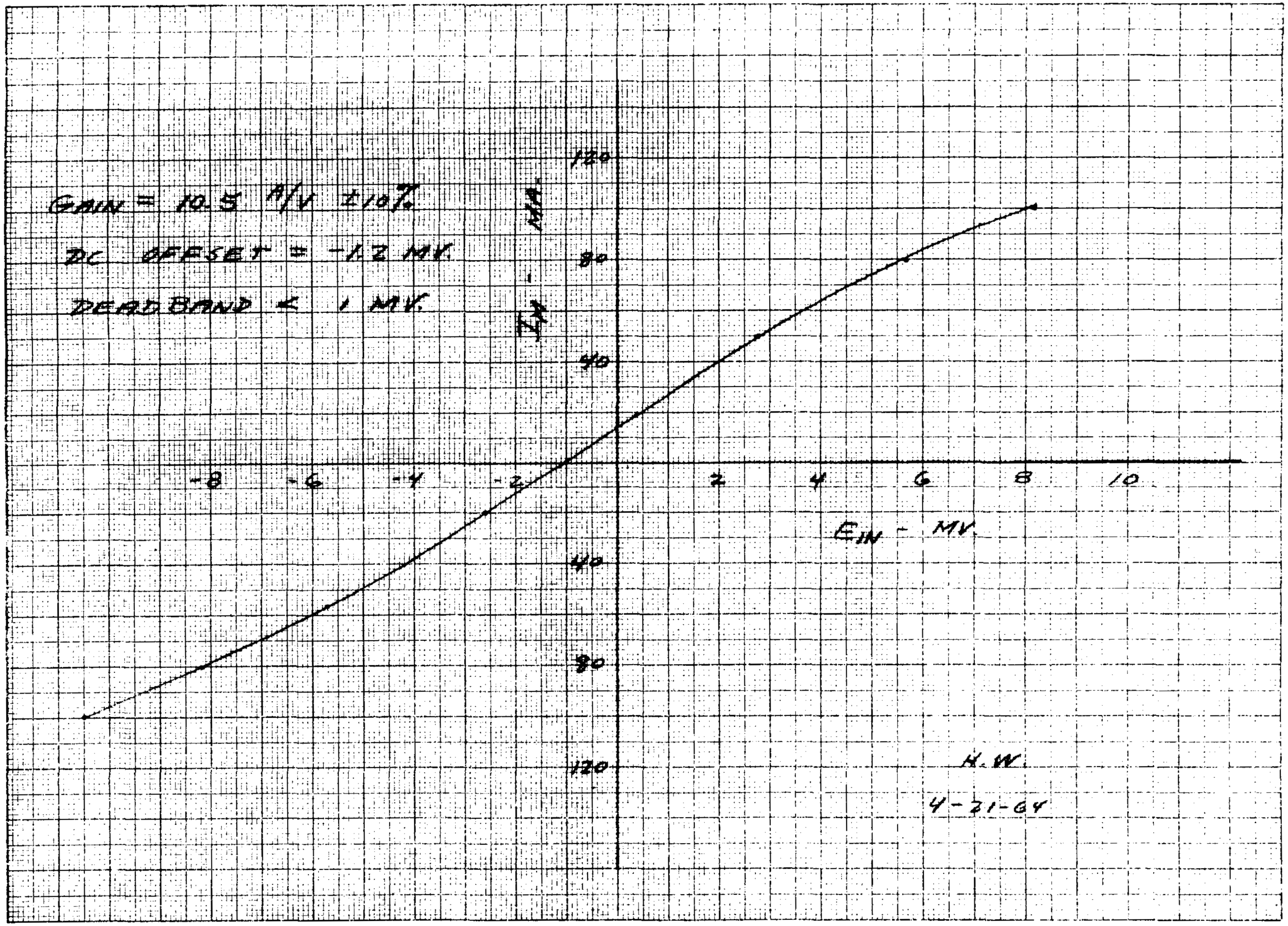

Figure 13. Torquer Amplifier No. 3; Low Level D–C Gain.

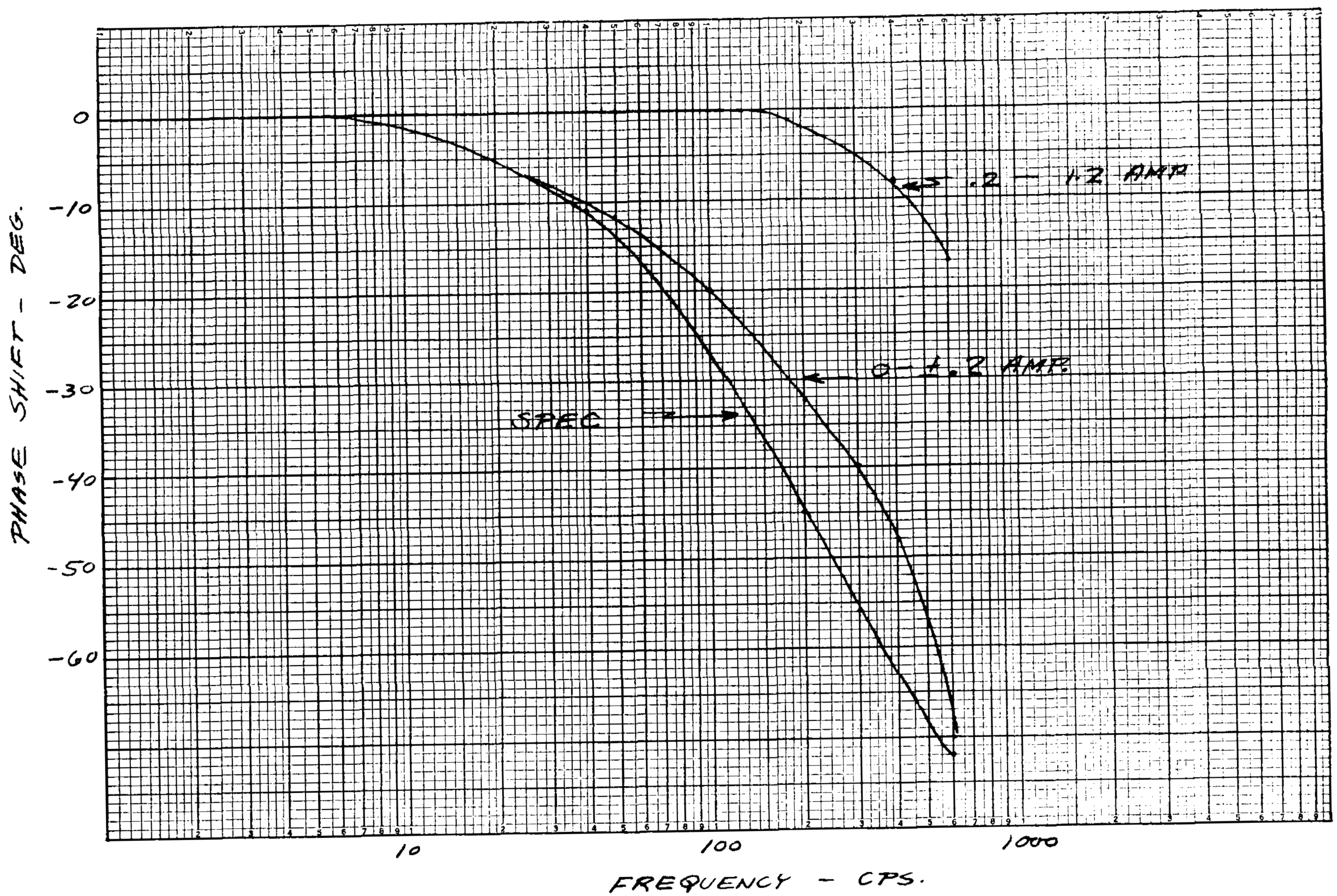

Figure 14. Torquer Amplifier No. 3; Closed Loop Phase Shift.

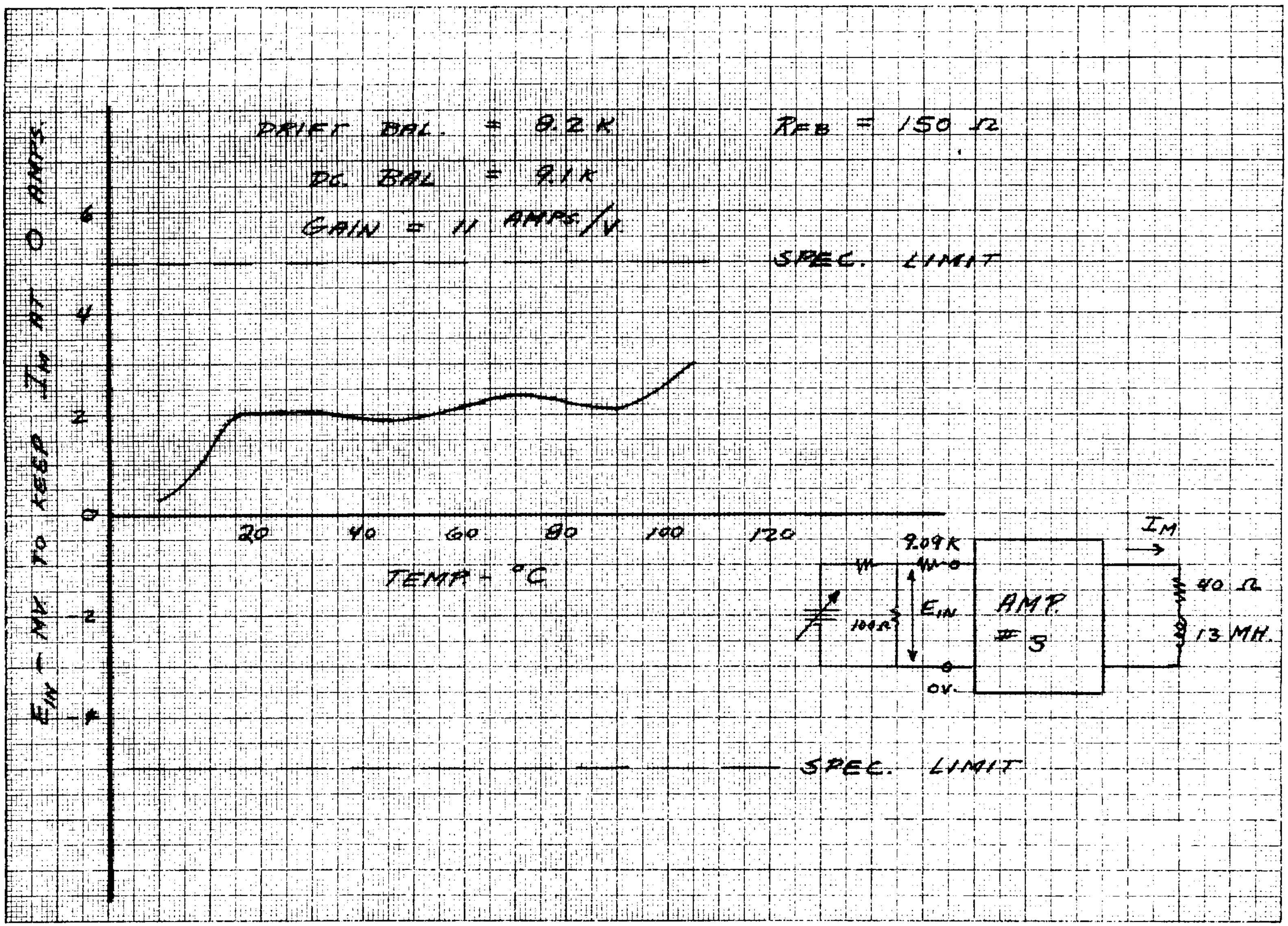

Figure 15. Torquer Amplifier No. 3; D–C Drift vs Temperature.

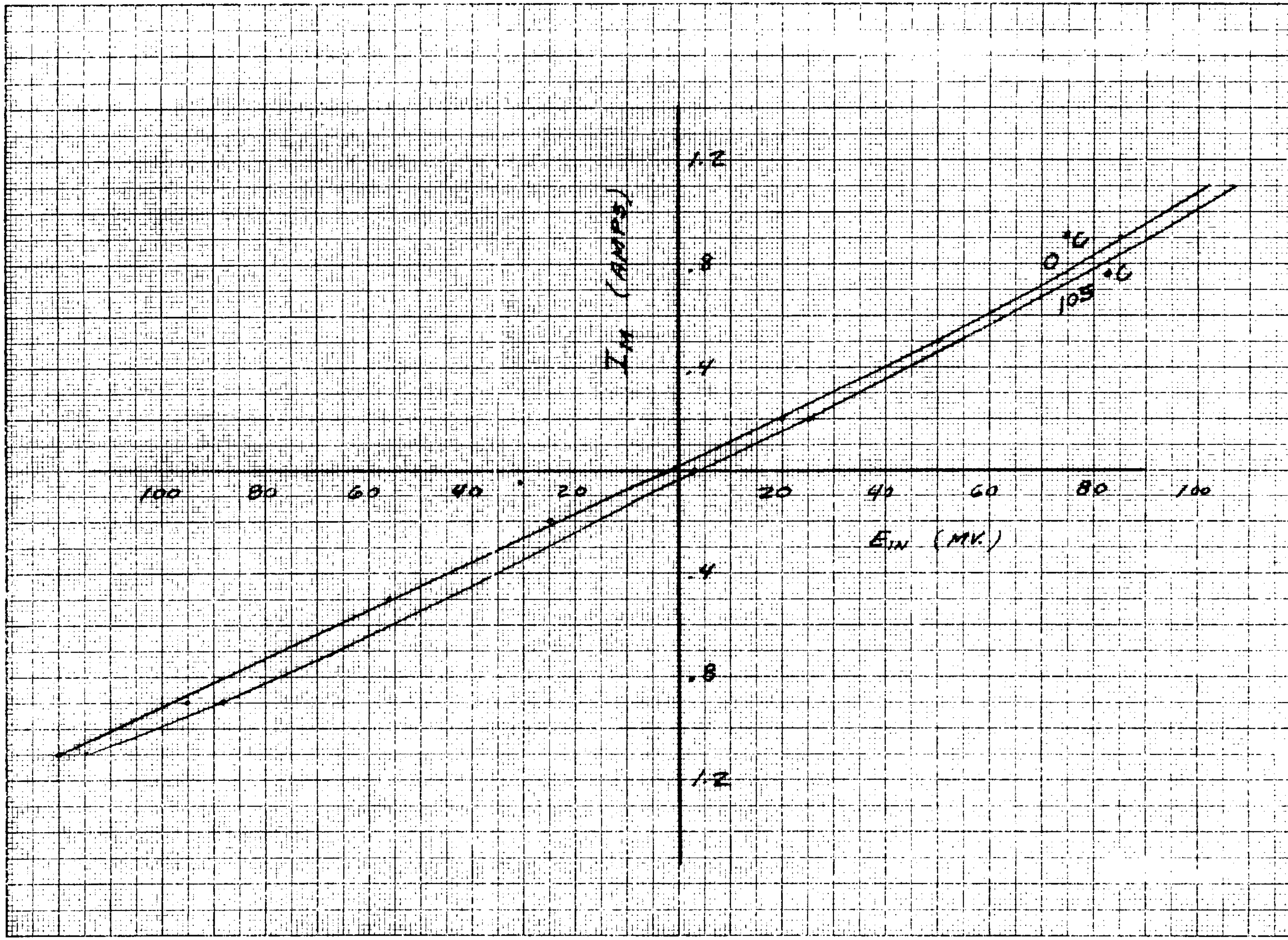

Figure 16. Torquer Amplifier No. 3; D-C Gain at Zero Degrees C and 105 Degrees C.

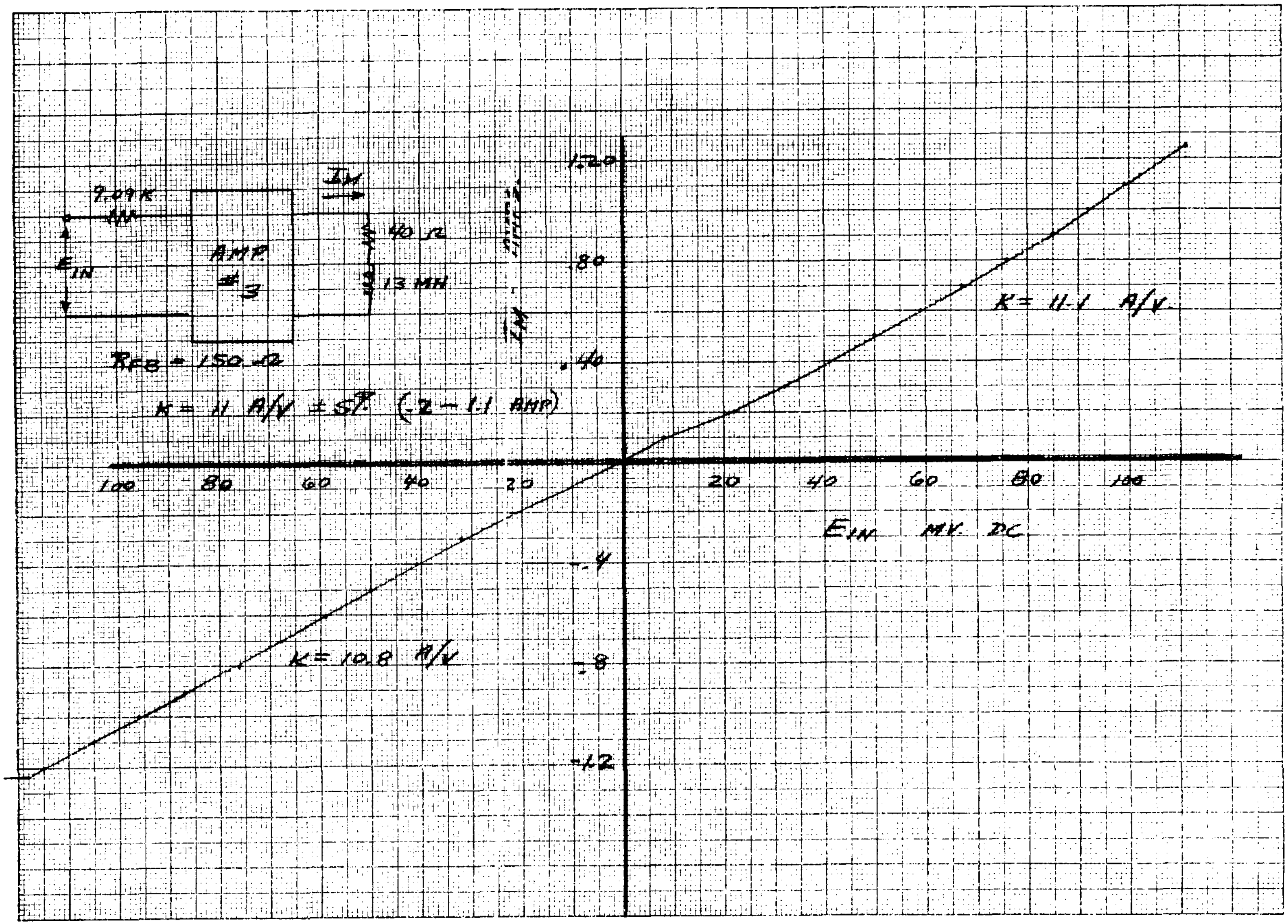

Figure 17. Torquer Amplifier No. 3; High Level D-C Gain.