MODIFICATION OF A MAGNETIC AIRBORNE DETECTOR (AN/ASQ-1A) FOR USE IN GEOPHYSICAL PROSPECTING

A Thesis
Presented to
the Faculty of the Department of Graduate Study
New Mexico Institute of Mining and Technology

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geophysics

by
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June 1955

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ACKNOWLEDGMENT

The work described in this paper was carried on under the direction of Professor Victor Vacquier of the New Mexico Institute of Mining and Technology. I am deeply indebted to him and to the many members of the Institute who gave freely of their time and effort in helping solve the multifarious problems which arose in the course of this study and in the preparation of this paper.

ABSTRACT

An obsolete military magnetic airborne detector (MAD, type AN/ASQ-1A) was modified to render it suitable for geophysical surveying. Modifications included (1) the replacement of an a-c amplifier in the detector channel with a d-c amplifier and (2) the provision of a steadier source of magnetic biasing current. Schematics of the modified instrument and calibration curves showing range, sensitivity, and time and temperature drift of the magnetometer are included.

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INTRODUCTION

Lack of sufficient water is a problem for the inhabitants of about one-third of the land areas of the world. Living as they do in one of these great semi-arid regions, the people of New Mexico face an ever-increasing need for new ground water resources to supplement depleted reservoirs and to permit cultivation of heretofore barren regions.

It has been stated that in those areas of the state which have been subject to a great deal of igneous activity in the past, well sites might possibly be located in mountain canyons which have been cut by intrusive dikes effectively impounding the ground water. There has also been a desire expressed in surface geologic mapping for some means of following contacts involving igneous rocks when these features have been obscured by overburden. Because of differences in magnetite content, the easiest method of locating such contacts presumably would be by use of magnetic methods. However, magnetic surveys are long and tedious. Some intrusives, such as dikes, are not large and, therefore, not easy to locate.

The usual type of magnetic survey using the Schmidt-type balance employs measurements taken at intervals along a line, and, if one is to locate a small anomalous feature, these intervals must be short. Hence, it is apparent that to eliminate the taking of innumerable station readings, a mobile, continuously recording magnetometer is desirable. The mounting of such an instrument for use in rough terrain requires that it meet several conditions: It should require no levelling, be independent of accelerations, and be relatively rugged. The Schmidt-type magnetometer, whose operation depends on the balancing of gravitational and magnetic forces acting on a needle suspended on delicate quartz knife-edges, is eliminated by each of the above criteria. However, the saturable-core type of magnetometer which was designed for airborne operation adequately satisfies the requirements.

The Research and Development Division, through Professor Vacquier, acquired an obsolete magnetic airborne detector for experimental use in geophysical surveying and for instructional purposes as a gift from the United States Navy. Certain modifications were necessary before this instrument could be utilized for geophysical exploration. These modifications and the subsequent calibration are the subject of this thesis.

HISTORY

The airborne magnetometer has been the subject of many articles since it was declassified following World War II. Thus, a great deal of information concerning the instrument and its use may be found in the literature. Only a rather brief background of its development will be given here.

Magnetic methods were probably the earliest geophysical techniques used for prospecting. More than a century ago the "Swedish mining compass" was used in locating magnetic iron ores. Later the dip needle and the Hotchkiss superdip supplanted the "mining compass"; in the 1920's the Schmidt-type field balance, which is still the standard surface magnetometer, was developed. During the 1920's and 1930's aircraft development accelerated the possibilities of rapid surveying of relatively inaccessible areas. Since the Schmidt-type balance is inherently unsuitable for mobile operation, research was begun to develop a device of adequate sensitivity which would be independent of accelerational influences.

In 1936 Logachev[1] flew an aerial magnetic survey, using an induction coil oriented to measure the vertical component of the earth's magnetic field. Orientation proved

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[1] A.A. Logachev, "The Development and Applications of the Airborne Magnetometer in the U.S.S.R.," Geophysics, XI, 2(1946), p. 135.

difficult to maintain and the coil lacked sufficient sensitivity. He reported that under favorable conditions he could detect anomalies exceeding 1000 gammas. (A gamma is 10^{-5} oersted, the unit of magnetic field strength. The average value of the earth's field is about 50,000 gammas, and the largest known anomaly is over 30,000 gammas.)

In the United States, Vacquier, then with the Gulf Research and Development Co., was investigating a saturable-core element which had been developed in Germany. The saturable-core reactor, or flux-gate, has the advantage of having no moving parts, but at this time it suffered from the insensitivity which was common to so many of the devices. By 1940, Vacquier had increased the sensitivity of this instrument so that field variations of 2 gammas could be detected.[2]

The potential of the flux gate as a submarine detector was demonstrated early in 1941 and further development work was supported by the National Defense Research Council. Under their auspices arose the Airborne Instruments Laboratory at Columbia University, which produced the final service model designated the MAD, type AN/ASQ-1.[3] A later model which pro-

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[2] V.Vacquier, Development of a Device Responsive to Changes in Magnetic Field and Designed to Indicate the Approach of Ferro-Magnetic Objects, Gulf Research and Development Co., Pittsburgh, Pa., NDRC Project NO 45 PI, Progress Report, 1 April 1941; cited by Homer Jensen, Geophysical Surveying with the Magnetic Airborne Detector (AN/ASQ-3A), U.S. Naval Ordnance Laboratory Report No. 937, 93(1945), p. 2.

[3] R.D. Wyckoff, "The Gulf Airborne Magnetometer," Geophysics, XIII, 2(1948), p. 183.

vided a third axis of rotation for the detector element was the AN/ASQ-1A.[4] It was this type of instrument which the Navy donated to the Institute.

At the same time, the Bell Telephone Laboratory, working with the Naval Ordnance Laboratory, developed a basically similar instrument known as the AN/ASQ-3. A modified version of this, the AN/ASQ-3A, was further revised by these organizations, and was used by the United States Geological Survey in 1944[5] in the first extensive airborne magnetometric surveys.

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[4] Airborne Instruments Laboratory. AN 16-30ASQ1-3, Handbook of Maintenance Instructions for AN/ASQ-1 and AN/ASQ-1A Equipment, (22 September 1943), p. 19.

[5] Jensen, op. cit., pp. 13-46.

PRINCIPLES OF OPERATION

The MAD employs field sensitive flux-gates to detect the presence of a magnetic object. The operation of the flux-gates is based on the properties exhibited by a magnetic material in a strong alternating magnetic field. When such material is placed in an increasing magnetic field, the flux in the material is proportional to the current up to a certain critical value, at which point the material is said to be saturated. Beyond this point the flux increases much more slowly. Thus, if a strong sinusoidal current is sent through a coil with a permeable core, the flux produced and, therefore, the voltage across the coil, will not be sinusoidal, but will be distorted and exhibit peaks or "pips." By employing two opposed windings which are slightly dissimilar, to prevent the output of one from exactly nullifying the other, one may produce alternate positive and negative pips. If flux produced by a unidirectional field, such as that of the earth, is present, one set of pips will increase in height and those of the opposite polarity will decrease. The polarity of the increasing pips is dependent upon whether the field strength is increasing or decreasing, and the differential peak height is proportional to the voltage difference in the two opposing coils, and, hence, proportional to the ambient field strength.

In the MAD there are three such flux-gates with opposed coil windings about a highly permeable core of permalloy. These coils are rigidly mounted so as to be mutually perpendicular. The middle coil, which is transverse to the major axis of the mounting, is the detector element which measures the field strength. The other two, whose axes are in a plane perpendicular to the detector element and which are perpendicular to each other, are the orientor elements. When these two coils are perpendicular to the earth's field so that the flux through them is zero, the detector element will then be parallel to the earth's total magnetic field. Thus, it may be used to measure the total field rather than the horizontal or vertical components of this field which are measured by the Schmidt-type balance.

The flux-gates in the AN/ASQ-1A are driven by a regulated and filtered 400 cycle oscillator (Figure 1). When the detector element is parallel to the total field vector, the only signal produced is that in the detector channel. This signal is filtered, amplified, and recorded. When the detector is misaligned, signals will be produced in the orientor channels as well. These provide the intelligence to the small servo motors which mechanically return the orientor, and, therefore, the detector coils to their proper positions. Since the orientors are in a much more sensitive position, a small misalignment which will produce almost no field change with respect to the detector will produce enough to activate the servo-system. For example, a misalignment of thirty minutes of angle means a 0.873 per cent change in the total field acting on the orientor coils, but only a 0.004 per cent change is seen by the detector.

To bring the detector into operating range in the presence of the earth's field, a D.C. current is passed through the detector coils in such a manner that the field of each coil is in opposition to the ambient field and nullifies all but a small portion of this field. This permits one to measure and record slight deviations from the average value of the earth's field. This may be done with much more accuracy than if the entire field is being measured.

Although the sensing elements are the same, military magnetic airborne detectors differ somewhat from exploration magnetometers. Because of the difference in desired data, the associated equipment is not entirely the same. For submarine detection an instrument was desired which would respond to a weak but high gradient anomaly such as that produced by the steel hull of a submarine, and which was insensitive to low gradient geological anomalies or day-to-day changes of the earth's field. Therefore, the instrument was designed to have an A.C. response peaked at a frequency appropriate for the detection of submarines by planes flying at about 120 knots per hour. Thus, to render it suitable for geophysical work, design changes were necessary in order to permit it to record steady magnetic fields and gradual changes in these fields, rather than only isolated transient signals.

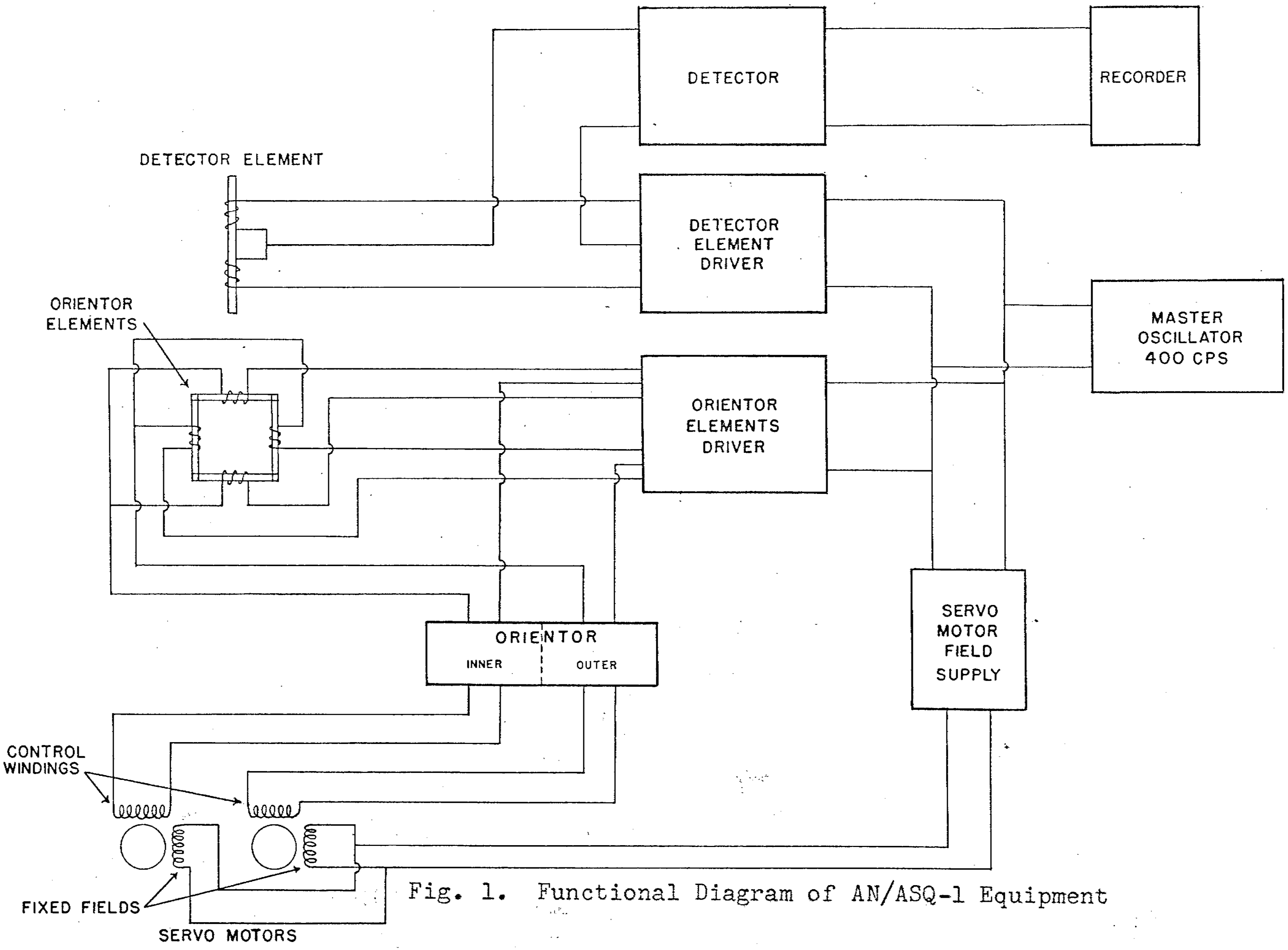

Fig. 1. Functional Diagram of AN/ASQ-1 Equipment

MODIFICATIONS

Before discussing the actual modifications it seems advisable to define the abbreviations which will be used to designate the various units of the AN/ASQ-1A. Because this thesis is intended to supplement the original Handbook of Maintenance Instructions for AN/ASQ-1 and AN/ASQ-1A Equipment, a certain amount of the nomenclature used in that volume will also be employed here to avoid confusion.

The AM-1/ASQ-1 amplifier unit, containing the detector channel, two orientor channels, and the magnetic compensator circuit, is situated in the top half of the instrument rack (See Figs. 6 and 8) and is the instrument involved in the modifications described herein. Its front panel contains the various controls which are used during its operation.

The O-1/ASQ-1 oscillator unit which drives the sensing elements is beneath the amplifier in the instrument rack. On the top of the rack is the DY-4/ASQ-1 dynamotor. This operates from a 24 volt D.C. supply and furnishes high voltage D.C. to the oscillator unit which in turn provides the regulated voltage used in the amplifiers.

The detector unit, DT-3A/ASQ-1A, consists of the detector and orientor elements in a gimbal system and the orienting servo-system mounted in a streamlined housing. (See Figs. 7 and 9) This unit differs from the DT-3/ASQ-1 in that it has a three-axis head instead of the original two-axis head.

Because of this extra axis, another orientor amplifier was required. This unit, the AM-9/ASQ-1A, is mounted at the rear of the equipment rack. Since the extra axis was added for following the maneuvers of the airplane at low latitudes, this unit will probably not be necessary in future operations. Disconnecting it will decrease the current demands of the dynamotor by about 2 amps, thus increasing by about 14 per cent the effective life of the batteries comprising the 24 volt supply.

The major modifications required to make the AN/ASQ-1A usable for geophysical work were (1) the replacement of the A.C. amplifier in the detector channel by an amplifier responsive to steady signals, and (2) the provision for a steadier source of compensating current with which to nullify most of the earth's field.

The function of the amplifier portion of the detector channel is simply to measure and record the differential peak height of the signals from the detector element. These alternately positive and negative pips, which are about 8-12 volts peak to peak, have a sensitivity of approximately 3 mv/gamma, so, it is necessary to amplify them and apply the resulting signals to an output stage capable of operating the Esterline-Angus recorder. Therefore, the natural choice for the first major modification was a push-pull direct-coupled amplifier.

A direct-coupled amplifier is inherently plagued by instability, since variations in components or filament voltage will be detected and amplified by succeeding stages. Therefore, the tubes must be carefully selected and the filament supply carefully regulated. For optimum results the tubes should be non-microphonic and have fixed operating points. On these bases the sub-miniature Victoreen 5800 tetrodes seemed a good choice. Since the instrument has an integral 300 volt regulated supply, it was only necessary to reduce this voltage to the desired levels.

The first stage of the amplifier serves as a clipper and plate rectifier. It may be noted that the screens are tied to the plates, so the tubes are essentially triodes in this stage. (The detector channel is shown in the top half of the schematic, Fig. 2.) The tube V1 receives on its grid a signal from the pulse transformer, T101. This grid is biased about 6.5 volts negative with respect to the filament by R5, so it detects only the tops of the positive pips. There then appears on the plate a D.C. signal whose voltage level is proportional to the peak height and which contains a 400 cycle sawtooth component. This output is filtered by the capacitor C2. The functions of V2 and C1 on the bottom half of this stage are the same as those described above, except that the output is proportional to the height of the negative peaks.

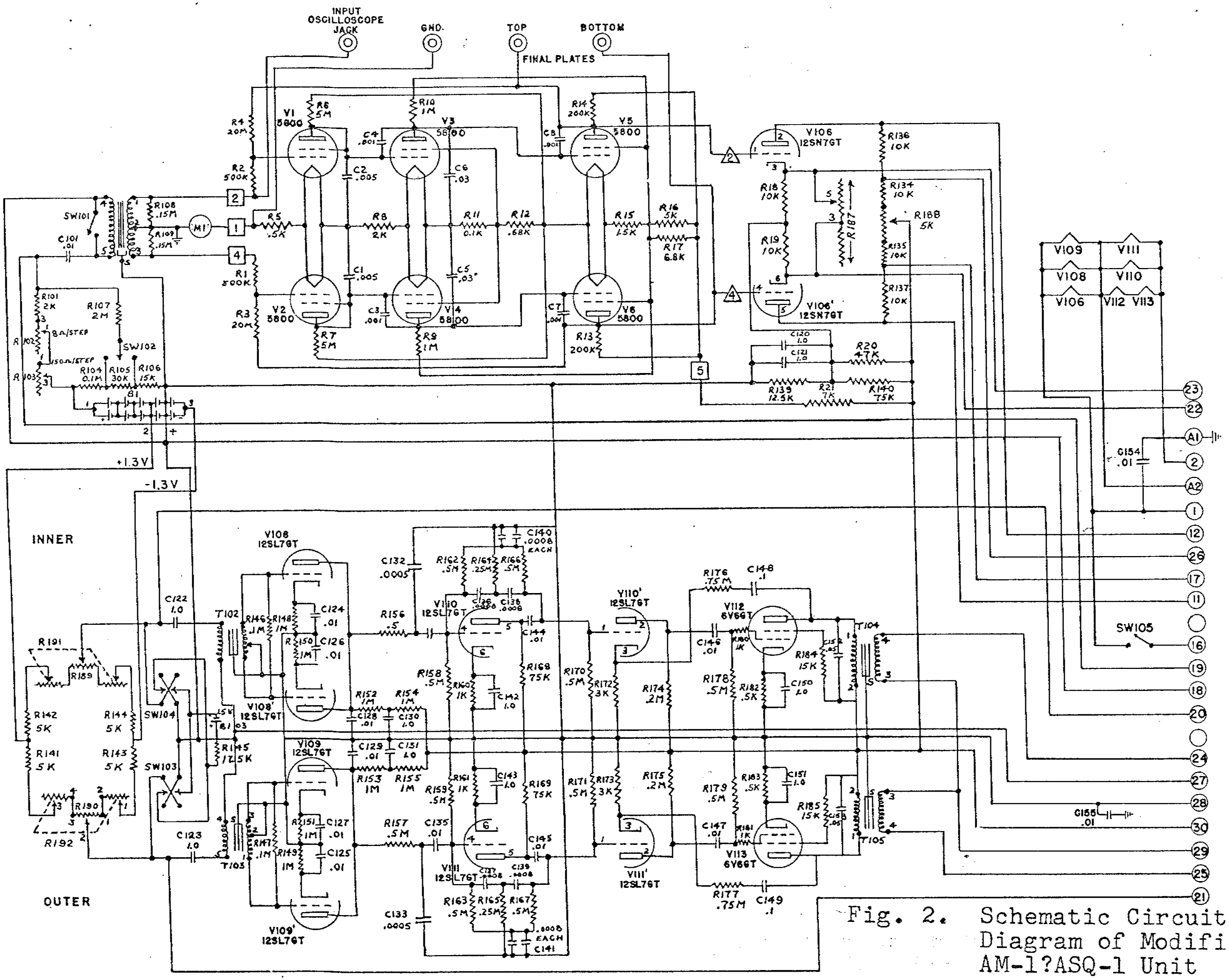

Fig. 2. Schematic Circuit Diagram of Modified AM-1?ASQ-1 Unit

The plate of V1 is conductively coupled to the grid of V3. The negative bias for the grids of this stage is provided by R8. This stage is simply a voltage amplifier. The feedback capacitor C4 and the shunting capacitor serve to attenuate the sawtooth component of the output. V4, C5, and C7 perform the identical functions in the other half of the stage.

The output of V3 is applied directly to the grid of V5, another amplifier stage whose negative grid bias is furnished by R11 and R12. The feedback capacitor has the same function as C4 in the previous stage. V6 and C9 have the corresponding functions in the other section of this stage. The output voltages from V5 and V6 are about 123 volts. Test jacks are connected to the plates to check these values.

Negative feedback for these three stages is provided by impressing a portion of the output of the third stage on the grid of the first stage. This fraction of the output is approximately equal to the ratio of R4 to R2. While negative feedback decreases the gain and cannot reduce the effect of zero drift, it does help to stabilize the gain with respect both to changes of circuit parameters at any given voltage and to changes of the output voltage itself.[6]

The tube filaments of the three amplification stages are connected in series; however, the filaments of

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[6] G.E. Valley, Jr. and Henry Wallman, editors, Vacuum Tube Amplifiers, (New York: McGraw-Hill Book Company, Inc., 1948), p. 469.

the two tubes in each stage are connected in parallel. Power for each stage is provided by the regulated 300 volt supply, and it is reduced to ground by successive resistors which furnish the appropriate voltage for each stage. This obviates the necessity of using batteries between stages to increase the filament voltage to match the increasingly larger grid voltages. The filament current, which should not exceed 10 milliamps per tube, or a total of 20 milliamps, is indicated by the meter M1 located in the center of the front panel of the AM-1/ASQ-1 unit. This normally shows about 19.6 milliamps.

The output of the third stage is applied directly to the grids of the final, or output, stage. This is the 6SN7 twin triode used in the original equipment whose function is to provide large enough plate currents to operate the recorder. The tube has a negative bias provided by R18, R20, R139, and R140. The potentiometer R187, which is connected across the cathodes, permits one to change the gain through this tube by adjusting the bias and, therefore, to change the sensitivity of the instrument. The gain through this stage ranges from slightly over 4 to less than 1/2, thus changing the total gain through the amplifier from over 40 to about 4. The control for R187, labelled SENSITIVITY, is located in the center of the front panel. The potentiometer R188 is simply a balancing device for the plates of this stage. The E-A recorder is connected directly to these plates.

The use of the sub-miniature tubes with very low filament currents and, consequently, low heat dissipation permitted the assembly of the new amplifier in a compace unit. It is contained in a 3" x 3½" x 7" aluminum box with two five-pin plugs in the base. These fit sockets mounted in the AM-1/ASQ-1 chassis and, being assymetrical, prevent mispluggimg of the unit. As may be seen in the photographs (Figs. 3 and 4), the six Victoreen tubes are mounted with the capacitors on a bakelite linen board. The resistors are mounted on a similar board which is back-to-back with the tube assembly, and the wiring is sandwiched between them. The positions of these assemblies with respect to each other and to the container is maintained by the bakelite linen bolt sleeves which can be seen at the corners of the mounting boards. On the top of the unit is an oscilloscope jack to check the input wave form, a jack at ground potential, and jacks connected to the plates of the third pair of tubes. Access to these test jacks is provided through the top of the jacket which encloses the AM-1/ASQ-1 unit during operation.

In Fig. 3 which shows the mounting boards bolted in place and the box lid removed, may be seen a foam rubber strip cemented to the inside of the lid. When the lid is in place, the tubes are held between this strip and the sponge rubber behind the tubes on the mounting board. This effectively shock-mounts tubes and takes their weight off the fine wire leads. Fig. 6 shows the amplifier plugged into place in the AM-1/ASQ-1 unit.

The resistors in the D.C. amplifier have been handpicked and matched to provide the proper voltages. The values of many of the resistors are quite critical and a change in value of 1-2% will definitely alter the characteristics of the instrument and may be sufficient to render it inoperative.

The second major modification was the provision of a steadier source of compensator current. As shown in the simplified schematic (Fig. 5), D.C. current furnished by the battery B1 flows through the detector coils L_1 and L_2 in such a direction that the D.C. field of each coil is in opposition to the earth's field. By means of R_c the amount of current may be varied so that within a wide range of values the earth's field may be almost completely nullified. This variable resistor represents the COARSE and FINE compensator control potentiometers. It may also be seen from this diagram that the detector coils form two legs of a bridge with the output transformer T101 and the D.C. blocking capacitor C101 as the neutral leg. The detector channel serves as the unbalance indicator for the bridge. The shunt resistor R_s gives slightly different electrical characteristics to that side of the detector element so that the outputs from the two sides do not exactly cancel one another. This makes the magnetically sensitive peaks stick out above the "hash."

Beside the leads from the oscillator are shown the wave form of the excitation voltage, and the output from the detector, exhibiting the typical positive and negative pips, is shown beside the leads to the D.C. amplifier.

When dry cells have been used in the compensator circuit, there has been a drift in the instrument of about 75 gammas per day. This is a consequence of the 10 per cent voltage drop such cells suffer throughout their useful life. However, since mercury batteries exhibit a nearly constant voltage of 1.345 volts during their operating lives, they are admirably suited for this application. An assembly of these batteries was constructed and removed from the instrument proper by means of a cable. Thus it could be kept in a vacuum bottle and isolated from the effects of temperature variations. For convenience this cable was fitted with a connector which plugs into the AM-1/ASQ-1 chassis.

During the modification of the detector channel, as many superfluous components as possible were removed to facilitate future maintenance. With but one exception all changes are recorded in both the accompanying schematics and pictorials which supersede Figs. 143, 147, and 152 in the military handbook. The meter M101 in the front control panel was replaced by meter M1, and the resistors R115 and R116 were removed. This is indicated in the schematic, but a new pictorial was not drawn to show this minor change. For convenience in future troubleshooting, the schematic (Fig. 2) of the modified AM-1/ASQ-1 unit was drawn to show both the altered detector channel and the unchanged orientor channels. It has been the intention to make these drawings

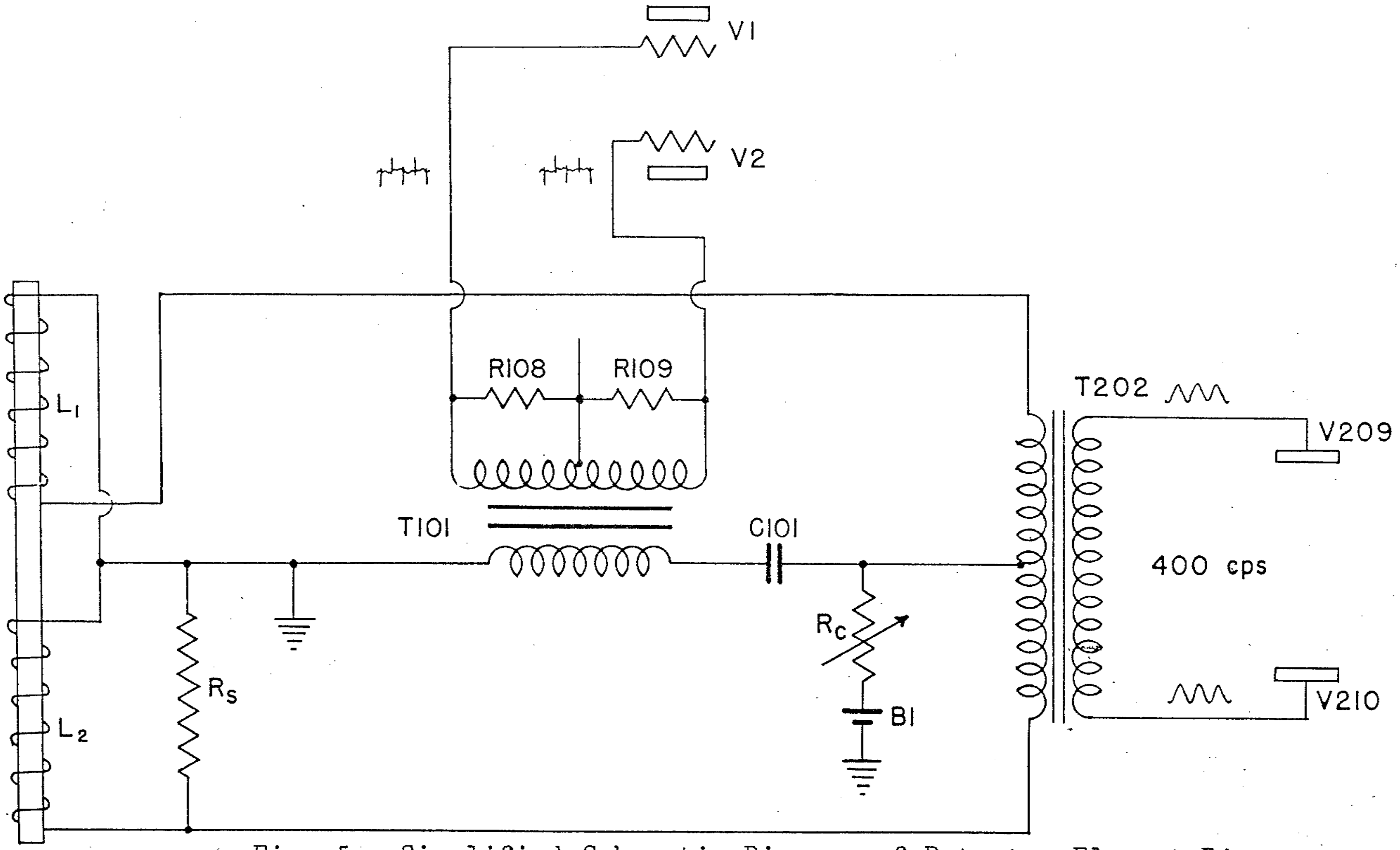

Fig. 5. Simplified Schematic Diagram of Detector Element Bias Circuit.

as clear as possible to serve as a useful supplement to the original military maintenance handbook. Also toward this end, new operating instructions, lists of new components, and voltage check points have been included in this paper.

CALIBRATION

For purposes of calibration, it was necessary to move from the laboratory to a magnetically quiet location. The detector was installed in a wooden building about 30 feet from a reinforced concrete blockhouse which housed the remainder of the instruments. Thus it was possible for the operator to have some freedom of movement with no noticeable change in the magnetic field at the detector. It also made possible independent variation of temperatures at the detector and amplifiers.

Fig. 8 illustrates some of the equipment assembled in the blockhouse during calibration. At the left is the AN/ASQ-1A instrument rack containing the AM-1/ASQ-1 amplifier unit above and the O-1/ASQ-1 oscillator unit below. The dynamotor unit is mounted on the top of the rack. To the right are an oscilloscope, which was used to observe the input wave-form in the d-c amplifier, and an Esterline-Angus recorder. In front of the rack are a vacuum-tube voltmeter, batteries, decade resistor, and milliammeter which were connected to the large Helmholtz coil. Out of the picture to the right was a control unit for the smaller Helmholtz coil.

In exploration work the instrument will be battery powered, although during calibration, power was supplied to the dynamotor by a 200 volt, three phase, variable trans-

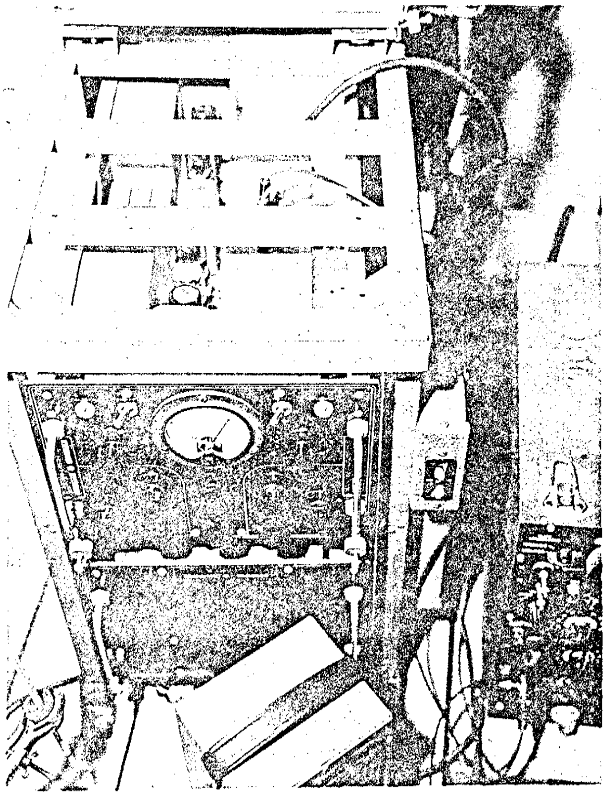

Fig. 6. Top View of Equipment Rack Showing the D-c Amplifier Unit in Place in the AM-1/ASQ-1 Unit.

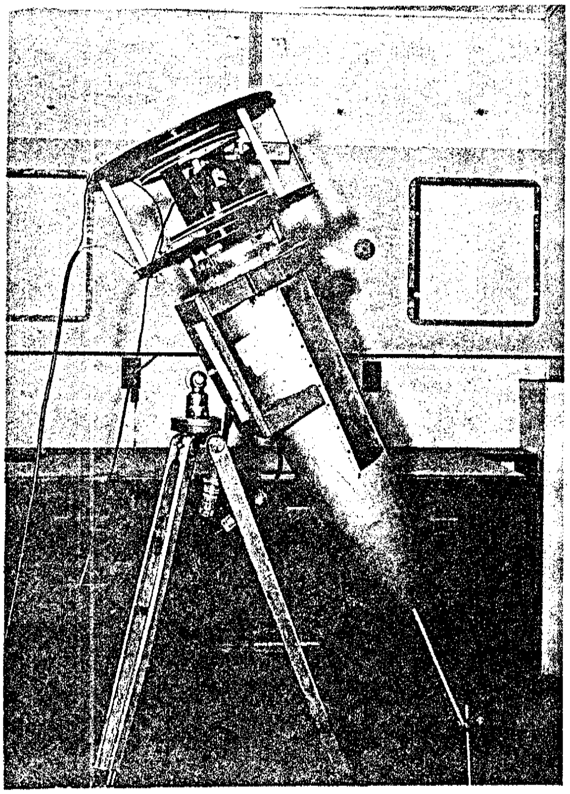

Fig. 7. Detector Unit Aligned for Calibration With Two Co-Axially Mounted Helmholtz Coils.

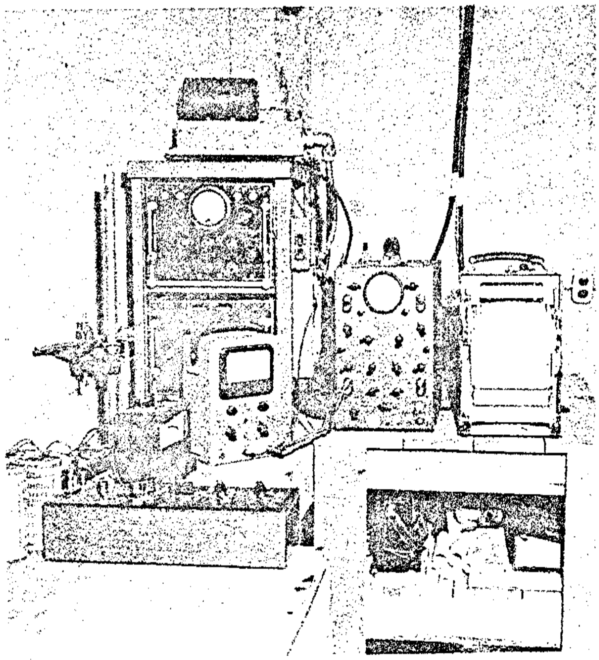

Fig. 8. AN/ASQ-1A Equipment Assembled in Blockhouse With Test and Calibration Equipment

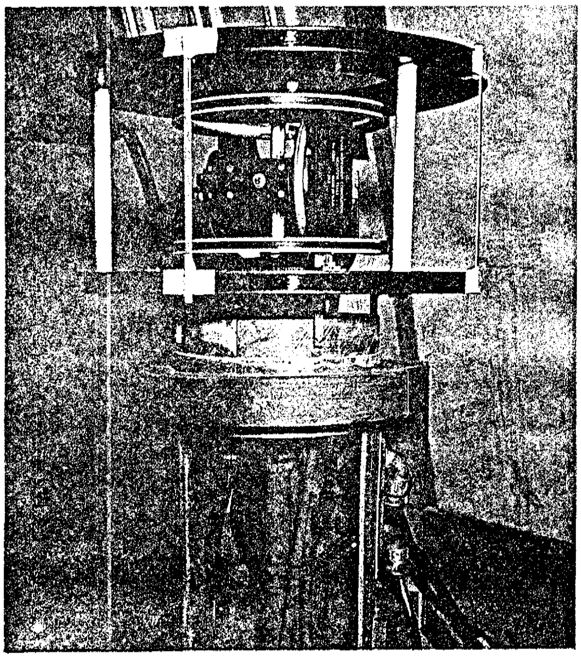

Fig. 9. Close-up of Detector Unit Showing Detector Element Surrounde by Helmholtz Coil Axes.

former-rectifier. This arrangement provided a flexible D.C. power supply which could be varied from about 20 to 35 volts. The dynamotor is designed to operate on 24-28 volts drawing about 14.5 amps, but it can be operated at values 4 volts above and below these figures without significant alteration of the instrument's characteristics. However, extended operation is not advised at voltages above the recommended values.

In the wooden building the "bird" (the streamlined housing containing the detector unit) was aligned parallel to the total field vector so that the detector element would be coincident with the axes of the two co-axial Helmholtz coils which were affixed to the bird. In Fig. 9 one may see the alignment of the coils with respect to the light-colored glass tube containing the permalloy strip and coils. The bird is supported at the tail (Fig. 7) to prevent slipping in the friction joint of the tripod head with resultant misalignment.

The larger of the two coils, which was borrowed from the physics department of the New Mexico Institute of Mining and Technology, has a coil constant of 200 gammas per milliamp, while the smaller one, which is a part of a Ruska Scout field balance equipment, has a constant of 29.2 gammas per milliamp. The larger one was used to produce gross changes in field, to simulate such changes in the earth's field and thus to permit operation of the magnetometer throughout its complete range. By means of the smaller coil, small known increments of field strength were applied to determine the sensitivity of the instrument throughout its operating range.

The instrument, designed to be operated at any latitude from the magnetic pole to the equator, has an operating range of about 50,000 gammas. This range is limited by the amount of compensating current available from the mercury battery to pass through the orientor coils. Since this current is determined by the settings of the compensator controls, it is desirable to know the relative values in gammas of various possible settings. Then in an increasing magnetic field where the recorder pen approaches the right-hand edge of the chart, the operator may, by rotating the FINE control in a counter-clockwise direction, bring the pen back toward the center of the chart by a known number of gammas. Such a procedure, in effect, changes the baseline by a given amount. This increment may be read from the compensator calibration curves, or it may be calculated knowing the sensitivity of the instrument in gammas per scale division.

Shifting of baseline may be kept to a minimum by the proper selection of instrument sensitivity. In the expected operating range the instrument provides full-scale E-A recorder deflections of from 75 to about 800 gammas. Where anomalies of from a few hundred to a thousand gammas are expected in the field, SENSITIVITY position 1 combines a full-scale deflection of about 300 gammas with a sensitivity which can easily be read to within 1 gamma. For most mapping purposes this will probably be much closer than the determination of instrument location.

In calibrating the compensator, both Helmholtz coils were used to zero the Esterline-Angus for each position of the compensator controls. The currents in each were measured and the total impressed field was calculated. The results of these calculations are shown on the graph, Fig. 10. The graph extends only through COARSE position 19, although there are twenty-one positions numbered from 0 through 20 on both the COARSE and FINE step switches. Step 20 on this control changes the resistance from a finite value to a nearly infinite value, thereby changing the compensating field by many thousand gammas and producing a discontinuity in the curve. Therefore, the useful operating range of the instrument extends only through COARSE 19. On both the complete curve and that interval shown in the inset, the lowest value of field strength is arbitrarily plotted as zero. The inset is an enlarged view of that portion of the curve thought to be the most probable operating range. From this one may read the value of the interval from one control position to the next. It is by means of these steps that the Esterline-Angus pen is kept on the paper, so it is important to know the exact amount by which the baseline is shifted each time. The local value of the earth's field at Socorro lies at a

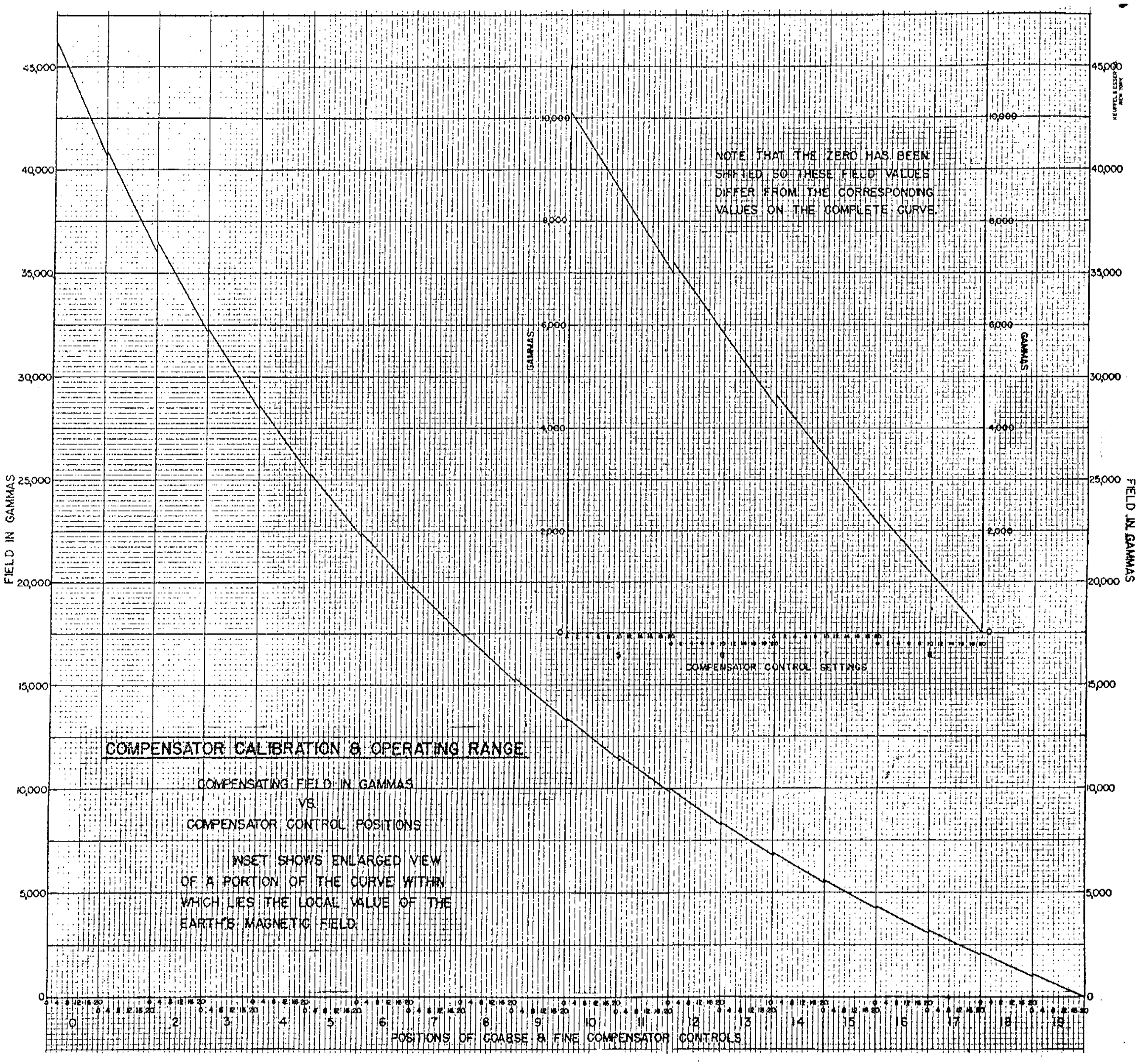

Fig. 10. Graph of Compensator Control Calibration and Magnetometer Operating Range.

point approximately corresponding to a setting of COARSE 7 and FINE 0, but there has been no effort to make these control positions direct-reading in terms of the earth's total field.

The graph indicates that the FINE steps are quite linear for any given setting of the COARSE control, but the slope is different for each COARSE position. Thus, the instrument is not linear over its complete range. This is because the COARSE and FINE potentiometers are divided into nearly equal steps of 150 ohms and 8 ohms, respectively; thus at COARSE position 0, the low resistance end of the scale, one FINE step represents a greater change in total resistance than at COARSE position 19 where total resistance is much greater.

The sensitivity curves, Fig. 11, show sensitivities across the entire range of the compensator controls for each of the eleven positions, numbered 0 to 10, of the SENSITIVITY control knob. These values are given in terms of gammas per scale division. The scale division referred to is the small division on the E-A recorder paper which has 50 divisions full scale. The sensitivities are also non-linear and for much the same reason as the compensator control settings. In addition sensitivity readings will vary as component characteristics change, so that after field use it may be necessary to calculate a multiplying factor reducing these curves to relative instead of absolute values.

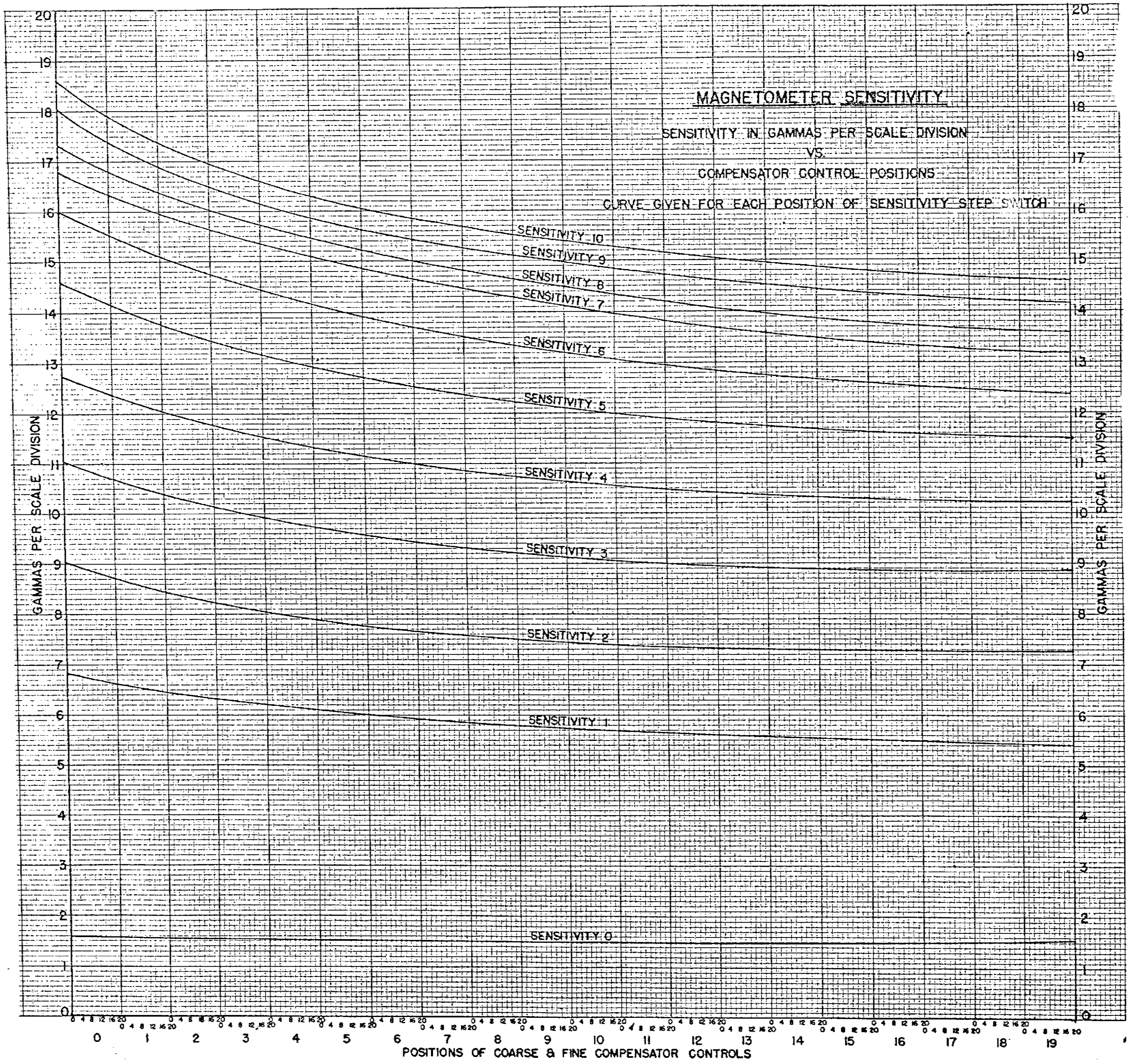

Fig. 11. Graph of Magnetometer Sensitivity Throughout Its Operating Range

The two-position control knob marked TEST on the front panel provides quick operating test. This switch applies a small change in bias current to the detector which corresponds to a small change in the earth's field. Rotating to the L position results in about 15.8 gammas change, and to the S position, about 4.8 gammas.

The drift curves, Fig. 12, indicate that a warm-up time of from one and one-half to two hours is required for the most drift-free operation. The upward direction on the graph is negative so that the drift is in the direction of decreasing field. From the information supplied by Curve II, it would appear advisable to operate the equipment continuously while in the field. Curve II also includes the effects of a gradual temperature rise of about 9° during the day.

The effect of temperature variations is more dramatically illustrated by Curve III and by the portions of this curve in the inset, where drift is plotted against temperature instead of time. The interval A-B of Curve III was produced by increasing the temperature in the building which housed the detector element, while a nearly constant temperature was maintained in the instrument block-house. The interval C-D shows the effect of increasing the latter temperature while maintaining a nearly constant temperature at the detector. After elevation both these temperatures were allowed to return to a near-normal reading. In the inset, two curves are shown for each of these intervals,

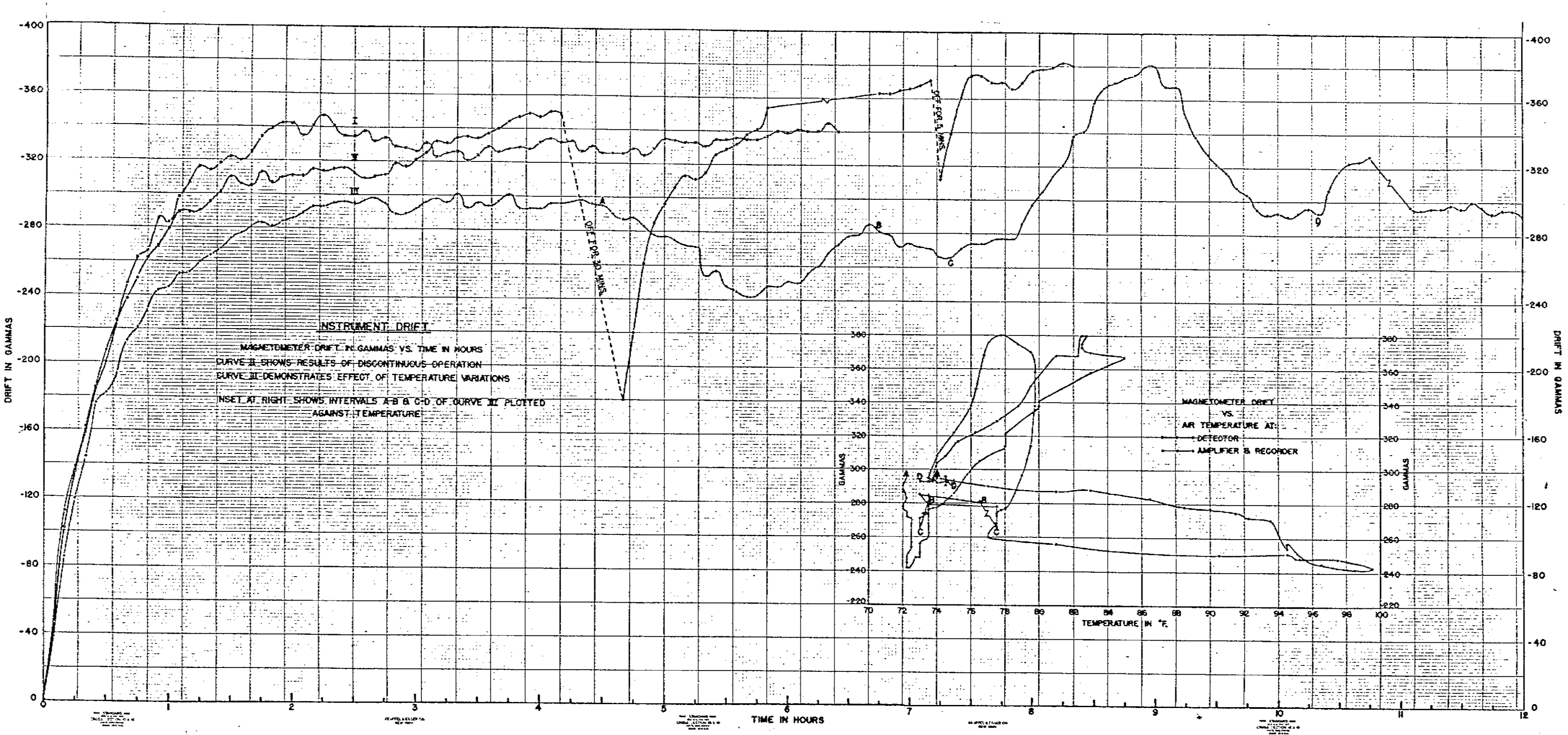

Fig. 12. Graph Showing Effects of Time and Temperature Drift of the Magnetometer.

with both the detector and amplifier temperatures plotted against the corresponding E-A reading in gammas. It should be understood that these temperatures are not instrument temperatures, but are the ambient air temperatures at the two locations. Due in part to the heat capacity of the instruments, the curves are not straight lines and are double valued in much the same manner as a hysteresis curve. As nearly as may be determined, the detector has a temperature coefficient of about 2 gammas/°F, while that of the remaining equipment is about -9° gammas/°F. Therefore, the net temperature coefficient is of the order of -7 gammas°/F.

These drift curves were all run with the jackets removed from the amplifier and oscillator chassis. Subsequently, a drift curve was run with the jackets on, and it was found to be nearly identical to Curve I. The warm-up period was about one and one-half hours, and the total drift was almost exactly the same. A check of the temperature dependence indicated that the coefficient was reduced from about -9 gammas/°F to about -4.5 gammas/°F. This would reduce the net figure to approximately -2.5 gammas/°F. This is about one order of magnitude greater than that of a Schmidt-type balance, but certainly not intolerable, considering the relative magnitude of the erratic instrument drift from other causes. It was also noticed that the heat capacity of the jacket prevented the instrument from recording small transient temperature variations.

CONCLUSIONS

At the present time the instrument is functioning quite well and should provide reasonably good results. In the interest of improved accuracy and convenience in operation, many other modifications could be made, but these would eventually entail re-building the entire instrument.

However, it would be desirable to replace the present compensator potentiometers with decade-type controls having equal steps in gammas. Also, a sensitivity control independent of the compensator setting and providing integral sensitivity values would be convenient. It is not expected that these failings in the present equipment will result in an appreciable loss of accuracy, but they will prove inconvenient in the analysis of data.

The oscillator could be re-designed to advantage, too. Probably much of the temperature drift could be avoided by eliminating the varistor, but, again, this represents reconstruction rather than a modification.

After some field operations have been conducted, other sources of difficulty will undoubtedly be disclosed; but if the instrument performs as well in the field as may be expected from its performance in the laboratory, it should prove to be a valuable supplement to other geophysical techniques in the search for new sources of ground water.

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APPENDIX A.

OPERATING INSTRUCTIONS

1. Mechanical Adjustments

   a. The meters associated with the AN/ASQ-1A should be checked for mechanical zeros.

      (1) D-c amplifier filament current meter (0-25 milliammeter)

      (2) Recorder

   b. With the POWER switch in the upper right corner of the front panel of the AM-1/ASQ-1 unit in the OFF position, adjust the mechanical zero on (1) above with a small screwdriver. With the tape running, adjust the pen of the recorder, (2), to the middle of the chart by means of the lever at the bottom of the case of the Esterline-Angus Recorder.

2. Electrical Adjustments

   a. Check the following connections to make sure that they are properly made.

      (1) The leads of the main power cable are marked plus and minus. They should be connected to the corresponding terminals of the 24 volt battery power supply.

      (2) The white and black leads of the recorder cable should be connected to the positive and negative

terminals, respectively, of the E-A recorder.

(3) The compensator battery and the d-c amplifier unit should be plugged into their sockets in the chassis of the AM-1/ASQ-1 unit.

(4) The AM-1/ASQ-1 and the O-1/ASQ-1 units should be plugged into the rack, and the cable connections to the bird should be secure.

b. Turn the latitude switch at the right side of the rack to the N position.

c. The following adjustments are made on the front panel of the AM-1/ASQ-1 unit.

(1) Turn the SENSITIVITY control, center of panel, to the 1 position.

(2) Turn the DRIVER switch in the upper left corner to OFF position.

(3) Turn main power switch at right of rack to ON position.

(4) Turn the POWER switch in the upper right corner to the ON position. Meter in center should show about 19.6 ma. Allow to warm up for 5 minutes.

(5) With the final plates of the d-c amplifier shorted together (these are the two rear test jacks located in the top of the AM-1/ASQ-1 unit) adjust the screwdriver SIGNAL control in the upper right corner until the pen on the recorder is at the middle of the chart with the

chart moving. (The screwdriver BALANCE control is disconnected, so no adjustment of it need be made.)

(6) Turn the DRIVER switch in the upper left corner to ON position.

(7) Adjust the pen of the recorder to the middle of the chart by means of the COARSE and FINE controls to the left and right of the meter. This should be at a COARSE setting of about 6-8. Remember that a clockwise movement of these knobs moves the pen to the right.

3. Orientation

a. The following adjustments refer to the controls located on the front panel of the AM-1/ASQ-1 unit.

(1) With the recorder tape moving adjust the INNER channel COARSE control, lower left, for maximum deflection to the right of the recorder pen.

(2) Bring the pen back to the middle of the chart by means of the COARSE and FINE controls to the left and right of the panel meter.

(3) Repeat procedures (1) and (2) for the OUTER channel COARSE control, lower right.

(4) Set the SENSITIVITY control, center, to 0.

(5) Rotate the INNER channel TEST switch, lower left, to the A position. Release this switch after the pen on the recorder has reached its maximum deflection to the left.

(6) After the pen on the recorder has settled to its normal position at the middle of the chart, rotate this same TEST switch to the B position. Again release the switch after the recorder pen has reached its maximum deflection to the left.

(7) Adjust the INNER channel FINE control, lower left, (and the COARSE control if necessary) until the deflections for the A and B position of the TEST switch are equal and to the left. The deflections should be equal to within about 1/2 of a small chart division when they are roughly 3 large chart divisions in size. Remember that by turning the FINE control clockwise the deflection for the A position is made smaller and that for the B position it is made larger.

(8) Bring the pen back to the middle of the chart as in step (2).

(9) Repeat steps (5), (6), (7), and (8) above for the OUTER channel. The OUTER channel controls are on the lower right corner of the panel.

4. Calibration

a. With the SENSITIVITY control on 0 rotate the TEST switch located immediately below the SENSITIVITY control, to the S position and then to the L position, and note the deflections on the recorder chart. The TEST signal given by rotating the TEST switch to the S position is about 4.8 gammas and to the L position about 15.8 gammas. These should produce deflections of about 3 and 10 small scale divisions, respectively, for this setting of the SENSITIVITY control.

5. Routine Operation

   a. Before actual surveying is begun, it will now be necessary to allow the instrument to warm up for about 1½ hours.

   b. After the warm-up and during every one to two hours of operation, the magnetometer should be re-oriented according to paragraph 3 above and re-calibrated for that setting of the SENSITIVITY control which is being used.

   c. During actual surveying, the instrument should be returned to a base station at frequent intervals and this fact recorded on the recorder chart so that the amount of instrument and diurnal drift may be determined.

6. Securing Equipment

   a. Turn the RECORDER off.

   b. Turn the DRIVER switch off.

   c. Turn the POWER switch in the upper right corner off.

   d. If operations are being suspended for a long period of time, disconnect the compensating battery at the chassis or unplug the AM-1/ASQ-1 unit or disconnect the cable to the detector head.

APPENDIX B.

MAINTENANCE PROCEDURES

If it should become necessary to service the modified AN/ASQ-1A, the information provided in the military maintenance handbook will suffice, with the exception of some of the sections treating the detector channel of the AM-1/ASQ-1 unit and the compensator battery. For these units a list of new components and a voltage data table have been included in Appendices C and D. There is also a pictorial view of the new d-c amplifier, together with top and bottom pictorial views of the modified AM-1/ASQ-1 unit (Figs. 13, 14, and 15).

To service the d-c amplifier unit, remove its cover by loosening the outermost four of the eight bolts in the rear of the box. If only the voltages on the tubes are to be checked, this may be done simply by removing the lid and inserting the voltmeter probe in the proper holes in the mounting blocks. These are identified in Fig. 13. Patch cords are provided to enable one to remove the box from the AM-1/ASQ-1 unit for this check. If it is necessary to inspect the wiring or resistors, loosen the other four bolts which thread into nuts countersunk into the tube mounting board. By pushing with these bolts on its back, the mounting board may be removed from the box. With the bolts removed, the resistor board will also slide out.

If any of the Victoreen tubes must be replaced, it would be well to replace both tubes of the inoperative stage to preserve a similarity of characteristics within the stage. In removing the tubes it should be noted that the leads are lightly cemented in the mounting blocks to prevent the possibility of their flexing and shorting. Care should be taken not to handle the tubes or leads in the region where the leads enter the glass envelope.

If a resistor must be replaced, a potentiometer should be used to bring the voltages back to their normal values, and the potentiometer then replaced by an equivalent fixed resistor. This is best determined by means of an impedance bridge. If the offending resistor is one of a pair, its replacement should be selected by matching the remaining one. Again, a bridge should be used to insure accuracy. Because the d-c amplifier is particularly sensitive to changes of grid bias in the first stage, the resistor R5 should not be disturbed unless it is necessary, and then the utmost care should be used in finding a replacement for it.

The mercury compensating battery assemblies were made on special order by the Battery Division of the P. R. Mallory & Co. Inc. and replacements may be obtained through them.

APPENDIX C.

VOLTAGE DATA CHART

All measurements from point to ground

Detector Channel of Modified AM-1/ASQ-1

Unit operating and oriented

POINT	D.C. VOLTS	POINT	D.C. VOLTS
V1 - G_1 Grid	3.2	V4 - G_1 Grid	45
V1 - G_2 Screen	45	V4 - G_2 Screen	51^{-}
V1 - P Plate	45	V4 - P Plate	60
V1 - F_- Filament	9.8	V4 - F_- Filament	48
V1 - F_+ Filament	11	V4 - F_+ Filament	49^{+}
V2 - G_1 Grid	3.35	V5 - G_1 Grid	59.5
V2 - G_2 Screen	45	V5 - G_2 Screen	93^{-}
V2 - P Plate	45	V5 - P Plate	122
V2 - F_- Filament	9.8	V5 - F_- Filament	64
V2 - F_+ Filament	11	V5 - F_+ Filament	65.5
V3 - G_1 Grid	45	V6 - G_1 Grid	60
V3 - G_2 Screen	51^{+}	V6 - G_2 Screen	93^{-}
V3 - P Plate	59.5	V6 - P Plate	123
V3 - F_- Filament	48	V6 - F_- Filament	64
V3 - F_+ Filament	49^{+}	V6 - F_+ Filament	65.5

POINT	D.C. VOLTS
D-c Amplifier Input Plug - 5 Power Supply	147
V106 - 1 Grid	122
V106 - 2 Plate	244
V106 - 3 Cathode	129
V106 - 4 Grid	123
V106 - 5 Plate	244
V106 - 6 Cathode	129

BATTERY VOLTAGES

Measured on battery terminals

Detector Magnetic Bias	5.380
Orientor Magnetic Bias	+1.345
Orientor Magnetic Bias	-1.345
Orientation Check	1.5

D-C AMPLIFIER CURRENT

Filament current indicated by meter M1

19.5 - 19.8 milliamps

BIAS VOLTAGES

Measurements made by measuring from each point to ground and subtracting

POINT	VOLTAGES
V1 - F_- to V1 - G_1	-6.6
V2 - F_- to V2 - G_1	-6.45
V3 - F_- to V3 - G_1	-3.0
V4 - F_- to V4 - G_1	-3.0
V5 - F_- to V5 - G_1	-4.5
V6 - F_- to V6 - G_1	-4.0
V106 - 3 to V106 - 1	-7.0
V106 - 6 to V106 - 4	-6.0

APPENDIX D.

LIST OF NEW COMPONENTS

Reference Symbol	Name of Part and Description
B1	BATTERY: 6.725 volts; Mallory Mercury Battery Assembly, SR-0959
C1	CAPACITOR: fixed; 0.005 microfarads.
C2	CAPACITOR: same as C1.
C3	CAPACITOR: fixed; 0.001 microfarads.
C4	CAPACITOR: same as C3.
C5	CAPACITOR: fixed; 0.03 microfarads.
C6	CAPACITOR: same as C5.
C7	CAPACITOR: same as C3.
C8	CAPACITOR: same as C3.
M1	METER: 0-25 D.C. milliammeter; G.E. Model 8D041.
R1	RESISTOR: fixed; 500,000 ohms; ¼ watt; matches R2.
R2	RESISTOR: same as R1.
R3	RESISTOR: fixed; 20,000,000 ohms; ¼ watt; matches R4.
R4	RESISTOR: same as R3.
R5	RESISTOR: fixed; 500 ohms; ½ watt.
R6	RESISTOR: fixed; 5,000,000 ohms; ¼ watt; matches R7.
R7	RESISTOR: same as R6.
R8	RESISTOR: fixed; 2,000 ohms; 1 watt.
R9	RESISTOR: fixed; 1,000,000 ohms; ¼ watt; matches R10.
R10	RESISTOR: same as R9.

Reference Symbol	Name of Part and Description
R11	RESISTOR: fixed; 100 ohms; 1 watt.
R12	RESISTOR: fixed; 680 ohms; ½ watt.
R13	RESISTOR: fixed; 200,000 ohms; ½ watt; matches R14.
R14	RESISTOR: same as R13.
R15	RESISTOR: fixed; 1,500 ohms; ½ watt.
R16	RESISTOR: fixed; 5,000 ohms; 1 watt; in parallel with R17 should give total of 2,900 ohms.
R17	RESISTOR: fixed; 6,800 ohms; 1 watt; in parallel with R16 should give total of 2,900 ohms.
R18	RESISTOR: fixed; 10,000 ohms; 1 watt; matches R19.
R19	RESISTOR: same as R18.
R20	RESISTOR: fixed; 47,000 ohms; 2 watts.
R21	RESISTOR: fixed; wire-wound; 7,000 ohms; 5 watts.
V1	TUBE: 5800 Victoreen sub-miniature pentode; matches V2.
V2	TUBE: same as V1.
V3	TUBE: same as V1; matches V4.
V4	TUBE: same as V1.
V5	TUBE: same as V1; matches V6.
V6	TUBE: same as V1.

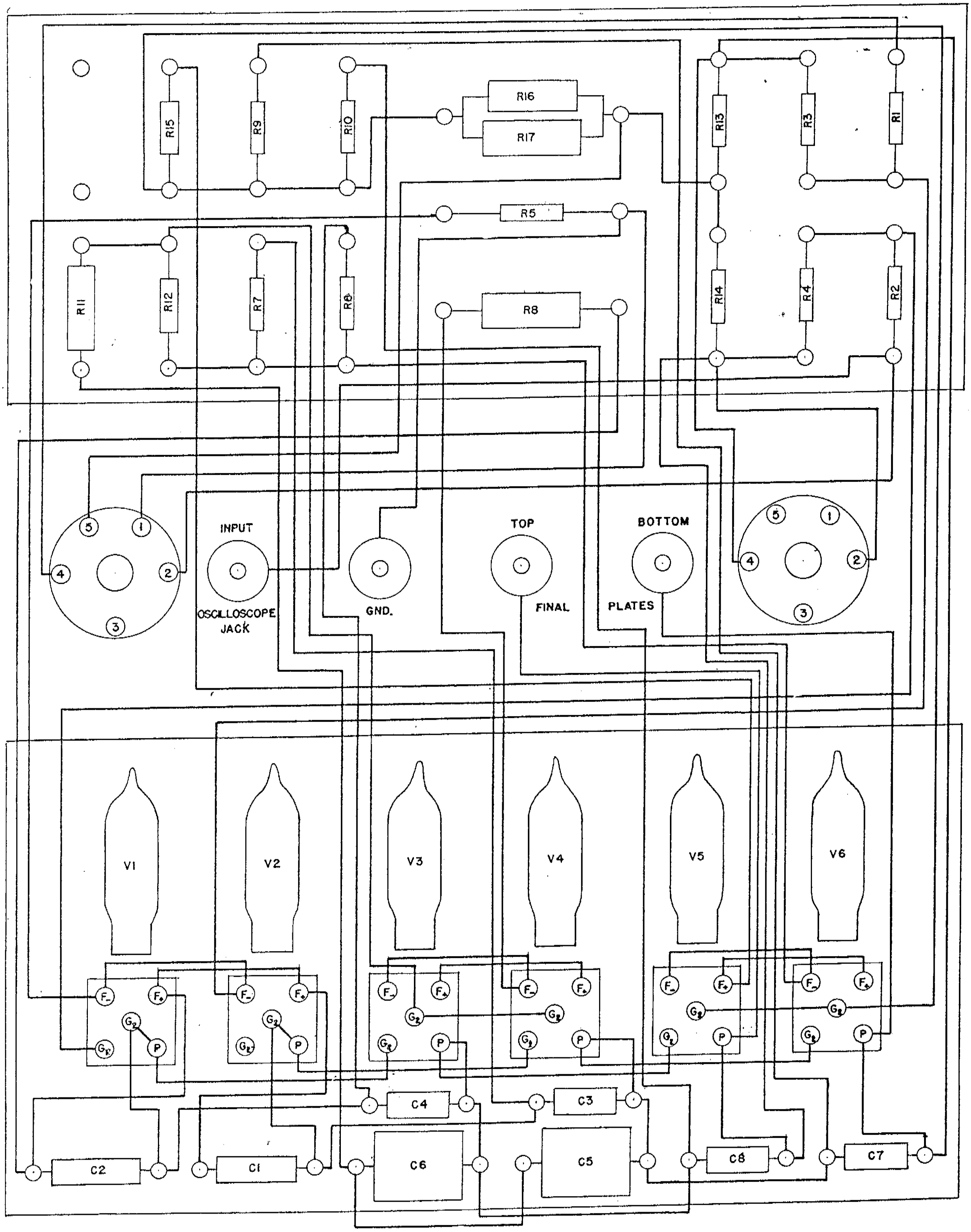

Fig. 13. D-c Amplifier Unit, Pictorial View

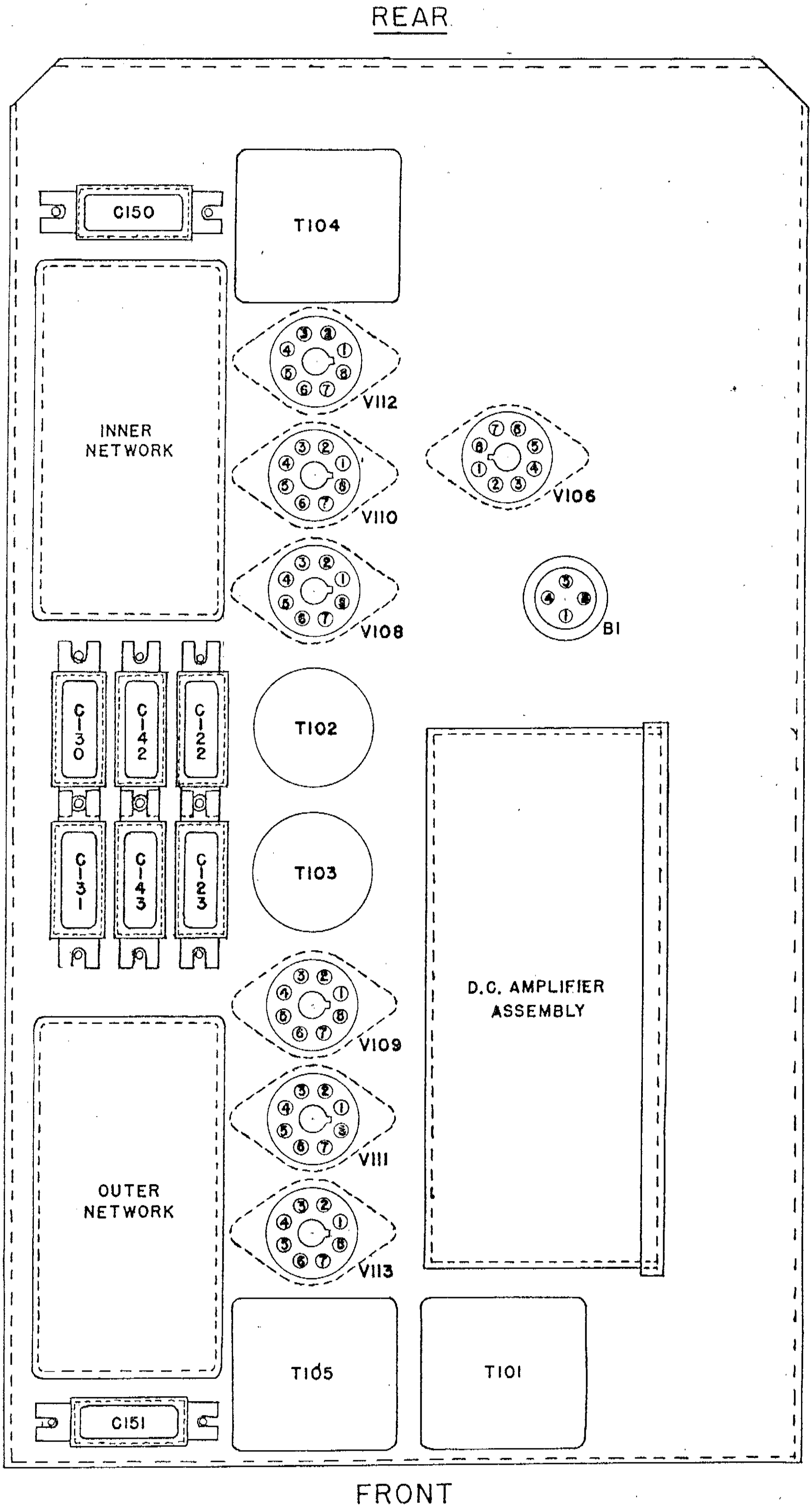

Fig. 14. Modified AM-1/ASQ-1 Unit, Pictorial Top View.

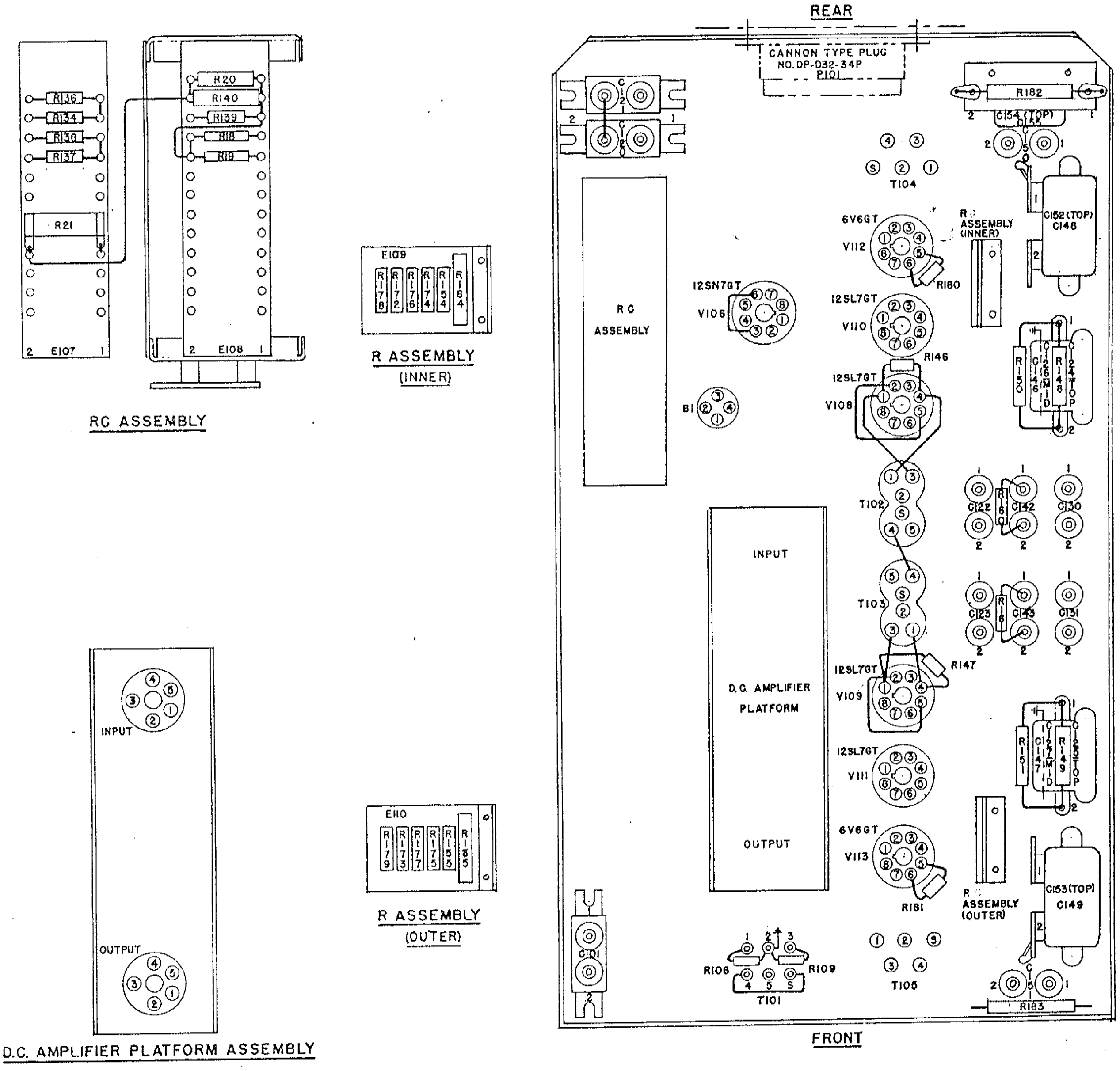

Fig. 15. Modified AM-1/ASQ-1 Unit, Pictorial Bottom View.