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THE TMB TYPE-15K160 STRAIN INDICATOR

BY HENRY B. O. DAVIS

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REPORT 648

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STRAIN INDICATOR, TYPE 15K160

Input circuit:

- A-C resistance bridge . . . . Two gage arms external
- Gage resistance . . . . 120 ohms

Carrier:

- Frequency . . . . 15,000 cps
- Potential . . . . 3 v
- Source . . . . External

Frequency response - within 2 per cent . . . . 0-2000 cps

Sensitivity range . . . . 0.25-10 milli-in. per in.

Output characteristics:

- Maximum output current . . . . 160 ma
- Departure from linearity . . . . . . Less than 4 per cent at 160 ma

Calibration . . . . Internal

Calibration current . . . . approx. 120 ma

Weight . . . . 30 lb

Size, in carrying case . . . . 10 by 20-3/4 by 14-3/4 in.

POWER SUPPLY, TYPE 17A

Power source: . . . . 117 v - 60 c regulated

Power consumption:

- One indicator . . . . 270 w
- Two indicators . . . . 420 w

Fuses . . . . Four 3 amp

Weight . . . . 80 lb

Size, in carrying case . . . . 12-1/4 by 20-3/4 by 16-3/4 in.

OSCILLATOR, TYPE OC-1C

Frequency . . . . 15,000 cps

Output voltage . . . . 3 v

Power source . . . . 117 v - 60 c

Power consumption . . . . 50 w

Fuse . . . . 3 amp

Weight . . . . 33 lb

Size, in carrying case . . . . 8-3/4 by 20 by 14-3/4 in.

THE TMB TYPE-15K160 STRAIN INDICATOR

by

Henry B.O. Davis

ABSTRACT

The TMB Type-15K160 Strain Indicator, an injected carrier type of indicator suitable for measuring static and dynamic strains at frequencies from zero to 2000 cycles per second, is described. The instrument employes the Type-A SR-4 wire-resistance strain gage and has a sensitivity range of 0.25 to 10.0 milli-inches per inch.

The special features of this strain indicator are high-frequency response, high-current output, and cable-length compensation.

Emphasis is placed on the installation, operation, and circuit details of the instrument. Schematic circuit diagrams, parts lists, and photographs are included.

INTRODUCTION

The TMB Type-15K160 Strain Indicator was developed by the David Taylor Model Basin at the request of the Civil Engineering Department of Columbia University (1).*

Since the wire-resistance strain gage became commercially available about 1938, the trend has been toward the measuring of strains at increasingly higher frequencies. The recording of signals with frequencies from zero to 1000 cycles per second or more becomes a problem because of the large driving current required by the high-frequency galvanometers, and the necessity of maintaining the current to zero frequency. This report describes an instrument which provides an essentially flat frequency response up to 2000 cps with sufficient output current to drive the high-frequency recording galvanometers. The increased frequency response and high output current are the distinguishing features of this strain indicator.

This report is intended to provide sufficient information to ensure proper installation, operation, and maintenance of the instrument. The response characteristics of the unit, the installation and operational procedure, and the circuit details are described.

In certain respects the instrument is similar to other strain indicators developed at the Taylor Model Basin (2). The distinguishing features

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* Numbers in parentheses indicate references on page 30.

represent modifications suggested by George W. Cook, Chief Supervisor of the Electronics Branch. The instrument was constructed by members of the Electronics Branch under the supervision of W.S. Campbell.

OPERATING PRINCIPLES

The instrument described in this report and shown in Figure 1 is one of several such instruments developed at the David Taylor Model Basin to facilitate the measuring and recording of static and dynamic strains in structures of various material.

The Type-15K160 Strain Indicator is designed for use with 120-ohm Type-A SR-4 wire-resistance strain gages. The operation, installation, and applications of these gages are described in the literature;* the use of the gages is generally well understood. Briefly, however, a wire-resistance strain gage consists of a resistance element which is cemented to the material or structure under test at the point where the strain is to be measured. The instrumentation therefore resolves itself into a means of measuring a change in resistance, determining if the change is due to an increase or decrease of the gage resistance, i.e., tension or compression, and converting the voltage changes into corresponding current changes to drive the recording galvanometer. The manner of accomplishing these ends is described in the following paragraphs.

The operation of the instrument may best be understood by referring to the block diagram of Figure 2.

Block 1 represents the oscillator chassis supplying the 15-kc carrier voltage to the system. After being amplified by the buffer amplifier, Block 2, the carrier is divided into two paths. One path is the low-impedance path for driving the bridge, Block 5. The other path is through a phase shifter, Block 3, and the isolator, Block 4, to the mixer, Block 9.

The bridge, Block 5, is composed of two internal and two external arms. The external arms, R_{g_1} and R_{g_2}, are made up of two wire-resistance strain gages. At bridge balance no output at the carrier frequency is applied to the preamplifier, Block 6. If, however, any resistance variation is produced in one of the strain gages, a voltage proportional to the bridge unbalance will be applied to the preamplifier. The attenuator, Block 7, is provided to limit the input voltage to the following amplifiers and is so arranged that the input to the voltage amplifier, Block 8, is constant for each calibration step regardless of the sensitivity setting of the attenuator. The signal from the amplifier, Block 8, is stepped down to a low impedance

* See references on page 30.

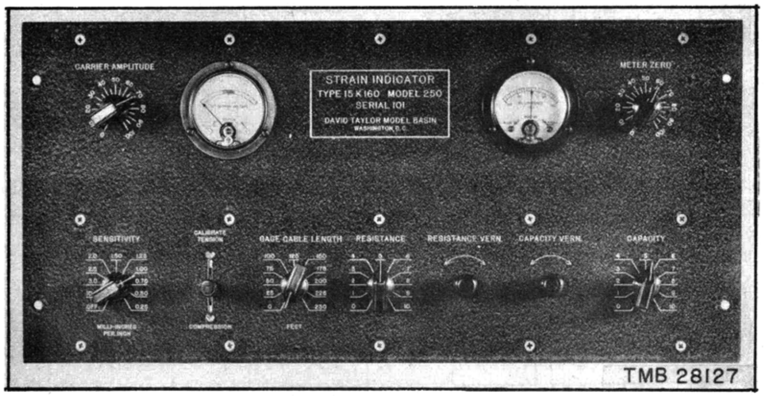

Figure 1a - Front

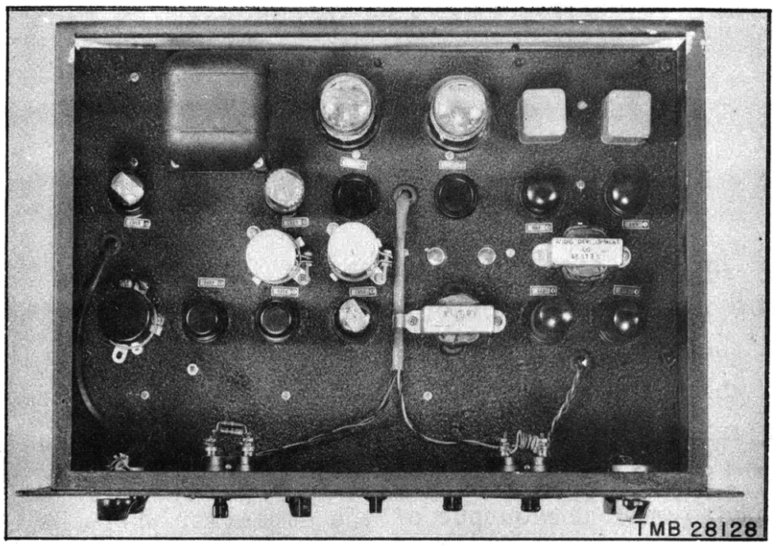

Figure 1b - Top

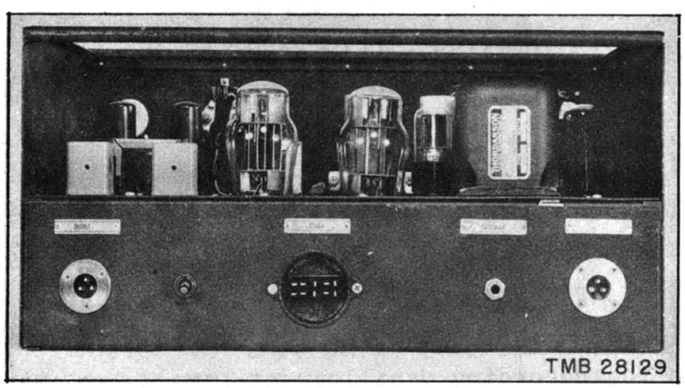

Figure 1c - Back

Figure 1 - Views of TMB Type-15K160 Strain Indicator

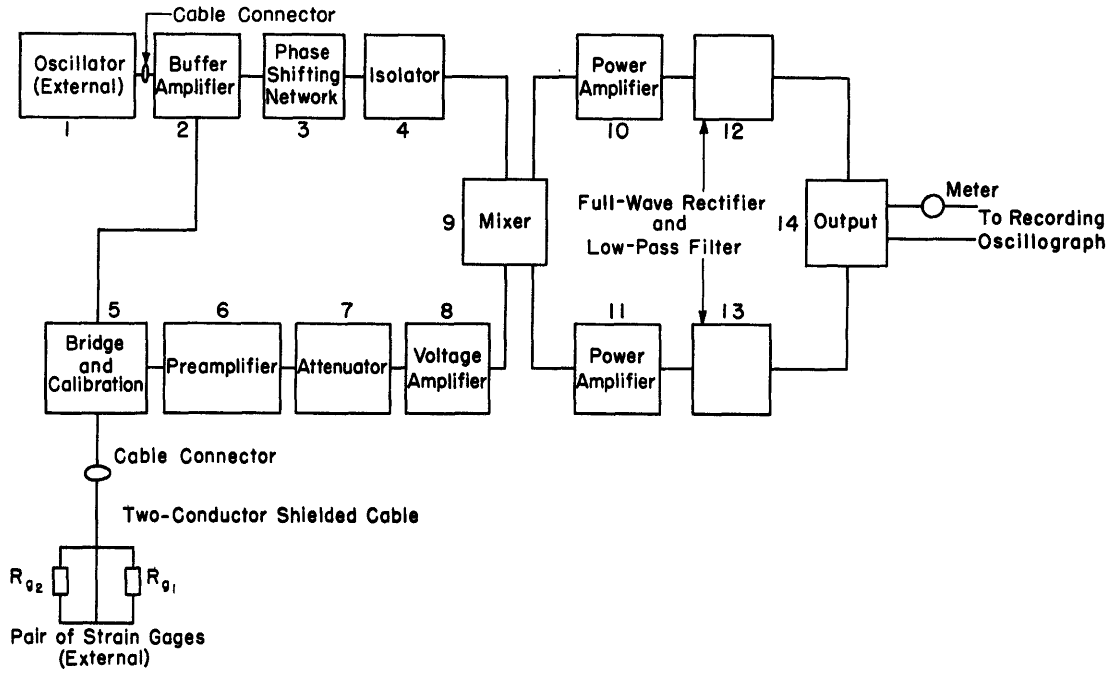

Figure 2 - Block Diagram of the Type-15K160 Strain Indicator

Strain gages and oscillator are external.

for mixing with the injection voltage from the isolator stage. Mixing is accomplished in a resistance-transformer arrangement represented by Block 9. The output from the mixer with no bridge unbalance consists only of the carrier frequency, which is injected at equal amplitudes and phase to both power-amplifier grids, Blocks 10 and 11. This injection voltage has been shifted in phase by the phase shifter, Block 3, so as to be in phase or 180 degrees out of phase with the output of the amplifier when the bridge is unbalanced in resistance. This carrier voltage is injected into the electrical center of the output from the signal voltage amplifier; consequently when the bridge is unbalanced, the injected carrier adds to the signal voltage applied to the grid of one power amplifier and subtracts from the voltage applied to the other power amplifier, Blocks 10 and 11. The output of each of these amplifiers is rectified by a full-wave rectifier, Blocks 12 and 13, and filtered. The d-c outputs of these rectifiers are applied differentially to the output stage, Block 14. With equal inputs to the output stage, i.e., with the bridge in balance, no output current is obtained. Output current appears if there is any difference in the two input voltages. The output of this stage is applied to the recording oscillograph through an output meter, which is used both as an indicator for balancing the instrument and as a means of determining the current produced in the galvanometer by the calibrating step.

DESCRIPTION AND CHARACTERISTICS

Two pieces of accessory apparatus are necessary for use with the Type-15K160 Strain Indicator; these are the oscillator Type OC-1C and the power supply Type 17A. These units, as well as the strain indicator proper, are described in the following sections.

OSCILLATOR

The oscillator chassis shown in Figure 3 consists of a regulated power supply, a 15-kc oscillator, a buffer amplifier, and a power amplifier. The oscillator in this instrument is a type of cathode-coupled oscillator (5) modified to give increased frequency stability and improved wave form. To prevent any load variations from reacting on the oscillator tank-circuit, a buffer stage is used to couple the oscillator to the power amplifier. A negative feed-back output circuit is used to provide a low-impedance low-distortion output stage.

Two screwdriver adjustments are provided on the chassis; see Figure 3. One, labeled OSC, sets the operating point of the oscillator tube. The other, marked AMP, is a gain control for setting the output signal to the desired level. Six output jacks are provided to drive up to six strain indicators simultaneously. Internal compensating shunts provide a constant load on the amplifier regardless of the number of strain indicators in use.

An oscillator common to all channels is necessary when several strain-indicator channels are in use at one location. When individual oscillators are used for each strain indicator a slight difference in frequency between two of the oscillators may cause spurious beats to appear in the indicator output because of coupling between gage cables. The possibility of this trouble is eliminated by the use of one oscillator. An output of as much as 5 volts may be obtained from the oscillator with less than 1 per cent second harmonic distortion. For normal operation the output is set to 3 volts.

Approximately 50 watts at 117 volts, 60 cps is required by this unit. Other characteristics are listed in the specifications facing page 1.

STRAIN INDICATOR

The 15K160-Strain Indicator (Figure 1) is a carrier-type balanced-bridge instrument utilizing an injected carrier system for providing a phase-sensitive output. The injected carrier system is necessary to differentiate between a tension and a compression unbalance when a balanced bridge is used. The instrument features high frequency response, a

Figure 3a - Front

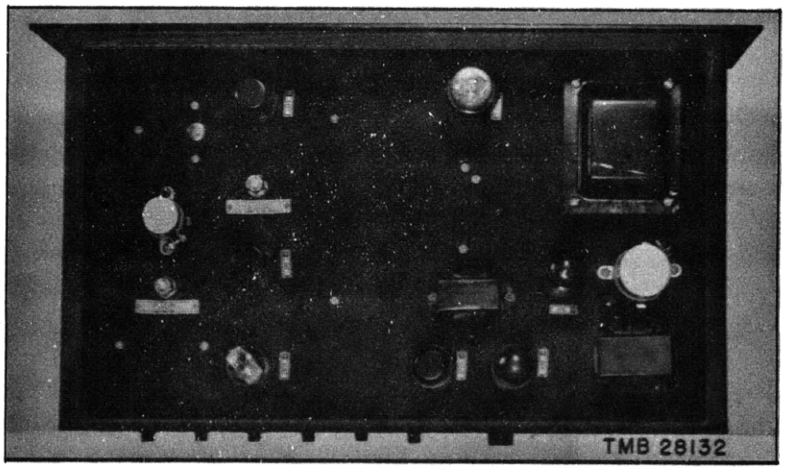

Figure 3b - Top

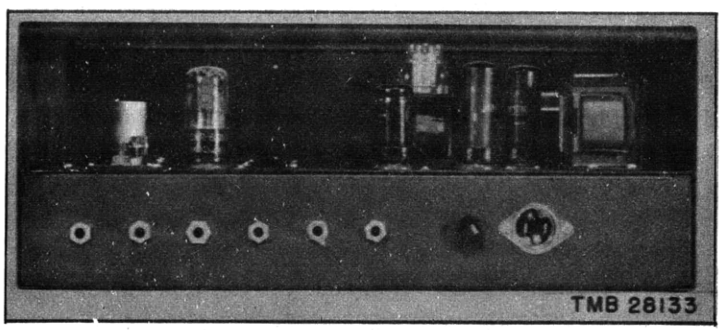

Figure 3c - Back

Figure 3 - Views of the Type-OC-1C Oscillator

sensitivity range of 0.25 to 10 milli-inches per inch, internal calibration, cable compensation switch, internal bridge balancing for resistance and reactance, and a low-impedance high-current-output circuit.

Frequency Response

By employing a carrier frequency of 15 kilocycles, the frequency response of the instrument has been extended to 2 kilocycles. The relatively high carrier frequency allows modulating up to 2 kilocycles, without the spurious beat effects introduced when a carrier is modulated at a frequency greater than approximately 20 per cent of its own frequency. The frequency response of the instrument is shown in Figure 4. It will be noticed that the response is flat to 1300 cycles but is down approximately 2 per cent at 2000 cycles and 6 per cent at 3000 cycles.

Sensitivity Range

A sensitivity range has been provided for full-scale galvanometer deflection on strains of 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 2.00, 2.50, 3.00, and 10 milli-inches per inch.

Calibration

A calibration system has been built into the instrument to provide a rapid and accurate means of checking the overall characteristics of the system. Calibration is accomplished by throwing a known change of resistance (ΔR) into either of two arms of the bridge so as to represent a strain in either tension or compression. The calibration resistor switch has been ganged with the sensitivity switch so that selection of the sensitivity range also selects the calibration resistor to produce a galvanometer deflection equal to a deflection which would result from a strain equal to the sensitivity setting. For example, when the sensitivity switch is set on the 1.5-milli-inch per-inch step, the calibration switch causes a galvanometer deflection in either tension or compression equal to the deflection caused by a strain of 1.5 milli-inch per inch. The accuracy of this calibration is approximately 1 per cent when used with the 120-ohm gages with a gage sensitivity factor of 2. Figure 5 shows calibration steps recorded in both tension and compression taken with a sensitivity setting of 1.0 milli-inch per inch and a film speed of 1 foot per second. The rise time is extremely short, and no overshoot is apparent in the record.

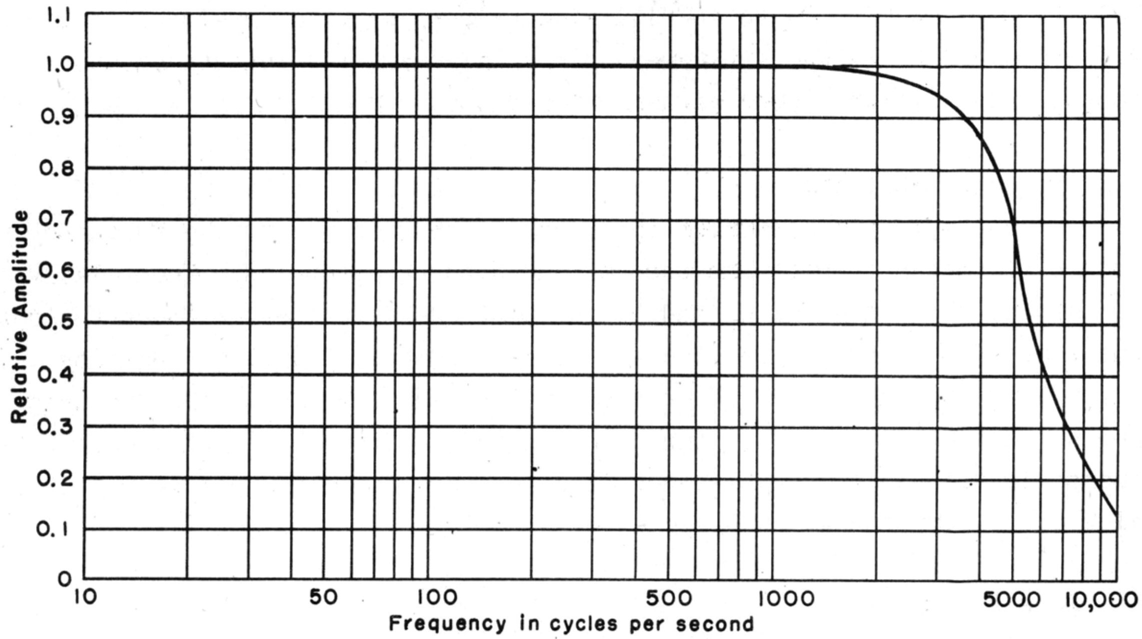

Figure 4 - Frequency Response of Type-15K160 Strain Indicator

Current was supplied through a 1-ohm load.

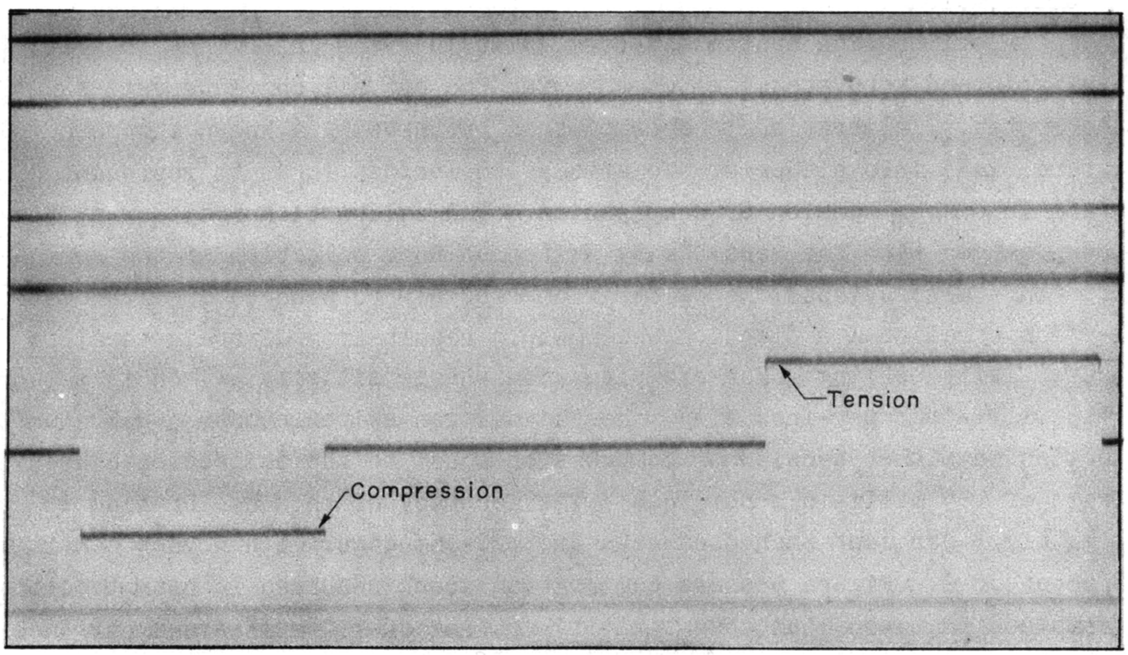

Figure 5 - Calibration Steps of the Type-15K160 Strain Indicator as Recorded on a General Electric Type-PM-10 Recording Oscillograph Equipped with GE "Yellow Dot" High Frequency Galvanometer

Sensitivity 1.0 milli-inches per inch, Film Speed 1 foot per second.

Cable Compensation

The change in resistance, or ΔR, introduced in the bridge circuit of the instrument may not accurately represent the same ΔR introduced in the gages at the end of a long cable because of the attenuation of the cable at the high carrier frequency. A cable-length switch has been provided for use with a long cable in order to maintain a calibration accuracy of about 1 per cent. This switch should be set to the cable-length position corresponding most nearly to the length of the cable in use. Functionally the switch serves to reduce the ΔR introduced in the bridge arm by the amount required to match the attenuation of the signal by the cable length. Compensation is provided for cables of 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250 feet.

Bridge Balancing

Provision has been made for balancing the bridge for both resistance and reactance. Two 11-position switches are provided for rough balancing of resistance and capacitance. Position 5 on both of these switches is the neutral position. The vernier resistance and capacitance controls have been designed to give vernier action over a range approximately 10 per cent greater than one rough resistance or capacitance step. Vernier action is therefore obtained over the complete range of the rough resistance and capacitance switches. The balancing system will compensate for any resistance unbalance up to 2 ohms and a capacitance unbalance of approximately 3000 micromicrofarads.

Output Stage

The high current available from the ouput stage is one of the major features of the Type-15K160 Strain Indicator. By using two Type-6AS7 tubes in a bridge arrangement, a low-output impedance stage is obtained which is capable of delivering up to 160 milliamperes to a 1-ohm galvanometer such as the General Electric "Yellow Dot." This galvanometer has a deflection sensitivity of 140 milliamperes per inch. Other galvanometers of higher resistance may be driven by this stage with less output current. The linearity of this output stage is shown in the curve of Figure 6. The departure from linearity is less than 4 per cent at 160 milliamperes.

It has been found that a drift exists in the output circuit when an input corresponding to a static strain is applied. This static-strain condition may be simulated by throwing and holding the calibration switch to either tension or compression. The drift for output currents of 50,

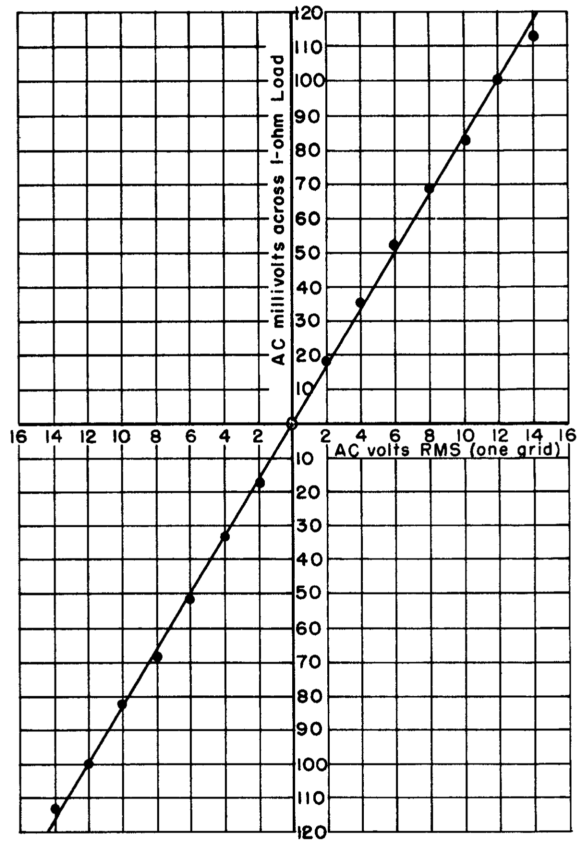

Figure 6 - Linearity Curve - Type-15K160 Strain Indicator Output Stage

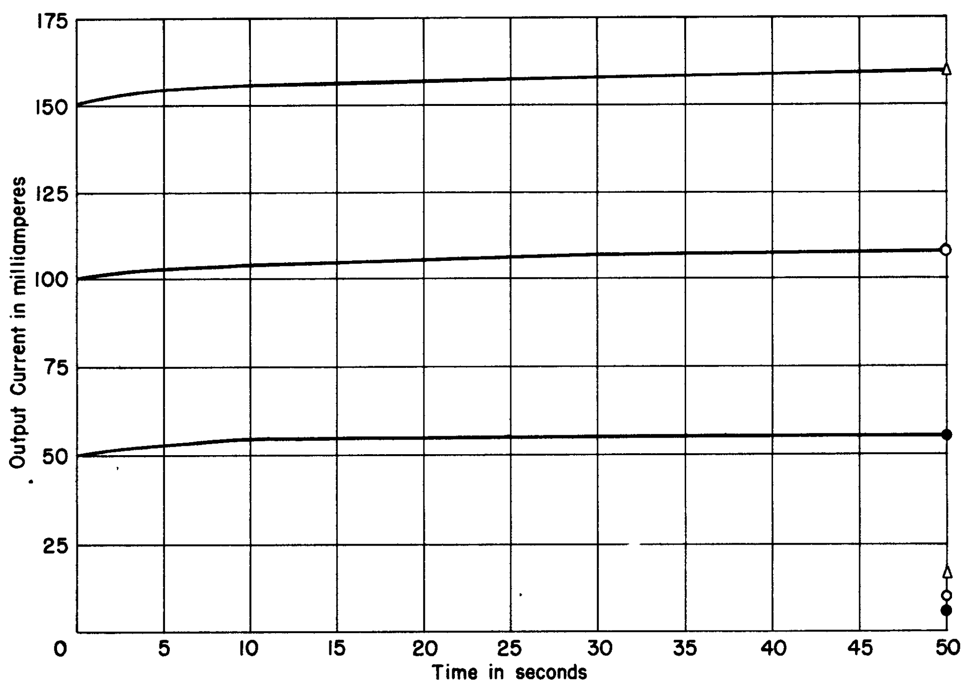

Figure 7 - Drift Curves - Strain Indicator Type 15K160

100, and 150 milliamperes has been plotted in Figure 7. The drift is of the order of 10 per cent in 50 seconds. When the strain or simulated strain returns to zero the output current does not immediately return to zero. The point to which the current drops after 50 seconds is indicated on the graph, Figure 7. This "residual" current drifts back to zero in a short time. The cause of this drift has not been determined.

POWER SUPPLY

The power supply Type 17A (see Figure 8) is designed to operate from a 115-volt 60-cycle regulated power source. A regulated line is specified because the high-current floating-power supply is unregulated. An appreciable variation of the line voltage may appear as a drift in the output current. This unit will supply two of the Type-15K160 Strain Indicators operating simultaneously. A separate output receptacle is provided for each strain indicator. The power required by this supply is 270 watts when only one strain indicator is operating, and 420 watts when two strain indicators are operating simultaneously. Other characteristics of the unit are shown in the specifications facing page 1.

INSTALLATION

The strain indicator is easily installed. All connections are made by means of plug-in cables to receptacles clearly marked on the rear of the instruments. The units may be rack-mounted in standard relay racks, or they may be operated in the shipping cases. In either event the strain indicator should not be placed directly above or below the power supply without providing several inches of vertical separation. This precaution will prevent magnetic coupling from the power transformers to the indicator circuits. When tests require the use of the instrument over an extended period of time it is advisable to remove the units from the cases to ensure adequate ventilation for the electronic components.

It is assumed that the gages have been installed in accordance with the manufacturers' recommendation and are in proper operating order. This phase of the installation has been adequately described in the literature (6), (7).

A block diagram showing the cable connections is given in Figure 9. The cable from the strain gages to the strain indicator may be any good two-conductor shielded microphone cable (Belden 8422 or equivalent). This cable, which is Cable A in Figure 9, terminates in a 3-pin locking Cannon plug, and should be wired so that the active gage is connected to Pin 2. Pin 3 connects to the lead serving the temperature-compensating gage and Pin 1 connects to the cable shield. The cable shield is connected

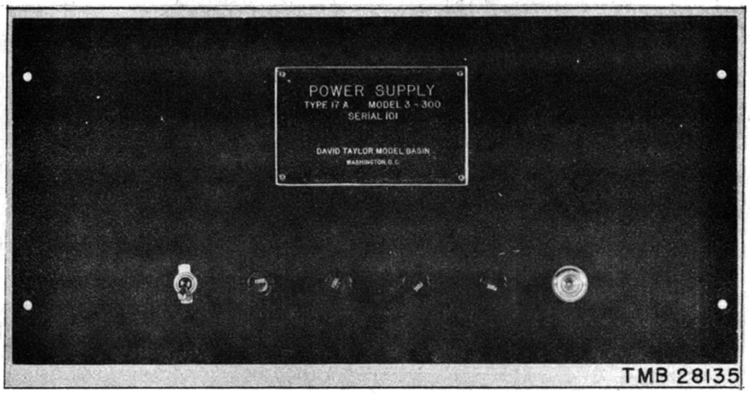

Figure 8a - Front

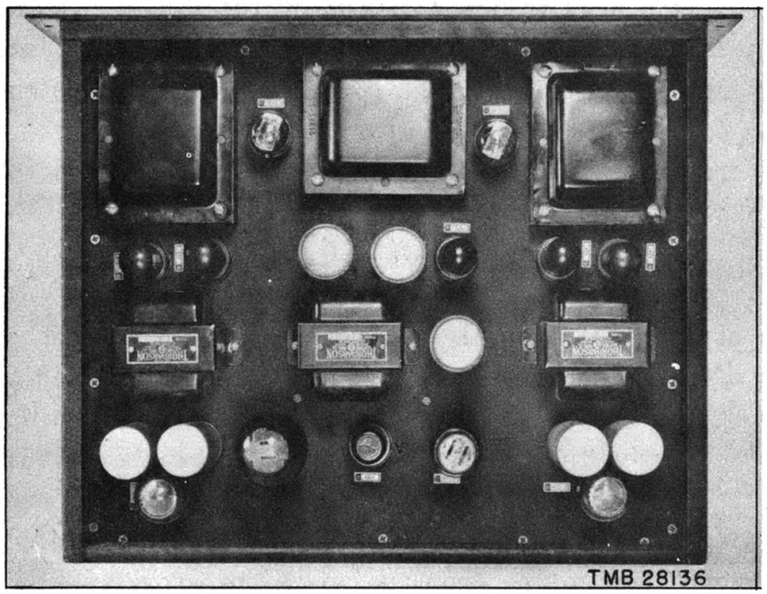

Figure 8b - Top

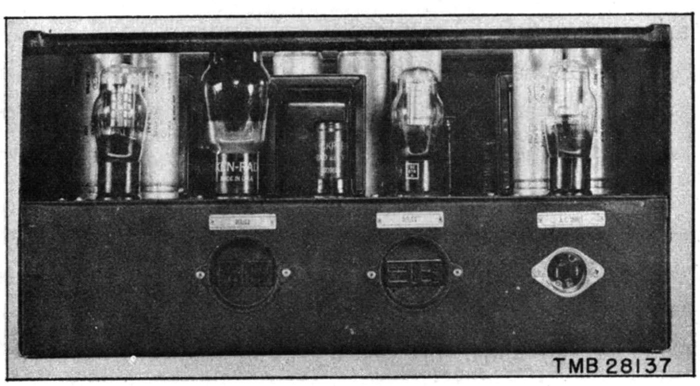

Figure 8c - Back

Figure 8 - Views of the Type-17A Power Supply

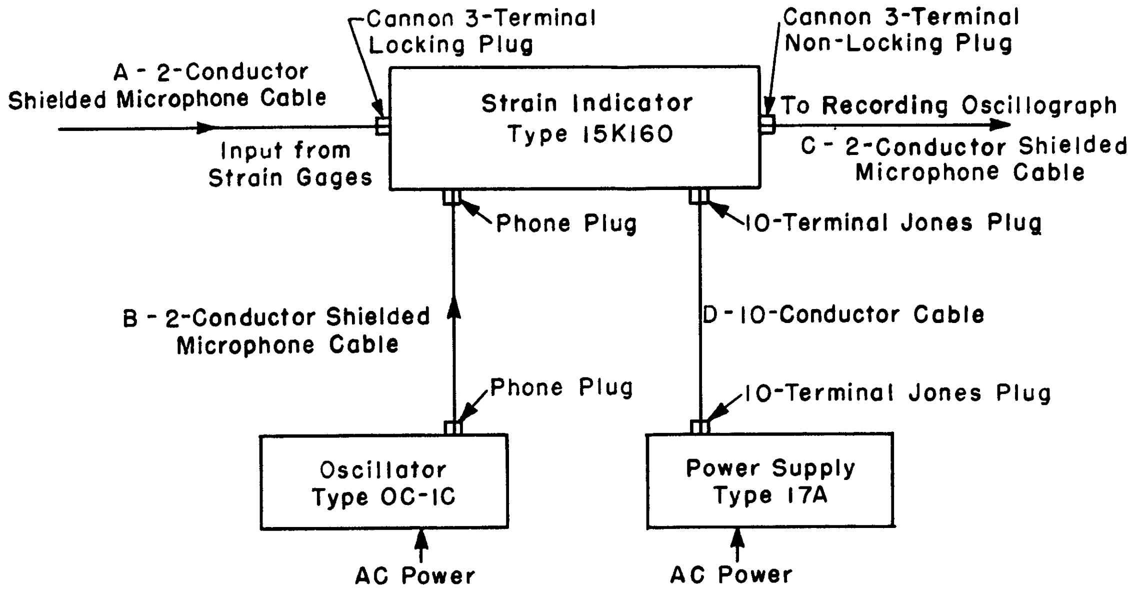

Figure 9 - Cable Diagram of the Type-15K160 Strain Indicator

at the gage end of the cable to the junction of the active and compensating gages as shown in Figure 10. It is important that the locking ring be securely tightened, since any variation in plug resistance may appear as a resistance change introduced by the gage. This cable, i.e., Cable A, plugs into the receptacle on the strain indicator marked "Input." The same type of cable may be used for Cables B and C, Figure 9. Cable B terminates on each end in a conventional phone plug. One end of this cable plugs into one of the oscillator output receptacles; the other end plugs into the strain-indicator jack marked "Oscillator." Cable C terminates in a Cannon 3-pin nonlocking plug and connects the string oscillograph to the strain indicator. This cable plugs into the receptacle on the strain indicator marked "Output." Cable D, the power cable, is a 10-conductor cable. It terminates in a male and female 10-terminal Series-400 Jones plug. The receptacles for Cable D are clearly marked on the power supply and strain indicator.

The installation is completed when the oscillator and power supply are plugged into the 117-volt 60 cycle regulated power source. The installation connections are summarized in Table 1.

OPERATION

This instrument is easily operated once it has been properly balanced and calibrated.

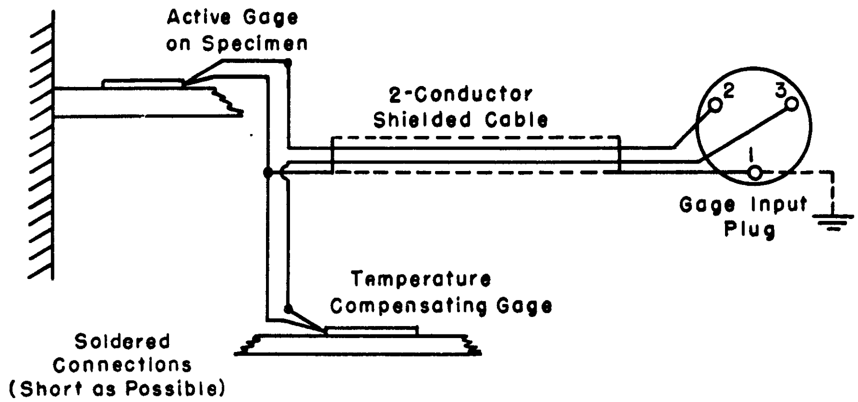

Figure 10 - Gage Cable Connections

TABLE 1

Summary of Cable Connections

From		To	
Unit	Receptacle	Unit	Receptacle
Strain gages		Strain indicator	Input
Oscillator	Output	Strain indicator	Oscillator
Power Supply	Power	Strain indicator	Power
Strain indicator	Output	Recording oscil-lograph	
	a-c line	Oscillator	a-c input
	a-c line	Power Supply	a-c input

BALANCING

The point of proper balance may be determined by watching the two meters on the panel of the indicator. The balancing procedure may best be described by a series of steps as follows:

1. Set the strain-indicator controls as follows:

    a. Sensitivity "Off."
    b. Gage Cable Length to setting nearest length of cable used.
    c. Resistance 5.
    d. Capacity 5.
    e. Carrier Amplitude 60.
    f. Meter Zero 50.

2. Turn on the power switches of the oscillator and the power supply. After the instruments have warmed up for about 10 minutes the bridge balancing may proceed. If the unit continues to drift after this time, extend the warm-up time.

3. Zeroize the output meter by adjusting the meter zero control until the pointer on the output meter indicates zero output current.

4. Set the pointer of the carrier amplitude meter to the black line on the meter scale. A control marked "Carrier Amplitude" is provided for the purpose.

5. Advance the sensitivity switch until an appreciable deflection is obtained on the output meter.

6. Adjust the resistance switch to return the output meter as near to zero as possible.

7. With the capacity switch, set the pointer of the carrier voltage meter as near as possible to the black line on the scale. This will usually be a step near position 5 on the switch.

8. Adjust the resistance vernier control to return the pointer of the carrier voltage meter to the black line.

9. The sensitivity switch may then be advanced to the position of maximum sensitivity.

10. Repeat steps 8 and 9 if necessary.

11. Throw the calibrate switch to "Tension" and set the carrier amplitude control to give the desired output current, normally 120 milliamperes. Throw the calibrate switch to "Compression." The current indicated on the output meter should be equal to that for tension but should be in the opposite direction. Equal deflection on either side of the zero setting indicates that the balancing adjustments have been made properly.

CALIBRATION

With the instrument balanced, and with everything in proper operating order for making the test, the calibration step should be recorded. This is done by starting the recording oscillograph and throwing the calibrate switch first to "Tension" and then to "Compression." This procedure is usually repeated several times to prevent the possibility of the calibration step being lost if it should coincide with a portion of the film that was fogged or not developed. Throwing the calibrate switch to "Tension" causes an output-meter deflection to the right. Throwing it to "Compression" causes an equal deflection to the left. It is frequently desirable to have all channels of a multichannel oscillograph deflect in the same direction for a tension and compression unbalance. A toggle switch has been provided in the rear of the strain indicator to allow reversing leads to the galvanometer without disconnecting or modifying the cables.

When the calibration step has been recorded, the strain record may be taken. It is good practice also to record the calibration step immediately after the record has been taken.

CIRCUITS

The circuits used in the oscillator and power supply are more or less conventional. The strain indicator circuit is one not commonly encountered and is discussed in some detail.

OSCILLATOR

A schematic circuit diagram of the 15-kc oscillator chassis is shown in Figure 11. The oscillator tube V-1 and associated components will be recognized as a form of cathode-coupled oscillator (5). The tank circuit of this oscillator has been modified from that of the conventional cathode-coupled oscillator by the introduction of the isolating resistors R-9 and R-10. Sufficient coupling is maintained to allow oscillator stability; however, the isolation is sufficient to prevent voltage or circuit-constant changes from reacting appreciably on the frequency of oscillation. The tank circuit, therefore, operates at a "Q" higher than is usually found in oscillator circuits; in this oscillator the tank circuit acts both as the frequency-determining element and as an output filter. A high "Q" toroid coil is used for L-3 to assist in obtaining a stable oscillation with good wave form. Capacitor C-14 has been provided to allow corrections to be made in the oscillator frequency if it should become necessary because of circuit-constant or oscillator-tube changes. The frequency of the oscillator may be set by comparing its frequency with a reliable oscillator set to 15 kc and adjusting C-14 to obtain the familiar stationary Lissajou pattern. Capacitor C-14 may be reached with a screwdriver by removing the plug on the oscillator chassis; see Figure 3.

The use of the isolator tube, V-2 prevents any loading on the power-amplifier stage from changing the oscillator frequency; it also removes the loading of potentiometer R-13 from the tank circuit.

Potentiometer R-4 is used to set the operating point of V-1 to insure sufficient feedback for stable oscillation and good wave form. This control is marked "OSC" on the chassis, Figure 3. R-13 is the gain control

Parts List for
Oscillator, Type OC-1C, Model 1-6

R-1	50 K	1 w
R-2	50 K	1 w
R-3	5 K	1 w
R-4	5 K	Potentiometer
R-5	1 M	1 w
R-6	2 M	1 w
R-7	7.5 K	1 w
R-8	2 K	1 w
R-9	1 M	1 w
R-10	300 K	1 w
R-11	50 K	1 w
R-12	10 K	1 w
R-13	200 K	Potentiometer
R-14	2 K	1 w
R-15	300 ohms	1 w
R-16	500 ohms	1 w
R-17	10 K	1 w
R-18	10 K	1 w
R-19	10 K	1 w
R-20	10 K	1 w
R-21	10 K	1 w
R-22	10 K	1 w
R-23	100 K	1 w
R-24	100 K	1 w
R-25	500 K	1 w
R-26	Balancing Resistor	
R-27	1 M	1 w
R-28	6 K	10 w
R-29	100 K	1 w
R-30	100 K	1 w

C-1, C-2 } 10-10 μf 450v. Mallory FP231
C-3 0.01 μf 400v. Paper
C-4 0.05 μf 400v. Paper

The unit for all resistances is ohms.
K corresponds to a multiplying factor of 10^3.
M corresponds to a multiplying factor of 10^6.

C-5	0.0025 μf	Silvered Mica
C-6	0.05 μf	400v. Paper
C-7	10 μf	50v. Blue Beaver

C-8, C-9, C-10, C-11 } 10-10-10-10 μf 450v. Mallory FP434

C-12	0.5 μf	450v. Paper
C-13	0.00115 μf	Silvered Mica
C-14	3.2-36 $\mu\mu f$	microcapacitor

L-1 Filter Choke Thordarson T-47C07
L-2 Filter Choke Thordarson T-47C07
L-3 Western Electric Type "B" Loading Coil D170714

J-1 Circuit Opening Jack
J-2 Circuit Opening Jack
J-3 Circuit Opening Jack
J-4 Circuit Opening Jack
J-5 Circuit Opening Jack
J-6 Circuit Opening Jack
J-7 Chassis Receptacle - A.C. Power

F-1 Fuse 2 amp

S-1 Switch, Toggle, S.P.S.T.

V-1 6SC7
V-2 6J5
V-3 6SN7
V-4 5Z4
V-5 6V6
V-6 6SJ7
V-7 VR-105

I-1 Pilot Light

T-1 Power Transformer T-13R13
T-2 Filament Transformer T-19F80
T-3 Audio Development Co. A-5311

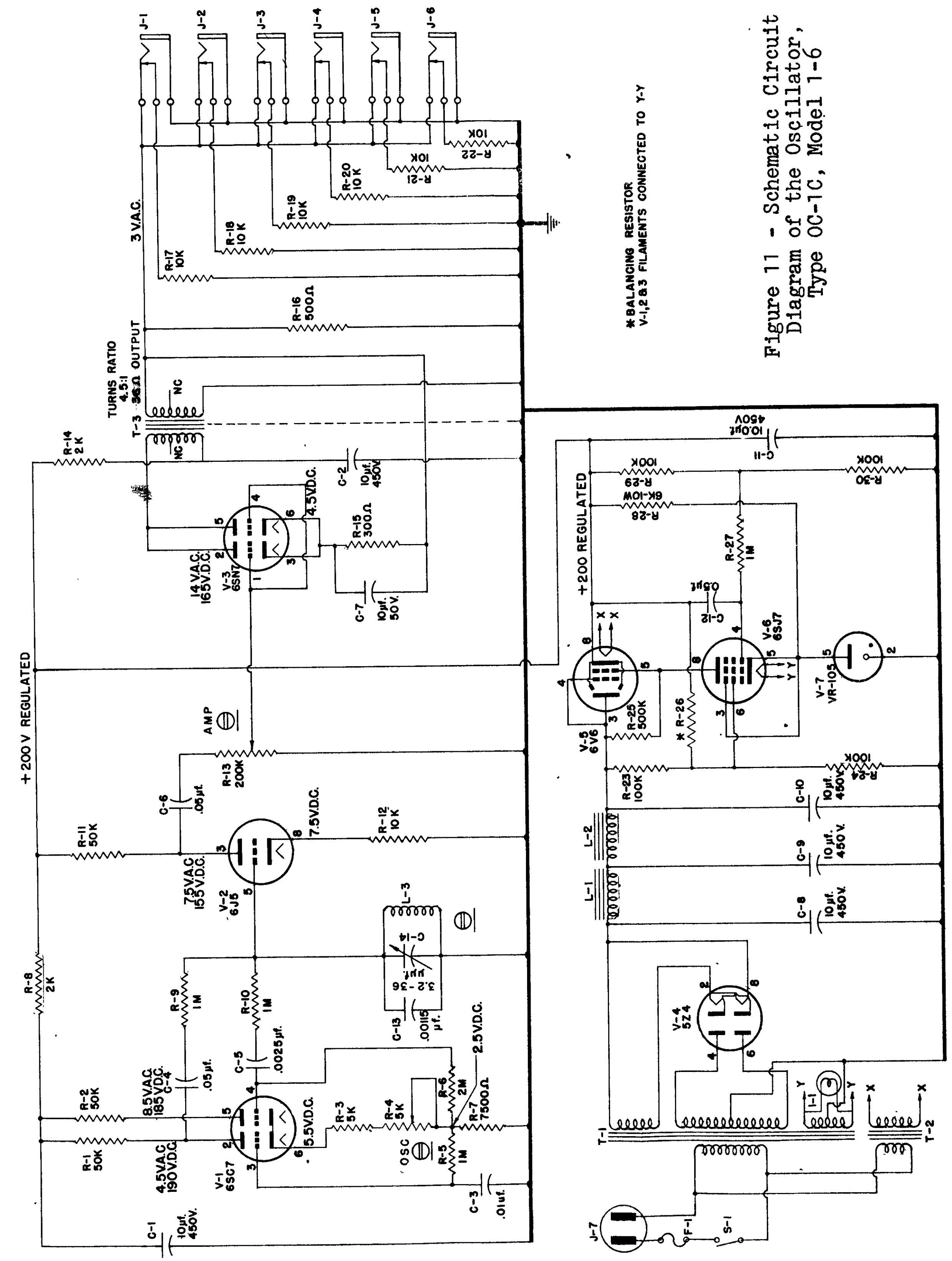

Figure 11 - Schematic Circuit Diagram of the Oscillator, Type OC-1C, Model 1-6

for the oscillator and is marked "AMP" on the chassis. This potentiometer allows setting the input to the amplifier stage, V-3, to the required level. The output stage consists of a 6SN7 tube with both triode sections operating in parallel. The cathode lead has been returned to the secondary of the output transformer, which introduces negative feedback with the corresponding low output impedance. An output impedance of approximately 36 ohms is obtained in this manner. A constant load is maintained on the amplifier tube by the use of resistance shunts on the output jacks J-1 to J-6. This shunt has the same resistance as the carrier input circuit in the strain indicator, and no voltage adjustments need be made if additional strain indicators are connected to the oscillator. As indicated on the diagram, the output voltage is to be set at 3 v rms

A regulated power supply is built into the unit to maintain a constant plate supply. Regulation is maintained to less than 1 per cent for line variations of plus or minus 10 per cent. The operation of this type of regulator has been covered in a previous TMB report (8).

The a-c and d-c voltage distribution in this unit is indicated on the diagram for ease in servicing. The a-c voltages indicated are rms values with reference to ground and are those indicated on a Ballantine Model-300 voltmeter. The d-c voltages are those indicated on a 20,000-ohms-per-volt meter with reference to ground. The bottom view of this unit showing the wiring and the arrangement of the parts is shown in Figure 12.

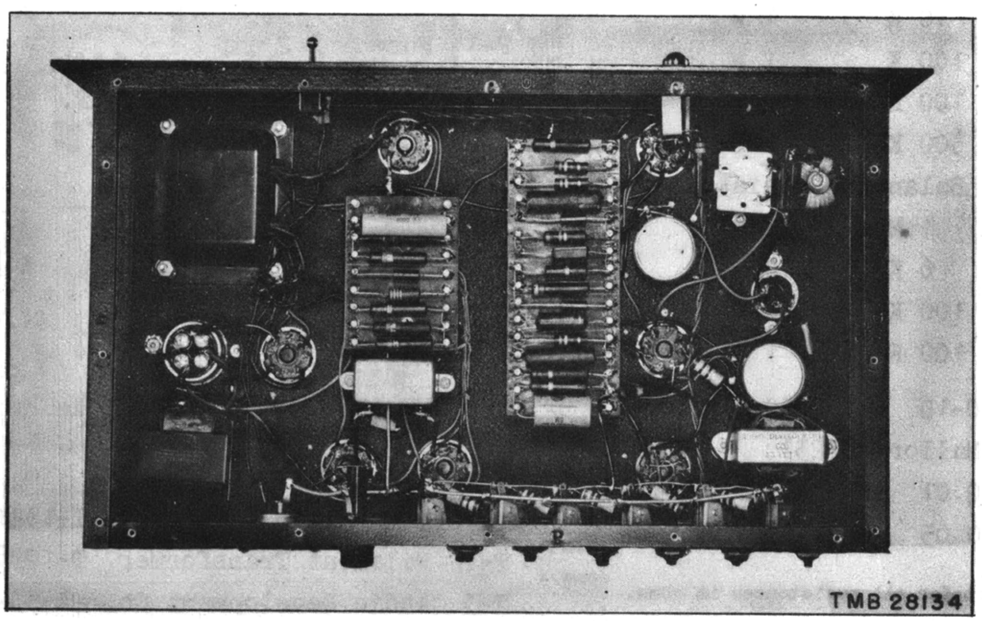

Figure 12 - Bottom View of Oscillator, Type OC-1C

STRAIN INDICATOR

The circuit diagram for the Type-15K160 Strain Indicator is shown in Figure 15. A bottom view of the chassis is shown in Figure 14. The function of the various circuits is described in the following sections.

The Bridge

A simplified drawing of the bridge circuit is shown in Figure 13. The basic bridge circuit is shown in Figure 13a. This is seen to be the conventional Wheatstone bridge circuit with R_{g1} and R_{g2} representing the active and temperature-compensating strain gages. Balancing of the bridge for both resistance and capacitance is accomplished by shunting a resistance or a capacitance or both across the gage resistors as shown in Figure 13b. In this figure, the resistance and capacity balancing components have been included in the diagram. Switch S-5 is arranged so that any of the rough balance resistances may be shunted across either R_{g1} or R_{g2}. The potentiometer, R-27, and resistor, R-84, provide the vernier adjustment. R-84 has been chosen to provide a range approximately 10 per cent greater than the rough resistance steps. A vernier adjustment may therefore be made at any point in the range of the resistance balance. A similar arrangement is provided for reactance balance by Switch S-4 and the potentiometer, R-26, in conjunction with C-1. An unbalance up to 3000 $\mu\mu$f may be covered by this arrangement, with vernier action anywhere in the range.

The calibration circuit is shown in Figure 13c. Two 4-ohm precision resistors, R-12 and R-13, have been put in series with each 120-ohm resistor in the upper arms of the bridge. Calibration is accomplished by shunting the calibration resistor across one of these 4-ohm resistors by means of Switch S-3. Shunting R-12 with the calibration resistor corresponds to a tension strain, whereas shunting R-13 with the calibration resistor corresponds to a compression strain. By ganging the calibration switch with the sensitivity switch, the proper calibration resistor is automatically selected for any setting of the sensitivity switch; i.e., the calibration step gives an indication equivalent to that obtained from a strain equal to the strain shown by the sensitivity-switch setting.

Figure 13d shows the addition of the cable-length compensator, which consists of a resistance shunt across the calibration resistors, R-12 and R-13. The effect of this shunt is to reduce the effective ΔR obtained by shunting R-12 or R-13 with the calibration resistor. The value of these resistors was empirically determined for Belden 8422 cable. Other similar types of cable give essentially identical performance. The complete bridge,

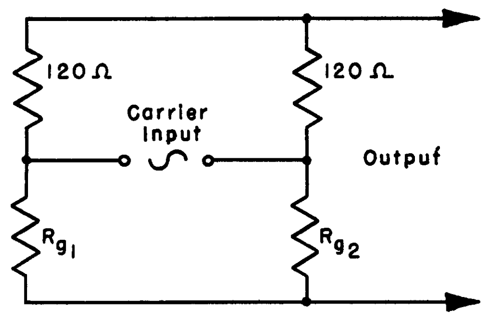

Figure 13a - Basic Bridge Circuit

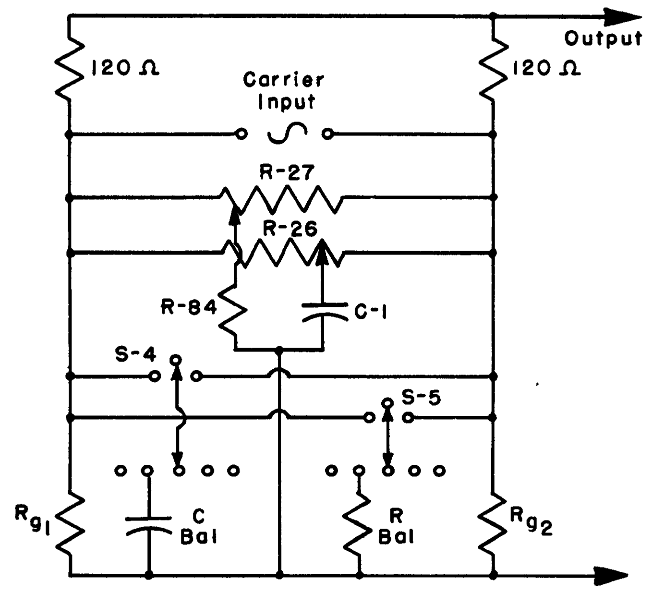

Figure 13b - Basic Bridge
with Balancing Circuits

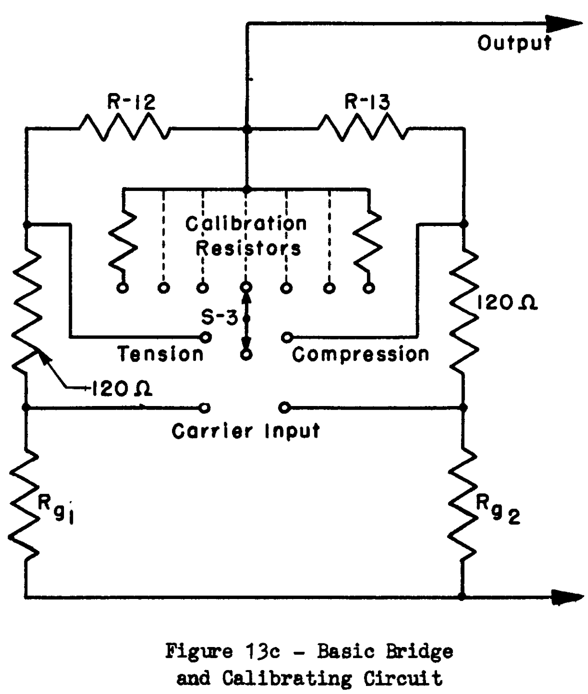

Figure 13c - Basic Bridge
and Calibrating Circuit

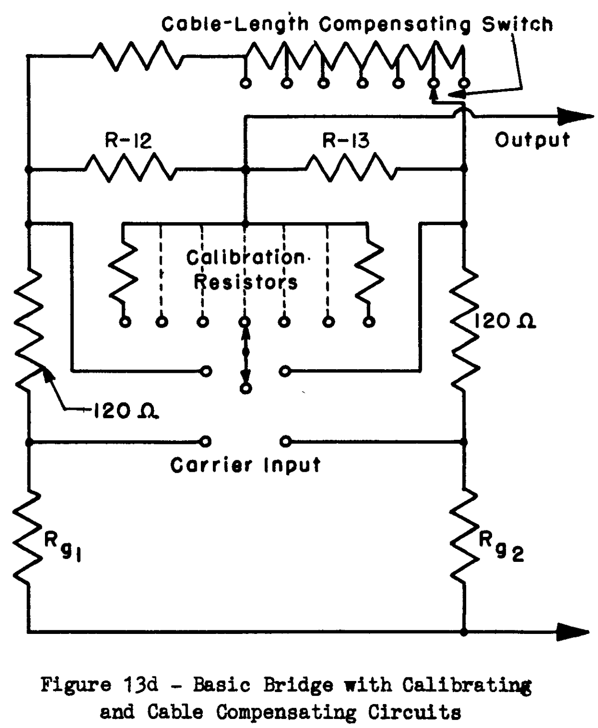

Figure 13d - Basic Bridge with Calibrating
and Cable Compensating Circuits

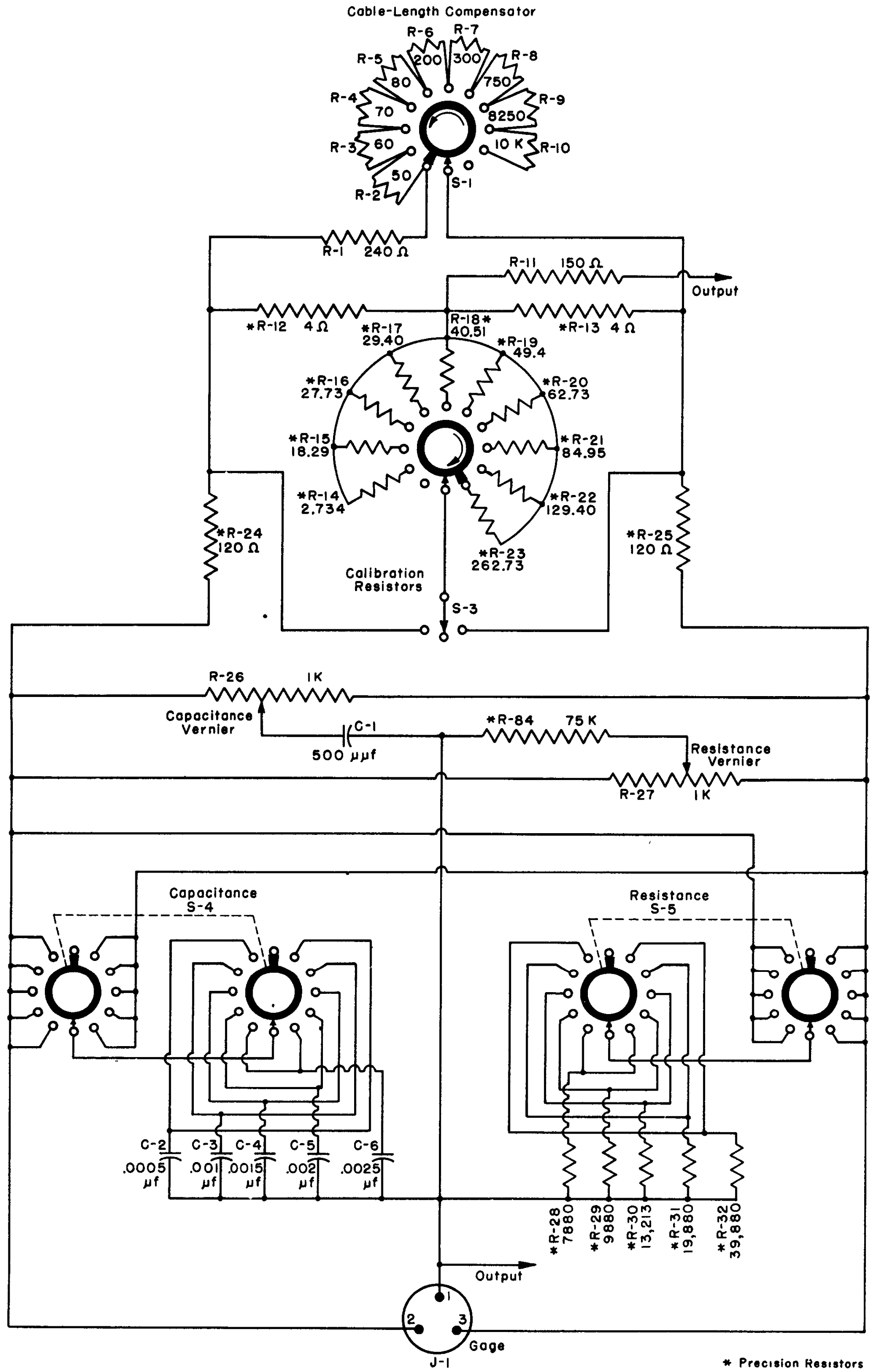

Figure 13e - Schematic Circuit Diagram of Strain Indicator, Type 15K160, Model 250

Figure 13 - The Bridge Circuit

The development of the strain indicator bridge circuit from the basic Wheatstone bridge is shown.

including resistance and capacity balancing, calibrating, and cable-length compensation circuits, is shown in Figure 13e. For normal operation the bridge voltage should be 0.44-v rms. This may be measured directly across the gage-input receptacle, Pins 2 and 3. Or from either side of the bridge to ground there should be 0.22-v rms, as indicated on the Ballantine Model-300 meter.

The Buffer Amplifier

The cable from the oscillator is plugged into J-2 to supply the carrier voltage to the strain indicator; see Figure 15. Tube V-8, a 6SN7 tube with parallel-connected elements, is the amplifier used to drive the bridge. Transformer T-5 is used as an impedance-matching device between the tube and the bridge. Since very little gain is required of this stage, the cathode resistance is un-bypassed. Negligible distortion to the carrier wave is introduced by this stage. Transformer T-5 is a specially built transformer with a pie-wound primary and secondary separated by an electrostatic shield. The bridge is driven from one-half of the 500-ohm winding. A decoupling network is used in all stages of the amplifier to prevent any carrier-frequency currents from getting into the amplifier from the power-supply lead.

The Preamplifier

The preamplifier, consisting of the pickup transformer T-1 and the tube V-1, is a conventional amplifier stage with an overall gain of approximately 1000. When operating in the highest sensitivity range, the output from the bridge may be less than 100 μv. Using the pickup transformer rather than working directly into the grid gives an advantage in signal-to-noise ratio of approximately 25 to 1 at the grid of Tube V-1. The gain of V-1 is approximately 40. The signal levels at the grid of this tube are so small that the complete sensitivity range of bridge outputs are handled by V-1 without danger of overloading. Resistor R-11 in series with the pickup transformer was found necessary to obtain a flat response in the amplifier over the desired frequency range of 13,000 to 17,000 cycles per second.

The Attenuator

The output of the bridge increases as the strain in the gage increases; a suitable attenuator is therefore necessary to prevent overloading the circuits following the preamplifier. The attenuator switch and calibration resistor switch have been ganged and labeled "Sensitivity" on the front panel of the instrument. The attenuator consists of ten resistors in the grid circuit of V-2 arranged so that at the higher sensitivities a greater percentage of the output of V-1 is applied to the grid of V-2. These resistors have been so proportioned that operating the calibration switch gives the same output current on any sensitivity step.

The Voltage Amplifier

The voltage amplifier consists of V-2 and V-3. As V-3 is a dual tube this is a more-or-less conventional three-stage amplifier. Negative feedback is introduced by means of R-55 to the cathode resistor of V-3A; see Figure 15. This resistor is used to set the gain of the amplifier to the proper level as well as to reduce distortion. Since this amplifier operates over a constant range regardless of the sensitivity setting, no variable adjustments are necessary. The output of V-3B is transformer-coupled to the mixing circuit and the grids of the power-amplifier stages.

The Mixing Circuit

The mixing circuit consists of a series-connected pair of matched 1000-ohm resistors, R-57 and R-58, shunting the secondary of T-2. The carrier is injected to the center of these resistors from the isolator tube

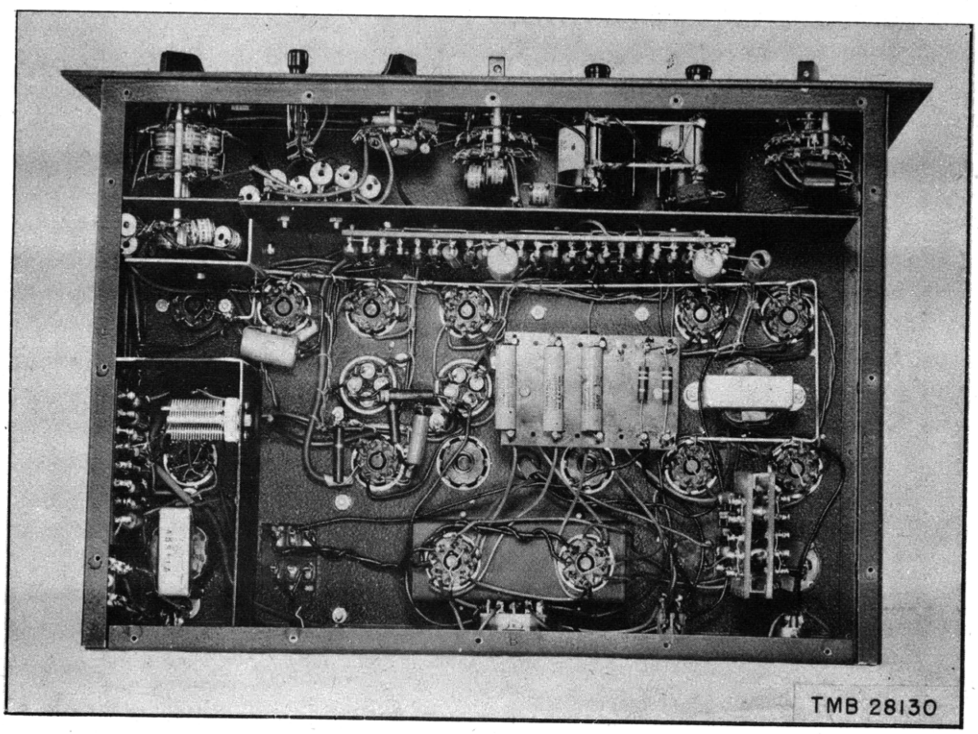

Figure 14 - Bottom View of Strain Indicator, Type 15K160

Parts List for Strain Indicator Type 15K160, Model 250

R-1	240 ohms	1 w 5 per cent Carbon Resistor (R-1 to R-10)
R-2	50 ohms	
R-3	60 ohms	
R-4	70 ohms	
R-5	80 ohms	
R-6	200 ohms	
R-7	300 ohms	
R-8	750 ohms	
R-9	8250 ohms	
R-10	10 K	
R-11	150 ohms	1 w
R-12	4 ohms	1/4 w 1/4 per cent Precision Resistor (R-12 to R-25)
R-13	4 ohms	
R-14	2.734 ohms	
R-15	18.29 ohms	
R-16	27.73 ohms	
R-17	29.40 ohms	
R-18	40.51 ohms	
R-19	49.40 ohms	
R-20	62.73 ohms	
R-21	84.95 ohms	
R-22	129.40 ohms	
R-23	262.73 ohms	
R-24	120 ohms	
R-25	120 ohms	
R-26	1 K	Helical Potentiometer
R-27	1 K	Helical Potentiometer
R-28	7880 ohms	1/4 w 1/4 per cent Precision Resistor (R-28 to R-32)
R-29	9880 ohms	
R-30	13,213 ohms	
R-31	19,880 ohms	
R-32	39,880 ohms	
R-33	10 K	1 w
R-34	47 K	1 w
R-35	1500 ohms	1 w
R-36	12,494 ohms	1/4 w 1/4 per cent Precision Resistor (R-36 to R-45)
R-37	4166.5 ohms	
R-38	2083.2 ohms	
R-39	1243.9 ohms	
R-40	839.3 ohms	
R-41	1041.6 ohms	
R-42	624.9 ohms	
R-43	416.6 ohms	
R-44	1458.2 ohms	
R-45	631.2 ohms	
R-46	10 K	1 w
R-47	47 K	1 w
R-48	1500 ohms	1 w
R-49	47 K	1 w
R-50	5 K	1 w
R-51	47 K	1 w
R-52	1500 ohms	1 w
R-53	470 K	1 w
R-54	5 K	1 w
R-55	30 K	1 w
R-56	1200 K	1 w
R-57, R-58	1 K	1 w Matched
R-59	750 ohms	1 w
R-60	100 ohms	Wirewound Potentiometer
R-61	200 K	1 w
R-62	200 K	1 w
R-63, R-64	60 K	1 w Matched
R-65	55 ohms	Shunt
R-66	10 K	Potentiometer
R-67	5 K	1 w
R-68	500 ohms	1 w
R-69	300 K	1 w
R-70	100 K	1 w
R-71	1 M	1 w
R-72	5 K	1 w
R-73	25 K	1 w
R-74	1 K	1 w
R-75	100 K	1 w
R-76	47 K	1 w
R-77	12 K	1 w
R-78	300 ohms	10 w
R-79	300 ohms	10 w
R-80	150 ohms	10 w
R-81	0.109 ohms	Shunt
R-82, R-83	47 K	1 w Matched
R-84	75 ohms	1/4 w 1/4 per cent Precision

C-1	500 μμf		Mica
C-2	.0005 μf	400 v	Mica
C-3	.001 μf	400 v	Mica
C-4	.00015 μf	400 v	Mica
C-5	.002 μf	400 v	Mica
C-6	.0025 μf	400 v	Mica
C-7	8 μf	150 v	Blue Beaver
C-8	.01 μf	400 v	Paper
C-9	10 μf	400 v	Sprague 47058 (C-9 to C-12)
C-10	10 μf		
C-11	10 μf		
C-12	10 μf		
C-13	.001 μf	400 v	Paper
C-14	8 μf	150 v	Blue Beaver
C-15	.01 μf	400 v	Paper
C-16	10 μf	400 v	Sprague 47058 (C-16 to C-19)
C-17	10 μf		
C-18	10 μf		
C-19	10 μf		
C-20	8 μf	150 v	Blue Beaver
C-21	700 μμf		Mica
C-22	700 μμf		Mica
C-23	700 μμf		Mica
C-24	700 μμf		Mica
C-25	.01 μf	400 v	Paper
C-26	.01 μf	400 v	Paper
C-27	9-139 μμf		Air Trimmer, Hammarlund APC-140
C-28	50 μμf		Mica
C-29	.005 μf	400 v	Paper

J-1	Chassis Receptacle, Male, Cannon X-3-14
J-2	Phone Jack
J-3	Chassis Receptacle, Male, Cannon XK-3-14
J-4	Chassis Receptacle, Male, Jones P-310-RP
M-1	Meter, Weston 506 0-1 Ma. with 55 ohm shunt
M-2	Meter, Weston 506 5-0-5 Ma. with 0.109 ohm shun
L-1	Choke, Audio, UTC Type VI-C15, 2.9 H.
L-2	Choke, Audio, UTC Type VI-C15, 2.9 H.
S-1	Switch, Rotary, Centralab K-121, 1-J Section
S-2	Switch, Rotary, Centralab K-121, 2-J Sections
S-3	Switch, Lever, Centralab 1455
S-4	Switch, Rotary, Centralab K-121, 2-J Sections
S-5	Switch, Rotary, Centralab K-121, 2-J Sections
S-6	Switch, D.P.D.T. Toggle

V-1	6SF5	V-7	6H6
V-2	6SF5	V-8	6SN7
V-3	6SN7	V-9	6SN7
V-4	6V6	V-10	6AS7
V-5	6V6	V-11	6AS7
V-6	6H6		

T-1	Transformer, Kenyon A-20
T-2	Transformer, Audio Development Co. A-5311A
T-3	Transformer, Audio Development Co. A-5311A
T-4	Transformer, Audio Development Co. A-5311A
T-5	Transformer, Audio Development Co. A-5311A
T-6	Filament Transformer, Thordarson T-11F60

The unit for all resistances is ohms.

K corresponds to a multiplying factor of 10^3.

M corresponds to a multiplying factor of 10^6.

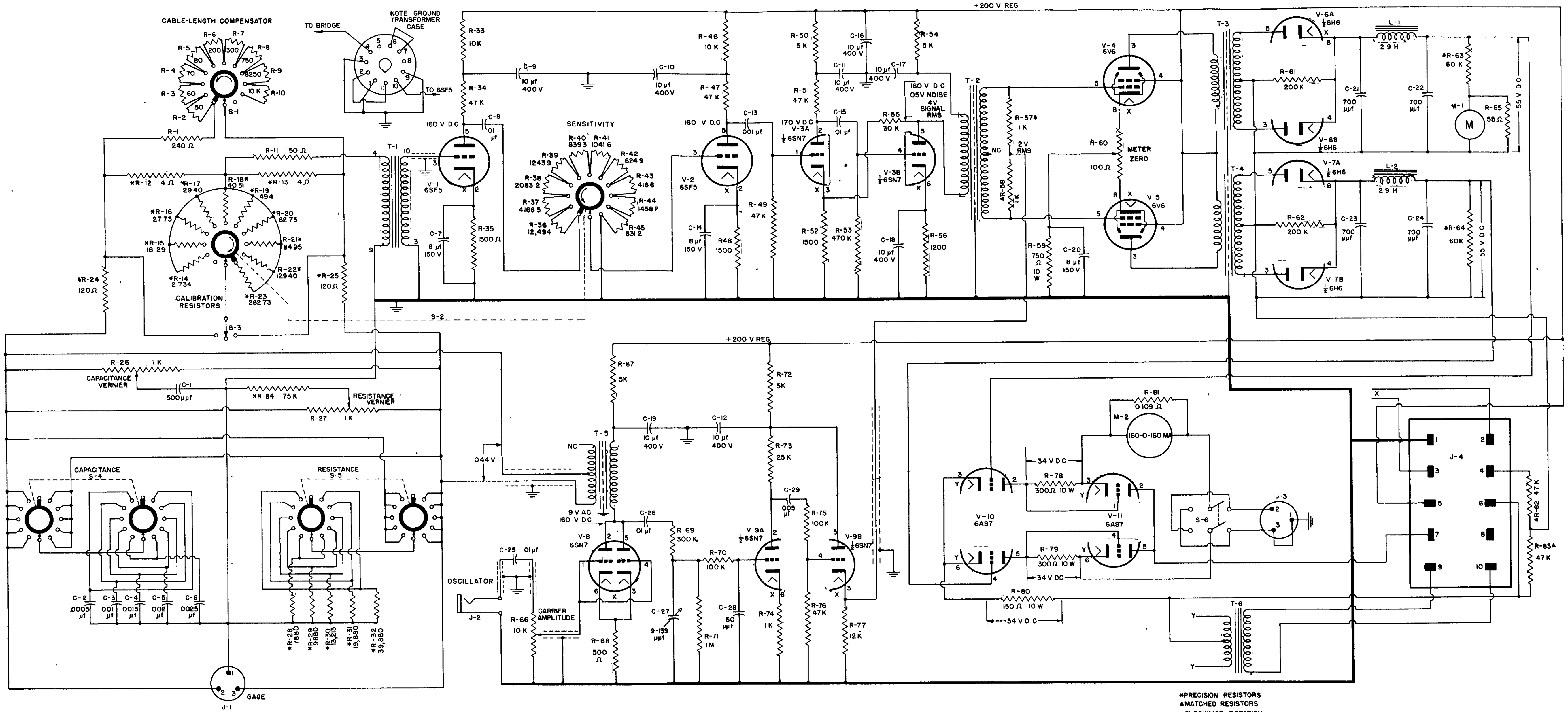

Figure 15 - Schematic Circuit Diagram of Strain Indicator, Type 15K160, Model 250

V-9B. The injected-carrier voltage is normally 1.8 to 2 v rms. Assuming that the phase-shifting network at the input to V-9A is properly adjusted, the voltage of the injected carrier is in phase with the signal to one of the amplifiers, V-4 or V-5, and 180 degrees out of phase with the signal to the other tube. The carrier thus adds to the grid-input voltage of one tube and subtracts from the input of the other tube. If the phase of the bridge output reverses, the phase reversal will be reflected at the grid of the amplifier tubes. If it should become necessary to make repairs on the strain indicator or oscillator, the phasing should be checked before the unit is again placed in operation. Correct phasing may be checked by balancing the bridge on the most sensitive position, 0.25 milli-inches per inch, and noting the effect of the capacity vernier control on the output meter. No deflection on the output meter should be noticed for a half turn of the capacity vernier control. Incorrect phasing may be corrected by adjusting the variable air condenser, C-27. The location of this capacitor may be seen in Figure 14.

The Dual Demodulator

The power amplifiers V-4 and V-5, in conjunction with V-6 and V-7, constitute a type of dual demodulator developed at the Taylor Model Basin. V-4 and V-5 are power amplifiers each operating into a 4-to-1 step-up transformer. With no signal input, equal voltage is applied to each grid from the injected carrier system. The voltages developed across the 200-K load resistors for the full-wave rectifiers V-6 and V-7 are then equal or can be made equal by adjusting R-60, the meter zero control. The wave-form output of these rectifiers is that of the conventional full-wave rectifier; however, the pie-section filter removes the ripple effectively. A d-c output of 55 volts is obtained from each of these filters with only the injected carrier and no signal input. Meter M-1 is included in the terminating circuit of one filter to serve as a carrier-level meter and to assist in the bridge-balancing operation. The d-c output voltages of these filters serve as bias for the output-stage tubes. Center scale indication of meter M-1 with no signal input is an indication that proper bias is being applied to the tubes in the output stage.

The Output Stage

A schematic circuit diagram of the output stage is shown in Figure 16 to illustrate more clearly the bridge arrangement of the circuit. The signal from the dual demodulator is applied to the grids of V-10. The 55 volts developed by the dual demodulator with no signal input is applied

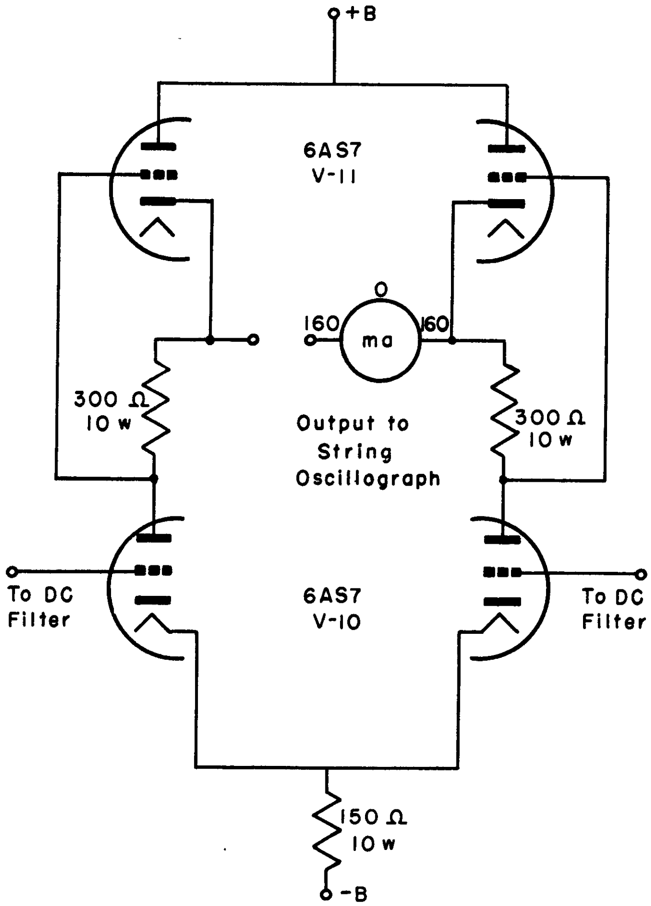

Figure 16 - Circuit Diagram of the Output Stage of the Type-15K160 Strain Indicator

directly to the grids of V-10 and serves as the bias voltage. With no signal input the quiescent current is approximately 100 milliamperes in each branch of the output circuit or a total of 200 milliamperes for the output stage.

The output is taken from the cathodes of V-11. With no signal from the bridge the two cathodes are at the same d-c potential, and no current flows in the output circuit. A signal from the gage circuit results in an unbalanced signal being applied to the grid of the power-amplifier tube in the dual demodulator. The d-c level from one demodulator filter rises while the other filter voltage drops. The result is that the bias on one grid of V-10 increases while the bias on the other grid decreases. The cathodes are no longer at the same potential, and a current flows in the output circuit which is proportional to the degree of unbalance of the bridge. The output impedance of this circuit is approximately 200 ohms. A reversing switch is provided to reverse the galvanometer deflection without changing the cable leads.

POWER SUPPLY

The schematic circuit diagram of the power supply Type 17A is shown in Figure 17. Three separate rectifier-filter arrangements are used. Two floating supplies - one for each strain indicator - are used to provide 280 volts to the output stage and 105 volts regulated for bias. No attempt was made to use a common regulator to power the output circuits in both strain indicators because of the relatively high currents required by these stages.

A regulated supply provides the 200 volts required by the other tubes. Sufficient capacity has been provided in this regulator to supply the current to all the low-voltage circuits in two strain indicators. The regulator on this supply is covered in detail in Reference (8).

For best results this supply should be powered from a 117-volt regulated line. A bottom view of the power-supply chassis is shown in Figure 18. Other specifications on the power supply are listed under Specifications facing page 1.

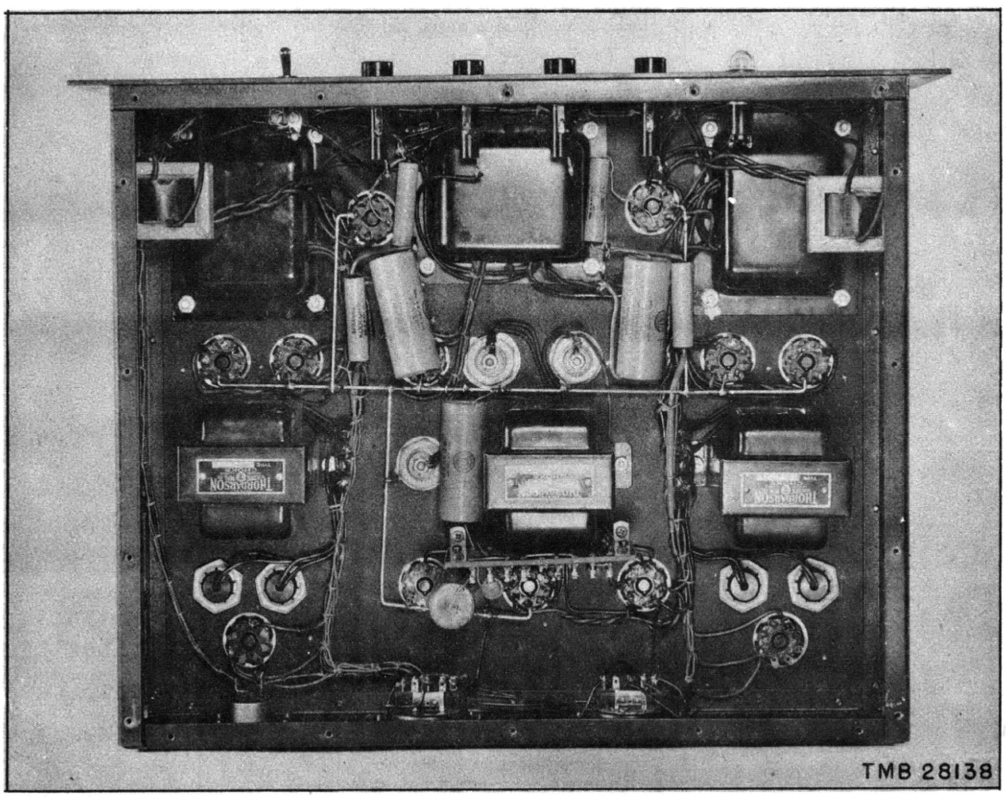

Figure 18 - Bottom View of Power Supply, Type 17A

Parts List for Power Supply Type 17A, Model 3-300

R-1	6 K	10 w	
R-2	6 K	10 w	
R-3	500 K	1 w	
R-4	200 K	1 w	
R-5	Balancing Resistor		
R-6	200 K	1 w	
R-7	6 K	10 w	
R-8	1 M	1 w	
R-9	100 K	1 w	
R-10	100 K	1 w	
R-11	6 K	10 w	
R-12	6 K	10 w	
C-1	8 μf	600 v.	Sprague KR-608
C-2	8 μf	600 v.	Sprague KR-608
C-3	20 μf	450 v.	Sprague KR-608
C-4	4 μf	600 v.	Cornell-Dubilier TLA 6040
C-5	4 μf	600 v.	Cornell-Dubilier TLA 6040
C-6	4 μf	600 v.	Cornell-Dubilier TLA 6040
C-7	0.5 μf	600 v.	Paper
C-8	8 μf	600 v.	Sprague KR-608
C-9	8 μf	600 v.	Sprague KR-608
C-10	20 μf	450 v.	Sprague KR-608
C-11	20 μf	450 v.	Sprague KR-608
L-1	Choke, Thordarson T-67C49		
L-2	Choke, Thordarson T-67C49		
L-3	Choke, Thordarson T-67C49		
L-4	Choke, Thordarson T-67C49		
L-5	Choke, Thordarson T-67C49		
L-6	Choke, Thordarson T-67C49		
F-1	Fuse	3 amp	
F-2	Fuse	3 amp	
F-3	Fuse	3 amp	
F-4	Fuse	3 amp	
J-1	Receptacle, Female, Jones S-310-RP		
J-2	Receptacle, Female, Jones S-310-RP		
J-3	Receptacle, A.C. Power		
S-1	Switch, S.P.S.T. Toggle		
T-1	Power Transformer, Thordarson T-13R16		
T-2	Filament Transformer, Thordarson T-21F08		
T-3	Power Transformer, Thordarson T-13R16		
T-4	Power Transformer, Thordarson T-13R16		
T-5	Filament Transformer, Thordarson T-21F08		

V-1	5Z4	V-7	6SJ7
V-2	5Z4	V-8	VR-105
V-3	6X5	V-9	5Z4
V-4	VR-105	V-10	5Z4
V-5	5Z4	V-11	6X5
V-6	6B4-G	V-12	VR-105

The unit for all resistances is ohms.

K corresponds to a multiplying factor of 10^3.

M corresponds to a multiplying factor of 10^6.

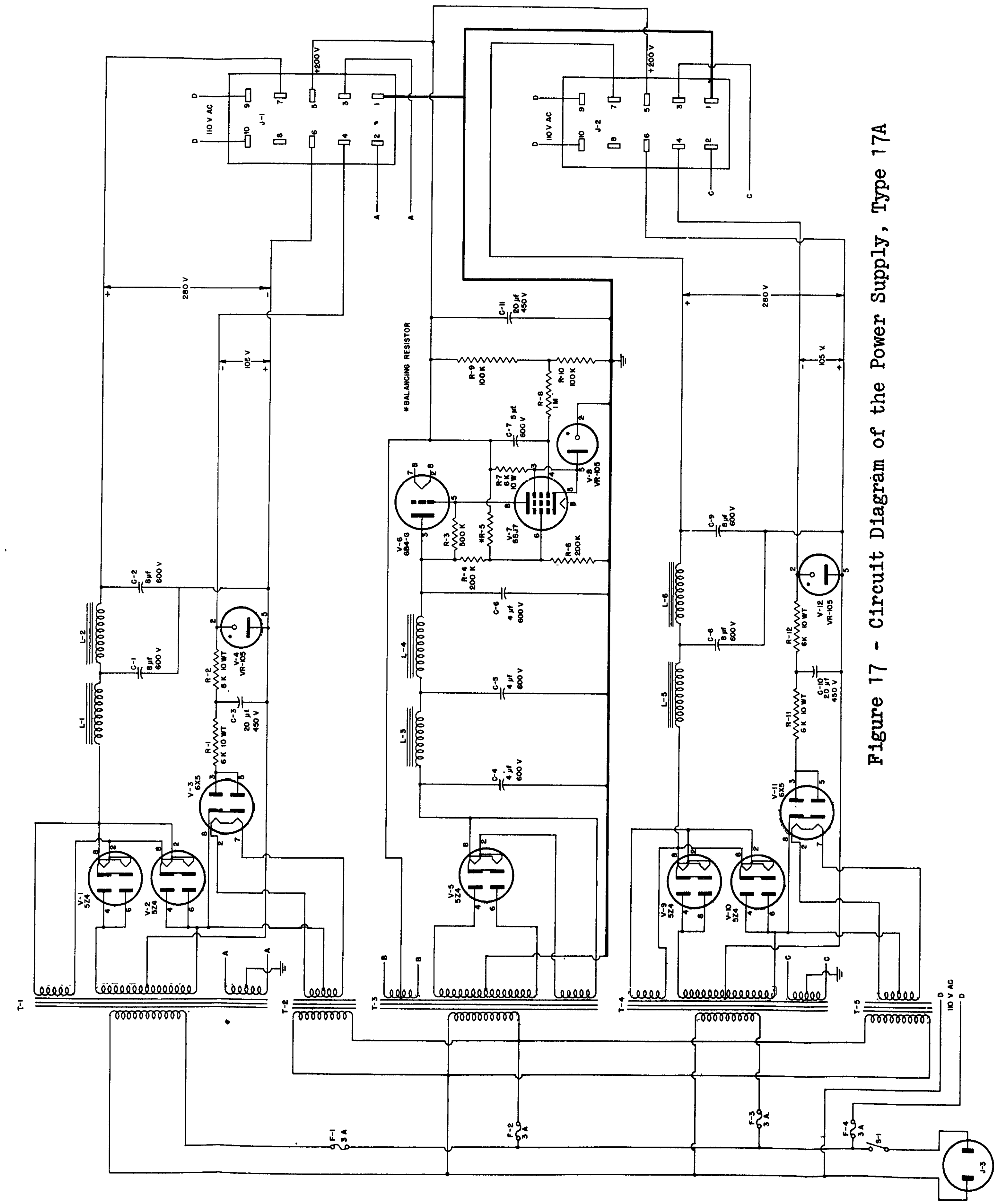

Figure 17 - Circuit Diagram of the Power Supply, Type 17A

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