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NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
Washington 7, D. C.

[redacted]

THE TMB TYPE 5A STRAIN INDICATOR

BY W.S. CAMPBELL

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REPORT 645

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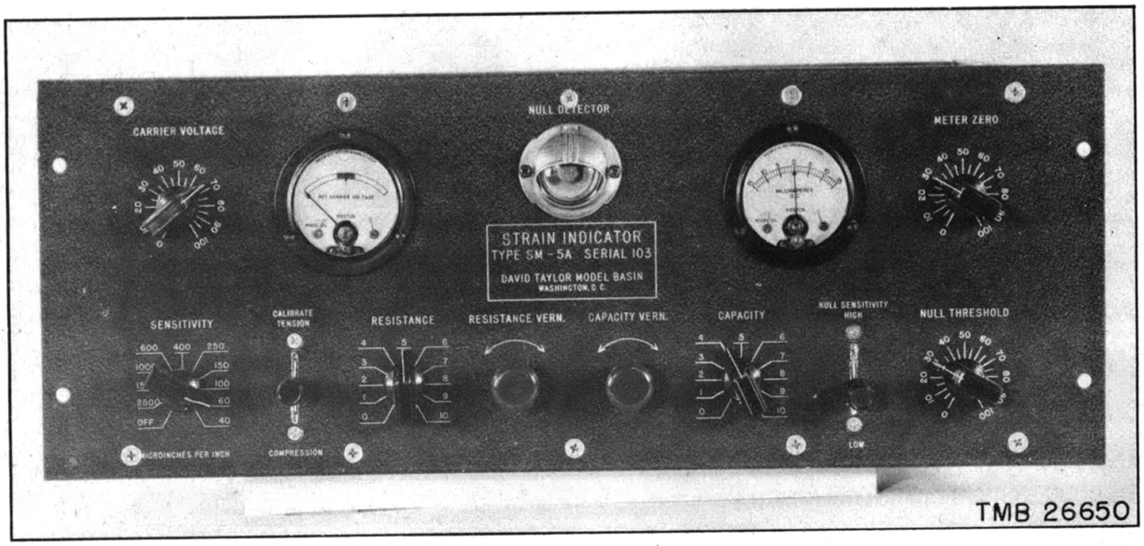
TABLE OF CONTENTS

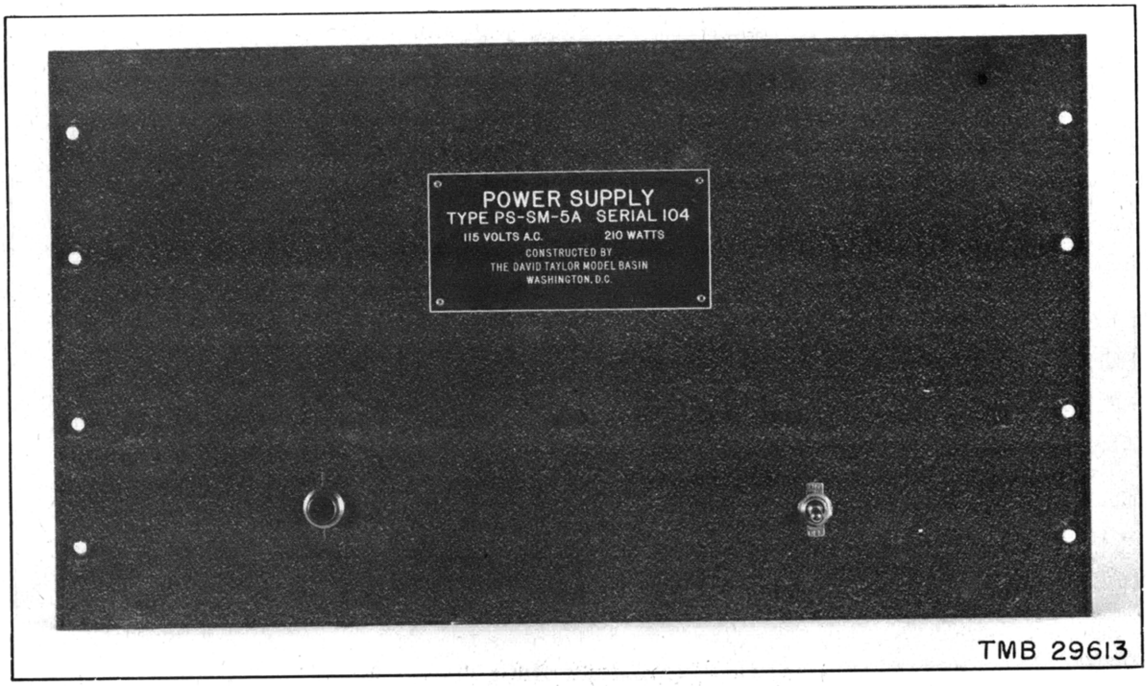
PART 1 - APPLICATION AND OPERATION

PART 2 - CIRCUIT DETAILS AND ADJUSTMENT

FRONTISPIECE



TMB Type 5A Strain Indicator



Power Supply

THE TMB TYPE 5A STRAIN INDICATOR

SPECIFICATIONS

Strain Indicator	
Gages:	
Type	Type A, SR-4
Resistance	120 ohms
Carrier:	
Frequency	5000 cps
Source	External Oscillator
Frequency Response:	
Uniform to 1000 cps, down 5 per cent at	1500 cps
Sensitivity:	
Range (Divided in ten steps as shown in Table 1.)	0 to 2500 μipi
Output impedance (nominal):	1250 ohms
Calibration:	
Method	Series ΔR
Accuracy	Plus or minus 0.75 per cent
Current Output:	
For calibration	Up to 15 ma
Maximum usable current output	30 ma
Physical Specifications (in carrying case)	
Size	8 1/2 by 20 1/2 by 13 in.
Weight	26 lb
Power Supply (accessory unit)	
Source	115-v 60-c line
Power Consumption	
(with one indicator connected)	155 w
(with two indicators connected)	210 w
Fuse Protection	5 amp
Size (in carrying case)	12 by 20 1/2 by 13 in.
Weight (in carrying case)	75 lb
Oscillator (accessory unit)	
Frequency	5000 cps
Power Consumption	55 w
Size (in carrying case)	8 1/2 by 20 1/2 by 13 in.
Weight (in carrying case)	30 lb

THE TMB TYPE 5A STRAIN INDICATOR

by

W.S. Campbell

ABSTRACT

The characteristics and general performance of a carrier-type strain indicator developed by the David Taylor Model Basin are discussed. Instructions for installing and operating the instrument are given, and circuit-adjustment procedure is outlined as an aid in servicing. Schematic diagrams and complete lists of component parts for the device, for its power supply, and for an accessory oscillator are included.

This instrument, which is known as the TMB Type 5A Strain Indicator, uses two SR-4 wire-resistance strain gages and furnishes the electrical power suitable for driving a "string-oscillograph" galvanometer. The circuit employed is based on the injected-carrier principle, which is described in detail in TMB Report 565, dated November 1946.

INTRODUCTION

The TMB Type 5A Strain Indicator, a carrier-type instrument, is shown in the frontispiece. It is designed for the measurement of strains in which it is necessary to achieve uniform response down to and including zero frequency. The many advantages of the carrier type of measuring instrument have been generally recognized and accepted by research workers in the field of physical measurements.

The Type 5A Strain Indicator is a modification of the TMB Type 1A Strain Indicator (1)*(2) which was developed in 1945 by the Electronics Section of the David Taylor Model Basin to meet a specific need for a device capable of indicating accurately, for recording purposes, the magnitude of strains which vary in the frequency range from zero to about 200 cps. The Type 1A indicator, which combines high stability, a direct calibration method, linear response, and simplicity of operation, has been used with great success in a wide variety of strain measurements, both in the laboratory and in the field.

The ever-expanding field of physical measurements continually presents new problems in instrumentation. It was decided that an instrument of this type would have even greater utility if the upper limit of uniform frequency response were extended above 1000 cps without sacrifice of any of the desirable features of performance inherent in the Type 1A Strain Indicator.

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* Numbers in parentheses indicate references on page 31.

The Type 5A Strain Indicator described herein was developed with this objective. The carrier frequency has been raised to 5 kc and a different output stage has been designed to furnish the higher output currents required to operate medium-frequency "string-oscillograph"* galvanometers.

A special model of the Type 5A Strain Indicator was developed for the measurement of very high strains, such as occur in plastic specimens. This instrument, which is known as the TMB Type 5C Strain Indicator, has a range that extends from zero to 60,000 microinches per inch (μipi). The circuit of the Type 5C Indicator is the same as that of the Type 5A instrument except for the electrical values of the component parts in the bridge and calibration circuits. Both instruments are designed for use with 120-ohm strain gages.

For convenience of reference, this report is divided in two major parts. Part 1 contains the essential information required to install, calibrate, and operate the instrument. Part 2 explains the functions of the various electronic circuits and outlines the circuit-adjustment procedure.

PART 1 - APPLICATION AND OPERATION

DESCRIPTION OF THE TMB TYPE 5A STRAIN INDICATOR

The TMB Type 5A Strain Indicator, the specifications for which are given on the page facing the frontispiece, uses two 120-ohm Type A SR-4 strain gages connected as adjacent arms in an a-c bridge circuit; the instrument converts the small changes of electrical resistance due to strain in one or both of these gages into the relatively large current changes required to deflect the string galvanometers in the recording device.

The function of the various circuits in the indicator can be visualized by reference to the block diagram shown in Figure 1.

PERFORMANCE CHARACTERISTICS

The range of the TMB Type 5A Strain Indicator extends from 0 to 2500 μipi or higher. This range is conveniently divided into ten steps. The full-scale range and sensitivity scale of each step is as shown in Table 1.

The accuracy of calibration is within plus or minus 0.75 per cent when the gage factor is equal to 2.00 and the gage resistance is 120 ohms.

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* Although not technically correct, the term "string oscillograph" has come into common usage in referring to the conventional multichannel recording oscillograph, which employs either bifilar or D'Arsonval-type galvanometers, the galvanometers themselves then being referred to as string galvanometers. This practice has been followed in this report.

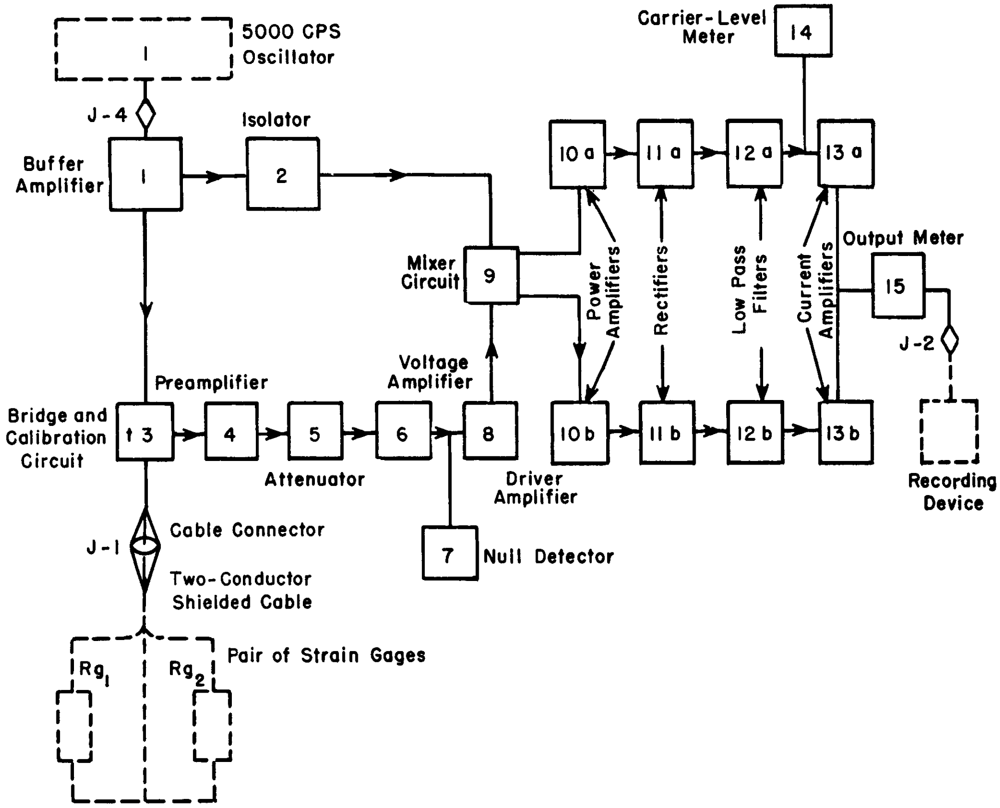

Figure 1 - Block Diagram of the TMB Type 5A Strain Indicator

Dotted lines indicate apparatus external to the strain indicator.

The bridge circuit is excited by a 5000-cps carrier voltage, which is furnished by an external oscillator and is fed to the bridge through the buffer amplifier, 1. Provision is made for balancing the bridge, 3, for both resistance and reactance.

When the bridge is balanced, the voltage input to the preamplifier, 4, is zero. Another voltage of constant amplitude and in phase with the bridge-driving voltage is injected by the isolator, 2, into the mixer circuit, 9, and impressed on the grids of the power amplifiers, 10a and 10b. The output from the mixer stage is divided into two separate channels, a and b. The amplitude of the injected carrier voltage in each of these two channels is equal and in phase when the bridge is in balance. The d-c component of this voltage, which is obtained from the full-wave rectifiers, 11a and 11b, and the low-pass filters, 12a and 12b, controls the grid bias voltage of the current amplifiers, 13a and 13b. When these bias voltages are equal, no current flows in the output circuit to the recorder.

Deviations from resistance balance, which occur when the material on which the gage is mounted is subjected to strain, produce a voltage proportional to the change in gage resistance, ΔR. This voltage, which has an angular phase displacement of either 0 or 180 deg with respect to the bridge-driving voltage, depending on the direction in which the bridge is unbalanced, is amplified through units 4, 6, and 8 and impressed differentially through the mixer circuit, on the grids of the power amplifiers, 10a and 10b. The action of the circuits is such that the bias voltage on one of the current amplifiers is decreased and that on the other is increased. One current amplifier now passes more current and the other less; the difference current, which is proportional to the strain being measured, flows through the recording device.

The carrier-level meter, 14, serves to indicate the amplitude of the injected carrier voltage. The output meter, 15, is connected in series with the recorder and indicates the magnitude of the d-c output current.

TABLE 1

Range and Sensitivity Scale of the Strain Indicator

Full-Scale Indications	
Strain microinches per inch	Approximate Stress in Steel pounds per square inch
40	1,200
60	1,800
100	3,000
150	4,500
250	7,500
400	12,000
600	18,000
1000	
1500	
2500	

This strain indicator is designed primarily for use with multichannel electromagnetic recording oscillographs which are equipped with either bifilar-suspension or D'Arsonval-type galvanometers. Linear output current up to 15 ma in either polarity is available for driving these galvanometers. Higher currents may be consumed at a slight sacrifice in linearity, i.e., about 2 per cent at 30 ma.

The output impedance of the indicator is about 1250 ohms resistive and remains practically constant within the operating range.

The frequency-response curve is essentially flat from 0 to 1200 cps and is down only 5 per cent at 1500 cps; see Figure 2.

ACCESSORY EQUIPMENT

The separate power-supply unit designed for use with this strain indicator is capable of furnishing the power required by two indicators operating simultaneously, without any intercoupling effects.

For reasons explained in Part 2 of this manual, a special 5000-cps oscillator was developed for use with the Type 5A Strain Indicator. This oscillator supplies the carrier-voltage requirements of as many as six indicators.

Both of these units - the power supply and the oscillator - operate directly from the standard 115-v 60-cycle power line. The power requirements are as listed in SPECIFICATIONS, which faces the frontispiece.

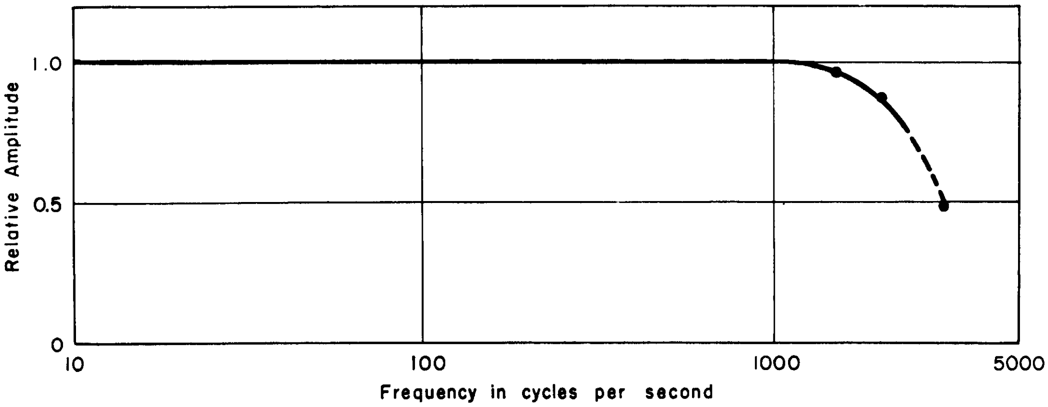

Figure 2 - Output Current as a Function of Frequency

If an alternating strain of constant amplitude is measured, the output current, as a function of the frequency of alternation, is as shown in this figure. Below 10 cps, the response is uniform down to and including zero frequency. The response shown is valid for any load that is purely resistive.

OPERATING PROCEDURE

In order better to illustrate the reason for certain details which must be observed for proper operation of the instrument, particular circuits or parts of circuits are touched upon lightly in this section. Detailed discussion of the functions of these circuits is confined to Part 2 of this manual.

INPUT AND GAGE CIRCUITS

The TMB Type 5A Strain Indicator input circuit is fundamentally that of a balanced bridge consisting of four arms; see Figure 3. Two arms of the bridge are formed by precision wire-wound resistors, R-2 and R-16, which are located within the instrument. The other two arms, R_{g_1}, and R_{g_2}, are 120-ohm Type A SR-4 strain gages, which are connected to the instrument by a two-conductor shielded cable. The shield of this cable serves a twofold purpose: It acts as the common return for the two gages and it effectively shields the two signal wires from external electrical fields through which the gage line may have to pass.

While the particular measurement or the conditions under which it must be made often dictate the arrangement of the apparatus, the gage circuits shown in Figures 4 and 5 or modifications thereof should be adhered to as closely as practicable.

Although the SR-4 gage possesses many desirable properties it does not actually measure strain, in the strict sense of the word, but measures changes in dimensions, due to strain, of the material to which it is attached.

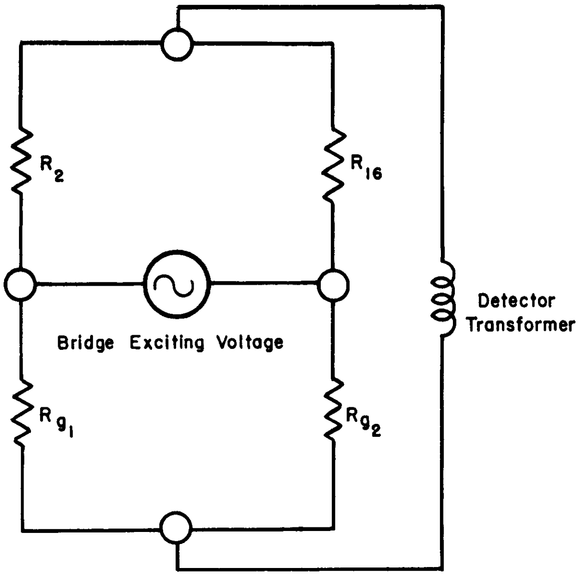

Figure 3 - Schematic Diagram of the Fundamental Bridge Circuit

Consequently, it also shows a change of electrical resistance when the material expands or contracts for any other reason. Figure 4 illustrates an arrangement of the gage circuit that minimizes indications due to temperature variations. Since the active gage and the compensating gage are adjacent arms of the bridge, no unbalance is detected if the resistance in these arms simultaneously increases or decreases by the same amount.

The wires of the shielded gage cable should be soldered to the gage leads as shown in Figure 4. The unshielded portion should be as short as possible to reduce extraneous noise-voltage pickup. In order to calibrate

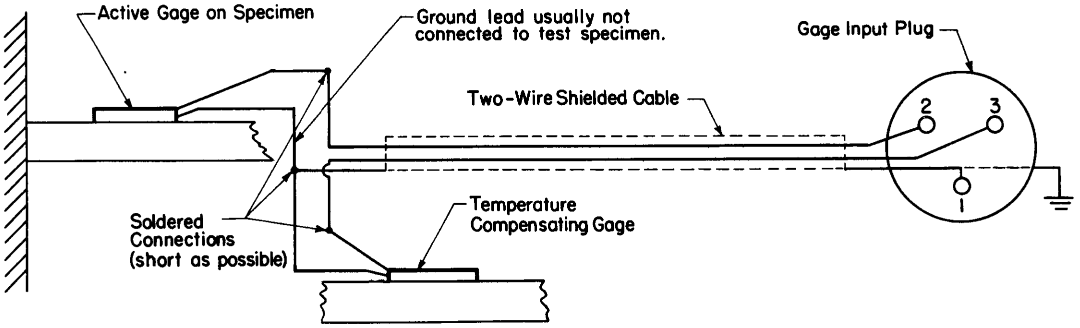

Figure 4 - A Gage Circuit Arrangement Which Provides Temperature Compensation

One gage, usually called the active gage, is mounted on the specimen; and the other, called the compensating gage, is attached to a piece of similar material, so placed as to be subject to the same temperature variations as the specimen, but not to strain.

for tension and compression in the correct polarity, the lead from the active gage must be connected to the wire in the cable that goes to Pin 2 on the input plug, and the lead from the compensating gage must go to the wire connected to Pin 3.

A high degree of accuracy in a strain measurement precludes the tolerance of spurious resistance changes in the gage circuits. **THEREFORE ALL CONNECTIONS IN THE GAGE CIRCUIT MUST BE SOLDERED AND THE PLUG ON THE GAGE INPUT JACK MUST BE TIGHTENED BY THE METAL RING ON THE PLUG. THE IMPORTANCE OF TIGHT CONNECTIONS CANNOT BE OVER-EMPHASIZED.**

Another gage setup is shown in Figure 5. This placement of gages, which also compensates for temperature changes, should be used to measure strain due to bending when both sides of the specimen are accessible. However, the calibration amplitude as shown by the indicator is lettered on the front panel for one active gage, and it must be divided by two when this two-gage arrangement is employed.

When several strain indicators are used, and more than one master oscillator is required, a phenomenon known as "beating" may occur if the gage circuits are in close proximity; it manifests itself as a sinusoidal variation in output current at the difference-frequency of the oscillators involved. Should this situation arise, the best procedure is to use the same external oscillator to drive all the indicators so affected. If an oscillator other than the one designed for this purpose is employed, **IT MUST BE ADJUSTED TO 5000 CPS AND THE LEADS THEREFROM MUST BE PLUGGED INTO THE PHONE JACKS ON THE REAR PANELS OF EACH UNIT.** The oscillator* used must be able to deliver the necessary voltage, about 3 v, with good wave form.

It is advisable to employ only one oscillator whenever the gages of different strain indicators are mounted very close to each other, as the

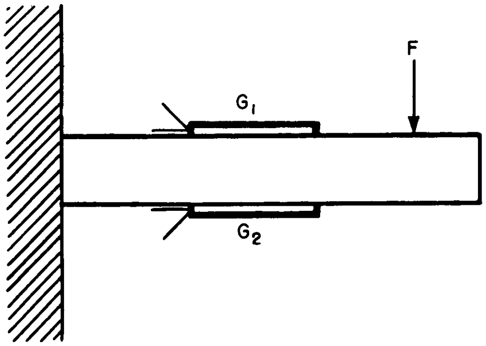

Figure 5 - Gages Mounted on Opposite Sides of the Specimen to Measure Strain Due to Bending

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* The Hewlett-Packard Model 205-A is suitable for this purpose.

variations due to intercoupling are not always discernible on the output meter, because of its inertia.

Gage cables up to 100 ft in length may be used, if required, without modification of the results obtainable. For longer cables, the error amounts to about 1 per cent per 100 ft.*

SETTING UP THE INDICATOR

Assuming that the gage circuit is complete, the next step to be considered is that of connecting the indicator and placing it in operation. For simplicity, this procedure is given here in outline form:

1. The power supply, which, as previously mentioned, is capable of furnishing the power to operate two indicators, is plugged into any standard single-phase 115-v 60-cycle a-c outlet. Wherever possible the power supply should be so placed as to allow free ventilation at the rear of the chassis, especially around the rectifier and voltage-regulator tubes. The connecting cords from the power supply to each indicator should not be more than 5 ft long. Greater lengths cause excessive drop in filament voltage unless very heavy wire is used. If for any reason the fuse burns out, it should not be replaced until the trouble has been found and corrected. **DO NOT USE A HEAVIER FUSE THAN THE RECOMMENDED 5-AMP RATING.**

2. The indicator is connected to the power supply by the power cord furnished. This cord may be plugged into either of the two 6-pin female Jones receptacles on the back of the power supply. **THE INDICATOR SHOULD NOT BE PLACED ATOP OR DIRECTLY BENEATH THE POWER SUPPLY.** A small separation avoids electromagnetic pickup from the power transformer.

3. Check the gage line with an ohmmeter from Pin 2 to Pin 1 on the plug and from Pin 3 to Pin 1. Each of these two resistances should be about 120 ohms. The resistance from Pin 2 to Pin 3 should be about 240 ohms.

4. **Plug the gage line into the GAGE INPUT jack, which is the 3-pin *locking-type* Cannon receptacle on the rear panel. Tighten the metal ring on the plug to insure a good connection.**

5. Plug the recording device into the RECORDER jack, which is the 3-pin *nonlocking* Cannon receptacle. Pin 1 on this plug is chassis-ground and Pin 2 is the signal lead.

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* Recent tests with similar equipment have shown that when gage cables of the order of 250 ft or more in length are used, a good null balance of the bridge may not be obtained on the most sensitive steps of the attenuator unless cable lead transposition is employed. Long gage cables should be cut in an even number of equal-length segments and the two leads transposed at each splice. The shield of each segment should, of course, be connected at each splice. For best results, the length of each segment should not exceed 150 ft.

6. Set the various front-panel controls on the indicator to the following positions:

SENSITIVITY	OFF
RESISTANCE	5
CAPACITY	5
NULL THRESHOLD	50
METER ZERO	50
CARRIER VOLTAGE	75

The NULL-SENSITIVITY control should be set on the low or medium position.

7. Turn on the power with the switch on the power supply, and allow about 10 min for the instrument to reach operating temperature.

8. Adjust the CARRIER VOLTAGE as read on the meter, at the left side of the panel, to the arrow pointer at midscale.

9. Set the output meter on the right side of the panel to zero, i.e., center scale, by the METER-ZERO knob. **THIS CONTROL WILL HAVE NO EFFECT UNLESS THE RECORDER, OR A DUMMY LOAD, IS IN THE OUTPUT CIRCUIT.**

BALANCING THE BRIDGE

The procedure followed in balancing the bridge is similar to that used to balance any other a-c bridge. Owing to several innovations peculiar to this instrument in particular, such as the special null detector, a detailed outline is here given as a guide.

To avoid unnecessary repetition, it is assumed that the indicator is set up as outlined in the preceding section and that the controls are set as directed therein.

1. Set the CARRIER VOLTAGE to about one-half of full scale on the meter.

2. With the SENSITIVITY control OFF, rotation of the NULL-THRESHOLD control counterclockwise should cause the shadow angle of the null detector, i.e., the eye, to open; rotation in the clockwise direction should cause it to close. Set this control so that the eye is nearly closed but not overlapping.

3. Advance the SENSITIVITY control to the first step that causes the eye to open; adjust the RESISTANCE control and its vernier until the eye again closes. Open the eye slightly by retarding the NULL-THRESHOLD control and repeat the process, this time closing the eye with the CAPACITY control and its vernier. By this method of successive approximations, i.e., closing the eye with the bridge-balance controls and retarding the NULL-THRESHOLD as

necessary, advance the SENSITIVITY control until balance is obtained on the 40-μipi position.

Balance is indicated when, by adjustment of the bridge-resistance and capacity controls, the eye cannot be completely closed. When balance is attained, the output meter should be indicating zero and should not deflect plus or minus as the SENSITIVITY control is rotated from OFF to the 40-μipi position.

THE OUTPUT METER SHOULD NEVER BE USED AS A NULL DETECTOR.

4. To check on the proper operation of the instrument, depress the calibration switch to COMPRESSION. The output meter should deflect to the left of zero approximately 12 ma; moving the switch to TENSION should cause an equal deflection to the right of zero. The magnitude of this calibration current can be increased or decreased by adjustment of the carrier-voltage level.

Balancing the bridge is not as difficult or tedious as the foregoing directions may imply. Actually after some familiarity with the instrument has been acquired, the bridge can be balanced in less than a minute. The outline just given shows the indications to be expected when the instrument is operating properly. The functions and locations of the various controls in the circuit are covered in Part 2 of this manual.

CALIBRATION, AND THE INTERPRETATION OF RECORDS

After the indicator has been set up, with the gage and recorder circuits complete and the bridge balanced for resistance and reactance, it is ready for calibration and use.

The output circuit is designed to drive a string-oscillograph galvanometer which has a deflection sensitivity of about 12 ma per in. and a resistance of as much as 20 ohms. Other types of recorders or indicating meters may be used, provided their required driving power and input resistances are within these ranges. The output meter is in series with the recorder and is intended to be used for an approximate indication of the magnitude of calibration current when the switch is thrown to the TENSION or COMPRESSION positions. **IT IS NOT TO BE USED FOR ACCURATE MEASUREMENTS OF STRAIN.** The zero reading, however, may be used for reference purposes. Calibration may be performed as follows:

1. Set the SENSITIVITY control on the step that most nearly corresponds to the maximum magnitude of the expected strain.

2. Check the bridge balance and the output-meter zero.

3. Check the recording circuit by moving the calibration switch from TENSION to COMPRESSION and by observing the movement of the light spot on the viewing screen of the string oscillograph.

When more than one strain indicator is used with a multichannel recording oscillograph, it is common practice to make all tension calibrations in the same direction on the film or paper. This can be conveniently accomplished by use of the REVERSE OUTPUT switch at the rear of the chassis deck.

4. Make certain that the string-oscillograph controls are set in RECORD position and that adjustment is set to obtain the desired paper speed.

5. Start the oscillograph motor; move the calibration switch on the strain indicator to TENSION and COMPRESSION two or three times. The strain record may now be taken. If the specimen is likely to be strained beyond the limits of elasticity, the calibration run is always taken prior to the record. Under other conditions it may be taken either immediately before or after the recording of strain, or preferably both.

Manipulation of the calibration switch first to TENSION and then to COMPRESSION produces two steps on the record trace, as shown in Figure 6. Assume that the sensitivity control has been set at the 100-μipi position. The height of these steps, as measured from the zero line, then represents bridge unbalance equivalent to that which would exist if one gage were subjected to a strain of 100 μipi. This is true if the gage resistance is 120 ohms and the gage factor is 2.00.

If the gage factor is other than 2.00, a correction multiplier can be applied to the record indication to regain exactness in test results. The height of the calibration step can be assigned a new value, obtained by multiplying the sensitivity-control setting by the fraction $\frac{2}{\text{Actual gage factor}}$. For example, in the case shown in Figure 6, if the gage factor had been 2.02, the value assigned to the height of the calibration step would be $\frac{2}{2.02} \times 100$, or 99.01 μipi.

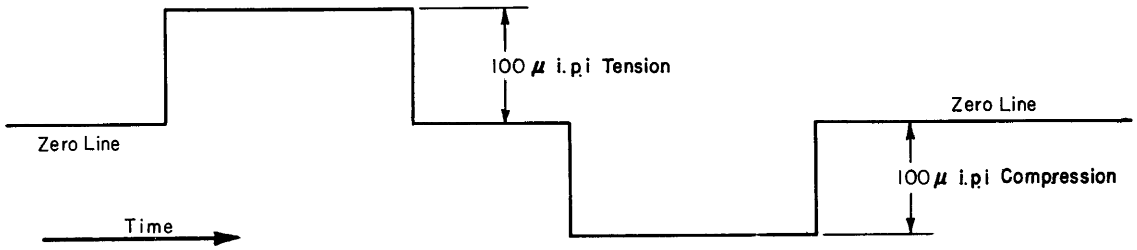

Figure 6 - Sample Calibration Record of the Type 5A Strain Indicator as It Appears on String Oscillograph Paper or Film

PART 2 - CIRCUIT DETAILS AND ADJUSTMENT

CIRCUIT DETAILS

In order to facilitate servicing and maintenance of the TMB Type 5A Strain Indicator, a thorough understanding of the functions of the various controls and of each part of the circuit is not only desirable but necessary. The object of this writing is not to justify the particular circuit and method of calibration used but rather to furnish the serviceman or operator with a working knowledge of this strain-measuring instrument.

For the purpose of discussion, the circuit can be divided into four major parts.

1. The bridge.
2. The calibration circuit.
3. The amplifier and null detector.
4. The mixer and output stage.

THE BRIDGE

Although the bridge consists of only four arms, it is complicated by the incorporation of resistance and reactance balance controls and a

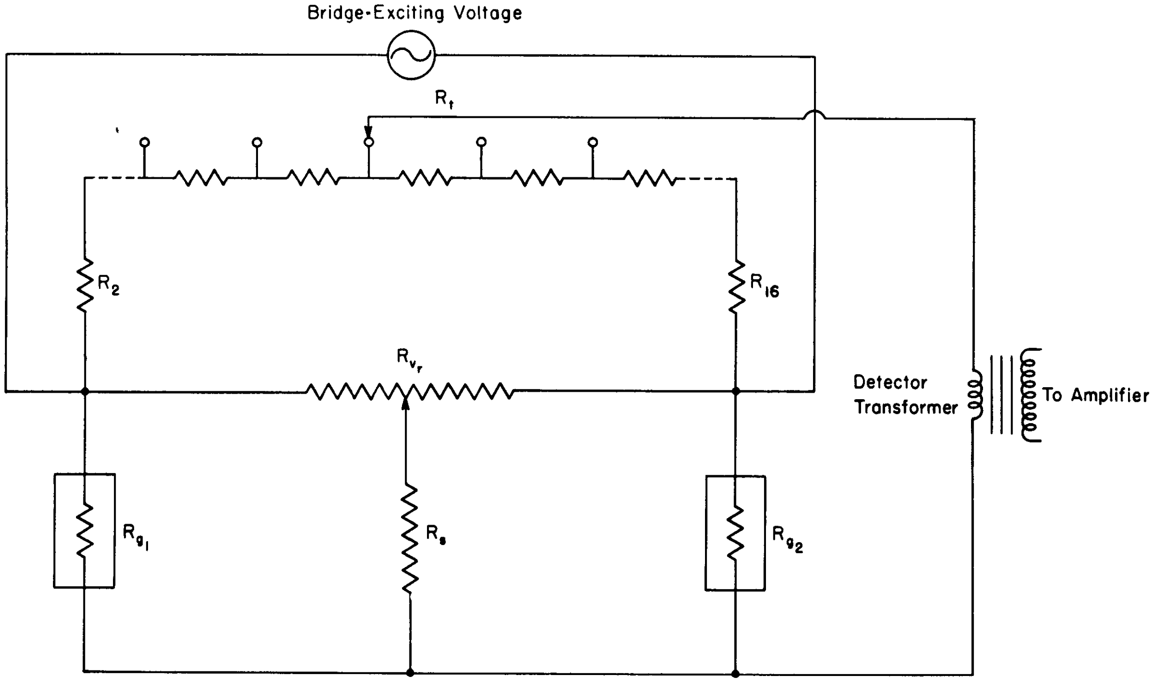

Figure 7 - Wheatstone Bridge with Resistance Balance

This simplified bridge circuit can be balanced for resistance by adjusting the rough control R_t and the vernier potentiometer R_{v_r}. The effectiveness of moving the vernier control from one extreme position to the other must of course be equal to or exceed the effectiveness of moving the rough control one step. A 10 per cent overlap is provided in this instrument.

series-type calibration circuit. The necessity for balancing the bridge will be apparent when the calibration method and the output stage are discussed.

The bridge is balanced for resistance in the manner shown in Figure 7. The lower arms of the bridge, indicated as R_{g_1} and R_{g_2}, are 120-ohm Type A SR-4 wire-resistance strain gages. The upper arms are precision resistors of 120 ohms each. The RESISTANCE control R_t consists of ten 0.585-ohm wire-wound precision resistors, mounted on an eleven-position switch. The potentiometer R_{v_r} is the RESISTANCE-VERNIER control, which is a 1000-ohm Helipot.

The range of these controls is adequate to obtain balance under all normal conditions of operation, since the resistors in the bridge are within

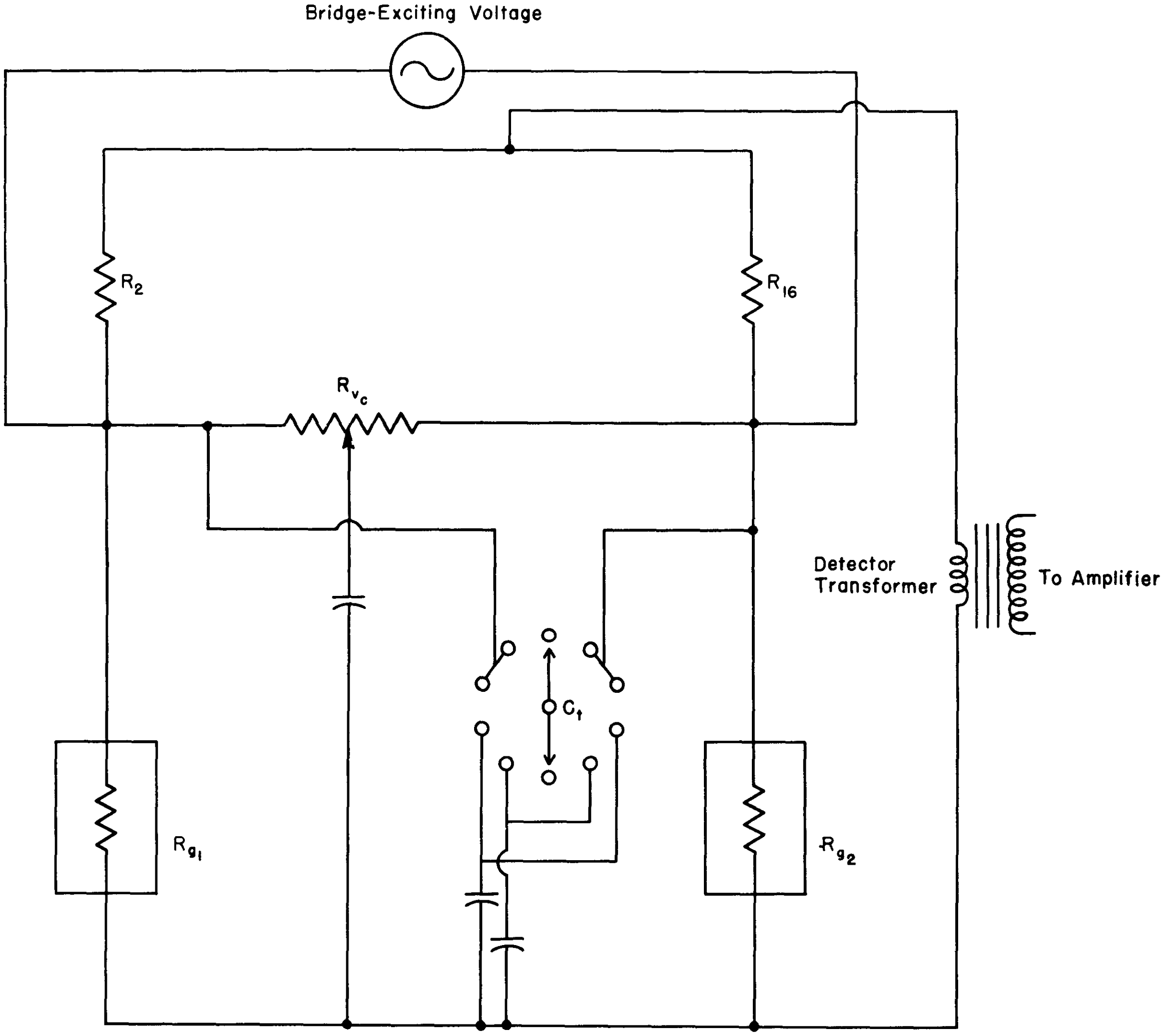

Figure 8 - Wheatstone Bridge with Reactance Balance

Assuming that resistance balance has been established, a capacitance or reactance balance can be accomplished by adjustment of the rough control C_t and the vernier control R_{v_c}. The effectiveness of moving the vernier control from one extreme position to the other overlaps the effectiveness of one step of the rough control by about 10 per cent.

a tolerance of 0.25 per cent and the 120-ohm gages are held by the manufacturer to within plus or minus 1 per cent.

The gages, R_{g_1} and R_{g_2}, are located at the end of the shielded gage cable. The two conductors of most cables do not have equal capacity to the shield. Consequently, in order to accommodate different lengths of gage cable, means must be provided to balance out this difference in capacity. The method of obtaining reactance balance is shown diagrammatically in Figure 8. The CAPACITY control, C_t, permits a rough degree of balance by switching one of five mica condensers to either side of the bridge. The remaining unbalance can be reduced to a very low value by the CAPACITY-VERNIER control, R_{v_c}.

CALIBRATION CIRCUIT

The design of the calibration circuit is based on the fundamental formula which applies to wire-resistance gages.

$$\Delta R = k \epsilon R \qquad [1]$$

where R is the electrical resistance of the gage in ohms,

ΔR is the change in R due to strain,

ϵ is the strain in inches per inch, and

k is the gage factor.

From Equation [1] it is evident that ΔR is proportional to the strain. In order to produce, for calibration purposes, a ΔR corresponding to a certain strain, it is necessary to introduce this known change of resistance in one gage arm. This change can be introduced as shown in Figure 9.

A 2.00-ohm wire-wound precision resistor is permanently connected in series with each gage arm of the bridge. By means of the calibration switches, S-2a and S-2b, another precision resistor of the same type and of such a value as to produce the desired ΔR is shunted across the 2-ohm resistor. For example, when the 2-ohm resistor is shunted by the 414.7-ohm resistor, the resultant ΔR is minus 9.6 milliohms; this same ΔR would be produced if the gage in that bridge arm were compressed 40 μipi.* If, on the other hand, the calibration switch is thrown so that the 2-ohm resistor in the opposite gage arm is shunted by the 414.7-ohm resistor, the same absolute value of ΔR is obtained, but the phase of the bridge output voltage is reversed. In effect, this is the same as a ΔR of plus 9.6 milliohms in the first-mentioned gage arm. By switching this resistor first to one side of the bridge and then to

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* This statement assumes a gage factor of 2.00 and a gage resistance of 120 ohms. Correction factors to be applied for gage factors other than 2.00 are given in the section "Calibration and Interpretation of Records," Part 1.

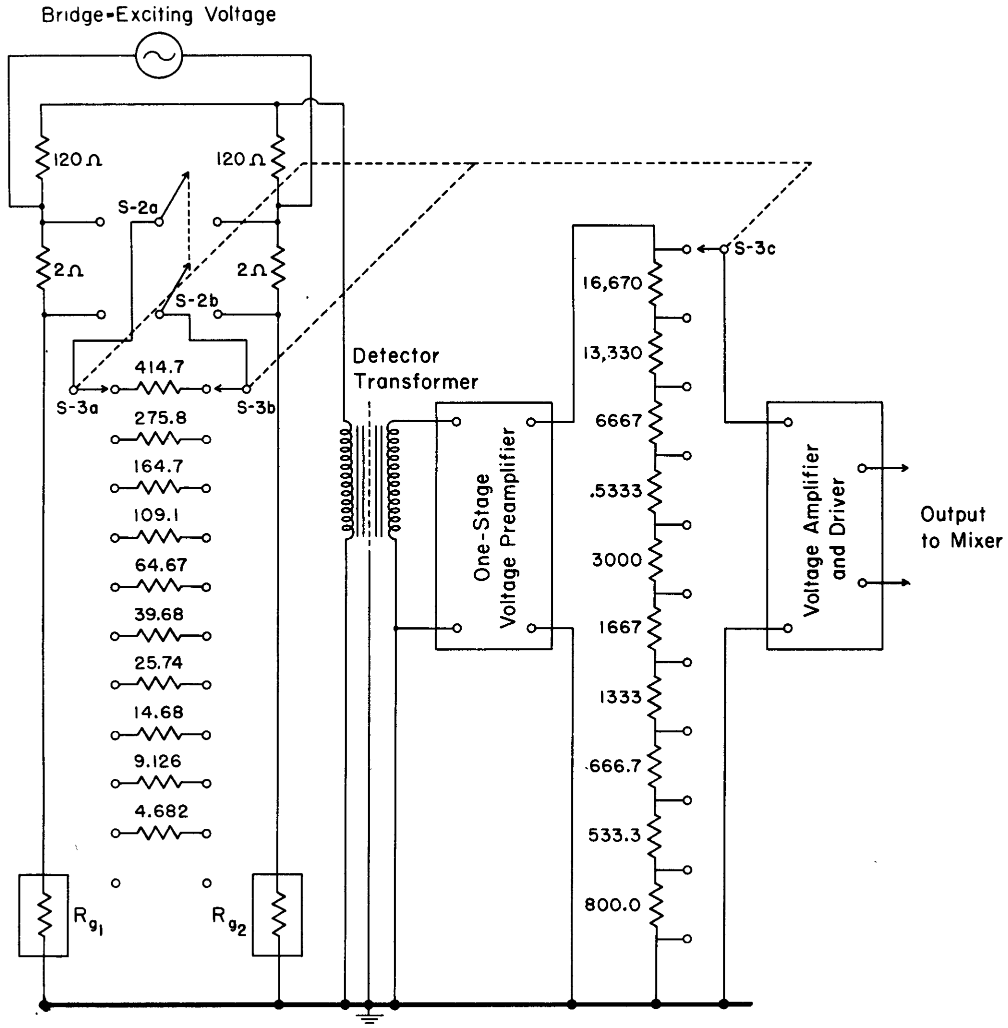

Figure 9 - Calibration Circuit

The desired calibrating resistor is selected by the switches S-3a and S-3b. Manipulation of the ganged switches S-2a and S-2b places the selected resistor in parallel with the 2-ohm resistor on either side of the bridge.

the other, calibrations corresponding to compression and tension in the specimen are indicated. Any one of ten predetermined calibration resistors may be selected by the SENSITIVITY control for full-scale calibration of the desired sensitivity range. Note that calibration is accomplished in one simple operation, that no accessory apparatus is involved, and that no tedious measurements or computations are necessary.

Of course, if a calibration resistor smaller than the 414.7-ohm resistor is selected, the resultant ΔR is larger and a correspondingly greater voltage is impressed across the detector transformer. Unless some means of attenuation is employed in the amplifying system, increasingly greater output indications would occur as still smaller calibration resistors were selected, with the result that the amplifier, the output stages, and the recording device would be overloaded. To prevent this undesirable situation, a special attenuator is ganged to the switch that selects the calibration resistors. For all steps on the SENSITIVITY control, the appropriate attenuation is imposed on the amplifier, so that for calibration the deflection of the recorder is uniform in amplitude.

This scheme permits the positions of the attenuator to be designated in microinches per inch for full-scale deflection, rather than in attenuation units, voltage-gain factors, or other arbitrary figures.

AMPLIFIER AND NULL DETECTOR

The amplifier consists of three major parts: a preamplifier stage, which receives the signal voltage directly from the detector transformer; the attenuator; and a two-stage voltage amplifier. The complete amplifier is of conventional design with the possible exception of its frequency response characteristic. Since the amplifier must pass only the side-band components of the carrier frequency and since the random noise-voltage output of any amplifier is proportional to the square root of the band width, the response is deliberately made poor at frequencies lower and higher than the required band. The attenuation of the amplifier at low frequencies minimizes the effect of microphonic disturbances and allows the use of a-c heated tubes. The voltage gain, including the stepup in the detector transformer, is approximately 64,000 times.*

As previously mentioned, the bridge is normally brought to balance, resistively and reactively, for conditions of zero strain. The function of the null detector is to indicate when this balanced condition prevails. A zero reading of the output meter cannot be accepted as an absolute indication of bridge balance. It can be readily demonstrated that, if the bridge is deliberately unbalanced by rotation of the capacity control, a zero reading on the output meter can be regained by adjustment of the resistance controls of the bridge. Now the bridge is unbalanced, both for resistance and capacitance, and still the output meter reads zero. It is easily possible, by certain adjustments of the controls, to have a zero reading on the output meter with the bridge unbalanced to such a degree that the amplifiers and output stages are overloaded. In this condition the instrument is unusable for strain measurement.

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* With the attenuator set on the 40-μipi position, 25 μv across the primary of the detector transformer produces about 1.6 v at the plate of the driver-amplifier tube, V-3-A.

It is evident then that some positive and reliable means of indicating the null balance point must be used. The null detector, a schematic circuit of which is shown in Figure 10, is built in for this purpose.

The operation of the null detector is as follows: Assume that the bridge is unbalanced, either resistively or reactively, or both. An a-c voltage, the magnitude of which is proportional to the degree of unbalance, is impressed on the amplifier. An amplified replica of this voltage appears at the grid of the cathode follower, V-3, and a portion, determined by the setting of the null-sensitivity switch, is fed to the grid of V-9, a high-gain pentode voltage amplifier which is used in a special reflex circuit. The a-c signal-voltage output of this tube is rectified by the lower half of the diode V-10. The d-c component of this rectified voltage is impressed on the control grid of the pentode as an increase in negative bias, thereby reducing its d-c plate current.* When the null threshold is set properly, a part of this plate current flows through the 0.5-megohm resistor connected between the cathode and grid of V-11, an electron-ray indicator tube, commonly known

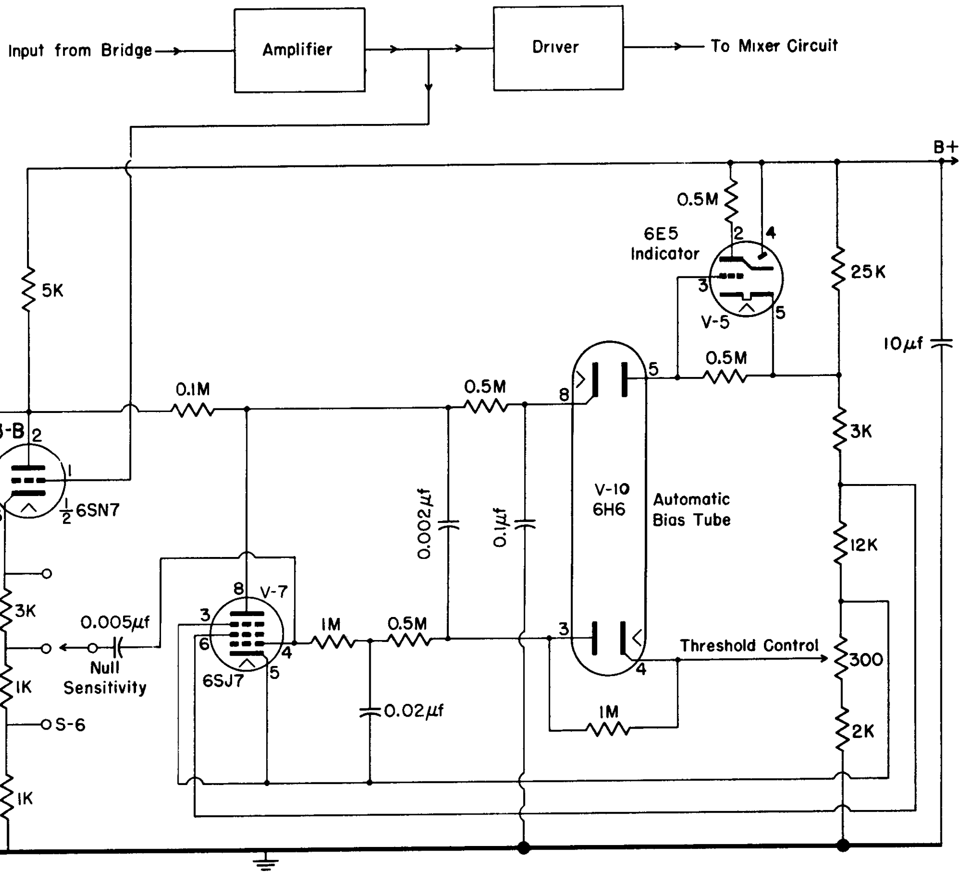

Figure 10-- Schematic Diagram of Null-Detector Circuit

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* This reflex action should not be confused with the principle of automatic volume control, wherein the gain of the amplifier tube is affected. The sharp cutoff pentode used here operates as an a-c and d-c amplifier simultaneously with virtually constant gain.

as a magic-eye tube. In the absence of signal input to the pentode, such as when the bridge is in balance, the voltage drop across this resistor appears as a sufficiently high negative bias to cause closure of the eye. However, if a signal voltage is present on the grid of the pentode, and its d-c plate current is reduced by the reflex action previously described, this biasing voltage on the indicator tube is lessened and the eye opens. As the bridge is brought closer to a balanced condition, the signal voltage impressed on the grid of the pentode becomes smaller and the eye starts to close. By lowering the null threshold and adjusting the bridge balance controls for smallest shadow angle, a very high degree of balance can be obtained.

MIXER AND OUTPUT STAGE

The output voltage of the amplifier is impressed on the mixer circuit through a step-down transformer. The use of this type of transformer imposes an overall loss in voltage gain of the amplifier but reduces the impedance of the mixer circuit. The grids of the tubes are driven differentially by the signal voltage developed across the secondary winding. The same grids are driven in a parallel manner by another voltage of carrier frequency and constant amplitude, furnished by the buffer amplifier, through a cathode follower isolator stage. This stage has a threefold function: It prevents a voltage feedback loop to the buffer amplifier by its unidirectional transmission characteristics; it acts as an impedance-matching device; and it sets the proper phase relation between the injected carrier and the signal voltages.

A skeleton circuit diagram of the mixer circuit and output stage is shown in Figure 11. Output voltage from the power amplifier tube V-4 is divided into separate channels, a and b, each of which drives its individual full-wave rectifier circuit. When the bridge is in balance, the signal voltage *between* the two power amplifier grids is zero. The injected carrier voltage is effective between each grid and ground. This voltage is amplified by the power amplifier tube V-4 and applied to the full-wave rectifier circuits in each channel. The d-c component is transmitted by the low-pass filters and produces equal currents through the terminating resistors, R-54 in channel a and R-55 in channel b. The potential drop across each of these resistors is opposite in polarity to the fixed bias voltages on the current amplifier tubes V-5 and V-6. The net effective bias voltage on each current amplifier tube is the algebraic sum of two voltages - the fixed bias voltage and the d-c voltage developed by the action of the full-wave rectifiers. As long as the bridge is balanced the effective bias voltages on the current amplifier tubes are equal. Since the plate voltage on

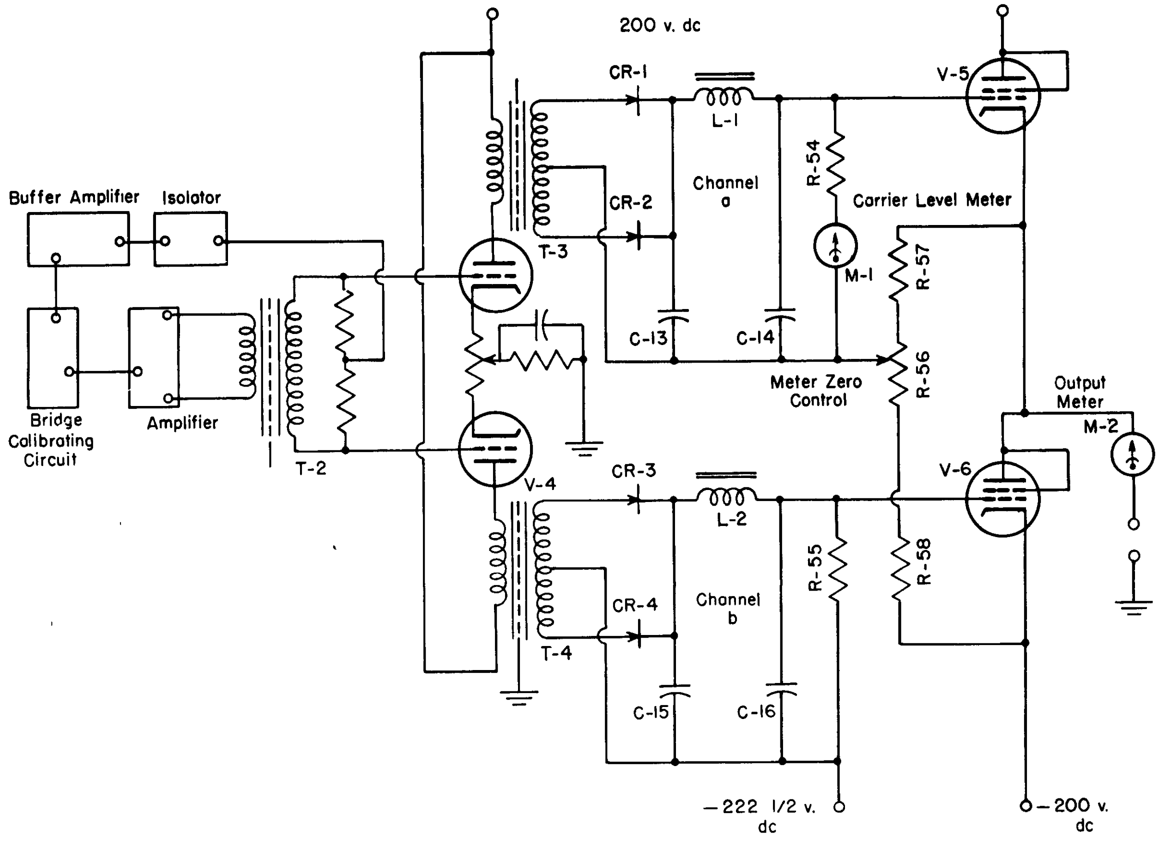

Figure 11 - Schematic Circuit Diagram of the Mixer and Output Stage

each of these tubes is also equal, they conduct equal plate currents and no current flows through the recording device.

The action of the output stage when the bridge is unbalanced a fixed amount, such as when the calibration switch is actuated, can best be shown by transposition of the circuit into its equivalent; see Figure 12. Neglecting d-c potentials and considering only the dynamic signal voltages, the open-circuit output voltage, e_{oc} , can be shown by the superposition theorem to be the algebraic sum of the two voltages produced by the two generators operating independently

$$e_{oc} = e_{oc_1} + e_{oc_2}$$

where e_{oc_1} is the output voltage produced by the effect of Δe and
e_{oc_2} is the output voltage produced by the effect of $-\Delta e$.

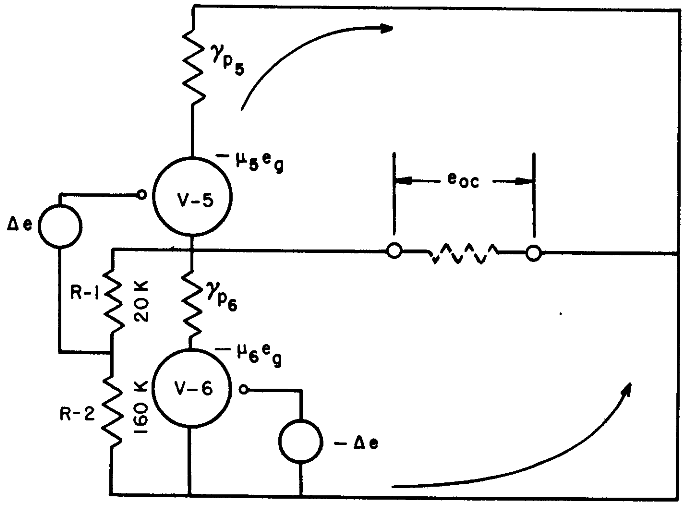

Figure 12 - Equivalent Circuit of the Output Stage

Unbalance of the bridge causes the mixer stage to deliver a larger voltage to channel a and a correspondingly smaller voltage to channel b. The change in the effective grid bias voltage on the current amplifier tube V-5 is shown as Δe; the change in the corresponding voltage on the current amplifier tube V-6 in channel b is $-\Delta e$.

By simple circuit theory

$$e_{oc_1} = \frac{\mu_5 \, \Delta e \, \gamma_{p_6} (R_1 + R_2)}{\gamma_{p_5} (\gamma_{p_6} + R_1 + R_2) + \gamma_{p_6} (R_1 + \mu_5 R_1 + R_2)}$$

$$e_{oc_2} = \frac{\mu_6 \, \Delta e \, \gamma_{p_5} (R_1 + R_2)}{\gamma_{p_5} (\gamma_{p_6} + R_1 + R_2) + \gamma_{p_6} (R_1 + \mu_5 R_1 + R_2)}$$

and therefore

$$e_{oc} = \frac{\mu_5 \gamma_{p_6} (R_1 + R_2) + \mu_6 \gamma_{p_5} (R_1 + R_2)}{\gamma_{p_5} (\gamma_{p_6} + R_1 + R_2) + \gamma_{p_6} (R_1 + \mu_5 R_1 + R_2)} \Delta e \qquad [2]$$

where μ_5 is the amplification factor of the tube V-5,
μ_6 is the amplification factor of the tube V-6,
γ_{p_5} is the dynamic plate resistance of the tube V-5, and
γ_{p_6} is the dynamic plate resistance of the tube V-6.

The current amplifier tubes V-5 and V-6 are of the same type and are operated under the same conditions, so that $\mu_5 = \mu_6$ and $\gamma_{p_5} = \gamma_{p_6}$. Equation [2] then simplifies to

$$e_{oc} = \frac{2\mu\,(R_1 + R_2)}{(\gamma_{p_6} + R_1 + R_2) + (R_1 + \mu R_1 + R_2)}\,\Delta e \qquad [3]$$

The open-circuit output voltage as given by Equation [3] is of general interest only, as the output stage is designed to furnish current to a resistive load. The expression, however, is of value in determining the output current that would flow through any load of resistance R that may be connected in the output circuit. For this purpose the equivalent circuit shown in Figure 12 may be transposed, by Thevenins' Theorem, into the more simple equivalent shown in Figure 13.

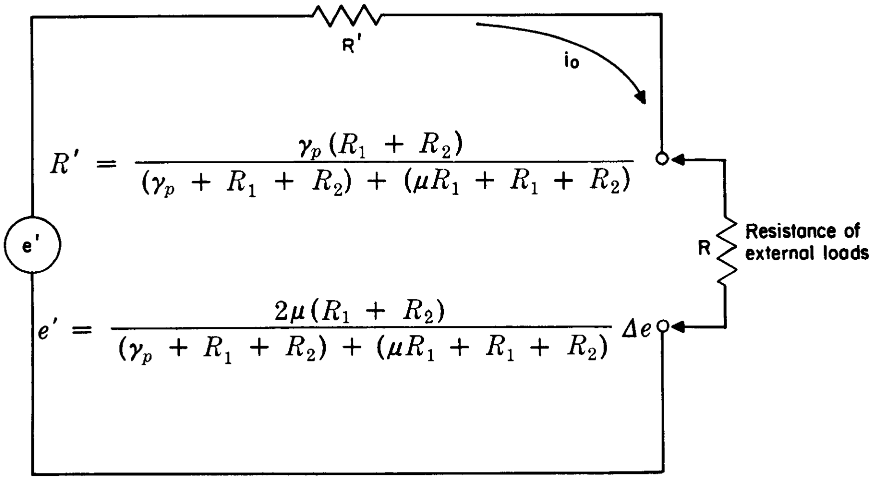

Figure 13 - Simplified Equivalent Circuit of the Output Stage

The two voltage generators shown in Figure 13 are replaced by one generator of voltage equal to the open-circuit voltage of the output stage. The series resistor, R', represents the internal impedance. The output current, i_0, which is available through the load resistor, R, may be readily computed by substituting the values of the circuit parameters.

In normal use, with string-oscillograph galvanometers whose electrical resistance lies between 0 and 10 ohms, the output current, i_0, can be found from the simple relation

$$i_0 = 2g_m \Delta e \qquad [4]$$

where g_m is the grid-plate transconductance of either V-5 or V-6, approximately 3500 micromhos, and

Δe is the change in grid bias voltage, approximately 1.7 v for calibration.

Equation [4] should not be used for accurate calculation of the output current since the values of g_m and Δe are only approximations.

CIRCUIT ADJUSTMENT

An outline of the procedure followed in the initial alignment of the various circuits of the strain indicator is given here as an aid in servicing. The instrument is very stable both mechanically and electrically, and in general these initial adjustments, if carefully made, hold for long periods of time. Abuse of the instrument or failure of circuit components may necessitate realignment. As all tubes used are of the common receiving type, replacement may be made from stock, with one exception, as noted later.

The following test instruments, or other instruments of similar characteristics, are required to align and check the indicator.

1. Audio oscillator, Hewlett-Packard 205-A.
2. Vacuum-tube voltmeter, a-c, Ballantine 300.
3. Volt-ohm-milliameter, d-c, Weston 772.
4. Cathode-ray oscillograph, DuMont 208.

Also useful, but not entirely necessary, are two other items.

5. A dummy gage set, consisting of two 120-ohm precision resistors wired into a locking-type 3-pin Cannon connector, can be substituted for the gage system for test purposes.

6. A 15-ohm resistor, wired across Pins 1 and 2 of a standard 3-pin Cannon connector, can be used as a substitute load in lieu of the recording oscillograph.

BUFFER AMPLIFIER AND ISOLATOR STAGE

This section of the instrument consists of the tubes V-7 and V-8 which are located within the shielded compartment at the rear of the chassis. Assuming that the indicator is connected to the power supply and that the base plate is removed, the measurements necessary to check the operation of this section may be made as follows:

1. Insert the dummy gage plug into the GAGE INPUT receptacle.
2. Set the SENSITIVITY control at the OFF position.
3. Adjust the Hewlett-Packard audio oscillator to 5000 cps and set the output to about 3 v rms. Be certain that the frequency calibration of the oscillator is accurate. Connect the leads from the oscillator to a phone plug and insert the plug into the single circuit jack on the rear of the indicator chassis. (The TMB Type OC-1A special-purpose 5000-cycle oscillator may be employed instead of the Hewlett-Packard if desired.)

4. Switch ON the power to the indicator and allow a few minutes for the instruments to reach operating temperature.

5. Connect the ground lead of the Ballantine voltmeter to the chassis-ground of the indicator and connect the signal lead to either end of the Helipot R-14, the RESISTANCE VERNIER control. The voltage from this point to ground should be about 0.6 v rms and may be adjusted to this value by the CARRIER VOLTAGE control on the front panel. (The voltage read with this meter connection is one-half the actual bridge exciting voltage.) Disconnect the voltmeter.

6. Under the conditions of 5, the injected carrier voltage, which may be measured by connecting the Ballantine to the cathode (Pin 8) of the isolator tube V-8, should be about 1.1 v rms. The carrier-voltage meter on the left side of the indicator panel should now rest exactly on the arrow pointer at midscale.

AMPLIFIER AND NULL DETECTOR

The three-stage amplifier, the circuit of which is shown at the top center of Figure 17, consists of the triode tubes V-1, V-2, V-3-A, and associated circuit components. Since the frequency response of the amplifier is predetermined by the characteristics of the input and output transformers and the time constants of the coupling networks, proper operation in general can be checked by measurements of gain and noise level, as follows:

1. With the SENSITIVITY control set at the OFF position, adjust the CARRIER VOLTAGE control so that the carrier level meter on the indicator shows one-half scale deflection, i.e., on the arrow marker. This meter reading should be obtained when the bridge driving voltage is approximately 1.2 v rms.

2. Connect the Ballantine voltmeter between the plate (Pin 5) of the driver amplifier tube V-3-A and ground. Set the SENSITIVITY control on the 40-μipi position and balance the bridge for resistance and reactance. At balance, the voltage indicated by the Ballantine voltmeter is the noise-voltage output of the amplifier, since the signal voltage from the bridge is zero or very nearly so. This output noise level with the bridge balanced should be about 0.05 v rms. A noise level higher than 0.05 v is very possibly due to cathode ripple in the first amplifier tube V-1. Tubes with low cathode ripple and low microphonic tendencies are selected for this stage.

3. The gain of the amplifier may now be checked. With the attenuator set on the 40-μipi position, depress the calibration to TENSION. The Ballantine voltmeter should indicate about 1.6 v rms, i.e., 25μv bridge output times 64,000, the gain of the amplifier. Moving the calibration switch to

the COMPRESSION position should produce an equal indication. If it does not, the bridge balance should be rechecked and the amplifier gain should be measured again.

The NULL-DETECTOR circuit, consisting of the tubes V-9, V-10, and V-11, is in the lower right corner of the schematic diagram, Figure 17. The operation of this circuit has been discussed previously. The circuit may be checked in the following manner.

1. Rotate the attenuator to the OFF position: When the NULL-THRESHOLD control is turned to the full clockwise position, the eye of the 6E5-G electron-ray indicator tube should close. In the counterclockwise position of this control the eye should open.

2. If such is not the case, determine with the aid of the Weston d-c voltmeter the potential of the cathode of the eye tube above ground. It should be about 92.5 v. Move the meter to the plate of the pentode V-9. Since the setting of the NULL-THRESHOLD control establishes the initial or zero-signal grid-bias voltage on the pentode, moving this control from full clockwise to full counterclockwise position will vary the grid-bias voltage by the amount of the voltage drop across the control, which is the 300-ohm potentiometer R-78. The changes in d-c plate current produced by these changes in bias appear at the plate of the pentode as changes in potential. By the NULL-THRESHOLD control, it must be possible to set the plate potential of the pentode higher and lower than the cathode potential of the eye tube. If this is not possible, try a new tube in the pentode socket. The d-c voltage distribution on the voltage divider, R-75, R-76, R-77, R-78, and R-79, is important, especially as regards the 75-v screen voltage point. The d-c voltages at the various points along this divider should agree closely with those shown on the schematic diagram, Figure 17.

3. If the eye of the indicator tube can be opened and closed by adjustment of the NULL-THRESHOLD control, but does not respond to signal voltage on the pentode grid, try replacing the 6H6 diode, V-10, with a new tube.

MIXER AND OUTPUT STAGE

The circuit of the mixer and output stage is shown at the top right of the schematic diagram, Figure 17. For this circuit to operate as explained on page 18, it must first be adjusted so that the proper amplitude and phase relations exist between the two a-c voltages at the mixing point. The rest of the instrument must be operating correctly before an attempt is made to align or check the output stage. Assuming that this is the case, the following procedure is recommended:

1. Check back to be sure the bridge driving voltage is about 1.2 v rms.

2. By the method outlined on page 9, balance the bridge as closely as possible on the 150-μipi step of the attenuator.

3. Check the amplitude of the injection voltage with the Ballantine voltmeter. This voltage can be measured between the midpoint of the two 1000-ohm resistors, R-49 and R-50, and ground. It should be approximately 1.1 v rms.

4. By depressing the calibration switch, check the output voltage of the amplifier. This voltage, which is measured between the plate (Pin 5) of the driver-amplifier tube, V-3-A, and ground, should be about 1.6 v rms.

5. Disconnect the Ballantine voltmeter. Connect the X-axis input of the DuMont 208 oscillograph to observe the injection voltage. Turn off the internal sweep oscillator and advance the X-axis gain control until about a 3-in. deflection is obtained.

6. Connect the Y-axis input of the oscillograph to observe the signal voltage output of the driver-amplifier tube, V-3-A. Set the Y-axis gain control so that depression of the calibration switch produces a 3-in. deflection on the Y-axis of the screen.

7. When the bridge is balanced for both resistance and reactance, the straight line shown in Figure 14a will be observed on the screen. If the bridge is not perfectly balanced reactively the pattern will be an ellipse, as shown by the broken line in the figure. Resistance unbalance will produce a straight line, but it will have an angle of inclination with the X-axis.

8. Now depress the calibration switch to the TENSION position. A straight line such as T-T' in Figure 14b should be obtained. A compression calibration should produce a line sloping in the opposite direction, C-C'. If either or both of these patterns are elliptical, the 0.0007 μf phasing-capacitor C-28, which is located on the resistor strip in the rear compartment, may have to be replaced by a capacitor of another value. When both of these inclined lines are straight, the phase relation of the injected voltage to the signal voltage is correct; i.e., zero deg and 180 deg, respectively, depending on the direction in which the bridge is unbalanced resistively.

When the phase is set correctly and the bridge is balanced, manipulation of the calibration switch will produce the inclined straight-line patterns shown in Figure 14b on all steps of the attenuator, except possibly the 40- and 60-μipi position. The departure from zero or 180 deg on these switch positions, which is caused by the slight change in capacity balance introduced by the operation of the calibration switch, is more marked, since the resistance change is very small and the gain of the amplifier is correspondingly higher.

Figure 14a

Pattern observed when the bridge is balanced for both resistance and reactance is the straight line X-X'. When the bridge is balanced for resistance only, and not for reactance, the pattern will be an ellipse, as shown by the dotted line.

Figure 14b

The line X-X' is the deflection produced by the injection voltage. Throwing the calibration switch to the tension position causes the line X-X' to assume the position shown by the dotted line T-T'. If the calibration switch is thrown to the compression position, X-X' moves to the angle indicated by the dotted line C-C'.

Figure 14 - Patterns Observed on the Screen of the Oscillograph When the Injection Voltage is Impressed on the X-Axis and the Signal or Bridge Unbalance Voltage is Applied to the Y-Axis

After the signal and injection voltages have been phased, the output circuit may be checked. The ratio of the amplitudes of the two voltages impressed on the mixer determines the percentage modulation of the carrier. The injected carrier voltage, which, as previously mentioned, is measured from the juncture of R-49 and R-50 to ground, should be about 1.1 v rms. The grid-to-grid signal voltage on the tube V-4 for full-scale calibration of all ranges is about 0.35 v rms. The percentage of modulation, under these conditions, is therefore approximately 15.

The germanium crystal rectifiers, which rectify the output voltages from Channels a and b, are connected in the conventional full-wave single-phase circuit. These rectifiers **ARE MATCHED AND PAIRED FOR SIMILARITY OF ELECTRICAL CHARACTERISTICS.**

The following measurements suffice to check the operation of the rectifier and output circuits.

1. Turn the attenuator to the OFF position. Connect the Ballantine voltmeter to the plate (Pin 2) of V-4 and ground. It should read about 6 v rms. The same reading should be obtained from the other plate (Pin 5) to ground. These voltages may be set equal by the screwdriver control R-52, which is located on the right side of the indicator chassis.

2. Under the conditions of 1, the d-c voltage drop across each of the 20,000-ohm load resistors, R-54 and R-55, should be about 10 v.

3. Plug the 15-ohm dummy load resistor into the OUTPUT receptacle and adjust the METER-ZERO control so that the output meter reads zero current.

4. Now advance the attenuator to any active step, for example the 400-μipi position, and carefully balance the bridge; the output meter will still read zero. Moving the calibration switch to TENSION should cause a deflection of 12 ma to the right of zero and to COMPRESSION should cause a deflection of the same magnitude to the left of zero. The deflection is proportional to the carrier-voltage level and may be increased or decreased by adjustment of the CARRIER-VOLTAGE control, R-59.

5. Should the TENSION and COMPRESSION calibrations produce unequal deflections of the output meter, proceed as follows: Turn the SENSITIVITY attenuator to OFF; set the CARRIER-VOLTAGE meter to the arrow pointer at midscale and zeroize the output-current meter. Adjust the screwdriver control R-52 until slight carrier-voltage increments as introduced by variation of the CARRIER-VOLTAGE control produce no deflection, either plus or minus, on the output-current meter. This adjustment serves to compensate for any small differences in the electrical characteristics of the tubes and of the component parts in Channels a and b.

6. For test purposes only, the output of the indicator may be observed by connecting the Y-axis input of the DuMont 208 oscillograph across the 15-ohm dummy-load resistor. Adjust the Y-axis gain control so that actuation of the calibrating switch produces about a 1-in. deflection on the screen. Some ripple will be observed on the trace, but since the recording galvanometers have very little response to this ripple frequency a clear record trace will be obtained from the string oscillograph.

ACCESSORY APPARATUS

Two external pieces of accessory apparatus were designed especially for use with the TMB 5A Strain Indicator: A dual-channel power supply and a special 6-channel master oscillator. Both of these pieces of equipment are of more or less conventional design and are described only briefly.

POWER SUPPLY

The power supply, which, as previously stated, is capable of furnishing power for two Type 5A Strain Indicators, is a two-channel unit in so far as its output is concerned; see Figure 18 for the schematic diagram. An alternating current of 6.3 v at 6 amp for heaters of tubes in the strain indicators, and regulated d-c potentials of 200 v positive and 200 v negative with respect to ground are available at each of the output connectors, J-2 and J-3. The 6.3-v alternating current is furnished to each output by a separate filament transformer; the 200-v positive potentials are taken in each case from a separate electronic d-c voltage regulator. The 200-v negative potential is furnished by an electronic voltage regulator common to both output connections. Each of the positive regulators is fed from its individual filter channel, but power for operation is derived from power transformer T-1. Power transformer T-3 supplies the negative-voltage regulator.

All tubes used in the power supply are of the common receiving type and are worked well within their designed ratings. The supply is somewhat overdesigned in the interest of stability and trouble-free operation.

OSCILLATOR

The Type OC-1A oscillator, the schematic diagram of which is shown in Figure 19, operates at a fixed frequency of 5000 cps and delivers an output of about 3 v rms. The oscillator unit contains its own power supply and operates from the standard 115-v 60-cycle single-phase power line. It may be used to furnish the carrier voltage for as many as six Type 5A Strain Indicators operated simultaneously.

Balancing the bridges of the indicators and phasing the injection voltages demand that the carrier-voltage wave remain constant in frequency and be of excellent wave form. The LC circuit in the oscillator feedback network acts as the frequency-determining element and as a wave filter. Output voltage from the oscillator is taken off across this tuned circuit. The harmonic content of the voltage at this point is very low, since the high-Q antiresonant circuit represents a high impedance at its natural frequency and a much lower impedance at all harmonic frequencies. Harmonic distortion is reduced further by resistance isolation of the tuned circuit from the oscillator tube V-1, which is operated at low amplitude. To avoid loading effects, two additional stages are employed after the oscillator. Both of these stages operate with a high negative-feedback factor in the interest of obtaining low distortion and a low output impedance. As a result of the design for good wave form, the oscillator also exhibits excellent frequency-stability characteristics.

The oscillator may be serviced with the aid of the schematic diagram, Figure 19. The a-c and d-c voltages as measured in the instrument should agree closely with those noted on the diagram. Only three adjustments are required to align the oscillator; they may be made as follows:

1. Turn the oscillator ON and allow a few minutes for it to reach operating temperature. Connect the Y-axis input of the DuMont 208 oscillograph to the plate (Pin 3) of the amplifier tube V-2. Connect the X-axis input of the oscillograph to the output of a frequency standard. Adjust the mica trimmer condenser C-14 until the oscillator frequency is 5000 cps.

2. Connect the Ballantine a-c voltmeter to the plate (Pin 3) of tube V-2 and adjust the screwdriver control R-4 until the Ballantine voltmeter indicates 7.5 v rms. If this adjustment cannot be made or if the oscillator fails to operate, try replacing the 6SC7 oscillator tube V-1 with a new tube.

3. Disconnect the Ballantine voltmeter from the plate of V-2 and connect it across the secondary of the output transformer T-3. Adjust the screwdriver control R-13 so that the meter reads about 3 v rms.

The output connections are phone jacks of the circuit-breaking type, each shunted by a 10,000-ohm resistor. No change in output voltage should occur when the strain indicators are connected or disconnected. **CARE MUST BE EXERCISED TO SEE THAT NONE OF THE CONNECTING CORDS TO THE INDICATORS IS SHORT-CIRCUITED AS THIS WILL DEPRIVE ALL THE INDICATORS OF CARRIER VOLTAGE.**

APPENDIX 1

SR-4 WIRE-RESISTANCE STRAIN GAGE

The SR-4 wire-resistance strain gage, a detail of which is shown in Figure 15, is manufactured in several types, suitable for a variety of applications. The Type A 120-ohm gage is wound of 0.001-in. Advance wire and cemented to a thin paper base.

The gage operates on the principle that a change in its length produces a proportional change in its electrical resistance. This fact may be expressed by

$$\frac{\Delta R}{R} = k\frac{\Delta l}{l} \qquad [4]^*$$

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* For best results the gage should be dried for an hour or so at a temperature of about 120 F and then moisture-proofed by beeswax or other suitable material. The change in electrical resistance with elongation of fine wires by several alloys is treated comprehensively in Reference (3).

where R is the electrical resistance of the gage,

ΔR is the change in R due to strain,

l is the length of the gage,

Δl is the change in length, and

k is a constant of proportionality.

The constant k is the figure of merit of the gage and is commonly called the gage factor. If $\frac{\Delta l}{l}$ is set equal to ϵ and evaluated in inches per inch, Equation [4] simplifies to

$$\Delta R = k\epsilon R$$

The change of gage resistance, ΔR, is plotted as a function of strain in microinches per inch in Figure 16.

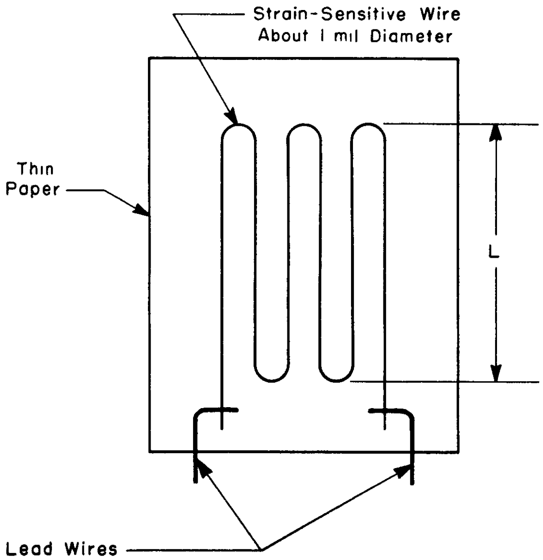

Figure 15 - Diagram of the SR-4 Strain Gage

The gage is put in service by cementing the paper base to the specimen at the point where the strain is to be measured. Duco or Baldwin-Southwark 13-41 cement is suitable for this purpose. The surface of the material must be perfectly dry, thoroughly cleaned, and slightly roughened where the gage is applied. All air bubbles under the gage must be worked out and the cement allowed to dry completely before the specimen is subjected to strain in order to avoid hysteresis. Drying time varies with the kind of cement, the temperature, and the relative humidity.*

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* The performance under static strains of Baldwin-Southwark SR-4 wire-resistance strain gages attached to tensile test specimens with three different cements was investigated to establish the drying period required for a cement-mounted gage to respond linearly at full sensitivity without hysteresis. The results of these tests, with illustrative graphs and data, are covered in detail in Reference (4).

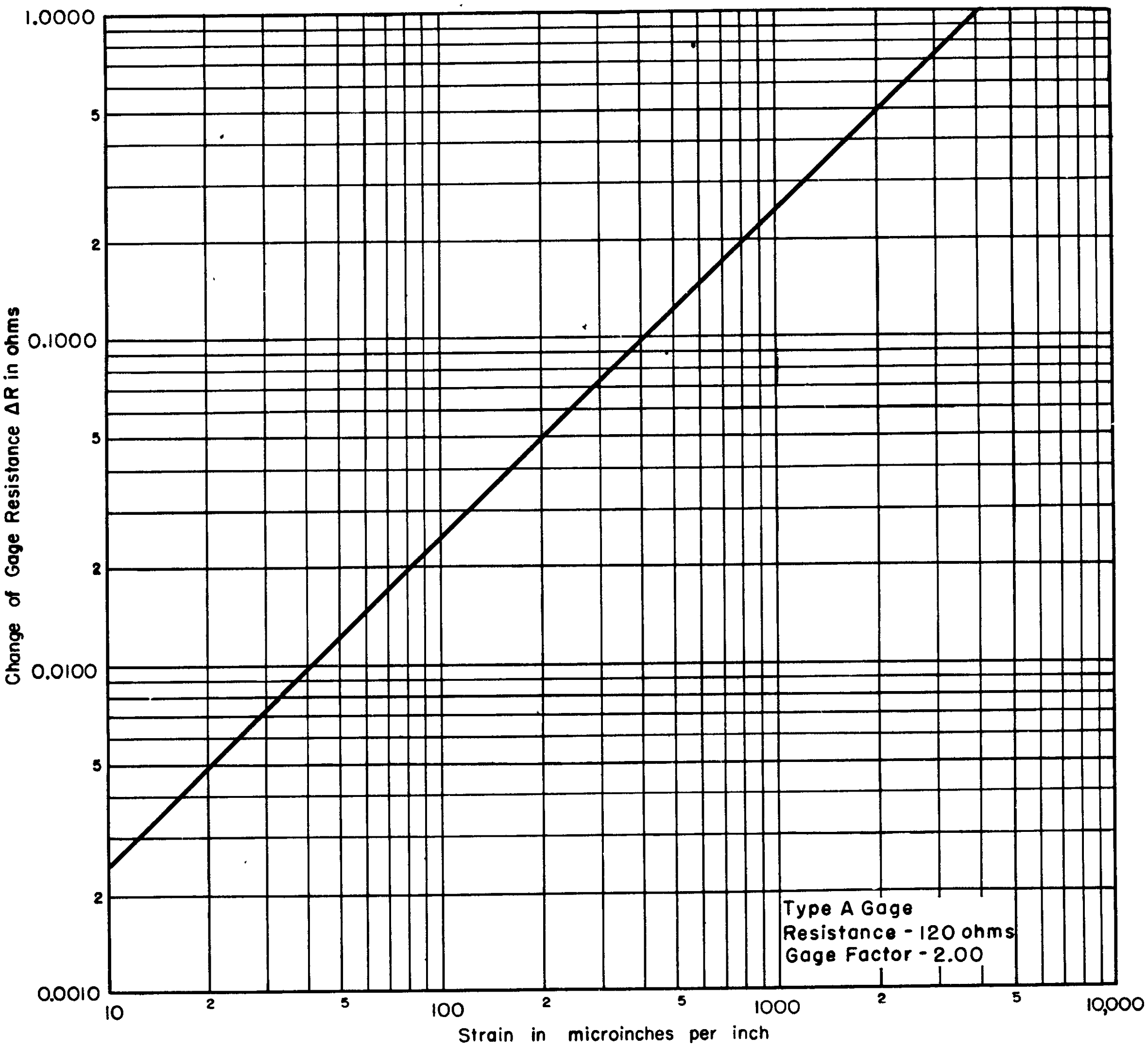


Figure 16 - Change in Gage Resistance as a Function of Strain

REFERENCES

(1) "A Carrier-Type Strain Indicator," by George W. Cook, TMB Report 565, November 1946.

(2) "Operating and Service Manual for the TMB Type 1A Strain Indicator," by W.S. Campbell, TMB Report R-351, July 1947.

(3) "Resistance-Strain Characteristics of Stretched Fine Wires," by W.J. Sette, L.D. Anderson, and J.G. McGinley, TMB Report R-212, September 1945.

(4) "The Performance of Wire-Resistance Strain Gages as Influenced by the Drying Time of Three Mounting Cements," by B.L. Miller, L.D. Anderson, and H. Shoub, TMB Report R-213, January 1946.

Parts List for the TMB Type 5A Strain Indicator

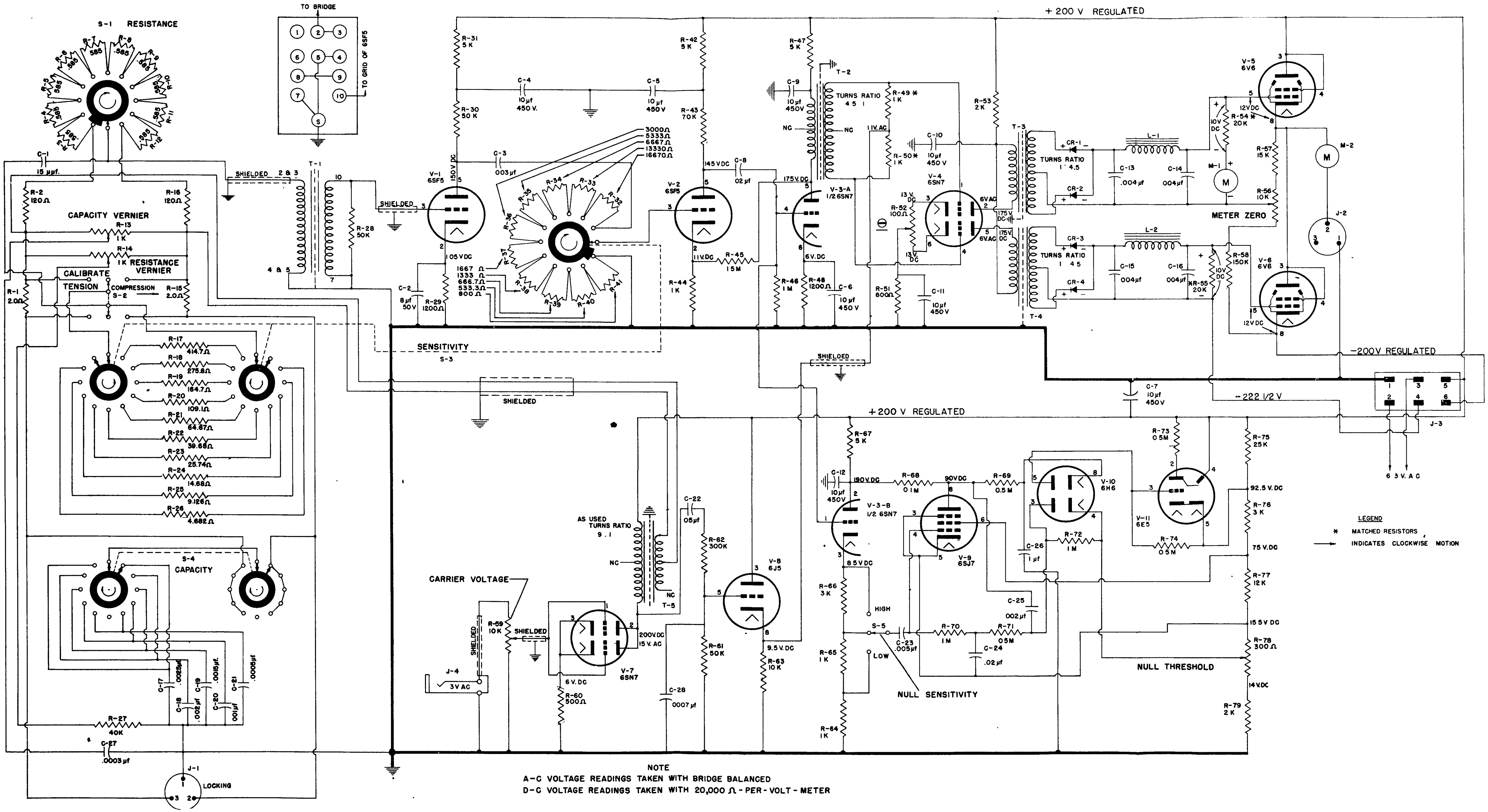
R-1	2.0 ohms	Precision, Shallcross Type BX172, ± 1/4 per cent
R-2	120 ohms	
R-3	.585 ohms	
R-4	.585 ohms	
R-5	.585 ohms	
R-6	.585 ohms	
R-7	.585 ohms	
R-8	.585 ohms	
R-9	.585 ohms	
R-10	.585 ohms	
R-11	.585 ohms	
R-12	.585 ohms	
R-13	1 K	Helipot
R-14	1 K	
R-15	2.0 ohms	Precision, Shallcross Type BX172, ± 1/4 per cent
R-16	120 ohms	
R-17	414.7 ohms	
R-18	275.8 ohms	
R-19	164.7 ohms	
R-20	109.1 ohms	
R-21	64.67 ohms	
R-22	39.68 ohms	
R-23	25.74 ohms	
R-24	14.68 ohms	
R-25	9.126 ohms	
R-26	4.682 ohms	
R-27	40 K	
R-28	50 K	1 w
R-29	1200 ohms	1 w
R-30	50 K	1 w
R-31	5 K	1 w
R-32	16,670 ohms	Precision, Shallcross Type BX172, ± 1/4 per cent
R-33	13,330 ohms	
R-34	6,667 ohms	
R-35	5,333 ohms	
R-36	3,000 ohms	
R-37	1,667 ohms	
R-38	1,333 ohms	
R-39	666.7 ohms	
R-40	533.3 ohms	
R-41	800 ohms	
R-42	5 K	1 w
R-43	70 K	1 w
R-44	1 K	1 w
R-45	1.5 M	1 w
R-46	1 M	1 w
R-47	5 K	1 w
R-48	1200 ohms	1 w
R-49	1 K	1 w Matched Resistors
R-50	1 K	1 w
R-51	800 ohms	1 w
R-52	100 ohms	Potentiometer
R-53	2 K	1 w
R-54	20 K	1 w Matched Resistors
R-55	20 K	1 w
R-56	10 K	Potentiometer
R-57	15 K	1 w
R-58	150 K	1 w
R-59	10 K	Potentiometer
R-60	500 ohms	
R-61	50 K	1 w
R-62	300 ohms	
R-63	10 K	
R-64	1 K	
R-65	1 K	
R-66	3 K	
R-67	5 K	
R-68	0.1 M	
R-69	0.5 M	
R-70	1 M	
R-71	0.5 M	
R-72	1 M	

R-73	0.5 M	1 w
R-74	0.5 M	
R-75	25 K	
R-76	3 K	
R-77	12 K	
R-78	300 ohms	Potentiometer
R-79	2 K	1 w
C-1	15 µµf	Silvered Mica
C-2	8 µf	50 v Electrolytic, Blue Beaver
C-3	.003 µf	500 v Paper
C-4	10 µf	450 v Mallory FP-434
C-5	10 µf	
C-6	10 µf	
C-7	10 µf	
C-8	.02 µf	600 v Paper
C-9	10 µf	450 v Mallory FP-434
C-10	10 µf	
C-11	10 µf	
C-12	10 µf	
C-13	.004 µf	500 v Mica
C-14	.004 µf	
C-15	.004 µf	
C-16	.004 µf	
C-17	.0025 µf	500 v Silvered Mica
C-18	.002 µf	
C-19	.0015 µf	
C-20	.001 µf	
C-21	.0005 µf	
C-22	.05 µf	400 v Paper
C-23	.005 µf	500 v Silvered Mica
C-24	.02 µf	400 v Paper
C-25	.002 µf	
C-26	.1 µf	
C-27	.0003 µf	500 v Silvered Mica
C-28	.0007 µf	
V-1	6SF5	
V-2	6SF5	
V-3	6SN7	
V-4	6SN7	
V-5	6V6	
V-6	6V6	
V-7	6SN7	
V-8	6J5	
V-9	6SJ7	
V-10	6H6	
V-11	6E5	
M-1	0-1 ma, Weston 506	
M-2	5-0-5 ma, Weston 506, Fitted with 15-0-15 scale	
J-1	Chassis Receptacle, Cannon XK-3-14	
J-2	Chassis Receptacle, Cannon X-3-14	
J-3	Chassis Receptacle, Jones P-306-RP	
J-4	Phone Jack, Open Circuit	
S-1	Switch, Centralab, K-121, 1B Section	
S-2	Switch, Centralab, 1455	
S-3	Switch, Centralab, K-121, 1B Section, 2J Section	
S-4	Switch, Centralab, K-121, 2J Section	
S-5	Switch, Centralab, 1454	
T-1	P-202, Kenyon Bridge Transformer	
T-2	A-5311, Audio Development Co.	
T-3		
T-4		
T-5		
L-1	Choke Coil UTC Type VIC-14	
L-2		
CR-1	Rectifier, Sylvania 1N34	
CR-2		
CR-3		
CR-4		

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.



NOTE
A-C VOLTAGE READINGS TAKEN WITH BRIDGE BALANCED
D-C VOLTAGE READINGS TAKEN WITH 20,000 Ω-PER-VOLT-METER

Figure 17 - Schematic Diagram of TMB Type 5A Strain Indicator

Parts List for the TMB Type PS-SM-5A Power Supply

R-1	125	K	1 w
R-2	200	K	
R-3	125	K	
R-4	200	K	
R-5	.5	M	
R-6	20	K	
R-7	.5	M	
R-8	20	K	
R-9	.5	M	1/2 w
R-10	.5	M	1/2 w
R-11	5	K	10 w
R-12	75	K	1 w
R-13	75	K	
R-14	75	K	
R-15	75	K	
R-16	200	K	
R-17	125	K	
R-18	.5	M	
R-19	20	K	
R-20	5	K	10 w
R-21	.5	M	1/2 w
R-22	75	K	1 w
R-23	75	K	
C-1	2	μf	600 v, DYR 6200
C-2	4	μf	600 v, TLA 6040
C-3	10	μf	450 v, Electrolytic, Mallory FP434,4 Section
C-4			
C-5			
C-6			
C-7	.25	μf	600 v, DYR 6025
C-8	.25	μf	600 v, DYR 6025
C-9	2	μf	600 v, DYR 6200
C-10	4	μf	600 v, TLA 6040
C-11	10	μf	450 v, Blue Beaver

C-12	25	μf	600 v, DYR 6025
C-13	10	μf	450 v, Blue Beaver
V-1	5Z4		
V-2	5Z4		
V-3	6AS7		
V-4	6SJ7		
V-5	6SJ7		
V-6	VR-105		
V-7	5Z4		
V-8	5Z4		
V-9	6B4-G		
V-10	6SJ7		
V-11	VR-105		
T-1	Power Transformer, Thordarson T-17R30		
T-2	Filament Transformer, Thordarson T-21F11		
T-3	Power Transformer, Thordarson T-17R30		
F-1	Littlefuse 5 amp		
S-1	SPST Toggle switch		
BT-1	22 1/2 v battery		
L-1	Filter choke, Thordarson T-67C49		
L-2	Filter choke, Thordarson T-57C54		
L-3			
L-4			
L-5			
J-1	Chassis receptacle, a-c power, 2 prong		
J-2	Chassis receptacle, Jones S-306-RP		
J-3			

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.

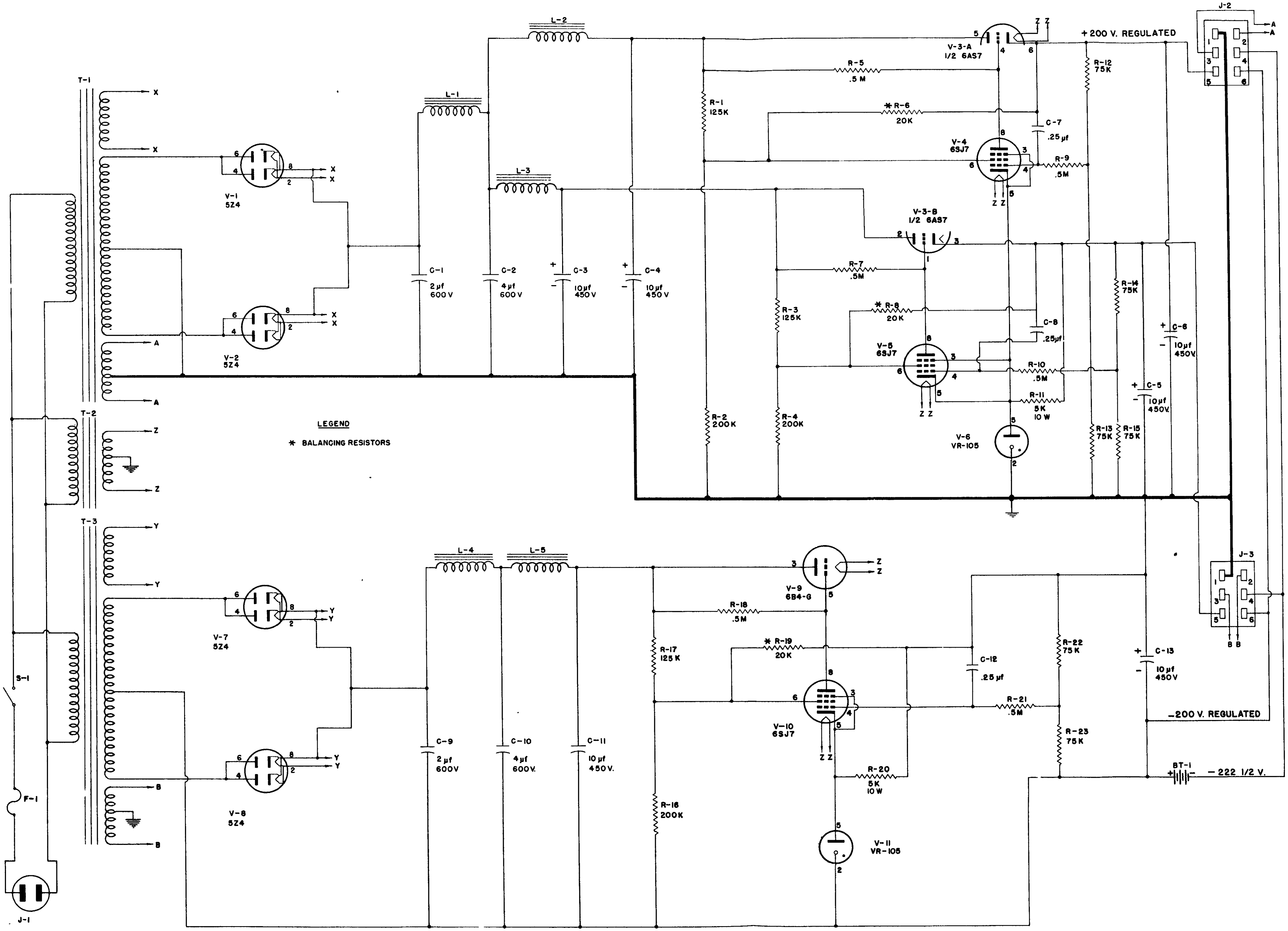


Figure 18 - Schematic Diagram of Type PS-SM-5A Power Supply

Parts List for the TMB Type OC-1A 5000-Cycle Oscillator

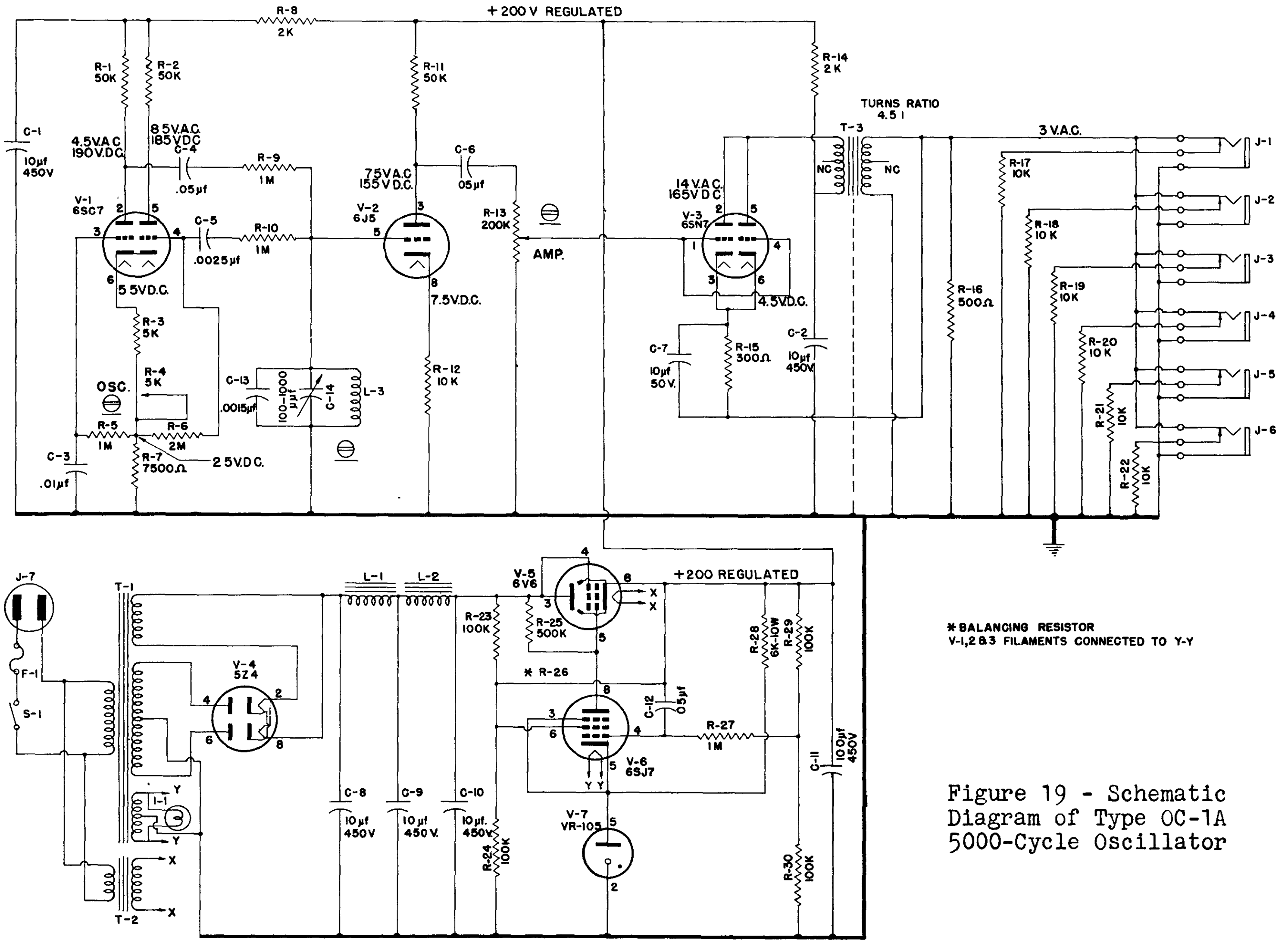
R-1	50 K	1 w
R-2	50 K	
R-3	5 K	
R-4	5 K	Potentiometer
R-5	1 M	1 w
R-6	2 M	
R-7	7.5 K	
R-8	2 K	
R-9	1 M	
R-10	1 M	
R-11	50 K	
R-12	10 K	
R-13	200 K	Potentiometer
R-14	2 K	1 w
R-15	300 ohms	
R-16	500 ohms	
R-17	10 K	
R-18	10 K	
R-19	10 K	
R-20	10 K	
R-21	10 K	
R-22	10 K	
R-23	100 K	
R-24	100 K	
R-25	500 K	
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	10 µf	450 v Mallory FP231
C-2		
C-3	0.01 µf	400 v, Paper
C-4	0.05 µf	400 v, Paper
C-5	0.0025 µf	Silvered Mica
C-6	0.05 µf	400 v, Paper

C-7	10 µf	50 v, Blue Beaver
C-8	10 µf	450 v, Mallory FP434
C-9		
C-10		
C-11		
C-12	0.5 µf	450 v, Paper
C-13	0.0015 µf	Silvered Mica
C-14	100 - 1000µµf	Mica Trimmer
L-1	Filter Choke Thordarson T-47C07	
L-2		
L-3	Western Electric Type "B" Loading Coil D170718	
J-1	Circuit-Opening Jack	
J-2		
J-3		
J-4		
J-5		
J-6		
J-7	Chassis Receptacle, a-c Power	
F-1	Fuse	2 amp
S-1	SPST Toggle switch	
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

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.



*BALANCING RESISTOR
V-1,2&3 FILAMENTS CONNECTED TO Y-Y

Figure 19 - Schematic Diagram of Type OC-1A 5000-Cycle Oscillator

APPENDIX 2

MATERIALS FOR THE TMB TYPE 5A STRAIN INDICATOR

RESISTORS

10	0.585	ohms	1/4-w, precision, Shallcross Type BX172, 1/4 per cent
2	2	ohms	
1	4.682	ohms	
1	9.126	ohms	
1	14.68	ohms	
1	25.74	ohms	
1	39.68	ohms	
1	64.67	ohms	
1	109.1	ohms	
2	120.0	ohms	
1	164.7	ohms	
1	275.8	ohms	
1	414.7	ohms	
1	533.3	ohms	
1	666.7	ohms	
1	800.0	ohms	
1	1,333	ohms	
1	1,667	ohms	
1	3,000	ohms	
1	5,333	ohms	
1	6,667	ohms	
1	13,330	ohms	
1	16,670	ohms	
1	40	K	
1	500	ohms	1-w, IRC BT-1
1	800	ohms	
3	1,000	ohms	
*2	1,000	ohms	
2	1,200	ohms	
2	2	K	
2	3	K	
4	5	K	
1	10	K	
1	12	K	
1	15	K	
*2	20	K	1-w, IRC BT-1
1	25	K	
3	50	K	
1	70	K	
1	100	K	
1	150	K	
1	300	K	
4	500	K	
3	1	M	
1	1.5	M	
1	100	ohms	Potentiometer, wire-wound
1	300	ohms	
2	1	K	Helipot, 10-turn
2	10	K	Potentiometer

CAPACITORS

1	0.000015	µf	500 v	Silvered Mica
1	0.0003	µf	500 v	
1	0.0005	µf	500 v	
1	0.0007	µf	500 v	
1	0.001	µf	500 v	
1	0.0015	µf	500 v	
1	0.002	µf	500 v	
1	0.0025	µf	500 v	
1	0.005	µf	500 v	
1	0.002	µf	400 v	Paper
1	0.003	µf	500 v	
1	0.02	µf	600 v	
1	0.02	µf	400 v	
1	0.05	µf	400 v	
1	0.1	µf	400 v	
4	0.004	µf	500 v	Mica
1	8.0	µf	50 v	Electrolytic, Blue Beaver
2	4x10	µf	450 v	Electrolytic, Mallory FP-434

* Matched Resistors.

APPENDIX 2 - (Continued)

METERS

1	0-1 ma	Weston 506
1	5-0-5 ma	Weston 506, fitted with 15-0-15-ma scale, shunted with 1.916 ohms

CONNECTORS

1	Cannon XK-3-14	Chassis receptacle
1	Cannon X-3-14	
1	Jones P-306-RP	
1	Phone jack, open circuit	

SWITCHES

3	Switch-kit, Centralab K-122	
1	Lever-action switch, Centralab 1455	
1	Lever-action switch, Centralab 1454	
2	B-section	Wafer, 11-position
4	J-section	

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.

TRANSFORMERS

1	Bridge transformer, Kenyon P-202
4	Transformer Audio Development Co A-5311A
2	Choke coil U.T.C. VIC-14

RECTIFIERS

4	Sylvania Rectifier 1N34

MISCELLANEOUS HARDWARE

11	Octal tube sockets, Amphenol S-8
6	Bar knobs
2	Round knobs

VACUUM TUBES

2	6SF5
3	6SN7
2	6V6
1	6J5
1	6SJ7
1	6H6
1	6E5

MATERIALS FOR THE TMB TYPE OC-1A 5000-CYCLE OSCILLATOR

RESISTORS

1	300	ohms	1-w, IRC BT-1
1	500	ohms	
2	2	K	
1	5	K	
1	7.5	K	
7	10	K	
3	50	K	
4	100	K	
1	500	K	
4	1	M	
1	2	M	
1	6	K	10-w, Sprague Koolohm
1	5	K	Potentiometer
1	200	K	Potentiometer

CAPACITORS

1	100-1000	$\mu\mu f$	Mica trimmer
1	0.0015	μf	Silvered mica
1	0.0025	μf	Silvered mica
1	0.01	μf	400 v, Paper
2	0.05	μf	400 v, Paper
1	0.5	μf	450 v, Paper
1	10.0	μf	50 v, Blue Beaver
1	2x10	μf	450 v, Mallory FP-231
1	4x10	μf	450 v, Mallory FP-434

MISCELLANEOUS HARDWARE

6	Phone jack, open circuit
1	a-c chassis receptacle
1	2-amp fuse Littlefuse 3AG
1	Fuse holder Littlefuse 1075, for Type 3AG fuse
1	SPST toggle switch
1	Pilot-light assembly

TRANSFORMERS AND CHOKES

1	Power transformer	Thordarson T-13R13
1	Filament transformer	Thordarson T-19F80
1	Transformer Audio Development Co.	A-5311
2	Filter choke,	Thordarson T-47C07
1	Loading coil, Western Electric Type B - No. D170718	

VACUUM TUBES

1	6SC7
1	6J5
1	6SN7
1	5Z4
1	6V6
1	6SJ7
1	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.

MATERIALS FOR THE TMB TYPE PS-SM-5A POWER SUPPLY

RESISTORS

2	5	K	10-w, Sprague Koolohm
3	20	K	1-w, IRC BT-1
6	75	K	
3	125	K	
3	200	K	
3	500	K	
3	500	K	1/2-w, IRC BT-1

CAPACITORS

3	0.25	μf	600 v, C.D. DYR 6025
2	2.0	μf	600 v, C.D. DYR 6200
2	4.0	μf	600 v, C.D. TLAD 6040
2	10.0	μf	450 v, C.D. Blue Beaver
1	4x10	μf	450 v, Mallory FP-434

TRANSFORMERS AND CHOKES

2	Power transformer	Thordarson	T-17R30
1	Filament transformer	Thordarson	T-21F11
1	Filter choke	Thordarson	T-67C49
4	Filter choke	Thordarson	T-57C54

BATTERY

1	22 1/2-v	Burgess battery

MISCELLANEOUS HARDWARE

1	a-c power chassis receptacle
2	Chassis receptacle Jones S-306-RP
11	Octal sockets Amphenol S-8
1	Fuse holder Littlefuse No. 1075, for 3AG fuses
1	5-amp Fuse Littlefuse 3AG
1	SPST Toggle switch

VACUUM TUBES

4	5Z4
1	6AS7
3	6SJ7
1	6B4-G
2	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.

Operating and Service Notes

Date	

PRNC-7899-10-27-48-75