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An Audio Amplifier Testing Unit

By the Engineering Department, Aerovox Corporation

WE previously have pointed out the value of gain, distortion, and output power measurements in checking the performance of audio amplifiers.[1] The apparatus commonly employed in taking these data in the laboratory and in the amplifier shop includes several independent instruments which must be connected together and to the amplifier each time a test is to be made. They are usually separated afterward. It frequently is inconvenient to keep the measuring assembly intact, and appreciable labor is apt to be involved in each re-assembly.

In this article we will describe a single, self-contained instrument for making amplifier gain, distortion, and output power measurements and for checking ac and dc voltages throughout the amplifier, as well. Examination of the circuit diagram will reveal that the stages in this instrument duplicate in simplified form the separate devices, such as low-distortion oscillator, ac-dc vacuum-tube voltmeter, input millivolter, and distortion meter, ordinarily gathered together for amplifier test runs. The instrument is designed for full ac power-line operation and for testing amplifiers or single audio stages of all types.

LAYOUT

Components of this instrument are (1) Low-distortion single-frequency audio oscillator for generating a sine-wave test signal; (2) A. F. millivolter for dividing the oscillator output voltage into small values for high-gain amplifier input circuits; (3) Vacuum-tube voltmeter for reading input a. f. voltage to the millivolter, amplifier a. f. output voltage, signal level at various points throughout the circuit, and both ac and dc operating voltages at high-order meter input resistance at any point in the amplifier; (4) Resonance bridge for use in conjunction with the oscillator and v.t. voltmeter stages to measure amplifier distortion; and (5) Power supply for the entire unit.

These stages are shown functionally in the block diagram of Figure 1. The low-distortion oscillator, designed for single-frequency sine-wave output, feeds into the millivolter. A terminal, T1, is also provided for external use of the oscillator output voltage. The oscillator circuit contains an output-voltage control.

The millivolter is a calibrated step-type potentiometer arranged for selection of signal levels of 1, 0.1, 0.01, 0.001, and 0.0001 volt when the input voltage to the potentiometer is adjusted (by means of the oscillator gain control) exactly to 1 volt. Small signal voltages from the millivolter circuit are fed directly to the input circuit of the amplifier under test via terminals T2 and T3.

The output circuit of the amplifier is connected to terminals T4 and T5 at the input circuit of the isolating

[1] Measuring Distortion in Audio-Frequency Amplifiers. *Aerovox Research Worker.* July 1940. Applications of the A.F. Test Oscillator. *ibid.* Jan. & Feb. 1941. Taking Complete A.F. Amplifier Data. *ibid.* May 1942.

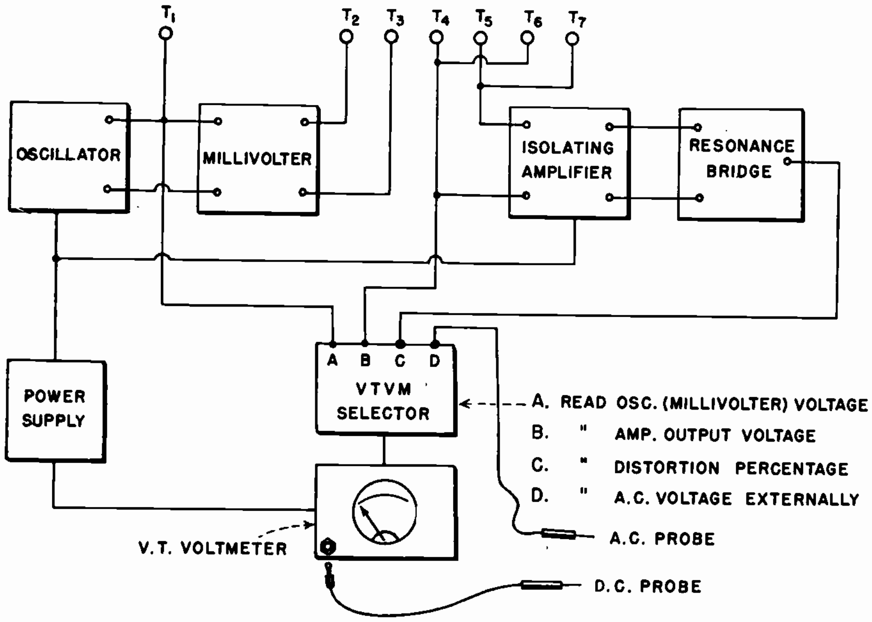

Figure 1

bridge amplifier. If the amplifier does not have a self-contained load device, a load resistor corresponding in resistance value to the recommended amplifier load impedance is connected to terminals TL1 and TL2.

The bridge stage is a conventional resonance bridge which has been preset to null at the oscillator frequency. A single-stage isolating amplifier connected ahead of the bridge presents a high value of input impedance to the output circuit of the amplifier under test.

The v.t. voltmeter may be switched into various circuits by means of a special selector switch. When the selector is in position A, the voltmeter reads oscillator output voltage and millivolter input voltage; at B, amplifier output voltage is indicated; at C, the voltmeter is at the output circuit of the resonance bridge for distortion indications; and at D, the meter is connected to terminals T6 and T7 for external measurement of ac voltages.

The power unit supplies oscillator, bridge amplifier, and v.t. voltmeter circuits. It is conventional in design and requires no particular refinements.

CIRCUIT DESCRIPTION

Oscillator. The circuit diagram for the entire instrument is shown in Figure 4. The audio oscillator employs a resistance - capacitance - tuned circuit with degenerative feedback. This unique circuit which has found wide acceptance was developed by Scott[2, 3] and is particularly recommended for distortion measurements.

The oscillator is essentially a direct-coupled amplifier embracing triode V1 and output-type tetrode V2. This amplifier is represented by the center block in Figure 2. Both regenerative and degenerative types of feedback are introduced into the amplifier circuit, as indicated in the block diagram.

The degenerative feedback circuit is a parallel T network[2] (C1, C2, C3, R1, R2, and R3 in Figure 4) having considerable selectivity. It resembles the Wien bridge in that it may be set to null at a frequency determined by its resistance and capacitance values. It is balanced for only one frequency with a given set of components. Degenerative feedback from output to input circuits of the amplifier tends to cancel gain and thereby prevent passage of a signal in the normal direction through the amplifier. When the sole degenerative path is through the parallel-T network, however, cancellation of gain occurs at all frequencies except the one to which the network is responsive. Accordingly, a signal at the network frequency passes through the amplifier readily, there being no degeneration at that frequency. But all signal harmonic frequencies are excluded. The result is an output voltage of unusually pure waveform. When a small amount of regeneration is introduced along with the degeneration, the amplifier becomes a low-distortion oscillator. Signals having a distortion percentage lower than one-tenth of one percent have been obtained with oscillators of this type.

The first stage of the oscillator includes the triode section of a 6SQ7 tube, V1, which receives fixed negative grid voltage from the 1.25-volt bias cell, BC. The diodes of this tube are not used in the circuit and are accordingly connected to the cathode terminal at the tube socket.

The first stage is direct-coupled to the second tube, V2, a 6Y6-G, which delivers audio-frequency output voltage to the millivolter and external-output terminal post via its cathode circuit and the output-voltage control, R12. A portion of the audio voltage, taken through the R8-R9 voltage divider, is impressed upon the grid of an electron-ray indicator tube, V3, which serves as a distortion-level indicator.

The tuned degenerative network comprises capacitors C1, C2, and C3 and resistors R1, R2, and R3. Values for these components given in Figure 4 are for 1000-cycle operation. They may be changed in accordance with the equations given in Figure 4, however, to enable oscillator operation at any other audio frequency.

R5 and R6 are harmonic controls operated while observing the deflection of the electron-ray indicator, V3. These controls are pre-set in the initial oscillator adjustment, with output control R12 fully advanced, and are subsequently not disturbed except during readjustments in servicing the instrument. The adjustment of these controls is "backed off", during the initial adjustment, until the indicator shows that oscillation is barely under way. At this point, the harmonic content of the output voltage is unusually low.

Millivolter. Resistors R13 to R17, rotary selector switch S1, and output terminal posts T2 and T3 comprise the millivolter. The purpose of this potentiometer is to reduce the oscillator output voltage to accurately-determined low values in the millivolt range to be fed into the input circuit of a high-gain amplifier under test.

Voltages provided by the circuit, for the resistor values recommended in the circuit diagram, are 1v., 100 m.v., 10 m.v., 1 m.v., and 0.1 m.v. These levels are adequate for all general test purposes. The points will be correct only when the audio-frequency voltage across the entire potentiometer is exactly 1 volt. The v.t. voltmeter, as will be explained later in the text, may be switched to the potentiometer input for indication, while the oscillator output-voltage control is set for 1-volt deflection. If higher values of output voltage than those provided by the millivolter are required for other test purposes, external connections may be made to terminal posts T1 and T3, the output voltage level controlled by potentiometer R12, and the value of voltage read by means of the v.t. voltmeter.

The resistors in the millivolter circuit must be selected with great care, with respect to accuracy of value and guaranteed stability, to insure excellence of millivolter performance. Treatment of the selected units with a high-grade wax and shielding of the entire millivolter circuit are advisable.

[2] A New Type of Selective Circuit and Some Applications. H. H. Scott. *Proc. I. R. E.*, Feb. 1938, p 226.
[3] A Low-Distortion Oscillator. H. H. Scott. *Gen. Radio Experimenter,* April 1, 1939.

Bridge. The resonance bridge, comprised of capacitors C9 and C10, inductors L1 and L2, and resistors R21, R22, R23, R24, and R25, is the nucleus of the distortion measuring circuit. This bridge is entirely conventional.

The series circuits L1-C9 and L2-C10 are made resonant at the signal frequency. The inductive and capacitive reactances consequently cancel and the bridge may be balanced at this frequency (by adjustment of the R23 arm) as if it contained four resistance arms. The bridge is thus set for null at the signal frequency and no voltage should appear across resistor R25. For any other frequency, such as a signal harmonic, the bridge is unbalanced and a measurable voltage will appear across R25. Some insertion loss is introduced by the bridge circuit.

Any potential appearing across resistor R25 when the bridge is balanced is due to total harmonic voltage, so the ratio of this reading to voltage registered when the bridge is thrown off balance is an indication of distortion percentage. The bridge is permanently balanced during the initial calibration of the instrument and this adjustment will ordinarily not be subsequently disturbed. For obtaining the off-balance voltage reading, a double-pole, single-throw switch is provided to open the two resonant arms. This switch is S2-S3 in Figure 4.

The values of bridge circuit components given in Figure 4 are for 1000-cycle operation, but individual experimenters may readily alter these for operation at other oscillator frequencies. Likewise, several resonant arms might be included in the circuit with an appropriate switching arrangement (ganged, perhaps, with a frequency-changing switch in the oscillator circuit) to enable distortion measurements at more than one frequency.

The single-stage isolating amplifier, around triode V4, provides high input impedance for the bridge, permitting distortion measurements to be made without drawing appreciable amounts of power from the instrument under test. At the same time, the gain control, R19, in this amplifier allows the bridge input signal to be adjusted to a voltage level for satisfactory meter deflection.

V. T. Voltmeter. The vacuum-tube voltmeter is basically a dc instrument employing circuit constants given by Rider[4] and employed in the Chanalyst. For dc measurements, a diode rectifier, V5, has been added to the original circuit. A single cell, B, and a potentiometer, R28, are employed to balance out the voltage due to diode contact potential. In the arrangement shown in Figure 4, the meter is available for either ac or dc measurements, as will be shown presently.

[4] See *Vacuum-Tube Voltmeters*, John F. Rider (pub. J. F. Rider), p. 111.

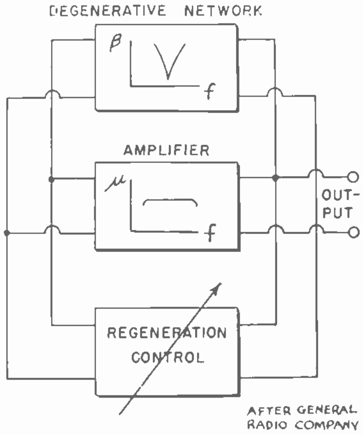

Figure 2

The various voltage ranges as indicated in Figure 4 are selected by means of switch S5. The indicated values are for dc. Circuit response is very nearly linear and will therefore correspond approximately to the microammeter graduations. When ac measurements are made through the diode rectifier, the values indicated on the instrument scale will be ac peak voltages except below about ten volts. For this reason, the lowest ranges will require a special voltage calibration.

Alternating voltages may be measured in external circuits with probes connected to terminal posts T6 and T7 when selector switch S4 is in position D. Millivolter input voltage or oscillator output voltage is read directly with S4 in position A. Amplifier output voltage is measured directly with S4 in position B. Bridge output voltage, in distortion checking, is measured with S4 in position C.

Direct voltages are measured by means of the special dc probe, P, which is placed in contact with the point of positive potential. A ground lead, connected to chassis of the instrument through an auxiliary terminal post, is placed in contact with the point of negative potential. An isolating resistor, R18, is built into the shielded probe to isolate the measuring circuit from the instrument under test. The lead from the dc probe is shielded throughout its length to reduce body capacitance effects. This lead is terminated by the plug, X, at its opposite end.

When the dc plug is inserted into jack J, the diode rectifier circuit is automatically disconnected and the v.t. voltmeter is responsive only to direct voltages. The plug is removed from the jack when ac measurements are to be made.

INITIAL CALIBRATION

Oscillator. If components C1, C2, C3, R1, R2, and R3 are carefully chosen with respect to capacitance and resistance, the oscillator frequency will agree very closely with the calculated value. However, the frequency may be compared (most satisfactorily against a good audio standard, using an oscilloscope set up to show Lissajou's figures) and a final close adjustment of frequency made by "pruning" the capacitor and resistor values until synchronism is obtained.

Output-voltage control R12 will afford smooth, continuous variation of the output voltage up to approximately 25 volts RMS at the value of plate voltage shown in Figure 4. The two harmonic controls, R25 and R26, are pre-set (with output control R12 fully advanced) to a point at which the shadow in the electron-ray tube, V3, barely opens, indicating that oscillation has just been initiated. This is the point of lowest distortion.

V. T. Voltmeter. This circuit is calibrated first with dc input. With the dc probe lead plugged-in, the voltmeter is allowed several minutes of preliminary heating in order to stabilize. The pointer of the microammeter is then brought to zero on the meter scale by adjustment of rheostat R36. Probe P and a ground lead are then connected to a source of variable direct voltage which is monitored by a reliable, high-resistance dc voltmeter. This source may be a battery or a line-operated power supply. The battery may be provided with an output-type potentiometer, as may also the power supply, for voltage regulation, while the power unit might alternatively be provided with an input Variac for the same purpose.

The actual value of the calibrating voltage is not particularly critical, although it should afford deflection in the upper quarter of the meter scale. It is also advisable to supply voltages for the upper ranges in order to test the efficacy of the range-selector resistors.

Some value of voltage, such as 5v., 25v., 125v., or 500v., is chosen for full-scale deflection on one of the meter ranges. The probe is connected to the source and the calibration adjustment rheostat, R34, is adjusted to bring the resulting meter deflection exactly to full scale. This adjustment need not be disturbed subsequently except when the v.t. voltmeter triode is replaced or when the instrument undergoes periodic servicing. The calibration for dc is completed when several points have been checked in each range. During the calibration, it may be found necessary to change individual resistors in the R29-R32 string in order to obtain exact voltage division according to specifications. If these resistors are of exact values, however, these changes will not be found necessary.

Before starting the ac calibration, the dc probe lead must be removed, taking the plug out of the jack. A steady deflection of the microammeter will then be noted. This is due to the 6H6 contact potential and may be corrected readily by means of the bucking voltage supplied by the cell, B. Adjustment of the potentiometer, R28, will thus bring the pointer to zero on the meter scale.

A source of continuously-variable alternating voltage, such as a transformer with output potentiometer or input Variac, monitored by a reliable, high-resistance ac voltmeter, is then connected to terminals T6 and T7 and v.t. voltmeter selector switch S4 is set to position D. As the voltage is adjusted, a deflection will be obtained on the meter scale. By reference to the monitoring ac voltmeter, this deflection will be observed to be peak ac voltage (1.41 times the RMS values shown by the monitoring voltmeter) for voltages of 10 or higher. The 500-, and 125-volt v.t. voltmeter ranges will indicate ac peak voltages directly, as will also the upper portion of the 25-volt range. However, lower values will not be indicated as peak ac voltages by the meter because of the non-linearity of the diode characteristic at low voltages. A curve in which ac voltage is plotted against microammeter deflections will be necessary for the lower voltage ranges, or a special voltage range may be drawn on the meter card.

Adjustment of Bridge Arms. The coil-capacitor arms of the bridge must each be adjusted to the oscillator frequency before permanent wiring into the bridge circuit. This resonating operation is accomplished by means of the circuit shown in Figure 3.

The test circuit is a simple pentode amplifier with common circuit component values. The tube may be a 6K7 or 6SK7 operated from a 100-to-250-volt dc power supply.

For the adjustment, an audio test oscillator is connected to the grid input circuit of the amplifier. This will be preferably the oscillator unit of the test set. Each bridge arm, comprising a choke coil and capacitor, is connected successively in the output circuit, as shown in Figure 3. The bridge-arm capacitor thus performs the functions both of blocking capacitor for the shunt-fed plate circuit and resonating capacitor for the L-C circuit. An ac vacuum-tube voltmeter is connected in parallel with the choke coil. (This will be preferably the v.t. voltmeter of the test set.)

If a variable-frequency audio test oscillator is employed, it is set to the frequency used in the test set. The v.t. voltmeter is then set to read the voltage across the choke, and the resonant frequency of the bridge arm under test is adjusted in the following manner:

(1) The initial value of capacitance C is chosen somewhat lower than that calculated to resonate the choke at the test frequency. A capacitor having that rating is then connected in series with the choke and the combination inserted into the test circuit of Figure 3.

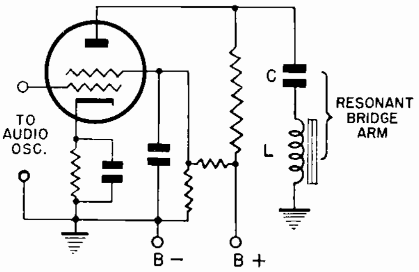

Figure 3

(2) With the oscillator delivering signal voltage to the amplifier grid circuit, an audio-frequency voltage will be developed across the choke, this voltage being indicated by the v.t. voltmeter.

(3) Small capacitance values are then added in steps to the initial capacitance, C, by successively connecting low-capacitance capacitors in parallel with C. At each addition, the capacitance will increase as resonance is approached, and the voltmeter deflection will increase proportionately. This deflection will be maximum *at resonance* and will drop back in the direction of zero as further increase in the capacitance of C tunes the circuit to some value beyond resonance.

(4) The capacitance of C accordingly is adjusted, in the manner just described, to the exact value (as indicated by peak deflection of the voltmeter) required to resonate the choke at the test frequency. The operation is to be performed carefully with each bridge arm. If the bridge arms are provided with shields, the latter must be in their normal position while these resonating operations are performed.

MANIPULATION

Gain Measurements. (1) Connect terminals T2 and T3 to input of amplifier under test (sample amplifier),

(2) Set sample amplifier gain control to desired level,

(3) Set v.t. voltmeter range switch S5 to 5 volts, and selector switch S4 to position A,

(4) Connect output of sample amplifier to terminals T4 and T5,

(5) If output of sample amplifier is not already terminated by a load device (such as loudspeaker), connect a heavy-duty resistor of the same ohmage to terminals TL1 and TL2,

(6) Set millivolter switch S1 to 0.0001v.,

(7) Adjust oscillator output - voltage control R12 for 1-volt deflection of meter,

(8) Change v.t. voltmeter range to 500v. and selector switch to position B, and read sample-amplifier output voltage. Gain of amplifier (or amplifier stage) will then be the ratio of output voltage to input voltage (the latter taken from the millivolter switch position).

Depending upon the gain of the amplifier or stage under measurement, it may be necessary to change the input voltage level, by means of the millivolter, and the range of the v.t. voltmeter for output voltage. However, the gain ratio calculation will remain the same.

A. F. Output Power Measurement. Take output voltage reading with sample amplifier connected to instrument as explained under *Gain Measurements.* The output power (in watts) may then be determined by dividing the square of the output voltage, shown by the v.t. voltmeter, by the value of load resistance or load impedance.

Amplifier Distortion Measurements. (1) With sample amplifier connected to instrument as explained under *Gain Measurements,* and with amplifier supplied with oscillator signal, select v.t. voltmeter range of 125v.,

(2) Open bridge switch S2-S3,

(3) Set switch S4 to position C,

(4) Adjust gain control R19 to give a convenient deflection near the upper end of the voltmeter scale. If the selected voltage range is too high, switch down to successively lower voltage ranges. Note this voltage value, calling it E_1,

(5) Close bridge switch S2-S3, and note that meter reading falls to a lower value. Call this new deflection E_2. If the reading is not visible on the scale, select a successively lower voltage range until a readable deflection is obtained,

(6) The distortion percentage may then be determined: $100(E_2/E_1)$.

Oscillator Distortion Measurements. Oscillator distortion may be measured, provided the oscillator frequency is the same as the distortion-bridge resonant frequency. Connections and procedure are the same as explained under *Amplifier Distortion Measurements,* except that the sample oscillator output is connected to terminals T4 and T5. Distortion of the oscillator stage of the instrument itself may be checked by connecting jumpers between T1 and T4, and T2 and T5 and proceeding as explained in the foregoing section.

External Alternating Voltage Measurement. (1) Set switch S4 to position D,

(2) Connect probe leads to terminals T6 and T7,

(3) Select appropriate voltmeter range.

External Direct Voltage Measurement. (1) Insert plug of *positive* dc probe into jack J,

(2) Connect a *minus* dc probe lead to ground (chassis) of instrument,

(3) Select appropriate voltmeter range.

External Use of Oscillator. (1) Set range switch S5 to 25v.,

(2) Set switch S4 to position A,

(3) Connect to terminals T1 and T3 equipment which is to receive the audio voltage,

(4) V.T. voltmeter will now indicate the strength of this voltage. Adjust oscillator output-voltage control R12 to give desired value of voltage.

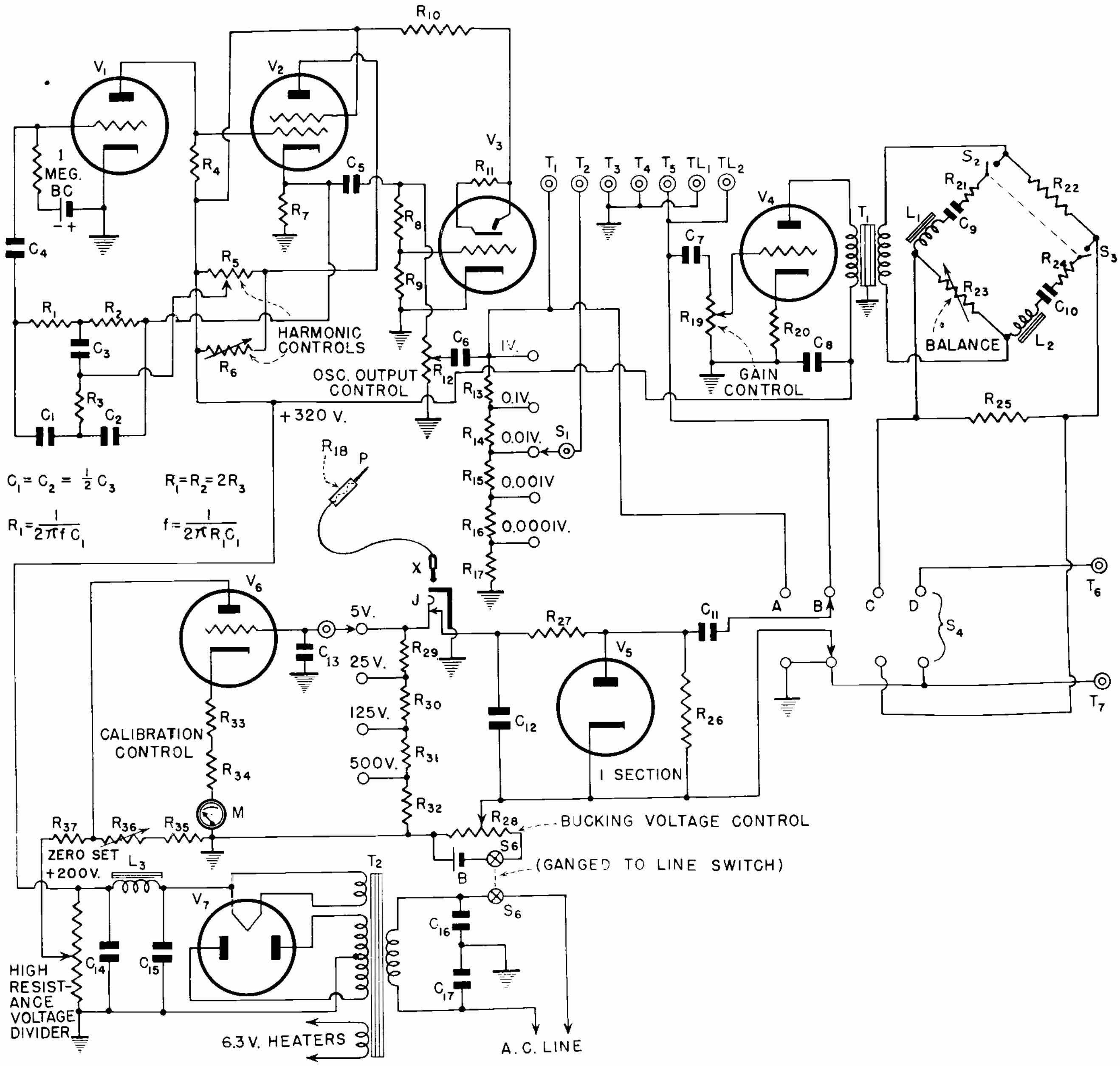

Figure 4

PARTS LIST

B—1.5-v. miniature dry cell
BC—1.25-v. bias cell
C1, C2—0.001-mfd. mica
C3—0.008-mfd. mica
C4—0.02-mfd. mica
C5, C6—0.1-mfd., 200-v. tubular
C7, C8—0.1-mfd., 600-v. tubular
C9, C10—0.00125-mfd. mica
C11—0.02-mfd. mica
C12—0.01-mfd. mica
C13—0.002-mfd. mica
C14, C15—8-mfd., 450 d.c.w.v. electrolytic
C16, C17—0.1-mfd., 200-v. tubular
J—miniature closed circuit jack
L1, L2—20 henries, 100 ohms
L3—20 henries, 100 m. a.
M—0-500 d.c. microammeter
R1, R2—40,000 ohms 1 watt
R3—20,000 ohms, 1 watt
R4—350,000 ohms 2 watts
R5—200-ohm wirewound potentiometer
R6—1000-ohm wirewound potentiometer
R7—6000 ohms 5 watts
R8—100,000 ohms 1 watt
R9—10,000 ohms 1 watt
R10—150,000 ohms 1 watt
R11—1 megohm ½ watt
R12—10,000-ohm wirewound potentiometer
R13—900,000 ohms 1 watt
R14—90,000 ohms 1 watt
R15—9000 ohms 1 watt
R16—900 ohms 1 watt
R17—100 ohms 1 watt
R18—1 megohm 1 watt
R19—500,000-ohm potentiometer
R20—5000 ohms 1 watt
R21—100 ohms 2 watts
R22—100 ohms 2 watts
R23—200-ohm wirewound potentiometer
R24—100 ohms 2 watts
R25—100,000 ohms 1 watt
R26—20 megohms ½ watt
R27—1 megohm ½ watt
R28—20,000-ohm wirewound potentiometer
R29—8 megohms 1 watt
R30—1.6 megohm 1 watt
R31—300,000 ohms 1 watt
R32—100,000 ohms 1 watt
R33—6200 ohms 1 watt
R34—2000-ohm wirewound rheostat
R35—6200 ohms 1 watt
R36—10,000-ohm wirewound potentiometer
R37—27,000 ohms 2 watts
S1—Single-pole, 5-position rotary switch
S2-S3 Combination—D.p.s.t. toggle switch
S4—Two-pole, 4-position rotary switch
S5—Single-pole, 4-position rotary switch
S6—D.p.s.t. toggle switch
T1—Shielded input transformer (10,000 ohms imp. to 160,000 ohms)
T2—Power Transformer: 350-0-350v., 75-100 m.a.; 5v., 2A.; 6.3 v., 4-5A.
V1—6SQ7
V2—6Y6-G
V3—6E5
V4—6C5
V5—6H6
V6—6P5-G
V7—5Z3

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