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The Aerovox Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 14, NO. 5 MAY, 1942 50c per year in U.S.A. 60c per year in Canada

Taking Complete A. F. Amplifier Data

By the Engineering Department, Aerovox Corporation

SOUND systems have found such wide application in recent years that the maintenance and repair of this equipment has become a distinct occupation.

Modern amplifiers approximate radio receivers in the number of their circuits and the increasing difficulty with which faulty operation is diagnosed and localized in them. Since in order to be profitable an amplifier test must be performed as quickly and completely as possible and the diagnosis must be precise. The test must be made according to a well-organized, time-saving plan.

This article will describe a procedure for the routine inspection of audio amplifiers in maintenance and trouble shooting. Some of the methods included have been borrowed from laboratory practice, others are common to radio servicing. The steps given below have been selected to disclose most amplifier troubles. The arrangement of tests and their sequence are believed logical for complete diagnosis of amplifier performance, whether trouble is present or not.

By sufficient rehearsal of the operations, the sound serviceman should acquire considerable dexterity in the speedy analysis of amplifier operation. The data he collects from the series of tests should enable him to recondition an amplifier completely or appraise its performance.

Following are the recommended tests in the order in which they should be made:

1. Tube Check
2. A. F. Signal Tracing
3. Static Voltage & Current Measurements
4. Gain Measurement
5. Frequency Response Check
6. Distortion Check
7. Check for Feedback
8. Impedance Measurement
9. Power Output Measurement
10. Hum and Noise Level Checks

The tube check (1) is preferably one which gives an indication of some dynamic characteristic (such as transconductance or *amplification* factor), rather than emission. A.F. signal tracing (2) consists of following the progress of an audio signal through the various amplifier stages, noting amplification, reduction, or distortion of the signal in the stages. This operation was fully described in the January 1941 issue of the Research Worker. The static voltages and currents (3) are measured at appropriate circuit points, generally directly at the tube socket terminals. A rectifier-type a.c. voltmeter is satisfactory for indicating the heater voltages, but an *electronic d.c. voltmeter* or potentiometer-type indicator is mandatory for plate and screen voltages. Most of the high-resistance non-electronic meters are totally useless for measurements in resistance-coupled amplifier circuits. The operations numbered from 4 to 10 in the list will now be discussed in detail.

GAIN

Gain measurements reveal the actual amplification obtained in the entire amplifier or in any of its stages. Gain measurements are quantitative. Both *voltage gain* and *power gain* are measurable and are of importance to sound engineers. However, voltage gain is of commonest concern and is generally implied by use of the single word, gain.

Both voltage and power gain are determined by the increase in output signal over input signal. In procedure, the ratio of output voltage or power to input voltage or power is discovered by measurement. There is no name unit for gain, this characteristic being expressed simply as the quotient indicated by the voltage or power ratio. For example, a gain of 10 (or 10 times) corresponds to the ratio 10:1, and indicates the amount of amplification in *any* case where the output voltage or power is ten times the input value. Since this is regardless of the actual magnitudes of the input and output signals, gain is seen to be a relative characteristic.

To determine the overall voltage gain of an amplifier, an a.f. voltage is applied to the input terminals of the amplifier and successive readings taken of the voltage impressed across the input circuit and the output voltage developed across a terminating resistance or impedance. Voltage measurements are made with a vacuum-tube

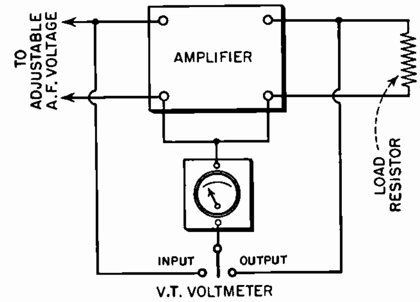

FIG.1

voltmeter in a circuit similar to those of Figures 1 and 2. The ratio of the two voltages is the overall gain. However, most amplifier manufacturers state overall gain as the number of decibels corresponding to this ratio.

It is advisable to make overall gain measurements with all volume controls set at maximum volume and to adjust the voltage of the input signal to deliver an output voltage corresponding to the rated amplifier output power. The proper output voltage may be determined from the equation:

$$E = \sqrt{PR} \qquad (1)$$

where E is the required e.m.f. (volts)
P the rated undistorted output power (watts)
R the load resistance or impedance (ohms)

An alternative method of measuring overall gain is shown in Figure 2. The source of audio-frequency test voltage is properly terminated and then connected to the amplifier input through a standard *gain set.* The amplifier is suitably terminated by a non-inductive load resistor of appropriate wattage, and a vacuum-tube voltmeter is arranged to give successive indications of input and output voltages.

The tap on the load resistor enables the operator to select for output indication an a.f. voltage within the full-scale range of the vacuum-tube voltmeter, while full power output is supplied to the load. This is an advantage since the amplifier will be operated at full output during the measurements without slamming the meter.

With the voltmeter in the input position, the a.f. voltage is adjusted to a value necessary to give full power output by means of the gain control in the oscillator. The meter is then switched to the output circuit and the gain set adjusted to restore the meter reading to this reference level. The gain may then be read directly from the dials of the gain set.

FREQUENCY RESPONSE CHECKING

The frequency response of the entire amplifier, of any one or combination of its stages, or of its transformers is studied by observing the output voltage magnitude as the frequency of a constant-level input signal voltage is varied. Values of a.f. output voltage are plotted against frequency to give a response curve. In frequency response checks, the input signal voltage must be delivered by a good variable-frequency oscillator with low-distortion output, and a vacuum-tube voltmeter or calibrated oscilloscope employed as the indicator.

It is customary to make response tests at as many points in the range, 30 to 10,000 cycles per second, as practicable. The frequency response of good PA amplifiers is such that the output voltage- (or output db) input frequency curve does not deviate from a straight line by more than plus or minus 2 db between 30 and 10,000 cycles per second. Amplifiers for broadcast, laboratory, and high-fidelity applications show even better response.

When checking the overall frequency response of an amplifier, it is recommended that the input signal voltage be maintained at the proper level required to produce maximum undistorted power output, and that gain controls be set for maximum volume. The tone control must be set at the mid-range or "mellow" position.

Single stages or any combination of stages may be checked for frequency response in the same manner, except that the constant voltage-variable frequency input signal is fed into the input circuit of the particular stage under investigation and the indicating instrument connected to its output circuit. Single-stage frequency response runs are invaluable in tracing the cause of overall response deficiencies.

DISTORTION CHECKS

The entire amplifier or each stage may be checked at various settings of gain controls and at various input-voltage frequencies for the presence of distortion. This test logically should follow the response run.

An input signal of very low harmonic content is supplied to the amplifier or stage under test by a high-grade oscillator, and distortion checked by observing the steady tube currents for fluctuations, or by an inspection of the output signal waveform.

When the simple qualitative check is employed, the cathode current in a single stage is the most satisfactory to examine. The d.c. component of cathode current in a class-A amplifier stage should, under normal operating conditions, show no fluctuation when the input signal is applied. Distortion is betrayed by a change in the value of current indicated by a d.c. milliammeter upon introduction of the input signal.

Each amplifier stage may thus be examined for distortion, the test advancing from input to output sections of the amplifier and distortion localized within one stage circuit.

The foregoing simple distortion test is useful only in class-A voltage amplifiers and others in which the cathode current does normally change with the input signal. It is obvious that this method would be of no value in class-B and class AB systems in which the total cathode current swings widely under dynamic conditions.

The output waveform is inspected for excessive harmonic content (distortion) by means of a distortion meter or wave analyzer, a low-distortion a.f. signal of normal voltage being applied to the amplifier or stage input. These instruments will indicate directly the actual percentage of each harmonic present in the output signal from each stage, values which may be compared with the tube charts or amplifier manufacturer's guarantee.

TESTS FOR FEEDBACK

Regenerative feedback is often quite perplexing to the amplifier serviceman, since it may not cause the amplifier to oscillate at an audible frequency, but nevertheless is present in sufficient quantity to cause serious distortion.

When regeneration is suspected, each stage should be examined for its presence by means of grid current or cathode voltage measurements. The presence of grid current in any class of amplifier receiving no input signal is a certain indication of feedback.

Each stage should be examined separately, progressing from input to output circuits of the amplifier. The presence of feedback over several stages, rather than in a single one, may be verified by opening the connection between a stage in which abnormal no-excitation d.c. voltages or currents have been discovered and the stages immediately preceding and following. Currents or voltages should fall to normal values when the contributing stages are thus uncoupled. Likewise, abnormal currents and voltages will not be found in the isolated stages.

Audible feedback in a previously efficient amplifier generally arises in one stage. In developmental units, it is most often due to unwise layout. In the first case, the a.f. voltage generated is passed along to each succeeding stage and into the loudspeaker. The offending stage is readily located if, in the absence of an input signal the output of each stage—from input to output ends of the amplifier—is inspected with a vacuum-tube voltmeter or sensitive headphones. The first

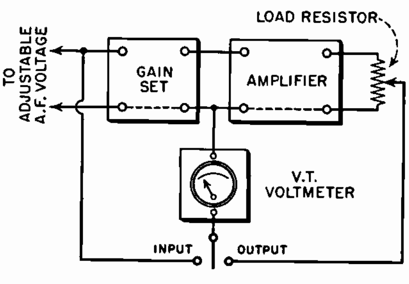

FIG.2

stage delivering a howl to the headphones or deflecting the meter is the one in which the audible feedback originates.

DETERMINATION OF IMPEDANCE

An investigation of the impedance of transformer windings logically will follow the discovery of distortion, although the impedance of an output transformer will be under surveillance when the loudspeaker signal is low. It may also be desirable to check an unknown transformer for secondary impedance when matching speakers to a strange amplifier.

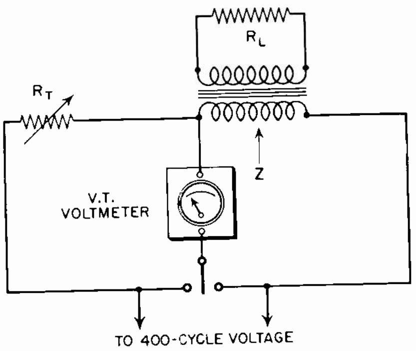

FIG.3

Figure 3 shows a simple method of measuring the impedance of a transformer winding. The unused winding is connected to its usual circuit points or to an equivalent resistor, R_L. The winding under test is connected in series with a variable resistor, R_T and a source of 400-cycle controllable a.f. voltage. R_T is a wire-wound rheostat or a laboratory decade box. A vacuum-tube voltmeter is arranged with a s.p.d.t. switch to measure successively the a.f. voltage drops across the resistor and winding.

In making the test, R_T is adjusted until its voltage drop is identical with that of the transformer winding. Its resistance at this setting then equals the impedance of the winding. The input voltage level is adjusted for a good, readable deflection of the meter.

The value of R_T at "balance" may be determined by means of a good ohmmeter or, for more accurate purposes, by means of a resistance bridge.

The impedance of a transformer winding (with the other winding appropriately loaded) might be found also by measuring its inductance upon a suitable bridge for the purpose, measuring its resistance. and calculating from the equation:

$$Z = \sqrt{R^2 + (2\pi f L)^2} \qquad (2)$$

where Z is the required impedance (ohms)
R the resistance (ohms)
f the frequency of the bridge voltage (c.p.s.)
L the measured inductance (henries)

If the turns ratio of a transformer has been determined previously, the impedance ratio or the separate impedances may be found with the aid of the following formulae:

$$\frac{N_S}{N_P} = \sqrt{\frac{Z_S}{Z_P}}, \quad \frac{Z_S}{Z_P} = \frac{N_S^2}{N_P^2}, \quad Z_S = \frac{Z_P N_S^2}{N_P^2},$$

$$\text{and} \quad Z_P = \frac{Z_S N_P^2}{N_S^2}$$

where N_P is the number of primary turns
N_S the number of secondary turns
Z_P the primary impedance, and
Z_S the secondary impedance or impedance of the load.

The turns ratio may be determined by applying a known alternating voltage across one winding and measuring the induced voltage across the other. The ratio of the two voltages will then correspond to the turns ratio.

Tube manufacturers state in their tables the values of load impedance (or load resistance) recommended for maximum undistorted power output. This load value is matched to the power-tube plate impedance by means of a transformer of proper turns ratio, as indicated above.

A rapid method for determining the impedance of an output transformer secondary of an amplifier in operation consists in adjusting a standard *output power meter* for maximum deflection and reading the impedance from the meter dials. The power meter is connected simply to the output transformer terminals, a 400-cycle signal voltage introduced into the input circuit of the operating amplifier. The meter-range switch is set to accommodate the maximum amplifier power output, and the meter input impedance is adjusted for maximum deflection of the indicating instrument. The reading of the impedance dial at this setting is the impedance of the output transformer secondary.

POWER OUTPUT MEASUREMENTS

The audio output watts may be measured with the audio-frequency output power meter or determined from voltage or current readings taken in a properly terminated output circuit.

Several models of non-electronic output power meters are now commercially available for a.f. measurements. The following ranges are provided by three of the currently advertised models: (A) 2.5 to 20,000 ohms input impedance in forty steps of a single rotary switch; indicating instrument reads full-scale ranges from 0.5 milliwatt to 5 watts in four ranges with a midscale accuracy of 5%. (B) 2.5 to 20,000 ohms input impedance in forty steps of a single rotary switch; indicating instrument reads full-scale values of 0.1 milliwatt to 50 watts in twenty ranges with a midscale accuracy of 2%. (C) 2.5 to 20,000 ohms input impedance in forty steps divided between a 10-position ohms selector switch and a 4-position ohms multiplier switch; indicating instrument reads full-scale values from 0.1 milliwatt to 5 watts in four ranges with an accuracy stated by the manufacturer as variable with frequency.

Since the output power meter presents to the amplifier under test a load impedance of widely adjustable value, this instrument may be connected directly to the amplifier output terminals without introducing any further load or matching device, provided the input impedance of the meter is set to the value of amplifier output impedance. If the latter is not known, the meter impedance may be adjusted for maximum deflection of the indicating instrument with the amplifier passing a 400-cycle signal, whereupon the output impedance may be read from the dials.

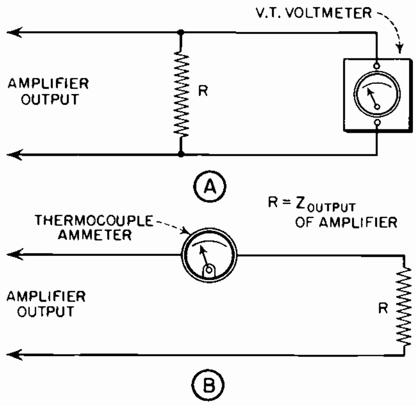

FIG. 4

Advantages of the output power meter are that its wattage readings are direct, requiring no calculations or conversions, and its input circuit may be closely matched to the amplifier output circuit.

By the voltmeter or ammeter method, output power levels are calculated from voltage or current values measured in a terminating circuit of proper resistance or impedance. This method is illustrated in Figure 4. Circuit A is that for the indication of a.f. power output in terms of voltage; Circuit B for power indications in terms of current readings. In both examples, the load resistor, R, terminates the amplifier output. Its resistance must accordingly be equal to the rated output impedance of the amplifier and its wattage must be sufficient to withstand the maximum power output.

The a.c. voltmeter used in Figure 4-A must have good accuracy at the test frequency. It is strongly recommended that a vacuum-tube voltmeter be used in this position.

The amplifier power output is determined, in the voltmeter method, by means of the equation:

$$P = \frac{E^2}{R} \qquad (3)$$

where P is the audio output (watts)
E the meter reading (volts)
R the load resistance (ohms)

Taking Complete A. F. Amplifier Data

(*continued*)

Alternatively, the value of the a.f. current flowing through the load resistor may be measured, as in Figure 4-B, and this value employed in a calculation of the a.f. power:

$$P = I^2 R \tag{4}$$

where P is the audio output (watts)
I the meter reading (amperes)
R the load resistance (ohms)

For best results, the current instrument should be a thermocouple type ammeter or milliammeter. As a substitute for this type of current meter, a vacuum-tube voltmeter may be employed in connection with a suitable shunt for reading the current in terms of the voltage drop across the shunt.

HUM AND NOISE LEVEL

Inherent hum and noise level of an amplifier or isolated stage may be quantitatively analyzed either by means of a vacuum-tube voltmeter of sufficient sensitivity or a standard output power meter.

Any output voltage present when the signal voltage is removed, and not due to feedback, may be attributed to hum and noise components. If the one is known to be present in the absence of the other, it may be identified by a simple headphone or speaker listening test.

The simple vacuum-tube voltmeter or output meter will indicate the total magnitude of hum and noise components and will not differentiate between the two nor separately evaluate them. To determine the amplitude of each component, it is necessary to select that component from the total. This operation is best performed by a wave analyzer, which is in principle a highly selective vacuum-tube voltmeter which may be tuned successively to the fundamental hum frequency and each of its harmonics. It will generally be necessary to measure only the fundamental, second, third, and fourth harmonic amplitudes with the wave analyzer.

Sound equipment manufacturers usually express the hum or noise level as a number of decibels below maximum output, and the experimenter may, if he desires, convert his measured values into these units.

After the hum level has been accounted for, the remainder of the no-signal output voltage may be attributed to noise. A certain amount of this arises from thermal agitation in the input stage. However, coupling capacitors in resistance-coupled stages should be inspected for low dielectric resistance, with a good megger, when the noise level appears excessive. A good coupling capacitor should show a dielectric resistance equal to 500 times the value of the grid resistor used in the succeeding stage.