THE W. E. 86-TYPE AMPLIFIER, UNIT OF THE 'MIRROPHONIC' SYSTEM

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THE circuit of Fig. 1, like that of W. E. 91-A amplifier traced in last month's issue, includes special provisions for suppression of harmonic distortion. In the present circuit, however, reverse feedback is not used for that purpose, but the same result is accomplished by novel arrangements introduced into the return line between the primary of the output transformer and the filaments of the output tubes. These arrangements are traced in detail herein, and constitute the "harmonic equalizer."

The present amplifier also uses a plate current meter calibrated in percentage and not in milliamperes, and reading (through a rotary switch) the current of eight separate circuits in terms of percentage of the correct value. The necessity for noting or remembering the correct values of eight circuits is thus eliminated, and possibilities of a mistake in operation are reduced.

Line power enters Fig. 1 through Terminals 15 and 16, at the bottom of the drawing, completing its circuit through switch D-1 and through the primary of the power transformer.

The left-hand secondary of the power transformer supplies the heaters of the first three tubes. Those heaters are wired in parallel. From the right-hand end of that secondary trace up, left and up to the heater of VT-3; thence down and right to the left-hand end of the same winding. Beginning again at Terminal 9 of the same secondary, trace up, left, and up to the first point of junction; then left and up to the heater of VT-2, and down, right and down as before, to transformer Terminal 1. Again beginning at transformer Terminal 9, follow up, left, up to the first point of junction, left as far as possible, up, through the heater of VT-1, down right as far as possible and down to transformer Terminal 1.

The center tap of this winding, transformer Terminal 8, serves as a means of reducing a.c. hum in the sound. From that center tap trace up, left and up to a point of junction. From that point straight up to the cathode of VT-3; left and up to the cathode of VT-2; still further left and up to the cathode of VT-1. The effect is to connect those cathodes [through the resistors in series with them, R-2, R-3 and R-4] to the mid-points of their respective heaters.

Moving right along the power transformer to transformer Terminal 4, trace up, right, up, right, up and right to the filaments of VT-4 and VT-5; and from those filaments right, down, left and down to Terminal 6 on the same winding. This winding, then, lights the filaments of the output tubes; and its center tap, at Terminal 5, serves as the return for the plate current of those tubes.

The extreme right-hand secondary of the power transformer lights the filament of the full-wave rectifier tube, VT-6.

The Plate Power Circuits

From the positive source of the rectifier circuit—the rectifier tube filament, or transformer Terminal 14—trace right, up as far as possible through filter choke L-2, left to the first junction; up, right through .424-ohm meter resistors, and through the output transformer to the plates of the output tubes. From plates to filaments, and then down, left and down through the filament supply leads to transformer Terminal 5; then up through the 570-ohm tapped grid bias resistor, R-5; then right and down to the center tap of the plate secondary, transformer Terminal 11, which is the negative terminal of rectifier circuit.

From transformer Terminal 14 to the right, up through L-2, left past C-12 filter condenser to the next point of junction, and then up through R-11, R-26 and R-10 and left to the plate of VT-3. From the cathode of that tube down through the grid bias resistor R-4, to a junction just below and to the right of L-1; then right to the second junction and down to transformer Terminal 11.

From transformer Terminal 14 to the right, up through L-2, left through choke coil L-1 and resistor R-23 to the next junction; up through R-25 and R-7 to the plate of VT-2. From the cathode of that tube down through R-3 as far as possible, and then right to the fourth junction and down to Terminal 11.

From Terminal 14 to the right, up and left as before, continuing left as far as possible; then up through R-14, R-24 and R-1 to the plate of VT-1. From the cathode of VT-1 down through R-2 and right to the fifth junction and down to Terminal 11 as before.

External Supply Circuits

Ten volts for the exciter lamps are supplied through Terminals 13 and 14, at the bottom of the drawing. This power is drawn from the same transformer secondary that supplies the heaters of the first three tubes.

High voltage is supplied through Terminals 7, 8, 9 and G-4, at the right of the drawing. From transformer Terminal 14 trace to the right and up through L-2 to the first junction; then left through Resistor R-6 and down to transformer Terminal 11. R-6 is connected across the full voltage output of the rectifier circuit and, being tapped, serves as a voltage divider. Terminal 7 is connected, through the meter resistor R-28, to the full voltage output of the rectifier. (This terminal supplies P. E. C. voltage through an external filter unit.)

Terminal 8, however, taps off only a portion of the voltage-drop across R-6, and Terminal 9 even a smaller portion.

Important Notice

The W. E. 86-type amplifier described in the accompanying article uses a "harmonic suppressor" circuit to eliminate distortion. "Harmonic equalizer" is the preferred term for this device. The foreword to the article describing the W. E. 91-type amplifier (I. P. for Nov., p. 19) stated erroneously that the 91-type utilized the harmonic equalizer. This is not the case; and the facts were stated correctly in the article itself.

***The 91-type amplifier uses "reverse feedback" to eliminate harmonic distortion, and not the harmonic equalizer, which is a different device and is described in detail in the accompanying article. A comparison of both these articles will serve to emphasize this difference in suppressor circuits.*—Editor.**

The return from all three external circuits is through Terminal G-4; then left to the first junction and down to transformer Terminal 11, or negative. Terminal G-4 is also grounded to earth.

Plate Current Meter

The blades of the double-pole rotary switch D-2, seen just below the rectifier tube VT-6, connect to the plate current meter through Terminals 5 and 6 at the lower right-hand corner of the drawing. By means of the switch the meter can be made to indicate the current flowing in any of eight different circuits. Each of the currents to be read by this meter has been made to flow through a resistance of suitable value. The meter itself is a voltmeter, reading the voltage-drop across the meter resistor to which it is connected by switch D-2. The value of each resistor is so chosen that when the correct current flows through it the meter will read 100%.

The meter, as drawn, is connected to Resistor 24. The wires running to that resistor have been omitted by the draftsman for the sake of clarity. Resistor 24 will be found in series with the plate of VT-1: from that plate trace up, right and down through R-1 to R-24. Note that the value of the resistor is 19.25 ohms.

R-25 serves the same purpose in the plate circuit of VT-2, and can be found by tracing similarly from that tube. Note that the value of this resistor also is 19.25 ohms.

R-26 will be found similarly placed in the plate circuit of VT-3, and likewise is 19.25 ohms. Thus, the d.c. plate current through the first three tubes should be identical. The plate current through VT-4 and VT-5 is, naturally, much higher, and the values of the meter resistors correspondingly lower. The resistors are R-30 and R-31, each 0.424 ohms, shown just left of the primary of the output transformer.

R-27, R-28 and R-29 read the current to the external leads through amplifier Terminals 7, 8 and 9 at the right of the drawing.

Grid Bias Circuits

From the cathode of VT-1 trace down through R-2 (2600 ohms), which is the bias resistor for that tube. Plate current returns to negative through that cathode resistor. Its lower end is therefore negative with reference to its upper end and to the cathode of the tube. From the grid of VT-1 trace up to amplifier Terminal 1 and to the jumper indicated by the dotted line. If the jumper is set at amplifier Terminal 3, trace down through R-16 to the upper end of R-17. If the jumper is set at Terminal 4, trace down and left to the upper end of R-17, down through R-17 and right through R-9 to the lower, or more negative, end of R-2.

From the cathode of VT-2 trace down through R-3 (2600 ohms); down and left through R-22, left and up through R-15, and either straight up to amplifier Terminal 8 or right and up to Terminals 10, 11 or 12. From whichever of these terminals is connected to the arrowhead jumper, right and down to the grid of VT-2.

From the cathode of VT-3 down through R-4 (also 2600 ohms) left and up through R-8, and either straight up to Terminal 16 or right and up to Terminal 18. From either of these terminals to the right to grid.

It will be seen that not only are the plate currents of these tubes the same, but their grid bias is the same, since in each case the identical current flows through bias resistors of identical value, 2600 ohms. The other resistors in series with the grids, of course, have no effect upon the fixed bias, since no d.c. flows through them and there is no d.c. voltage-drop across them.

From the filaments of VT-4 and VT-5, trace down, left and down to power transformer Terminals 4 and 6. Thence to power transformer Terminal 5, and straight up to the grid bias resistor, R-5, total value 570 ohms. The tap on that resistor, which divides it into sections of 60 ohms and 510 ohms, forms part of the harmonic equalizer, and will be discussed in detail subsequently. The upper end of R-5 is negative and may be traced up, right and down to the negative d.c. source, transformer Terminal 11. From the upper or negative end of R-5 trace left through R-13, up, right, up through R-12, and right, up and left to the mid-point of the secondary winding of coupling transformer T-2. Through the two halves of that winding to the grids of the two tubes.

The Speech Circuits

Speech a.c. enters Fig. 1 at the input transformer, T-1, shown at the right top of the drawing. This transformer is completely shielded to avoid inductive pick-up of hum from the power circuits. The alternating voltage generated in the secondary of T-1 is impressed across R-16 and R-17, which total 500,000 ohms. The potential difference across 500,000 ohms is impressed upon the grid of VT-1, if the jumper is set at Terminal 3; but if the jumper is set at Terminal 4, the grid is swung only by the voltage developed across 280,000 ohms. The drawing indicates that the difference in sound level amounts to 5 db. The return is from the cathode of VT-1 to the left, down C-1 and right to the bottom of R-17.

Taking the plate and cathode of VT-1 as the poles of a generator of speech a.c., the load upon the tube may be traced from the plate to the right, down through R-1 and R-24, left through C-3, up through C-2 and right to cathode. A parallel circuit exists which may be traced from the plate of VT-1 up and right through the jumper; right through C-5, right through the fixed jumper to Terminal 8; down through R-18, R-19, R-20 and R-15; right and up through C-14, right through C-2; down as far as possible, left as far as possible; up, left, up through C-2 and right to cathode.

Resistors R-18, R-19, R-20 and R-15 constitute a tapped voltage divider, any tap of which may be connected to the grid of VT-2 through Terminals 8, 10, 11 or 12. The return to the cathode of VT-2 is to the right from the bottom of R-5 and up through C-14 as far as possible, then right to cathode. The maximum potential difference, and therefore maximum volume, is coupled to VT-2 when Terminal 8 is used. The drawing states that if the arrowhead jumper is connected, instead, to Terminal 10, the loss in volume will be 10 db; if to Terminal 11, the loss is 20 db; while a 30 db loss results when the arrowhead jumper is tied to Terminal 12.

From the lower end of R-15 the line to the cathode of VT-2 runs to the right, up through C-14 and then right.

The load across VT-2 may be traced from the plate down through R-7 and R-25, and down as far as possible through C-4 and C-7. Thence left to the next junction, up, left through C-2, and up and right.

From the plate of VT-2 trace a parallel path up, right, up, right, down and right through C-6; then up and right through a fixed jumper to Terminal 16. From that terminal down through R-21 and R-8 and right to the lower end of R-4; down to the next junction, left to the second junction, and up to the cathode of VT-2 as before.

R-21 and R-8 total 500,000 ohms, and the full voltage-drop through that resistance is connected across the grid and cathode of VT-3 when the grid jumper of VT-3 is set at Terminal 16. When that jumper is set at Terminal 18, the grid of VT-3 is swung only by the drop across 160,000 ohms, and the difference in volume is 10 db.

From the cathode of VT-3 trace the return left, down through C-2 and left to the lower end of R-8.

Checking with the drawing, it will be seen that a total variation in volume of 45 db can be effected by suitable connections of the grids of VT-1, VT-2 and VT-3.

From the plate of VT-3 trace the plate load right, down through R-10 and the meter resistor R-26, down, left, up through C-8; left, up through C-2, and right. Trace the parallel path from the plate of VT-3 right to the primary of T-2, down through that winding, left, up through C-9, and right to cathode.

From the two outside terminals of the secondary of T-2 trace to the right to the grids of the two output tubes. From the filaments of those tubes follow the filament leads down, left and down to the second secondary of T-4. From the center-tap of that secondary trace up, left, up through C-11 as far as possible; then right, up through R-12, right, and up and left to the center-tap of the secondary of T-2.

From the plates of VT-4 and VT-5 trace the load upon those tubes to the right to the output transformer primary; from Terminals 4 and 5 of that winding left through the two small meter resistors, then down as far as possible; left to the third junction, down and right through C-10-C-13; down through the 60-ohm section of R-5 to the mid-point of the second secondary of T-4; then back along the filament leads to the filaments of VT-4 and VT-5.

The output transformer secondary, like the input transformer primary, is center-tapped to provide a choice of coupling impedances.

The 'Harmonic Equalizer'

The harmonic content, or harmonic distortion of an amplifier, which impairs tone quality and causes sound to seem unnatural, is created by the inherent nature of amplifying tubes. The pattern of the output sound wave never matches exactly the pattern of the input sound wave. The extent of the distortion created by tube action depends upon the conditions under which the tube is operated. The grid bias is among the operating conditions that have an important influence upon the accuracy of amplification. But with the most favorable of operating conditions there is always some degree of distortion which is manifested as unnatural sound.

The input and output wave patterns of an ampliying tube can be studied in a number of ways, and analysis reveals that the effect of the distortion now being considered is exactly the same as if certain extraneous frequencies were introduced into the sound by the action of the tube. These frequences bear a definite arithmetical relation to the original or fundamental wave, and are called "harmonics."

If the fundamental frequency be, say, 500 cycles, there will be a second harmonic of 1,000 cycles, a third harmonic of 1500 cycles, and so on. Harmonic distortion is that action, on the part of the amplifying circuits, that alters the pattern of the sound frequency in a way which corresponds exactly to the addition of harmonic frequencies. Conversely, if suitable electrical means are used to draw off or filter off harmonic frequencies, the distortion is removed and sound resumes its original clarity.

A further discussion of harmonic distortion, and of one method for removing it (reverse feedback) was discussed in the last issue of I. P. (Nov., p. 19).

The amplifier of Fig. 1 of the present article also incorporates means for removing harmonic distortion but the method in no way resembles reverse feedback. A different arrangement is used to achieve the same result.

The W. E. 91-A amplifier traced herein last month used a single-end output stage instead of push-pull output. Reverse feedback, which removes all harmonic distortion, made this possible without sacrifice of quality. The 86-type amplifier now under consideration gets rid of one-half the harmonic distortion [the second and other even harmonics] by the common device of a push-pull output stage. The even harmonics balance out in the primary of a push-pull output transformer, where they meet 180 degrees out of phase. The third and other odd-order harmonics, however, remain in ordinary push-pull circuits, and a certain amount of distortion appears in the sound.

The "harmonic equalizer" in Fig. 1 consists of the 60-ohm portion of the grid bias resistor, R-5, and the 16 microfarads of C-10-C-13. These two units are in series with the return from the center-tap of the primary of the output transformer to the filaments of the output tubes. Trace again from Terminals 4 and 5 of the primary of T-3 through the meter resistors (which are too small in value to be considered); thence down, left to the third junction, down, right through C-10-C-13, down through 60 ohms to the center-tap of the second secondary of T-4, and then back to the filaments of VT-4 and VT-5.

Sixty ohms and 16 microfarads constitute the only impedance in this line.

The second and other even-order harmonics cannot manifest themselves in the primary of a push-pull output transformer, where they meet out of phase and cancel, but commonly appear as voltage in the return between the center-tap of that primary and the output filaments. They also appear in the space of the output tubes themselves.

The very low impedance of 60 ohms in series with 16 microfarads, in the present circuit, prevents the even-order harmonics from developing any appreciably large voltage drop in the filament-to-primary-center-tap lead, and thus concentrates them almost entirely in the space of the tubes. But in the tubes they react with the fundamental frequency to produce third- and other odd-order harmonics which are 180 degrees out of phase with the odd-order harmonics already present there. The result is, that while even-order harmonics are kept from the speakers by meeting out of phase in the primary winding of the push-pull output transformer, odd-order harmonics are cancelled in the tubes themselves by the generation, within those tubes, of the identical harmonic frequencies in reverse phase.

The action in the tubes is very similar to that which takes place in the mixer,

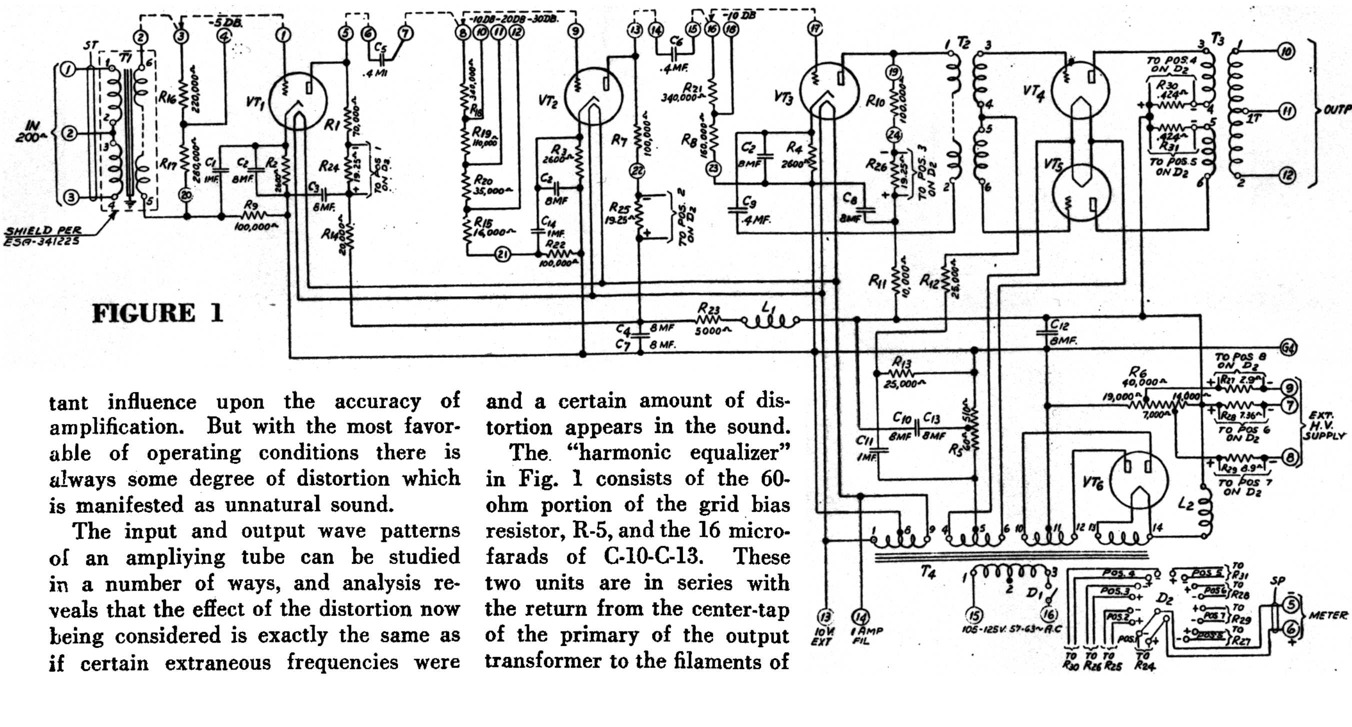

FIGURE 1

or converter, tube of a super-heterodyne radio receiver, in which two frequencies are made to "beat together" to produce other frequencies. Thus, 500 cycles and 1000 cycles "beat" to produce a difference frequency of 500 cycles (difference frequencies are the ones used in radio receivers) and a sum frequency of 1500 cycles. The sum frequency is used in Fig. 1 to cancel the 1500-cycle, third-harmonic distortion which is already present.

The critical factor in this circuit is the value of the lower half of R-5, 60 ohms. At any other value the third harmonics generated in the output tubes would either be too weak to cancel the original distortion entirely, or so strong as to more than balance it and thus introduce distortion themselves. It is imperative, therefore, that this value, as well as the 16 microfarads of C-10-C-13, be maintained undisturbed in any work that may be done on the amplifier, if the quality of its output is to be preserved.