Fig. 1. Over-all view of amplifier. Power supply is built on a separate chassis.

A Wide-Range FEEDBACK AMPLIFIER

Inverse feedback over 4 stages proved no problem to author in designing this American version of the "Williamson Amplifier."

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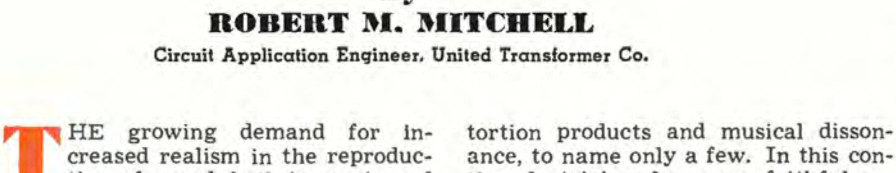
THE growing demand for increased realism in the reproduction of sound, both in music and speech, has necessitated a reconsideration of several basic problems in the design of audio amplification equipment. These problems are concerned with psychological as well as physical phenomena, and involve such varied considerations as system bandwidth, room acoustics, the sensation of loudness, and the relationship between distortion products and musical dissonance, to name only a few. In this continued striving for more faithful reproduction, negative feedback plays an indispensable part.

At one time negative feedback was used somewhat as a remedy, that is, it ameliorated gross defects in equipment of mediocre quality until some of the resultant specifications were comparable to those of higher quality equipment. Fortunately for the music-lover, those days are largely past, and feedback is now more profitably employed in refining the characteristics of an already superior system. Thus, it is becoming more common to find large amounts of feedback being used with medium-power, all-triode amplifiers of very linear characteristics, employing parts of the highest quality. The employment of such large amounts of feedback requires that, for stability's sake alone, the gain-frequency and phase-frequency characteristics of the original amplifier be controlled over a range much greater than that over which the benefits of the feedback are desired. Terman, in his "Radio Engineers Handbook," page 226, gives as an approximate rule the relation of one octave extension of range for every 10 db. of feedback desired, plus one or two octaves as a margin of safety. Thus, if it is desired to produce an amplifier with 20 db. of feedback and a useful range of 20 to 20,000 cycles, it is necessary that the characteristics of the feedback loop be controlled for at least three octaves beyond this range, or from 2.5 cycles to 160,000 cycles. Since the control of gain characteristics is a comparatively simple matter for resistive-capacitive coupled stages, the crucial component in a high-quality amplifier is the output transformer.

A high-quality amplifier of excellent linearity and utilizing 20 db. of feedback around all four stages and the output transformer has recently

Fig. 2. Schematic diagram and parts list covering the amplifier power supply.



C_1, C_2—.1 μfd., 400 v. cond.
C_3, C_4, C_5—8 μfd., 600 v. elec. cond.
T_1—Power trans. 400-0-400 v. @ 200 ma.; 5 v. @ 3 amps.; 6.3 v. @ 6 amps. c.t. (UTC R-113)
PL_1—6.3 v. pilot light
CH_1—12 hy. @ 150 ma. filter choke (UTC CG-100)
CH_2—75 hy. @ 50 ma. filter choke (UTC CG-48C)
S_1—D.p.s.t. sw.
F_1—3 amp. fuse
V_1—5R4GY or 5U4G tube (See text)

been developed in England by Mr. D. T. N. Williamson. This "Williamson" amplifier was literally designed around a special output transformer, and used standard English parts. It is the purpose of this article to describe an outstanding version of this amplifier which uses a stock output transformer and standard American parts.

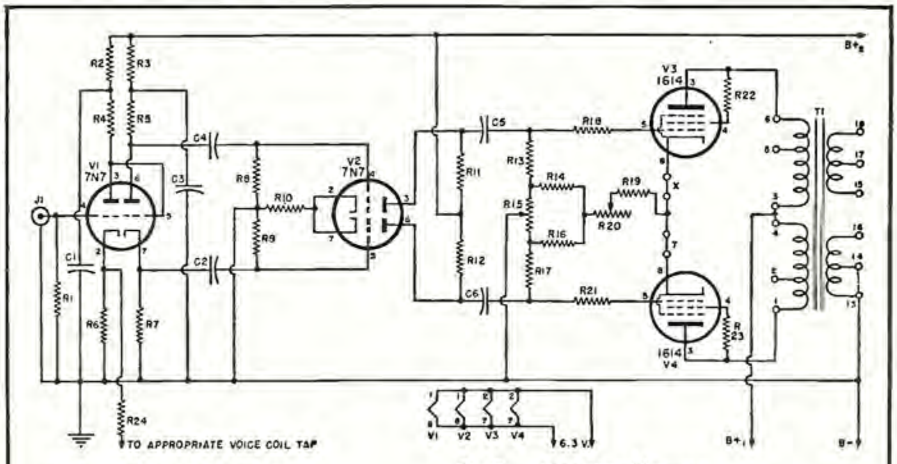
The heart of the amplifier is the output transformer, *UTC* LS-63. This transformer matches push-pull loads of 10,000 and 6000 ohms to a wide range of voice coil impedances. The frequency response of the transformer alone extends smoothly within 1 db. from 15 cycles to 50 kc. at medium power levels. This response enables the entire amplifier to be incorporated in the feedback loop with complete freedom from instability. The resulting feedback amplifier has a frequency characteristic which is flat within 1 db. from 10 cycles to 100 kc.!

The amplifier circuit is straightforward and simple. As may be seen from Fig. 3, it consists of four stages; a voltage amplifier, direct-coupled to a split-load phase inverter, a push-pull voltage amplifier, and a push-pull power amplifier stage. The output tubes are 1614's, connected as triodes, with self bias. Except for a lower maximum plate voltage rating, this tube is electrically identical to the 807, but has the additional advantages of being single-ended in construction and having a standard octal base.

In order to permit flexibility of operation, the amplifier was built on two chassis, one containing the amplifier proper, and the other the power supply. Figs. 1 and 5 show the top-chassis and under-chassis views respectively of the two units. Point-to-point wiring is used throughout, with short, rigid leads and a common ground bus serving to reduce stray coupling and hum pickup. The ground bus picks up the individual grounds in order, starting at the highest level stages and progressing in order to the lower stages, where it is finally grounded to the chassis at the input.

The performance of the amplifier depends to a large extent on the balance of the push-pull stages. The output transformer constants (inductance, leakage, etc.) are precision-balanced, so that no adjustments are needed for that component. The plate load resistors for the push-pull driver stage should be matched, as should also the plate and cathode resistors in the phase inverter stage. Before the amplifier is placed in operation, two simple adjustments must be made. These adjustments set the operating conditions for the output stage, and normally need be made only once.

Since the total plate dissipation for the two 1614's is 50 watts, the total cathode current must be limited to 120 milliamperes. This is accomplished by inserting a milliammeter in the common leg and adjusting R_{20}. This will produce a bias of about 38 volts when the plate to ground voltage is 440 volts, and will keep the static plate



R_1, R_8, R_9—470,000 ohm, ½ w. res.
R_2—33,000 ohm, 1 w. res.
R_3—22,000 ohm, 1 w. res.
R_4—47,000 ohm, 1 w. res.
R_5, R_7—22,000 ohm, 1 w. matched res.
R_6—470 ohm, ½ w. res.
R_{10}—390 ohm, ½ w. res.
R_{11}, R_{12}—47,000 ohm, 2 w. matched res.
R_{13}, R_{17}—100,000 ohm, ½ w. res.
R_{14}, R_{16}, R_{22}, R_{23}—100 ohm, 1 w. res.
R_{15}, R_{20}—100 ohm, 2 w. wirewound pot.
R_{18}, R_{21}—1000 ohm, ½ w. res.
R_{19}—150 ohm, 5 w. res.
R_{24}—1200 × $\sqrt{\text{voice coil impedance}}$
C_1, C_3—8 µfd., 600 v. elec. cond.
C_2, C_4—.05 µfd., 400 v. cond.
C_5, C_6—.25 µfd., 600 v. cond.
T_1—Output trans. 10,000 ohms to v.c. (UTC LS-63)
J_1—Amphenol connector
V_1, V_2—7N7 tube
V_3, V_4—1614 tube

Fig. 3. Complete schematic diagram of the wide-range feedback amplifier unit.

dissipation within the 50 watt rating. After this is done, the standing currents in each tube are adjusted to equality by placing milliammeters at points *X* and *Y*, and adjusting R_{15}. This adjustment reduces the unbalanced d.c. current in the output transformer primary, and, consequently, improves the low frequency response.

When adjusted according to the above instructions, the amplifier is operating almost completely in Class A, and will deliver 8 watts of power with almost undetectable distortion (less than 0.1%). Although this may seem to be a rather low power output, it is more than adequate for home listening. For reproduced music to sound at

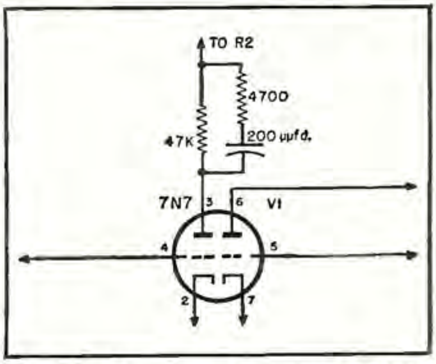
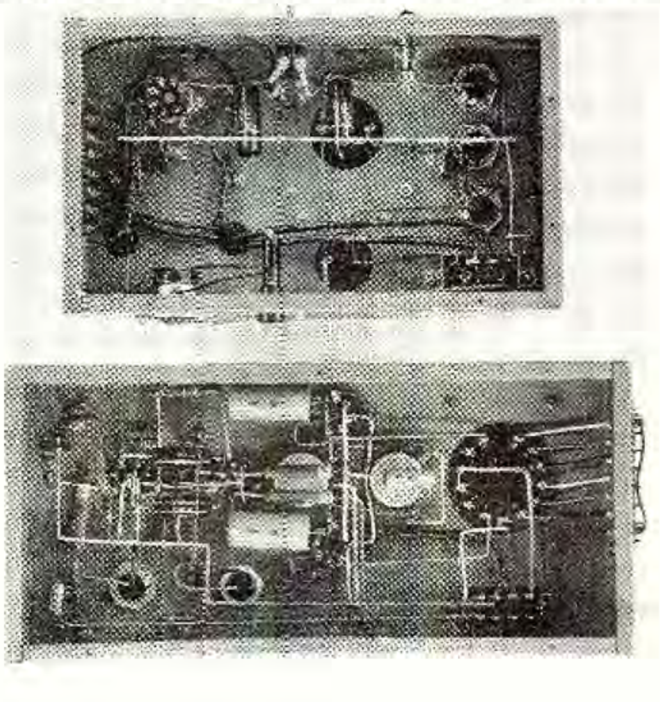


Fig. 4. Phase correcting network which can be used to eliminate the effects of excessive stray capacity or capacitive loads.

Fig. 5. Under chassis views of the audio amplifier and accompanying power supply.



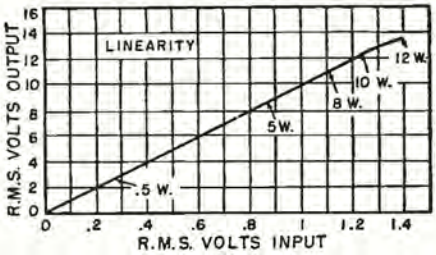
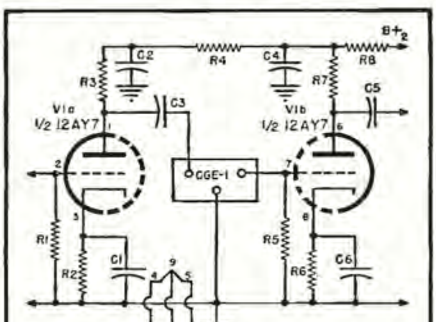


Fig. 6. Linearity curve of the amplifier.



R_1—500,000 ohm, 1/2 w. res.
R_2, R_6—2700 ohm, 1/2 w. res.
R_3, R_7—20,000 ohm, 1/2 w. res.
R_4, R_5—10,000 ohm, 1/2 w. res.
R_8—39,000 ohm, 1 w. res.
C_1, C_6—50 μfd., 25 v. elec. cond.
C_2, C_4—20 μfd., 450 v. elec. cond.
C_3—.5 μfd., 400 v. cond.
C_5—.05 μfd., 400 v. cond.
V_1—12AY7 tube
CGE-1—Tone control network (UTC CGE-1)

Fig. 7. An equalizing circuit, giving up to 15 db. boost or cut at either end of the spectrum, which may be used with amplifier.

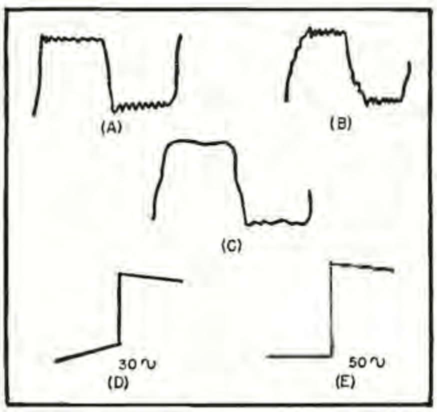


Fig. 8. Frequency response of the amplifier. See text for an explanation of waveforms.

about concert level to the listener in a large-sized living-room requires an average of about 5 milliwatts of acoustic power. In a fair-sized living-room of say, 2500 cubic feet volume, a value half this great is adequate. Allowing an average of 20 db. (100 times as much power) for peaks, a value of 0.25 watts is obtained. To produce this acoustic power through a speaker system of 10% efficiency requires an electrical power of 2.5 watts. Under these condition the 8 watt amplifier has a safety margin of undistorted power of more than 3 times, or 5 db. If more power is required, the bias may be changed so as to operate the output stage more in Class AB_1, by adjusting R_{20} for 110 ma. total current (approximately −40 volts bias), and adjusting R_{15} for equal currents as before. Under these conditions the distortion is 0.3% at 10 watts and 1% at 12 watts.

In the English design, a phase correcting network across R_4 is a permanent part of the amplifier. This tends to increase the margin of stability at high frequencies. The leakage inductance of the *UTC* LS-63 is so low that this network is ordinarily not required. However, if the secondary load is highly capacitive or other stray capacities are introduced in the amplifier, it may be desirable to add this network. If the output tube currents are high when all components are properly connected and all other measurements are correct, it is usually an indication that the circuit is oscillating at a very high frequency due to the stray capacities mentioned above. In such cases, the phase correcting network shown in Fig. 4 will eliminate this.

The power provided by the power transformer and that dissipated by the output tubes in particular is considerably larger than in most home amplifiers. Consequently, the constructor must allow for adequate ventilation when mounting the unit in cabinets, etc.

If the "B+$_1$" voltage is too high, because of high line voltage, for example, the 5R4GY tube (Fig. 2) should be used in place of the 5U4G. This tube may be plugged directly in the same socket, since the basing is identical, and due to its larger internal drop, will give a lower output voltage.

The performance characteristics of this amplifier are illustrated in tabular and graphic form in Figs. 6, 8, and 9. All of the measurements were made with a source resistance of 50,000 ohms and a non-inductive resistor of 15 ohms connected to the 15 ohm secondary terminals of the output transformer.

Fig. 9A shows the frequency response at different output levels for Class A operation, while Fig. 9B shows the response for Class AB_1 operation at higher levels. The response of the amplifier with 40 volts bias is essentially the same at low levels as that of Fig. 9A. The linearity of the amplifier over the entire power range is shown in Fig. 6.

The low distortion content of this amplifier is outstanding. At 8 watts (actual measured power dissipated in the load resistor, not an "equivalent power") the distortion is less than one-tenth of one per-cent. Because the distortion is so minute, it is necessary that several precautions be taken in measuring it, in order to insure that spurious voltages such as noise, hum, etc. are not included in the results. The author has found that a satisfactory procedure is to pass the audio generator output through a low-pass filter of at least 60 db. attenuation and measure the harmonic components of the amplifier output with a wave analyzer.

One of the desirable features of audio amplifiers is low output impedance, and in this respect a negative feedback amplifier is unsurpassed. The ratio of the load resistance to the effective output impedance is called the damping factor, since it determines the effectiveness of the amplifier in damping vibrations originating in the loudspeaker.

A common value of damping factor for beam tubes with feedback or triodes without feedback is 3. The damping factor of this amplifier is 27, equivalent to an output impedance of 0.55 ohm at the 15 ohm secondary. This ability of the amplifer to damp the loudspeaker contributes substantially to the "cleanness" of reproduction.

Another factor contributing to clarity in reproduction is the transient response. Because of the ease of interpretation involved, transient response is usually tested by means of square waves. The high frequency square wave response of the amplifier is shown in Fig. 8. In this diagram (*A*) represents the response of the entire amplifier to a square wave of 10 kc. repetition rate. The rapidity with which the maximum value is attained, *i.e.*, the short rise time, is a graphic indication of the extremely small leakage inductance and stray capacitance of the output transformer. For comparison purposes the high frequency square wave response of a poorly designed unit is shown in Fig. 8B.

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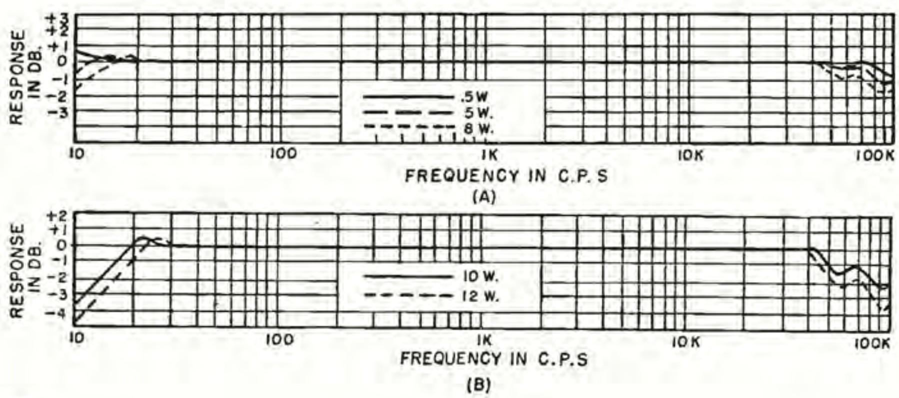
Fig. 9. (A) Frequency response at different output levels for Class A operation, and (B) the frequency response of the amplifier in Class AB_1 operation at higher levels.



Feedback Amplifier
(*Continued from page* 68)

The curvature of the leading edge is an indication of poorer high frequency characteristics. The amplifier's response without feedback may also be seen in Fig. 8C. The small oscillations on the top of the square wave pattern are due to the shock excitation and are quite normal. They are of small amplitude and very high frequency, and have no effect on the amplifier performance in the audio range.

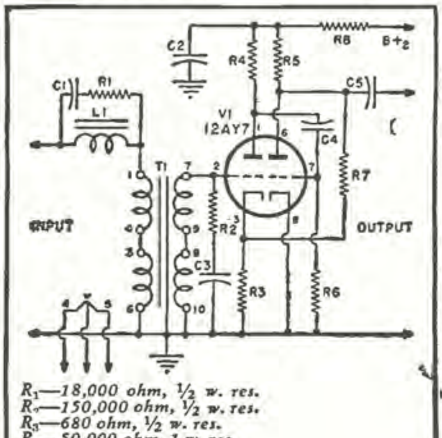
In making square wave tests it is essential that a wide range oscilloscope be used, since otherwise the waveform seen on the screen will be completely different from that entering the oscilloscope. Ordinary oscilloscopes are generally quite unsatisfactory for this purpose, since the required flat frequency range is at least from 10 cycles to 2 megacycles.

The low frequency square wave response is shown in Figs. 8D and E. The extremely slight tilt in the top of the wave is indicative of the large primary inductance (150-200 henrys) and small phase shift (12 windings interleaved) of the transformer.

The amplifier described was designed to be a power-amplifier unit of such optimum characteristics that improvements in other components in a complete system would never make the main amplifier the weak link in the chain. Consequently, there have been no provisions for control functions or frequency compensating equipment, since these could be more readily changed if they were physically separate from the main amplifier.

In order to make a complete unit

Fig. 10. Diagram of a commercial equalizer-amplifier for a variable reluctance pickup.



R_1—18,000 ohm, ½ w. res.
R_2—150,000 ohm, ½ w. res.
R_3—680 ohm, ½ w. res.
R_4—50,000 ohm, 1 w. res.
R_5—30,000 ohm, 1 w. res.
R_6—10 megohm, ½ w. res.
R_7—68,000 ohm, ½ w. res.
R_8—47,000 ohm, 2 w. res.
C_1—.02 μfd., 200 v. cond.
C_2—20 μfd., 450 v. elec. cond.
C_3—.04 μfd., 200 v. cond.
C_4—.02 μfd., 400 v. cond.
C_5—.05 μfd., 400 v. cond.
L_1—Audio choke, 5 hy. @ 13 ma. (UTC HQA-15)
T_1—Input trans. Pri. 50, 125/150, 200/250, 333, 500/600 ohms, Sec. 50,000 ohms (UTC A-11) (The UTC A-10 may also be used)
V_1—12AY7 tube

for highest-quality home listening, the following auxiliary equipment is desirable: 1. Volume Control, 2. Bass and treble equalization, 3. Reluctance-type pickup compensation.

The first control is readily achieved merely by making R_1 a 500,000 ohm potentiometer. This is the only control which can be added to the body of the amplifier. Any additional tone controls or equalizing circuits must be placed before the amplifier, since if inserted internally, they would upset the feedback loop.

An excellent circuit giving up to 15 db. boost or cut at either end of the spectrum is shown in Fig. 7. When this circuit is used before the amplifier, the volume control should be R_1 of the equalizer, in order to prevent overload of that circuit.

Fig. 10 shows a professional type equalizer-amplifier for the variable reluctance type pickup. This provides not only more accurate low frequency compensation, but also a slight high frequency roll-off to compensate for recording pre-emphasis.

Because it combines the desirable features of fidelity, simplicity, and economy, this amplifier is unusually attractive to the home builder. With this amplifier in his possession, the high fidelity enthusiast may be confident that he has a sound design that cannot be rendered obsolete by improvements in program material quality. —30—

TV IN BRAZIL

ON July 30 the Tupi television station at Rio de Janeiro, Brazil, transmitted the first of an announced series of four experimental public telecasts.

The show was broadcast from the studio of Radio Tamoio and viewed through receivers placed in the studio of Radio Tupi and at the entrances of the buildings housing the respective stations. The first broadcast was reported to be very successful and was enthusiastically received both by the studio audiences and the large crowds which gathered in the street.

Regular telecasting was scheduled to begin within thirty days of the original program, according to the U. S. Embassy report from Rio. —30—

"It gives better results than my outside antenna!"