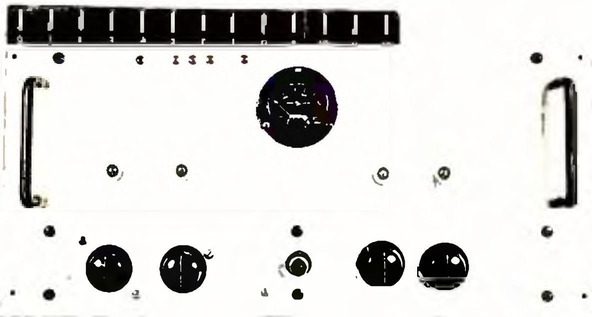

A 15-Watt Direct-Coupled Amplifier

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Describing a stable, well designed amplifier suitable for high quality music reproduction or for small commercial program distribution systems.

Some time ago the author commenced the design and construction of a high quality audio amplifier for his personal use at home. Complexity of circuit design or difficulty of adjustment were considered unimportant, for it was not intended to publish the circuit. The amplifier was finally completed and gave satisfactory results. Only then did it occur to the author that perhaps others would be interested in the design finally adopted.

The circuit is not complex, though it may appear so because of unconventional circuit arrangements. The unorthodox features include a duplex thermostatically controlled power supply, a unique form of loudness control, direct coupling throughout (except preamplifier), push-pull throughout (except preamplifier), and an input circuit permitting the use of either an unbalanced or push-pull signal. At the least, the design is an interesting study in wire. At most, in the author's opinion, it is an excellent amplifier.

Design specifications are used to define certain objectives. In this case, we wanted an amplifier that sounded as we thought it ought to sound, had no hum or tube noise, and had output power sufficient for home use. How are these requirements expressed in figures? It is difficult to say. Experts argue the problem interminably.

But there must be something more specific to aim at than the generalities just mentioned, so the following specifications were set up:

Power output: 15 watts maximum; 10 watts below 1% distortion from 30 to 10,000 cps
Frequency range: 20–20,000 ± 0.5 db
Hum and noise: inaudible at all volume levels
Gain: full output with 0.5 volts or less rms input. A preamplifier permitting the use of magnetic phonograph pickups is to be incorporated.

Circuit Details

The design program commenced with a study of the better known commercial circuits and a number of published diagrams. Most of these designs were more or less conventional. By great refinement, a high degree of excellence had been attained in many of them. Nevertheless, there appeared to be two general ways in which conventional design might be improved somewhat. First, almost all of these circuits employed either transformers or capacitor-resistor networks for interstage coupling, and it appeared that a part of the overall distortion of the amplifier originated in these coupling devices. Obviously, then, the elimination of coupling circuits would result in an improvement of the quality of amplification, provided the system used in lieu of conventional coupling was itself distortion free. Secondly, most of the circuits employed single-ended stages for part of the circuit rather than push-pull arrangements. It was thought that a fully push-pull circuit, if feasible, would assist in reducing the second harmonic distortion produced in most equipment.

With these preliminaries in mind, design was commenced. Low-mu triodes were tentatively decided upon for the output stage. 6A5G's were attractive, for they produced the desired power output at small distortion values: they did not require nearly as much driving voltage as the 6AS7G; they had reasonably low plate current and voltage requirements; and they were almost completely hum free.

After design and construction had been completed, it was found that the drivers were capable of providing a peak-to-peak potential of about 210 volts. This is sufficient to drive almost any output tube. Consequently, with appropriate changes, an experimenter may substitute his favorite tube for the 6A5G's shown in the schematic. The author tried 6L6's (tetrode connected), 807's (triode connected), and 6B4G's. 6A5G's seemed to give better results than any of the others, though this is difficult to prove.

Glass enclosed triodes are used for voltage amplifiers. Both 6SN7's and 6SL7's are rugged and non-microphonic. The glass envelopes facilitate trouble shooting. In addition, glass tubes are somewhat less gassy than their metal counterparts. The use of dual triodes cuts down on the total number of tubes required and is also desirable because the two triode sections are more likely to have similar characteristics than separate tubes.

To eliminate conventional coupling devices, direct coupling is used throughout. Direct coupling is inherently free of all forms of distortion. Its principal disadvantages are the high plate supply voltage required, critical balancing, and the possibility of operating tubes at incorrect potentials. Of these problems, maintenance of balance of the circuit was found to be the most difficult to overcome. Balance was finally secured by the use of direct-coupled inverse feedback from the cathodes of the drivers. This arrangement not only corrects for tendencies of the tubes to shift their operating potentials and currents, but also maintains signal balance between the two halves of the push-pull voltage amplifier circuit.

It can be shown that plate supply resistors common to both tubes of a push-pull arrangement assist in stabilizing the d.c. potentials of a direct coupled circuit. Resistors R_{15}, R_{16}, R_{17}, and R_{18} have such an effect.

This feedback does not, of course, correct distortions which may arise in the output tubes and output transformer.

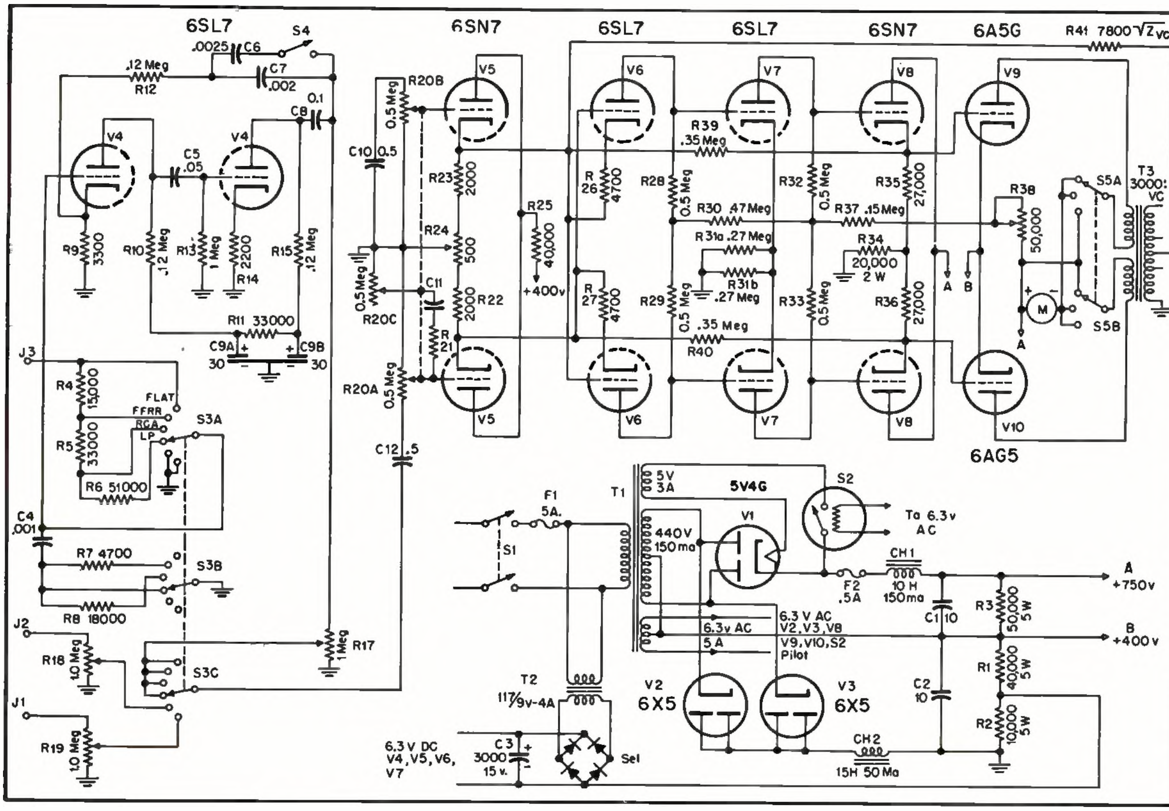

Fig. 2. Over-all schematic of the direct-coupled amplifier.

Such distortions are cancelled by inverse feedback from the output transformer secondary tap to which the loud-speaker voice coil is attached. This arrangement effectively feeds back an accurate sampling of the voltage supplied to the loud-speaker. The feedback resistor used in this circuit should have a resistance equal to 7800 times the square root of the voice coil impedance.

The values of the feedback resistors were selected after considerable investigation of the effect of feedback on signal waveform. Both sine and square wave inputs were used and the resultant oscilloscope patterns were carefully studied. Because of the small phase shift inherent in this direct-coupled circuit, unusually large amounts of feedback can be used. However, feedback in excess of that recommended will result in reduced amplification and may cause high-frequency oscillation.

Signal input can be either single ended or push-pull. Referring to *Fig. 2*, phase inversion is accomplished by V_5 and V_6 in case a single-ended signal is used. This type of phase inverter has no frequency discrimination and produces a perfectly balanced push-pull signal, provided the corresponding parts of the circuit are matched. The design was adapted from similar circuits which have been published recently. A unique form of loudness control is shown as the three-section ganged potentiometer R_{20}, capacitor C_{11} and resistor R_{21}. It will be observed that the high frequencies fed to the grid of V_5 are automatically attenuated as volume is decreased, thus giving an increased proportion of lower frequencies at reduced volume levels. The values of R_{21} and C_{11} can be varied to suit the individual. The author used a value of .04 µf for C_{11} and a value of 0 ohms for R_{21}. After values have been established for the elements of this loudness control, it will work with greatest effectiveness for input signals which have the same average strength as the signal for which the loudness control was originally designed. Therefore, individual semi-adjustable volume controls (R_{17}, R_{18}, R_{19}) have been provided for each signal device.

In case a balanced signal is to be used instead of a single ended signal, the signal should be fed to the ungrounded ends of R_{20A} and R_{20B}. C_{10} is then attached to R_{20B} in the same way as C_{12} is attached to R_{20A}. A fourth potentiometer should be ganged to the loudness control and wired similarly to R_{20A} and R_{20C}.

The slightest trace of d.c. appearing on the grid of V_5 will upset the balance of the entire amplifier. Therefore, C_{12} is used to insure that d.c. from the signal sources is eliminated.

It will be noted that V_5 is a cathode follower and hence produces no amplification. V_6 and V_7 amplify in the normal manner. The common cathode resistor of V_7 tends to correct for any signal unbalance which may occur. Finally, the balanced feedback from V_8 to V_6 corrects for any small residual signal unbalance. Oscilloscope tests show that the signals supplied to the output tubes are balanced under all conditions. This is an important requirement in push-pull circuits.

It will be noted that V_6 has an unbypassed cathode resistor. The resultant degeneration improves frequency response and stability.

V_8 is a cathode-follower driver. Since the 6A5G's are to be operated Class AB_1, and presumably draw no grid current, it may be wondered why V_8 is used. The principal reason for the presence of this tube is that the grids of the 6A5G's do draw current, even though they are not driven positive. This characteristic is typical of many triode-output tubes. V_7 cannot supply current from its plate to the grid of the following tube without suffering serious distortion in its output. However, a cathode follower can supply the small amounts of power required without ill effects, and so this arrangement is used for the driver. An inspection of the circuit diagram will show that R_{38} controls the total plate current of the output tubes and that R_{34} balances the plate current.

A number of excellent preamplifier designs are available. The one shown has been described previously.

Power Supply

At first glance, the power supply may appear to be unusual. Actually, the high voltage secondary of the power transformer merely employs a bridge type rectifier (V_1, V_2, V_3) so arranged that the center tap of the winding is +400 volts. This type of power supply is sometimes referred to as a "duplex" power supply.

The thermostatic delay relay is included to prevent the application of plate voltage to the output tubes before the indirectly heated cathodes of the voltage amplifiers have warmed up sufficently to provide correct bias.

The 6.3 volt a.c. heater winding is baised at +400 volts. The cathodes of V_2 and V_3 are biased at +400 volts, so the same heater winding that supplies the output tubes can be used for the 6X5 heaters. Also, it will be noted that the cathode of V_8 operates at approximately +327 volts which permits this same source of 6.3-volt a.c. to be used for the heater of V_8.

A full-wave selenium rectifier and associated transformer are used to provide d.c. heater current for V_4 to V_7, inclusive. The use of d.c. heaters in these tubes reduces hum disturbances.

Construction

The entire amplifier can be mounted on a 15 x 19 chassis, but it is recommended that the power supply be mounted on a separate chassis. If only one chassis is used, the parts must be arranged so compactly that a cooling fan is almost a necessity, especially if the amplifier is to be placed in a confined box. If a single chassis is used, the parts should be laid out so that the power supply is at the opposite end of the chassis from the low level stages. Since the circuit is completely push-pull (except for the preamplifier), hum is minimized and shielded wire need not be used. However, the preamplifier must be carefully shielded.

The use of a single ground and grounding bus is recommended to avoid hum which sometimes results from multiple grounds. In this case of the preamplifier, an insulated input jack should be used. The grounded side of this jack should be attached to the grounded end of R_9. If this precaution is not observed, a high hum level will almost invariably result.

In the interest of good construction. filter capacitors C_1 and C_8 should be oil filled. Because of the push-pull arrangement with its inherent hum cancellation characteristics, no large capacitance electrolytic capacitors are required except in the case of the preamplifier and d.c. heater supply.

It is not absolutely essential to match resistors, capacitors, tubes, etc., of the two halves of the push-pull circuit, because cross-coupling, cathode degeneration, inverse feedback, and balancing potentiometers provide for a reasonably well balanced output, even if exact push-pull symmetry is not maintained. Nevertheless, accurate balance and superior performance of the amplifier can be attained only by electrical and mechanical symmetry. Furthermore, changing line voltage will result in unbalanced operation if parts are not fairly carefully matched. Therefore, matching of corresponding parts is recommended insofar as possible.

Wiring of those portions of the circuit operating at +400 volts or less should follow conventional procedure. For the higher voltages, wire with fibre glass insulation is recommended.

Potentiometers R_{11} and R_{12} should be so located that they can be reached easily with a screwdriver while the amplifier is in operation.

Transformers and chokes should be of good quality. The output transformer is especially important. The quality of the entire amplifier will depend largely on this item. This circuit was designed, among other things, to eliminate expensive interstage audio transformers. and the money so saved can be invested in the output transformer. A number of excellent makes are available. The author used a UTC linear standard LS55, and found it very satisfactory.

Tubes V_4, V_5, and V_6 should be mounted in non-microphonic tube sockets. Switches S_3 and S_6 should be the shorting type to prevent noisy switching. The feedback loop attached to the secondary of the output transformer should not be finally soldered in place until adjustments of the amplifier are completed.

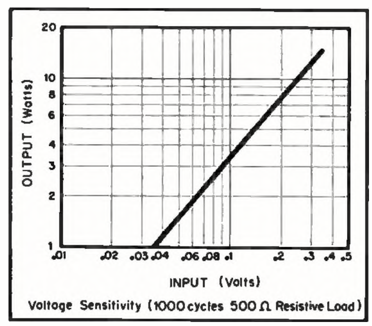

Fig. 3. Curve showing voltage sensitivity of the amplifier when feeding a 500-ohm resistive load.

Adjustment

After completing the construction, insert all tubes heated by d.c. Turn on the amplifier and check the heater voltage to make sure it is 6.0 to 6.3 volts.

Next, insert all tubes heated by a.c. The thermostatic switch should not be inserted until later. Turn on set and measure a.c. heater voltage.

If everything is operating normally, place the thermostatic switch in its socket and turn on the amplifier. Adjust R_{11} and R_{12} to produce correct operating current and voltages for the output tubes. If parts have been well balanced, minimum hum will be obtained when plate currents are balanced. If parts have not been carefully selected, minimum hum may occur when plate currents are slightly *un*balanced. Adjust R_{11} for minimum hum.

Finally, attach feedback loop from output transformer secondary to one of the cathodes of V_5. If noise increases when feedback loop is attached, the loop has been reversed and should be attached to the other cathode.

A final check of voltages should be made; Table I shows typical values for plate, grid, and cathode potentials referred to ground. If everything is in correct working order, hum and noise will be inaudible when the ear is held more than three or four inches from the speaker. When the preamplifier is switched into the circuit, a small amount of noise will become apparent, though this noise should be so slight as to cause no objection.

In order to maintain balance of the amplifier, potentiometers R_{11} and R_{12} will have to be adjusted periodically as the tubes age. The frequency of these adjustments will decrease after the first few weeks of operation. during which time the tubes' characteristics are changing quite rapidly. Since line voltages will vary throughout the day, it is suggested that balancing be done when the line voltage is at its average value. The amplifier should be adjusted only after it has warmed up at least half an hour.

Performance

Full output of 15 watts is attained with an input voltage of 0.35 volts rms. An output of over 20 watts can be attained, though the amplifier begins to produce appreciable distortion over 15 watts.

Frequency response is flat to approximately 20.000 cps, with a gradual droop above that point. Voltage sensitivity is shown in *Fig* 3. Hum and noise voltages were so low that they could not be measuered with equipment available.

Conclusions

In the past, direct-coupled amplifiers have proved unpopular probably because of several problems associated with this type of design. The circuit described herein overcomes all these difficulties by unconventional arrangements, except that periodic adjustment of the current of output tubes will be required.

However, for those who require unusually good performance, and enjoy the work of achieving it, it is believed that this circuit will provide satisfactory results. Its superiority to most typical designs can be shown either by instruments or by listener tests.

TABLE I

Tube	Plate	Grid	Cathode
V5	170	0	6.5
V6	120	6.5	8
V7	309	120	122.7
V8	750	309	327
V9	745 @ 42 ma	327	400
V10	745 @ 42 ma	327	400

NOTE 1. Actual voltages may vary as much as 15 per cent from figures shown without detrimental effect. However. output tube plate current and voltage should be adjusted as accurately as possible. The exact voltage of output tube grids is unimportant, provided plate current and voltage are correct.

NOTE 2. Voltage measurements should be made with a vacuum tube voltmeter.

PARTS LIST

R_1	40,000 ohms, 5-watt, wire wound
R_2	10.000 ohms, 5-watt, wire wound
R_3	50,000 ohms, 5-watt, wire wound
R_4	15,000 ohms, ½-watt
R_5	33,000 ohms, ½-watt
R_6	51,000 ohms, ½-watt
R_7	4700 ohms, ½-watt
R_8	18.000 ohms, ½-watt
R_9	3300 ohms, ½-watt
R_{10}, R_{15}	0.12 meg. 1-watt
R_{11}	33,000 ohms, 1-watt
R_{12}	0.12 meg, ½-watt
R_{13}	1.0 meg. ½-watt
R_{14}	2200 ohms, ½-watt
R_{16}	75.000 ohms, 1-watt (Not shown, but connects C_{9b} to 400-volt supply at "B")
R_{17}, R_{18}, R_{19}	1-meg potentiometer
R_{20}	3-sect. ganged potentiometer, 0.5 meg. each section
R_{21}	See text
R_{22}, R_{23}	2000 ohms, 1-watt
R_{24}	500-ohm wire-wound potentiometer
R_{25}	40,000 ohms, 10-watt, wire wound
R_{26}, R_{27}	4700 ohms, 1-watt
R_{28}, R_{29}, R_{32}, R_{33}	0.5 meg. 1-watt
R_{30}	0.47 meg, 1-watt
R_{31}	0.135 meg (2 0.27-meg 1-watt resistors in parallel)
R_{34}	20.000 ohms, 2-watt
R_{35}, R_{36}	27.000 ohms, 2-watt
R_{37}	0.15 meg, 1-watt
R_{38}	50.000-ohm wirewound potentiometer
R_{39}, R_{40}	0.35 meg. 2-watt
R_{41}	7800 $\sqrt{\text{V.C.}}$ impedance
C_1, C_2	10 µf, 600-volt, oil filled
C_3	3000 µf, 15-volt electrolytic
C_4	.001 µf, mica
C_5	.05 µf, 600-volt, tubular
C_6	.0025 µf, mica
C_7	.002 µf, mica
C_8	0.1 µf, 600-volt, tubular
C_9	30-30 µf, 450-volt, electrolytic
C_{10}, C_{12}	0.5 µf, 600-volt, oil filled
C_{11}	See text
V_1	5V4G
V_2, V_3	6X5
V_4, V_6, V_7	6SL7
V_5, V_8	6SN7
V_9, V_{10}	6A5G
S_1	DPST toggle switch
S_2	Amperite 20-sec delay relay
S_3	3-gang, 6-position, shorting type
S_4	SPST toggle switch
S_5	2-gang, 3-position, shorting type
T_1	440-0-440v at 150 ma; 5v at 3a; 6.3v at 5a
T_2	9v at 4a filament transformer
T_3	20-watt output transformer, 3000 ohms plate-to-plate
F_1	5-amp fuse
F_2	0.5-amp fuse
SEL	15-volt. 4-amp selenium rectifier
M	Milliammeter, 0-100 ma
Ch_1	10-henry, 150-ma choke
Ch_2	15-henry, 50-ma choke
J_1, J_2, J_3	Input jacks