A Simple High-Quality Phono Amplifier

R. D. MIDDLEBROOK*

An inexpensive audio amplifier with sufficient gain to drive a loudspeaker from a magnetic pickup and which uses an unusually large amount of negative feedback over the output tube and transformer.

THE BEST AUDIO AMPLIFIER is wasted if the associated equipment can not take advantage of it. Many high-quality amplifiers are available commercially, all of them using push-pull output stages. Their capabilities are impressive—and so are their prices. Of the thousands of non-technical people who have bought these amplifiers, how many have spent a *proportionate* amount of money on their loudspeaker systems?

There is room for a cheaper and simpler audio amplifier which can still be considered high-quality. It is not generally believed that a single-ended output stage is capable of producing results in keeping with present-day standards; yet it can be done. This article will describe how excellent listening quality can be obtained from a circuit which, at first glance, doesn't look as though it would sound any better than a small table radio.

The secret of this transformation is negative feedback. It is the writer's belief that most of the unpleasantness of the reproduction from an ordinary single tetrode or pentode output is due to the low speaker damping, and not to the harmonic distortion. Without entering into the fierce discussion on the merits or otherwise of negative output impedance of amplifiers, it can be stated with some confidence that an output resistance somewhat less than the speaker resistance is desirable in order to obtain satisfactory damping. By using enough negative feedback this can be achieved with a tetrode output tube, with all the attendant advantages of reduced distortion and extended frequency response. The amplifier to be described uses a single 6V6 beam tetrode tube, with an ordinary universal output transformer. The performance figures show that the results obtained are definitely in the "high-quality" class:

Maximum output:	3 watts
Total distortion:	1 per cent at 3 watts (1000 cps)
Frequency range:	3 db down at 20 cps and 25,000 cps
Output resistance:	0.1 ohm

The maximum power output of 3 watts is obtained at middle frequencies; the maximum power obtainable at extreme low and high frequencies depends on the quality of the output transformer. No amount of negative feedback can effect any improvement in this respect. Using the Thordarson Type T22S58 universal output transformer, the maximum available power output falls to 3 db below 3 watts at 80 cps and at 8000 cps.

Since most present-day amplifiers profesing to be "high fidelity" are capable of at least 10 watts output, a word in defense of 3 watts may not be out of place. 10 or 20 watts certainly give a considerable margin of safety, so that even the peaks of the signal give rise to distortion less than the figures quoted for maximum output. What the loudspeaker does to the transient is, of course, another story. In this amplifier, owing to the large amount of negative feedback, the signal contains very small percentages of distortion right up to the maximum output of 3 watts, and if the signal is increased further, the peaks are clipped. This effect is clearly visible on an oscilloscope, not only for a sine wave but also for the complex waves of music or speech. As mentioned previously, the guiding principle in the design of the amplifier is economy in construction while maintaining adequate performance for ordinary home listening: the acid test for success is therefore a listening test. If an oscilloscope is connected across the loudspeaker, while reproducing heavily-recorded music, it will be seen that the gain can be increased until the volume is sufficient to drown all conversation before the peaks start to clip. In other words, all activity must cease while the music is at full volume—a condition which must surely warm the heart of any hi-fi enthusiast. Need more be said about the adequacy of 3 watts?

The complete amplifier has sufficient gain to produce full output from a magnetic pickup, such as the General Electric variable reluctance type. *Figure* 1 is a block diagram of the various stages, and it is seen that the circuit can be divided into two distinct parts, each embodying heavy overall negative feedback.

Circuit Description

Figure 2 shows the complete circuit in detail. The grid resistor R_1 is chosen to be a suitable load for the pickup. The first two triode sections form a straight cascaded amplifier with a gain of 1400 times, which is reduced to an over-all gain of 100 times by the negative feedback from the plate of V_1 to the cathode of V_1. This link contains the tone control circuits. Various tone control arrangements are possible, and can be chosen to suit the individual: however, two networks which have been found adequate are described here.

Figure 3 is the bass control, which gives a maximum of 12 db bass boost, the magnitude of the rise being controlled by the potentiometer. The point at which the rise begins is selected by the switch. These turnover frequencies are 80, 140, 200, 300, 400, and 500 cps. The bass boost is sufficient to compensate for the recording characteristic of LP records, and in practise it will be found that usually the maximum amount of boost is unnecessary.

Figure 4 shows the treble control, which has one position giving 3 db rise,

* 1928 Cooley Ave., East Palo Alto, Calif.

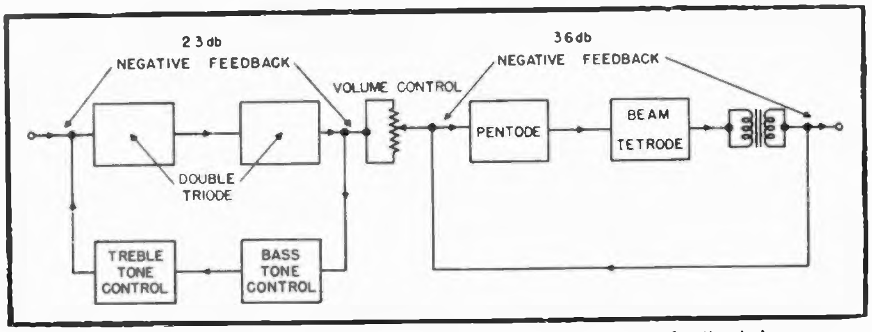

Fig. 1. Block diagram of the amplifier, showing the two negative feedback loops.

one flat position, and four positions giving treble cut. The potentiometer determines the degree of cut, and the switch selects the turnover frequency. These turnover frequencies are 1500, 2000, 4000, and 7000 cps. The 0.1 megohm resistor is merely to prevent a thump at the speaker when switching from the flat to the lift position.

Raised in level by 40 db by V_1 and V_2, the signal is fed to the volume control and then to the grid of V_3. This tube has the unusually high plate load, R_{10}, of 2.2 megohms, and is direct-coupled to the grid of V_4. Using a 2.2 megohm load enables a gain of 340 times to be realized; if a.c. coupling were used, the grid resistor of V_4 would have to be at least 10 megohms to avoid shunting the load of V_3, and this exceeds the tube manufacturer's maximum permissible value of 1.0 megohm. Using direct-coupling also has the advantage that no low-frequency phase shift is introduced.

For an 8-ohm loudspeaker load, an output transformer turns ratio of 32 to 1 should be used. The voltage "gain" from the grid of V_4 to the transformer secondary is approximately 0.76, thereby giving a gain from the grid of V_3 to the transformer secondary of 340 × 0.76 = 260 times. Since the feedback voltage returned to the cathode of V_3 is one fourth of the output voltage, by virtue of the 470- and 1500-ohm resistors forming a voltage divider, the over-all gain is reduced from 260 times to 4 times: that is we have $20\log(260/4)$, or 36 db of negative feedback.

V_3 obtains its bias voltage from the very small grid current flowing through the 4.7 megohm grid resistor; this is commonly described as "contact potential." Bias amounts to about minus 0.75 volt. The voltage developed across the 470-ohm cathode resistor is only some 0.07 volt, and is therefore negligible. The reason for using this method of biasing is that it avoids the low-frequency phase shift which would be introduced by the conventional cathode resistor and bypass capacitor.

One of the troubles inherent in direct-coupled stages is the drift of operating point. This is avoided here by deriving the screen voltage of V_3 from the cathode of V_4, through the 0.47-meg resistor. The operation is as follows: suppose the plate current of V_3 decreases, then its plate voltage increases, carrying the grid of V_4 with it. The plate current of V_4 then rises, and its cathode voltage increases. This also raises the screen voltage of V_3, tending to increase the plate current of V_3 and restore the operating point. Thus we have in effect an internal negative feedback loop which stabilizes the working points of V_3 and V_4. This feedback loop is made inoperative for signal voltages by decoupling the screen of V_3.

The resistor R_{13} and capacitor C_7 between the plate of V_4 and the cathode of V_3 are to suppress high-frequency oscillations. The capacitor should be a high-quality mica type rated at 1000 volts. If different taps are used on the output transformer, or if a different transformer is used, the values of these two components may need to be adjusted. The series grid resistor of V_3 and the screen resistor of V_4 are included to guard against parasitic oscillations.

The total current drain of the complete amplifier is only about 40 milliamperes, and hence the power pack requirements are modest. Using a 350-0-350 volt high voltage winding on the power transformer, sufficient voltage is available to dispense with a choke in favor of the much less expensive resistor for smoothing purposes. The less efficient smoothing thus obtained is nevertheless quite adequate, because the large amount of negative feedback reduces the 120-cycle hum from the B+ line to complete inaudibility. It is desirable to use one or more of the standard methods for reducing 60-cycle hum from the heater of V_1, such as tapping a ground connection across the heater winding, (as shown) or raising the heater winding to some positive potential with respect to ground.

Only one other point need be mentioned in connection with practical construction. The cathode resistor, both grid resistors, and grid capacitor of V_3 should be mounted as close as possible to the tube socket. This is because the input impedance to V_3 is extremely high and the grid leads are very sensitive to hum pickup.

All figures quoted above are measured values, not calculated. Aural results are excellent: the cleanness of the bass response is particularly pleasing. The entire amplifier can be built on a chassis 8 by 6 inches, and the quality of its reproduction bears comparison with that of amplifiers many times more expensive.

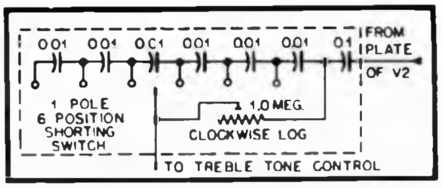

Fig. 3. A suggested bass-boost circuit. This section corresponds to box "A" in Fig. 2.

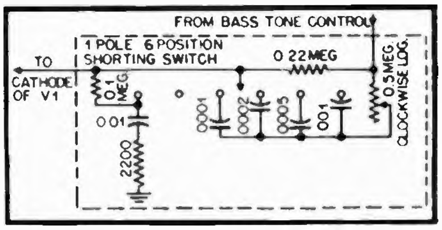

Fig. 4. A suggested treble tone-control circuit. This corresponds to box "B" in Fig. 2.

PARTS LIST—AMPLIFIER

C_1	0.1 µf, 600 v, paper
C_2	50 µf, 6 v, electrolytic
C_3	.01 µf, 600 v, paper
C_4	.001 µf, 500 v, mica
C_5	0.5 µf, 200 v, paper
C_6	500 µf, 50 v, electrolytic
C_7	100 µµf, 1000 v, mica
$C_{8a,b}$	10-10 µf, 450 v, electrolytic
C_9, C_{10}	20 µf, 500 v, electrolytic
R_1	pickup load resistor (see text)
R_2, R_5	0.12 meg, 1 watt
R_3, R_6	2200 ohms, ½ watt
R_4, R_{14}	0.47 meg, ½ watt
R_7	0.5 meg audio taper potentiometer
R_8	4.7 meg, ½ watt
R_9, R_{21}	27,000 ohms, ½ watt
R_{10}	2.2 meg, 1 watt
R_{11}	470 ohms, ½ watt
R_{12}	56,000 ohms, ½ watt
R_{13}	330 ohms, ½ watt
R_{15}	1250 ohms, 5 watts
R_{16}	1500 ohms, 1 watt
R_{17}	47,000 ohms, 1 watt
R_{18}	10,000 ohms, 1 watt
R_{19}	1000 ohms, 5 watts
R_{20}	0.27 megs, ½ watt
T_1	Output transformer, "Universal" type, 32:1 ratio for 8-ohm loudspeaker
T_2	Power transformer, 350-0-350 v at 50 ma; 6.3 v at 2.0 amps

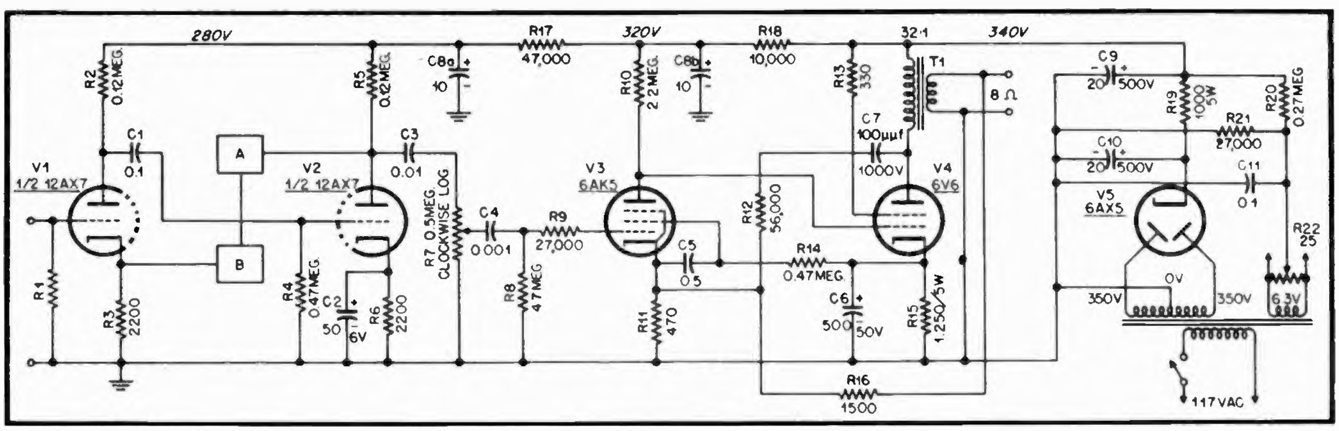

Fig. 2. The complete schematic of the amplifier.