Solid-State Audio Circuits

Part 2 (Conclusion)

Analyzing audio preamplifiers and tone-control circuits

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Last month in Part 1 of this article, we discussed the various elementary circuits used in audio amplifier designs. This month, our focus is on detailed analyses of audio preamplifiers and tone-control circuits.

Audio Preamplifiers

The purpose of a preamplifier is to boost the minuscule output voltage from sources such as microphones, tape heads, phonograph cartridges, etc. In audio, the preamplifier might have a gain of as little as 2 or 3, and as great as 5000. The gain required of the preamplifier is a function of the input signal required by the power amplifier (or other load) and the voltage available from the source. Let us suppose that a microphone's output is 5 millivolts at normal speaking levels and that the power amplifier requires a 250-millivolt input to deliver maximum output power. This gives us the V_{in} and V_{out} potentials of the preamplifier. The required voltage gain can now be calculated from the formula $A = V_{out}/V_{in} = 250\ mV/5\ mV = 50$.

Several options are open when designing preamplifiers for audio use. One popular approach is the use of a special-purpose integrated circuit like the LM-381. Ordinary operational amplifiers, such as the 741 or LM-301 can also be used, as can special operational amplifiers designed for audio and stereo applications, such as the LM-1303. All

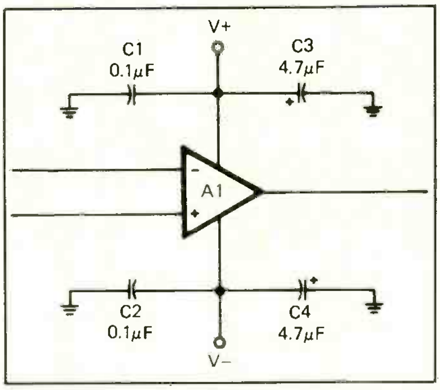

Fig. 1. To assure stable operation, it may be necessary to bypass each power-supply line with two capacitors to handle entire audio range.

these devices are easily obtained by hobbyists.

An IC audio preamplifier may have quite a bit of gain and could oscillate under some conditions. It also might easily influence, or be influenced by, other circuits because of signals passed between stages over the dc power lines. These potential problems make it necessary for the dc power lines of the IC preamplifier to be properly bypassed. Figure 1 shows correct bypassing of an operational amplifier, although the same decoupling methods apply to other audio integrated circuit devices

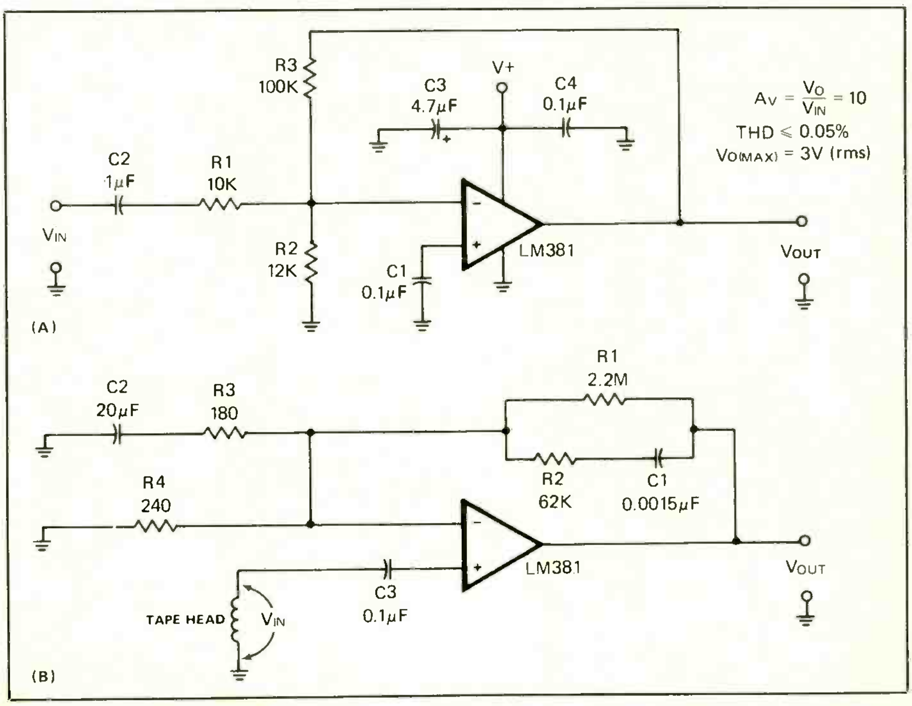

Fig. 2. Audio amplifier circuits based on the LM-381 IC amplifier. Circuit A is a common input preamp for phono cartridges, microphones, etc. Circuit B is generally used to preamplify the low-level signal from tape player heads.

whether single- or dual-polarity power supplies are used.

Each power supply line must be bypassed with at least one capacitor, and preferably two, as shown in Fig. 1. Capacitors *C1* and *C2* are 0.1 μF each and are used to decouple high-frequency signals. Capacitors *C3* and *C4* have larger values (typically 4.7 μF) and are used to decouple lower-frequency signals. Usually, *C3* and *C4* are tantalum electrolytics.

You may well ask why two capacitors are used in bypass circuits. The reason for this is that you want bypassing across the entire 20 kHz or so audio range. A relatively large value electrolytic will not work well at the higher-frequency extreme, and a small value capacitor is ineffective at the lower-frequency extreme. Therefore, we are forced to parallel a lower-value capacitor with a higher-value electrolytic capacitor to assure stable broad-spectrum preamplifier operation. In many cases, however, the single 0.1-μF capacitor on each dc power supply line is sufficient, so this "overkill" is not needed.

Several companies make IC preamplifiers especially for audio applications. Typical of these are the LM-381 and LM-382 from National Semiconductor (see the *Linear Data Book* for details). Two circuits based on the LM-381 are shown in Fig. 2.

Similar to a dual operational amplifier, the LM-381 differs in that it requires only a single-polarity dc power supply. With the values shown in the Fig. 2A wideband, low distortion audio preamplifier, the voltage gain is 10 at a total harmonic distortion (THD) of less than 0.05 percent. The frequency response of this circuit is essentially flat throughout the audio spectrum (up to the limit of the amplifier).

A large number of cassette tape players use the LM-381 as shown in Fig. 2B. The tape head is coupled to the noninverting (+) input of the LM-381 through a 0.1-μF capacitor. Because of its low input bias, the preamplifier does not require a resistor from the noninverting (+) input to ground. (Many versions of this circuit require a resistor to prevent charging of the capacitor by input bias currents.)

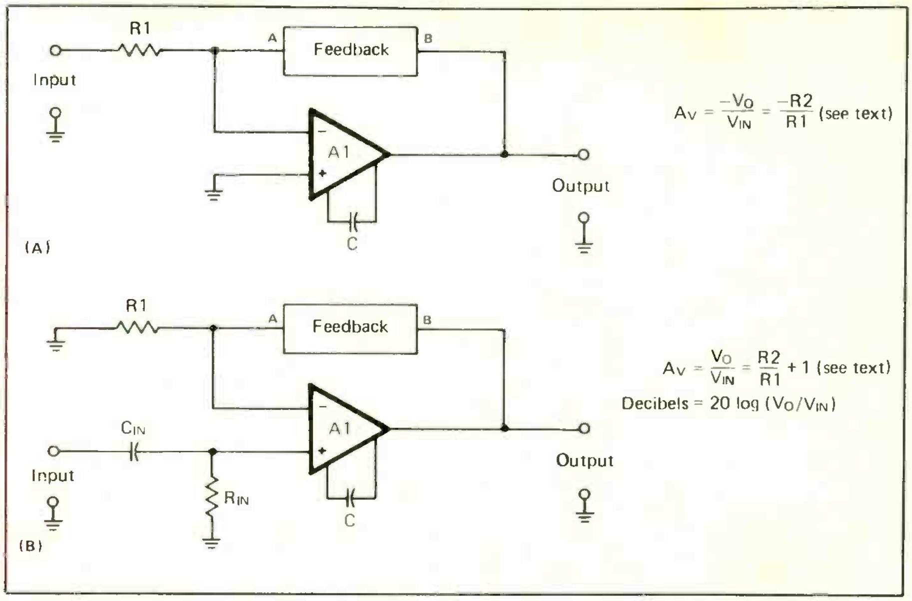

Fig. 3. Basic op amp inverting follower (A) and noninverting follower (B).

Figure 2B's low-frequency response is set by resistor *R3* and capacitor *C 2* and is calculated using the formula $F = 10^6/(6.28C2R3)$. Here, *F* is the low-end −3-dB frequency in hertz (Hz); *C2* is in microfarads; and *R3* is in ohms. Values shown for *R3* and *C2* yield a low-end frequency of about 45 Hz. The shape of the frequency response curve of this preamplifier is set to correspond to that required for the cassette tape equalization curve.

The classical operational amplifier is one of the most useful ICs available for audio amplificaion. The op amp is easy to use, usually well-behaved and low in cost. Designing circuits with the op amp is generally so easy that one wag was tempted to correctly claim that it makes ". . . the contriving of contrivances a game for all." Circuits that only very advanced hobbyists could tackle before the ubiquitous IC op amp became available are now open to even the newcomer.

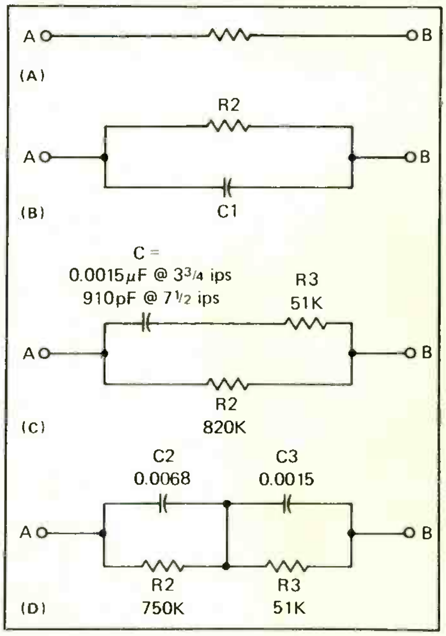

Fig. 4. Feedback networks commonly used in op amp circuits.

Figure 3 shows the basic operational amplifier configurations used in audio circuits. Figure 3A is the inverting follower, Fig. 3B is the noninverting follower. In the inverting circuit, the output signal will be 180 degrees out-of-phase with the input signal (reversed in polarity). In the noninveting circuits, the output signal is in-phase with the input signal.

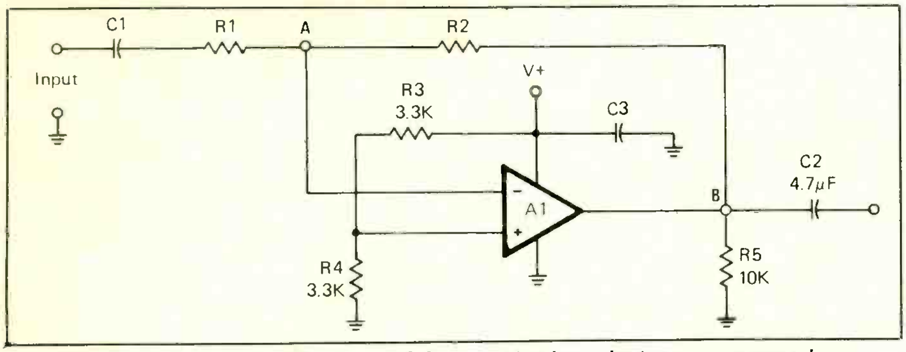

Fig. 5. Op amp circuit powered from a single-polarity power supply.

In both cases, gain is set by the values of the input resistor (*R1*) and a feedback network. The expressions for the special cases where the feedback network is a single resistor (see Fig. 4A) are shown with each circuit.

Several popular variations of the feedback network that find application in audio preamplifiers are shown in Fig. 4. Figure 4A is a wideband amplifier that has a frequency response with no tailoring except by the natural bandwidth of the amplifier. The approximate available bandwidth for this circuit is calculated from the gain-bandwidth product (F_t) of the device, which is the frequency at which gain drops to unity (1). The formula is F_t = gain × bandwidth.

One use of this formula is for determining which op amp is needed. For example, suppose a frequency response of 20,000 Hz is needed in an amplifier with a gain of 150. The required F_t is 150 × 20,000 = 3 MHz.

The formula can also be rearranged to provide the means for calculating the maximum frequency response of any given circuit where F_t is known. for example, suppose a 1-MHz op amp is to be used in a circuit with a gain of 100. Maximum frequency response will be F_t/Gain = 3 MHz/100 = 30 kHz.

Figure 3B's feedback network produces a flat gain at low frequencies equal to that of the resistor alone. At frequencies above a certain point, however, gain will roll off at −6-dB per octave. The "break-

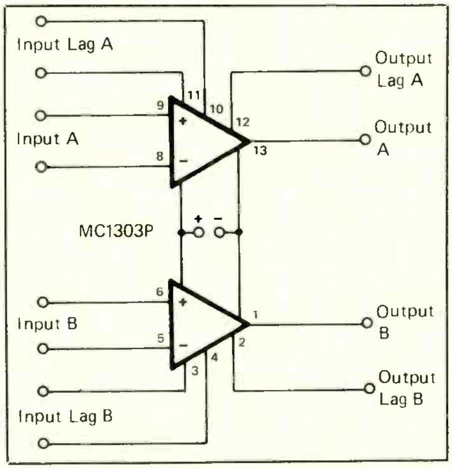

Fig. 6. Example of a stereo audio preamplifier based on the op amp.

point" between the low-frequency gain and the rolled off segment (high end − 3-dB point) is calculated using the formula $F = 10^6/(6.28C1R2)$. Where: *F* is in hertz (Hz); *R2* is in ohms; and *C1* is in microfarads.

Remaining feedback networks in Fig. 4 are used in special preamplifiers. That in Fig. 4C is used for NAB-compensated tape preamplifiers, Fig. 4D for RIAA-compensated phonograph preamplifiers.

Operational amplifiers are normally used in dual-polarity power supply circuits. In cases where the op amp must be used in single-polarity supply circuits, a configuration like that shown in Fig. 5 can be used. In this type of circuit the V− power supply terminal is grounded and the V+ terminal is connected to the single power supply. The + input is biased to a point midway between V+ and ground by the *R3/R4* divider. The value of *R3/R4* can be any resistance between 2,000 and 100,000 ohms. The value shown, 3,300 ohms, is very common in audio preamplifiers.

A problem with this circuit is that the inverting input and the output terminals are also biased to a high dc potential. To prevent these voltages from affecting other circuits, capacitor coupling is required for this circuit. Capacitor *C1* couples the input signal to the amplifier while preventing the dc bias at point "A" from affecting the input source. Similarly, *C2* will pass the audio output signal while blocking the dc offset bias.

An example of a stereo audio preamplifier based on the op amp is shown in Fig. 6. Once called the MC-1303 when Motorola was the sole source of the chip, other manufacturers now offer it as the LM-1303. The chip contains two operational amplifiers that are completely independent of each other except for the V− and V+ dc power supply connections.

Tone Control Circuits

Tone controls allow the user to custom-tailor the frequency response of an audio preamplifier. The BASS control emphasizes the low frequencies, the TREBLE control the high frequencies. In some circuits a single TONE control serves both ends of the spectrum. Several varieties of tone control circuit are shown in Fig. 7.

A simple roll-off tone control found in low-cost equipment is shown in Fig. 7A. Consisting of just two components series-connected across the audio line, this is the simplest and least-desirable type of tone control. These components form a treble roll-off circuit that mimics the effect of "bass boost" (poorly) by rolling off the high frequencies. Unfortunately, while simple, this type of tone control reduces the amplitude of the signal.

Another variety of tone control is

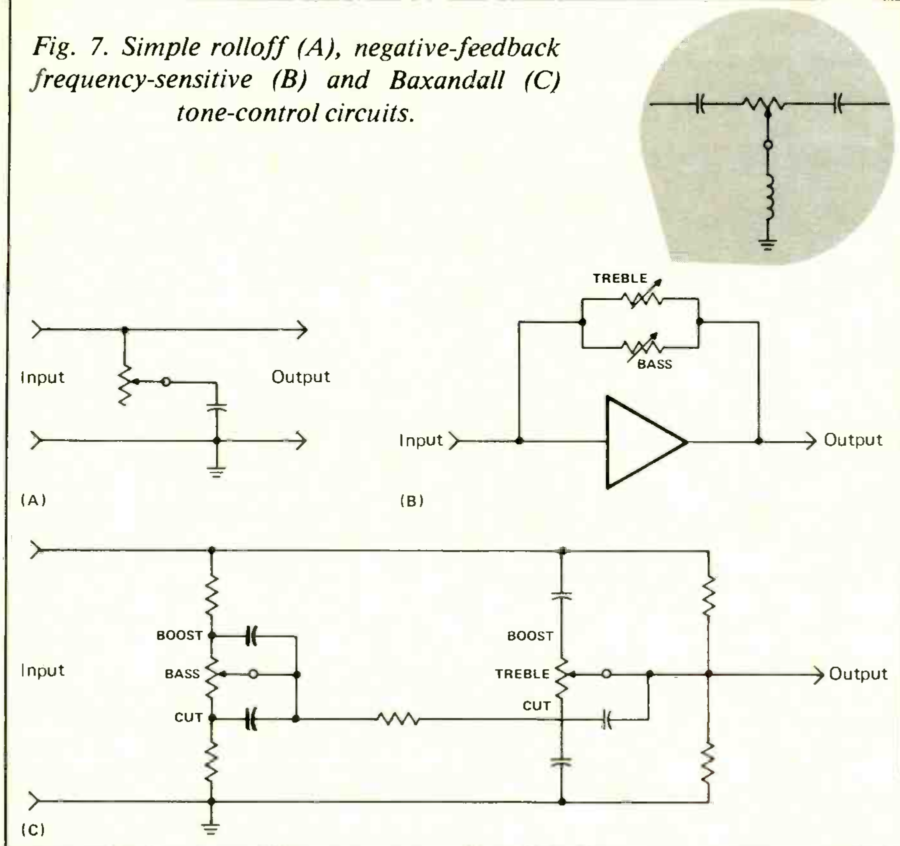

Fig. 7. Simple rolloff (A), negative-feedback frequency-sensitive (B) and Baxandall (C) tone-control circuits.

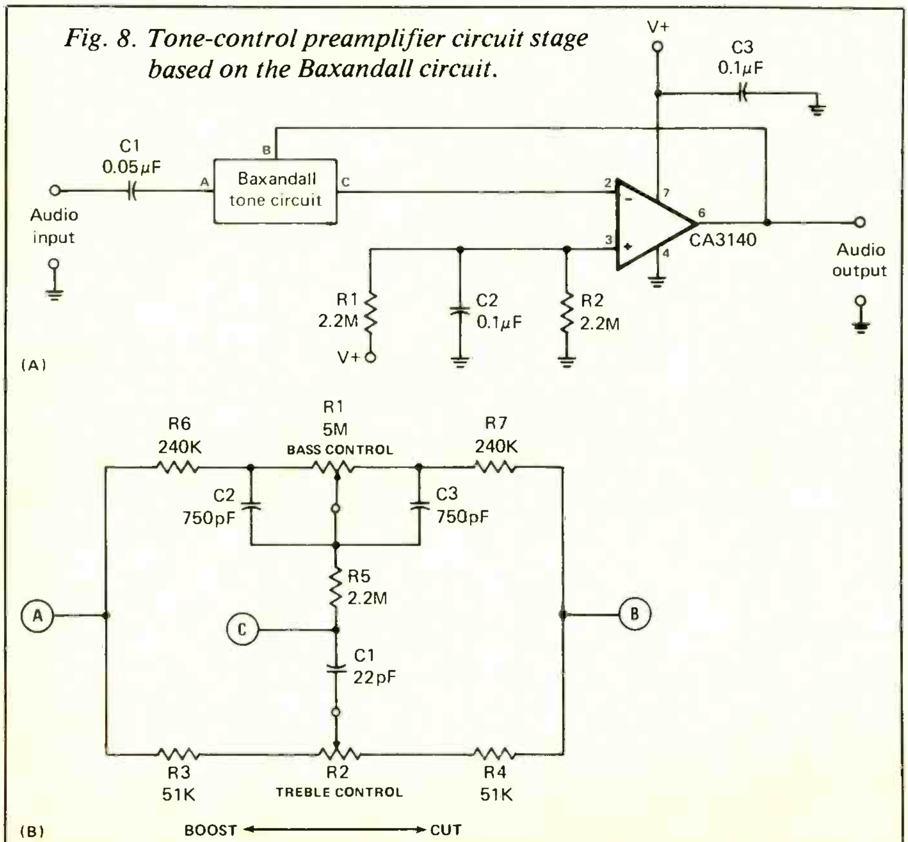

Fig. 8. Tone-control preamplifier circuit stage based on the Baxandall circuit.

shown in Figure 7B. In this version, a pair of frequency-sensitive RC or RLC networks is placed in the negative-feedback circuit of the amplifier. These circuits selectively amplify different bands of frequencies. An example of the RLC version is shown in the inset in Fig. 7B.

The Baxandall tone control circuit shown in Fig. 7 is used in almost all decent audio amplifiers. The Baxandall circuit consists of two cascaded frequency-selective RC networks, one each for bass and treble ranges. Each control boosts its design frequencies at one end of the control's range, and cuts it at the other end of the range.

Figure 8 shows the circuit for a tone control preamplifier stage based on the Baxandall circuit. The basic circuit is a CA-3140 op amp connected in a basic inverting follower configuration, with a single power supply. Resistors *R1* and *R2* bias the + input to V+/2. These resistors are higher in value than in certain other op amps because of the very-large input impedance of the BiMOS CA-3140 op amp. The three-terminal Baxandall tone circuit shown in Fig. 8B is essentially the same as in Fig. 7C, and is used as shown in the circuit of Fig. 8A. It provides a boost or cut of about 20 dB of either the bass or the treble.

In Closing

Now that you have some idea of what kinds of circuits are used and, more importantly, *how* they are used, you are ready to begin experimenting with them on your own. As you design your own circuits, you will find that preamplifiers and tone-control circuits may or may not be needed, depending on the requirements of your circuits. Whether or not you do need preamplifier or tone-control circuits, you will soon discover that experimenting with audio circuits is a lot of fun and that very little time is required to breadboard them. **ME**