Experimenting With Audio Circuits

★ Very Imp

To prevent Loading The Signal Source also Critical w/ Transistor Stages P36/P37 Fig 5 600-Ω — [redacted] Line Amp Telco use 600-600 Ω

Using op-amps to build a variety of professional audio circuits to suit different requirements

By Joseph J. Carr

Perennial favorites with electronics experimenters and hobbyists, audio projects are both useful and well-behaved. Though vhf radio circuits and home computers may require special expertise to build successfully, even a newcomer to electronics can quickly assemble almost any audio circuit and have it work the first time out. In this article, we will discuss some of the types of audio circuits that have become popular over the years. Perhaps one or more of these circuits will fill a specific need you have.

Because most easily built audio projects are based on the [redacted] operational amplifier, we will discuss a little op amp theory preliminary to getting into the projects portion of this article.

Setting the Stage

Shown in Fig. 1 are the schematic representations of the classical inverting and noninverting op-amp configurations that are in common usage. In Fig. 1(A) is the inverting follower amplifier configuration, while in Fig. 1(B) we see the noninverting amplifier configuration. Output from the Fig. 1(A) circuit is exactly the opposite of the input (inverted 180 degrees). Conversely, the Fig. 1(B) circuit's output is the same as its input signal (no inversion). In either case, the output can be lower or higher in amplitude than the input signal or the same amplitude as the

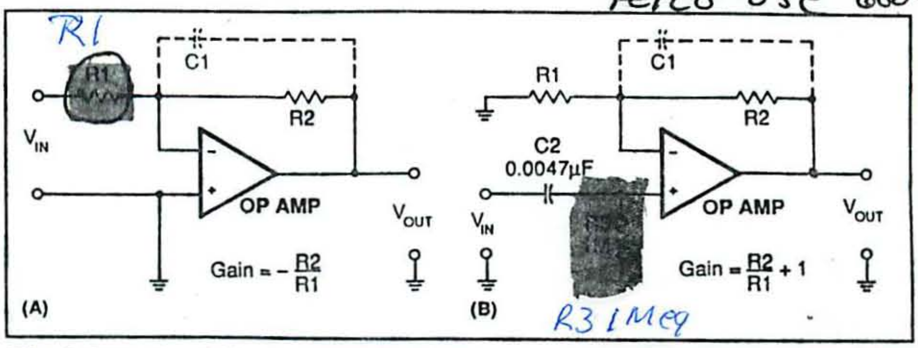

Fig. 1. Inverting follower (A) and noninverting follower (B) op-amp circuit configurations.

input signal, depending on the values selected for *R1* and *R2*.

Gain of the Fig. 1(A) inverting amplifier is merely the ratio of feedback resistor *R2* to input resistor *R1* and is derived from the formula Gain = −(R2/R1). The minus sign in the equation simply means that a 180-degree inversion has taken place. The value of input resistor *R1* is usually kept at a minimum of 10 times the output impedance of the signal source to minimize loading effects.

For most low-impedance sources (low-impedance microphones, other amplifiers, etc.), the value of *R1* should be 10k ohms or more. For high-impedance sources, *R1*'s value should be at least 10 times the source's impedance. For example, a microphone specified to have a 50k-ohm impedance would require a value for *R1* of 50k ohms × 10 = 500k ohms.

Figure 1(B)'s noninverting amplifier uses the noninverting (+) input of the operational amplifier and has an input impedance equal to the value of input resistor *R3*. In this example, the input impedance of the amplifier is 1 megohm. Gain of this configuration is given by the formula Gain = (R2/R1) + 1.

In both circuits in Fig. 1, optional capacitor *C1* across the *R2* feedback resistor tailors the upper end −3-dB point in the frequency response of the circuit. For example, if you wish to design an amplifier for use as a microphone preamplifier in a communications system, you would want to limit the frequency response from a lower limit of 300 Hz to an upper limit of 3 kHz. These are the frequencies at which gain drops off by 3 dB below the center band's gain.

Capacitor *C1* sets the upper −3-dB point, while capacitor *C2* in Fig. 1(B) sets the lower −3-dB point. In both cases, the required values of the capacitors are calculated from the respective desired −3-dB frequencies and associated resistances. The formula for calculating these capacitances is $C = 10^6/(6.28FR)$, where C is in microfarads, F is the required −3-dB frequency and R is the value of the associated resistance (*R2* or *R3* in this circuit).

In Fig. 1(B), 0.0047-microfarad capacitor *C2* is shown associated with 1-megohm resistor *R3*. If you plug these values into the equation, you will find that this combination of values gives a lower −3-dB frequency of 34 Hz.

Suppose, as an example, you have a feedback resistor—*R2* in Figs. 1(A) and 1(B)—of 220k ohms. What value of shunting capacitor *C1* will yield a 3-kHz upper −3-dB point in the frequency-response curve? You would solve for this value as follows:

$C = 1{,}000{,}000/(6.28R2F)$
$C = 10^6/(6.28 \times 220{,}000 \times 3{,}000)$
$C = 0.000240$ microfarad

As you can see the final required capacitance value needed would be 240 picofarads.

Power Supply Considerations

Operational amplifiers and other linear ICs frequently require a dual-polarity dc power supply to operate properly. The V+ supply must be positive and the V− supply must be negative with respect to circuit ground or common. In most audio projects, these supplies will be +6 and −6 volts to +15 and −15 volts dc. In other applications, supply potentials down to 1.5 and up to 22 volts are used. Keep in mind, however, that special types of devices are needed for operation at potentials below and above the ±6- to ±15-volt range.

Shown in Fig. 2 are the classical methods of connecting a bipolar power supply to an operational amplifier. Decoupling and bypassing shown on the dc power-supply lines is common to most audio linear IC devices, not just op amps. Each power-supply line is bypassed by two capacitors: a 4.7-microfarad electrolytic (usually tantalum) and a 0.1-microfarad Mylar or other type. The higher-value electrolytic provides low-frequency decoupling, while the lower-value capacitor provides high-frequency decoupling.

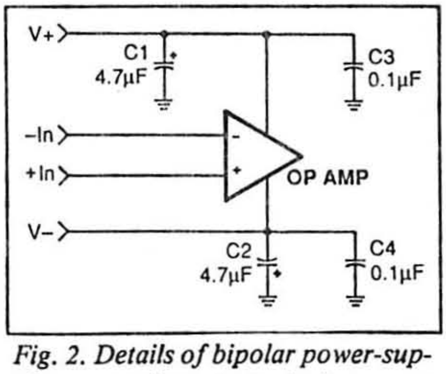

Fig. 2. Details of bipolar power-supply connections to typical op amp with high- and low-frequency decoupler/bypass capacitors.

At this point, you might be wondering why two capacitors are used for decoupling/bypassing, especially when a high and a low value capacitor are connected in parallel with each other. The reason for using both capacitors is that electrolytics are almost useless at higher frequencies. Hence, at frequencies where a high-value electrolytic capacitor would be virtually useless, the low-value capacitor comes into play.

For maximum effectiveness, these capacitors should be mounted as close as possible to the body of the IC they are to serve. If space limitations require a tradeoff, place the 0.1-microfarad capacitors closer to the IC than the electrolytics, but do not allow any capacitor to be positioned too far from the IC or its effect will be virtually useless.

Audio Mixers

An audio mixer is a circuit that combines audio signals from two or more inputs into a single-channel output. Application examples for mixers include multiple microphone public-address systems, multiple guitar systems and radio-station console service where inputs from tape players, record players and two or more microphones are combined into a single line that goes to the transmitter's modulator input.

Shown in Fig. 3 is an example of a simple audio mixer in which an op amp is used for combining signals from three separate sources. The audio input lines are identified as AF1, AF2 and AF3. Each source is applied to the inverting (−) input of the op amp, and each "sees" gains of R4/R1, R4/R2 and R4/R3, respectively. Because all resistors have values of 100k ohms, the gains for all three channels are 1 or unity.

Gain on any given channel can be customized to the requirements of each source simply by using the appropriate value of resistance in each case. Gain of any given channel will be 100k ohms/R, where *R* is the value of input resistance *R1*, *R2* or *R3*, depending on the channel to be customized. When calculating values to use, however, be careful to avoid reducing the input resistance to a

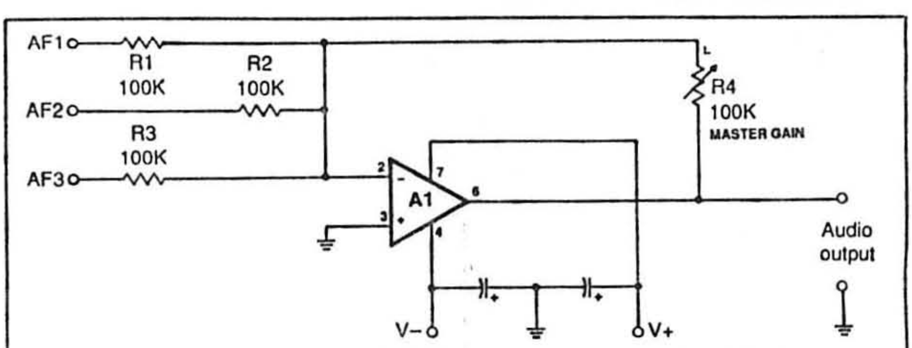

Fig. 3. Simple audio mixer circuit.

[redacted] However, if the source is a high-impedance phono cartridge or some similar device, [redacted]

In some cases, it might be beneficial to increase the value of the feedback resistor to 1 megohm or so to make the corresponding input resistances greater for any given gain. Keep in mind that the input impedance seen by any single channel is the value of the input resistance.

Master gain control *R4* is used as the feedback resistor in the Fig. 3 circuit. By using a potentiometer here, feedback resistance can be varied from 0 to 100k ohms. If no control over gain is required, *R4* would be a fixed-value resistor.

If an application calls for a one-time set-and-forget gain adjustment (as might be the case in radio station applications), make *R4* a trimmer potentiometer. Otherwise, the feedback potentiometer should be a panel-mounted unit that is adjusted via a standard control knob.

Almost any good operational-amplifier integrated circuit that has a gain bandwidth (GBW) that is sufficient for your proposed application can be used in the mixer circuit shown in Fig. 3. Because gain is unity, and GBW of more than 20 kHz will suffice, all op amps except those in the 741 family will suffice in communications applications.

An improved audio mixer circuit design is shown schematically in Fig. 4. This one is based upon the RCA CA3048 amplifier array IC, which provides approximately 20 dB of gain for each channel. The CA3048 is a 16-pin DIP IC that contains four independent ac amplifiers. Offering a gain of 53 dB with a typical GBW of 300 kHz, the CA3048 has a 90k-ohm input impedance and 1k-ohm output impedance. It produces a maximum low-distortion output signal of 2 volts rms and can accommodate inputs of up to 0.5 volt rms.

Each dc power supply can be up to 16 volts. Notice that there are two V+ and two ground pins on the CA3048. These multiple connections reduce internal coupling between amplifiers. The two V+ pins and two ground pins tie together externally as shown. The V+ pins are bypassed with two capacitors, *C5* and *C6* for high- and low-frequency bypassing, respectively. These capacitors must be mounted as close as possible to the body of the IC, with *C5* taking precedence over *C6*, since high-frequencies are more critical.

RC network *R3/C2* from the output to ground stabilizes the amplifier and prevents oscillation. Like the power supply bypass/decoupling capacitors, these components must be mounted as close as possible to the body of the IC.

Only one channel is shown in detail in Fig. 4; each of the other three channels is identical and all are joined together with the circuitry shown at the input side of *C4* as shown. Each channel has its own *R1* level control, which also provides a high input impedance for the mixer.

600-Ohm Audio Circuits

[redacted]. As an example, a remote preamplifier will have a 600-ohm balanced output and will connect to the next stage through a three-conductor line. Such a system uses two "hot" lines and a ground line to provide interstage connections.

[redacted] while an amplifier with a 600-ohm balanced input is a line receiver. Of course, some amplifiers function as both line drivers and line receivers.

Shown in Fig. 5 is the schematic diagram of a line receiver amplifier built around an LM301 op amp operated with unity gain input via the noninverting input terminal. Input to the circuit [redacted] former [redacted]

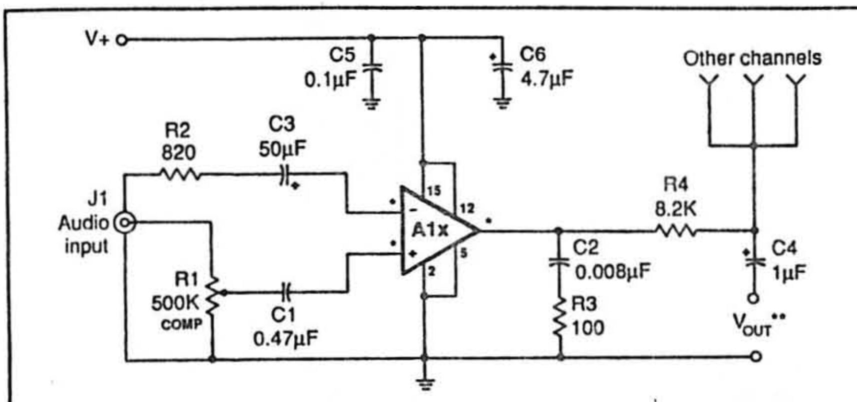

Fig. 4. Improved audio mixer circuit.

X = A, B, C or D

AMPLIFIER	–INPUT	+INPUT	OUTPUT
A	3	4	1
B	7	8	6
C	10	9	11
D	14	13	16

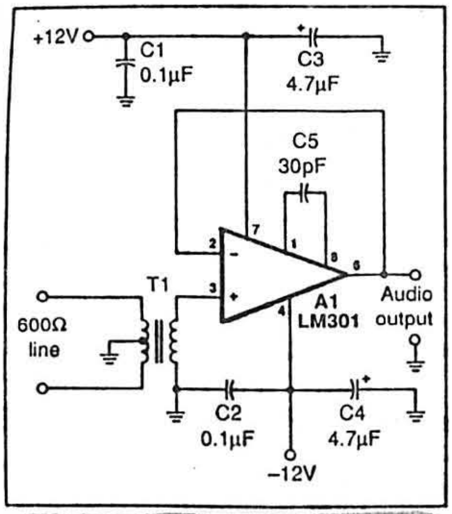

Fig. 5. A 600-ohm line receiver amplifier circuit.

turns ratio of the transformer. Suppose, for example, a 600-ohm input, 10k-ohm output transformer is selected. This transformer will have a secondary/primary impedance ratio of approximately 17:1. Turns ratio is the square root of 17, or about 4.1. This means that the voltage applied to the input of the op amp in this case would be 4.1 times greater than would be the case if a 600-ohm 1:1 line transformer had been used.

Like most op-amp circuits, the Fig. 5 circuit requires a dual-polarity dc power supply feeding its V+ and V− terminals. These power supplies can typically provide between +6 and +15 volts. Each supply line must be decoupled by high- and low-frequency bypass capacitors *C1* and *C3* with the same considerations as in the Fig. 4 circuit.

Output from the Fig. 5 circuit is an ordinary single-ended voltage, as is the case in other op-amp circuits. Hence, the output will typically have a very low impedance. It is possible to get away with a 600-ohm 1:1 transformer if the natural output impedance of the op amp is on the order of 50 ohms or so. A general rule of thumb in this regard is that the primary impedance of any transformer selected should be 10 times the natural output impedance of the device for best voltage transformation.

Another way to make a 600-ohm line-input amplifier is to use the simple differential dc circuit shown in Fig. 6. Make sure that input resistors *R5* and *R6* have values of 300 ohms, though. (Note: A 270-ohm value is shown for these resistors because this is the closest standard value that can be easily obtained from most sources. In most cases, derating the values to 270 ohms will have no discernible effect on circuit performance.)

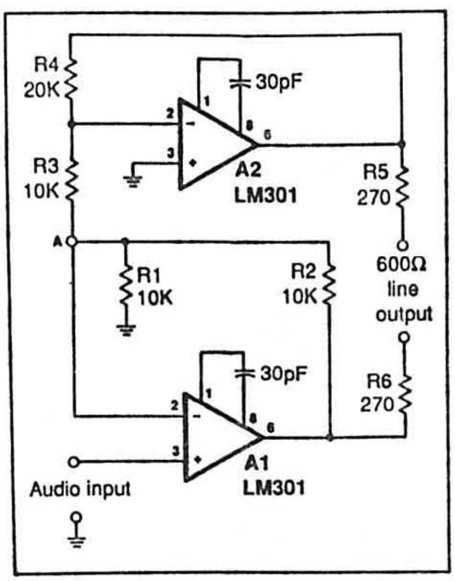

Fig. 6. A 600-ohm line driver amplifier circuit.

Figure 6 shows a line driver based on a pair of ordinary operational amplifiers, with power connections deleted but all pinouts the same as in Fig. 5. The output circuitry is balanced because it is made from two single-ended op amps that are driven 180 degrees out-of-phase with each other. The low output impedance of the operational amplifier plus the 270-ohm series resistances make the balanced output impedance a total of approximately 600 ohms.

The Fig. 6 circuit is a good example of clever usage of one property of the ideal op amp. Applying a voltage to one input causes the same voltage to appear at the other input. In this case, the audio input signal voltage applied to the noninverting input of amplifier *A1* also appears at the inverting input of the same amplifier. Thus, V_{in} appears at both inputs and point A, which allows point A to feed the other half of the balanced circuit made up of amplifier *A2*.

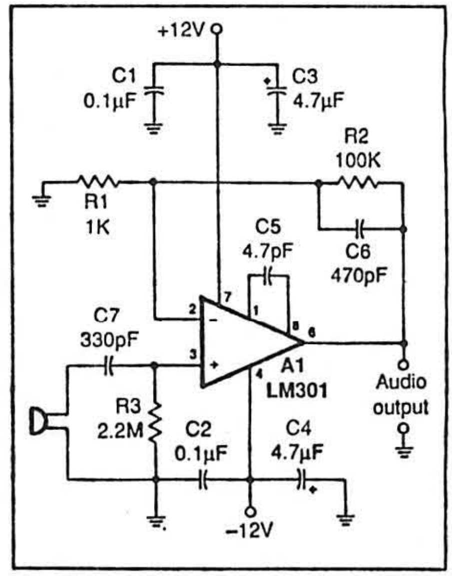

Fig. 7. Simple microphone preamplifier circuit suitable for use in communications and restricted-frequency-response PA applications.

Because *A1* is a noninverting gain-of-2 circuit and *A2* is an inverting gain-of-2 circuit, the two sides of the circuit are 180 degrees out-of-phase with each other. This is the condition required of the two "balanced" output lines.

Preamplifier Circuits

A preamplifier is an audio amplifier that gives some initial amplification to the signal before passing it to another circuit for additional amplification and processing. For example, [redacted] drives a loudspeaker or the input of a transmitter's modulator.

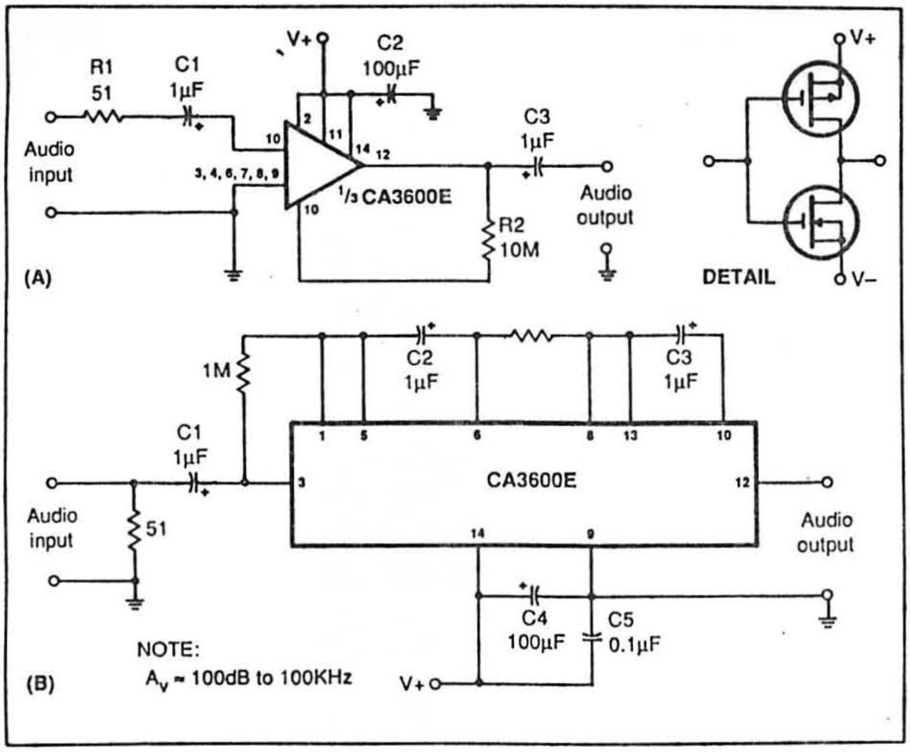

Fig. 8. Single- (A) and multiple-stage (B) general-purpose preamplifier circuits suitable for use in hi-fi applications.

A schematic diagram of a simple microphone preamplifier is shown in Fig. 7. This circuit is suitable for PA and communications use but not for high-fidelity applications because of its narrow bandwidth. Built around a common LM301 op amp wired in a noninverting follower configuration and using the values shown for input and feedback resistors *R1* and *R2*, the circuit has a gain of 101.

A microphone is capacitively coupled to the noninverting input of the op amp. To keep the op amp's input bias currents from charging *C7* and thereby latching up the op amp, 2.2-megohm resistor *R3* is placed between the op amp's noninverting input and circuit ground.

This circuit can be made less complicated if a dynamic microphone is used to drive it. This type of microphone uses a high- or low-impedance coil that is permanently connected into the circuit. In this arrangement, *R3* and *C7* are omitted and the microphone is connected between pin 3 of *A1* and circuit ground. If you anticipate having to disconnect the microphone from the circuit, however, keep *R3* in the circuit to prevent the op amp's output from saturating at or near V+ when the noninverting input is left open.

Frequency response of this circuit is tailored by *C5* and *C6*. With the values shown for these capacitors, the upper −3-dB point in the response curve will be slightly beyond 3 kHz and will roll off at about 6 dB/octave beyond this frequency.

Two general-purpose preamplifiers based on RCA's CA3600E IC are shown schematically in Fig. 8. The CA3600E is a complementary COS/MOS transistor array device. Single- and multiple-stage designs are shown in Fig. 8(A) and (B), respectively. The internal transistor array equivalent for one transistor pair is shown in the inset in Fig. 8(A). This design

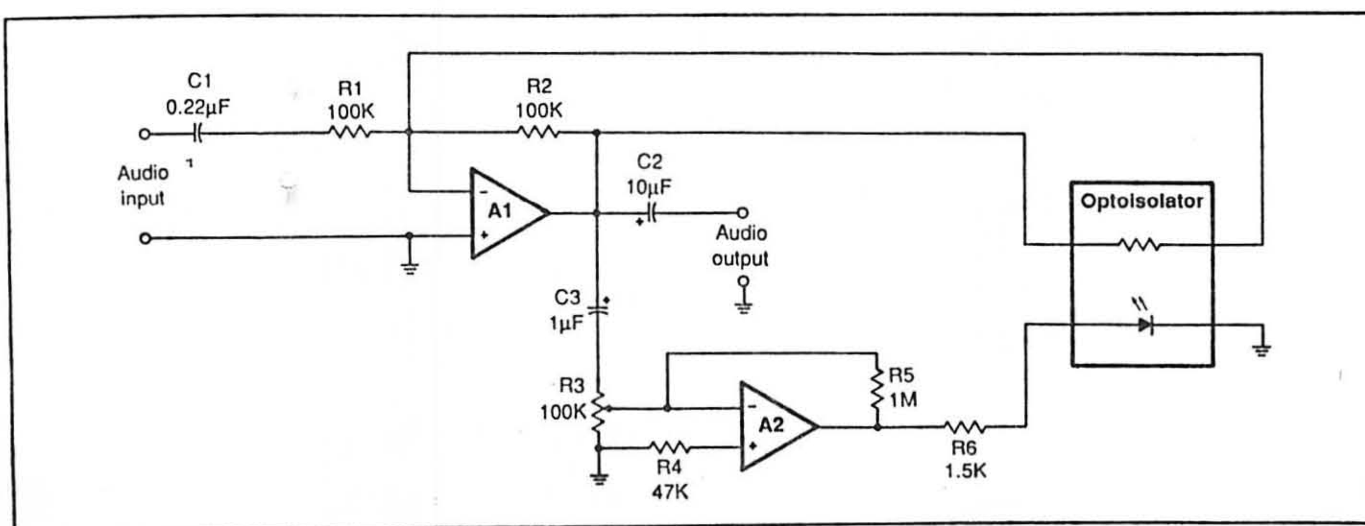

Fig. 9. A typical compression amplifier circuit.

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is capable of up to 30 dB of gain at a V+ of 15 volts dc, slightly more at lower potentials but only at a sacrifice of the 1-MHz – 3-dB point in the response curve.

Figure 8(B)'s multi-stage design is capable of gains up to 100 dB at frequencies up to 1 MHz, assuming a 10-volt dc supply (gain drops to 80 dB when a +15-volt supply is used). This gain and frequency response are very useful in audio and other applications. However, it must be approached with caution when you actually build the circuit. Be sure to keep the power supply decoupling capacitors as close as possible to the body of the IC.

Unless a preamplifier stage with a higher impedance is provided, the 50-ohm input impedance of the Fig. 8(B) circuit takes this amplifier out of the audio-amplifier category because audio amplifiers expect to "see" higher impedances.

★ *Compression Amplifier*

An amplifier that reduces its gain on input signal peaks and increases gain in signal valleys is known as a "compression" amplifier. Such a circuit is usually used by electronic musicians and broadcasters to raise the average power in the signal without creating appreciable distortion. Shown in Fig. 9 is the schematic diagram of a typical compression amplifier circuit.

Amplifier *A1* is any good audio op amp, such as the LM301 (see earlier circuits for power supply and compensation details). Circuit gain is set by input resistor *R1* and a feedback resistance composed of *R2* and the optocoupler's output resistor element. Resistance of the optocoupler is set by the intensity of the light-emitting diode's brightness, which is, in turn, set by the amplitude of the signal fed to the LED from *A2*.

Because the output signal from *A2* is proportional to the output signal from *A1*, overall gain reduces itself, or compresses. Any high-resistance output device, such as those from Clairex, or an H11A1 optocoupler that uses a JFET for the resistance element can be used in this circuit.

Assembly Notes

Any one or all of the circuits discussed here can be quickly and easily assembled using any of a variety of wiring techniques. If all you want to do is experiment, you can build the circuits on a solderless breadboarding block. For more permanent circuitry, you can mount and wire the components on small printed-circuit boards of your own design or perforated board with holes on 0.1-inch centers and suitable hardware.

There is nothing really critical about layout of the components in any of these circuits. However, to be on the safe side, always keep inputs and outputs as far apart as possible. It is also a good idea to use a socket for any integrated circuit used in a given circuit. ME