A Universal Rear End

This simple op-amp circuit gives frequently overlooked attention to the outputs of your projects

By Joseph J. Carr

One of the major failings of hobbyist-designed projects, and not a few supposedly professionally designed instruments, is inadequate attention to the rear-end circuitry. In most instruments, the really neat circuits are in the front end. So by the time you get to the rear end, you think of it as just the output section and, thus, don't give it much consideration. But proper design of the back end of an electronic instrument/control circuit can spell the difference between ho-hum operation and a really useful project.

In this article, we'll explore how to build a "Universal Rear End" you can actually use in your designs.

Terminology

Before we begin, let's get a little terminology straight by defining what is meant by the terms "front end" and "rear end." In electronics parlance, the front end of an instrument or other device is the section where input signals are received. Typical examples of front ends are the r-f amplifier in a communications receiver, a transducer amplifier in a temperature monitor, and the differential amplifier in an ECG (electrocardiogram) amplifier or Wheatstone bridge transducer circuit. Almost all signal processing and shaping are performed in the so-called front end.

Though less glamorous than the front end, the rear end is nevertheless very important in overall instrument and project design. By definition, the rear end is the section that contains the output stage(s).

About The Circuit

Shown in the schematic diagram is a semi-universal rear-end circuit I've used professfionally in numerous cases. I've built this circuit into physiological (biopotential) amplifiers, transducer amplifiers, and numerous other projects. The circuit has several very useful features: it has (1) gain when *R2* is greater than 10,000 ohms (otherwise gain is unity); (2) a gain control with a range of 0 to 1 or 0 to A_V; (3) a dc balance control/offset null; and 4) a position control.

The circuit is built around two 1458 operational amplifiers, each of which contains a pair of 741-family op amps in an 8-pin miniDIP package. Any other standard op amp will also work here, though use of the 1458 has the advantage ofreducing parts count and wiring times.

Power for this circuit must be from a bipolar source that delivers both positive-to-ground (V+) and negative-to-ground (V−) dc. Potentials between ±4.5 and ±15 volts dc will serve nicely.

The circuit in the schematic diagram consists of four inverting followers in cascade. As arranged, it serves overall as a noninverting follower. Removing any one on stage (*IC1B* recommended) will make the circuit into an inverting follower, since there would be an odd number of inverting stages.

The gain of an inverting follower operational amplifier stage is set by the ratio of the feedback and input resistors. For example, the gain of stage *IC1A* is −*R2/R1,* where the negative sign indicates that inversion (180-degree phase reversal) is taking place. Similarly, the gain of *IC1B* is −*R6/R5;* of *IC2A,* −*R8/R7*; and of *IC2B,* −*R10/R9.* Overall gain for the entire circuit is simply the product of all the individual gains, or $A_{vt} = A_{V1} \times A_{V2} \times A_{V3} \times A_{V4}$.

Since all gains in the circuit shown are unity, overall gain is one. However, you can increase or decrease the overall gain by varying individual stage gains. The recommended procedure is to vary the gain of fixed stage *IC1B*. In this case, you can assume that the gain of the overall circuit will be −*R6/R5.* Leave *R5*'s value at 10,000 ohms in most cases, unless it's impossible to find a value for *R6* that will result in the correct gain without modifying the value of *R5.* In any event, don't let the value of *R5* become less than 100 ohms. The rules for changing the gain are: 1) unity gain: leave as is (*R5* = *R6* = 10,000 ohms); for less than unity gain, *R5* is greater than *R6* (e.g. if *R5* = 10,000 ohms and *R6* = 2000 ohms, gain is 2,000/10,000 or 0.20); 3) for greater than unity gain, *R5* is less than *R6* (e.g. if *R5* = 10,000 ohms and *R6* = 100,000 ohms, gain is 100/10 = 10).

Gain control *R8* is used to vary overall gain of the circuit from zero to full. If the values are as shown in the schematic, *R8* varies the gain from 0 to 1. This potentiometer is usually a front panel control and is accessible to the user of the project.

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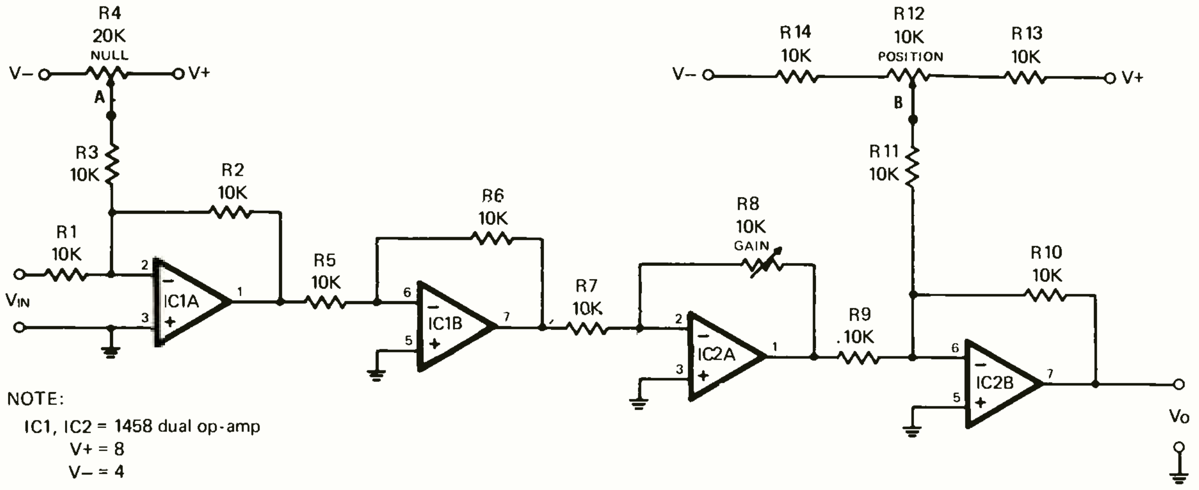

PARTS LIST

IC1, IC2—1458 dual op amp (see text)
R1, R2, R3, R5, R6, R7, R9, R10, R11—10,000-ohm, ¼-watt, 10% tolerance resistor
R4—20,000-ohm, linear-taper potentiometer
R6, R12—10,000-ohm, linear-taper potentiometer
R13, R14—See text
Misc.—Printed-circuit board or perforated board with solder posts; 8-pin DIP sockets (2); control knobs (3); input, output, and power connectors; suitable enclosure; machine hardware; hookup wire; solder; etc.

Null control *R4* is used to cancel the effects of dc offsets created both in this circuit and in previous stages. It also provides the dc balance effect noted earlier. The dc balance controls on some instruments are used to cancel the change of output baseline as the sensitivity control is varied—a most disturbing effect to someone making a measurement! Potentiometer *R4* is adjusted using a dc output meter at V_o, and is adjusted until there's no shift in dc output when *R8* is varied through its full range. If there are dc offsets present in the input signal (V_{in}), there will be such a shift noted in the output.

The function of *R4* is to provide an equal but opposite polarity offset signal to cancel the offset from all other sources. In some cases, there might be 10,000-ohm resistors (similar to *R13* and *R14* near *R12*) between the end of the potentiometer and the power supply potentials. These resistors reduce the offset range, while increasing the resolution of the adjustment. Use these resistors only if there's a problem in homing in on the correct value.

Position control *R12* is optional. It's normally used when the output signal is to be displayed on an analog paper chart recorder or dc CRT oscilloscope. Poteniometer *R12* provides an intentional offset to final stage *IC2B* independent of the input signal. It's used to position the output waveform anywhere on the scope's or chart recorder's vertical axis.

In some cases, the range of the *R12* may be too great. Only a small adjustment of the potentiometer will send the trace off-screen. You can counteract this problem with the simple expedient of selecting values for *R13* and *R14* (note that *R13*=*R14*) that allow the trace to just disappear off the top when the *R12* reaches the limit of its upward travel and off the bottom when the potentiometer reaches its lower limit.

Adjustment

Adjustment of this circuit requires either a dc voltmeter or a dc-coupled oscilloscope that has a scale grid on the screen or graticule to permit potentials to be read. If an oscilloscope is used for that purpose (set the switch to GND in AC/GND/DC arrangements), and set the trace to exactly the center of the vertical lines on the grid. Select a sweep speed that yields a nonflickering line. Next, place the switch into the DC position. The vertical deflection factor should be around 0.5 volt/vision.

Now, follow this procedure:

(1) Disconnect Vin from the front-end circuit and short this input to ground;

(2) Using a dc voltmenter, set the potential at point "A" to 0.00 volt;

(3) Similarly, set the potential at point "B" to 0.00 volt;

(4) Set *R8* to maximum resistance (highest gain);

(5) Make all adjustments to the front-end circuits as needed and then return to the rear-end circuit;

(6) Adjust *R8* through its range

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from 0 to 10,000 ohms several times while monitoring scope or meter connected to the output. If the output potential shifts, adjust *R4* until the shift is canceled. You'll have to continually run *R8* through its range while adjusting *R4*. Because this adjustment is somewhat interactive, try it several times, or until no further improvement is attainable.

(7) Check the range of the position control.

In Closing

The universal rear-end circuit is a simple project that can give your instrument and control projects that final "professional" touch that makes them more useful to you and anyone else who uses them. **ME**