Low-distortion discrete buffer amplifier handles bipolar signals

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Sometimes, the need arises for a low-distortion buffer amplifier capable of handling bipolar signals. You can use an op amp or integrated buffer for these applications, but for more flexibility, a discrete design may prove useful. Applications include buffering the input of an ADC or the output of a DAC, or an audio line driver.

The buffer in Figure 1 provides unity gain, low output impedance, and low distortion. It uses two emitter followers configured as symmetrical class-A amplifiers; current sources replace the usual emitter resistors (Figure 2). To obtain the best results, you should use complementary transistors (Q1 and Q2) with closely matched dc gain (beta).

This topology has advantages over a conventional emitter follower. It produces a lower level of even-order harmonics and lower noise, it can provide low I\textsubscript{BRAS} and V\textsubscript{BRAS} at the input and low offset voltage at the output, and it exhibits a high power-supply rejection ratio. The circuit doesn’t require temperature compensation and is dc stable. Like conventional voltage followers, it has local feedback only. This setup is advantageous in some applications where a long feedback loop can introduce additional distortions or instability.

Resistors R\textsubscript{1} and R\textsubscript{2} sum the two outputs. For even harmonics cancellation, their values should be matched. Preferred devices—metal film/foil, for example—should be stable and linear, and should produce low noise.

The voltage drop across R\textsubscript{1} is equal to the base-emitter voltage, V\textsubscript{BE} of Q\textsubscript{1}; thus, R\textsubscript{1} = K\times V\textsubscript{BE}/I\textsubscript{1}, where K is in the range of 3 to 20.

R\textsubscript{2} is set equal to R\textsubscript{1}. The same resistors also provide stability when driving a capacitive load, so the value of K depends on this capacitance. For the ac-equivalent circuit, these resistors appear to be connected in parallel, thus providing low output impedance. Diode D\textsubscript{1} protects the emitter junctions of both transistors from excess input voltages.

When the buffer is used as an output stage, you can eliminate D\textsubscript{1}.

The dc gains of the two transistors usually are not perfectly matched, resulting in a slight output offset voltage. To compensate, note the addition of base-emitter resistors R\textsubscript{5A} and R\textsubscript{5B} in Figure 1. To reduce the output offset voltage to almost zero, you can add R\textsubscript{5A} or R\textsubscript{5B} not both. As an example, assume that β\textsubscript{2} > β\textsubscript{1}; R\textsubscript{5B} is then used at Q\textsubscript{2}. If Q\textsubscript{1} has the higher beta, R\textsubscript{5A} would be used at Q\textsubscript{1}. You can estimate R\textsubscript{5}'s value from the following equation: R\textsubscript{5} = β\textsubscript{1} × β\textsubscript{2} × V\textsubscript{BE}/(I\textsubscript{1} × (β\textsubscript{2} − β\textsubscript{1})), where β\textsubscript{1} and β\textsubscript{2} refer to the beta of Q\textsubscript{1} and Q\textsubscript{2}.

When the output is balanced with the help of R\textsubscript{5}, input bias current is also minimized because the currents I\textsubscript{3} and I\textsubscript{4} cancel out each other.

The circuit shown in Figure 3 is a version of the circuit shown in Figure 1 that will automatically servo the output to a voltage close to zero. The integrator, IC\textsubscript{1}, averages the output voltage but does not pass the ac signal, because it is acting like a high-pass filter; its corner frequency, f\textsubscript{C}, can be calculated from this equation: f\textsubscript{C} = 1/(2\times π\times R\textsubscript{3} \times C\textsubscript{3}). In this circuit, f\textsubscript{C} is approximately 1.6 Hz.

NOTE: USE R\textsubscript{5A} OR R\textsubscript{5B}; DO NOT USE BOTH.

Figure 1 The buffer provides unity gain, low output impedance, and low distortion; see Figure 2 for details of the current sources in the transistors’ emitters.

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The output of the integrator drives an optocoupler that uses a photoresistive element on the output side. This resistor replaces the upper and lower R₅ resistors. The circuit in Figure 3 provides an output offset voltage of almost zero even with an input offset voltage applied, as long as it isn’t too high. The op amp, IC₁, should have low noise, low bias current, and low offset voltage; also, resistor R₃ and capacitor C₃ should be high-quality, stable devices.

One of the optocouplers in Figure 3 will always be inactive, but unless you know in advance which of the two beta values is higher, you won’t know which optocoupler is not active. High-quality photoresistor optocouplers can be rather expensive, so if you know the transistors’ beta values, you can replace one device with a diode, D₂, as shown in Figure 4. In this version, β₂ > β₁, so the photoresistor shunts Q₂. R₄ also can be omitted if the optocouplers’ LEDs can tolerate the maximum output current from the integrator.

Incidentally, an optocoupler with an incandescent (filament type) lamp can be used; in this case, the integrator is not needed, because the filament acts as an integrator. Change the integration capacitor to 1M and the input resistor value to 1k (Figure 5). The last circuit has low dc gain (compared with the integrator), so the output dc offset can be rather high—tens of millivolts. Diode D₂ prevents possible “latching” of the circuit.

NOTE: D₁ AND D₂ SHOULD BE IN THE SAME PACKAGE TO MAINTAIN THERMAL TRACKING; D₃ AND D₄ ALSO SHOULD BE IN THE SAME PACKAGE.
Many applications—such as driving modern ADCs, transmitting signals over twisted-pair cables, and conditioning high-fidelity audio signals—require differential signaling to achieve higher signal-to-noise ratios, increased common-mode noise immunity, and lower second-harmonic distortion. This requirement presents a need for a circuit block that can convert single-ended signals to differential signals; that is, a single-ended-to-differential converter.

For many applications, an AD8476 precision, low-power, fully differential amplifier with integrated precision resistors is more than adequate to perform the single-ended-to-differential conversion function. For applications that require improved performance, however, an OP1177 precision op amp can be cascaded with the AD8476, as shown in Figure 1. This single-ended-to-differential converter has high input impedance; 2-nA (max) input bias current; 60-μV (max) offset voltage, referred to the input; and 0.7-μV/°C (max) offset voltage drift, referred to the input.

The presented circuit is a two-amplifier feedback arrangement in which the op amp determines the circuit’s precision and noise performance, while the differential amplifier performs the single-ended-to-differential conversion. This feedback arrangement suppresses the errors of the AD8476, including noise, distortion, offset, and offset drift, by placing the AD8476 inside the op amp’s feedback loop, with the op amp’s large open-loop gain preceding it. In essence, the arrangement attenuates the errors of the AD8476 by the open-loop gain of the op amp when referred to the input.

External resistors $R_F$ and $R_G$ set the gain of the single-ended-to-differential converter in Figure 1 such that

$$GAIN = \frac{V_{OUT, DIFF}}{V_{IN}} = 2 \left(1 + \frac{R_F}{R_G}\right).$$

A minimum gain of two can be achieved by replacing $R_F$ with a short and $R_G$ with an open.

As with any feedback connection, care must be taken to ensure the system is stable. The cascade of the OP1177 and the AD8476 forms a composite differential-out op amp whose open-loop gain over frequency is the product of the OP1177’s open-loop gain and the AD8476’s closed-loop gain. The closed-loop bandwidth of the AD8476, therefore, adds a pole to the open-loop gain of the OP1177. To ensure stability, the bandwidth of the AD8476 should be higher than the unity-gain frequency of the OP1177. This requirement is relaxed when the circuit is in a closed-loop gain greater than two, because the resistor feedback network effectively reduces the unity-gain frequency of the OP1177 by a factor of $R_G/(R_F+R_G)$. The AD8476 has a bandwidth of 5 MHz, and the OP1177 has a unity-gain frequency of 1 MHz, so the circuit shown does not exhibit stability issues at any gain.

When using an op amp with a unity-gain frequency that is much larger than the differential amplifier’s bandwidth, you can insert a bandwidth-limiting capacitor, $C_F$, as shown in Figure 1. Capacitor $C_F$ forms an integrator with the feedback resistor $R_F$ such that the bandwidth of the overall circuit is given by

$$BANDWIDTH = \frac{1}{\pi R_F C_F}.$$
Many single-voltage power supplies consist of a transformer, a rectifier, and a filter capacitor, as shown in Figure 1. This circuit is relatively inexpensive and easy to build but supplies only a single voltage. Circuits employing op amps, data converters, and other analog circuit blocks often require additional voltages to operate. These extra voltages can be either higher than the main supply voltage or negative. In such cases, additional transformer windings and rectifiers are added. This approach is practical if all supply voltages have similar power requirements, but analog bias voltages usually have relatively low power requirements that may not justify the

**Figure 1** Many single-voltage power supplies comprise a transformer, rectifier, and filter capacitor.

**Figure 2** With some modification, a voltage doubler can be implemented.
overhead of additional transformer windings, rectifiers, and filters. Note that for voltages lower than the main supply voltage, a series voltage regulator or resistor divider generally is sufficient.

Because the bridge input and output do not share a common reference, standard negative peak detectors and voltage multiplier stages cannot be used. The bridge ac inputs, however, do have the ability to sink and source current with reference to the bridge-rectifier outputs. With some modification, a voltage doubler can be implemented (Figure 2).

Using the same structure and referencing it to the 0V rail can produce a negative bias. Note that positive and negative boost rails can operate at the same time. Figure 3 shows a modified version of the circuit with both positive and negative boost voltages added.

A supply using a 12V transformer has been used as an example, but the technique can be used for other voltages, as well. Note that series and boost capacitors have a higher voltage rating than do filter capacitors. Filter capacitors see only the peak of the rectified ac waveform, while series and boost capacitors see about two times the peak value (less extra diode drops). Capacitance values of series and boost caps vary with output power, and there is no inherent need for series and boost capacitors to be the same value.

In theory, negative and boost rails are capable of power levels similar to those of the main supply voltage. Larger power losses are due mainly to the $C_{\text{SERIES}}$ capacitor(s). Larger capacitors can be used to reduce losses, but they require an adequate ripple-current rating. If substantial power is required from boost voltage rails, you should still consider a separate transformer or additional windings.

**Figure 3** A modified version of the circuit has both positive and negative boost voltages added.

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**Standalone digital voltmeter uses a multichannel ADC**

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This Design Idea was realized for voltage/current measurement on a four-channel analog voltage source but has wide use in many other applications. The design is based on the Atmel ATmega8-16AC microcontroller and the Maxim MAX1230 12-bit ADC (references 1 and 2). Although the microcontroller has an internal 10-bit ADC, it’s more efficient to use an external multichannel ADC than to multiplex more analog channels to the ATmega8-16AC differential ADC inputs.

You accomplish the communication between IC$_1$ and IC$_2$ via the SPI according to the instructions in Reference 2. $R_{23}$ and $R_{24}$ are pull-ups for the end-of-conversion flag and chip-select modes. Signals for the SPI communication are tapped at header P$_1$ for a programmer connection. Pushbutton S$_2$ connects the IC$_2$ reset pin to ground; $R_{22}$ and $C_{33}$ debounce IC$_2$. Similarly, $R_{25}$ and $C_{34}$ debounce the auxiliary S$_1$ button connected to the INT0 pin of IC$_2$, which is used to switch between resolution patterns on the display.

IC$_2$ pins 23 to 28 are used through P$_2$ for communication with the 20x2-character BC2002BNHEH$\S$ LCD Bolymin display (Reference 3). Trimpot $R_{23}$ sets the display contrast. You can use IC$_2$ outputs RXD and TXD for USB communication via an optional USB-to-UART interface, such as the FTD232BM (not shown in Figure 1), for the purposes of data logging. IC$_1$ analog inputs AIN0 to AIN15 are connected to eight voltage dividers R$_{11}$ to R$_{18}$. The divide ratios depend on the maximum input voltage to be measured. Also, you should take into account the reference voltage on pin REF+ to use the full bit resolution of the ADC. The IC$_1$ analog inputs work in track-and-hold mode, so input impedance can affect the conversion acquisition time. As a result, input capacitors $C_{11}$, $C_{12}$, and $C_{13}$ with values...
Figure 1 You can use a multiple-channel ADC, along with a microcontroller and LCD display, to make this low-power, multichannel voltmeter.

Select power transformer TR1 for your local ac voltage (the schematic shows 230V ac with a 0.25A fuse) and fuse appropriately; that is, 0.5A when used at 120 V ac. The transformed voltages are rectified with diode bridges D1 and D2 and stabilized with 7805 series regulators. One 5V branch is used directly to supply the multichannel voltmeter; the other is auxiliary for global use.

Code listings for IC2 are available with the online version of this Design Idea at www.edn.com/4400220. This work was supported by the Slovak Research and Development Agency under contract No. APVV-0062-11.

REFERENCES
1-IC design monitors ajar doors

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If someone in your family has the habit of not completely closing a drawer—or perhaps the food freezer's door—you'll appreciate this design. It senses an ajar door and, if the situation isn't corrected within 20 sec, sounds a beeping alarm.

The circuit, shown in Figure 1, is controlled by a magnetic reed switch that mounts within the cabinet (food freezer in this case) and the magnet on the door. So long as the door remains closed, the switch is closed and the alarm is disarmed.

Opening the door in turn opens the switch, and C₁ starts charging up through R₁. Approximately 20 sec later—the delay allows for authorized usage—the voltage at pin 9 is high enough to turn on the oscillator formed from C, D, R₂, R₃, and C₂. This oscillator, operating at approximately 1 Hz and a 50% duty cycle, in turn pulses the piezoelectric transducer's 3-kHz oscillator.

Closing the door allows C₁ to discharge through R₆, an action that disables the low-frequency oscillator and, therefore, the transducer's oscillator. You can override the alarm via S₁ when the door must remain open.

Editor's Note: You might want to consider using other values for R₁ and C₁. The values shown for R₁ and R₆ result in a continuous 27-μA battery load when the door switch is closed. This drain is approximately 10 times greater than what the rest of the circuit consumes in standby. Changing R₁ to, say, 66 MΩ (3×22 MΩ) and C₁ to a 1-μF Mylar capacitor preserves the 20-sec delay and reduces the resistor's loading to approximately 0.1 μA. Additionally, by using the 1-μF Mylar unit rather than a 60-μF capacitor, you considerably reduce the possibility of the 60-μF device's leakage current adversely affecting the timing.

Figure 1 If the door and its switch are open, the low-frequency oscillator (C and D) pulses the transducer's 3-kHz driver ON and OFF.