Amplifiers deliver accurate complementary voltages

Marián Štofka, Slovak University of Technology, Bratislava, Slovakia

The circuit in Figure 1 generates two analog voltages, which you can vary in a complementary manner. When the straight output voltage rises, the complementary output voltage decreases, and vice versa. The sum of both output voltages is a constant: \( V_{\text{OUT}} + V_{\text{OUTC}} = V_{\text{REF}} \), where \( V_{\text{OUT}} \) is the straight output voltage, \( V_{\text{OUTC}} \) is the complementary output, and \( V_{\text{REF}} \) is a reference voltage you derive from bandgap cell IC\(_1\). You choose the ratio of the resistor divider that connects to the output of IC\(_1\), so that the reference voltage is approximately 400 mV. Potentiometer \( R_p \) sets the desired analog voltage, which connects to the noninverting input of voltage follower IC\(_{2A}\). The output of IC\(_{2A}\) provides the straight output voltage, which connects to the inverting input of unity-gain inverter IC\(_{2B}\). The noninverting input of IC\(_{2B}\) has a gain of two and connects to the middle of the high-precision resistive divider comprising \( R_1 \) and \( R_2 \), which halves the reference voltage. The following equation calculates the output voltage of IC\(_{2B}\) with respect to ground: \( V_{\text{OUTC}} = -V_{\text{OUT}} + 2 \times (V_{\text{REF}}/2) = V_{\text{REF}} - V_{\text{OUT}} \). Thus, the straight output voltage plus the complementary output voltage give the desired constant value equal to the reference voltage.

You should use either a quad resistor or two pairs of matched resistors for precision resistors \( R_i \) through \( R_4 \). Resistors \( R_1 \) and \( R_4 \) form the negative feedback in IC\(_{2B}\), and the other pair of resistors halves the reference voltage. You can omit these four resistors if you use an instrumentation amplifier instead of IC\(_{2B}\). In this case, you must use an RRIO (rail-to-rail-input/output) type of instrumentation amplifier. The output of a contemporary RRIO instrumentation ampli-

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**Figure 1** The circuit outputs two analog voltages whose sum always equals the reference voltage.

**TABLE 1** COMPLEMENTARY VOLTAGES FOR THREE INPUT SETTINGS

<table>
<thead>
<tr>
<th>( V_{\text{SET}} )</th>
<th>( V_{\text{OUT}} ) (mV)</th>
<th>( V_{\text{OUTC}} ) (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{\text{REF}} )</td>
<td>411.45</td>
<td>0.15</td>
</tr>
<tr>
<td>0</td>
<td>0.45</td>
<td>410.45</td>
</tr>
<tr>
<td>( V_{\text{REF}}/2 )</td>
<td>205.8</td>
<td>205.1</td>
</tr>
</tbody>
</table>

**NOTES:** \( R=R_1=R_2 \).

\( R_S=2\times(2R_1R_2) \).
You often need to measure current during circuit design and debugging. You can perform that task by breaking a path, inserting a shunt resistor, measuring its voltage, and converting the voltage to current. Unfortunately, that approach is sometimes impractical with an oscilloscope because one side of an oscilloscope probe connects to ground. Thus, you need to isolate the oscilloscope from the circuit under test.

The circuit in Figure 1 produces a voltage proportional to current and isolates the oscilloscope from the measurement point. The circuit uses IC1, an HCPL7800 isolation amplifier, which adds input-to-output isolation of as much as 1000 V. The output of the Analog Devices (www.analog.com) AD8692 op amp, however, typically approaches the lower rail by 0.75 mV at a 10-µA load current. The guaranteed value of the margin is 1 mV at this current.

The circuit has undergone testing for three values of test voltages: the reference voltage, which represents a full-scale; half the reference voltage; and 0V. Table 1 lists the measured voltages at both outputs. Any of the output voltages can approach the lower supply rail with an error of less than 0.25% at 400 mV full-scale.

![Figure 1](image.png)

**Figure 1** This circuit produces a voltage proportional to current and isolates the oscilloscope from the measurement point.
as 890V. It also amplifies its input voltage by eight. Table 1 shows the overall gain for each input range. The circuit’s bandwidth is typically 100 kHz.

A set of switches lets you select a range of current to measure by inserting resistors into the circuit. Use resistors with 1% or less tolerance to minimize errors. For example, when you close $S_4$, you select the 100-$\mu$A range. The unknown current passes through serial resistors $R_1$ and $R_2$, which have values of 1 and 0.25 $\Omega$, respectively. Thus, the voltage at IC1’s inputs is $I_{IN} \times 1.25 \, k\Omega$; if the input current is 100 $\mu$A, the voltage at IC1 is 125 mV. The circuit has a gain of eight, yielding 125 mV times 8, or 1V. The LM358 acts as a unity-gain differential amplifier. For best linearity, the input voltage at IC1 should not exceed $\pm200$ mV.

<table>
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<tr>
<th>Switch</th>
<th>Gain</th>
<th>Maximum input current</th>
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</thead>
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<tr>
<td>$S_1$</td>
<td>1V/100 mA</td>
<td>160 mA</td>
</tr>
<tr>
<td>$S_2$</td>
<td>1V/10 mA</td>
<td>16 mA</td>
</tr>
<tr>
<td>$S_3$</td>
<td>1V/1 mA</td>
<td>1.6 mA</td>
</tr>
<tr>
<td>$S_4$</td>
<td>1V/100 $\mu$A</td>
<td>160 $\mu$A</td>
</tr>
</tbody>
</table>

The HCPL7800 has a 3% tolerance. When you are using resistors with 1% tolerance, the 3% tolerance dominates the overall uncertainty of the circuit.

The circuit uses two independent voltage supplies. A 9V battery supplies the input part of IC1. A stabilized 9 to 11V wall-wart power supply powers the output side of IC1 with IC2, an LM358 successive amplifier.

When battery switch $S_5$ closes and the voltage of the battery is sufficient for the circuit, LED1 illuminates for approximately 3 seconds. The duration of this illumination minimizes drain on the battery. LED1 is on when the 9 to 11V power supply is operating. IC5, an L272, provides an additional ground potential halfway between the supply voltage. With this split supply, you can measure both positive and negative currents.

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**TABLE 1** GAIN FOR EACH INPUT RANGE

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**A 9 TO 11V WALL-WART POWER SUPPLY POWERS THE OUTPUT SIDE OF IC1 WITH IC2, AN LM358 AMP.**
Acquire images with a sensor and a microcontroller

Ioan Ciascăi, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, and Liliana Ciascăi, Babes-Bolyai University, Cluj-Napoca, Romania

The TAOS (Texas Advanced Optoelectronic Solutions, www.taosinc.com) TSL1412S image sensor, IC2, can acquire a linear image of 1536×1 pixels, or 400 dpi (Figure 1). It uses a single voltage supply, and you can control it with just a few digital signals. Thus, you can design an image-acquisition system that uses the sensor and an AVR (www.atmel.com) ATmega328 microcontroller, IC1.

Figure 1 shows how you can connect the sensor to the microcontroller. You program the microcontroller to generate the control signals for the sensor. The design uses a 16-MHz clock frequency. The microcontroller’s 8-bit Timer 2 generates the command signals. In Mode 2, the timer generates hard clock signals CLK1 and CLK2 and soft strobe signals SI1, HOLD1, and HOLD2. The TSL1412S uses serial connections. The SO2 signal connects to the ICP input of TSL1412S when you activate flag ICF1.

Timer 2 generates a handler interrupt, which ensures the correct phase of the clock signal, generates the strobe signal, and acquires and saves the TSL1412S’s output analog data. You can see a model for the interrupt subroutine in the online version of this Design Idea at www.edn.com/100923dia. The code sets the microcontroller’s stack, register, ADC, Timer 2, and interrupt functions. To save image data, you must set the T bit in SREG to 1 and set pointer X=0x0200. You can do these settings in the last clock of time integration (R25, R24=0x0001).

By modifying the data from the register, you can set the sensor’s integration time at 2.5 to 50 msec, or 100 msec with the prescaler of T2. Knowing that the sensor acquired the data in the previous cycle, you can perform a data-acquisi-

**Power-supply circuit operates from USB port**

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Every PC has a USB (Universal Serial Bus) port that can supply 5V±5% at 500 mA for peripherals. Powered USB hubs also provide this power. You can use a USB port to power an external circuit, which is useful when you have no other dc source available.

A USB port has VBUS, the power pin; a return pin, GND (ground); and two signal pins. If you need just a simple 5V supply, you can tap the power pins from a USB connector, but you should place a 10-µF filter capacitor between the ground and power-supply pins.

You can, however, use an adjustable voltage regulator to get voltages of 1.25 to 3.75V, a range that many circuits use. The circuit in Figure 1 covers that range. You use R1 to change that range, as the following equation:

\[
V_{\text{out}} = V_{\text{in}} \times \frac{R1}{(R1+R2)}
\]
The trick is to choose the supply voltage. Because LT1932 can work at voltages as low as 1V, using a two-cell, 3V supply results in the lowest working voltage: 0.5V per cell. Choosing a three-cell, 4.5V supply results in a lower voltage of 0.33V per cell. A 4.5V supply can power as many as eight LEDs. Tests show that this circuit works from 4.5V to 0.94V, which is lower than the data-sheet-specified 1V. The LED driver uses a 4.7-µH inductor.

Setting the value of resistor \( R_1 \) regulates the constant current through the LEDs. Setting a higher resistance results in lower brightness. In this case, the current is 18 mA. If you use a 200Ω potentiometer for \( R_3 \), you get a current range of 1.25V when \( R_1 \) is 0Ω, causing a short, to 3.75V when \( R_1 \) is 200Ω.

To prevent circuit damage if the output becomes shorted or when you don’t know the load, you can add a current-limiting circuit that keeps the maximum current at 500 mA. A polyswitch fuse or pair of transistors can easily implement this current-limiter site at the power-supply input line.

The filter capacitor shouldn’t exceed 10 µF. That level keeps the inrush current under control in the absence of a current-limiting circuit. Generally, capacitors of 1 to 10 µF work best.

Most commercial LED flashlights use three AAA or AA batteries in series that produce 4.5V. The batteries then drive four white LEDs that connect in parallel. These LEDs can work at voltages as low as 2.7V and, in some cases, 2.4V. At those voltages, the LEDs become dim, and you must frequently change the batteries. Thus, the lowest working voltage in this case is approximately 0.8 to 0.9V per battery.

When a 1.5V alkaline battery discharges to 0.9V, it still has more than 10% of its original energy left. If you replace or discard the battery, you waste that energy. You can, however, use this small amount of battery energy with the circuit in Figure 1. The Linear Technology (www.linear.com) LT1932 LED driver is a step-up voltage-booster chip with constant-current capability for LED lighting. It works with input voltages of 1 to 10V, and it can drive several serial LEDs.

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