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Twin-T power oscillators work as dc-biased ac sources

Tiger Zhou and Robert Dobkin, Linear Technology, Milpitas, CA

AC test equipment often needs a low-distortion signal source to excite the device under test. The common practice is to use a signal generator to produce a low-distortion reference, which you feed to a power amplifier to drive the device under test. This Design Idea suggests a less cumbersome alternative.

Figure 1 shows an oscillator that generates a low-distortion sinusoidal signal with power-driving capability. The power oscillator consists of two major parts: a twin-T network and a high-power low-dropout regulator. The twin-T network has two T-type filters in parallel: one lowpass filter and one highpass filter. The twin-T network is

highly frequency-selective as a notch filter. The low-dropout regulator amplifies the signal and drives the load. The regulator in this circuit incorporates a current-reference voltage-follower architecture. It is unity gain from the Set to the Out pins, and the current reference is a precision 10- μ A current source. The R_{SET} resistor on the Set pin programs the output-dc level. By connecting a twin-T network between the Out and the Set pins, the resulting notch filter attenuates both high- and low-frequency content, allowing the center frequency to freely pass through. The resistors and capacitors program the center frequency, f_0 : $f_0 = 1/(2\pi RC)$.

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Small-signal analysis of the twin-T network indicates that the gain is maximum at the center frequency. The twin-T oscillator's maximum gain increases from one to 1.1 when the K factor increases from two to five (Fig-

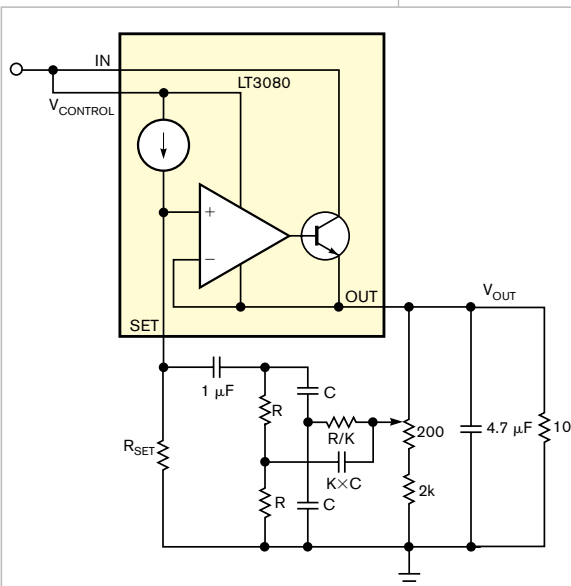


Figure 1 This oscillator generates a low-distortion sinusoidal signal with power-driving ability.

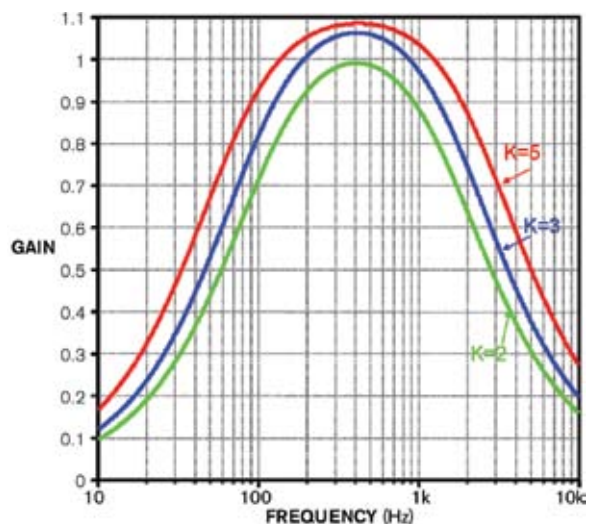


Figure 2 The twin-T network's gain changes with the value of K from Figure 1.

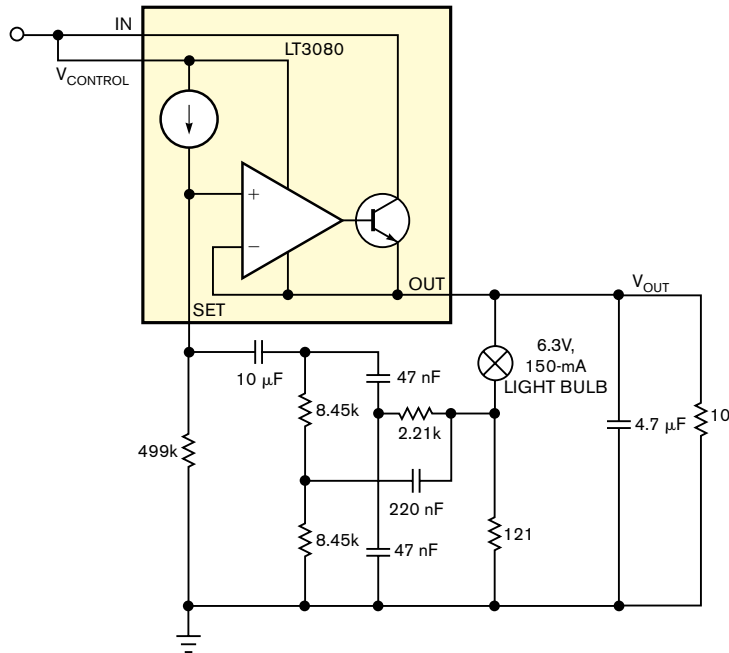


Figure 3 To automatically control the gain, you can replace the potentiometer with a light bulb.

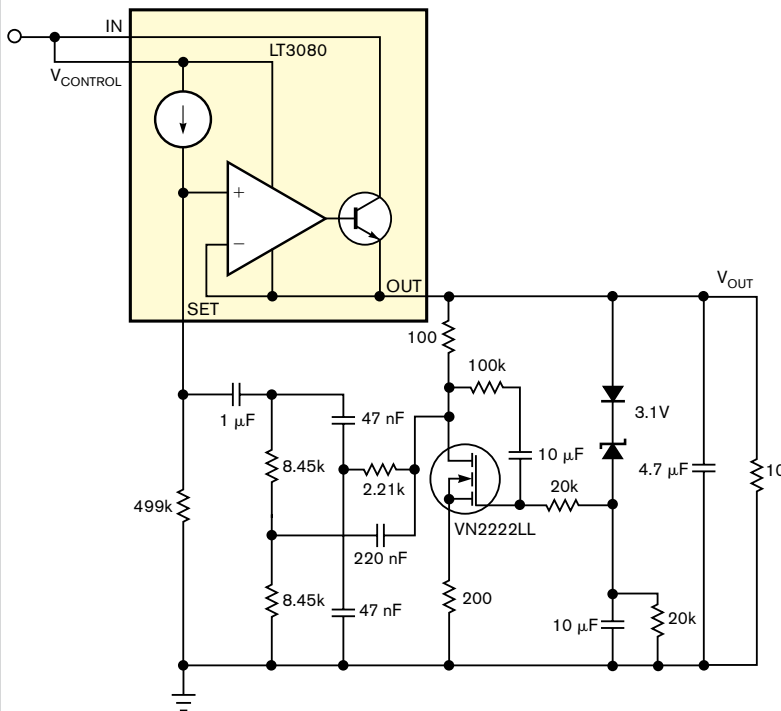


Figure 4 You can automatically control the gain by replacing the potentiometer with a variable-resistance MOSFET.

ure 2). The maximum gain decreases when the K factor is larger than five. Therefore, select a K factor of three to five for a gain larger than unity gain. The loop gain must be unity to maintain a steady oscillation. Thus, you need a potentiometer to tune the loop gain to control the oscillation amplitude.

The twin-T oscillator can drive inductive, capacitive, or resistive loads. The low-dropout regulator's current limit, which is 1.1A for the Linear Technology (www.linear.com) LT3080, is the only limit on the oscillator's drive capability. The load characteristics limit the maximum programmable frequency. For example, a 10Ω resistive load with a 4.7-μF output capacitor causes a 7% THD (total harmonic distortion) at a frequency higher than 8 kHz, although THD is 0.1% at 400 Hz in the circuit of **Figure 3**. The twin-T oscillator has the same performance in line and load regulation as the LT3080. It also works in a wide temperature range.

To automatically tune the gain, you can replace the potentiometer with a light bulb (**Figure 3**) or a voltage-modulated resistive MOSFET (**Figure 4**). The light bulb's resistance increases with the oscillation amplitude due to a self-heating effect, so it serves the loop gain to maintain the oscillation. In **Figure 4**, by detecting the peak voltage using a zener diode, the MOSFET resistance decreases when the oscillation amplitude is high. The loop gain also decreases to maintain the oscillation.

Figure 5 shows the test waveform of the twin-T oscillator using a light bulb. The output is tuned to a 4V-p-p voltage with 5V-dc bias voltage (**Figure 6**). The twin-T oscillator has a 400-Hz frequency and 0.1% THD. The most significant harmonic contribution is from the second harmonic at less than 4 mV p-p. **Figure 6** shows the test waveform of the twin-T oscillator using the MOSFET. The THD is 1% with a 40-mV-p-p second harmonic.

Start-up is another important aspect of the oscillator. Both circuits exhibit no low-frequency swing, which is common to other types of oscillators. The waveforms in **figures 7** and **8** exhibit little overshoot. The oscilla-

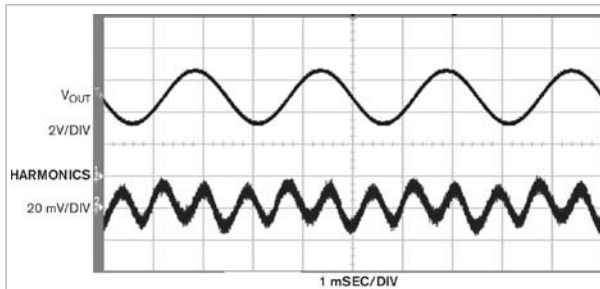


Figure 5 The test waveform for the oscillator in Figure 3 shows low distortion at a THD of 0.1%.

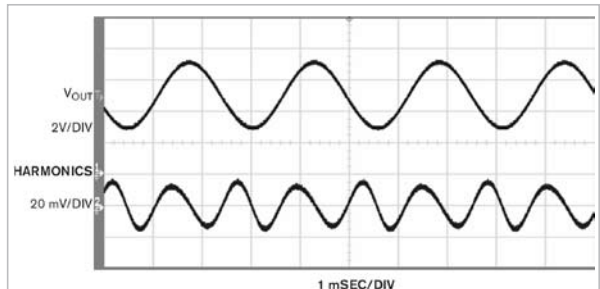


Figure 6 The test waveform for the oscillator in Figure 4 shows low distortion with a THD of 1%.

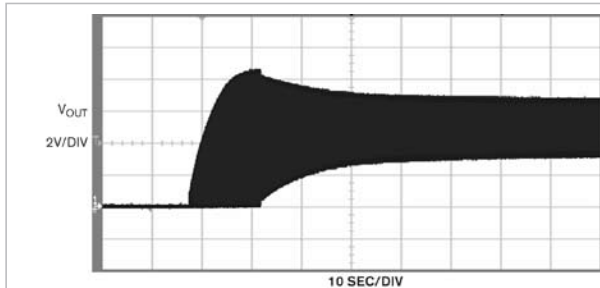


Figure 7 The waveform for the circuit in Figure 3 shows a slow start-up of the light-bulb oscillator.

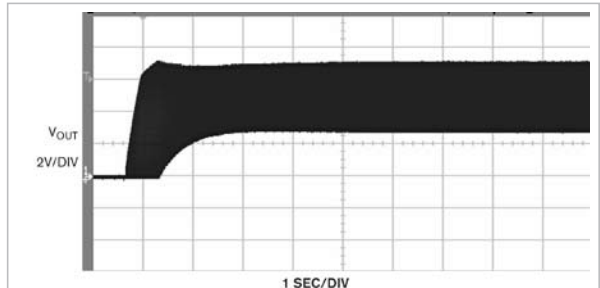


Figure 8 The waveform for the circuit in Figure 4 shows a quick start-up of the MOSFET oscillator.

tor using the MOSFET stabilizes faster than the one using the light bulb because the light bulb has a long thermal constant due to the heating effect. You

can use the simple circuit as a dc-biased ac source in applications requiring low distortion and power-driving capability. **EDN**

ACKNOWLEDGMENT

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Diagnose LEDs by monitoring the switch-mode duty cycle

Fons Janssen, Maxim Integrated Products Inc, Bilthoven, the Netherlands

Engineers often monitor the forward voltage, V_{F1} of HB LEDs (high-brightness light-emitting diodes) to assess the LEDs' health. Big changes in forward voltage can indicate deterioration or even a complete failure of one or more LEDs connected in series. For several LEDs in series, the sum of their forward voltages can reach 40V or more, and, if you do not reference that voltage to ground, it requires a differential measurement. In addition to the challenges of high voltage and differential measurement, HB LEDs are often dimmed using PWM (pulse-width modulation). If so, you can't measure forward voltage during the low portion of the PWM duty cycle when the LEDs are unlit and the forward voltage is not present. For a hysteretic buck-LED driver driving three LEDs in series (Figure 1), you must measure the anode and cathode voltages of the string when the Dim pin is high.

To avoid the need for a differential high-voltage measurement, you can take the indirect approach of measuring the duty cycle at the driver pin, DRV. For this LED driver, a first-order estimate of forward voltage for

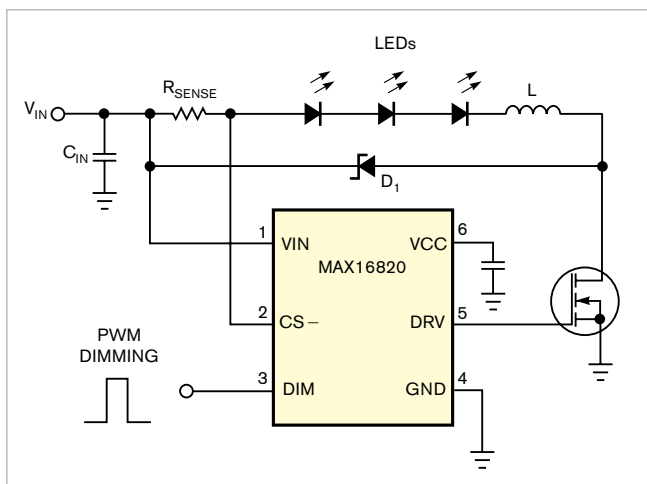


Figure 1 For a hysteretic buck-LED driver driving three LEDs in series, you must measure the anode and cathode voltages of the string when the Dim pin is high.

the LED string is $V_F = D \times V_{IN}$, where D is an internal duty cycle that the IC's switch-mode section produces; do not confuse this duty cycle with that at the Dim pin. You reference the driver signal to ground and limit it to the power-supply voltage, V_{CC} , at 5V. That condition allows the use of low-voltage ADCs or comparators, which the LED driver's V_{CC} output, a maximum of 10 mA, can power.

Figure 2 shows how to detect a short-circuited LED with the aid of a comparator. Filter R_1C_1 converts the ac PWM signal at the driver to a dc voltage, V_D , proportional to $D \times V_{CC}$. You should sample V_D when its value is greater than perhaps 90% of its steady-state value; this sampling requires a period of at least $2.3R_1C_1$. Because the comparator's LE (latch enable) latches the output when LE is low, LE should assert not earlier than $2.3R_1C_1$ after the Dim pin goes high. R_2 , C_2 , and D_2 ensure that LE deasserts immediately after the Dim pin goes low. The value of R_2C_2 is higher than that of R_1C_1 , so the comparator enables when the input signal reaches at least 90% of its steady-state value. D_2 immediately discharges C_2 after the Dim pin goes low, which latches the output as soon as the LEDs turn off.

Because the reference voltage is lower than $D \times V_{IN}$, the comparator output is normally low. If an LED fails

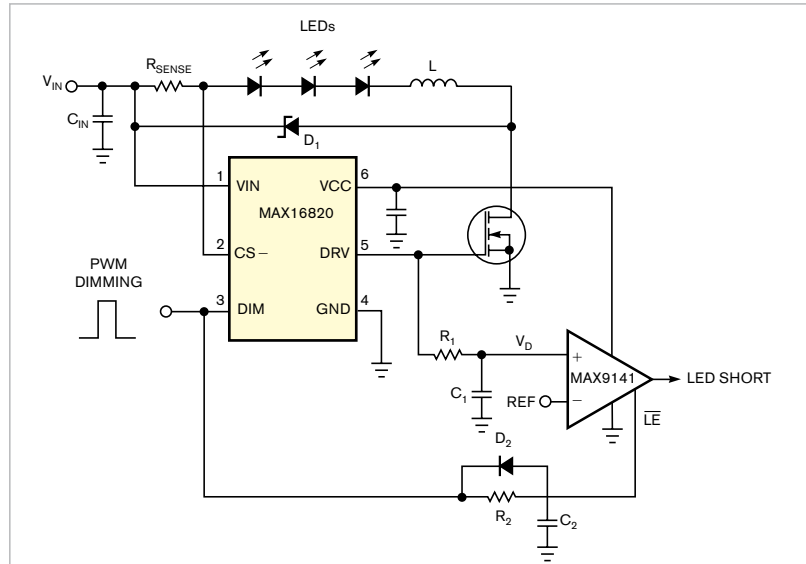


Figure 2 Adding this comparator circuit to the Figure 1 circuit provides detection of shorted LEDs.

shorted, its forward voltage drops and causes the duty cycle at the driver to drop. V_D then drops below the reference, causing the comparator's output to go high, indicating a shorted LED. Because the output latches when the Dim pin goes low, the error signal remains asserted even when the LEDs are off. Figure 3 shows the filtered Dim pin and driver signals for normal operation versus a shorted-LED condition.

For a system with an input voltage of 12V and three LEDs in series, which the forward voltage is approximately 3V

per LED (Figure 3a), the filtered driver signal (green) stabilizes at approximately $D \times V_{CC} = (9V/12V)5V = 3.75V$. The comparator latches when the filtered Dim signal (yellow) goes lower than 2.5V, so the comparator begins interpreting the filtered driver signal after approximately 100 μ sec. Clearly, V_D is higher than the threshold-reference voltage (red) when the comparator is active. After one of the LEDs shorts out (Figure 3b), V_D stabilizes at approximately $(6V/12V)5V = 2.5V$ and no longer exceeds the threshold. That condition causes the comparator's output to go high, indicating that one of the LEDs has become a short circuit.

The choice of filter constants R_1C_1 and R_2C_2 depends on several parameters. The cutoff frequency should be low enough to properly filter the driver signal yet small enough to allow the filtered signal to stabilize near the steady-state value achievable within the shortest dimming pulse. You can easily adjust this circuit to detect open-circuit LEDs. When an LED breaks and stops conducting current, the driver's duty cycle goes to 100% when the Dim pin is high. If you then swap the comparator-input connections and put the reference voltage slightly below V_{CC} , the comparator output goes high in response to an open LED. **EDN**

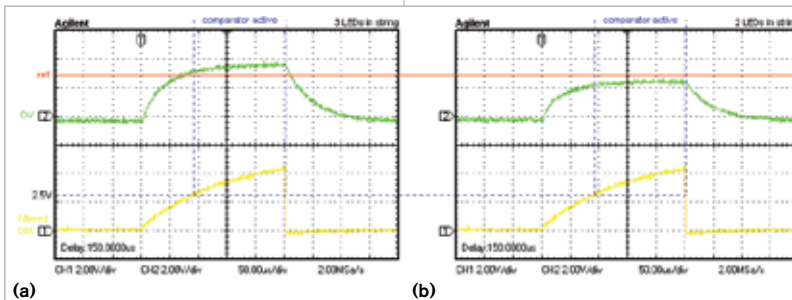


Figure 3 For a system with an input voltage of 12V and three LEDs in series, in which the forward voltage is approximately 3V per LED (a), the filtered driver signal (green) stabilizes at approximately $D \times V_{CC} = (9V/12V)5V = 3.75V$. The comparator latches when the filtered Dim signal (yellow) goes lower than 2.5V, so the comparator begins interpreting the filtered driver signal after approximately 100 μ sec. Clearly, V_D is higher than the threshold reference voltage (red) when the comparator is active. After one of the LEDs shorts out (b), V_D stabilizes at approximately $(6V/12V)5V = 2.5V$ and no longer exceeds the threshold.

Single pin controls relay, intermittent buzzer, and status LED

Kartik Joshi and Manik Chugh,
Netaji Subhas Institute of Technology, Delhi, India

Switching applications involving controlling devices or appliances using digital-I/O lines through a relay often need to indicate the change of state of the I/O line and, hence, the connected device. This indication

could be in the form of a buzzer that turns on for a few seconds every time the line changes state. Designers generally employ an additional I/O pin to trigger the buzzer whenever the state of the primary I/O line changes. This De-

sign Idea discusses a circuit that controls a device through a relay and an intermittent buzzer with only one digital-I/O pin.

Pin PA1 of the digital device controls a relay, which switches an appliance on and off (**Figure 1**). NPN transistor Q_3 activates the relay coil when the I/O line is in the high state. Status LED D_1 connects in parallel to the relay coil and turns on when the I/O line is high and off when the line is low.

The buzzer remains on for a small amount of time when the relay changes state. You accomplish this task by employing a push-pull-inverter topology using complementary BJTs (bipolar-junction transistors) NPN Q_1 and PNP Q_2 . The output of this stage connects to a bridge rectifier with a buzzer as a load because buzzers usually are unidirectional. The bridge rectifier connects in series both with resistor R_{12} to regulate the maximum current through the buzzer and with capacitor C_1 to ensure that the buzzer “fades off.” When the line is low, transistor Q_2 is on, the capacitor charges to a positive voltage, and the buzzer operates until the current through it is sufficient. When the line goes high, transistor Q_1 switches on, the capacitor discharges to approximately 0V, and the buzzer operates again for a short duration. The on-time of the buzzer depends on the values of R_{EQ} , the series combination of R_{12} and the buzzer resistance, and C_6 . To change the time constant and hence the on-time of the buzzer, you should change the value of the capacitor rather than that of the resistor. You can also design this circuit using only one BJT instead of two, but the transistor would always draw some current at steady state.

This topology is useful when no separate I/O lines are available for controlling the buzzer. You can also employ this topology to indicate the change of state of any input stage directly by connecting it to the given circuit or through a buffer. **Figure 2** shows a Spice simulation of the buzzer circuit. This simulation replaces the buzzer with 50Ω resistance and plots the current through the buzzer along with the status of the I/O line. **EDN**

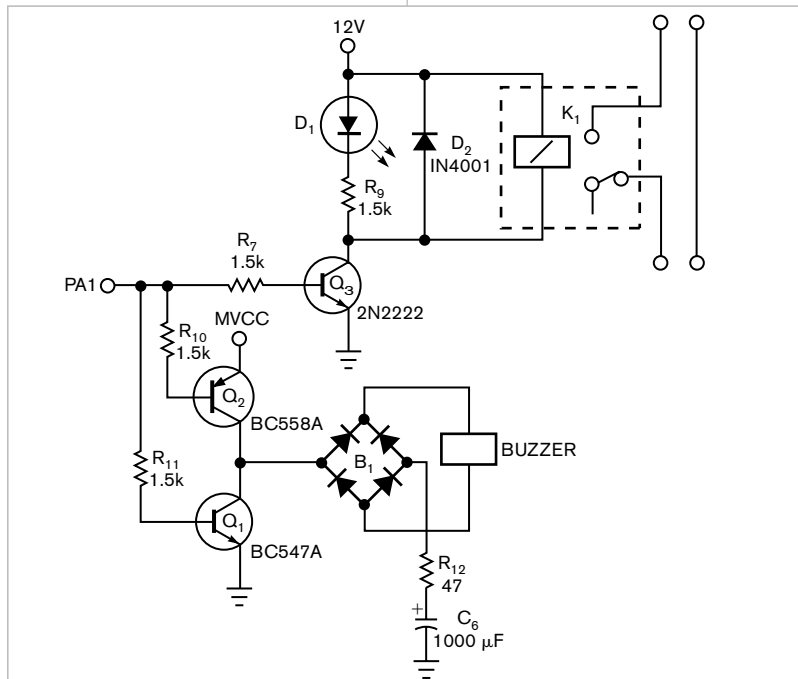


Figure 1 This circuit controls a device through a relay and an intermittent buzzer with only one digital-I/O pin.

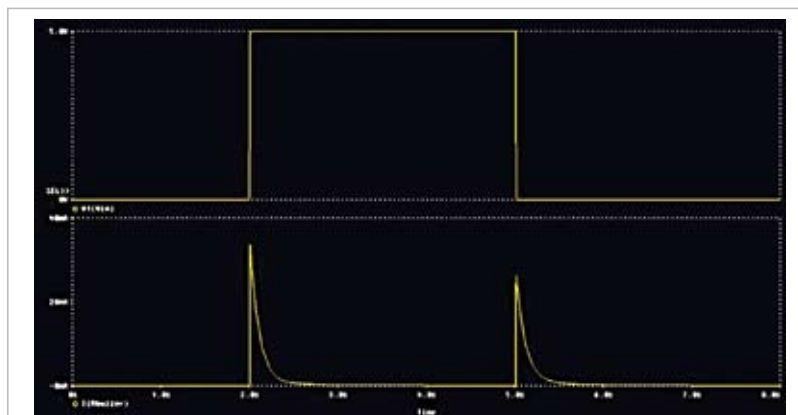



Figure 2 A Spice simulation of the buzzer circuit replaces the buzzer with 50Ω resistance and plots the current through the buzzer and the status of the I/O line.

Simple two-transistor circuit lights LEDs

Barry A Tigner, Michigan State University, East Lansing, MI

 A previous Design Idea describes a circuit that uses an astable multivibrator to drive an LED ([Reference 1](#)). The circuit in **Figure 1** uses a simpler alternative approach. The circuit uses a 2N3904 NPN transistor and a 2N3906 PNP transistor, which operate as a high-gain amplifier.

The 1-M Ω resistor supplies bias current. The 1-k Ω resistor helps linearize the oscillator waveform into one that is close to a square wave with about a 50-to-50 duty cycle. The capacitor supplies positive feedback from the output of the amplifier to the noninverting input. The frequency of oscillation depends mostly on the RC constant of

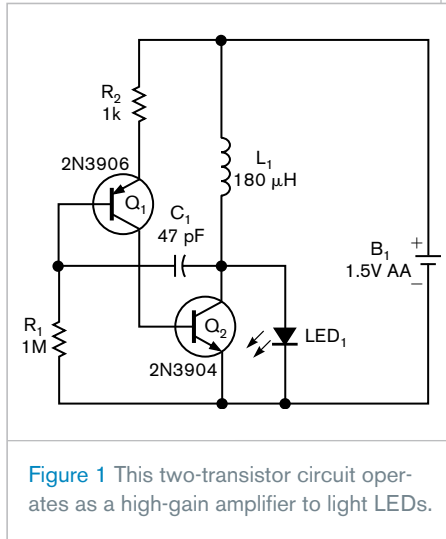


Figure 1 This two-transistor circuit operates as a high-gain amplifier to light LEDs.

the feedback capacitor and the input-stage impedance. The circuit oscillates at 91 kHz with a 48% duty cycle. You can use almost any common NPN or PNP transistors, as long as they have moderate forward-current gain of 50 or more and can handle 100-mA collector currents.

The LED connects across the output transistor because this approach lets the inductive kickback voltage add to the battery-supply voltage and makes the LED brighter. This circuit operates well from approximately 0.8 to 1.6V, which is the useful range of an alkaline battery. The LED-light output decreases as the supply voltage decreases from 1.6 to 0.8V.[EDN](#)

REFERENCE

1 Bruno, Luca, "Astable multivibrator lights LED from a single cell," *EDN*, Aug 21, 2008, pg 53, www.edn.com/article/CA6586223.