Single cell flashes white LED

Anthony Smith, Scitech, Biddenham, Bedfordshire, UK

MANY PORTABLE appliances and other products that must operate from a single cell are restricted to working at very low voltages. It is thus difficult to drive white LEDs that typically have a forward voltage of 3 to 5V. The ability to flash the LED with a supply voltage as low as 1V presents additional complications. The circuit in the **Figure 1** provides a discrete approach to these problems and allows a white LED to flash at a rate set by an RC time constant. Components Q_1, Q_2, R_3, R_4, and R_5 form a simple Schmitt trigger that, together with R_1, R_2, and C_1, controls the flashing of the LED. Q_4, Q_5, L_1, and associated components form a voltage booster that steps up the single-cell voltage, V_S, to a level high enough to

drive the LED. Transistor Q_3 functions as a switch that gates the booster on and off at a rate determined by the Schmitt-trigger section.

To understand how the booster section works, assume that Q_3 is fully on, such that Q_4's emitter is roughly at the battery-supply voltage, V_S. Q_4 and R_8 provide bias for Q_5, which turns on and sinks current,

I_L, through inductor L_1. The inductor current ramps up at a rate determined mainly by V_S and the value of L_1; during this time, LED_1 and series diode D_1 are reverse-biased. The current continues to ramp up until it reaches a peak value, I_{LPEAK}. Q_5 can sustain no further increase, and the voltage across the inductor at this point reverses polarity. The resulting "flyback" voltage raises LED_1's anode to a positive voltage higher than V_S, sufficient to forward-bias LED_1 and signal diode D_1. The flyback voltage is also coupled through C_3 and R_{10} to Q_4's base, thus causing Q_4 and, hence, Q_5 to turn off rapidly.

The inductor current now circulates around L_1, LED_1, and D_1, and, as the energy stored in L_1 decays, the current ramps down to zero. At this point, the inductor voltage again reverses polarity and the negative-going change is coupled through C_3, rapidly turning on Q_4 and, in turn, Q_5. Current again begins to ramp up in L_1, and the process repeats. The booster section oscillates at a rate determined by several factors. The important factors determining the rate of oscillation include the values of V_S, L_1, and R_8; the forward-current gain of Q_5; and the forward voltage of LED_1. With the component values in the **figure**, the oscillation frequency is typically 50 to 200 kHz. On each cycle, a pulse of current with a peak value equal to I_{LPEAK} flows through LED_1 and, because this scenario occurs thousands of times every second, LED_1 appears to be continuously on.

The low-frequency oscillator formed around the Schmitt trigger turns the booster section on and off at a low rate. To understand how this works, assume that Q_1 is off and Q_2 is on. Provided that Q_2 has reasonably large forward-current gain, you can ignore the effects of its base current and say that V_S and the R_3-R_5 voltage divider set Q_2's base voltage, V_{B2}.

With the values of R_3 and R_5 in **Figure 1**, V_{B2} is approximately 800 to 900 mV when $V_S = 1V$. This voltage produces approximately 300 to 400 mV across R_4, resulting in a collector current of at least 15 μA in Q_2 with $R_4 = 20$ kΩ. Q_2's collector current provides base drive for Q_3, which saturates, turning on the booster section and illuminating LED_1. When LED_1 is forward-biased, C_4 charges to a positive voltage, V_P, roughly one diode drop above V_S.

Figure 1

This circuit provides boosted voltage and flashes a white LED from a single cell.

Timing capacitor C_1 now charges via R_1 at a rate determined mainly by the values of V_P, R_1, R_2, and C_1. Provided that you carefully choose the ratio of R_1 to R_2, Q_1's base voltage, V_{B1}, eventually exceeds the quiescent level of V_{B2} (roughly equal to the Schmitt trigger's upper threshold voltage, V_{TU}), causing Q_1 to turn on and Q_2 to turn off. At this point, Q_3 also turns off, thereby disabling the booster section and turning off LED_1.

With LED_1 off, V_P rapidly decays, and C_1 begins to discharge at a rate determined mainly by the values of R_2 and C_1 and by Q_1's base current. The LED remains off until V_{B2} has fallen below the Schmitt trigger's lower threshold voltage, V_{TL}, at which point Q_1 turns off, Q_2 turns on, and the booster section again activates, illuminating LED_1. Provided that R_1, R_2, and C_1 are large enough, LED_1 can flash at a low rate. For example, if R_1 and

R_2 have values of approximately 1 MΩ each and C_1 has a value of 1 μF or greater, a rate of less than one flash per second is possible. Remember, however, that R_1 and R_2 form a voltage divider that sets Q_1's base voltage, V_{B1}; therefore, R_2 must be sufficiently larger than R_1 to ensure that V_{B1} can cross the Schmitt trigger's upper threshold voltage as C_1 charges. With this fact in mind, you can with some trial and error fairly easily find the optimum values of R_1, R_2, and C_1 necessary for a given flash rate.
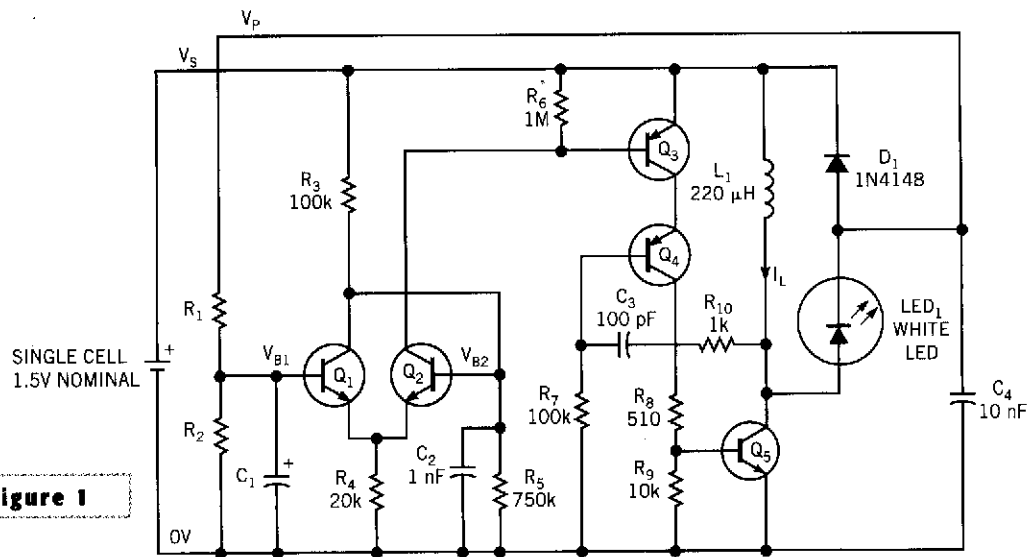
The value of V_P significantly influences the charging and discharging of C_1, and V_P's value hence varies according to the prevailing battery supply voltage, V_S. However, changes in V_{B2}, which also varies with V_S, somewhat balances this dependence. Nevertheless, the flash rate and duty cycle do vary somewhat as the battery voltage falls. For example, with $R_1 = 2.2$ MΩ, $R_2 = 10$ MΩ, and $C_1 = 1$ μF, the test circuit's flash rate at $V_S = 1.5V$ is approximately 0.52 Hz with a duty cycle of 66%. With a V_S of 1V, the flash rate increases to approximately 0.75 Hz but with a lower duty cycle of 44%. The Schmitt-trigger thresholds, V_{LT} and V_{TU}, are typically approximately 0.7V and 1.2V at $V_S = 1.5V$, falling to approximately 0.6V and 0.8V when V_S is 1V.

The LED's intensity is proportional to

its average forward current and is thus determined by the peak inductor current, $I_{L.PEAK}$, and by the duration of the current pulse through the LED. Provided that L_1 is properly rated such that it does not saturate, the peak current depends largely on the maximum collector current that Q_5 can sustain. For a given supply voltage, this figure depends primarily on Q_5's forward-current gain, and on the value of R_8 that you can select to give optimum LED brightness at the lowest supply voltage. Experiment with different values of R_8 to get the best intensity for a given LED type. Take care, however, that the peak current does not exceed the LED's maximum current rating when V_s is at a maximum. The actual value of L_1 is not critical, but values in the range 100 to 330 μH should provide good performance and reasonable efficiency. The transistor types in the circuit are not critical; the test circuit works well with general-purpose, small-signal devices having medium to high current gain. If possible, select low-saturation types for Q_3, Q_4, and Q_5. C_2 is not essential to circuit operation but helps to decouple any switching noise at Q_2's base.

C_4 acts as a charge reservoir and ensures that R_1 can charge C_1 from a stable voltage source (V_p) when LED$_1$ is on. Because the charging current is likely to be low, C_4 can be fairly small; a value of 10 nF should be adequate. Note that C_4 must connect to the junction of D_1 and LED$_1$ as shown, rather than being charged, via a rectifying diode, from the flyback voltage at Q_5's collector. The reasons for this caveat are, first, that this approach ensures that V_p is only a diode drop above V_s, thereby minimizing the value of R_1 necessary for a given C_1 charging current. Also, and more important, this approach places the forward voltage of the LED in the path from V_s through L_1 and R_1 to Q_1's base. Because the forward voltage of a white LED is usually at least 3V, this connection prevents Q_1 from being turned on via this route, which could otherwise cause the circuit to lock in the "off" state.

At first sight, it might appear that you can turn the booster section on and off by gating current to Q_4's base, thus obviating the need for Q_3. However, under certain conditions, once you activate the booster section, the feedback to Q_4's base via C_3 and R_{10} is sufficient to maintain oscillation without feeding any dc bias to Q_4's base. Therefore, the only reliable way to gate the booster on and off is via Q_3, as shown. The test circuit starts up and operates with V_s as low as 0.9V, although the LED is dim at this voltage. The LED's intensity is good at $V_s = 1.5V$ (equivalent to a fully charged alkaline cell) and remains acceptable with V_s as low as 1V. The circuit should find applications in toys, security devices, miniature beacons, and any other products that must provide a flashing visual indication while operating from a single cell.□