Abstract

In the digital-to-analog conversion (DAC) lab, the output of the JK flip-flop used in the analog-to-digital conversion (ADC) lab needs to drive a heavy load. The flip-flop output can only supply 1 mA maximum, but the infrared LED needs to be driven by at least 10 mA and probably will need to operate at 35–50 mA in this lab. So we need to build a current driver. Current drivers can easily be built with a single NPN or PNP transistor acting as either a current source or sink. Here, we review the prototypical follower and switch circuits that could be used as drivers in this laboratory.

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1 LED Operation

The QEE113 infrared light-emitting diode (LED) should be operated with a current limiting resistor, as shown in Figure 1.1, so that the forward current through the diode is between 10 mA and 50 mA.

\[
\begin{align*}
+ & \quad i \approx 40 \text{ mA} \\
\downarrow & \quad R_L \\
\sim 1.25 \text{ V} & \quad \downarrow
\end{align*}
\]

Figure 1.1: Typical operation of QEE113 infrared light-emitting diode (LED).

In this laboratory, a forward current of 40 mA (or less) will be sufficient for eye-to-eye transmission of up to ~0.5 m to a QSE157 receiver. At 40 mA, the potential drop across the LED is 1.25–1.30 V. We use this approximation to derive a nominal value for current-limiting resistor \( R_L \).

In the following, we show four different current driver architectures. In section 2, we show an NPN transistor being used as a current source in a follower (i.e., active) configuration and as a current sink in a switch (i.e., saturation) configuration. In section 3, we show a PNP transistor being used as a current source in a switch (i.e., saturation) configuration and as a current sink in a follower (i.e., active) configuration.
2 NPN Current Drivers

In both driver configurations shown in Figure 2.1, the current-limiting resistance \( R_L \) must be set to deliver \( i \approx 40 \text{ mA} \) to the LED.\(^1\)

![Figure 2.1: NPN (2N3904) current drivers for QEE113 infrared LED. The follower configuration in (a) biases the transistor into active mode. The switch configuration in (b) biases the transistor into saturation mode. Circuit values are shown for both high and low logic input \( Q \). In the low case, transistor current is cutoff.](image)

Although \( R_L \) can be implemented with a variable resistor (e.g., two adjacent pins of a potentiometer), tuning its value\(^2\) may have less of an impact than tuning the distance between the QEE113 and the QSE157.

NPN Current Source

In Figure 2.1(a), with input \( Q \) high, the transistor is in active mode. A BJT transistor in this mode dynamically adjusts its effective collector-emitter resistance so that the base-emitter potential is maintained at approximately 0.65 V. Therefore, the resistor–diode combination is driven by 0 V or 9.35 V depending on whether \( Q \) is low or high, respectively. To make the high current equal to 40 mA, the current-limiting resistor

\[
R_L \approx \frac{8.1\text{V}}{40\text{mA}} = 202.5\Omega. \tag{2.1}
\]

NPN Current Sink

In Figure 2.1(b), with input \( Q \) high, the transistor is in saturation mode. A BJT transistor in this mode is not able to reduce its collector-emitter potential any farther. So it assumes a value of approximately 0.2 V. Therefore, the resistor–diode combination is driven by 0 V or 9.8 V depending on whether \( Q \) is low or high, respectively. To make the high current equal to 40 mA, the current-limiting resistor

\[
R_L \approx \frac{8.55\text{V}}{40\text{mA}} = 213.75\Omega. \tag{2.2}
\]

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\(^1\) Active-mode analysis uses rail-to-rail logic assumption that is untrue for TTL; however, BJT saturation mode is slow.

\(^2\) That is, increase current if too little power is received and decrease current if the receiver triggers too easily.
3 PNP Current Drivers

In both driver configurations shown in Figure 3.1, the current-limiting resistance \( R_L \) must be set to deliver \( i \approx 40 \text{ mA} \) to the LED.\(^3\) \( \text{NOTE THAT } \overline{Q}, \text{ NOT } Q, \text{ is used as an input.} \)

![Figure 3.1: PNP (2N3906) current drivers for QEE113 infrared LED. The switch configuration in (a) biases the transistor into saturation mode. The follower configuration in (b) biases the transistor into active mode. Circuit values are shown for both low and high input \( \overline{Q} \). In the high case, transistor current is cutoff.}

Although \( R_L \) can be implemented with a variable resistor (e.g., two adjacent pins of a potentiometer), tuning its value\(^4\) may have less of an impact than tuning the distance between the QEE113 and the QSE157.

PNP Current Source

In Figure 3.1(b), with input \( Q \text{ high} \), the transistor is in saturation mode. A BJT transistor in this mode is not able to reduce its collector-emitter potential any further. So it assumes a value of approximately 0.2 V. Therefore, the resistor–diode combination is driven by 0 V or 9.8 V depending on whether \( Q \) is low or high, respectively. To make the high current equal to 40 mA, the resistor current-limiting resistor nominally be

\[
R_L \approx \frac{8.55 \text{ V}}{40 \text{ mA}} = 213.75 \Omega.
\] (3.1)

PNP Current Sink

In Figure 3.1(a), with input \( Q \text{ high} \), the transistor is in active mode. A BJT transistor in this mode dynamically adjusts its effective collector-emitter resistance so that the base-emitter potential is maintained at approximately 0.65 V. Therefore, the resistor–diode combination is driven by 0 V or 9.35 V depending on whether \( Q \) is low or high, respectively. To make the high current equal to 40 mA, the resistor current-limiting resistor nominally be

\[
R_L \approx \frac{8.1 \text{ V}}{40 \text{ mA}} = 202.5 \Omega.
\] (3.2)

\(^3\) Active-mode analysis uses rail-to-rail logic assumption that is untrue for TTL; however, BJT saturation mode is slow.

\(^4\) That is, increase current if too little power is received and decrease current if the receiver triggers too easily.
A Parts

(a) 2N3906 PNP BJT transistor

(b) QEE113 infrared LED

(c) 2N3904 NPN BJT transistor

Figure A.1: Part pin-outs.