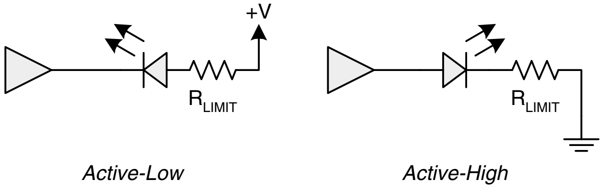

FIGURE 13.13 Direct connection of logic output to LED.

drive two 20-mA LEDs when a 74LS logic pin goes high. This circuit is shown in Fig. 13.14. Given the 74LS output specification, the base resistor is chosen to pull maximum current from the logic IC: 0.4 mA. V_B = 0.7 V, because it is known that $V_B = V_E + 0.7$ V and $V_E = 0$ V. The logic output is at least 2.7 V, resulting in a voltage drop across R_B of 2 V. Selecting R_B = 4.7 kΩ will pull slightly more than 0.4 mA, but this will not damage the logic IC; it may just cause the output voltage to sag a little below 2.7 V.

With the transistor's base circuit determined, attention turns to the collector. When the transistor is conducting, voltage is dropped by R_C, the LEDs, and the transistor. A range of values for R_C may be chosen that will allow the transistor to conduct the full 40 mA desired. Smaller values of R_C will result in higher collector-emitter voltage, V_{CE}. Larger values of R_C will reduce V_{CE} until the transistor enters saturation, after which increasing R_C will decrease I_C. Higher V_{CE} will result in higher transistor power dissipation for a constant current of 40 mA. It is usually preferable to minimize the power dissipated by active components such as transistors, because prolonged heating reduces their life span. Heat in general reduces a circuit's reliability. Typical manufacturers' specifications for an NPN transistor's saturation V_{CE}, $V_{CE\,(SAT)}$, are 0.3 V at moderate currents. $V_{CE\,(SAT)}$ can be lowered to less than 0.2 V by injecting more current into the base. Assuming an LED V_F = 2 V, R_C will have to drop 5 V – 2 V – 0.3 V = 2.7 V at 40 mA, yielding an approximate value of R_C = 68 Ω. The 2N2222 and 2N3904 are two widely available NPN transistors suitable for general applications such as this LED driver. These transistors have been around for a long time and are produced by multiple manufacturers. They are leaded devices whose surface mount equivalents are the MMBT2222 and MMBT3904, respectively.

If the load requirement is substantially increased, this NPN transistor circuit with β = 100 will be insufficient, because more base current will be required, violating the bipolar logic-1 output specification. Aside from trying to find a single transistor with a higher beta, there are alternative solutions that use two transistors instead of one. The idea is to keep the existing NPN transistor that is directly driven by the logic output and have it drive the base of a second transistor instead of directly driving

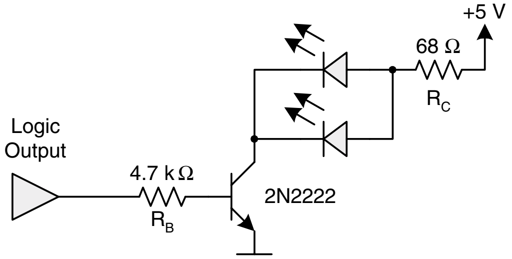

FIGURE 13.14 NPN LED driver.

the load. The collector current of the first transistor, $\beta_1 I_{B1}$, becomes the base current of the second transistor and is multiplied to yield a final load current of $\beta_2 I_{B2}$, which equals $\beta_1\beta_2 I_{B1}$.

A two-stage NPN/PNP transistor circuit is shown in Fig. 13.15. A PNP transistor's pn junctions have the opposite polarity as compared to an NPN. The base-emitter junction is forward biased by applying a higher voltage to the emitter than to the base. Thus, the PNP circuit topology is flipped in comparison to the NPN. This example assumes that a current of 500 mA is required to drive an array of LEDs. Standard convention is to label transistors with the letter Q and then append a number to uniquely identify each device. At I_{C2} = 500 mA, Q2 should be saturated to minimize V_{CE2}; therefore, the voltage drop across R_{C2} is 5 V – $V_{CE2\,(\mathrm{SAT})}$ – V_F = 2.7 V, the same as in the previous example. With the current higher than before, R_{C2} is selected to be 5.6 Ω, which is fairly close to the calculated value of 5.4 Ω. A common general-purpose PNP transistor that would be suited to an application such as this is the 2N3906 or its surface mount equivalent, the MMBT3906.

Assuming that β_2 = 100, I_{B2} = I_{C1} = 5 mA, and so I_{B1} = 0.05 mA. Practically speaking, I_{B1} does not have to be set to such accuracy, because the circuit is ultimately current limited by R_{C2}. R_{B1} can be conservatively selected to guarantee that at a minimum of 0.05 mA is injected into the NPN transistor's base. If I_{B1} turns out to be greater than 0.05 mA, slightly more power will be dissipated by both transistors, but heating will not be a problem at these submilliamp current levels. Selecting R_{B2} = 22 kΩ (logic-high output = 2.7 V) lightly loads the bipolar logic output with approximately 0.1 mA. This results in Q1's collector current being greater than 10 mA, assuming β_1 = 100. When the circuit is conducting, V_{CE1} is held at 4.3 V by the fixed V_{EB} of Q2 equal to 0.7 V. Therefore, Q1 dissipates slightly more than 43 mW.

The power dissipated by the PNP transistor is 500 mA × 0.3 V = 150 mW. This may not sound like much power, but a small transistor will experience a substantial temperature rise at this sustained power level. For the most part, this level of heating will not cause a problem in most circuits, but care should be taken to analyze the thermal characteristics of semiconductor packages when designing circuits. These issues are discussed later in this book.

Considering this mixed NPN/PNP circuit, the question may come to mind as to why the logic output cannot directly drive the base of the PNP transistor, simplifying the circuit by removing the NPN transistor. A bipolar logic output certainly has the drive strength at logic 0 to sink sufficient current. The problem is that a bipolar output is not specified with a high enough logic-1 voltage level. For the Q2 to be turned off, V_{B2} must be driven higher than 4.3 V, a requirement that is outside the guaranteed specifications of a typical bipolar logic device. If a CMOS output were used, the situation would be different, because most CMOS drivers are guaranteed to emit a logic-1 voltage that is much closer to the system's positive supply voltage.

An alternative dual-transistor circuit is two NPN transistors arranged in what is commonly termed a *Darlington pair*. As shown in Fig. 13.16, a Darlington pair connects the emitter of the first stage

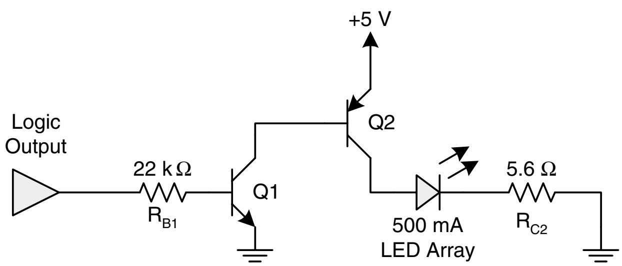

FIGURE 13.15 NPN/PNP LED driver.