Schmitt trigger uses two transistors

Einar Abell - November 24, 2014

This Design Idea shows how to add positive feedback to a Darlington pair to create a Schmitt trigger with very high current gain (typically 10,000). I don't know of any similar circuits to compare this to except ICs. However, it performs a very common function in a very simple manner. The circuit can be designed to handle load currents in the range of milliamps to amperes, with input impedance above 100MO for lower load currents.

![Figure 1](image_url) Two-transistor Schmitt trigger

**Figure 1** shows the basic circuit in its 'NPN', active low version, and **Figure 2** shows the 'PNP', active high version. R2 and R3 create a voltage (through R(L)) at Q1's emitter. As the input voltage
increases from zero to the $V_{on}$ point given by Equation 1, Q1 starts to turn on. Its collector current will be amplified by Q2, pulling down $V_{out}$, which will reduce the voltage at Q1’s emitter, turning it on more. This process will continue until Q1 is saturated, assuming the positive feedback from R3 is greater than the negative feedback caused by the current from Q1’s emitter.

$$V_{in(on)} = V_{be1} + \frac{R_2 V^+}{R_2 + R_3 + R_L}$$

Equation 1: $V_{in(on)} = V_{be1} + \frac{R_2 V^+}{R_2 + R_3 + R_L}$

**Figure 2** Active-high version

Equation 2 describes this situation; the equation should satisfied by at least a factor of two. The greater the inequality, the greater the amount of hysteresis. Eq. 2 can be solved to give limits to the circuit elements as shown in Eq. 3 for R(L), and Eq. 4 for Rin (a.k.a. R1). Eq. 4 and Eq. 5 also give the limit for R3, which must be less than R(L) times the gain of Q2 to keep Rin a positive value; typically R3 will be one half or less of this amount. Obviously, it helps if Q2 is a high gain part. Choosing R3 (and $V_{on}$) allows calculation of R2 with Eq. 6.
In the 'on' state, $V_{out}$ is approximated with Eq. 7. Because the dominant term depends on the gain of $Q_2$, the measured voltage is usually somewhat different, but is typically in the 2 to 3 volt range. The current in $R_{in}$ also adds into the voltage on $R_2$ (Eq. 9), and if $R_1$ is too small, the current will significantly increase $V_{R2}$ (in fact, if $R_{in}$ is zero, $V_{out}$ will follow $V_{in}$). As the input voltage drops, the output will stay on until $Q_1$ comes out of saturation. At this point, the positive feedback will turn both $Q_1$ and $Q_2$ off. Eq. 8 describes this $V_{off}$ point. Since you will usually want to keep $R_2$ at a minimum to keep $V_{out}$ low, adjusting $V_{off}$ will rely on varying $R_1$, but again, this $V_{off}$ value is dependent on the betas of $Q_1$ and $Q_2$.

$$2: \quad \frac{V^+ - V_{out}}{1 + \frac{R_1}{R_2}} > \frac{V^+ - V_{out}}{\beta_2 R_L} \left( \frac{R_2 R_3}{R_2 + R_3} + \frac{R_1 + R_s}{\beta_1} \right)$$

$$3: \quad R_L > \frac{(R_2 + R_3)}{\beta_1 \beta_2 R_2} R_{in} + \frac{R_3}{\beta_2}, \quad R_{in} = R_1 + R_s$$

$$4: \quad R_{in} < \frac{\beta_1 [(\beta_2 R_L) - R_3]}{1 + \frac{R_1}{R_2}}$$

$$5: \quad R_3 < \beta_2 R_L$$

$$6: \quad R_2 = \frac{V_{in(on)} - V_{be_1}}{V^+ - (V_{in(on)} - V_{be_1})} (R_3 + R_L)$$

$$7: \quad V_{out(on)} = V_{ce_2} = V_{R_2} + V_{ce_1} + V_{be_2}$$

$$8: \quad V_{in(off)} = V_{R_2} + V_{be_1} + \frac{V^+ - V_{out}}{\beta_1 \beta_2 R_L} R_{in}$$

$$9: \quad V_{R_2} = \frac{V^+ - (V_{ce_1} + V_{be_2})}{\beta_2 R_L} + \frac{V_{ce_1} + V_{be_2}}{R_3} + \frac{V_{in} - V_{be_1}}{R_{in}}$$

$$\frac{1}{R_2} + \frac{1}{\beta_2 R_L} + \frac{1}{R_{in}}$$

With $V_{ce_1} + V_{be_2} \approx 1 \text{ V}$ and $V_{be_1} \approx .8 \text{ V}$

This loosely defined turn-off point is one of the shortcomings of this circuit. However there are still
plenty of applications that don't need precisely defined trip points. Generally, you would select R2 and R3 to be as low as practical, keeping in mind quiescent current flows through R(L), and make R1 as large as needed (or allowed by Eq. 4), and be satisfied with whatever $V_{off}$ you end up with. The other main shortcoming is the relatively high voltage on Q2 when it is conducting, making it impractical for currents above a few amperes. This also limits the circuit to higher V+ voltages, making its niche use at higher currents and voltages than that of most ICs.

**Figure 3** is **Figure 1** redrawn to include three extra components that will be used in many applications. D1 prevents breakdown of the Q1 base-emitter junction if the voltage at the emitter should exceed 6 to 7 volts while in the off state. D2 reduces the contribution of R3 to the on-state output voltage. D2 is especially important if you make R3 equal or less than R2. R4 improves turn off of Q2 and keeps it from tripping on leakage current from Q1.

Q2 may be Darlington transistor (there seems to be little advantage to making Q1 a Darlington). Alternately, either or both transistors may be MOSFETs (with appropriate changes to the equations).

**Also see:**
- **Schmitt trigger provides toggle function**
- **Configurable logic gates' Schmitt inputs make versatile monostables**