SCHMITT TRIGGER

Typical ``real world'' signals consist of a superposition of a ``noise'' signal and a signal or signals of interest. For example, the signal at the bottom of Figure 19 shows a superposition of slow variations of large magnitude as well as faster variations of smaller magnitude. Let us assume that the slower, larger signal is our signal of interest. We could try using a high pass filter to eliminate the smaller, faster signal. However, if we are only interested in knowing when and for how long our signal of interest is above some threshold, we could use transistors to produce a circuit with an output voltage that is high or ``on'' when its input signal is above a ``turn on'' threshold and low or ``off'' otherwise. This circuit would produce several very short output pulses due to noise fluctuations as the signal crossed the threshold. If we refine the design so that the output only swings low after the signal crosses a second *lower* ``turn off'' threshold, we limit the sensitivity of the circuit to noise. In order for this idea to work, the difference between our ``turn on'' and ``turn off'' voltage thresholds should be somewhat larger than the peak to peak magnitude of the noise as shown in Figure 19.

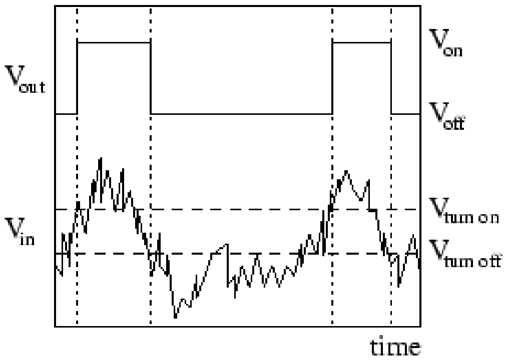

Figure 19: A ``noisy" input signal is shown below the desired output - high or ``on" when the input signal has passed a ``turn on" threshold and has not yet fallen below a *lower*``turn off" threshold. The two thresholds are arranged to prevent the circuit from responding to fluctuations due to noise.

The device described above is known as a Schmitt trigger. It is an example of a class of devices called **bistable multivibrators** or **flip flops**. These devices, because they have two possible output states dependent on the history of the input signal have (at least short term) memory.

Design considerations

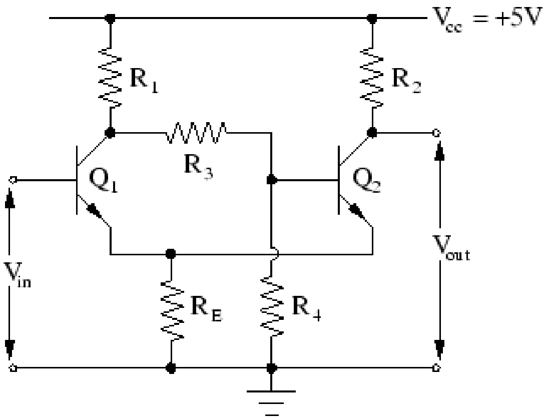

Figure 20: Nonlinear two state amplifier with different ``on" and ``off" input thresholds called a Schmitt trigger.

The circuit of Figure 20 is a Schmitt trigger circuit. The two transistors Q_1 and Q_2 are the key to the bistable behavior of the circuit. With the circuit in the ``on'' state, $Q_1$ is active ($V_{BE1} \approx 0.7$ V) while $Q_2$ is inactive ($V_{BE2} < 0.7$ V). In the ``off'' state, they trade roles. Neither transistor is saturated. It is important to note that these are not conclusions one can draw looking Figure 20 in the absence of resistance values. Instead, these are assertions that get us started in understanding the behavior of the circuit. It is further helpful to start at the left of Figure 19 and think through the generation of an output pulse as follows.

- V_{in} **low,** V_{out} **low (trigger ``off'')**

The trigger is ``off'' in this state. We start with the assumption that in this state, Q_1 is inactive and Q_2 is active. If we mentally remove Q_1 from the circuit as depicted in Figure 21(a), we have what looks like a somewhat tangled common emitter amplifier. The base voltage of Q_2 is set by the voltage divider consisting of $R_1 + R_3$ and R_4. If Q_2 is active but not saturated, $V_{BE2} = V_{B2} - V_{E2} \approx 0.7$ V, or

$$\left(\frac{R_4}{R_1 + R_3 + R_4}\right) V_{cc} - I_{C2} R_E \approx 0.7 \text{ V} \tag{9}$$

- where I_{C2} is the collector current of Q_2. For our purposes, we can and do consider the collector and emitter currents to be equal. Further, the output voltage corresponding to the ``off'' state is given by

$$V_{off} = V_{cc} - I_{C2}R_2. \tag{10}$$

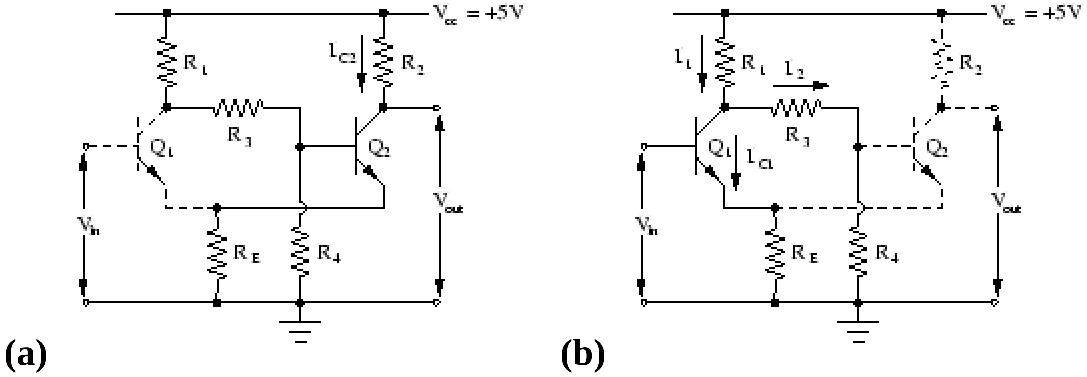

Figure 21: Schmitt trigger in the (a) ``off'' ($Q_1$ inactive) and (b) ``on'' (Q_2 inactive) states.

- **V_{in} rising, V_{out} low (trigger ``off'')**

Noting that the emitters of Q_1 and Q_2 are tied together, we conclude that the base and base emitter voltages at which they activate are equal. We already know the voltage of the base of Q_2 when the circuit is in the ``off'' state.

Hence, we have the input threshold for turning on Q_1 and triggering the transition to the ``on" state,

$$V_{turn\ on} = \left(\frac{R_4}{R_1 + R_3 + R_4}\right) V_{cc}. \tag{11}$$

- **V_{in} high, V_{out} high (trigger ``on'')**

The trigger is in the ``on" state (see Figure 21). Once Q_2 is inactive, $I_{C2} = 0$, and there is no voltage drop across R_2. We can conclude that

$$V_{on} = 5 \text{ V}. \tag{12}$$

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- **V_{in} falling, V_{out} high (trigger ``on'')**

In this state, there are three unique currents I_1, I_2, and I_{C1} flowing in the circuit as shown in Figure 21(b). The node rule gives

$$I_1 = I_{C1} + I_2. \tag{13}$$

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We can further observe, via the loop rule, that

$$I_1R_1 + I_2(R_3 + R_4) = V_{cc}. \tag{14}$$

- The key to finding the ``turn off'' threshold input voltage $V_{turn\ off}$ is recognizing that the base emitter voltages of Q_1 and Q_2 are both ≈ 0.7 V when Q_1 is deactivating and Q_2 is activating. This yields a third constraint

$$V_{turn\ off} \approx I_{C1}R_E + 0.7 \approx I_2R_4 \tag{15}$$

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- which, together with Equations 13 and 14 allows us to eliminate the three unknown currents. In this way, it can be shown that

$$V_{turn\ off} \approx \frac{R_4(V_{cc} + \frac{R_1}{R_E}\ 0.7\ \mathrm{V})}{R_1 + R_3 + R_4 + \frac{R_1R_4}{R_E}}. \tag{16}$$

Source: http://webpages.ursinus.edu/lriley/ref/circuits/node4.html