Experimenter's Corner

By Forrest M. Mims

THE SCHMITT TRIGGER

THE SCHMITT TRIGGER is a bistable (two-state) circuit with several useful applications, including threshold detection, signal conditioning, and sine-to-square wave conversion. In this column, we'll look at some practical circuits after we've learned the Schmitt trigger's operating principles.

Fig. 1 shows how you can make a Schmitt trigger from two of the inverters in a 7404 IC or half of a 7400 quad NAND gate. The Schmitt trigger consists of the two logic elements and resistors R2 and R3. Voltage divider R1 provides a variable input voltage to the Schmitt trigger, and the LED indicates when the circuit has triggered.

If we assume R2 is disconnected from the wiper of R1, what happens? The TTL gates we're using interpret an open input as a logic 1. Therefore, the first gate inverts the logic 1 to a logic 0, the second gate inverts the 0 to a 1, and the LED turns on.

Now let's connect the wiper of R1 to R2. When R1 is adjusted so that R2 is at or near ground, the logic state at the input to the first gate is logic 0. Therefore, the LED turns off.

As R1's wiper approaches the positive supply, an increasingly positive voltage is applied to the input of gate 1. The output of this gate will switch from 1 to 0 when the input voltage exceeds the logic 1 threshold. However, R3 provides a

negative feedback voltage which requires that the input voltage from R1 rise somewhat beyond the logic 1 threshold before the output of gate 1 changes states. When this happens, the output of gate 2 immediately switches from 0 to 1 and the LED turns on.

When the wiper of R1 approaches ground, positive feedback voltage from R3 requires that the input voltage from R1 be somewhat lower than that which normally switches the output of gate 1 from logic 0 to 1. When the output of gate 1 goes high, the output of gate 2 immediately switches from 1 to 0 and the LED turns off.

The result of this feedback path is two distinctive switching voltages for the circuit. The LED turns on at one voltage, and then turns off at another, somewhat lower, voltage.

These switching points are called *trip* or *threshold* points. The region between them is called the *hysteresis zone*. Fig. 2 shows how the hysteresis zone looks when the circuit's response is plotted on a graph. The hysteresis of a Schmitt trigger is important because it prevents unwanted oscillation. If the two switching points were identical, the circuit would tend to oscillate when the input was at or near the switching voltage.

You can build the circuit in Fig. 1 on a solderless prototyping breadboard in a minute or two to observe its operation.

Connect a voltmeter between the wiper of R1 and ground so you can measure the trip voltages. Then rotate the potentiometer's shaft so the wiper approaches ground. The LED will go off.

As you slowly rotate R1 in the opposite direction, the LED will suddenly switch on and the meter will read about 1 volt. When you rotate R1 back toward
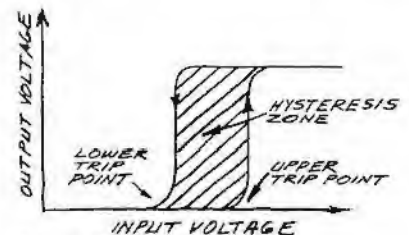

Fig. 2. Hysteresis curve for a Schmitt trigger circuit.

ground, the LED will switch off when the meter reads about 0.5 volt.

Here are the exact trip voltages I measured using the components shown in Fig. 1 and a 5-volt power supply:

Trip Voltages		
	7400	7404
ON	1.12	1.08
OFF	.47	.58

The 7413 Dual Schmitt Trigger.
Several TTL and CMOS Schmitt triggers are available. One low-cost TTL IC is the 7413 dual Schmitt trigger. You can buy this 14-pin DIP for less than 50 cents (only a quarter per trigger!)

Recently, I used one of these handy chips to perform two completely different
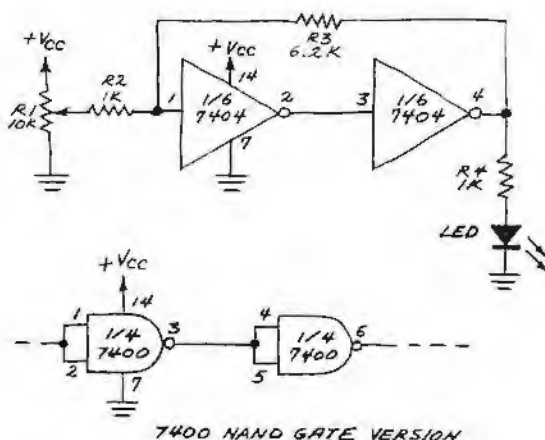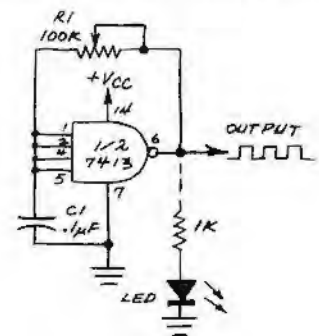

Fig. 3. Connecting one of the two triggers in the 7413 as an oscillator to provide pulses.

operations in a digital controller circuit. One of the Schmitt triggers was connected as a variable frequency oscillator to provide a clock for the controller circuit. The other was used as a threshold buffer for a phototransistor at the input of the controller. Let's look at both these applications.

Fig. 1. A basic two-inverter Schmitt trigger.

7400 NAND GATE VERSION

Schmitt Trigger Oscillator. Fig. 3 shows how to connect one of the two Schmitt triggers in the 7413 as an oscillator that provides a reasonably stable source of pulses with fast rise and fall times. The frequency of oscillation and the pulse width are determined by $R1$ and $C1$. With the values shown, the pulses have an amplitude of 2 volts, a width of 25 microseconds, and a rise time of less than 100 nanoseconds. The oscillation frequency can be varied from a low of 70 Hz to a high of about 300 kHz by adjusting $R1$.

Increasing $C1$ to 100 microfarads will reduce the frequency of oscillation to a few Hertz, making the circuit useful as a light flasher or visual logic indicator. For the latter application, remove the connection to pin 1 and replace it with a suitable probe. When the probe is floating or connected to $+V_{CC}$, the LED will flash. When it's connected to ground, the LED will glow continuously.

Schmitt Trigger Threshold Buffer. Using the other half of the 7413 as a threshold buffer for a phototransistor is illustrated in Fig. 4. Assume the light
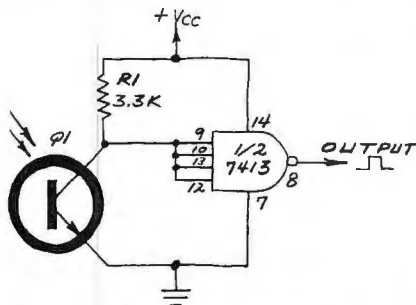
Fig. 4. Using half of a 7413 as a threshold buffer for a phototransistor.

reaching phototransistor $Q1$ varies in intensity or flickers. When the light level at $Q1$ is high, the phototransistor turns on and provides a low resistance path from the input of the Schmitt trigger to ground. Thus the trigger switches high. When $Q1$ is dark, its resistance is high and the low resistance path to $+V_{CC}$ through $R1$ forces the output of the Schmitt trigger low. Incidentally, these switching conditions are reversed from those of the two-gate Schmitt trigger in Fig. 1 because the outputs of the 7413 are inverted.

The net result of all this is that the Schmitt trigger cleans up erratic signals and converts them into more easily processed pulses. Fig. 5 illustrates this graphically.

Fig. 5. How a Schmitt trigger cleans up an erratic waveform.

Other Applications. After a little experimentation, you will be able to come up with Schmitt trigger circuits of your own. For starters, try a bounceless pushbutton. Or build a sine-to-square wave converter. You can also try using a Schmitt trigger in some monostable multivibrator applications. Finally, be sure to experiment with Schmitt trigger IC's, such as the 7414 TTL chip with six Schmitt triggers, and the 4093 and 4584 CMOS Schmitt triggers. ◊