COMPARATORS AND SCHMITT TRIGGER

It is quite common to want to know which of two signals is larger, or to know when a given signal exceeds a predetermined value. For instance, the usual method of generating triangle waves is to supply positive or negative currents into a capacitor, reversing the polarity of the current when the amplitude reaches a present peak value. Another example is a digital voltmeter. In order to convert a voltage to a number, the unknown voltage is applied to one input of a comparator, with a linear ramp (capacitor + current source) applied to the other. A digital counter counts cycles of an oscillator while the ramp is less than the unknown voltage and displays the result when equality of amplitudes is reached. The resultant count is proportional to the input voltage. This is called single-slope integration; in most sophisticated instruments a dual-slope integration is used (see Section 9.21).

4.23 Comparators

The simplest form of comparator is a high-gain differential amplifier, made either with transistors or with an op-amp (Fig. 4.59). The op-amp goes into positive or

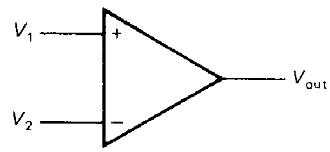

Figure 4.59

negative saturation according to the difference of the input voltages. Because the voltage gain typically exceeds 100,000, the inputs will have to be equal to within a fraction of a millivolt in order for the output not to be saturated. Although an ordinary op-amp can be used as a comparator (and frequently is), there are special integrated circuits intended for use as comparators. Some examples are the LM306, LM311, LM393, NE527, and TLC372. These chips are designed for very fast response and aren't even in the same league as op-amps. For example, the high-speed NE521 slews at several thousand volts per microsecond. With comparators, the term "slew rate" isn't usually used; you talk instead about "propagation delay versus input overdrive."

Comparators generally have more flexible output circuits than op-amps. Whereas an ordinary op-amp uses a push-pull output stage to swing between the supply voltages (±13V, say, for a 411 running from ±15V supplies), a comparator chip usually has an "open-collector" output with grounded emitter. By supplying an external "pullup" resistor (that's accepted terminology, believe it or not) connected to a voltage of your choice, you can have an output swing from +5 volts to ground, say. You will see later that logic circuits have well-defined voltages they like to operate between; the preceding example would be ideal for driving a TTL circuit, a popular type of digital logic. Figure 4.60 shows the circuit. The output switches from +5 volts to ground when the input signal goes negative. This use of a comparator is really an example of analog-to-digital conversion.

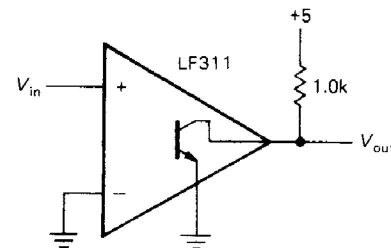

Figure 4.60

This is the first example we have presented of an *open-collector* output; this is a common configuration in logic circuits, as you will see throughout Chapters 8–11. If you like, you can think of the external pullup resistor as completing the comparator's internal circuit by providing a collector load resistor for an *npn* output transistor. Since the output transistor operates as a saturated switch, the resistor value is not at all critical, with values typically between a few hundred ohms and a few thousand ohms; small values yield improved switching speed and noise immunity at the expense of increased power dissipation. Incidentally, in spite of their superficial resemblance to op-amps, comparators are never used with negative feedback because they would not be stable (see Sections 4.32–4.34). However, some *positive* feedback is often used, as you will see in the next section.

Comments on comparators

Some points to remember: (a) Because there is no negative feedback, golden rule I is not obeyed. The inputs are not at the same voltage. (b) The absence of negative feedback means that the (differential) input impedance isn't bootstrapped to the high values characteristic of op-amp circuits. As a result, the input signal sees a changing load and changing (small) input current as the comparator switches; if the driving impedance is too high, strange things may happen. (c) Some comparators permit only limited differential input swings, as little as ±5 volts in some cases. Check the specs! See Table 9.3 and the discussion in Section 9.07 for the properties of some popular comparators.

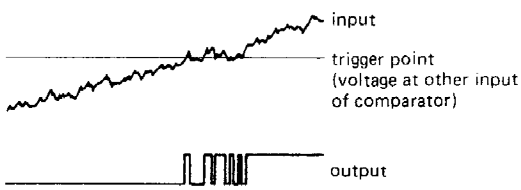

Figure 4.61

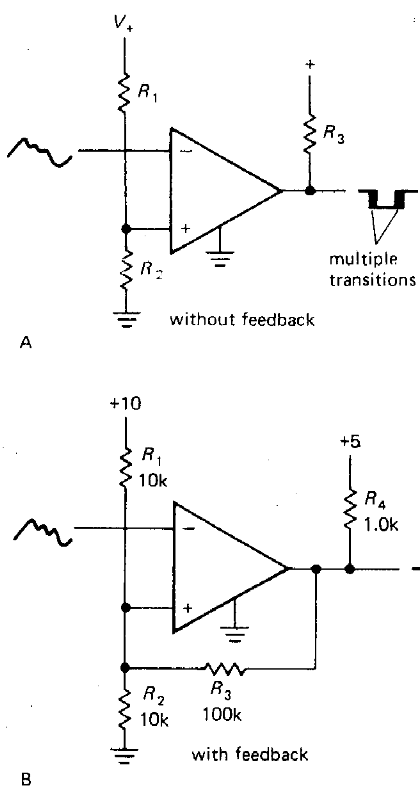

Figure 4.62

4.24 Schmitt trigger

The simple comparator circuit in Figure 4.60 has two disadvantages. For a very slowly varying input, the output swing can be rather slow. Worse still, if the input is noisy, the output may make several transitions as the input passes through the trigger point (Fig. 4.61). Both these problems can be remedied by the use of *positive* feedback (Fig. 4.62). The effect of R_3 is to make the circuit have two thresholds, depending on the output state. In the example shown, the threshold when the output is at ground (input high) is 4.76 volts, whereas the threshold with the output at +5 volts is 5.0 volts. A noisy input is less likely to produce multiple triggering (Fig. 4.63). Furthermore, the positive feedback ensures a rapid output transition, regardless of the speed of the input waveform. (A small "speedup" capacitor of 10–100pF is often connected across R_3 to enhance switching speed still further.) This configuration is known as a Schmitt trigger. (If an op-amp were used, the pullup would be omitted.)

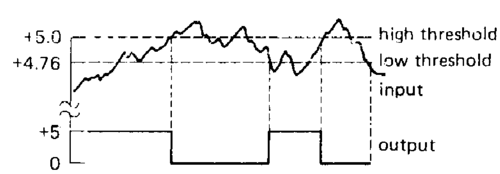

Figure 4.63

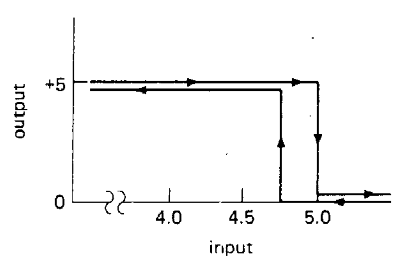

Figure 4.64

The output depends both on the input voltage and on its recent history, an effect called *hysteresis*. This can be illustrated with a diagram of output versus input, as in Figure 4.64. The design procedure is easy for Schmitt triggers that have a small amount of hysteresis. Use the circuit of Figure 4.62B. First choose a resistive divider (R_1, R_2) to put the threshold at approximately the right voltage; if you want the threshold near ground, just use a single resistor from noninverting input to ground. Next, choose the (positive) feedback resistor R_3 to produce the required hysteresis, noting that the hysteresis equals the output swing, attenuated by a resistive divider formed by R_3 and $R_1 \| R_2$. Finally, choose an output pullup resistor R_4 small enough to ensure nearly full supply swing, taking account of the loading by R_3. For the case where you want thresholds symmetrical about ground, connect an offsetting resistor of appropriate value from the noninverting input to the negative supply. You may wish to scale all resistor values in order to keep the output current and impedance levels within a reasonable range.

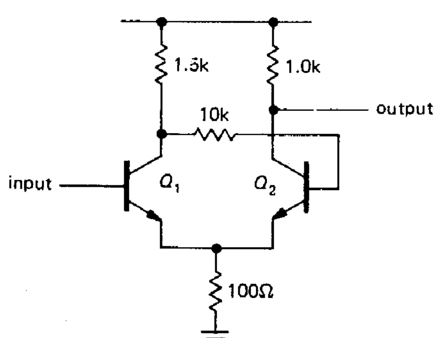

Figure 4.65

Discrete-transistor Schmitt trigger

A Schmitt trigger can also be made simply with transistors (Fig. 4.65). Q_1 and Q_2 share an emitter resistor. It is essential that Q_1's collector resistor be larger than Q_2's. In that way the threshold to turn on Q_1, which is one diode drop above the emitter voltage, rises when Q_1 is turned off, since the emitter current is higher with Q_2 conducting. This produces hysteresis in the trigger threshold, just as in the preceding integrated circuit Schmitt trigger.

EXERCISE 4.10

Design a Schmitt trigger using a 311 comparator (open-collector output) with thresholds at +1.0 volt and +1.5 volts. Use a 1.0k pullup resistor to +5 volts, and assume that the 311 is powered from ±15 volt supplies.