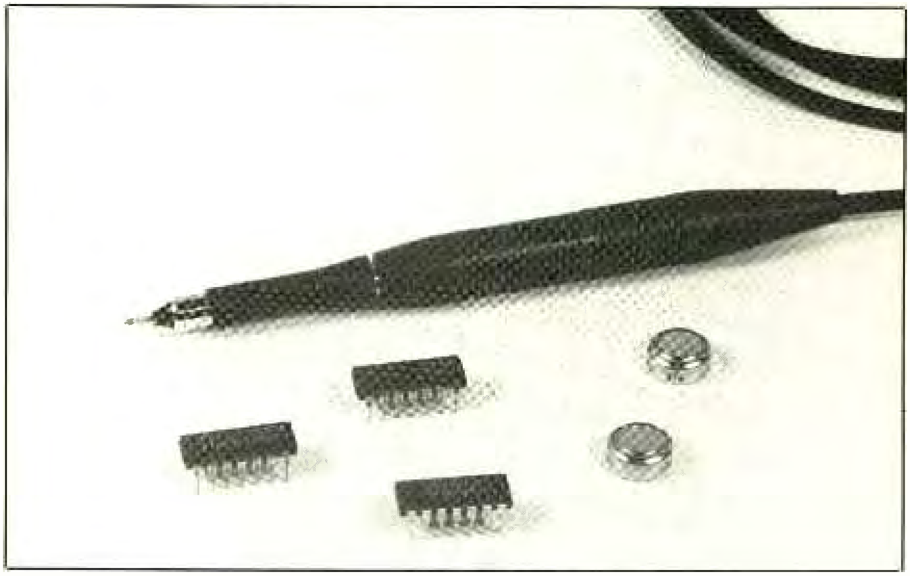
High-Speed CMOS: The Best of Both Worlds

Offers the low power consumption, high noise immunity of CMOS and the speed and drive capability of LSTTL

By Jan Axelson



An essential step in designing a logic circuit is deciding upon which IC family to use. This usually means a choice between TTL and CMOS technologies, each of which has its own advantages and disadvantages.

TTL devices have long been familiar to circuit designers and are readily available from a host of suppliers. During the past few years, however, there has been a growing shift away from TTL toward CMOS as the designer's technology of choice. This is due to the low power consumption, wide power-supply voltage range and high immunity to noise that characterize CMOS devices. The popular 4000 series of CMOS devices offers these benefits—but not without some tradeoffs.

To obtain highest operating speed and maximize noise immunity, 4000-series CMOS requires a 9- to 15-volt power supply, which may not be as conveniently available as the 5-volt supplies used to power TTL circuits. This is certain to change as CMOS becomes more firmly established. Be aware, though, that even at higher operating voltages, 4000-series CMOS devices are relatively slow performers, with propagation delays averaging several times those of TTL.

In comparison with TTL devices, CMOS devices have a low output drive capability. Also, circuit designers who have become familiar with TTL devices will have to learn a whole new set of identification numbers and pinout arrangements for CMOS devices. You can eliminate the last by choosing devices from the 74C CMOS family, which follows TTL numbering and pinouts, though these devices also are relatively slow and have low output drive.

The newer HC, or High-speed CMOS, family of logic chips overcomes these limitations, while offering advantages that aren't available in other individual logic families. In this article, we'll introduce you to high-speed CMOS and show you how to use it and take advantage of its capabilities.

Improved HC Technology

High-speed CMOS has the low power consumption and high noise immunity that typifies CMOS-technology IC devices. This family of logic elements includes devices that follow the numbering system and have the functions and pinouts of TTL. Just about every function available in TTL is now available in high-speed CMOS, including gates, flip-flops, counters, decoders/encoders and more. Additionally, HC devices are available with functions formerly found only in 4000-series CMOS, such as the popular 4066 analog switch (in the HC family, it's the 74HC4066).

Figure 1 shows how HC devices "match" familiar ICs from other families. Other functions, such as the 74HC943 modem chip, are unique to the HC family.

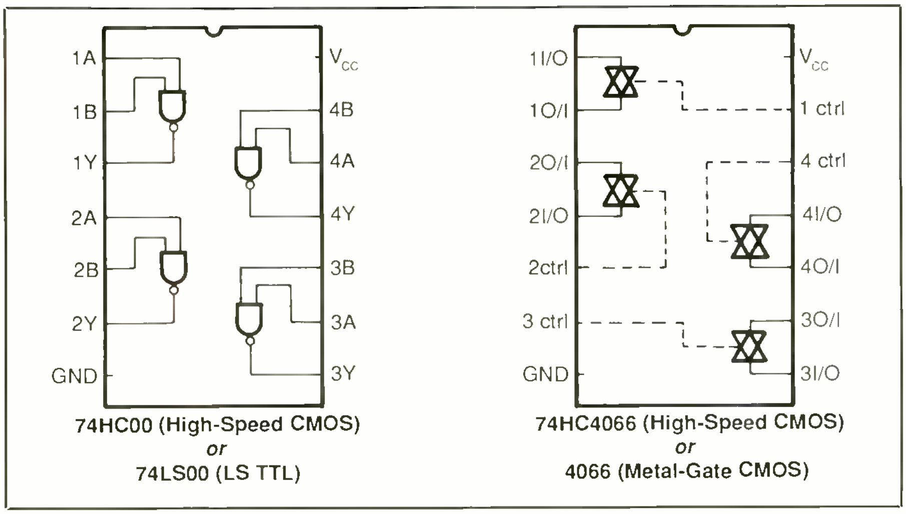


Fig. 1. Many HC devices, like the 74HC00 quad NAND gate, follow the same numbering scheme and pinouts as TTL devices. Others, like the 74HC00 quad bilateral switch, duplicate functions and pinouts of 4000-series CMOS devices.

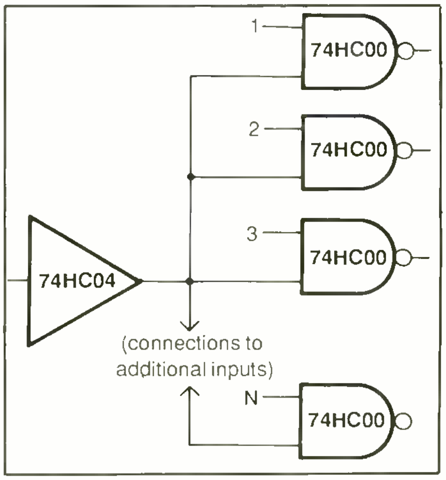


Fig. 2. Fanout from an HC output to HC inputs is virtually unlimited. Here output of 74HC04 inverter fans out to series of NAND inputs.

High-speed CMOS has been made possible through improved manufacturing technologies. The transistors in HC devices use 3-micron polysilicon gates, rather than the 7-micron metal gates used in 4000-series CMOS. In addition, overlap between the gate and source and drain areas is minimized due to a "self-aligned" gate process.

These and other improvements provide increased gain while at the same time reducing unwanted parasitic capacitances (the unavoidable capacitance due to the IC's structure). The result is devices with high operating speed as well as low power consumption.

Electronics experimenters will be gratified to learn that there are plenty of sources for HC devices in small (as well as large) quantities. Many manufacturers— including Texas Instruments, RCA, National Semiconductor and Motorola—now offer HC devices, and publish data books giving application notes and complete specifications.

Prices are comparable to, and sometimes lower than, those for LSTTL and 4000-series CMOS. Table I lists a few of the many mail-order suppliers who have added high-speed CMOS to their inventories.

Table I. HCMOS Mail-Order Sources

All Electronics Corp.
P.O. Box 567
Van Nuys, CA 91408
1-800-826-5432

Digi-Key Corp.
701 Brooks Ave. S.
P.O. Box 677
Thief River Falls, MN 56701
1-800-344-4539

JDR Microdevices
110 Knowles Dr.
Los Gatos, CA 95030
1-800-538-5000

Jameco Electronics
1355 Shoreway Rd.
Belmont, CA 94002
415-592-8097

Mouser Electronics
2401 Hwy. 287 N.
Mansfield, TX 76063
1-800-34-MOUSER

Note: The above is only a partial listing of possible mail-order suppliers of HCMOS devices.

Power Consumption

Table II summarizes the features and operating characteristics of the devices in the high-speed CMOS logic category.

Power-supply voltage range for CMOS devices is wide. Supplies that can deliver anywhere from 2 to 6 volts are recommended, but absolute maximum must be 7 volts. With a minimum of 2 volts at the low end, CMOS devices are ideal for low-voltage operation, such as 3 volts from two AA (or AAA) cells in series, or even small button-type cells.

Quiescent power consumption (power consumed when all inputs are tied to V_{cc} or ground and outputs are open) is trivial at only 25 microwatts per gate. Like other CMOS devices, HC devices consume power only when switching. The higher the operating frequency, the more transitions there are, and the greater the power consumption.

Even at the highest frequencies, power consumption of HC devices doesn't equal that of standard 74LS ("LS" stands for "low-power Schottky") TTL devices until they're operating at several megahertz. A typical HC gate powered at 5 volts consumes just 0.1 milliwatt when operating at 100 kHz. This increases to 1 milliwatt at 1 MHz and to 10 milliwatts at 10 MHz. Keep in mind, too, that these are average operating frequencies. A device that spends a lot

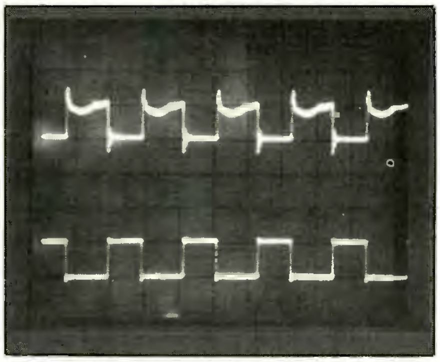


Fig. 3. Upper trace is a noisy square-wave input to a 74HC04 inverter; lower trace shows how HC's wide noise margin allows inverter to ignore noise and give a clean output.

Table II. Features & Characteristics of High-Speed CMOS

Power-supply voltage range	2 to 6 volts dc
Power consumption	
quiescent power consumption per gate	25 μW
operating power/gate at 100 Hz	0.1 mW
1 MHz	1 mW
10 MHz	10 mW
Operating speed	comparable to LSTTL
Propagation delay	8 ns
Noise immunity margin (4.5-V supply)	1.4 volts (high) 0.9 volt (low)
Output drive capability	4 mA source/sink current (same as LSTTL)
Operating temperature range	−40° to +85° C
Same functions and pinouts of TTL and 4000-series CMOS	
Easily interfaces with other logic families and operating voltages	

of time "idling" will have a very low average frequency, even if it operates at high speeds some of the time.

Low power consumption means you can use smaller-capacity power supplies, with less need for heat sinks and cooling fans. Because HC devices run cooler than other ICs, they're more reliable. The bottom line, then, is that HC devices are actually a great deal less expensive to use than TTL devices, perhaps not in terms of the devices themselves but certainly in terms of the cost of the components used in their power supplies.

Inputs and Outputs

Because of their extremely high input impedance, input current requirements of HC devices are very small, averaging less than 1 microampere per gate. Output drive capability is 4 milliamperes for both source and sink currents and is as much as 6 milliamperes for bus-driver outputs, with an absolute maximum of 25 milliamperes. This is more flexible than LSTTL, which can sink but not source 4 milliamperes.

There is virtually no restriction on fanout of HC devices to other HC devices. Figure 2 shows how one HC output can "fan out" to drive as many HC inputs as you'll ever need.

As with other CMOS devices, input switching levels vary with supply voltage. The maximum input guaranteed to be considered a low is $0.2V_{cc}$, and the minimum high input is $0.7V_{cc}$. So with a 5-volt supply, inputs less than 1 volt are lows, while those greater than 3.5 volts are highs. But with a 2-volt supply, a low must be 0.4 volt or less, and a high must be 1.4 volts or greater.

Outputs of HC devices can swing virtually from rail to rail, to within 0.1 volt of ground and V_{cc}. Output buffering gives sharp output signal transitions.

These input and output characteristics mean that HC devices exhibit good immunity to noise. In a 5-volt circuit, for example, the maximum low output is 0.1 volt, but any input up to 1 volt is considered a low. So you have at least 0.9 volt of noise margin between an HC "low" output and the input it connects to. Logic "high" inputs do even better, with 1.4 volts of noise margin between V_{out} (4.9 volts minimum) and V_{in} (3.5 volts minimum). Figure 3 shows how a considerable amount of input noise doesn't affect the output of an HC gate.

Operating Speed

At 4.5 volts, the propagation delay of HC is 8 nanoseconds, which is comparable to LSTTL and three times faster than 4000-series CMOS devices operating at 15 volts. This means that HC devices can be used at speeds of up to 40 MHz. Propagation delays vary somewhat with voltage. With a 2-volt supply, for example, the delay increases to 22 nanoseconds.

Are there any reasons not to use high-speed CMOS? Its fast switching speed means that HC devices are

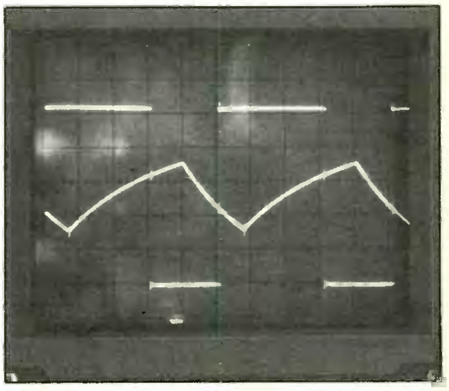


Fig. 4. A Schmitt trigger, such as the 74HC14, "squares up" slowly changing inputs to HC devices. Triangular wave in center is input to 74HC14 inverter. Square wave superimposed on it is inverter's output that has sharp rise and fall times required by HC devices.

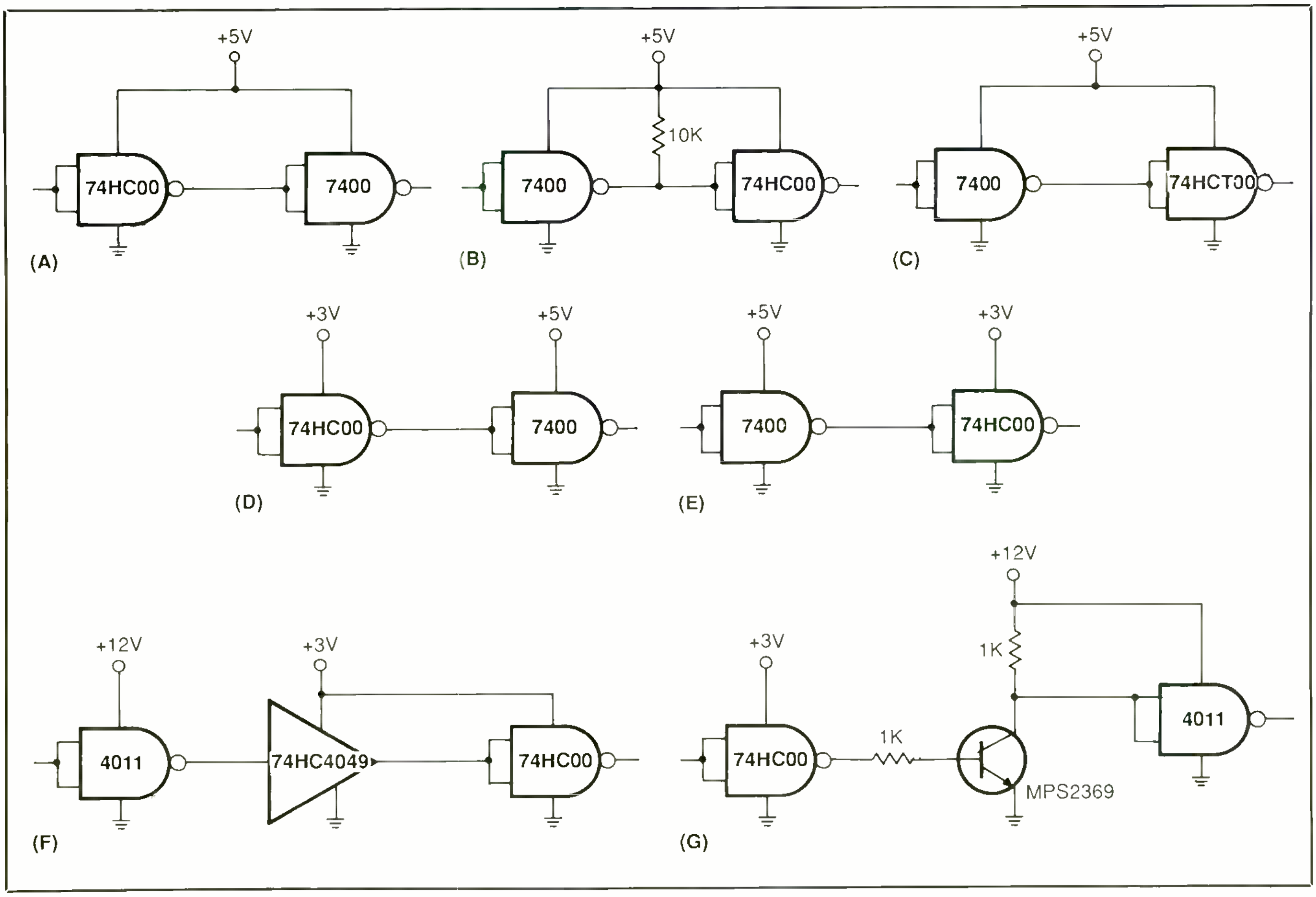


Fig. 5. High-speed CMOS is easy to interface to other logic families and operating voltages. Circuits in (A) through (E) interface HC to TTL, while (F) and (G) interface HC with 4000-series CMOS operating at higher voltage.

more likely to generate high-frequency noise spikes, compared to the slower 4000-series CMOS. Therefore, power-supply regulation and decoupling considerations are more critical for HC devices.

At the same time, for truly high-speed applications, Schottky TTL (identified by a 74S prefix) is more than twice as fast as HC logic. The next generation of CMOS, ACL (Advanced CMOS Logic), improves on HC, with propagation delays of 3 nanoseconds coupled with 24-milliampere drive capability.

Rules for Using HC

Precautions and other special considerations to remember when using HC devices are similar to the usual rules for any other MOS device. Unused inputs should be tied either to ground or to V_{cc}, whichever is more convenient, to keep input gates from self-biasing into their linear operating range and, thus, drawing unnecessary current and possibly affecting circuit operation.

Most HC inputs and outputs include diode-resistor networks that are designed to protect them against damage resulting from electrostatic discharge. Even so, it is good insurance to carefully handle HC devices to avoid static charges at the origin.

Like other CMOS ICs, HC devices may be vulnerable to latch-up, which can occur if an input voltage goes higher than V_{cc} or lower than ground and forces the input-protection diodes to conduct. A low-resistance path from V_{cc} to ground may then be created, causing the IC to draw a large amount of current, possibly enough to "fry" the IC. To prevent this, input currents should be limited to 20 milliamperes or less.

This is particularly important for off-board inputs, such as from signal generators, which may be left on after the CMOS circuit is powered down. Current-limiting resistors in series with such inputs will prevent large latch-up currents from flowing.

Another consideration with HC devices, again typical of all CMOS, is that input clocks must have fast rise and fall times—0.5 microsecond or less at 4.5 volts is recommended. This will prevent output oscillations or false triggering caused by noise generated during slow input signal transitions.

For unavoidably slowly changing inputs such as RC timing ramps, a Schmitt trigger (such as the 74HC14) can be used to square up the signal. Figure 4 illustrates the effect of a Schmitt trigger on a slowly changing input. Several HC devices—including the 74HC73, 74HC74, 74HC107, 74HC109 and 74HC112 flip-flops—have Schmitt-triggers already built in at their inputs.

Although you have wide latitude in choosing a supply voltage for an HC circuit, the supply should be regulated and decoupled to minimize noise spikes caused by HC's fast switching speeds. If of sufficient amplitude, this noise can generate rfi (radio-frequency interference) or cause false triggering. As a rule of thumb, use a 10- to 50-microfarad electrolytic capacitor for power supply decoupling, along with a 0.01-microfarad capacitor for every 2 to 5 packages and a 0.1-microfarad capacitor for every 10 packages, to minimize the switching noise.

As you can see, there are some rules that must be observed when using HC devices, but for the most part they're no more restrictive than those required for other CMOS devices. Improved technology is making electrostatic discharge damage and latch-up less of a problem than they've been in the past.

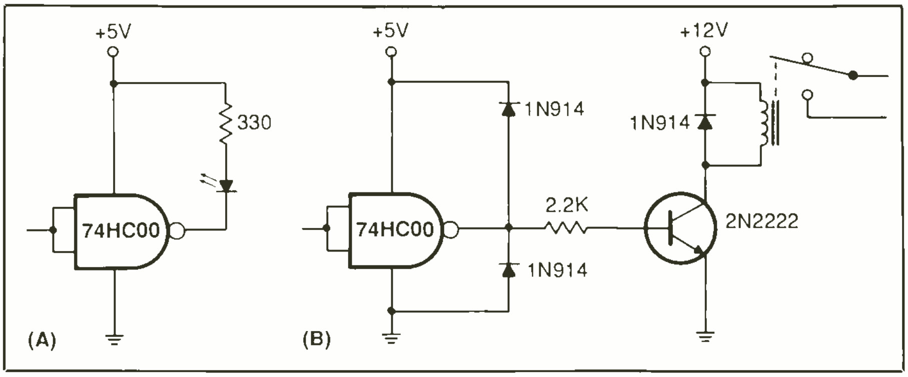


Fig. 6. An HC output can be used to directly drive a LED (A), while a transistor (B) provides increased drive current to operate a relay.

Interfacing to HCMOS

The HC family is unique in that it includes some functions of 4000-series CMOS as well as those of TTL. This should limit the need to mix logic families within a circuit. But when it can't be avoided, HC devices can easily be interfaced with other logic families and operating voltages.

Figure 5 shows several examples of this. The circuits shown use NAND gates, but the interfacing techniques can be used with other devices in the families shown.

In Fig. 5(A), an HC output powered at 5 volts directly drives two TTL inputs (or it can drive up to 10 LSTTL inputs). In the other direction, a pull-up resistor is needed at the TTL output to be sure it provides the 3.5 volts required for the HC gate's high-level input, as in Fig. 5(B). Another solution, shown in Fig. 5(C), eliminates even the need for a pull-up resistor.

A sub-family of the HC family, the HCT series, is similar to HC but with TTL-compatible input levels, in which a low is 0.8 volt or less and a high is 2 volts or greater. HCT also has stricter power-supply requirements (4.5 to 5.5 volts), reflecting its more narrow purpose.

Because of their different input-level specifications, HCT devices have less noise immunity than regular HC devices. But as TTL-to-HC interfaces, they're ideal. In most cases, HCT devices can also serve as drop-in replacements for LSTTL, with lower power consumption.

In general, the same rules for interfacing HC with TTL also apply to interfacing to NMOS devices such as microprocessors and memories. Also, HC is ideal for maintaining the low power consumption of circuits that use CMOS microprocessors.

Operating at 3 volts, HC can interface directly with 5-volt TTL, as shown in Figs. 5(D) and 5(E). If both devices use the same supply voltage, 4000-series CMOS can also interface directly with HC. At different supply voltages, Fig. 5(F) shows how a 4049 or 4050 buffer (either the HC or metal-gate version) can be used as a "down" voltage converter.

A transistor is a convenient way to convert up to a higher voltage, as illustrated in Fig. 5(G). For best results at high frequencies, use a high-speed switching transistor.)

The absolute maximum output drive rating for HC devices is 25 milliamperes (35 milliamperes for bus-driver outputs). At currents above 4 milliamperes, the outputs will no longer swing rail to rail, but they can still can be used to drive LEDs or other higher-current loads. Figure 6(A) shows an HC output powering a LED at 10 milliamperes.

A transistor can be used to boost the output drive even further. Figure 6(B) shows an HC output controlling a transistor, which in turn controls a relay. Diodes at the output of the NAND gate protect the gate from

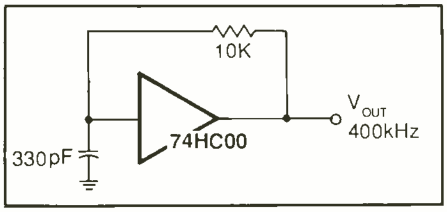


Fig. 7. A Schmitt-trigger inverter can be configured as a simple oscillator that can be used to clock other HC circuits.

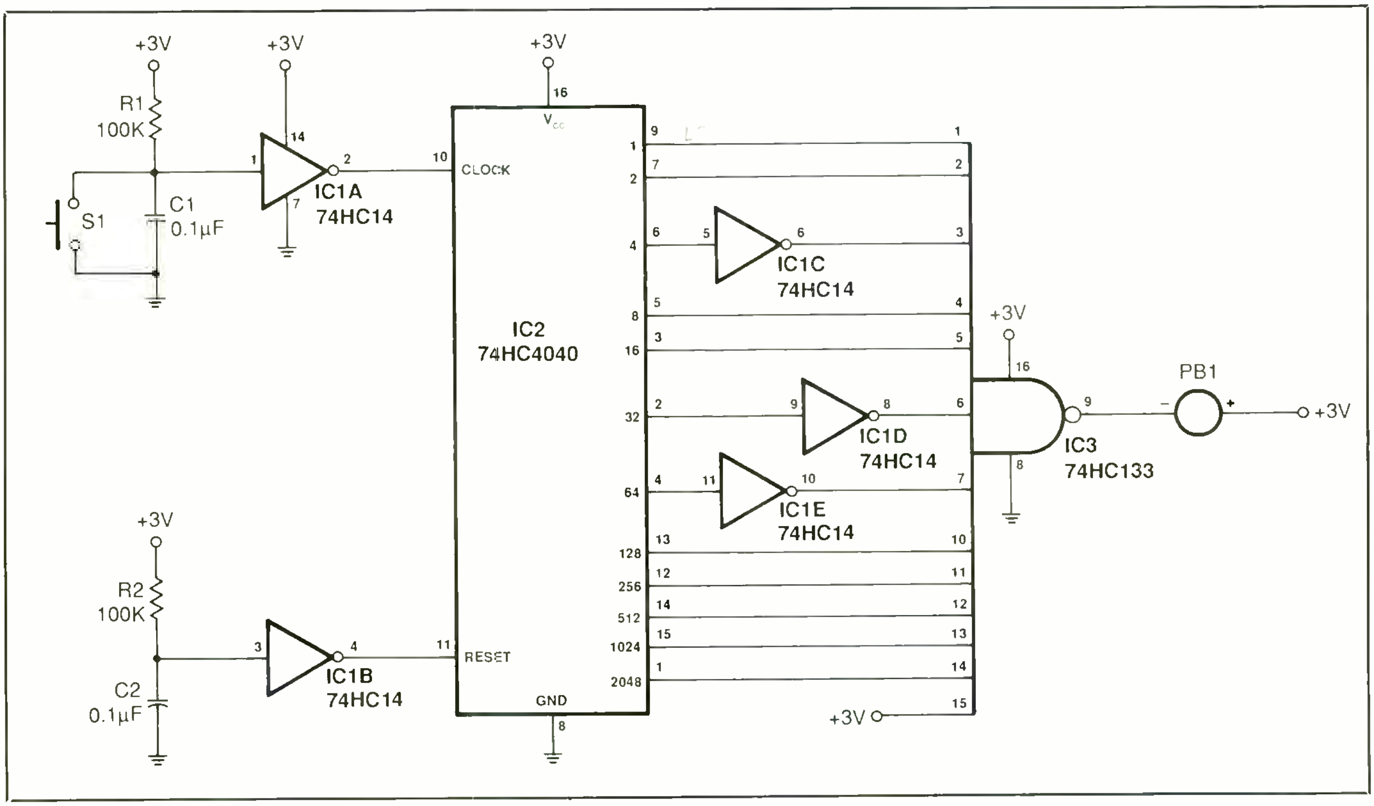


Fig. 8. This circuit uses three HC devices to sound an alarm when S1 is toggled 100 times.

current spikes caused by the relay's switching.

Figure 7 shows a simple oscillator configured from a 74HC14 Schmitt trigger. Substituting different resistor or capacitor values changes the frequency of the oscillator, which can serve as a clock oscillator for other HC circuits.

Another candidate for a clock circuit for HC devices is the TLC555, a low-power CMOS version of the popular bipolar 555 timer chip. The TLC555 can use power supplies that deliver at little as 2 volts, and operates at frequencies up to 2 MHz.

An HCMOS Counter

Figure 9 shows a counting circuit built around HC devices. This circuit counts the number of times a switch toggles. At a count of 100, it turns on a buzzer.

Integrated circuit *IC2* is a 12-bit binary counter. On power up, the charging of *C2* through *R2* holds pin 3 of *IC1* low for a few milliseconds. This causes a "high" to appear at pin 11 of *IC2*, which resets the counter. Resistor *R1*, capacitor *C1* and another inverter in *IC1* make up a debouncing circuit that ensures that each switch toggle produces one and only one clock pulse.

Each time switch *S1* is pressed, the count of *IC2* advances. Inverters are used at the appropriate counter outputs so that all inputs to *IC3*, a 13-input NAND gate, are high at a count of 100 (binary 1100100). When this occurs, the output of *IC3* goes low and piezoelectric buzzer *PB1* sounds. By changing the number and locations of the inverters at *IC2*'s output, the circuit can be programmed to sound the alarm at any count between 1 and 4,095.

Because it uses HC devices, the Fig. 8 circuit can be powered by two AA (or AAA) cells. It uses virtually no power until the buzzer comes on. Therefore, the circuit can be left "waiting" for counts without worry of battery run-down.

This is just one example of a circuit that is well suited for design with HC devices. High-speed CMOS is especially appropriate for circuits like this, which require low power consumption or low-voltage operation. But just about any type of logic circuit can be built, and often built better, with this new and useful family of integrated circuits.

In parting, a couple of final notes are in order. Unlike the case with 4000-series CMOS, you can't conveniently power an HC circuit directly from a 9-volt battery, though there are plenty of other power-supply options. Also, if you're already stocked up with TTL or other CMOS ICs, you may be reluctant to invest in a new technology. However, if you need low power, low operating voltage, and/or (moderately) high switching speeds, high-speed CMOS is ideal technology to use. ME