HOW IC LOGIC

Low-cost computer logic gates

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PRICE REDUCTIONS ON MANY DIGITAL INTEGRATED CIRCUITS have made the logic gate practical for many "everyday" circuits. Besides their obvious use as computer logic elements, these gates readily form the active elements needed for conventional pulse and digital circuits, multivibrators, triggers and a host of other circuits.

By adding a biasing resistor, logic gates may be made into class-A linear amplifiers, useful in many low-level applications. Let's look at some of the more popular gates.

What's available

There are many advantages in using IC logic gates to replace conventional transistors, resistors and diodes. Foremost is cost. One $1.08 package, for example, contains *six* complete integrated gates—only 18¢ per gate. This is far less than the price of a single transistor or diode.

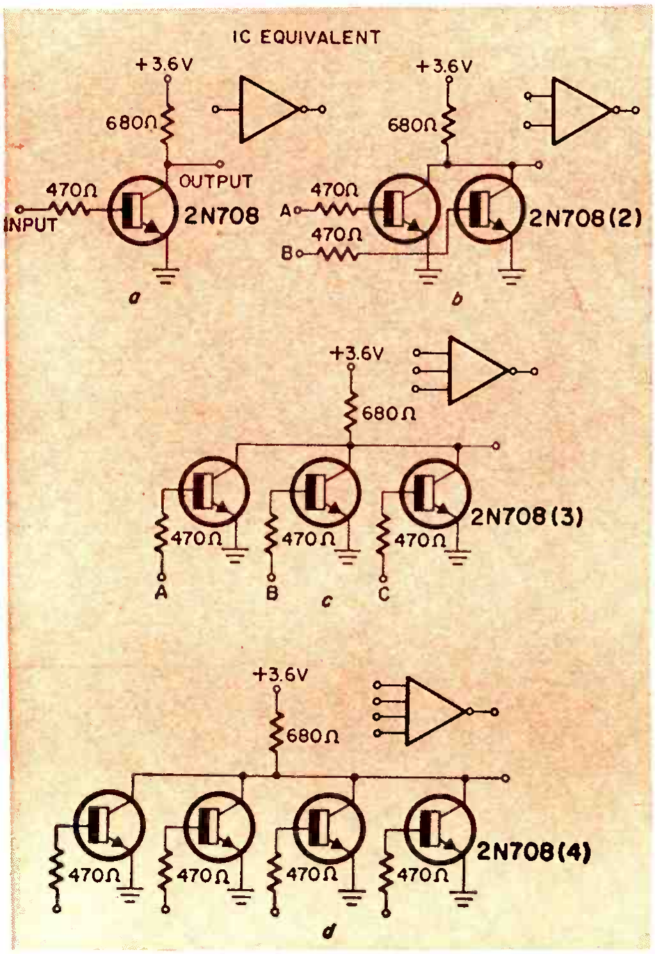
As logic gates may be directly connected together and require no biasing or coupling circuitry, the need for external resistors and capacitors is greatly reduced. Logic gates are very compact, with two to six in a single plastic package. Circuit design is greatly simplified, since you know operating temperature range, speed, drive capability and power requirements ahead of time. For many applications, one or two penlight cells operate the circuit.

A logic gate obeys certain rules to turn an output off or on upon some coincidence of signals at its input. A kitchen sink faucet is a logic gate—it gives you an output if *either* the hot or cold input is provided with an on signal. This is an example of an OR circuit. A garden hose is an example of an AND logic gate, since both the outdoor faucet and the nozzle valve must be on to get an output.

There are many forms of logic gates: mechanical, hydraulic, chemical, pneumatic, optic, electric and electronic. The electronic logic is far and away the most prevalent; millions upon millions of gates are used in the computer industry. Integrated circuits were called upon a decade ago to reduce the size, cost and power consumption of computers.

As a result, many forms of IC logic gates are available today. Those we'll talk about are called RTL gates, because they are the integrated equivalent of Resistor Transistor Logic. Fig. 1 shows the discrete equivalent circuits for the one-, two-, three- and four-input RTL gates and their integrated equivalents.

The two-input gate consists of two npn transistors sharing a common-collector resistor. Each base has a cur-



◄ *Fig. 1-a—This is a one-input RTL logic gate and its IC equivalent symbol. Parts* b, c *and* d *are two- three- and four-input gates respectively with their IC symbols. All circuits run as saturated-logic switches. When any base receives current, the output of that gate goes near ground. If all bases do not receive current, the output goes positive to 3.6 volts.*

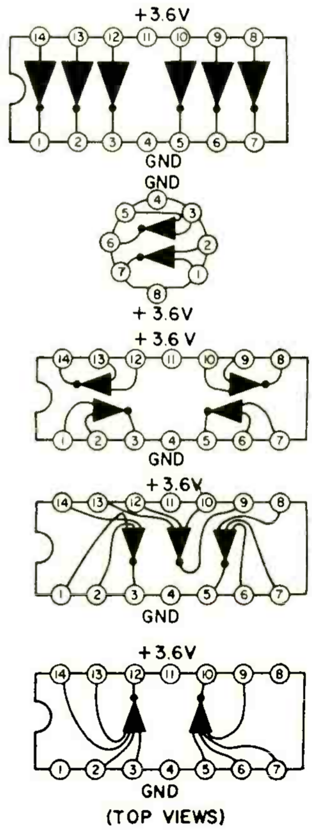


Table 1—A few of the gate combinations available in 14-lead "caterpillar" and 8-lead TO-5 cases. Top to bottom: Hex inverter, dual two-input, quad two-input, triple three-input, dual four-point. In each case, gates are independent.

CIRCUITS WORK

make 'everyday' circuits easy to build

rent-limiting resistor attached to an input. If *either* input receives base current, the output goes to ground. If *neither* input receives base current, the output goes positive to the supply voltage.

Using this basic configuration and choosing our definitions carefully, we can interconnect logic gates to perform all computer functions, and any set of logic rules we wish.

A few of the more popular gates available are IC's that come in an eight-pin TO-5-size epoxy package or a 14-lead in-line "caterpillar" package. Both types are interchangeable and operate from a single +3.6-volt supply. For many applications 1.5—4.5-volt battery supplies will work as well. The gates have a transition time around 15 nanoseconds. This is very slow as computer circuits go, but for everyday applications the gates are useful from dc to beyond 10 MHz.

Note that all the packages contain more than one gate. All the gates are independent, and the only common connections are supply voltage and ground. For instance, a quad two-input gate contains four independent gates, each gate being the two-input variety. A dual four-input gate has two separate gates, each of which has four separate inputs.

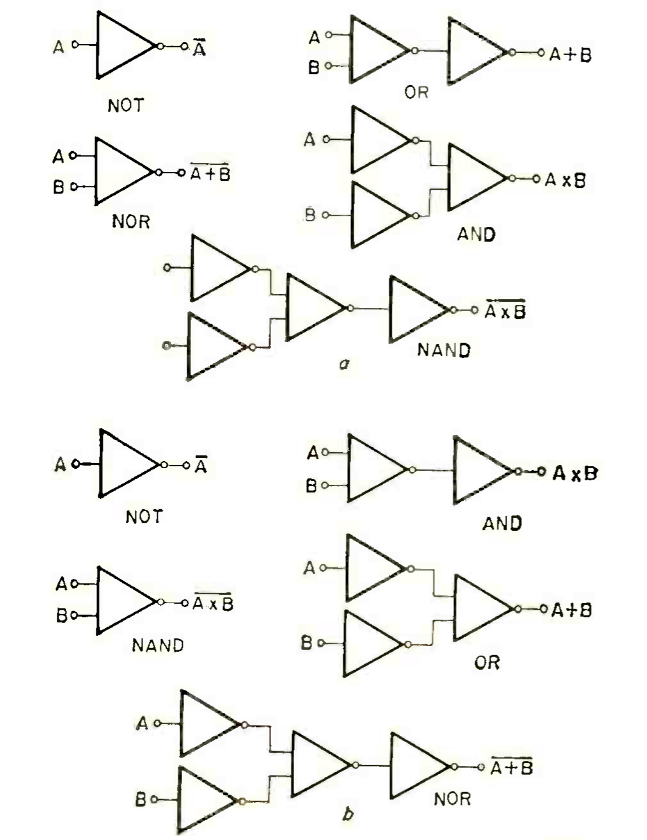


Fig. 2—Computer logic functions depend on definitions. Top (a) *drawings show positive logic: "1" is positive and "O" is ground. In negative logic* (b), *"1" is ground and "O" is positive.*

Pin conventions are shown in Table I. The eight-pin version has a flat or color dot adjacent to pin 8, while the in-line package has an identifying notch and top-view pin connections as shown. IC's are good over a +15°–55°C temperature range. Each gate consumes about 12 mW of supply power. Each gate's output can drive *five* similar gate inputs; where more output power, or *fanout*, is required, a different IC, called a *buffer*, is needed.

Logic circuits

What integrated logic gates will do in computer applications depends, not only on the circuit connection, but also on definitions. For example, if we define "+" as "1" and ground as "0," we are using a *positive* logic gate, and the NOT, NOR, NAND, OR, AND logic gates are built up with circuits of Fig. 2-a. If, on the other hand, we define ground as "1" and "+" as "0," we are using *negative* logic, and the NOT, NAND, AND, OR and NOR functions are generated with the *different* gate connections shown in Fig. 2-b.

To analyze any logic function, consider what the actual gate does. The NAND coincidence is based upon *neither* transistor receiving base current, thus allowing the output junction to swing *positive*. The NOR coincidence is based upon *any* gate transistor receiving base current and thus forcing the output junction to *ground*.

As an example of a more complicated computer logic circuit, the EXCLUSIVE OR circuit, also known as a *half-adder*, is shown in Fig. 3. This circuit directly performs binary addition. Usually two half-adders are used together, one to add two binary numbers and a second to handle a possible *carry* from the previous addition. Note that a considerable number of inverting gates may be eliminated, if the *complements* of the input and output are available or useful elsewhere in the circuit.

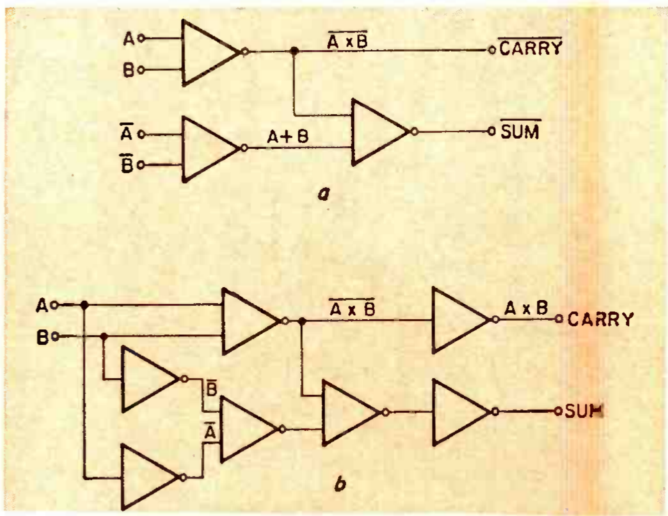


Fig. 3—The EXCLUSIVE OR circuit (half adder) is one of the more complex computer functions. Part a *shows arrangement with usable complements available;* b *has self-generated complements.*

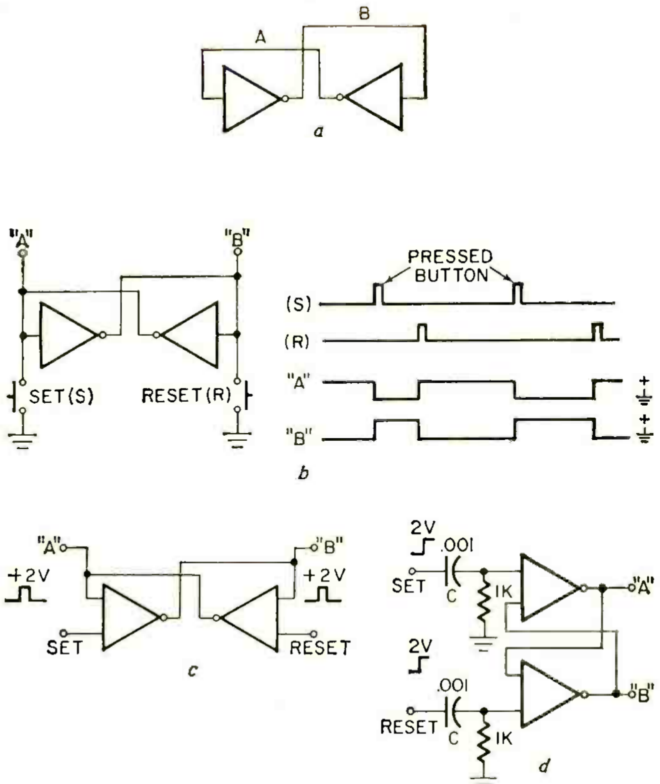


Fig. 4—Various configurations of bistable multivibrators. In a, *two one-input gates are back to back. Part* b *shows same circuit wired for pushbutton operation. Circuit in* c *uses two-input gate for a pulse set-reset latch. The pulse-coupling, set-reset flip-flop in* d *triggers with long input pulse.*

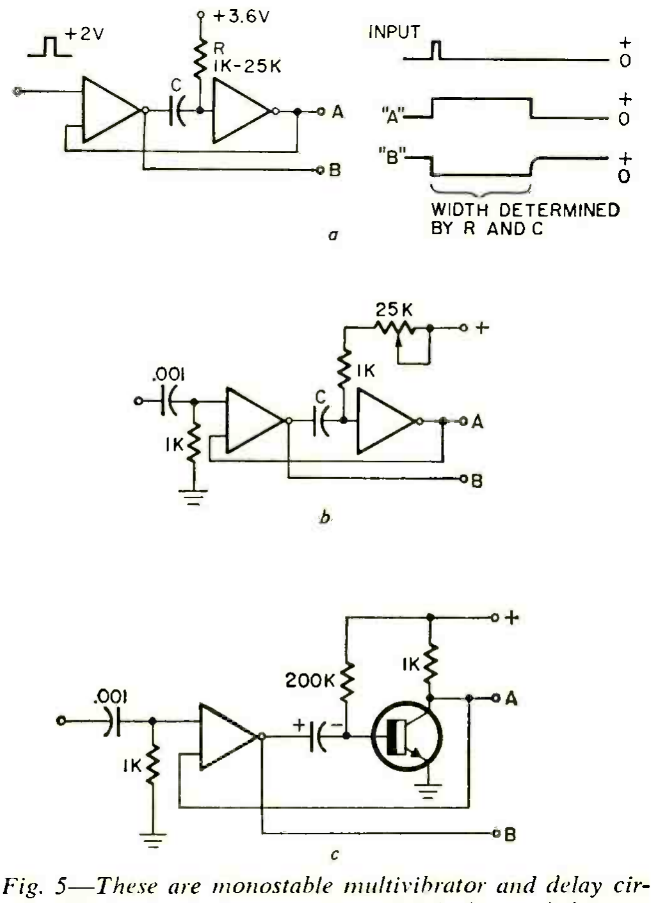


Fig. 5—These are monostable multivibrator and delay circuits. Basic circuit in a *requires a brief, dc-coupled input. With circuit in* b, *the output is variable over a 10:1 range. High-gain transistor in* c *permits long time delays of output.*

Suppose we connect two one-input gates back to back as in Fig. 4-a. If the left gate's output happened to be grounded, it would allow the right gate's output to be positive, which in turn would provide the base current to keep the left gate's output grounded. The circuit is stable and, if undisturbed, will stay in either of the two possible states. This is called a *bistable multivibrator.*

The circuit is more useful if we force the bistable to go into either of the two states upon command. This is done by adding two pushbuttons as in Fig. 4-b. Push the SET pushbutton, and point A goes to ground and stays there after the button is released. Push the RESET button and point A goes "+" and point B goes to ground, and stays there after the button is released. We can use this circuit as a memory or latch; it is somewhat similar to a relay latching itself on its own make contact.

It is often desirable to change states upon electrical command. For this, we go to the two-input gate configuration of Fig. 4-c. Here one gate input on each side is used for feedback; the other for an input. A short positive pulse at either input then sets or resets the latch, depending upon the input selected.

For the circuit to operate properly, the inputs must "see" a dc return path and the input pulses must be brief. To ac-couple signals, or to trigger on the leading edge of a long input pulse, requires the pulse coupling circuit of Fig. 4-d. The 1000-ohm resistors are essential; if they are omitted, the gate's base–emitter pn junction will act as a dc restorer and charge up the input capacitor after one or two operating cycles.

If input signals appear simultaneously, *both* outputs will go to ground and the last input to disappear determines the state the bistable will go into.

The circuits shown will *not* count and will not automatically steer input pulses from one side to the other if the inputs are connected together. To do this, an integrated circuit called a JK flip-flop is needed.

Monostable circuits

Suppose we break one of the feedback connections of the latch and insert a capacitor and recharging resistor (Fig. 5-a). If we let the circuit sit long enough, it will go into the state in which the left gate's output is positive and the right output is grounded. Capacitor C will charge to roughly the supply voltage.

Now, if an input trigger pulse is delivered, the left gate's output will immediately go to ground. Since the charge on a capacitor cannot immediately change, the right end of C abruptly drops *negative*, removing base current from the right gate. The right gate's output swings positive, and thus provides base current for the left gate, holding the circuit in the new state.

So far things have gone just as they did in the bistable circuit. But resistor R now starts charging the right end of C positively, until the voltage on the right end of C is positive enough to provide base current for the right gate. The right gate's output starts to ground, and the circuit snaps back to the original state.

This is another form of multivibrator. It has one stable state and one unstable one. Called a *monostable multivibrator,* it is used to generate a time delay or a rectangular pulse of controlled width upon command. To vary the output width or delay, R or C is varied. A 10:1 range is obtained by the circuit of Fig. 5-b. Here we have also added input capacitors for ac coupling or for triggering an input that is long compared to the delay time.

There are several important design considerations. The input signal (either directly or through the capacitor differentiation network) must be brief compared to the delay time, or the circuit will not operate properly. As with the bistable circuit, the 100-ohm resistor on the input is essential if capacitor coupling is used. The timing resistor may vary from 1000 to 25,000 ohms, while C may range from 200 pF up to several hundred microfarads. The time constant of RC roughly equals the delay time, with intervals from 200 nsecs to several seconds possible.

The monostable has a recovery time. It cannot be immediately retriggered, since C must recharge completely to the supply voltage. Constant-width operation may be obtained with a duty cycle less than 30%, while a duty cycle as great as 75% may be used if considerable change in timing is permissible. The generated pulse width does not vary greatly with small changes in temperature or supply voltage.

Time intervals longer than a fraction of a second require unreasonably large values of C as resistor R cannot be made larger than 25,000 ohms without running out of gain in the second gate. For long time intervals, a gate may be combined with a very-high-gain transistor to allow a much larger value of R, and a resultant reduction in capacitor size. (Fig. 5-c).

Other trigger circuits

Figure 6-a shows a nonregenerative pulse stretcher that provides a monostable output with a single, one-input gate. It produces a rectangular output pulse upon command, and is used only when the input is dc-coupled and *goes to ground and stays there* for a time longer than the pulse period. Since there is no feedback, the fall time is not nearly as good as can be obtained with a true monostable.

To trigger the circuit, the input is made positive long enough to charge C. The input is then abruptly brought to ground *and held there*. Since the charge on C cannot change instantaneously, the right end of C swings negative, turns off the gate and produces a positive output. Resistor R then charges C just as in the conventional monostable.

A monostable circuit with "negative" recovery time is shown in Fig. 6-b. Here the output goes positive immediately upon an input command and stays positive for a time delay determined after the *last* pulse or input command chain is received. An input pulse discharges C. which then recharges through the internal collector resistor of the right gate until it is positive enough to allow the right gate to turn on. As C is "emptied" each time an input pulse arrives. the time delay begins anew with each input pulse.

The output fall time is not very good. and very large C values are required for millisecond pulse intervals. The circuit is also rather dependent on supply and temperature and requires input pulses long enough to discharge C completely. One interesting application for this circuit is with voice-operated relays. Another is for missing-pulse detection or producing an output only after an entire string of input pulses has passed.

A Schmitt trigger is shown in Fig. 6-c. This is an emitter-coupled multivibrator that is sensitive to input voltage. As the voltage exceeds a given level, the Schmitt circuit snaps into one state. As the voltage drops below a second level, the circuit snaps back into the original state.

The two levels are made different, producing hysteresis and eliminating chatter or noise sensitivity. The circuit shown snaps on with an input exceeding 1.5 volts, and off with the input voltage dropping below 1.1 volts.

Since the ground lead must be broken and a 27-ohm resistor inserted in series with the negative return on the IC, the circuit will work only with a dual two-input gate. The 27-ohm resistor determines the trip points, while the output resistor determines the amount of hysteresis obtained. The circuit is used as an alarm or a voltage-level

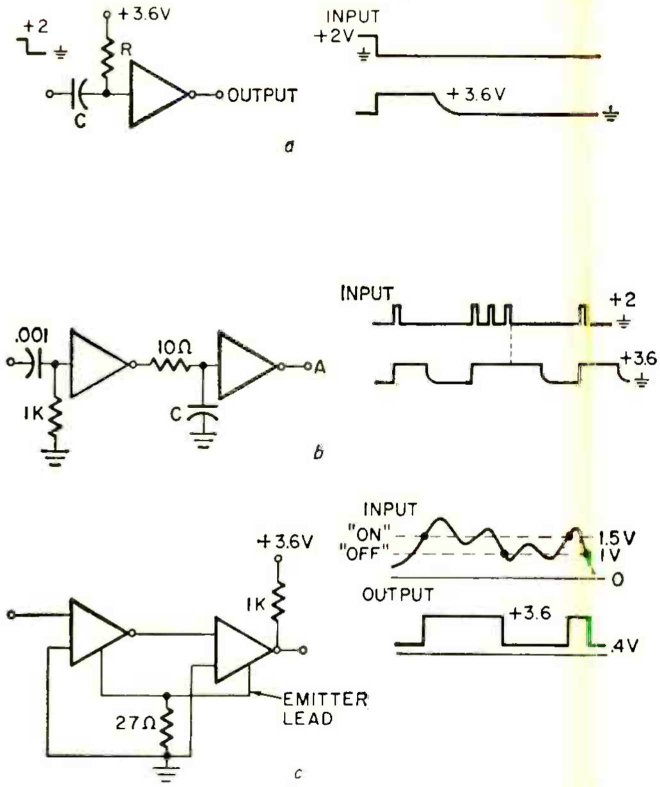


Fig. 6-a—Nonregenerative pulse stretcher in this circuit requires an input staying at ground for duration of the output. The nonregenerative monostable in b is controlled by last pulse in input chain. A Schmitt trigger is shown in d.

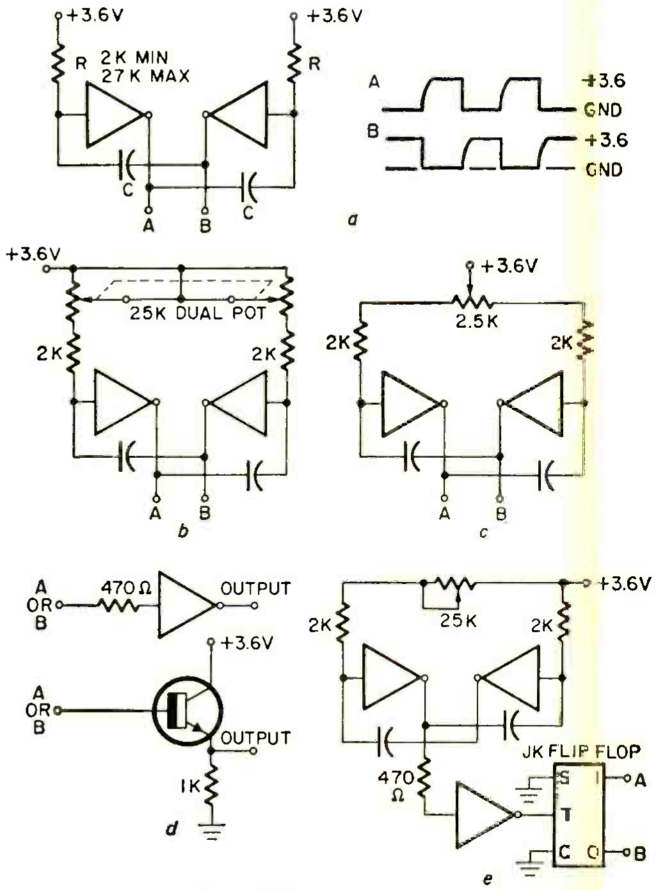


Fig. 7—Various free-running multivibrators: Circuit a *is a basic astable,* b *is astable with dual-pot frequency control,* c *has variable symmetry output. Part* d *shows resistor and transistor load isolation;* e *shows JK flip-flop division by 2.*

detector. Signal conditioning of the output may be required before driving additional logic gates.

An astable multivibrator has no stable state and is thus free-running, forming a square-wave oscillator circuit (Fig. 7-a). Once again, timing is determined by the RC products. The waveform will be asymmetrical unless the RC products are equal. Fig. 7-b adds a *dual* 25,000-ohm potentiometer to obtain a 10:1 control range. For wider ranges, various values of C are switched in.

The circuit of Fig. 7-c provides a fixed output with variable symmetry. The minimum recommended value of R is 2000 ohms; the maximum, 25,000 ohms. Capacitor C may vary from 200 pF up to several tens of microfarads.

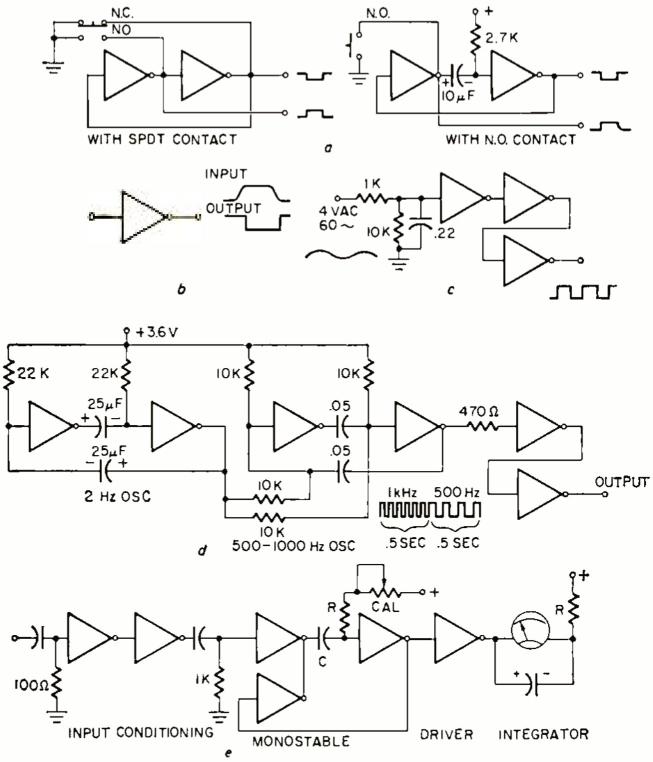


Fig. 8—Here are a few practical applications. Part a *shows bounceless pushbuttons (spdt on left, and n.o. on right). A squaring circuit is in* b, *and a 60-Hz driver for high-speed JK's is in* c. *Single IC in* d *can be two-tone oscillator or alarm. A hex-inverter tachometer is shown in circuit* e.

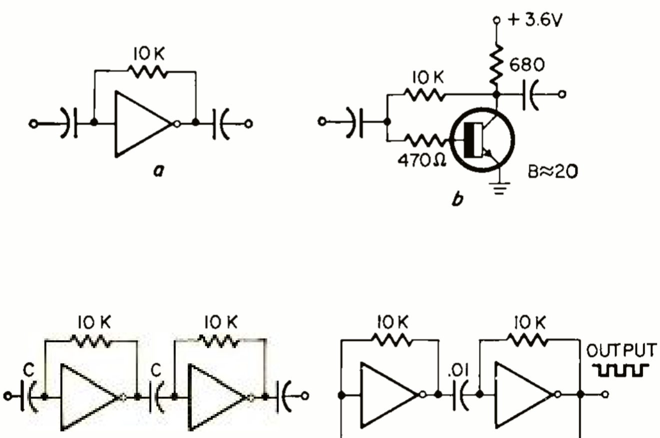


Fig. 9—Biasing scheme for class-A amplifier operation of gates is shown in a *and the equivalent circuit in* b. *Circuit in* c *is gain-of-400 amplifier, and* d *is a crystal oscillator.*

There does not seem to be any starting problem with an IC astable of this type.

The circuit operates properly only if lightly loaded. Two load-isolating techniques are shown in Fig. 7-d, one of which requires a resistor and a gate, the other a transistor emitter follower and a resistor.

Single-potentiometer operation will result in a highly asymmeterical waveform. A very nearly square wave with excellent symmetry may be obtained by dividing the astable multivibrator's output by 2 with a JK flip-flop; the flip-flop's output is perfectly symmetrical, except for a possible small transition time (Fig. 7-e).

Some applications

Let's look at how we can use these logic gates in other useful circuits. Fig. 8-a shows two bounceless pushbutton circuits, essential whenever mechanical contacts are used with high-speed integrated counter circuits. A dual circuit or an spdt pushbutton may be used to drive a set-reset bistable multivibrator directly. This circuit requires two one-input gates. If an spst or make contact is the only one available, the 15-msec multivibrator circuit may be used. This requires an additional resistor and capacitor.

A single one-input gate is used as a squaring circuit to sharpen rise and fall times of an input signal (Fig. 8-b). Around 20 nsecs of delay will also be picked up, and a single gate can be used as an ultra-short delay line. Fig. 8-c shows a filter and three cascaded one-input gates. This circuit is used to square 60-Hz power-line or other low-frequency audio sine waves. The output is a square wave with a very fast fall time, a feature essential when integrated JK flip-flops are to be used in low-frequency circuit applications.

The dual-tone oscillator of Fig. 8-d produces a commanding alarm that switches between 500 and 100 Hz twice each second. In operation, the left two gates operate as a 2-Hz oscillator that alters the charging current and hence the frequency of the high-frequency astable formed by the middle two gates. The remaining gates serve as load isolation. The circuit drives any amplifier; with a companion driver transistor, it will directly drive a speaker to ear-splitting volume. Note the extreme simplicity possible by using a hex inverter—only *one* active component is needed for the circuit.

The same hex inverter is useful in tachometer circuits, again with a significant parts reduction. Fig. 8-e shows the technique. By keeping the monostable duty cycle well under 30% and isolating the indicating meter from the monostable, a considerable improvement in stability over simpler circuits is obtained. As with any pulse duty-cycle-type tachometer, the supply must be regulated and a suitable input network must be chosen to isolate ignition spikes and noise.

Linear operation

Gates may be biased up into the class-A region to produce a very-low-cost linear amplifier. Fig. 9-a shows the biasing scheme, while Fig. 9-b shows the approximate equivalent circuit. Discrete versions of this circuit are not often seen as the input impedance is rather low—even though the configuration has good gain and bias stability. The stages may be cascaded.

A gain-of-400 amplifier is shown in Fig. 9-c. Note that coupling capacitors are essential to keep the proper bias levels on each stage. Up to three stages may be cascaded, producing gains above 60 dB. Maximum linear peak-to-peak output is around 1 volt. A practical application of the class-A technique is the crystal oscillator of Fig. 9-d, which produces square waves at the fundamental resonant frequency of a series-resonant crystal. **R-E**