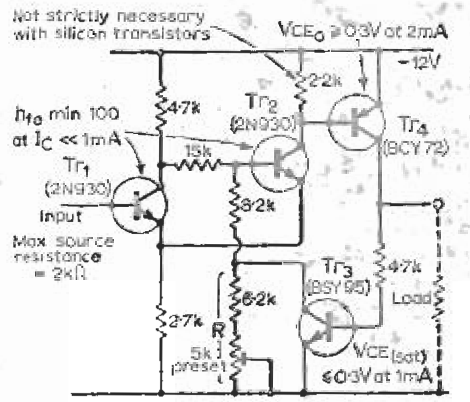
Circuit Ideas

Schmitt trigger with "zero" backlash

To the conventional Schmitt circuit (Tr_1 and Tr_2) is added a level shifter Tr_3, and an electronic switch Tr_4. The circuit has two stable states. When the input signal is



Schmitt trigger with "zero" backlash.

above the upper trip-point Tr_1 is on, Tr_2, Tr_3, and Tr_4 off and R is in circuit. When the input signal is below the lower trip-point Tr_1 is off, Tr_2, Tr_3 and Tr_4 on and R shorted. Lowering the value of R will reduce backlash to zero. It is possible to go below zero "backlash" and cause the circuit to oscillate.

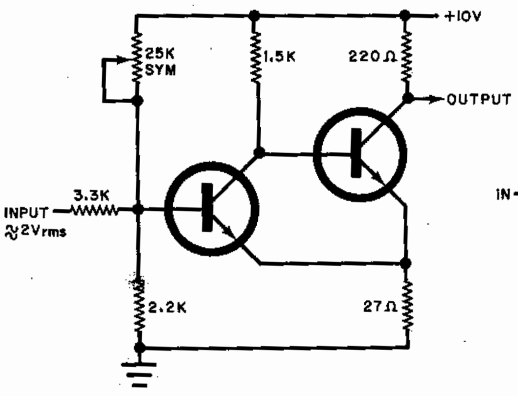
A. E. Crump,
Broadstone,
Dorset

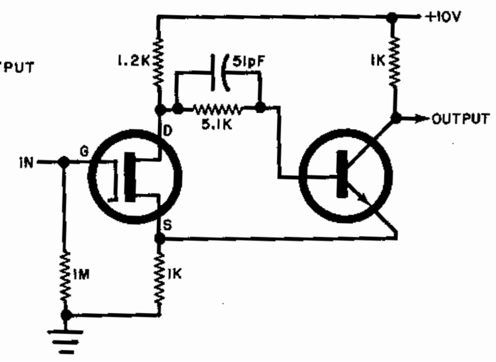
SQUARE WAVES FROM SINE WAVES

Q. ***I have a decent solid-state sine-wave generator that I use quite often. Is there a simple circuit that I can use with the generator to get clean square waves? The circuit should be small enough to mount within the present case.***

A. There are several approaches to this problem. You can use a low-cost TTL flip-flop (with a +5-volt supply) driven from the sine-wave source. Although the square waves will be clean, they will be at half the dial frequency. (The flip-flop divides by two.) You can also use a TTL Schmitt trigger; or, you can use the simple circuit shown here. Any decent silicon switching transistors can be used. Set the potentiometer for the desired symmetry. Once adjusted, this potentiometer should not have to be reset. The circuit will cover the audio range from about 10 Hz to 100 kHz. It requires a drive of about 2 volts.

Another reader asked the same question, but he was also concerned with the loading of the square-wave converter on his audio generator. The second circuit shows a high-input-impedance Schmitt trigger using a MOS front end. Because of the high input impedance, the circuit should not load the generator. The trip point is between 3 and 3.5 volts.





Engineer's newsletter

String of diodes sets new hysteresis

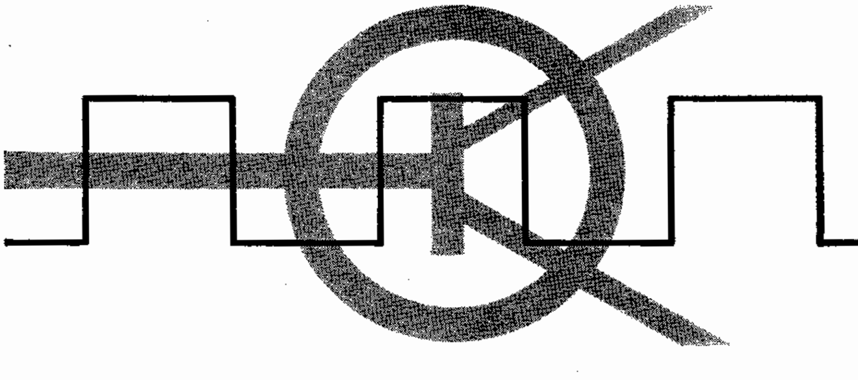
A few diodes and a resistor will easily adjust the hysteresis of any Schmitt trigger, says M. S. Suresh of Bangalore, Ind. The voltage drops across diodes added to the input circuit do the job, independent of the upper trip point. A diode (or string of diodes) that has its cathode connected to the Schmitt input sets the upper point. **Then the lower one can be set to any lower number of diode voltage drops by placing another diode (or string) in inverse parallel across its upper-trip-point counterpart.**

However, there's a trick to getting different current paths for upper and lower points: connect a feedback resistor on the order of a megohm or so from the Schmitt trigger's output back to between the Schmitt input and the parallel diode network. Then the trigger's on/off condition will either forward- or reverse-bias the upper-trip or lower-trip diode strings. Zeners may be used in place of longer diode strings, of course.

The only point to keep in mind, adds Suresh, is that the output impedance of the signal source should be very much less than the feedback resistor. In most applications, this is no problem.

Transistorized Square-Wave Shaper

By **PAUL S. LEDERER**



Simple circuit produces good square waves with 5-volt (p-p) amplitude when driven by 3-20 volt sine waves.

SQUARE-WAVE testing is becoming increasingly popular for the checking and servicing of all types of electronic equipment ranging from simple audio circuits to complex wide-band equipment like video amplifiers and radar gear. It not only offers a very rapid method of obtaining network characteristics like frequency response, phase response, and transient response, but also makes it comparatively easy to observe the effects of changes in the network parameters on these characteristics.

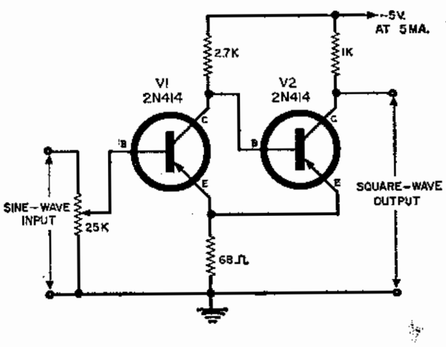
The article "Practical Techniques of Square-Wave Testing" by E. G. Louis[1] covered the subject of square-wave testing pretty thoroughly with discussion of the technique, its applications, some of its limitations, and the equipment required. The main pieces of equipment specified by the author were a square-wave generator and an oscilloscope. The article pointed out that while a specially designed square-wave generator is desirable for testing of wide-band equipment in the video frequency range, square waves derived from sine waves by means of a suitable clipper amplifier can be used for applications with narrower bandwidths or lower frequencies.

Most networks encountered by experimenters will be of the low-frequency type and many of their labs are already equipped with the required oscilloscopes and sine-wave generators. To use square-wave testing techniques, then, calls for a device which converts sine waves into square waves.

The simplest circuit which performs this function uses biased diodes as peak clippers. Such a circuit and a modification are described in another article[5]. This modified circuit was capable of squaring sine waves of frequencies from 20 to 20,000 cps. In order to get a good square wave (one with a fast rise time) from a simple clipping circuit, an input signal on the order of 50 to 100 volts was required. This is beyond the output capabilities of most audio oscillators.

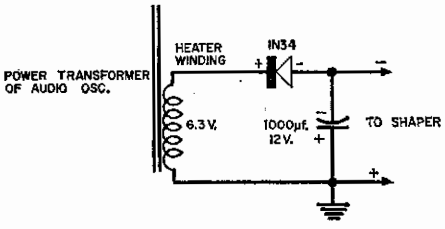
The transistorized sine-wave clipper covered in an early article[4] required a sinusoidal input voltage of only about 3 to 5 volts and appeared to operate up to approximately 25,000 cps. The device generated clipped pulses with slightly rounded edges but information on the rise time was not included.

One vacuum-tube square-wave shaper which was described[3] used a Schmitt trigger type of double-triode stage to convert the incoming sine wave into a square wave. With about 7 volts input it delivered about 50 volts peak-to-peak. Power supply requirements for this shaper were listed at about 20 ma. at 150 volts.



◀ Fig. 1. A Schmitt trigger circuit is used.

Fig. 2. Simple power-supply circuit used.



The author's transistorized square-wave shaper to be described provides a square-wave output of about 5 volts peak-to-peak when driven by sine-wave signal between 3 and 20 volts r.m.s. and requires a power supply delivering about 5 ma. at −5 volts. It is capable of operating over a frequency range of from 20 to about 400,000 cps, producing square waves with a rise time (10% to 90%) of less than 0.5 microsecond.

The circuit uses two transistors and three fixed and one variable resistors. The shaper is essentially a Schmitt trigger circuit. Referring to the schematic of Fig. 1, with no input applied V_2 conducts and keeps V_1 cut off. This is because the base of V_1, a *p-n-p* transistor, is more positive than its emitter due to the voltage drop in the 68-ohm resistor which is caused by the emitter current of V_2. Due to V_1 being cut off, the base of V_2 is supplied with a large negative bias current, causing it to conduct heavily. When a small negative signal is applied to the input of the circuit, it will cause V_1 to start conducting. This, in turn, not only lowers the bias current into the base of V_2, but also brings the potential of the emitter of V_2 closer to that of its base. Both of these effects augment each other, resulting in a *very rapid* cut-off of V_2. V_2 remains cut off as long as the amplitude of the negative-signed signal exceeds a small threshold level.

When the input drops below this level, V_2 switches to conduction and V_1 is cut off. For a positive signal, this state persists unchanged. Thus when sine waves are fed into this circuit, sharp square waves will appear at the output, *i.e.*, the collector of V_2.

V_1 and V_2 are *Raytheon* 2N414 *p-n-p* junction transistors designed for high-frequency operation. Their *alpha* cut-off frequency is about 7 mc. The potentiometer serves to adjust the symmetry of the square wave to some extent. The output impedance of the shaping circuit is about 400 ohms. The amplitude of the square waves produced by the circuit can be adjusted conveniently by varying the *power supply voltage*. The only precaution which must be observed is not to exceed the maximum allowable collector voltage of −20 volts.

The entire circuit can be mounted on a piece of terminal board measuring 2½ inches square. It is small enough to be built into an existing audio oscillator, if desired. In such a case, the necessary power can be derived from the heater supply, as shown in Fig. 2.

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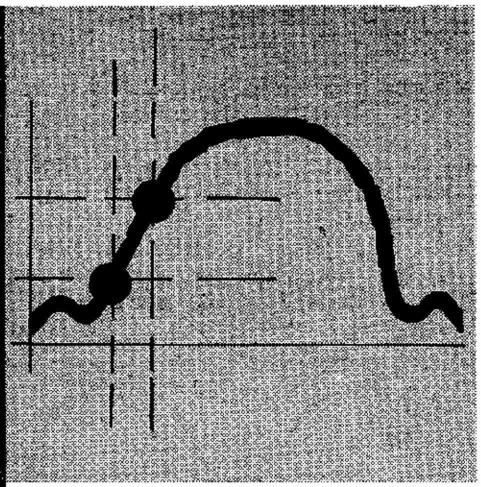
1. *Louis, E. G.: "Practical Techniques of Square-Wave Testing,"* RADIO & TV NEWS, *July 1957.*
2. *Smith, Mark: "Transistor Switching Circuits," Electronic Design, October, 1957.*
3. *Jones, G. E., Jr.: "A Square-Wave Shaper,"* RADIO & TELEVISION NEWS, *September 1953.*
4. *Garner, L. E., Jr.: "A Transistor Sine-Wave Clipper,"* RADIO & TELEVISION NEWS, *May 1953.*
5. *Garner, L. E., Jr.: "Wide Frequency Range Square-Wave Clipper,"* RADIO & TELEVISION NEWS, *March 1950.* —30—

RISE TIME SPECIAL

by A.A. Mangieri



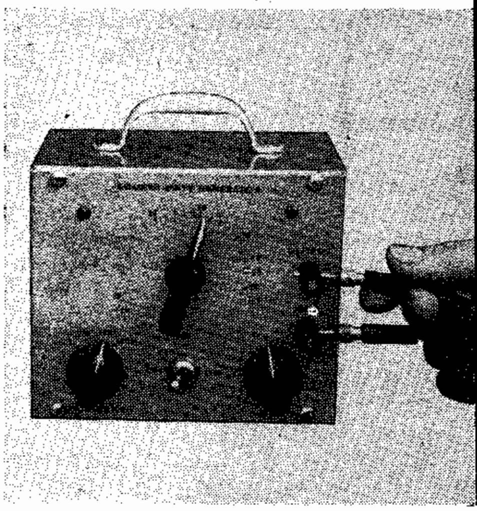
TIME WAS when the words "square wave generator" meant visions of pie-in-the-sky-priced test gear. Those hobbyists adventurous enough to homebrew a square-waver found the conclusion to this undertaking in an aspirin bottle or a jug of something stronger. Order of The Ohm Devotees, hassle your minds no longer! For 25 bones and some build 'em patience, our Rise Time Special will reward your urge to plot and compensate.

Rise Time Special (RTS) really shines in the *clean* square-wave department; over its frequency range of roughly 1 Hz to 100 kHz the instrument cranks out waveforms totally devoid of overshoot, excessive rise time, ringing, or undershoot.

Audio buffs are sure to take a special shine to RTS. Your system's moment of truth has arrived. Plug RTS into your favorite amplifier; by hanging a scope across the amplifier load, you'll quickly judge amp behavior as it is. The highest frequency passed through your amp *without* visible waveform rounding, times ten, clues you in on your amplifier's high-frequency response.

The face of poor frequency response can wear six distinct masks. Note our drawings showing low- and high-frequency-deficient square waves. All amplifiers, regardless of advertiser claims, suffer in varying degrees particularly at the hands of low frequencies. Don't be too surprised when you see one of these patterns staring back as you make your frequency check rounds. Whether you want to check out a recently completed kit-built amplifier, or if you're the individualist who prefers to roll his own, RTS helps you to extract more hi from your fi.

Any oscilloscope owner who doubts his



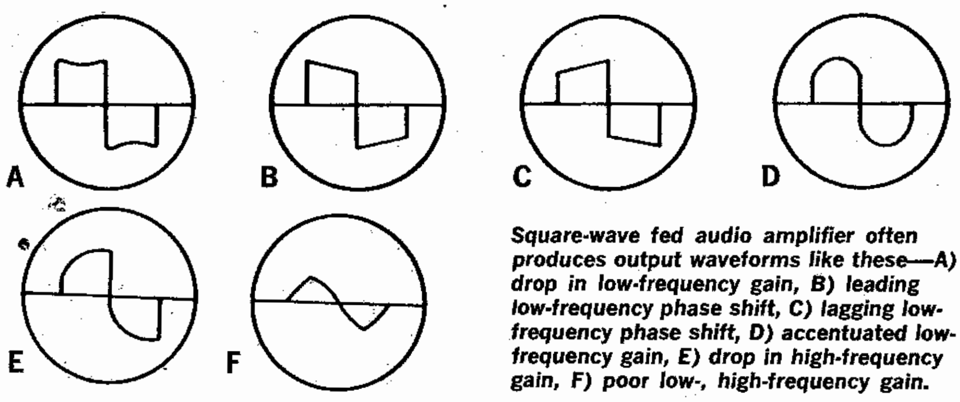
Sweeten your test-gear cake with a square-wave frosting!

instrument waveform reproduction accuracy's off has reached the end of his alignment rainbow. RTS'll give your scope a real shot in the arm when you retrim the vertical amp and compensation capacitors.

Super-complicated instructions aren't needed to operate our Special, either. There's a *frequency* and *level* pot, a *multiplier* and *on/off* switch. And last, but not least, RTS delivers 2 volts peak to peak at 200 ohms from universal binding posts labeled *Output* and *Gnd*. Consider most of your test equipment needs met if your scope can meet the demands placed upon it by our RTS.

How It Works. Looking at the schematic you'll see that there are three major circuit sections. Unijunction transistor Q1, connected as a relaxation oscillator, feeds sawtooth-shaped pulses to buffer Q2. An npn silicon job, Q2 is direct-coupled to bi-stable flip-flop IC1. Each time IC1 receives *two* pulses from Q2, *one* clean square wave emerges from it. Output travels to *level* pot R2, then on to output jacks J1 and J2, which are connected to the intended load.

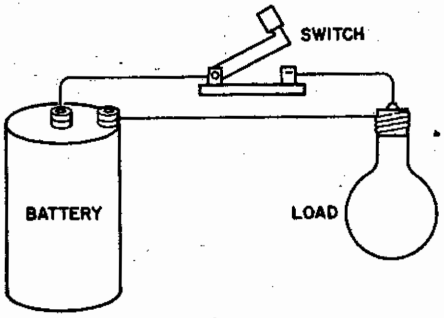
As you may have already guessed, IC1 is responsible for those really clean square waves. Packed into its innards are a dozen transistors and a handful of resistors. When IC1 receives an input pulse (or *toggles*, in integrated-circuit lingo), it rapidly shifts from one voltage condition to another. The IC holds this new condition until another toggling pulse arrives at the input. Then the IC reverts to its original voltage state. Technically, we've just described a bi-stable flip-flop—every output pulse is generated by two input pulses.



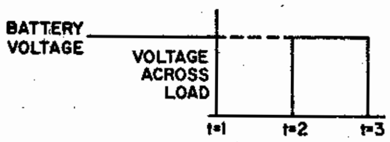
Square-wave fed audio amplifier often produces output waveforms like these—A) drop in low-frequency gain, B) leading low-frequency phase shift, C) lagging low-frequency phase shift, D) accentuated low-frequency gain, E) drop in high-frequency gain, F) poor low-, high-frequency gain.

Generating pulses this way gives some built-in benefits. If the load draws power only half the time, then it follows that the battery is *on* half the time. Theoretically, this arrangement is 100% efficient. In practice, the gadget that does the flip-flopping needs a few milliwatts to remain in the *off* state—indeed a small price to pay for Rise Time's performance.

Think of this flip-flop action as a battery hooked up in series with a switch and connected to a load (see our drawing). You'll see that when the switch is open at time 1, voltage appearing across the load is at one value. The value in this case is zero. Toggling the switch at time 2 (flipping it to the closed position) puts a different voltage across the load. Of course, this new voltage is equal to the battery voltage. Another toggling operation at time 3 opens the switch



Simple load/battery/switch series setup can be considered square-wave generator. If switch contacts are clean, you'll see pseudo-square waves on your scope as you flip switch rapidly on, then off, again.

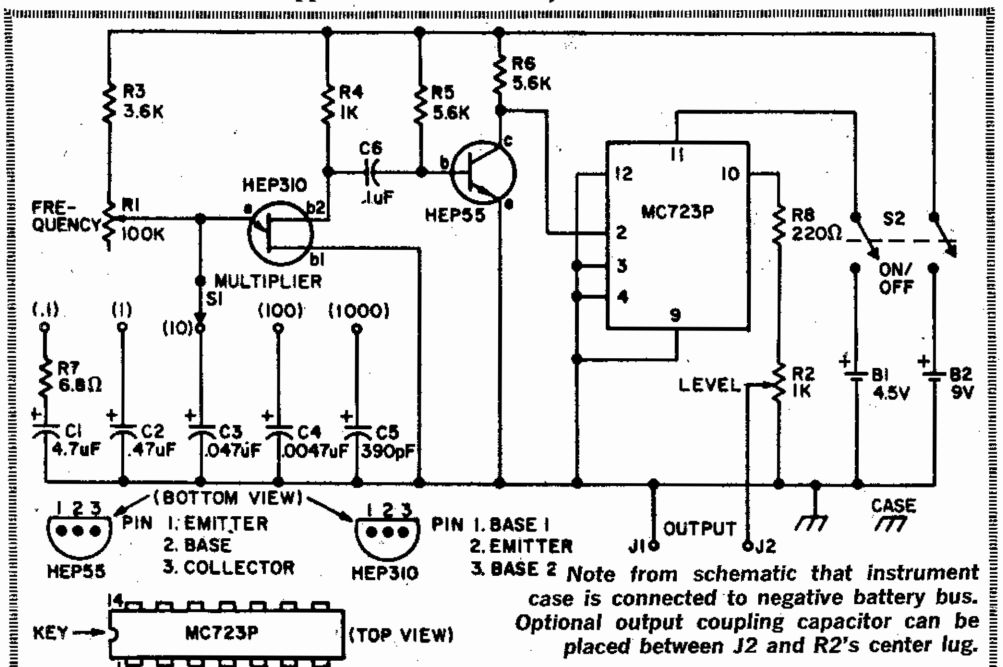


—now the load voltage is equal to zero again.

Economy of operation isn't RTS's only virtue. Most square-wave generators work by clipping a sine wave. This brute-force method employs driving an ordinary amplifier until it saturates (there's no further increase in output with an increase in input voltage). Electrically pounding away at an amplifier is an easy way of generating square waves—that's why you find this circuit arrangement appearing in the cheapest test equipment.

Back-to-back diode clipper/DC source circuits also produce square waves when fed with sine waves. But if the DC source has even a trace of ripple in its output, your square wave will look like a Turkish belly dancer grinding across the scope screen! Integrated circuit technology allows RTS to neatly step around both compromising configurations.

Sawtooth Oscillator. Congratulate yourself—the stickiest part of the circuit theory is now under the belt. We'll finish circuit discussion with a brief description of the sawtooth generator, Q1, and buffer Q2. A unijunction transistor, Q1 is hooked up as



Note from schematic that instrument case is connected to negative battery bus. Optional output coupling capacitor can be placed between J2 and R2's center lug.

PARTS LIST FOR RISE TIME SPECIAL

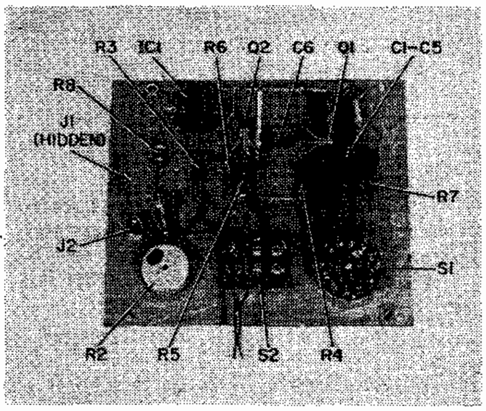
B1—4.5-V battery (3 "D" cells, Burgess 230 or equiv.)
B2—9-V transistor battery (Burgess 2U6 or equiv.)
C1—4.7-uF, 10-V tantalum capacitor (Mallory TAC 475K010P02 or equiv.)
C2—0.47-uF, 200-V, 10% capacitor
C3—.047-uF, 200-V, 10% capacitor
C4—.0047-uF, 100-V, 10% capacitor
C5—390-pF, 1000-WVDC, 10% capacitor
C6—0.1-uF, 400-V, 20% capacitor
IC1—J-K flip-flop integrated circuit (Motorola MC723P)
Q1—Silicon unijunction transistor (Motorola HEP 310)
Q2—Silicon transistor, npn (Motorola HEP 55)
R1—100,000-ohm linear carbon potentiometer (Mallory U41)
R2—1000-ohm linear carbon potentiometer (Mallory U4)
R3—3600-ohm, ½-watt, 10% carbon resistor
R4—1000-ohm, ½-watt, 10% carbon resistor
R5, R6—5600-ohm, ½-watt, 10% carbon resistor
R7—6-8-ohm, ½-watt, 10% carbon resistor
R8—220-ohm, ½-watt, 10% carbon resistor
S1—1-pole, 5-position switch (Mallory 3215J)
S2—Dpst toggle switch (Arrow-Hart 20902CX)
Misc.—Battery holders, 4 x 5 x 6 cabinet (Bud AU-1029-HG), 14-pin IC socket (Allied 47D5701), knobs, Vector 32A-A18 pre-punched terminal board, Vector T 9.4 push-in terminals, hardware, clear lacquer spray, dry transfer lettering, etc.
*All semiconductors available from Allied Radio Corp., 100 N. Western Ave., Chicago, Ill. 60680. Order MC723P as 50D26MC723PMOT.

a relaxation oscillator. As the switch-selected capacitor (C1 through C5) is charged through resistor R3 and pot R1, Q1's emitter voltage rises toward the 9-volt supply, B2.

When sufficient voltage reaches the emitter, it becomes forward biased. Emitter/base 1 resistance falls sharply, allowing the capacitor to discharge through the emitter/base 1 junction to ground. The emitter voltage continues to drop to its original voltage level, and the entire operation starts all over again.

Transistor Q1's sawtooth output is tapped off R4 via C6 and fed to buffer Q2. Note that Q2 is direct-coupled to the IC; this ensures positive IC toggling on the lowest frequency range.

Construction Procedures. You've got lots of leeway with circuit layout; point-to-point wiring is the most important rule here. Begin construction by cutting out a piece of 2½ x 5-in. pre-punched terminal board, and drilling a couple of mounting holes at the

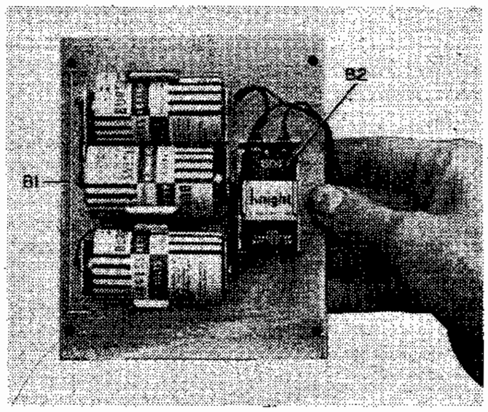


Follow author's perf-board parts layout. Though it's hidden from view, pot R1 (Frequency) is mounted on instrument front panel. Also note author's S2 is DPDT job.

corners. After inserting the push-in terminals, concentrate your efforts on the plus and minus 9-volt busses. Figure out which components directly connecting to these busses go where and solder them first.

Now steer your peepers towards capacitor C1. Though it's rated in *uF*, *don't* buy an electrolytic. You'll need the tantalum job called out in the Parts List. It has the tighter tolerance (10%) needed to maintain capacitor ratios.

Positioning and soldering IC and transistors on the board is your next job. Exercise caution when soldering these heat-sensitive devices home. Even if you do follow the industry-wide precaution of grasping the semiconductor leads with a pair of pliers while soldering them, it would be a good idea to wrap an alcohol-soaked cotton wad



Rear instrument panel holds both batteries B1, B2. B1 consists of three D-size cells connected in series. Remember to connect both B1, B2 negative leads to minus bus.

around the transistors as you apply heat to their leads. No special precautions are needed when soldering the IC socket to the push-in terminals.

Tackling the front panel next, drill 5/16-in. holes for jacks J1 and J2, touching up the holes with a round file. Next, drill holes for R1, R2, S1, and S2.

Spare parts box depletion is a perfectly acceptable way to scrounge up these various control elements. For instance, you can get away without a separate S2 if you can dig up an old 3-pole, 6-position rotary switch. Two of the poles are substituted for each half of S2 while the third pole retains its original capacitor selector function.

Another acceptable switch alternate substitutes a 1000-ohm IRC Q Control pot (Q11-108) for the Mallory U4 called for in the Parts List. Attach an IRC Q Control dpst switch (IRC #76-2) to the rear of the pot and, presto, another good idea invades your workbench! These substitutes are mentioned because some members of the Order are too lazy to drill and properly dress a third hole for S2.

Take a breather. Check your efforts for the usual bugaboo-boos—cold solder joints,

(Continued on page 98)

Rise Time Special

Continued from page 76

reversed transistor leads, and other construction traumas. One of the least sought after experiences in a hobbyist's life appears as the all-buttoned-up-flick-the-switch . . . NUTS!—nothing happens syndrome. If you're reasonably sure that the wiring is AOK, then it's alright to proceed into the home stretch.

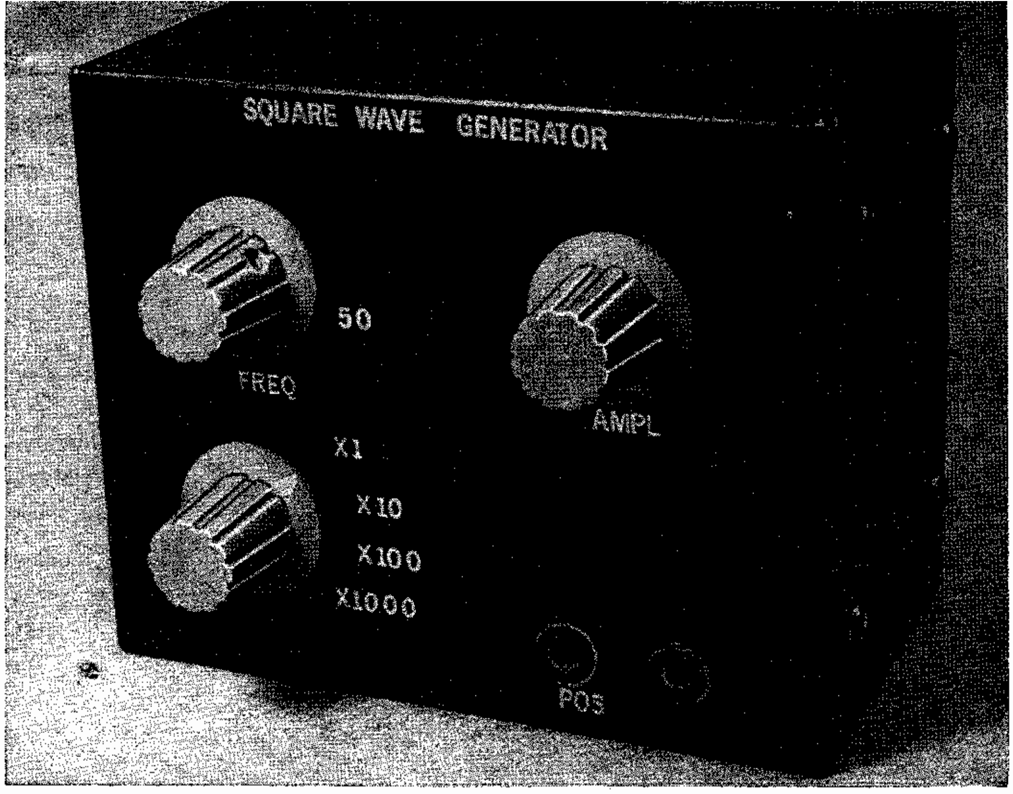
Mount the battery holders to the cabinet rear plate and make the necessary circuit connections. Again, spare parts box exploration can pay off. Finish the innards construction by mounting the circuit board, pots, jacks, and switches to the front panel and solder the necessary interconnections between these components.

Calibrating and labeling Rise Time Special is like taking lollies from a baby. First, treat the multiplier switch to instant lettering. Note that for capacitor C1 through C5 called out in the schematic, a corresponding multiplying factor exists. Label the multiplier switch area on the front panel according to these factors. Finish by labeling the output level pot and jacks.

Reading Lissajous patterns from a scope face is the easiest way to calibrate the *Frequency* control. Feed a signal from the Special into the scope's vertical input. Set the frequency calibrating source to 60 Hz (an audio oscillator or 60-Hz line source will do), and connect up to the horizontal channel. With the *Multiplier* switch in the X1 position and the *Level* control open half way, rotate the *Frequency* control until a stationary circle or ellipse appears on the scope screen. You've just found the 60-Hz frequency setting for the square-wave generator.

Continue turning the control (in either direction) until the pattern you see on the scope face stops jittering. If the new pattern looks like two or more whole circles stacked on top of one another, you're looking at an even sub-harmonic of 60 Hz (30 Hz, 20 Hz, 15 Hz, etc.) Divide 60 by the number of ellipses seen on the screen—that's your new frequency-control setting. If whole ellipses lined up in a horizontal row greet you, you're looking at harmonics of 60 Hz. This time *multiply* the number of ellipses by 60 to get the new frequency.

Remember that any frequency can serve as the reference; 60 Hz is the most convenient since it comes out of a wall socket. Merely follow the multiply/divide rules when working with these new reference frequencies. If the multiplier capacitors have reasonable tolerances, only one calibration scale will serve all multiplying factors. Otherwise, calibrate each scale. ■



SQUARING WITH AN IC

A SQUARE-WAVE GENERATOR THAT'S HIGH ON QUALITY, LOW IN COST

BY PHILIP E. HARMS, North American Rockwell

A SQUARE-WAVE generator is an invaluable tool for the electronics enthusiast—whether his primary interest is in radio or audio frequencies. The generator can be used as a scope trace calibrator, a driving source for digital pulse circuits or, most important, as a test instrument in checking both broadband and audio amplifiers.

Unlike a sine-wave generator, whose frequency must be capable of being set precisely and continuously across a particular band, the square-wave generator can be used to "wring out" an amplifier from about 1/10th of the fundamental of the square wave to 10 times this frequency. There are many excellent discussions in the reference books of the procedure for using a square-wave generator to check an amplifier. In simple terms, however, amplifier response characteristics can be determined rapidly by applying the square wave to the input and examining the output on an oscilloscope. The output risetime is determined by the amplifier high-frequency limits, while the square-wave tilt indicates the low-frequency cutoff.

Although there are many ways to build a square-wave generator, the availability of multi-purpose integrated circuits and UJT's makes possible the design of a simple, yet highly efficient circuit, that far surpasses most generators using vacuum tubes or standard transistors. Specifications for this new generator are given in the table.

Construction. The circuit for the square-wave generator is shown in Fig. 1. The author built the unit in a 3″ × 4″ × 5″ aluminum box, which was sufficient

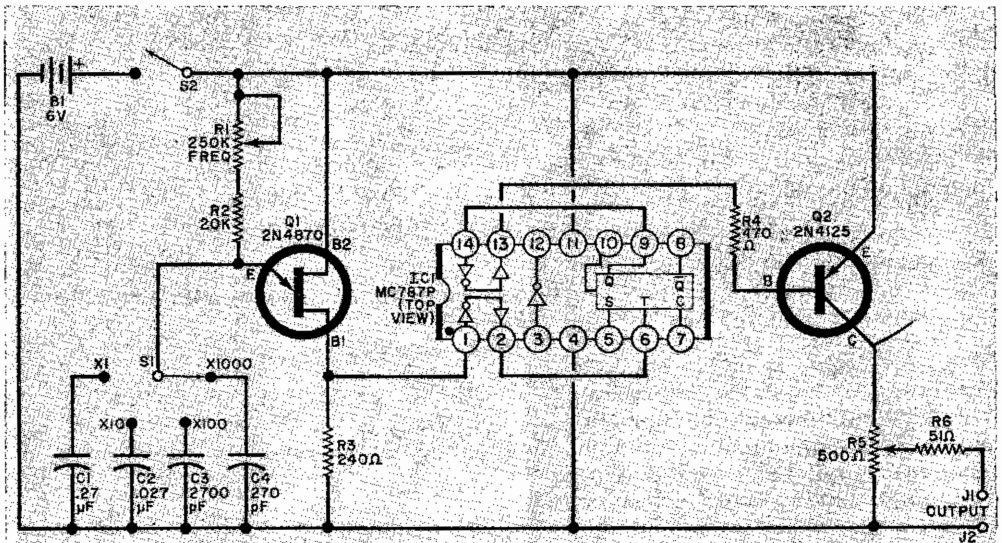


Fig. 1. Sharp spikes, generated by the UJT, are shaped and used to trigger the flip-flop. Its output is a sharp square wave at half the frequency of original.

PARTS LIST

B1—Four C or D cells
C1—0.27-μF, 10% capacitor
C2—0.027-μF, 10% capacitor
C3—0.0027-μF, 10% capacitor
C4—270-pF, 10% capacitor
IC1—Integrated circuit (Motorola MC787P)
J1,J2—Banana jack (one black, one red)
Q1—Unijunction transistor (Motorola 2N4870)
Q2—Transistor (Motorola 2N4125)
R1—250,000-ohm, linear taper potentiometer (with S2)
R2—20,000-ohm, ¼-watt resistor (see text)
R3—240-ohm, ¼-watt resistor
R4—470-ohm, ¼-watt resistor
R5—500-ohm, linear taper potentiometer
R6—51-ohm, ¼-watt resistor
S1—Single-pole, four-position rotary switch (Mallory 3234J or similar)
S2—S.p.s.t. switch (on R1)
Misc.—3" x 4" x 5" aluminum box, perf board 2¾" x 3", PC board terminals or flea clips (5), transistor sockets (2, optional), IC socket (14-pin in-line, optional), battery holder, battery clip, knobs (3), mounting hardware, etc.

to hold the perf board, the controls, and a battery holder. Wiring is not critical, although wire no smaller than #22 AWG should be used to insure a good signal path between components.

As shown in Fig. 2, the author built the electronic portion on a perf board using sockets to mount the IC and the transistors. Although the sockets are not absolutely necessary, they are advantageous to protect the semiconductors from heat during soldering. If you do not use sockets, be very careful when soldering the IC and the transistors, using a heat sink (such as long-nose pliers) between the end of the lead being soldered and the body of the device. Neat, point-to-point wiring is used on the perf board, with clips used as take-off terminals on the board.

The remainder of the components are mounted on the front panel of the chassis as shown in the photos. The battery holder is mounted on the rear of the cover.

Design Considerations. Since the characteristics of the UJT may vary as

SPECIFICATIONS

Frequency: 5 Hz to 50 kHz
Amplitude: 0 to 6 volts, variable
Risetime: less than 40 nanoseconds
Falltime: less than 250 nanoseconds
Overshoot: less than 10%
Undershoot: negligible
Non-symmetry: less than 200 nanoseconds, all ranges
Output impedance: 51 ohms, short-circuit protected
Power supply: four C cells, current drain 50 mA

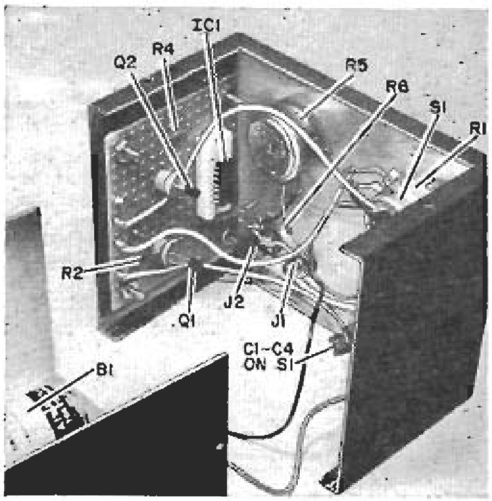
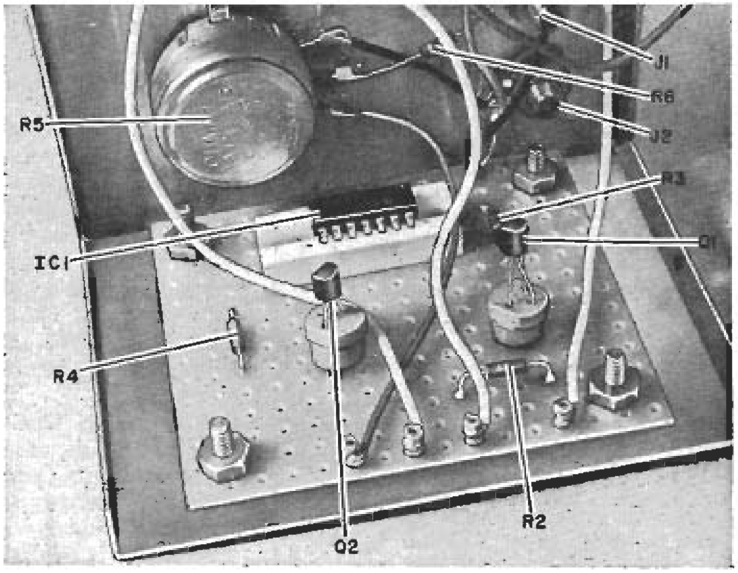


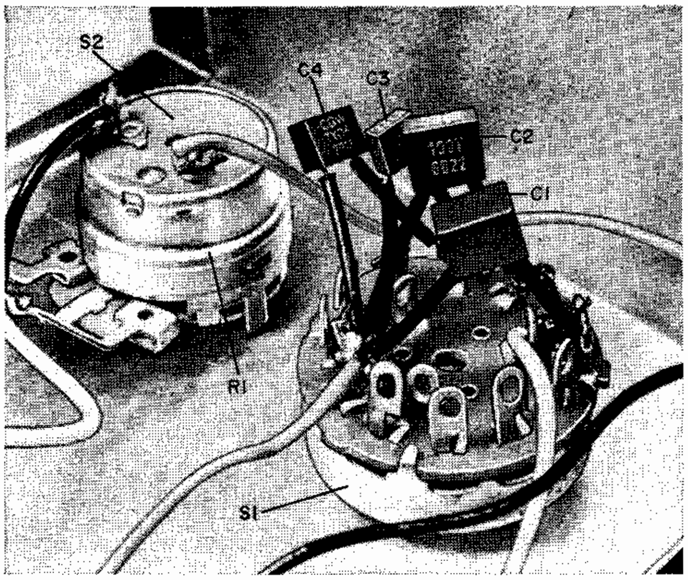
Fig. 2. The entire generator can be mounted in a small aluminum chassis as shown at the left. The four C or D cells are mounted in a holder affixed to the rear of the chassis half. The bulk of the circuit can be constructed on perf board (as shown below) or you can make a printed circuit board. The use of semiconductor sockets prevents heat damage to the semiconductors when installing but is an optional feature of design.



much as 10%, it is difficult to pick components that will result in a frequency range of exactly 5 Hz to 50 kHz. Capacitors *C1* through *C4* influence over-all accuracy; but for most applications, precise frequency increments are not required. If necessary, one, or all, of the timing capacitors can be "juggled" (parallel or series connections) to achieve exact decade intervals. For realistic results, capacitors with 10% tolerances should be used.

Resistor *R2* has a composite value which should give excellent results on all ranges. For exact calibration, *R2* can be replaced by four separate resistors, selected by using vacant terminals on *S1*. To calibrate these resistors, set *R1* for maximum resistance. Then assuming, for example, that *S1* is on X10, trim the value of *C2* (increasing the capacitance decreases the frequency, and vice versa) to achieve a frequency about 5% above 50 Hz. This is done to allow for slight changes in the value of *R2* in the next step.

Rotate *R1* to its minimum resistance. Select the value of *R2* that will give the correct upper frequency (500 Hz). The value of *R2* will be approximately 20,000



The four timing (octave) capacitors are mounted directly on the selector switch. The closer the capacitors are matched, and the better their tolerance, the more accurate the octave ranges are.

HOW IT WORKS

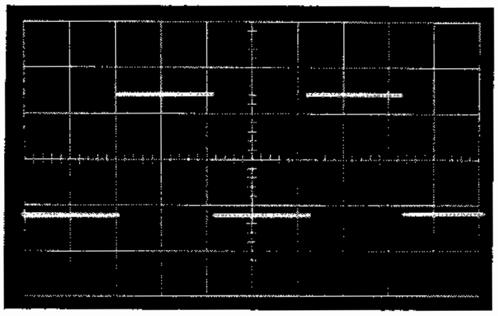
The frequency source for the square-wave generator is a unijunction transistor oscillator (*Q1*) whose frequency is determined by the resistors and capacitors in its emitter circuit. A sharp pulse at the selected frequency is developed across *R3* which drives the inverter-buffer in *IC1*. The IC contains one JK flip-flop, two inverter-buffers, and a single (unused in this case) inverter.

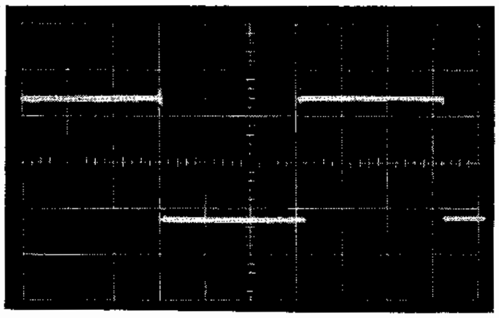
The inverter-buffer squares up the pulse generated in the UJT, and the pulse then triggers the flip-flop. The output waveform of the flip-flop is at half the UJT frequency and is sharply square on both transitions. The second buffer isolates the flip-flop and inverts the output. Transistor *Q2* acts as an amplifier isolator to provide an isolated output through *R5*. This potentiometer provides amplitude adjustment and *R6* protects the output circuit against short circuits.

ohms. Once the proper upper frequency has been obtained, increase the resistance of *R1* to maximum again and check that the 50-Hz point is correct.

Each range can be calibrated similarly; and each is independent of the others if separate resistors are used for *R2*. The generator should never be operated without a series resistor (*R2*) in the UJT emitter circuit or the UJT may be damaged.

Because of the self-contained power supply, the generator output leads can be reversed to produce a negative-going signal. A battery can be used in series with the square-wave output to "bias" the output if desired. –30–





The output waveshape for both low and middle frequencies is shown at the left. Note the almost perfect square wave. For high frequencies, the output (right) is a good square wave with a little overshoot.

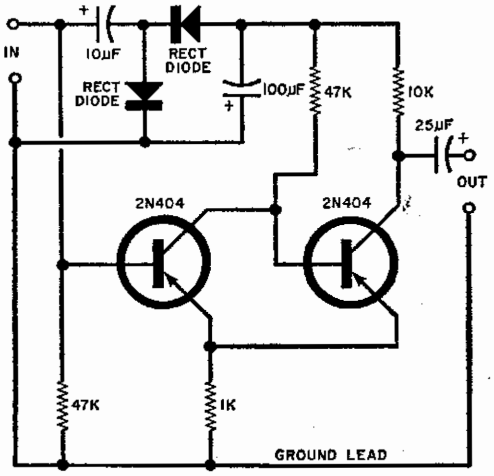
SIGNAL-POWERED SIGNAL SQUARER

THIS INEXPENSIVE ADDITION TO A SINE-WAVE GENERATOR PRODUCES FAST RISE-TIME SQUARE WAVES OF THE SAME FREQUENCY

By LESLIE SOLOMON, Technical Editor

MOST EXPERIMENTERS either have, or have access to, conventional audio frequency sine-wave generators. However, there may come a time when you are finishing some project and the instructions call for the use of a square-wave signal—but you don't have a square-wave generator! After being hit this way a couple of times, the author decided to either buy a composite sine/square wave generator, or cook up some circuit that could be used with an existing sine-wave source. The result is shown in the diagram below.

The circuit is a conventional two-transistor Schmitt trigger having a built-in power supply with both signal and a.c. power derived from the output signal of the audio generator. Operation of the Schmitt trigger is such that the frequency of the output square wave is the same as the frequency of the incoming sine wave. Unlike a bistable multivibrator, commonly used in squaring circuits, the Schmitt circuit does not divide the frequency by two. Also, rise time is excellent.



The incoming sine waves play a dual role: they trigger the Schmitt circuit and supply d.c. power.

Input signal requirements are rather broad. The circuit will accept almost any source of a.c. between 50 and 15,000 Hz, with a voltage level between 0.5 and 10 volts r.m.s. Output signal level is a function of input signal level.

Component values are not critical and may vary broadly from those shown in the schematic. If *npn* transistors are used, reverse the polarity of the rectifier diodes and the electrolytic capacitors. In fact, a little experimentation with various values of resistors and capacitors will teach you a lot about Schmitt trigger operation. The rectifier diodes can be any type, of almost any voltage or current ratings, that you happen to have on hand.

Mounting is up to the builder. Several units have been made, ranging from small PC boards that can be directly plugged into the output jacks of the sine-wave generator to perforated board projects that are mounted within the generator and provided with separate output terminals. -30-

BUILD THE ADD-ON SQUARER

NO OVERSHOOT AND 70-NANOSECOND RISE/FALL TIME

BY JAMES BONGIORNO

WITH THE QUALITY of audio equipment and the "know-how" of the serious audio experimenter constantly improving, better test gear (usually meaning ultra-low distortion) is a must. One of the primary tools in this area is the audio sine-wave generator. Although most audio generators have characteristics that greatly exceed those of even a few years ago—many enthusiasts have built the "Ultra-Low-Distortion Sine-Wave Generator" (POPULAR ELECTRONICS, October 1969)—there is one aspect in which there is room for improvement. This is in the generation of good clean square waves, which are essential for proper audio testing.

Of course there are all types of squaring circuits that can be permanently coupled to the output of sine-wave generators, permitting a choice in the type of output. The big drawback to this approach, however, is that some form of regenerative Schmitt trigger is used to create square waves from sine waves. Unfortunately, although the square waves are good, large switching transients are produced back in the sine-wave generator so that the sine waves have disturbances that appear as spikes or notches when that type of output is being used.

The "Add-On Squarer" described here is a new approach to squaring circuits in that no disturbances are reflected into the sine-wave source. In addition, the circuit has essentially no overshoot, ringing, or transistor storage time; and the symmetry remains constant up to about 1 MHz. Rise and fall times have also been improved and are approximately 70 nanoseconds each. If desired, rise and fall times can be improved further by the use of faster transistors and a minor resistance change. As is, the circuit will satisfy the most critical of audio experimenters, and the same circuit can be used to trigger most logic circuits as well.

The output of the Add-On is short-circuit proof and has no triggering offset or hysteresis. It triggers as the input sine wave goes through zero.

About the Circuit. The Add-On is basically a d.c. operational amplifier (see Fig. 1) having positive rather than negative feedback. There are, however, two distinct differences between this circuit and other regenerative feedback systems. First, none of the stages will saturate under any condition. This insures an absolute minimum of overshoot and ringing. Second, there is no storage time so that rise and fall times of 70 nanoseconds can be achieved. Incidentally, you will need a top-quality laboratory scope to measure such fast rise times.

Since the output stage is non-saturating, loading does not have any effect on the quality of the output square waves—only on the amplitude. The Add-On will

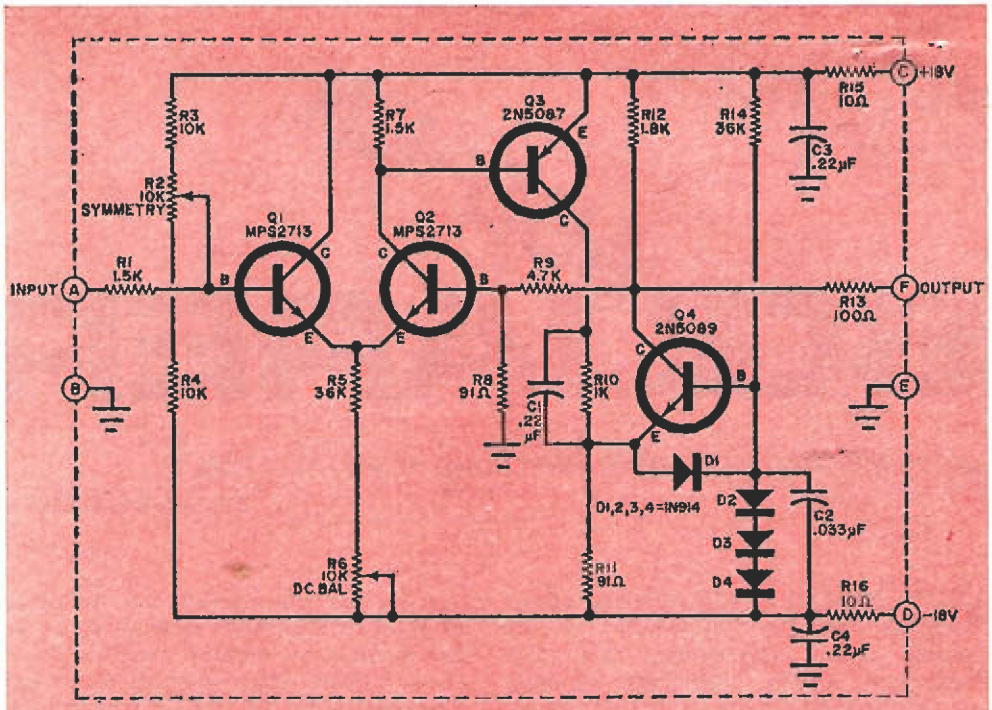


Fig. 1. Basically a d.c. operational amplifier, the circuit can change states in less than 70 nanoseconds—much faster than most scopes can display. Besides high-quality audio testing, the pulses can be used with many digital circuits.

PARTS LIST

C1,C3,C4—0.22-μF Mylar capacitor
C2—0.033-μF Mylar capacitor
D1-D4—1N914 or similar diode
Q1,Q2—Transistor (Motorola MPS2713)
Q3—Transistor (Motorola 2N5087 or 2N3906)
Q4—Transistor (Motorola 2N5089)
R1,R7—1500-ohm
R3,R4—10,000-ohm
R5,R14—36,000-ohm
R8,R11—91-ohm
R9—4700-ohm
R10—1000-ohm
R12—1800-ohm
R13—100-ohm
(All resistors ½-watt, 5%)
R2,R6—10,000-ohm PC-type trimmer potentiometer
R15, R16—10-ohm, ½-watt, 10% resistor
Misc.—Small heat sinks for Q3 and Q4.
Note—An etched and drilled G-10 glass epoxy circuit board is available for $4.25 postpaid from Lambert Laboratories Ltd., 48 Washington St., Westfield, N.Y. 14787. Residents of New York state add sales tax.

deliver 15 volts peak-to-peak into an essential open load and will trigger with any input signal of a half a volt or more.

The circuit will trigger and deliver a symmetrical output waveform up to approximately 1 MHz.

Construction. A foil pattern for a printed circuit board for the Add-On is shown in Fig. 2. If you do not use a PC board, make sure that you follow the physical placement of the components as shown in Fig. 3 as closely as possible to insure clean, fast waveforms. Wire the circuit as shown in Fig. 1.

If you want to further reduce the rise and fall times, use a faster switching transistor for *Q3* and *Q4* and raise the value of *R8* to about 200 ohms. The only critical transistor in the circuit is *Q3*, and you must use the one specified (or a faster one). Small heat sinks may be used on *Q3* and *Q4*.

If you suspect that you have fluctuating line voltage and you want to insure the quality of the square-wave output, remove *R5* and *R6*, and substitute the circuit shown in Fig. 4.

Calibration. After applying power to

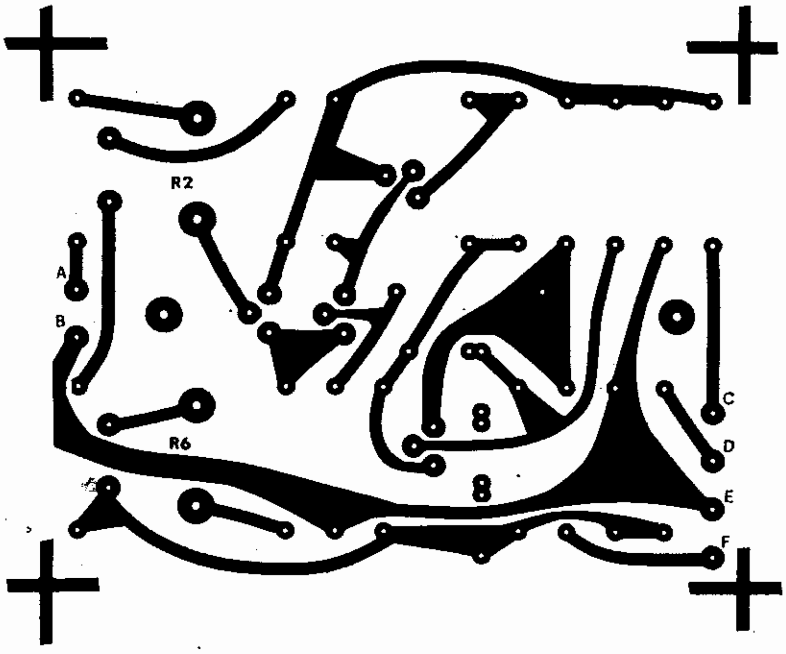


Fig. 2. Actual size printed circuit foil pattern. The marks at the corners are for board dimensions. The two mounting holes are shown along the center line.

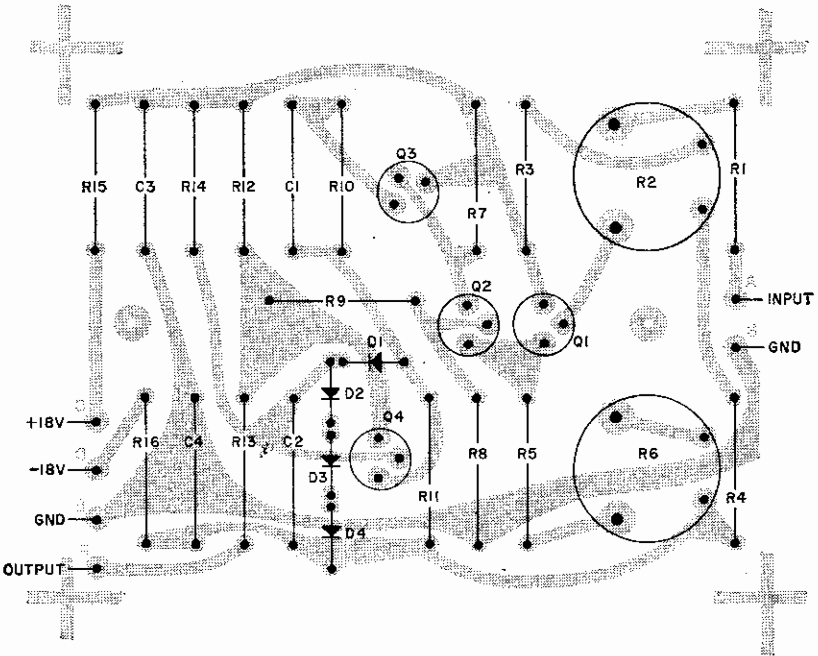
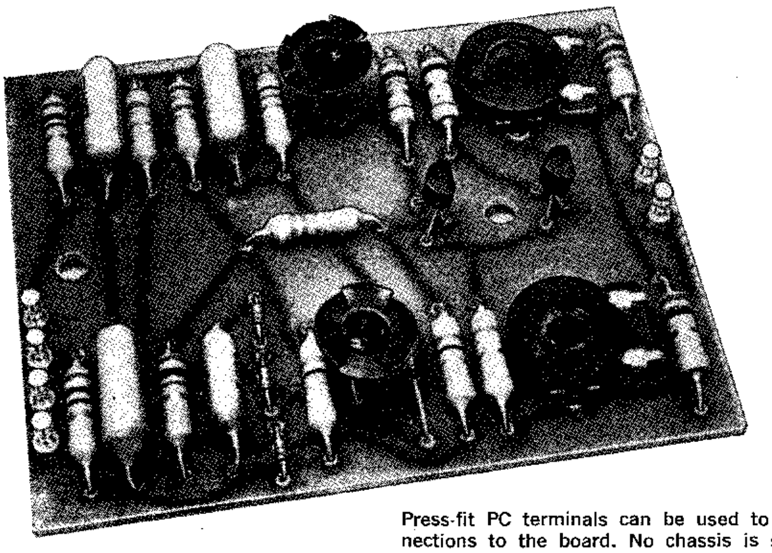


Fig. 3. When installing the components, make sure that the semiconductors are properly installed. This figure also shows external connections to be made.



Press-fit PC terminals can be used to make connections to the board. No chassis is shown here because board is designed to be mounted in an existing single-wave generator and get its d.c. power either from the generator supply or a built-in source of +18 and −18 volts. The squarer can be switched in through a switch on the front panel.

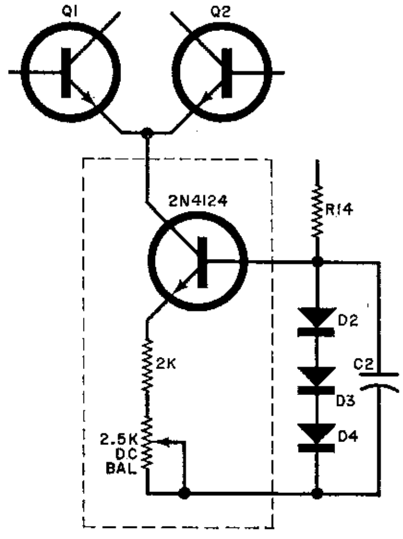


Fig. 4. This optional circuit is used in case of severe power-line fluctuations. It helps stabilize the output.

the circuit, wait at least one minute to allow charges to build up on the capacitors. The d.c. balance control, *R6*, is the key to making the unit work properly. Once *R6* is adjusted, it should not have to be reset unless you have a badly fluctuating line voltage.

After the unit has been on for a couple of minutes, apply a 10-kHz sine wave to the input and mechanically center *R2*. Connect an oscilloscope to the output and adjust *R6* until a swing of 15 volts peak-to-peak is obtained. If you can't get 15 volts, slightly lower the value of *R5*. Having made this initial adjustment, let the unit sit for about 5 or 10 minutes to allow all voltages to settle. If the bottom of the visible square wave starts to show some slight tilt, adjust *R6* to make it square. The unit is now calibrated and should remain stable.

When using the Add-On to test systems where rise and fall times are important, use an absolute minimum of connecting cable since cable capacitance has a distinct effect on these sharp transients.

The Add-On Squarer makes an ideal companion to the Sine-Wave Generator mentioned above. It can be built within the same cabinet and can use the same +18- and −18-volt power supply. —30—

Integrated timer operates as variable Schmitt trigger

by Maj. Arthur R. Klinger
United States Air Force, McCoy Air Force Base, Fla.

The bargain-priced 555-type IC timer—already a proven and versatile circuit building block—can also be used as a variable-threshold Schmitt trigger. The triggering circuit has a high input impedance, a latching capability, a threshold voltage that can be adjusted over a wide range, and simultaneous open-collector/totem-pole outputs.

The usual circuit diagrams (a) of the timer can be redrawn with conventional logic symbols to illustrate the operation of the triggering circuit. As shown in (b), the timer can be thought of as a comparator that has a high input impedance and that drives a Schmitt trigger having a high-input-impedance latch and a buffered strobed output.

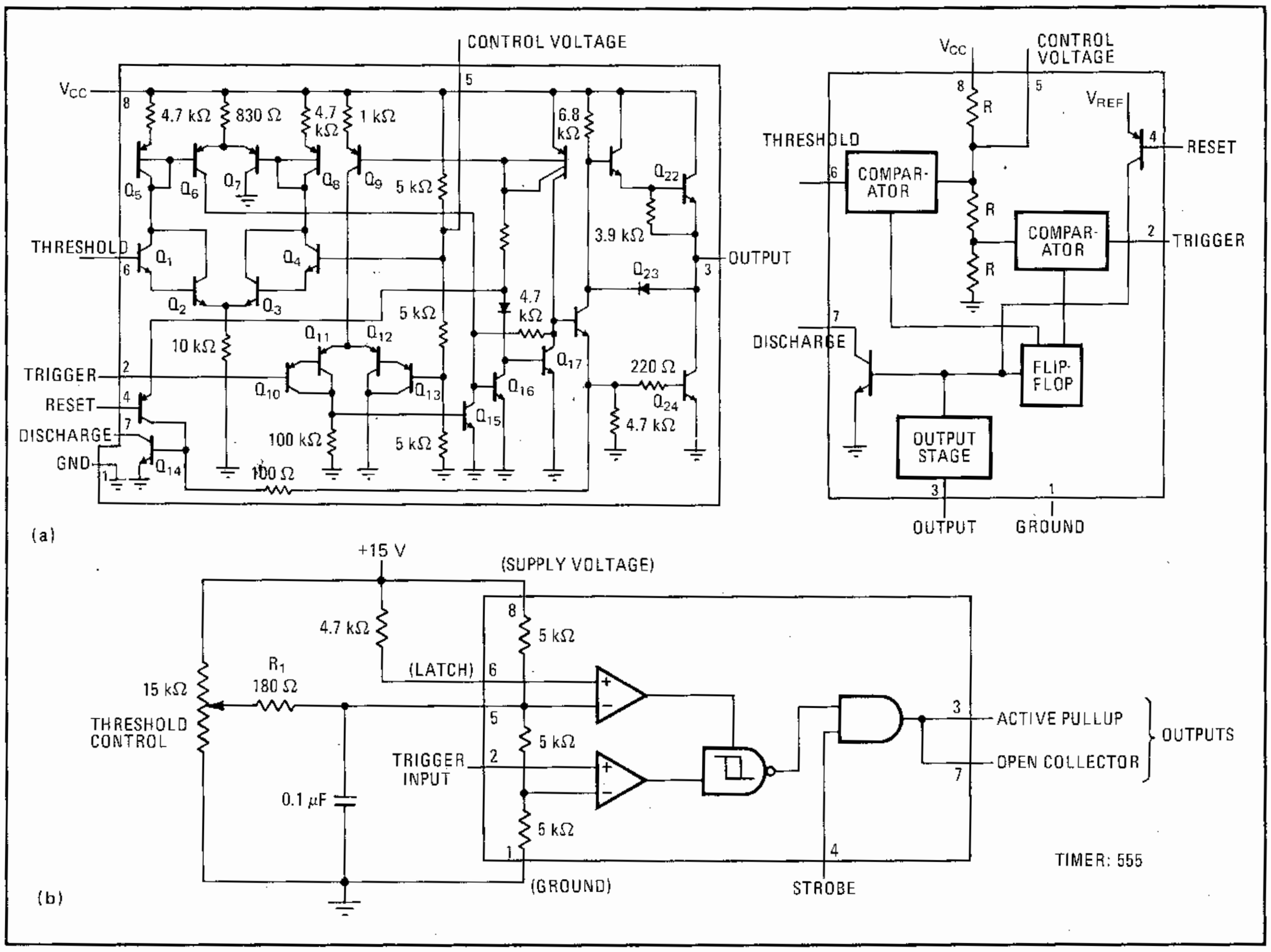
Transistors Q_1 through Q_8 make up one of the noninverting comparators, while transistors Q_9 through Q_{13}, as well as transistor Q_{15}, form the second noninverting comparator. This last comparator drives the Schmitt trigger created by transistors Q_{16} and Q_{17}.

Although it seems that the two comparators are simply ANDed together at the input of the Schmitt, the limited source/sink current capability of the first comparator allows the second comparator to take precedence. The first comparator, then, merely acts as a latch, allowing the other comparator, in combination with the Schmitt, to be triggered when the latching input (pin 6) is high. When this input goes low, the Schmitt and, therefore, the circuit's output are locked in whatever state the Schmitt is in.

A resistor (of 4 kilohms to 100 kilohms) from the latching input to the supply unlatches the Schmitt and, at the same time, tends to decouple this input from high-frequency line noise. Theoretically, in some applications, the timer's control input (pin 5) and latching input could be tied together directly to the supply, but both inputs are very susceptable to noise.

The timer's trigger input (pin 2), which has an input impedance of approximately 1 megohm, drives the Schmitt. The Schmitt's threshold can be varied from about zero to just below the bias voltage existing at the latching input by controlling the voltage at pin 5.

Analog/digital interface. Standard 555-type timer (a) can be regarded as a Schmitt trigger having two high-impedance driving comparators and a buffered strobed output. Triggering circuit of (b) provides a controlled threshold range, which can be varied from almost zero to 8 volts. Upper comparator acts as a latch, while the lower comparator and the Schmitt provide the normal triggering action.

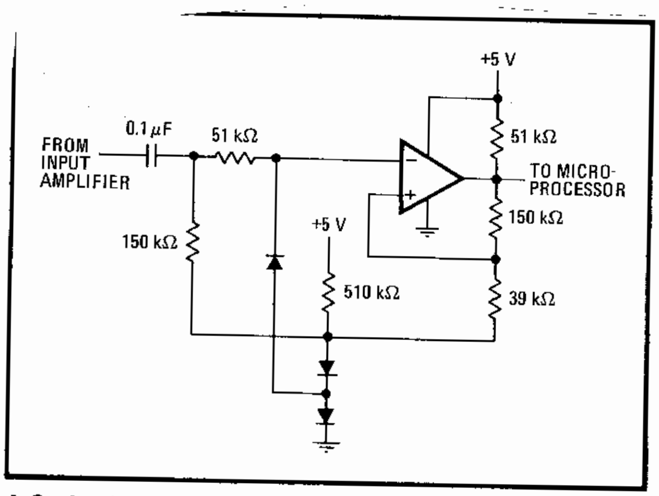


A normal strobe function is provided by the timer's reset input (pin 4); the timer is active when the reset input is high. The latching input, of course, can be pulled low to catch the last device state whenever desired. Active pull-up and open-collector outputs are available simultaneously at pins 3 and 7. Both of these outputs can sink a considerable amount of current.

If intermediate control voltage levels are used at pin 5, the threshold level at pin 6 will still be predictable, and the impedance level for this input will remain high. Supply voltage can range from 4.5 to 16 V, and operating frequency can range from slowly varying dc to at least 2 or 3 megahertz.

As with any high-speed functional IC, certain precautions should be observed for the timer. Since its comparators can respond to pulses as short as 20 nanoseconds, the control and threshold inputs should be bypassed or decoupled from the supply line whenever possible. Also, the source impedances at the two comparator inputs should be kept balanced to minimize the effects of offset currents. Moreover, when the trigger input is overdriven to about -0.2 V or lower, the timer's output returns to its high state, doubling the frequency of recurring input waveforms.

Because of noise and bias levels, problems may arise occasionally when the control input is tied directly to the supply or to less than about 0.5 V. (The latter bias condition corresponds to a 0.25-V input threshold.) Resistor R_1 should be 180 ohms or more to avoid these potential problems. □



4. Cost-cutting counter. Since frequency or event counting is often required in industrial-measurement situations, the 3421A has a built-in signal-conditioning circuit for driving the unit's microprocessor. The low-cost circuit squares-up a signal before passing it on.

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.

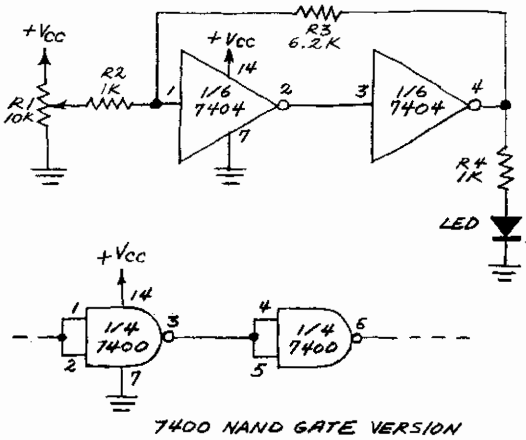


Fig. 1. A basic two-inverter Schmitt trigger.

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

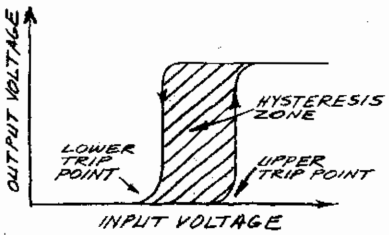


Fig. 2. Hysteresis curve for a Schmitt trigger circuit.

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

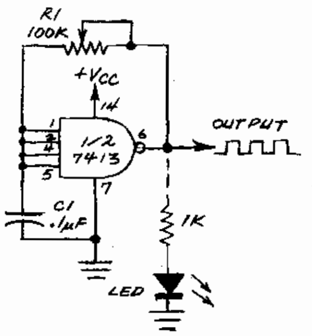


Fig. 3. Connecting one of the two triggers in the 7413 as an oscillator to provide pulses.

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.

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

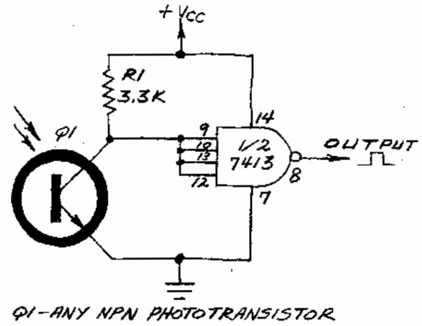


Fig. 4. Using half of a 7413 as a threshold buffer for a phototransistor.

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.

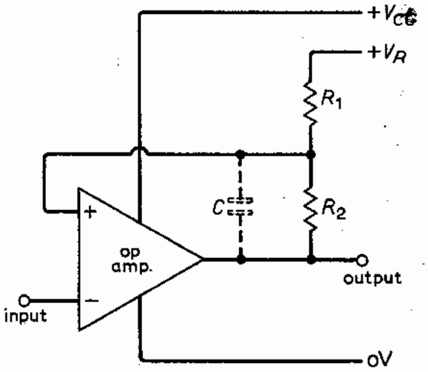
The net result of all this is that the Schmitt trigger cleans up erratic signals and converts them into more easily processed pulses. Fig. 5 illustrates this graphically.

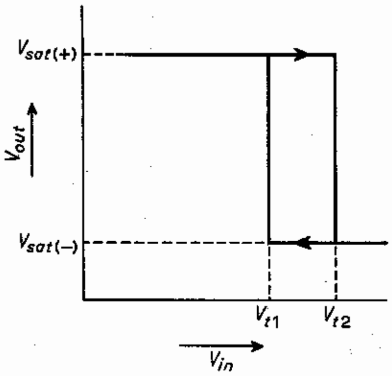
Fig. 5. How a Schmitt trigger cleans up an erratic waveform.

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. ◇

Schmitt trigger with op-amp

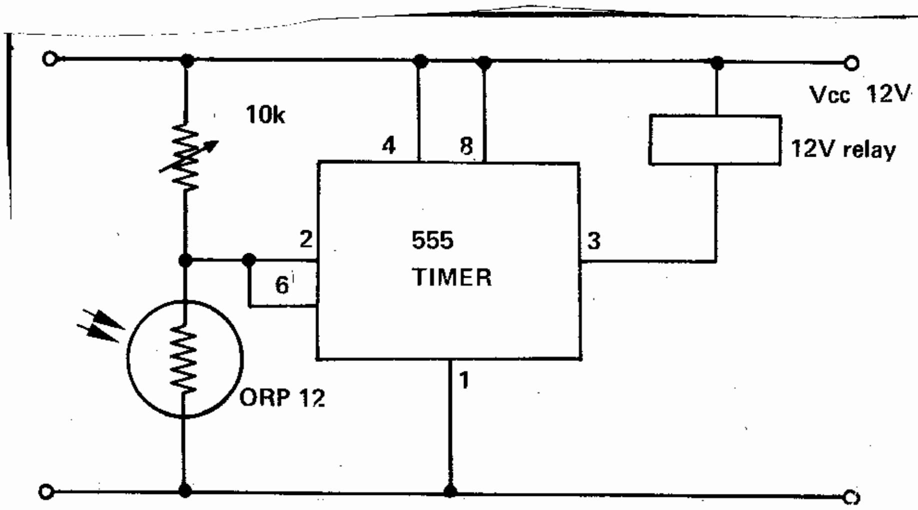
Any operational amplifier can be used as an efficient and precise Schmitt trigger. With a conventional Schmitt trigger circuit the two triggering voltages V_{t1} and V_{t2} are not only very temperature dependent and widely spread, but it is also difficult to know their exact value. Using an operational amplifier overcomes all these problems. Both V_{t_1} and V_{t_2} can be set accurately, either very close together (a few millivolts difference) or far apart and are much less temperature dependent.





For the circuit to work $(R_1+R_2)/R_2$ must be less than the open-loop voltage gain of the amplifier. Capacitor C ensures that the slew rate is as large as possible, but it should be carefully selected — above a certain value it may cause oscillation. If maximum slew rate is not required it can be omitted.

J. Rowley
St Andrews
Bristol

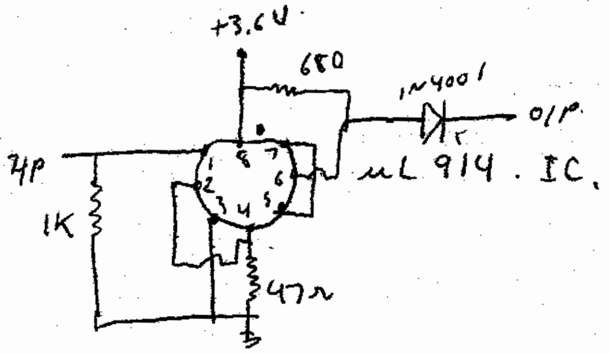


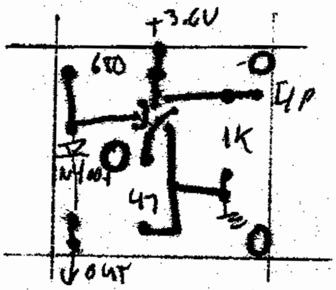
SCHMITT TRIGGER

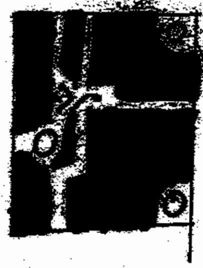
A very useful schmitt trigger can be made by utilising a single 555 timer with its trigger and threshold inputs connected together. The schmitt has a very low input current (1.5uA) and can directly drive a relay taking up to 200mA of current.

The circuit shows a 555 schmitt being used to energise a relay when the light level on a photoconductive cell falls below a preset value; the relay energises when the voltage on pins 2 and 6 is greater than 2/3Vcc and de-energises when the voltage falls below 1/3Vcc. This gives a hysteresis of 1/3Vcc. The circuit can be used in many other similar applications where a high input impedance and low output impedance are required with the minimum component count.

SINEWAVE TO SQUARE WAVE CONVERTOR.



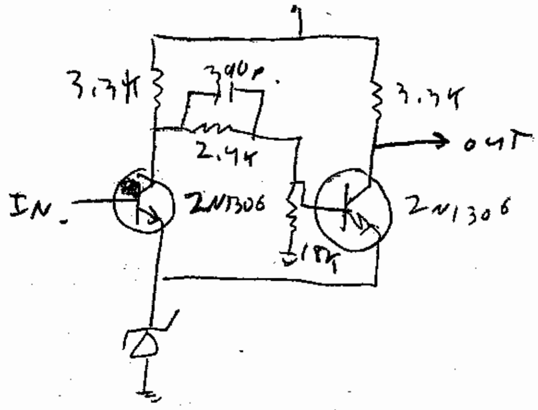




BOTTOM OF BOARD.
NOTCH -PIN1

Will convert a sine wave to a square wave of the same frequency.

Zero Hysteresis Schmitt Trigger



nitt trigger design with op-amps

Graphical technique eases design procedure

by R. D. Tuthill

The common form of a Schmitt trigger design using discrete components as shown in Fig. 1 has several disadvantages. If V_{in} is 0V, transistor Tr_1 is switched off and Tr_2 will therefore be switched on. It can be seen that V_{out} has a minimum voltage level, set by the ratio of R_5 and R_6 values, which is the first disadvantage. If the potential of V_{in} is raised, Tr_1 will start to conduct and the potential at the collector will fall. This starts to switch off Tr_2 which causes the voltages across R_6 to fall and Tr_1 to switch on. Although the change of state is now complete, there is now a current flowing into the base of Tr_1 which changes the input impedance of the circuit. This is also a disadvantage. The basic Schmitt trigger in Fig. 1 is a non-inverting type, and this can also be a disadvantage.

Using integrated circuit op-amps these disadvantages can easily be overcome. From Fig. 2(a) and (b) the only apparent difference between inverting and non-inverting configurations is the reversal of functions at the two inputs. However, for the same specified input and output conditions, different values of R_i, R_f and reference potential are required. Note that when using op-amps, switching always occurs when there is virtually no potential difference between the two inputs. Secondly, because the input impedance of an op-amp is high, virtually all of the current in the feedback resistor also flows through the input resistor. Therefore, the potential at the amplifier input can be calculated by knowing the voltage applied to R_i, the output voltage, the values of R_i and R_f or just their ratio.

The design procedure relies on the last-mentioned point. In the non-inverting configuration V_{IH} is the upper input voltage limit, V_{IL} the lower limit, V_{OH} the positive output voltage, V_{OL} the negative output and V_R the reference voltage. When the voltage ranges have been selected, a suitable voltage scale as shown in Fig. 3, can be chosen. A vertical line is drawn through Q and using the same scale as that on the left-hand side, V_{OH} and V_{OL} are marked. For the example shown V_{OH} is + 10V,

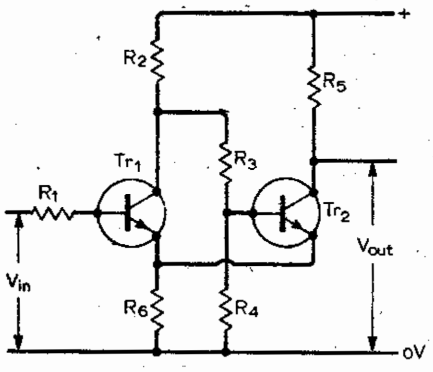


Fig. 1. Common form of non-inverting Schmitt trigger.

V_{OL}–10V, V_{IH} 8V, and V_{IL}–1V. This gives hysteresis of $V_{IH}-V_{IL}$ which is 8–(–1)=9V. At the left-hand end of the 0V line, point P is chosen and a vertical line through P is marked with V_{IH} and V_{IL}, again using the same voltage scale. Referring now to Fig. 2(a), the inverting input of the op-amp is connected to the reference voltage. Note that the non-inverting input must also be at potential V_R for switching to occur. This potential is not yet known but a line from V_H to V_{OL}; the conditions which exist just prior to switching, can be drawn. If the length of this line represents the impedance R_i+R_f, then, by knowing their ratios or values, the value of R_F can be found. Unfortunately neither of these are known but a second set of conditions is, and this may have the samé reasoning applied to it, i.e. just prior to the output switching from V_{OH} to V_{OL} the voltage at the non-inverting input is also V_R. Therefore, a line from V_{OH} to V_{IL} can be drawn. The intersection of the two lines gives the value of V_R when scaled vertically from the 0V line.

The ratio R_f:R_i can be found as well as the value of R_i if a suitable value for R_f already exists. Using the scale of resistance, R_f is marked on the horizontal axis, in this case 100kΩ, and a line is constructed from this point through R to interset the vertical line at point X. Using X as a starting point a second line is constructed through W to finish at Z.

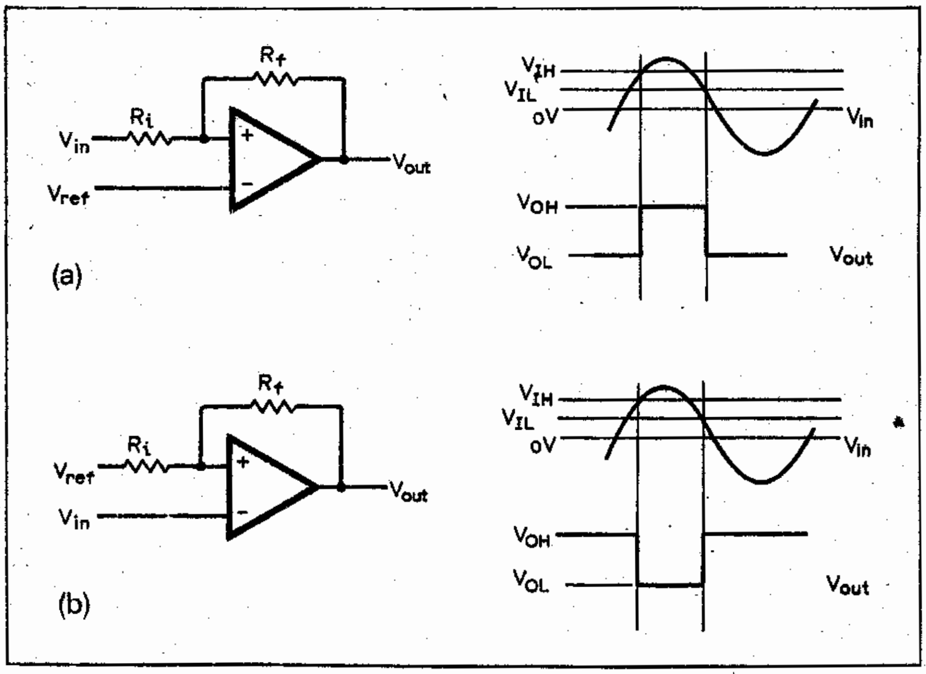


Fig. 2. (a) Non-inverting and (b) inverting Schmitt trigger both using a single op-amp.

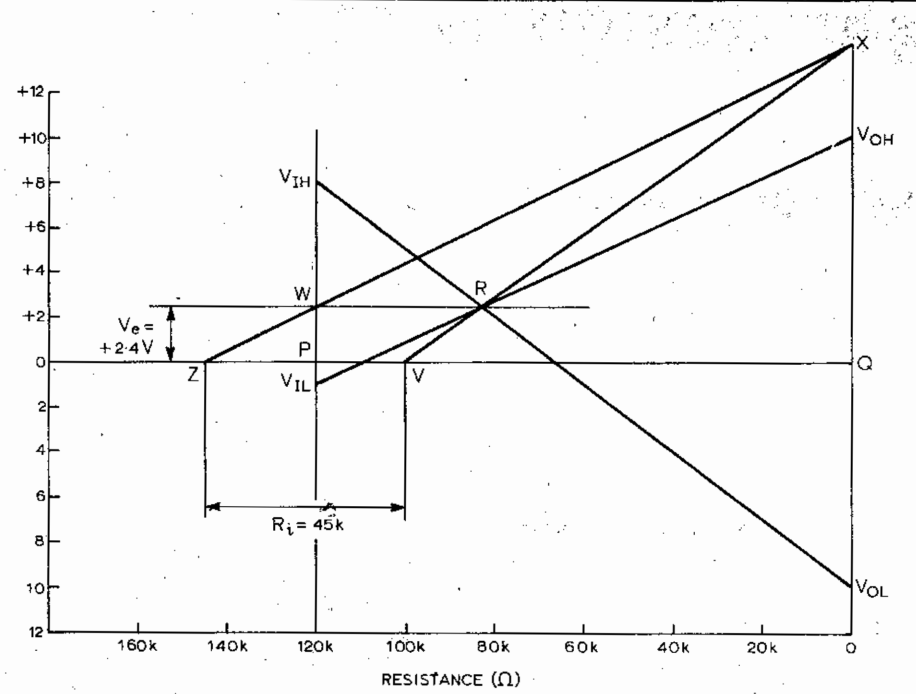
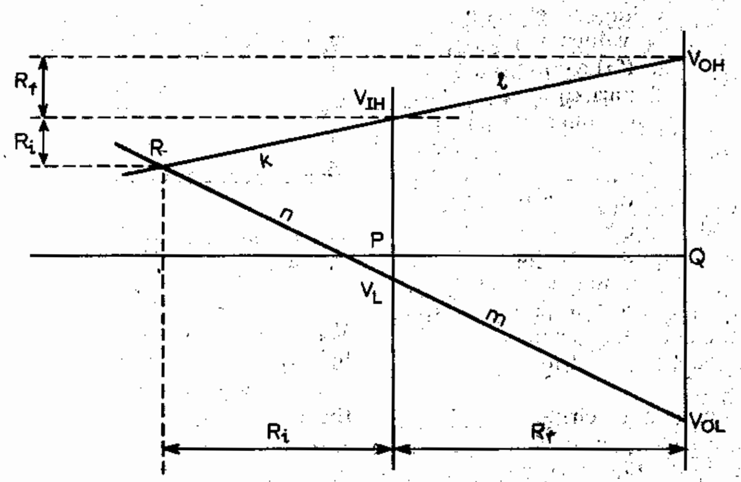


Fig. 3. Graphical method for calculating R_i in the non-inverting Schmitt trigger mode.

Fig. 4. Graphical method for calculating R_i in the inverting Schmitt trigger mode.



On the same resistance scale the distance V–Z gives the value of R_i.

If necessary a resistance scale in the horizontal axis can be used to begin with. In this case, values for R_i and R_f are marked off as point P and Q accordingly, and the distance from Q to the line vertically dropped from R is measured to obtain R_f, and from this point to P for R_i. The only disadvantage of this method is that there may be two awkward values of resistance rather than one.

This covers the graphical technique. For the trigonometrically minded it can be proved that $k/l=n/m$ and from this a mathematical formulae can be deduced. The vertical component of k is $V_{IH}-V_R$, l is $V_{OL}+V_R$ (where V_{OL} is negative), n is $V_{IL}+V_R$ (where V_{IL} is negative), and m is $V_{OH}-V_R$

Therefore:

$$\frac{k}{l}=\frac{n}{m}\text{ becomes}$$

$$\frac{V_{IH}-V_R}{-V_{OL}+V_R}=\frac{-V_{IL}+V_R}{V_{OH}-V_R}.$$

Solving for V_R gives

$$V_R=\frac{V_{IL}\cdot V_{OL}-V_{IH}\cdot V_{OH}}{(V_{IL}+V_{OL})-(V_{IH}+V_{OH})}$$

It is also true that $k/l=R_i/R_f$, therefore

$$R_i=R_f\cdot\frac{k}{l}=R_f\frac{(V_{IH}-V_R)}{(-V_{OL}+V_R)}.$$

Once R_f has been selected it is a simple matter to evaluate R_i

For the inverting configuration more care has to be taken in positioning point P because the lines of construction may be well to the left of this point. From Fig. 2(b) the voltage on the non-inverting input of the op-amp changes every time the output changes state. However, the inverting and non-inverting inputs must be virtually at the same potential for a change in output voltage to occur.

A line can be constructed from V_{OH} to V_{IH} with its length representing only the potential across R_f, and not R_f+R_i as in the non-inverting case. A similar state exists for V_{OL} and V_{IL}. The intersection produces a point from which the ratio R_f:R_i can be obtained. Also, the value of V_R is, as before, the vertical separation of point R from the 0V line. Resistors R_f and R_i can also be marked off as before. From Fig. 4 it can be trigonometrically proved that $k/l=n/m$, therefore $k/k+1=n/n+m$ and, from deduction

$$\frac{V_{IH}-V_R}{V_{OH}-V_R}=\frac{-V_{IL}+V_R}{-V_{OL}=V_R}$$

Solving for V_R gives

$$V_R=\frac{V_{IH}\cdot V_{OL}-V_{IL}\cdot V_{OH}}{(V_{IH}+V_{OL})-(V_{IL}+V_{OH})}$$

Also $k/l=R_i/R_f$, therefore

$$R_i=R_f\frac{(V_{IH}-V_R)}{(V_{OH}-V_{IH})}$$

Once R_f has been selected it is again a simple matter to evaluate R_i.

Linsley Hood cassette deck

The final part of this article, containing details of the motor-control circuit, will be published in the next issue. Readers who have used Garrard mechanisms will find that the motor-control unit is supplied but we will provide the information for the convenience of readers who have obtained the Goldring CRV mechanism.

ELECTRONICS -it's easy! PART 20

Generating non-sinusoidal waveforms.

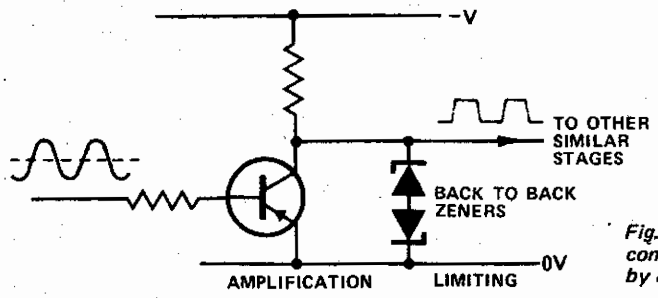


Fig. 1. A sinewave may be converted to a squarewave by amplifying and clipping.

SQUARE WAVES

Square and rectangular waves are most important in digital circuitry because they have signal levels that can be only one of two definite states. (the transition times being considered negligible). They also are used as the starting point for generating pulse trains in which the signal consists of narrow pulses. Three main methods are used to generate square waves. Two start with sinewaves, converting them to square waves, the other generates the square wave directly from a dc voltage.

If a sinewave of the same frequency as the squarewave needed is greatly amplified, the slopes of the sinewave at the zero crossing point are raised more toward the vertical. Also if the amplifier is overdriven the upper and lower limits of the original sinewave will be clipped. A crude square wave results. A more positive clipping process uses two oppositely connected zener diodes placed across the output, as is shown schematically in Fig. 1. If the process is repeated two or three times a quite reasonable square wave results with fast rise-times and clean tops.

A second way, originating from a sinewave, uses a special circuit called a Schmitt trigger. In this circuit, another of the basic family of digital circuits, the output is either low or high depending upon whether the input-voltage level is above or below (respectively) a preset input level. Although the input can exist at any analogue level the output will always be only in one of two states. To produce square waves a sine-wave is fed into the Schmitt trigger which is set to trigger at the point where the symmetrical sinewave passes through zero. The result is a square wave, if the trigger level is exactly at zero, or rectangular if above or below. The advantage of this method is that very low-frequency square waves can be generated.

A typical Schmitt trigger circuit (Schmitt first described this two-state circuit in 1938) is given in Fig. 2. For the values given the output swings from its high value of 12 V to a low value of 1.0 V when the input passes through 1.8 V on the way up. The output swings back again as the input goes through 1.0 V on the way down. The difference between the up and down trigger levels is known as hysteresis (or backlash). Design methods exist that enable the trigger level, backlash and output swing to be set as required. To produce symmetrical square waves from a sine-wave source, with this circuit, the sine-wave would have to have its dc zero placed at 1.5 V. The 150 pF capacitor is added to reduce the impedance of the 1.8 k resistor at high frequencies, that is, whilst the circuit is switching. It is called a "speed-up" capacitor.

As well as being a convenient way to produce square waves, the Schmitt trigger also provides a mechanism whereby a hesitant effect is made positive. Take for example the case where daylight is used to operate a street lamp. As the light falls to around the operating point a relay-switch would chatter on and off with minor changes, until the average light level had fallen below the critical region. By adding a trigger circuit with reasonable amount of backlash, the relay is made to switch on the first time the light falls below the preset level. The relay cannot again change state without a significant rise occurring in light level.

The third way to produce square waves is to generate them using another digital circuit building-block, the free-running multi-vibrator, or astable as it is also called.

There are three main types of multi-vibrator — astable, monostable and bistable. The astable automatically switches continuously between two states, thereby producing a square or rectangular wave signal. The monostable is normally in one state, and is triggered by an input signal into its second state. It stays there for a predetermined time before automatically toggling back again thus producing a fixed-length, single, square pulse. The bistable (or flip-flop),

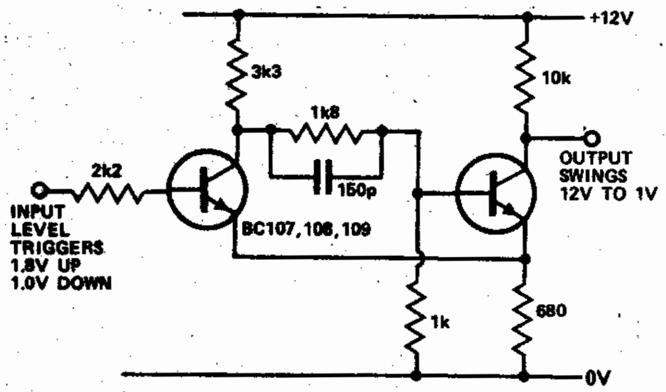


Fig. 2. The Schmitt trigger circuit.

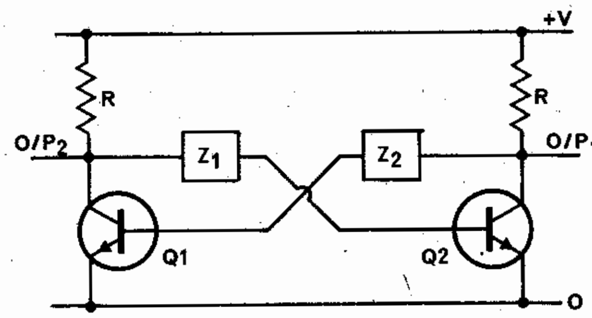


Fig. 3. The basic arrangement of the multivibrator family of circuits.

toggles from one state to the other with each successive input control pulse. It thus gives one output pulse for every two input pulses.

Each type can be used to produce "square" wave signals — the astable as a free running source, the monostable and the bistable as sources initiated by a train of pulses or changing levels.

Basically each type of multi-vibrator is formed from two common-emitter stages that are coupled together with impedances as shown in Fig. 3. This provides positive feedback from one stage to the other causing the device to always be in one state or the other — never between states for any length of time. This kind of impedance — resistors, capacitors or a mixture — determines the kind of positive feedback applied, and hence which of the three functions is generated.

Free-running astable — here the impedances are identical in both sides and are capacitors. Bias, or charging, resistors are added to each base as shown in Fig. 3. A suitable circuit for generating a 1 kHz square wave signal is given in Fig. 4a, Figure 4b is another circuit that will flash a small lamp at 1 Hz. Astable design is reasonably easy and is fully explained in numerous books, especially those devoted to digital circuitry. The period of the square wave produced is given approximately by T = 1.4RC (refer Fig. 4a) from which the frequency f = 0.7/RC. The other main requirements needed is to ensure that the transistors are capable of handling the current demands of R_L when switched on. The output can be taken from either collector — the two are said to be complementary, that is, when one is high the other is low. Alternately the load can be wired directly into the collector circuit as shown in Fig. 4b.

If the base resistors are fed from an independent source the frequency can be varied by external means. This produces a voltage-to-frequency convertor, or, voltage-controlled oscillator VCO. Referring to the approximate period

$$T = 2RC \ln\left(\frac{1 + V_{cc}}{V_{bb}}\right)$$

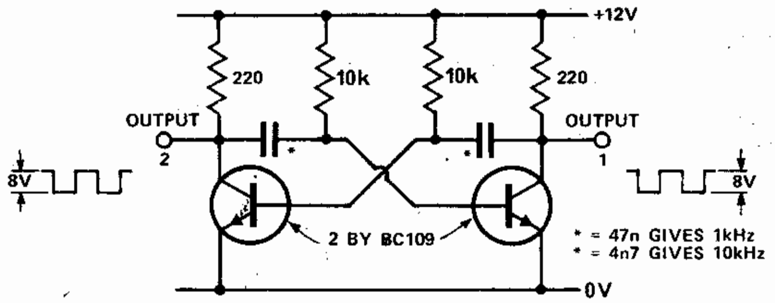
If the VCO is fed with a sawtooth signal the frequency output sweeps in synchronism — the well-known police siren sound.

Monostable or one-shot — if the requirement is for a train of pulses of uniform envelope height and width yet of variable repetition rate, then a monostable driven by a pulse train of the required frequency is the answer. A monostable has one transistor base connected as the astable above, the other is resistance coupled. Figure 6 shows a monostable set to provide a 20 µs wide pulse for a very wide variety of pulse inputs. Monostables are often used to reshape pulses back to a standard shape; they also serve to introduce a finite time delay because the initial input pulse can be regenerated later in time from the trailing edge of the monostable pulse. Thus the input pulse is delayed by the time duration of the monostable pulse width. An approximate value for the pulse duration is given by T = 0.7RC.

The circuit given in Fig. 6 features a second voltage rail. This ensures that the off-state transistor, which ever it is at any one time, is adequately switched off. It is, however, possible to design monostables that operate between only two lines — this has been the trend with semiconductor designs.

Bistable or flip-flop — this is the basic element used in digital computer counting as it produces an output pulse for every second input pulse, thereby dividing the input frequency by two. These have the two stages connected with resistors in both sides. Initially the circuit will start in either state — a set voltage is applied to the SET or RESET input thus conditioning the circuit to the initial plate required. Input pulses or step voltages applied to both sides will cause the unit to change state at each input pulse. Figure 7 shows a typical simple design of flip-flop. The need for a negative voltage rail has been avoided by adding an emitter resistor. Triggering inputs, not shown, can be arranged to drive into the base, emitter or collector in order to provide the toggle action.

Designs come in two varieties — those in which the on-stable holds the transistor well into saturation, and those in which the transistor is never saturated. The latter are capable of faster switching times but need much more careful design. We omit the design of the bistable for that is also well described in texts. It is a rare event, these days, for one to design flip-flops because they are now marketed in IC forms using over 10 transistors to achieve a much more stable and versatile unit at a price less



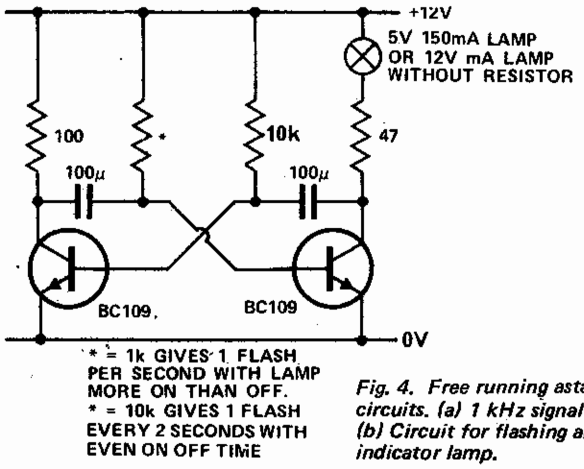


Fig. 4. Free running astable circuits. (a) 1 kHz signal source. (b) Circuit for flashing an indicator lamp.

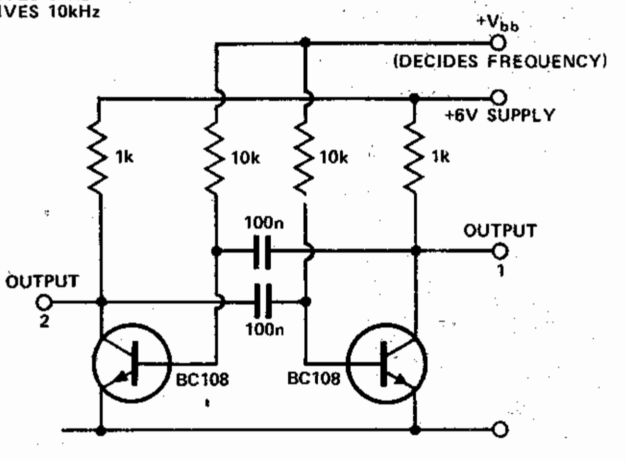


Fig. 5. The output frequency of an astable can be varied by altering V_{bb} — it becomes a voltage-controlled oscillator VCO.

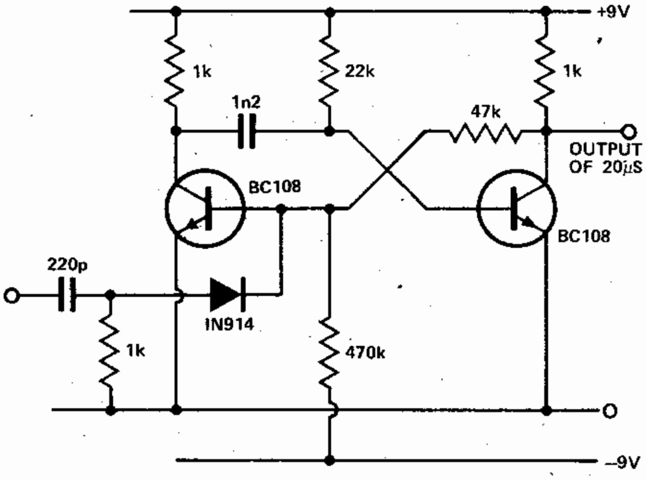


Fig. 6. Simple form of monostable – it produces a 20 microsecond wide pulse for each positive going input pulse.

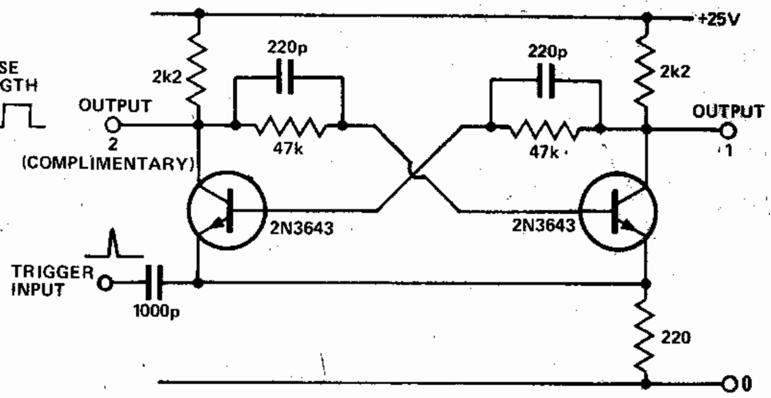


Fig. 7. Basic flip-flop or bistable circuit.

than that of the two discrete transistors needed for the circuit shown in Fig. 7. Monostables and Schmitt triggers are also available in IC form. The latter effect can also be obtained using a linear op-amp with suitable connections.

PULSES

The logical follow on from square-wave generation is that of pulse generation. In Part 8 we described how LR and (more usually) CR networks could produce pulses by differentiating the square wave. The circuits for doing this are shown in Fig. 8. Figure 8d shows the standard differentiation circuit used. It produces signals, as shown in Fig. 17.7, in voltage form from (a) square-wave input waveform. The technique applies equally well for a single pulse requirement. Pulses produced this way alternate in sign. If both pulses are needed it is usually easier to produce two separate trains from anti-phase square waves selecting and combining the pulse polarities needed. This is easier in practice than attempting to invert every second pulse generated by a single differentiator circuit.

GENERATING EXTREMELY HIGH FREQUENCIES

The upper frequency limit for transistor operation is at present just approaching the gigahertz region (10^9Hz); beyond this quite different techniques are employed. These techniques use devices such as magnetrons and klystrons, millimetre travelling wave tubes, masers and lasers. Figure 9 illustrates the frequency range over which each of these devices is useable.

In the earlier valve era it was very difficult to generate signals for radar needs (300 megahertz to 30 gigahertz) due to limitation of electron transit time, but late in the 1940's special self-resonating structures overcame this problem by using fields combined with valve concepts to 'bunch' electrons in a beam – typical such devices are magnetrons and klystrons. Such devices are still the best where high-power is demanded: microwave cooking ovens use magnetrons to generate kilowatt power levels for heating purposes.

The travelling-wave tube is another special electron device capable of UHF and microwave frequency amplification. In this tube an electron beam interacts with an electromagnetic wave travelling along the tube; again the electron bunching effect overcomes the transit time limitation. The design and use of these forms of generator are very specialised. Circuitry at such high frequencies is not accomplished with wires but with waveguides that look more like a piece of precision plumbing than an electronic circuit.

Still higher frequencies can now be generated using various kinds of laser.

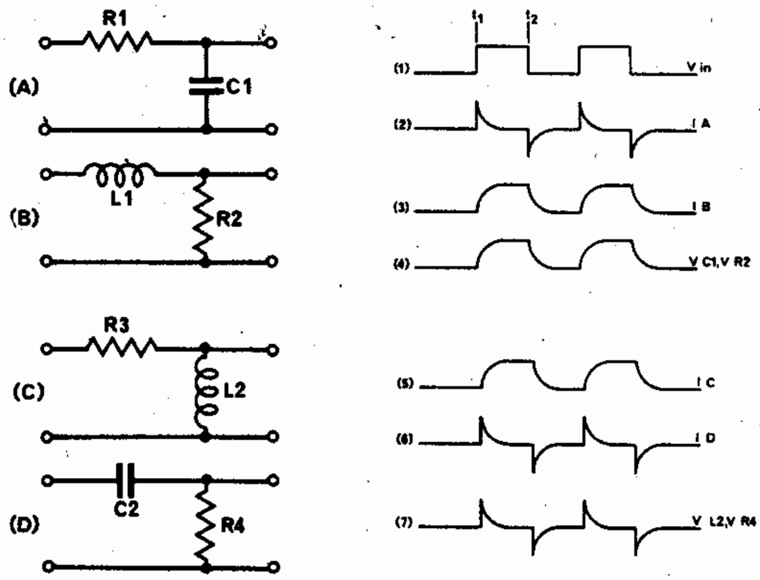


Fig. 8. Differentiation or integration may be crudely achieved by means of LR and CR circuits. Short pulses may be produced from square waves by differentiating with circuit (D).

COHERENT RADIATION

A proper understanding of what is meant by 'coherent' radiation' is essential to understanding why devices such as lasers are so important.

There are plenty of devices which produce radiation at super-high frequencies – eg, a hot soldering iron produces infra-red, an x-ray tube produces x-rays and a tungsten filament lamp produces visible light. But none of these sources produce coherent radiation. That is, their output consists of a multitude of separate packets of radiation which, although they may have the same frequency, have randomly different phase. Thus it is only possible to modulate such sources in bulk amplitude. It is not possible to modulate in frequency or phase on a cycle by cycle basis.

Devices such as lasers do produce *coherent* radiation. That is, the radiation is all in step, in terms of phase, and consequently can be modulated on a cycle by cycle basis.

Lasers can provide signal sources ranging from the far infra-red (10^{12}Hz) right through to x-rays (10^{19}Hz). At present no one device can cover this entire range. Some are tunable over a limited part of the spectrum, but most produce a single frequency within this spectrum.

Many laser sources are still in the exotic class and many problems remain to be solved. A major problem still outstanding is detection of such high frequencies. To date the highest frequency detected on a coherent wave by wave basis (that is, not as an incoherent bundle of energy as do most photo detectors) is 88 376 245 000 000 Hz. This is the frequency of the infra-red emission line of the now well developed helium-neon laser. It is just five times lower than visible light. Above that it is still not possible to detect the individual cyclic changes of the coherent sources that now exist.

FURTHER READING

Most books on electronic circuits cover the design of generators. Try "Transistor Manual" — General Electric, 1969.

Application notes for ICs also show how to produce various waveforms.

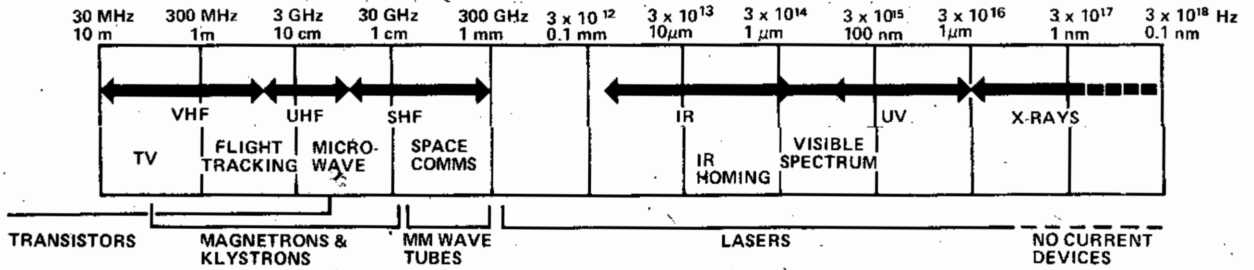


Fig. 9. Chart showing the various regions in the higher electromagnetic spectrum and the devices used in each.

Test Equipment Scene

By Lesile Solomon

REJUVENATING ELDERLY EQUIPMENT

ALTHOUGH most of us would like to purchase the best test gear that we can afford, we often have to compromise when it comes to cost. This means that many workbenches may have test gear whose specifications are not much better than the equipment being tested. In which case, we may be violating one of the basic rules of good engineering (and servicing): test gear must be at least one order of magnitude more accurate than the device being tested.

In many instances, a few more years can be squeezed out of the old gear simply by "swiping" partial or whole circuits out of magazines like POPULAR ELECTRONICS. Although most of us never build even a small percentage of the various circuits we see, we should take a close look at them with an eye for ideas to improve our present test equipment. Over the past few years, we have found many circuits that could be used to upgrade our test gear. The best part of this approach is the very low cost involved. (The few hours of bench time required to assemble the circuits are actually enjoyable when you're accomplishing something.)

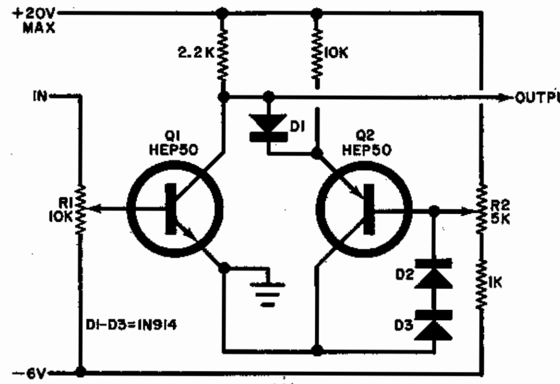
Consider an elderly square-wave generator. This old timer might do very well at the lower audio frequencies; but as the frequency goes up, the output square wave probably resembles a badly warped triangle wave, at best. You can try to improve the high-frequency response by using the output to drive some digital logic, such as a flip-flop. This would work, but you will need a 5-volt power supply, and the frequency will be halved. A Schmitt trigger circuit would probably work fine. However, you might want to try the circuit shown at (A). It converts the battered old waveform into an impressive square wave with fast rise and fall times, reaching way out in frequency. The amplitude is also constant over the entire span. We built this circuit right into the old generator, taking the required power from the internal supply. Any silicon switching transistors and diodes can be used.

The input potentiometer *(R1)* is adjusted for the best output waveform. Once set, this control requires no further calibration. Potentiometer *R2* is used to set the output amplitude. Diode *D1* protects the *Q2* emitter-base junction while diodes *D2* and *D3* prevent the clamp voltage from reverse biasing. *Q1*. The input is driven from the maximum output of the old square-wave generator.

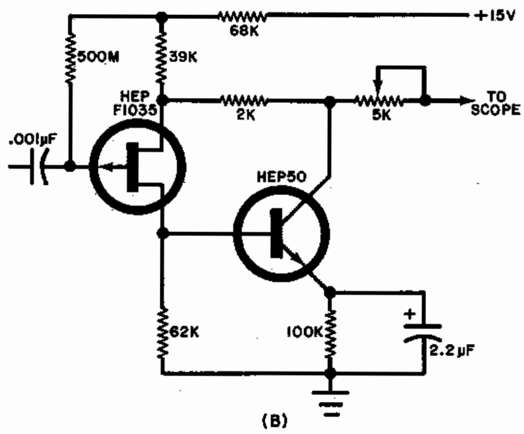
Another piece of gear that needed help was an old oscilloscope. Although it had the usual l-megohm impedance, we found that it did load some of the newer circuits, especially where CMOS or bootstrapping were used. To reduce this loading effect, we began using a 10:1 divider to increase the input impedance. But this, naturally, reduced the signal level available to the scope. We then had to crank the vertical gain way up, and sync sometimes became unstable.The circuit shown at (B) uses a form of bootstrapping to produce an input impedance somewhere around 1000 megohms. The circuit has unity gain, while the upper frequency equalization is determined by the setting of the 5000-ohm potentiometer.

The rise time is quite fast, and is estimated at about half a microsecond. The circuit was built on a narrow pc board and mounted within an old metal cigar tube container, as a probe. We have had no circuit loading problems.

Although we have shown only a couple of relatively simple ideas, there are many more. Where do these ideas come from? When we receive our quota of construction and ham magazines, besides reading those articles that interest us, we take a look at all the circuits, searching for ideas that may sometime be useful. Once we see something that could be of use, we clip it out and file it in a set of folders that are categorized by applications—audio, test gear, power supplies, etc. If you don't like the idea of cutting up



(A)



(B)

Circuit (A) can be used to improve the waveform on a square-wave generator; while (B) can be added to an oscilloscope to reduce input impedance.

magazines, then start a card file, recording the title of the article, the magazine, the month and year, the page number, and the idea you have in mind. At some later date when you are looking for help, all you do is look in your files under the proper heading, find the article, break out the soldering iron, and update.

Circuit Loading. Several times in the past, we have mentioned that measuring voltage with a VOM is not the same as measuring it with a VTVM, VTM, DMM or any other high-input-resistance instrument.

Let us take the case of a circuit having a 10-volt power supply and a series output resistance of 50,000 ohms. If you are using a VOM with a 20,000-ohm dc resistance, the current flow through the circuit will be $10/(7 \times 10^{4})$, with the 70,000 ohms being the sum of the 50,000-ohm series resistance and the 20,000-ohm VOM resistance. The current is then 1.43×10^{-4} amperes. The voltage drop available to the VOM $(1.43 \times 10^{-1})(2 \times 10^{1})$ or 2.86 volts. The error is then (10-2.86)/10 times 100 or 71.4%.

If you plug the VTVM 10-megohm input resistance into the above equations in place of the 20,000 ohms of the VOM, you will find that the current now becomes 9.95×10^{-7} amperes. The voltage drop across the VTVM is now 9.95 volts, and the error is only 0.5%.

You can use the dc resistance of your own VOM and VTVM (or other high input resistance voltage instrument) to determine for yourself just how inaccurate those voltage measurements have been in the past. You will see that the higher the input resistance of the voltage measuring device, the greater the accuracy. ◈

C-MOS Schmitt trigger can be more than an interface

by R.L. Morris
Audichron Co., Atlanta, Ga.

A Schmitt trigger makes a convenient interface between any type of logic family and signals that have slow transition times and possibly contain some noise component. When complementary-MOS circuits are being used to take advantage of their high input impedance and convenient switching threshold level, it is particularly necessary to employ an interface circuit that provides sufficient hysteresis.

A versatile C-MOS Schmitt trigger can be built with a minimum of parts—with only a couple of resistors and a conventional C-MOS noninverting buffer, such as the type CD4050 device. The circuit, which is drawn in Fig. 1, is actually quite similar to a standard comparator circuit having hysteresis. Unlike a comparator, however, the source impedance required to drive the C-MOS Schmitt trigger can be considerably lower than the value of its input resistor (R_1). If the source resistance is a relatively fixed value, it can even be added to R_1 for calculation purposes.

To see how the C-MOS Schmitt trigger operates, first let output voltage V_3 be at ground level. As input voltage V_1 increases from below the circuit's positive-going threshold point, voltage V_2 is divided by resistors R_1 and R_2. When the threshold point of the C-MOS buffer is reached, the output of the buffer will begin to increase, producing positive feedback through resistor R_2. This causes a fast transition at the circuit's output and latches the circuit into its other state.

Now, let output voltage V_3 be at the V_{DD} supply level. The same circuit action takes place, but it occurs in the opposite direction. The scope display in Fig. 1 shows the superimposed waveforms for V_1, V_2, and V_3 for typical values of these voltages. The total circuit hysteresis, in this case, is approximately 2.3 volts.

Only a few circuit equations are needed to describe circuit behavior with reasonable accuracy. The feedback factor can be expressed as a resistance ratio:

$$K = (R_1 + R_2)/R_2$$

The circuit's positive-going threshold voltage is then given by:

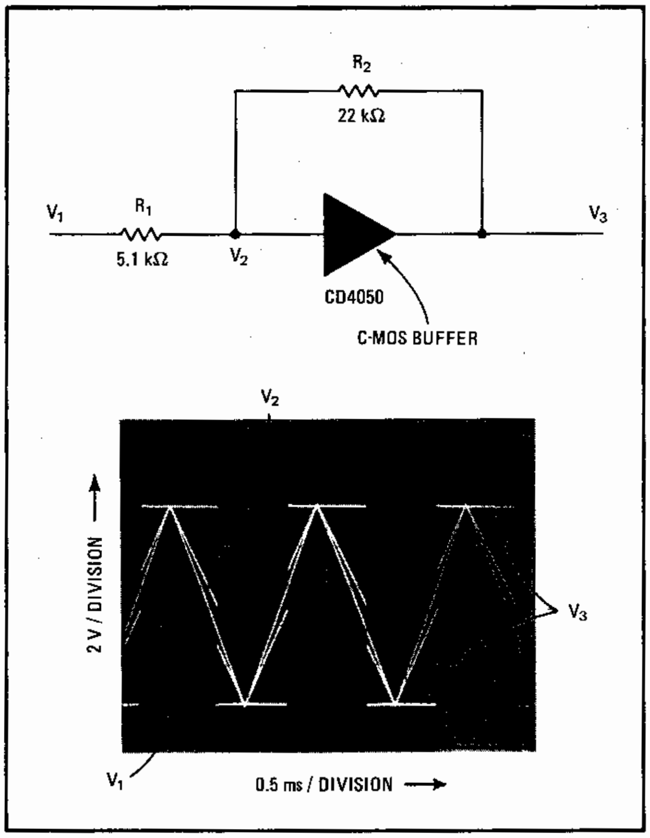
$$V_{T+} = V_T K$$

where V_T is the threshold voltage of the C-MOS buffer being used. The negative-going threshold voltage can be written as:

$$V_{T-} = K(V_T - V_{DD}) + V_{DD}$$

And the total hysteresis of the circuit is the difference between the two threshold voltage levels:

$$V_H = V_{T+} - V_{T-} = (K - 1)V_{DD}$$



1. Simple circuit. C-MOS buffer and two resistors form a Schmitt trigger circuit that provides a high input impedance, fast output transitions, and a wide range of hysteresis voltage. The scope display illustrates the circuit voltages when the input is a triangular wave.

These equations can be further simplified by assuming that $V_T = 0.5V_{DD}$, which is a good approximation for a C-MOS buffer. Then, the positive-going and negative-going threshold voltages can be expressed as:

$$V_{T+} = 0.5V_{DD}K$$
$$V_{T-} = (1 - 0.5K)V_{DD}$$

Of course, there are a number of ready applications for the C-MOS Schmitt trigger of Fig. 1. One is as a delay element to generate time delays with a simple RC integrator network. The delay may be desired for logic timing functions or for filtering noise. Figure 2a shows the configuration for a delay element. In this circuit, as long as resistance $10R_3$ is less than or equal to resistance $(R_1 + R_2)$, the circuit's hysteresis and time constant can be considered to be independent of each other. A word of caution, though—the threshold point for a type CD4050 buffer is only specified to within ±40% of the ideal V_T threshold of $0.5V_{DD}$. However, the stability of V_T with temperature for any particular device is very good.

Another possible application for the C-MOS Schmitt trigger, one which is based on the delay element of Fig. 2a, is as an edge detector or differentiator (Fig. 2b). Three different outputs can be obtained from this circuit. With a NAND gate at the output, the circuit detects only the leading edge of the positive input pulse.

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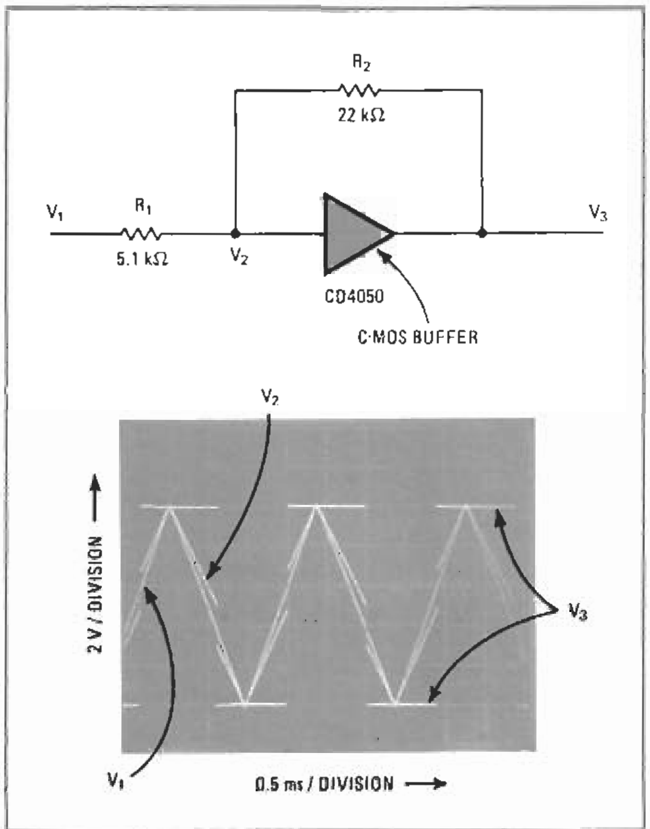

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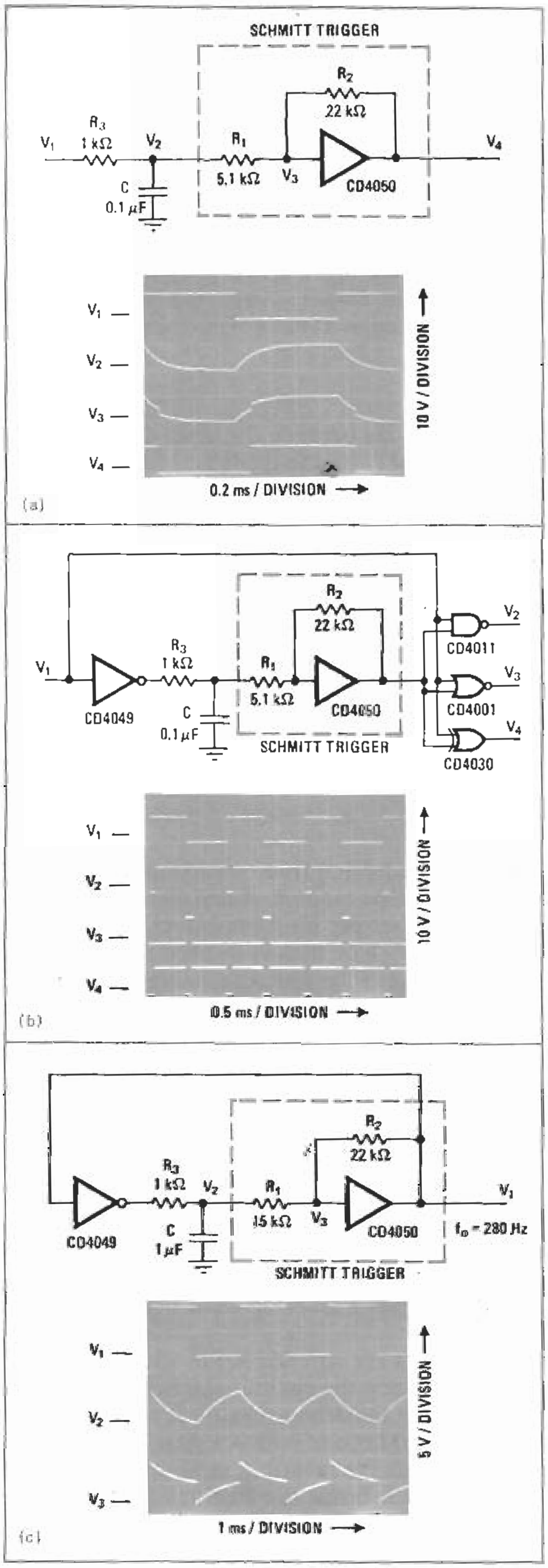
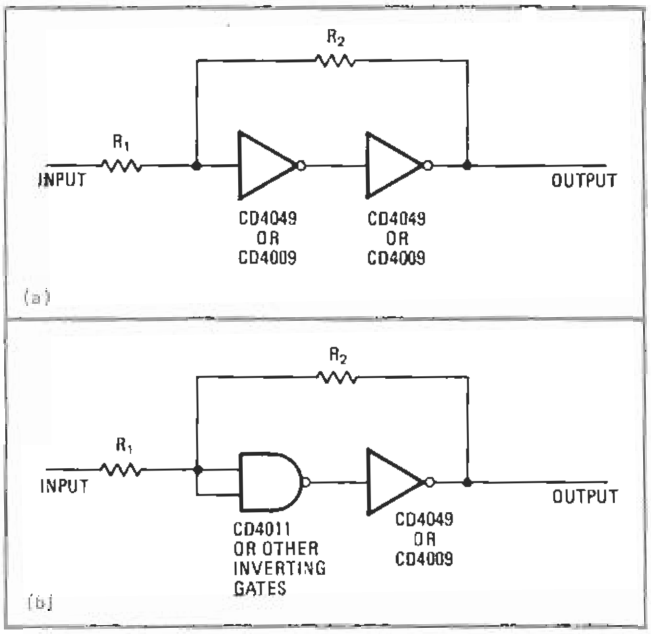


2. Applications. With an RC network at its input, the C-MOS Schmitt trigger can operate as a delay element (a), an edge detector (b), or an oscillator (c). Depending on the output gate employed, the edge detector will mark leading and/or trailing pulse edges.



3. Alternate implementations. Instead of a buffer, two inverting-type C-MOS gates can be used to obtain a Schmitt trigger, as long as very fast output transitions are not needed. Two inverters can be substituted, as in (a), or, as in (b), a gate and an inverter.

With a NOR gate at the output, the circuit detects only the trailing edge of the positive input pulse. And with an exclusive-OR gate at its output, the circuit will detect both edges of the input pulse, as well as doubling the input pulse frequency. Output pulse width for this edge detector is controlled by the delay introduced by the RC network.

The delay element can also be used to construct a simple RC oscillator, as shown in Fig. 2c. Because of the Schmitt trigger circuit, the slow transition from the RC network is never applied directly to the device being driven by the oscillator. In this circuit, the hysteresis range of the C-MOS Schmitt trigger is expanded to make use of the RC time constant. By increasing the value of resistor R_1, the hysteresis voltage of the Schmitt-trigger portion of the oscillator is raised to 6.4 V.

For designs where only one or a few Schmitt triggers are needed, it may be desirable to use some other C-MOS device, rather than the CD4050 buffer. Any two inverting-type gates can be substituted, as indicated in Fig. 3. Although a buffer is preferable for driving resistor R_2, a gate-type device, which has a lower output drive, will do, provided that the proper values are selected for resistors R_1 and R_2. The lower-gain gate-type device will result in slower output transition times.

If several Schmitt triggers are needed for a design project, dual-in-line packaged resistor networks, instead of discrete resistors, can be used to help conserve circuit board space. □

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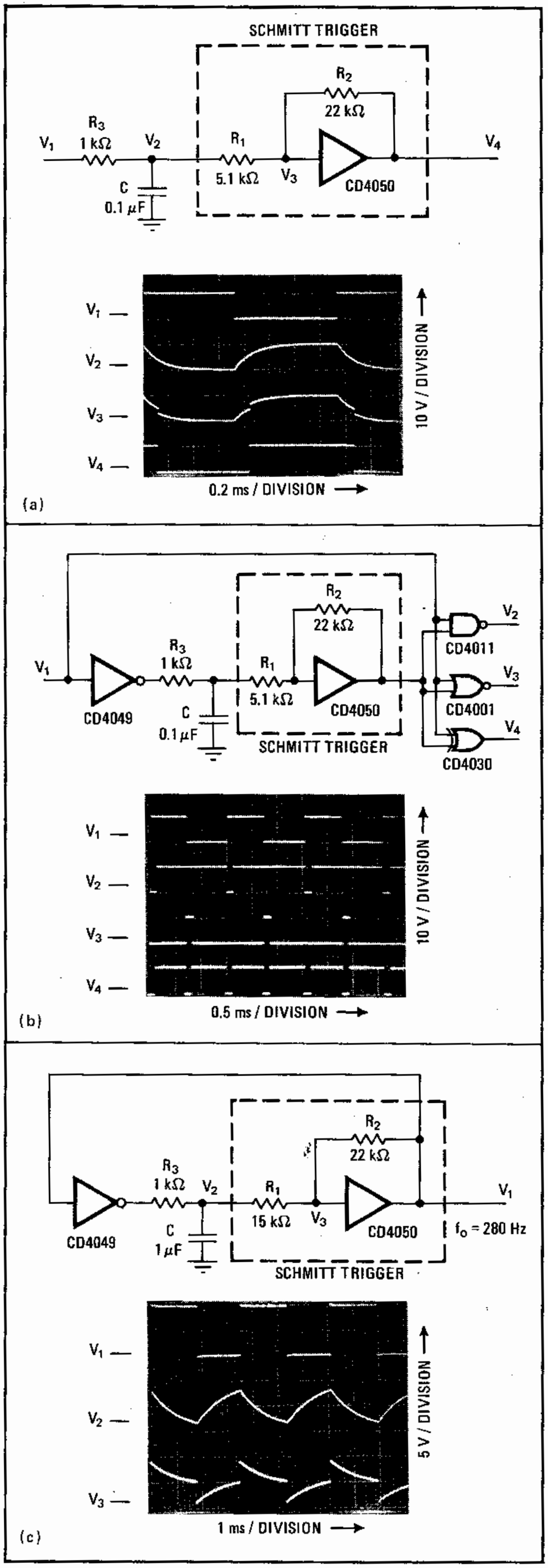

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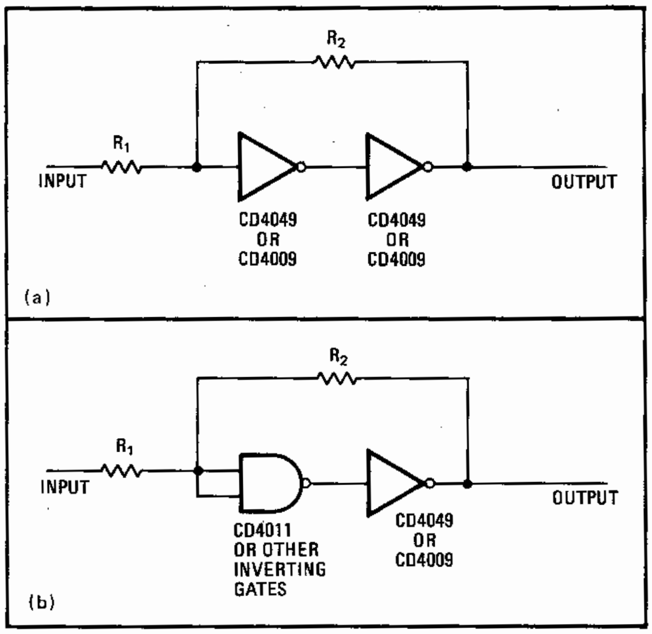

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Solid State

PROGRAMMABLE SCHMITT TRIGGER

By Lou Garner

THERE is never a lack of new IC's on the market. Many of the latest ones are in the microprocessor area, but there are plenty of others that are also of interest to the imaginative expermenter or hobbyist. RCA's Solid State Division (Box 3200, Somerville, NJ 08876), for example, has recently introduced a versatile programmable Schmitt trigger with memory suitable for use in a variety of control circuit applications. Depending on its accessory devices and peripheral circuitry, the new IC, designated type CA3098, can be used to activate relays, heaters, LEDs, incandescent lamps, thyristors, solenoids, and similar units. It can serve as an on/off switch for pump, fan or positioning motors and in signal reconditioning, phase or frequency modulator, and square or triangular-wave generator circuits. The CA3098 can be used, too, for time-delay operations, for level control and sensing, or to provide overvoltage, overcurrent, or over/under temperature protection. With relatively low power requirements, it can be used effectively in either battery-powered or line-operated projects.

A monolithic silicon IC comprising more than 20 transistors and a number of diodes and resistors, as shown schematically in Fig. 1A, the CA3098 can be operated with either a single (16 volts max.) or a dual (±8 volts max.) power source. It can control currents up to 150 mA, having only microwatt power dissipation under standby conditions when the controlled current is less than 30 mA. Offered in three different package styles—an 8-lead DIP (type CA3098E), an 8-pin TO-5 case (type CA3098T), and an 8-pin TO-5 case with formed inline leads (type CA-3098S), as well as in chip form (type CA3098H)—the new device has an operating temperature range of −55 to +125°C, and can dissipate up to 630 mW at an ambient temperature of 55°C or, with a suitable heat sink, up to 1.6 W at the same temperature. When used at temperatures above 55°C, it is derated linearly at 6.67 mW/°C without a heat sink and at 16.67 mW/°C with a heat sink. It will accept sensors ranging in value from 100 ohms to 100 megohms, offers a programmable hysteresis characteristic from 20 mV to the supply-voltage level, and has an extremely low output leakage current of 10 µA max. As a switching device, the CA3098 has a low delay time of 600 ns, with fall and rise

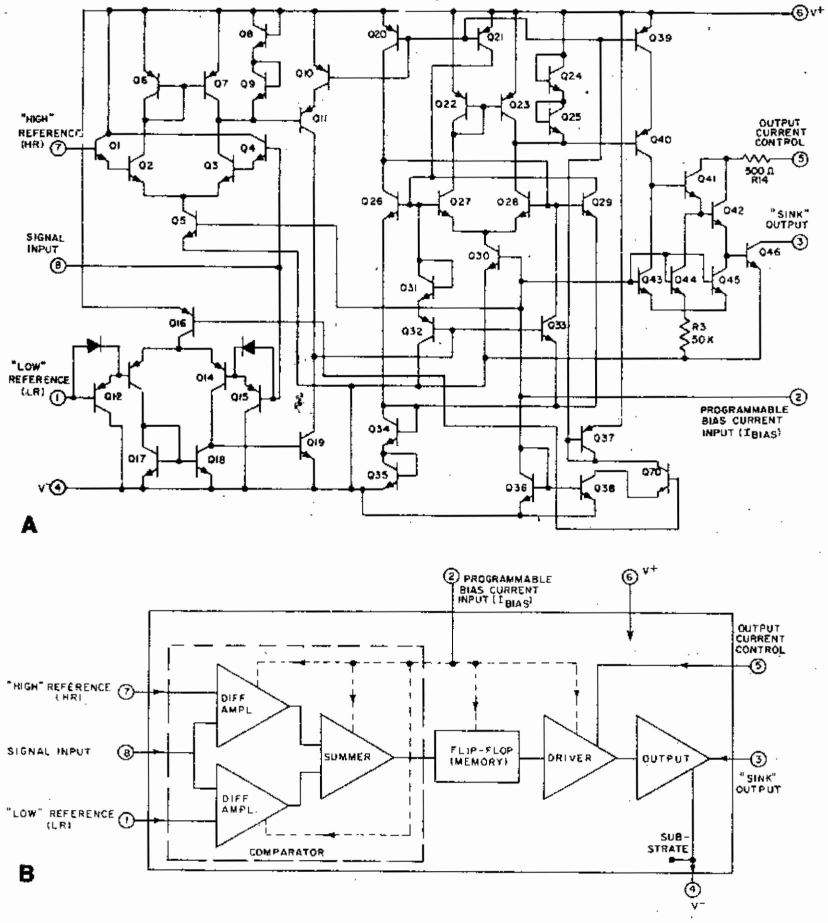


Fig. 1. RCA's CA3098 programmable Schmitt trigger: (A) internal schematic; (B) functional diagram.

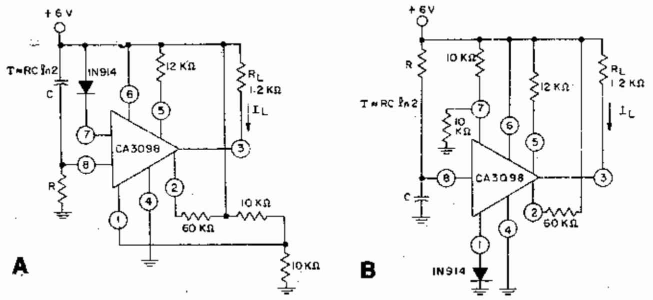
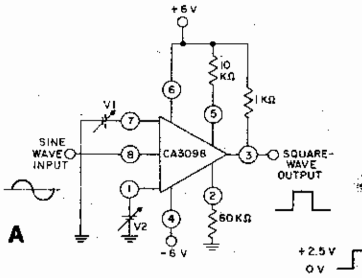


Fig. 2. CA3098 time-delay circuits: (A) switches on after delay; (B) switches off after delay.



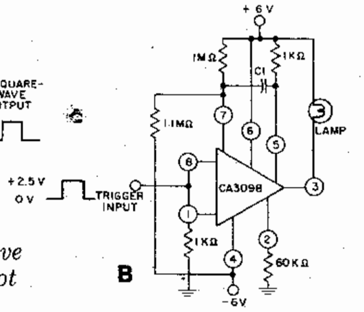
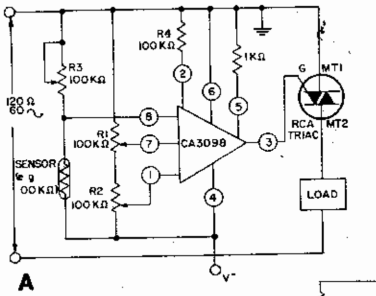


Fig. 3. Sine-to-square-wave converter (A) and one-shot multivibrator (B).

times of 50 and 500 ns, respectively, coupled with a storage time of only 4.5 µs under typical operating conditions.

Functionally, the device consists of two differential input amplifiers, a summing circuit, a flip-flop which serves as a bistable "memory" element, a driver amplifier, and a power output stage (Fig. 1B). The input signal voltage (pin 8) is compared to a prefixed higher reference voltage (HR, pin 7) by one differential amplifier and to a lower reference voltage (LR, pin 1) by the other, with the resultant output signals applied to the summer. The latter delivers a trigger signal to a flip-flop that changes state in response to each trigger command. The flip-flop, in turn, supplies a signal to the driver amplifier which controls the power output stage. The output stage serves to "sink" current from the power supply through an external load device, such as a lamp, relay, solenoid, or thyristor gate circuit. When the applied signal voltage is equal to or less than the present low



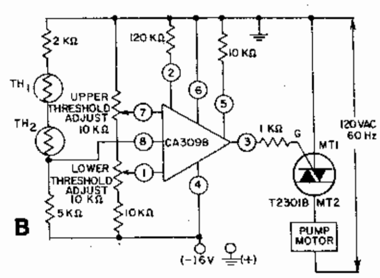


Fig. 4. Triac control circuits: (A) basic switch; (B) pump control.

reference voltage, the output stage is in a conducting state. This state is maintained until the input voltage rises to or exceeds the high reference voltage, at which point the output state switches to a nonconducting or "open" state. The "open" condition is maintained until the input signal again drops to or below the LR level, and the output stage is switched back to a conducting state. In addition to establishing the switching points by presetting the HR and LR levels, the device's operation may be programmed for optimum performance by means of an external bias current applied to the differential amplifiers, summer, flip-flop and driver stages through pin 2, while the maximum load current can be limited by the application of a separate bias current to the output stage through pin 5.

Representative examples of the CA-3098's potential circuit applications are illustrated in Figs. 2 through 4. These can be used either for the development of a specific projects or, if preferred, simply as guides in the design of original circuits. Abstracted from RCA's 8-page data bulletin for the CA3098, File No. 896, the circuits use standard components and, in most cases, can be duplicated quite easily in the home laboratory or workshop, for neither layout nor lead dress should be overly critical. Of course, good technical practice should be followed when wiring the circuits, with care taken not to overheat semiconductor device leads, and all dc polarities carefully observed.

The circuit shown in Fig. 2A is designed to switch the load current on following a predetermined delay after power is applied. The circuit in 2B switches the load current off after a suitable delay. Although resistive output loads are shown, relays, lamps, or other devices might be used in the circuits. In both, the time delay is dependent upon the time constant of the RC input network. Large values of *either* R or C will provide a longer time delay. If adjustable time delays are required, several capacitor values can be provided, selected as needed by a rotary switch. A fine adjustment can be provided by using a small trimmer rheostat in series with a fixed resistor for the R component.

Typical signal conditioning circuits featuring the CA3098 are illustrated in Fig. 3. The square-wave converter (Fig. 3A) features an adjustable duty cycle, achieved through the use of variable bias levels (V1 and V2) applied to the HR and LR inputs. The one-shot delivers an output pulse of fixed amplitude and duration to its lamp load when triggered by a positive-going input pulse. The output pulse width is determined by the value of the feedback capacitor *C1*. With a 0.01-µF unit, the pulse width is 15 ms, while a

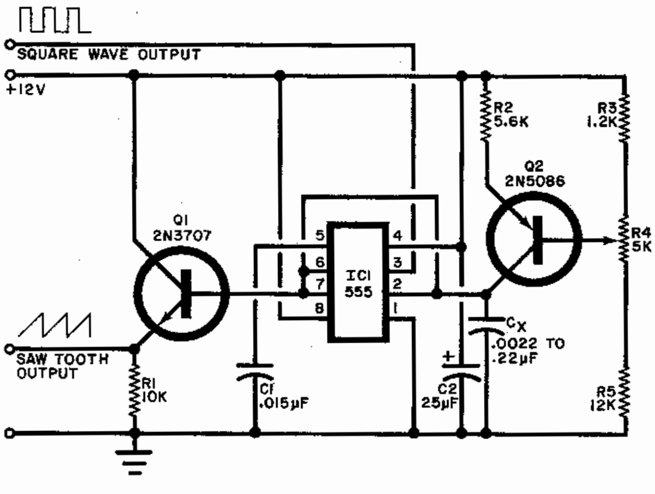


Fig. 5. Design for a function generator.

300-ms pulse is obtained with a 0.2-μF capacitor. For optimum performance with the circuit values specified, the input pulse should have an amplitude of at least 2.5 volts and a duration greater than 1 ms, but less than the output circuit's "on" time. Naturally, other output loads can be used in place of the lamp shown on the diagram.

Finally, circuits featuring the use of the CA3098 in conjunction with bidirectional thyristors (triacs) are show in Fig. 4. In both examples, ac line power is supplied to the thyristor and its load, with a separate dc source provided for the CA3098 control circuit. In the basic switching circuit (Fig. 4A), a voltage divider made up of a single sensor (such as a photoresistive cell or thermistor) in series with a rheostat supplies the input control signal, while potentiometers *R1* and *R2* serve to preset the HR and LR levels, respectively. A modified version of the basic circuit intended specifically for maintaining the water level in a storage tank is given in Fig. 4B. Here, two thermistors, *TH1* and *TH2*, operated in self-heating modes, are used as sensors and the triac controls a pump-out motor. The thermistors are mounted in the tank on each side of the desired mean water level, with *TH2* at the top. In operation, the pump-out motor is activated when the water level rises above *TH2* and switched off when the water level falls below thermistor *TH1*.

Readers' Circuits. Most experimenters probably can discover a half-dozen or more applications for the simple function generator circuit illustrated in Fig. 5. Capable of supplying linear sawtooth and square-wave signals simultaneously, it might be used, typically, in test equipment, as a tone source for a basic electronic musical instrument, or as a linear sweep generator for an oscilloscope. Submitted by reader Craig K. Sellen (48 Briarwood Road, Wayne, NJ 07470), the design offers yet another application for the ubiquitous and inexpensive 555 timer IC. The circuit has an emitter-follower (*Q1*) as a buffer amplifier and an adjustable constant-current source (*Q2*) for the timing capacitor (*Cx*) to insure good linearity and optimum overall performance. Intended for operation on a 12-volt dc source, the circuit can be powered either by batteries or a well-filtered line-operated power supply.

Depending on individual preferences, the circuit can be breadboarded for experimental tests or duplicated on a perf or pc board, for neither the parts placement nor wiring arrangement should be especially critical. Aside from the active devices, *IC1* (type 555), *Q1* (2N3707), and *Q2* (2N5086), the fixed resistors can be ¼- or ½-watt types, potentiometer *R4* a standard linear control, bypass capacitor *C1* a paper or low-voltage ceramic type, and power-supply decoupler *C2* a 12-to-15-volt electrolytic

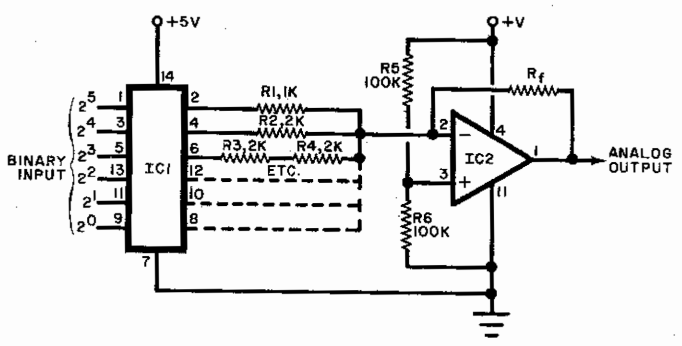


Fig. 6. Digital/analog converter circuit.

capacitor. The circuit's operating frequency is determined primarily by timing capacitor *Cx*, which can be a plastic film, paper or ceramic type, with values from 0.0022 to 0.22 μF, depending on application requirements. According to Craig, the circuit will deliver a linear sawtooth of approximately 4 volts, p-p.

Recognizing that many of today's hobbyists are working with digital projects, reader Robert L. Schuman (R.R. #2, Winthrop, IA 50682) has suggested the circuit given in Fig. 6 as an inexpensive solution for those requiring a simple digital-to-analog (D/A) converter. Using only two IC's, a hex inverter (*IC1*) and an operational amplifier (*IC2*), the circuit accepts digital binary input pulses and converts these to an equivalent analog signal. In operation, the actual conversion process takes place in a weighted resistive divider network (*R1, R2, R3, R4*, etc.) connected to the hex inverter's output terminals and which, in turn, becomes part of the op amp's inverting input feedback/bias circuit. The output resistance for each binary digit from 2^5 (32) to 2^0 (1) is doubled in value so that the summed resistive output connected to the op amp is inversely proportional to the input binary signal, thereby insuring that the op amp's output is directly proportional to the original binary number.

Robert has specified standard components in his design, with hex inverter *IC1* a type 7406 and *IC2* one section of a 324 quad op amp, a type amenable to operation on a single-ended power source. For optimum performance, precision resistors (1% or better) must be used in the divider network. Op amp input bias resistors *R5* and *R6* may be standard ¼- or ½-watt types, while feedback/bias resistor *Rf* should have a value less than half that of the smallest resistor connected to the hex inverter outputs (i.e., less than 500 ohms). The D/A converter circuit can be assembled using any construction technique, for neither layout nor wiring dress should be critical.

Data Sources. If our mail is any criterion, one problem plaguing many experimenters is that of finding technical data on IC's and discrete devices acquired through surplus stores and other outlets. As a general rule, of course, the best source of data is the original manufacturer, for virtually all of them publish detailed specification sheets, data bulletins, and, often, application notes covering their products. A number of the larger firms, including Motorola, RCA, and National Semiconductor, also publish comprehensive data books covering their entire product lines which are available at modest cost. Unfortunately, not all manufacturers will honor individual requests for data. This is often true of small-to-medium-size firms catering primarily to the large OEM market, even though their products may be available through surplus outlets and local distributors. In addition, original data sheets may not be available on obsolete or discontinued devices. However, if the need for information is great enough to justify the relatively high cost, complete specification data on virtually every semiconductor device ever manufactured is available from *D.A.T.A., INC.* (32 Lincoln Avenue, Orange, NJ 07050). This firm publishes a series of data books covering devices in every basic category from diodes to microcomputers. Each book is offered on an annual subscription basis and separate books are available covering discontinued devices. Prices range from, typically, $12.75 for the book on *Discontinued Thyristors* to $54.50 for the book on *Optoelectronics*.

Device/Product News. Fairchild Semiconductor (4001 Miranda Ave., Palo Alto, CA 94304) has announced a new 190 x 244-element charge-coupled device (CCD) area image sensor for use in imaging and video systems. The second member of Fairchild's family of area sensors, the new solid-state device, type CCD211, contains 46,360 sensing elements organized in an array of 190 vertical columns and 244 horizontal lines, which is equivalent to one-quarter of the standard television resolution. The X-Y format of the array provides a 3:4 vertical to horizontal ratio, which is ideal for use with Super 8 movie camera lenses. Converting light focused by a camera lens into a video signal, the new CCD211 can operate at data rates up to 15 MHz, providing a picture frame rate up to 200 frames per second, in contrast to the 30 frames per second rate of broadcast TV and 18 frames per second rate of movie cameras. In addition to the image sensing elements, the device, which dissipates only 100 mW, includes 190 columns of 2-phase vertical analog transport registers, a 200-element horizontal analog transport register and a

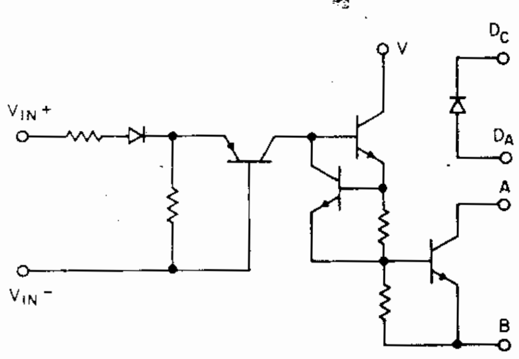


Fig. 7. Schematic of Dionics' power driver.

low-noise output amplifier. Featuring Fairchild's ion-implanted buried n-channel technology, the new CCD211 is offered in a 24-pin DIP.

A high-voltage, high-current power driver designed for use as an interface device between low-power MOS or TTL circuits and higher-power system elements, such as relays, lamps, and actuators, is now available from Dionics, Inc. (65 Rushmore St., Westbury, NY 11590). With an 80-volt maximum rating and the capability of controlling load currents up to 125 mA, the new device, designated type DI-445, has a power dissipation rating of 500 mW and features an adjustable logic threshold voltage. A monolithic silicon device comprising four transistors and several resistors, as shown in Fig. 7, the DI-445 includes an isolated high-current diode for transient suppression when used to drive inductive loads. The unit is supplied in a standard 8-pin plastic miniDIP.

Featuring an aluminum chassis and offering optional two-sided wiring, a versatile new breadboard system is now available from the Vector Electronic Co., Inc. (12460 Gladstone Ave., Sylmar, CA 91342). Designed for solderless interconnections, the new system includes eight *Klip-Bloks* capable of accommodating a maximum of twelve 14- or 16-pin DIP's, or four 24- or 40-pin devices, such as microprocessors and calculator or memory IC's. Additional *Klip-Bloks*, sockets, or discrete components can be added to expand the basic system's capacity. Two versions are currently available: the Model 51X, priced at $25.50 and featuring a 4.5-by-8-inch glass-epoxy board, and the Model 51X-GP, which includes an etched ground plane on the underside of the board for improved high-frequency performance, priced at $29.95.

The Hildreth Engineering Company (P.O. Box 3, Sunnyvale, CA 94088) has added a new member to its family of op amp design instruments, the Quadri QUICK-OP, a four position unit. Featuring 38 quad solderless connectors providing 152 tie-points, the new type is available in two versions, the Model 440-741, which includes four type 741 op amps, and the Model 440-MD, which offers 8-pin miniDIP sockets in each position, permitting the user to work with his choice of devices. Both models are priced at $39.95 each, less batteries.

An exciting new *three terminal* adjustable voltage regulator IC has been announced by the National Semiconductor Corp. (2900 Semiconductor Drive, Santa Clara, CA 95051). Capable of supplying over 1.5 A output current at any output level from 1.2 to over 37 volts, the new device is supplied in *standard* power transistor packages which may be heat-sinked easily using conventional hardware. Functionally, the device comprises a constant current source, a 1.2-volt band-gap reference diode, a voltage comparator, and a Darlington pass transistor. The new IC offers 0.01%/volt line regulation, 0.1% load regulation over its full range, 80-dB ripple rejection, full overload protection, and a minimum input/output differential of 2.5 volts. Two external resistors are needed to set the output voltage. The new IC is offered in three basic versions: the LM117, rated for operation from −55°C to 150°C, the LM217, −25°C to 150°C, and the LM317, 0°C to 124°C. All three devices are available in both TO-3 and TO-5 packages, while the LM317 also is furnished in a TO-220 Epoxy package. ◈