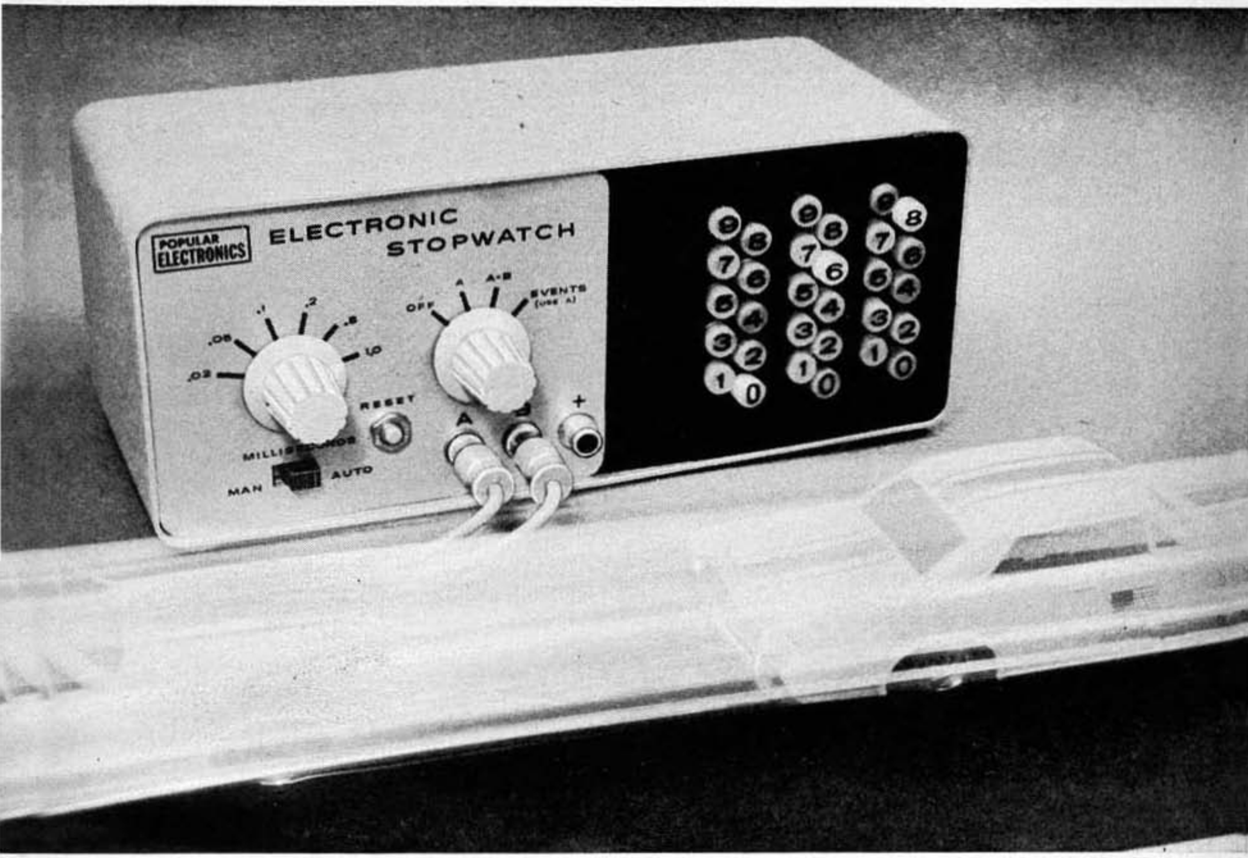


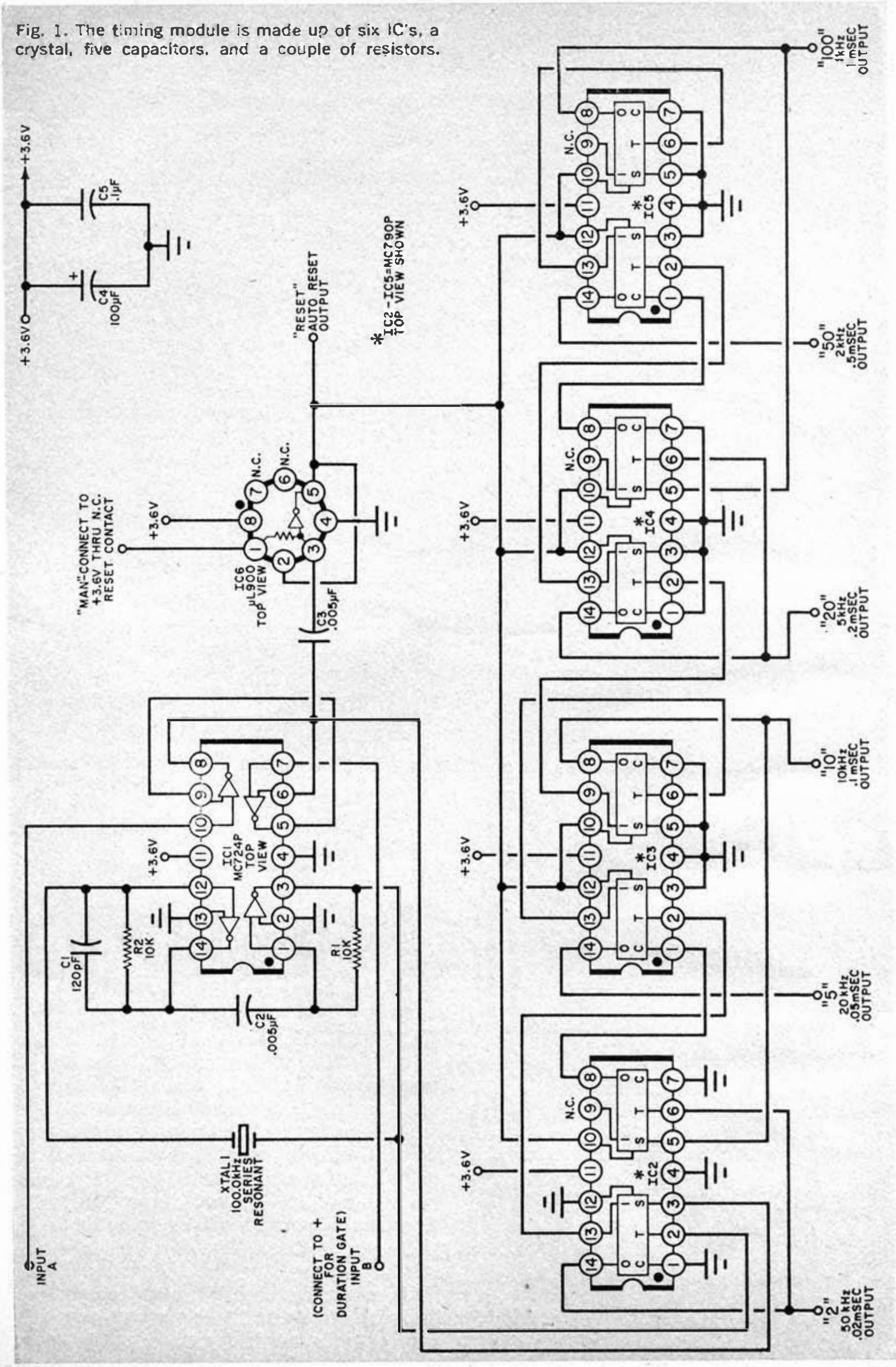
Build Ultra-Fast Electronic Stopwatch

BY DON LANCASTER

USING OUR LOW-COST DECIMAL COUNTING UNIT

PROBABLY the most accurate time measurement instrument ever to be made available to the electronics experimenter, this "Electronic Stopwatch" is a small-size, precision, multi-use instrument that can count events from 0 to 999 at any speed up to 10 million counts per second. It can accurately time the *duration* of any single event with 0.1% accuracy, or it can indicate the time interval *between* two different events with hoth occurring within a one-second time interval—in fact, it can very easily time a speeding bullet in flight!

Fig. 1. The timing module is made up of six IC's, a crystal, five capacitors, and a couple of resistors.



TIMING MODULE PARTS LIST

C1—120-pF, dipped mica capacitor
C2, C3—0.005-µF, 50-volt Mylar capacitor
C4—100-µF, 6-volt electrolytic capacitor
C5—0.1-µF, 10-volt disc capacitor
IC1—Quad two-input gate (Motorola MC724P)
IC2, IC3, IC4, IC5—Dual JK flip-flop (Motorola MC790P)
IC6—Buffer (Fairchild µL900)
R1, R2—10,000-ohm, ¼-watt resistor
XTAL—100.0-kHz series-resonant crystal
1—1/16" x 3" x 3½" printed circuit board—see text
Misc.—Crystal clip (1), small eyelets (2), #22 solid wire jumpers (7), PC terminals (14), mounting hardware, solder

NOTE: The following are available from Southwest Technical Products Corp., Box 16297, San Antonio, Texas, 78216: Etched and drilled PC board, $3.25; complete kit of timing module parts, $24.00.

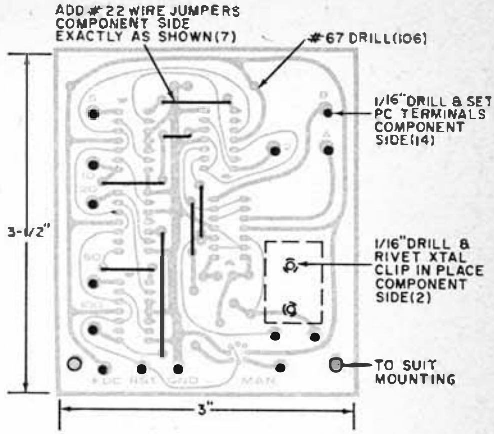


Fig. 3. Drilling guide for the timing module PC board. Mount parts called out on component side.

There are six built-in switch-selectable time resolutions ranging from 20 microseconds to one millisecond; or, you can select external manual timing up to as long as you want. Readout is on a series of three decimal counters (see "Low-Cost Counting Unit," Feb., 1968).

The circuit includes a special synchronizer that prevents any last digit "bobble," while a reset selector allows either automatic or manual resetting of the instrument, or will allow the reading to pile up for long-term accuracy.

If desired, you can add an optional output jack to get very precise one-second timing pulses for use in electronic clocks or other timing applications. You can also scale any input frequency by 10, 100, or 1000, as well as use the instrument as a highly accurate oscilloscope

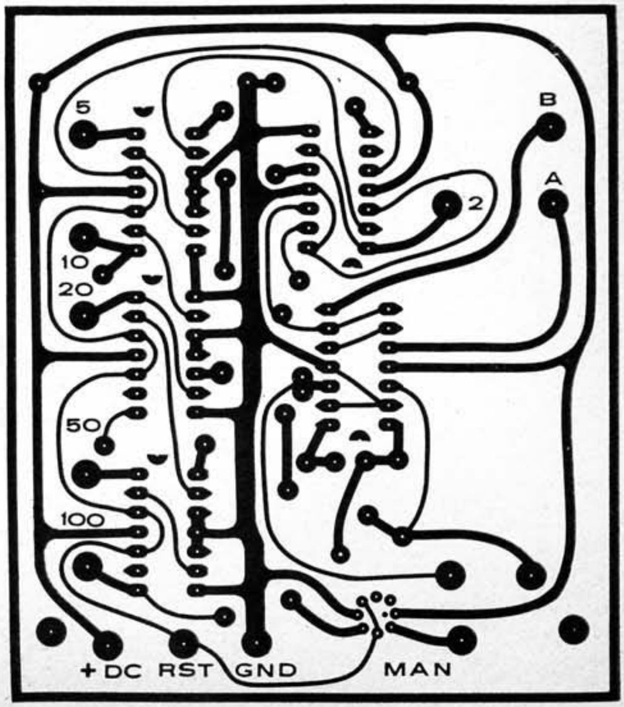


Fig. 2. Actual-size printed board for the timing module. This board is the same size as that used for the decimal counting unit, greatly simplifying the packaging of the completed stopwatch.

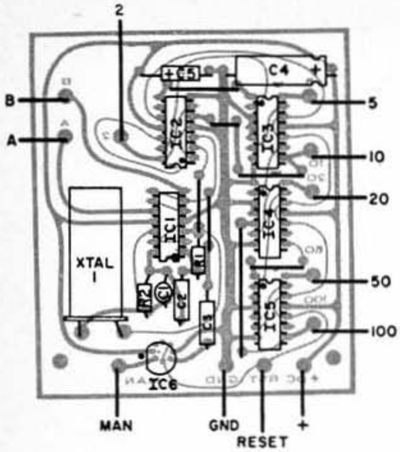


Fig. 4. Timing module components. Observe polarity of the capacitors and alignment of the six IC's.

sweep time calibrator. It even generates random three-digit numbers for contests or probability studies, and it does all this powered by either the a.c. line or a six-volt battery.

Cost of this project? You can build one complete for $50 to $80 depending on how fancy a cabinet and finish you want. Dialplates, circuit boards, and complete kits are available (see Parts Lists). While not a beginner's project. the stopwatch is not difficult to construct; and when it is finished, you will have a piece of test equipment equal in performance to units costing ten times as much.

Timing Module. Because complete construction information for the decimal counting unit was given in the February issue, only the remainder of the "Electronic Stopwatch" will be covered here: the timing module; associated power supply; and all internal switching.

The schematic for the timing module is shown in Fig. 1. As with the decimal counters, because of the complexity of the circuit, the printed circuit board shown actual-size in Fig. 2 should be used. The board should be drilled and the seven wire jumpers installed as shown in Fig. 3. Then, install the components in accordance with Fig. 4.

Use a small, clean soldering iron and fine solder, double-check the orientation of all parts, and make clean solder joints.

POWER SUPPLY PARTS LIST

C1, C2—18,000-µF, 10-volt computer-grade electrolytic capacitor (Sprague 183G010AC or similar)
C3, C4—0.1-µF, 10-volt disc capacitor
D1, D2—1N4001, 1-ampere, 50-volt silicon power diode
F1—0.5-ampere fuse
RECT 1—1.5-ampere, full-wave bridge rectifier (Motorola MDA942-1 or similar)
T1—Filament transformer, 6.3 volts, 1.2 amperes (Knight 54B1419, Stancor P6134, Thordarson 26F60 or similar)
Misc.—1/2" x 3" x 3" aluminum mounting bracket to suit enclosure, capacitor mounting clips (2), fuse holder, small terminal board, pop rivets (4), ground lug, #6 hardware, terminals for C1, C2, wire, solder

NOTE: A complete kit of all the above parts is offered by Southwest Technical Products Corp., Box 16297, San Antonio, Texas 78216 for $11.00 *(plus 2 pounds postage).*

Optional Parts for battery operation

D1—1N4001 diode
F2—1-ampere slow-blow fuse
S1—S.p.d.t. slide switch
Misc.—Fuse holder, rear case terminals and battery connectors, 6-volt automotive storage battery, optional mounting for BATT/A.C. switch

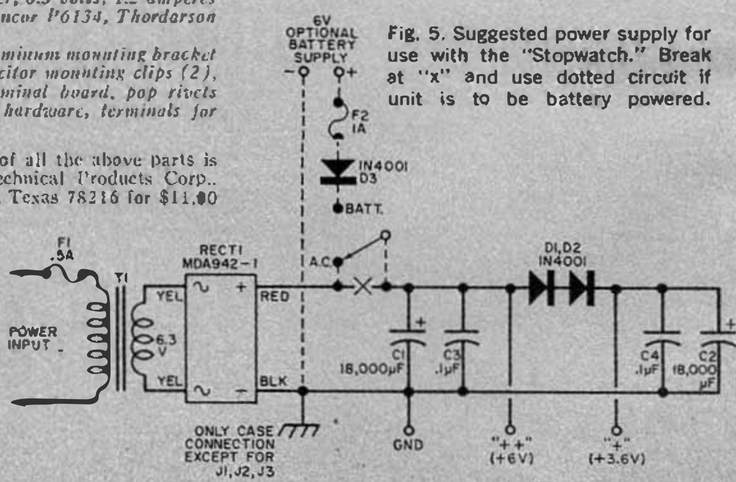


Fig. 5. Suggested power supply for use with the "Stopwatch." Break at "x" and use dotted circuit if unit is to be battery powered.

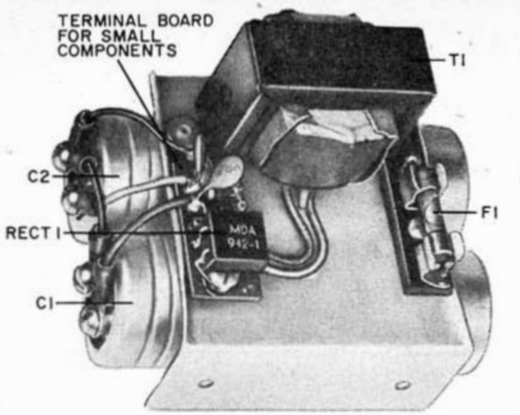


Fig. 6. The power supply is built on a 3" x 3" piece of heavy-gauge aluminum with a 1½" mounting lip.

STOPWATCH PARTS LIST

J1, J2, J3—Phono jack (RCA type)
M1—Electronic stopwatch timing module
M2, M3, M4—Decimal counter module (see "Low-Cost Counting Unit," February, 1968)
M5—Power supply module
R1—47-ohm, ½-watt resistor
R2, R3—1000-ohm, ¼-watt resistor
R4—100-ohm, ¼-watt resistor
S1—Three-pole, four-position, non-shorting selector switch (Mallory 3234J or similar)
S2—Single-pole, six-position non-shorting selector switch (Mallory 3226J or similar)
S3—S.p.d.t. slide switch
S4—S.p.d.t. push-button switch
Misc.—Case, chassis, line cord and strain relief, knobs (2), backup plate for controls, feet, module mounting hardware, trim panel, wire nut, wire, solder

NOTE: Hard anodized aluminum dialplate available from Reill's Photo Finishing, 4627 N. 11th St., Phoenix, Arizona 85014, as Stock ESW-1; in silver for $2.75; red, gold, or copper for $3.25; postpaid in U.S.A.

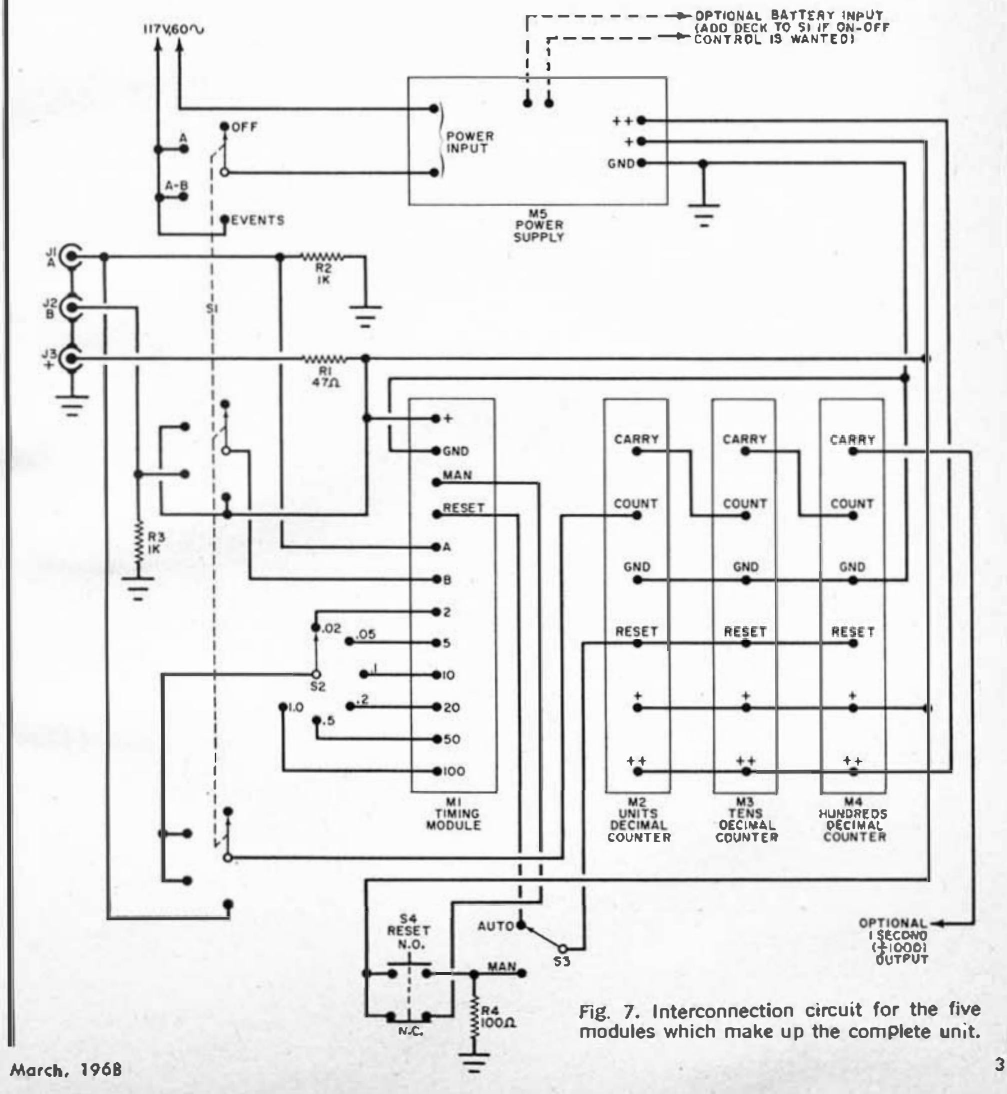


Fig. 7. Interconnection circuit for the five modules which make up the complete unit.

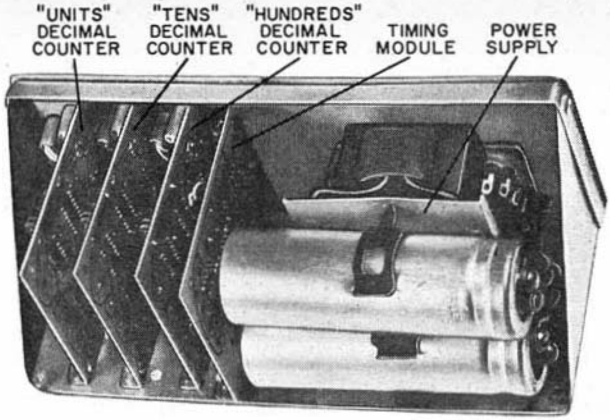


Fig. 8. Rear of author's "Stopwatch" before wiring. Looking from the front, the "units" counter is on the right, the "tens" counter in the center, and the "hundreds" counter at left. Power supply occupies the empty area behind the switching.

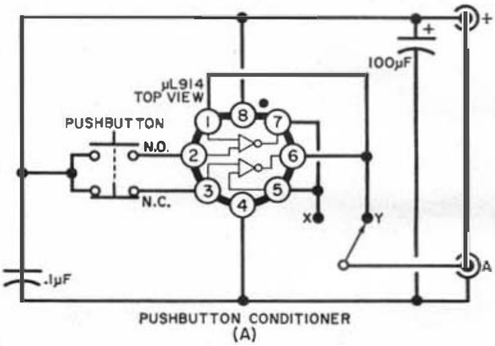
Note that all rectangular IC's are identified by a notch and dot code on one end, while the one round one (*IC6*) has a flat side opposite pin 8.

Power Supply. The power supply has to supply both 3.6 volts (+) and 6 volts (++) at one ampere and with a low ripple. A suitable supply, shown in Fig. 5, consists of a transformer-powered bridge rectifier followed by a capacitor-input dynamic two-diode regulator. Do not skimp on the value of *C1* or *C2*, as the values given are the smallest satisfactory capacitance values.

It is probably best to build the power supply on its own small subchassis, as illustrated in Fig. 6, which is simply an L-shaped aluminum bracket, cut to suit your particular case. Mount all components on this bracket, using a small terminal board to support the smaller electronic components. Make certain that you use only one ground lug (as shown in Fig. 5), and make sure that no other wiring touches the metal chassis.

If you desire the convenience of battery operation (6 volts only), add the circuit shown by the dotted lines of Fig. 5. The power supply circuit must be broken at point "X" and a battery/a.c. selector switch installed so as to switch the filter circuit from either the a.c. power source, or the external battery d.c. source.

Overall Assembly. Figure 7 is the complete stopwatch interconnection schematic diagram. The overall assembly



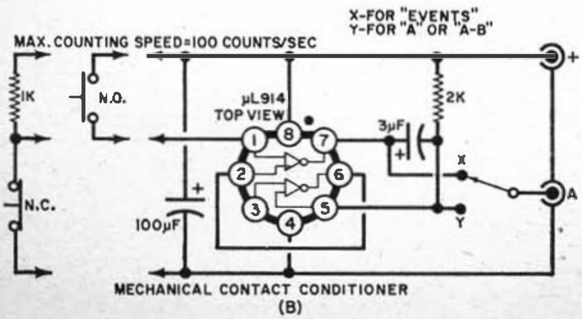
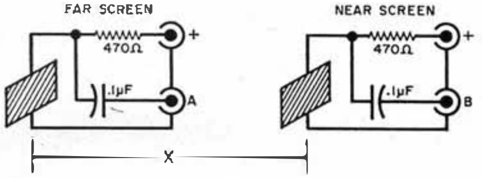


Fig. 9. A push-button signal conditioner is shown above (a), while a mechanical contact signal conditioner is shown at left (b). Both of these circuits provide a bounceless pulse each time they are operated by the external switches.

consists of three decimal counter modules, the timing module, the power supply module, four resistors, four switches, and three input jacks.

Almost any case configuration can be used for the instrument, and the photo on page 27 shows the one used by the author. A commercially available dial-plate (see Parts List) can be used as a layout guide for the front-panel selector switches and input jacks. Figure 8 shows the author's version before the interconnections were made.

Wire the various modules and switches together in accordance with Fig. 7. Use color-coded leads, and note that the deci-



$$\text{VELOCITY IN FEET PER SECOND} = \frac{\text{X IN FEET} \times 1000}{\text{RESOLUTION} \times \text{COUNTER READING}}$$

Fig. 10. For ballistic velocity measurement (vehicle, projectile, or other speeding object), use a break-wire contact. Set the "Stopwatch" in the "A-B" position to make the measurement. Break-wire "A" must be broken before break-wire "B" for correct operation.

mal counters are wired from left to right, viewed from the rear—so that when viewed from the front (in the normal operating position), "unit's" are indicated on the right, "ten's" on the middle, and "hundred's" on the left counter.

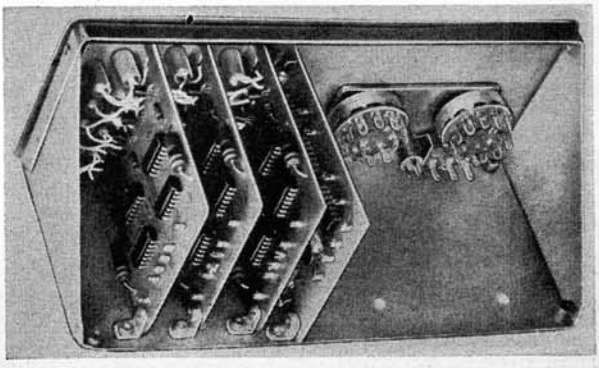
Preliminary Checkout. Once you are sure that all wiring is correct, place the function switch (*S1*) in any position other than "OFF." One lamp in each counter should light. Depressing the "RESET" push button (*S4*) should return all counters to "000."

Place the function switch in the "A" position, and the timing switch (*S2*) in the 1.0 millisecond position. Plug a phono cable into the front-panel "+" jack and touch the other end of the cable (center contact) to the "A" input internal contact. The counters should cycle only *during* the time that this connection is made.

Note that the "unit's" indicator lamps have a dull glow (signifying very rapid counting), the "ten's" lamps flicker slowly, while the "hundred's" counter ripples from 0 to 9 (and repeats) once each second. Rotating the timing switch progressively through the .5-, .2-, .1-, .05-, and .02-millisecond positions produces a corresponding speedup of the flicker on all counters.

Place the function switch in the "A-B" position and "RESET" for all zeros on the counters. Return the timing switch to 1.0 for best viewing of the counters. Using the phono cable, application of the "+" to input "A" should start the counters cycling, and they should continue cycling even after the cable is removed from "A." Inserting the "+" to input "B" should stop the counters.

Place the function switch in the "EVENTS" position, and "RESET" for all zeros. Place the "MAN/AUTO" switch (*S3*) in the "MAN" position. In this mode, the instrument will count once for each time that you apply the "+" to the "A" input. This count will be erratic since there is no way that you can keep from bouncing the contact as you make and break it; this is also why you have



Author's unit before the power supply was mounted and interconnections made. Any other arrangement can be used depending on cabinet available. The dial-plate will give exact front-panel layout, and also has switch position identification.

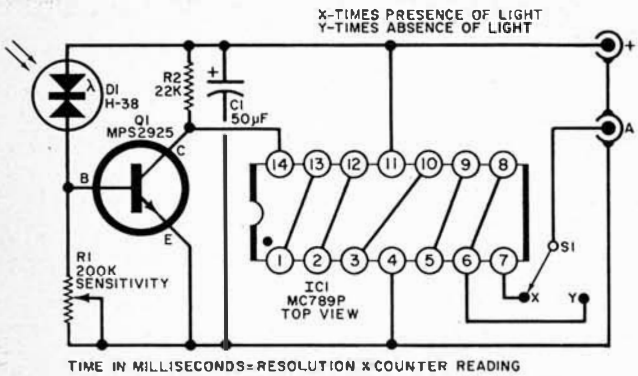
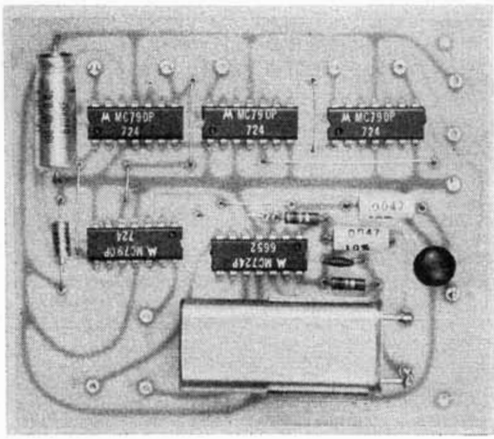


Fig. 11. This high-speed photo pickoff employing a silicon photo-diode is extremely useful in timing fast camera shutters, dragsters, or any high-speed phenomena where a beam of light can be interrupted. The switch permits operation either with presence or absence of light.

PHOTO PICKOFF PARTS LIST

C1—50-µF, 6-volt electrolytic capacitor
D1—Silicon photodiode (Texas Instruments H-38—Do NOT substitute)
IC1—Hex inverter (Motorola MC789P)
Q1—MPS2925 transistor (Motorola)
R1—200,000-ohm miniature potentiometer
R2—22,000-ohm, ¼-watt resistor
S1—S.p.d.t. slide switch
Misc.—Photocell shroud, interconnecting cables, phono plugs, solder

NOTE: A complete photo pickoff kit is available from Southwest Technical Products, Box 16297, San Antonio, Texas 78216, for $8, postpaid in U.S.A.



Top view of the timing module PC board with all components mounted. Connections to the board are made via the PC terminals affixed to the board.

to "condition" all inputs for meaningful measurements.

Signal Conditioning. Proper signal conditioning is a *must* for accurate use of the stopwatch. As the counters "read" each input pulse, the input signal must be bounceless; that is, there must be one, and only one, pulse for each time that the sensor operates.

A signal conditioner for use with a mechanical push button is shown in Fig. 9(a), while Fig. 9(b) shows one method of signal conditioning for use with a mechanical contact.*

Velocity Measurement. For a ballistic velocity meter (bullet or "break-wire" pickoff), use the circuit shown in Fig. 10. In this case, make sure that event "A" stops before event "B" starts, and that the spacing between the two pick-offs is measured to within 0.1% accuracy, if you want your instrument to be that accurate.

If you are going to measure the speed of a bullet, place the first screen ("A" input) far enough from the gun muzzle to avoid blast effects. As the bullet passes through the first screen, it starts the "Stopwatch"—when it passes through the second screen the instrument stops.

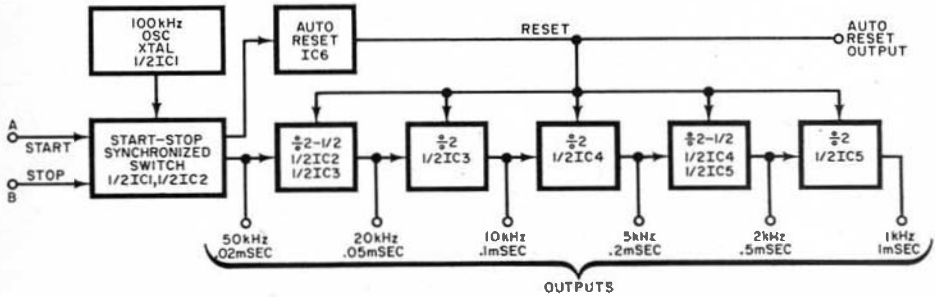
To measure the velocity of a car, or other speeding objects, make sure that the same portion of the object whose speed is being measured breaks both wires. The velocity in feet-per-second for an object traveling between the screens is clearly shown in Fig. 10. For example, if counter resolution is set at .02 milli-

(*Continued on page* 92)

*A few signal-conditioning circuits were shown in Fig. 7 of the "Counting Unit" article which appeared in the February 1968 issue. Figure 7(a) and (b) showed two approaches with mechanical switches, while Fig. 7(c) and (d) illustrated two methods of signal conditioning with sine-wave generators.

ELECTRONIC STOPWATCH

(*Continued from page 34*)



HOW IT WORKS

Operation of a decimal counting unit was described in the February 1968 issue: therefore, only the operation of the timing module will be described here.

As shown above, the basic timing circuit consists of a 100-kHz crystal-controlled oscillator consisting of one-half of *IC1*—two of its four gates are biased to their class-A region and capacitor-coupled to form the oscillator—in conjunction with a 100-kHz crystal. The oscillator output pulses drive a synchronizing switch made up of one flip-flop of *IC2*.

If allowed to run freely, the synchronizer switch would merely divide the oscillator output by two, and drive the remainder of the divider chain. However, a set-reset gate, made up of the two remaining gates of *IC1*, determines how long the synchronizer switch remains open. Operation of the set-reset gate, in turn, is controlled by signals applied to its two inputs—"A" (start) and "B" (stop)—which are located on the front panel of the electronic stopwatch.

A positive-going voltage pulse applied to input "A" will open the synchronizing gate and allow the 100-kHz oscillator pulses to pass down the divider chain until a positive-going signal applied to input "B" shuts down the set-reset gate, thus preventing the oscillator signals from reaching the divider chain. When input "B" is connected to a constant positive voltage source, the set-reset gate becomes a *duration* gate that remains open, allowing the oscillator pulses to pass down the divider only as long as a signal is applied to input "A."

Because the synchronizer switch is basically a flip-flop, it automatically divides the 100-kHz oscillator signal by two, producing a 50-kHz output. (Divide the frequency in kHz into 1 to get the time period in milliseconds; in this case, the 50-kHz output is also the 0.02 millisecond output.) The remaining divider chain produces outputs at 20 kHz (0.05 msec), 10 kHz (0.1 msec), 5 kHz (0.2 msec), 2 kHz (0.5 msec), and 1 kHz (1.0 msec). The final IC (*IC6*) is the reset generator which synchronizes the low frequency outputs and provides an automatic reset signal for the decimal counters.

The 100-kHz crystal may be replaced with almost any other low-frequency unit if a different set of output frequencies (or pulse time intervals) is desired.

seconds, and an eight-foot screen spacing is used (accurate to 1/16"), a counter indication of 162 will correspond to a velocity of 2470 feet per second.

Photo Pickoff. A photo pickoff is shown in Fig. 11. The pickoff selector switch decides whether the "Stopwatch" operates on the presence or absence of light at the sensor. You must use a high-speed photocell for this circuit, as conventional cadmium sulfide cells are too slow for accurate timing. To test the speed of camera shutters, place the counter function switch in the "A" position, and allow the camera shutter to interrupt the light from the light source to the photocell.

For timing dragster or other vehicle races, two photo pickoffs can be used with the "Stopwatch" function switch at the "A-B" position. One pickoff starts the timer at the "A" input, while the second pickoff stops the timer at the "B" input. The elapsed time in milliseconds equals the numerical value on the timing switch multiplied by the decimal counter indication. For example, the timing switch at

MODES OF OPERATION

When the function switch is in the "A" position, the presence of a +3-volt signal at input "A" turns on an internal gate which routes a precise, known reference frequency into the counters for *only* the period of time that the d.c. signal on input "A" is present. The count stops when this signal is removed. The front-panel "MAN/AUTO" switch can be placed either in the "MAN" position to retain the count indication, or in the "AUTO" position to provide automatic clearing at the beginning of the next measurement: or the counters can be set to zero by manually depressing the "RESET" push button.

If the function switch is placed in the "A-B" position, the application of a positive-going pulse at input "A" will start the counters operating. The counters keep on operating after the stimulus has been removed from input "A" until a positive-going pulse is applied to input "B." The electronic stopwatch will then indicate the time interval between these two events.

When the function switch is in the "EVENTS" position, properly conditioned positive-going input pulses applied to input "A" are connected directly to the cascaded counters. Each input pulse advances the counters one step and the total count at any time will appear on the counter readouts. The "AUTO/MAN" switch should be set to "MAN," or the counters will reset to zero at each input pulse. The counters can be manually zeroed at any time merely by depressing the "RESET" push button.

The recorded time in milliseconds is determined by multiplying the indicated numerical value by the value of the time switch position. For example, assume that the readouts show 765 and the time switch is in the 1.0 position. The actual time value is then 765 milliseconds or 0.765 second.

To calibrate the sweep time of an oscilloscope, extract the desired timing pulse from the stopwatch timing module printed board and apply this signal to the scope vertical terminals. For example, if it is desired to calibrate the scope horizontal sweep in milliseconds per centimeter (or inch, or graticule marker), use the "1 msec" output of the board (see Fig. 1). As these pulses are one millisecond apart, the scope horizontal sweep circuit should be adjusted until one timing pulse lies on the desired graticule markers. For other speeds, select the appropriate timing output of the module.

To generate random (to three digit) numbers, place the function switch in the "A-B" position and apply a positive-going pulse to input "A". The timing switch should be placed in one of the faster speeds, so as to blur the decimal counter indicator lamps. At some random time after starting the timer, apply a positive-going pulse to the "B" input to stop the counting.

1.0 millisecond and the counters at 725 means a total time value of 725 milliseconds or 0.725 second.

If desired, the optional one-second output line in Fig. 7 can be used to drive an external "seconds" counter. -30-

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