Construction project:

Super Timer

Here's a low cost but very flexible 4-digit timer which can be used to measure intervals from a few microseconds to hundreds of seconds. Very handy for checking times and speeds involved in all sorts of physical events – like the speed of a slug from an air rifle, or the time your camera shutter stays open for each shutter speed.

by IAN PAGE

Ever wanted to measure the speed of a bullet, a golf ball, or a snail? The timer to be described will measure intervals of time ranging from microseconds to 999.9 seconds, with an accuracy equal to that of the timebase plus or minus 1 digit. A four figure display provides good resolution with high accuracy when ultra short times are being measured.

Three types of inputs are provided: a START/STOP input T1 which can be used to measure, for example, the ON period of a 555 timer; or T2 and T3 which provide separate inputs for start and stop signals. Input C accepts a clocking impulse (suitably conditioned) to operate the display as a 1-9999 counter. A six position switch permits a suitable timing range to be selected at will.

While the high resolution possible may not be required for most applications, it does provide the born experimenter with the means to make all kinds of timing measurements with which to amaze his friends, or satisfy his own curiosity. The scope of these depends upon the ingenuity displayed in the design and construction of various triggering devices required to start and stop the timer.

For instance, the author, having purchased a high powered air rifle, wished to check the maker's claim of 280m/s muzzle velocity. Having decided upon a method of triggering the timer, the construction of the timer itself became a matter of providing the required accuracy. Need for an accurate timer for the work bench gave additional justification.

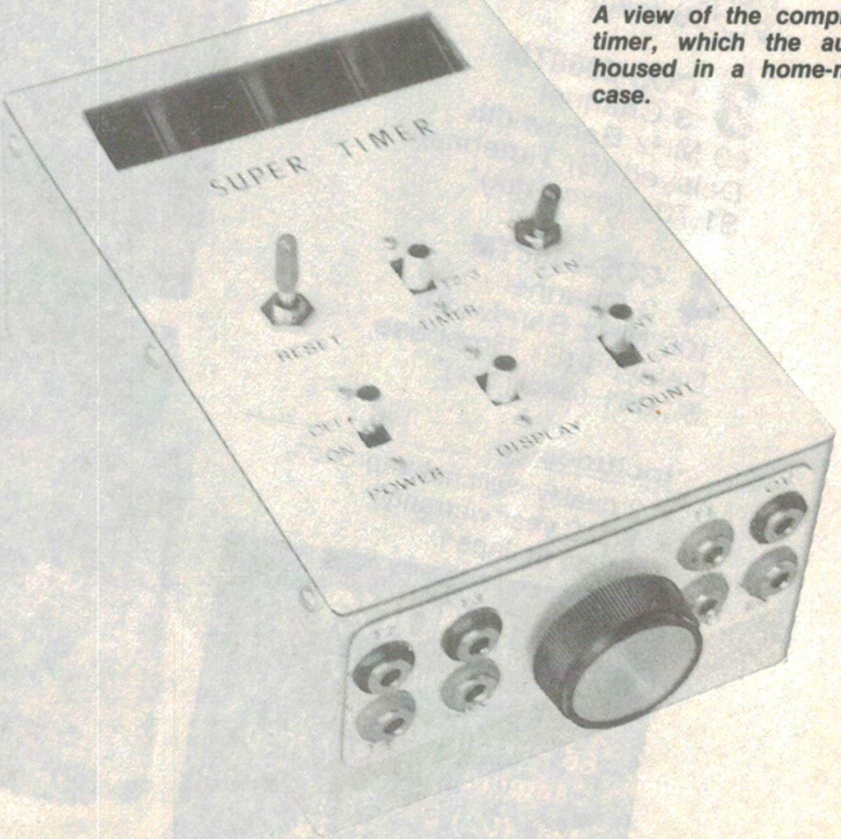
For those interested in the bullet speed measurement a description of the trigger device used is given at the conclusion of this article.

How it works

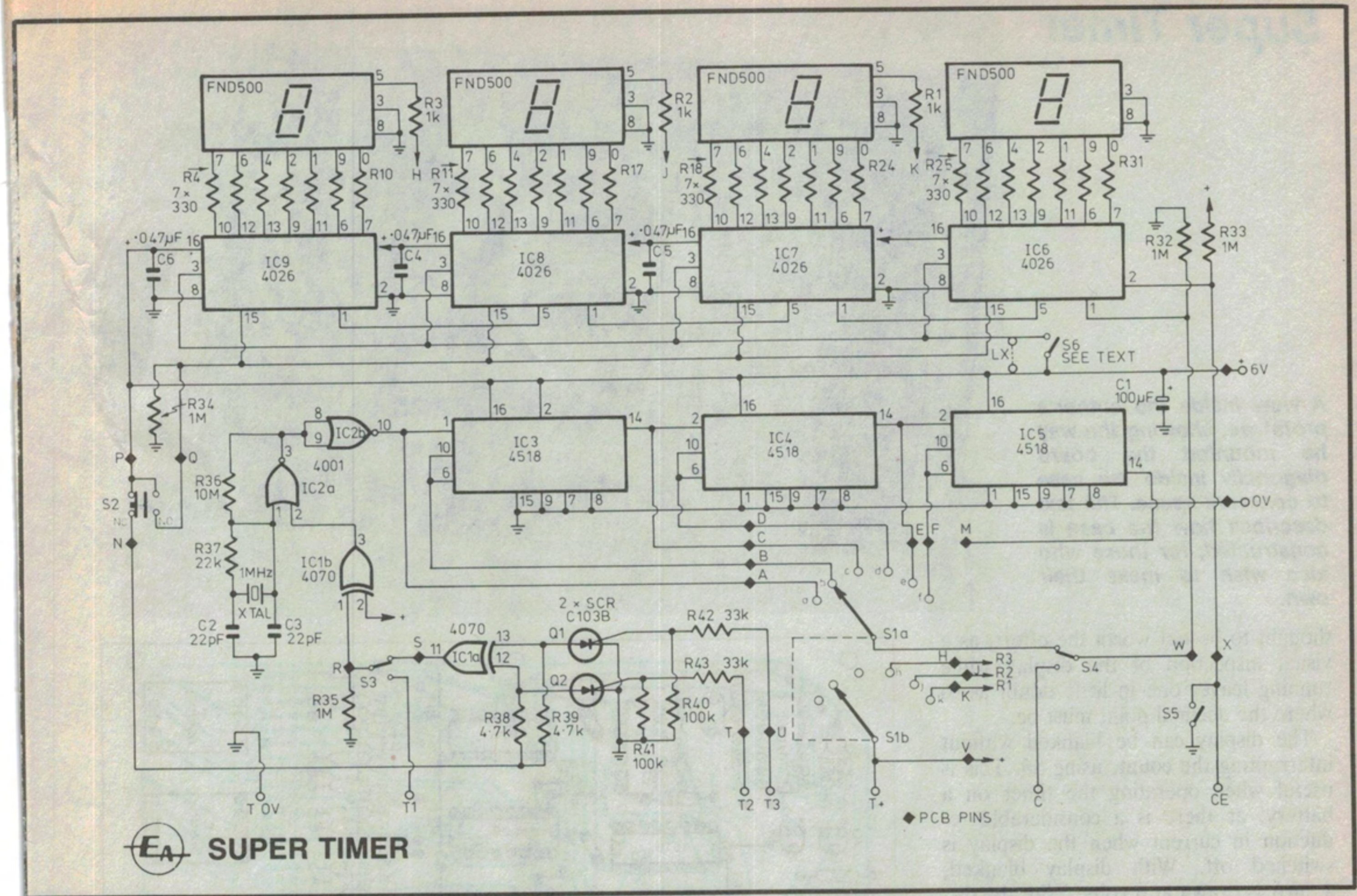
Basic accuracy results from the use of a crystal oscillator. This comprises a 4001 NAND gate with resistors, capacitors and 1MHz crystal forming a tuned network. The dividing string consists of three 4518 dual decade dividers (ICs 3,4 and 5). At each decade, commencing with the oscillator, an output is taken via a six-way selector switch S1a and switch S4 to the clock input of a counter, using four 4026 counter/display drivers (ICs 6-9).

Control of the timing period is obtained by disabling the oscillator via pin 2 of IC2a. If this pin is held low the oscillator runs. When taken high, it stops. Control at this point ensures that maximum accuracy of count is achieved.

There are two timing inputs: T1 is used to measure the duration of an output, such as a 555 monostable. When T1 is switched in via S3, it is held low by R35. A HIGH received at T1 will cause the output of EX-OR gate IC1b at pin 3 to go LOW, thus enabling the



A view of the completed timer, which the author housed in a home-made case.



The complete circuit of the timer, which can be used to time a wide variety of events.

oscillator. When T1 goes low the oscillator stops. 1MHz clock pulses are divided (counted) by the decade dividers, whose output is drawn off at the desired frequency by S1a, from which the pulses are taken via S4 to pin 1 of the counter display IC6 and thence down the counter chain to IC9.

Inputs T2 and T3 are used when separate start and stop signals are required to time extremely short intervals, or when the two trigger points are individually controlled, such as, for example, when timing a slot car, or the speed of an arrow. These terminals require HIGH signals, to fire the thyristors Q1 and Q2 which first must be switched off by using push switch S2 to momentarily disconnect supply to them.

If a HIGH signal is received at T2 or T3 (it doesn't matter which) the corresponding thyristor will fire, taking its load resistor R38 or R39 to ground. With one input HIGH and the other now LOW, the output of EX-OR gate IC1a at pin 11 will go HIGH, taking pin 1 of IC1b HIGH. Since pin 2 of this gate is tied to the positive rail, output at pin 3 will go LOW, thus enabling the oscillator.

When a HIGH signal is received at the other input terminal T2/T3, the second thyristor will fire, taking its load resistor to ground and causing the other input pin of IC1a to go LOW. This will result in pin 3 of IC1b going LOW, thus disabling the oscillator.

The use of thyristors to start and end the timing period rules out any possibility of false or ragged triggering inputs resulting in faulty readings.

Terminal C allows an external count signal to be applied via S4 directly to the clock pin 1 of IC6, thence to the remaining counters. For counting to commence, pin 2 of IC6 must be held low. Normally it is kept high by R33, but switch S5 when closed grounds it and allows counting to begin. S5 must be kept closed for all timing operations. For counting, it may be used as an ON/OFF switch, or alternatively, it may be left open and the count enabled by an external switch connected at terminal CE.

TABLE 1
MEASUREMENT RANGES

Switch Position	Time Range
A	0 – 9.999 ms
B	0 – 99.99 ms
C	0 – 999.9 ms
D	0 – 9.999 seconds
E	0 – 99.99 seconds
F	0 – 999.9 seconds

Table 1: The 6 measurement ranges.

Timing ranges

It should be noted that the contacts of switch S1a are identified by letters which represent timing periods as shown in Table 1.

A connection to pin 14 of IC5 is provided (referenced by letter "M"), at which point a 1Hz pulse is available which can be used as a one second standard clock signal – or, if desired, switched through the six position switch in lieu of one of the other frequencies.

The second pole of the 6 way switch (S1b) is used to switch in the usable decimal points on the display, giving readings of xxx.x, xx.xx, and x.xxx seconds. The provision of decimal place indications for the higher frequencies was

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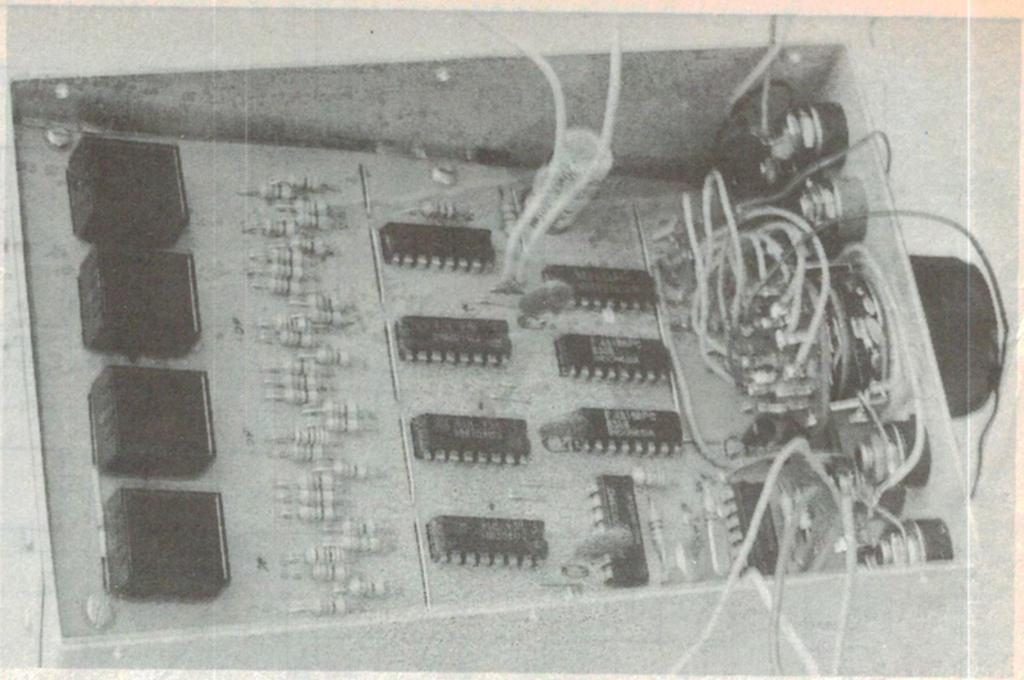


A view inside the author's prototype, showing the way he mounted the board diagonally inside the case to conserve space. The text describes how the case is constructed, for those who also wish to make their own.

thought to be not worth the effort, as a visual inspection of the display while running leaves one in little doubt as to where the decimal point must be.

The display can be blanked without interrupting the count, using S6. This is useful when operating the timer on a battery, as there is a considerable reduction in current when the display is switched off. With display blanked, 4.5mA is drawn at 6 volts. With the display ON, consumption is about 120mA.

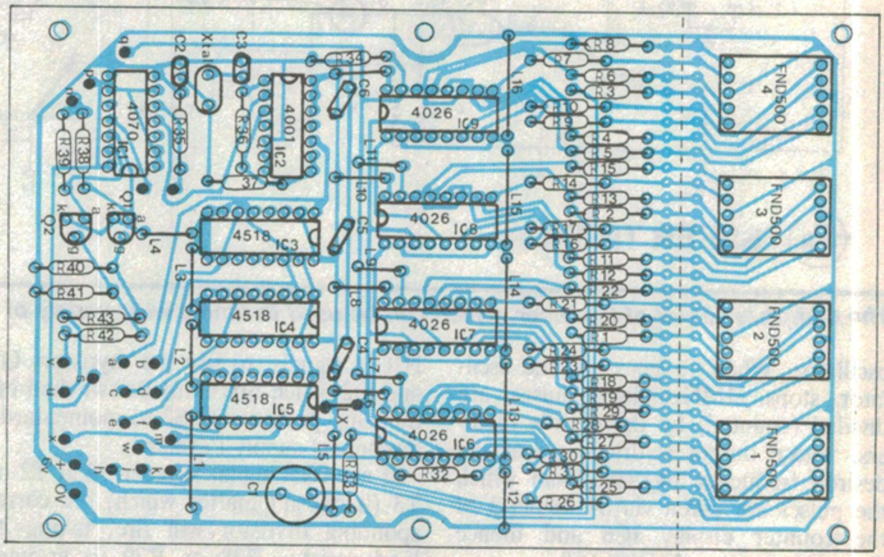
Where power consumption is not a problem, the blanking switch S6 can be omitted. In this case the link LX must be fitted. If the switch is used the link is left out.

The display need only be read at the conclusion of the timing period. Switch S2 is a momentary action 2-pole changeover which serves two purposes. When pressed it (a) resets the display to zero, and (b) resets thyristors Q1 and Q2 to the OFF state.

Resetting of the display is done by making the reset pin 15 of each counter/display driver HIGH momentarily by closing the NO contacts of S2. Also, when S2 is operated, the NC contacts disconnect power to Q1 and Q2, causing them to reset to their OFF state.

Oscillator

The quartz crystal should not be very far off the nominal frequency, but if it is, a moderate adjustment can be made by altering the value of C2 or C3. Use of a frequency counter is helpful but can introduce its own (unknown) error. In the following section reference is made to this and a method of determining the accuracy is given.



The PCB overlay diagram, showing the location of all components. Take care with the polarisation of all ICs, also the LEDs.

Construction

Some thought must be given as to how the board and controls are to be housed. This will depend upon whether the unit is to be used indoors, outdoors, or both, and for what purpose.

If to be used outdoors, a battery supply must be considered. In this case, it is advisable to fit the display switch S6 so as to conserve battery power. If power consumption is not an issue, omit S6 and fit a link in the PC board at this point.

If the timer is to be used only for fairly short intervals, four AA cells should suffice. In this case, they could be mounted in the project box.

Next you'll need to tackle the problem of keeping it all compact while at the same time providing room for switches and plugs, and their connections. And last but not least, how is the display to be made visible. Separating the display section from the main section involves extra work in reconnection and should be avoided if possible.

In the author's version, the problems were solved by mounting the PC board at an angle to the horizontal so as to provide room under the display end of the board for a 4 x AA battery holder. At the other end, the tilted PCB also provided room to mount the rotary switch and six input sockets above the board – see Fig.1. An extra socket was provided to give a connection to the 1

A trigger for camera shutter timing

Used in conjunction with the Super Timer, this device will check the speed of shutter settings on cameras with focal plane or between the lens shutters, provided that the film window at the back of the camera is accessible. Modifications to the size of cover plate (see drawing) may be necessary to adapt to smaller or larger film windows.

The cover plate (60 x 38mm or as necessary) should be made of an opaque material – PCB with the foil intact is ideal. Make the tube by rolling a strip of 30mm wide paper on a 7/32 or 5.5mm drill shank, pasting adjoining layers together until a thickness of about 3mm is built up.

The tube material MUST be opaque and it may be necessary to add a final layer of aluminium foil or black paper. A metal tube of the right bore is ideal. Use a fine paint brush to paint the inside of the tube a matt black. Indian ink or poster paint is suitable for this.

Now cut a piece of strip board 50mm long and five tracks wide, and remove all five tracks for a distance equal to the diameter of the tube. Work out a suitable layout for the circuit wiring shown and mount the resistors and BC557. Now turn the circuit board upside down and hold it firmly in a vice with the board horizontal. Place the photo diode with its leads pointing downwards thorugh holes in the blank end of the board, splay the diode leads out a little to keep it in place, and use Araldite to cement the tube to the strip board as shown.

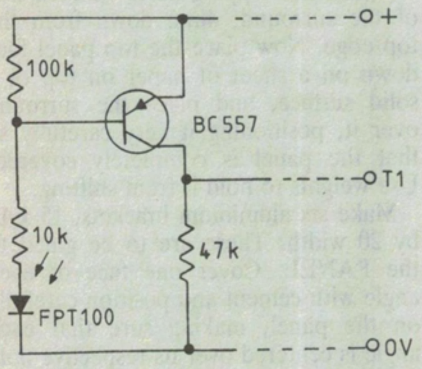
When the cement is set, remove from the vice, and cement vertically to the cover plate as shown. See that the tube does not project through the plate by more than 1mm, or damage to the shutter could result.

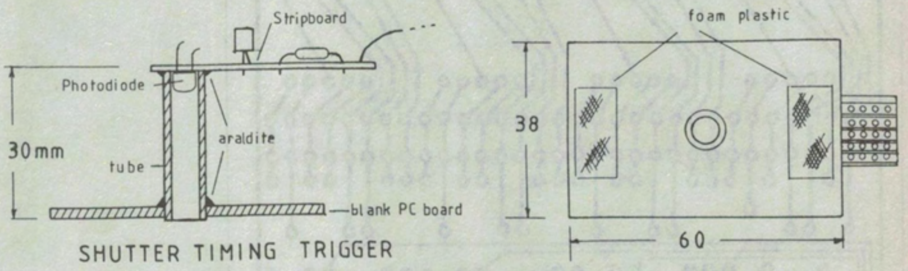
Check the polarity of the FPT100 photo diode and connect to the strip board with short leads. It is important that the diode cannot pick up light entering the back of the tube, and it may be necessary to block any small opening with black paper, pierced for the diode leads. Now connect three flexible leads to the strip board, and solder banana plugs to their ends to allow connection to the timer as shown.

Plug in the timer and check that, with the leads connected correctly, the timer switched ON, and the device held flat against a table, for example, the timer does not begin to count. Raising the plate to allow light to enter should start the timer. It should be appreciated that light is striking the diode from a comparatively small opening, and therefore the tube will need to point at a fairly bright light source.

With the camera set on full aperture, and the back open, hold the device over the film window, set the timer to zero, and with the camera pointing at an open window or bright light, trip the shutter.

To judge how the shutter markings compare with measured time, it is advisable to first convert the fractional shutter speeds to decimal, for example, 1/60=0.0166, 1/125=0.008 and so on. While marked shutter speeds are not exact, there can be wide differences between nominal and measured speeds, due perhaps to the age of the camera. This can be important particularly in the case of 1/60 sec, which speed is almost invariably used for flash photography.





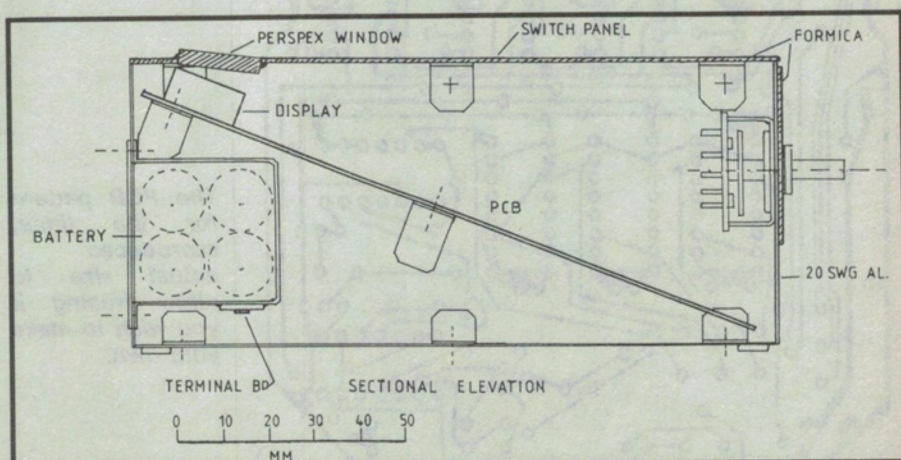
Above: Details of the author's adaptor for measuring the speed of a camera shutter. The tube needs to be opaque to light.

second clock output, reference "M" on the wiring diagram.

20 swg aluminium sheet was used for the author's case, the box size being 142 x 98 x 62mm depth. Screws are self tapping, #4 x 5mm.

A strip of metal 62mm wide is bent into a rectangle of the above dimensions, the ends butting at the centre of the near end. Use high strength Araldite to cement a 58 X 25mm lap vertically over the joint, on the inside, to provide strength.

Note that the length of this lap piece is less than the height of the box, so that it can clear the bottom which will fit within the rectangle formed by the sides. Angle pieces, three per side are



A detailed drawing of the author's case construction, to scale.

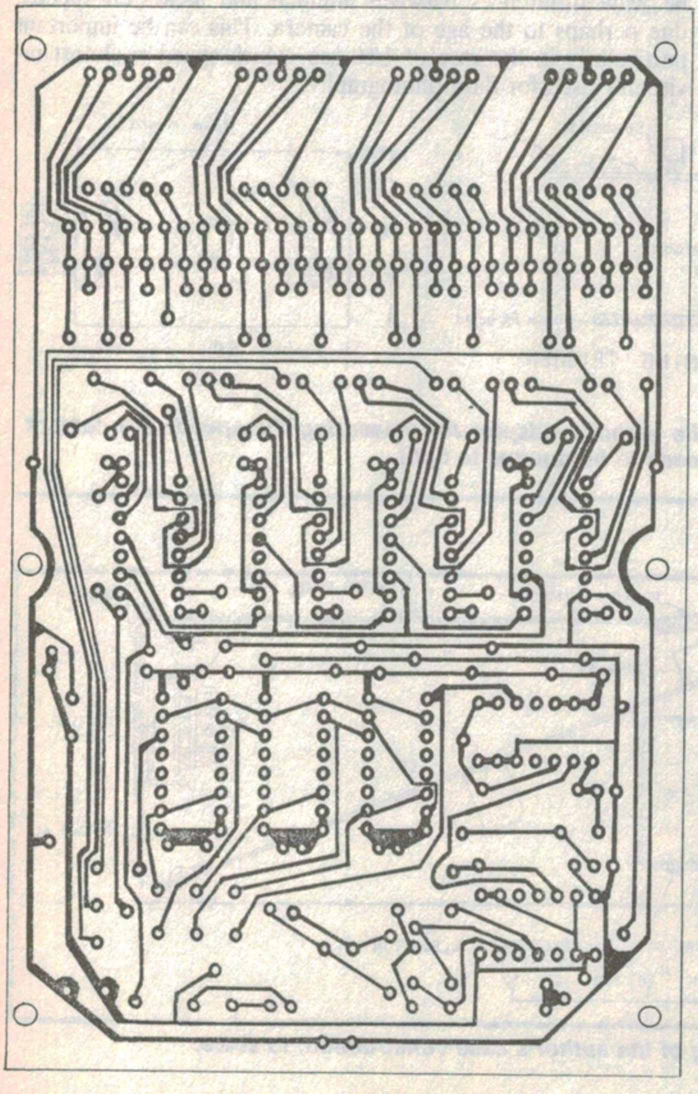
cemented to the sides with the bottom in position so that when finished the bottom is flush with the sides. Allow 24 hours for the cement to harden, then drill and fasten. Attach rubber feet, such as discs cut from an old inner tube. These should be thicker than the screw heads.

The front panel was made from a piece of white matt Formica veneer which readily accepts lettering, and has an attractive appearance. Cut to the exact dimension of the box, mark out and drill for the switches, using a small square file to form rectangular openings where slide switches are used. Don't cut out for the display at this stage.

Fitting the PCB

It has been mentioned that by fitting the board in an inclined position, a very compact arrangement can be achieved. To do this, lay the box, with bottom removed, on its side, and place the PCB on edge in the box, with its lower end against the front (socket end) and resting on the bottom if this were in place. The top (display) end of the board should be located so that the top edge of the display is about 2-3mm below the lower surface of the panel when fitted. Wedge the board in position, and with a pencil mark the position of the under surface of the board to each side, and mark the position of the upper and centre mounting holes of the PCB. The lower holes will not be used as they will not be accessible with wiring in place.

Make four angle pieces, 10mm wide. The side of the angle which is to be cemented to the box should be 20mm long, to give adequate gluing area. The other side, which is to be drilled for mounting the PCB, should be just long enough, but not so long as to bridge any track on the PCB. It doesn't matter if it contacts the 0V track at the outer edge of the board. You can trim up the length of each bracket with a file later, if you are careful. When the cement is set, drill tapping holes in each bracket and fit the PCB temporarily.



The PCB pattern for the timer, reproduced actual size to allow tracing if you wish to make your own.

Display window

With the PCB in place, lay the panel on top of the frame and transfer the position of the display to the top of the panel. Allow for the fact that the display will probably be read from an oblique position and the window should be deep enough to allow this. In the project as made, an opening 75 x 18mm was satisfactory.

The opening can be filled with some clear plastic, or, to provide a nice touch, use some thick clear acrylic, 4-5mm thick. Cut it to be a push fit lengthwise in the opening and tilted so that its lower back edge is flush with the underside of the panel while its upper front edge is flush with the upper face of the panel.

With the panel inverted run a thin line of Araldite along each of the sides, but be careful not use enough to be visible from the top. With the transparent cover at a similar angle to the PCB there is a particularly good view of the display.

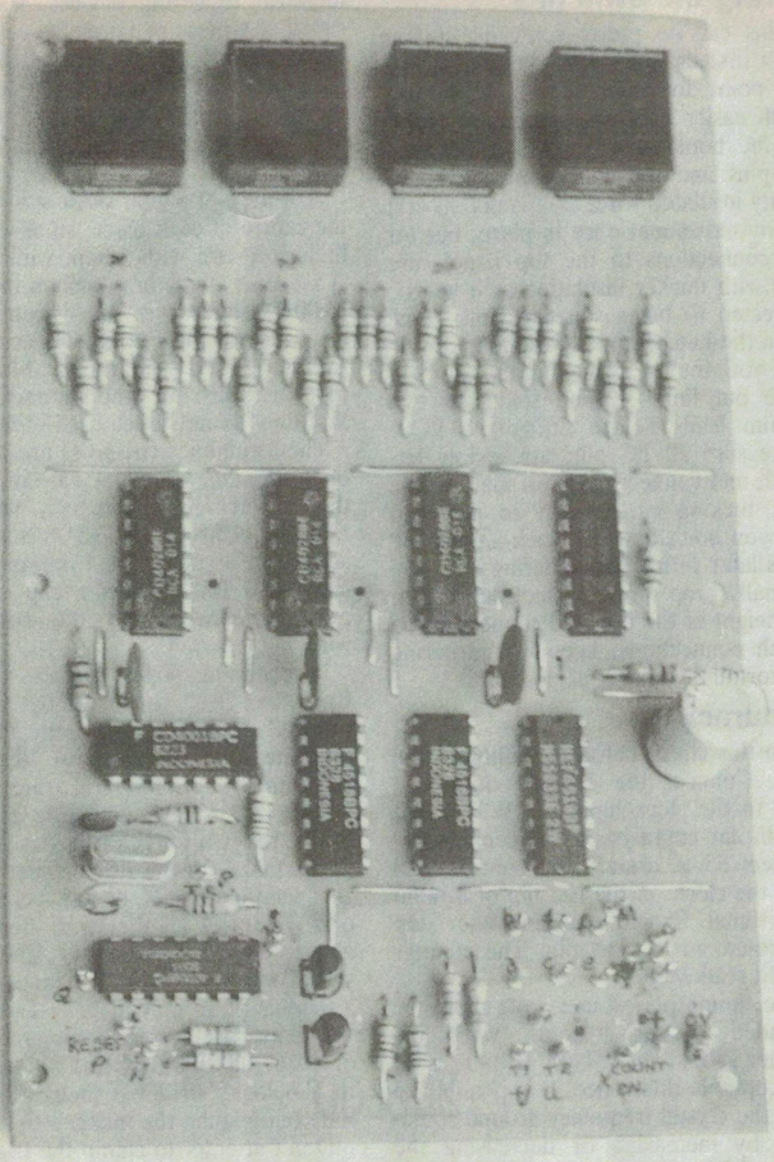
Fitting the panel

Drill three tapping holes on each side of the surround, 4mm down from the top edge. Now place the top panel face down on a sheet of paper on top of a solid surface, and place the surround over it, positioning it very carefully so that the panel is completely covered. Use weights to hold it from shifting.

Make six aluminium brackets, 15 x 15 by 20 width. These are to be glued to the PANEL. Cover one face of each angle with cement and position carefully on the panel, making sure that each angle is centered over its respective hole in the sides of the surround. Don't use excessive Araldite, otherwise it is likely to run on to the side pieces. Or worse still, if you haven't used a sheet of paper, you may find the whole thing firmly attached to the mahogany dining table.

Make sure that each bracket is pressing closely against the side walls. Check that there are no unwelcome glue attachments, and give plenty of time to set. With the panel in place, use a tapping drill to mark the position of the hole on each bracket, then finish drilling while holding the bracket in the vice to avoid undue strain on it. Now open the holes in the sides with a clearance drill. Voila!

Although not absolutely necessary, the white Formica used for the top panel makes a nice overlay for the end of the box containing the rotary switch,



A look at the PCB with components added, to help in assembly. Sorry for the fuzzy shot, but it's all that the author could provide.

and makes labelling easy and effective. Cut a piece of Formica a few millimetres smaller than the end of the box, mark if for switch and sockets and clamp it to the end of the box. Then drill through the two parts. It is not necessary to glue the panel in place, and the components will hold it in position.

Battery compartment

Note that the following relates to the use of a four AA holder with the four cells in a square configuration.

At the display end of the box, cut a rectangular opening with its lower edge about 7mm from the bottom of the box. The height of the opening should be 2-3mm greater than the battery holder with AA cells in place, and longer than the holder by about 15mm.

Make up a small four-sided box from aluminium (don't bother to join at the corners) into which the holder will fit neatly as regards height and depth. When making the box allow sufficient depth to bend a flange of 5mm on all four sides, and drill a largish hole in the back at one end for the battery leads.

When the box is made, fasten the PCB temporarily in place and make sure that when the battery box is in position there will be at least 3mm clearance from the printed circuit. When ready, cement the box flanges and clamp it to the frame until set. A cover plate completes this part of the operation.

On the underside of the battery box glue a small 2-way terminal board, on which to terminate the leads from the battery holder, and from which heavier flexible leads will be taken, (a) the positive lead to one side of the panel ON/-OFF switch, and (b) the negative lead to 0V on the PCB. These leads can be taken through the small gap between the side of the PCB and the box sides, or, if preferred through small holes drilled through the PCB.

Note: If Araldite is used where suggested, prepare the surfaces before cementing by scoring a criss cross pattern with a sharp pointed file, or coarse sandpaper. If properly carried out the aluminium will bend before the joints give way.

Wiring

First check the PCB tracks for shorts and discontinuities, and fit PC pins at +6V and 0V points. Solder in all the links, with a temporary link at LX (see above). Put power on and check with meter or buzzer that power exists between pin 16 and the 0V pin of each IC position. Now solder in resistors R1-R31, noting that R1-R3 should be 1k. Fit the four displays and with a 330 ohm resistor (for safety) in series with a 6 volt supply, connect the 0V lead and run the positive lead along the bottoms of the resistors, checking that each segment of the display lights as its associated resistor is energised.

Now solder in IC6 and power up. If all is well, display No 4 should show a figure, usually a "0". Carry on fitting IC7-9, testing at each stage to see that each display lights up. Systematic progress checks like this can save an awful lot of strife at the finish.

Fit all the remaining resistors and PC pins at "W", "X" and "Q". With power ON, ground "X" and introduce a few positive pulses at "W". The display should show a reading. Then touch "Q" with a positive test lead – the display should reset to zero.

Assuming everything is normal up to this point, the oscillator section can be commenced by fitting IC2, C2 and C3, and the 1MHz crystal. Unless you have access to an oscilloscope or a frequency counter, it will be difficult to determine if the oscillator is running.

Take a temporary lead from pin 10 of IC2 to PC pin "W", power up and ground display enable "X" – the display should show 8888.

Alternatively, solder in all remaining PC pins, and the IC's 3-5. Connect "M" to "W", ground "X" and power up. The display should count in seconds. In turn, connect "W" to each of the pins "F" to "A", checking that counter speed increases at each change.

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If all is well, mount IC1, and Q1-Q2, and connect P-N with a removable jumper. Also connect F to W and R to S (temporarily). Power up, separate P-N momentarily to reset Q1-Q2, and touch a jumper between T and V. The counter should begin counting in 1/10 seconds. Make a brief connection between U and V, and the counter should stop. The thyristors are reset by opening the link P-N for a moment.

After testing all functions to ensure that everything is OK, the unit can be mounted in its enclosure and the various switches connected, Banana plug connectors are used to bring timing and control signals into the box.

PARTS LIST

1 PCB measuring 145 x 90mm
4 AA cells (see text)
1 4 x AA holder (see text)
1 6 way 2 pole rotary switch and knob
1 momentary contact SPDT or DPDT switch
2 SPDT or DPDT switches
2 SP on/off switches
1 1MHz quartz crystal (PCB mounting)
1 on/off switch if internal battery is used.
OR...
1 panel plug and socket for external battery.
7 4mm banana sockets, and plugs to suit

Semiconductors

1 4001 quad NAND gate.
1 4070 EX OR quad gate
3 4518 dual BCD up counters
4 4026 decade counter/decoders
2 C103B silicon controlled rectifiers.
4 FND500, or similar, 7 segment displays.

Capacitors

1 100uF 16VW PC electrolytic
2 22pF ceramic
3 47nF ceramic

Resistors (0.25W, 5%)

3 x 1k (R1-R3)
28 x 330 ohms (R4-R31)
4 x 1 megohm (R32-R35)
1 x 10 megohm (R36)
1 x 22k (R37)
2 x 4.7k (R38-R39)
2 x 100k (R40-R41)
2 x 33k (R42-R43)

Miscellaneous

22 1mm PC pins solder, tinned copper wire hook up wire.

Wiring the switches

This can be pretty confusing if you don't first draw a rough sketch showing the point to point wiring. It is also much easier if several colours are used for the hook-up wire. Wiring between PC pins and the end panel can be of lightly insulated wire, as it is not subject to any movement once in place, but for the connections to the top panel, use wire with thicker insulation as it will be subjected to being squeezed into place when the hatch is finally clamped on.

If you intend switching the display, leave out link LX and solder in two 100mm leads before fitting the PCB. Make sure all PC pins are legibly lettered, and connect the most inaccessible first, tucking each neatly in place so that you don't have to reach among the wires later with a hot soldering iron.

Finally prop the top panel on edge at the height of the box and connect in the switch connections, keeping the wiring as short and compact as possible.

Accuracy

Do this check before installing in the case. Connect the seconds output at "M" to the clock input at "W" so that the display counts seconds. Temporarily connect S5 as a start-stop control, and start the clock on the last pip of a radio time signal. Exactly one hour later stop the count on the last pip. The counter should read 3600.

The timing period can quite easily be extended to, say 4 hours, when the counter should show 4400. If there is an unacceptable difference, it is possible to push the crystal frequency around somewhat by increasing or decreasing the value of C2 or C3.

The author found it necessary to increase C2 to 100pF to shift the cyrstal frequency from a frequency meter reading of 1000070 to 1000004.

Testing as described, and using 22pF capacitors as specified, there was no observable difference between the radio time and displayed time, and no adjustment was necessary. It is unlikely that the frequency of any crystal oscillator would be so far off nominal as to prejudice the value of this timer for most practical purposes.

Making measurements

At the commencement of this article, mention was made of a measurement of bullet speed (actually an air-rifle slug), as an example of the very short time intervals which can be measured with this timer. Here are the details.

The apparatus used to measure the speed of an air rifle slug comprised two identical triggering devices. Each consisted of a piece of Formica veneer 1/16" thick, 100mm square.Alternatively, stiff cardboard can be used. It is much easier to cut out, but not so durable or rigid, and must be kept perfectly dry to avoid leakage.

A square of 80mm sides was cut from the centre of each piece, so as to form a hollow square with 10mm wide border. A piece of aluminium kitchen foil 90mm (0.001") square, is taped centrally to each face of the Formica so as to allow a 5mm distance all round. Make sure that the foils are smooth and flat, so that they do not touch each other.

The assemblies (triggers) are mounted on a wooden or metal batten, so that they are at right angles to it, and separated by a distance of 12" (measured as accurately as possible). Contact is made with each foil by spring clip or other means, connected to the connecting wires.

A common power supply is taken from the "T+" socket of the timer to one foil of each trigger unit, while the opposite foils are taken to T1 and T2 respectively. If the foils are spaced about 1/16" apart, the rifle slug will bridge the two foils as it passes through.

The maker of the rifle claimed a muzzle speed of 280m/s, or 918 feet per second. To travel 12" therefore should take about 0.001089 seconds. The timer switch was set in the "A" range to give a reading of around 1089.

The average of four tests gave a time of 1086 (0.001086sec) and this equated to a velocity of 280.8 metres/sec, or a little better than the maker's figure.

Don't attempt to clamp the trigger assembly to the barrel of the rifle, as the heavy recoil tends to cause premature triggering of the timer (probably due to air pressure on the foil as the rifle trigger and avoid physical contact between the barrel and the timing assembly. Needless to say, STRINGENT SAFETY PRECAUTIONS must be taken during such tests, to protect oneself and the general public.

The speed of a golf ball was also measured. Its probable speed was estimated at about 100mph, or 146 feet per secdond, so that over a distance of 3" a measured time of 0.0205 seconds could be expected.

The timer was set to 0 – 0.09999 ("b" range), for an expected reading of 2050. The golf club was wielded by a 24 handicapper, but the ball luckily sped straight and true, giving a reading of 1987 or 0.01987 seconds. This equated

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to 103 miles per hour. A second drive gave a speed of 87 mph. Must have been getting tired! The measuring apparatus certainly was.

The thyristor based timer control was particularly effective and performed without fault during the various tests.

The timer can make many kinds of measurements with the highest accuracy. It is very effective for obtaining or confirming (useless?) information, and poses a challenge to the designer to produce the endless range of triggering devices required to make timing measurements, particularly over short distances or short intervals. Try making triggers to measure the speed of a slot car or radio controlled model! EA