CHRONOSCOPE

Paul Brow shoots off about an ingenious device to measure the speed of air gun pellets.

A chronoscope is a device for measuring the velocity of an air gun pellet. Those of the shooting fraternity will realise how useful a chronoscope can be, to check the consistency of the gun, monitor its power output and compare how different pellets perform.

Commercial products are available but as usual they are expensive! This unit can be built for less than half the cost and perform equally as well.

The chronoscope is basically a counter with start and stop sensors. A pellet passes through the start sensor triggers the counter, covers a measured distance and halts the counter by passing the stop sensor. The pellet velocity can then be calculated from the display reading. Pellet velocities cover a wide range but typical values are 500 feet per second (0.22 calibre) or 800 feet per second (0.177 calibre).

Infra-red LEDs and photodiodes are used in two groups of three to detect the moving pellet. Three sensors are used to ensure that the small diameter of the pellet is reliably detected by providing a large detection zone (see Fig. 1). 0.177 calibre pellets are smaller, faster and more difficult to detect but this arrangement works well.

The chronoscope is mains powered, although it can easily be modified for battery operation. The display is a four digit LED type with a separate LED as an overflow indicator (counter exceeded 9999). The display units are 0.5 μs counts of frequency 2MHz, this value being convenient for the formulae described later.

Construction

The chronoscope has been designed to maximise the use of printed circuit boards to ease construction. Only two components (infra-red emitters) are mounted separately. Following the component overlays (Fig. 3, 4 and 5) assemble each PCB with the smallest components first — wire links, then resistors, IC sockets, capacitors, transistors with regulators and the transformer last.

Double check polarities. Use reasonable caution when soldering semiconductors. Don't keep the iron on the joint too long. Do not insert the ICs yet. Note the regulators require a substantial heatsink which should be made up as shown in Fig. 6.

The digital display is designed to plug on to the main board using 0.1in pitch PCB connectors. Wire links could be used but are not recommended.

On the subject of wire links, make sure that you solder the three links *under* the displays before inserting them in place. The display board is secured to the main board with small right angle brackets using the holes marked. The same type of brackets secure the sensor board vertically next to the plastic sensor tube.

The LED on the display board should stand slightly off the board to match the seven segment displays — a transistor mounting pad can be used here. The sensor board needs special attention when mounting the six infra-red photodiodes. These are soldered on the track side of the PCB and must be *exactly* six inches apart (no metric units around here!) centre to centre. Use the component overlay to align the photodiodes, as shown. Ensure the sensitive face is to the PCB track side when soldering to the board (see Fig. 7 for photodiode details), with the type markings to the component side.

The preset potentiometers are not the usual 0.4in standard type and may be difficult to obtain (see *Buylines*). Solder the 4-way ribbon cable to the sensor

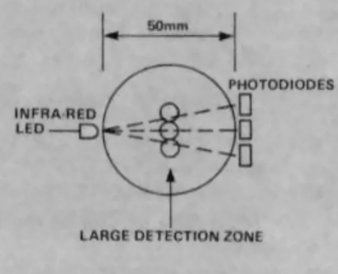


Fig. 1 The enlarged detection zone

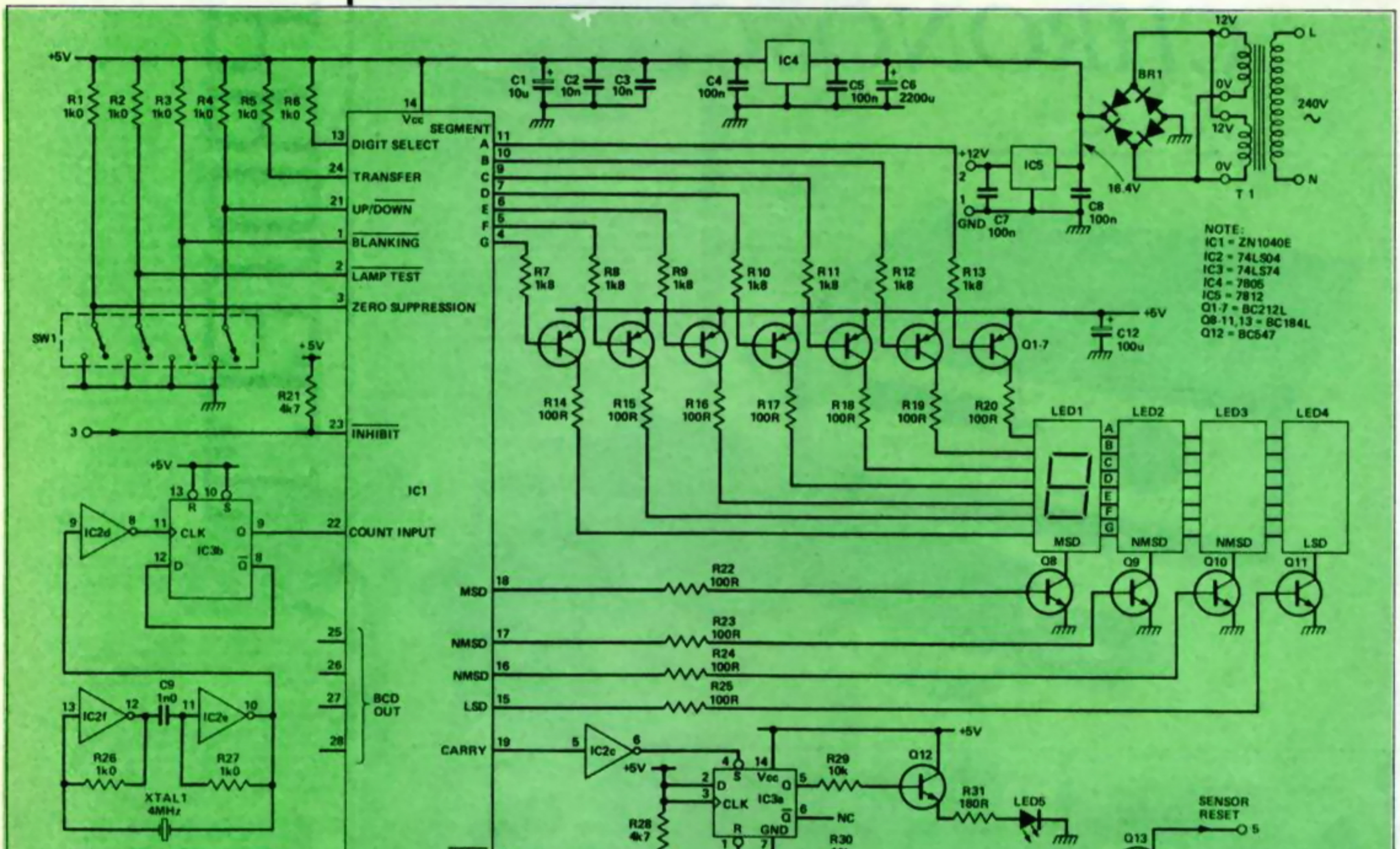


Fig. 2(a) The circuit diagram of the chronoscope main board

HOW IT WORKS

The heart of the chronoscope is the ZN1040E counter. This provides all the counter logic and display multiplexing. Two inverters of IC2 form a simple crystal oscillator with a frequency of 4MHz.

This is divided down to 2MHz by bistable IC3b, which supplies IC1 counter input (pin 22). While IC1 inhibit (pin 23) is held low, IC1 will not count. The inhibit input is toggled by the sensor board whenever a pellet is detected. If the counter overflows, the carry output (IC1 pin 19) is used to set bistable IC3a indicated by LEDs. IC3a is reset by SW5, which also zeros the counter IC1. R28 and C11 provide power on reset. SW1 selects various options on the counter IC1. SW1a ON enables leading zeros. SW1b ON provides a segment test on the display. SW1c ON blanks the display (really useful?). SW1d forces IC1 to count down (well, 4-way DIL switches are easy to obtain!)

Q1-7 are the segment drivers. Q8 and Q11 are digit drivers (multiplexing).

The sensor board controls IC1 inhibit. Six very high gain operational amplifiers together with their associated photodiodes form the detectors. Infra-red light from LED6 causes a current flow in D1-3 holding the non-inverting inputs below the bias voltage set by RV1.

If light to any photodiode is interrupted momentarily, the non-inverting input rises above the bias voltage, causing a high output. The outputs feed an OR gate IC7b. Any one causes bistable IC8a to be set driving IC1 inhibit high via Q15 and starting the counter. An identical arrangement IC9, IC7, IC7a will reset IC8a and stop the counter. IC7a OR gate allows reset from SW5. Q14, D10 and Q16, D11 monitor the bias setup, both LEDs set just off, for maximum sensitivity.

C15 are power supply decoupling to suppress unwanted spikes and noise.

The power supply is a standard bridge rectifier capacitor arrangement, supplying two voltage regulators IC4 and IC5 for 5V and 12V respectively. C1-8 provides decoupling for the ICs.

board. This then plugs on to the main board with a 0.1in PCB connector (SK4).

Solder twin ribbon cable to the infra-red LEDs and again use PCB connectors to plug on to the sensor board, observing polarity. The LEDs are fitted to the specially made brackets (see Fig. 8) using standard LED clips.

The main counter PCB is fairly straight forward but note the transformer pinout arrangement. I have noticed variations among suppliers. The DIL switch SW1 is optional and can be replaced with links to save costs. Secure the regulators to the heatsink with suitable nuts and bolts.

The boards must be mounted in a case for mains safety and to enclose the photodiodes from external light sources. A suitable tube, 5⅝ inches long was used in the prototype to protect the electronics from stray pellets and to give the unit a more professional finish. A piece of plastic gutter downpipe (2in diameter) is idea. The tube, infra-red emitter brackets and sensor board are secured to a base plate, made from plain SRBP, aluminum or fibreglass.

Secure the tube centrally to the baseplate and then position the sensor PCB and LED brackets to mark the fixing holes. See Fig. 9 for the case layout. Secure the sensor chassis and main board to the case with small self tapping screws. Fig. 10 shows the panel drilling details. The sensor hole in the front and rear panels is large (1½in). I used a Q-Max hole punch for this but if you don't have one, then drill small holes inside a marked circle and file to finish (you'll wish you had bought a Q-Max punch!)

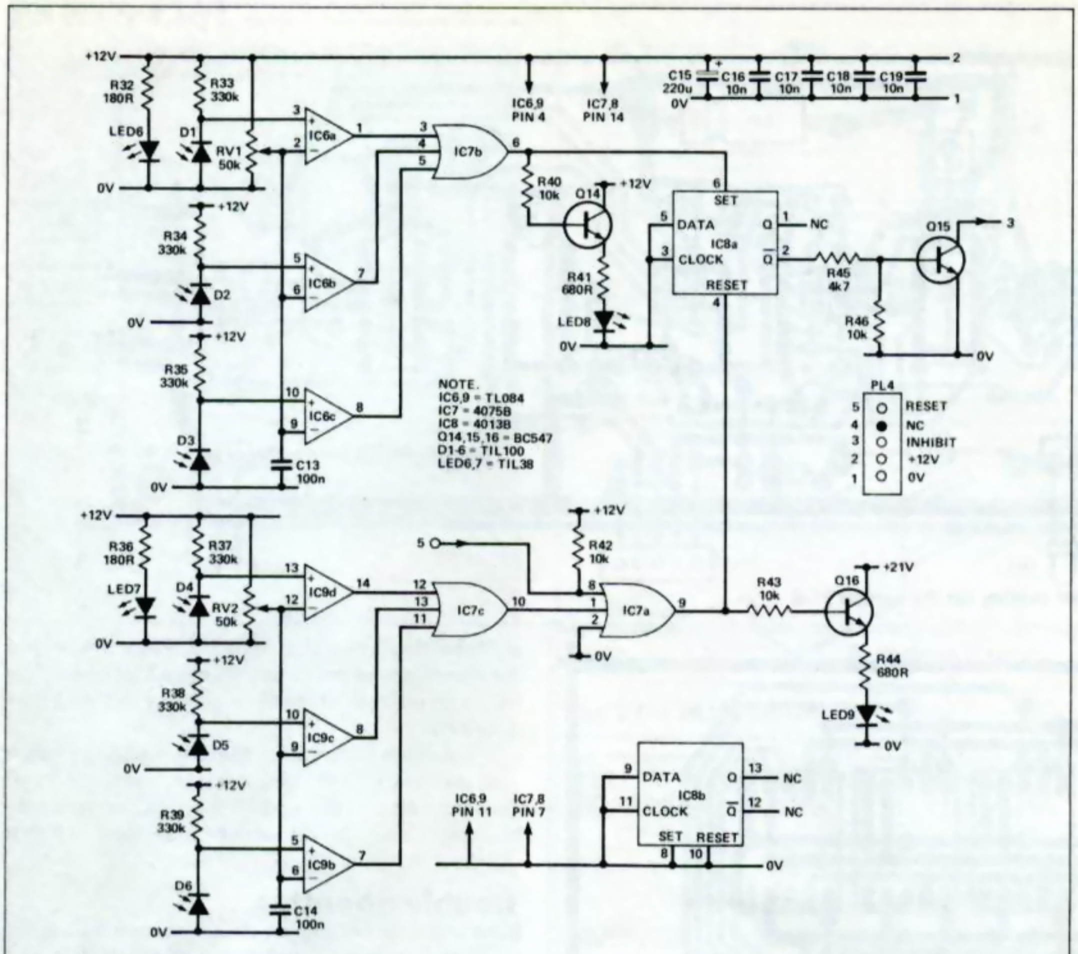


Fig. 2(b) Circuit diagram of the sensor board

Unfortunately, the rectangular hole for the display must be drilled out and filed laboriously, unless you also have a suitable rectangular punch. Paint the inside surface of the front and rear panels near the sensor hole with matt black paint to limit stray light. Fit a red diffuser (any piece of red transparent plastic film) behind the front panel to enhance the display digits. Slide the panel into the case slots — you will have to 'bow' the panel slightly to clear the *reset* switch.

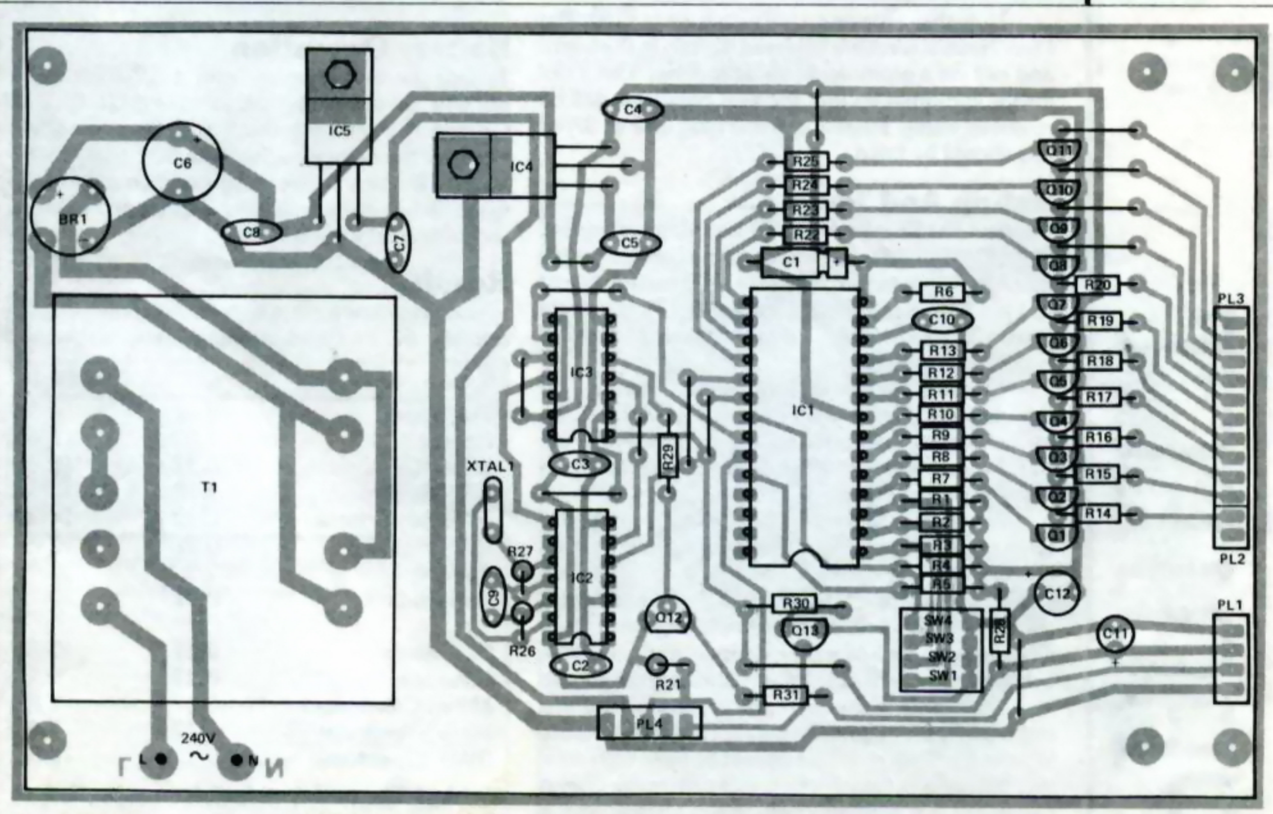


Fig. 3 The component overlay for the counter PCB

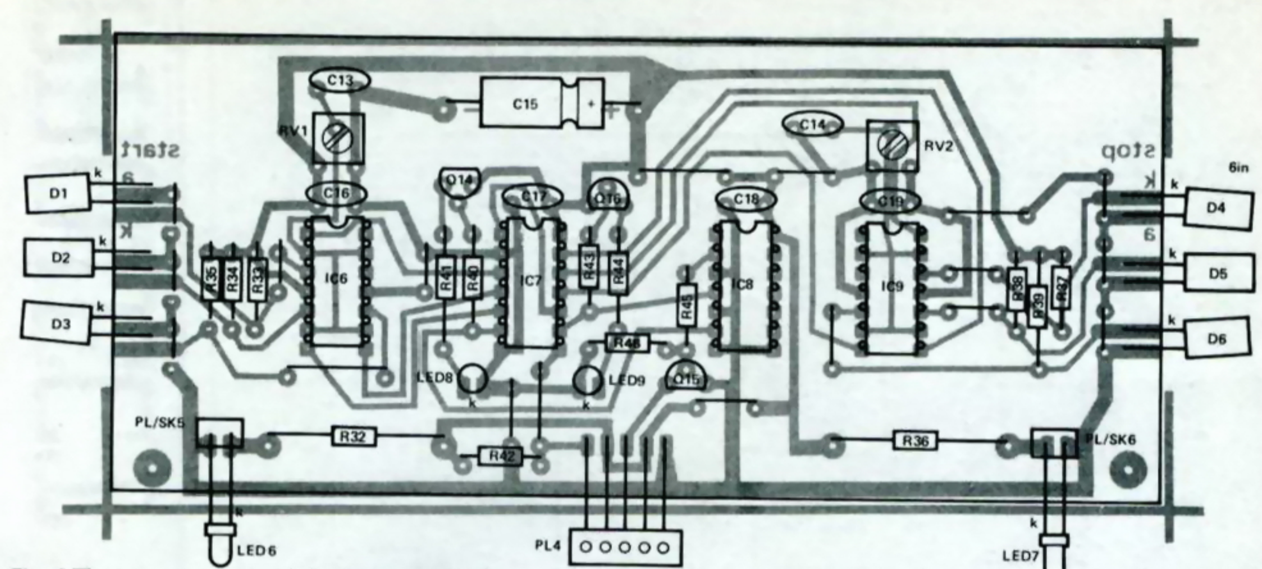


Fig. 4 The component overlay for the sensor PCB

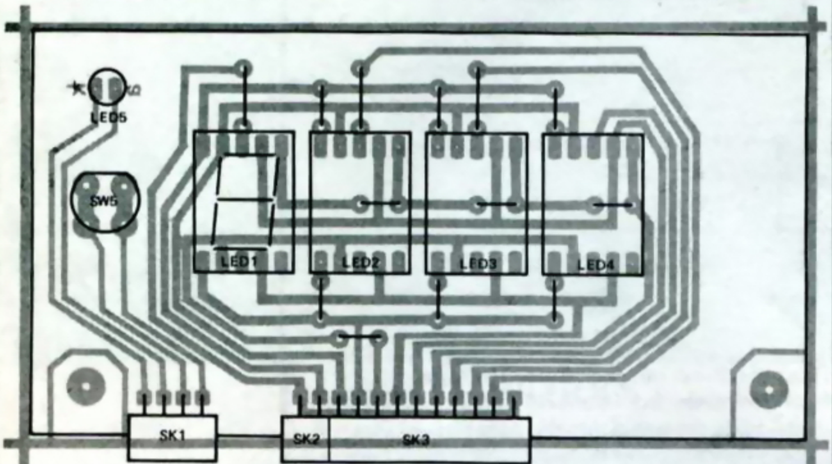


Fig. 5 The component overlay for the display PCB

Note that a mains on/off switch is not used. The Live/Neutral wires are soldered directly to the board and exit via a grommet in the rear panel. Cut a slot for the grommet so that the rear panel can still be removed easily. Finally, a mains plug fuse of 3A or less should be fitted.

Set-up And Testing

Caution! The PCB tracks near the transformer are live! Before inserting the ICs, check all the connectors are made and power up. Check that 5V is present across IC1 pin 14 and IC1 pin 8. Check that 12V is present across C15 on the sensor board. Power off and if all is OK, insert the ICs.

Set the 4-way switch bank all off. Power up and the display should illuminate. If you have an oscilloscope, you could check the clock circuit. There should be a 4MHz square wave (roughly!) at IC2 pin 8 and 2MHz at IC3 pin 9.

Set up the sensors in normal light conditions (with no strong direct sunlight and shield them from artificial lights). Adjust RV1 and RV2 so that LED8 and LED9 just go off. Press RESET and the display should now zero. Interrupt the infra-red beam at D1-3. The counter should clock happily and overflow! Interrupt the beam at D4-6 and the counter should stop. If all is well, fit the cover and prepare for the final testing with an airgun. Be careful! Air weapons are inherently dangerous and should be used with care! If you have a pellet trap, fine — if not, make one! A cardboard box with an opening 4in square, with a thick (1in to 2in) piece of wood (or ¼ steel) in the end, stuffed with old rags should be OK. Place this behind the chronoscope pellet 'exit' within a foot or so. This will catch your pellets safely and avoid shooting next door's cat.

Fabricate a mount for the rifle muzzle so that it rests centrally and straight, at the chronoscope 'inlet'. Zero the unit and fire a pellet through the tube, into the trap. You should obtain a reading without overflow.

Trouble Shooting

If the unit does not trigger, check that stray light is not interfering with the sensors and re-adjust RV1 and RV2. If this fails, suspect the IC2,3 clock circuit.

If the clock is started but will not stop, re-adjust RV2. (Check you are shooting straight, too!) No display at all means the 5V supply is missing or that SW1c is on.

A corrupt display shows a fault around Q1-7 or IC1 and a missing digit signifies a fault in Q8-11 or IC1.

Battery Operation

To use the chronoscope with a 12V battery for portable, on-the-range operation, omit Q1, BR1, C7, C8 and IC5 and link the two outer pads of IC5. Connect the battery to the + and − pins of BR1.

A 12V rechargable battery is recommended due to the fairly high current consumption of the chronoscope (typically 450mA).

Results

The chronoscope display actually shows only the number of clock cycles measured between the pellet

Type	Cal.	Grains
Eley Wasp	0.22	14.55
Hustler	0.22	12.4
Milbro Caledonian	0.22	13.0
RWS Superpoint	0.22	14.34
RWS Superdome	0.22	14.33
RWS Hobby	0.22	12.2
Bulldog	0.22	13.9
Barracuda	0.22	20.7
Eley Wasp	0.177	7.2
Silhouette	0.177	9.15
Milbro Caledonian	0.177	7.85
RWS Superpoint	0.177	7.9
RWS Superdome	0.177	8.3

Table 1 The pellet weight for a selection of types

PARTS LIST

RESISTORS (all ¼W 5%unless othewise stated)

R1-6,26,27	1k0
R7-13	1k8
R14-20, 22-25	100R
R21,28,45	4k7
R29,30,40, 42,43,46	10k
R31	180R
R32,36	180R 1W
R33-35, 37-39	330k
R41,44	680R
RV1,2	50k horiz preset
CAPACITORS	
C1	10µ 16V axial electolytic
C2,3,10,16, 17,18,19	10n polyester
C4,5,7,8, 13,14	100n polyester
C6	2200µ 25V radial electrolytic
C9	1n0 polyester
C11	47µ 16V radial electrolytic
C12	100µ 16V radial electrolytic
C15	220µ 25V axial electrolytic
SEMICONDUCTORS	
IC1	ZN1040E
IC2	74LS04
IC3	74LS74
IC4	7805
IC5	7812
IC6,9	TL084 OR TL074 quad op amp
IC7	4075B
IC8	4013B
Q1-7	BC212L
Q8-11,13	BC184L
Q12,14,15,16	BC547 (BC107 or similar)
LED 1-4	FND500 ½in 7-segment display
LED 5,8,9	Red LED
LED 6,7	TIL38 infra-red LED or similar
D1-6	TIL100 or similar
BRI	W005
MISCELLANEOUS	
PL1	4-way PCB connector
PL2,5,6	2-way PCB connector
PL3	10-way PCB connector
PL4	5-way connector
SK1	4-way angled PCB connector
SK2	2-way angled PCB connector
SK3	10-way angled PCB connector
SK4	5-way PCB connector
SK5,6	2-way PCB connector
SW1	4-way DIL switch
SW2	push button SPST
T1	0-12 0-12V 0.5A PCB mounting mains transformer
XTAL1	4MHz crystal

PCBs. Case. IC sockets. Display filter. 2in drain pipe. Cable. Nuts and bolts.

passing the front and back sensors. To calculate the speed of the pellet or the power of the gun, some calculations must be performed.

$$\text{Velocity} = \frac{\text{distance}}{\text{time}}$$

$$= \frac{\text{counter frequency} \times \text{measured distance}}{\text{display reading}}$$

The measured distance is 6in (½ft) and the clock frequency is 2MHz, so:

$$\text{velocity (ft/s)} = \frac{2000000 \times \frac{1}{2}}{\text{display}}$$

$$= \frac{1000000}{\text{display}}$$

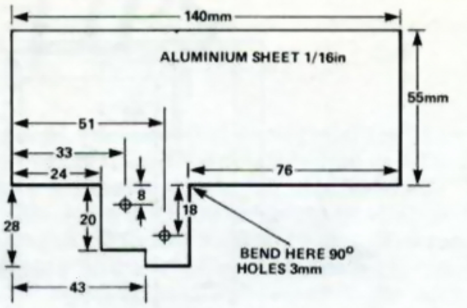


Fig. 6 The heatsink for IC4,5

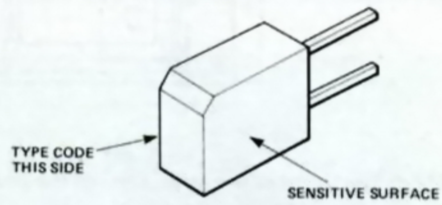


Fig. 7 The TIL100 photodiode

PELLET TYPE: ELEY WASP (7.2 grains)
READINGS: 1188, 1178, 1194, 1180, 1177, 1182, 1176, 1209, 1207, 1163.

AVERAGE OF ABOVE READINGS: 1185

$$\text{VELOCITY} = \frac{1{,}000{,}000}{1185} = 843\text{ft/s}$$

$$\text{POWER} = \frac{843 \times 843 \times 7.2}{450240} = 11.36$$

Table 2 Typical results obtained by the author

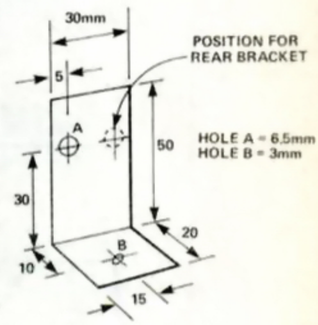
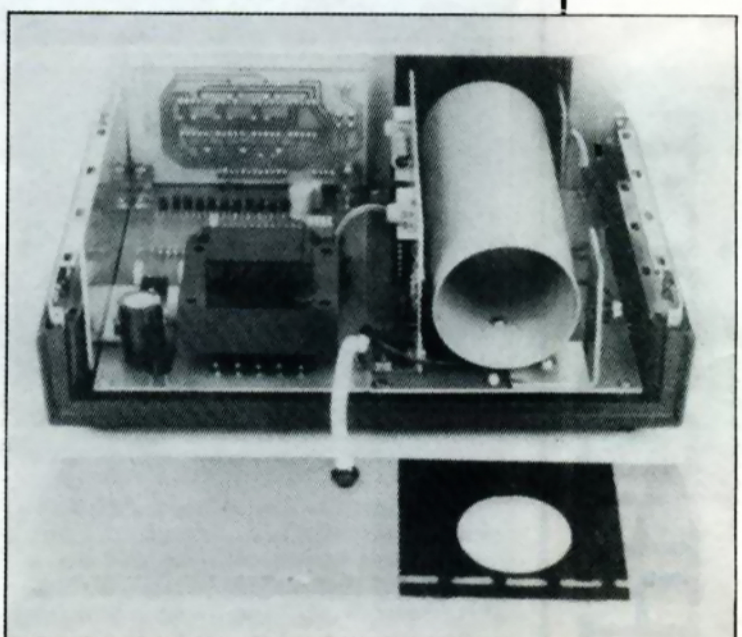


Fig. 8 The bracket to hold the sensor diodes in place (front shown)



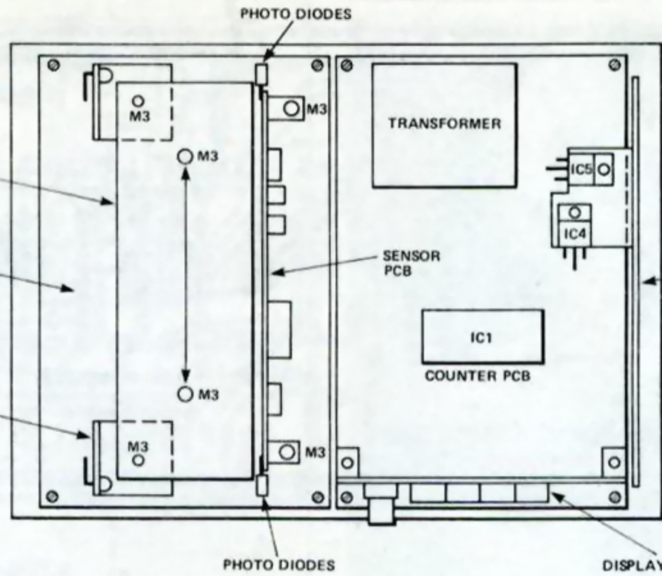


Fig. 9 The layout of the major parts of the prototype chronoscope

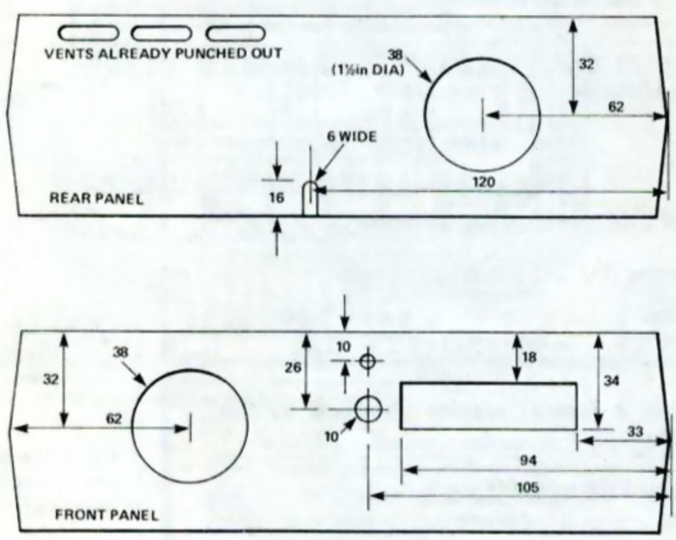


Fig. 10 Case cutouts for the recommended case

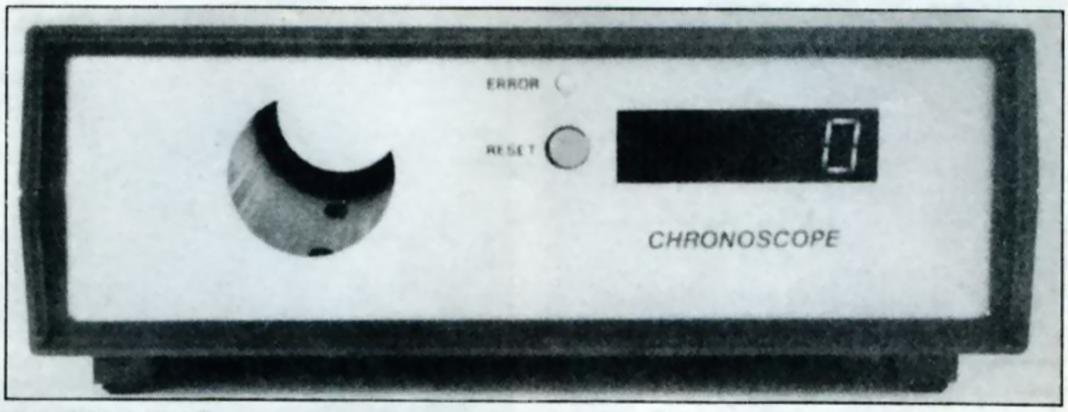
The power output of the gun can be calculated with:

$$\text{power (ftlbs)} = \frac{\text{velocity}^2 \times \text{pellet weight}}{450240}$$

The pellet weight is in grains (438 grains = 1 ounce). If you don't know the pellet weight your local airgun stockist should be able to help. Some are given in Table 1. Alternatively, the author can supply a list for common pellets (see *Buylines*).

Typical results are shown in Table 2, obtained using a BSA Mercury S 0.177 calibre air rifle. Note that the legal power limit for an air pistol is 6ftlbs and for a rifle 12ftlbs, above which you need a firearms licence.

To conclude, we should stress again the care that must be exercised when firing guns and rifles through the chronoscope. *Always* use a pellet trap of some sort.



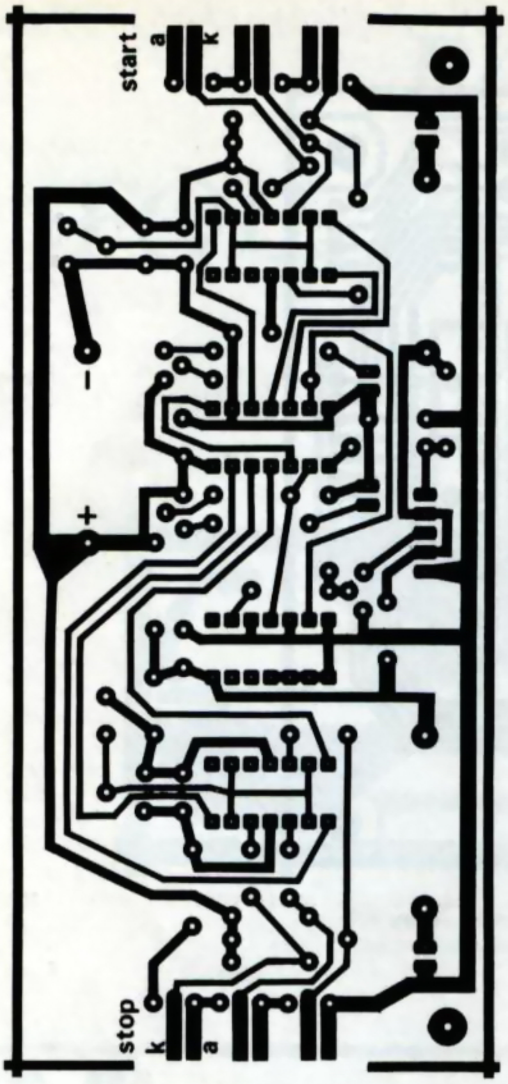
BUYLINES

Most of the components are readily available. Rapid Electronics (Tel: (0206) 272730), Maplin (Tel: (0702) 552911), Electromail (Tel: (0536) 204555) and Farnell (order from Trilogic on (0274) 684289) can supply the more unusual parts.

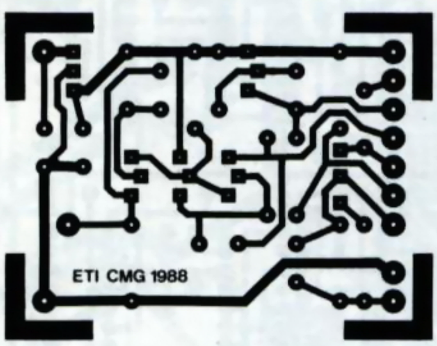
The transformer is available from Farnell as part 141-481 as are the presets. The 7-segment displays are available from Maplin (FR41U) or Rapid (57-0115). IC1 (the ZN1040E) is available from Electromail as part 306-285. The case used for the prototype is a Retex RE3 type available from Rapid as part 30-0910.

The author is able to supply any or all parts for the Chronoscope. Send a SAE to ETI Chronoscope, 40 Victoria Avenue, East End Park, Leeds LS9 9DG for a price list. For a list of the weights of pellets, send a SAE to the same address.

PROJECT



The Chronoscope sensor PCB



The Burglar Buster PCB — available free with ETI next month

OOPS!

Dream Machine (December 1987)
The transistors used in this project are ST1702. BC108s can be substituted.

Heating Management System
(December 1987)
A 4116 is not a suitable alternative to the 6116 specified. A 4016 RAM chip will suffice. In Fig. 1 the junction of R1/D5 should connect to D1-4/C1 and not cross. The zener diodes above the temperature sensor ICs (IC16-19) should be deleted. C4 should be 220n and not 220μ. C7-10 should be 10μ. Q2-7 should be 2N3904 and not BC3904.

RGB Auto-Dissolve (January 1988)
In Fig. 5 there are marked two D6's. The right hand one should be D5 (they are both 1N148's anyway). In the text the reference to zener diode D5 should read ZD1.

Power Conditioner (January 1988)
There is confusion between the values of R7 and R8 in the Parts List and Fig. 1. These should be: R7-27k, R8-10k and not as given in the Parts List. In addition, ZD1 is incorrectly orientated in Fig. 3. The positive terminal should be at the southern end.

Passive Infra-Red Alarm
(January 1988)
Fig. 2(a) shows the base of Q1 connected to ground and to R14. It should be connected only to R14.

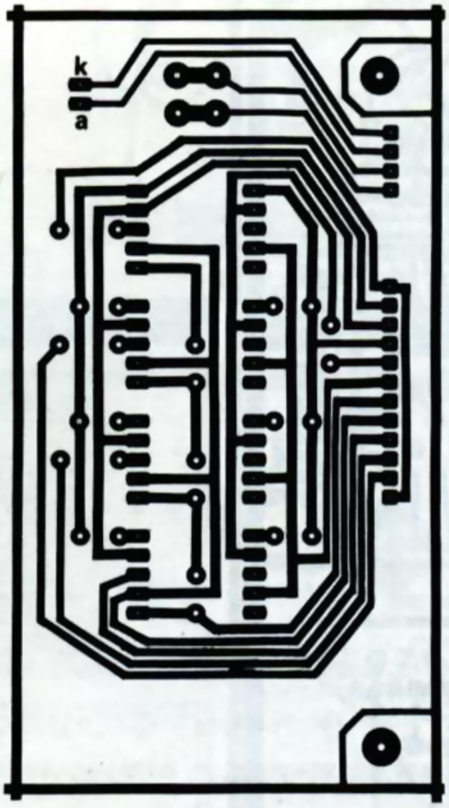
Transistor Tester (February 1988)
The foil pattern for the main board was printed reversed left-right on the foil pages.

Spectrum Co-processor (March 1988)
Mogul Electronics, given in the Buylines as suppliers of the RAM chips, have moved to: Unit 11, Vestry Estate, Sevenoaks TN14 5EU. Tel: (0732) 741841.

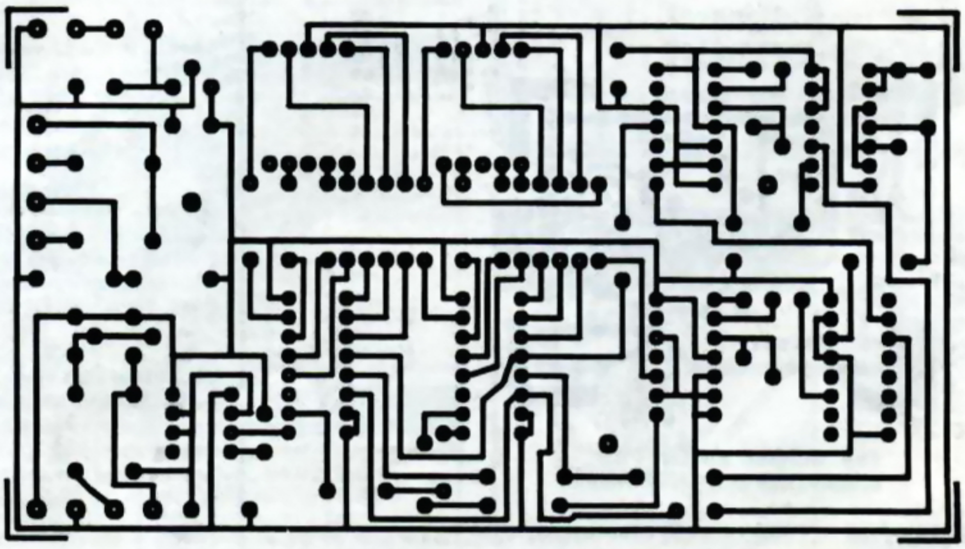
Dynamic Noise Reduction (May 1988)
The LM1894 is no longer available from the sources listed but it can be obtained from the author. Please address orders to Manu Mehra, 88 Gleneagle Road, Streatham, London SW16 6AF.

QL Output Port (Tech Tips May 1988)
Several problems with the diagram for this one. A5 should read AS — that is, address strobe. Pins 22 and 24 should be connected to +5V and the junction of the (only) resistor and diode connected to VPA on the QL.

QWL Loudspeakers (August 1988)
Some dimensions were missing from Fig. 7. The bass driver port centre should be 3¾in above the base of the baffle panel. The notches in the side of the tweeter cut-out are ½in wide. The top plate is missing from the cutout diagram (Fig. 6). This is 7 × 4⅝in.

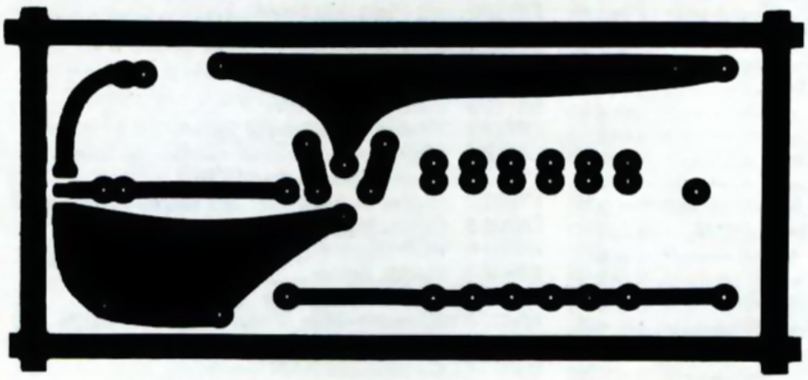


The Chronoscope display PCB

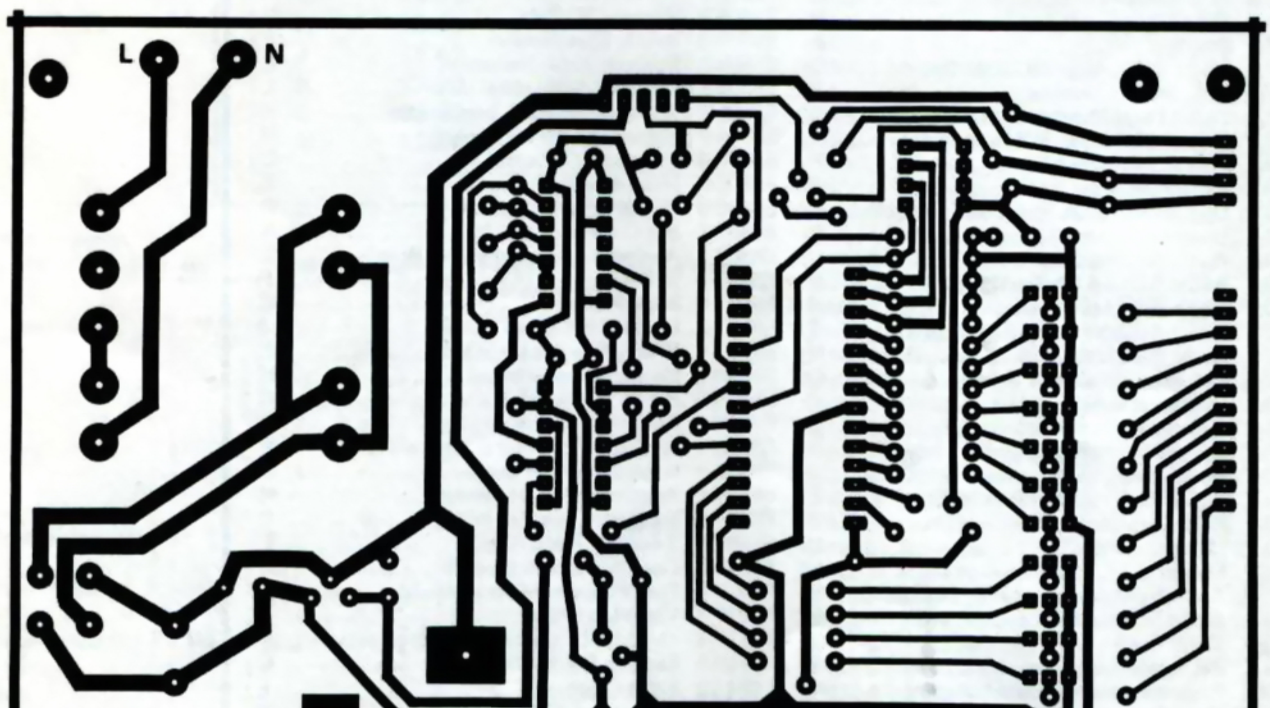


The Digital Transistor Tester PCB

PCB FOIL PATTERNS



The 1st Class NiCd charger PCB



The Chronoscope counter PCB