Measure the speed of rotating machines

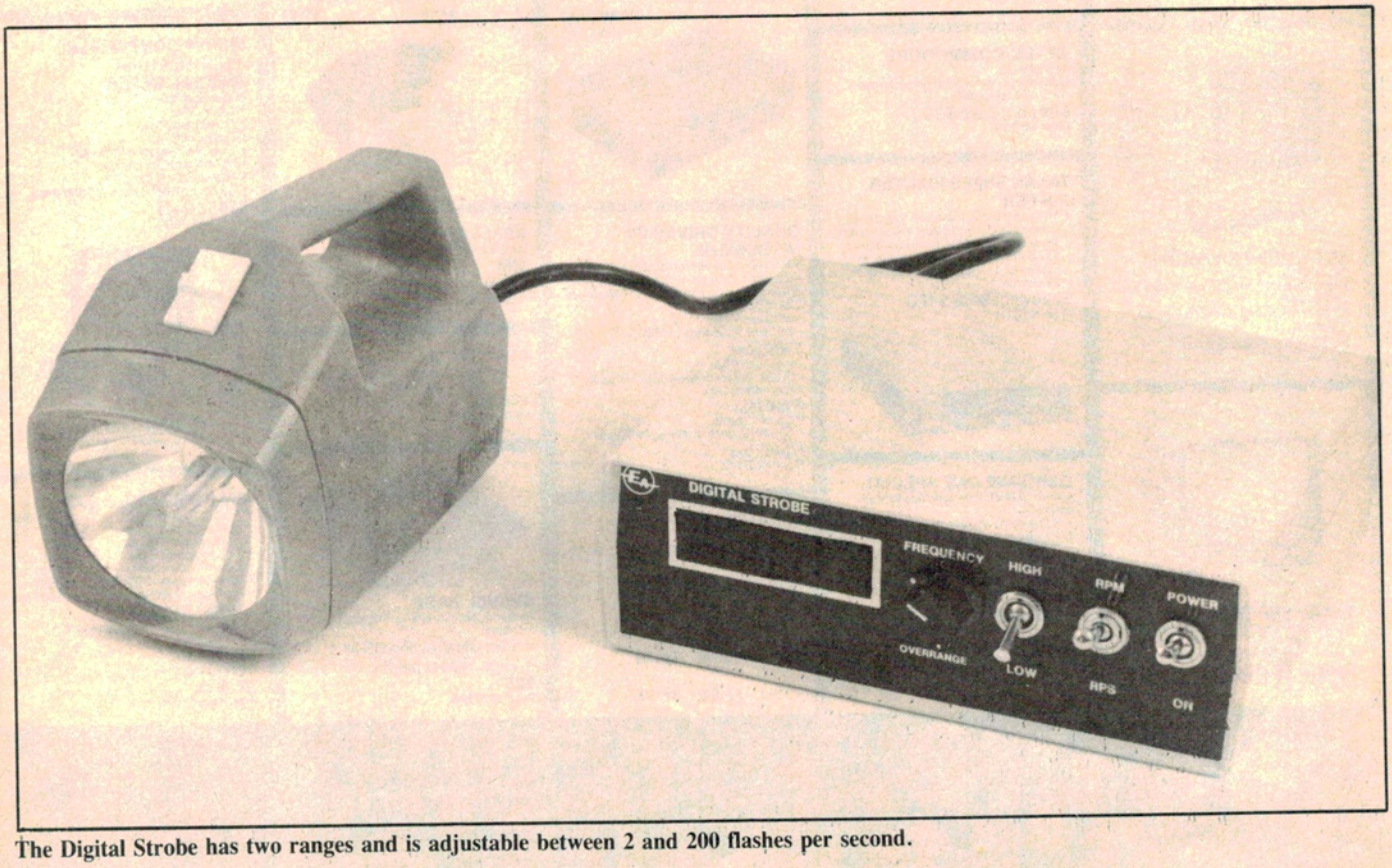
Build this digital strobe

How do you observe and measure the speed of rotating machinery without resorting to high speed photography? The answer is to use a stroboscope. Our Digital Strobe lets you monitor rotating machinery operating at up to 20,000 revolutions per minute and has a digital display.

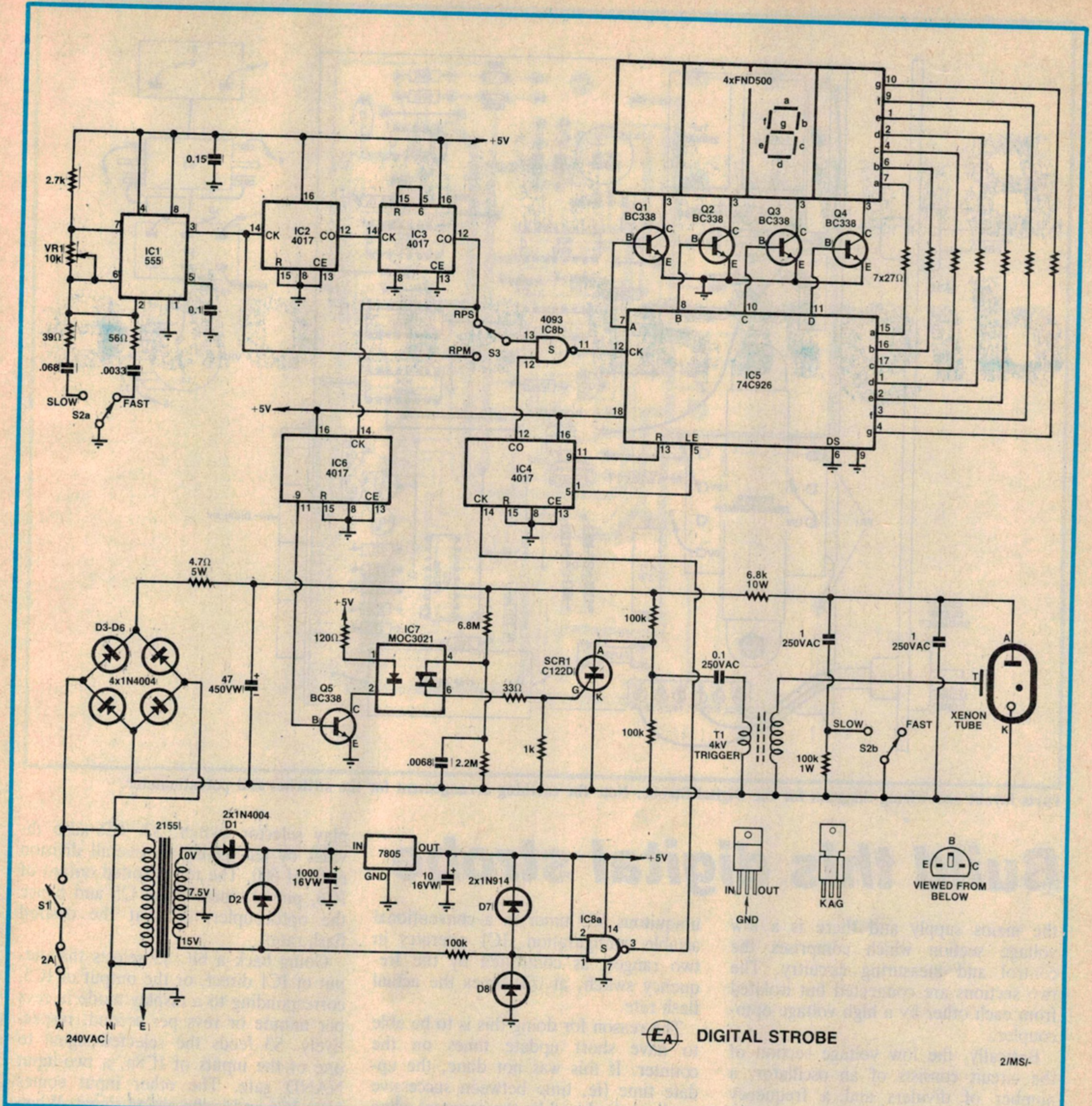
by LEO SIMPSON

These days the most popular use of strobe lights is as a "prop" to blitz the senses of people listening to modern pop groups and to otherwise distract them from the mediocrity of the performance. A more serious use of a strobe light is as a monitoring instrument for rotating machinery.

By synchronising the flashes of light from the strobe, the machine or motor can be made to appear stationary or, by a slight change to the flash rate, to be rotating slowly, either forward or back-



The Digital Strobe has two ranges and is adjustable between 2 and 200 flashes per second.



The high and low voltage sections of the circuit are isolated from each other by a high-voltage optocoupler (IC7).

wards. This makes it easy to observe the precise meshing of gears, the operation of crankshafts and belts and so on.

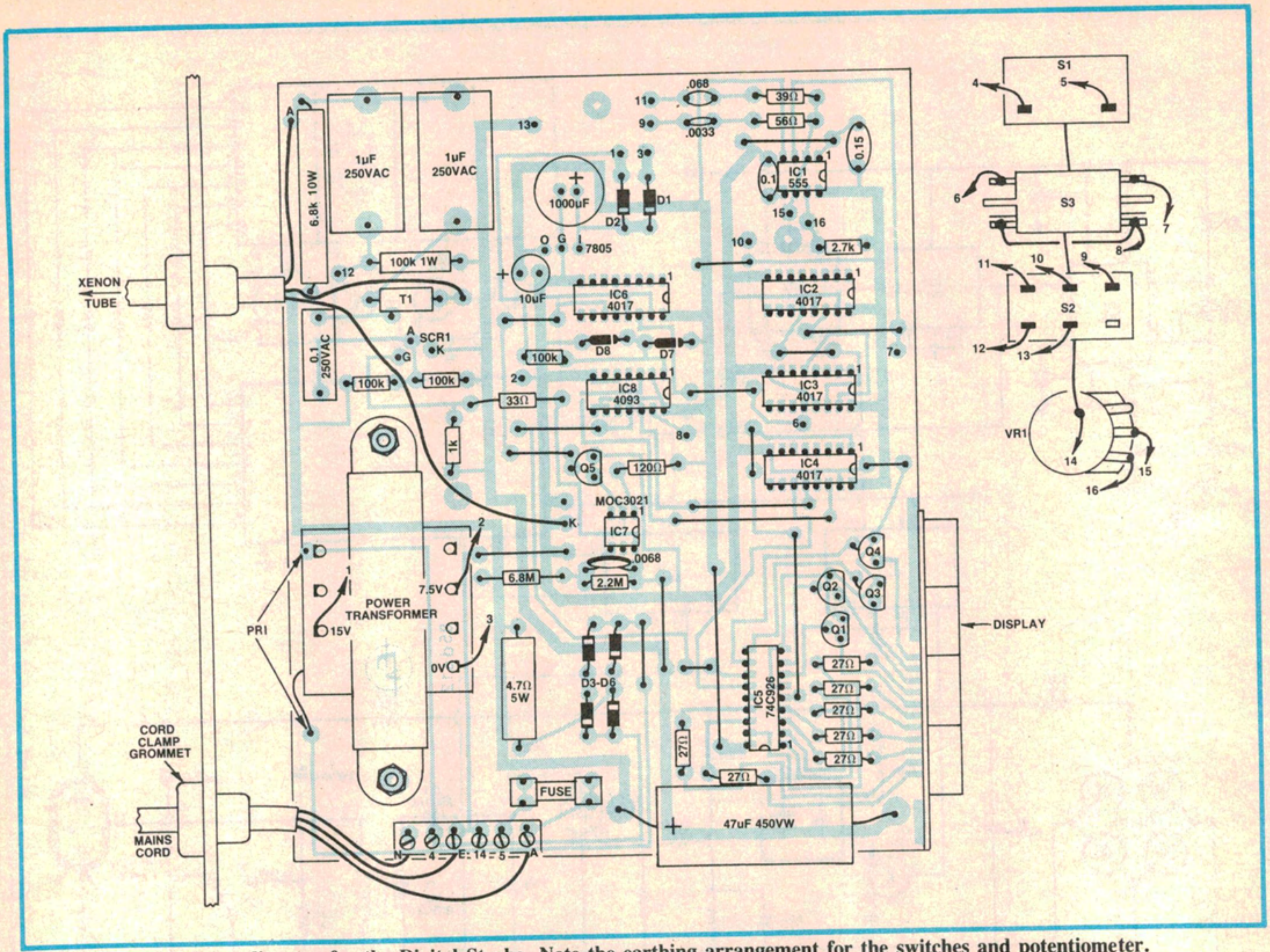
A strobe is also the ideal instrument to measure rotational speed as no connections to the machine are required. And you can use it to set the ideal speed of any motor, be it two-stroke or four-stroke petrol or diesel.

Our new Strobe comes in two parts permanently connected together by a cord. One part is a standard flashlight which houses the Xenon lamp and the other is an instrument case which houses all the circuitry.

On the front of the instrument case is a four digit LED display, a frequency control knob and three toggle switches. The display can be switched to indicate the flash frequency from 2 to just over 200 flashes per second, or switched to display RPM (revolutions per minute). To avoid confusion, this display switch is marked in RPS (revs per second) and RPM. The other switches are for Power and for frequency range: Low, from 2 to 40 flashes per second and High, from 36 to over 200 flashes per second.

Circuit Description

The circuit can be simply divided into two sections. There is a high voltage section which is powered directly from



Parts layout and wiring diagram for the Digital Strobe. Note the earthing arrangement for the switches and potentiometer.

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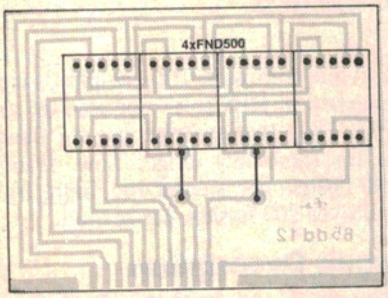
the mains supply and there is a low voltage section which comprises the control and measuring circuitry. The two sections are connected but isolated from each other by a high voltage opto-coupler.

Basically, the low voltage section of the circuit consists of an oscillator, a number of dividers and a frequency counter. IC1 is the oscillator and is the



Parts layout for the display board. Note that the ribbed edge of each display goes towards the top.

ubiquitous 555 timer in a conventional astable configuration. IC1 operates in two ranges, as controlled by the frequency switch, at 600 times the actual flash rate.

The reason for doing this is to be able to have short update times on the counter. If this was not done, the update time (ie, time between successive readings displayed by the counter) when measuring the relatively low frequencies of the flashing strobe could be a minute or more.

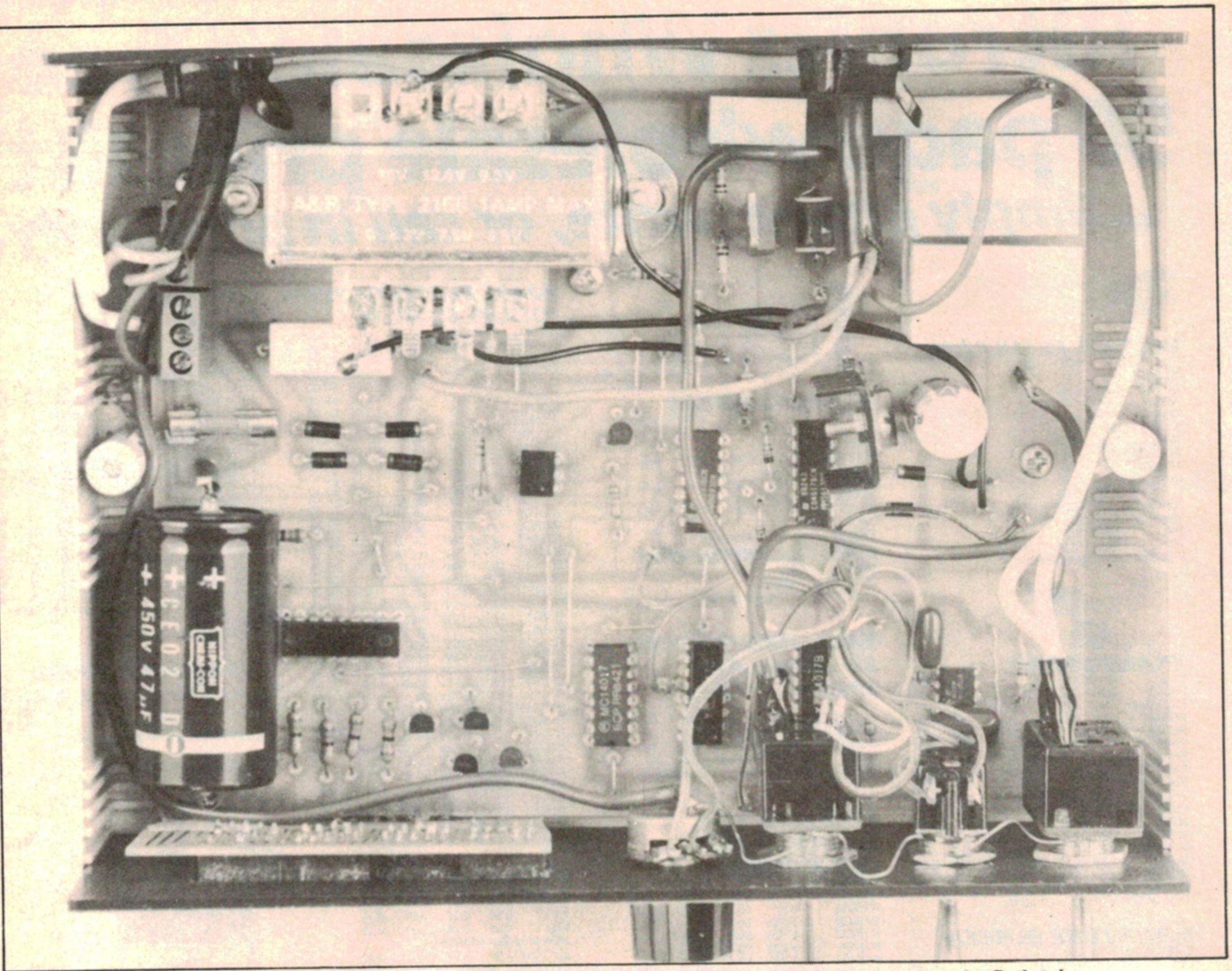
Since IC1 is operating at 600 times the flash rate it cannot be used to control the strobe tube directly; it must be divided down by counter stages IC2, 3 and 6. These are all 4017 Johnson counters which can be set to divide by any number up to ten. IC2 divides by ten and IC3 divides by six, giving an overall division ratio of 60 times.

The output of IC3 (pin 12) is then fed to the clock input of IC6 and to the display selector switch, S3. IC6 also divides by ten, giving an overall division ratio of 600. The ten decoded output of IC6, pin 11, then drives Q5 and hence the optocoupler, IC7, at the desired flash rate.

Going back a bit, S3 selects the output of IC1 direct, or the output of IC3, corresponding to a display mode in revs per minute or revs per second, respectively. S3 feeds the selected signal to one of the inputs of IC8b, a two-input NAND gate. The other input comes from IC4 and is the gating signal. When the gating signal is high, the signals are fed from S3 into the four-digit counter, IC5.

House-keeping signals

The function of IC4 is to provide the "house-keeping" signals for IC5. The three signals in question are the clock gating signal (already mentioned and fed to pin 12, IC8b) plus the reset and latch enable signals. The sequence of these signals is as follows. Consider that IC5 has been reset and is displaying the last value counted which can be any-



View inside the prototype. Keep mains wiring neat and tidy and use 240VAC 3-core mains cord to connect the flash tube.

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where from "0000" to "9999".

Now a high signal from pin 12 of IC4 allows the signal to be counted through IC8 and into the clock input. Then, at the end of the gating period, the clock signals are turned off. Then the value counted by IC5 is fed through to the display latches by a high "latch enable" signal so that the count can be displayed.

Then the four internal decade counters are reset, ready for another count cycle. Note that resetting the counters does not change the value displayed and stored in the latches.

In a frequency counter where accuracy is paramount, these housekeeping signals are normally derived from a crystal oscillator feeding a series of counter stages. Here, though, we do not need crystal accuracy and can rely on the accuracy of the 50Hz mains supply as the timbebase.

Hence the 50Hz signal is fed from the transformer secondary via a 100kΩ resistor to the input of IC8a which functions as a Schmitt trigger to produce a "squared up" 50Hz signal suitable for feeding to the input of IC4. Diodes D7 and D8, in conjunction with the 100kΩ resistor, protect the input of IC8a from being over-driven. They clip the mains sinewave to about +5.6V and −0.6V.

As noted above, IC4 provides all three housekeeping signals, in the following way. A 4017 has ten decoded outputs, each of which go high for their respective clock period, ie, 20 milliseconds. The carry output of the 4017 goes high for the decoded outputs from "0" to "4" and low from "5" to "9".

Initially the carry out is high and gates the clock signals into the counter for exactly 100 milliseconds via gate IC8b. Then the "5" output (pin 1) goes high, allowing the contents of the IC5 counters to be loaded into the display latches.

Finally, the "9" output (pin 11) goes high and resets IC5 via 13.

We will leave the low voltage section of the circuit now although we will come back later to tie up a few loose ends.

High voltage circuit

The high voltage circuitry is a little more straightforward and is similar to a photoflash circuit. The difference is that whereas a photoflash tube is designed for high energy discharge at very low repetition rates, a strobe is designed for relatively low energy discharge at high repetition rates. The limiting factor is the 5W power dissipation rating on the Xenon tube.

Basically, the high voltage circuitry consists of a 340-volt DC supply which is derived directly from the 240VAC mains supply via a bridge rectifier and

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47μF/450VW electrolytic capacitor (with current limiting via the 4.7Ω/5W resistor). This 340V supply is then used to charge one or two 1μF capacitors (via the 6.8kΩ/10W resistor) which are then discharged via the Xenon tube to make it flash.

The tube is "fired" and breaks down to a low impedance circuit when it receives a high voltage pulse of 4kV. This is produced by trigger transformer T1.

The circuit operates as follows: Consider that the optocoupler IC7 is driven by Q5 with a signal having a 1:10 duty cycle. Each time Q5 conducts, the internal Triac of IC7 is fired to discharge the contents of the .0068μF capacitor at pin 4 into the gate of SCR1 via a 33Ω current-limiting resistor.

SCR1 then fires and discharges the 0.1μF/250VAC capacitor at its anode via the trigger transformer T1. This produces a 4kV pulse at the trigger electrode of the Xenon tube and fires it.

In order that the 5W power dissipation rating of the Xenon tube is not exceeded at high flash rates, one of the 1μF storage capacitors is switched out of circuit. This is accomplished by switching a 100kΩ resistor in series with one of the capacitors, using one pole of the Slow/Fast Switch, S2.

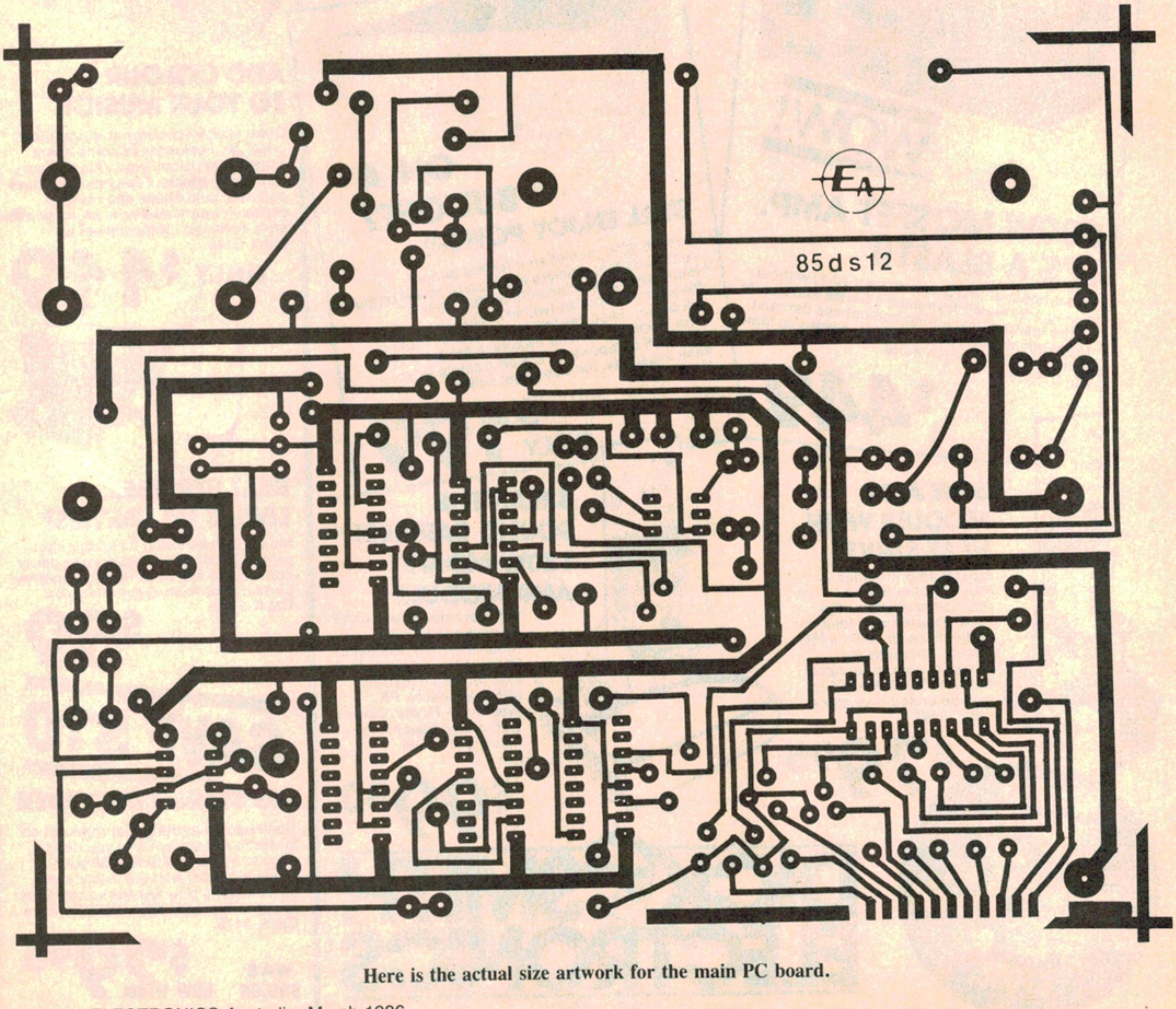
The other pole of S2 is used to switch the capacitors for IC1, to provide the two frequency ranges. Each capacitor has an associated low value resistor with the values selected to ensure that the two ranges overlap.

Power for the low voltage circuit is derived from a 15V centre-tapped transformer driving a full-wave rectifier and 1000μF filter capacitor. This drives a three-terminal regulator to provide a 5V supply.

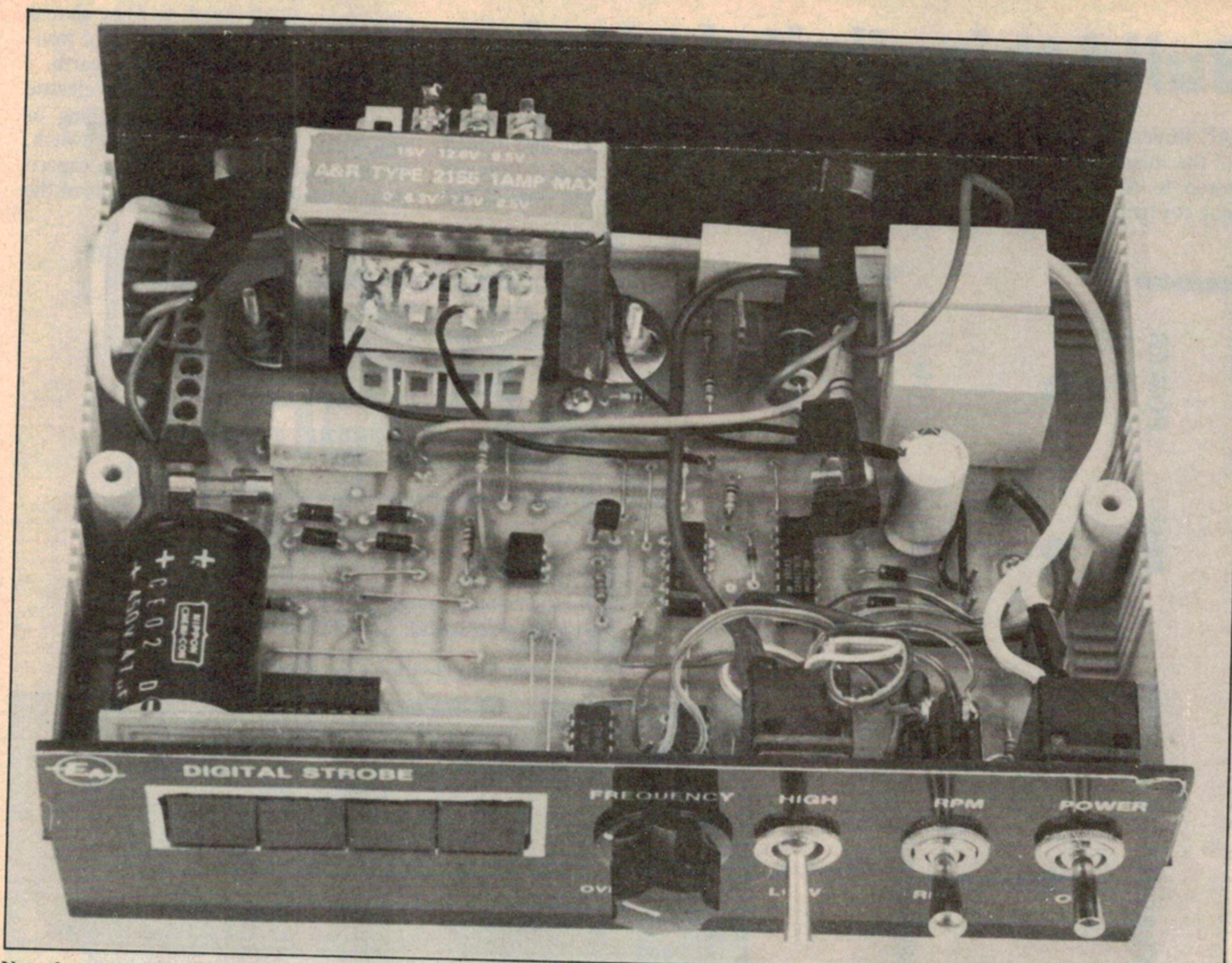
The output of the regulator is bypassed with a 10μF capacitor to ensure a low output impedance which is important to keep the multiplex display currents from interfering with normal circuit operation. The 0.15μF bypass capacitor adjacent to the 555 timer performs a similar function.

Construction

As mentioned above, the new strobe is a two part unit employing a torch housing and a standard instrument case, the latter as supplied by Altronics (Cat. No H-0480). It measures 200 x 160 x 80mm and accommodates two printed circuit boards, one for the LED displays and the other for the rest of the circuit. They are designated 85ds12 (171 x 137mm) and 85dd12 (73 x 56mm).



Here is the actual size artwork for the main PC board.



Note that a small heatsink should be fitted to the 3-terminal regulator. Sleeve all high-voltage terminals with heatshrink tubing.

The main circuit board is arranged to keep the low voltage and high voltage sections of the circuitry essentially separate, the only points where they link up being at the switches and opto-coupler. For this reason (the need for isolation), the switches should be standard 240-VAC toggle types and not of the miniature sort.

Assembly of the boards should not begin until they have been carefully checked for breaks or bridges in the copper tracks and to see that all holes have been drilled.

No special procedure needs to be followed when assembling the board although we suggest installing the small passive and active components first, then the larger capacitors and the transformer, leaving the CMOS ICs until last.

Be careful about the orientation of the semiconductors and electrolytic capacitors when they are being inserted. When soldering the CMOS ICs, use a small iron with the barrel earthed to the negative electrode of the 1000μF electrolytic capacitor and solder the positive and negative supply pins of each IC before soldering the other pins.

Take care when inserting the trigger transformer as the leads are very fragile. The leads should be bent to avoid stressing them when the transformer is being inserted.

Mount the mains transformer with the mounting screws pointing up to allow subsequent easy removal, should this ever be necessary. Note that the mains connections to the board should be via a six-way PC-mounting terminal block.

When mounting the LED displays on their board, make sure they are correctly oriented. The ribbed edge of each display should be at the top. Don't forget the two wire links that are also on the board. The completed board should be checked very carefully now for solder bridges or open circuit tracks as these are the most common assembly faults in a project of this nature.

The two boards can now be soldered together. Set the lower edge of the display PCB to overlap the bottom edge of the main PCB by about 2mm and check that the two are exactly perpendicular to each other. Solder tack the two end strips but do not solder the remaining edge connections at this stage.

If not supplied ready-drilled and cut, the front panel should now be prepared. The Scotchcal label can be used as a template for this job. When the cutout is complete, the panel can be assembled into the case and the printed board assembly checked for fit. The main PCB is secured to three of the integral pillars of the case, using self-tapping screws. If the PCB assembly does fit, the remaining edge connections to the display board can be soldered.

With that done, all the hardware can be assembled into the case and the wiring completed. Use 240VAC-rated wire for all the high voltage circuitry and keep the high voltage and low voltage wiring as separate as possible. The output lead to the flash tube should be 240-

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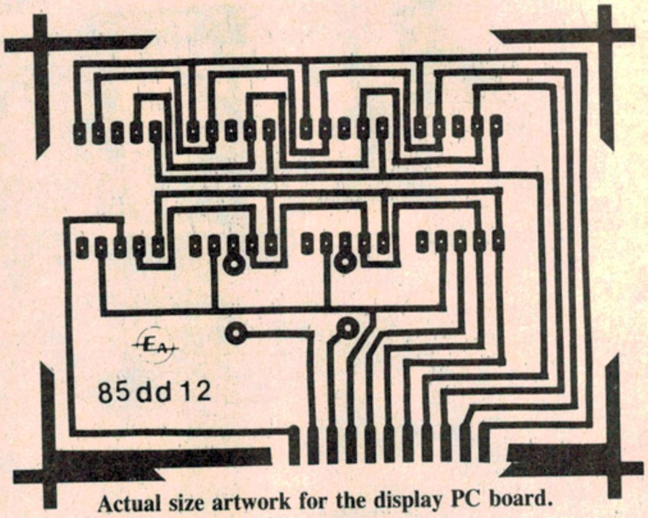
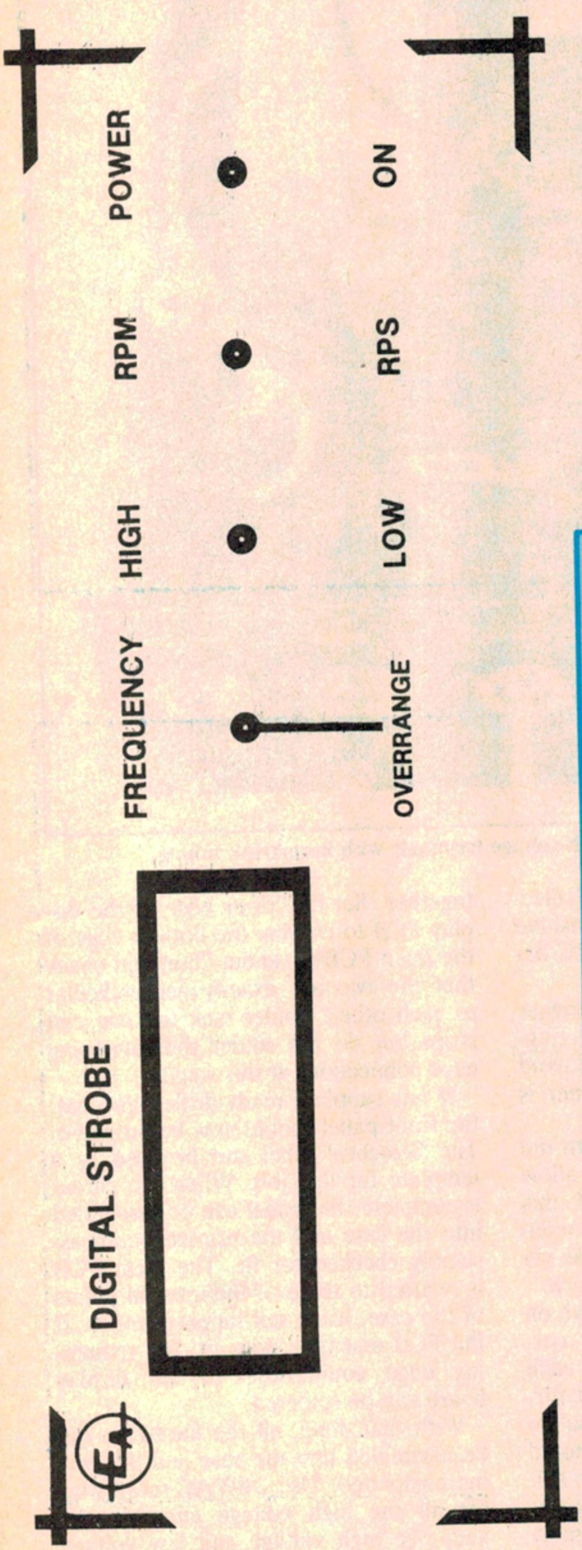
VAC three-core mains cord and both it and the mains input cord should be anchored to the back panel of the case using cordgrip grommets.

The three switches should be mounted flush with the front panel and tinned copper wire should be used to connect each switch flange and the case of the potentiometer all together. They should then be connected via a length of insulated hook-up wire to the mains earth.

To prevent the possibility of electric shock, slip some heatshrink tubing or insulation tape over the mains switch, the terminals of the high voltage capacitor and the high voltage terminals of the



Actual size artwork for the display PC board.



Here is an actual size front panel artwork.

PARTS LIST

- 1 Plastic case, 200 x 160 x 70mm (W×D×H), Altronics H-0480 or equivalent
- 1 Scotchcal label
- 1 PCB, code 85ds12, 171 x 137mm
- 1 PCB, code 85dd12, 73 x 56mm
- 1 15V 1A transformer, A&R 2155 or equivalent
- 1 Xenon flashtube, DSE Cat. No. S-3882 or equivalent
- 1 4kV trigger transformer, DSE Cat. No. M-0104 or equivalent
- 1 SPST 240VAC 1A toggle switch
- 2 DPDT 240VAC 1A toggle switches
- 1 50cm length of two-core mains cable
- 1 150cm length of three-core mains cable
- 1 10cm length of rainbow cable
- 3 cordgrip grommets
- 1 six-way PCB-mounting insulated terminal block
- 1 TO-220 heatsink
- 1 flashlight
- 1 2A fuse and fuseclips to suit
- 1 pointer knob

Semiconductors

- 4 4017 decade counters
- 1 4093 Schmitt trigger
- 1 NE555 timer
- 1 74C926 4-digit counter
- 1 MOC3021 optocoupler
- 1 7805 three terminal voltage regulator
- 1 C122D SCR
- 4 FND500 7-segment LED displays
- 5 BC338 NPN transistors
- 6 1N4004 1A silicon diodes
- 2 1N914, 1N4148 small signal diodes

Capacitors

- 1 1000μF 16VW PC electrolytic
- 1 47μF 450VW pigtail electrolytic
- 1 10μF 16VW PC electrolytic
- 2 1μF 250VAC metallised dual dielectric, Philips MKT-P
- 1 0.15μF greencap
- 1 0.1μF 250VAC metallised dual dielectric, Philips MKT-P
- 1 0.1μF metallised polyester (greencap)
- 1 0.068μF greencap
- 1 0.0033μF greencap
- 1 0.0068μF 630VW ceramic

Resistors (0.25W, 5%)

1 × 6.8MΩ, 1 × 2.2MΩ, 3 × 100kΩ, 1 × 100kΩ/1W, 1 × 6.8kΩ/10W wirewound, 1 × 2.7kΩ, 1 × 1kΩ, 1 × 120Ω, 1 × 56Ω, 1 × 39Ω, 1 × 33Ω, 7 × 27Ω, 1 × 4.7Ω/5W wirewound, 1 x 10kΩ linear potentiometer.

Miscellaneous

Machine screws and nuts, self-tapping screws, tinned copper wire, heatshrink tubing, PCB bins, epoxy adhesive or Super Glue, solder.

range switch.

Virtually any flashlight can be used to house the Xenon tube although it is desirable to use one which has a reasonably large reflector. We used one made by Eveready. Most such flashlights these days have plastic reflectors with vapour-deposited metallisation. These can be easily cut to make a suitable opening for the Xenon tube. It can be fixed in place with epoxy adhesive or "Super Glue".

Be careful not to put finger prints on the reflector surface or spill glue on the plastic lens. The cord should be anchored to the flashlight housing using a cordgrip grommet.

Final checks

Now that assembly is complete, the unit should be very carefully inspected for wiring errors. Then power can be applied. Check that the display is alight and the tube flashes in response to the front panel controls. If the tube is not working, there is probably a fault in the power supply. If this section has to be checked with a multimeter remember that it is all floating at half mains voltage. Take great care.

On the other hand, if there is a fault in the low voltage section, it is possible to make the circuit safe to work on by removing the mains rectifier, diodes D3 to D6.

Assuming that the unit works as it should, all that remains is to correctly position the frequency knob. Rotate the frequency knob so as to give a reading of 166 to 167 on the digital display, with the display selector set to "RPS". Then set the frequency knob so that its pointer is aligned with the overrange marker.

When the knob is rotated clockwise beyond this overrange marker, the display will be in the overrange condition when reading RPM. This means that 10,000 should be added to the reading.

As an example of how the system works, a setting of 180 RPS on the display will give a reading of 0800 on the display when in the RPM mode. Adding 10,000 to the reading gives the correct result of 10,800 revolutions per minute.

For best results when using the strobe, keep the ambient lighting as low as possible, for best strobe visibility. For direct reading of RPM, on say a revolving shaft, place just one marker (using white correction liquid such as "Tippex") on it. For higher shaft speeds, use two markers, equally spaced around the shaft and reduce the resultant display reading by half, for the lowest stationary pattern. EA