LED TACHOMETER

A unique two-range tach that gives an analogue RPM display on a bar of 21 LEDs. The display flashes to indicate an alarm condition when the RPM exceed a preset limit.

THE ETI TACH/ALARM is an all solid-state project. It displays engine speed in analogue form (like a conventional tach) as an illuminated section of a line of 21 LEDs. The length of the illuminated section is proportional to the engine speed, so that half of the scale is illuminated at half of full-scale speed, and so on. In other words, the display is in bar rather than dot form.

The Tach/Alarm can be used with virtually any type of multi-cylinder gas engine. It has two speed ranges, each of which can be calibrated by a preset pot to give any full-scale speed range required by the individual owner. Our prototype is calibrated to give full scale readings of 10,000 RPM and 1,000 RPM on a four-cylinder, four-stroke engine. The lower range is of great value when adjusting the engine's ignition and carburator for recommended idle speeds. The upper range has adequate resolution (500 RPM per step in our case).

A unique feature of our product is the provision of a visual over-speed alarm facility, which causes the LED display to rapidly flash on and off when the RPM exceed a preset level; the tach continues to indicate the actual RPM under the alarm condition. Tachs are normally placed directly in front of the driver in sports/racing cars, so this visual alarm system is a highly effective 'attention getter' in such vehicles.

The unit is designed for use only on vehicles with 12V electrical systems. It can be used with conventional or capacitor-discharge (CD) ignition systems and is wired into the vehicle with three connecting leads. It can be used on vehicles with either negative or positive ground electrical systems.

Construction

The complete unit, including the 21 LED display, is mounted on a single PCB. Take care over the construction, paying special attention to the following points:

(1) Our prototype uses a display comprising a linear row of 21 square LEDs, mounted horizontally on the PCB. You may prefer to use a semicircular display of LEDs, in which case you can mount the display on a separate board of your own design, with suitable connections to our board. In either case confirm the polarity and functioning of each of the 21 LEDs, by connecting in series with a 1K0 resistor and testing across a 12V supply, before wiring into place on the PCB. Note that the LED colours can be mixed, if required.

If you use the same display form as our prototype, bend and adjust the LED leads so that each LED slightly overhangs the edge of the PCB when soldered into place.

(2) Seven link connections are made on the PCB. Also note that the external connections to the unit (0V, + ve and points) are made via solder terminals (Veropins).

(3) Range-changing is achieved via a three-pole two-way switch. On our prototype we've used a slide switch for this purpose.

(4) Note that the values of C2 and C3 must be chosen to suit the engine type and full-scale RPM ranges required (see the conversion graph). Our prototype, calibrated to read 10,000 RPM and 1,000 RPM on a four-cylinder four-stroke engine, uses C2 and C3 values of 22nF and 220nF respectively.

When the construction is complete, connect the unit to a 12V supply and check that only LED1 illuminates. If all LEDs illuminate, suspect a fault in the wiring of IC1.

Calibration

The unit can be calibrated against either a precision tachometer or against an accurate (2% better) audio generator that gives a square wave output of at least 3V peak-to-peak. The method of calibration against an audio generator is as follows.

Connect the tach to a 12V supply and connect the square wave output of the audio generator between the 0V and points terminals of the unit.

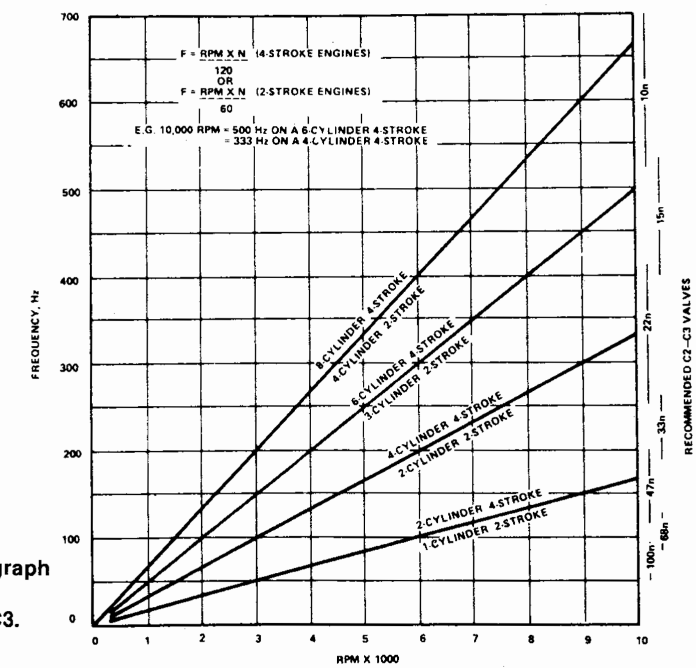
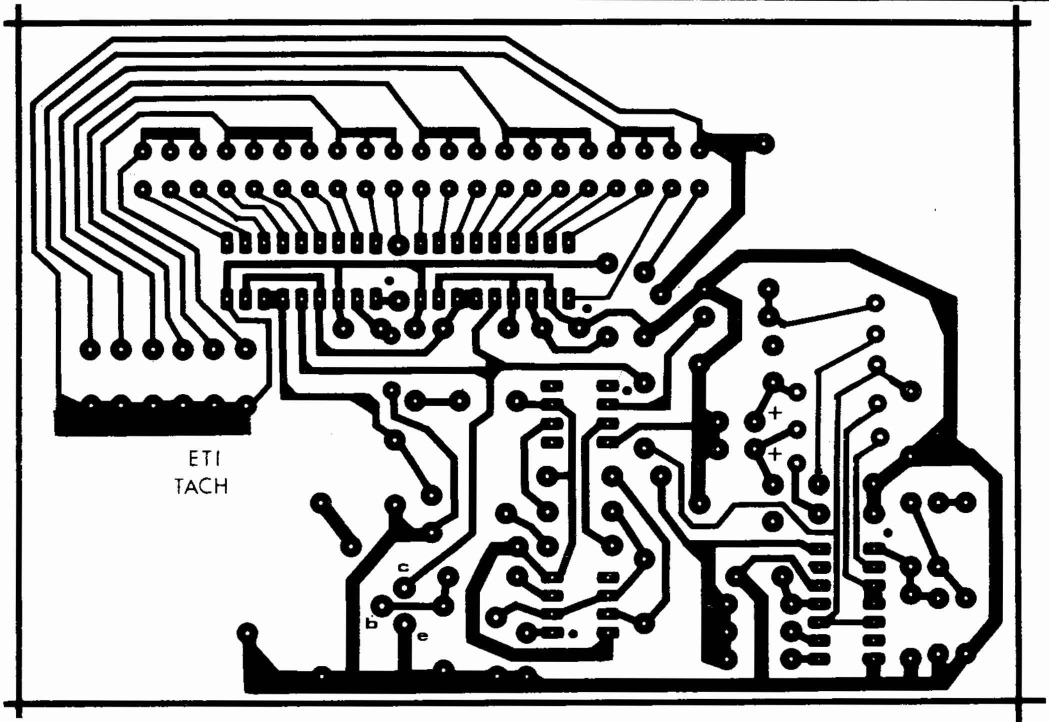


Fig. 2 Conversion graph to determine the values of C2 and C3.



Check against the conversion graph to find the frequency needed to give the required high range full-scale RPM reading on the type of engine in question and feed this frequency into the tach input. Switch SW1 to its high range (10,000 RPM on our prototype) and adjust PR1 for full-scale reading. Now set the generator to the alarm frequency and adjust PR3 so that the display flashes. Recheck both adjustments.

Now switch SW1 to its low range (1,000 RPM on our prototype), set the required full-scale frequency and adjust PR2 for a full-scale reading on the tach. Note that the alarm facility is inoperative on this range.

Installation

The completed unit can either be mounted in a special cut-out in the vehicle's instrument panel or (preferably) can be assembled in a home-made housing and clipped on top of the instrument panel. In either case try to fit some kind of light shield to the face of the unit, so that the LEDs are shielded from direct sunlight.

To wire the unit into place, connect the supply leads to the tach via the vehicle's ignition switch and connect the unit's points terminal to the points terminal on the vehicle's distributor.

The lower range of the tach is of great value when adjusting the engine for correct idle. It is thus advantageous to arrange the tach housing so that it can be easily dismounted from the instrument panel.

PARTS LIST

Resistors all ¼W, 5%

R1,2,5	10k
R3,13	22k
R4	470R
R6,15	1k2
R7,9,10,12	330R
R8,11	270R
R14	27k
R16,20	2k2
R17	270k
R18,19	12k
R21	1M0
R22	6k8
R23	4k7

Potentiometers

PR1,2	100k miniature horizontal preset
PR3	47k minature horizontal preset

Capacitors

C1,2	22n polycarbonate
C3,8	220n polycarbonate
C4	1u0 35V tantalum
C5	4u7 35V tantalum
C6,7	47u 16V tantalum
C9	100u 25V electrolytic

Semiconductors

IC1	LM2917N
IC2,3	LM3914
IC4	CA3140
IC5	ICM7555
Q1	2N3904
ZD1	400mW 12V
D1,2	1N4148
D3	1N4001
LED1-21	Red, square type.

Miscellaneous

SW1	3-pole double throw switch

PCB, case.

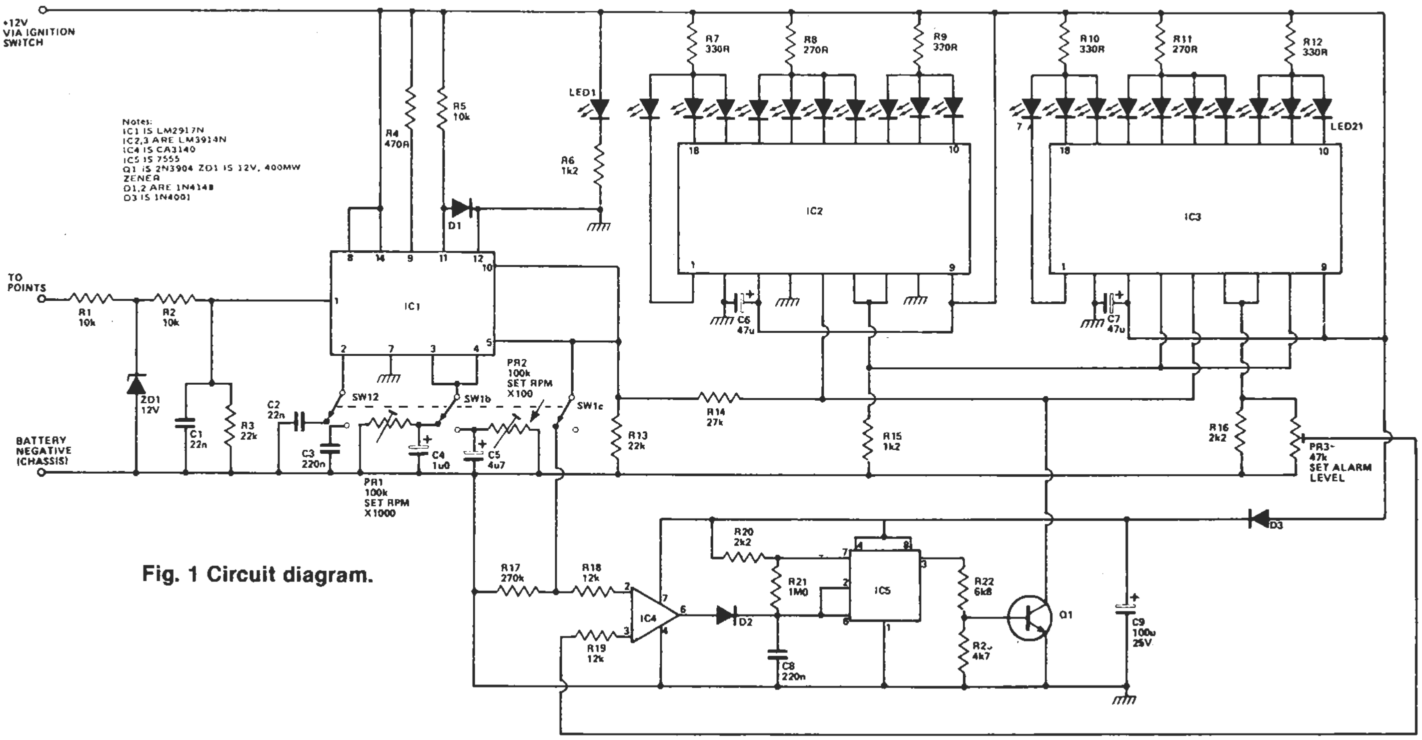


Fig. 1 Circuit diagram.

Cont. on p. 70

HOW IT WORKS

The ignition signal appearing on a vehicle's points has a basic frequency that is directly proportional to the RPM of the engine. Our tach works by picking up the signal, extracting its basic frequency, converting the frequency to a linearly-related DC voltage and then displaying this voltage (and thus the RPM) on a line of 21 LEDs. The basic tach can thus be broken down, for descriptive purposes, into an input signal conditioner section, a frequency-to-voltage converter section and a LED voltmeter display section.

The input signal conditioner section comprises R1-R2-R3-ZD1-C1. The points signal of a conventional ignition system consists of a basic RPM-related rectangular waveform that switches alternately between zero and 12V, onto which various ringing waveforms with typical peak amplitudes of 250V and frequencies up to 10 kHz are superimposed. The purpose of the input signal conditioner is to cleanly filter out the basic rectangular waveform and pass it on to the F-to-V converter. It does this first by limiting the peak amplitude of the signal to 12V via R1 and ZD1 and then filtering out any remaining high frequency components via R2-R3-C1. The resulting clean signal is passed on to the input (pin 1) of IC1.

IC1 is a frequency-to-voltage converter chip with a built-in supply voltage regulator. The operating range of the IC is deterimined by the value of a capacitor connected to pin 2 and by a timing resistor and smoothing capacitor connected to pins 3-4. In our application, two switch-selected presettable ranges are provided. The DC output of the IC is made available across R13 and is passed on to the high-impedance input terminals of the IC2-IC3 LED voltmeter circuit via series resistor R14. R14 is essential to the operation of the alarm section of the tach.

IC2 and IC3 are LED display drivers. Each IC can drive a chain of 10 LEDs, the number of LEDs illuminated being proportional to the magnitude of the IC's input signal. Put simply, the ICs act as LED voltmeters.

In our application, the two LM3914 ICs are cascaded in such a way that they perform as a single 20-LED voltmeter with a full-scale range of 2V4. This full-scale value is determined by precision voltage references built into the ICs. The full-scale reference voltage (2V4) is generated across R16 and PR3. The configuration of our voltmeter is such that it gives a bar display, in which LEDs 1 to 11 are illuminated at half-scale or LEDs 1 to 21 are illuminated at full-scale. R7 to R12 are wired in series with the display LEDs to reduce the power dissipation of the two ICs. LED 1 is permanently illuminated so that the RPM display does not blank out completely when the engine is stationary with the ignition turned on.

The alarm section of the tach is fairly simple. IC4 is wired as a voltage comparator with a stable reference voltage fed to its non-inverting (pin 3) input from PR3 and with an RPM-related voltage fed to its inverting (pin 2) input from R13 via SW1c. The output of IC4 is used to enable or disable astable multivibrator IC5 and the output of IC5 is used to enable or disable the inputs to the IC2-IC3 voltmeter via Q1 and R14.

At low engine speeds (below the alarm level) the input of IC4 is driven high, thereby disabling the IC5 astable by preventing C8 from discharging. Under this condition the output of IC5 is driven low, cutting off Q1 and enabling the tach circuit to operate in the normal way.

At high engine speeds (at or above the alarm level) the output of IC4 is driven low, thereby enabling the IC5 astable to operate at a rate of roughly 2 Hz and alternately drive Q1 on and off. In the moments that Q1 is cut off, the tach operates in the normal way, but in the moments that Q1 is driven on its collector pulls the pin 5 input terminals of IC2 and IC3 to near-zero volts and thereby effectively blanks the LED displays. The LEDs flash rapidly under the alarm condition, but continue to indicate RPM vlaues.

The alarm point can be set in any position on the tach scale by PR3. SW1c is used to diable the alarm section when the tach is set to its low (1,000 RPM in our prototype) range. Note that the power supply to the alarm is decoupled from the main supply by D3 and C9.

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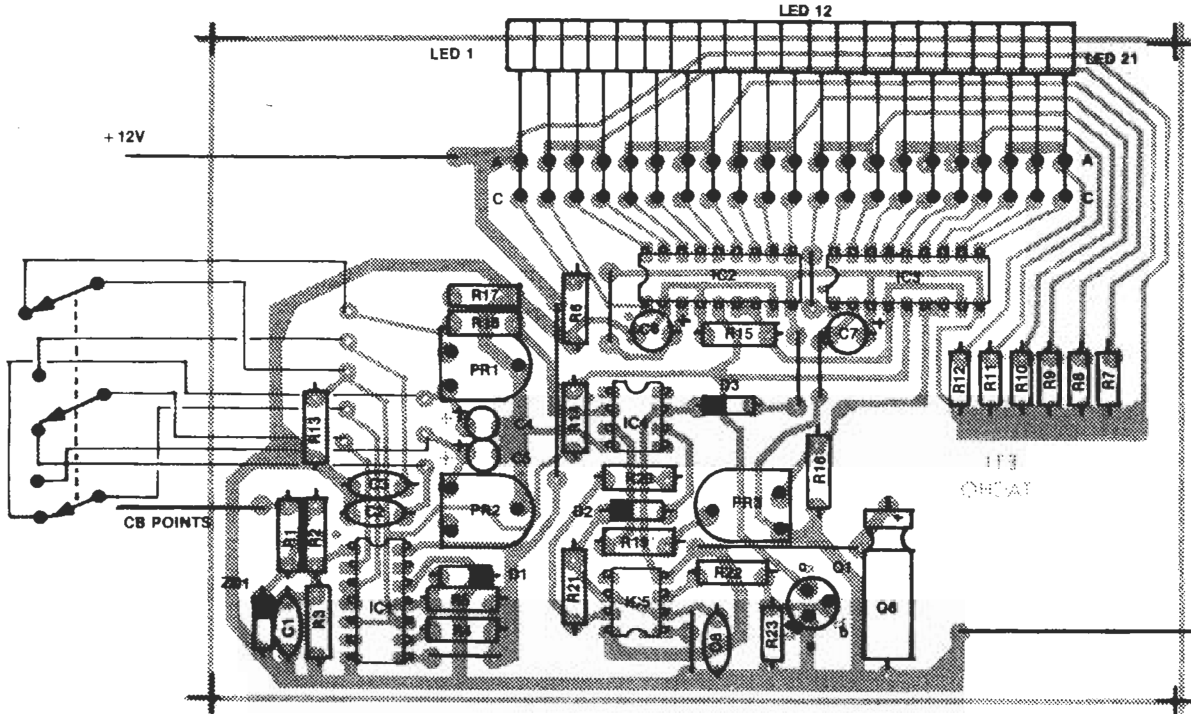


Fig. 3 Component overlay.

20 The pecularity of this rev. counter is that it responds to differences in luminous intensity. Consequently, if this circuit is to be used as a rev. counter, the motor shaft must be provided with a vane which periodically intercepts the light incident on the light sensor. Little can be said about the choice of light sensitive element, because they come in numerous types. Instead of a photo diode, photo transistors or photo darlingtons can be used. In practically all cases it will be necessary to experiment with the value of R1. A first setting can be obtained by applying half the supply voltage to point A by means of R1.

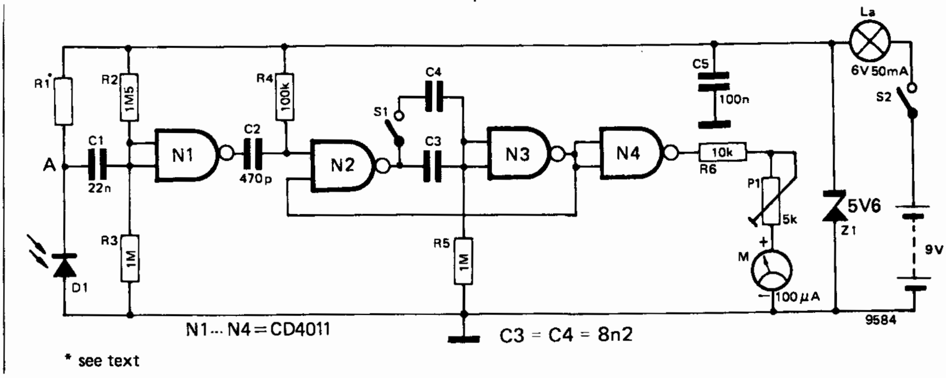
For slow-running machines, D1 can sometimes be replaced by an LDR. As soon as more light is incident on D1, the current through D1 will increase so that the voltage on point A drops. Via C1 and C2 this voltage drop is fed to the monostable multivibrator N2/N3.

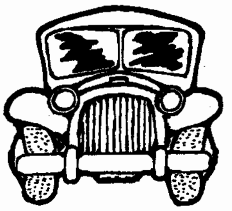
In the quiescent state both inputs of N3 are earthed via R5, so the output of N3 is 'high'. Consequently, the two inputs of N2 are 'high' so that its output is 'low'.

As soon as a negative pulse arrives at one of the inputs of N2, the output of N2 changes to 'high' and causes gate N3 to change state, so that the second input of N2 goes 'low'. Even when the trigger pulse on the input of N2 cuts out, the circuit remains in this condition. Only after C3 (+C4) is (are) charged to such an extent that the voltage on the inputs of N3 are 'low' again will the circuit return to the initial state. Thus the monostable multivibrator changes any input pulse on D1 into a pulse of constant width. These pulses are fed to the meter via buffer stage N4.

The lamp in the supply line provides a better stabilization than a resistor, at the same time giving an on/off indication for the meter.

The measuring range can be doubled with S1. When S1 is closed, the range is from 0 to 33 Hz (0 – 2000 r.p.m.); when S1 is open the range is from 0 to 66 Hz (0 – 4000 r.p.m.).





tachometer

This Tachometer adapter was primarily designed to be used in conjunction with the UAA 170 LED meter (Elektor 12, April 1976, p. 441) and will give a clear 'analogue' indication of the number of revolutions made by the car engine. This article gives a short re-cap of part of the original article plus the additional information needed to make a full-fledged Tack.

For some time Siemens has been marketing two ICs suitable for driving analogue LED displays. One of these is the UAA170, a 16 pin IC with 8 encoded outputs capable of driving a column of 16 LEDs. Only one of these LEDs is lit at any time, which one is lit being dependent on the input voltage; as the voltage is increased a point of light will move up the column. The possible applications for LED meters are numerous, but they are particularly useful in applications requiring mechanical robustness, such as use in the presence of mechanical vibrations, which could damage moving coil instruments. Here the absence of moving parts gives the LED indicator not only an almost unlimited life, but also, the ability to follow very rapid input signal changes, since there is no inertia to overcome.

Reference voltage inputs

To establish the input voltage range over which the circuit operates a reference voltage must be applied between pins 12 and 13 of the IC, with pin 13 being the more positive of the two. The voltage at pin 13 sets the full-scale reading of the meter. For input voltages in excess of the voltage at this point the last LED in the column will light and stay lit. The voltage at pin 12 establishes the lowest reading of the meter. For input voltages equal to or less than the voltage at pin 12 the first LED in the column will be lit.

30 LED display

For applications requiring greater resolution than can be provided by 16 LEDs the circuit may be extended using two ICs as shown in figure 1. Both ICs receive the same input voltage at pin 11 but the reference voltages are arranged so that the first IC operates over the input voltage range of say $0 - \frac{V}{2}$, and the second IC over the range $\frac{V}{2} - V$, where V is the full-scale input voltage. It is necessary to omit the last LED from the display of the first IC and the

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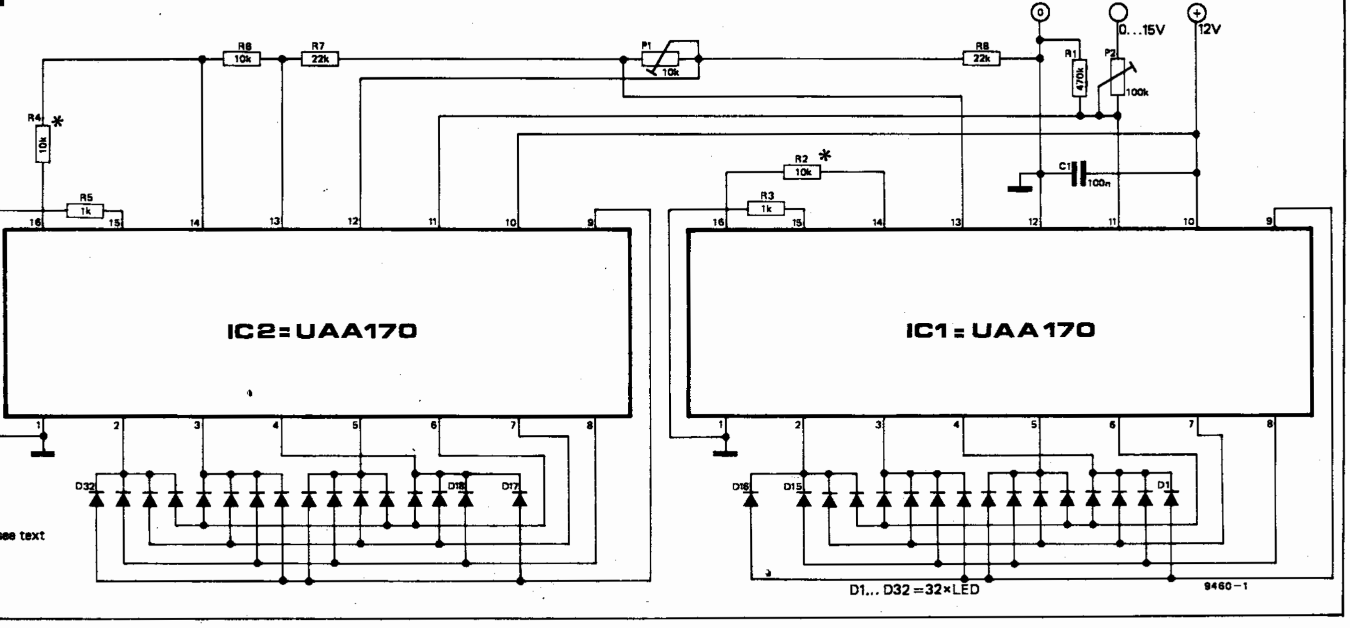

first LED from the display of the second IC, otherwise for voltages in the lower half of the range the first LED of the second IC would always be lit, and for voltages in the upper range the last LED of the first IC would always be lit. For this reason only 30 LEDs may be used, not 32. This means that D16 and D17 should not be part of the scale, although they must be included in the circuit.
So that the omission of these two LEDs does not cause a 'blind spot' in the middle of the display it is necessary to arrange that the second LED of the second IC lights as the 15th LED of the first IC extinguishes. This is accomplished by having the reference voltage on pin 12 of the second IC lower than the voltage on pin 13 of the first IC. The voltage difference between these two points can be adjusted so that D18 begins to light as D15 extinguishes. There should be no blind spot where both LEDs are extinguished, nor should two or more LEDs be fully lit at the same time.

Brightness Control

The output current delivered to the LED display, and hence the brightness, can be altered by a brightness control connected between pins 14 and 16 of the IC. This may take the form of an LDR or phototransistor to adjust the display brightness to suit ambient lighting conditions, or it may be a manual control such as a potentiometer. The control is connected in place of the two fixed resistors R2 and R4. A fixed resistor between pin 15 and ground adjusts the control characteristics of the brightness control.
Figure 2a shows two methods using a photo-transistor, and a LDR. Since there are two ICs in the circuit they would both require a photo-transistor. These transistors must then be mounted in close proximity to each other, otherwise differences in lighting could cause uneven scale brightness. However, it has also proved possible to intercon-

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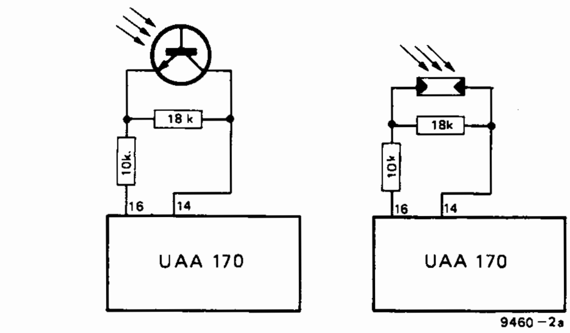

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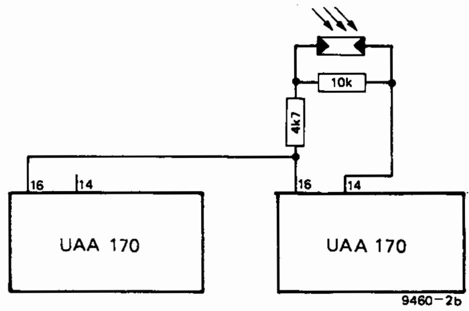

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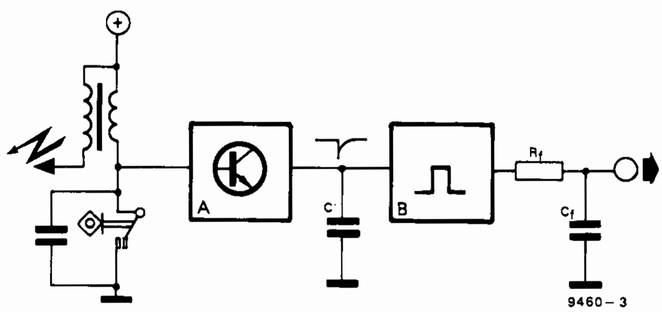

Figure 1. The original LED meter circuit diagram. D16 and D17 must be included in the circuit, although they can not be used as part of the scale.

Figure 2. Two methods for obtaining automatic display brightness control.

Figure 3. Block diagram of the tachometer.

Parts list for figure 1

Resistors:	Capacitors:
R1 = 470 k	C1 = 100 n
R2,R4,R6 = 10 k	
R3,R5 = 1 k	Semiconductors:
R7,R8 = 22 k	IC1,IC2 = UAA170
P1 = 10 k preset	D1 . . . D32 = LED
P2 = 100 k preset	

nect the pins 16 of the two ICs, and use one photo-transistor or LDR between these pins and either of the pins 14. This is shown in figure 2b.

Tachometer converter

The circuit to adapt the LED meter to a full-fledged tachometer need not be complex, a simple monostable multivibrator will do. At the Elektor Labs a simple but effective design was developed using only one 555 IC. This design uses an input stage with one transistor and a filter in the output.
The block diagram of figure 3 gives an impression of how the circuit functions. Due to the fact that the crank shaft and the breaker contacts are coupled the pulse train produced by the breaker contacts is some multiple of the engine's rev's. These pulses are fed to the input stage (block A in figure 3) which, in conjunction with capacitor C, gives them a better shape. After shaping they are used to trigger the monostable multivibrator (block B). For each pulse applied to the input of the monoflop, a positive going pulse appears at the output. These positive pulses all have the same width and amplitude irrespective of the input pulse train. As the input frequency goes up, the duty cycle of the output also goes up. These pulses are fed through an integrating filter (Rf and Cf) which changes the pulsed output into a DC voltage with very little ripple. The ripple should be as low as possible because the LED meter responds so quickly that severe ripple on the DC will cause several LEDs to light up 'simultaneously'.
Depending on the number of revolutions made by the engine, the monostable multivibrator will produce many or few pulses per unit time. A low number of pulses will give a low output voltage and a high number of pulses will produce a higher voltage at the filter output. This voltage is displayed by the LED meter.

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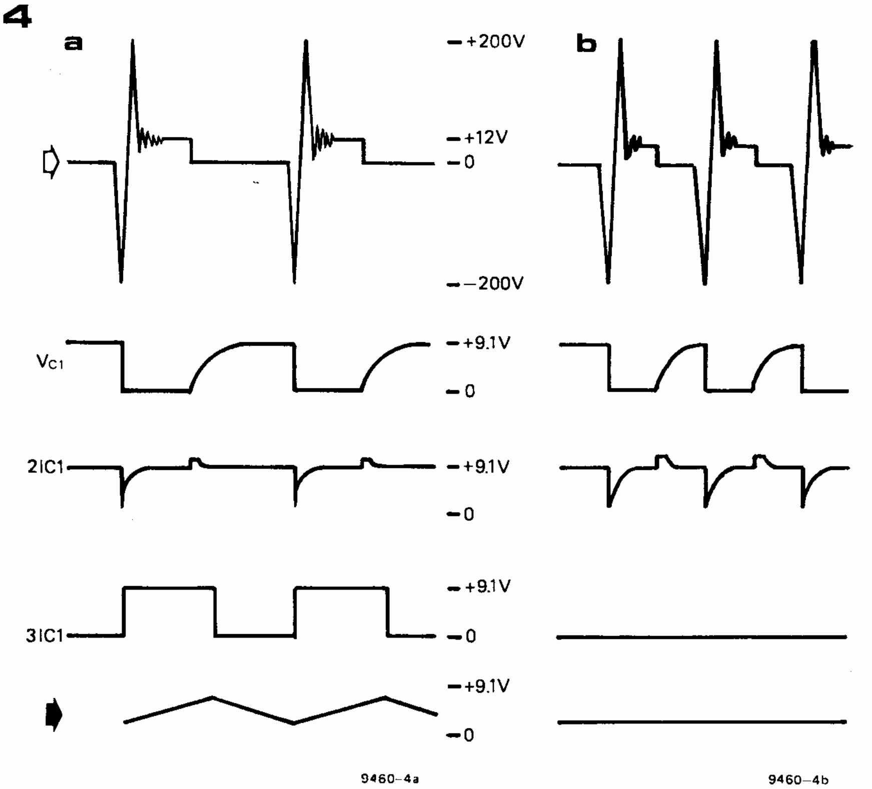

The input stage

The input resistor R1 (figure 5) is connected to the junction of the contact breakers and the ignition coil. R1 and R2 and the zener diode D1 protect the input transistor against high voltages. The moment the contacts open and the plugs spark, an oscillation occurs involving negative and positive peaks of a few hundred volts (see figure 4a, upper voltage form).
During the time that there is a positive voltage across the breaker contact, T1 is driven and the collector voltage drops. IC1 is triggered by this negative edge. Capacitor C1 serves to prevent the 555 from being triggered by short pulses.

The frequency at which the contact breaker feeds pulses to the input stage depends on the type of engine: the 'stroke' number of the engine (two-stroke or four-stroke), and the number of cylinders. The frequency f at which the contact breaker opens and closes is:

$$f = \frac{N}{30} \times \frac{C}{S},$$

where N is the number of revs per min. C is the number of cylinders, and S is the number of strokes in one complete cycle.
So for a four-stroke four-cylinder engine we have:

$$f = \frac{N}{30} \times \frac{4}{4} = \frac{N}{30}$$

At an engine speed of 6000 r.p.m. the corresponding frequency is 200 Hz. By using this formula it is possible to calculate the frequency of breaker pulses for other types of engines. This can be useful when calibrating the instrument.

The monostable multivibrator

The monostable multivibrator is built around the 555 (IC1 in figure 5), an old acquaintance whom we need not introduce again. The IC requires only a few external components for reliable operation. P1, R6, and C3 determine the duration of the output pulses; P1 is variable, so that the circuit can be adjusted to maximum output voltage at a given number of revs. The IC is triggered via pin 2 by means of a short negative pulse (<5 V). Capacitor C2 has been added to ensure that the trigger pulses are of short duration. Otherwise at low engine r.p.m.'s the collector of T1 could remain low longer than the monostable time, and the 555 might then be triggered again. As a result, a multiple of the actual number of revolutions would be indicated. This is prevented by the combination of C2 and R5.

The diodes D2 and D3 ensure that the input voltage at point 2 does not exceed or drop below the supply voltage, as this would damage the IC.

If the output pulses last too long, i.e. longer than the period of the input frequency, but shorter than twice that period, the IC will not yet have returned to the initial position when the next trigger pulse arrives. This will mean that every second pulse has no effect. (The 555 is not re-triggerable). If alternate pulses are lost, it will seem as if the engine is running at only half its actual speed. To prevent this P1 must be adjusted so that the mono-time is shorter than the shortest period (corresponding to the highest input frequency).

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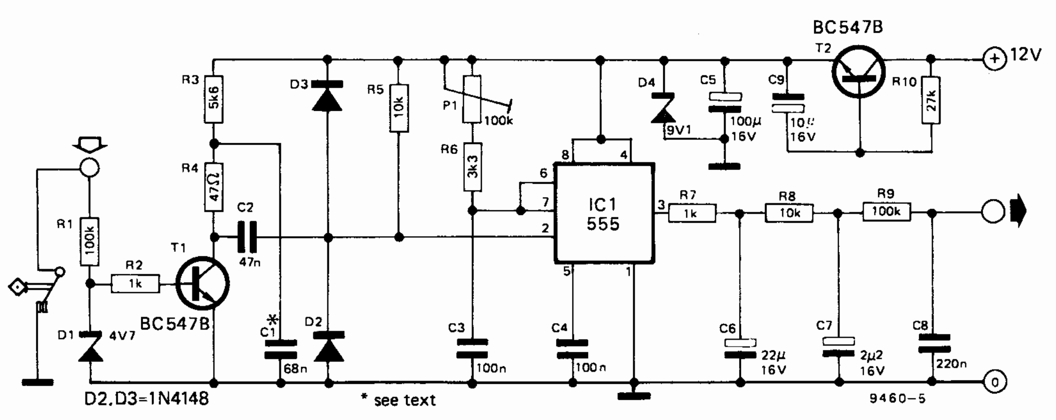
Parts list for figure 5

Resistors:
R1,R9 = 100 k
R2,R7 = 1 k
R3 = 5k6
R4 = 47 Ω
R5,R8 = 10 k
R6 = 3k3
R10 = 27 k
P1 = 100 k preset

Capacitors:
C1 = 68 n
C2 = 47 n
C3,C4 = 100 n
C5 = 100 µ/16 V
C6 = 22 µ/16 V
C7 = 2µ2/16 V
C8 = 220 n
C9 = 10 µ/16 V

Semiconductors:
T1,T2 = BC 547 B, BC 107 B, 2N3904
IC1 = 555
D1 = zener 4V7/400 mW
D2,D3 = 1N4148
D4 = zener 9V1/400 mW



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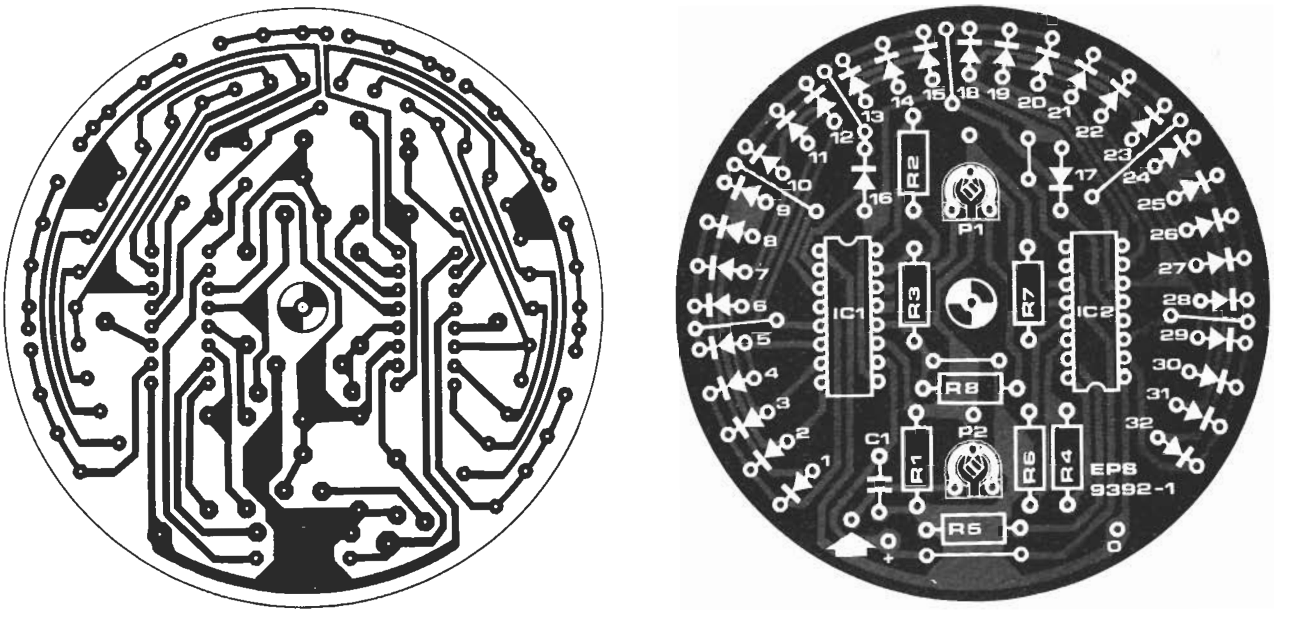

Figure 4. Some waveforms as they occur in the circuit of figure 5. In 4a the trigger pulses on point 2 of IC1 are large enough; in 4b the pulses are insufficient owing to the influence of C1. For the sake of clarity, the ripple voltage at the output is shown exaggerated.

Figure 5. The diagram of the tachometer. The input is connected to the breaker contacts of the car engine; the output drives the LED meter.

Figure 6. The p.c.b. and component layout for the LED meter (EPS 9392-1).

Figure 7. The p.c.b. and component layout of the tachometer (EPS 9460).

The output filter and display

An output filter is not needed in normal rev counters because of the type of readout employed. A moving coil meter cannot possibly follow the pulses of the monostable because of its mass and self inductance.

When using a high-speed electronic read-out however, it is necessary to carefully filter the output to avoid having several LEDs light up simultaneously. This filtering is achieved by a series connection of three RC networks. Consequently, the output impedance is fairly high. This is no problem when it is used with the LED meter, but it is not suitable for a moving coil instrument! The output from the adapter is connected direct to the input of the LED meter (figure 1). Note the value of R1 (470 k); in the original article a different value was shown to obtain a wider input voltage range.

Supply and construction

Although the pulse duration of the square waves at the output of the 555 is practically independent of the supply voltage, it is still necessary to stabilize the supply voltage because the amplitude of the square wave voltage is equal to the supply voltage, thus directly influencing the output voltage of the circuit. Stabilization is provided by means of a zener diode. However, here the usual series resistor for the zener has been replaced by a simulated self inductance (see Elektor nr. 2, page 253) consisting of one transistor. The total current consumption of the circuit remains below 10 mA.

The three p.c.b.s. can be mounted by using a long bolt pushed through the central hole in each board. Spacers are used between the boards.

The whole assembly can now be accommodated in a suitable housing. For this, even a round VIM tin, or something

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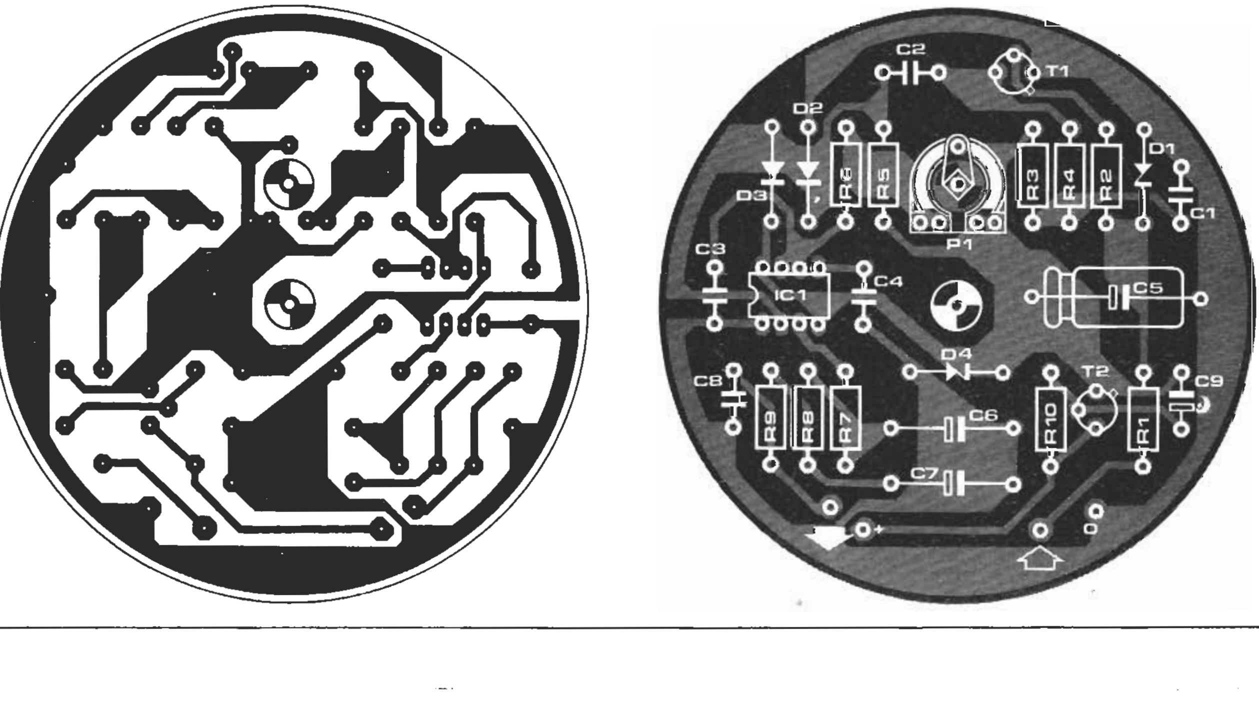

similar could be used. An alternative solution is to build the circuit into a P.V.C. sleeve link for drain pipes (see photograph 3).

Adjustment

The circuit in figure 5 is intended for use with four-stroke four-cylinder engines running at a maximum of 5800 r.p.m. For other engines the highest occurring frequency can be calculated by means of the formula given earlier. C1 is adapted accordingly by multiplying the value from figure 5 by $\frac{200}{f\ max}$. In most cases the adjustment range of P1 is sufficiently wide to compensate for extreme cases, but C3 can be adapted if required.

A simple adjustment procedure is as follows:

- turn P1 on the tachometer p.c.b. fully anti-clockwise
- turn P2 on the LED meter p.c.b. fully anti-clockwise
- apply the supply voltage (+12 V)
- connect the input to the secondary of a step-down transformer giving 5 to 15 V at 50 Hz
- turn P1 on the tacho board until the read-out indicates 1500 r.p.m. (50 Hz corresponds to $\frac{50}{200} \cdot 6000 =$ 1500 r.p.m.).

This completes the adjustment, and the circuit can be built into the car. Owners of an audio signal generator can follow a slightly different adjustment procedure:

- turn P1 and P2 anti-clockwise
- apply a frequency to the input which is 10% higher than the maximum occurring frequency
- Turn P1 clockwise, the readout should be slowly increasing; at some point the readout will jump back to about half reading; leave P1 at this setting
- now apply a frequency which corresponds to the fastest revs possible, the readout should now have jumped back up to almost the correct reading
- adjust P2 to a correct r.p.m. indication.

If the r.p.m. reading in the car suddenly jumps over to double-value indication, this can be remedied by experimenting with R1 on the tachometer board. The latter should, however, never be less than 4k7.

If the reading suddenly changes over to half-value indication, P1 is not properly adjusted, and the entire procedure must be repeated. ◀

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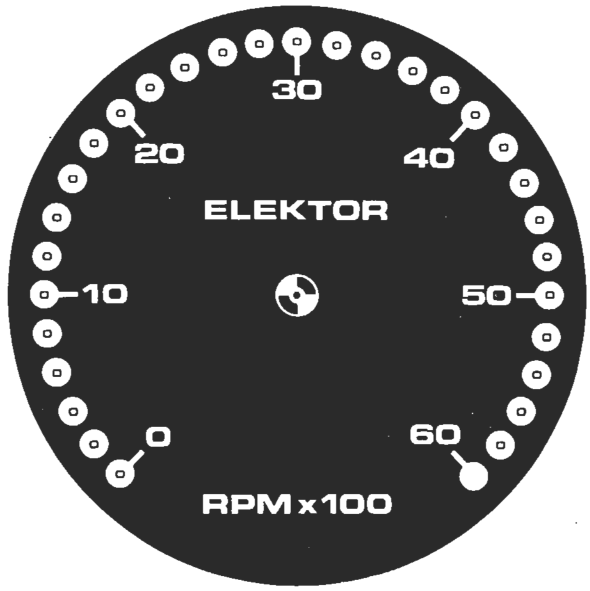


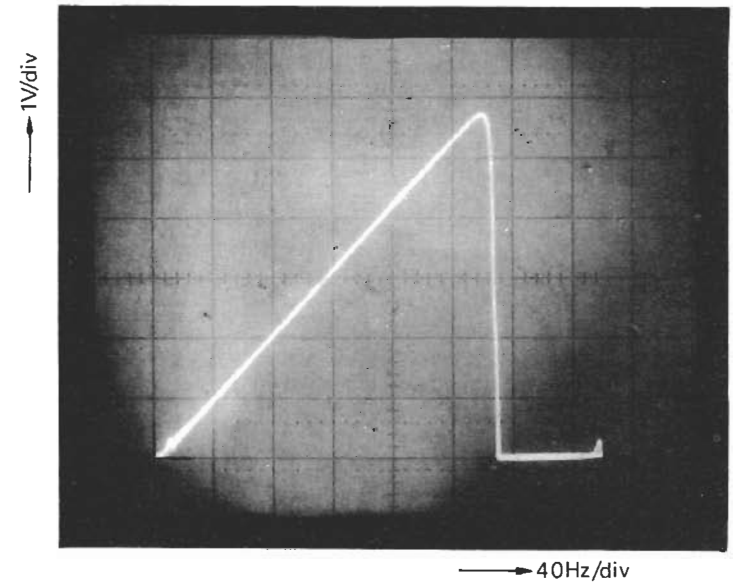
Figure 8. Front panel (EPS 9392-2).

Photo 1. This photograph clearly shows the linearity of the rev. counter. The output (1 V/div) is plotted as a function of the frequency of the input signal (40 Hz/div.)

Photo 2. The complete p.c.b. of the tachometer.

Photo 3. A possible suggestion for the assembly of the entire rev. counter. Because this is a demonstration model, the spacing between the boards is excessive.

1



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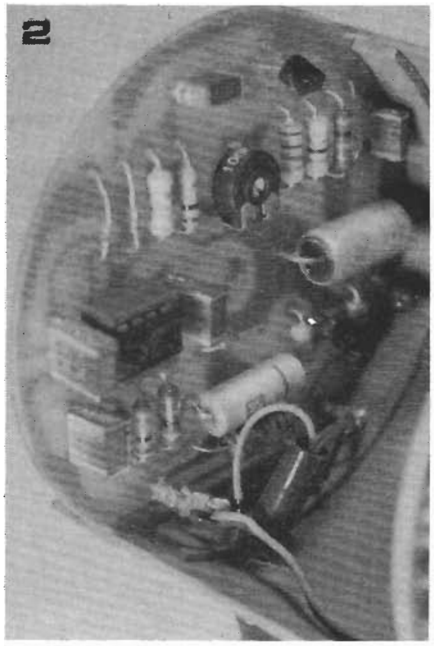

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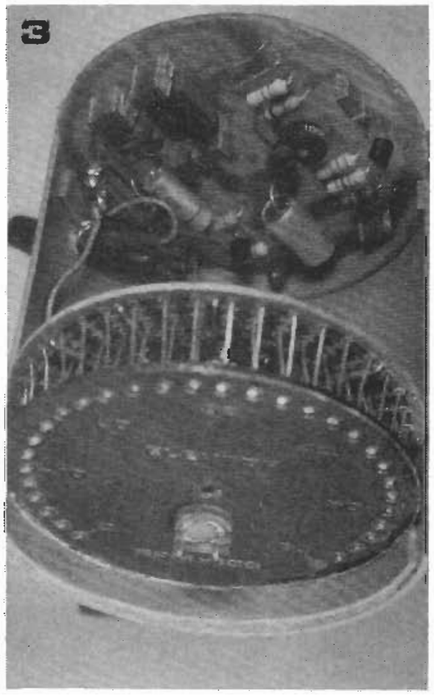


digital rev counter

Until recently, the speed of a car engine (r.p.m.) was measured with an analogue system. It stands to reason that a digital method would do equally well. In principle this can be done with a common frequency meter. Since in this case the number of revolutions per minute (r.p.m.) is to be measured, the time base will have to be somewhat adapted.

The contact breaker in every car (except diesels) and on every engine closes and opens a certain number of times per minute. This number is determined by the following factors: the number of cylinders, the type of engine (two-stroke or four-stroke) and the number of revolutions per minute. If the first two data are known, it can be calculated how many pulses a certain contact breaker gives per second at a certain number of revolutions per minute.

A one-cylinder two-stroke engine gives one pulse per revolution. A one-cylinder four-stroke engine produces one pulse per two revolutions. So a four-stroke engine gives half the number of pulses at the same number of revolutions. This leads to the formula for the number of pulses per second any type of engine produces at a certain number of revolutions (per minute):

$$p = \frac{n \times c}{60 \times a}$$

where p = pulses per second (p.p.s.)
n = revs per minute (r.p.m.)
c = number of cylinders
a = 1 for two-stroke, 2 for four-stroke.

By means of this formula we can now set up Table 1 which immediately shows the fixed r.p.m./p.p.s. ratio for each type of engine. For instance, a most common engine is the four-cylinder four-stroke. At 6000 r.p.m. this engine produces 200 p.p.s. To express the r.p.m. in four digits will therefore take some 30 seconds. This is, of course, out of the question because within the time span of 30 seconds the number of r.p.m. is subject to variation. Consequently, the number of digits shown is reduced to two. The measuring time is then only three tenths of a second. The engine speed can thus be measured with an accuracy of $< 1\%$, which is amply sufficient. Nobody will care whether an engine makes 3418 or 3457 r.p.m.

The circuit

The pulses produced by the contact breaker are usually a bit frayed due to contact 'chatter', and the voltage produced is variable because of the resulting inductance voltages.

Since electronic circuits in general have a severe dislike of inductive voltage peaks, these voltages will have to be suppressed, or at least limited. A zener with a capacitor in parallel for the sharp peaks provides sufficient protection. This protective network is formed by R_1, C_1 and D_1 (see figure 1). Thus the inductive peaks, and to some extent also contact chatter, are suppressed. The remaining chatter is suppressed by means of a monostable multivibrator, which uses half of a 7400 IC. This one-shot responds to pulses with a width of 50 μs or more. In addition, the one-shot passes pulses wider than the characteristic pulse time for their entire length, so that spurious pulses have no effect.

The timebase is provided by a simple, yet relatively stable UJT-oscillator. Its pulse width can be adjusted over a wide range by means of potentiometers R_5 and R_6; the first is for coarse adjustment, the second for fine. In some cases the value of R_7 must be changed (larger or smaller) to enable the required pulse width to be set.

In contrast to the usual circuits, the output pulse is not used to drive a counter gate. The signal to be counted is fed continuously to the counter input of the digital counter used. This is possible because the measuring time is so long that the measuring error due to the latch- and reset time is negligible.

The signal for the buffer memory used in the counter is derived from the discharge pulse the UJT produces across R_9. The transistors T_3 and T_4 provide a level suitable for TTL circuits.

The latch signal thus obtained is a positive pulse. The negative edge of this pulse is used for triggering a one-shot, so that a reset pulse can be produced after the latch pulse. The decade counter, type 7490 (generally applied in digital counters) must be reset with a positive pulse. However, the one-shot produces a negative pulse. Moreover, the delay between latch and reset is too small to ensure optimum functioning. Therefore, the positive trailing edge of the negative pulse is used. After differentiation with C_5 and R_{15} a useful signal appears on the reset output. Diode D_2 suppresses the differentiated pulse caused by the negative flank.

So far the overall control circuit. Its layout is shown in figure 2.

In principe any digital decade counter can be used, and one that is eminently suitable is the minitron counter. This decade counter consists of a display board with several counter boards mounted at right angles to it. For this application the display board is shortened to about 5 cm, so that it can accomodate only two minitrons. The complete minitron counter with two decades is then a block of no more than 5 x 6.5 cm. The dimensions of the control circuit board are reduced correspondingly.

The diagram of the minitron counter is shown in figure 3. The 7490 is connected as a normal divide-by-ten circuit. The buffer memory, or latch, is a 7475. This IC contains four D-flipflops that store the information from the 7490 or pass it on continuously, as required. When mounting the IC on the board, pin 8 must be cut off; or, if IC sockets are used, pin 8 can be removed from the IC socket.

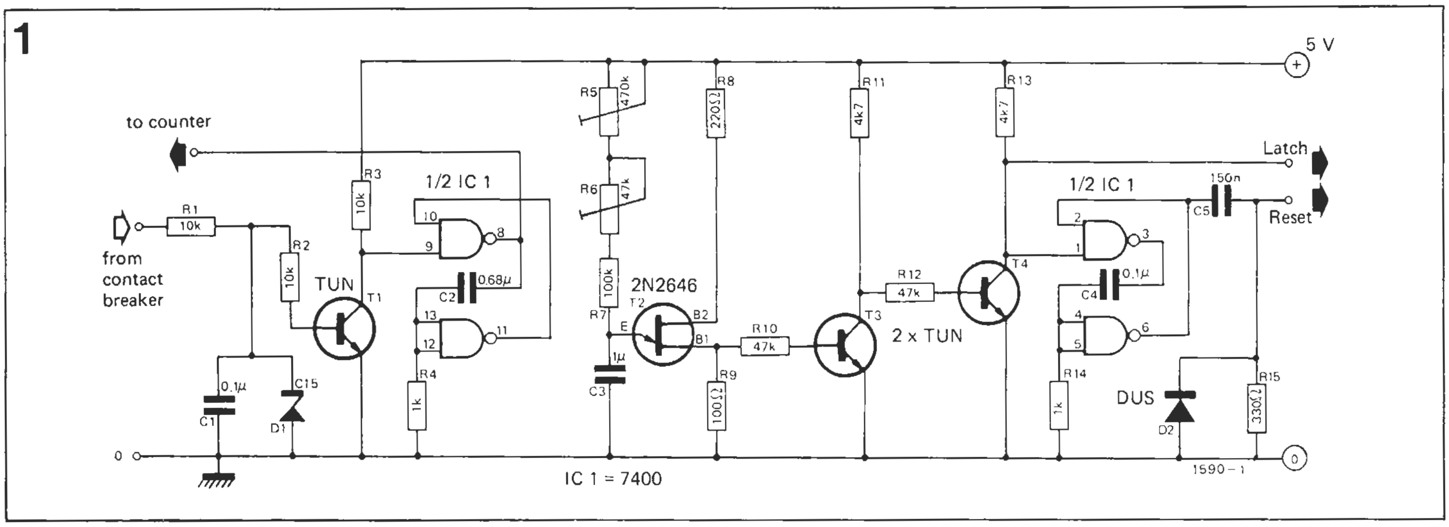
Via the 7475, the BCD information is fed to the 7-segment decoder 7447 which drives the minitron directly. The board is shown in figure 4. By means of soldered connections the display and counter circuit boards are joined to form a kind of block. Figure 5 shows how and where the soldered connections must be made. The width of the control board matches that of the counter boards so that that, too, can be soldered to the display board.

Supply

The rev. counter operates on the usual voltage for TTL-ICs, that is 5 V.

Figure 1. Circuit diagram of the control circuit.

Figure 2. Printed circuit board and component lay-out for the control circuit.



Parts list

Resistors:
R_1, R_2, R_3 = 10 k
R_4, R_{14}, = 1 k
R_5 = 470 k, trim.
R_6 = 47 k, trim.
R_7 = 100 k
R_8 = 220 Ω
R_9 = 100 Ω
R_{10}, R_{12} = 47 k
R_{11}, R_{13} = 4k7
R_{15} = 330 Ω

Capacitors:
C_1, C_4 = 0.1 μ
C_2 = 0.68 μ
C_3 = 1 μ
C_5 = 150 n

Semiconductors:
T_1, T_3, T_4 = TUN
T_2 = 2N2646 (UJT)
IC_1 = 7400
D_1 = zener 15 V, 250 mW
D_2 = DUS

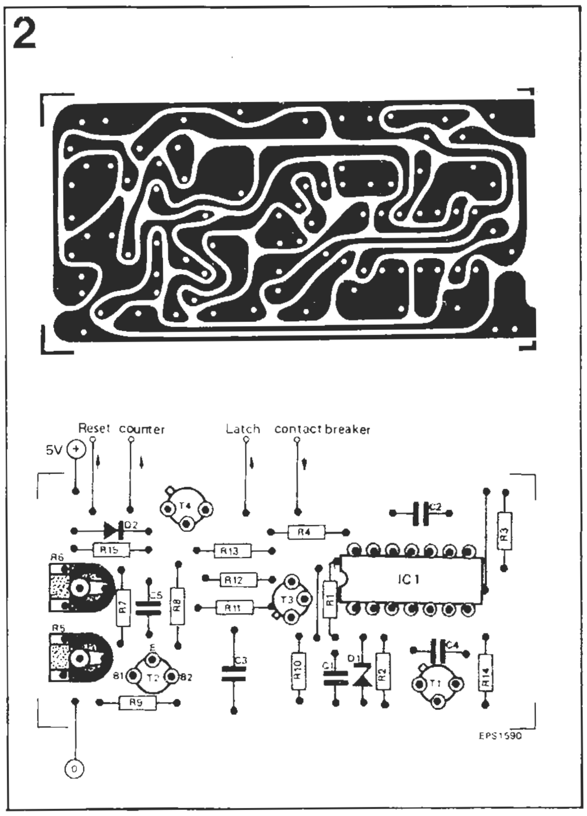


Table 1.

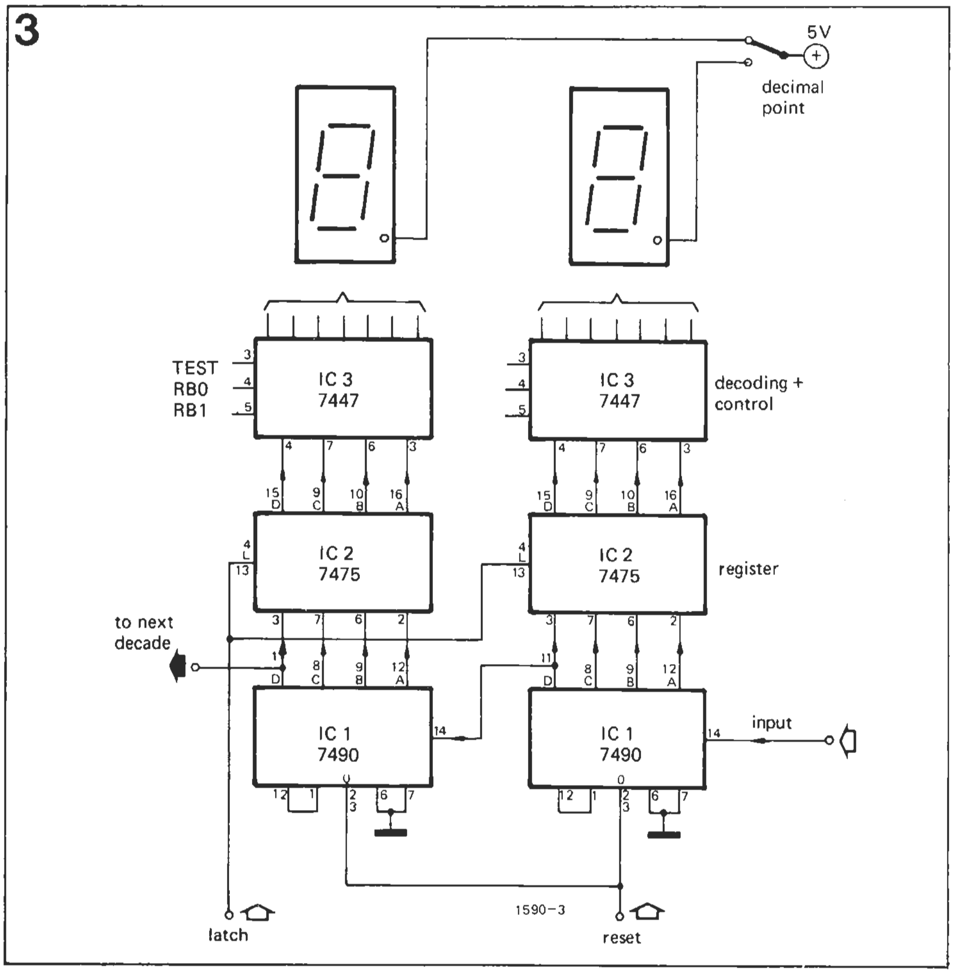
	6000 r.p.m.	8000 r.p.m.
Engine type	Pulses per second	
1 cyl. 2-stroke	100	133
2 cyl. 2-stroke	200	267
3 cyl. 2-stroke	300	400
1 cyl. 4-stroke	50	67
2 cyl. 4-stroke	100	133
4 cyl. 4-stroke	200	267
6 cyl. 4-stroke	300	400
8 cyl. 4-stroke	400	533

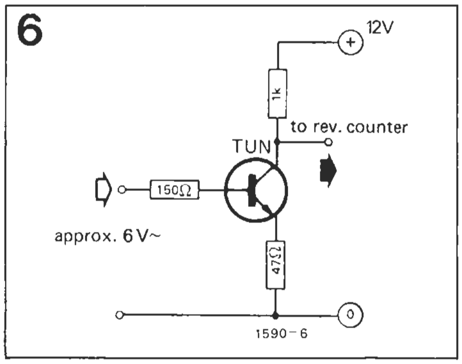
Adjustment

There are several ways of adjusting the rev. counter. The most accurate method is by using the mains frequency or a crystal time base. Unfortunately, the latter will not always be available.
Another possibility is to use a tone generator. Both mains frequency - and tone generator adjustment are discussed below.

Adjustment with the tone generator

For this method of adjustment, a tone generator with calibrated tuning scale for reasonable accuracy is a first requirement. Table 1 gives the frequencies corresponding to a certain type of engine running at 6000 or 8000 r.p.m. Furthermore, each frequency corresponding to a certain engine speed can be calculated with the formula given above. So far so good.
However, the circuit responds only to square wave voltages, so the tone generator will have to produce a square-wave output, or the conventional sine-wave must be converted into a square wave.
This can be done with the simple circuit





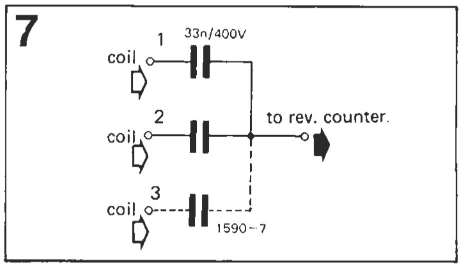
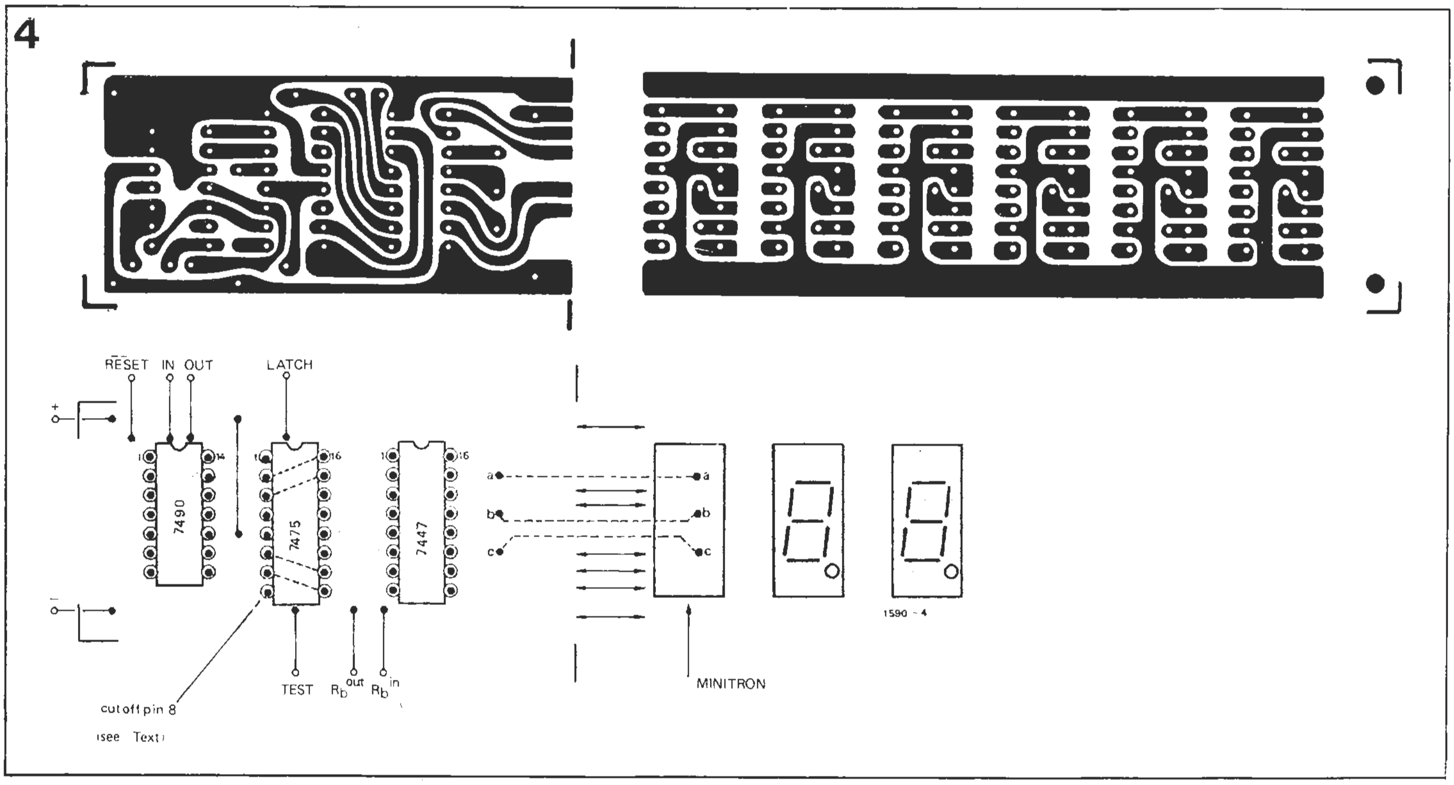


Table 2.

Engine type	rpm indication at 50 pps
1 cyl. 2-stroke	3000
2 cyl. 2-stroke	1500
3 cyl. 2-stroke	1000
1 cyl. 4-stroke	6000
2 cyl. 4-stroke	3000
4 cyl. 4-stroke	1500
6 cyl. 4-stroke	1000
8 cyl. 4-stroke	750



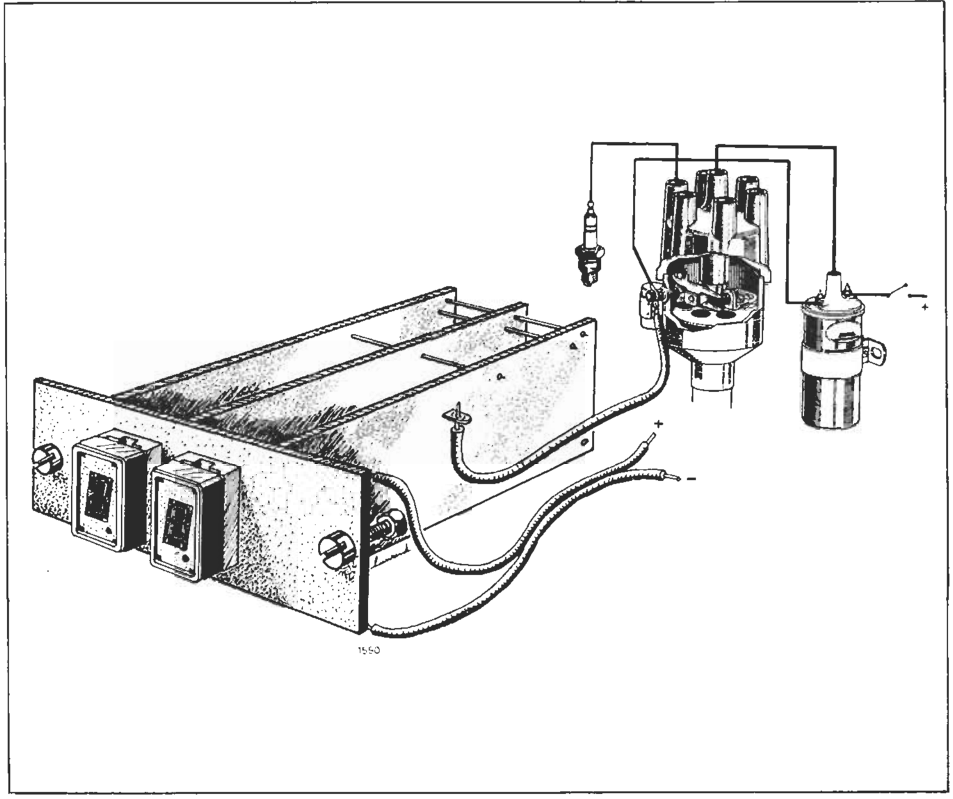
in figure 6. The output signal of this circuit is about 10 V, which is sufficient to operate the rev. counter.

Adjustment with mains frequency

Here again the auxiliary circuit of figure 6 is used, for the mains voltage is a sine wave. A simple bell transformer, or something similar, will provide the required voltage of 6 V.
The square wave output from the circuit is applied to the input of the control circuit.
Table 2 shows what the rev. counter should indicate when used with a given type of engine, and operating on a 50 Hz input signal. While the input signal is applied, the counter can be accurately adjusted by means of R_5 and R_6. Adjustment must be such that the reading fluctuates as little as possible between various values. As is usual for most digital counters, the last digit can jump plus or minus one.

Engines with several ignition coils

Some engines have more than one ignition coil and contact breaker. In this case the various channels from the contact points should be coupled with capacitors. Figure 7 shows how this is best done. A little of experimenting may sometimes be necessary to find the best values for the capacitors.



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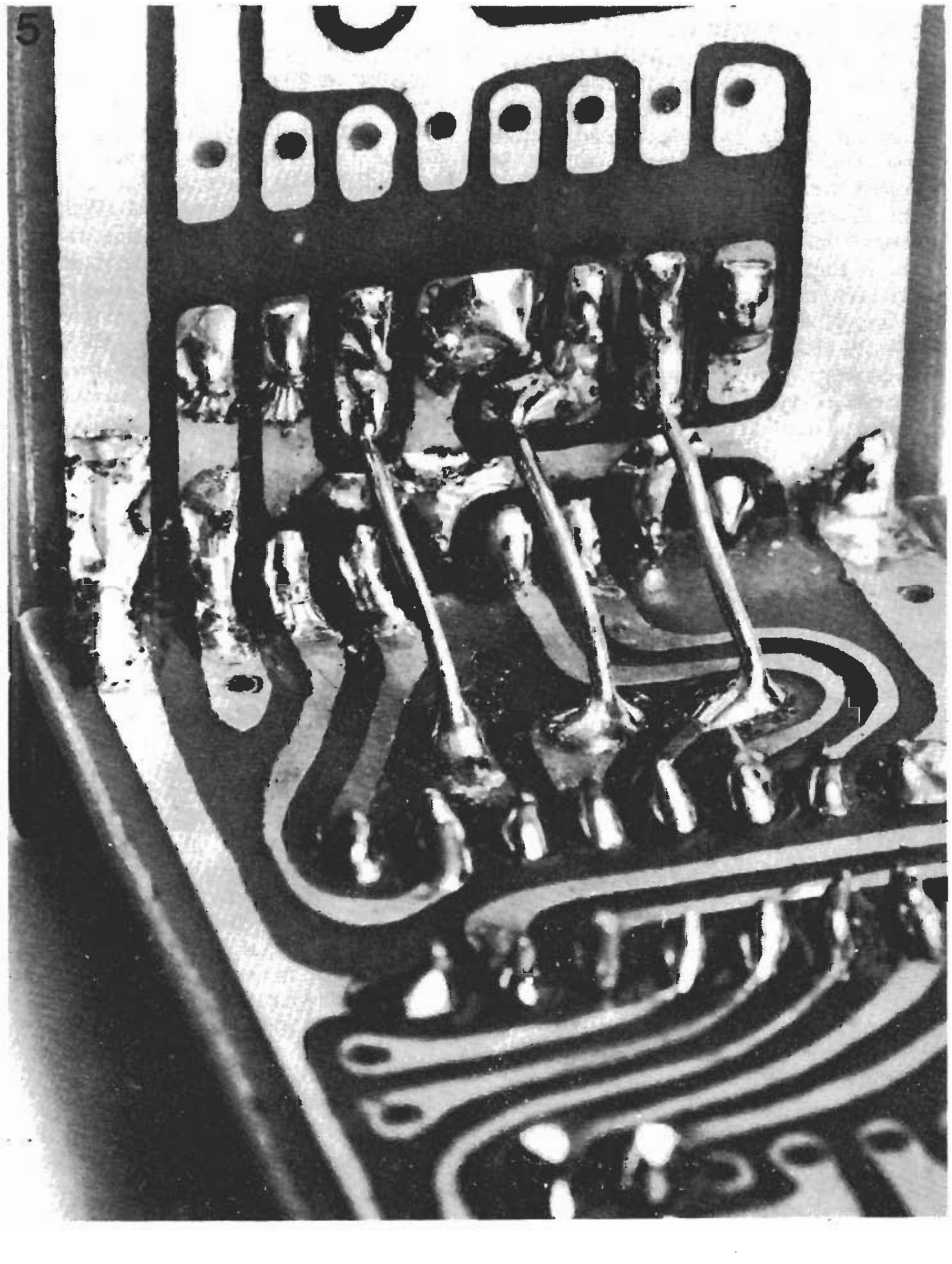


Figure 3. Circuit diagram of the minitron decade.

Figure 4. Printed circuit board and component lay-out for counter plus display. For this particular application the display board can be shortened to about 5 cm.

Figure 5. The photograph shows clearly how the soldered connections between the two boards must be made.

Figure 6. Auxiliary circuit for adjusting the rev. counter by means of a tone generator or with the mains frequency.

Figure 7. If the engine has more than one ignition coil, this auxiliary circuit can be used to obtain a correct speed indication.

LIGHT ACTIVATED TACHOMETER

By using optical sensing this unit allows measurement of rotational speed without the need for actual contact!

THE USE OF a non-contact method of measuring RPM is not only convenient but sometimes the only method possible. Some motors used for model aircraft have a capacity of only 0.15cc yet run at speeds in the 25000 RPM region. The power required to turn a mechanical tacho would be many times the power of such a motor. Also on some machines there is no convenient place a normal tacho can be fitted.

Design Features

As the main application for this unit was to be outdoors it was decided that an LCD display would be preferable to an LED and more easy to read than an analogue meter. Unfortunately LCDs are not yet readily available, and nor are the ICs needed to drive them.

However the Intersil Evaluation kit which we have used in the past is fairly easy to get hold of, and so we based the design around this unit. This meant converting the pulses from the sensor into a voltage. This however has another benefit in that a greater resolution can be obtained more quickly. To have a resolution of 10 RPM with a two bladed propeller a sample time of three seconds would be necessary.

The use of the BPW34 photodiode in the photovoltaic mode, ie actually generating a voltage, simplifies the biasing otherwise needed.

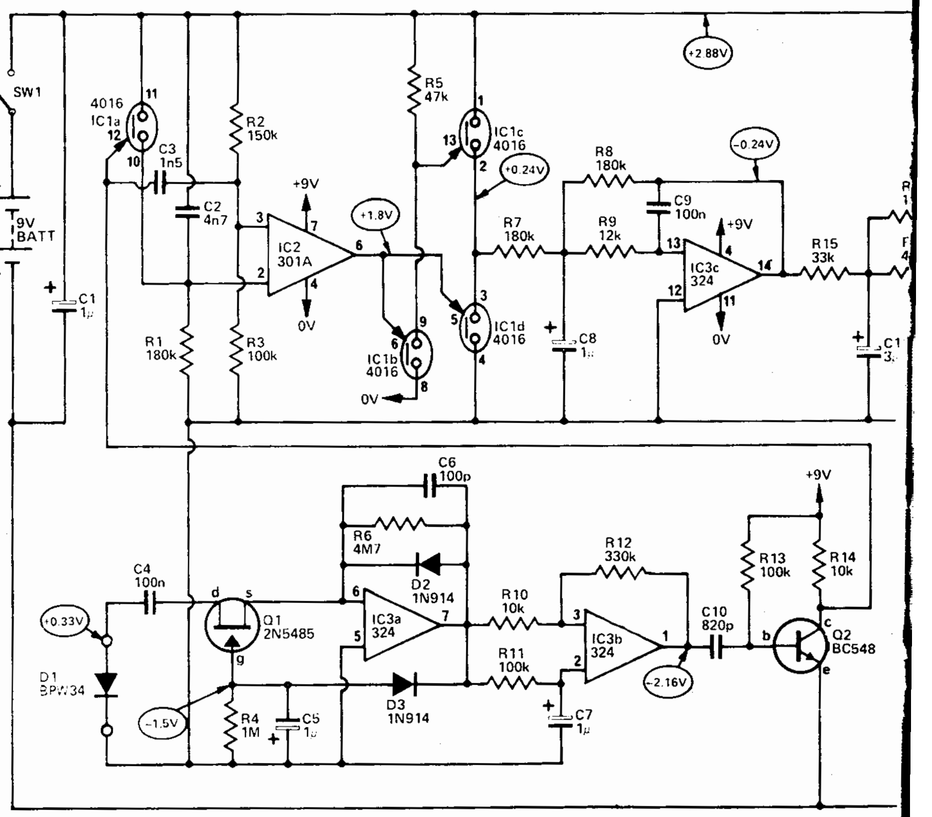
Construction

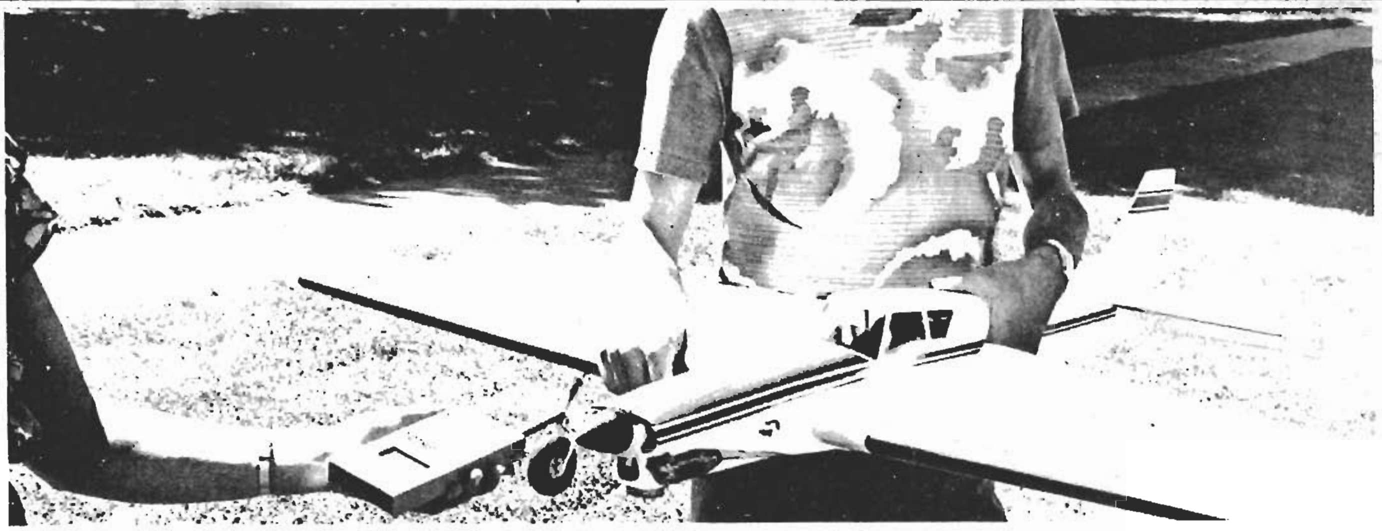
All the electronic components are mounted on a single card with the exception of the photodiode. To save on real estate the main voltmeter IC is mounted under the display.

Initially, assemble all the components apart from the ICs and the

SPECIFICATION

RPM range	
Low	0 – 20000
High	10000 – 30000
Resolution	10 RPM
Display	12mm LCD
Detection method	reflected light
Power	9V @ 4mA
Battery life (216)	about 150 hours





HOW IT WORKS

When using this unit to measure RPM, be the application a model aircraft motor or some other rotating object, the propeller or the white line (see operation section) gives rise to a changing light level. D1 which is a photo diode used in the photovoltaic mode, sees this light level and gives out a voltage proportional to the light. As this is only a small signal it has to be amplified before it can be used. This is done by IC3a. The transistor Q1 is included to provide some gain control allowing the unit to be used in differing light conditions without the need for any adjustment. The output of the amplifier is rectified by D3 to provide a negative voltage on the gate of Q1. When the output of the amplifier is small the gate to source voltage will be near zero and the FET will appear as a low value resistor giving high gain to the amplifier. If the light change is such that the output of the amplifier is large, the rectified voltage on the gate of Q1 will cause the resistance of the FET to increase decreasing the amplifier gain. In this way the output of the amplifier is held relatively constant irrespective of the light level. Diode D2 is necessary to prevent the amplifier from saturating on the positive swing.

The output is then squared up by IC3b where the positive feedback provided by R12 ensures that the output switches quickly. The output from this IC then triggers the monostable formed by Q2. What we have now is a pulse about 50µs long every time the propeller blade passes the light sensor.

Before continuing, you may have noticed that besides the +9V and 0V we also have a line marked Vref. This is derived from IC4 which is a voltmeter chip and is a stable voltage of about 2.8 volts below the +9V line.

The output of the monostable (Q2) turns on IC1a for 50µs, discharging C2 which is then allowed to recharge to Vref. This voltage is compared (by IC2) to the voltage set by R2 and R3. The output of IC2 is a negative pulse of about 900µs. As it is on a stable voltage supply, variations in battery voltage will have very little effect on the output pulse width. Capacitor C3 is used to force the positive input of IC2 above the negative one for the 50µs pulse ensuring that this time is not included in the output pulse. IC1b is used to invert this pulse and its output, and the output of IC2, control IC2c/IC2d. The output of IC2c/IC2d is a positive pulse switching between Vref. and the +9V line.

This is then filtered by two 2 pole active low pass filters, IC3c and IC3d. As these have a cutoff frequency of around 10 Hz the output for most applications will be the DC voltage component only. This is measured by IC4 which is a complete voltmeter.

As offset voltages and currents can cause the output of the filters not to be exactly zero with no input, the positive input of IC3d is biased up about 30mV and then by injecting a current into the negative input (by R19 and RV1) correction can be made. For measuring RPMs above 20000 and below 30000 a current is injected into the negative input via R18 and this subtracts 10000 RPM from the reading.

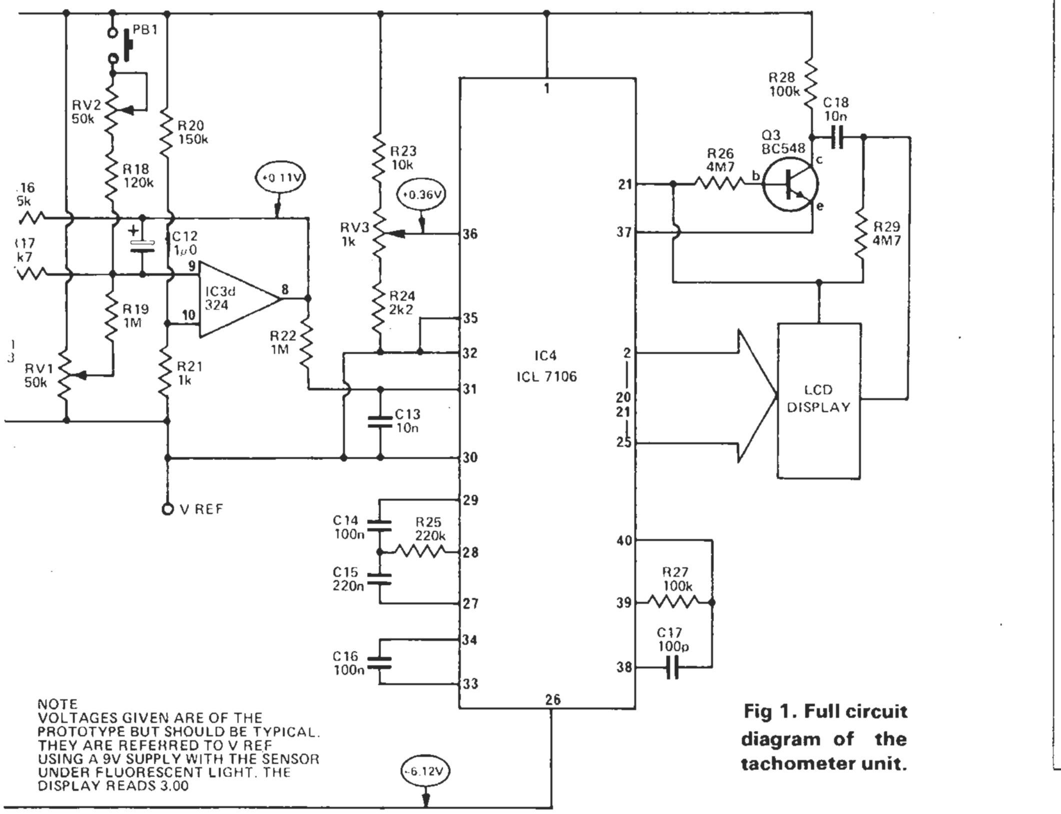


Fig 1. Full circuit diagram of the tachometer unit.

BUYLINES

The only awkward component here will be the BPW 34 photo diode. However a quick hunt through some catalogues showed us that Electrovalue sell the item at £1.73. .evaluation kits should be available from people like Technomatic and Marshalls.

PARTS LIST

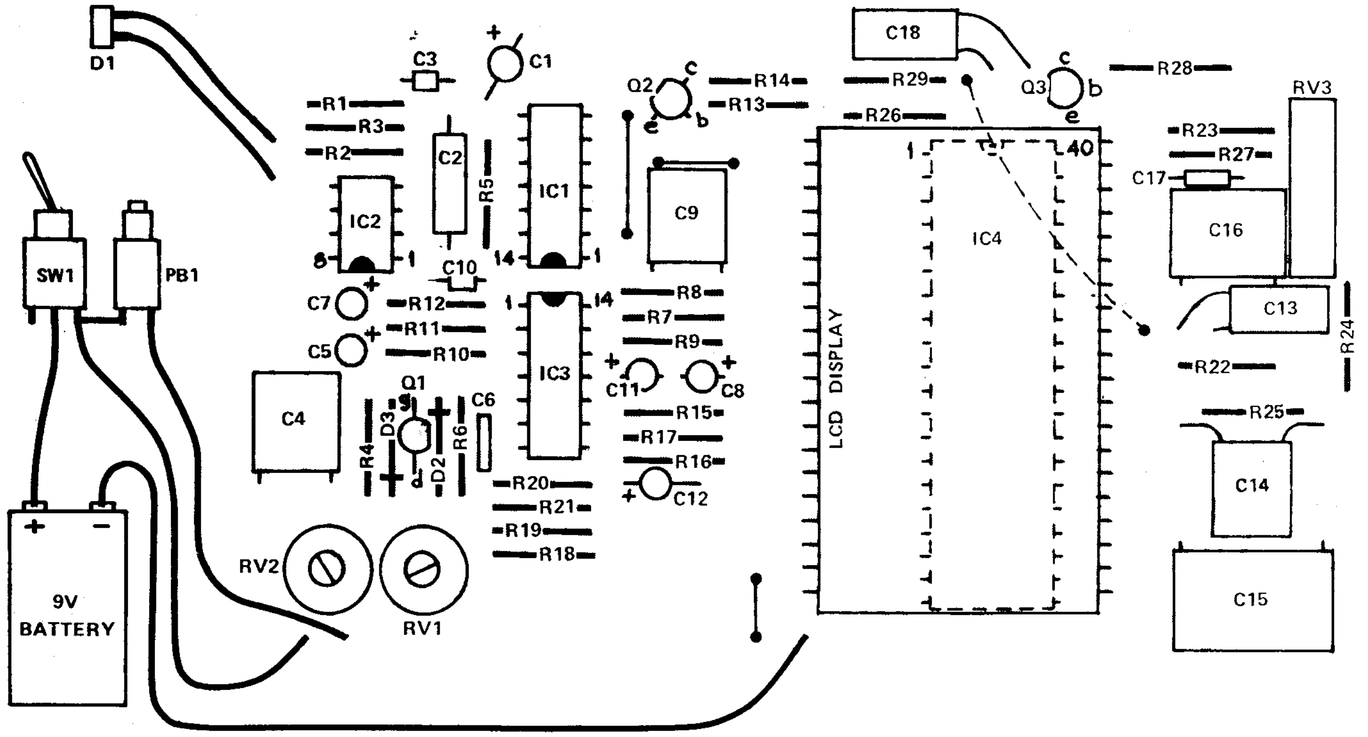
RESISTORS (all ¼ w 5%)	
R1, 7, 8	180k
R2, 20	150k
R3, 11, 13, 27, 28	100k
R4, 19, 22	1M
R5	47k
R6, 26, 29	4M7
R9	12k
R10, 14, 23	10k
R12	330k
R15	33k
R16	15k
R17	4k7
R18	120k
R21	1k
R24	2k2
R25	220k
POTENTIOMETERS	
RV1, 2	50k trimmer
RV2	1k trimmer — 10 turn type

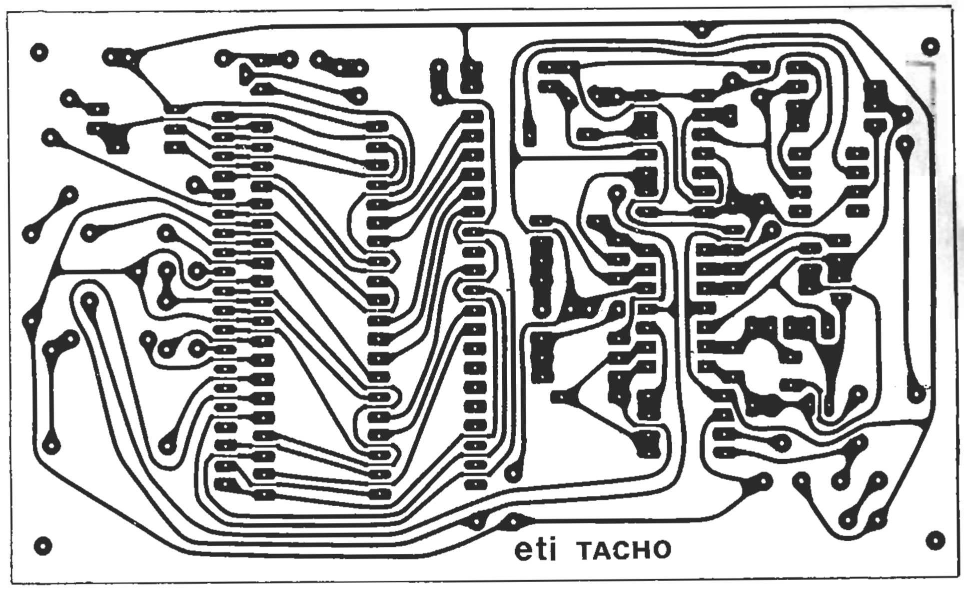
CAPACITORS	
C1, 5, 7, 8, 12	1u 35V tantalum
C2	4n7 Polystryene
C3	1n5 Polyester
C4, 14, 16 9	100n Pollyester
C6, 17	100p Ceramic
C10	820p Ceramic
C11	3u3 16V Tantalum
C13, 18	10n Polyester
C15	220n Polyester
SEMICONDUCTORS	
IC1	4016
IC2	301A
IC3	324
IC4	ICL 7106
Q1	2N5485
Q2, 3	BC548
D1	BPW34
D2, 3	1N914

MISCELLANEOUS

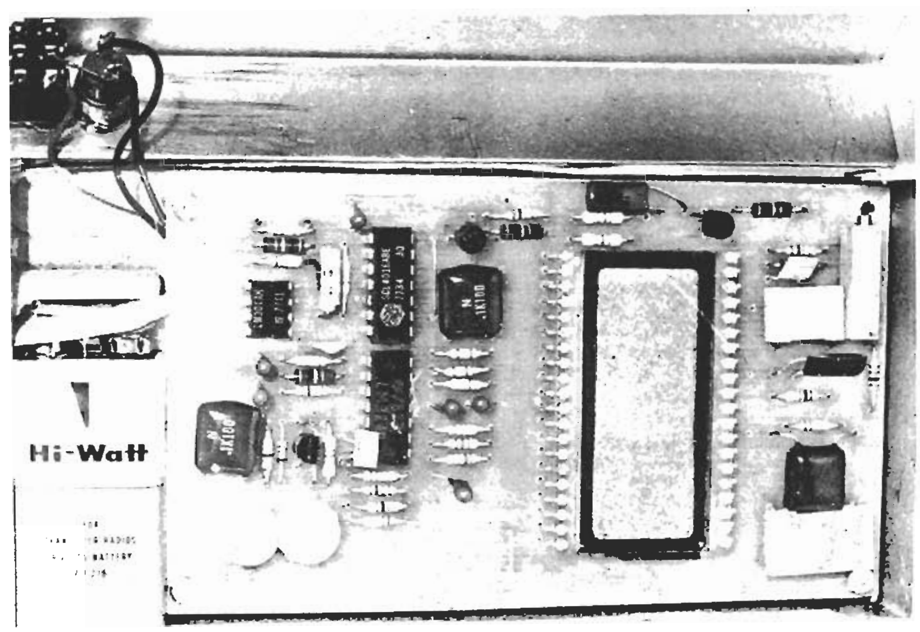
PCB, toggle switch, pushbutton, LCD display (evaluation kit?) case, battery clip.

Left: the BP34 photo-diode mounted on its lead. Shielding it from ambient conditions, in a tube for example, helps operation. Below: Fig 2 the overlay and wiring diagram. Note the D1 polarity is not important.





Above: full size foil pattern for the tacho unit.
Below: An assembled pCB. Comparing this with the overlay shown opposite should help with construction.



display, taking care not to bridge between the tracks with solder. Also note that some of the capacitors have to be laid on their side to give a low height.

The ICs can now be added being careful to polarize them correctly. Due to the display being mounted over the main IC it is not posible to use a socket. A socket can be used for the display if desired however it will have to be modified by cutting it into two strips.

As there are no polarity marks on the display it is necessary to hold it at the light and look for the outline of the digits. A link for the decimal point should be added as shown in the diagram.

We mounted our unit in a metal box we made with the photodiode mounted about 25mm from the end of a 75mm long tube in front of the box. This narrows the field of view of the diode as well as giving a little more clearance between high speed propellors and the fingers!

Calibration

Switch on the unit and cover the photodiode to prevent any light reaching it. Now adjust RV1 until the display reads zero.

Uncover the diode and point it at a fluorescent light. It will now give a reading and RV3 should be adjusted to indicate 3000 RPM.

Again cover the diode, then press the high range button and adjust RV2 to give a reading of −10000 RPM. Under fluorescent light it should read −7000 RPM

Operation

This unit relies on a changing light level for its operation. For use with a model aircraft, holding the unit near the propeller enables detection of the changes in the reflected light level. To measure the speed of other rotating equipment it may be necessary to paint a series of white lines to give the sensor something to 'see'.

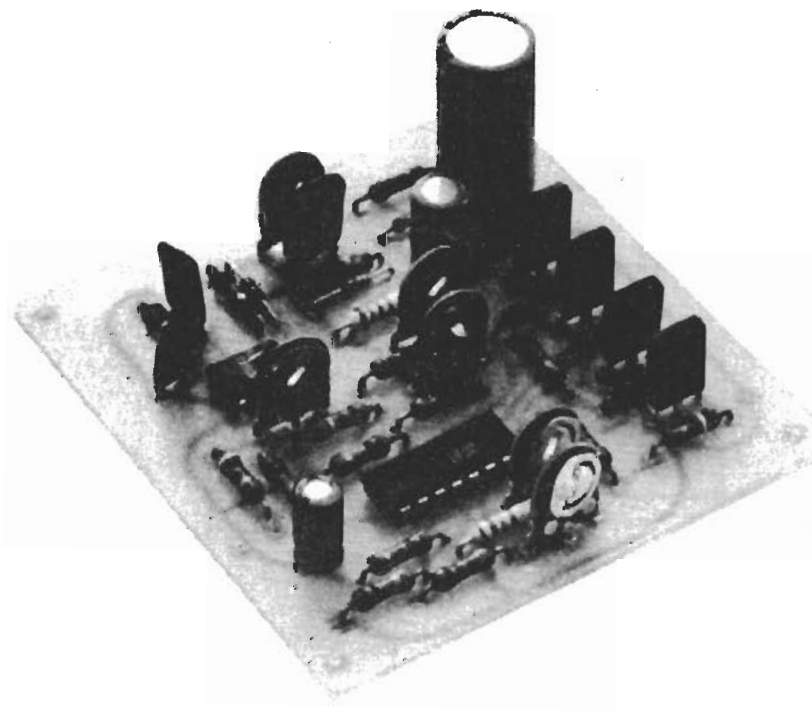
However the unit cannot be used under fluorescent lights as it will see the 100 cycle flicker (see calibration section). In cases where this has to be done, and places where the ambient light is low, a small incandescent globe can be used to shine on the spot looked at by the sensor.

The unit, as described, is scaled to read up to 20000 RPM with a 10 RPM resolution, assuming two input pulses per revolution. If a different number of input pulses is to be used, e.g. a three or four bladed propeller, the value of R1 can be changed. (R1 ≈ 360k / number of pulses). The use of more than four pulses per revolution is not recommended on this range. If 2000 RPM is more than is needed for your application the value of R1 can be increased by a factor of 10, preferably with more than ten pulses per revolution.

Unlike a frequency meter, overranging this unit will cause the display to blank and greater resolution cannot be obtained simply by using a lower range. However an offset of a fixed number of RPM can be used as described in the 'How It Works' section. Using the values given, when the high range button is pressed, 10000 RPM must be added to the reading. ETI

REV. MONITOR – COUNTER

This design uses light bulbs to indicate the upper and lower limits of ideal rev ranges. Details are also given of an optional analogue tacho which can easily be added.



WE HAVE HAD many requests to publish the design of a digital tachometer for use in cars. However, a couple of factors make this less than a practical proposition.

The most important drawback is difficulty of reading the digital display. Many cars can rev out over a 5000 rpm range in less than two seconds; even with 100 rpm resolution this would have the second digit changing every 0.04 seconds.

Additionally, the simplest design principle — counting the number of pulses from the distributor over a period of time — would not offer acceptable resolution for a reasonable sampling rate. On a four-cylinder car, a two-digit readout, i.e. 100 rpm resolution, calls for a sampling time of 0.3 sec, while 3 sec is needed for a three-digit readout.

Analogue meters are easier to read but may be a little sluggish with cars which can rev out quickly in first gear. We therefore decided to design an analogue tacho and add three indicator lamps to give an instant indication or warning of engine speed. One of these is on below a set rpm indicating that the motor is below the ideal minimum, a second which is on between certain limits indicating the working range of the engine and the third comes on above a set rpm indicating too high an engine speed. All the limits are adjustable and by overlapping the limits five bands of engine speed can be indicated.

Where the vehicle is already fitted with a tacho, or one is not wanted, the lights can be used by themselves. This reduces the cost considerably, while the lights still give an indication of engine speeds and when to change gear.

Construction

The electronics can be assembled on the printed circuit board with the aid of the overlay in Fig 3. Due to the number of components, the use of the printed circuit board is recommended. The value of R4 should be selected from Table 1.

The mechanical arrangment for the lights and meter we have left to the constructor as variations in style required make it difficult to give any details.

Adjustment

The potentiometer RV1 should be adjusted to give stable readings over the entire rpm range. Calibration of the meter is done by RV2 and this should be done against a known instrument. The lights are adjusted by RV3, RV6, RV4 and RV5 (from the lowest to the highest limit) to whatever levels are required.

BUY LINES

All the components for this project should be available from most of the larger component suppliers advertising in this issue.

The cost of this project, excluding meter and case, is approximately £6.50.

REV. MONITOR – COUNTER

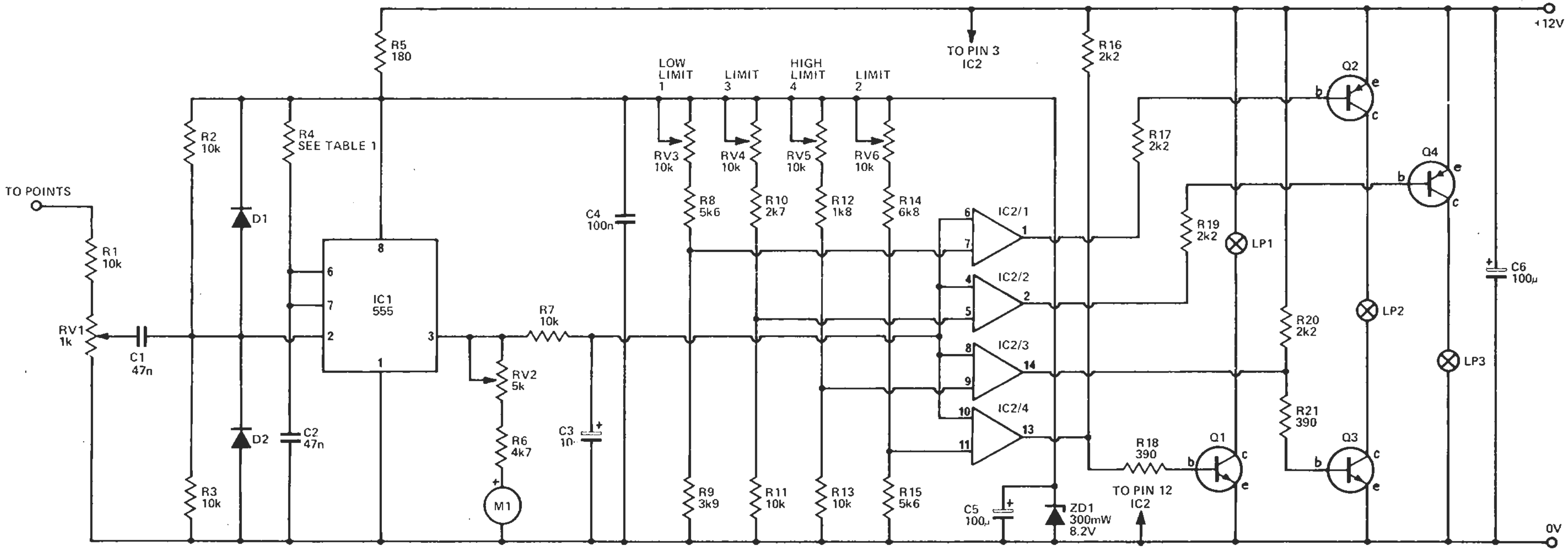
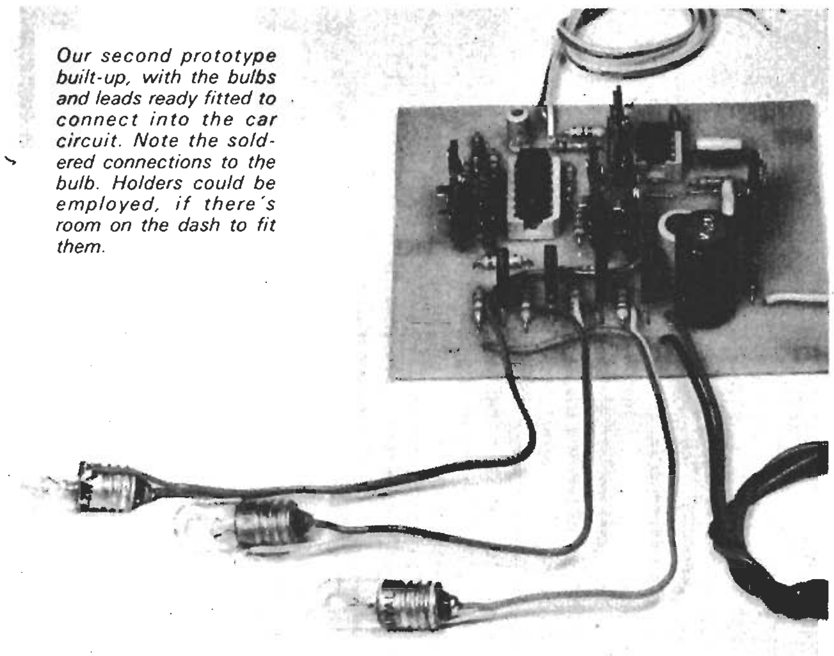
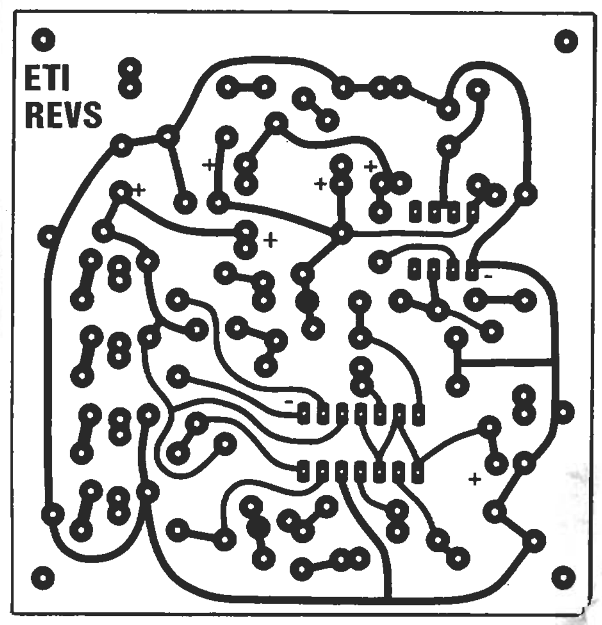


Fig. 1. Circuit diagram of the rev. monitor - counter.



Our second prototype built-up, with the bulbs and leads ready fitted to connect into the car circuit. Note the soldered connections to the bulb. Holders could be employed, if there's room on the dash to fit them.

Fig. 2. Printed circuit layout. Full size 80 x 75 mm.



HOW IT WORKS

The pulses from the spark coil are used to trigger a 555 timer IC1. This is connected as a monostable where the pulse width is 1.1 x R4 x C2 seconds. Pin 2 is normally at about 4 volts and the input pulse causes this to drop to less than the 2.7 V trigger point. The supply voltage for this IC is regulated to 8.2 V by ZD1. The output of this IC is a positive pulse on pin 3 and this is used to drive the meter to give a readout of rpm.

The output is also filtered by R7 and C3 to give an output voltage which is proportional to rpm. IC2 is a quad comparator which compares this voltage with four preset levels. If the input voltage is lower than the set level the output of the comparator will high. The output of the LM339 is an open collector transistor and can only sink current and therefore appears as an open circuit when high.

The outputs of IC2 control the transistors Q1 to Q4 which handle the current required by the lamps. If the rpm is below the lower limit Q1 and Q3 will be on lighting LP1 but as Q2 is off LP2 will be off. Above the first limit Q2 will be turned on and so LP2. Above the next limit Q1 and LP1 will turn off, above the next Q4 and LP3 will turn on, and finally when the upper limit is reached Q3 will turn off LP2 leaving only LP3 on.

TABLE 1

Value of R4	Number of cylinders		
Max. RPM	4	6	8
5000	100k	68k	47k
6000	82k	56k	39k
7000	68k	56k	39k
8000	68k	39k	33k

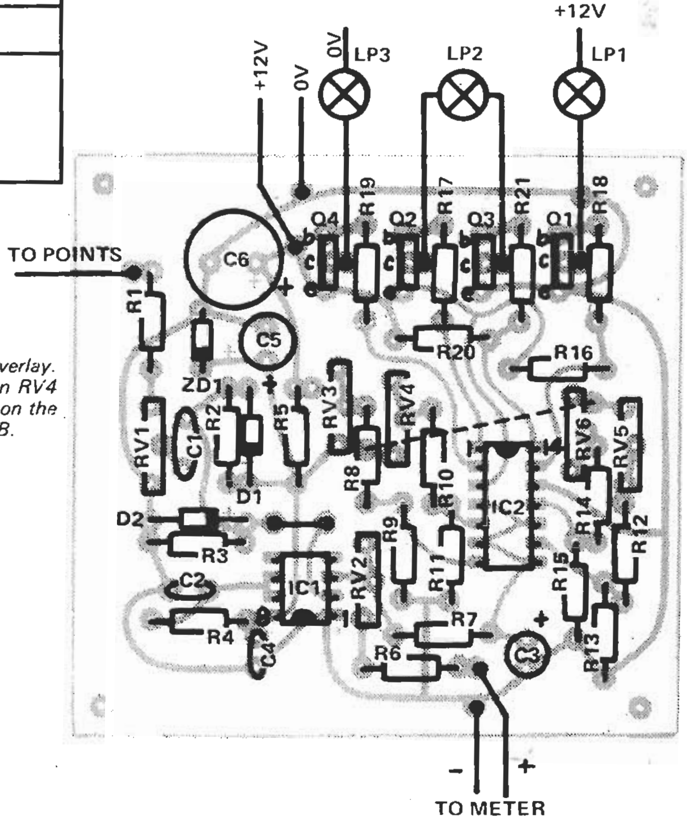


Fig. 3. Component overlay. Note the link between RV4 and RV6. This link is on the copper side of the PCB.

PARTS LIST

RESISTORS all ½W 5%

R1-3,7,11,13	10k
R4	See table 1
R5	180R
R6	4k7*
R8,15	5k6
R9	3k9
R10	2k7
R12	1k8
R14	6k8
R16,17,19,20	2k2
R18,21	390R

CAPACITORS

C1,2	47n polyester
C3	10u 16V electrolytic
C4	100n disc ceramic
C5	100u 16V electrolytic
C6	100u 25V electrolytic

POTENTIOMETERS

RV1	1k Vertical trim type
RV2	5k Vertical trim type*
RV3-RV6	10k Vertical trim type

SEMICONDUCTORS

IC1	555
IC2	LM339 see 'Buy-lines'
Q1,3	BD139
Q2,4	BD140
D1,2	1N914
ZD1	8V2 400mW

MISCELLANEOUS

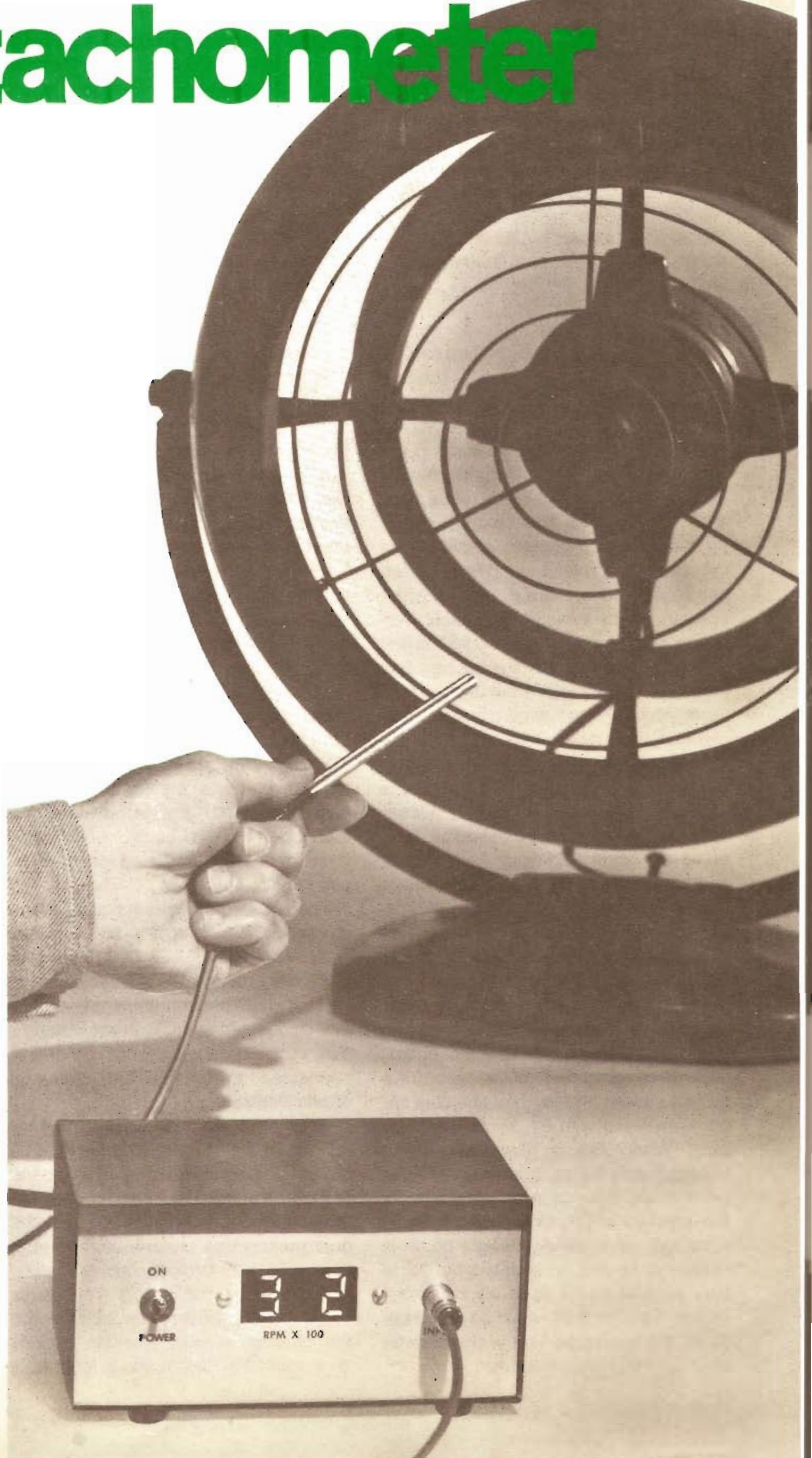
PCB as pattern, LP1-3 12V lamps (2W2 Max) 1mA FSD Meter*, flexible wire, case to suit.
*Delete if tacho is not needed.

BUILD A

By Walter Sikonowiz

Digital Phototachometer

Low-cost unit measures rotational speeds by optical coupling.



MOST ANALOG and digital tachometers require a mechanical or electrical interface with a rotating shaft. By contrast, this project, a digital phototachometer, measures rpm by optical means. It features a two-digit LED readout to display rotational speeds from 100 to 9900 rpm and a time base derived from the 60-Hz ac line, obviating the need for calibration adjustments.

Stability of the time base is good enough so that tach readings are accurate to the usual ±1-count uncertainty in the least significant digit. Modifications of the counting circuitry or sensing system can extend the measuring range one decade above 9900 or below 100 rpm, respectively. Total project cost is about $30.

Optical Sensing. As its name implies, the photo tach measures rpm by

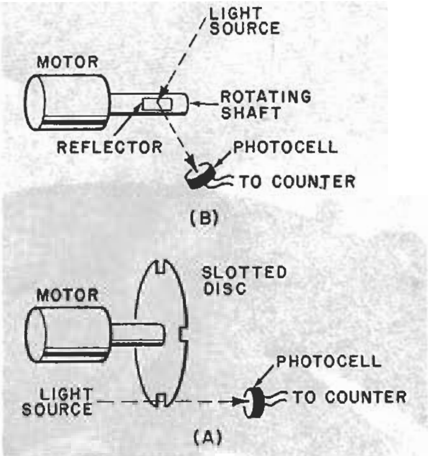


Fig. 1. Transmissive (A) or reflective (B) mode can be used to chop light for photosensor.

optical interaction with a rotating device. Measurements can be made by either of two basic means, which we'll call the transmissive and reflective modes. In the transmissive mode, the rotating device momentarily interrupts the optical path between a light source and a photosensor (Fig. 1A). This mode has limited usefulness. Although it's ideal for measuring the rotational speed of a fan or similar device, there are many situations in which it cannot be used. The transmissive mode requires a light chopper such as fan blades or a notched disc mounted on the motor shaft. If there isn't room enough to accommodate the chopper, this mode is impracticable.

The reflective mode is illustrated in Fig. 1B. A small strip of reflective tape is mounted on the motor shaft. If necessary, contrast can be increased by darkening the shaft background with black paint or tape. The light source and photo sensor are arranged so that light is reflected from the foil and toward the sensor as the shaft rotates.

About the Circuit. The schematic diagram of the phototach is shown in Fig. 2. Phototransistor *Q1*, the optical sensor, is connected to the rest of the project by a short length of shielded cable terminated with *P1*, an RCA phono plug. When *Q1* is illuminated by a chopped light beam, it alternately turns on and off. The resulting waveform at the collector of *Q1*, which approximates a square wave when the light beam is sharply chopped, is coupled by *C1* to *IC1*, a comparator used as a Schmitt trigger. Feedback provided by *R6* establishes the hysteresis that is characteristic of Schmitt trigger behavior.

Resistors *R2* through *R5* are close-tolerance components that maintain nearly equal biasing on the inverting and noninverting inputs of *IC1*. The output of the Schmitt trigger is a square wave compatible with the TTL integrated circuits forming a two-decade frequency counter.

Output pulses from *IC1* are gated by flip-flop *IC2*. The control signal for *IC2* is the time-base waveform, which is generated from the 60-Hz line in the following manner. Transformer *T1* and diodes *D2* and *D3* form a full-wave rectifier which develops a 120-Hz output. Diode *D4* isolates the cathodes of *D2* and *D3* from filter capacitor *C5*. The full-wave rectified sinusoid at the cathodes of the rectifier diodes is coupled to the base of *Q2* by *R11*.

This transistor saturates so easily that it converts the input waveform into a square wave appearing at its collector. The 120-Hz square wave is applied to *IC6*, a TTL ÷12 counter. Output signals from *IC6* are applied to *IC7*, another ÷12 counter. The net result is a square wave with a 50% duty cycle and a 1.2-second period. This is the time base that controls the gating and counter IC's.

Flip-flop *IC2* performs the gating function in a synchronous manner so that no spurious pulses reach the counters as a result of the gating process itself. The K input of the flip-flop is permanently grounded. Its J input is driven by the time-base signal, and output pulses from Schmitt trigger *IC1* are applied to the clock input. During the 0.6-second interval when the time base is at logic 1, pulses from *IC1* are gated to counter *IC3*. When the time base returns to logic 0, no more pulses are passed to the counter circuit.

The two-decade counter and readout comprises *IC3*, *IC4*, and *LED* displays *DIS1* and *DIS2*. TTL 74143 counter chips are employed in this project. They contain BCD decade counters, latches, and decoder/drivers. Current limiting is built in, so that the chips can be directly connected to the DL-747 common-anode displays.

Counter *IC4* counts the overflow pulses of *IC3*. The negative transition of the time-base waveform, which appears at the end of the 0.6-second counting interval, triggers one half of *IC8*, a 74123 dual monostable multivibrator. A negative-going, 100-microsecond wide pulse appears at pin 12 of *IC8*. This strobe pulse causes the transfer of data from the counter outputs into the latches. When pin 12 of *IC8* returns to logic 1, the second one-shot in *IC8* is triggered. A second negative-going pulse is generated, this time at pin 4 of *IC8*, which clears counters *IC3* and *IC4*. When the time base returns to logic 1, pulses are gated to the counter to repeat the process.

If more than 99 pulses are applied to *IC3* and *IC4* during the counting interval, the BCD outputs of both counters return to 0000 and *IC5* catches the overflow pulse from *IC4* in the following manner. Assume that the clear pulse has just appeared. This pulse not only clears the counters, but resets one half of *IC5*, a 7474 dual D flip-flop, so that the Q output (pin 5) is at logic 0. When the time base returns to logic 1, *IC3* and *IC4* begin to count. If more than 99 pulses are received, a positive transition occurs at pin 22 of *IC4*. This pulse is applied to the clock input of the first D flip-flop, causing the Q output to go to logic one.

The strobe pulse at pin 12 of *IC8* clocks the second flip-flop in *IC5* after the counting interval is over. This flip-flop's D input is connected to the Q output of the other flip-flop in the *IC5* package. If the Q output (pin 5) is at logic one when the strobe pulse appears at the second flip-flop's clock input, a logic 0 appears at pin 8, the second flip-flop's $\overline{Q}$ output. This causes the decimal points on both displays to glow, indicating the overflow condition. The clear pulse then resets the first flip-flop, but the overflow information remains safely stored in the second flip-flop.

The power supply furnishes both a regulated dc voltage and, as mentioned earlier, a full-wave rectified sinusoid which is converted into the time-base waveform. Transformer *T1* and diodes *D2* and *D3* form a full-wave rectifier whose output is applied to switching transistor *Q2* and to filter capacitor *C5*. Diode *D4* isolates the signal driving the base of *Q2* from the filtering effect of *C5*. The stable +5 volts dc required by the TTL integrated circuits is provided by regulator *IC9*. Capacitors *C6* through *C9* shunt any noise on the +5-volt line to ground, and improve the IC regulator's transient response.

Construction of the photo tach is straightforward because circuit layout is not critical. Suitable pc etching and drilling and parts placement guides are shown in Fig. 3. Molex Soldercons or sockets can be used with the IC packages. Be sure to observe pin basing and polarity of all semiconductors and electrolytic capacitors. Mount regulator *IC9* on the project's metallic enclosure for

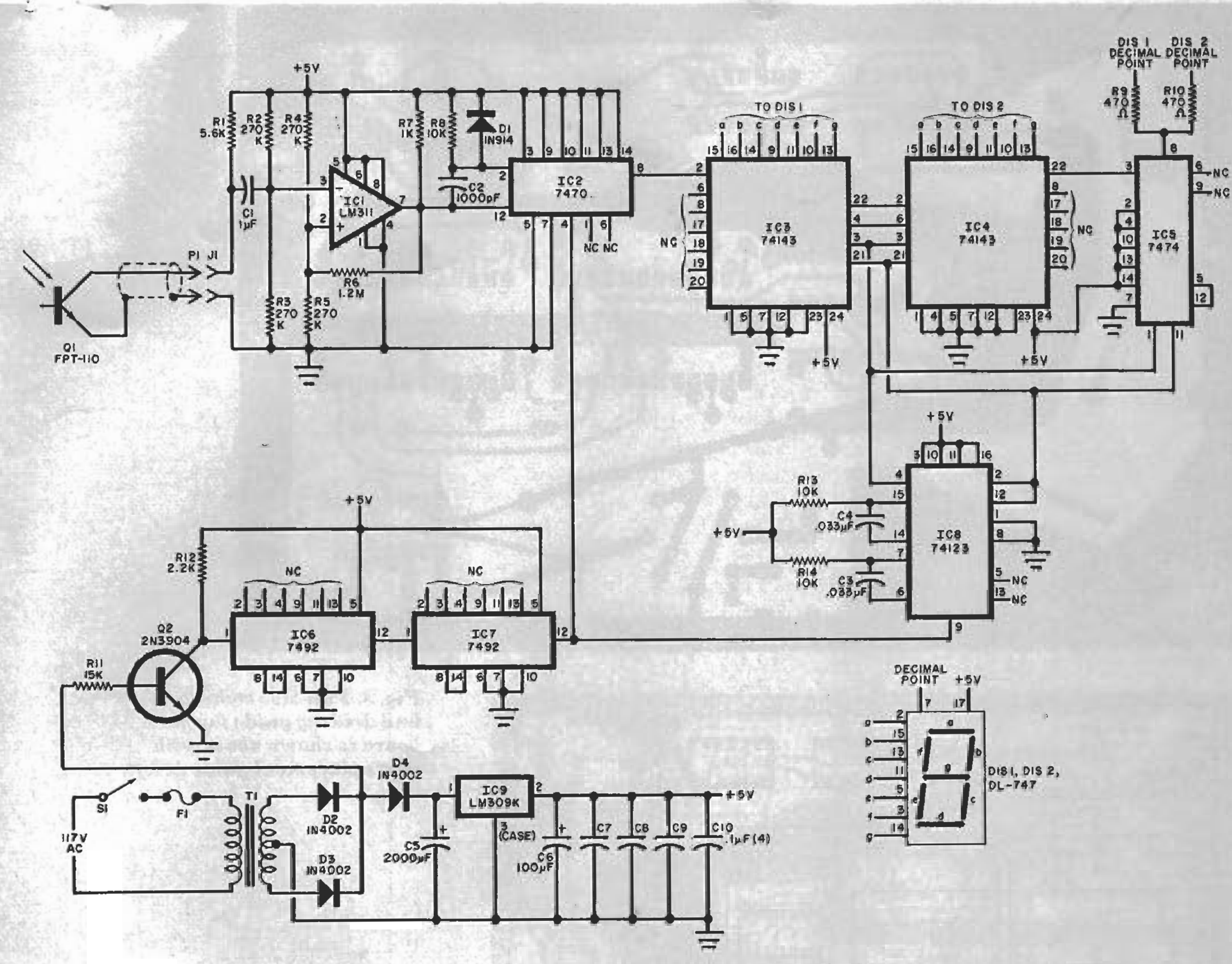


Fig. 2. Schematic diagram shows how pulses from sensor Q1 are squared up by IC1, gated by IC2, and counted by IC3 and IC4.

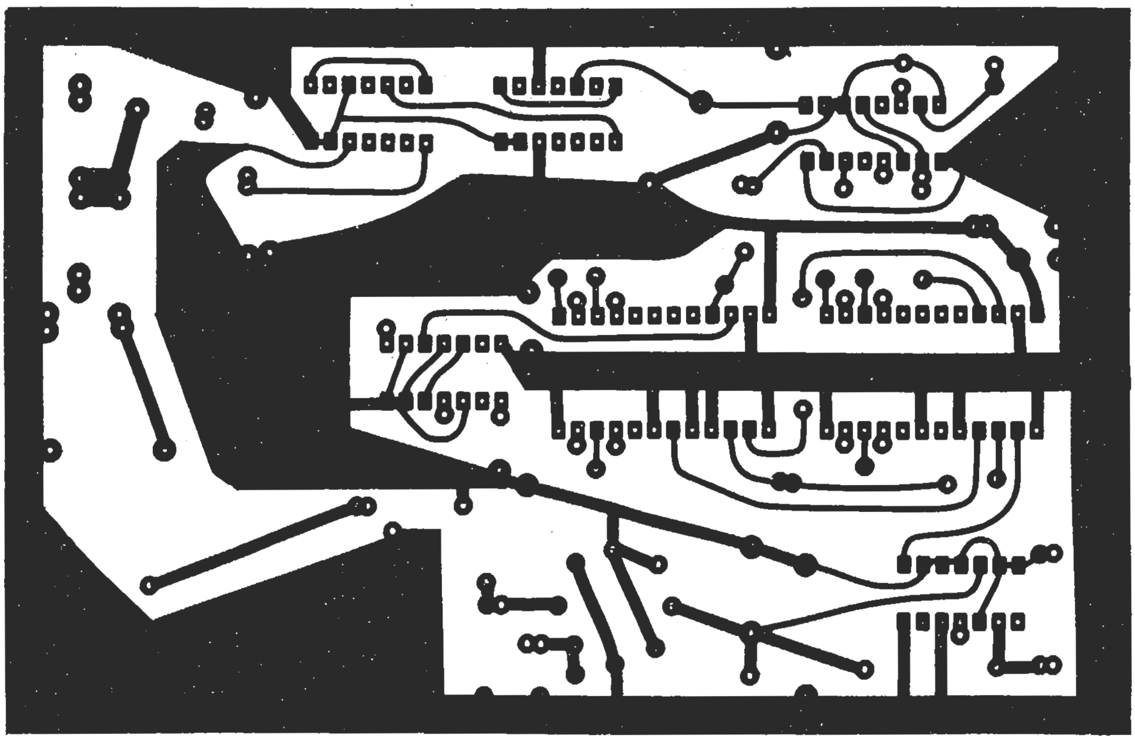
heat sinking. Spread a thin layer of silicone heat-sink compound on the bottom of the TO-3 can before mounting it. This will ensure a good thermal bond between the IC and the enclosure.

The seven-segment displays should be mounted on a small piece of perforated board installed upright inside the enclosure. Interconnect the displays and integrated circuits with short lengths of hookup wire. Insulated hookup wire should also be used for the eight jumpers on the pc board. The power transformer, switch, and phono jack fuseholder for *F1* are mounted off the board. A probe assembly must be fabricated to house transistor *Q1*. The plastic barrel of a spent ballpoint pen provides a good basis for the probe. Discard the point and exhausted ink tube. Then prepare the phototransistor by clipping its base lead (see Fig. 4). Remove 1" (2.54 cm) of the vinyl jacket from one end of a suitable length of RG-174-U or RG-58-U coaxial cable. Comb out the braid and

PARTS LIST

C1—1-μF Mylar capacitor
C2—1000-pF polystyrene
C3, C4—0.033-μF Mylar
C5—2000-μF, 35-volt electrolytic
C6—100-μF, 16-volt electrolytic
C7, C8, C9, C10—0.1-μF disc ceramic
D1—1N914 signal diode
D2, D3, D4—1N4002 rectifier diode
DIS1, DIS2—DL-747 common-anode, seven-segment LED display
F1—¼-ampere fuse
IC1—LM311 comparator
IC2—7470 J-K flip-flop
IC3, IC4—74143 decade counter/decoder/display driver
IC5—7474 dual-D flip-flop
IC6, IC7—7492 ÷12 counter
IC8—74123 dual monostable multivibrator
IC9—LM309K 5-volt regulator
J1—RCA phono jack
P1—RCA phono plug
Q1—FPT-110 phototransistor (Fairchild)
Q2—2N3904 npn silicon transistor
The following are ½-watt, carbon composition resistors with 10% tolerance unless specified otherwise:
R1—5600 ohms
R2 through R5—270,000 ohms, 5%
R6—1.2 megohms
R7—1000 ohms
R9, R10—470 ohms
R8, R13, R14—10,000 ohms
R11—15,000 ohms
R12—2200 ohms
S1—Spst switch
T1—16-volt center-tapped, 1-ampere transformer (Signal No. 241-5-16)
Misc.—Suitable enclosure, printed circuit board, hookup wire, RG-174-U or RG-58-U coaxial cable, solder, machine hardware, display bezel, etc.

Note—Phototransistor *Q1* is available (No. 22A21011-6) for $3.50 from Burstein-Applebee, 3199 Mercier, Kansas City, MO 64111. Decade counter/decoder/display drivers *IC3* and *IC4* are available for $3.25 (each IC), from James Electronics, 1021 Howard Avenue, San Carlos, CA 94070. Transformer *T1* is available from Signal Transformer Co., 500 Bayview Avenue, Inwood, NY 11696 for $5.50. Postage and sales tax (if applicable) extra.



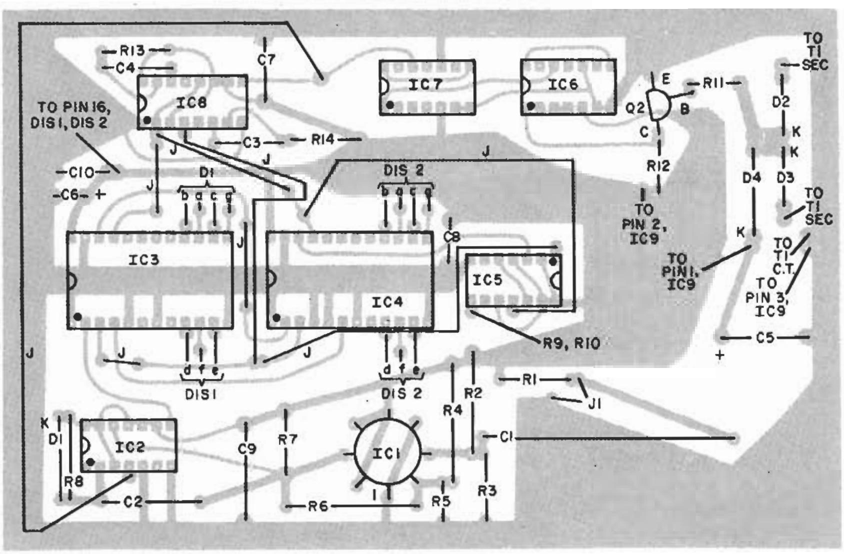


Fig. 3. Full-size etching and drilling guide for pc board is shown above with parts placement guide at left.

twist the strands together. Expose ¼" (6.3 mm) of the inner conductor. Tin the inner conductor and braid with a small amount of solder.

Feed the coax through the pen barrel until the prepared leads extend through the other end. Then attach the inner conductor to the collector of the phototransistor and the braid to the emitter. Pull the coax so that the phototransistor retracts into the barrel, stopping when the light-sensitive surface of *Q1* is recessed about 1" (2.54 cm). Cement or otherwise secure the phototransistor in place, and apply silicone glue where the coax leaves the barrel. Finally, terminate the free end of the cable with an RCA phono plug.

Checkout. No calibration of the photo tach is necessary. With *P1* (the phono plug at the end of the probe cable) removed from *J1*, apply power to the photo tach. Two digits may flash on, but will disappear in about a second. No input pulses are being received, and the outputs of the counters are 0000. Automatic ripple-blanking is built in to the IC counters, so the readouts are darkened and do not display "00."

Apply a 60-Hz, 2-volt p-p sine wave to *J1*. Use either a signal generator or the circuit shown in Fig. 5 as a test source. If the project is functioning properly, "36" will be displayed by the LED readouts. This corresponds to an input of 60 Hz or 3600 rpm.

The operation of the overflow indicator can be verified by either applying a 2-volt p-p sine wave at a frequency of 167 Hz or more, or by optically coupling the probe to an object rotating at 10,000 or more rpm. Both display decimal points will glow, indicating an overflow.

Extending the Range. The photo tach can be modified to measure rotational speeds greater than 9900 rpm by inserting another decade of counting and display between *IC3* and *IC4*. Sever the following connections: pin 22 of *IC3* to pin 2 of *IC4* and pin 4 of *IC3* to pin 6 of *IC4*. Pins 2 and 6 of the additional decade counter should be connected to pins 22 and 4 of *IC3*, respectively. Also, pins 22 and 4 of the additional decade counter should be connected to pins 2 and 6

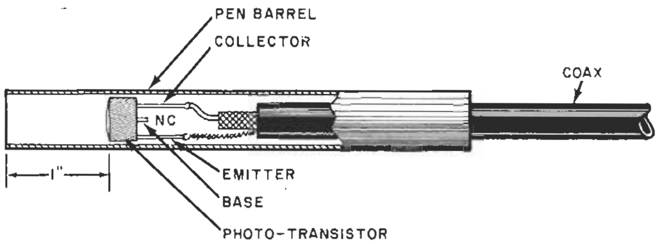


Fig. 4. To make probe, phototransistor is mounted in an old pen barrel and connected to a coaxial cable.

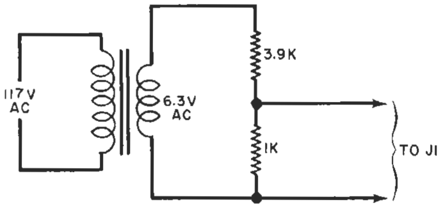


Fig. 5. Schematic diagram of a suitable test source to verify proper circuit operation.

of *IC4*, respectively. Of course, the new counter must be a 74143 IC, and it should be connected to an additional DL-747 display and to the positive supply and ground in the same manner as *IC3* and *IC4*. When this modification has been made, *IC3*'s count will represent hundreds of rpm, the newly installed counter thousands of rpm, and *IC4* tens of thousands. The project's power supply has enough reserve to handle the extra components' demand without any strain.

It is also possible to obtain resolution smaller than hundreds of rpm. If ten light pulses occur during each shaft resolution, the bit significance of each decade of the display is reduced by a factor of ten. Let's consider a specific example.

To measure the speed of a slowly turning power drill, a circular disc of metal or plastic should be formed. Ten slots should be punched out at equal intervals along the perimeter and a hole drilled through the center of the disc. Then pass a bolt through the center hole, secure with a nut, and install the entire assembly in the drill's chuck. The rotational speed will then be measured using the transmissive mode and displayed in hundreds and tens of rpm. The addition of another decade of counting and display, as described earlier, can be combined with this multiple triggering technique to display thousands, hundreds, and tens of rpm.

Using the Tach. The optical mode used in a given situation will depend largely on practical considerations. In any event, avoid using fluorescent bulbs as light sources because they are strong electrical noise generators. Ordinary 75- or 100-watt frosted incandescent lamps are well suited for use with the photo tach, as is sunlight. Just remember, however, that if you're checking the speed of a four-blade fan, the actual rate of rotation is one-fourth of what is displayed by the readouts. ◇

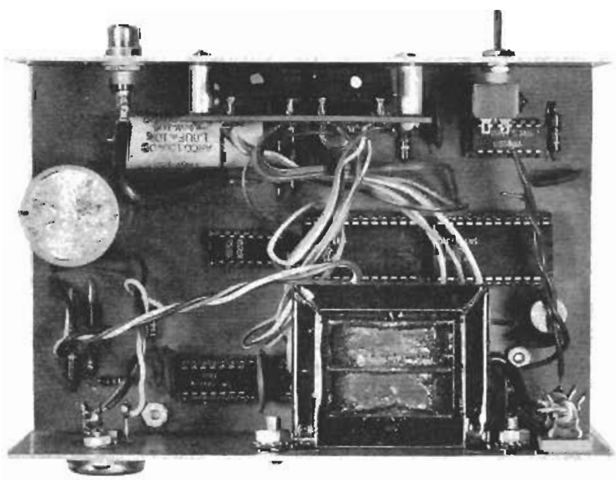
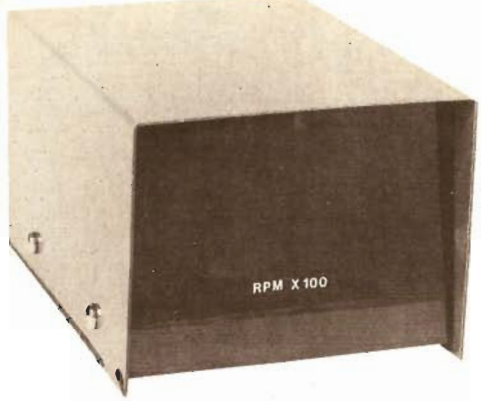


Photo of author's prototype shows layout of components in chassis.

BUILD

Automotive/Marine Digital Tachometer

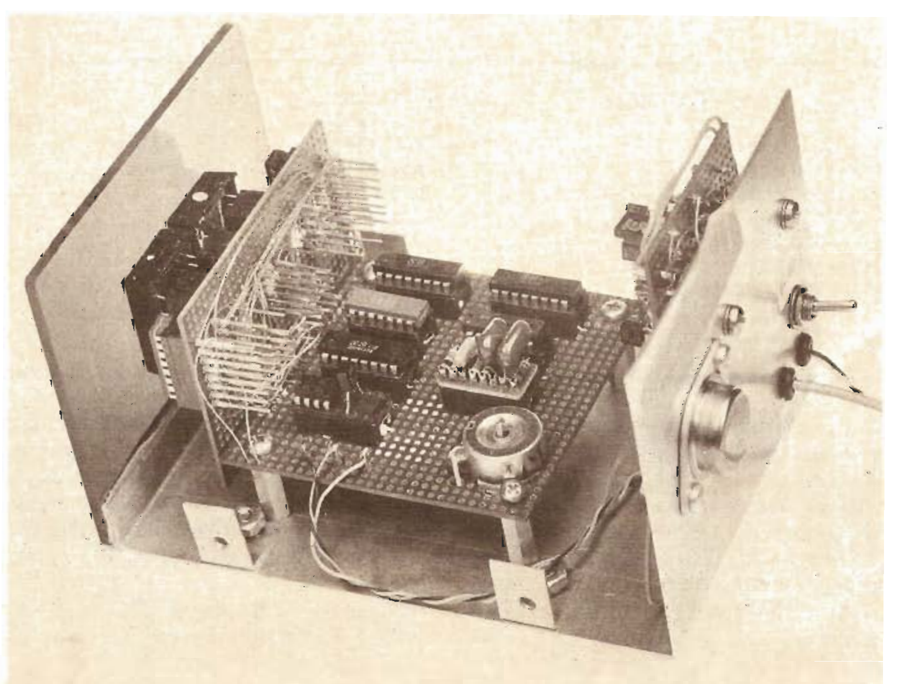


Operate your car or boat at maximum efficiency by monitoring engine speed. This easy-to-build tach lets you keep a finger on your engine's pulse

MICHAEL H. KUHN

A CONSTANT AND ACCURATE CHECK ON engine RPM's is essential to the motorboatsman for the following reasons:

1. It is vital if the boat is to be operated at top efficiency and maximum fuel economy. By running a measured course at a constant engine speed, it is possible for the operator to determine fuel consumption per mile and per hour under average conditions.
2. Engine speed can be a valuable navigation aid. Knowing the distance between two buoys or other points, an experienced boatsman can determine the engine speed needed to traverse the two points in a given time.
3. Similarly, knowing the craft's most economical cruising speed, the pilot will be able to estimate the sailing time between two known points.
4. Perhaps the most important reason for knowing the speed of a marine engine is the relationship between RPM's and cruising range. Safety afloat demands that the pilot know how much fuel he must have on board to reach his destination or an intermediate fueling point with an adequate reserve.



PERF-BOARD AND WIRE-WRAP was used exclusively to build the prototype. A total of three separate perf-boards was used.

An accurate engine-speed indicator is an important instrument for an aware automobile driver. For only by knowing engine RPM's can he obtain most efficient performance with minimum strain on the engine.

This digital tachometer overcomes the ambiguous swing of the analog-meter instrument. It can be used to measure the speed of 2- or 4-cycle automobile and marine engines having from two to sixteen cylinders. It works on any 12 to 24 volt DC electrical system that has a negative ground. Its 7-segment display is visible in darkness and shaded or dim sunlight and is not bright enough to affect the night-vision of a driver or pilot.

How it works

Digital and analog electronic tachometers operate by processing the voltage pulses developed by the make-and-break of the breaker points of an internal combustion engine. These tachometers are basically frequency counters modified to indicate revolutions per minute. Before going further, let's look at the operation of a 4-cycle internal combustion engine. (1) The points open and close once per crank-shaft revolution per cylinder. (2) For all cylinders to fire (regardless of the number of cylinders) the crankshaft makes *two* revolutions. (3) The distrib-

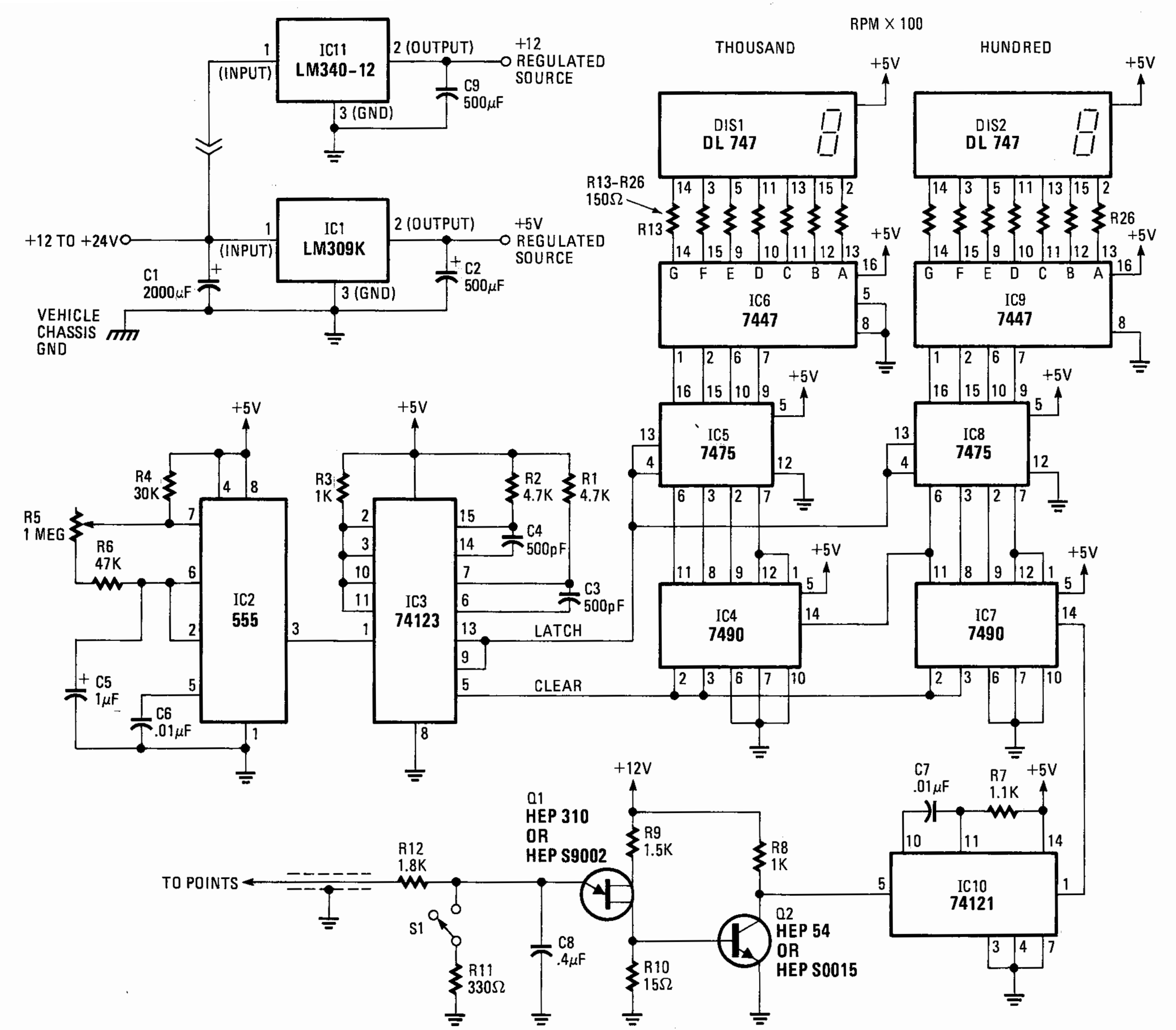


FIG. 1—TACHOMETER provides a direct readout of RPM × 100 on a 2-digit 7-segment LED display.

PARTS LIST

C1—200 µF, 50V, electrolytic
C2, C9—500 µF, 50V, electrolytic
C3, C4—500 µF, 50V, tantalum
C5—1 µF, 50V, electrolytic
C6, C7—.01 µF, 50V, disc
C8—.4 µF, 50V, disc
All resistors are ¼ watt, 5%.
R1, R2—4700 ohms
R3, R8—1000 ohms
R4—30,000 ohms
R5—1 megohm potentiometer
R6—47,000 ohms
R7—1100 ohms
R9—1500 ohms
R10—15 ohms
R11—330 ohms
R12—1800 ohms
R13-R26—150 ohms
Q1—HEP310
Q2—HEP54
IC1—LM309K
IC2—555
IC3—74123
IC4, IC7—7490
IC5, IC8—7475
IC6, IC9—7447
IC10—74121
IC11—LM340-12
S1—SPST toggle
DIS1, DIS2—DL747 common-anode 7-segment LED display

utor makes one-half revolution during each revolution of the crankshaft.

Since the distributor makes one revolution for every two revolutions of the crankshaft (No. 3 above) and since the crankshaft must make two revolutions for all cylinders to fire; the distributor points make-and-break—during each crankshaft revolution—only one-half as many times as the number of cylinders. Thus, in a 6-cylinder engine, the points make-and-break only three times for each engine revolution. Therefore, the tachometer divides the number of pulses picked up from the distributor by half the number of cylinders.

Since a tachometer is calibrated in *revolutions per minute*, it would seem that we would count pulses for a full 60 seconds and then divide by half the number of cylinders to get a RPM reading. However, this is not the case. The tachometer electronics counts pulses for a second or fraction thereof and then multiplies that number by a factor that yields the number of revolutions per minute.

Consider an 8-cylinder engine running at 900 RPM. The breaker points operate 3600 times (900 × 4) per minute. If we divide this by 60 (seconds), we arrive at 60 as the number of pulses developed *per second*. Thus, at 900 RPM, the points generate 60-Hz pulses. Then, for the tachometer to display a "9" (for 900 RPM) we divide 9 by 60 and arrive at 0.15 second or 150 ms. This is the update time. If we want to display ten's, we divide 90 by 60 and arrive at a 1.5-second up-date time. Similarly, should we want to display the full 900, we would divide 900 by 60 and come up with 15 seconds as the up-date time. The last two examples are of up-date times that are far too slow to provide accurate instantaneous readings.

The digital tachometer is shown in the schematic in Fig. 1 and block diagram in Fig. 2. Only two decades are used; indi-

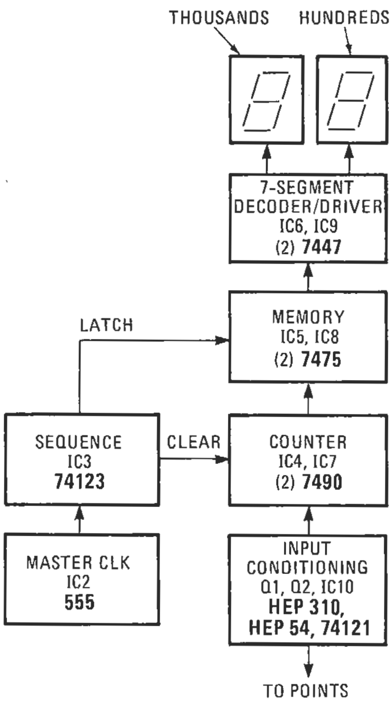
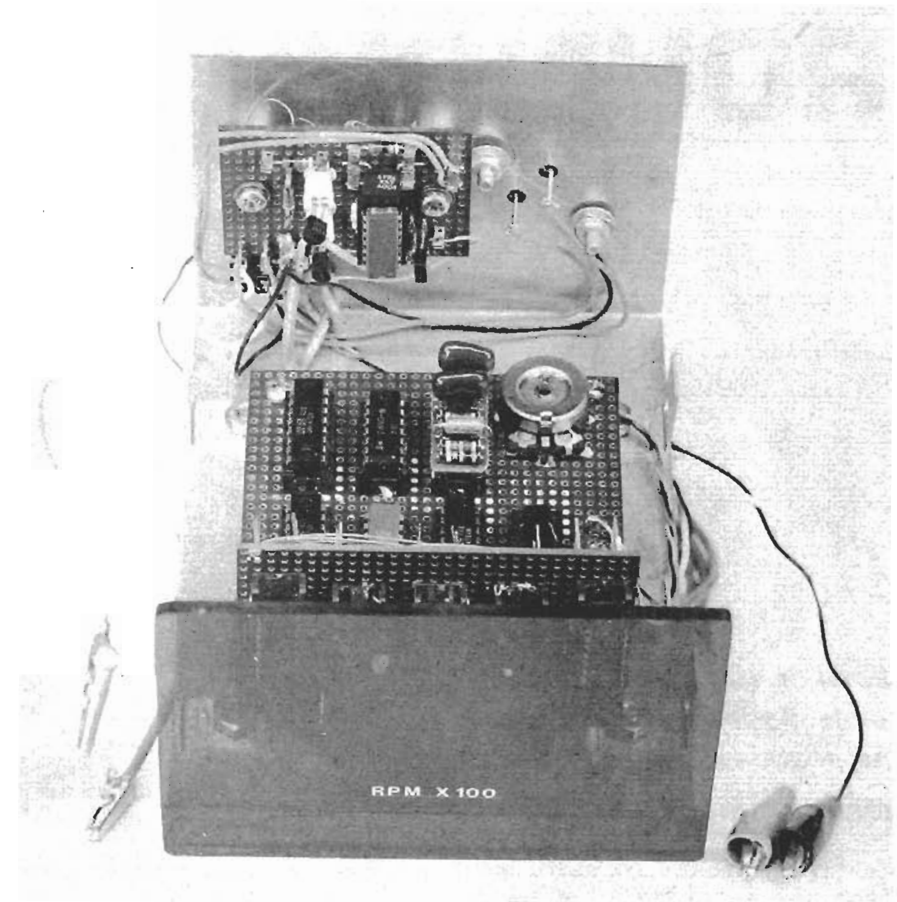


FIG. 2—BLOCK DIAGRAM of tachometer circuit. Master clock signals are provided by a 555-timer IC.



FRONT-PANEL OF TACHOMETER is made of red translucent plastic. Seven-segment LED display is mounted directly behind this.

cating thousands and hundreds. Tens and units are not displayed as they would wander so much that the distraction would be greater than that of an erratically bouncing needle of an analog instrument. Also, by displaying only thousands and hundreds, we can take advantage of a faster up-date time. For a 4-cycle, 8-cylinder engine, we up-date at 150 ms. This provides a new reading approximately seven times a second.

To convert breaker-point openings and closings to engine RPM, the tachometer electronics performs all the math necessary for a direct read-out. The 555 timer, IC2, is the master clock. Its frequency must be adjusted, by R5, to suit the type of engine being monitored. Once set, this adjustment need not be touched unless the tachometer is switched to an engine of another type.

A dual retriggerable one-shot, IC3, provides the clear pulses for IC4 and IC7 and the latch pulses for IC5 and IC8. Transistors Q1 and Q2 and IC10 condition the input pulses from the distributor to produce a TTL-compatible signal. Switch S1 is used to adapt the tachometer to either standard or electronic ignition systems. Close the switch when the tach is used with electronic ignition.

The TTL devices and the displays operate from a regulated 5-volt DC line fed from regulator IC1. The regulator input is 12 to 24 volts DC. Transistors Q1 and Q2 operate from a 12-volt source so 12-volt regulator IC11 should be installed if you plan to use the tach in a vehicle that has an electrical system supplying more than 12 volts DC. By the same token, do not use IC11 if the tachometer is going in a vehicle with a 12-volt electrical system. Add a switch to bypass IC11 if the tach is to be used in both 12- and 24-volt vehicles.

Construction

I assembled the digital tachometer on perforated board using the wire-wrap method. Sockets were used for the IC's, transistors and most other components. Be sure to use heat sinks on the regulator IC's. Use shielded cable or coax for the hook-up between the tachometer and breaker points.

Calibration and use

Calibrate the tachometer before in-

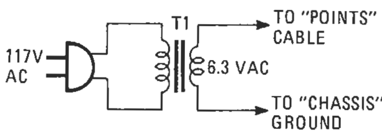


FIG. 3—CALIBRATION of the tachometer requires a low-level 60-Hz AC signal. An inexpensive filament transformer will do nicely.

stalling it in the vehicle. For this, you need a low-level 60-Hz signal—6.3 volts AC from a filament transformer (Fig. 3) will do nicely. Connect one lead to the shielded lead marked "to points" and

CALIBRATION TABLE

Engine Type (Stroke/ Cylinder)	Display Readout at 60 Hz (× 100)
2/2 4/4	18
2/3 4/6	12
2/4 4/8	9
2/6 4/12	6
2/8 4/16	4*
* Halfway between 4 and 5	

connect the other lead to the shield. Connect the tach to a +12 to +24 volt DC source capable of delivering at least 1 ampere.

Refer to the calibration table and adjust trimmer R5 until the read-out displays the number corresponding to the type of engine in your car or boat. For example, when properly calibrated, the tachometer reads "18" for a 4-cycle, 4-cylinder or 2-cycle, 2-cylinder engine.

Now, install the tachometer in your boat or car, hook up the cable and you are set to go. **R-E**

PUT A DIGI-TACH On Your Dashboard

Digital readout for checking your mill's rpm's at a glance. Easy-to-read numbers promote driving safety day and night

by P. J. BUNGE

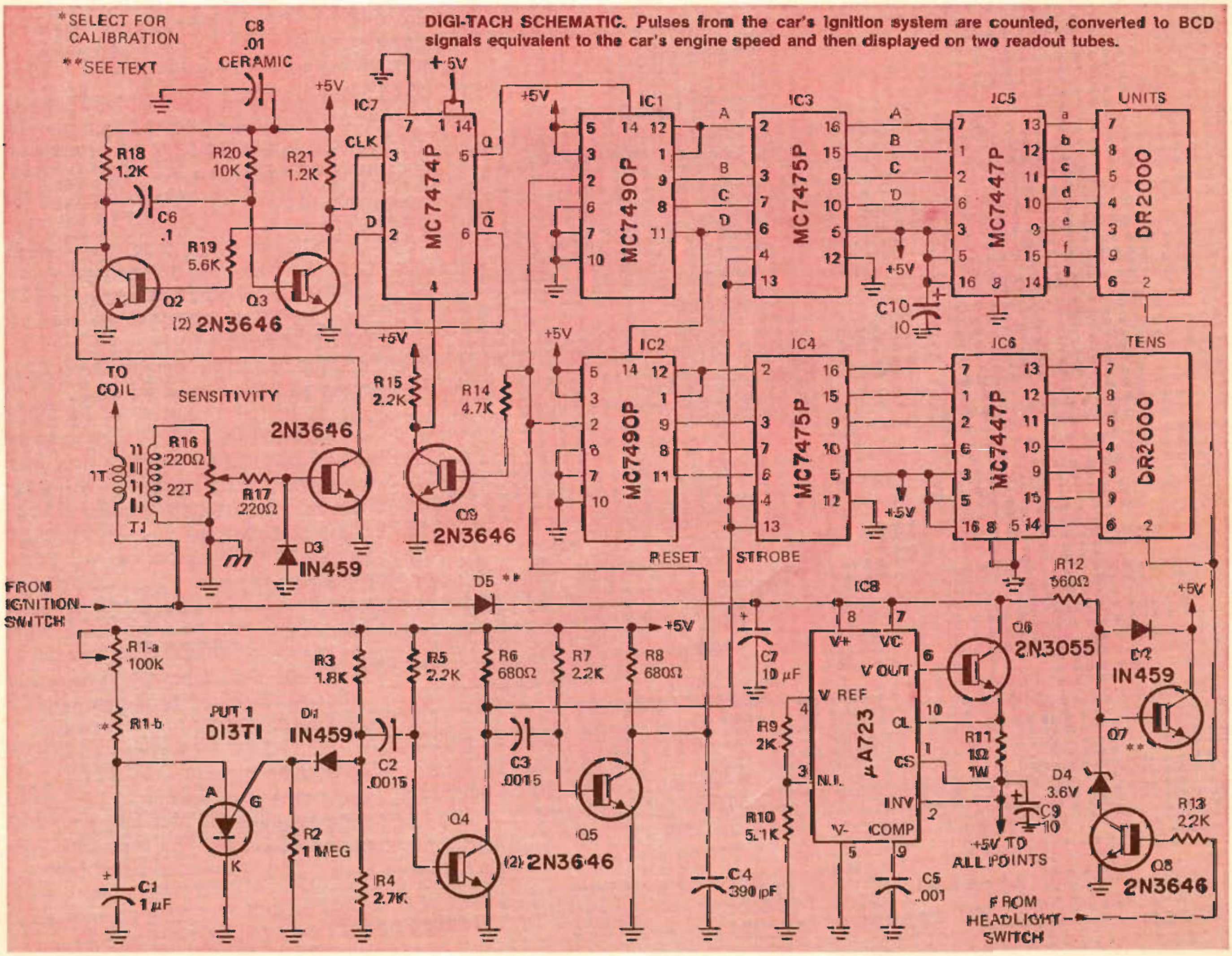
WHEN I WAS UNABLE TO LOCATE A 270° meter suitable for building a tachometer, I began to consider a digital display as a substitute. The novelty of the idea, together with the availability of low-cost readouts made this choice very attractive. How the readability would compare with a meter-type display was completely unknown. In fact, the only literature I could find on the subject seemed to be the vague mention of a digital speedometer used in an experimental car.

It was hard to visualize whether it would be easy, or even possible, to take a reading during the brief glimpse permitted from driving. How distracting would the constantly changing numbers be? It seemed that the only way to tell would be to build a digital tachometer and find out.

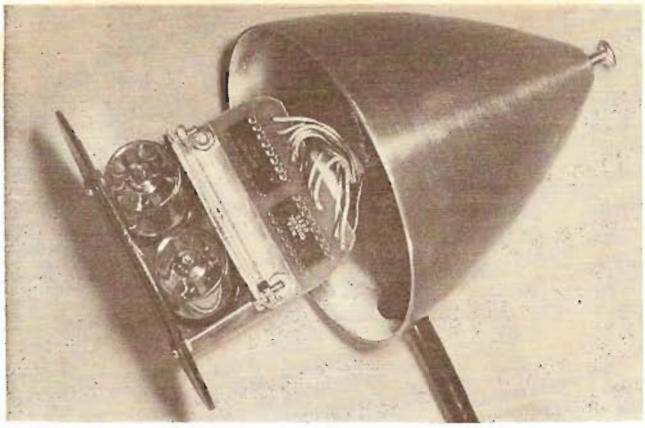
Design and construction proved to be quite straight-forward. The biggest problem was locating the correct wire in the Corvair in which the tach was installed. A quick adjustment of the SENSITIVITY control and the display registered 500 rpm. A few miles of driving soon showed that the project was a complete success and extremely easy to read. Perhaps it was psychological, or maybe a better physical location, but it did seem more convenient to read than the speedometer. For those interested in trying the idea here are the necessary details.

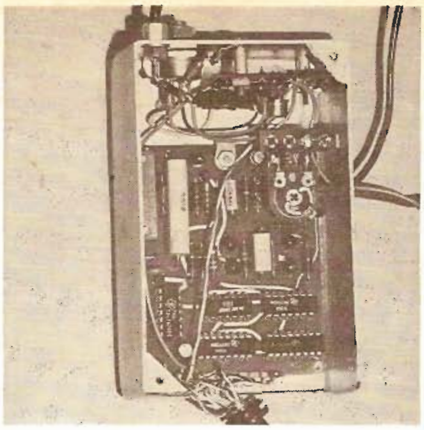
Circuit description

IC1 and IC2 are decade counters with BCD (Binary Coded Decimal) outputs. Their four outputs go to IC3 and IC4, quad latches or temporary



DIGI-TACH SCHEMATIC. Pulses from the car's ignition system are counted, converted to BCD signals equivalent to the car's engine speed and then displayed on two readout tubes.





DIGITAL DISPLAY (far left) makes it easy to keep an eye on the engine's rpm's.

DISPLAY TUBES and decoder/driver IC's (center) form the tachometer head. The CD2501E IC is a substitute for one of the MC7447P's.

THE SENDING UNIT (left) is on a double-sided PC board. Its housing can be any sturdy metal container.

stores. These IC's sample and hold the states of the counter outputs whenever they are strobed with a positive pulse on pins 4 and 13. IC's 5 and 6 decode this information and provide signals to illuminate the required numbers on the DR2000 displays.

To register engine RPM's the ignition pulses are counted for a fixed time, the latches are then strobed, and the counters reset for the start of another count. A D13T1 PUT (Programmable Unijunction Transistor) is used to provide the timing. It works much the same way as a unijunction with the time set by the C1-R1 time constant. D1 is for temperature compensation. The negative pulse produced discharges C2 through R5 and turns off Q4 which results in a positive strobe pulse. Termination of the strobe cuts off Q5 and produces the reset pulse which forces the counters to zero. Once C3 discharges, the reset pulse ends and a new count starts.

T1 senses the ignition coil current for each spark plug firing and turns on Q1. R16 is the SENSITIVITY contact and D3 prevents negative pulses from avalanching Q1's base. The negative pulse at the collector of Q1 triggers a monostable multivibrator consisting of Q2, Q3, C6, and the various resistors. This multivibrator prevents multiple counting, due to hash, from each plug firing.

IC7 is a prescaler to reduce flickering of the units digit. It is a D flip-flop wired to toggle as a divide by two. Other flip-flops could also be used. Q9 provides the necessary negative reset pulse.

The output from pin 5 of IC7 drives the clock input (pin 14) of the units decade, IC1. The carry from IC1 (pin 11) drives the clock input on IC2.

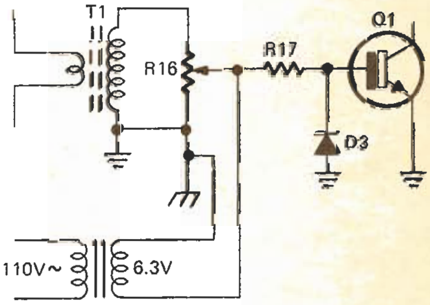
IC8 is an integrated voltage regulator that provides +5v from the 12–15 volts auto supply. It features protective current limiting at 1 amp. D5 protects the regulator in case the input voltage polarity is inadvertently reversed when testing or calibrating.

When the ignition key is on, 12 volts is applied through R12 to saturate Q7. This applies the full 5 volts to the displays and they run at maximum intensity. When the headlights are turned on, power is applied through R13 to turn on Q8. This pulls the base of Q7 down by about 2 volts, and since Q7 is an emitter follower it also reduces the voltage to the displays by 2 volts. Thus turning on the headlights dims the display for night driving.

Construction and adjustments

Many of the parts can be substituted. For example an SN7490N will replace the MC7490P and almost any silicon npn transistors will do for the 2N3646's. The 2N3055 dissipates a fair amount of power and should be mounted on the box, or preferably on a separate heat sink. I used 2N3568 for Q7 but this transistor is just barely adequate and gets rather hot. A metal T05 type with a clip-on heat sink would be preferable—a 2N2219 would do. Drill a few holes in the box for ventilation.

The displays and decoder drivers were mounted in an old fender mirror shell. Shield the ten wires and use the shielding as ground. Do not ground to the case at the display end. The only connection to the car frame should be near the ground on T1—this will prevent noise pickup and false triggering. T1 was wound on a ½-inch toroid core but a small audio transformer core would probably work just as well. The primary consists of one or two loops of the wire which goes from the ignition switch to the coil. Reverse the primary to check for highest sensitivity and adjust R16 one-quarter turn higher then the minimum trigger point.



CALIBRATING CIRCUIT is used to perform initial adjustments. See text for details.

R1-b will need to be about 400,000 ohms for a six-cylinder engine and should be selected to bring R1-a within calibration range. A six-cylinder engine fires three times per revolution or 24,000 pulses per minute at 8,000 rpm. 24,000 ppm is 400 pulses per second which is what was used to calibrate the prototype tach to read "80". The calibrating pulses are fed in on the wiper of R16 when it is ad-

PARTS LIST

All resistors ¼-watt 5% unless noted

R1-a, R1-b—Selected value (see text)
R2—1 megohm
R3—1800 ohms
R4—2700 ohms
R5, R7, R13, R15—2200 ohms
R6, R8—680 ohms
R9—2000 ohms
R10—5100 ohms
R11—1 ohm, 1 watt
R12—560 ohms
R14—4700 ohms
R16—220-ohm potentiometer
R17—220 ohms
R18, R21—1200 ohms
R19—5600 ohms
R20—10,000 ohms
C1—1 µF
C2, C3—.0015 µF
C4—390 pF
C5—.001 µF
C6—0.1 µF
C7—10 µF 20V
C8—.01 µF ceramic
C9, C10—10 µF 10V electrolytic
D1, D2, D3—1N459 or any Silicon diodes
D4—3.6V Zener
D5—-amp 50-piV silicon diode
Q1, Q2, Q3, Q4, Q5, Q8, Q9—2N3646 or any npn silicon transistor
Q6—2N3055
Q7—2N2219
PUT 1—D13T1
IC1, IC2—MC7490P
IC3, IC4—MC7475P
IC5, IC6—MC7447P
IC7—MC7474P or MC7479P
IC8—µA723
T1—See text
Two seven segment incandescent displays RCA DR2000, Luminetics Series 90 "Minitron" etc.

justed half way. 60-Hz line from a 6.3-volt filament transformer can be used if an accurate pulse generator or frequency counter is not available. In this case the tach should read "12".

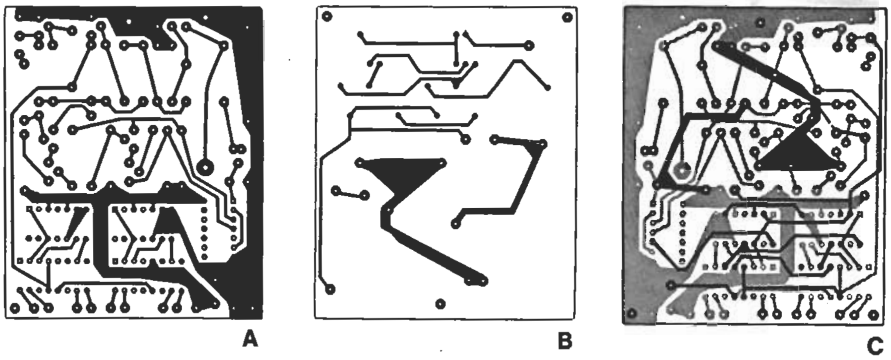
A filter may be necessary on the 12-volt input if false triggering occurs. However, the only trouble experienced was on the bench set-up using a relay and coil which was a poor simulation of an actual ignition system. In this case a .01μF capacitor cured the problem.

The prototype tachometer was road tested through winter and summer and two problems which showed up are worth mentioning. The first problem was that when the windshield wipers were turned on the tach stopped counting. The cause was traced to the fact that the wire from the ignition switch goes to the wiper motor and then to the coil. Current from the wiper saturated T1 and no pulses were counted. The problem was cured by reconnecting the wiper motor through a separate wire to the ignition switch. The second problem occurred when the weather got warm and the display went erratic over 2700 rpm. It turned out that the current pulses to the coil dropped in amplitude with increasing temperature; probably because of coil resistance increasing with temperature. They also decreased with rising rpm. The result was that the temperature increase rendered the system marginal so that it started dropping counts at higher rpm. The cure was simply to adjust the threshold setting, R16.

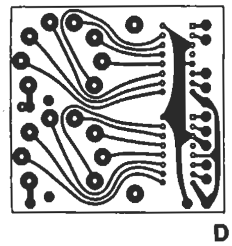
The more ambitious soul might want to add a high-limit indicator. The easiest way is to AND a couple of segment signals off the tens display which would trigger a one-shot controlling a light or Sonalert beeper. The ultimate would be to compare the eight 7490 outputs with the outputs of two BCD switches.

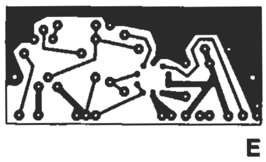
A digital speedometer is also possible, as well as a solid-state odometer. A few calculations and measurements might be of interest: a 775/14 tire has an approximate diameter of 27 inches and a measured circumference of 85.25 inches. This works out to 746.7 revolutions per mile. At 10 mph this is only 2 revolutions-per-second which means a long gate time and sluggish response due to slow updating. An 8-hole disc, light and photocell gets around this problem and gives 16 pulses-per-second at 10 mph. The gate time to read mph in this case is then 625 ms. (assuming a 1:1 ratio between speedometer cable and wheels).

The circuit also offers possibilities for those not interested in digital tachometers. Slight modifications to the input signal conditioning circuit and you have a frequency counter. Any number of decades can be added and a crystal time base could replace the PUT. R-E

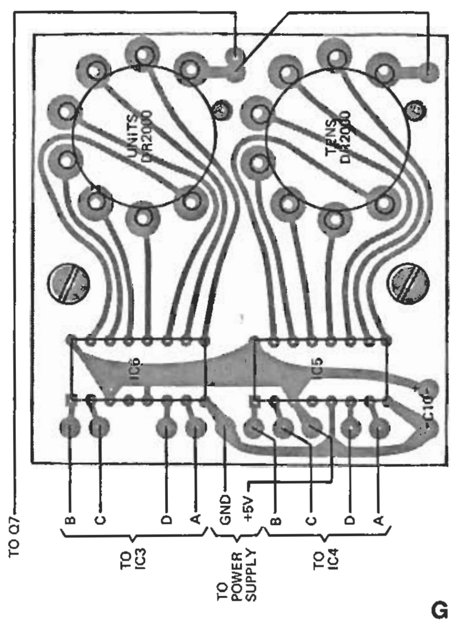


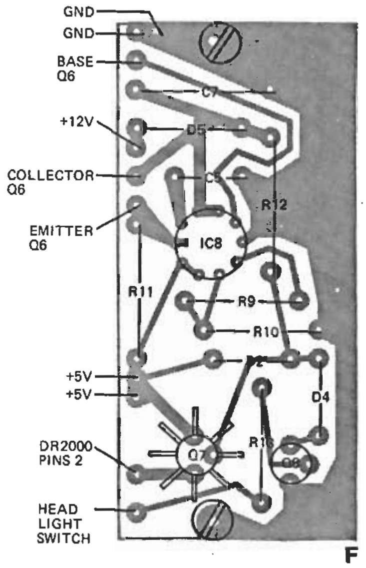
HALF-SIZE CIRCUIT board patterns. A—component side of main board. B—reverse side of main board. C—overlay shows both sides of main board. D—display board. E—power-supply board.

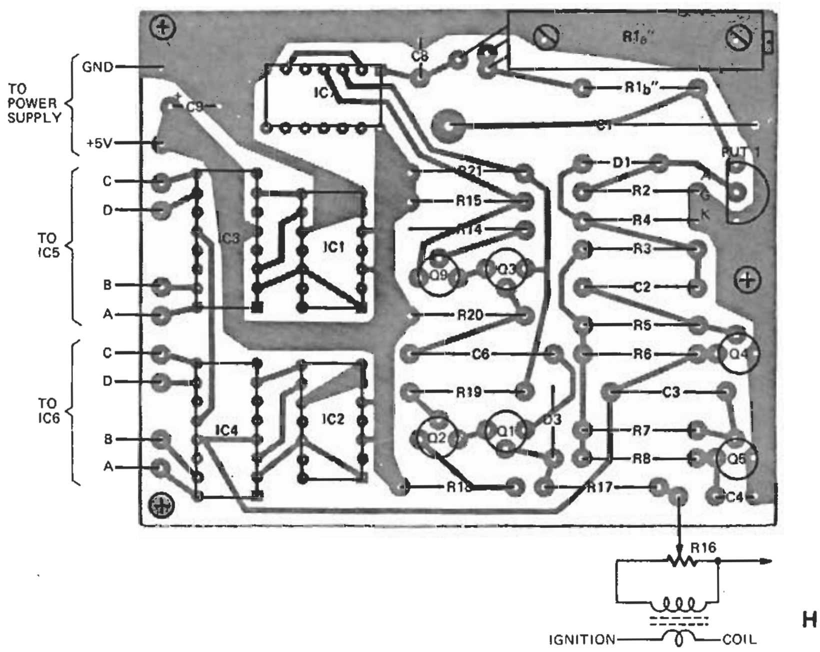




PARTS PLACEMENT on circuit boards. F—power supply board. G—display board. H—main board.







CAR TACHOMETER

We've been contemplating a digital car tacho, but have been put off by resolution and response speed problems. However this Phase Locked Loop design overcomes these quite neatly — so here it is!

WE HAD OFTEN considered the design of a digital tacho for automobile use, but had rejected several schemes as we were unable to get both good resolution and response time — the two seemed to provide a very good demonstration of Heisenberg's Uncertainty Principle.

Consequently, we were rather pleased when Mike Pratt of SM Electronics came to us with his phase-locked loop based design which got round the problem. Would we like to do it as a project, he asked? Obviously, we said yes, and here it is.

This tacho features a fast response time, coupled with 10 Hz resolution, through the use of a phase locked loop frequency multiplier. It can be set up, by means of a single link, to work on 4, 6 or 8 cylinder motors.

Design Features

To measure the revolutions per minute of a motor is simply a matter of counting the number of ignition pulses over a given time. With a four-cylinder, four-stroke motor there is such a pulse twice per revolution. Therefore if we count these pulses for 30 seconds we will have revs/min with a one cycle resolution. Obviously this is much too long a sample period for practical use in a motor car and some compromise has to be made.

The usual solution is to use a 100 rev resolution and a sample time of 0.3 seconds (on 4 cylinders). We considered this inadequate which is why we have not published a design until now.

In this design an oscillator is used which is phase locked to the ignition pulses except at a higher frequency (x8 for 4 cylinder) allowing a short sample time (0.375sec) with a 10 rev resolution. By using a different multiplication factor compensation for different numbers of cylinders can be made. Unfortunately with the multiplication factors used (x8, x6, x4) the sample time for 6 cylinders is not exactly the same as that used for 4 and 8 cylinder motors. Altering the ratios to x12, x8 and x6 would enable a 0.25 sample time to be used for all ranges, but this is not possible with the divider IC utilised in this design.

Construction

Assemble the PCB with the aid of the overlay ensuring the components are orientated correctly. The tantalum capacitors normally have a + mark indicating the positive load, or a dot on the side. When soldering the CMOS ICs (4, 6, 7) earth the tip of the soldering iron.

Note that there is one feedthrough or link between the two sides of the board near C10

Calibration

Initially place a link between the point 'C' and the terminal corresponding to the number of cylinders. Now with the power supply connected feed a 50 Hz signal of between 12 and 30 V into the points input using the 0 V as common. Now adjust RV1 until the display reads 1500 RPM for 4 cylinders, 1000 for 6 or 750 for an eight cylinder car. ►

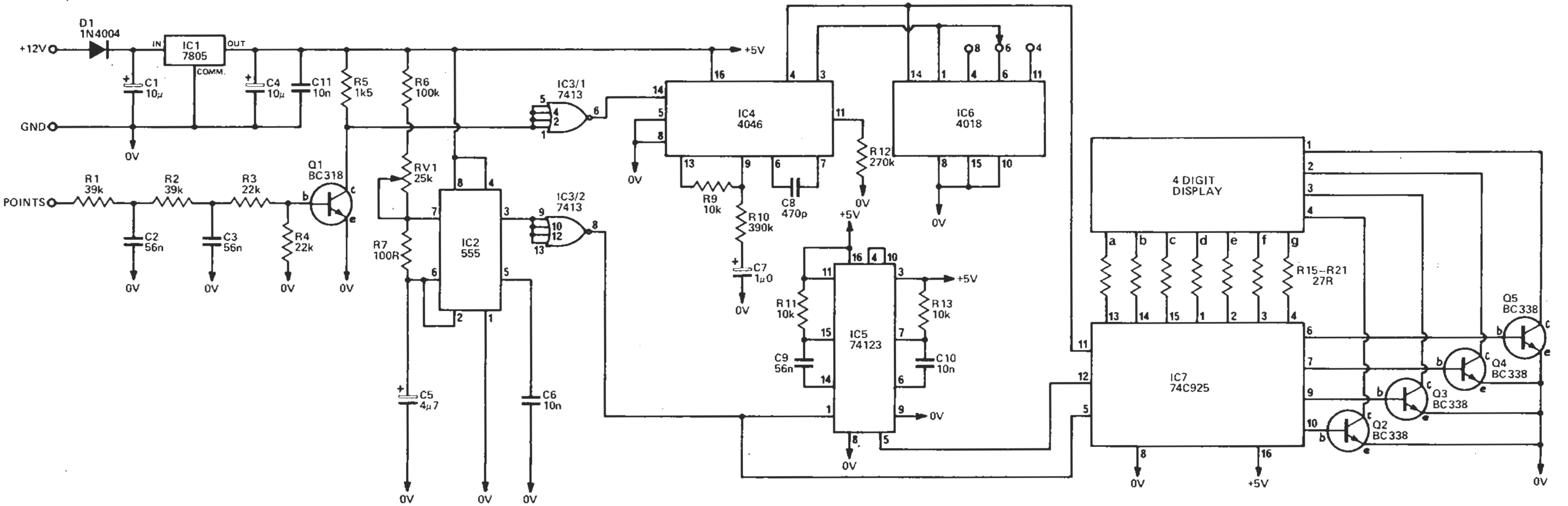


Fig. 2. Full circuit diagram for the digital car tacho unit.

HOW IT WORKS

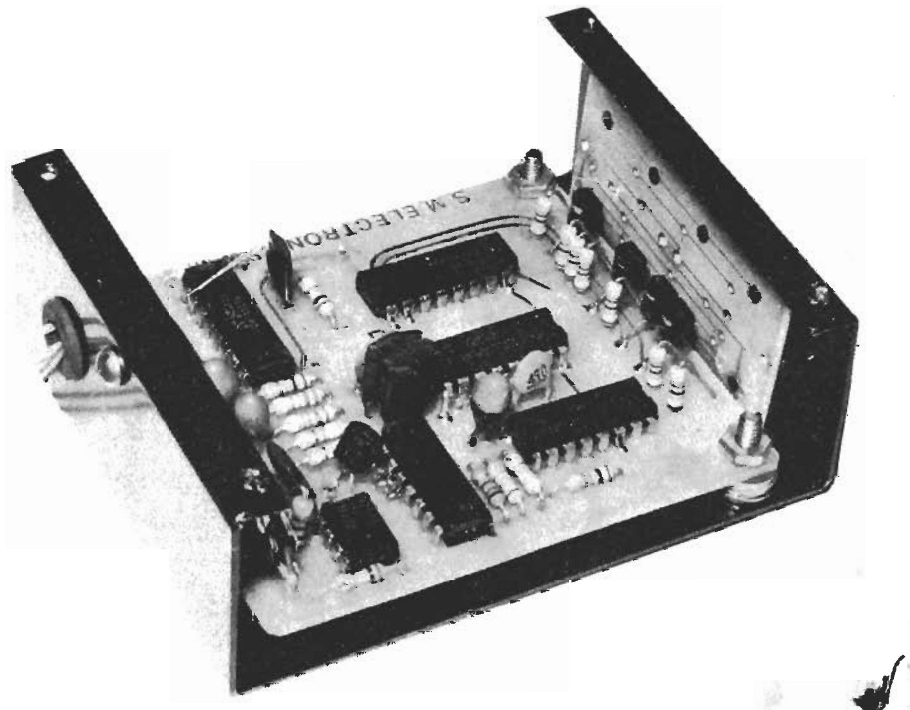
The output from the points of the distributor is basically a 0 to 12V square wave with a 200 volt pulse on the rising edge. A filter network, R1-R4, C2, 3 is used to remove the high voltage pulse (and points bounce) and Q1 buffers it giving a +5 to 0V output on its collector. As the filter network removes the sharp edge of the input a schmitt trigger is needed on the output of Q1 to give fast edges. IC3/1 is used for this.

The output of IC3/1 is connected to the input of the phase-locked loop IC (4046). This IC has an internal voltage controlled oscillator and its output is divided by 4, 6 or 8 by IC6 and this lower frequency is fed back to the phase-locked loop IC. The IC then compares this frequency to that at its input and adjusts the internal oscillator until it is the same. The result is a frequency which is an exact multiple of the input.

The time base is generated by IC2 (555) which has a negative output pulse, about 300 µs wide every 375 ms (or 333 ms for 6 cylinder). This is inverted by IC3/2 and is used as the strobe pulse for the 4 digit counter IC7. This pulse also triggers the first of the monostables in IC5 which gives a 200 µs delay before triggering the second half of IC5; this gives a 40 µs pulse to reset IC7 back to zero.

IC7 is a 4 digit counter with a latch (store) and seven segment decoder driver. It needs four external transistors to drive the digits but the segment drivers are internal. As we need only a three digit counter, i.e. for good resolution, with the right hand permanently zero the least significant digit is connected to the second right digit, etc, with the most significant digit connected to the right hand digit. Provided one does not exceed 9990 RPM this digit will remain on 0 as intended!

The 555 timer, the TTL and the 74C925 needs a regulated +5V and IC1 provides this with D1 preventing damage due to reverse polarity inputs.



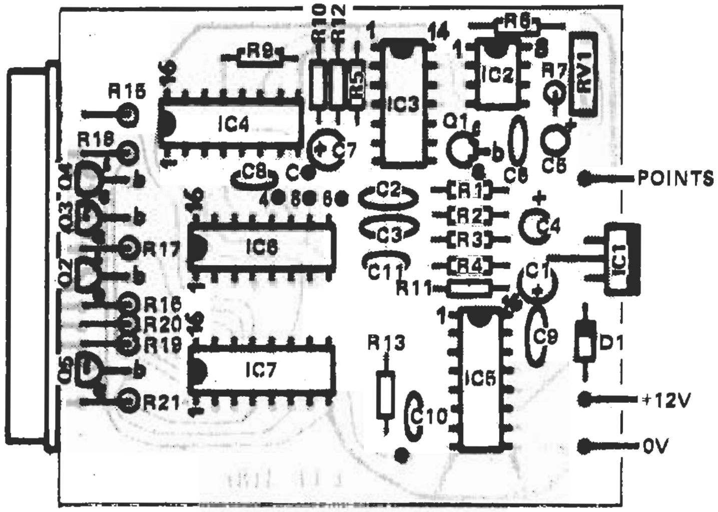


Fig. 1. The component overlay for the board. The board is double sided although only the lower surface is shown here. Note the link between the two surfaces of the board near C10.

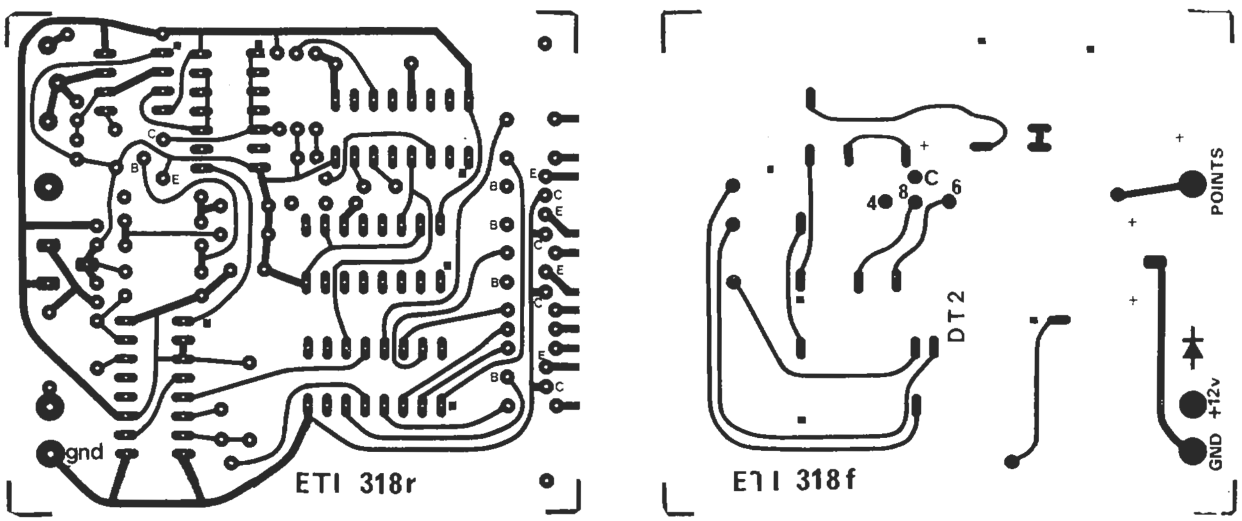
SPECIFICATION

Range	**100 to 9990 RPM**
Resolution	**10 RPM**
Reading rate	
4 or 8 cylinders	**2.66 per second**
6 cylinders	**3 per second**
Power supply	**7 to 15V@ 400mA**
Suitable ignition systems	**standard**
	CDI
	transistor assisted
	***it will not operate on 'pointless' systems**

BUYLINES

The components employed here are all readily available from any of the major mail order companies advertising in this issue. Note that the counter is a CMOS chip, and not a standard bi-polar TTC chip. The standard component will not operate on this mode.

Fig. 3. PCB foil patterns shown full-size.



PARTS LIST

RESISTORS	all ¼ W, 5%
R1,2	39k
R3,4	22k
R5	1k5
R6	100k
R7	100R
R8	not used
R9	10k
R10	390k
R11	10k
R12	270k
R13	10k
R14	not used
R15-R21	27R
POTENTIOMETER	
RV1	25k trim
CAPACITORS	
C1	10u 25V tantalum
C2,3	56n polyester
C4	10u 25V tantalum
C5	4μ7 25V tantalum
C6	10n polyester
C7	10u 25V tantalum
C8	470p ceramic
C9	56n polyester
C10	10n polyester
C11	10n ceramic
SEMICONDUCTORS	
IC1	7805 regulator
IC2	555 timer
IC3	7413 dual schmitt
IC4	4046 PLL
IC5	74123 dual mono
IC6	4018 divide by n
IC7	74C925 4 digit counter
Q1	BC318
Q2-Q5	BC338
D1	1N4004
Display	NSB5881
MISCELLANEOUS	
PCB	
Case to suit	

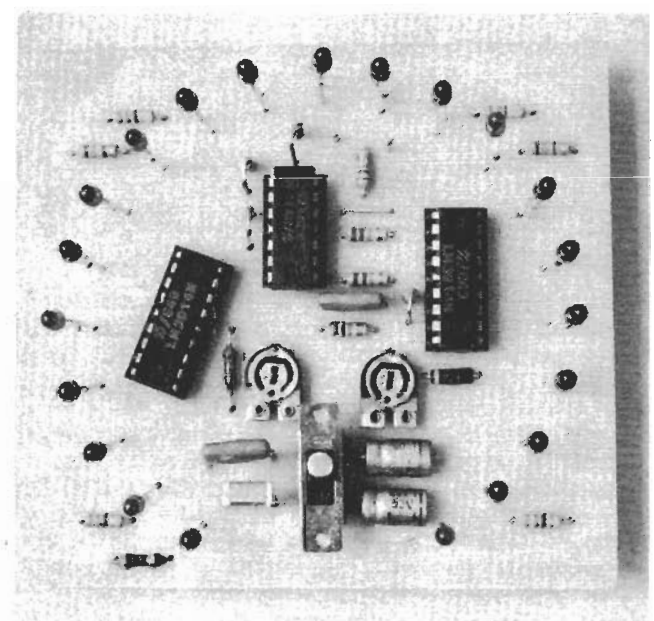
LED TACHOMETER

The HE Tacho uses 21 LEDS to give a solid-state analogue RPM display. It's an ideal project for the motoring or motor-cycling enthusiast.

THE HE LED TACHO or 'Rev Counter' is an all solid-state project. It displays engine speed in analogue form (like a conventional tacho) as an illuminated section of a semicircle of 21 LEDs (light-emitting diodes). The length of the illuminated section is proportional to the engine speed, so that half of the semicircle is illuminated at half of full-scale speed, and the full semicircle is illuminated at full speed. In other words, the display is in 'bar' rather than 'dot' form.

The HE Tacho can be used with virtually any type of multi-cylinder gas engine. It has two speed ranges, each of which can be calibrated via a pre-set pot to give any full-scale speed range required by the individual owner. Our prototype is calibrated to give full scale readings of 10000 RPM and 1000 RPM on a 4-cylinder 4-stroke engine. The lower range is of great value when adjusting the engine's ignition and carburation for recommended tick-over speeds.

The unit is designed for use only on vehicles fitted with 12 volt electrical systems. It can be used with conventional or CD (capacitor-discharge) ignition systems, and is wired into the vehicle via three connecting leads. It can be used on vehicles fitted with either negative or positive ground electrical systems.



The HE tachometer, make sure all polarised components are inserted the correct way round.

Construction

The complete unit, including the 21-LED display, is wired up on a single PCB. Take extra care over the construction, paying special attention to the following points.

(1). Confirm the polarity of each of the 21 LEDs, by connecting in series with a 1k0 resistor and testing across a 12 volt supply, before wiring into place on the PCB. Note that LED colours can be mixed, if required.

(2). Take care to connect all semiconductor devices and electrolytic capacitors into circuit as shown on the overlay. Note the orientation of the three ICs.

(3). Note that four LINK connections (using insulated wire) are used on the underside of the PCB: if in doubt about these connections, cross-check with the circuit diagram. Also note that the external connections to the unit (0 V, + ve, and CB) are made via solder terminals (Veropins).

(4). Note that the values of C2 and C3 must be chosen to suit the engine type and the full-scale RPM ranges required (see the conversion graph). Our prototype is calibrated to read 10 000 RPM and 1000 RPM on a 4-cylinder 4-stroke engine, and uses C2 and C3 values of 22n and 220n respectively.

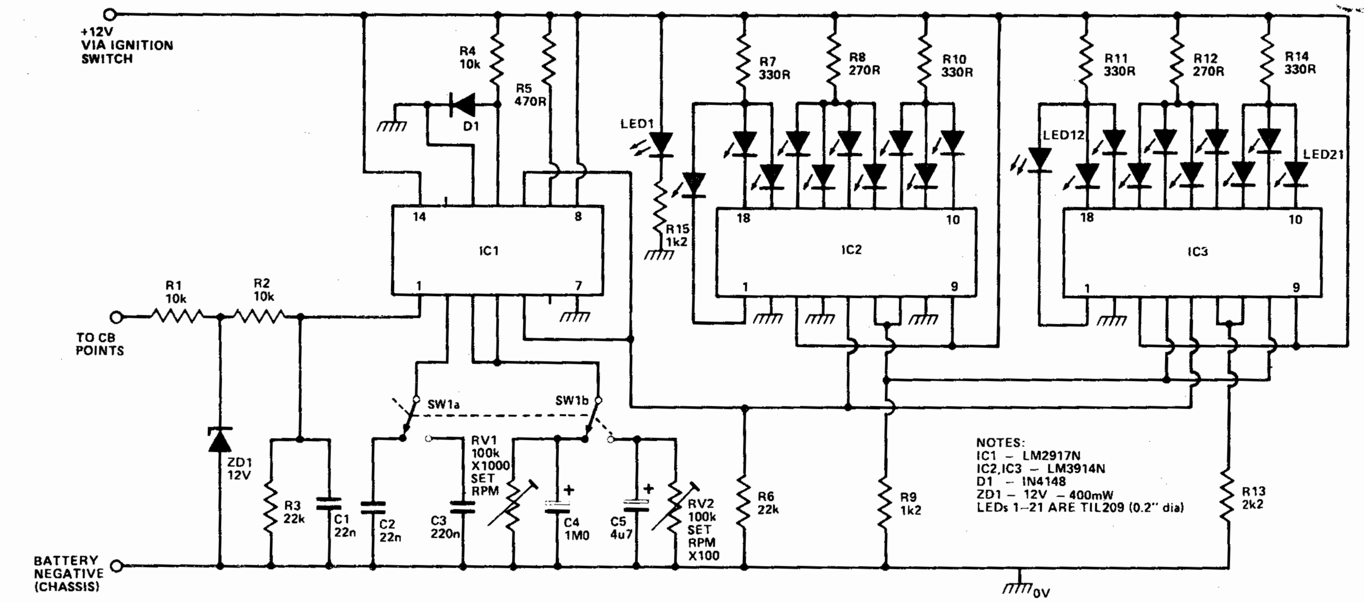
When the construction is complete, connect the unit to a 12 volt supply and check that only LED 1 illuminates: if all LEDs illuminate, suspect a fault in the IC1 wiring.

Calibration

The unit can be calibrated against either a precision tachometer or against an accurate (2% or better) audio generator that gives a square wave output of at least 3 volts peak-to-peak. The method of calibration against an audio generator is as follows:

Connect the tacho to a 12 volt supply, and connect the square wave output of the audio generator between the 0V and CB terminals of the unit. Check against the conversion graph to find the frequency needed to give the required HIGH range full-scale RPM reading on the type of engine in question, and feed this frequency into the tacho input. Switch SW1 to it's HIGH range (10 000 RPM on our prototypes) and adjust RV1 for full-scale reading.

Repeat the procedure on the LOW range of the tacho (1000 RPM on our prototype), adjusting RV2 for full-scale reading.



Circuit diagram of the LED Tacho, refer to the conversion graph for values of C2, C3.

HOW IT WORKS

The ignition signal appearing on a vehicle's contact-breaker (CB) points terminal has a basic frequency that is directly proportional to the RPM of the engine. The HE LED Tacho works by picking up the CB signal, extracting its basic frequency, converting the frequency to a linerarly-related D.C. voltage, and displaying an analogue representation of this voltage (and thus the RPM) on a semicircular scale of 21 LED's (light-emitting diodes). The tacho can thus be broken down, for descriptive purposes, into an input signal conditioner section, a frequency-to-voltage converter section, and LED voltmeter display section.

The input signal conditioner section comprises R1-R2-R3-ZD1-C1. The CB signal of a conventional ignition system consists of a basic RPM-related rectangular waveform that switches alternately between zero and 12 volts, onto which various ringing waveforms with typical peak amplitudes of 250 volts and frequencies up to 10 kHz are superimposed. The purpose of the input signal conditioner is to cleanly filter out the basic rectangular waveform and pass it on to the frequency-to-voltage converter. It does this by first limiting the peak amplitude of the signal to 12 volts via R1 and zener diode ZD1, and then filtering out any remaining high frequency components via R2-R3-C1. The resulting 'clean' signal is passed on to input pin 1 of IC1.

IC1 is a frequency-to-voltage converter chip with a built-in supply-voltage regulator. The operating range of the IC is determined by the value of a capacitor connected to pin 2, and by a timing resistor and smoothing capacitor connected to pins 3-4. In our application, two switch-selected presettable ranges are provided. The D.C. output of the IC is made available across R6, and is passed on to the input terminals of the IC2-IC3- LED voltmeter.

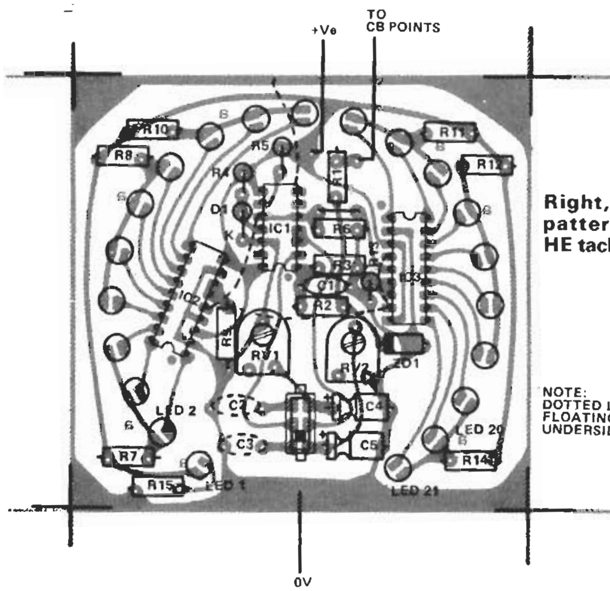
IC2 and IC3 are LED display drivers. Each IC can drive a chain of ten LED's the number of LED's illuminated being proportional to the magnitude of the IC's input signal. Put simply, the IC's act as LED voltmeters. In our application, the two IC's are cascaded in such a way that they perform as a single 20-LED voltmeter with a full scale range of about 2.4 volts: the configuration is such that the voltmeter gives a 'bar' display, in which the first 10 LEDS are illuminated at full scale voltage.Resistors R7-R8-R10-R11-R12-R14 are wired in series with the display LED's to reduce the power dissipation of the two IC's. LED1 is permanently illuminated so that the RPM display does not blank out completely when the vehicle's engine is stationary with the ignition turned on.

Installation

The completed unit can either be mounted in a special cut out in thevehicle's instrument panel, or (preferably) can be assembled in a home-made housing and clipped on top of the instrument panel. In either case, try to fit some kind of light shield to the face of the unit, so that the LEDs are shielded from direct sunlight.

To wire the unit into place, connect the supply leads to the tacho via the vehicle's ignition switch, and connect the unit's CB terminal to the CB terminal in the vehicle's distributor. Note that the unit can be fitted to vehicles using either positive or negative ground systems.

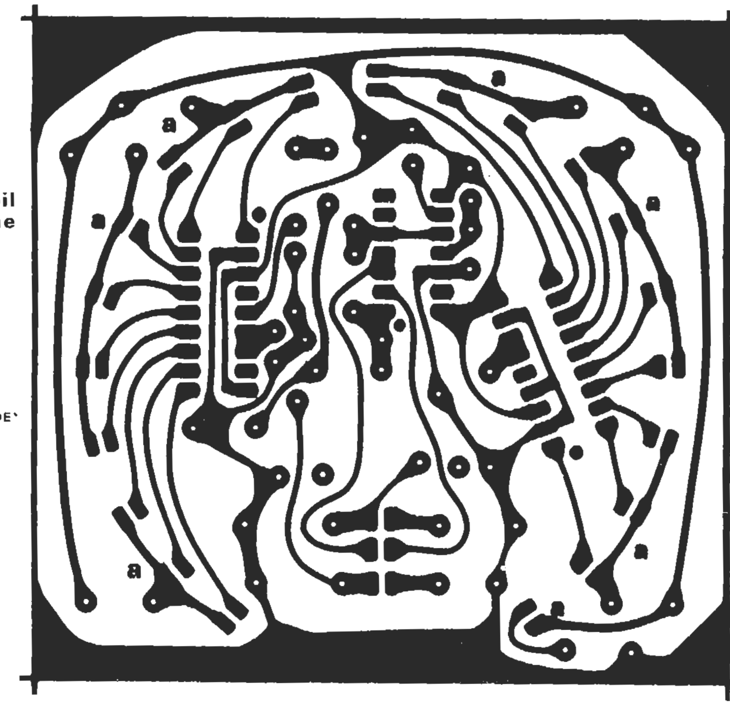
The lower range of the tach (1000 RPM on our prototype) is of great value when adjusting thevehicle's engine for correct tick-over: it is thus advantageous to arrange the tacho housing so that it can be easily dismounted from the vehicle's instrument panel.●



Component overlay for the Tacho.

Right, PCB foil pattern for the HE tachometer.

NOTE:
DOTTED LINES SHOW FLOATING LINKS MADE UNDERSIDE OF PCB



PARTS LIST

RESISTORS

R1, R2, R4	10k
R3, R6	22k
R5	470R
R7, R10, R11, R14	330R
R8, R12	270R
R9, R15	1k2
R13	2k2

POTENTIOMETERS

RV1, RV2	100k Sub. min. preset

CAPACITORS

C1, C2*	22n polyester
C3*	220n polycarbonate
C4	1µ0 elect. 63V
C5	4µ7 elect. 63V

*=values used on prototype: see text

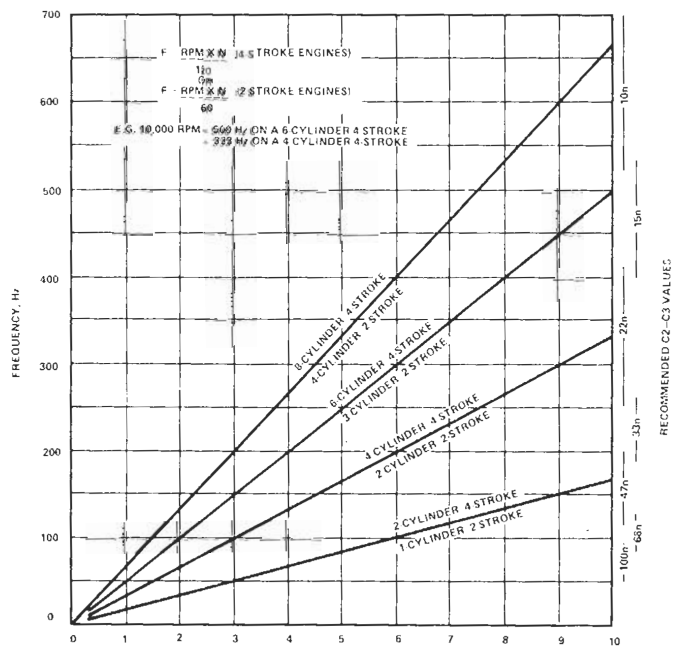
SEMICONDUCTORS

IC1	LM2917N
IC2, IC3	LM3914N
ZD1	12V @ 400mw
D1	IN4148

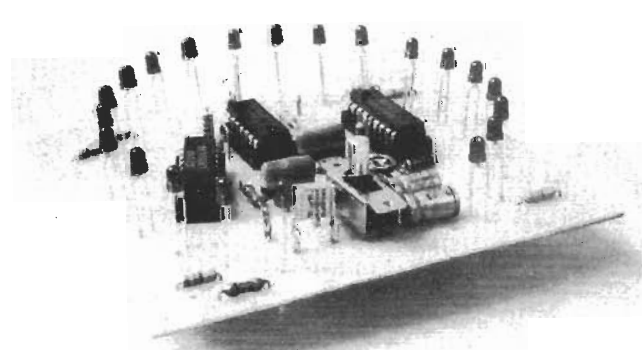
LEDS 1-21 are TIL209 0.2" dia.

MISCELLANEOUS

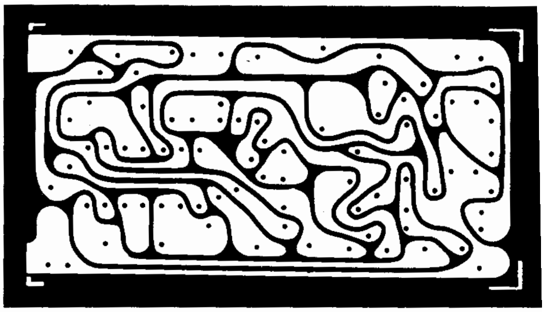
Miniature slide switch (two position double pole). PCB foil pattern.

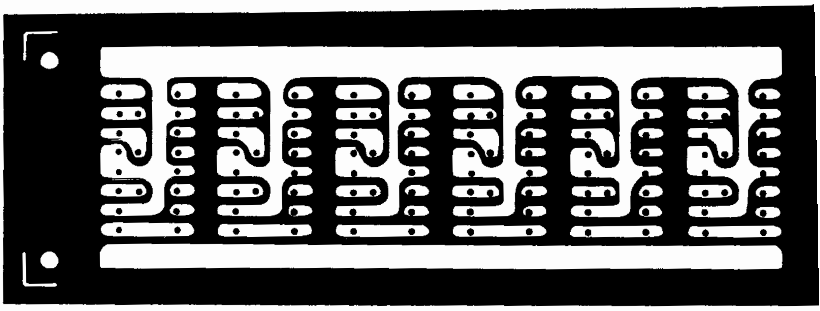


Conversion Graph for determining values of C2, C3.



The Tacho prior to installation.





DIGITAL TACH

ELEKTOR 1

Out of Tune

In "Digital Marine/Auto Tachometer" (June 1975), the connection where the line coming from pin 5 crosses the line between pins 1 and 8 of *IC2* in the schematic should be removed. Also, the IC's are sensitive to the r-f noise from the car's ignition system. To cope with this problem, it may be necessary to install r-f suppression-type spark plug cable in older cars and extensive capacitive bypass techniques in the circuit. Route the coaxial feed cable close to the metalwork on the bottom of the car and locate its grounding point experimentally. In most cases it will be on the car's body or frame, rather than on the engine.

In "How to Design Your Own Power Supplies" (June 1975), Fig. 10, page 39, the polarity of the zener diode should be reversed.

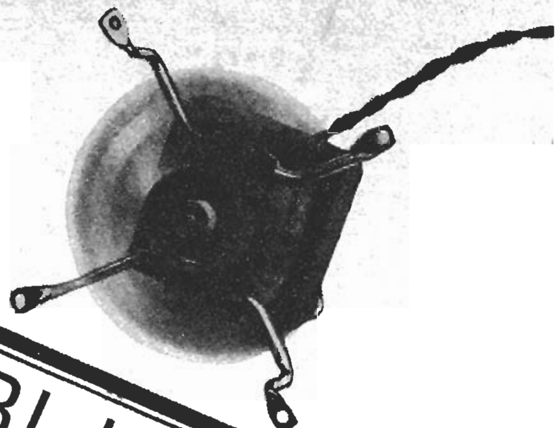
CALIBRATE THE "OP TACH"

The "Op Tach" article ("Build Op Tach," March 1969) describes two methods of calibration that will undoubtedly work. I would like to suggest yet another method; one that is simple and does not require special extra circuitry. Simply hold the Op Tach directly in front of a fluorescent tube or fixture with the power applied, and adjust R7 until the meter indicates 3600 r/min. The tube pulses at a rate of 60 Hz—or 3600 repetitions/min.

RICHARD E. TAVANO
Wayne, N.J.

It's usually the obvious—and easiest—approaches to a problem that slip by us. Your method of calibration will certainly work. Also, the author of the article advises us that he accidentally listed R9 in the project as 680 ohms when it should be 6800 ohms. If any readers built the Op Tach using locally obtained parts and are having trouble with calibration, this resistor is the culprit.

COVER STORY
BY JOHN S. SIMONTON, JR.

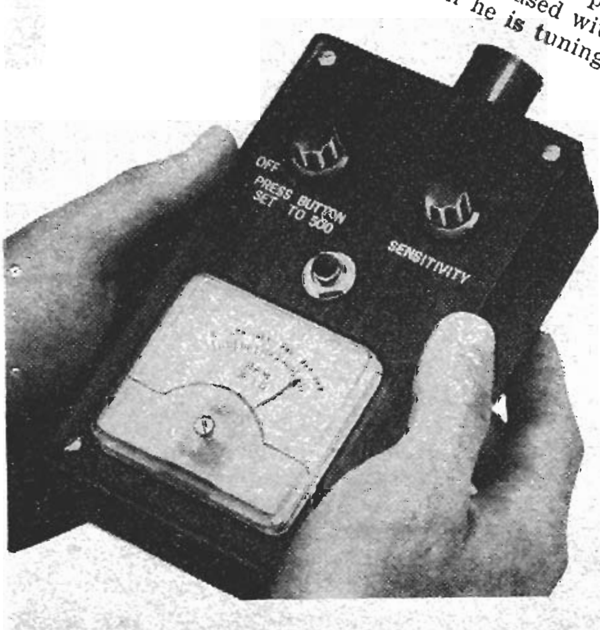


BUILD "OP-TACH"

COUNT REVOLUTIONS WITH HAND-HELD INSTRUMENT

WHEREVER there is a wheel spinning or a motor shaft turning, the chances are that, sooner or later, somebody is going to ask how fast it is revolving. To find out, he'll have to use a tachometer of some sort. Most commercial and industrial tachometers are designed for a specific purpose and are either permanently installed or fairly expensive, or both.

In the home workshop, the experimenter needs a low-cost, portable tachometer that can be used with any motor or engine when he **is** tuning up or testing.



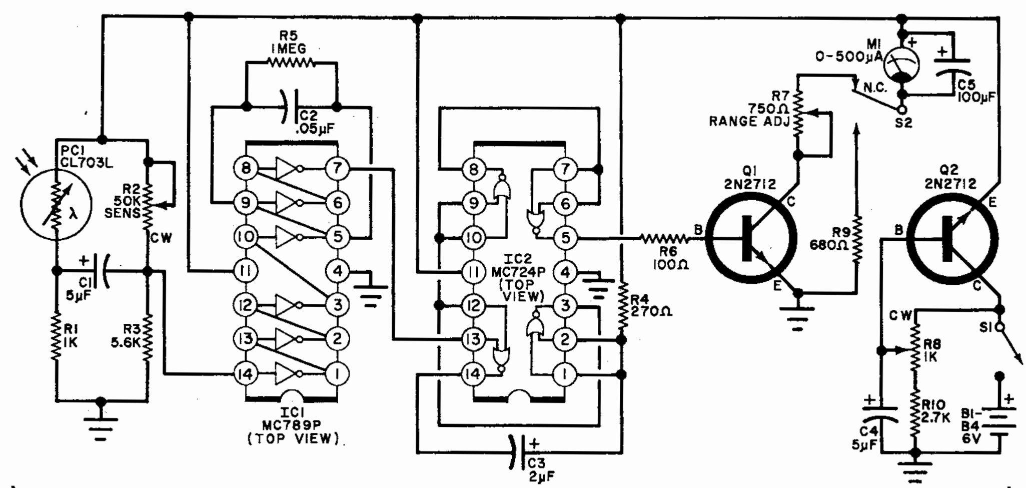


Fig. 1. The meter indicates the average current flowing through Q1 as a result of the number of light pulses striking PC1. Capacitor C5 permits the system to operate only on light pulses and not be affected by the amount of ambient light.

PARTS LIST

B1-B4—1.5-volt AA cell (penlight)
C1, C4—5-µF, 6-volt electrolytic capacitor
C2—0.05-µF, ceramic disc capacitor
C3—2-µF, 6-volt electrolytic capacitor
C5—100-µF, 6-volt electrolytic capacitor
IC1—Integrated circuit (Motorola MC789P)
IC2—Integrated circuit (Motorola MC724P)
M1—0-500-µA meter, 100-ohm internal impedance
PC1—Photocell (Clairex CL 703L or similar)
Q1, Q2—2N2712 transistor
R1—1000-ohm
R3—5600-ohm
R4—270-ohm
R5—1-megohm
R6—100-ohm
R9—680-ohm
R10—2700-ohm
(All resistors ½-watt)
R2—50,000-ohm linear taper potentiometer
R7—750-ohm trimmer potentiometer
R8—1000-ohm linear taper potentiometer with switch attached
S1—S.p.s.t. switch (part of R8)
S2—S.p.d.t. pushbutton switch
Misc.—Case (6½" x 3⅜" x 2", plastic with mating aluminum cover), hardware, dual battery holder (2), wire, solder, 5-dram plastic pill container with cover, PC board, etc.*
**The following are available from PAIA Electronics, P.O. Box 14359, Oklahoma City, Okla. 73120: printed circuit board, $2.50; meter with RPM x 10 designation on dial, $5.25; complete kit of parts with PC board, hardware and case (not machined), $18.50. Oklahoma residents, add 3% sales tax.*

There are very few tachometers of this type.

Here's one, however, that will measure the speed of practically anything that rotates in the lab or workshop. It's called the "Op-Tach" and is battery-operated, wholly self-contained and handheld. A beam of light senses the speed of the rotating object. In many cases, using the Op-Tach is simply a matter of pointing the instrument at the rotating object and reading the speed in revolutions per minute directly from the meter.

Construction. The schematic diagram for the Op-Tach is shown in Fig. 1. As with any project using integrated circuits, you will be ahead of the game if you use a printed circuit board. You can make your own, using Fig. 2 as a guide, or you can buy one (see Parts List of Fig. 1). In assembling components on the circuit board (Fig. 3) be sure that both the board and your soldering iron are as clean as possible and keep them that way. In inserting the integrated circuits, notice that the notches on the IC's correspond to the semicircular locating marks on the PC board. When all soldering is complete, a coat of spray acrylic or clear nail polish will keep the copper circuit from oxidizing.

To protect the photocell from high levels of ambient light and restrict its field of view, the photocell is glued to the bottom of the inside of a 5-dram pill container which has been painted flat black on the inside. A pair of holes is drilled for the photocell leads. The pill container is then mounted in an appropriate size hole in one end of the 6½" × 3¾" × 2" plastic utility box which houses the instrument. To conserve space, mount it so that approximately half of the pill bottle protrudes from the case. Save the cap from the container and use it as you would the lens cap on a camera—to prevent dust from settling on the photocell.

The two dual-battery holders are mounted on opposite sides of the case so that, when the cover is in place, the meter is between them. The PC board should be mounted with 6-32 screws and raised from the bottom of the case with short spacers. The meter, switch *S2* and controls (*R2* and *R8*, with *S1* attached) are mounted on the aluminum faceplate of the utility box as shown in Fig. 4. In the author's prototype this faceplate was covered with a mahogany-grain, contact-adhesive paper and labels were applied using dry transfers. All wires from the PC board to the controls and meter were run through a piece of large tubing, but they could be laced together in a neat bundle. Be sure to make these leads long enough to permit removal of the front cover. Notice that capacitor *C5* is mounted directly on the meter terminal lugs and not on the printed circuit board.

The suggested meter has scale markings from 0 to 500. Carefully remove the

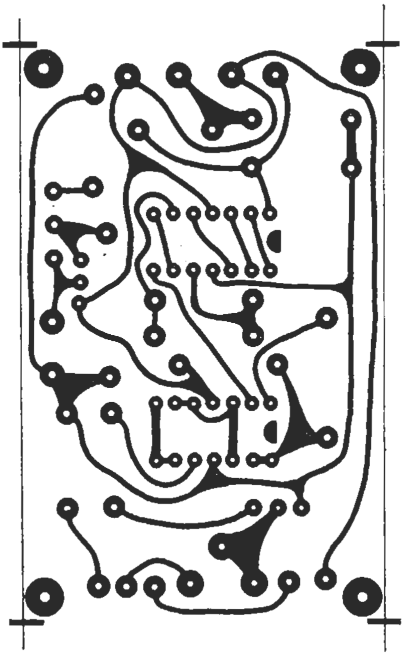


Fig. 2. Actual size printed-board foil pattern for the Op-Tach. Note the semicircular end identifiers for the IC's.

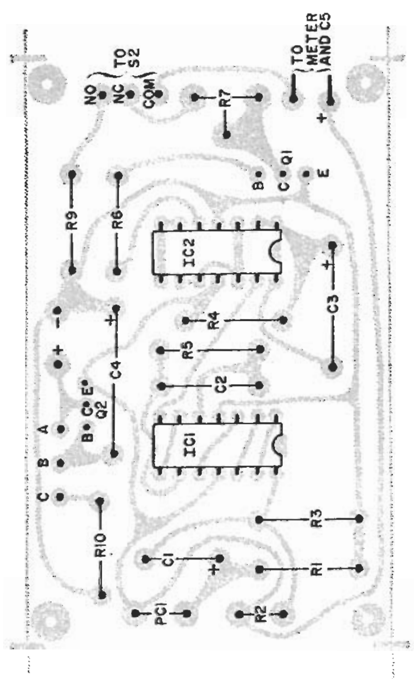


Fig. 3. Component installation. Observe correct polarity for the indicated parts.

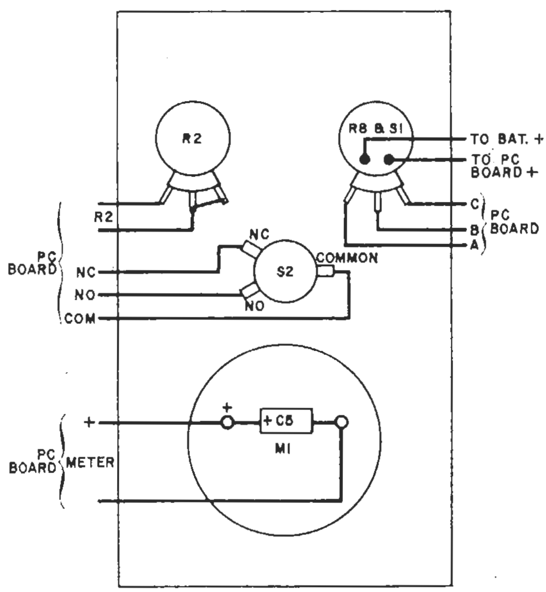
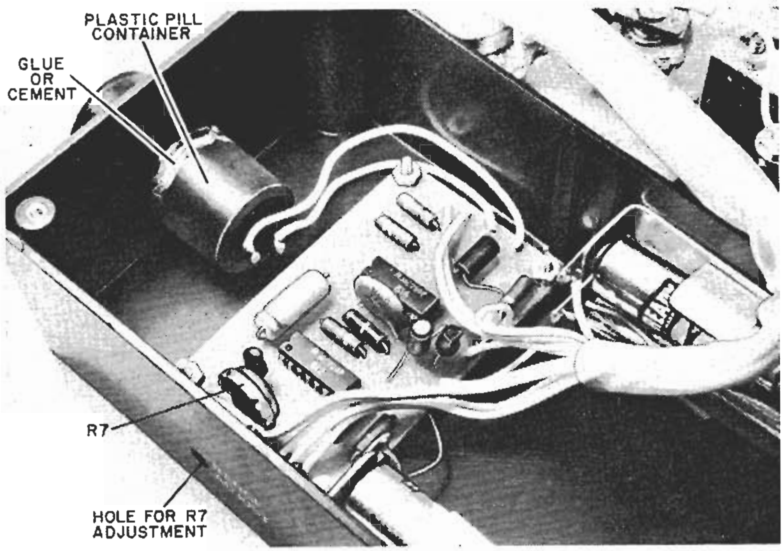


Fig. 4. Layout of rear of front panel. As circuit layout is not critical, any arrangement can be used.

Two holes must be drilled in the plastic case. One is for the pill container that mounts PC1, while the other is for making R7 adjustments. For maximum rigidity, mount the pill container half way in the case and use high-quality cement. Use the pill container cover as a cap when the Op-Tach is not in use. This keeps dust away from the photo cell.



clear plastic front of the meter and use a pencil eraser to remove the "D.C. MICROAMPERES" marking. You can then use either pen and ink or dry transfers to relabel the meter "RPM × 10". If at all possible, remove the scale before doing any lettering on it and, in any case, be very careful not to bend the meter needle or damage the movement.

Calibration. The best way to calibrate the Op-Tach is by comparing it to a tachometer of known accuracy, but if such an instrument is not available, you can use one of the following methods:

Signal-Generator Method. Figure 5 shows a calibration setup using an audio signal generator. Set the generator for an output of 50 Hz and 1.5 volts peak-to-peak. Turn on the Op-Tach and set *R8* so that the meter reads 500 with *S2* depressed. Release *S2* and set sensitivity control *R2* at its least sensitive point (counterclockwise). You may get a reading with the sensitivity control at this position but if you don't, advance *R2* slowly until the meter shows a steady reading. Adjust the range potentiometer, *R7*, to give a reading of 3000 RPM (the equivalent of 50 Hz). While you have the equipment set up, you may want to check the tachometer at several other frequencies. Remember that indicated RPM is frequency times 60.

The electronic portion of the Op-Tach is inherently linear above about 500 RPM so any nonlinearity you may find is in the meter movement. Since most inexpensive meters have a nominal accuracy of 5%, you can expect an error of less than 250 r/min on the 5000 RPM range (usually much less).

Power-Line Method. If you don't have a signal generator, the best thing to do is to use a filament transformer and a voltage divider set up as shown in Fig.

HOW IT WORKS

Each time a sharp change of light hits the Op-Tach's photocell, the resistance of *PC1* changes and a voltage pulse is created at terminal 14 of *IC1*. This pulse is amplified and shaped by the six inverters in *IC1*. SENSITIVITY control, *R2*, is used to set the amount of forward bias in the first inverter in *IC1*. Capacitor *C2* isolates the last two inverters from any cascaded d.c. bias in the first four stages; and *R5* prevents an excess charge from accumulating on *C2*, which would reverse bias the last two inverter stages.

The output at pin 7 of *IC1* triggers a monostable multivibrator composed of *R4*, *C3*, and two of the four logic gates in *IC2*. Even though the reflected light detected by *PC1* varies in duration and intensity, the output of the multivibrator is a pulse of constant height and width whose frequency is determined by the number of times that the reflected light strikes *PC1*.

The pulses are squared up and buffered by the other two gates in *IC2* and applied to the base of *Q1*. When a pulse is applied to *Q1*, it is turned on and a short pulse of current flows through meter *M1*. As the speed of the object increases, the pulses become closer together and the average value of current flowing through *M1* increases. Capacitor *C5* smooths this waveform and helps keep the meter needle from jiggling.

When pushbutton *S2* is pressed, the meter is taken out of the collector circuit of *Q1* and put in series with *R9*. The voltage across the meter is then determined by *Q2* and can be varied by adjusting *R8*. Variations in battery output due to aging are eliminated by setting *R8* for a current flow of 500 microamperes before each reading.

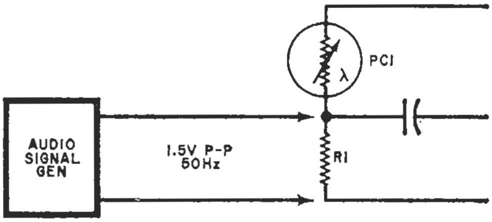


Fig. 5. To calibrate, use an audio signal generator delivering 1.5 volts peak-to-peak at 50 Hz as the input and adjust R7 (through its hole) for 3000 RPM.

6. The procedure is the same as that above except that you adjust *R7* for a meter reading of 3600. (Unless you happen to have a power line with a 50-Hz frequency; in which case, the reading would be 3000 RPM.)

Of course the meter doesn't have to be calibrated for a full-scale reading of 5000 RPM. You can set *R7* for 10,000 or 15,000 RPM and change the meter scale markings accordingly. However, you will have to use an audio signal for calibration in the higher ranges. Select a frequency near the center of the range. For instance, for a 10,000-RPM scale, use 83 Hz, which is equivalent to 4980 RPM (make the setting for 5000). Don't try to get a full-scale range of more than 15,000 RPM or you may run into serious nonlinearities.

Operation. The Op-Tach can be used in one of two ways: by reflection or by transmission of light.

Reflective. In the first method, light is reflected from a rotating spot which is of a different reflectivity from the rest of the object. The shafts of some motors have flats machined on them and these serve as good reflective spots. In most cases, however, the contrasting area must be made artificially. You can use a small piece of aluminum foil attached with clear cellophane tape or simply a piece of paper of a color which contrasts with the background. A small area painted in contrast will also be satisfactory.

Position the Op-Tach so that light is reflected from the surface of the rotating body into the photocell. A light source is not included as part of the instrument since quite often ambient light is sufficient. If it is not, use an auxiliary light such as a flashlight or drop light.

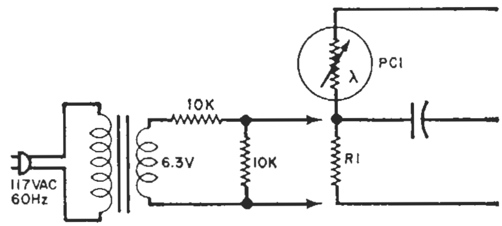
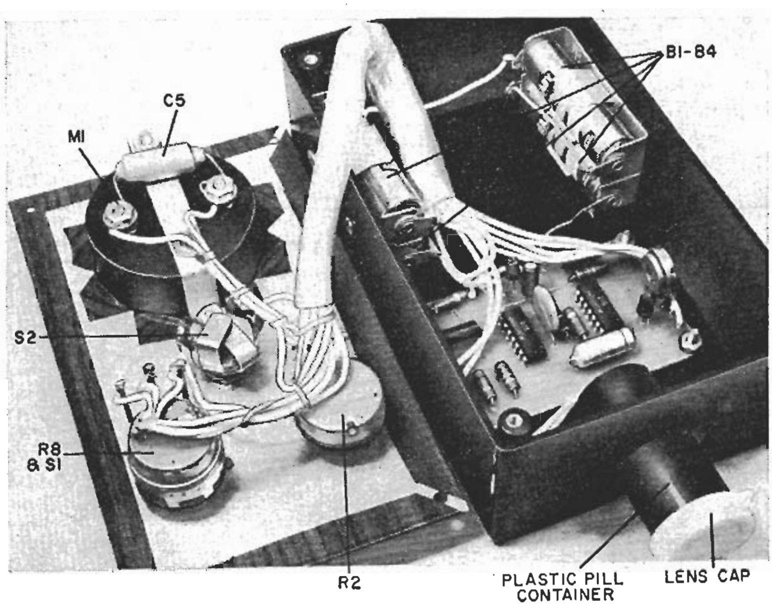


Fig. 6. You can use the commercial 60-Hz power line as a calibration source, with the divider network shown here, to calibrate the Op Tach to 3600 RPM.

Look at the rotating object from the direction and position in which the tachometer is located. If you can see a direct reflection from the light source, you can use the Op-Tach. If not, change the position of the light or the tachometer, or both. You can hold the Op-Tach in your

(*Continued on page* 113)



The wiring between the PC board and the front panel can be made neat by passing it through a piece of plastic tubing.

OP-TACH

(*Continued from page* 31)

hand if it is sufficiently steady to get constant readings. Otherwise, place the Op-Tach on a solid surface. For the best accuracy, always have the tachometer case in a position as close to horizontal as possible.

Turn on the Op-Tach by rotating *R8* clockwise until *S1* turns on. This supplies power to the meter. Depress *S2* and continue to rotate *R8* until you get a full-scale deflection. Then release *S2*. With the photocell pointed at the rotating body, advance the SENSITIVITY control (*R2*) until you get a steady reading. If the sensitivity is made too high, the photocell will begin to pick up minor differences in reflectivity due to surface imperfections. This results in an erratic reading on the meter, which can be cured by decreasing the sensitivity.

If the rotation being measured is below about 500 RPM the meter may "dance" somewhat. This effect is not objectionable, however, until the speed is below 200 RPM. To avoid this problem, try using more than one contrasting area on the rotating object. This has the effect of multiplying the speed of the object by the number of reflecting surfaces you add, and the speed read on the meter can be converted to true speed by dividing by that number. For instance, if you have placed six contrasting strips on a rotating object and the tachometer reads 1200 RPM. Then the true speed is 1200 divided by 6 or 200 RPM.

Transmissive. The measurement method using the transmission of light through a rotating object to the Op-Tach works extremely well for slowly rotating fans. The light source is placed on one side of the fan and the Op-Tach on the other so that each blade interrupts the beam as it passes between the source and the tachometer. The instrument is turned on and the voltage is adjusted as before. Because of the extreme difference in light levels, the sensitivity adjustment may have to be increased slightly. The indicated RPM must be divided by the number of times the beam is interrupted during one revolution of the fan (number of blades). -30-

OUT OF TUNE

Build "Op-Tach" (March 1969). The value of *R9* shown in Fig. 1 and specified in Parts List, both on page 28, should be 6800 ohms—not 680 ohms.

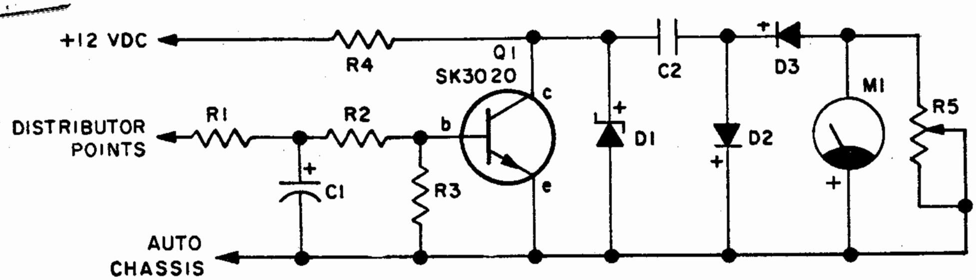
"Build Op Tach" (March 1969). In a letter in our July issue, a fluorescent light method of calibrating the "op tach" was proposed. This will work but the repetition rate is 7200 times/min not 3600. Since 60-Hz power has two maximum peaks the fluorescent fires 120 times/sec.

2 Solid Tach

UPDATED

You can adjust a car engine to specified idle and choke rpm with this one-transistor tachometer.

Wiring is not critical and the unit can be assembled in a plastic box or metal cabinet. Zener diode D1 is any 250-milliwatt



unit rated as close to 9 V as possible.

The unit can be used only on cars with a negative ground. The power lead connects to a positive 12-V point in the car's wiring, the ground lead connects to the car chassis. The distributor lead connects to the lead between the distributor and ignition coil. Do not connect it to a solid-state ignition system.

The meter scale is linear, with full scale representing approximately 10,000 rpm. Calibrate the tach against a commercial tach (at your local garage?) by noting the commercial tach's reading and adjusting R5 till your tach reads the same.

PARTS LIST FOR SOLID TACH

C1—1-uF, 100-VDC electrolytic capacitor
C2—0.47-uF, 15-VDC capacitor
D1—9.1-V, 250-mW Zener diode—Motorola HEP-104
D2, D3—100-mA, 50-PIV silicon rectifier—Motorola HEP-154
M1—0-1 mA DC meter
Q1—SK3020 npn transistor (RCA)
R1—200-ohm, ½-watt resistor
R2—220-ohm, ½-watt resistor
R3—1500-ohm, ½-watt resistor
R4—330-ohm, ½-watt resistor
R5—1000-ohm potentiometer

Low-Cost Speed Indicator

By CHARLES GREEN

MANY home craftsmen have discovered that working with the latest generation of infinitely-variable, speed-controlled tools is a frustrating experience. The tools have the capacity to work at full, half, or any speed down to zero. Problem is, few if any of these tools give you the shaft or blade speed for a given trigger setting.

A few years ago, the solid-state speed controller was introduced to the handyman. Plug that old-fashion, single-speed tool into this gadget and variable speed is yours for the dialing. But just like their more recent shopmates, the add-on speed controller cannot give you any inkling of tool RPM.

It's easy to determine the speed of any power tool, especially those driven via electronic speed control, with our Low-Cost Speed Indicator. This indicator works with a hand drill, lathe, drill press or any rotating workshop instrument. And with practice you can learn to gauge the speed of a saber saw or any other reciprocating tool.

Our indicator works on the persistence of vision effect. A blinking light is aimed at a moving target. When the number of light bursts at a given moment almost equals the target's speed, the device appears to move slowly. If the light bursts accurately coincide with the moving object, it appears to stand still.

The speed indicator utilizes a neon timing light. The lamp is driven by a solid-state timing circuit. And the dial is calibrated to read speed directly from 125 to 3,000 rpm.

How it Works. Unijunction transistor Q1 and associated components are connected as a sawtooth oscillator. When power is applied to the circuit, current flows through resistor R2 and pot R1 (*rpm*). Capacitor C1 charges up to a voltage of sufficient value to force transistor Q1 to conduct.

When Q1 conducts, a sawtooth-shape current pulse flows through Base 1 and Base 2 of the transistor. This pulse is coupled via resistor R4 to the base of transistor Q2.

Transistor Q2 helps to turn the sawtooth signal into a somewhat squarewave-shape voltage. The waveform is processed to give output autotransformer T1 adequate time to build up energy in the windings.

Transistor Q3 completes the voltage-shap-

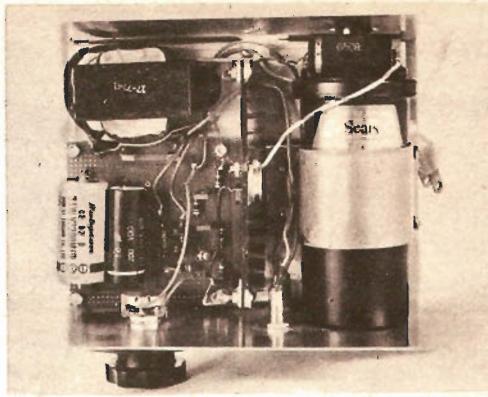
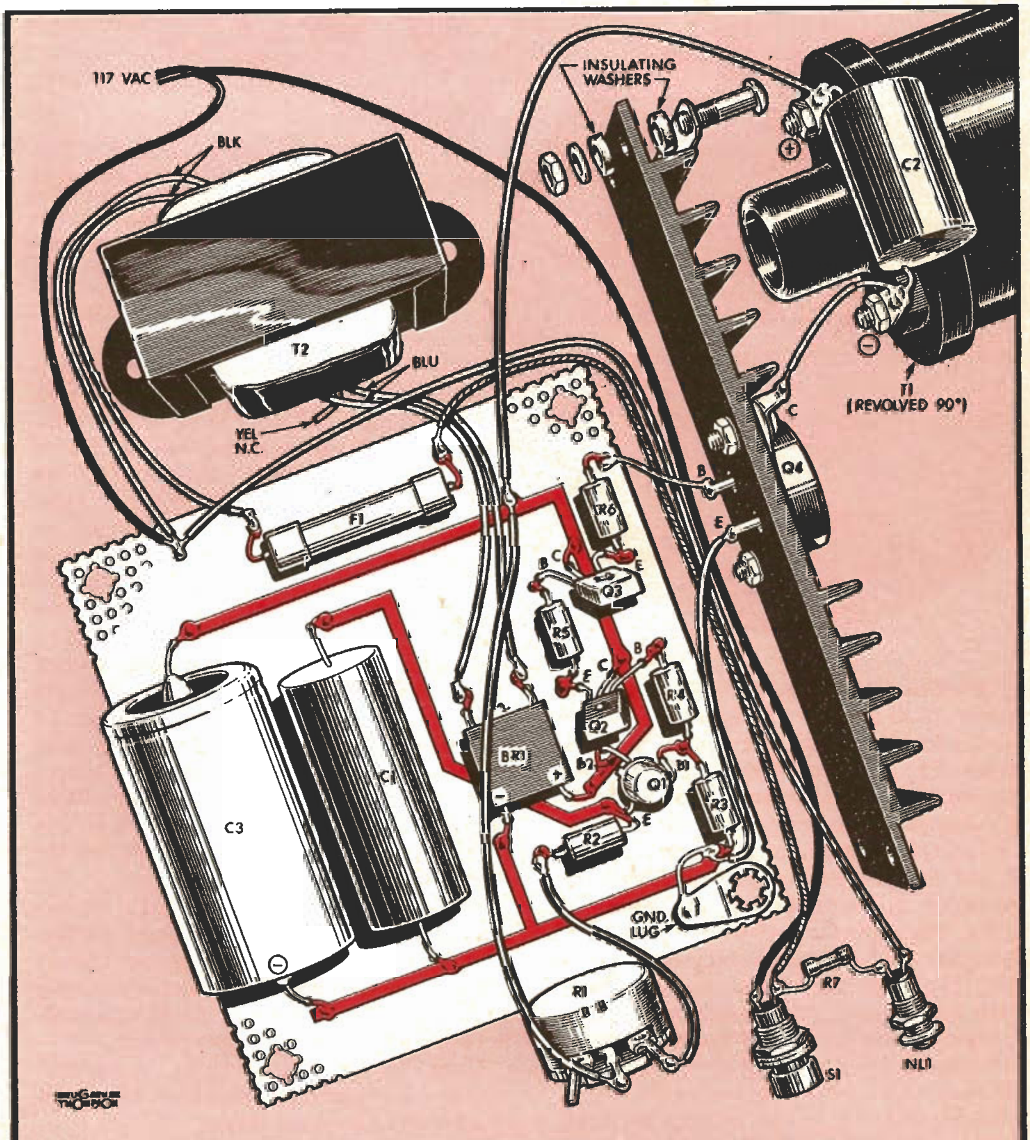
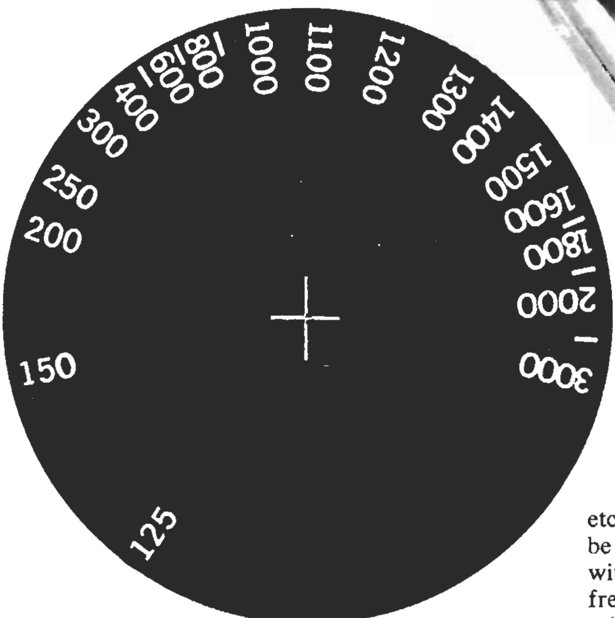


Fig. 1—For clarity, autotransformer T1 was revolved 90° to show its terminal post wiring detail. Heatsink holding Q4 must be electrically insulated from chassis as seen below in pictorial.



Low-Cost Speed Indicator

Fig. 2—Cement dial to piece of plastic. Mount dial to R1 with its shaft in maximum CW position so that 125 RPM reading is at vertical, or 12 o'clock, setting.



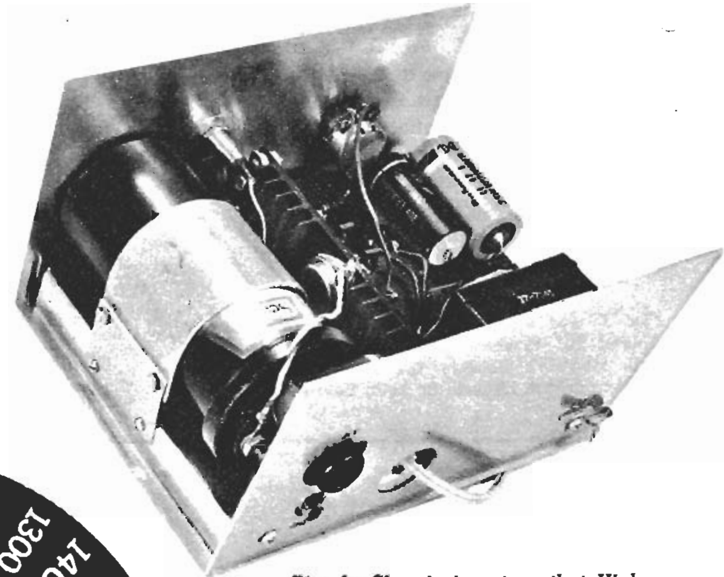


Fig. 3—Chassis is cut so that High Voltage tower of T1 protrudes slightly. Below T1 is ground terminal. Note aluminum strap clamping T1 with masonite holding strap to chassis.

ing process. The output of Q3 is fed via resistor R6 to the base of transistor Q4. This semiconductor couples the signal to transformer T1. The secondary winding of T1 steps up the induced waveform to a voltage high enough to fire timing lamp NL2.

When Q1 conducts, it discharges capacitor C1 and the process is repeated. The firing rate of Q1 is determined by the setting of pot R1. The lower the pot's overall resistance, the higher the output frequency of the sawtooth. The neon lamp flashes at a frequency which equals the highest speed measured by the indicator. As the potentiometer resistance is increased, the frequency of the sawtooth decreases, slowing the flash rate of NL2.

Transformer T2, bridge rectifier BR1 and electrolytic capacitor C3 form the indicator's power supply. About 12 VDC is supplied to Q1-Q4.

Building the Speed Indicator. The circuit is housed in a 6 x 8 x 4½-in. aluminum cabinet. Most of the components are mounted on a 3⅜-in. square perfboard. Connections are made with pressure-sensitive, pre-etched copper patterns. Components also can be mounted with push-in clips and connected with wire. Since the circuit operates at low frequencies, component placement is not critical.

Two of the components, autotransformer T1 and neon timing light NL2, can be bought at automotive-parts stores. Transformer T1 is a standard ignition coil for any auto using an *external* ignition ballast resistor. Component NL2 is a neon automotive timing light. If you buy a timing light with a remote starting switch, disregard this switch. See the Parts List.

Start construction by cutting out a 3⅜-in.-square piece of perfboard. Mount components to the adhesive-backed copper pattern as shown in our pictorial. Wires leading away from the perfboard are terminated with push-in clips soldered to the copper pattern.

Once perfboard wiring is completed, mount it to a corner of the chassis. Use ½-in. spacers at each board corner.

Fasten Q4 to the heatsink and mount the

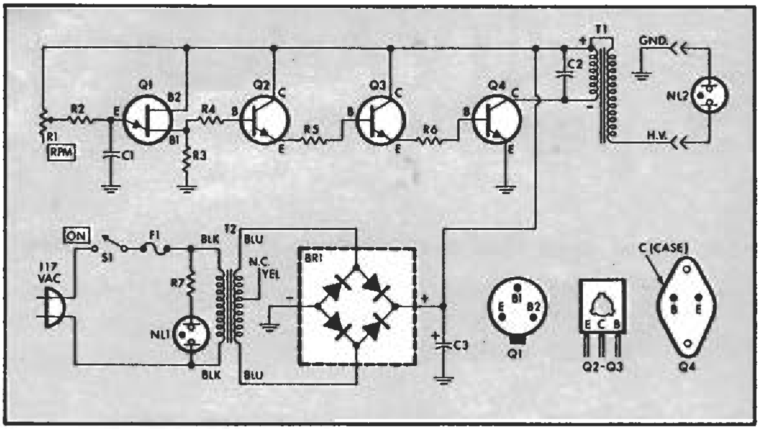


Fig. 4—For proper operation of neon timing lamp NL2, wire autotransformer T1 polarity as shown in schematic. If on/off indicator lamp has built-in current-limiting resistor, omit R7.

PARTS LIST

C1—1 μf, 25V capacitor
C2—0.5 μf, 100V capacitor
C3—2200 μf, 25V electrolytic capacitor
BR1—Bridge rectifier; minimum ratings: 50 PIV @ 1.5A (International Rectifier 18DB6A-6 or equiv.)
F1—1.5A fuse
NL1—Neon pilot lamp assembly (includes R7)
NL2—Automotive timing lamp (Sears, Roebuck & Co. 28AR2159 or equiv.)
Q1—Unijunction transistor (Motorola HEP-310)
Q2, Q3—Npn transistor (Motorola HEP-245)
Q3—Npn transistor (Motorola HEP-247)
Resistors: ½-watt, 10% unless otherwise noted
R1—500,000 ohms, audio-taper pot. (Calectro B1-688 or equiv.)
R2—10,000 ohms
R3—1,000 ohms
R4, R5, R6—47 ohms
S1—SPST switch (Calectro 34-098 or equiv.)
T1—12V automotive ignition coil, external resistor type (Sears, Roebuck & Co. 28AR8245 or equiv.)
T2—Power transformer; secondary: 12.6V @ 1.5A (Triad F-25X or equiv.)
1—Heatsink (International Rectifier IR132-C or equiv.)
Misc.—6 x 8 x 4½-in. aluminum cabinet (LMB CB-2), perforated board, ½-in. aluminum spacers, AC line cord, sheet aluminum for bracket, adhesive-backed, copper circuit patterns.

heatsink with insulating washers and angle brackets to the chassis. The heatsink must be electrically insulated from chassis and bracket. Both angle brackets are cut from sheet aluminum to 5/16-in. wide by 1¾-in. high. The bracket foot is about ½-in. long.

Autotransformer T1 is mounted to the chassis with a J-shaped sheet aluminum section wrapped around T1. A piece of Masonite is slipped between T1 and the chassis, allowing the lip of the ignition coil to clear the chassis. T1's high-voltage terminal protrudes out of a hole cut in the rear of chassis. Position T1 on the chassis as shown in the photo.

Mount T2 to the chassis with No. 6 hardware. Finally, install NL1, S1 and pot R1 on the front panel. Interconnect all switch components. Remember to keep the leads away from the heatsink. A bent ignition wire terminal serves as the chassis ground connection for NL2 but a large fahnestock clip works as well.

Calibrating the Speed Indicator. Connect one lead of the neon timing lamp to T1's HV terminal. The remaining lead is attached to the chassis. If an external ground is handy, run a separate ground lead to the chassis. This minimizes any chance of an electrical shock hazard, especially if your shop floor is damp. Remember, do not touch the ignition coil HV terminal while it's operating.

Plug in the AC line cord and turn S1 on. Rotate R1 from minimum to maximum resistance setting and check the timing-lamp flashes. The frequency of the flashes should have a long dwell period at R1's maximum setting. As R1 is rotated toward minimum resistance, the flashes should increase.

The pot's dial can be accurately calibrated after it is mounted. Connect a triggered time base oscilloscope to the collector of Q4 and directly measure off pulse frequency.

Or, place a silicon photo cell connected to a scope in front of the neon timing lamp. This method was used to calibrate our indicator.

Measure the pulse rate per second (frequency) with the scope. Then multiply this reading by 60 to obtain rpm. For example,

[Continued on page 101]

Low-Cost Speed Indicator

Continued from page 79

if you read 10 pulses per second on the scope multiply by 60 for a 600-rpm reading.

The speed indicator can be calibrated against an automotive tachometer by aiming NL2 at an engine flywheel timing mark.

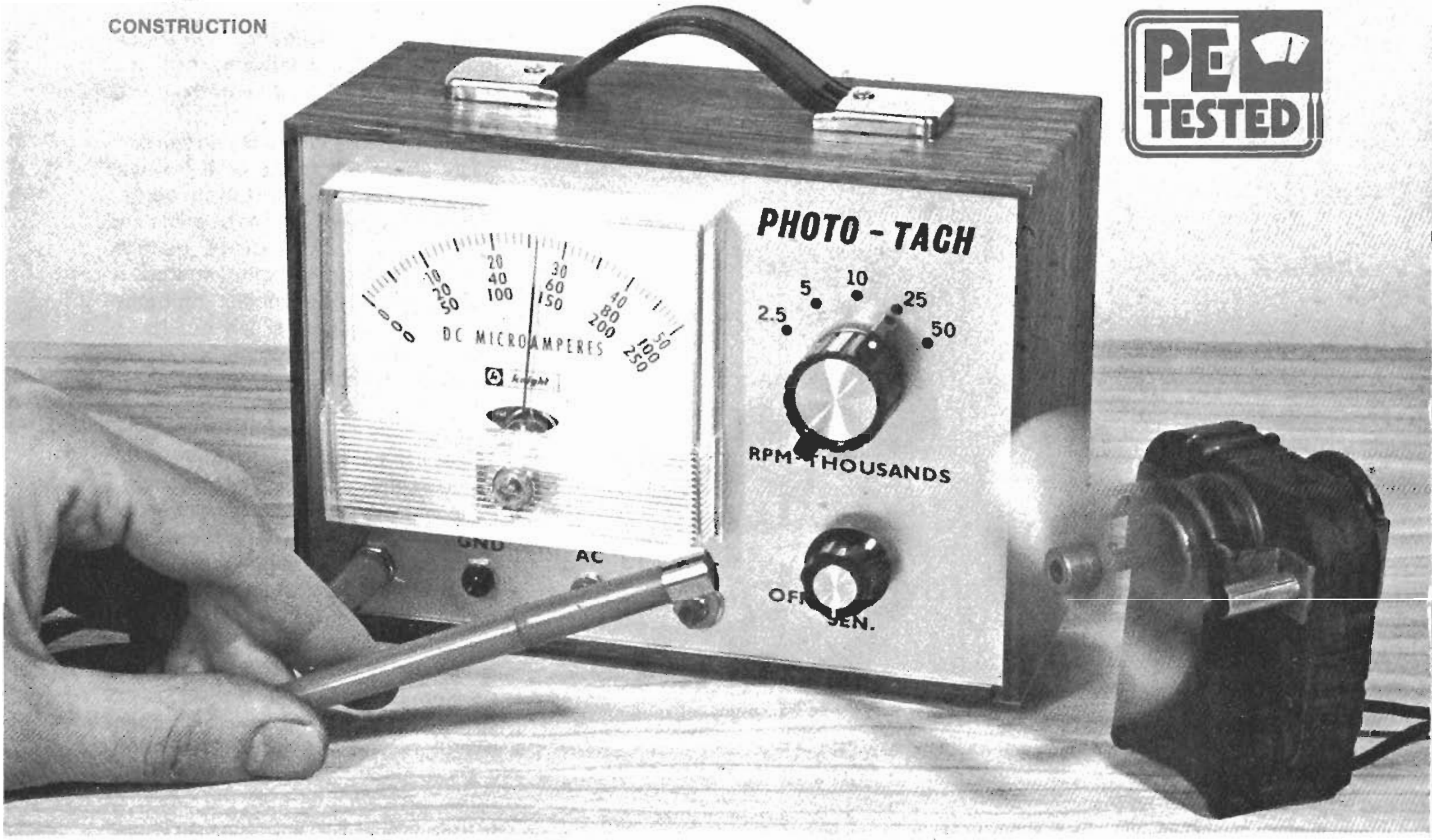
Close calibration can be made by tracing the dial on a piece of cardboard. Our dial is 3⅛-in. in diameter and is cut from a sheet of plastic. Position the dial so that the 125-rpm marking coincides with the dial index when the pot is rotated to maximum resistance point.

Operating the Indicator. If the speed of the object and the light pulse repetition rate are matched exactly, a mark on the object will appear as a stationary reference mark.

The single-image stroboscopic effect will also occur when NL2's pulse frequency is a sub-multiple (half, third, quarter, etc.) of the rotating object. Multiple images occur when the light pulse frequency is a multiple of the rotating object frequency. Reason is, the rotating object is illuminated more than once each cycle.

To measure the rpm of a rotating object, set the dial to the 3,000-rpm mark. The rotating object should be marked with chalk, a pasted-on marked paper tab or engraved line. Lower the dial slowly until the first single image appears.

The Ham Shack



MEASURE RPM OF ROTATING ELEMENTS WITH

THE IC PHOTO TACHOMETER

Battery-operated device gives accurate readings up to 50,000 rpm without physical contact.

BY ADOLPH A. MANGIERI

IF YOU service the numerous motor-driven appliances and tools found in the home, shop, or factory, consider building this photo tachometer. By recording normal rotational speeds for comparision with later measurements, you can easily detect the effect of worn gear trains or motor brushes and gauge improvement of performance after repairs. With no mechanical coupling required, the Photo-Tach measures the rpm of any type of rotating element, including miniature high-speed, low-power motors. You can also use the Photo-Tach as an analog frequency meter, useful for checking inverters and auxiliary ac generators.

Operated in either the incident or reflected light mode, the Photo-Tach includes five ranges up to 50,000 rpm. A plug-in light probe, using a high-speed photo-transistor, facilitates speed measurements. Using low-cost, high-performance IC's, the battery-operated tachometer features high accuracy and stability. The schematic diagram is shown in Fig. 1.

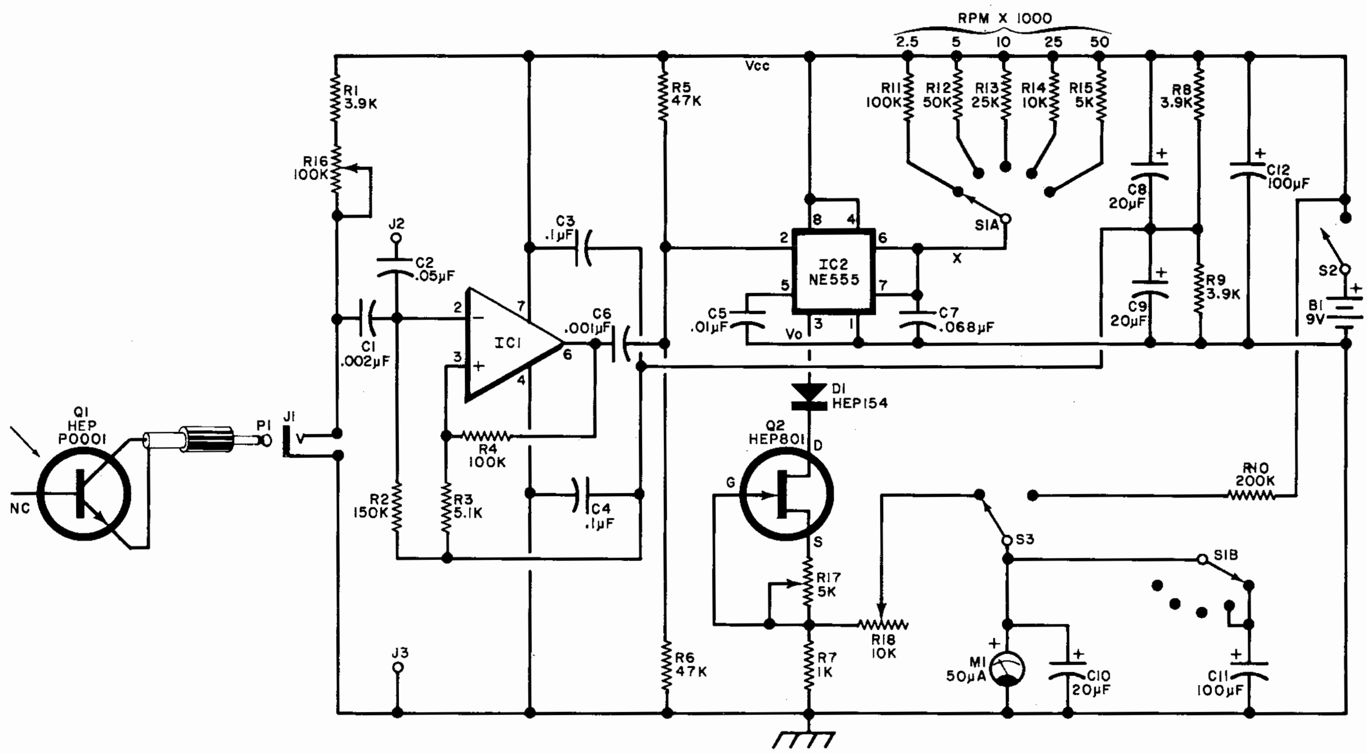
How It Works. Light pulses striking photo-transistor *Q1* produce voltage pulses at the input of operational amplifier *IC1*, connected as a Schmitt trigger which produces a sharply squared output pulse for each input pulse. Resistors *R3* and *R4* provide positive feedback and also determine the input voltage hysteresis or deadband. This prevents the tach from responding to noise components of the main signal and rejects the small 120-Hz modulation of 60-Hz incandescent light sources. Input high-pass filter, *C1*-*R2*, favors response to fast-changing light signals.

Output pulses from *IC1* are differentiated by *C6*-*R6* forming voltage spikes which are applied to the trigger input terminal (2) of timer *IC2*, connected as a monostable. When a negative-going trigger pulse drives pin 2 below one-third V_{cc}, the timer delivers a precise output pulse V_0 at pin 3. Output pulse duration, independent of supply voltage, depends on timing capacitor *C7* and a timing resistor selected by range switch *S1*. Output pulses V_0 pass through diode *D1* and energize FET constant-current source *Q2-R17*, producing constant-amplitude pulses across *R7*. Diode *D1* blocks the small residual voltage when V_0 is low. Constant-duration pulses of constant amplitude are averaged by meter *M1* which responds linearly to the repetition rate of input light pulses.

Potentiometer *R16* adjusts the input sensitivity while capacitor *C11* dampens meter pointer vibration at low (2500) rpm. With a pulse duty cycle of near one-third at full scale, meter overrange is within safe limits.

Construction. Assemble the PhotoTach in a 3″×4½″×6½″ metal case. In the prototype, perf board construction was used but you can make a printed circuit board using the foil pattern shown in Fig. 2. Use sockets for *IC1*, *IC2*, and *Q2*, and use short, heavy buses on the circuit board as common tie points to avoid ground loops. Install bypass capacitors *C3* and *C4* close to their *IC1* pins. Wire *R16* so that its resistance is zero with the control set counterclockwise. Voltage-range multipler resistor *R10* is, preferably 1% tolerance.

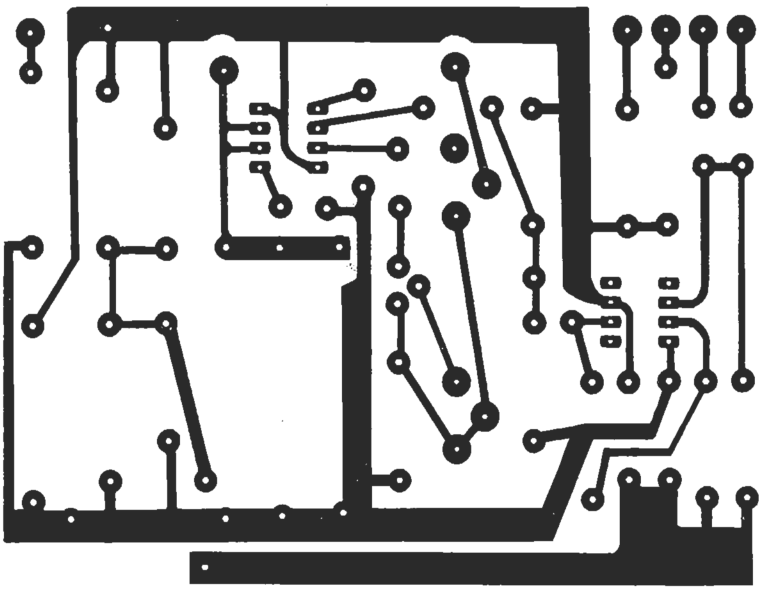
Connect the supply minus to case (ground). Tape over any unused pins of the IC sockets and carefuly observe correct installation of the IC's. Remove the meter dial card and mark the additional scales using dry transfers (see photograph). Otherwise, mark rpm range switch *S1* with multipliers



PARTS LIST

B1—9-volt battery (Burgess 2U6 or equiv.)
C1—0.002-µF 10% ceramic disc capacitor
C2—0.05-µF ceramic disc capacitor
C3, C4—0.1-µF ceramic disc capacitor
C5—0.01-µF ceramic disc capacitor
C6—0.001-µF 10% ceramic disc capacitor
C7—0.068-µF 10% Mylar capacitor
C8, C9, C10—20-µF 15-V electrolytic capacitor
C11, C12—100-µF, 15-V electrolytic capacitor
D1—Silicon diode (HEP 154 or equiv.)
IC1—Operational amplifier (HEP C6052P or 741C)
IC2—555 timer IC
J1—Miniature phone jack
J2, J3—Phone tip jack (one red, one black)
M1—0-50-microampere dc meter
P1—Miniature phone plug
Q1—Photo transistor (HEP P0001, HEP 312, or equiv.)
Q2—N-channel JFET (HEP 801 or equiv.)
R1, R8, R9—3900-ohm, ½-watt 5% resistor
R2—150,000-ohm, ½-watt 10% resistor
R3—5100-ohm, ½-watt 10% resistor
R4—100,000-ohm, ½-watt 10% resistor
R5, R6—47,000-ohm, ½-watt 5% resistor
R7—1000-ohm, ½-watt 5% resistor
R10—200,000-ohm, ½-watt 1% resistor
R11—100,000-ohm resistor
R12—50,000-ohm resistor
R13—25,000-ohm resistor
R14—10,000-ohm resistor
R15—5000-ohm resistor
(R11–R15: 5% or better)
R16—100,000-ohm audio taper potentiometer, with spst switch S2. (Radio Shack 271-1727 or equiv.)
R17—5000-ohm trimmer (Radio Shack 271-217)
R18—10,000-ohm trimmer (Radio Shack 271-218)
S1—Dp, 5-pos. shorting switch (Centralab PA-1002 or equiv.)
S2—Spst switch (on R16)
S3—Sp, 2-circuit momentary pushbutton switch
Misc.:—Transistor socket; DIP sockets (2); metal case 4½″×6½″×3″ (Vector W30-66-46B or equiv.); P-pattern perforated board; knobs (2); battery clip; miniature shielded cable; flea clips (Vector T42-1 or equiv.) hardware; etc.
Note: If you choose to use a printed circuit board, an etched, undrilled board (# Phototach 874) is available for $3.95, postpaid, from Techniques Inc., 235 Jackson St., Englewood, NJ 07631. New Jersey residents please add 5% sales tax.

Fig. 1. The light pulses at Q1 are squared up in IC1 and turn on precision monostable IC2. Constant-current output pulses through Q2 are averaged by the meter as rpm. Five ranges permit testing up to 50,000 rpm.



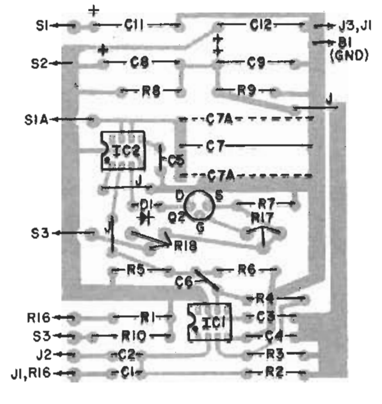


Fig. 2. Though the prototype of the tachometer was assembled on perforated board, it is convenient to use a printed circuit board. C7A is two 0.033 capacitors if this is preferred to one 0.068. (See Parts List to order board.)

of the 0-50 scale. Do not connect a meter protector across *M1*.

Mount the meter, range switch *S1*, sensitivity control *R16*, battery test switch *S3*, probe input jack *J1*, ac input connector *J2*, and the ground connector *J3* on the front panel as shown in the photographs.

For photo-transistor *Q1*, use either a glass lens (HEP P0001) or plastic lens (HEP 312). Clip off or insulate the unused base lead of the P0001 transistor. Connect the outer braid of a three- to four-foot length of miniature shielded cable to the emitter of *Q1* and center conductor to collector. Make sure the braid is connected to the grounding side of the P1-J1 combination. Install *Q1* within an opaque plastic tube, such as the barrel of a ballpoint pen. Position the lens about one-quarter inch from the tip of the probe. Install battery *B1* on the back plate of the cabinet.

Calibration and Checkout. Set *R17* and *R18* to mid-position and *S1* to 2500 rpm, then connect a dc voltmeter across *R7*. This test voltmeter input resistance should be at least 50,000 ohms on the selected voltage range. Disconnect wire "X" from the rotor of switch *S1A*. Operate sensitivity control *R16* to close *S2*. If *M1* is not pegged upscale, short *R6* momentarily, causing V_0 to go high. Adjust *R17* until the voltmeter indicates one volt. Remove the voltmeter, open *S2*, and reconnect wire "X" to *S1A*.

Breadboard the calibration circuit shown in Fig. 3, which supplies a 120-Hz signal (equivalent to 7200 rpm) and connect to jacks *J2* and *J3*. Set *S1* to 10,000 rpm, close *S2* and adjust *R18* until *M1* indicates 7200 rpm. With accurate range resistors, all ranges are simultaneously calibrated to high accuracy. You can use a signal generator to calibrate, check, or trim rpm ranges provided frequencies can be set to high accuracy, as with a frequency counter. Multiply frequency by sixty to obtain equivalent rpm.

Next, check rejection of the small 120-Hz modulation of incandescent light sources. Insert the probe in *J1* and aim the probe at a 50- or 75-watt lamp at distances of two inches to three feet while varying *R16* (sensitivity control) over its range. If *M1* does not remain at zero under all conditions, increase input hysteresis by increasing *R3* to 8200 or 12,000 ohms. If further remedy is required (not likely), reduce *R2* to 100,000 or 82,000 ohms and/or reduce *C1* to 0.001 µF.

Connect a 1500-ohm potentiometer (set for minimum resistance) in series with the plus lead of *B1*. Connect the calibrating signal to *J2* and *J3*. Increase the potentiometer resistance until *M1* drops to 7100 rpm or about 1% lower. Depress pushbutton switch *S3* and observe battery end-point voltage on *M1*, read as 0-10 volts dc. End-point voltage should be near 6.6 volts or less. If the voltage is above 7 volts, use a 12-volt battery for *B1* (made up of eight AA cells connected in series). The additional supply voltage accommodates a FET (*Q2*) having a pinch-off voltage above 3 volts.

Applications. In the incident-light mode of operation, the rotating element whose rpm is to be checked chops or gates the light traveling directly from a light source to the probe. This provides a noise-free, large-signal input to the tach. A reflectorized handy light with a 50- to 100-watt lamp proved a most convenient light source but you can use a desk lamp, drop cord, or a flashlight.

Position the light source about two feet behind the blades of an operating electric fan. Hold the probe near the front of the fan, aimed at the lamp. Advance *R16* until *M1* shows a steady and maximum indication. Observe that *R16* can be varied over much of its range while *M1* remains steady. For a fan with four blades, divide indicated rpm by four, etc.

To check the speed of a drill, construct a light chopper using a three-

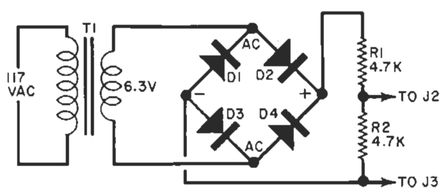
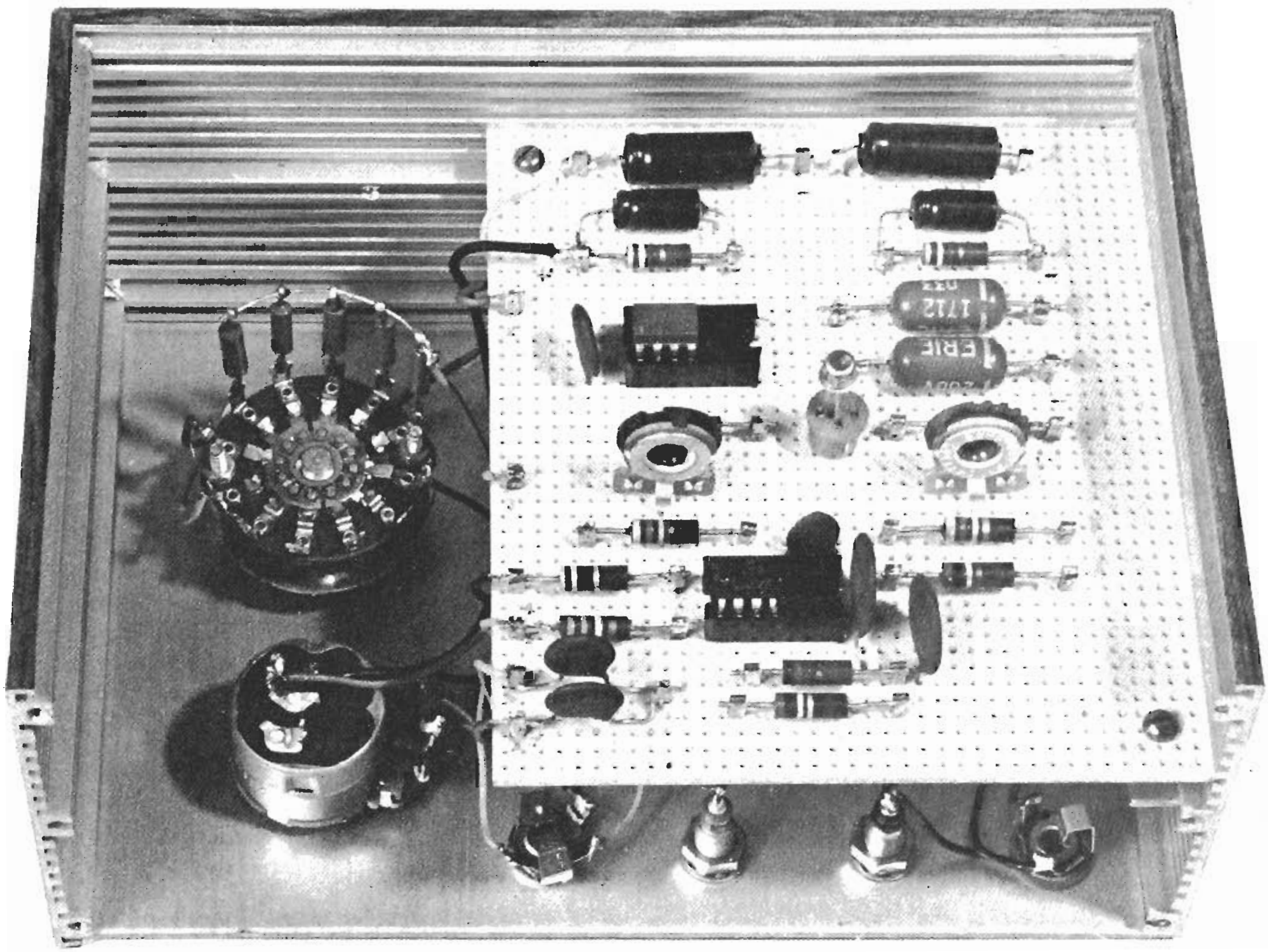


Fig. 3. Calibration circuit delivers a 120-Hz signal equivalent to 7200 rpm. Multiply frequency by 60 to obtain the equivalent speed.



Photograph of prototype, assembled using a perforated board, shows how parts were assembled in chassis. The arrangement of the front panel is shown in the title photo.

inch diameter cardboard disc. Cut out a ¾"×¾" light gate at the edge and chuck the disc in the drill using a machine screw. To check motors having various shaft sizes, attach a light chopper disc to a suitable wheel, shaft collar, or knob. The spokes of a large pulley can serve as a light chopper.

In the reflected-light mode, the sensor views light reflected from contrasting surfaces. If surface reflectivity is excessively uneven due to rust spots, discolorations, or other irregularities, a reflected-light pulse may contain excessive noise. This will be recognized as a very high and erratic indication on the meter. Involving two directions of light travel, the reflected-light mode may require rigging of probe or light source, or both, to maintain steady indications.

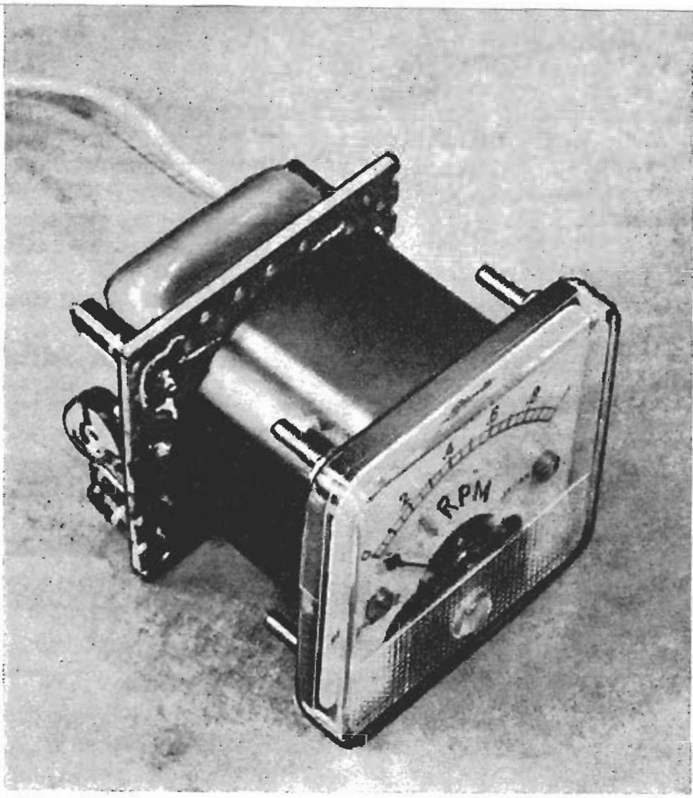
To check the speed of a motor having a half-inch shaft or larger, wrap a strip of electrician's tape (cloth friction type, not glossy surface vinyl) around the shaft. Place the band on a shaft flat if possible. Place a strip of white surgical adhesive tape lengthwise across the band. Or, paint a white strip using fast-dry flat paint. Rig the probe horizontally about one inch from the shaft facing the band.

For the flatted shaft with white strip on the flat, hold the light source directly above the shaft at a distance of about 8 to 12 inches. For the round shaft, hold the lamp about 6 inches above the end of the probe handle. Advance *R16* and verify that the meter indication remains steady over some portion of pot rotation, proving adequate light input. For motors having smaller shafts, attach a reflective disc to a suitable wheel or knob. Paint half of the disc flat black and the balance flat white. Fan speed can be checked by this method provided the fan blades are clean and uniform in appearance. By sighting the running fan from several angles, you can pick a suitable direction to aim the probe. Particularly with very small fans, a slightly twisted blade can result in a missed light pulse.

Meter-pointer vibration becomes apparent below 400 rpm. In this case, include a second light gate or reflective surface and divide indicated rpm by two, etc. Position additional light gates or reflective surfaces in an approximately symmetrical pattern.

Keep tabs on the normal running speeds of appliances and tools for later comparisons. Use speed measurements to isolate problems between motor and drive train and observe effect of repairs. Speed measurements on major heavy-duty appliances such as washers and dryers can forewarn you of progressive wear which may lead to motor overload and possible fire hazards.

The tachometer can be used as a low-range frequency meter to check frequencies from about 10 to 800 Hz. Inject one or two volts ac into jacks *J2* and *J3* and divide indicated rpm by 60. Also, by connecting *J2* and *J3* to a scope, you can observe input to the tach as you vary lighting and sensitivity settings. ◈



BUILD $6 ELECTRONIC TACHOMETER

TRANSISTORIZED CIRCUITRY KEEPS WATCH ON YOUR ENGINE SPEED FOR BETTER GAS MILEAGE, MAXIMUM EFFICIENCY, AND SMOOTHER PERFORMANCE

By RICHARD E. STAERZL

IF YOU DRIVE a manual shift auto, at what engine speeds—rather than road speeds—should you shift gear for top fuel economy with maximum horsepower and torque? At 65, 100, or 1800 r/min? The answer lies in the horsepower rating, number of cylinders, engine cycle, and other factors related to engine design.

Car makers' manuals usually contain information on specific engine r/min from idling speed through full acceleration, and specify when to shift gears, or when maximum torque is reached. However, if your car is not equipped with a tachometer, this information will be of little value to you.

For under six bucks you can build and install an accurate transistorized tachometer that can be used with any 4-, 6-, or 8-cylinder, 2- or 4-cycle engine having either a standard or transistorized negative-ground ignition system. This tach will tell you what your idling speed should be, when to up-shift for best acceleration and maximum efficiency, and when to down-shift to avoid engine lugging.

How It Works. The tachometer circuit (Fig. 1) is nothing more than a simple monostable multivibrator (*Q1* and *Q2*) triggered by a shaped positive-going rectangular pulse produced by the opening and closing of the auto's ignition points. Pulse shaping is accomplished by the *C2-R6* combination.

The average current in *Q1*'s collector is monitored by a 0-1 mA full-scale meter. Since the collector current will be directly proportional to the trigger frequency, determined by the engine r/min, the meter can be calibrated in terms of r/min. The accuracy of the reading is determined essentially by the accuracy of the meter used. The economy meter shown is accurate within ±2% of full scale.

Construction. A convenient layout for the tachometer is given in Fig. 2. The parts are laid out on a 1½" x 1½" perforated phenolic board, and the circuit

PARTS LIST

C1, C2—0.1-µF, 200-volt capacitor
M1—0-1 mA d.c. milliammeter—see text
Q1, Q2—2N414 transistor
R1, R2—2200-ohm, ½-watt resistor
R3—1000-ohm printed-circuit miniature potentiometer
R4—6800-ohm, ½-watt resistor
R5, R6—1000-ohm, ½-watt resistor
R7—120-ohm, ½-watt resistor
Misc.—Transistor sockets, phenolic circuit board, wire, solder, enclosure (optional)

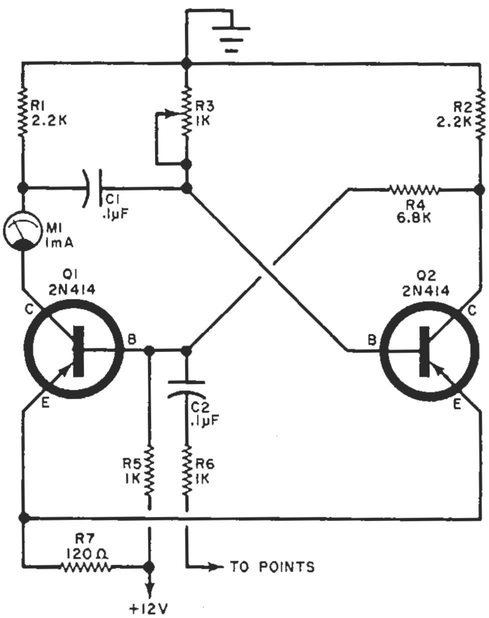


Fig. 1. This tachometer features the naked simplicity of a monostable multivibrator being triggered by the pulses generated by the ignition points.

board is then mounted on the back of a d.c. milliammeter. Although an inexpensive 0-1 mA d.c. meter was selected to keep the cost low, a 3½"- or 4½"-wide view panel meter is preferable.

The entire unit can be housed in a plastic or metal case for use as a portable test instrument, or the meter case can

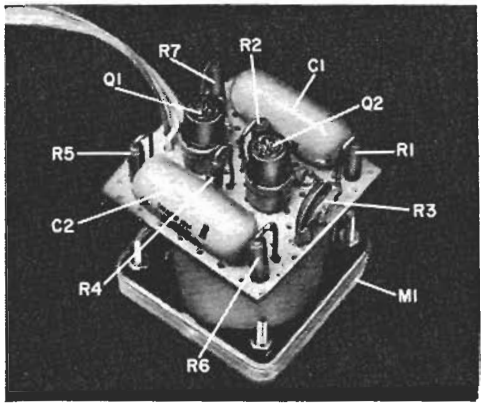


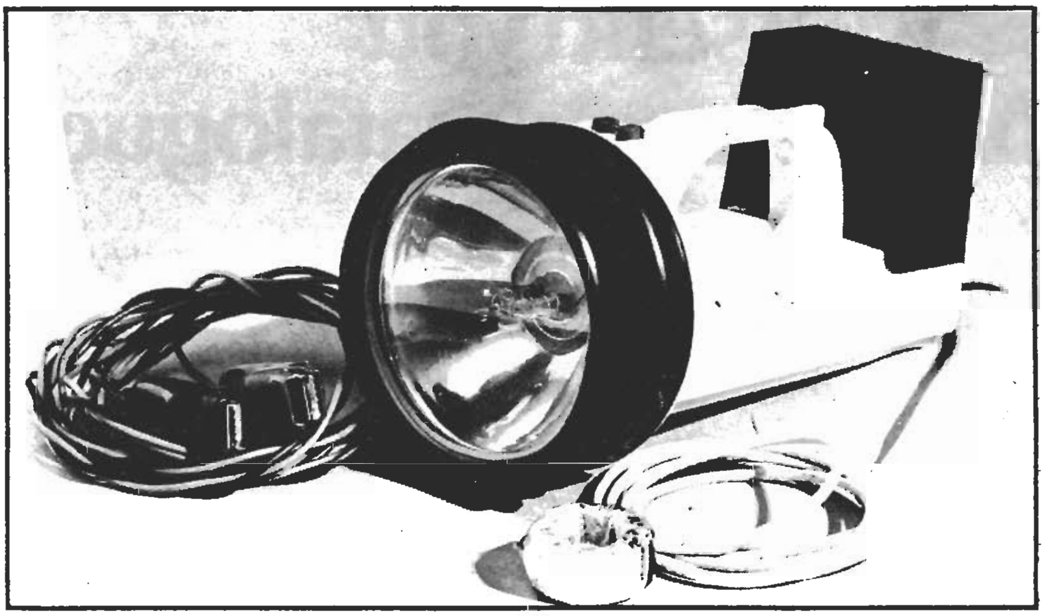
Fig. 2. The electronic circuitry is first put together on a suitable sized circuit board, and the assembly is mounted on the back of the meter case. You could also house the circuit board separately.

be mounted separately on the dash while the electronic circuitry can be housed and stored in the glove compartment, or fastened under the dash.

Calibration. The easiest way to calibrate your tachometer is with another tachometer. Connect both tachs in parallel and rev the engine up to 1000 r/min. Then adjust *R3* for a reading of 0.1 mA on the meter being calibrated. With this adjustment, the meter is calibrated so that each 0.1 mA increment on the dial represents 1000 r/min. If you wish, you can also calibrate the meter directly in r/min.

Another method of calibration is to use a high-output square-wave generator as a signal source. Set the generator frequency to 33 hertz for a 4-cylinder car, to 50 hertz for a 6-cylinder car, or to 67 hertz for an 8-cylinder car, and adjust the generator to any output from 6 to 24 volts peak-to-peak. Now adjust potentiometer *R3* until you get a reading of 0.1 mA on the meter. With this adjustment, your tach is calibrated for 1000 r/min per 0.1 mA. —30—

TACHO TIMING LIGHT



Extended circuitry allows timing check over full speed range.

This instrument incorporates a calibrated delay which gives a meter indication of the exact advance of the ignition in degrees — at any engine speed. It has a built-in tachometer so a serious enthusiast could check the complete distributor advance curve.

The use of such an instrument will allow checks on the correct operation of the distributor particularly with respect to mechanical and vacuum advance with increasing RPM.

CONSTRUCTION

The layout and construction of the timing light will vary depending on the housing.

We purchased a cheap torch which takes four HP2 batteries.

Our layout and method of construction can be seen from the illustration but this can readily be varied to suit the housing used.

Most of the electronic components are mounted on a printed circuit board which can be assembled with the aid of the circuit diagram and the component overlay, Fig. 2. Check the polarity of diodes, capacitors and transistors etc before soldering. All external wiring to the PC board is numbered and interconnections from the PC board to external components should be made with the aid of the circuit diagram, note that C4 is mounted on the back of the meter and C12 on the rear of the reflector.

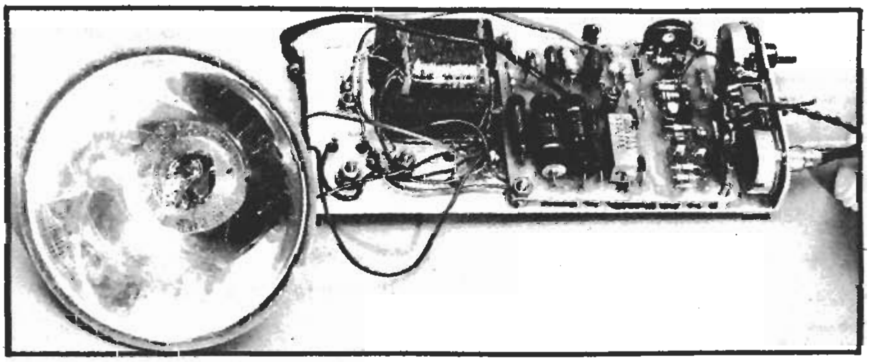
The inverter power transistors should be mounted on, but insulated from, a heatsink made from aluminium sheet of at least 40 square centimetres area.

If the unit will not oscillate, (you will hear a 2 kHz whistle when it is oscillating) try reversing the feedback winding.

The secondary voltage is around 350 volts and care should therefore be taken to insert insulation as specified in Table 1, between the primary and secondary windings in the transformer, and to keep the windings separate on the matrix board.

The reflector of the torch may be modified to house the flash lamp in the following manner.

Remove the existing socket, using a pair of pliers or cutters, and file the



Assembly of the unit may be seen from this photograph.

WARNING

On some cars the fan blades rotate close to or at a multiple of the crankshaft speed. When strobed by the timing light, the fan may appear to be stationary or rotating slowly.

This is common to all strobe light timers and failure to remember this can result in serious personal injury, or a wrecked timing light.

ALWAYS — keep well clear of the fan, or remove the fan belt whilst timing the engine.

opening until it is large enough to accept the flash lamp with about one millimetre clearance all round. Insert the lamp from the front and use modelling clay at the rear of the reflector to hold the lamp and seal the opening. Then pour quick-dry epoxy cement into the reflector until there is sufficient around the base of the tube to secure it in place. Be careful not to get epoxy elsewhere on the reflector. When dry, remove the clay and use more epoxy to fill any recesses in the rear.

If and when the tube is to be replaced a hot soldering iron may be used to destroy the epoxy thus permitting removal.

The discharge capacitor C12 should be mounted on the rear of the flash-tube/reflector assembly as shown in the photograph.

The pick-up coil is wound on a toroidal ferrite core, as shown in the photograph, using screened audio cable as follows. Remove about 0.8 metres of the inner cable from its shield and wind 20 turns of this around the ferrite core. Then solder the end of the inner conductor to the screen thus creating a complete loop.

The coil should also be shielded to prevent the magnetic field around nearby spark-plugs (other than number one plug) from triggering the timing light. To do this we cut strips of aluminium foil about 10mm wide and sandwiched them between two layers of 12mm wide cellulose-tape to produce a continuous strip of insulated foil 1 metre long. A length of wire should be connected to one end so that the strip may be connected to the screen of the coaxial cable. The foil is wrapped around the coil, in a similar manner to the coax, except that the ends of the foil must not touch. Should the ends touch, a shorted turn would be created which would prevent the transducer from operating at all. The coil should be completely covered and will appear as shown in the photograph.

CALIBRATION

Two different methods may be used to calibrate the timing light. In method A, the preferred method, you will need an oscilloscope with a triggered and calibrated time base, and an accurate tacho. In method B you will have to prevail on the local garage to allow you to calibrate your unit against their accurate (?) unit.

Method A.

1. Connect the unit to the engine with the transducer over number 1 spark lead.
2. Switch the timing light to "tacho" mode.
3. Start the engine and adjust the sensitivity control to the minimum setting that allows the meter to move smoothly as engine revs are increased.
4. With the CRO monitor between the common line and the collector of Q4, the voltage should swing from zero to +9 volts and back to zero each time the number one plug fires.
5. Adjust RV2 such that the pulse width at Q4 collector is 1.67 milliseconds.
6. Remove the CRO leads and set the engine revs to 3000 with the aid of the accurate tachometer.
7. Adjust RV4 such that the meter reads 3000 RPM. This completes the calibration.

Method B.

1. Connect both your timing unit and the garage unit to the car.
2. Switch the unit to "timing" mode.
3. Start the engine and set the RPM to 3000.
5. Now using your own unit adjust the sensitivity control as in step 3 method A.
6. Adjust RV1 until the timing marks coincide.
7. Adjust RV4 such that the same reading is obtained on meter M1 as on the garage unit.
8. Switch to tacho and adjust RV2 to read 3000 RPM.

Note that the engine must be held at constant speed throughout this process.

USING THE UNIT

The workshop manual for most cars contains details of the timing changes with respect to engine RPM and vacuum. If an engine is to perform at maximum efficiency these characteristics need to be checked and corrective measures taken if out of tolerance.

To check mechanical advance:

1. Remove vacuum line to distributor.
2. Fit transducer over number 1 spark-plug lead.
3. Switch timing light to "TACHO"
4. Start engine and switch on timing light.
5. Adjust sensitivity such that meter indicates correct RPM over full range without undue jitter.
6. Set the idle speed as specified in manual.
7. Switch to TIMING and set "timing adjust" potentiometer until the flywheel mark corresponds with TDC mark on the crankcase. (If some other mark than TDC is used, simply add the number of degrees the mark is BTDC (before top dead centre) onto the meter reading). If this is less than 2° advance (minimum obtainable with delay) switch SW3 may be used to remove all delay.
8. Switch back to tacho and increase speed to next calibration point as detailed in the manual.
9. Whilst holding engine revs steady at this setting, switch back to "TIMING" and set "TIMING ADJUST" until the marks again coincide. The meter now indicates the number of degrees of advance. Note that engine revs must not change otherwise the reading will be in error.
10. Repeat 8 and 9 for all other specified calibration points.

To check vacuum advance:

The only points on vacuum advance that need checking are the maximum advance with vacuum and that a vacuum is held, ie no leaks in the distributor.

1. With the motor idling check the timing with the vacuum line disconnected.

2. Draw a vacuum in excess of the normal vacuum (sucking the line by mouth will be sufficiently effective) and check the timing advance against that specified in the manual.

3. Hold the vacuum in the line and check that the timing does not shift (due to leak in distributor vacuum mechanism).

If a more accurate check is required the above checks can be done in conjunction with a vacuum gauge.

SPECIFICATION

Energy per flash	0.2 joule
Maximum flash rate	>50/sec (6000 rpm)
Trigger method	current transformer on No 1 spark lead.
Input voltage	10-14 volts dc
Timing meter range	0-50°
Minimum delay	<4°/1000 rpm
0° is switchable	
Maximum delay	>40°/1000 rpm
50° maximum	
Tacho meter range	0-6000 rpm

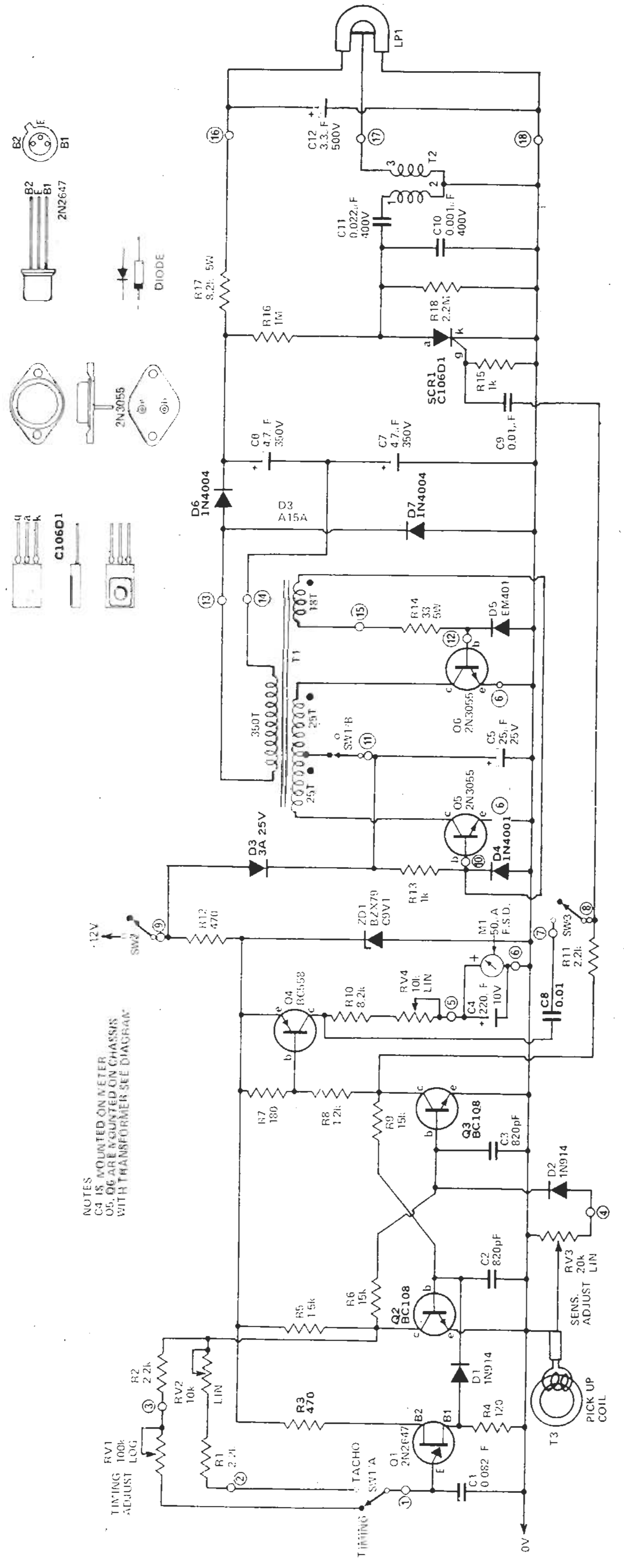
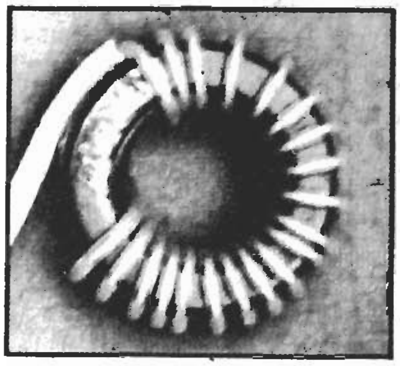


Fig. 1. Circuit diagram of the Tacho Timing Light.



This picture shows how the transducer is wound with the inner core of screened cable. Aluminium foil shielding is wound over the completed coil as detailed in the text.

PARTS LIST
TIMING LIGHT
ETI 311

R14	Resistor	33 5W	5%
R4	"	120 ¼W	"
R7	"	180 ¼W	"
R3	"	470 ¼W	"
R12	"	470 ½W	"
R13,15	"	1k ¼W	"
R8	"	1.2k ¼W	"
R5	"	1.5k ¼W	"
R1,2,11	"	2.2k ¼W	"
R10	"	8.2k ¼W	"
R17	"	8.2k 5W	"
R6,9	"	15k ¼W	"
R16	"	1M ¼W	"
R18	"	2.2M ¼W	"
RV1	Potentiometer	100k log rotary	
RV2,4	"	10k trim type VTU or similar	
RV3	"	20k lin rotary	
C2,3	Capacitor	820pF ceramic	
C10	"	0.001μF 400V polyester	
C11	"	0.022μF 400V polyester	
C8,9	"	0.01μF polyester	
C1	"	0.082μF polyester	
C12	"	3.3μF 500V electrolytic	
C6,7	"	4.7μF 350V electrolytic	
C5	"	25μF 25V electrolytic	
C4	"	220μF 10V electrolytic	
Q1	Transistor	2N2647	
Q2,3	"	BC108	
Q4	"	BC178	
Q5,6	"	2N3055	
SCR1	SCR	2N6240 C106D1	
D1,2	Diode	IN914 or equivalent	
D3	"	3A, 25V.	
D4,5	"	1N4001	
D6, 7	"	1N4004	
ZD1	Zener diode	BZX79C9V1 (9.1V 400mW)	
T1	Transformer	see text	
T2	Pulse Transformer	"	
T3	Pickup coil	"	
LP1	Flash tube	"	

PC board ETI-311
M1 meter 0.50μA FSD
SW1 Switch 2 pole 2 position.
SW2,3 switch single pole on-off.
(There were already incorporated in the torch housing used in our prototype)
reflector, heatsink, housing for electronics.

HOW IT WORKS ETI 311

The flash tube used requires a supply of 300 to 400 volts. This is obtained by stepping up the vehicle 12 volts supply by means of an inverter.

Transformer T1, together with transistors Q5 and Q6 form a self oscillatory inverter. The frequency of operation, about 2 kHz on a 12 volt supply, is primarily determined by the core materials, the number of primary turns and the supply voltage. Protection against reversed-polarity supply leads is provided by diode D3.

The output from the secondary of transformer T1 is voltage doubled by D6, D7, C6 and C7 to provide about 400 volts dc which is fed to the flash tube via R17. Capacitor C12, in parallel with the flash tube, charges to this voltage and thus stores the energy needed for the flash.

Capacitor C11 is also charged up via R16 and the energy stored in this capacitor is used to trigger the flash as follows. When the SCR is triggered by a pulse on its gate it conducts and rapidly discharges C11 through the primary of pulse transformer T2. The pulse of current through the primary of T2 induces a 4000 volt pulse in the secondary winding which fires the flash tube.

When C11 is fully discharged the current through R16 is not sufficient to hold the SCR on and it turns off. Thus the flash is fired at a time determined by timing of the trigger pulse to the SCR.

The pulse from number one spark-plug lead is picked up by transducer T3 and used to trigger a monostable consisting of Q1, 2 and 3. Each time a spark-plug pulse occurs Q3 turns on and Q2 turns off, and remains off for a predetermined time before resetting. Whilst Q2 is off C1 charges via RV1/R2 (or RV2/R1) and when the voltage across it reaches about 6 volts the unijunction transistor Q1 fires, discharging C1, producing a pulse which resets the monostable. By varying the setting of RV1 the time duration of the monostable pulse can be altered.

Transistor Q4 simply inverts the output pulse train from Q3 and drives the meter M1. When Q3 is on Q4 is on and its collector is at +9 volts, and when Q3 is off Q4 is off and its collector at zero volts. Thus capacitor C4 will charge to a voltage which is proportional to the average of the on/off ratio, and this voltage is read by the meter. Zener diode ZD1 stabilizes the supply to Q4 at 9.1 volts.

The output of Q3 (Q4 in the no delay mode) is used to trigger the SCR. Since the SCR requires a positive pulse to trigger it, it will fire when Q3 turns off, that is, at the end of the delay period produced by the monostable. Since the output of Q4 is "inverted", when this output is selected the SCR fires the instant Q3 turns on, that is without any delay.

In the timing mode the delay period is adjustable by means of RV1 so that the timing mark on the flywheel is aligned with that on the block. The meter M1 will then read the number of degrees of spark advance. In the tacho mode the inverter is disconnected to disable the strobe and a preset delay of 1.66 msec is selected. The meter now reads RPM with full scale of 5000 RPM.

The picture shows how the transducer is wound with the inner core of shielded cable. Aluminium foil shielding is wound over the completed coil as detailed in the text.

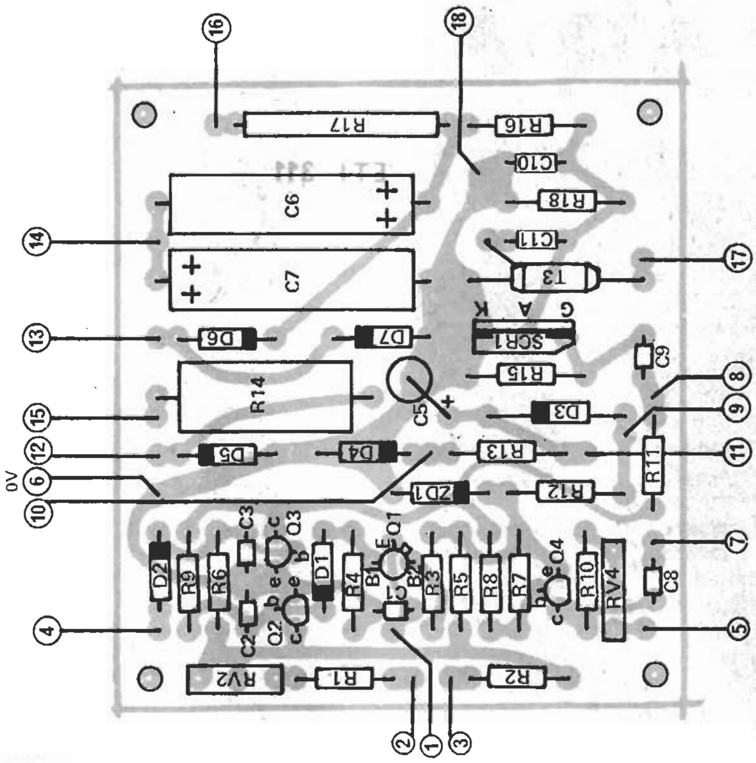


Fig. 2. Compont overlay for the Tacho Timing Light (this drawing has been placed sideways on the page to simplify checking against main circuit drawing).

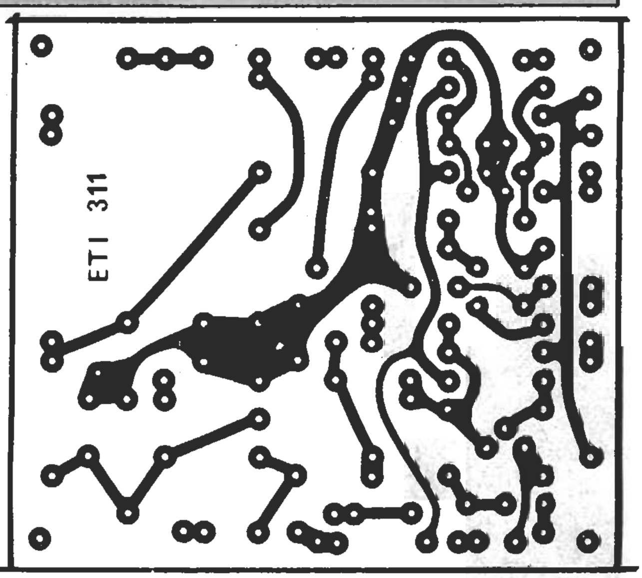


Fig. 3. Printed circuit board dimensions 74mm x 82mm (full size).

GETTING HOLD OF THE COMPONENTS

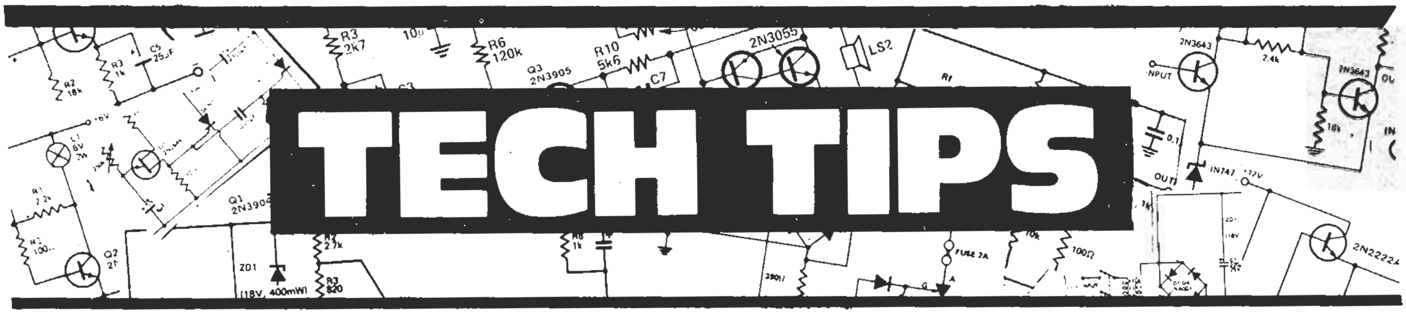
THE TRANSFORMER
This is available for £2.37 including VAT and postage from RCS, MCQ or Henry's. The RCS transformer will not fit the PCB mentioned below. Winding details were given in our September issue.

THE XENON FLASH TUBE AND TRIGGER TRANSFORMER
These can be bought from Music Craft, 367 Edgware Road, London W2. The ZFT-8B tube is slightly different from the one in our prototype, but the same mounting method will work.

THE PICK-UP COIL
This is made from a ferrite ring with an inside diameter of 1". The Mullard FX1588 will do. Further details are given in the text.

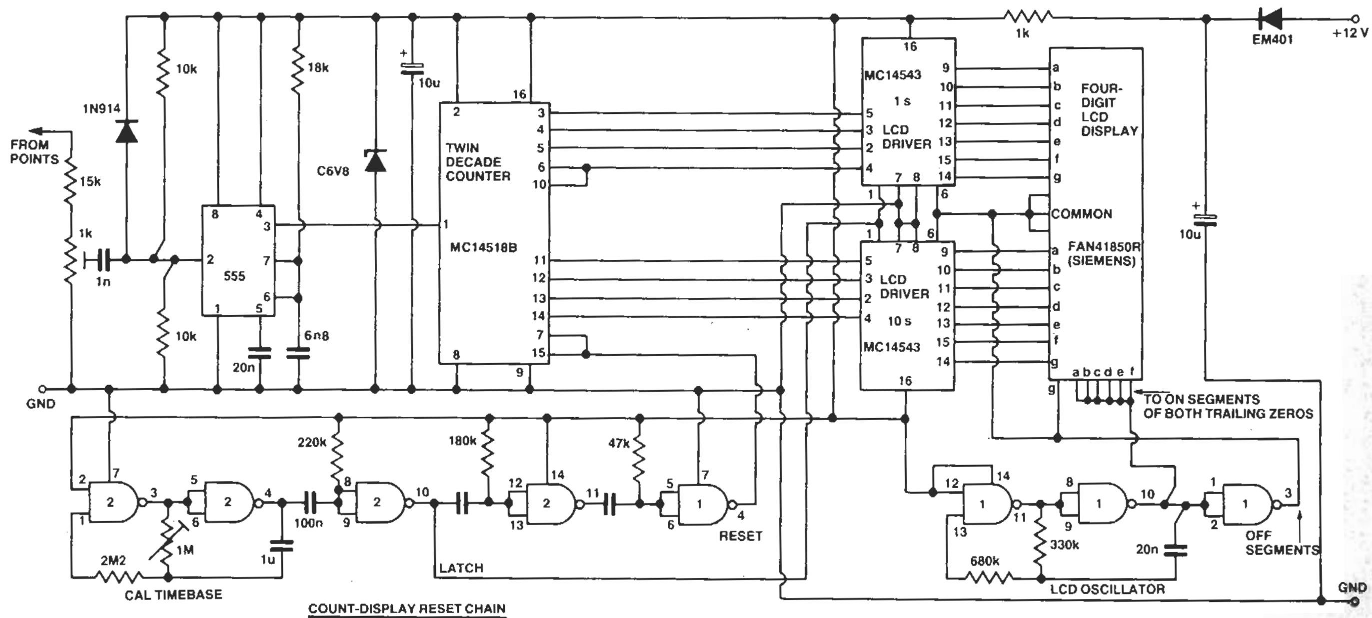
THE PCB
PCB's are available for this project or the simpler version for £1.25 plus 15p P & P, from MCQ. However these are suitable only for the transformers from MCQ or Henry's.

RCS Products Ltd, 31 Oliver Road, London E.17.
Music Craft, 367 Edgware Road, London W.2



LCD tacho

L.W. Brown



This rev counter circuit was built as an automotive tacho and has functioned for several years.

The tacho consumes very little power because of the use of CMOS ICs and a liquid crystal display. At night a dash lamp is necessary for viewing, and the type of display I used does not function in extreme heat, nor did it work completely on frosty mornings, so it may be preferred to use a display with a wider temperature specification.

I used a display featuring a single edge connector, and the pc board was built the same size as this display-plus-edge connector. A very compact module of approximately 77 x 44 x 24 mm was constructed by mounting the pc board behind the display.

The circuit uses a conventional 555 type tacho stage, driving two decade counters. Each decade counter drives a latch decoder driver and then the display. A 60 Hz square wave oscillator supplies the ac drive to the LCD and to the drivers. As this is a four-digit display reading directly in rpm, the two trailing digits are fixed at zero. These 'on' segments of the display are driven with an out-of-phase signal, while the 'off' segments are driven with the same signal as the common terminal.

The timebase provides the necessary gating for couting by generating the display latch followed by the counter reset signal. The gate times required for a four-stroke engine are:

0.3 s for four cylinders
0.2 s for six cylinders
0.15 s for eight cylinders.

For a single cylinder two stroke engine the gate time is 0.6 s.

If a dc supply is not available, try connecting a 10k resistor from the points to the 12 V input. I have not tried this 'self power' modification, however.

Continued on page 80

LED Tachometer

A unique two-range tach that gives an analogue RPM display on a bar of 21 LEDs. The display flashes to indicate an alarm condition when the RPM exceed a preset limit.

THE ETI TACH/ALARM is an all solid-state project. It displays engine speed in analogue form (like a conventional tach) as an illuminated section of a line of 21 LEDs. The length of the illuminated section is proportional to the engine speed, so that half of the scale is illuminated at half of full-scale speed, and so on. In other words, the display is in bar rather than dot form.

The Tach/Alarm can be used with virtually any type of multi-cylinder gas engine. It has two speed ranges, each of which can be calibrated by a preset pot to give any full-scale speed range required by the individual owner. Our prototype is calibrated to give full scale readings of 10,000 RPM and 1,000 RPM on a four-cylinder, four-stroke engine. The lower range is of great value when adjusting the engine's ignition and carburetor for recommended idle speeds. The upper range has adequate resolution (500 RPM per step in our case).

A unique feature of our product is the provision of a visual over-speed alarm facility, which causes the LED display to rapidly flash on and off when the RPM exceed a preset level; the tach continues to indicate the actual RPM under the alarm condition. Tachs are normally placed directly in front of the driver in sports/racing cars, so this visual alarm system is a highly effective 'attention getter' in such vehicles.

The unit is designed for use only on vehicles with 12V electrical systems. It can be used with conventional or capacitor-discharge (CD) ignition systems and is wired into the vehicle with three connecting leads. It can be used on vehicles with either negative or positive ground electrical systems.

Construction

The complete unit, including the 21 LED display, is mounted on a single PCB. Take care over the construction, paying special attention to the following points:

(1) Our prototype uses a display comprising a linear row of 21 square LEDs, mounted horizontally on the PCB. You may prefer to use a semicircular display of LEDs, in which case you can mount the display on a separate board of your own design, with suitable connections to our board. In either case confirm the polarity and functioning of each of the 21 LEDs, by connecting in series with a 1K0 resistor and testing across a 12V supply, before wiring into place on the PCB. Note that the LED colours can be mixed, if required.

If you use the same display form as our prototype, bend and adjust the LED leads so that each LED slightly overhangs the edge of the PCB when soldered into place.

(2) Seven link connections are made on the PCB. Also note that the exter-

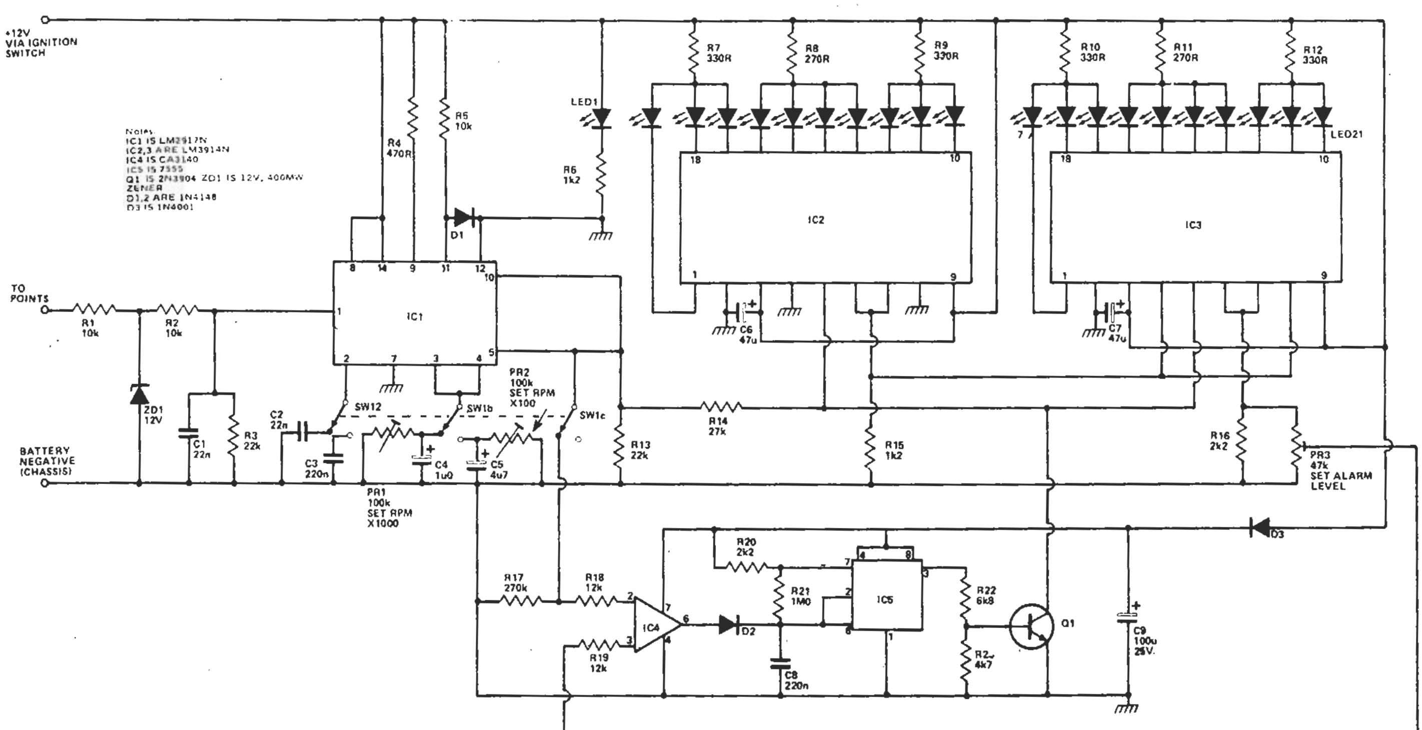


Fig. 1 Circuit diagram.

nal connections to the unit (0V, + ve and points) are made via solder terminals (Veropins).

(3) Range-changing is achieved via a three-pole two-way switch. On our prototype we've used a slide switch for this purpose.

(4) Note that the values of C2 and C3 must be chosen to suit the engine type and full-scale RPM ranges required (see the conversion graph). Our prototype, calibrated to read 10,000 RPM and 1,000 RPM on a four-cylinder four-stroke engine, uses C2 and C3 values of 22nF and 220nF respectively.

When the construction is complete, connect the unit to a 12V supply and check that only LED1 illuminates. If all LEDs illuminate, suspect a fault in the wiring of IC1.

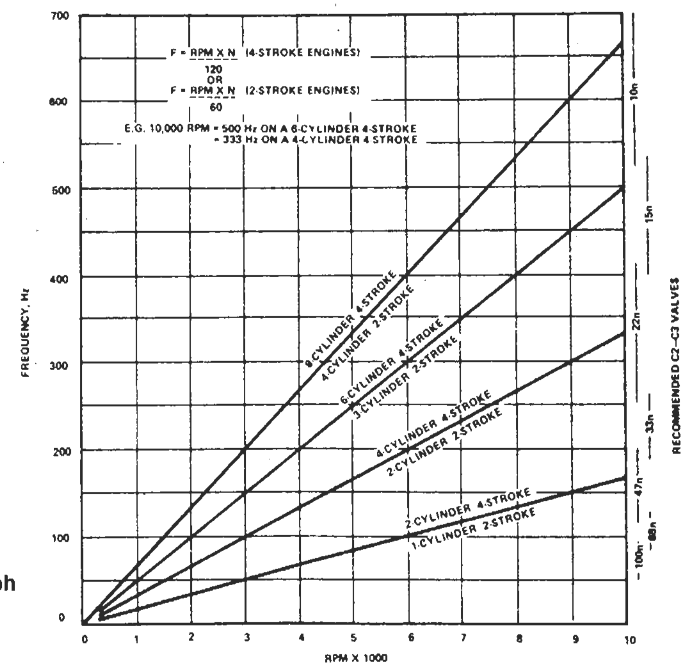


Fig. 2 Conversion graph to determine the values of C2 and C3.

Calibration

The unit can be calibrated against either a precision tachometer or against an accurate (2% better) audio generator that gives a square wave output of at least 3V peak-to-peak. The method of calibration against an audio generator is as follows.

Connect the tach to a 12V supply and connect the square wave output of the audio generator between the 0V and points terminals of the unit. Check against the conversion graph to find the frequency needed to give the required high range full-scale RPM reading on the type of engine in question and feed this frequency into the tach input. Switch SW1 to its high range (10,000 RPM on our prototype) and adjust PR1 for full-scale reading. Now set the generator to the alarm frequency and adjust PR3 so that the display flashes. Recheck both adjustments.

Now switch SW1 to its low range (1,000 RPM on our prototype), set the required full-scale frequency and adjust PR2 for a full-scale reading on the tach. Note that the alarm facility is inoperative on this range.

Installation

The completed unit can either be mounted in a special cut-out in the vehicle's instrument panel or (preferably) can be assembled in a home-made housing and clipped on top of the instrument panel. In either

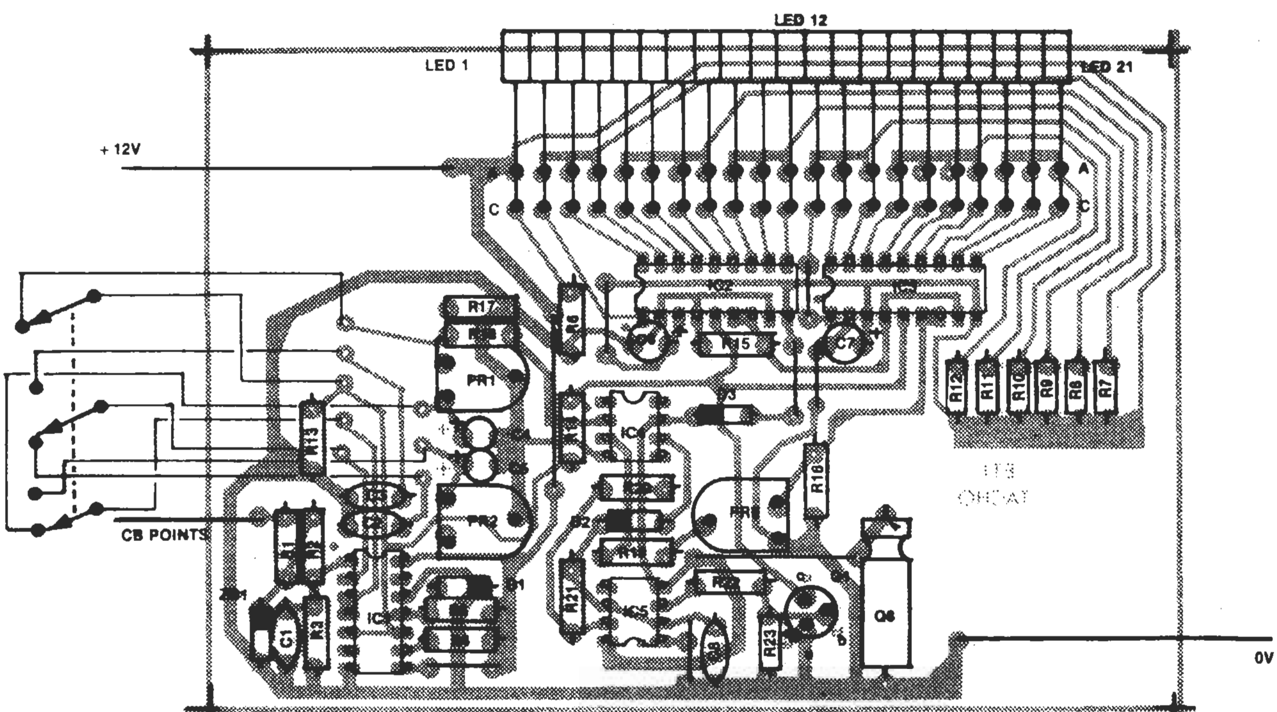
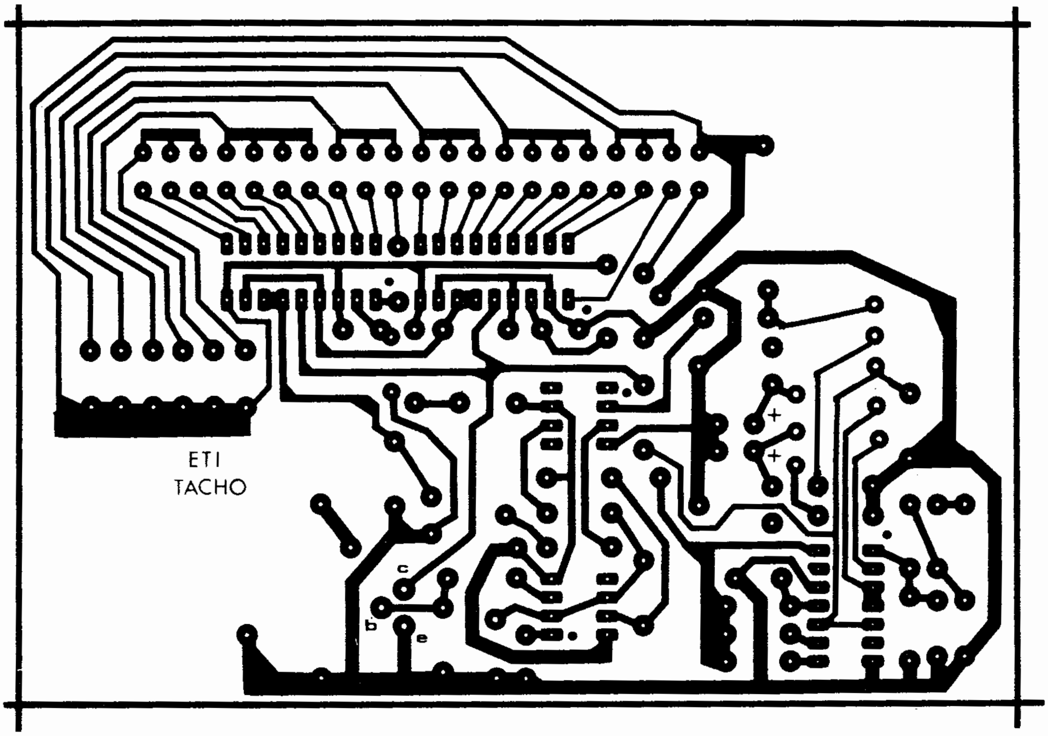


Fig. 3 Component overlay.



How It Works

The ignition signal appearing on a vehicle's points has a basic frequency that is directly proportional to the RPM of the engine. Our tach works by picking up the signal, extracting its basic frequency, converting the frequency to a linearly-related DC voltage and then displaying this voltage (and thus the RPM) on a line of 21 LEDs. The basic tach can thus be broken down, for descriptive purposes, into an input signal conditioner section, a frequency-to-voltage converter section and a LED voltmeter display section.

The input signal conditioner section comprises R1-R2-R3-ZD1-C1. The points signal of a conventional ignition system consists of a basic RPM-related rectangular waveform that switches alternately between zero and 12V, onto which various ringing waveforms with typical peak amplitudes of 250V and frequencies up to 10 kHz are superimposed. The purpose of the input signal conditioner is to cleanly filter out the basic rectangular waveform and pass it on to the F-to-V converter. It does this first by limiting the peak amplitude of the signal to 12V via R1 and ZD1 and then filtering out any remaining high frequency components via R2-R3-C1. The resulting clean signal is passed on to the input (pin 1) of IC1.

IC1 is a frequency-to-voltage converter chip with a built-in supply voltage regulator. The operating range of the IC is determined by the value of a capacitor connected to pin 2 and by a timing resistor and smoothing capacitor connected to pins 3-4. In our application, two switch-selected presettable ranges are provided. The DC output of the IC is made available across R13 and is passed on to the high-impedance input terminals of the IC2-IC3 LED voltmeter circuit via series resistor R14. R14 is essential to the operation of the alarm section of the tach.

IC2 and IC3 are LED display drivers. Each IC can drive a chain of 10 LEDs, the number of LEDs illuminated being proportional to the magnitude of the IC's input signal. Put simply, the ICs act as LED voltmeters.

In our application, the two LM3914 ICs are cascaded in such a way that they perform as a single 20-LED voltmeter with a full-scale range of 2V4. This full-scale value is determined by precision voltage references built into the ICs. The full-scale reference voltage (2V4) is generated across R16 and PR3. The configuration of our voltmeter is such that it gives a bar display, in which LEDs 1 to 11 are illuminated at half-scale or LEDs 1 to 21 are illuminated at full-scale. R7 to R12 are wired in series with the display LEDs to reduce the power dissipation of the two ICs. LED 1 is permanently illuminated so that the RPM display does not blank out completely when the engine is stationary with the ignition turned on.

The alarm section of the tach is fairly simple. IC4 is wired as a voltage comparator with a stable reference voltage fed to its non-inverting (pin 3) input from PR3 and with an RPM-related voltage fed to its inverting (pin 2) input from R13 via SW1c. The output of IC4 is used to enable or disable astable multivibrator IC5 and the output of IC5 is used to enable or disable the inputs to the IC2-IC3 voltmeter via Q1 and R14.

At low engine speeds (below the alarm level) the input of IC4 is driven high, thereby disabling the IC5 astable by preventing C8 from discharging. Under this condition the output of IC5 is driven low, cutting off Q1 and enabling the tach circuit to operate in the normal way.

At high engine speeds (at or above the alarm level) the output of IC4 is driven low, thereby enabling the IC5 astable to operate at a rate of roughly 2 Hz and alternately drive Q1 on and off. In the moments that Q1 is cut off, the tach operates in the normal way, but in the moments that Q1 is driven on its collector pulls the pin 5 input terminals of IC2 and IC3 to near-zero volts and thereby effectively blanks the LED displays. The LEDs flash rapidly under the alarm condition, but continue to indicate RPM values.

The alarm point can be set in any position on the tach scale by PR3. SW1c is used to disable the alarm section when the tach is set to its low (1,000 RPM in our prototype) range. Note that the power supply to the alarm is decoupled from the main supply by D3 and C9.

Continued on page 119

Continued from page 117

case try to fit some kind of light shield to the face of the unit, so that the LEDs are shielded from direct sunlight.

To wire the unit into place, connect the supply leads to the tach via the vehicle's ignition switch and connect the unit's points terminal to the points terminal on the vehicle's distributor.

The lower range of the tach is of great value when adjusting the engine for correct idle. It is thus advantageous to arrange the tach housing so that it can be easily dismounted from the instrument panel.

Parts List

Resistors all ¼ W, 5%

R1,2,5	10k
R3,13	22k
R4	470R
R6,15	1k2
R7,9,10,12	330R
R8,11	270R
R14	27k
R16,20	2k2
R17	270k
R18,19	12k
R21	1M0
R22	6k8
R23	4k7

Potentiometers

PR1,2	100k miniature horizontal preset
PR3	47k minature horizontal preset

Capacitors

C1,2	22n polycarbonate
C3,8	220n polycarbonate
C4	1u0 35V tantalum
C5	4u7 35V tantalum
C6,7	47u 16V tantalum
C9	100u 25V electrolytic

Semiconductors

IC1	LM2917N
IC2,3	LM3914
IC4	CA3140
IC5	ICM7555
Q1	2N3904
ZD1	400mW 12V
D1,2	1N4148
D3	1N4001
LED1-21	Red, square type.

Miscellaneous

SW1	3-pole double throw switch

PCB, case.

LETTERS

DIGITAL DASHBOARD

I would like to notify builders of the "Digital Tachometer" and "Digital Speedometer" (**Radio-Electronics**, June and July 1987) of a fix for a possible problem that they may have encountered.

After several units were built using IC's from different manufacturers, a problem developed that caused the digital readout to occasionally jump to a reading of "000" during normal operation. That timing problem can be corrected by soldering a .001-µF capacitor across pins 8 and 10 of IC7 on the tachometer; across pins 11 and 13 of IC5 on the speedometer.

The cause of the problem is that the MC14553 needs a minimum amount of time between the latch and reset pulses. If the CD4001 NOR gate used to build the projects is too fast—has too little propagation delay—the reset pulse will arrive before the internal latches have stabilized and locked in the current reading.

My apologies go out to anyone who has been struggling with that problem.
ROSS ORTMAN
Dakota Digital

DIGITAL TACHOMETER FOR YOUR CAR

Monitor your car's engine speed with digital accuracy and analog readability.

ROSS ORTMAN

UNTIL RECENTLY, THE DIGITAL dashboard has been seen only in movies and custom show cars. Automobile manufacturers now incorporate digital displays in selected models, but only as an extra-cost option. But that leaves the rest of us in the dark—literally! So here's an inexpensive, easy-to-build tachometer that displays engine speed in both analog and digital form. The circuit is versatile enough to be adapted for use as a speedometer; we'll show how to do so in a future issue.

Why did we provide both analog and digital displays? Mainly because a digital readout can be harder to read and interpret under rapidly changing engine speeds than an analog dial. After the circuit is calibrated, you can get a good idea of engine speed just by glancing at the gauge. After calibration, the digital readout will display accurately from 0 to 9990 RPM in increments of 10 RPM.

Theory of operation

The tachometer works by counting pulses from the distributor points for a period of time, and then scaling and displaying that number. The digital display has three significant digits; the forth (and least significant) digit always displays "0," so that RPM's can be read from the display directly.

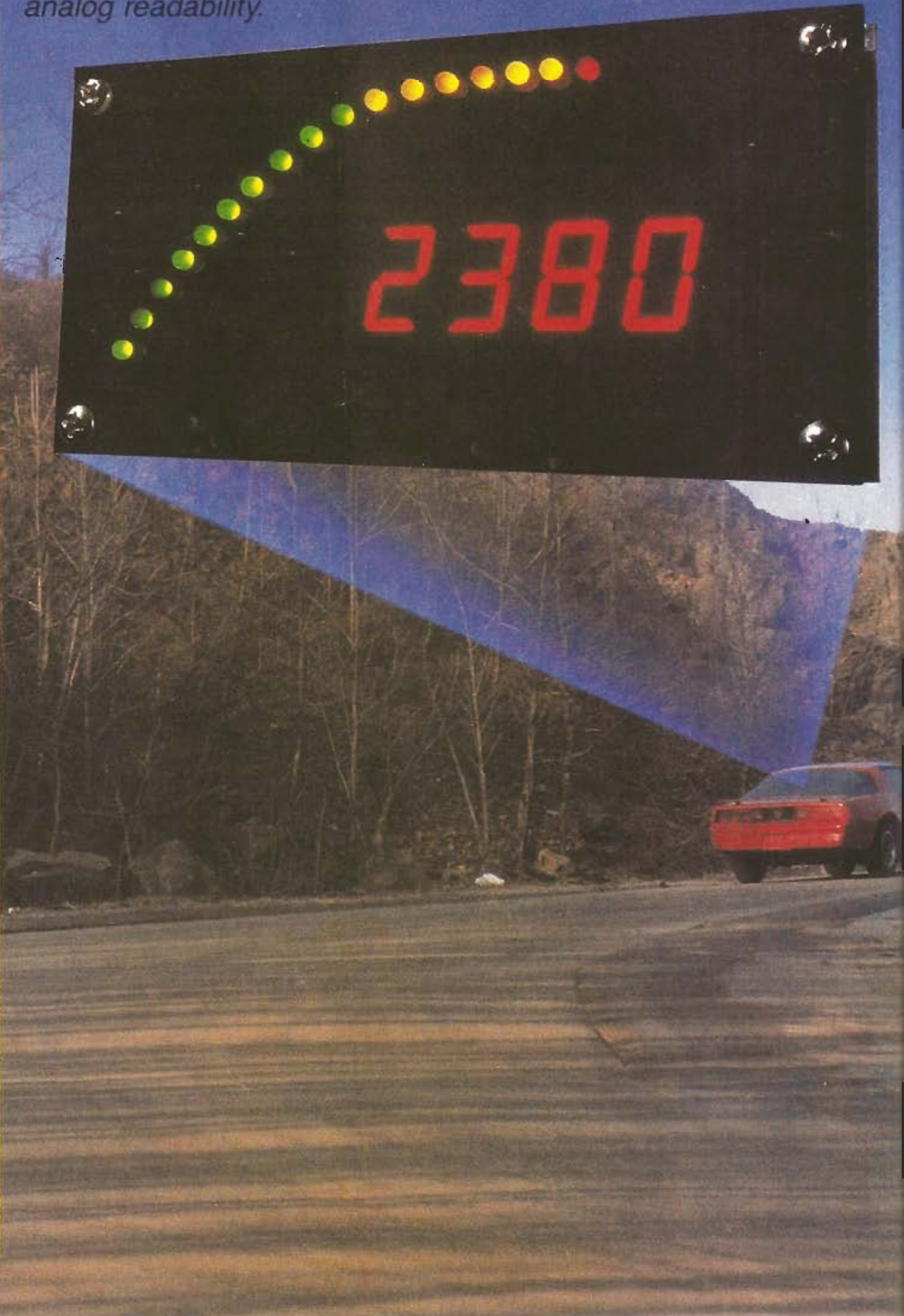
Breaker-point frequency is determined by this formula:

$$f = \text{RPM} \times (\text{Number of cylinders} / 120)$$

For example, with a speed of 600 RPM on an eight cylinder engine, breaker-point frequency is $600 \cdot (8/120) = 40$ Hz. At 3000 RPM, it is 200 Hz.

Now let's use the 600-RPM value to establish how to display the correct value on the tachometer. With an input frequency of 40 Hz, the display must read 600. Because the least-significant digit is zero and the counter section controls only the three active digits, we need to end up with a value of 60 in our counter. With a timebase of 0.5 second (2 Hz), 60 pulses must be read within 0.5 second. Dividing 0.5 by 60 gives us 8.33 ms; the reciprocal of that is 120 Hz—the value we must feed the counter section to obtain the correct reading. So we must multiply the 40-Hz incoming frequency by 3. The circuit that does that will be described later.

Following the same procedure, we find that, to obtain accurate readings for a 4-, 6-, or 8-cylinder engine, the input frequency must be multiplied by a value of 6, 4, or 3, respectively.



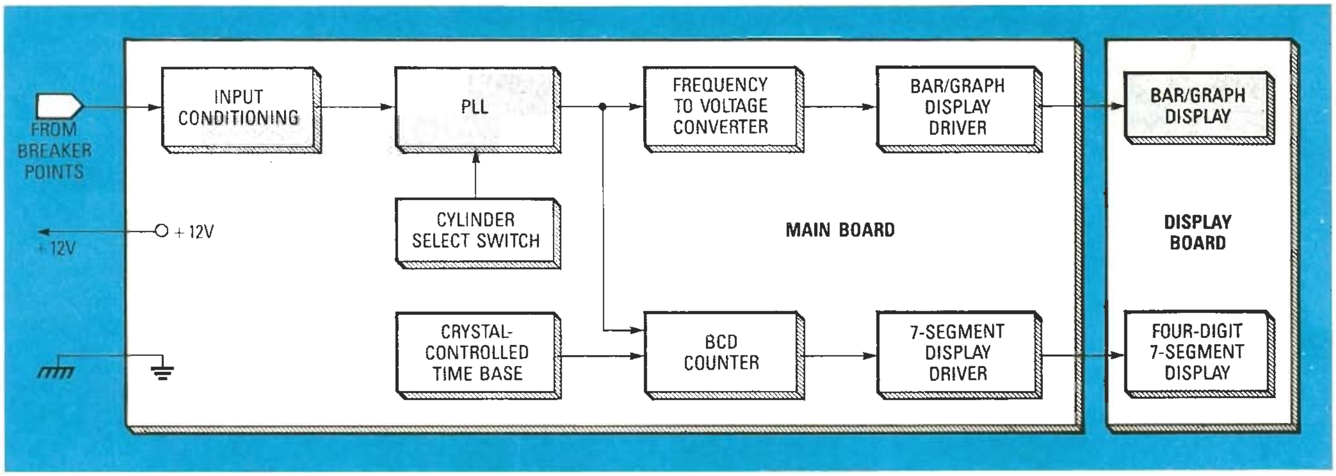


FIG. 1—BLOCK DIAGRAM OF THE TACHOMETER: The PLL scales the breaker-points signal for display directly in RPM.

Circuit overview

A block diagram of the circuit is shown in Fig. 1. After conditioning the noisy input signal, a PLL (*P*hase-*L*ocked *L*oop) is used to multiply the incoming frequency by the value set by the cylinder-select switch (S1). The output of the PLL drives both the analog and digital sections that follow.

The BCD counter is the heart of the digital circuit; it counts the multiplied input signal. After a predetermined sampling interval, a latch pulse latches the number present in the counter at that instant. Immediately following the latch pulse, a clear pulse resets the counter so that counting may start from zero for the next sampling period. The readout is updated every 0.5 second. Figure 2 shows the circuit's timing diagram.

The latch and clear pulses that control the counter are derived from a crystal-controlled oscillator. The oscillator uses a 3.58-MHz TV color-burst crystal to generate a 0.5-second gate time that is stable over a wide range of temperatures.

To produce the analog display, the output of the PLL section is converted to a voltage by a frequency-to-voltage converter. That relative voltage is then displayed on a row of twenty LED's that are driven by a pair of bar/graph display-driver IC's.

Circuit description

The input-conditioning circuit, PLL, and timebase are shown in Fig. 3. Pulses from the points (or tachometer hookup on an electronic ignition system), are fed through a coaxial cable to the input circuit. Waveshaping is accomplished by rectifying the pulses, filtering out spikes, and squaring the signal up by using a comparator with hysteresis. The input circuit limits the amplitude of the 200–300-volt pulses from the points to about nine volts in order to avoid damaging the PLL. Negative pulses are clipped by D1, and positive pulses are filtered by C1 and C2.

Pulses are next squared by IC1, an LM741 op-amp that functions as a comparator. The comparator uses positive feedback via resistor R6 to produce hysteresis, which helps square up the signal.

The PLL section is made up of IC5 (a 4046), its associated circuitry, and IC6, a 4018 presettable divide-by-*n* counter. The setting of IC6 is what determines the PLL's multiplication factor. If IC6 is set to divide by 3, the output frequency of the PLL section will be locked at 3 times the input frequency. Switch S1 determines the number by which IC6 will divide the PLL's output frequency.

The clock is built around an MM5369 17-stage programmable oscillator/divider (IC2); it uses a 3.58 MHz crystal to produce an output of 60 Hz. The 60-Hz output is then divided down to 2 Hz by IC3. The 50-millisecond latch pulse is produced by IC7-a; a delayed version of that pulse is generated by C11, C12, R14, R15, IC7-b, and IC7-c. The delayed pulse functions as the clear signal that was described earlier.

Now let's examine the digital display section (shown in Fig. 4). Counting, latching, and display multiplexing is done by IC9, an MC14553 three-digit BCD counter. The common-cathode LED segments are driven by IC8 (a 74C48); the LED's common cathodes are driven by the three PNP transistors (Q1–Q3).

The analog display (shown in Fig. 5) is based on a frequency-to-voltage converter IC12, an LM2917. It produces a voltage that is proportional to the frequency of the signal fed to its pin-1 input. That voltage is fed to the two bar/graph display drivers, IC10 and IC11, through potentiometer R34, which allows the display to be calibrated. The display drivers are cascaded to drive the 20 discrete LED's. Cascading is accomplished by referencing IC11's internal comparator reference voltage to the final reference voltage of IC10. Resistor R29 limits the amount of current the drivers must dissipate.

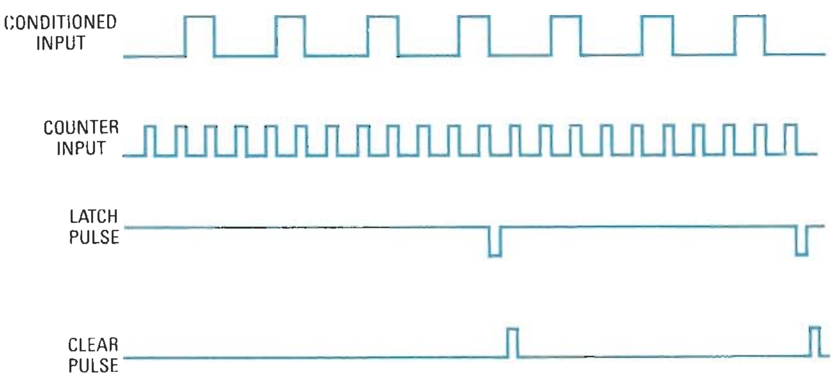


FIG. 2—THE SIGNAL FROM THE POINTS is multiplied by the PLL and counted until a latch pulse is received. The counter is then reset.

Construction

The tachometer is built on two PC boards, a display board, and a main board. The display board (Fig. 6) contains four seven-segment LED displays, twenty discrete LED's, and several current-limiting resistors. The main board (Fig. 7) contains the remainder of the circuitry. The PC boards can be made using the foil patterns shown in PC Service, or a set of boards with plated-through holes can be bought from the supplier mentioned in the Parts List. If you etch your own boards, be sure to solder both sides of the board wherever necessary. If possible, use machined-type IC sockets that don't have plastic bodies, as they can be soldered on both sides of the board easily.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—4700 ohms
R2, R3, R5, R12, R14, R15, R30, R33—10,000 ohms
R4, R7, R8, R10—100,000 ohms
R6—470,000 ohms
R9—22 megohms
R11—2.2 megohms
R13—1 megohm
R16, R17, R18, R27—1000 ohms
R19–R25—220 ohms
R26, R31—470 ohms
R28, R36—22,000 ohms
R29—50 ohms, 5 watts, wire-wound
R32—33,000 ohms
R34—10,000 ohms vertical trimmer pot
R35—2200 ohms

Capacitors

C1—0.22 µF disc
C2—0.022 µF disc
C3—0.01 µF disc
C4—10 µF, 16 volts, electrolytic
C5—33 pF disc
C6—22 pF disc
C7, C8, C15—1 µF, 16 volts electrolytic
C9—0.1 µF disc
C10—0.05 µF disc
C11, C12, C13—0.µF 001 disc
C14—0.022 µF mylar

Semiconductors

IC1—LM741 op-amp
IC2—MM5369 17-stage oscillator/divider
IC3—CD4518 dual synchronous up counter
IC4—CD4081 quad AND gate
IC5—CD4046 micropower phase-locked loop
IC6—CD4018 presettable divide-by-*n* counter
IC7—CD4001 quad NOR gate
IC8—74C48 BCD to 7-segment decoder/driver
IC9—MC14553 three-digit BCD counter
IC10, IC11—LM3914 bar/graph display driver
IC12—LM2917N frequency-to-voltage converter
D1–D3—1N4004 rectifier
D4—1N4739A, 9.1 volts, 1 watt Zener
D5—1N4148 switching diode
D6—1N4001 rectifier
Q1–Q4—2N3906 PNP transistor
LED1–LED10—0.125" green diffused LED
LED11–LED16—0.125" yellow diffused LED
LED17–LED20—0.125" red diffused LED
DISP1–DISP4—7-segment common-cathode display (Panasonic LN516RK, Digi-Key P351. P352, P353, & P354 may also be used.)

Other components

S1—DP3T slide switch (CW Industries GPI154-3013, Digi-Key SW115-ND)
XTAL1—3.58 MHz color-burst crystal
F1—1 amp slo-blow automotive fuse
P1, P2—0.1" 2-pin Molex connector

Note: The following are available from Dakota Digital, R. R. 1 Box 83, Canistota, SD 57012: Single-sided display board, $6.95; double-sided (with plated-through holes) main board, $12.95. All orders add $1.50 for shipping and handling. South Dakota residents and 4% sales tax.

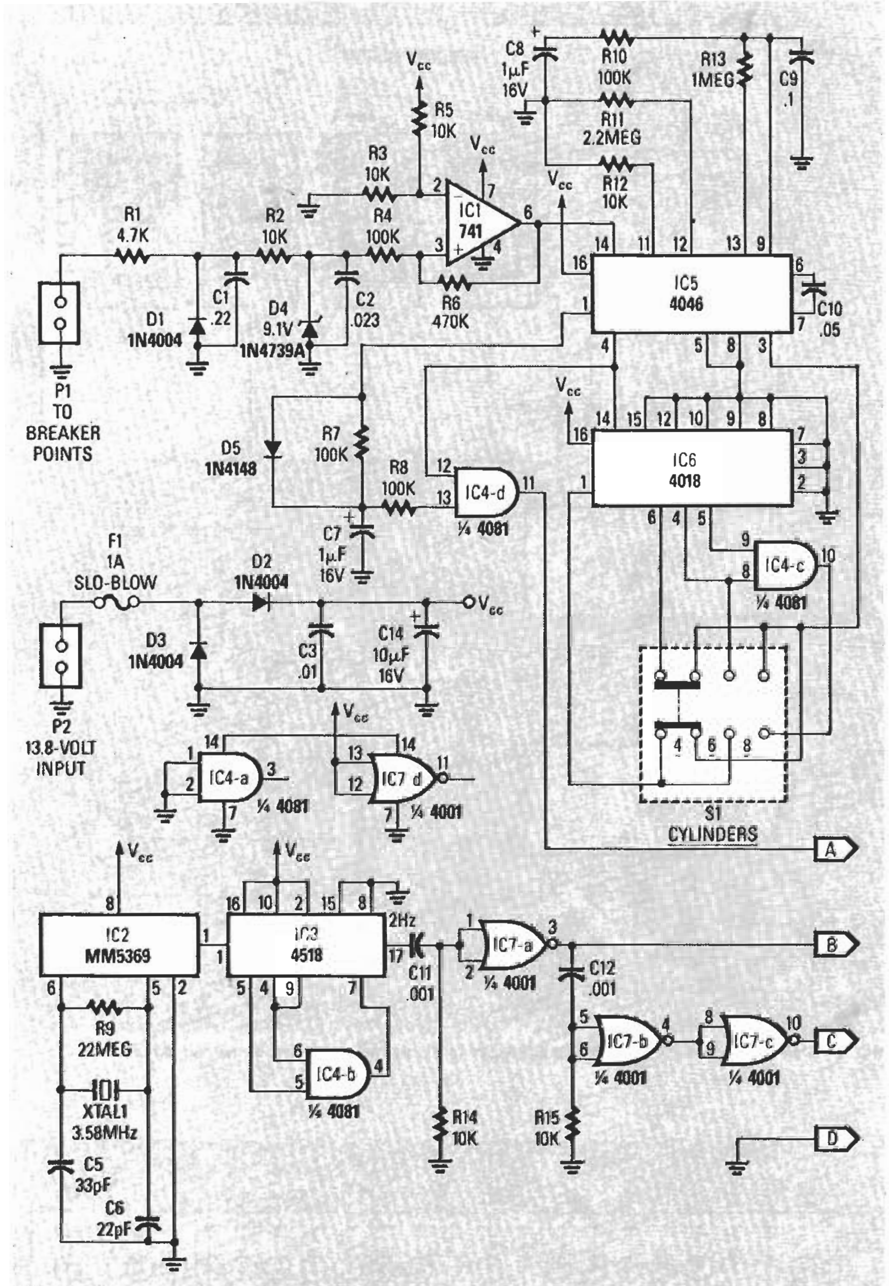


FIG. 3—THE TIMEBASE, INPUT CONDITIONING, and PLL circuits are shown here. Op-amp IC1 functions as a comparator that squares up the input signal for processing by the PLL.

When stuffing the display board, begin with the eight resistors and the three jumpers; then install the four seven-segment displays. Next, insert the twenty LEDs into their respective holes. Pay close attention to the polarity of the LED's. The cathode (or flat side) goes toward the row of holes at the lower edge of the board. After the LEDs have been set in place, carefully turn the board over and lay it down on a flat sturdy surface. Now position the LED's and the displays so they are the same height above the board. If they're not, the LED's must be inserted into their mounting holes further. After the LED's and displays are at the same approximate height, solder one lead of each LED to the board. Then turn the board over and align the LED's so they stand up straight and follow a smooth curve. Now, finish soldering the LED's and set the display board aside.

The next step is to stuff the main board. Begin with the smaller parts: resistors and diodes. Next install the IC's. Because they're mainly CMOS IC's, the use of sockets is recommended, but not essential. If you don't use sockets, insert the IC's carefully, and solder only a few legs at a time to keep heat to a minimum. If sockets are used, install them now and insert the IC's later. Doing so will lessen any chances of static damage. Remember, if you don't use boards with plated-through holes, you'll have to solder most components on both sides of the board.

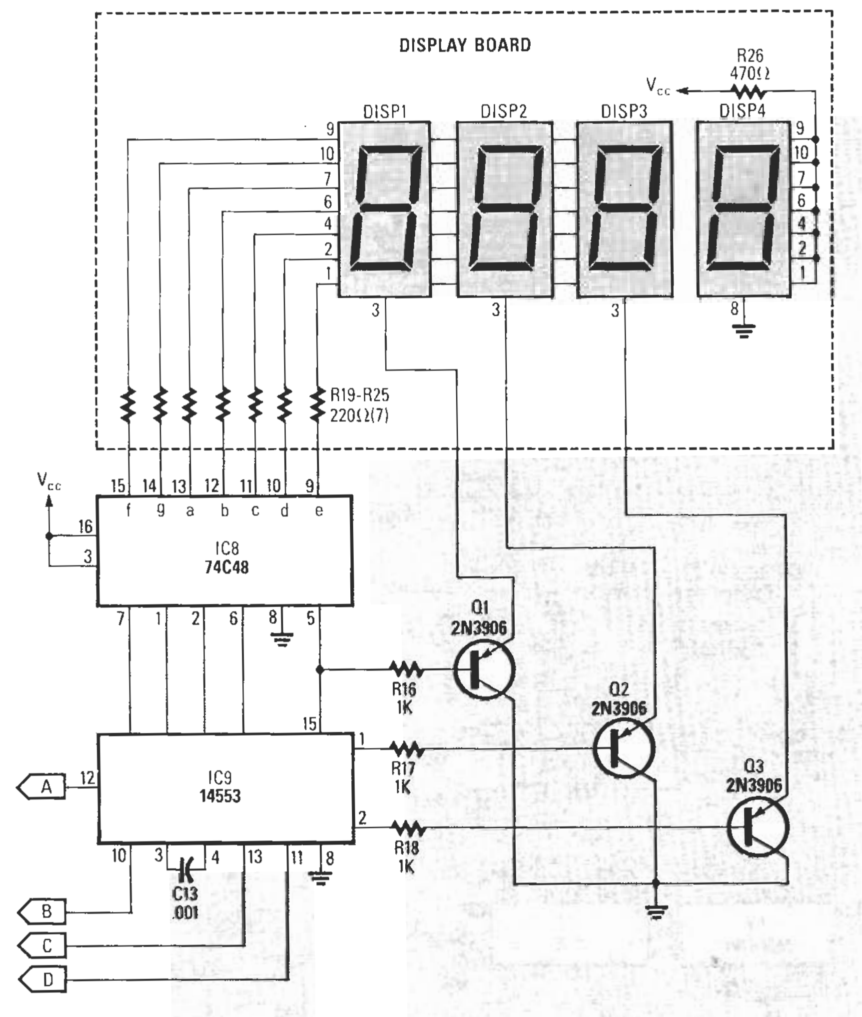


FIG. 4—THE TACHOMETER'S DIGITAL DISPLAY is a conventional decoder/driver circuit.

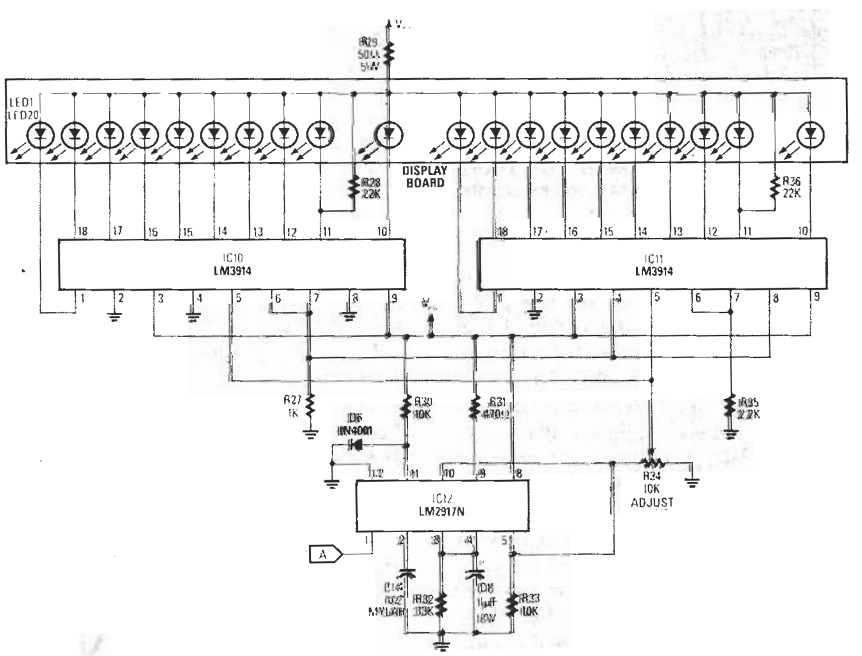


FIG. 5—THE TACHOMETER'S ANALOG DISPLAY is built around a frequency-to-voltage converter (IC12) that drives two bar/graph drivers (IC10 and IC11).

Install the remaining components (capacitors, connectors, and transistors). The base or center leg of each 2N3906 is bent toward the flat side of the package; the transistor should rest about ¼ inch off the board. Install the remaining parts on the board and double-check both boards for errors.

Mechanically, the boards are mounted back to back, separated by ¼-inch stand-offs. Note that each PC board has a row of 35 holes along the lower edge. The boards were designed so that corresponding holes in each should be connected electrically using short pieces of bare wire. Trimmed resistor legs work admirably. If troubleshooting should prove necesssary, you can separate the boards by bending those wires carefully.

Before soldering the wires, connect the boards together using stand-offs and #6 hardware. Assemble the boards with the foil side of each facing that of the other. Then lay the assembly down and insert a bare wire through each hole in the top board and into the corresponding hole in the bottom board. Insert and solder several wires at a time; continue until all wires have been inserted and soldered.

Testing

After the two boards are stuffed and connected together, apply 12 volts to P2 using a power supply or battery. The three right-hand digits should display zero's, and the left hand digit should show nothing. Also, no LED's should be lit. Now, using an audio-frequency function generator, apply a 9-volt peak-to-peak 40-Hz squarewave to the junction of D4 (the 9.1-volt Zener diode) and R2. If your generator cannot supply a squarewave with a DC offset, you may have to feed the test point through a 1K resistor and use a higher-amplitude signal.

Set the cylinder-select switch to 8. The readout should now display something close to 600. Change the cylinder-select switch to 6; the display should read 800. Last, set the switch to 4; the display should read 1200.

Now we'll calibrate the analog display. Set the cylinder-select switch to the setting you plan to use. Next, set the generator to the frequency that will produce the "redline" RPM reading for your engine (i. e., the speed above which the manufacturer recommends you not run the engine.) For an eight-cylinder engine, that speed is typically 5000 RPM. When the redline reading is obtained on the digital readout, adjust R34 so the first red LED lights up. The tachometer is now calibrated and ready for installation.

Installation

First decide where the tachometer will be installed. You'll have to find a spot that provides a good view, that doesn't interfere with pre-existing components, and

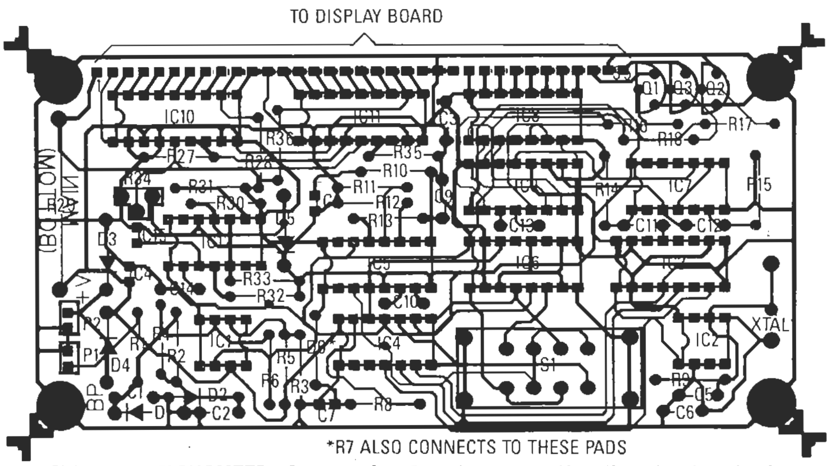


FIG. 6—STUFF THE TACHOMETER'S MAIN BOARD as shown here. Use clipped resistor leads to make the connections to the display board.

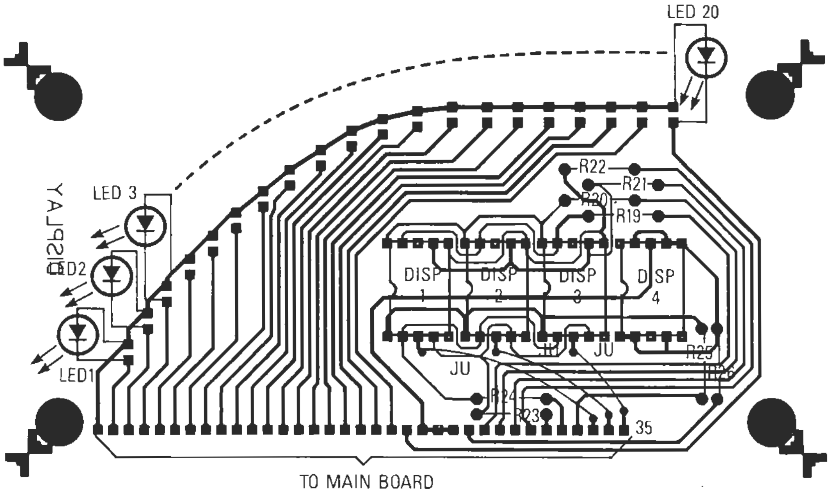


FIG. 7—STUFF THE DISPLAY BOARD as shown here. The flat side of each LED should point toward the bottom of the board. The two boards are sandwiched together, and corresponding pads on the boards are connected with short pieces of stiff wire.

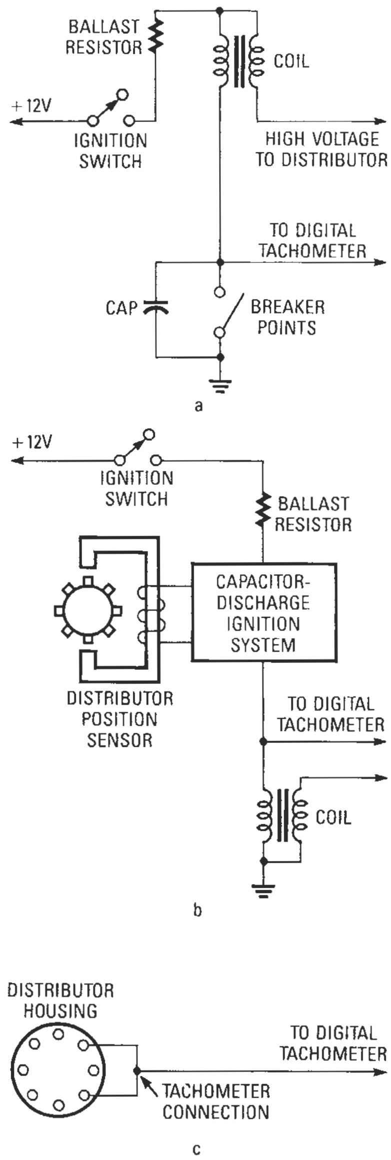


FIG. 8—TO INTERFACE THE TACHOMETER, follow one of these circuits. A conventional (Kettering) ignition system is shown in (*a*), a capacitor-discharge system in (*b*), and a General Motors hook-up in (*c*).

one that you can get to without being a Chinese contortionist!

When a suitable mounting site has been chosen, run a wire from your ignition system to the PC-board assembly. Three possible wiring schemes for different types of ignition systems are shown in Fig. 8-*a*, Fig. 8-*b*, and Fig. 8-*c*. Whatever type of ignition system you have, run a piece of coaxial cable from the distributor points or tachometer hookup to the mounting location. An easy and reliable way to make the connection is to attach the center conductor of the coax to the terminal labeled DIST or - on the ignition coil. Many electronic ignition systems also use a conventional coil, and the connection is made in the same manner as to a distributor/points system. Some electronic ignition systems do not use a conventional coil, so the connection must be made by fastening the center conductor of the coax to the terminal marked TACH.

After putting a connector on the opposite end of the signal coax, connect the power wires. Connect the black wire to chassis ground and the red one to a source that is on only when the ignition key is in the ON position.

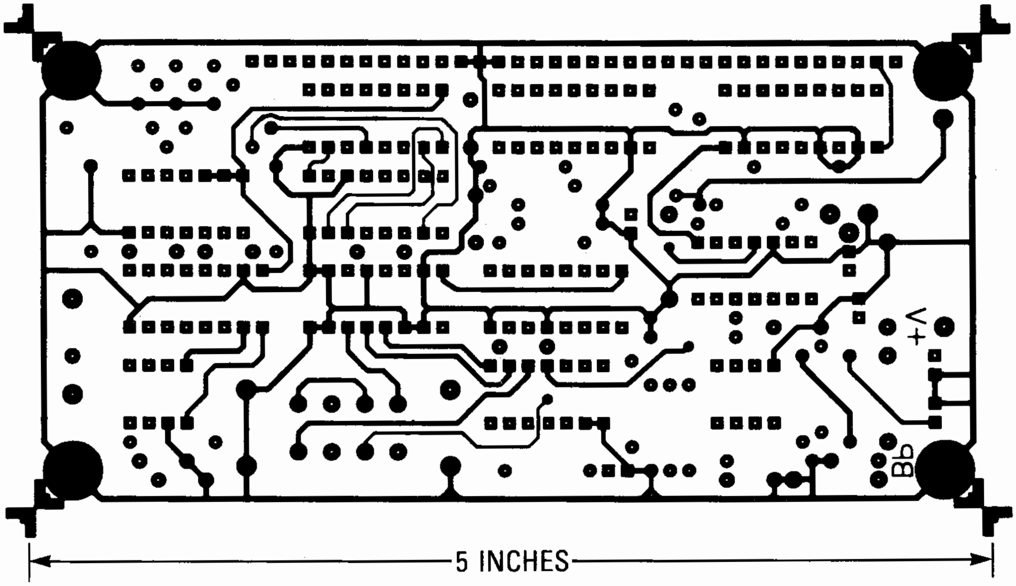
Now you're ready to install the tachometer. A case can be built from just about any type of material, but an attractive, durable front panel is important. The use of bronze-colored Plexiglass for the front panel will not only protect the displays, but also make them more visible. Don't use red filter plastic because it will wash out the green and yellow LED's of the bar/graph display. To enhance appearance further, the front panel can be masked on the inside to allow only the LED's and displays to show, thus hiding the rest of the display board. Masking can be done by taping over the area through which the displays will show, and painting the uncovered area black. You may also want to label the front panel using using white dry-transfer lettering.

After building your enclosure, mount the PC-board assembly in it, and then install the enclosure in your vehicle. Be sure to install it and the connecting wires so they will not present a safety hazard. Now plug in the power and signal connectors. The installed digital tachometer is now ready to display your engine's speed with both digital accuracy and analog readibility.

Conclusions

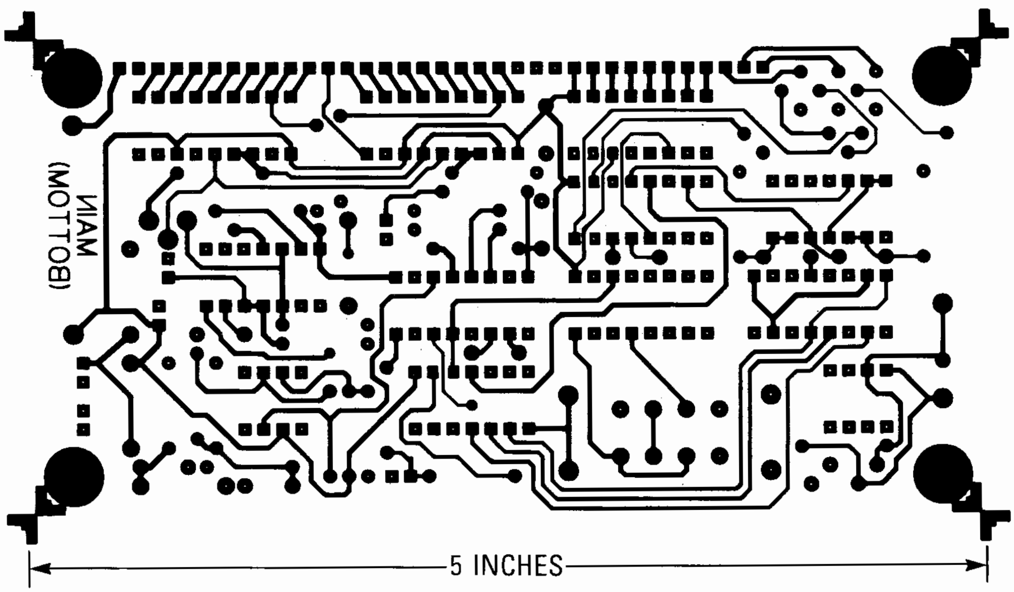
The circuit can be used in a car, truck, boat, or wherever an accurate and reliable tachometer is needed. If you're interested in adding other digital display equipment to your car, see the July, August, and September 1983 issues of **Radio-Electronics.** Those issues contain circuits for displaying voltage, water temperature, and oil pressure in digital form. In addition, the circuit shown here can also be adapted for use as a speedometer—we'll show you how to do it next time. **R-E**

PC SERVICE



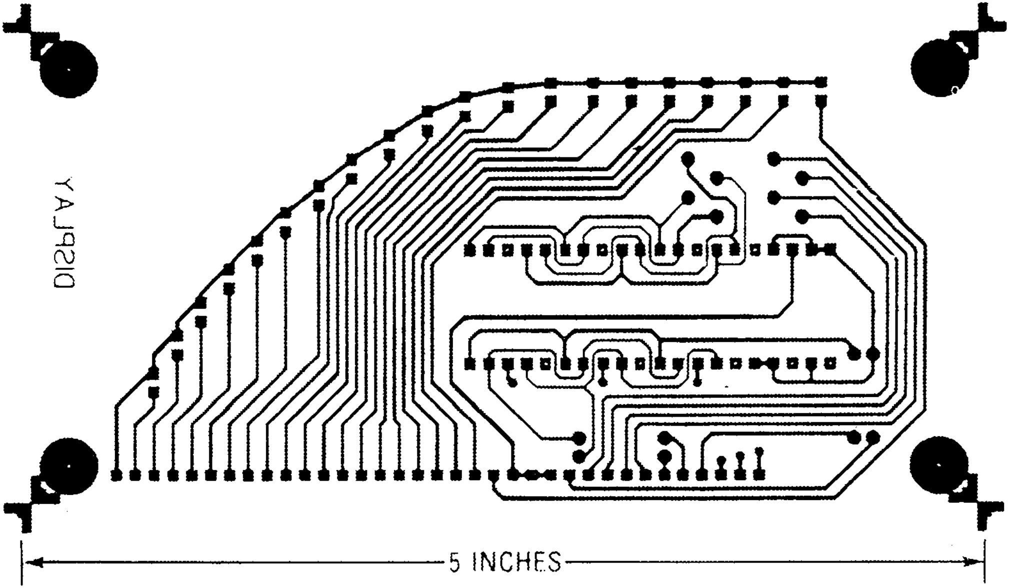
THE COMPONENT SIDE of the digital tachometer

PC SERVICE



THE SOLDER SIDE of the digital tachometer is shown here.

PC SERVICE



USE THIS BOARD to assemble the digital tachometer's display board. The article appeared in the June 1987 issue.

Richardson, TX

DIGITAL TACHOMETER

I recently built the Digital Tachometer that appeared in the June 1987 issue of **Radio-Electronics**, and it works very well. It is the only digital tachometer circuit I've ever seen that offers accurate tachometer readings without calibration. That is accomplished by the use of a built-in 60-Hz crystal-controlled time base. The author is to be congratulated on that fine project.

It worked perfectly on several standard and *C*apacitive-*D*ischarge (C-D) ignition systems. However, the tachometer will not work on some C-D systems that use input-triggering circuits that generate extremely low pulse levels across the ignition points. On one such system, which incorporates an unusual triggering network designed primarily to eliminate point "bounce" or "flutter" at high engine speed, the pulse obtained across the ignition points was far too small for tachometer pickup.

To eliminate that problem, I used a miniature broadband amplifier between the ignition points and the tachometer input. I chose the broadband amplifier described by Earl "Doc" Savage in "Hobby Corner" in the April 1980 issue of **Radio-Electronics**. It is small enough to fit easily within the tachometer enclosure. I added a switch to allow the amplifier to be switched in or out of the circuit.

I hope that my solution may prove useful to other readers experiencing similar difficulties. Many thanks for a fine magazine.

PAUL SCHULTZ
Carmichael, CA