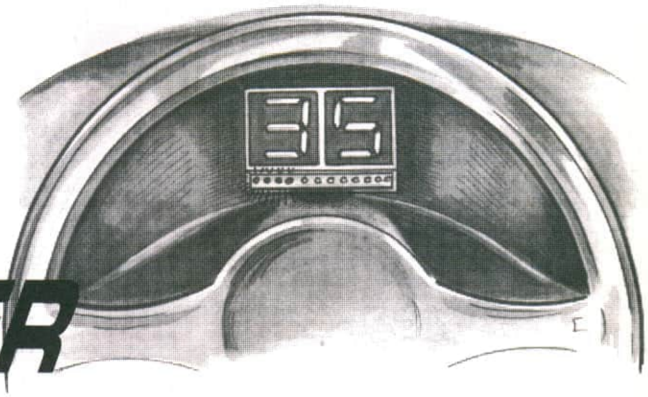
Constructional Project

PIC DIGITAL/ ANALOGUE TACHOMETER



HARBANSE DEOGAN

By taking your PIC, you can have the best of both worlds – Digital and Analogue. Reads from 100 r.p.m. up to 9900 r.p.m.

TACHOMETERS are used in a wide variety of fields, e.g. they are found in automobiles to indicate engine speed, in meteorology to measure wind speed from an anemometer, to measure the rotational speeds of lathes and drills, etc. A tachometer will also be used where it is necessary to know if a motor is operating in its specified range or at peak efficiency.

Most tachometers are either digital or analogue, each with its advantages and disadvantages. The digital ones clearly indicate a steady r.p.m., but are not good for indicating trends or where the rotation rate is not steady.

On the other hand, analogue types are excellent for displaying trends but the accuracy of the reading is limited by how accurately you can read the meter scale. Typically the meter movements used in automobiles and motorcycles are heavily damped to give a slow response time, because there is a lot of vibration in these environments and a sensitive, light, highly responsive meter movement would be constantly deflected by the mechanical vibrations giving rise to unsteady readings as the needle judders around the actual reading.

The benefit of using a bargraph to emulate a meter movement is that it does not suffer interference from vibrations and thus need not be damped. The bargraph can indicate changing r.p.m. with less hesitation than a conventional meter. At the same time the digital display will accurately show steady or slowly changing readings.

OPERATION

A petrol engine works by compressing a fuel/air mixture and igniting it at the right moment to provide power which is transferred to the rotating crankshaft and onto the road wheels via the transmission system. The ignition pulses are produced by a step-up coil which will elevate the 12V it receives to around 15000V necessary to produce a spark in the cylinder.

The timing of the spark is controlled by the distributor and contact breaker – see Fig 1. In modern cars the contact breaker is replaced by a transistorised switch but the basic principle remains the same. The tachometer measures the frequency of the pulses supplied by the contact breaker (which is directly linked to the rotating crankshaft of the engine).

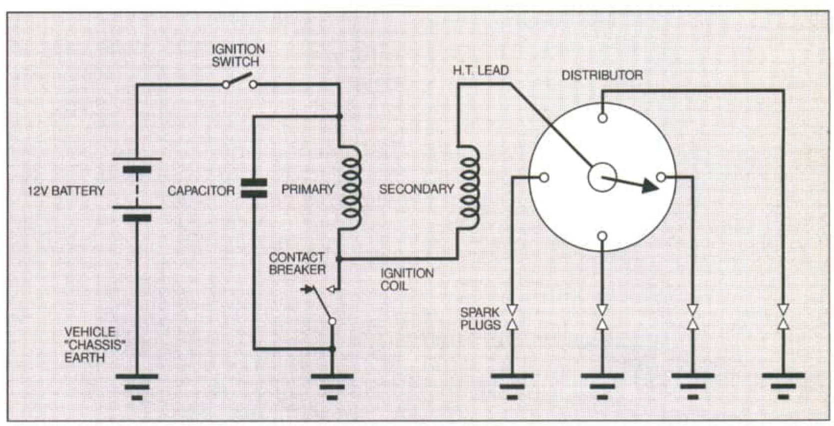


Fig. 1. Conventional set-up for a 4-cylinder vehicle ignition system.

DIGILOGUE

The design presented here combines both digital and analogue displays in a compact, simple design based around a single chip microcontroller, the PIC16C54XT. The digital display is a two-digit seven-segment type which will display the r.p.m. as multiples of 100 up to 9900 r.p.m.

The analogue display consists of two 10-segment bargraph arrays with only 16 elements used. The length of the bar display indicates the r.p.m. The resolution of the bargraph corresponds to 500 r.p.m. per l.e.d.

The purpose of this design was to extract the maximum functionality from a minimum component count. This was made possible by the use of a small single chip micro which incorporates on board program memory (ROM), data memory (RAM) and good input/output capability.

The use of a microcontroller to make a tachometer may be likened by some to ''using a sledge hammer to break open a nut'', but this design will demonstrate how the microcontroller gives the circuit maker a great deal of flexibility in the design – which could not be realised using TTL or CMOS logic devices.

Thus, the tachometer is essentially a frequency counter with the measurement being expressed as r.p.m. (revolutions per minute) instead of Hz (cycles per second). There are basically two ways of measuring frequency:

- Count the number of pulses arriving over a fixed period of time (the gate period).
- Measuring the time elapsed between successive pulses – pulse period – and then calculating the frequency ($f = 1/t$).

The former method is used here as the actual measurement uses less processing

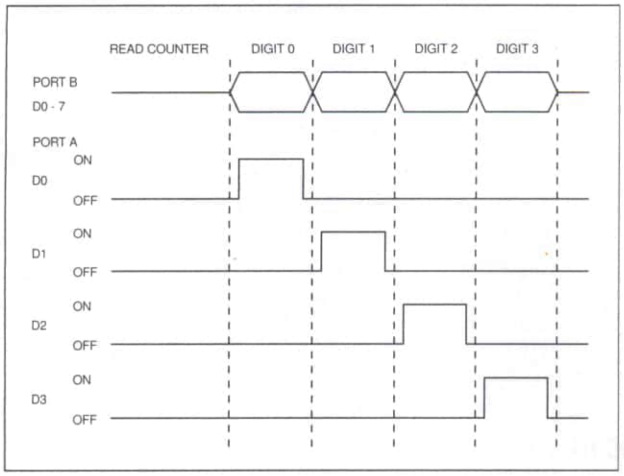
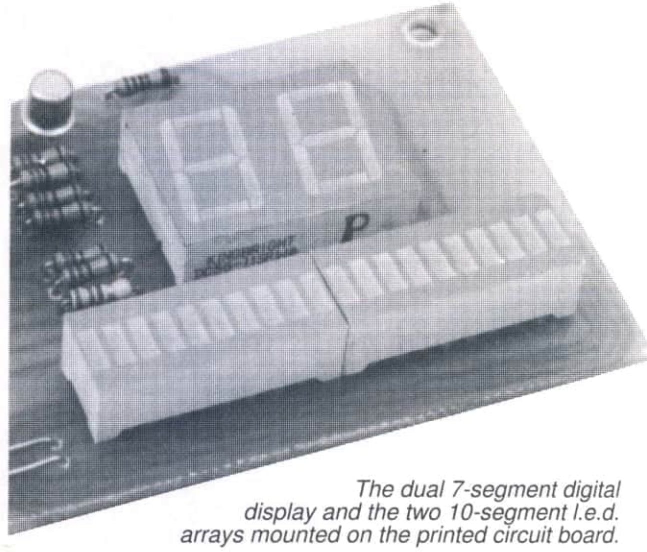


Fig. 2. Multiplex timing sequence.



The dual 7-segment digital display and the two 10-segment l.e.d. arrays mounted on the printed circuit board.

time. The PIC microcontroller has a built-in 8-bit counter which can be clocked directly by an external signal completely independent of what the microcontroller is doing.

When the pre-set gate period has expired the accumulated pulse count in the counter is read, stored and the counter reset ready for the next cycle. The stored values are converted into a form suitable for display (as digital and analogue) and the displays are updated.

DRIVING DISPLAY

The input/output (i/o) capability is not sufficient to drive all the l.e.d.s at the same time – this would require a total of 32 output lines! For this reason the displays are multiplexed as four groups of eight l.e.d.s.

A multiplexed system takes advantage of the property of persistence of vision; if you take a light source and rapidly turn it on and off very quickly (>25 times a second) the eye will perceive it as being constantly on. The same property is utilised when displaying a TV picture, watching a film in a cinema and in a.c. mains operated lighting. In reality the output from all these sources is changing several times a second (25 to 100 in fact for these examples) but the eye cannot respond quickly enough to register the flicker that is there.

As already described, the display of the tachometer consists of four groups (or digits) of eight l.e.d.s. Each digit has power applied for 25 per cent of the time. By rapidly cycling through the digits the eye is fooled into thinking that all the digits are on simultaneously – see Fig 2.

The use of a microcontroller makes the task of multiplexing feasible. Furthermore, it allows one to arbitrarily choose the bit patterns allocated to each digit so that, any combination of l.e.d.s can be lit and also the l.e.d.s can be arbitrarily wired up (in the easiest or tidiest route) and the necessary corrections for the wiring made in software – this is something else that would not be possible if TTL or CMOS logic i.c.s were used.

PROGRAM

The program handles all the timing, counting and display functions. The gate period is set to 300ms for a 4-cylinder 4-stroke petrol engine. The number of pulses from the ignition coil in that time is equal to the r.p.m./100 so no conversion is needed.

For different engines simply change the loop counter to alter the gate period but ensure that the number of pulses counted is always equal to the actual r.p.m./100. No other adjustment is needed.

During the gate period the microcontroller will drive the multiplexed displays. Each display is switched on for around 5ms and a complete cycle takes 20ms. Therefore, the gate period can only be set to a multiple of 20ms.

At the end of each gate period the displays are all turned off and the new pulse count read in from the counter and stored, a value for the bargraph is calculated ready for display, at the same time the counter is reset. All this is done very quickly and does not significantly affect the duty cycle of the displays.

The display multiplexing routine works as follows. Each digit has its own bit pattern specific to the way it is wired up to the microcontroller and whether it is a

COMPONENTS

See SHOP TALK Page

Resistors

R1	1M
R2	100Ω
R3 to R10	220Ω (8 off)
R11 to R14	1k (4 off)

All 0·25W 5% carbon film

Capacitors

C1, C2	22p disc ceramic (2 off)
C3	100µ radial elect. 16V
C4	100n polyester
C5	100p polystyrene (see text)

Semiconductors

D1, D2	1N4002 1A 100V rect. diode (2 off)
TR1 to TR4	BC108 *npn* silicon transistor (4 off)
IC1	PIC16C54XT microcontroller (pre-programmed – see text)
IC2	LP2950 5V low-power voltage regulator
X1/X2	dual 0·56in. 7-segment l.e.d. display, common cathode
X3, X4	10-segment l.e.d. array (2 off)
X5	4MHz crystal

Miscellaneous

Printed circuit board available from *EPE PCB Service,* code 127; plastic ABS case, size 111mm x 57mm x 22mm; 18-pin d.i.l. socket; small piece of red filter for l.e.d. displays; auto-type connecting wire; solder pins; solder etc.

Approx Cost Guidance Only **£35**

7-segment display or a bargraph array. The 8-bit port B is used to drive the segments while the 4-bit port A is used to control the digit drivers (buffered through the transistors).

Initially, all the segment drivers are off, the bit pattern for the first digit is output to port B and then the first digit driver is switched on. This lights up the first display.

After 5ms the digit driver is turned off, the bit pattern for the second digit is output to port B and then the second digit driver is switched on. This procedure is repeated for both digits and both bargraphs, at any given instant only one of them is lit but to the eye it appears as if they are all on – thanks to persistence of vision.

CIRCUIT DESCRIPTION

The full circuit diagram for the Digital/Analogue Tachometer is shown in Fig. 3. The power supply regulator (IC2) circuit is also included.

The microcontroller, IC1, which forms the heart of the Tachometer is Arizona Microchip's PIC16C54XT, an 18-pin device. It has 12 input/output (i/o) pins (made up of a 4-bit port and an 8-bit port) with high current capability (about 20mA), 0·5K of program memory, 32 bytes of data memory, an 8-bit counter, an 8-bit prescaler and a watchdog timer. It is more or less a stand-alone device requiring a minimal support circuitry.

A 4MHz crystal X5 is used to drive the clock and since this determines the accuracy and stability of all the timing functions it is this factor that determines how accurate the Tachometer will be. By knowing the clock frequency beforehand, the program can be written in such a way that the Tacho does not need to be calibrated before use.

The 8-bit port (pins 6 to 13) is used to drive the segment l.e.d.s of each digit directly through current limiting resistors R3 to R10, but the digit drivers are buffered by transistors TR1 to TR4 because the total current drawn, when all eight l.e.d.s are on, will exceed the current capability of a single pin.

PULSE COUNTING

The pulse counting and display driving functions are all handled by the PIC (IC1). The input circuit is designed to give good sensitivity while providing adequate protection against overloading and reverse voltages.

The input port for the 8-bit counter (pin 3) has a high impedance so that it will not significantly load the signal source. A high value series resistor (R1) limits the current that can flow into the pin. A diode (D1) is used to shunt away high voltage positive going spikes to the supply line and the microcontroller has a built in clamping diode to safely dissipate any negative going spikes. Since the supply has a very low impedance it will absorb these signals without unduly affecting circuit operation.

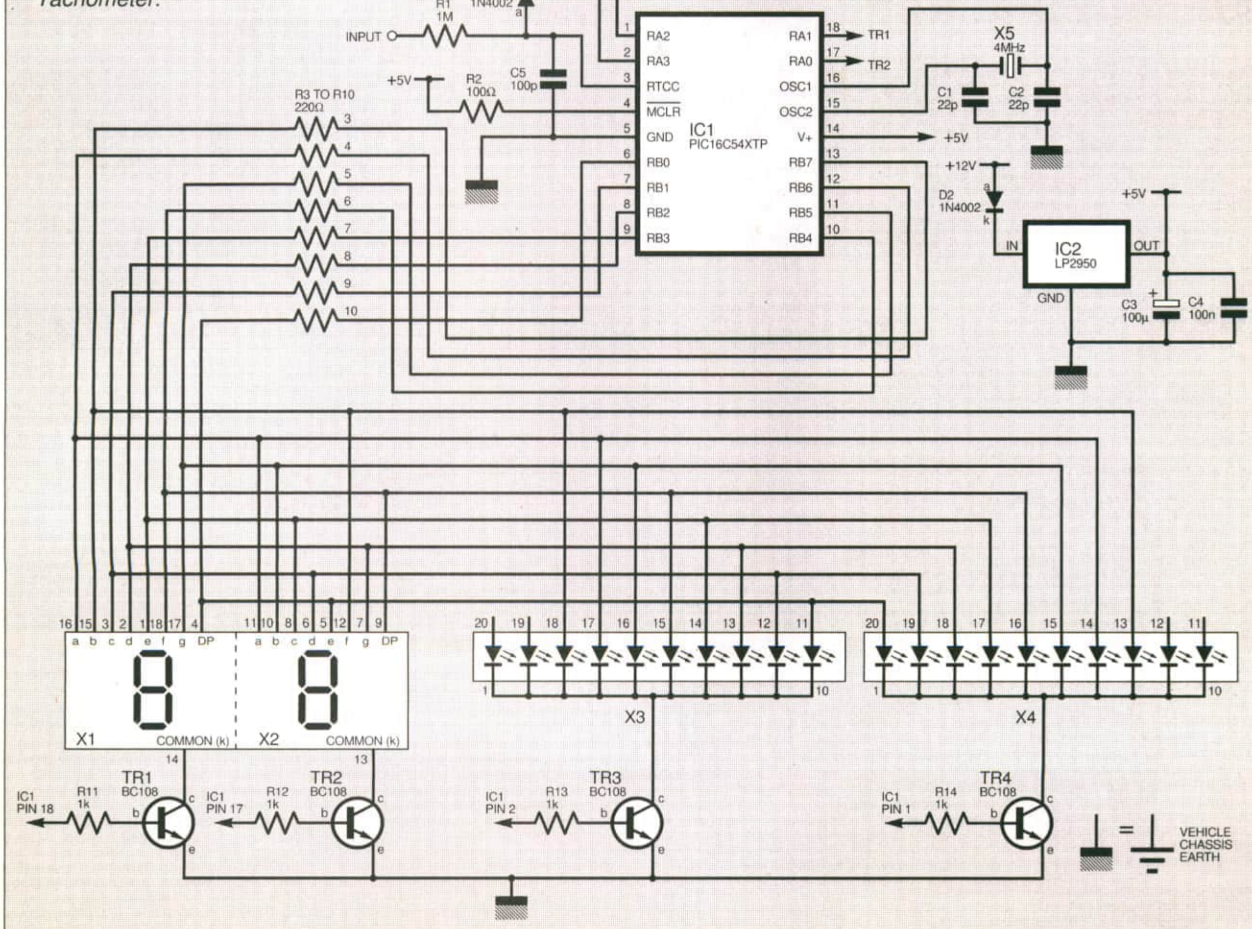
This microcontroller input has a Schmitt trigger to help with noise immunity, however, capacitor C5 has been introduced to help in suppressing any high frequency "ringing" produced when the vehicle contact breaker points (or switch) open. The precise value of C5 is not important and the optimum value may vary from vehicle to vehicle. It should be large enough to absorb any unwanted signals but small enough to allow the ignition pulses through.

It may be necessary to experiment to find the most suitable value for any particular case. From the circuit it is clear that the capacitor is functioning as a low-pass filter in conjunction with the input resistor R1. If the resistor value is changed then it may be necessary to change the capacitor value too.

The bargraph (X3 and X4) consists of two cascaded 10 l.e.d. arrays and of these only 16 l.e.d.s are actually used. The 16 l.e.d.s light up in sequence as the r.p.m. increases, the size of the "bar" being proportional to the r.p.m..

The l.e.d. arrays can be replaced with individual l.e.d.s so that as the r.p.m. approaches a dangerously high level the colour of the bargraph changes. A suitable choice would be green for OK, orange or yellow when approaching a dangerous level and red for danger level.

Fig. 3. Complete circuit diagram of the PIC Digital/Analogue Tachometer.

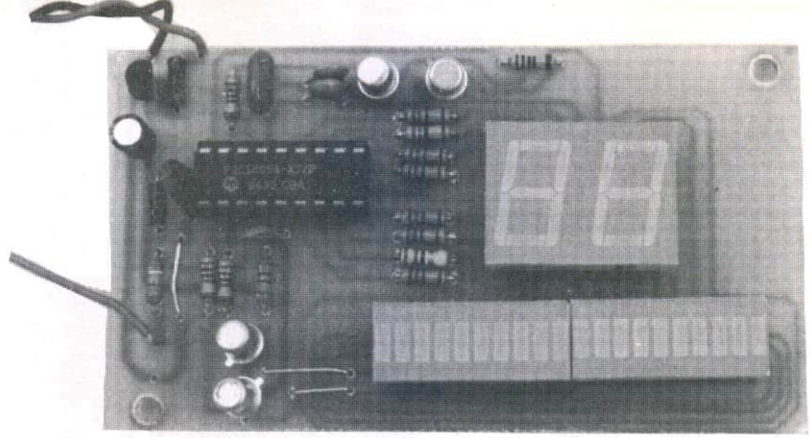


POWER SUPPLY REGULATION

The LP2950, IC2, is a low power voltage regulator that can handle input voltages of up to 30V. A reverse protection polarity diode D2 is provided to protect against wrong connections and reverse voltage transients.

Although specified as operating at 12V a car's electrical system often sees very large variations in the supply voltage even if very briefly. When a car is being started the voltage available can fall to as low as 6V as the starter motor turns over. Once started the alternator is the main source of electric current and the available voltage will typically be about 14V. Switching off the ignition produces "field transient decays" which can cause the voltage to "shoot up" to -100V for a 100µs or so.

This should give you an idea of how hostile the cars electrical system can be and how an unprotected voltage regulator could be easily destroyed.



CONSTRUCTION

With the small number of components used, the Digital/Analogue Tachometer can be built quite easily on a small single-sided printed circuit board (p.c.b.). The topside component layout and full size copper foil master pattern are shown in Fig. 4. This board is available from the *EPE PCB Service*, code 127.

The microcontroller should be mounted in a socket since it is a static-sensitive part. The displays are also semiconductor devices and therefore susceptible to electrostatic and heat damage; however, they are generally quite robust and will survive soldering as long as the technique used is good. Besides, using i.c. sockets for the displays will give these parts a very high profile on the board.

The segment driver resistors have been chosen with standard power l.e.d.s in mind. If you plan to use low power types then the value of these resistors should be increased accordingly. Note that you *cannot* mix standard and low power l.e.d.s in this circuit since they will be sharing the same segment driver resistors. For a bright display it is recommended that you use high efficiency l.e.d.s (sometimes referred to as "super red").

The bargraph is made up of two ×10 l.e.d. arrays in order to make installation easier and because they usually cost less than buying discrete l.e.d.s. The spacing between the anode (a) and cathode (k) pins gave sufficient space for routing tracks on the p.c.b.

Before you start construction make sure that all the surfaces to be soldered are clean and free of any grease, that includes the component wires as well as the board. Begin the assembly with the three wire links first and then install the resistors and the diode followed by the capacitors.

Next come the transistors and voltage regulator IC2, ensure that they do not protrude too high off the board so that they will fit in the chosen box. The i.c. socket can be fitted next followed by the dual 7-segment display and l.e.d. arrays.

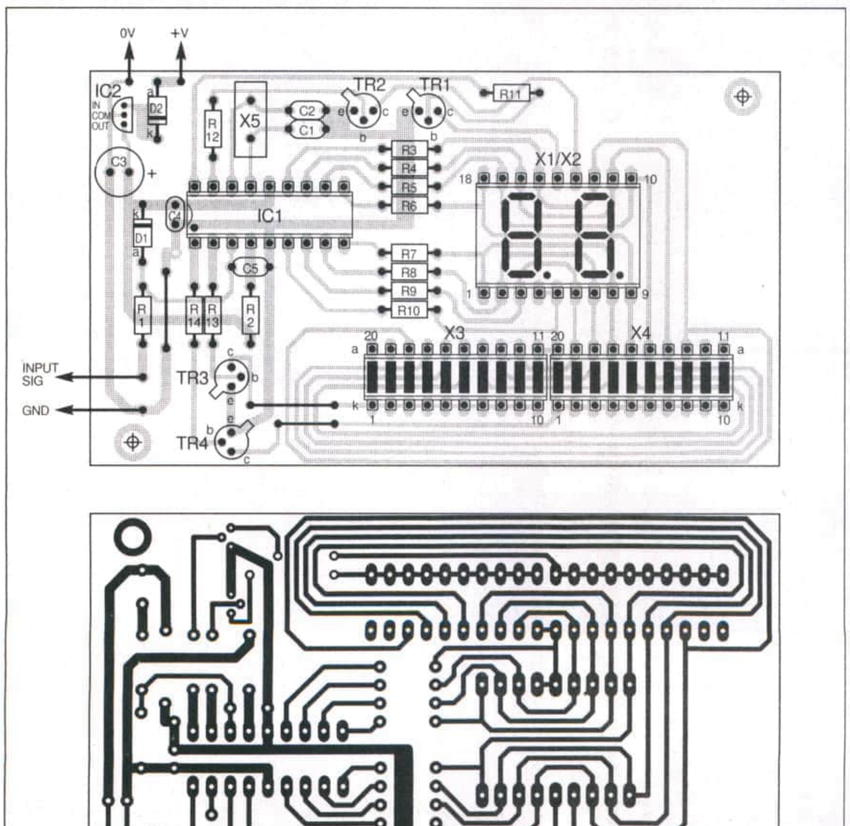


Fig. 4. Printed circuit board component layout and full size copper foil master for the PIC Digital/Analogue Tachometer.

SOFTWARE

Before the PIC16C54XT microcontroller can be asked to "perform" its duties, it needs to be programmed. A software 3·5in disk containing the source-code and a Hex file for the PIC Digital/Analogue Tachometer is available from the Editorial Office for the sum of £2·50 UK, £3·10 overseas surface mail or £4·10 airmail. This is to cover admin costs and postage, the disk is *free*. It can also be down-loaded *free* on the Internet from our FTP site: **ftp://ftp.epemag.wimborne. co.uk** .

A pre-programmed PIC16C54XT chip, (set up for a 4-stroke, 4-cylinder engine – see later) ready to plug straight in, is obtainable from Magenta Electronics. See *Shoptalk* page for details. A detailed description and listing is beyond the scope and space for this article.

The listing supplied on the *EPE* disk is for a PIC16C54XT. The configuration code will need to be set by you as it is not embedded in the source file. Set the configuration for XT, protection ON, watchdog ON.

Another PIC microcontroller besides the 16C54XT can be used as long as it will work with a 4MHz crystal. The source file will require some minor modifications to be made. The listing shows the changes needed to program a 16C84XT (this device uses EEPROM and so can be reprogrammed over and over again).

Do not use parts with the suffix ***RC*** as these are designed to be used with a resistor and capacitor in place of the crystal as a clock source and the clock frequency then generated is not stable or predictable necessitating the need for checking the calibration of the Tachometer frequently.

Having programmed or obtained a ready "blown" microcontroller, double-check the board over once again before installing the PIC and applying power to the circuit.

The walls of the specified plastic case taper inwards so the width of the case starts at approx. 53mm and then reduces gradually. Ideally, the p.c.b. should be 52·7mm wide to fit snugly inside this case, so it isn't absolutely necessary to use the mounting holes if you don't want to – but it is recommended, otherwise the p.c.b. may work loose in time.

NOTE: There can be some variation in the manufacturing process, and if the p.c.b. is too wide for the case try inserting it at a slight angle and then using the mounting holes to hold it in place.

The infra-red l.e.d. filter sheet can be glued to the outside of the case (glossy side down) in order to cover the cutouts for the bargraphs neatly and the whole project smartened up with some white graphics transfer text.

TESTING

Commence testing by apply about 12V to the p.c.b., the exact value is not important and a battery or unregulated supply will do as a temporary power source. The digital display should light and display 0 with the leading zero blanked, the bargraph should not be lit.

Now touch the input with your finger to feed a "50Hz mains hum" signal to the Tachometer. The display should now change to "15" and three l.e.d.s of the bargraph should light up. The 15 represents 1500r.p.m.

On a 4-stroke, 4-cylinder petrol engine (as found in most cars) the ignition coil will produce a frequency of 50Hz when the engine is turning at 1500 r.p.m.. If the engine you wish to fit the Tachometer to happens to have a different number of cylinders then you will need to change a number in the program to change the gate time. See Table 1 for details.

Table 1: Constants for Gate Periods

HEX	DEC	period/ms	Applications
30	48	150	4 pulses/revolution, e.g. 8 cylinder 4 stroke engines
40	64	200	3 pulses/revolution, e.g. 6 cylinder 4 stroke engines
60	96	300	2 pulses/revolution, e.g. 4 cylinder 4 stroke engines engines
C0	192	600	1 pulse/revolution e.g. single cylinder two stroke engines

To thoroughly test the circuit board get hold of a Signal Generator, which can output between 10Hz and 350Hz. Connect it to the Tachometer input and slowly sweep up the frequency range at the same time checking the displays. The bargraph should increase in length steadily and the digital display should count up steadily.

As the display steps past "99" it should change to show "--" which is an over-range indication and the bargraph should remain fully lit.

INSTALLATION

Having verified that the unit is working properly it is time to install it in the car.

Locate the ignition coil and identify the wires coming from it. The large thick wire at the very top of the coil is the HT lead which goes to the distributor and on to the spark plugs. Either side of this are two thinner wires, one of which goes to the +12V supply and the other to the contact breaker, *it is this side* (which may also be labelled CB-) from which the tachometer signal is picked up.

To make the connection from the Tachometer to the CB- side of the coil use a "lucar" spade connector (tap splice) or a "snap-lock" type which will let you tap into the wire without cutting it. Once the Tachometer pickup has been connected, carefully route it back to the passenger compartment in such a way that it does not come close to any leads that will carry high voltages or heavy currents or anything hot such as the engine.

The power supply for the Tachometer will have to be taken from a suitable point in the wiring harness. It is not possible to give specific details for this as the wiring varies so much from manufacturer to manufacturer. As a general guide find a point where +12V is present only when the ignition is *on*, thereby ensuring that when the engine is off so is the tachometer.

Ensure that there is a fuse between the 12V battery and the Digital/Analogue Tacho, if there is any doubt fit an in-line fuse. The 0V line (or chassis) can be connected to any good "ground" point on a *negative earth system.*

CASE DETAILS

If you choose the specified case then refer to Fig. 5 for the position and sizes of the cutouts. There are three apertures to be made: for the dual 7-segment display, the bargraphs and the entry/exit point for the wires.

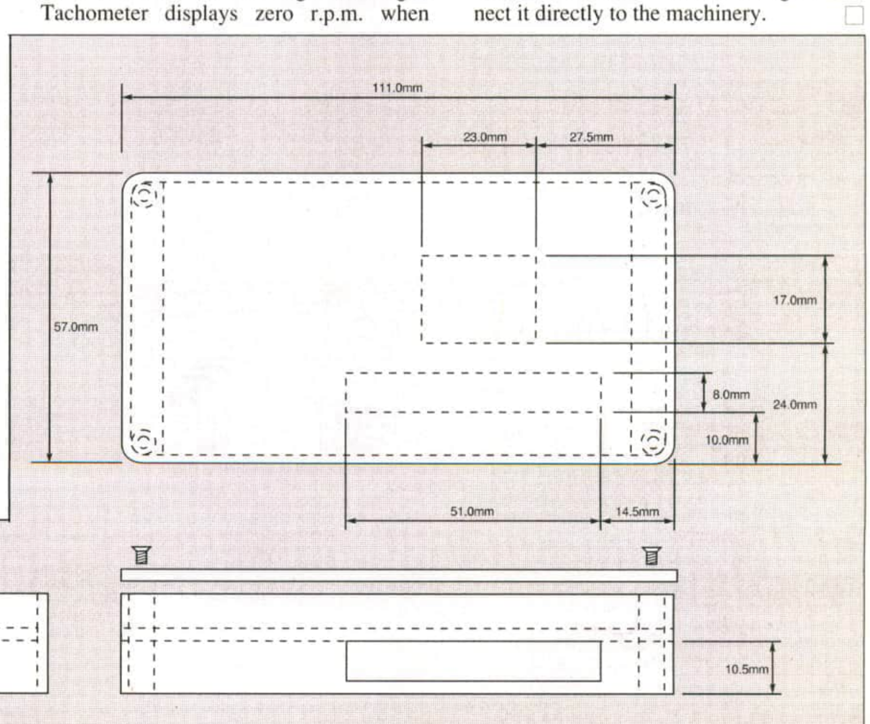
APPLICATIONS

As it stands, the PIC Digital/Analogue Tachometer displays zero r.p.m. when there is no input, and none of the bargraph l.e.d.s light up. When the input reaches 500r.p.m. the first l.e.d. will light.

Some people may prefer to have an l.e.d. lit even when the r.p.m. is zero, and another l.e.d. lighting when 500r.p.m. is reached. To do this simply connect a low value resistor (about 200 to 500ohms) between the +5V supply and the anode (a) of the l.e.d. in the bargraph preceding the one which lights up at 500r.p.m.

The envisaged application for the Tacho is as a rev-counter for petrol engined cars. With a little imagination its uses can be extended. For example, it could be used on motorcycles or boats as a rev-counter and diesel engines can be accommodated by placing a suitable sensor in front of the Tacho, such as one that can detect the vibrations from the fuel injectors. Interfacing the Tachometer to a Hall-effect sensor will permit its use with anemometers that rotate a magnet.

A non-contact Tachometer can be constructed by using a phototransistor at the input to pickup a beam of reflected light from a rotating shaft with a dab of white paint or a small piece of reflective tape paced on the shaft. The light source will need to be modulated and a high-pass filter incorporated into the receiver to provide rejection of ambient light. This form of tachometer can be used in the workshop to measure the rotational speeds of drills, lathes, motors, etc. without having to connect it directly to the machinery.



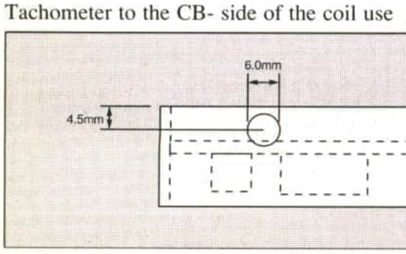


Fig. 5. Case dimensions and drilling details.