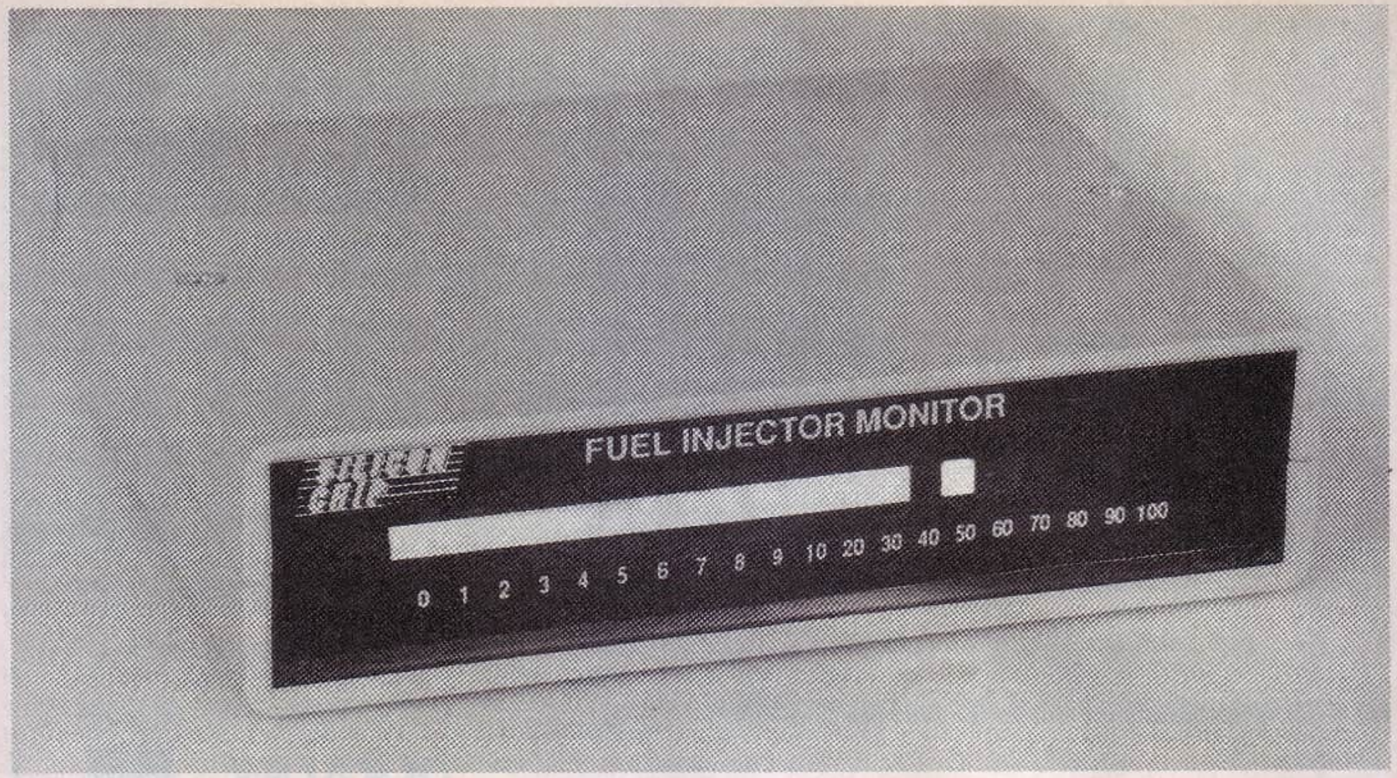


A FUEL INJECTOR MONITOR FOR CARS

Have you ever wondered how much petrol you use when you accelerate away from the traffic lights? Perhaps you would like to know how your fuel consumption increases as you climb a hill. If you have a fuel injected car, this project is for you.

By RICK WALTERS & LEO SIMPSON

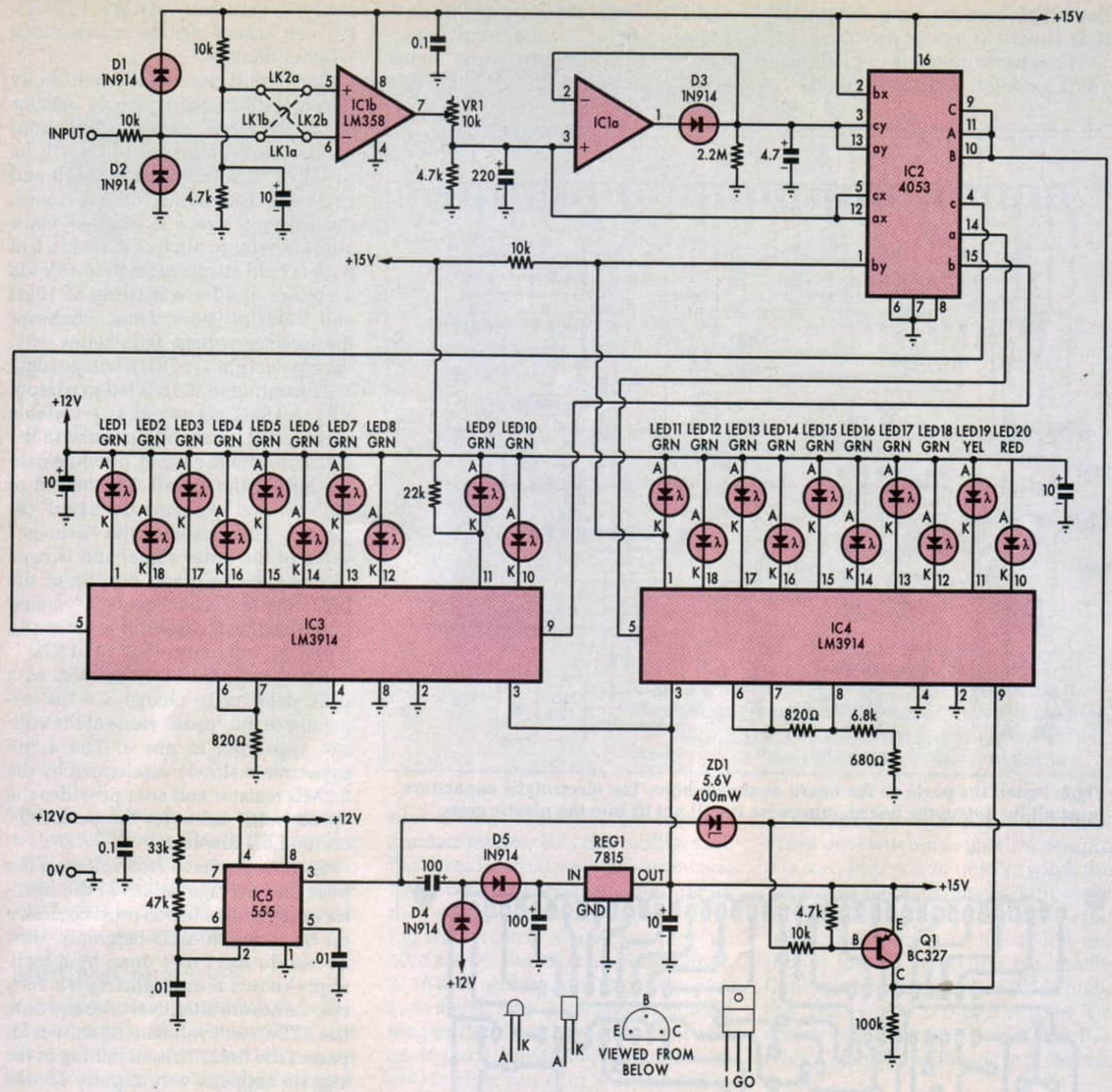
Back before cars had engine management computers, they often had a vacuum gauge which was supposed to give an indication of fuel economy. Low vacuum readings meant you were using lots of juice while high vacuum meant that you were driving with a light throttle. In practice, a vacuum gauge was often a distraction as it fluctuated wildly each time you depressed the accelerator, as you moved up or down through the gears. Some drivers even went so far as to cover up the vacuum gauge to avoid its distraction.

Now we're in the 90s and vacuum gauges are decidedly "old hat". Most modern cars have fuel injection and the drive signal to the injectors can be monitored to provide a very good guide to fuel use. The amount of fuel provided by the injectors is controlled by the amount of time they are open. When your car is at idle, the injectors are open only about 5% of the time. During normal driving, the injectors are open between 10% and 20% of the time. And when you are accelerating absolutely flat out, with the engine wound out to 5000 RPM or more and the accelerator fully open – "pedal to the metal" – the injectors will be open for more than 90% of the time.

Since the injectors are fed from the fuel rails at essentially constant pressure, the fuel used by the motor is directly proportional to the injector opening time.

The Fuel Injector Monitor is housed in a compact case, allowing it to be conveniently placed on your car's dashboard at eye level. The straight-line display consists of 20 light emitting diodes (LEDs), 18 green, one orange and one red. The display is semi-logarithmic, with the first 10 LEDs showing 10 steps of 1% from 0-9%, while the second group of LEDs covers from 10% to 100%.

The LED display takes the form of a bargraph which shows the average



FUEL INJECTOR MONITOR

Fig.1: the 4053B multiplexer (IC2) enables the LM3914 LED drivers to give a dot and bar display to indicate the average and peak injector duty cycles. The 555 timer (IC2) controls the switching of the 4053 and also steps up the battery voltage to provide for a +15V regulated supply.

opening times, combined with a brighter "peak" LED which shows more rapid fluctuations of the injector openings, as can happen, for example, when you blip the throttle. The peak LED is actually a "peak-hold" display which captures the rapid transients and "holds" them so that they can be more easily seen.

Unlike some car circuits, installation of the Fuel Injector Monitor is quite straightforward: one lead to ground (chassis) and two leads to the injector leads (one switched and the other battery positive) – more about that later.

Circuit details

The circuit of Fig.1 consists of five ICs plus a regulator, the 20 LEDs and a few other minor components.

In most modern cars, all the injector solenoid coils are wired in parallel with one side connected to the battery positive, through the ignition switch. The coils are switched to ground via a transistor when fuel is to be injected. This means that the pulse waveform fed from the injectors to our monitor is a +12V signal going to ground.

While most cars have negative-going pulse injector waveforms, we have provided for vehicles with the opposite waveform polarity. This is done via two links to allow the selection of either system. The input circuit consists of IC1, a dual operational amplifier. IC1b is used as a comparator while IC1a is used as a peak detector.

The injector signal is applied via a 10kΩ isolation resistor to diodes D1 and D2. These diodes provide transient protection for the following op amp by clamping any input signal between ground and +15V (more precisely, to between -0.6V and +15.6V). IC1 can accept signals in this range without damage.

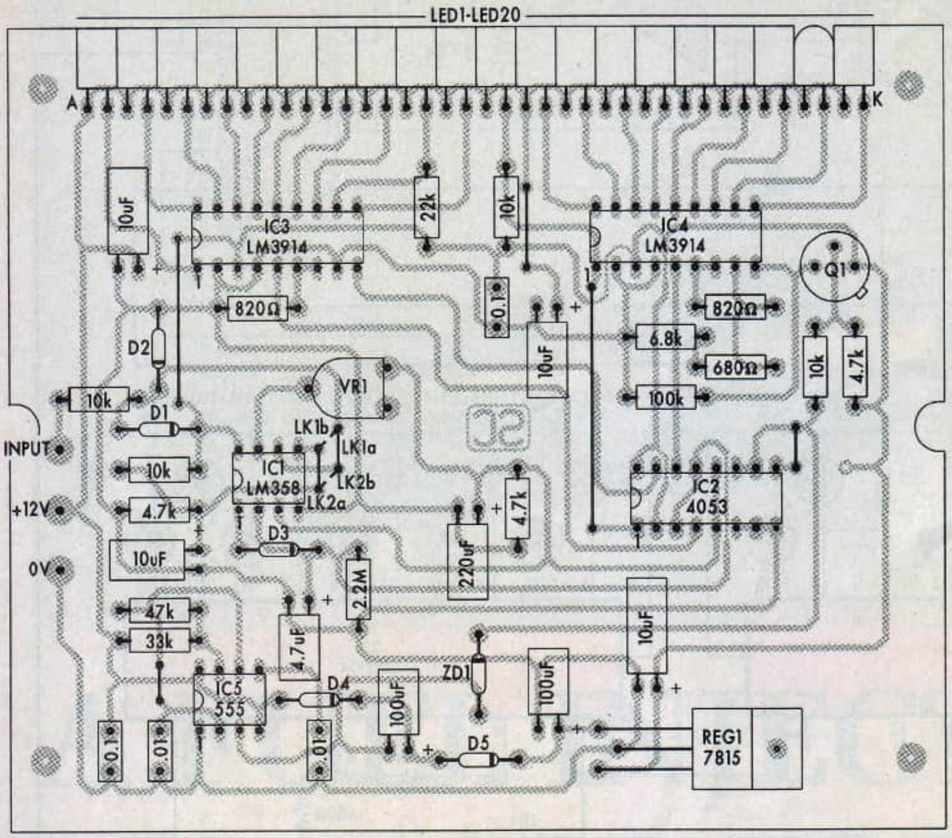


Fig.2: install the parts on the board as shown here. The electrolytic capacitors must all lie flat on the board, otherwise it will not fit into the plastic case.

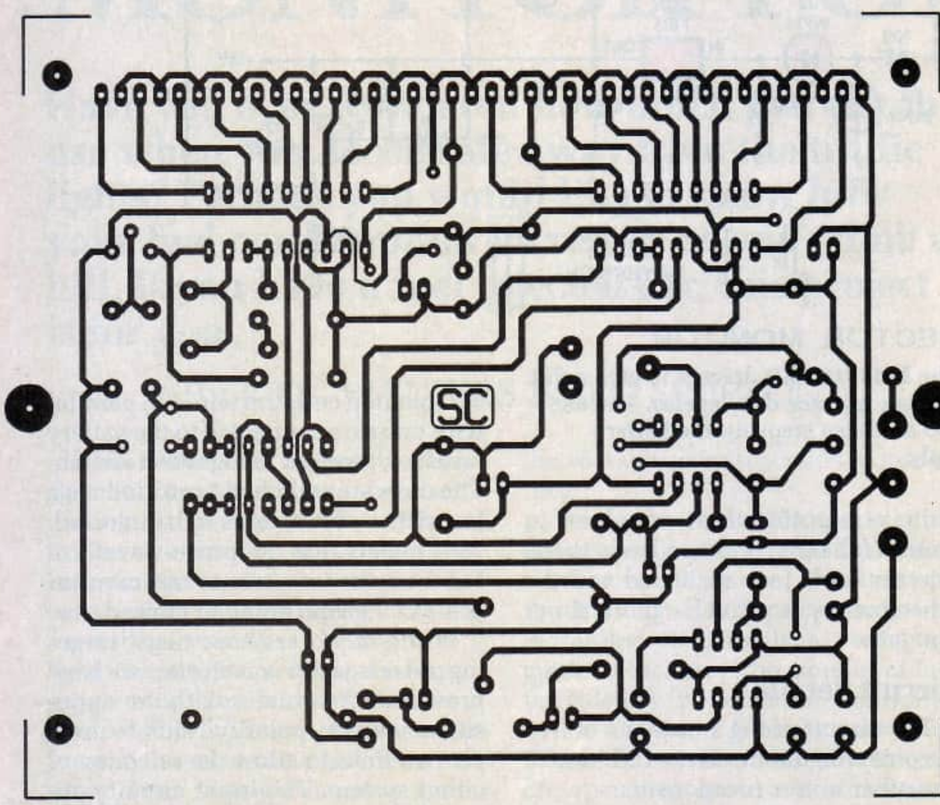


Fig.3: this is the full-size etching pattern for the PC board.

Our circuit description will apply to cars with a negative-going injector signal (the most common situation) and so links LK1a and LK2a will be installed. Ignore the links LK1b and LK2b which are shown dotted. Hence, the injector signal is applied via a 10kΩ resistor to pin 6 of IC1b. Pin 5 of IC1b is held at approximately +5V via a voltage divider consisting of 10kΩ and 4.7kΩ resistors. Thus, whenever the injector voltage falls below +5V, the output (pin 7) of IC1b will go high.

The output of IC1b is fed to trimpot VR1, a 10kΩ pot wired as a variable resistor. VR1, in conjunction with the 4.7kΩ resistor to ground, provides calibration for the circuit. The output of IC1b is used to charge the 220µF capacitor. This becomes the "average" value of the pulse signal and is used to drive the bargraph portion of the LED display. The "average" signal from the 220µF capacitor is fed to pin 3 of IC1a and to pins 5 & 12 of IC2.

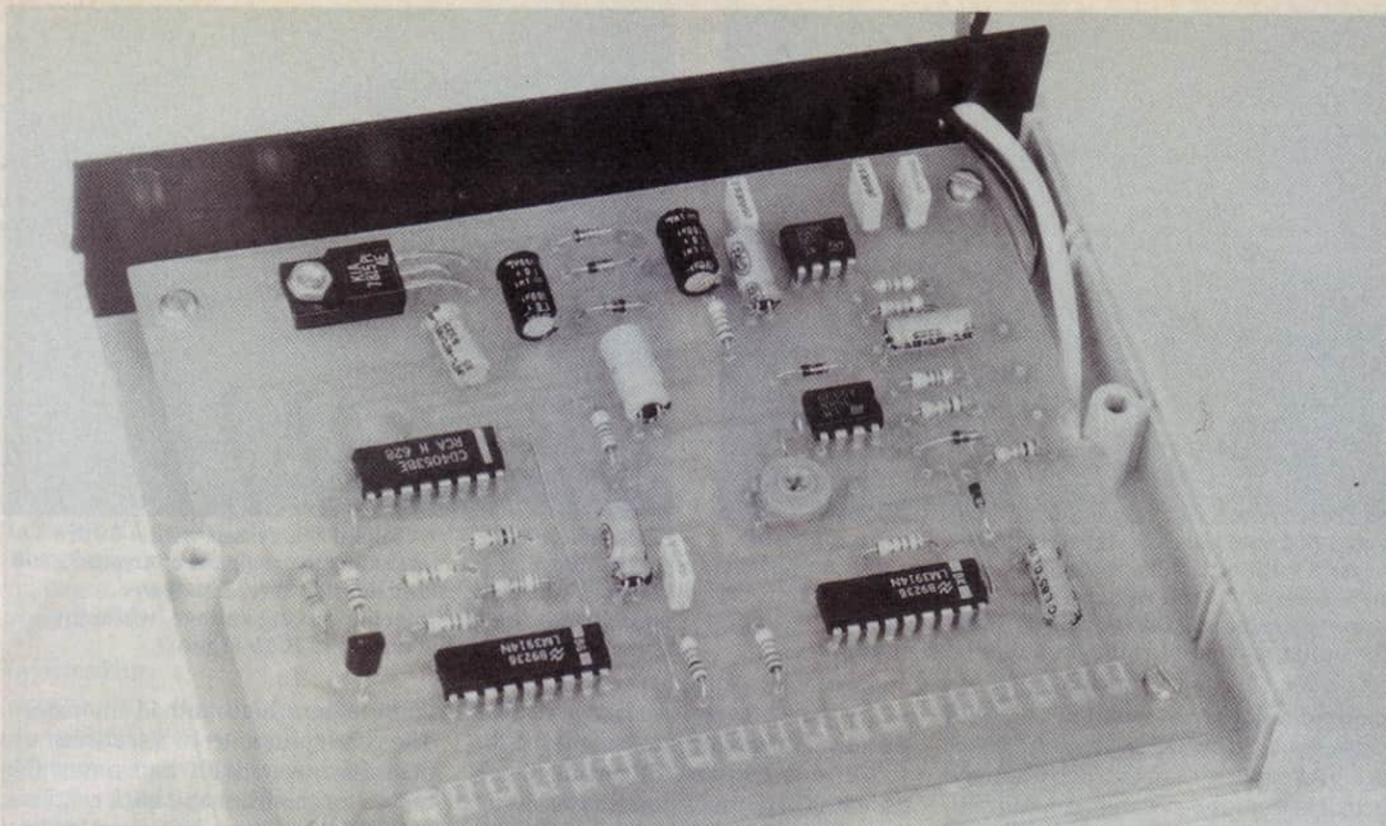
IC1a and diode D3 function as a peak detector to charge a 4.7µF capacitor to the "peak" value of the voltage appearing at pin 3. The 4.7µF capacitor is slowly discharged by the 2.2MΩ resistor and so it provides the "peak hold" value for the peak DOT on the LED display.

So now we have two voltages, the peak and average values of the injector pulse widths which must be shown on the same 20-LED bargraph. How do we do this? It is done by a technique known as multiplexing whereby two values are alternately flashed onto the LEDs, each value being shown for part of the time. This switching of the signals happens very rapidly so that our eyes are not aware of it.

IC2, a 4053, does the multiplexing and is described as a triple 2-channel analog multiplexer. It alternately switches the bar signal (pins 5 & 12) and the dot signal (pins 3 & 13) to the LED display drivers (IC3 & IC4).

IC5 controls the switching of IC2 and serves another purpose – to step up the car's battery voltage. The voltage step-up is necessary to enable the display drivers to handle the full range of signal voltage from IC1. We'll explain more about this later.

The 555 timer is arranged as an astable oscillator, with a frequency of about 1kHz. Its pulse output wave-



All the LEDs are arranged to sit flat along the edge of the PC board but because of the pin layout of the LM3914 drivers, the display reads from right to left. Consequently, the board hangs upside down in the case to make the display read from left to right.

form is fed to a voltage doubler consisting of diodes D4 & D5 together with two 100μF electrolytic capacitors. The resulting voltage of about +19V is fed to the 7815 regulator which delivers a stable +15V.

Multiplex operation

We have already referred to multiplex operation so let's now look at it in more detail. As noted above, we need to display two signals (the "average" and "peak" values) and at the same time we need to switch the display drivers, IC3 & IC4, between dot and bar modes. IC2, the multiplexer, has three internal switches and while these are not shown on the circuit, they can be identified in the following way. Switch A involves pins 11, 12, 13 & 14; switch B involves pins 1, 2, 10 & 15 and switch C involves pins 3, 4, 5 & 9. Pins 9, 10 and 11 control the position of each associated switch; eg, if pin 9 (the C switch control input) is high, pin 4 (c) is connected to pin 3 (cy) while if pin 9 is low, pin 4 is connected to pin 5 (cx).

Returning now to IC5, which provides the switching signal, when pin 3 is low, pins 9 & 11 of IC2 switch the "average" signal to the pin 5 inputs of the display drivers IC3 and IC4. At the same time, pins 9 of IC3 & IC4 are pulled low to select the bar mode. Conversely, when pin 3 of IC5 is high, the "dot" signal at pins 3 & 13 of IC2 are switched to pins 5 of IC3 & IC4 which are then switched into the dot mode.

Just to reiterate, the bar mode displays the average signal while the dot

RESISTOR COLOUR CODES

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	2.2MΩ	red red green brown	red red black yellow brown
❑	1	100kΩ	brown black yellow brown	brown black black orange brown
❑	1	47kΩ	yellow violet orange brown	yellow violet black red brown
❑	1	33kΩ	orange orange orange brown	orange orange black red brown
❑	1	22kΩ	red red orange brown	red red black red brown
❑	4	10kΩ	brown black orange brown	brown black black red brown
❑	1	6.8kΩ	blue grey red brown	blue grey black brown brown
❑	3	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑	2	820Ω	grey red brown brown	grey red black black brown
❑	1	680Ω	blue grey brown brown	blue grey black black brown

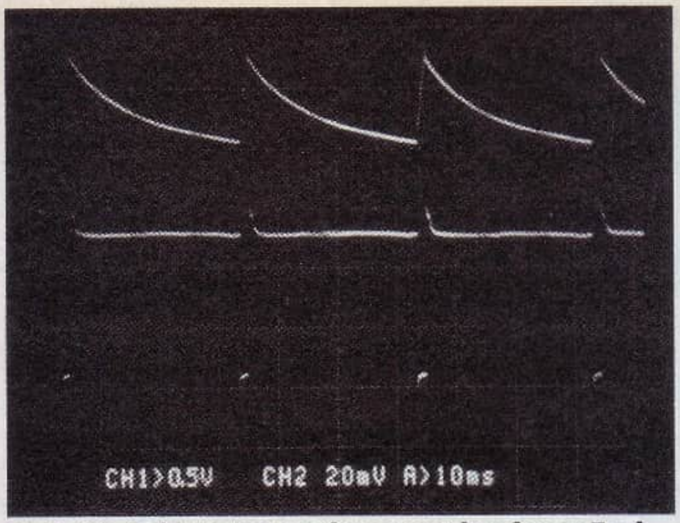


Fig.4: this fuel injector waveform was taken from a Ford Laser S with a 1.8 litre engine. The duty cycle is under 10% at around 2000 RPM with the car stationary. The lower waveform is taken directly from the injector, while the upper waveform is the output of IC1b at pin 7.

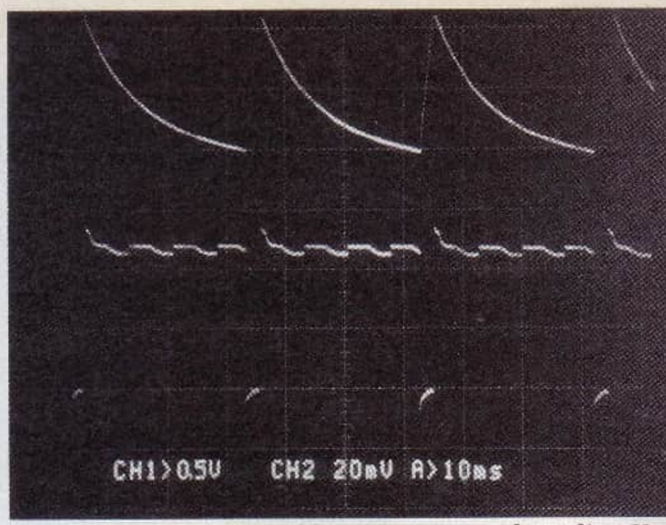


Fig.5: taken from a VP Holden Statesman with a 5-litre V8 engine, these injector waveforms are again at around 2000 RPM and the duty cycle is under 20%. The lower waveform is the fuel injector driving voltage, while the upper waveform is the output of IC1b at pin 7.

mode displays the peak which is always equal to or higher than the average. To make the peak (dot) display brighter than the average, it is turned on for longer than the average and this is arranged by giving the pulse signal from IC5 a duty cycle of more than 50%.

Part of the switching function controlled by IC5 is performed by transistor Q1 but because IC5 runs from 12V rather than 15V, its output cannot swing to the +15V necessary to ensure that Q1 is turned off. Therefore, zener diode D4 is included to allow Q1 to turn off when IC5's output is high.

IC3 and IC4, the LM3914 dot/bar display drivers, which accept analog input signals from IC1, have 10 internal comparators which drive 10 external LEDs. The input range is determined by one or two resistors. IC3 is set by the 820Ω resistor between pins 6 and 7 and ground, to accept 0.125-1.25V and display 10 output steps from 0-9%. IC4 with its extra resistors accepts 1.265-12.65V for its 10 outputs, from 10% to 100%.

Actually, these display steps should not be thought of as being absolutely precise. For example, if the 10% LED is lit, the injector pulse width can only be regarded as being above 10% but less than 20%. Similarly, if the 30% LED is lit, the injector pulse width is above 30% but below 40%.

Construction

All the components for this project, including the 20 LEDs, are mounted on a small PC board coded 05108951 and measuring 120 x 102mm– see Fig.2. The PC board is mounted in a small plastic case measuring 141mm wide, 36mm high and 110mm deep. The case splits into two sections, upper and lower, with two removable pieces for the front and back sections. The lower section has four integral pillars for the PC board but because of a layout constraint caused by the LM3914 display drivers, the PC board has had to be designed so that the LEDs run from right to left (to minimise the number of links required). To make the display read from left to right as it should, the PC board is mounted on the base of the case and then it is inverted, so that it "hangs from the roof".

Before you begin assembly, carefully check the PC board for broken or shorted tracks, especially between the pads on IC2 and IC4.

First, install the six links, diodes and resistors. The capacitors are next. Be sure to lie the electrolytics flat, as the board will not fit into the case if you stand them up. Be sure to bolt the regulator down flat onto the PC board. Lastly, fit the LEDs, ICs, trimpot and transistor. The LEDs should be mounted so that they are flush with the front edge of the PC board. We could not obtain a 5mm square orange LED for our prototype so we fitted a 5mm round one in that position.

We used a thin piece of tinted plastic for our front panel and made an adhesive front-panel label with a rectangular cutout for the LEDs. The PC board is mounted to the integral pillars using 6mm spacers and 12mm long self-tapping screws.

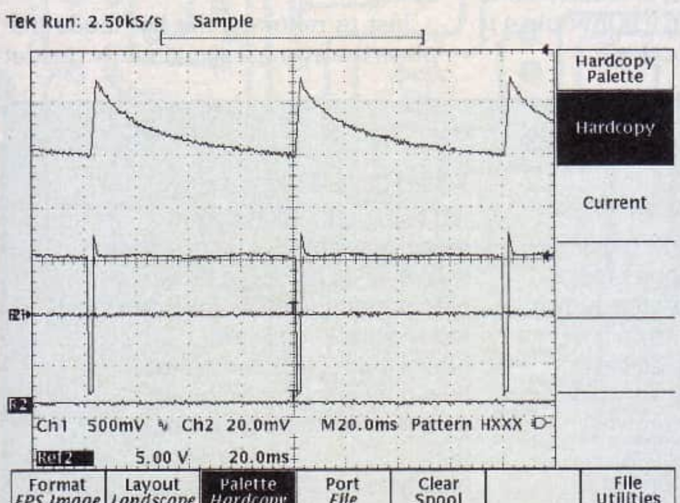


Fig.6: this is another injector waveform, taken with a Tektronix TDS744A digital oscilloscope from a Ford Laser S at idle. Note the very narrow pulse width.

After you have carefully checked all your assembly work and soldering, you are ready to do an initial power check. If you don't have a 12V power supply, you could apply power from a 12V car battery or from your car's cigarette lighter socket. Make sure that you connect the 12V leads the right way around otherwise you will damage the circuit, with IC5 (the 555 timer) the most likely casualty.

Just connect the 12V supply at first, without connecting the input lead from the injectors. All the LEDs should flash once and then the peak LED moves slowly from right to left. Now connect the injector input lead to 0V and most, if not all, LEDs should come on and stay on. If that checks out OK, you can move to the next step which is calibration.

Calibration

This will be the easiest calibration you have ever done. With the input lead connected to the 0V terminal, carefully adjust the trimpot until the red LED just comes on. You will need to wind the trimpot anticlockwise initially and then clockwise until the red LED just comes on. This calibrates the unit to correctly display an injector opening of 100%.

Installation

The trickiest part of the installation is to identify which of the two injector leads to make the connection to. Unless you have a wiring diagram for your car, you will need to make a voltage measurement on the two leads while the engine is running.

In practice, the easiest way to make a temporary connection to your injector leads is to push a pin right through the centre of each of the wires. Now start the car and let it idle for a couple of minutes to let the battery voltage stabilise. Now measure the voltage between each injector lead and chassis. One injector lead will be at the same voltage as the battery (eg, 14.4V) while the other injector lead will be slightly less, at around 13.8V. This latter lead is the one we're looking for and is the one which we will make the permanent connection to.

Now remove the pin from the other injector lead. To make a permanent connection, again the easiest method is to use a pin. This time, push the pin right through the centre of the injector lead and bend it over and twist the ends together. This way, the integrity of the injector lead itself is preserved. Now solder a lead to the pin while making sure that you don't damage the injector lead insulation. (Perhaps you might like to practice soldering to a sample pin before you do the actual job on your car!)

Having made the connection, carefully wrap it with insulation tape. Having done that, the most convenient place to pick up +12V to power the circuit is from the other injector lead, so repeat the pin soldering to the other injector lead. Now anchor the two leads running away from the injector harness with a plastic cable tie to a convenient point on the engine so that vibration is unlikely to dislodge them.

You will need to pass the two leads through the firewall into the passenger compartment. You will then need to make a connection to chassis for the 0V lead. It would also be prudent to install an in-line 1A fuse in the +12V line from the injector harness.

Now make your connections to the Fuel Injector Monitor and turn on the ignition. With the engine stopped, all LEDs should be alight. When the engine is started, the LEDs will light up to about 60% or higher and then gradually drop back to the normal idle value of around 5% or 6% as the engine warms up.

Fault finding

If you have a problem, the first thing to check is the +15V rail. There should be about +19V into the 7815 regulator and +15V at its output. If the input voltage is 0V to the 7815, then IC5 is not oscillating. Check the component values and soldering around this IC.

With the input connected to 0V (as explained in the calibration procedure), pin 7 of IC1 should measure around +14.5V. When the injector input is not connected, pin 7 should be near 0V.

If your monitor reads 100% at idle and falls as you accelerate, it means your injector signal is the wrong polarity. Remove links LK1a and LK2a and replace them in positions LK1b and LK2b. **SC**

PARTS LIST

- 1 PC board, code 05108951, 120 x 102mm
- 1 plastic case, 141 x 36 x 110mm
- 1 front-panel label, 132 x 28mm
- 1 10kΩ horizontal trimpot (VR1)
- 1 3mm x 8mm roundhead screw
- 1 3mm nut
- 1 3mm SP washer
- 4 6mm spacers
- 4 12mm self-tapping screws

Semiconductors

- 1 LM358 dual op amp (IC1)
- 1 4053B triple 2-channel analog multiplexer (IC2)
- 2 LM3914 dot/bar display drivers (IC3,IC4)
- 1 555 timer (IC5)
- 1 7815 15V regulator (REG1)
- 1 BC327 transistor (Q1)
- 5 1N914 diodes (D1-D3, D5, D6)
- 1 5.6V 400mW zener diode (ZD1)
- 18 LTL9234A 5mm square green LEDs or equivalent (LED1-18)
- 1 5mm square or round orange LED (LED19)
- 1 LTL4223A 5mm square LED or equivalent (LED20)

Capacitors

- 1 220µF 16VW PC electrolytic
- 2 100µF 25VW PC electrolytic
- 4 10µF 50VW PC electrolytic
- 1 4.7µF 50VW PC electrolytic
- 2 0.1µF MKT polyester
- 2 .01µF MKT polyester

Resistors (0.25W 1%)

1 2.2MΩ	4 10kΩ
1 100kΩ	1 6.8kΩ
1 47kΩ	3 4.7kΩ
1 33kΩ	2 820Ω
1 22kΩ	1 680Ω

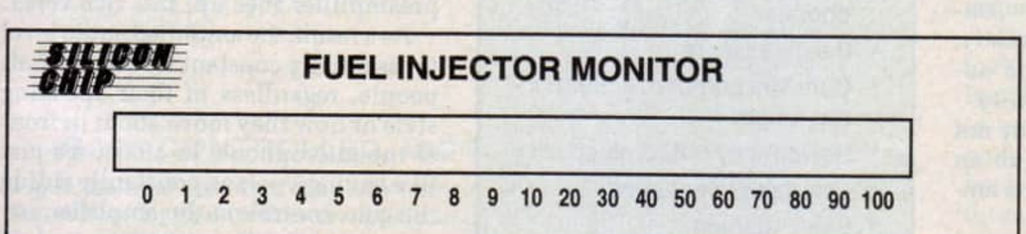


Fig.7: this is the full-size front panel artwork.