PROJECT

# Engine Efficiency Meter

### A unit that helps you to drive in the most fuel efficient way.

### Steve Garrison

We have our own domestic version of a black hole known as the family car fuel tank — whatever the noxious substance we attempt to run our car on, be it gasoline, diesel, cooking oil, etc., we are constantly astounded by the rate at which the needle plummets towards the red line. There have been a myriad of additives proposed to alleviate this depressing syndrome, some mechanical, some chemical, and of course a plethora of electronic circuits. If you're frightened of performing major surgery on your pride and joy, try this little circuit instead.

## Design Basis

The project is based on the simple fact that the engine is a device designed to convert energy stored in the chemical bonds of the chosen fuel into rotational kinetic energy — torque — at the wheels. The efficiency of this conversion is expressed by the torque curve of the engine — the curve for a typical car engine is shown in Fig. 1.

It shows that the engine produces more torque at some speeds than at others, the peak being somewhere near 3,500rpm in this case. This is different from the maximum power, which peaks much higher up the rev range and in a very inefficient operating range of the engine. Using this knowledge — that we get a higher efficiency of conversion at the top of the torque curve — the basis for this meter can now be understood.

The design intent is that the circuit should be able to pick out the peak of the torque curve, and be able to display its successful detection to the driver of the vehicle. It uses an engine speed input taken from the ignition coil which is then processed by a digital band-pass filter to drive a tricolor LED as the indicator. The LED shows red outside the chosen band, and green when the area of peak torque (and thus efficiency) is reached.

The circuit is continuously variable when it comes to setting the speed band, allowing you to match it to any vehicle easily. It could, therefore, easily be used as a "red-line" warning for cars without rev-counters.

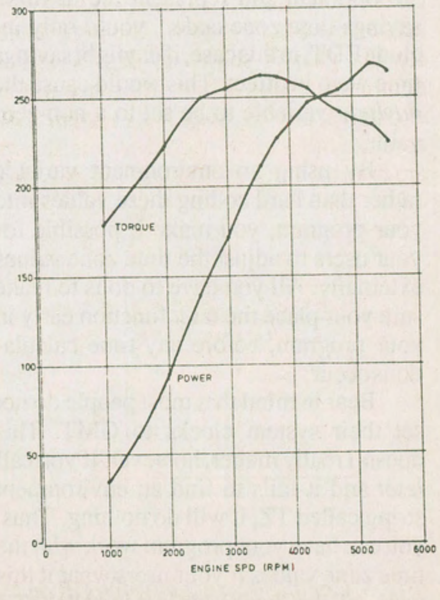
## Circuit Description

The input signal for the circuit (Fig.2) is taken from the ignition coil of the vehicle, where we can obtain a signal proportional in frequency to the speed of the engine. The connection is made to the low tension terminal of the ignition coil which is switched by the points (remember those?), or, more commonly these days, the ignition amplifier. This point is switched between car supply and ground at controlled times to generate the HT in the secondary of the coil, which is generally visible as sparks at the plugs.

The input circuit components (R1, D1, C1) clamp this signal to prevent any high voltage spikes or high frequency noise from entering the system, which could cause spurious triggering or fried chips. The components are mounted at the engine end of the cable to prevent the undesirable signals getting anywhere near our circuit board. This sanitized signal is then relayed via the protective shielded cable to the main body of the circuit, where it is to be used as a clock signal, varying with the speed of the engine, and thus available for digital filtration

The speed signal is used to trigger two monostable blocks, contained in the 4538(IC1). The construction of these electronic blocks allows us to trigger their outputs into a transitory (or unstable) state for a period of time which we can set by external components i.e. pulses to order. These blocks are monostable since they

*Fig. 1. The relationship of torque and power to engine speed.*



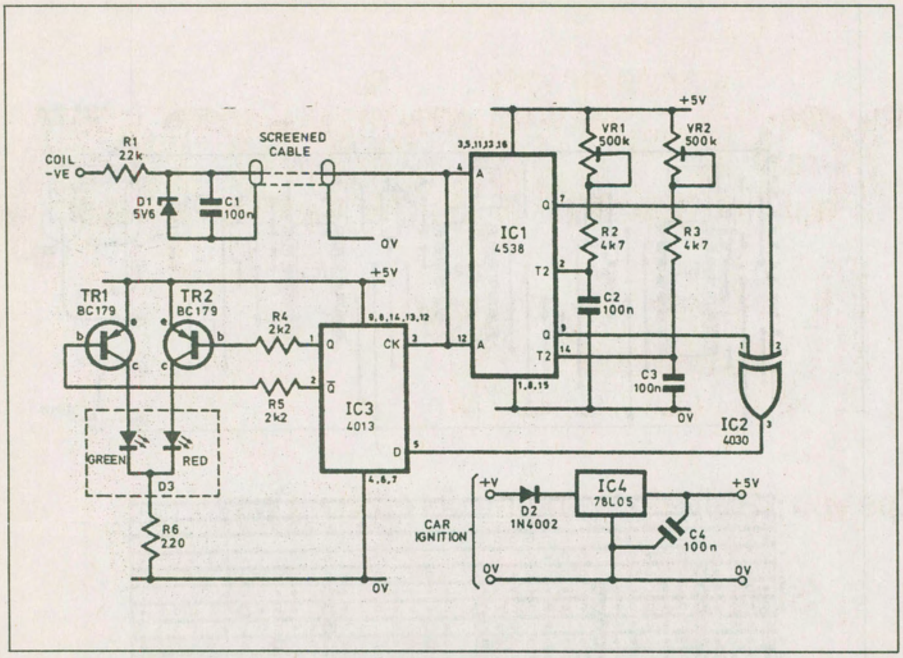


*Fig. 2. Circuit diagram of the Engine Efficiency Meter.*

return to their rest (or stable) state after the timed period, whereas a bistable block would remain in the new state until it was retriggered — it has two stable states.

The circuit shows that we use both of the monostables in IC1 and that both have similar timing components specified around them. Preset multiturn potentiometers are used to set the pulse times accurately, since it is these that will determine the filter cut-off points.

As mentioned already, both monostables are triggered together and the pulses that appear at their outputs are fed to an exclusive OR gate (IC2) which effectively acts as the filter element. The logic table for the gate is shown in Fig. 3 and it demonstrates the subtle difference of the exclusive device over its standard OR companion, namely that if all the inputs are high the output switches low. It is this characteristic that creates the opportunity for its use in this role.

| | INPUTS | | OUTPUTS | | |
|---|---|---|---|---|---|
| | A | B | OR | EXOR | |
| | 0 | 0 | 0 | 0 | |
| | 1 | 0 | 1 | 1 | |
| | 0 | 1 | 1 | 1 | |
| → | 1 | 1 | 1 | 0 | ← |

*Fig. 3. Comparison of two input OR and EXOR gate functions.*

## Filtering

To explain how the filtering is achieved, we must consider another characteristic of the particular monostable we are using, namely that it can be retriggered while still in its "unstable" state. Therefore, we can extend the length of the pulse at its output indefinitely if we keep triggering the block before it gets a chance to "time-out".

By careful specification of the point where the monostable just starts retrigger-

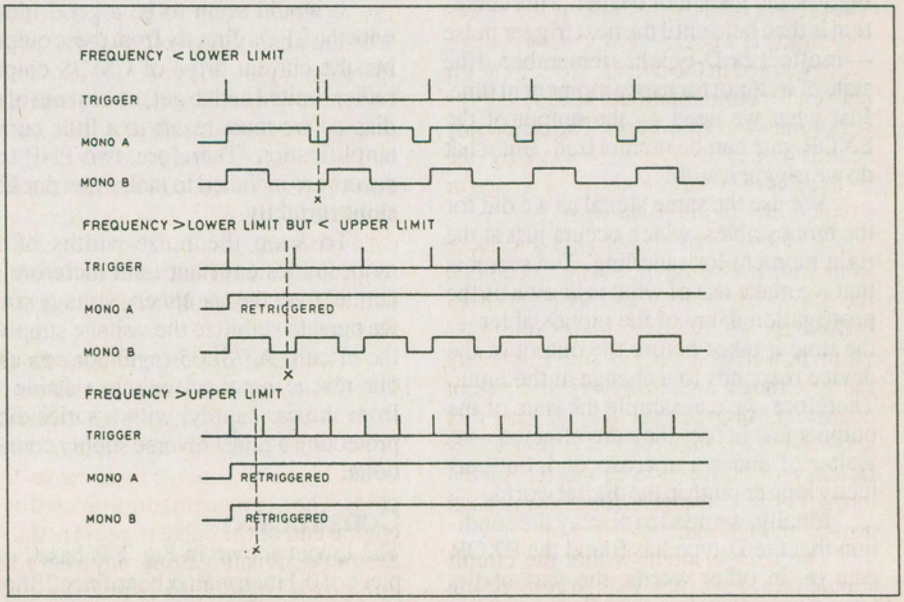


*Fig. 4. Changes in monostable output as engine speed increases.*

## Parts List

### Resistors

| | |
|---|---|
| R1 | 22k |
| R2,3 | 4k7 |
| R4,5 | 2k2 |
| R6 | 220 |

### Potentiometers

| | |
|---|---|
| VR1,2 | 500k multiturn trimmer |

### Capacitors

| | |
|---|---|
| C1-4 | 100n |

### Semiconductors

| | |
|---|---|
| D1 | 5V6 Zener |
| D2 | 1N4002 |
| D3 | tricolor LED |
| TR1,2 | BC179 or BC479 |
| IC1 | 4538B |
| IC2 | 4030B |
| IC3 | 4013B |
| IC4 | 78L05 |

### Miscellaneous

Shielded connecting lead — see text; Veroboard, 38 holes by 16 strips; auto type connecting wire; plastic case approx. 115 x 75 x 35mm; DIP IC holders, 16 pin, 14 pin; connectors; fasteners, etc.

ing, we can pinpoint a particular frequency of the trigger/clock pulses, and therefore, define the cut-off points for our filter. By setting the monostable pulse-widths to different values, we can define a window of frequencies that can correspond to the peak of the torque curve, and Fig. 4 shows the three states of the monostable outputs as the frequency increases.

In the figure, monostable A is set to a longer pulse width than monostable B, which means it will begin retriggering at a lower frequency than monostable B. Take a careful look at the output states — can you see how the exclusive OR gate is going to help us? If we sample the monostable outputs at the point marked X, just before we trigger them, we can use this gate to determine what frequency state we are in. At a frequency below that for retrigger of A the gate output is 0, and above this but less than the retrigger frequency of B we get an output of 1, and at a frequency when both monostables are retriggering the output returns to 0. A digital filter perhaps?

## Output

The remaining task, as I have suggested, is to sample the output of the EXOR gate to determine the frequency range we are in. And also latch it in some sort of memory to be able to display it to the driver. This function is achieved by a cousin of the monostable — the bistable. We use a specialized version in this circuit, known as the D-type, and in the configuration shown here (IC3), whenever it is triggered, the output assumes the same state that if finds on the D input at the instant of trigger. This condition is then held until the next trigger pulse — in effect the D-type has remembered the state of its input for us at a moment in time. Just what we need — the output of the EXOR gate can be memorized. But what do we trigger it with?

We use the same signal as we did for the monostables, which occurs just at the right moment for sampling. The secret is that we make use of what is known as the propagation delay of the monostables — the time it takes before the output of the device responds to a change at the input. Therefore, we can sample the state of the outputs just before they are affected — a matter of under a microsecond, but perfectly long enough in the digital world.

Finally, we need to display the condition that the D-type has found the EXOR gate in, in other words, the part of the torque curve that we are on. By using other circuitry in the D-type to good effect, we can do this quite simply. The bistable has complementary outputs, which means that there is a "straight" output and an inverted output, known as Q and **Q**. When the circuit detects a 1 at the output of the EXOR gate, Q is 1 and **Q** is 0, and the reverse when it detects a 0.

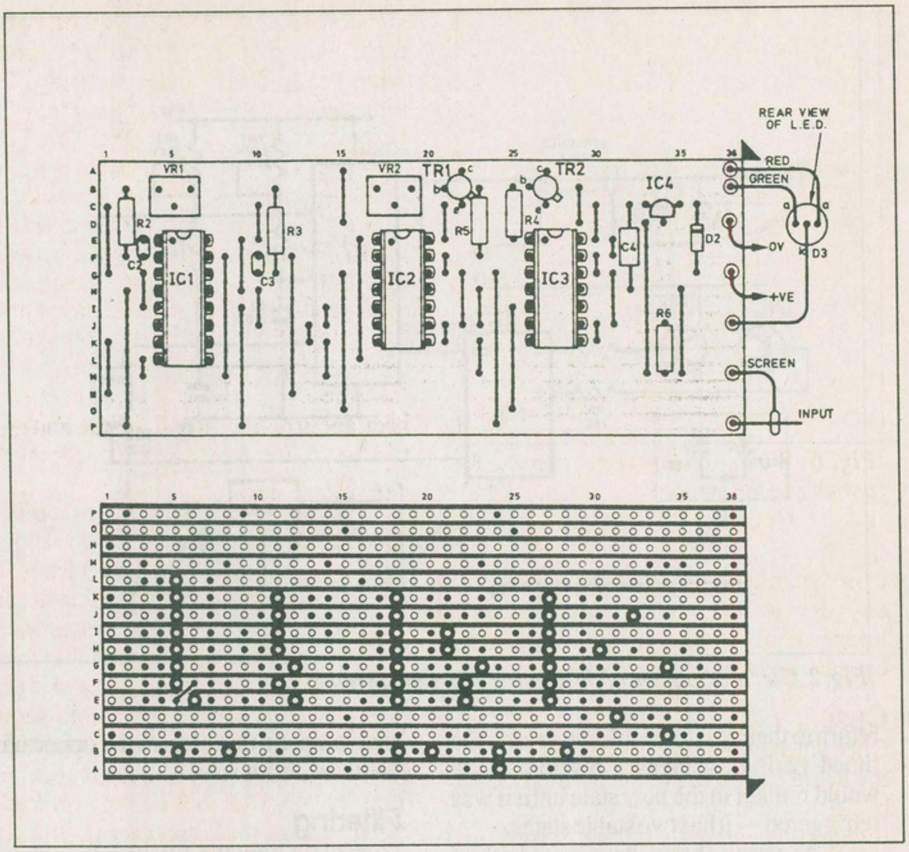


*Fig. 5. Veroboard layout and wiring. Note the underside link on IC1.*

It would seem to be a good idea to wire the LEDs directly from these outputs, but the current drive of CMOS chips is rather limited and to get the best out of our display we must resort to a little current amplification. Therefore, two PNP transistors are included to make sure our LED shines brightly.

To keep the pulse-widths of the monostables constant (and therefore accurate) over the car battery voltage range, we need to stabilize the voltage supply to the circuit. A 78L05 regulator comes to our rescue here, providing a stable 5V from the car supply, with a series diode protecting against reverse supply connections.

## Construction

The layout shown in Fig. 5 is based on a piece of 0.1 inch matrix board size 38 holes by 16 strips. This may, of course, be increased to suit a particular box, or if mounting holes are to be included, but the size is felt to be the minimum to keep construction easy. Having cut the board, the track breaks should be made as indicated, either by using the appropriate spotface cutter, or a sharp drill bit. Before component assembly commences, the board mounting holes should be drilled — the location of these is shown on the layout diagram, with adjacent track breaks to prevent electrical shorts if metal mounting equipment is used.

And so to the component assembly stage, and it is recommended that this sequence is followed — IC sockets, links, capacitors, resistors, and terminal pins. Make sure that the copper tracks are bright and clean before beginning to solder — a rub with a piece of emery cloth or a PCB cleaning stick would do the job. Not forgetting also that a soldering iron tip in a similar condition helps enormously. The result of a little care and attention here will be quick soldering, tidier joints, not to mention a more reliable construction.

On the completion of the population of the board, a few careful minutes should be spent checking the board layout — the component positions, the links, all the track breaks, and most importantly, a

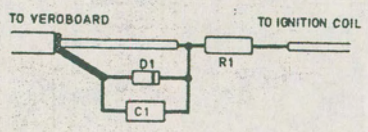


*Fig. 6. Wiring of the protection components in the input lead.*

close examination of the copper side for any dry joints, solder splashes, and bridges between tracks. Time spent here can save hours of trouble later on.

## Case

Once you have confidence in your efforts, the board can be temporarily fitted in the box using stand-off pillars as necessary. Flying connections to the circuit can now be added — these being to the tricolor LED (D3), signal input, and power.

If it has been decided to mount the LED on the box itself, a suitably sized and positioned hole should be drilled (taking care not to demolish the circuit board). A plastic bezel and collar may be used, or the LED simply pushed through and glued. Wiring should be undertaken with care as there are various approaches to tricolor LED leg identification by different manufacturers. Careful sleeving of the connections is recommended here to prevent shorts.

Alternatively, if it is decided to mount the LED on or in the car dashboard, remote from the box, a long flying lead can be fitted. Sleeving of the connections would be essential here to provide strain relief. Individual wires could be used or some low current 3-way power cable.

## Car Connections

Another hole in the box will be required for the signal pick-up cable, which is specified as single core, overall shielded. There are two connections to the board for this cable — one for the shield and one for the signal wire. Cut back about half an inch external insulation, and separate all shield wires from the central wire, twisting them into a bunch that can be soldered onto the shield terminal pin. Trim the insulation from the signal wire carefully back a quarter of an inch, and, having twisted the exposed wires neatly, solder to the signal pin. Tinning the cable ends and the terminal pins beforehand makes life a little easier.

The other end of this cable is a little more complicated, for this is where the connection to the signal source will be made. First assess the distance between the box mounting position and the car ignition coil — not as the crow flies, but by the safest route avoiding fan blades, exhaust pipes, battery acid, etc. then cut the cable to length. Strip the outer insulation back about one and a half inches, and refer to Fig. 6 for how the components fit together.

Note that an extra piece of cable is added at the extreme end, and this should be of the type used for the power leads. To improve the long-term survival chances of the assembly in the engine compartment, it is recommended to lacquer/conformal coat the components than seal them in heat shrink or epoxy resin. The photo shows the final item with the connection wire protruding from the sensor. Finally, a hole needs to be provided for the power leads, which should be attached to the appropriate terminal pins, and cut to the desired length, having decided on the power supply point in the vehicle.

Before inserting the integrated circuits, a couple of final checks are advisable. Measure the resistance across the power leads to see if there are any shorts that haven't been spotted, then if all's well, remove the meter and apply 12V to the circuit. Use the meter to check that the ICs get a 5V supply to their power pins (see circuit diagram_ — wire extensions to the meter probes are useful to get into the IC sockets. Remove the supply ready for the grand finale — the insertion of the ICs, not forgetting to take care over identification, orientation, static, and pins bent underneath.

## Testing and Calibration

With the whole circuit assembled, it must now be calibrated to produce a meaningful display. The simplest way is to use a vehicle with a believable rev-counter and make the adjustments with the unit temporarily connected. Check the workshop or owners manual for the vehicle into which the unit is to be finally installed to find the engine speed at which the peak torque is developed, and that the engine on the calibration car has the same number and configuration of cylinders.

To define our window of peak torque, write down a figure for the upper limit 500 RPM above this speed, and the lower limit 500 RPM below, these figures being chosen so that the "green" window is not too difficult to maintain when driving. Hook up the unit ot the vehicle to be used for calibration, taking care with the polarity of the supply connections. The fused radio supply may be a handy point to use for a supply source. Now attach the end of the sensor cable to the switched terminal of the ignition coil (normally marked -ve) ideally by using a Lucar connector on to the spare blade, or with a Scotchlock connector.

Having verified that the cable is away from moving parts and the LED is lit up, turn VR1 and VR2 clockwise to their positions of least resistance. Then start the engine and rev to the lower limit calculated above. While holding the speed at this value, turn VR1 slowly anti-clockwise until the LED just changes from red to green. This pot. is now adjusted. Now rev to the upper limit and adjust VR2 similarly until the LED just changes from green to red.

The unit is now calibrated and can be permanently installed on the chosen vehicle. If the adjustments don't appear to be having much affect on the LED, check all the connections, especially the one to the coil which should be switching between 0V and 12V either through the action of the points or the drive of the ignition amplifier.

## In Use

The Efficiency Meter seems to be of the most use when the vehicle is cruising, and thus under stable throttle conditions where the "green" can be maintained quite easily. You may be surprised to learn the difference between what feels like a "happy" cruising speed, in comparison with that indicated by the meter.

Since the settings for the thresholds are continuously variable, the circuit can be used for a variety of tasks on the car that are engine speed linked — such as a rev limit warning to prevent engine overspeed, or even, with a few imaginative modifications, a radio volume control which increases the sound level in "harmony" with engine noise.

In fact, the unit can be driven by any square wave applied at the input as long as the amplitude is 5V or greater. As a consequence, the circuit finds applications far beyond vehicle systems. ■