Part 1: By John Clarke

High-Energy Electronic Ignition System

This new circuit improves upon a traditional high energy electronic ignition system. It uses an IGBT ignition driver rather than the expensive high-voltage Darlington used in older designs. You can use it to replace a failed ignition module or to upgrade a mechanical ignition system when restoring a vehicle.

IT'S HAPPENED TO many of us – one day, you are driving around in a perfectly serviceable if older vehicle and then it quits on you, or it simply won't start the next morning. You take it to your local friendly mechanic who tells you that the ignition module has failed and will need to be replaced, but because of the age of the vehicle (and possibly its overseas origin) the repair job will cost you many hundreds.

However, you are an *EPE* reader, so you have a big advantage; you can build this substitute module for a fraction of the cost. Or maybe you have an older vehicle which has the old points ignition and you want to upgrade it to electronic ignition. Once again, our new module is the answer.

This new *High-Energy Ignition* suits vehicles with points, Hall effect/Lumenition sensors, optical sensors (eg, Crane or Piranha) and reluctor pickups. In fact, it will work with virtually any ignition system that uses a single coil, even those controlled by an engine management computer.

Better and simpler

We've improved on older electronic designs in a number of important ways. The main change is the use of an IGBT (insulated-gate bipolar transistor) ignition driver. This features integrated protection and is the type of device used in virtually all new cars.

The Darlington transistors used in older designs are not only larger and more expensive, but require a string of Zener diodes to protect them against the high-voltage back-EMF from the ignition coil. Plus, they require extra driving circuitry, some of which is bulky, that the IGBT simply does not need. The resulting, much smaller module will be much easier to install, especially in motorcycles.

We have also built a self-test feature into this unit, which means you can do a bench test to check it's working without needing a signal source to

Features

- Multiple trigger source options
- Trigger invert option
- Adjustable dwell time
- Option for output to follow input
- Spark test mode
- Tachometer output
- Adjustable debounce period
- Dwell compensation for battery voltage
- Simplified design using ignition IGBT to switch the coil
- Coil switch-off with no trigger signal

drive it. Similarly, it can be used as a stand-alone ignition coil tester.

This system uses a PIC16F88 microcontroller as the 'smarts', and naturally we have worked hard to improve the software over older designs.

Advantages of the IGBT

Older electronic ignition designs used a Darlington transistor to switch the ignition coil (eg, the BU941P and the MJH10012) – both are high-voltage transistors specifically intended for use in automobile ignition systems. But that approach has been obsolete for some time and all new cars now use IGBT ignition drivers, enabling a much simpler circuit.

Our previous Darlington circuits (eg, *EPE*, Sep-Nov 2009) were similar to that shown in Fig.1(a). The 100Ω 5W resistor provides 120mA of base drive to ensure that the Darlington transistor switches on fully – ie, it is saturated. Transistor Q2 is driven from a 5V signal and when on, shunts Q1's base drive to ground to switch it off. Q1 also required four series 75V Zener diodes to clamp the coil voltage to about 300V (to protect the transistor).

With an IGBT coil driver (Fig.1(b)), none of this extra circuitry is required. The IGBT is effectively a cross between a transistor and a MOSFET (a hybrid, if you like). Like a MOSFET, it is easy to drive from a voltage source, but it has the high-voltage performance of a bipolar transistor and is capable of switching the inductive load of the ignition coil.

As with a logic-level N-channel MOSFET, it is switched on when 5V is applied to its gate terminal via the 1kΩ resistor, while a low gate voltage switches it off.

The Zener diodes are no longer necessary because this type of IGBT incorporates internal voltage clamping to protect both the gate and the collector. When the collector voltage exceeds about 360V, an internal Zener diode conducts and switches the IGBT on to shunt the current to ground. The gate is protected from over-voltage with internal back-to-back Zener diodes.

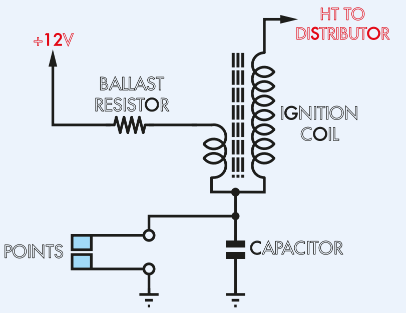


Fig.2: the Kettering ignition system uses points to interrupt the current through a coil. When the points open, the coil's magnetic field collapses and this produces a high voltage in the secondary, which is fed to the spark plugs via the distributor and the plug leads.

Kettering system

Fig.2 shows the arrangement for a Kettering ignition, which is the good old-fashioned points system. It comprises points (operated by a cam in the distributor), a capacitor (also known as the 'condenser'), an ignition coil and a distributor.

The primary winding of the ignition coil is connected to the +12V supply, and when the points are closed, current flows through the coil, causing energy to be stored in its magnetic field. This field collapses when the points open, generating a high voltage. The coil secondary has many more turns

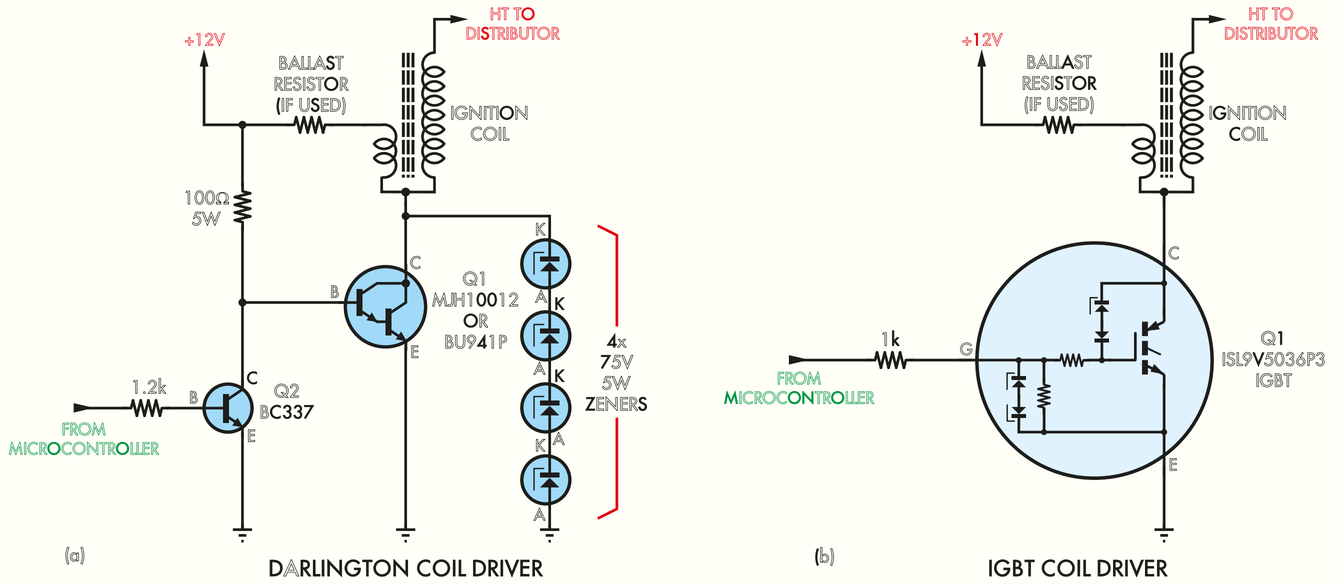


Fig.1: most cars of the last 20 years use an electronic trigger pick-up and an engine management computer to drive an electronic power device to switch the ignition coil on and off. Our previous designs used a Darlington transistor to switch the ignition coil as shown at (a), while our latest design uses an IGBT ignition coil driver to do the job, see: (b). The IGBT has in-built protection and this greatly reduces the parts count, increases reliability and simplifies construction.

Specifications

Debounce: 166µs to 5ms in 30 steps

Dwell: 129µs to 26ms in 200 steps (graded for more resolution at the lower values) for signals above 3.125Hz. Below 3.125Hz, the dwell automatically increases to the full period between firing minus the 1ms spark period.

Latency from trigger edge to firing: 18µs (10µs due to the IGBT response time)

Spark test rate: 15-75Hz (adjusted using trimpot VR2)

Spark test dwell: 129µs to 26ms (no dwell extension with battery voltage included)

Coil switch-off delay: after 10s with no trigger signal for debounce period above 2ms; after 1s for debounce period below 2ms

Dwell extension with battery: progressively increases from 2x below 12V through to 4x at 7.2V supply and below

Spark period: 1ms minimum

Maximum RPM for 1ms debounce and 1ms spark: 15,000 RPM for 4-cylinder, 10,000 RPM for 6-cylinder and 7500 RPM for 8-cylinder engine (4-stroke)

than the primary and so it produces a higher voltage again, creating a spark across the spark plugs in the engine.

The capacitor is there to prevent unnecessary arcing across the points, which would otherwise quickly become pitted and worn. Even so, there will always be some contact damage to the points due to sparking and so they need to be replaced on a regular basis – unless, that is, you install our electronic ignition module.

The coil charge period and the spark duration is set by the points' opening and closing periods. These are determined by the distributor cam lobe design and the points gap setting. During the dwell period, the points are closed to charge the coil. This dwell period reduces as RPM increases; at high RPM, spark energy can drop off badly as the coil does not have sufficient time to fully charge between each spark.

Refinements to the Kettering system allow the ignition timing to vary with RPM and manifold vacuum (ie, engine load). The RPM advance uses a system of centrifugal weights that move outward with higher rotational speed. These weights then advance the position of the cam and its lobes relative to the distributor drive shaft from the motor.

To vary the spark with engine load, a vacuum-driven actuator can rotate the points relative to the camshaft to produce timing changes with varying manifold pressure.

When starting the engine, the high starter motor current draw drops the battery voltage, reducing the spark voltage. This effect is worst right when maximum spark energy is needed; especially starting in cold weather. To solve this problem, the ignition coil is designed to deliver a healthy spark even with a ballast resistor connected in series with the 12V supply. During starting, the ballast resistor is shorted to increase the coil current drive and thus maintain sufficient spark energy.

Electronic ignition

Adding a switching transistor to a Kettering ignition system has many advantages. The main one is that the points no longer need to carry a high current – only enough to switch the transistor (and to keep the points clean). This minimises points wear, so that the only significant wear is to the rubbing block. That wear is insignificant and so the engine doesn't need to be re-tuned anywhere near as often.

Alternatively, the points can be replaced by Hall Effect, reluctor or optical triggering, thereby reducing ignition system maintenance to virtually nothing.

A secondary advantage of electronic ignition is that the dwell and spark duration are much more consistent, giving smoother engine running. The effect of reduced spark energy at higher RPM can also be alleviated, since with the electronic ignition module, coil charging can begin immediately after spark firing if necessary and the spark period can be kept low (1ms).

Features

Note that this particular design does not incorporate programmable timing. Instead, it uses the existing timing advance curve that is incorporated into the distributor. If you need a programmable electronic ignition system, we published a suitable design in the Sep-Nov 2009 issues of *EPE*.

This new unit includes an adjustable debounce period, adjustable dwell time and increased dwell with low battery voltage. It also features a special 'follow' operational mode for points if the distributor shaft, points cam and points are badly worn (more on this later). In addition, there is a spark test facility that allows the dwell to be easily adjusted to suit the ignition coil in use.

The spark test feature also allows an ignition coil to be tested on the bench over a range of spark frequencies.

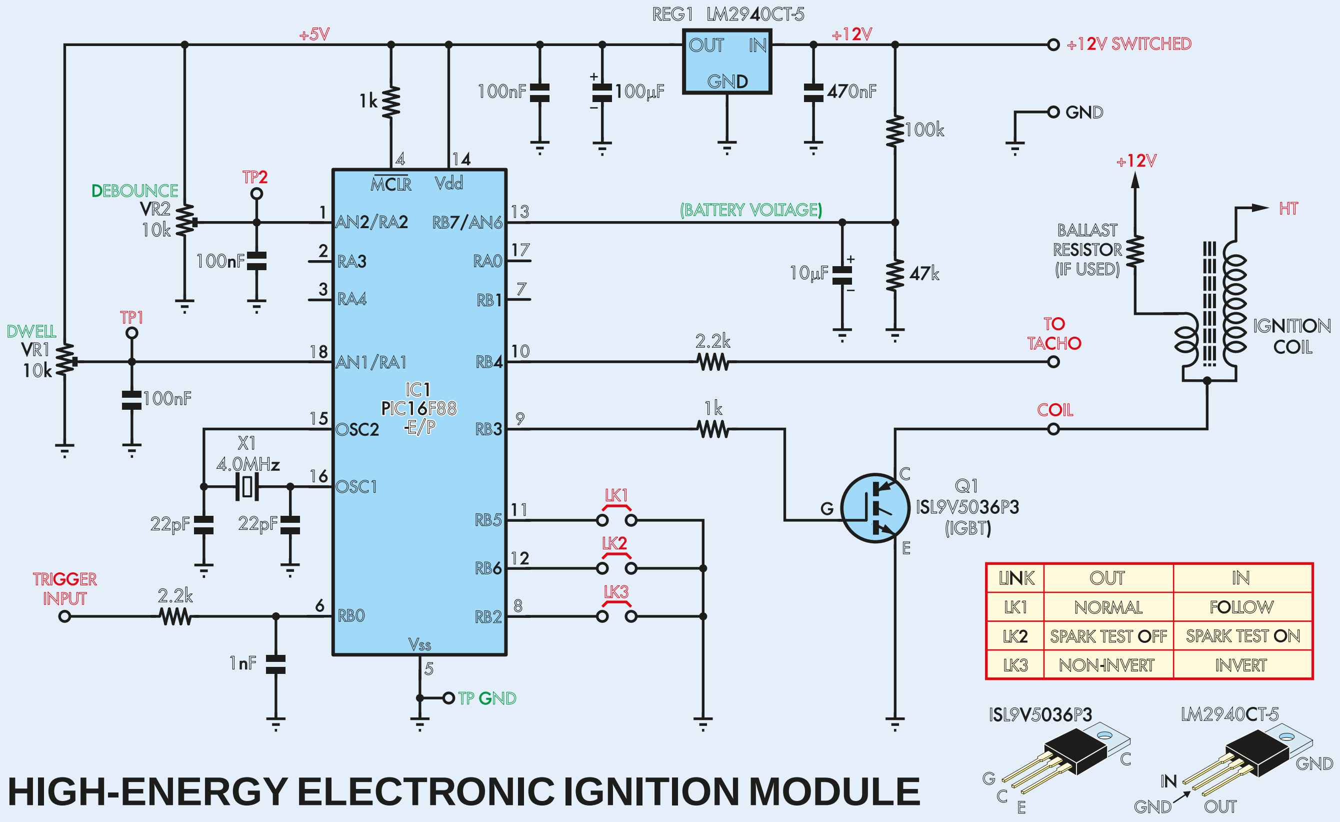
During normal operation, the ignition coil is switched on for a sufficient dwell period just before firing. This allows the coil to charge fully without consuming any more power than necessary or overheating due to high saturation current. If the engine RPM becomes so high that the dwell period cannot fit between successive firings of the coil, the dwell period is reduced. The firing period is a minimum of 1ms, sufficient for the coil to deliver a healthy spark.

Dwell time

The dwell can be set between 129µs and 26ms in 200 steps, with more resolution available for the shorter periods. Some coils require a minimum 4ms dwell, while high-performance sports coils need less. The spark test feature basically allows the dwell to be adjusted to its optimal value while watching the spark delivered from the coil across a spark plug gap.

The dwell time is automatically extended when the battery voltage falls below 12V, to compensate for the longer charging period required. This helps maintain spark energy when starting the engine. This is disabled in the spark test mode.

Another important feature with this electronic ignition module is that the coil is not energised until after the engine has begun to turn. This prevents the coil from overheating and possibly burning out when the ignition is first switched on but the engine is not turning over (ie, not being cranked). Also, if the engine stops with the ignition still switched on, the coil is automatically switched off after one second.



LINK	OUT	IN
LK1	NORMAL	FOLLOW
LK2	SPARK TEST OFF	SPARK TEST ON
LK3	NON-INVERT	INVERT

HIGH-ENERGY ELECTRONIC IGNITION MODULE

Fig.3 the circuit is based on PIC microcontroller IC1 It accepts the trigger signal, calculates the dwell and the spark period and produces an output at RB3 to drive IGBT transistor Q1 Output RB4 provides the tachometer drive signal.

However, this one-second period could be too short for a single-cylinder motorcycle engine to start when kick-starting. To solve this, if the debounce setting is more than 2ms, the coil switch-off delay is increased to 10s. In this case, the ignition coil must be able to withstand the application of 12V for 10s. Most coils designed for use with points are suitable as they are designed to cope if the motor stops with the points closed.

Debounce is included to prevent the ignition from being re-triggered due to noise on the trigger input. A 0.5ms period can be used with most sensor types, but a longer period is needed for points as they do not tend to open or close cleanly. Instead, points can bounce back open after closing and this can result in a series of rapid openings and closings.

The debounce feature enables the circuit to ignore this. However, there is a limit to the length of this debounce period. If it is made too long, then the upper RPM range can be severely limited as the time between plug firings approaches the debounce period.

A 2ms debounce period for a single-cylinder engine will not present such a problem. In fact, the upper RPM limit with a 5ms debounce period and a 1ms spark duration is 20,000 RPM for a single-cylinder 4-stroke engine.

Follow mode

In order to cope with severe points bounce, we have provided a 'follow' mode. When this mode is selected, the ignition system's output simply follows the input. This means that the coil begins charging as soon as the points close and the spark duration is not limited to 1ms.

In other words, much of the internal 'smarts' which attempt to optimise coil charging are disabled in the follow mode. However, the debounce setting is still effective, to prevent false triggering.

Note that the follow mode should only be selected when using points that produce erratic firing with the normal setting.

Finally, the system also includes an option to invert the input sense, so that the coil can fire on either the rising or falling edge of the input signal. For points, coil firing always occurs when the points open (ie, on the rising edge). However, for other triggers, you may need to fire on either the rising edge or the falling edge.

Circuit description

Refer now to Fig.3 for the main section of the *High-Energy Electronic Ignition System* circuit. The various trigger section options are shown in Fig.4.

Microcontroller IC1 is at the heart of the circuit. As shown, the trigger signal is applied to its pin 6 input (RB0). IC1 then processes this trigger signal and produces an output signal to drive the IGBT (Q1) at pin 9 (RB3).

The pin 6 input is protected from voltage spikes by a 2.2kΩ resistor. This limits the current if the internal clamping diodes between the input and each supply rail conduct. The associated 1nF capacitor provides high-frequency filtering to prevent false triggering.

In operation, IC1's RB3 output is alternately switched high to +5V to turn on Q1 and charge the coil, then to 0V in order to turn off Q1 and fire the spark plug when required. In addition, a second output is made

Restoring an older vehicle

Ignition systems for cars and motorcycles have improved greatly over recent years, with increased spark energy across the entire rev range of the engine. Much of this improvement has been achieved by using separate ignition coils for each spark plug. The 'old-fashioned' single coil and distributor is now rapidly becoming a relic.

But some older cars and motorcycles have a particular appeal and many are still in regular use. Enthusiasts often claim that these vehicles have more 'personality' and are more 'fun' to drive than modern counterparts.

So, restoring an older vehicle to its former glory has a certain appeal. Commonly restored cars include the original VW Beetle and Kombi vans with air-cooled horizontal engines, early model Vauxhall, Ford and Leyland vehicles, and classic marques such as MG, Morgan, Ferrari, Lancia, Citroen, Jaguar, Porsche and others.

Similarly, motorcycle enthusiasts revere the Norton Commando, Triumphs, BMWs, Moto Guzzis, Ducatis, Indians and Harley Davidsons. Many of these companies are still in business, but their older models are still popular.

These older cars and motorcycles use a Kettering ignition system, ie, one that comprises points, an ignition coil and distributor (Fig.1). This system usually benefits greatly with the addition of an electronic ignition module and that's where this project's unit comes into play.

Note, however, that this ignition module is not suitable for use with, or as a replacement for, a magneto ignition or a capacitor discharge ignition (CDI). These are found on some older motorcycles and in particular 2-strokes. To cater for these units, we published a replacement CDI module in the October 2010 issue of *EPE*. This design uses the high voltage generated by the vehicle's magneto to charge a capacitor. That charge is then dumped into the spark plugs via the ignition coil when triggered.

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available at RB4 (pin 10). This produces a 5V square-wave to drive a suitable tachometer via a 2.2kΩ resistor. Note, however, that an impulse tachometer will usually be connected to the ignition coil instead.

In order to correctly process the trigger signal, IC1 monitors three separate voltages. The first is the battery voltage, at the AN6 input (pin 13). The battery voltage is first divided by 3.13 by the 100kΩ and 47kΩ resistors and filtered by a 10µF capacitor. The resulting voltage is then converted to a digital value using the micro's internal ADC and this is used to adjust the dwell time with low battery voltages.

The dwell and debounce periods are set using trimpots VR1 and VR2, each connected across the 5V supply. VR1 (dwell) is monitored by input AN1 (pin 18), while VR2 (debounce) is monitored by input AN2 (pin 1).

The dwell is adjustable from 129µs to 26ms and is set by monitoring the voltage at TP1. However, this voltage is not linearly proportional to the dwell period, to allow finer resolution for shorter dwell periods. The relationship between the two is shown in a graph to be published next month.

By contrast, the debounce period can be set anywhere from 0-5ms. This is done by monitoring the voltage at TP2, with 1V on AN2 equivalent to 1ms (ie, the relationship is linear).

Links LK1-LK3 are used to select the various operational modes (see Table on Fig.3). These links connect to the RB5, RB6 and RB2 inputs (pins 11, 12 and 8) respectively. Internal pull-up resistors are enabled by IC1, so these inputs are held high with no jumper fitted. If a link is fitted, its corresponding input is pulled to 0V.

The default setting is with all jumpers out, for normal operation. The invert link (LK3) is fitted if the trigger sense needs inverting, while LK1 is fitted to enable the 'follow' mode (this mode is used with very noisy points, as explained earlier).

The spark test mode, selected when LK2 is fitted, causes the unit to charge and fire the coil at a rapid rate, regardless of the state of the trigger input. This allows a coil (or the module itself) to be tested without installing the unit in a vehicle. In this mode, trimpot VR1 is set to a fully anti-clockwise setting and then wound clockwise to give the best visual spark. VR2 can be used to set the spark rate, with a range of 15-75Hz (clockwise for increased frequency).

Bits and pieces

IC1 operates with a 4MHz crystal to ensure accurate debounce and dwell

All the parts for the *High-Energy Ignition Module* go on a single PCB that fits inside a small metal diecast case (reluctor pick-up version shown). The full construction and installation details will be in Part 2 next month.

Parts List: High-Energy Ignition

1 PCB, available from the *EPE PCB Service,* code 05110121, 89mm × 53mm
1 diecast aluminium case, 111mm × 60mm × 30mm
2 cable glands to suit 3-6mm cable
1 transistor insulating bush
2 TO-220 3kV silicone insulating washers
1 4MHz HC-49 crystal (X1)
1 18-pin DIL IC socket
3 2-way pin headers, 2.54mm pitch
3 shorting links for headers
1 solder lug
1 crimp eyelet
4 6.3mm tapped nylon standoffs
8 M3 × 5mm screws
3 M3 × 10mm screws
3 M3 nuts
2 M3 star washers
9 PC stakes
1 2m length of red automotive wire
1 2m length of black automotive wire
1 2m length of green automotive wire
1 2m length of white automotive wire

Semiconductors
1 PIC16F88-E/P microcontroller programmed with 0511012A.hex (IC1)
1 ISL9V5036P3 ignition IGBT (Q1) (X-On; x-on.com.au, or eBay.co.uk)
1 LM2940CT-5 low drop out 5V regulator (REG1)

Capacitors
1 100µF 16V PC electrolytic
1 10µF 16V PC electrolytic
1 470nF MKT
3 100nF MKT
1 1nF MKT
2 22pF ceramic

Resistors (0.25W 1%)
1 100kΩ 2 2.2kΩ
1 47kΩ 2 1kΩ
2 10kΩ mini horizontal trimpots (VR1,VR2)

Miscellaneous
Angle brackets for mounting, automotive connectors, self-tapping screws, heatshrink tubing

Points version
1 100Ω 5W resistor (R1)

Reluctor version
1 BC337 NPN transistor (Q2)
1 2.2nF MKT capacitor
1 470pF ceramic capacitor
1 100kΩ top adjust multi-turn trimpot (VR3)
1 47kΩ 0.25W 1% resistor
1 10kΩ 0.25W 1% resistor
1 10kΩ 0.25W 1% resistor (R4)
1 1kΩ 0.25W 1% resistor (R3)
2 PC stakes

Hall Effect/Lumenition Module
1 1kΩ 0.25W 1% resistor (R3)
1 100Ω 0.25W 1% resistor (R2)
2 PC stakes

Optical Pick-up
1 optical pick-up (Piranha or Crane)
1 22kΩ 0.25W 1% resistor (R3 or R6)
1 120Ω 0.25W 1% resistor (R4 or R5)
2 PC stakes

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settings, regardless of temperature. We recommend using the extended version of IC1 (ie, the PIC16F88-E/P) which will operate reliably up to 125°C, compared to 85°C for the industrial version (PIC16F88-I/P).

IC1 is powered from a regulated 5V supply. This is derived using REG1, an LM2940CT-5 low-dropout regulator designed specifically for automotive use. It features both transient overvoltage and input polarity protection and it provides a regulated 5V output even if its input voltage drops as low as 5.5V, eg, when starting the engine in cold weather with a partially flat battery.

REG1 has a 470nF bypass capacitor at its input and a 100µF filter capacitor at its output, both of which are required for stable operation. The input capacitor is non-polarised so that it will not be damaged if the supply polarity is inadvertently reversed.

Trigger input options

Fig.4 shows the various trigger input circuit options. We'll look at each of these in turn:

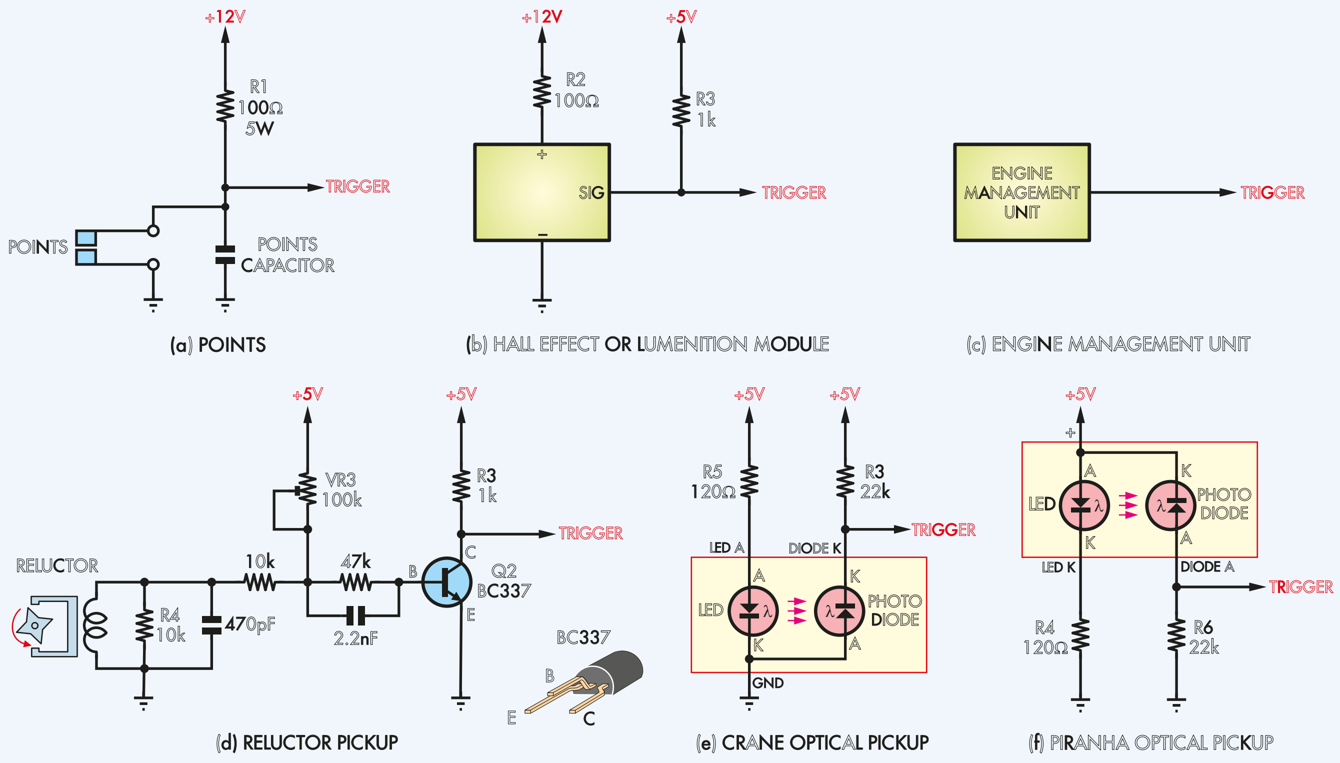

Fig.4: the six input trigger circuits: (a) points triggering; (b) Hall effect (and Lumenition) triggering; (c) triggering from an engine management module; (d) reluctor pickup; (e) Crane optical pickup; and (f) Piranha optical pickup. These different trigger options are all catered for on the PCB and it's simply a matter of installing the relevant parts.

- **Points:** Fig.4(a) shows the points input circuit. This simply comprises a 100Ω 5W resistor (R1) which connects between the top of the points and the 12V supply (the points capacitor is already present in the vehicle). This 100Ω resistor acts as a pull-up for the trigger input and it also provides a 'wetting current' to ensure that the contacts remain clean.

The points are connected between the trigger input and ground. As a result, the trigger input is pulled low each time the points close and high (via the 100Ω resistor) each time they open.

- **Hall Effect:** Fig.4(b) is for a Hall effect or Lumenition (optical trigger) sensor module. This module is powered via a 100Ω resistor (R2) from the 12V rail, to limit the current into an internal clamping diode. A 1kΩ resistor (R3) on the output is also included, to pull up the output to 5V when the internal open-collector transistor inside the sensor module is off. Conversely, the trigger output falls to nearly 0V when that transistor is on.
- **ECU:** the circuit for a vehicle with an engine management computer is shown in Fig.4(c). It's very simple – the 5V output signal from the computer simply connects to the trigger input of the ignition module.
- **Reluctor:** the reluctor input circuitry is shown in Fig.4(d). In operation, the output from the reluctor produces an AC signal, switching transistor Q2 on and off. Initially, with no reluctor output voltage, transistor Q2 is switched on via current through trimpot VR3 and the 47kΩ resistor to its base. The actual voltage applied to Q2's base depends on VR3, the two 10kΩ resistors (one across the reluctor coil) and the internal resistance of the reluctor itself.

Trimpot VR3 allows the circuit to be adjusted to suit a wide range of reluctor resistance values. In practice, VR3 is adjusted so that Q2 is just switched on when there is no signal from the reluctor. When the reluctor signal goes positive, Q2 remains switched on. Conversely, when the signal swings negative, Q2 switches off.

The signal output is taken from Q2's collector and this provides the trigger signal for the ignition module.

Resistor R4 provides the necessary load for the reluctor, and the parallel 470pF capacitor shunts very high frequency signals to ground. The 2.2nF capacitor across the 47kΩ base resistor speeds up Q2's switch-on and switch-off times.

- **Optical:** finally, Figs.4(e) and 4(f) respectively show the Crane and Piranha optical trigger pick-up circuits. The Crane trigger has a common-ground connection, while the Piranha has a common positive, but apart from that, they operate in similar fashion.

For the Crane trigger, resistor R5 limits its internal LED current from the 5V supply, while R3 pulls up the photodiode output. Similarly, for the Piranha system, R4 is the LED current-limiting resistor, while R6 pulls down the photodiode output.

All the different trigger options shown on Fig.4 are catered for on the ignition module's PCB. It's just a matter of installing the relevant parts (more on this next month).

What's coming

That's it for now. Next month, we will go through the construction, set-up and installation of the *High-Energy Electronic Ignition System.*