A high-energy capacitor discharge ignition system

This completely new capacitor discharge ignition system has been designed from the ground up to provide a high energy "multiple spark discharge" to cope with engines which have very high RPM rates. It is intended particularly for use with two stroke engines, high performance four strokes and older vehicles.

Twenty or so years ago. Capacitor Discharge Ignition (GDI) was the acknowledged "solution for automotive enthusiasts wanting a high energy ignition circuit. GDI gave a really hot spark which would fire virtually any spark plug no matter how fouled or grotty it was. Tens of thousands of enthusiasts installed them on their cars and hence forward swore by them as the greatest innovation system since Karl Benz thought of the horseless

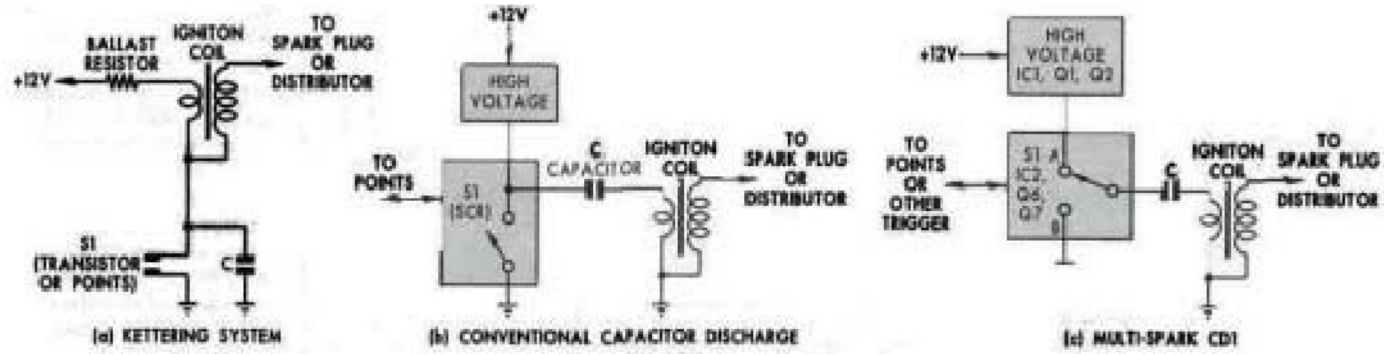

Fig.1: these three circuits show the three types of ignition circuit. Fig.l(a) is the original points-based system. Fig.lb) shows a typical CDI system which uses a DC-to-DC inverter to charge a capacitor which typically has a value of luF. Each time the switch points in the distributor open, it fires an SCR to dump the capacitors's charge into the coil primary winding. Fig.l(c) shows the arrangement of our new CDI system. It has a DC-to-DC inverter with a regulated 300V DC output which charges up a luF capacitor. Instead of using an SCR to dump the capacitor's charge into the coil, it uses a pair of Mosfets which are depicted as S1, a single pole double throw switch.

.carriage. Well, maybe it wasn't quite that good but you get the picture. But there was another aspect of CDI which wasn't good and that was "cross-fire". Because the CDI spark was so hot and more importantly, because it had such a fast rise-time of only a few microseconds, it often fired the plugs in other cylinders. This problem was most troublesome in V8s, in some sixes and even some four cylinder cars such as the air-cooled VW which had the spark leads running close and parallel right across the en-gine fan housing.

Cross-fire is caused by the capacitance between adjacent spark plug leads. The capacitance between the leads causes the fast-rising voltage from the coil to be coupled into the adjacent leads and thereby can de-liver unwanted sparks in other cylinders.

Cross-fire can cause severe engine damage and sounds similar to pinging.

Ultimately, CDI fell into disuse for mainstream cars because of the introduction of lean fuel mixtures in an attempt to meet rising anti-pollution standards. The very fast and very short spark of CDI wasn't all that good at igniting lean mixtures. Car manufacturers introduced transistor-assisted ignition with long spark durations to ensure that lean mixtures did bum properly. There was one CDI design which attempted to overcome the lean mixture drawback and that was the so-called "multiple spark discharge" system. However it was a complex design which never really caught on.

These days, there is no modern car with an engine management system which uses CDI, to our knowledge. Whether they are single coil, multi-coil or direct-fire systems, they are all variants of the tried and true transistor assisted ignition (TAI) system. So why design a new CDI?

At SILICON CHIP, we have tended to disparage CDI systems for years, knowing that our very popular high-energy TAI system has a well-earned reputation for reliability. Gut some readers were not about to be put off. They wanted a CDI design and they wanted it for a number of reasons. They wanted them for two-stroke and four-stroke motors on motor bikes, out-boards and Go-Karts. And they wanted them for older cars which don't have lean mixtures and which can be par-ticularly hard, if not impossible, to start when the ignition system gets wet. Old Mini Coopers and 850s are legendary in this regard.

Some readers also wanted a CDI for racing applications where multiple spark discharge systems still have a keen following.

With all of these reasons being cited, < who were we to say that all these people were wrong? So we went back to the data books and put on our thinking caps. A new CDI design had to be a distinct improvement over the 20-year old designs which did have their fair share of drawbacks. Like what, for example?

First, many CDIs had very high voltages applied to the ignition coil, as much as 500V or 600V in some cases. They did this to avoid the inevitable fall-off in spark energy as the engine RPM rose. This very high coil voltage had the drawback of often causing internal breakdown in ignition coils, it made the cross-fire problem significantly worse than it would have

Main Features

Suitable for 2-stroke, older 4-stroke and performance engines (racing).

Multiple spark output (see Table 1).

Operates on reluctor, points or Hall effect signals.

Two points inputs for twin coil engines.

Usable to beyond 1000 sparks/second (equals 15,000 rpm for a V8).

Regulated 300V supply for consistent spark energy.

High frequency operation eliminates audible oscillator noise.

Efficient circuitry **for minimum** heat **generation.**

Components rated to operate **up** to **100°C.**

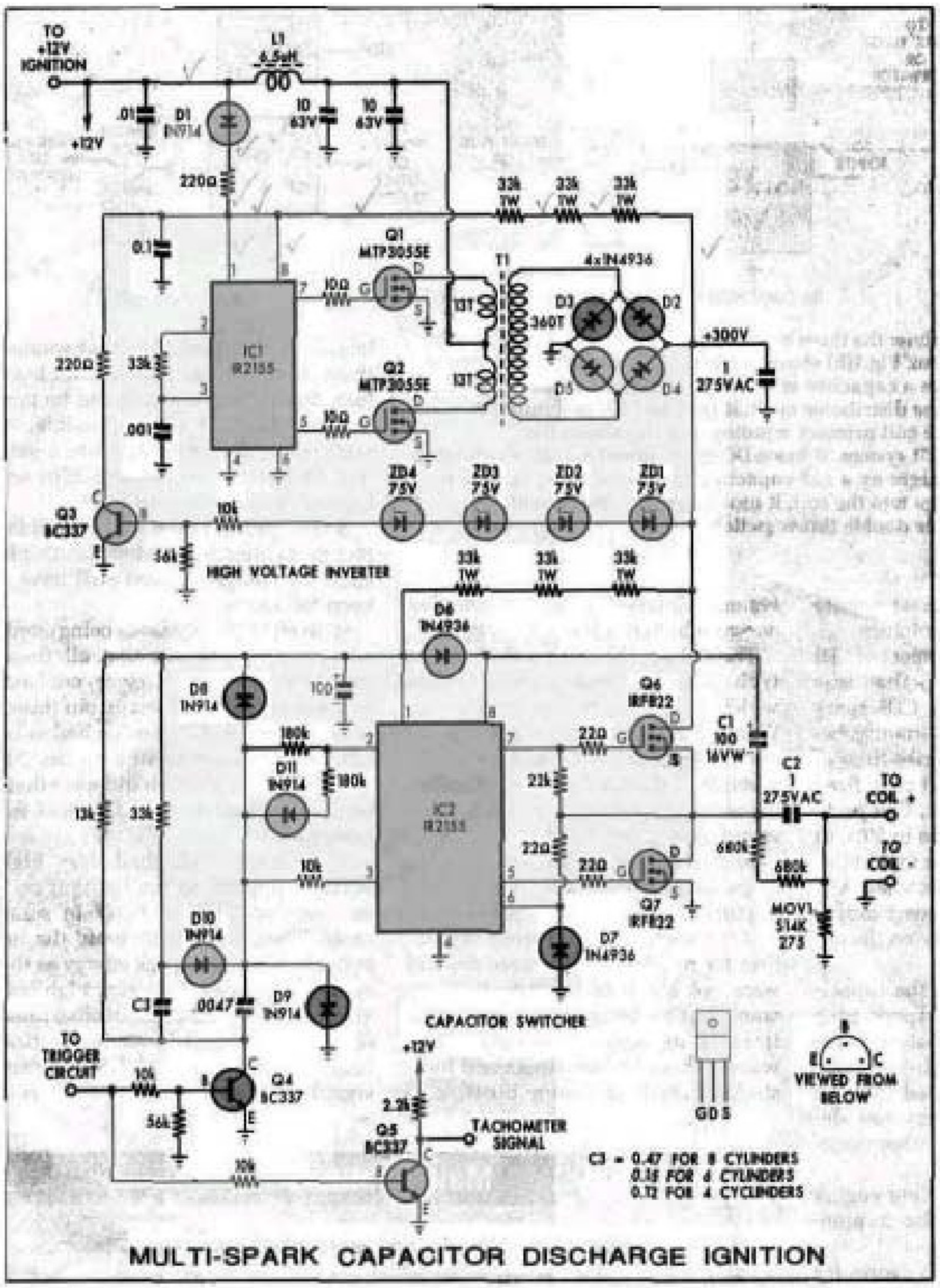

Fig.2; the circuit of the Multi-Spark CDI can be split into two separate sections, each using an IR2155 self-oscillating half bridge Mosfet driver. ICl and Mosfets Ql & Q2 comprise the 12V DC to 300V DC inverter. IC2 and Mosfets Q6 & Q7 charge and discharge the dump capacitor via the ignition coil primary and provide the multiple spark feature.

WARNING!
This circuit produces 300V DC which can give you a nasty shock. Do not touch any part of the circuit while it is operating.

been with a lower coil voltage and it put considerably more stress on the ignition leads. So design aim number one was to set the coil voltage to a much more moderate level of about 300V.

Second, because the DC-DC inverters of the time used relatively slow bipolar transistors (eg, 2N3055s), the inverter frequency was typically only 2kHz. This typically sets an upper limit on the maximum spark rate of about 300 to 400 sparks per second, as the inverter needs a couple of cycles of operation after each discharge in order to recharge the dump capacitor.

The 2kHz inverter operation was quite audible too and could often be heard through car radios. So the new design would use Mosfets in the inverter and would operate at above 20kHz to make it inaudible.

Third, CDIs used an SCR (silicon controlled rectifier) to discharge the dump capacitor and these are typically rated for an AC supply frequency of 400Hz maximum. While the SCRs will operate at higher frequencies, it is an unspecified condition and it ultimately also sets a limit on the maximum spark rate. That effectively rules out using an SCR in the new design.

Fourth, and a rather serious drawback this one, some CDI systems would not operate when the battery was low. This meant that while the battery might be able to slowly crank the engine, the CDI's inverter would not start and hence there would be no spark. In other words, just when you most wanted the CDI to work, it would not be on the job.

Another factor which limited the inverter operating frequency was the speed of the rectifier diodes. High speed fast recovery diodes were expensive and so, even if the inverter could have run much faster, the standard rectifier diodes could not have handled the high frequency output.

Applications

While we have addressed all the above disadvantages, the drawback of potential cross-fire remains even though we have reduced the high voltage to 300V. Therefore, we do not rec-ommend using the system on six cylinder and V8 engines unless you can improve the lead dress of the spark plug leads so that each lead is more widely separated from its neighbour.

Nor do we recommend using this CDI on any car with an engine management computer. We take the attitude that the factory designed ignition system will always be optimum far the particular car.

On the other hand, if you have an older car with factory electronic ignition there is no reason why this CDI system should not be a satisfactory substitute, particularly if the original module has failed and is expensive to replace.

The new CDI system can be connected to distributors with conven-tional points, Hall effect or reluctor pickups. It is capable of operation to very high engine speeds, much higher than even racing engines. For example, it can run as high as 30,000 RPM in a 4-cylinder engine. This figure is so high that it's academic but it does indicate that full spark energy is maintained over the entire RPM range of any practical engine.

All the other features of the new design are summarised in the features and specifications panels elsewhere in this article. However, we do need to explain one of the key features and that is "multiple spark discharge".

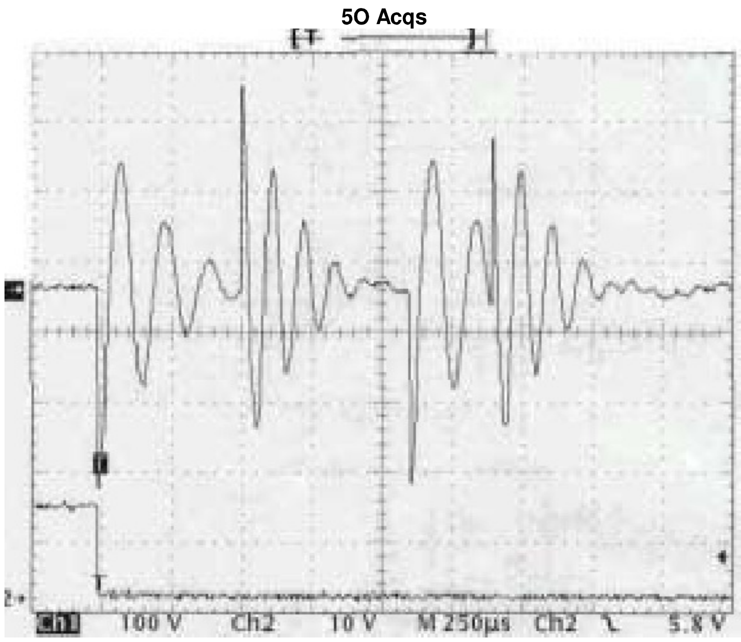

Fig.3: this is the primary coil voltage when producing four sparks (top waveform). Note the 284V negative excursion for the first and third sparks and the 292V positive excursion for the second spark. The lower trace is the tachometer output signal which was used to trigger the oscilloscope.

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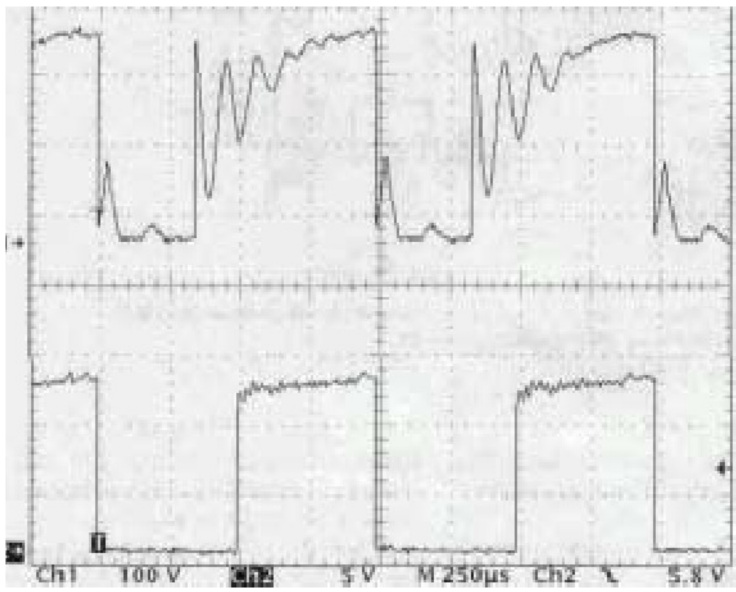
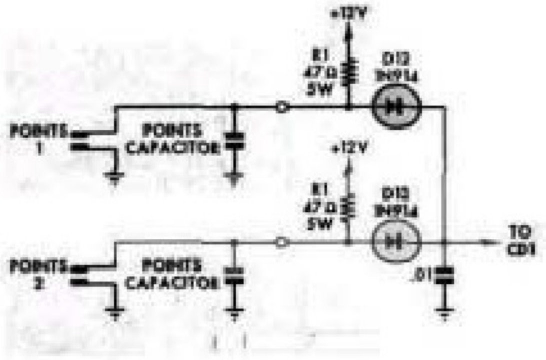


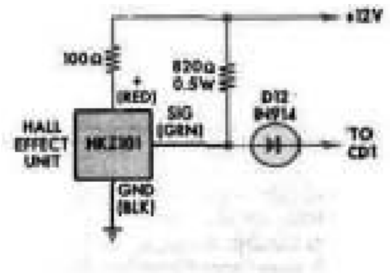
Fig.4: the CDI produces very **high spark rates. The top** trace **shows the voltage** measured **at the** source **of Q6** when **driving the** ignition coil, **while** the **lower** trace **is the tachometer output which indicates that the rate is 1000 sparks/ second.** Note **that** capacitor C2 charges up to the **full 300V (308V shown) before** Firing **into the coil on the negative edge of the lower trace. This means that the** circuit **can** deliver the **full spark** energy **even at this excessively high engine** speed.

Multiple spark discharge

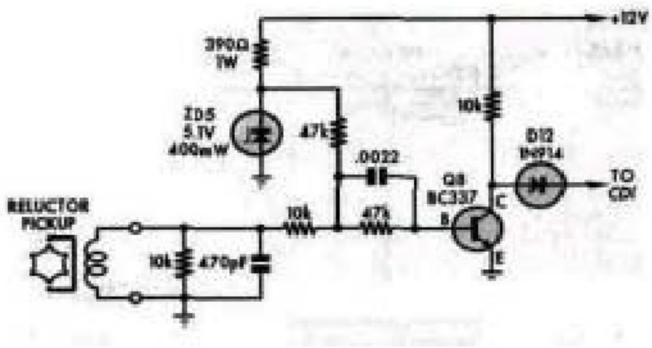
Whereas the original CDI designs produced just one spark each time the points opened, the multi-spark discharge (MSD) CDI was able to produce several sparks in quick succession each time the points opened. Our new design incorporates this feature and produces up to 10 sparks each time a spark plug is to be fired, depending on the engine speed. This feature can be disabled so that the CDI



a| POINTS TRIGGER



b)] HALL **EFFECI** TRIGGER



c) RELUCT0R TRIGGER

Fig.5: the circuit caters for distributors with (a) points; (b) Hall Effect sensors; or (c) reluctor pickups.

'produces just two sparks for each cylinder firing, regardless of engine speed.

Now let us have a look at some of the details of the new design. Fig.l(a) shows the schematic diagram of the conventional Kettering ignition system which has been used on cars for over 60 years. It comprises an ignition coil which has its primary winding connected to the battery supply with a switch at the negative side.

The switch can be a conventional set of points or a switching transistor, as used in most modem ignition systems. When the switch is closed, current builds up in the primary winding with the ultimate value limited by the internal resistance of the coil and a ballast resistor, if used. This current is usually around 3 to 5 amps.

When the switch opens, the resulting collapse of the coil's magnetic field causes the secondary winding to produce a high voltage to fire the spark plug. As the engine speed rises, the current has less time to build up in the coil primary and so inevitably the spark energy is reduced. Modern transistor assisted ignition systems get around this problem by using dwell extension, lower inductance coils or more than one ignition coil.

Fig.l(b) shows a typical CDI system which uses a DC-to-DC inverter to charge a capacitor which typically has a value of luF. Each time the switch points in the distributor open, it fires an SCR to dump the capacitor's charge into the coil primary winding. The poor old coil gets such a belt that it produces a much higher voltage in the secondary and fires the spark plug.

Fig.l(c) shows the arrangement of our new CDI system. It has a DC-to-DC inverter with a regulated 300V DC output which charges up a luF capacitor. Instead of using an SCR to dump the capacitor's charge into the coil, it uses a pair of Mosfets which are depicted as S1, a single pole double throw switch. The capacitor charges up via the coil to 300V when SI is in position A and discharges through the coil when the switch is in position B.

Thus each time a spark plug is to be fired, two sparks are produced, one with positive polarity and one with negative polarity. With a simple change to the timing circuitry controlling the two Mosfets, the cDI can be made to produce more than two sparks by repetitively charging and discharging the dump capacitor during each spark plug firing period.

The oscilloscope waveforms in Fig.3 show the primary coil voltage when producing four sparks (top waveform). Note the 284V negative excursion for the first and third sparks and the 292V positive excursion for the second spark. The lower trace is the tachometer output signal which was used to trigger the oscilloscope.

Table 1 shows the multi-spark information for four, six and eight cylinder engines. Here we show the RPM versus the number of sparks produced. As you can see, the number of sparks ranges from as many as six sparks per firing at 600 RPM in a 4-cylinder en-. gine down to two sparks per firing at 15,000 RPM, again in a 4-cylinder engine.

Circuit description

Fig.2 shows the circuit diagram of the Multi-Spark CDI. It can be split into two separate sections, each using an IR2155 self-oscillating half bridge Mosfet driver. ICl and Mosfets Ql & Q2 comprise the 12V DC to 300V DC inverter. IC2 and Mosfets Q6 & Q7 charge and discharge the dump capacitor via the ignition coil primary and provide the multiple spark feature.

ICl oscillates at about 22kHz as set

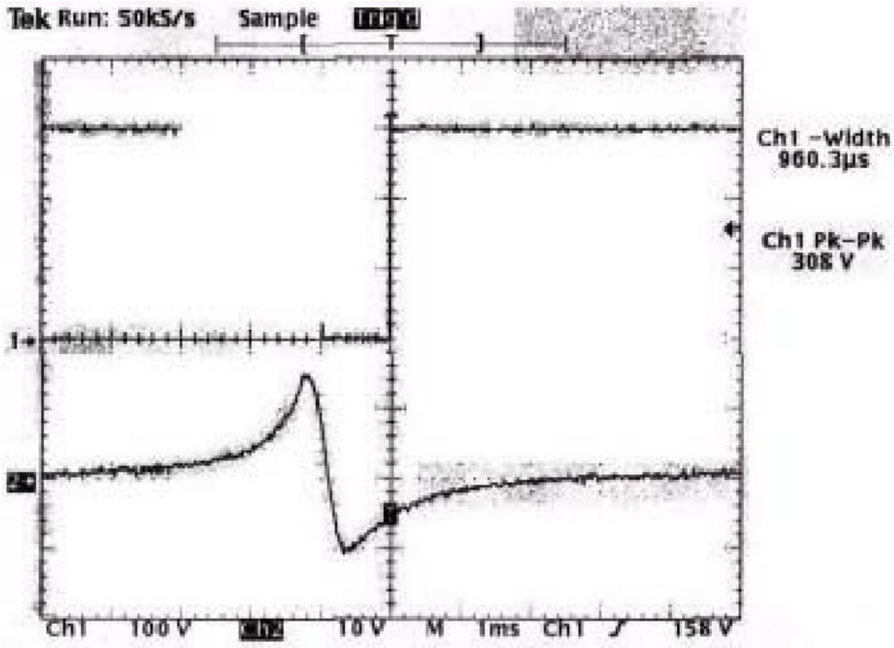


Fig.6: these waveforms show the reluctor output (lower trace) and the resulting source voltage of Q8 with no **coil** connected. Note that the coil fires on the negative edge of the reluctor waveform.

Table 1: RPM vs Spark No & Duration		
RPM	NO. Of 1 Sparks	Spark Duration (Crankshaft Degrees
4-Cylinder 4-Stroke Engines		
600	6	8
900	6	13
1200	6	16
1500	6	*20*
2250	4,	19
3000	4	25
4500	4	*37*
9000 .	2	21
15,000	2	36
6-Cylinder 4-Stroke Engines		
400	8	8
600	8	12
800	6	11
1000	6	14
1500	6	21
2000	4	16
3000	4	24
6000	2	14
10.000	2	22
8	CYL 4	STROKE Engines
300	14	
450	12	13
600	10	15
750	*10*	18
1125	8	21
1500	8	20
2250	6	29
4500	4	32
7500	2	15

by the 33kohm resistor between pins 2 and 3 and the .00luF capacitor from pin 3 to ground. Two complementary outputs at pins 5 & 7 alternately switch Mosfsts Ql & Q2 to drive the centra-tapped primary winding of trans-former Tl.

With Ql on, the full 12VDC is applied to the top half of the transformer primary winding. Because of the transformer coupling to the second primary winding, the lower half of the transformer primary winding also has 12V across it. Similarly, when Q2 turns on the 12V is also impressed across the top primary winding. The resulting waveform on the primary is stepped up by the secondary winding.

Ql & Q2 have internal avalanche protection. Should the switch off transient across them reach 60V, the internal zener diode will safely quench the spike voltage. The 1011 resistors in series with the gates of the Mosfets are included to slow their switching speed and thus reduce the interference which would otherwise be induced into the vehicle's electrical system.

Two 10(iF MKT capacitors are used to decouple the DC supply to transformer Tl. They effectively bypass the supply lead inductance so that the full 12V supply is delivered to the, transformer at the high switching rate. Inductor LI is connected in series with the supply to prevent 22kHz switching currents from appearing on the vehicle's electrical supply. The .01uF capacitor on the 12V input is there for the same reason.

The stepped up secondary voltage of Tl is full-wave rectified by high speed diodes D2-D5 and the resulting 300VDC is filtered with a luF 275 VAC capacitor.

Voltage feedback trickery

As described so far, the circuit does not have any means of maintaining a constant 300V DC output and so variations in the battery voltage and spark rate would inevitably cause the high voltage DC output to vary over a fairly wide range which would be undesir-able. However, the IR2155 Mosfet driver has no inbuilt means of providing voltage regulation. Therefore, we have to trick the circuit into maintaining a more or less constant voltage.

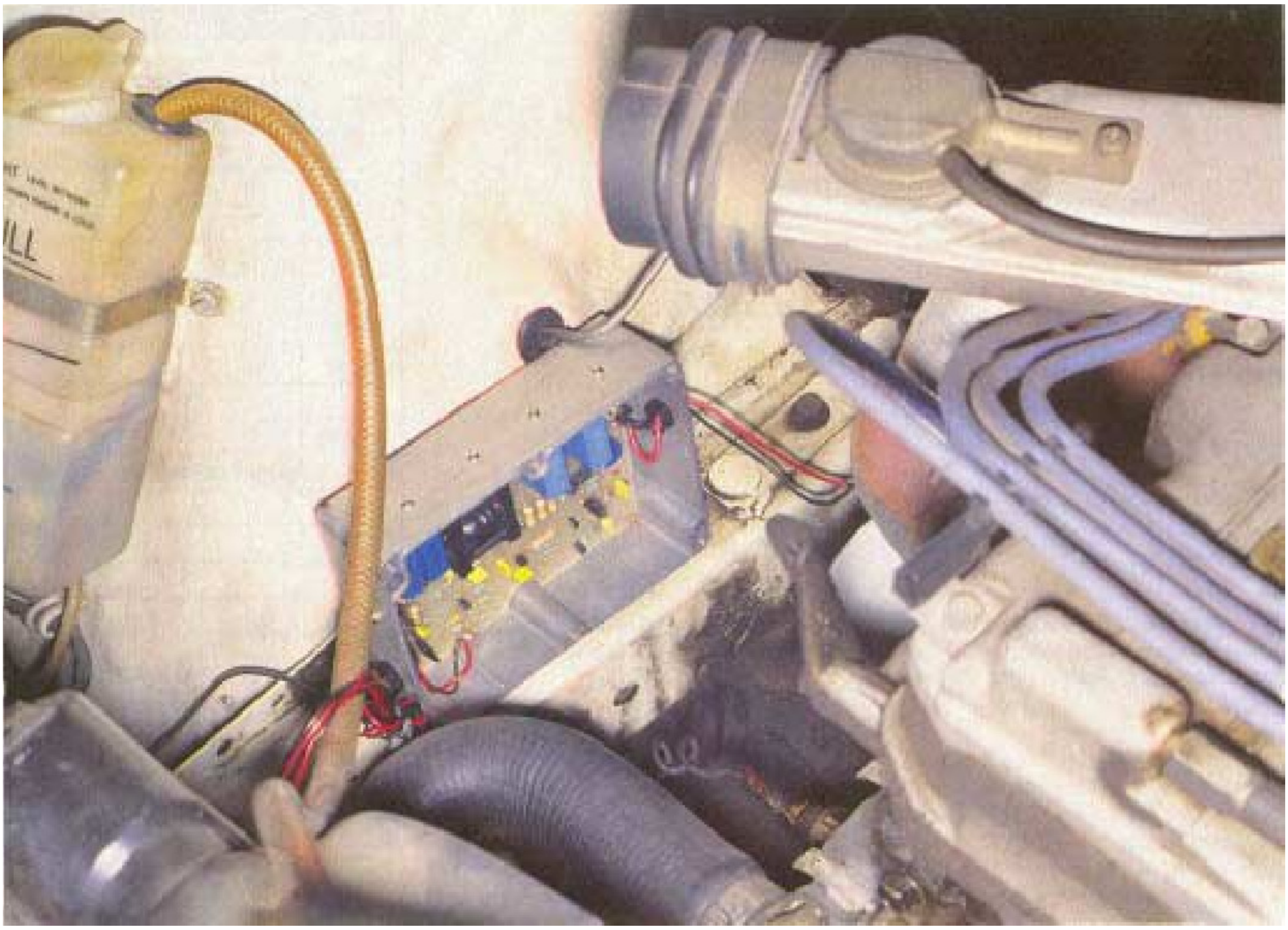
The voltage feedback comprises four 75V zener diodes ZD1-ZD4 which are connected in series so that they begin to conduct at 300V. When current flows through the zeners they switch on transistor Q3 via a 10kohm base resistor.

When transistor Q3 turns on, it pulls pin 1 of ICl from close to +12 V down to around +6V and this tricks the IC into activating its internal undervolt-age cutout circuit [threshold +8.4V) which switches both pins 7 and 5 low. This stops the Mosfets from driving transformer Tl and this situation *is* maintained until the zeners stop conducting; ie, when the high voltage supply drops back below 300V.

Transistor Q3 then switches off and ICl resumes normal operation. Thus, the output voltage is stabilised at 300V while Q3 turns the oscillator on and off at a rate dependent on the load current drawn from the 300V supply and the actual DC supply voltage.

Circuit feeds itself

Three 331dl resistors in series feed current from the 300V output back to the supply pins of ICl and an internal



Here the new Multi-Spark CDI is shown mounted in the engine compartment of a Mitsubishi Sigma. Note the long parallel run of the spark plug leads. We suggest that the spacing between these leads should be increased to reduce any possibility of cross-fire.

zener limits the resulting voltage to 15V. With +15V present at pins 1 & 8 of ICl, diode Dl is reverse biased and therefore the IC no longer draws current from the +12V battery line. The idea behind this to make sure that the circuit will run even with a very flat battery. Hence the circuit will start with as little as 9V from the battery and then will continue to run even if the battery drops down to 5V.

This could make all the difference when you have a sick battery which can barely crank the engine over or if you have to push start the car.

The 300V supply also feeds IC2, the second IR2155. Note that IC2 is connected to operate in a different fashion to ICl. In this case, the drain (D) of Q6 is connected to the 300V supply which is at a much higher potential than the +I5V at pin 1 of IC2. For Q6 to fully turn on, its gate (G) must be raised above the drain by several volts. This is achieved using diode D6 and capacitor Cl.

Initially, IC2 starts with a 15V supply derived from the 300V rail, as mentioned above. Q7 is the first to be switched on and it pulls one side of capacitor Cl low. Cl then charges to the +I5V supply via D6 and Q7.

When Q7 turns off and Q6 turns on, Q6 pulls pin 6 of IC2 up to the 300V rail and so pin 8 is jacked up above +300V by the 15V across Cl. Cl maintains the voltage between pins 7 and 8 until next recharged via D6 and Q7. (Note that pins 6, 7 & 8 of the IR2155 are floating outputs which can be shifted to 600V above the pin 4 ground).

Cl needs to be relatively large at 100uF since it can he called upon to keep its charge for up to 100ms during slow cranking of the motor. The totem-pole output of Mosfets Q6 and Q7 drives the ignition coil primary via the 1uF 275VAC capacitor C2.

Diode D7 is included to prevent pin 6 from going much below the pin 4 ground while D7 itself is current limited by the series 22ohm resistor. The 22kohm resistor between pin 7 and the source of Q6 ensures that this Mosfet is held off when there is initially no supply between pins 8 and 7. The *22R* gate resistors slow the turn on and turn off times for Q6 and Q7 to limit transients when switching the luF 275VAC capacitor.

Multi-sparking

Pins 2 and 3 of IC2 are connected to an assortment of resistors, diodes and capacitors and these are instrumental in providing the multi-spark operation. These components comprise a timer and an astable (oscillator) connection. The astable oscillator is formed by the 180kohm resistor at pin 2 and the .0047uF capacitor at pin 3.

The 10kohm resistor between pin 3 and the .0047uF capacitor is there to prevent excess current into this pin when driven by the monostable part