Project 342

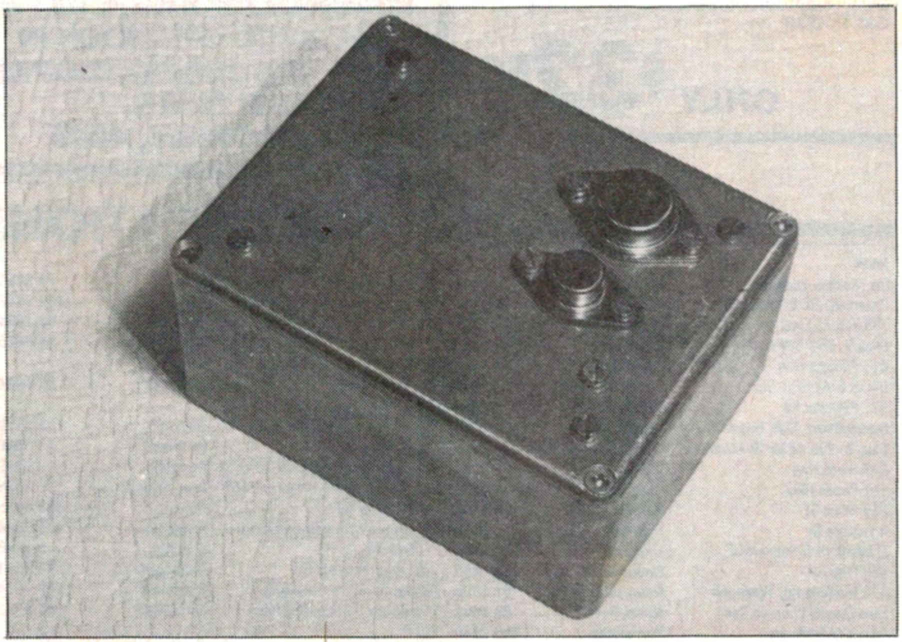
IMPROVED CDI

— using shaped pulses

Part 1

by Ian Thomas

Capacitor discharge ignition systems are much more efficient than conventional or transistor assisted systems, and they're also much better at getting maximum performance from today's engines. Unfortunately early CDI systems were also unreliable and plagued by problems such as engine cross-firing. Here's a new design which gets around all of the problems, but still gives you all of the benefits.



THERE HAS BEEN a lot of criticism of capacitor discharge ignition systems in the technical magazines recently. Some of it was well founded and some was merely relevant to particular designs. From what I've read the principle has often been blamed for problems in certain circuit realizations and so, after some discussion with our beloved editor, I decided to set the record straight.

Desirabilities

The first thing to get clear is exactly what is desirable in an electronic car ignition system. The basic requirement is to generate a spark to set fire to the air fuel mixture in the engine cylinders at exactly the right time. As most cars today have to meet emission control requirements, this means that the air fuel mixture is leaner than optimum and so the spark should last for as long as possible. The next requirement is that the voltage pulse applied to the spark plugs rises rapidly so that, if the plugs are fouled comparatively little energy is lost in the fouling and most of the energy actually goes into the spark. CDI systems are exceptionally good at this, in fact, they're too good. This means that the pulse applied to one plug will capacitively couple to other plug leads and possibly fire the fuel in other cylinders at terribly wrong times. This creates two mutually opposed requirements for the ignition system; the firing pulse leading edge should be fast but not too fast. Clearly if we are to design an ideal system the output voltage pulse rising edge should be a controlled parameter.

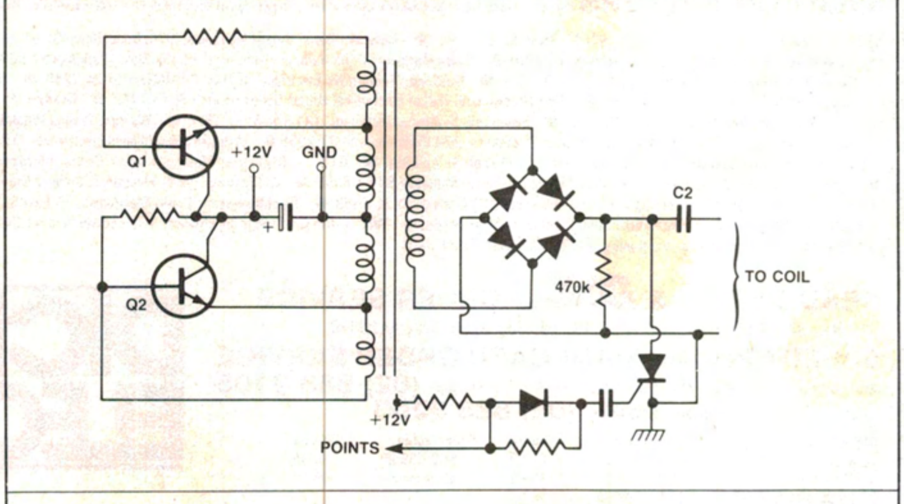


Figure 1. Basic circuit for a conventional CDI system.

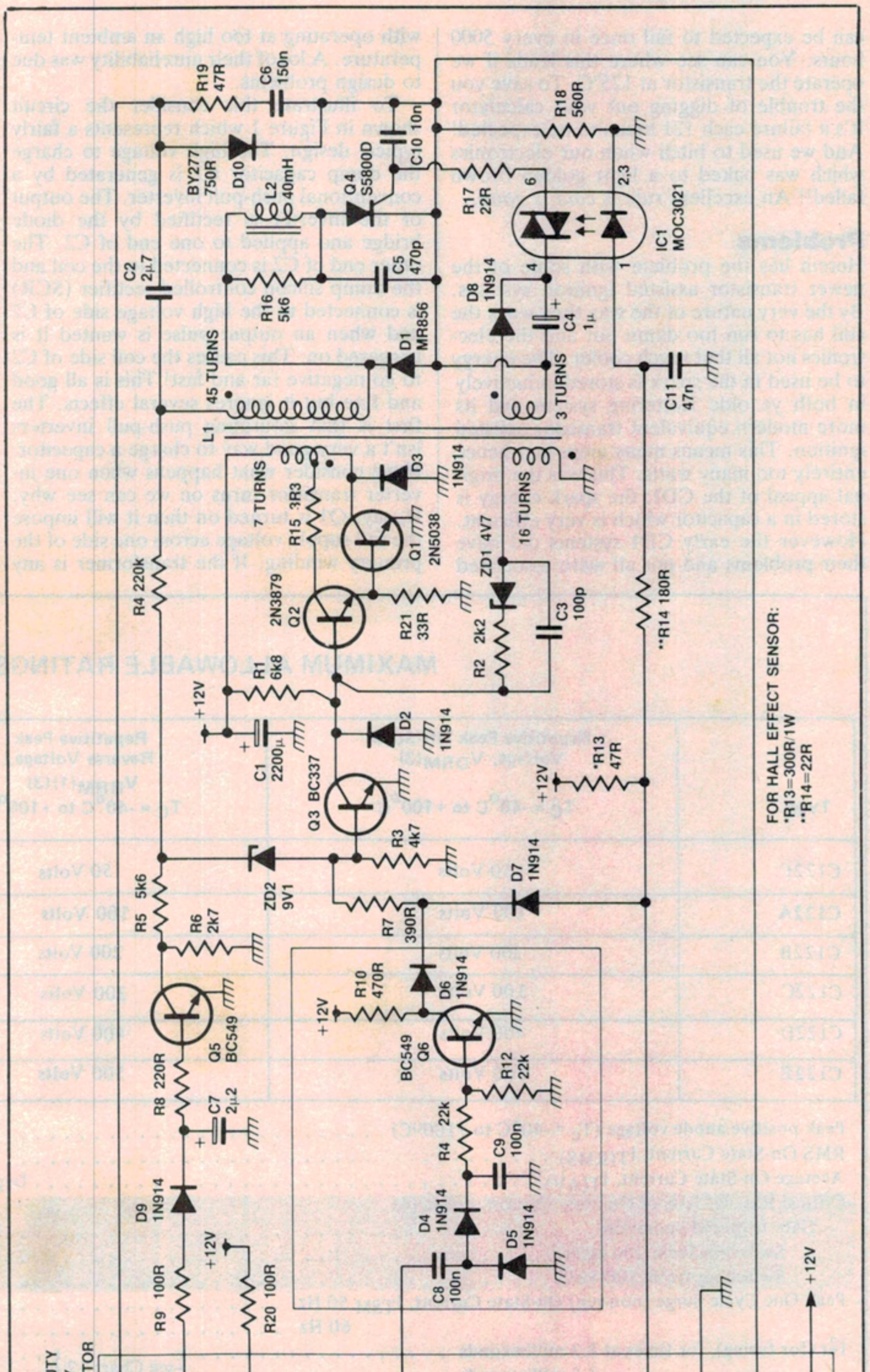
The third and, in my opinion, the most important requirement is that the system *must be reliable*. The most incredible whizz-bang, mind blowing device ever contrived could be built, but if it only works 90 per cent of the time it's not worth a damn and shouldn't be let anywhere near a vehicle. In the good old days when CDIs first made their appearance it simply wasn't appreciated just how hostile the environment under the bonnet of a car is for electronics. I'm sure that if the Marquis de Sade was alive today and thought about what electronics is subjected to near a running petrol engine he'd get that kinky warm feeling all over. It's stinking hot. There are fierce voltage transients everywhere. The power supply is subject to violent excursions. There are corrosive fluids around. All in all it's a good place not to put sensitive semiconductors. Nonetheless we went blithely ahead and attached our crude systems right next to the coil and cursed everything in sight when they fell over even though we'd used only the cheapest commercial components available.

In these more enlightened times all devices used for automotive operation are usually specified for the full military temperature range of −55°C to +125°C. In Australia the −55° may not be necessary but the +125° *is*.

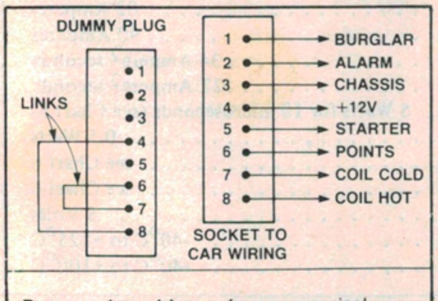
Finally, our ideal system should allow for the output pulse to be increased during starting and also it should be controllable so a car burglar alarm can shut it off. It should be triggerable from a Hall effect sensor or existing points. It goes without saying that it should not be possible to damage the device from any terminal by wrong connection or inadvertent shorts.

In the "wouldn't it be nice if . . ." category I thought an ideal system would not be effected by supply variations and would give the same output pulse no matter what the supply voltage.

As a matter of technical nicety it would also be good if the device was as efficient as possible so things didn't get too hot (see above about reliability). As a general rule the reliability of any electronic component halves for every 11°C temperature rise. That is, if a device (say a transistor) is expected to fail once in 10 000 hours at an operating temperature of 55°C then at 66°C it



The complete circuit for our new design. Note that the section in the tone rectangle is optional. The wiring details will be given next month.



Dummy plug wiring — for emergencies!

can be expected to fail once in every 5000 hours. You can see where this leads if we operate the transistor at 125°C. To save you the trouble of digging out your calculator it's a failure each 121 hours to be expected! And we used to bitch when our electronics which was baked to a light golden brown failed!! An excellent rule is *cold is good.*

Problems

Herein lies the problem with some of the newer transistor assisted ignition systems. By the very nature of the way they work the coil has to run too damn hot and the electronics not all that much cooler. The energy to be used in the spark is stored inductively in both ye olde Kettering system and its more modern equivalent transistor assisted ignition. This means many amps and hence entirely too many watts. This was the original appeal of the CDI; the spark energy is stored in a capacitor which is very efficient. However the early CDI systems did have their problems and not all were associated with operating at too high an ambient temperature. A lot of their unreliability was due to design problems.

To illustrate this consider the circuit shown in Figure 1 which represents a fairly typical design. The high voltage to charge the dump capacitor C2 is generated by a conventional push-pull inverter. The output of the inverter is rectified by the diode bridge and applied to one end of C2. The other end of C2 is connected to the coil and the dump silicon controlled rectifier (SCR) is connected to the high voltage side of C2 and when an output pulse is wanted it is triggered on. This causes the coil side of C2 to go negative far and fast! This is all good and fine but it ignores several effects. The first is that saturating push-pull inverters isn't a very good way to charge a capacitor. If we consider what happens when one inverter transistor turns on we can see why. If, say, Q1 is turned on then it will impose the full supply voltage across one side of the primary winding. If the transformer is any good then the voltage across the output winding is exactly the primary to secondary turns ratio times the supply voltage. If the capacitor is just beginning to charge then a conflict occurs and the voltage across the secondary must be taken up by other com-

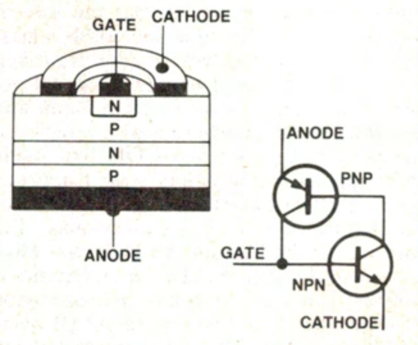


Figure 2. Internal construction of an SCR, together with its equivalent circuit.

MAXIMUM ALLOWABLE RATINGS

Type	Repetitive Peak Off-State Voltage, V_{DRM}(3) T_C = -40°C to +100°C	Repetitive Peak Reverse Voltage, V_{RRM}(1)(3) T_C = -40°C to +100°C	Non-Repetitive Peak Reverse Voltage, V_{RSM}(1)(2)· T_C = -40°C to +100°C
C122F	50 Volts	50 Volts	75 Volts
C122A	100 Volts	100 Volts	200 Volts
C122B	200 Volts	200 Volts	300 Volts
C122C	300 Volts	300 Volts	400 Volts
C122D	400 Volts	400 Volts	500 Volts
C122E	500 Volts	500 Volts	600 Volts

Peak positive anode voltage (T_c = -40°C to +100°C)		560 Volts
RMS On-State Current, $I_{T(RMS)}$		8 Amperes (all conduction angles)
Average On-State Current, $I_{T(AV)}$		Depends on conduction angle (See Charts 3 and 4)
Critical Rate-Of-Rise of On-State Current, di/dt: (4)		
Gate triggered operation		(see Chart 10)
Switching from 200 volts		100 Amperes per microsecond
Switching from 500 volts		50 Amperes per microsecond
Peak One Cycle Surge (non-rep) On-State Current, I_{TSM} 50 Hz		82 Amperes
60 Hz		90 Amperes
I^2t (for fusing), for times at 8.3 milliseconds	see Chart 12	34 Ampere^2 seconds
1.5 milliseconds		27 Ampere^2 seconds
Peak Gate Power Dissipation, P_{GM}		5 Watts for 10 microseconds (see Chart 6)
Average Gate Power Dissipation, $P_{G(AV)}$		0.5 Watts
Peak Positive Gate Current I_{GM}		see Chart 6
Peak Positive Gate Voltage, V_{GM}		see Chart 6
Peak Negative Gate Voltage, V_{GM}		5 Volts
Storage Temperature, T_{stg}		-40°C to +125°C
Operating Temperature, T_J		-40°C to +100°C

Figure 3. Data for a typical SCR showing the limit for the rate of rise of on-state current. (Courtesy of GE Semiconductor Data Book.)

ponents. Normally this voltage appears across the ignition coil and for the inverter to work correctly the coil must be entirely inductive. If there are large stray parasitic capacitances in the ignition coil primary then the load they present to the inverter may stall it or at best hold the main inverter transistors out of saturation until they're charged. This process is inefficient and makes for a hot inverter. Certainly the push-pull inverter will not tolerate a highly capacitive load.

The next and far more serious effect occurs when the dump SCR is triggered on. The actual works of an SCR consist of a piece of silicon, shown in cross section in Figure 2, along with an equivalent two transistor circuit. Physically the gate lead is connected to a point in the centre of the silicon die. When the SCR is triggered on a positive pulse is applied to the gate in the centre to momentarily turn on the NPN transistor in the equivalent circuit. This in turn turns on the PNP transistor and the very high positive feedback of the two transistors causes the SCR to go to a highly conductive state where it will remain until the current is removed.

However when the trigger pulse is first applied *only the region near the gate terminal is turned on.* It takes a microsecond or so for the on state to spread across the whole SCR. If the current is allowed to rise through the SCR faster than the on state spreads then the small part of the SCR that has latched on will be overloaded *and the SCR will be destroyed!* The region of the SCR will have far too high a current density flowing through it and will be burnt out. Figure 3 shows part of the data sheet of an SCR and is the absolute maximum ratings for the device. The line in colour relates to this problem. It shows that the on state current must not be allowed to rise faster than 100 A/µs. If such a circuit is to operate reliably then the current through the SCR *must* be controlled. This is normally done by inserting an inductor in series with the SCR and will ensure the SCR will survive most forms of abuse but if it's left out the CDI will have almost no resistance to a shorted coil or a highly capacitive coil primary. It doesn't matter how big the SCR is; it's easy to destroy it during the first instants of turn on.

The choice of capacitor for the dump capacitor is very important too. During the dump cycle the capacitor is discharged in about 50 microseconds (give or take) and this means torrents of amps. The old standby is Philips 'liquorice allsort' capacitors aren't good enough; devices rated for high current must be selected. If the capacitor is rated for 240 Vac operation then it's a good bet it'll be OK for CDI usage too.

Another mistake made in a lot of the earlier designs was to overdo things. Just because it was easy to do, people used to use outrageous voltages on the dump capacitors which in turn generated ridiculous ignition voltages. In my earlier days I was guilty of this sin also. I recall looking in awe under the bonnet of my car in the dark when the engine was running. The whole ignition harness was outlined in blue corona discharge. Gadzooks but it was spectacular!! Not a whole lot of use though.

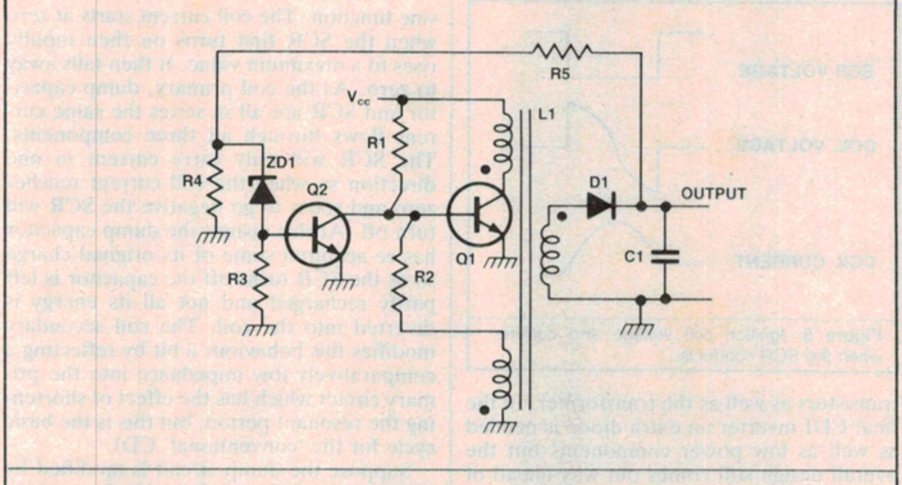


Figure 4. Basic circuit for the CDI's ringing-choke inverter.

What should be done

This more or less outlines the things to avoid doing, but what should be done? Since CDI was to be used the first decision was the choice of an inverter configuration. One of the most flexible inverter circuits available is the so-called flyback, single ended or ringing choke inverter. The basic circuit is shown in Figure 4 and works as follows. When power is first applied Q1 is biased on through R1 and current flows through the primary winding of L1. Because this imposes the full supply across the primary, the base drive winding generates a voltage equal to the primary-to-base winding turns ratio times V_{cc}. The base winding is connected with the polarity such that R2 also turns on Q1. As the voltage across L1 is constant (ignoring the saturation voltage of the transistor) the current through it will rise linearly with time and the current is described by:

$$I_{peak} = \frac{V_{cc}t}{L}$$

After a certain time R1 and R2 will not be able to provide enough base current to hold Q1 in saturation and its collector voltage will start to rise. This reduces the base drive voltage for R2 and further pulls the transistor out of saturation. The whole process runs away and results in Q1 being turned hard off. Before Q1 is turned off the current flowing through L1 represents energy stored in the inductor and this energy must go somewhere. Thus when Q1 turns off its collector voltage rises very rapidly and, as the output winding is also on the same core its voltage also rises until diode D1 is turned on. The energy stored in the inductor is dumped out through D1 into the output filter capacitor C1. As soon as all the energy is removed from L1 the voltages across all the windings go to zero (ignoring stray ringing effects) and the whole cycle can repeated. Thus C1 is 'pumped up' until its voltage is sufficient to turn on the zener diode ZD1 and hence Q2. When this happens Q2 steals all the base drive from Q1 and stops the oscillation. In fact if Q2 is removed or fails then the output voltage will rise until something breaks!

This circuit configuration has many advantages. The first is that when the current is being run up on the inductor the output diode is off and vice versa. This results in the output circuit being completely isolated from the input which means that doing bad things to the load doesn't bother the inverter at all. Even shorting out C1 completely doesn't damage anything. All that happens is that the current in L1 runs down to zero very slowly and the whole inverter acts as a constant current generator into the short. As soon as the short is removed the output voltage will rise to its regulated value again.

The second advantage is that the output voltage is determined by R4, R5 and ZD1 *only*. There is no relationship between the primary supply voltage and output at all. This enables the inverter to generate the same output voltage for a very wide range of input voltages always with (more or less) the same high efficiency. As an example the final inverter used in the ignition system will run off 2 volts to 25 volts in and the final voltage on the dump capacitor is 300 volts *over the entire input range.* The only thing that varies is the time taken to charge the capacitor.

The third advantage is that the circuit contains very few components and therefore should be very reliable. The only components that have to handle the full output power are Q1, L1 and D1. This compares *most* favourably with the more conventional circuit where there are four diodes and two ▶

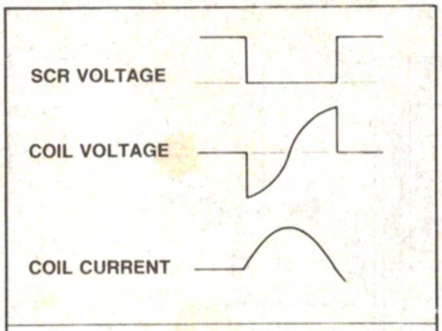


Figure 5. Ignition coil voltage and current when the SCR conducts.

transistors as well as the transformer. In the final CDI inverter an extra diode is needed as well as low power components but the overall design still comes out way ahead of the push-pull CDI system. It even compares well with the components needed for the transistor assisted ignition.

If this type of inverter has all these advantages then why hasn't it been used before? To be quite honest I have to admit I don't know. The only real drawback is that the inverter inductor has to store all the energy being transferred. This makes the inductor somewhat larger than the transformer in a push-pull inverter. Another disadvantage is that the peak current in the inductor is large (in the final design it's about 18 to 20 amps) so the power drawn from the supply is 'lumpy'. This makes supply bypassing more important and a good quality bypass capacitor must be used (but more about this later). The recent upsurge in switchmode power supplies has made both of these problems very easily solved as ferrite cores are easily available to make a suitable inductor and good electrolytic capacitors are also now common.

Since the flyback inverter will do all we want it's a cert for the final design. The next problem to be addressed is that of short spark duration with a CDI system. Referring back to the circuit diagram of a 'conventional' CDI it is instructive to consider what happens during the entire dump cycle. The first thing to happen is that the SCR is triggered on and the voltage across it collapses to zero from the original 300 to 400 volts. As the voltage across a capacitor cannot change instantly the other side of the dump capacitor which is connected to the coil immediately goes to −300 to −400 volts. The voltage rise across the coil is usually of the order of a microsecond or so. The SCR remains on and clamps the inverter end of the dump capacitor so the coil end of the capacitor resonates with the ignition coil primary inductance. Typically the coil inductance is of the order of 10 millihenries and the usual value of dump capacitor is 1μF so the combination resonates at about 1.6 kHz. The waveforms appearing on the coil primary and the coil primary current are both shown in Figure 5. The coil primary voltage is described by a −cos function and the coil current is described by a sine function. The coil current starts at zero when the SCR first turns on then rapidly rises to a maximum value. It then falls away to zero. As the coil primary, dump capacitor and SCR are all in series the same current flows through all three components. The SCR will only carry current in one direction so when the coil current reaches zero and starts to go negative the SCR will turn off. At this instant the dump capacitor has re-acquired some of its original charge so as the SCR turns off the capacitor is left partly recharged and not all its energy is diverted into the coil. The coil secondary modifies this behaviour a bit by reflecting a comparatively low impedance into the primary circuit which has the effect of shortening the resonant period; but this is the basic cycle for the 'conventional' CDI.

Suppose the dump circuit is modified by adding a diode in parallel with the ignition coil as shown in Figure 6 along with the coil primary voltage and current. The first part of the dump cycle is exactly as for the earlier circuit. The SCR turns on and forces the coil-capacitor node negative. This reverse biases the diode which has no effect on the first quarter cycle of the dump. The coil primary current rises following a sine curve and peaks when the coil voltage passes through zero. The coil secondary voltage rises very (very!) rapidly following the primary voltage until the spark gap breaks down, then collapses to a comparatively low value (only 1000 volts or so). The coil secondary current then rises following a sine curve similar to the primary except at a lower level.

However when the primary voltage attempts to change sign due to resonance with the dump capacitor the clamp diode turns on and shorts out the coil primary. This forces the currents in both the coil primary-clamp diode circuit and secondary-spark gap circuit to decay away due to losses in the two circuits and the dominant loss is the spark gap. Thus all the energy in the dump capacitor is transferred to the coil and thence to the spark gap. This has the effect of lengthening the spark duration exactly as is wanted! Even if the turbulence in the combustion chamber momentarily blows out the arc it is open circuiting an inductor carrying high current so the gap voltage immediately rises to (very) high levels again and restrikes the arc. This would seem to be a pretty good way to have things as in the final design the arc duration is usually about 0.6 to 0.8 milliseconds — about the same as in the newer transistor assisted ignition systems. The only drawback with inserting a clamp diode in a 'conventional' push-pull inverter system is that during the capacitor recharging cycle the inverter must drive into an almost purely capacitive load, as during charging the clamp diode is forward biased and shorts out the coil for the inverter. For reasons already discussed push-pull inverters just won't work into this sort of load. As luck would have it the flyback inverter is perfectly happy working into these conditions (not entirely coincidentally). There is also the further slight advantage that when the inverter is recharging the dump capacitor, the coil is inherently shorted out by the clamp diode and absolutely no charge voltages appear at the coil output. It also means that after the first quarter cycle of the dump the diode is turned on and, if necessary (if you're really in a hurry) capacitor recharging can be allowed to commence, but more of this later.

Rise time & pulses

This seems to solve all the so-called problems associated with CDI except that of too fast a rise time on the output voltage. To be honest this one had me worried for a while and the CDI which I used with great success for many years had the so called cross firing problem (but never gave a sign of it). The car I had then was a Mazda R100 and in fact there were two CDIs in it as the car had dual ignition. The rotors were fired alternately and it would seem an ideal arrangement for cross firing but then the leads were spaced well apart. All in all I have very fond memories of that car — apart from the fact that engines had to be regarded as consumables but no matter. My current iron steed is a 4.2 litre V8 Torana so cross firing had to be dealt with.

To understand the way the coil primary voltage rise time is controlled it's necessary to look into the design of the flyback inverter in some detail. A decision that was made very early on in the design was that the inverter transistor on time was to be about 20 microseconds. This is about as fast as the inverter can be run before transistor switching losses become a nuisance. For the dump capacitor to be recharged in 2 milliseconds or so the peak inverter current has to be allowed to run up to 15 to 20 amps before turn off. At first this may seem a bit fierce but there's no trouble finding suitable transistors and the main inverter transistor has a much easier life than the one used in a transistor assisted ignition! The high currents make it a good idea to run the inverter at as high a frequency as possible to make bypassing manageable. Given the inverter peak current and runup time the value of inverter primary inductance can be calculated from:

$$Lp = \frac{Vt}{I_{pk}} = \frac{13.6 \times 20 \times 10^{-6}}{20}$$
$$= 13.6 \text{ microhenries}$$

For many and varied reasons the inverter primary to secondary turns ratio needs to be 6 or 7 to 1. This from simple arithmetic means that the inductance seen looking into the inverter transformer secondary will be 36 or 49 times the primary inductance. In the final inverter the turns ratio is 6.4 to 1 so the inverter secondary inductance is about 550 microhenries. So what did I hear you say? Tut! have patience!

It isn't written in words of fire that the in- ▶

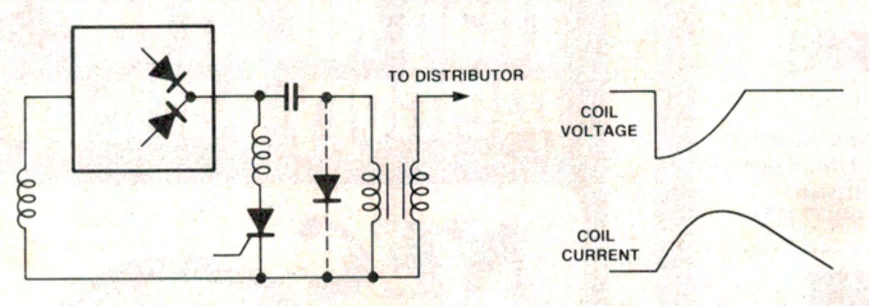


Figure 6. Using a parallel diode to modify coil current and voltage.

verter-rectifier-SCR-coil combination must be as shown in Figure 6. In the final design D1 is the rectifier diode, Q4 is the dump SCR and C2 is the dump capacitor. As long as D1 points the right way (it does) C2 will charge correctly. The only effect of moving the diode is that the secondary winding of the inverter operates at the dc voltage of C2 instead of ground (take note when deciding how much insulation is required). For the moment assume L2 and R16 are shorted out and C5 is removed. After capacitor charging is completed the inverter coil secondary, the anode of Q4 and the cathode of D1 are all at 300 volts. When the SCR, Q4 is triggered on to start the dump cycle it imposes the full 300 volts across the inverter coil secondary and the other side of the secondary starts to drive the dump capacitor negative. Everything proceeds as before *except that the output to the ingition coil is driven through 550 microhenries.* The very low impedance of the SCR is buffered by the inverter coil secondary. This means we are free to put components in parallel with the ignition coil to shape and tailor the rise time on the coil primary *exactly as we desire.* In the final design I chose to use a 150 nF capacitor so the rise time for the ignition coil primary is set by the inverter coil secondary and C6. For purposes of calculating output rise time the ignition coil can be treated as an open circuit (it's very large) and the dump capacitor can be treated as a short circuit (it's also very large). The rise time is completely controlled by the inverter secondary resonating with C6. To stop the two ringing a resistor R19 is included in series with C6 to complete the shaping of the rising edge of the voltage applied to the coil. All problems solved!

Moving the SCR to the other side of the inverter secondary has some other desirable features too. If the inverter is still charging the capacitor when the SCR is triggered, then the SCR immediately turns the inverter off as it forces 300 volts across the coil secondary which turns the base winding for the inverter off. This ensures that if there is ever any dispute for control of the inverter coil the SCR wins!

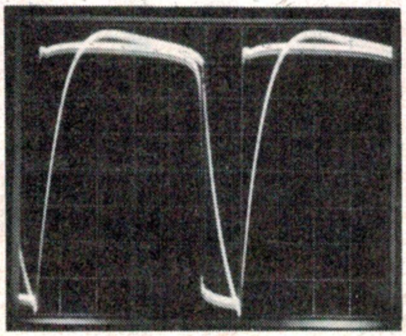


Figure 7(a). Inverter output voltage and SCR anode voltage, showing the effect of L2.

This solution did give a few problems and these are the reason for L2, R16 and C5. Since the C2 side of the inverter secondary has only the steady state charging voltage on it all the switching voltage of the inverter appears on the anode of Q4 (see Figure 7[a]). This means that the SCR anode has a very large changing voltage applied to it. An SCR, like any other device has stray capacitances between anode and PNP base, and PNP base and NPN base (refer to Figure 2 again). If the anode is driven positive very fast then capacitive currents are induced in both bases of the four layer structure. The SCR cannot distinguish between capacitive currents and gate trigger currents and so if the anode voltage changes too fast then the SCR will turn on. The manufacturers specify this effect as the maximum rate of change of off state voltage or off $\frac{dV}{dt}$ and for most el cheapo SCRs it is usually a mini mum of only 10 V/μs — trouble! RCA (which seems to be pretty good at making power semiconductors) makes a device with an off $\frac{dV}{dt}$ of 100 V/μs which is the S5800 series. Lo and behold they were available in Australia!

One hundred volts per microsecond still isn't anywhere good enough but it gave me a chance! To completely solve the problem I had to use the old 'saturating inductor snubber trick'. This works as follows. L2 is an inductor wound on a toroid with very high permeability and R16 in parallel with it makes a very low Q inductor assembly. In fact its Q is so low that it forms a critically damped resonant circuit with C5 and the SCR strays (about 100 pF). This means that when the inverter secondary applies a submicrosecond square wave edge to the input of L2 and R16 the SCR only sees a controlled rising edge of (surprise! surprise!) 100 V/μs. Because R16 makes the LCR network critically damped there is no ringing and the SCR is happy (and so, presumably, are we).

But what happens when the SCR is triggered? While it is possible to make quite large inductance values with a toroidal core they are very easy to saturate with direct currents. When the SCR is off no dc can flow and the toroid passes only the small amount of ac needed to charge C5 and the SCR strays. When the SCR is triggered the resultant dc saturates the toroidal core in three or four microseconds and the inductance almost completely disappears. Clever eh? More than that it works just fine! This really completes the discussion of the basic shaped pulse CDI; the design gave me complete control over all parameters of the output spark. The system is completely insensitive to the type of ignition coil used, any sort at all will work well. In general if you have a coil with a ballast resistor for start boost it will work better if the resistor is not included but leave it in if you want. The current rundown is predominantly damped by the secondary spark voltage reflected into the primary.

Once the basic system was working fine I started to consider all the 'bells and whistles' that would be nice. The first to go in was to give the inverter some boost during engine starting. The final charge voltage on the dump capacitor is determined only by R4, R5 and R6 together and the zener diode ZD2. When the cathode of ZD2 is raised to about 10 volts through R4 it turns on Q3 and stops the inverter. R5 and R6 form a potential divider with R4. If R6 is shorted out the input to R4 must go more positive before ZD2 starts to turn on. Q5 does exactly this when the starter voltage is applied through the input network to its base and the output of the inverter goes up to somewhere over 400 volts during starting. This pushes the rating of the S5800D SCR so I don't recommend you use it this way all the time but for short periods it's OK.

The next nicety to be incorporated arose because of the remarkable performance of the final inverter. The final inverter would charge the dump capacitor to 300 volts from an input supply of *1.8 volts.* It took a while to get there (see 'Testing') but get there it did! This was wonderful but there weren't enough volts to reliably trigger the SCR. Ridiculous! All those ergs there and no way to get at them! One of the nice things about a flyback inverter is that if several output windings are wound on the coil they all give output voltages related to each other by only their turns ratios. So three quick turns around the core, a five cent diode and a 20c capacitor and a regulated 20 volt rail was available to fire the SCR. This also ensured that an optimum trigger pulse could be applied no matter what the supply voltage.

One very nasty possibility did occur to me. Inside the inverter there is a diode directly across the output to the coil. If the 'earthy' side of the output to the coil was directly connected to ground and some misguided individual connected the hot output to the battery supply then the diode would be destroyed. It's big but not that big. To stop this possibility I connected the output ground to earth through a resistor (R18 on the circuit diagram). This would have almost no effect on the inverter regulation but very nicely prevents any mishaps. Since the secondary and primary sides of the inverter were no longer tied together this required a little thought concerning triggering. As the energy to trigger the SCR is referred to the secondary ground an optocoupler ensured that no matter what was done triggering would always happen when wanted and, better, wouldn't happen if not wanted due to stray currents in R18.

Very little modification is needed to make the circuit operate from a Hall effect sensor. A little performance is lost as the Siemens HKZ101 won't work on less than 4.5 volts but all that's needed is to change R13 from the 47 ohms for points to 300 ohms and replace the 180 ohm R14 with a 22 ohm resistor. Thus when the points input is open circuit (or off for the HKZ101) at least 8 mA flows into the optocoupler at the lowest supply voltage. R20 provides the recommended current limiting for the sensor as per data sheet.

Testing the prototype

After a certain amount of fiddling around with a rats nest, I built a prototype and had the wonderful experience of having everything work almost perfectly the first time. The board layout had no errors (amazing!) and the whole thing just happened. I had an ignition coil that I'd used on the development of the earlier CDI built some years ago that served just fine for testing. It has a primary resistance of 3 ohms and a turns ratio of near enough to 100:1.

The first thing to do was ensure that all the calculations about arc duration were correct. Photographs were taken with the coil and CDI rigged up on the bench. A rats nest version of a transistor assisted ignition was also built for comparison purposes. Calculations for the transistor assisted ignition said that the rate of rise of primary voltage should be about 15 V/μs and the tests confirmed this exactly. For the CDI I had already done the design for a rate of rise (in this case fall — the pulse is negative for the CDI) of twice this value as there is a compromise between fast voltage change firing dirty plugs and the risk of cross firing. Figure 7(b) shows that, once again the calculations were spot on. The negative going pulse leading edge has a $\frac{dV}{dt}$ of so near 30 V/μs as not to matter. The photograph also shows that the coil secondary voltage also changes nearly twice as fast for the CDI.

The arc duration was measured for the CDI and the result is shown in Figure 7(c). The timebase for the CRO was changed to 100 microseconds/division and the arc duration was measured at 0.75 ms. This is almost exactly the same as is obtained in the currently fashionable transistor assisted ignition except that the CDI will maintain this arc duration up to 330 pulses per second *with no reduction in spark power at all.* This corresponds to an engine speed of 5000 rpm in my trusty V8 or 10 000 rpm in a four cylinder car. A transistor assisted ignition with dwell extension can equal this performance *but only at the expense of very high coil currents.* The pulse shaped CDI draws about 5 amps at these unrealistically high speeds and for normal driving usually draws about one amp.

The next point of interest with the CDI system is the coil secondary voltage and current. Figure 7(d) shows how these parameters vary with time during the spark. The lower trace is the secondary voltage and the upper is the current. It can be seen that before gap breakdown no current flows (reasonable!). After the gap arcs over, the gap voltage drops to about 1 kV and the current rises in a sine wave following the primary resonance of C2 and the coil primary. The secondary current peaks at about 70 mA when D10 turns on and shorts out the primary. After this the coil primary and secondary currents decay away to zero. When the secondary current reaches zero the arc is extinguished and the small amount of energy left in capacitances rings. This confirmed that all was happening as designed for in the system.

To show how the inverter works a photograph (Figure 7 [e]) is also given of the collector waveform for Q1. These pictures correspond to an engine speed of about 2600 rpm for a V8 or 5400 rpm for a four cylinder and so are representative. In the test fixture the dwell angle was 50 per cent as a square wave was used to trigger the system. The photograph shows the inverter recharging the capacitor in two milliseconds then shutting down. The rather ragged waveform a millisecond after the inverter shuts down is the CDI triggering, and voltage is due to C2 discharging through the inverter secondary being reflected back into the primary circuit. When Q1 is off its collector voltage sits at the supply voltage. It's interesting to note that the supply rail is being pulled down by the inverter when it's running and takes several milliseconds to recover. This is because rather light leads were used in the test fixture. It illustrates that when the unit is installed in a car good solid supply lines should be used.

A rough estimate of inverter efficiency was made by accurately measuring the value of C2 then measuring the current drawn by the inverter for exactly 100 pulses per second. The power out of the inverter is $\frac{1}{2}CV^2 \times 100 = 11.8$ W. To produce this output 1.4 A was needed from a 12 volt rail which gives an efficiency of 70 per cent but there are many uncertainties in the measurement.

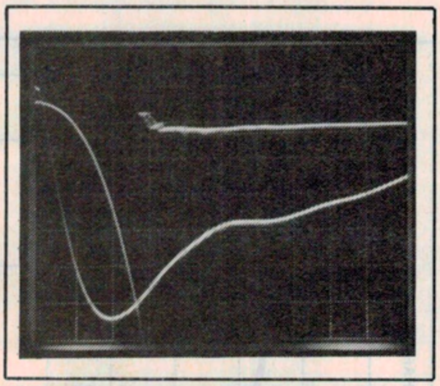


Figure 7(b). Coil primary (lower) and secondary voltage for the new CDI. Time 10 μs/div, prim 50 V/div, sec 2 KV/div.

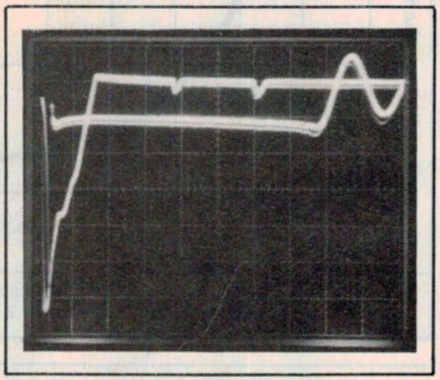


Figure 7(c). As above, but with 100 μs/div to show arc duration.

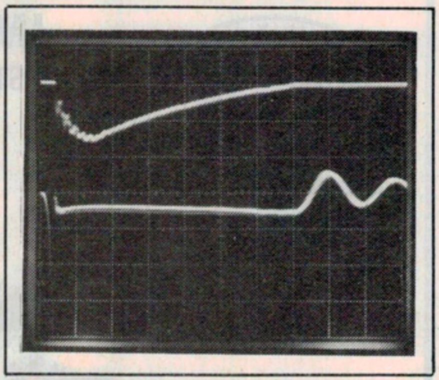


Figure 7(d). Coil secondary current (top, 50 mA/div) and voltage (bottom, 2 KV/div).

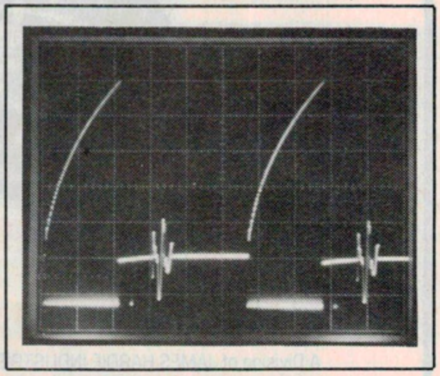


Figure 7(e). The waveform at Q1's collector (10 V/div, 1 ms/div).

▶

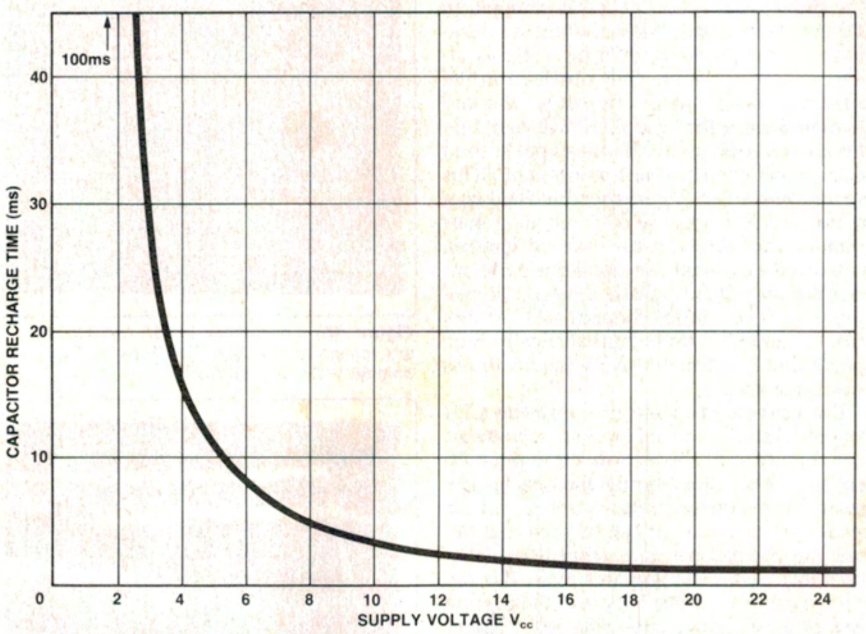


Figure 8. The time taken to recharge dump capacitor C2, plotted against battery voltage. The inverter only stops when the supply drops below 2 volts!

Finally the time taken for the inverter to recharge C2 was measured as a function of the supply voltage and the results are shown in Figure 8. For normal operating voltages of 13.6 volts the capacitor is recharged in two milliseconds but even if the voltage drops to 7 or 8 volts (not unusual during starting in winter) the inverter still gives full spark power after five milliseconds. At 25 volts in (don't ask me how you'd ever get this supply voltage in a 12 volt system) the inverter recharged the capacitor in one millisecond.

The inverter stopped operating at about 1.9 volts and at just over 2 volts was still giving the full 300 volts out. It's hard to imagine how you'll start an engine with the battery this flat but it's nice to know that the ignition system isn't the cause of the engine not starting!

Just to satisfy myself that the design was right I operated the CDI in an oven at 70°C for half an hour. This was a far more severe test than was ever expected in real life as the hot air in the oven wasn't moving and made heat dissipation a major problem for the CDI. Nonetheless the system came through with flying colours. However, I can't emphasise enough that if you build the CDI up it's *far* better to mount it under the dash or somewhere else that's cool. ●