Why do we need to Control Ignition?

Controlling when the mixture is ignited is very important, as an air fuel mixture takes time to ignite fully after the spark plug fires. It is not an instant conversion from a fuel/air mixture to a gas and it is the conversion that produces the pressure on the piston. In order to ignite the fuel at the right time, so the main explosion (maximum pressure) happens as the piston is just starting it's downwards motion, we need to fire the spark plug before the piston reaches the top of the stroke, **Top Dead Centre (TDC)** . Ignite it too early and it will cause detonation, too late and the exhaust gases will increase, causing melted valves, etc. A leaner mixture will usually take longer to ignite, so more advance is needed in order to get the maximum performance. A richer mixture will ignite quickly, so it will need less advance. In order to get the maximum power from an engine it's ignition timing needs to be correct, likewise, emissions can be effected a great deal with timing at cruising loads. With a boosted engine the timing is even more critical as the boosted air pressure will be a lot warmer, this means it is easier to ignite. So less advance is needed to stop it firing at the wrong position causing detonation. Too small advance and you'll have very high exhaust gases. So, you see, timing is very important.

Ignition Advance is measured in degrees of the crank BEFORE the relavent cylinder reaches the top of its stroke (TDC), so the higher the advance the earlier it fires.

It is usually measure using #1 cylinder as the reference.

The crank should have a TDC mark and maybe a few marks to indicate 5-10 deg BTDC (Before TDC) and possibly ATDC (After TDC).

Generally the idle and low speed area's have a lower advance of around 8-20deg, usually idle will be around 8-12deg, but this depends on your engine's design. The cruising area of the engine should have a reasonably high advance, (low to high 30's) as the mixture will be reasonably lean and therefore will give a slower burn. The overrun area can have an even greater advance, this will allow you to run lean in that section. At Wide Open Throttle (WOT) the spark map needs to be RPM based (analogous to centrifugal advance on an old style distributor) coming in at the right rate relative to engine RPM. Typically, you want it "all in" by about 2800-3200 RPMs for a street performance motor.

In the following example (my RV8 engine) we can see that at 100% (WOT) the maximum advance is reached by 2700RPM, as the load reduces (<100%) the advance increases as the mixture will become leaner (14.7AFR) for economy rather than richer (12.5AFR) for power. At idle (40%) the advance is lowered to around 8deg. **Note: The load in this graph is Manifold Pressure (MAP) in KPa, so 100KPa = Atmosphere and anything lower is vacuum. Idle and cruise KPa is around 40%, any lower is when the engine is on over run.**

Spark Advance Table1

File Tools

% \ RPM	800	1100	1200	1500	2000	2500	2700	3500	4000	4500	5000	5500
100.0	18.0	18.0	18.0	18.0	22.0	28.0	30.0	30.0	30.0	30.0	30.0	30.0
95.0	18.0	18.0	18.0	18.0	22.0	28.0	30.0	30.0	30.0	30.0	30.0	30.0
90.0	18.0	18.0	18.0	18.0	22.0	29.0	31.0	31.0	31.0	31.0	31.0	31.0
80.0	12.0	12.0	16.0	18.0	22.0	29.0	32.0	32.0	32.0	32.0	32.0	32.0
70.0	12.0	12.0	16.0	18.0	22.0	36.0	36.0	36.0	34.0	34.0	34.0	34.0
60.0	8.0	8.0	10.0	18.0	22.0	36.0	36.0	36.0	34.0	34.0	34.0	34.0
55.0	8.0	8.0	8.0	18.0	22.0	34.0	36.0	36.0	36.0	36.0	36.0	36.0
50.0	8.0	8.0	8.0	19.0	22.0	28.0	36.0	36.0	36.0	36.0	36.0	36.0
40.0	8.0	8.0	8.0	19.0	22.0	26.0	36.0	36.0	36.0	36.0	36.0	36.0
30.0	8.0	8.0	8.0	19.0	22.0	26.0	36.0	36.0	36.0	36.0	36.0	36.0
25.0	8.0	8.0	14.0	18.0	21.0	24.0	36.0	36.0	36.0	36.0	36.0	36.0
20.0	8.0	8.0	14.0	18.0	26.0	30.0	39.0	36.0	36.0	36.0	36.0	36.0

(deg)

Note: the optimum amount of total advance is not necessarily the most that doesn't cause detonation. For example, with a modern cylinder head design, you might get maximum power at 32°BTDC, but might not experience any detonation until 38°- 40°. However you will still want the advance to come in as quickly as possible (without knocking) up to 32°. My Rover based V8 produces max power around 30°BTDC at WOT, but even at 36° at WOT, I have no detonation. The only real way to tune the spark map for peak power is to use a rolling road, but normal road tuning can produce some very acceptable results in the real world.

As the load increase the spark map should have less advance as the mixture will be richer and the chances of detonation will also increase with load. When going into boost (anything above atmospheric pressure) the advance table values will need to be lower than when out of boost and as the boost level increases the advance will need to decrease with it, as detonation is more likely. It has been said that 1deg of advance should be removed for every 2PSI of boost; this is simply a rough guide and lots of things can depend on how much to remove, including compression ratio. Detonation Cans are a great option for tuning in boost, use a piece of copper pipe flattened at one end with a flexible tube connected to it. Bolt the flattened end to the cylinder head. Get an old set of ear defenders and drill a hole into the side of them, push the other end or the tube into the hole you've just drilled in the defenders and you should be able to hear any detonation as it occurs.

Cruising is probably the hardest part of the spark map to tune, shunting in the cruising area is usually down to too much advance, or too weak a mixture. If the mixture is correct (16.0 to 13.5 depending on your cam) then it may be worth removing advance until the shunting subsides. Too little advance will reduce throttle response so don't go too far, too little advance can also create higher exhaust gas temperatures.

Ignition Hardware

Ignition control can vary a great deal from one engine to the next in that it can be distributor based, coil pack based (wasted spark), one coil per cylinder (COP) or even 2 plugs per cylinder.

Coils

All the systems discused here use one or more coils. They all work using the same theory, just some have 2 spark plugs permanently connected to the coil, others have one spark plug and some have a distributor to send the HT to the correct cylinder. It is a relatively simple device which has 2 windings inside it. The central winding is the **Primary** and then theres a **Secondary** winding wound around that. The secondary has 100's of times more windings than the primary, this makes it similar to a 'step up' transformer.

The Primary winding has a 12V ignition feed to it and the other side (-ve) is grounded by the points, amplifier or the ECU. When the -ve side is grounded the coil charges up untill it is saturated (reaches its maximum current) this is know as the **dwell time**. The -ve side of the primary is then suddenly opened by the points or ECU, etc. As the primary voltage collapes it creates a massive magnetic field that in turn induces a huge voltage to flow into the secondary winding (due to the very large number of turns in the winding).
This voltage is then sent to the spark plug via the HT lead or distributor, etc. The secondary winding's voltage is searching for a ground, the nearest ground will be on the tip of the spark plug where it will jump across to create a spark. The larger the spark plug gap, the larger the voltage needs to be to jump across it. Modern coil pack systems can easily jump a 1.2mm spark gap.

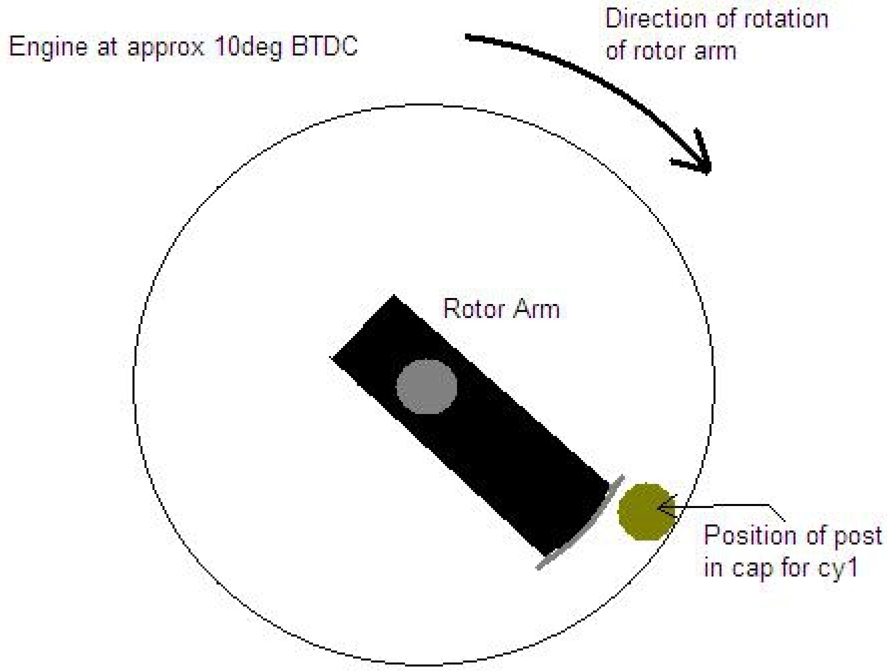
Distributor (Dizzy)

This will have a single ignition coil (The odd setup may have 2 coils) and a rotor arm that lines up with the HT lead on the distributor cap for the cylinder to be fired during the firing window. There are basically two styles:

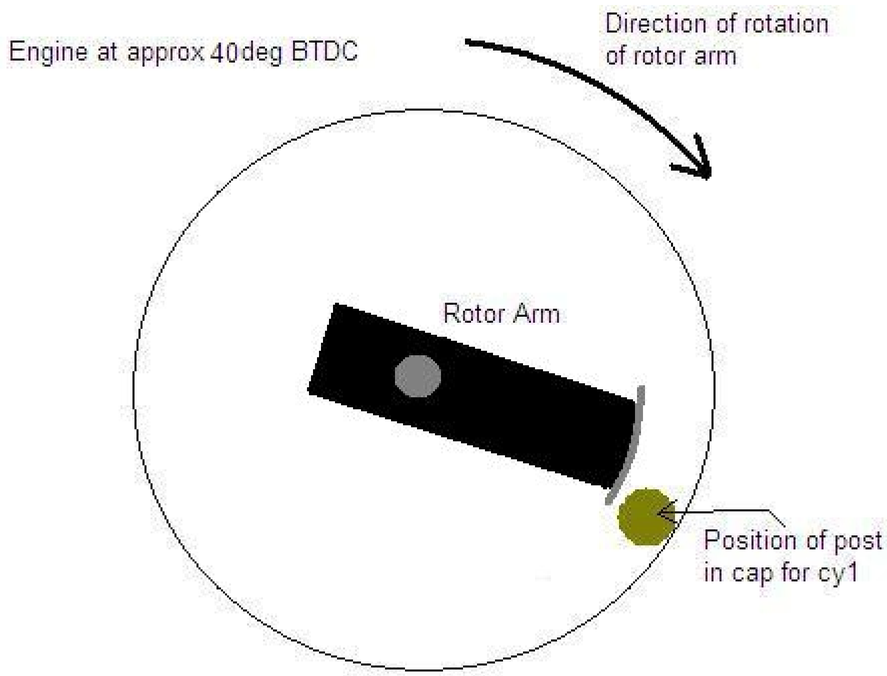
i) Movable triggering sensor. This style has a plate that the sensor/points is moved on with weights and a vacuum diaphragm. These weights open up against springs as the rotational inertia gets greater (increase in RPM) making the angle the sensor triggers at change. When the trigger occurs the coil will be fired either directly or via an amplifier, so the angle the spark occurs at is directly controlled by the weights and the vacuum advance. The fact that the angle changes all the time makes it impossible for an ECU to control the firing angle, because the trigger isn't happening at a known constant. So to use these with an ECU the mechanism would have to be locked into a fixed position.

ii) Fixed triggering sensor. These can have points/hall sensor within the distributor or a sensor that is triggered from the crank or even off a cam sensor, but they do not move around. The sensor is fixed so the angle that it fires at will never change. This means the ECU will have to control the spark angle. (Note: If using a movable triggering sensor then it must be fixed in order to get mappable ignition from a MegaSquirt ECU). The ECU can calculate the engine speed from the trigger inputs and it has a known angle when the sensor triggers so it can calculate how long to leave before it fires the coil, thus changing the firing angle. There will be an internal table that the ECU uses to look up what angle (delay) there needs to be at xxxRPM and engine load.

Most engines will be fired across the angles of 10deg BTDC to around 45deg BTDC, depending on load, etc, this is the firing window. So the rotor arm needs to be big enough to line up with the post in the distributor cap for around 30-35deg, otherwise the coil could fire when it's not lined up causing a cross fire to another cylinder.



So with the engine at 10deg BTDC the rotor arm will still be lined up with the post in the cap (e.g. cylinder #1) but it will be on the trailing part of it, as this is the least advanced angle it will probably be needed to fire at. Angles of 35-40 will be lined up with the same post by the leading edge of the rotor:



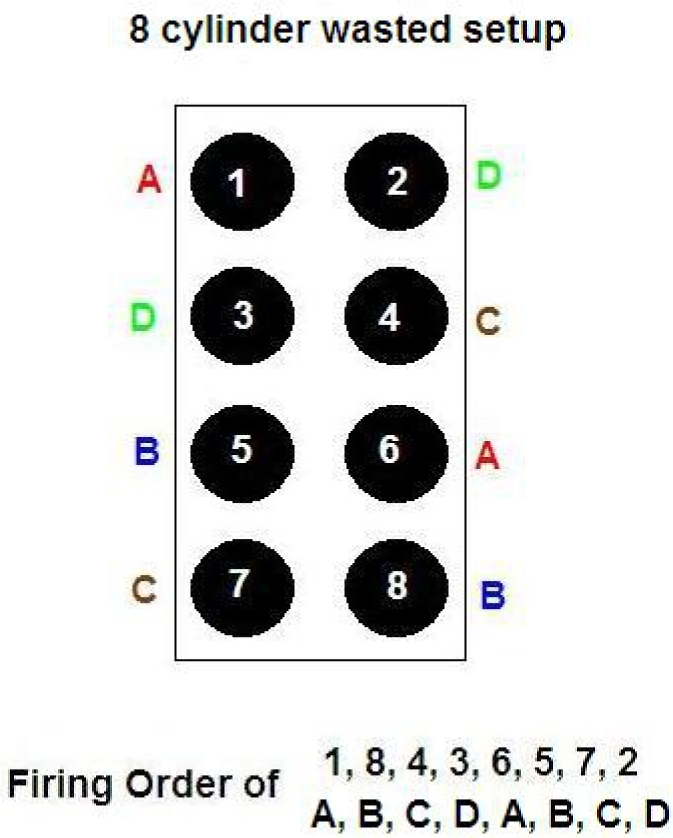
So you can see that the rotor has to be positioned correctly so the correct cylinder is fired across the used firing angle. Older distributor's have weights inside and a vacuum advance to change the angle mechanically. These weights may even alter the rotor arm against a spring. So if you lock it up to use the trigger as a fixed input to the MegaSquirt ECU you must carefully check that the rotor arm has a large enough contact area to cover the firing window. To line it up place the engine around 20-25deg BTDC (in the middle of the firing window) and line the center of the rotor arm up to the correct post. You may have to phase the distributor to do this.

Coil Packs (Wasted Spark)

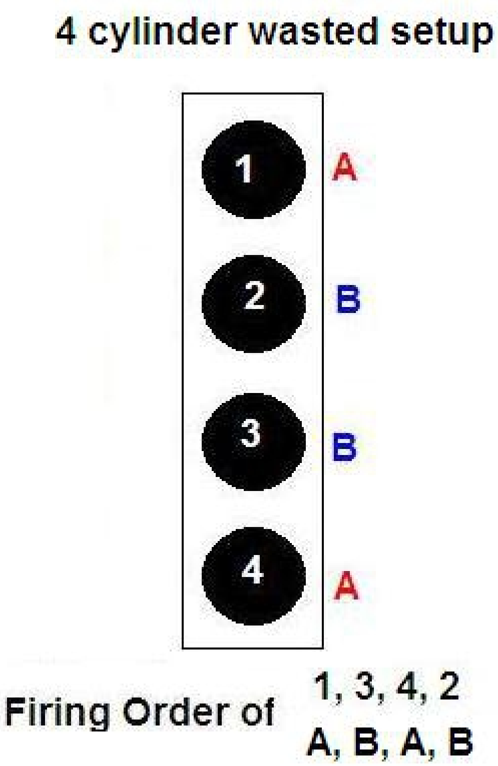
This is used without a distributor, the ECU will fire the coils directly or via an amplifier using the fixed trigger input / pattern from either the cam using a Cam Angle Sensor (CAS) or a sensor on the crank as its referencing. On an engine with more than two cylinders there will be more than one coil, so a 4cy will have 2 coils, a 6cy will have 3 coils, a V8 will have 4 coils, etc. Each coil will fire 2 spark plugs, the cylinder on its compression stroke and its firing order opposite cylinder which will be on the exhaust stroke.

For example:

Rover V8 firing order = 1, 8, 4, 3, 6, 5, 7, 2 This would be 2 rotations of the crank, so 720 degs. To fire this engine in wasted spark we would fire 1+6 together **(A)** as these are opposite in the firing order, so the pair of pistons move up and down together. Then 90deg later we would fire 8+5, **(B)**, again these are opposite in the firing order, then 90deg later 4+7 **(C)** then finally a further 90deg we would fire **(D)** 3+2, **this repeats every crank revolution.**



Ford 4 cylinder firing order = 1, 3, 4, 2 This would be 2 rotations of the crank, so 720 degs. To fire this engine in wasted spark we would fire 1+4 together, **(A)** as these are opposite in the firing order, so the pair of pistons move up and down together, then 180deg later we would fire 3+2 **(B)** again these are opposite in the firing order, **this repeats every crank revolution.**



This style of firing can only be used on an evenly spaced crank, which is 99% of engines. So on an odd fire setup this won't work as there would be no piston opposite to the one on the compression stroke.

The ECU needs a fixed trigger input from either the cam using a Cam Angle Sensor (CAS) or a sensor on the crank. The signal pattern varies enormously from one manufacturer to another, but for a wasted spark setup it will need to have at least the same amount of triggers off the crank as the number of cylinders the engine has. It will also need some form of a reference pulse or missing tooth so it knows where the crank angle is. So take for instance a Ford 36-1 crank wheel. This has space for 36 teeth (one every 10deg apart) and it has one tooth missing (36-1) so the missing tooth is the reference for the ECU. It can then count the teeth from when it notices the missing one, giving it the exact angle where the crank is at any given time. So if the missing tooth lines up with the sensor at 90deg BTDC, then when it counts to 5 teeth from the missing one the engine will be 40deg BTDC (5 teeth at 10deg apart = 50deg - 90deg = 40deg). So the ECU can use the pattern to calculate when to fire the coils. As a wasted spark format is repeated every CRANK revolution, theres no need for a cam signal, but a cam signal can still be used as it rotates at half the speed of the crank.

For more information on converting over to a wasted spark setup click here.

Coil on Plug (COP)

Like the coil pack setup, this has no distributor, instead it has one ignition coil per spark plug. This setup can sequentially fire the cylinders if theres a cam signal or it can fire in a wasted spark format as above. The ECU needs a fixed trigger input from either the cam using a Cam Angle Sensor (CAS) or a sensor on the crank. The signal pattern varies enormously from one manufacturer to another, but for a sequentially fired setup it will need to have a pattern that includes a reference pulse or missing tooth pattern from the cam (as the cam timing starts the firing sequence over again). Like the wasted spark setup, the ECU calculates the angle to fire from the crank/cam pattern. It knows which cylinder to fire as it will use the cam signal to reset the sequence, so once it detects the cam is at the correct angle it will know what cylinder to fire to start the sequence off and it can calculate the angle to fire it at from the other pulses it receives. These other pulses can come from the cam or the crank, but the reset signal will be from the cam.

Some COP's have built in ignitors, this means the ECU simply sends a signal to the COP and the COP has a built in amplifier to fire it's own coil. Older COPs are simply a coil that the ECU will drive or there may be an external ignitor/amplifier. For more on COP's click here.