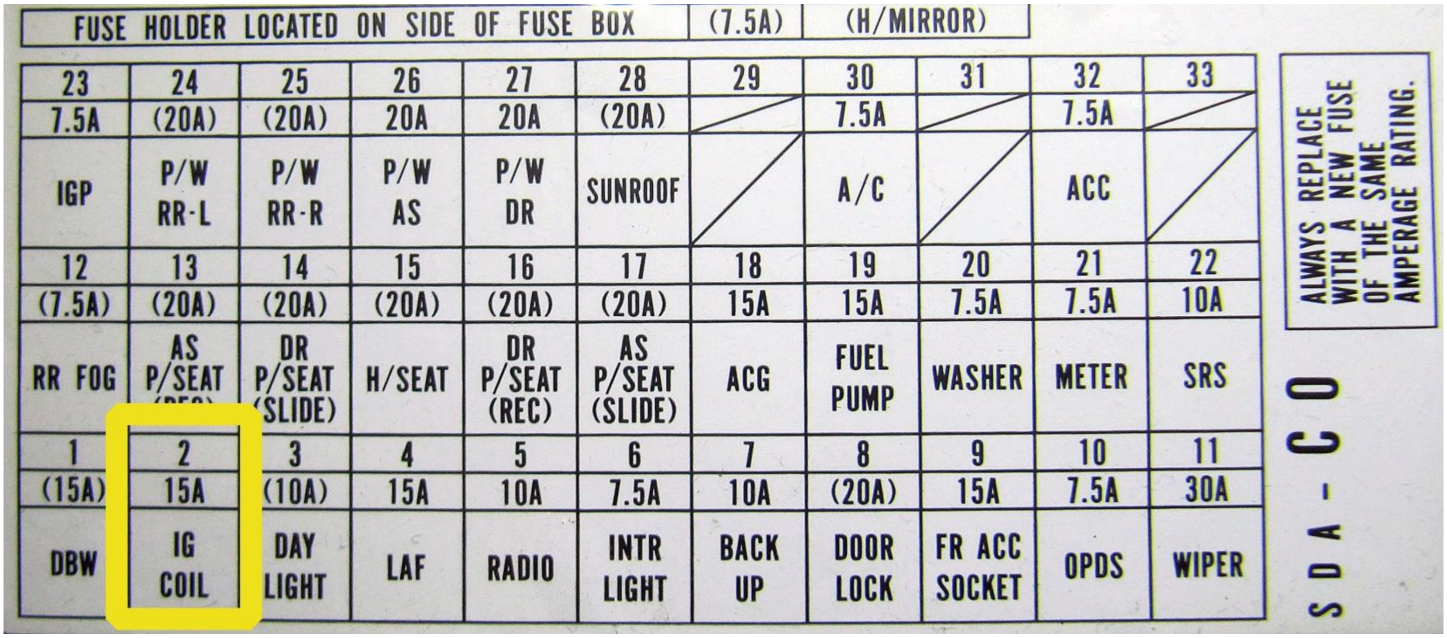
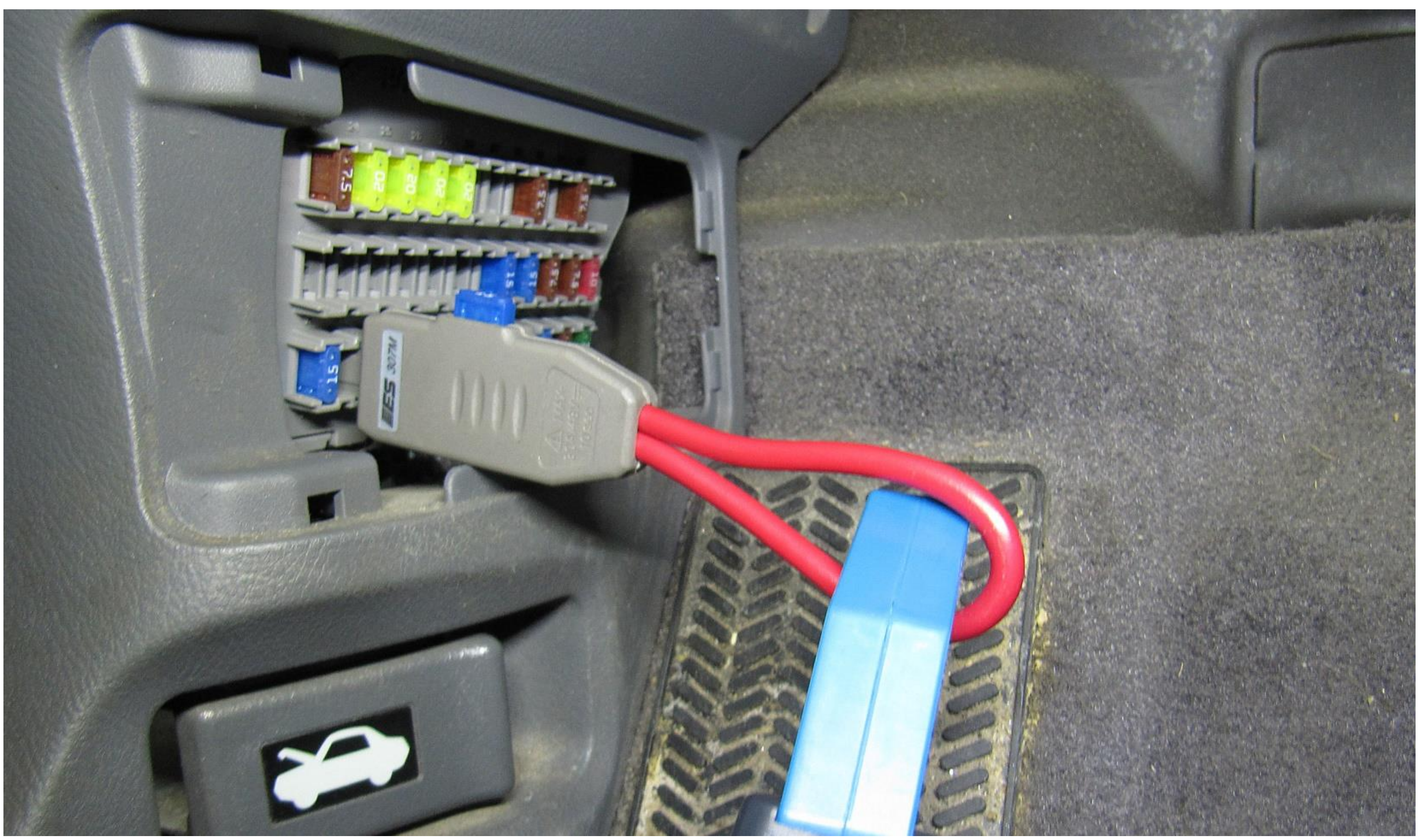
Ignition Coil Current Waveforms
2007 Honda Accord SE 4CYL

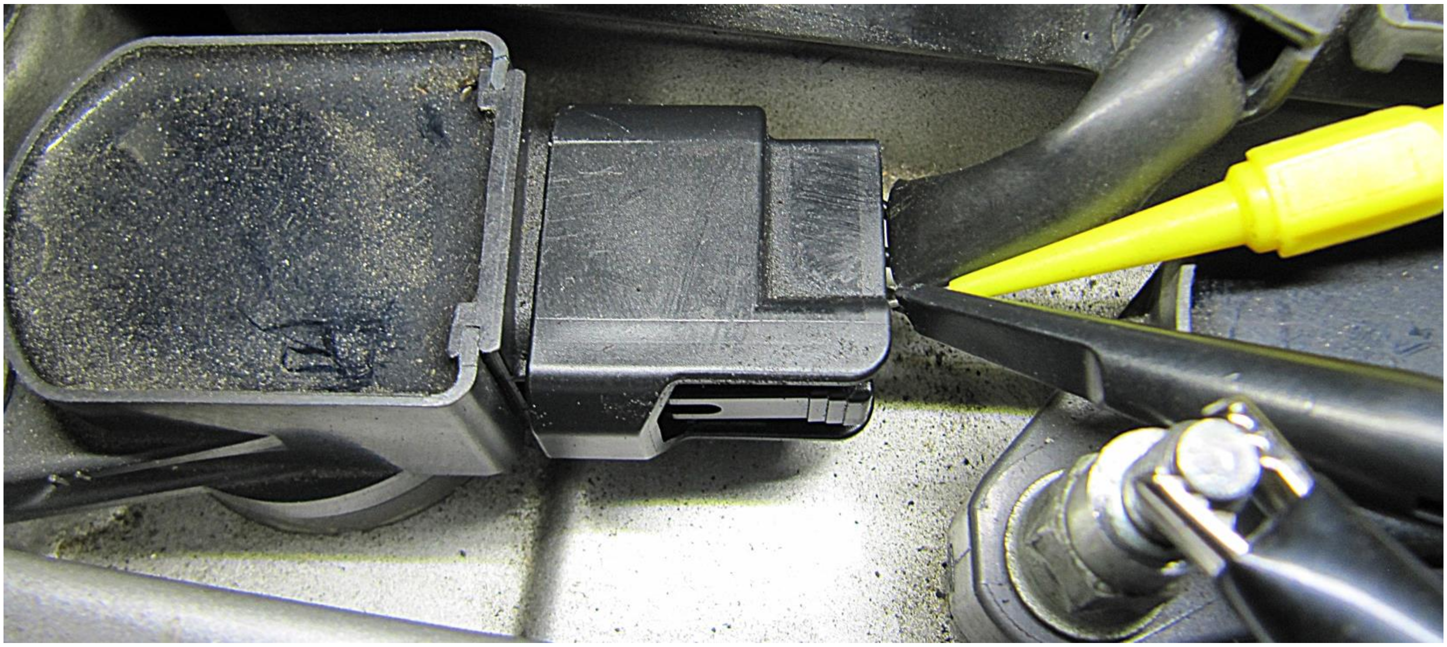
With a current clamp and a cheap scope, it is easy to monitor the ignition coil currents and quickly diagnose a bad ignition coil. The ignition coils are powered through Fuse #2 in the under-dash fuse panel:

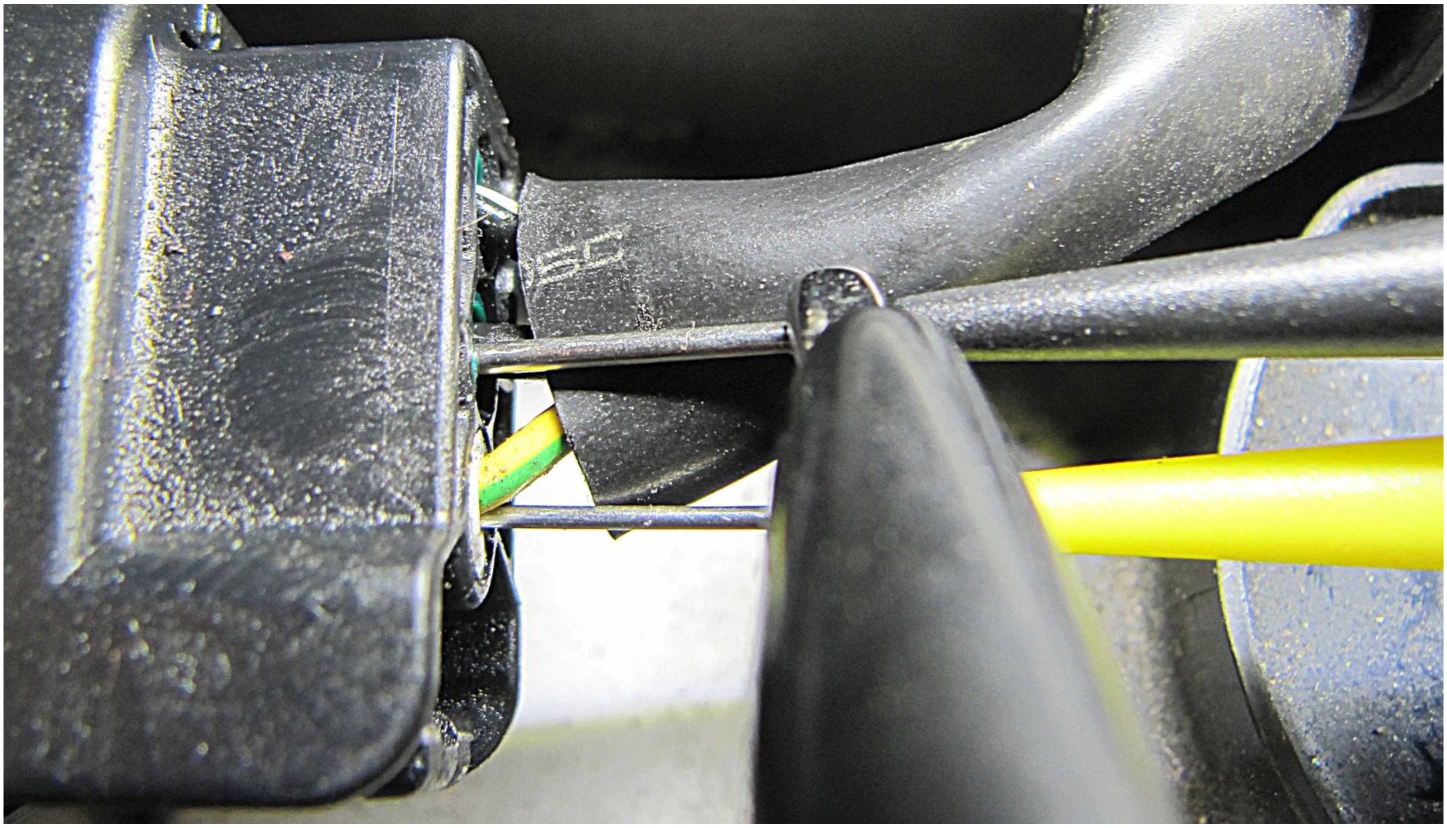


Remove Fuse #2 and insert a current loop and current clamp:

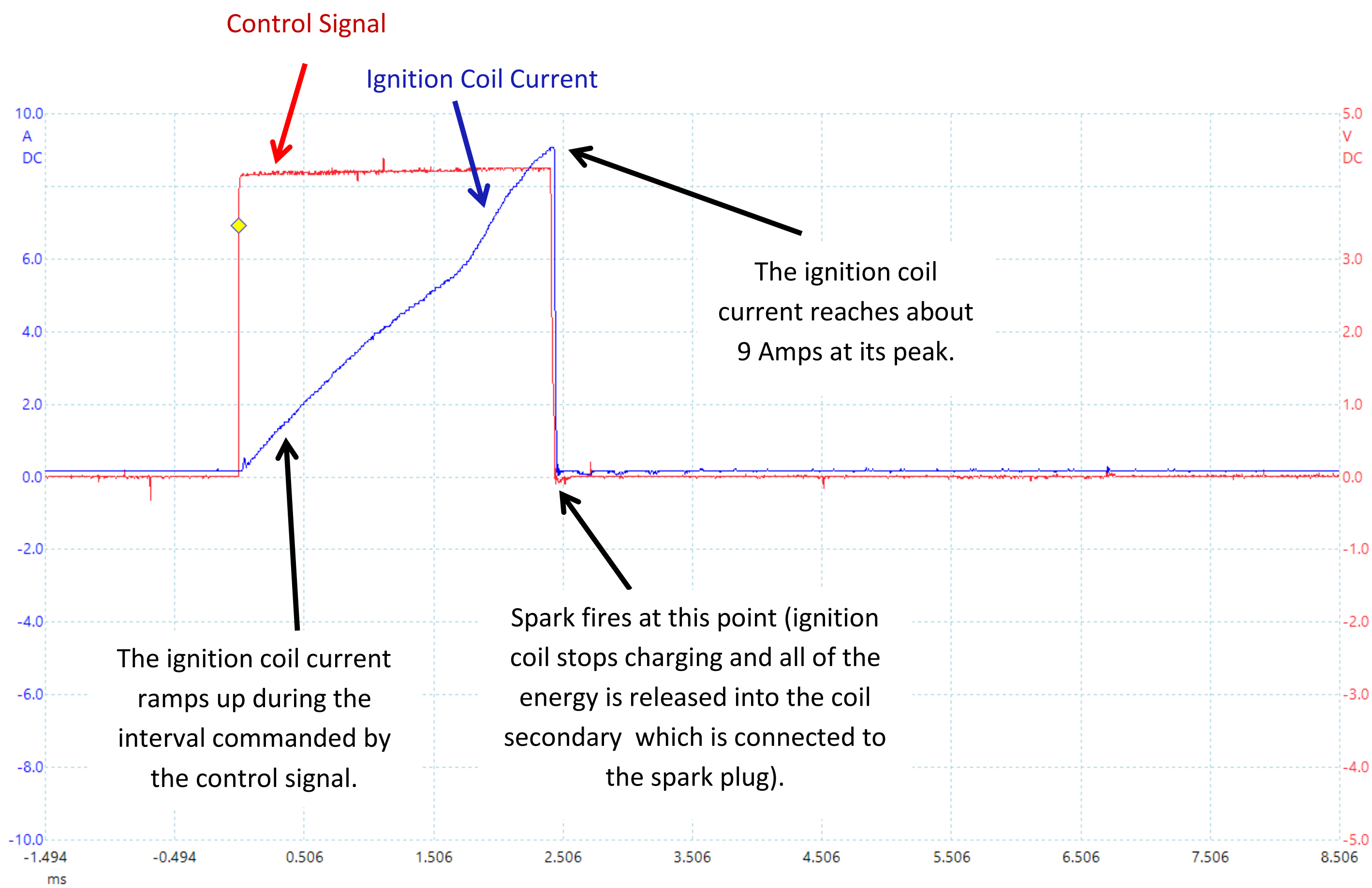


In order to determine the cylinder number for each coil current waveform, you can backprobe the green-on-yellow control wire for the cylinder #1 ignition coil (closest to the crank pulley, left side of engine looking into the engine compartment). This will give you an indication when cylinder #1 fires:

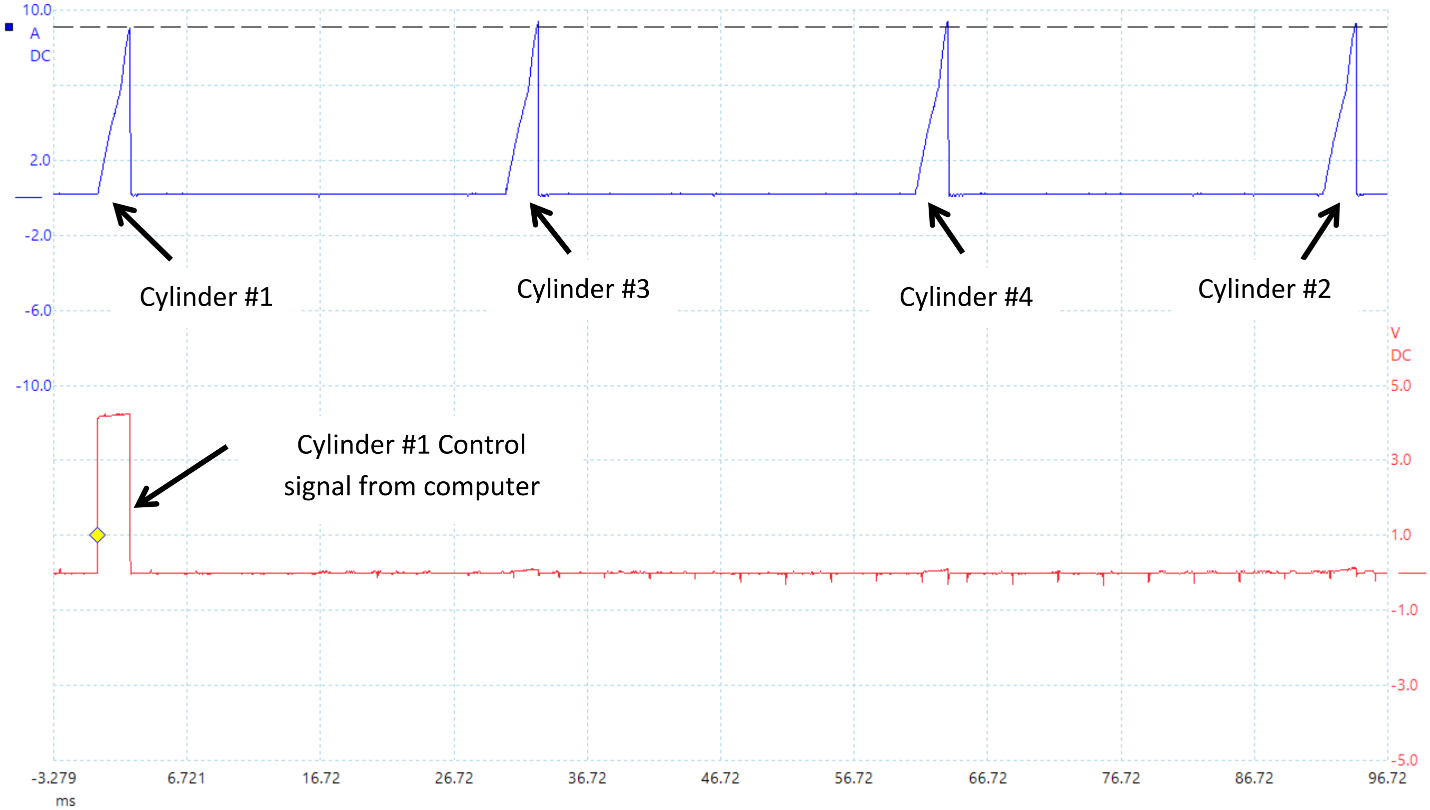




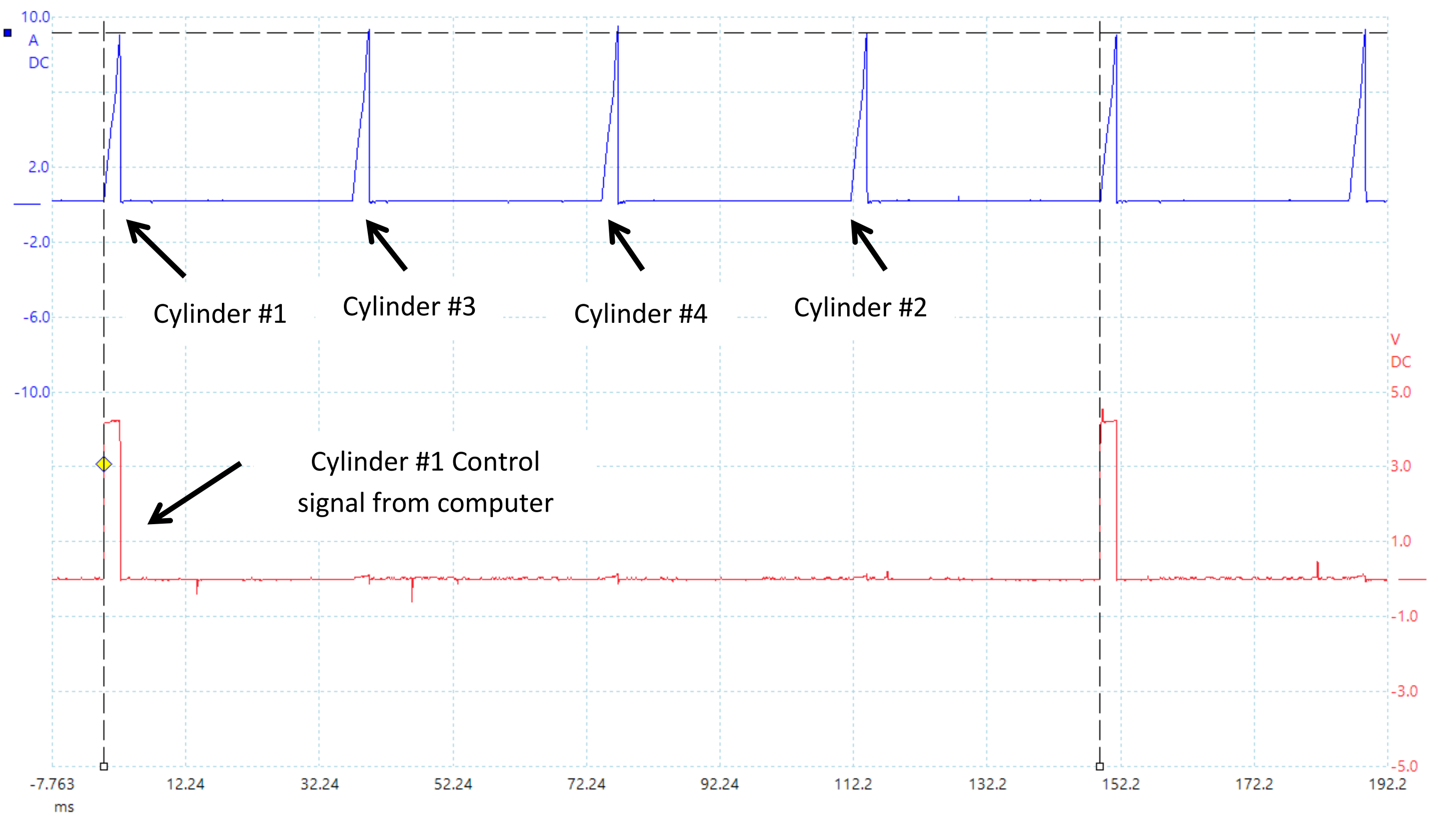
Here is a ignition coil control signal (RED) and good ignition coil current ramp (BLUE) for cylinder #1 at idle. The ignition coil current should ramp up smoothly while the control signal is high:



Here is a view of good ignition coil current waveforms for all cylinders:

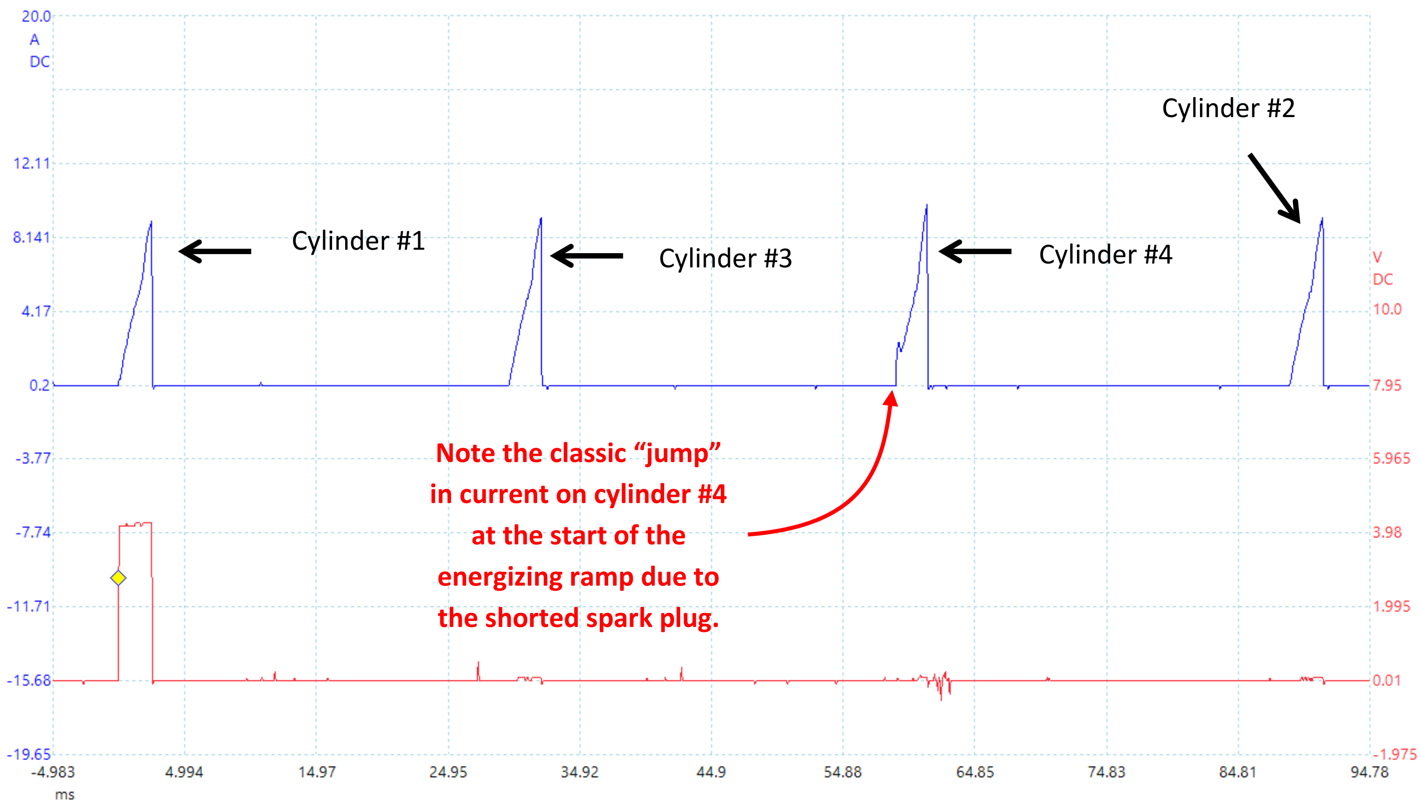


Another view at Idle, 400 RPM:

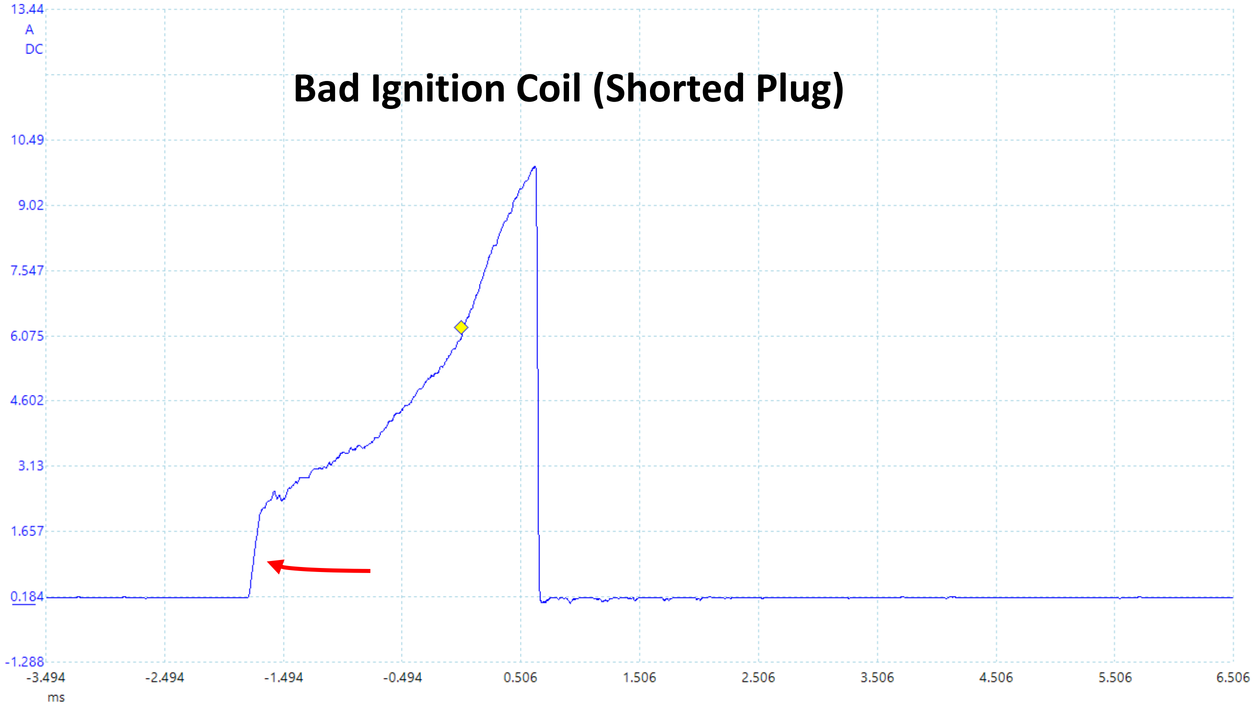


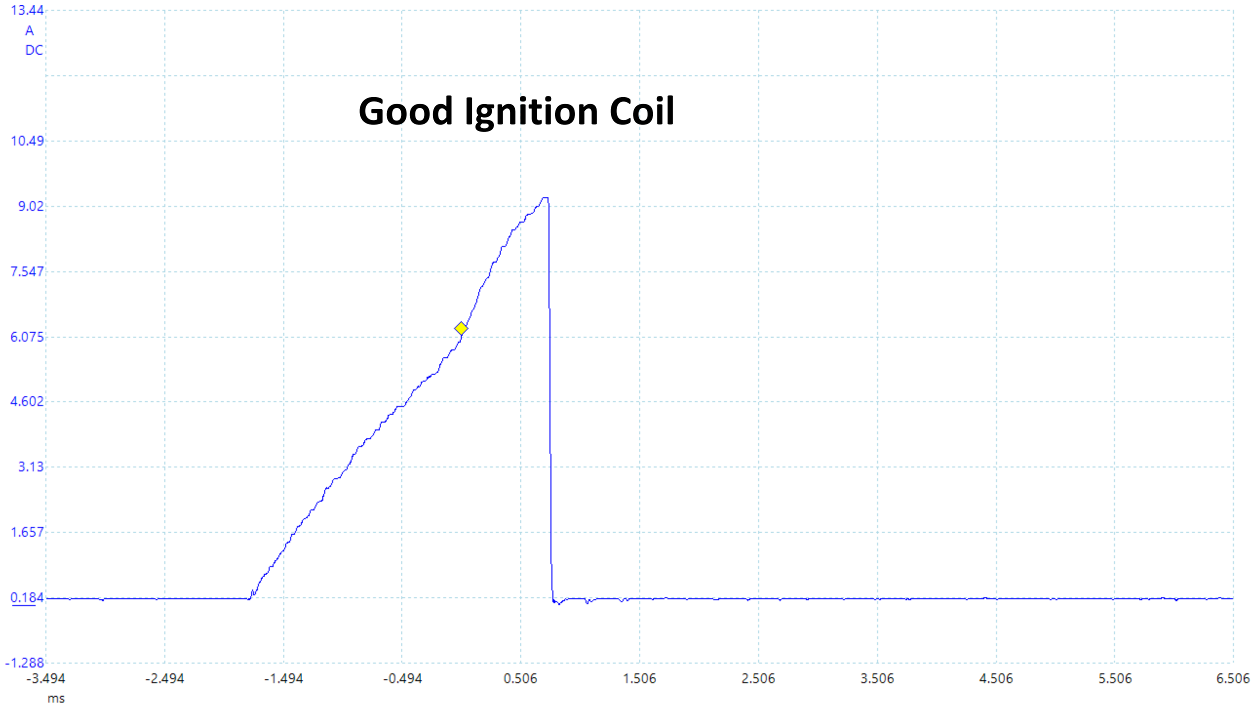
It is also helpful to know what the ignition coil waveforms will look like under various fault conditions. First I looked at what a shorted plug/secondary would look like by plugging the ignition coil #4 connector into a spare ignition coil and then inserting an old spark plug and shorting the plug electrode to chassis ground. As shown below, this results in the classic symptom of a bad ignition coil – a jump in the current at the beginning of the current ramp:

Shorted Plug/Secondary on Cylinder #4:



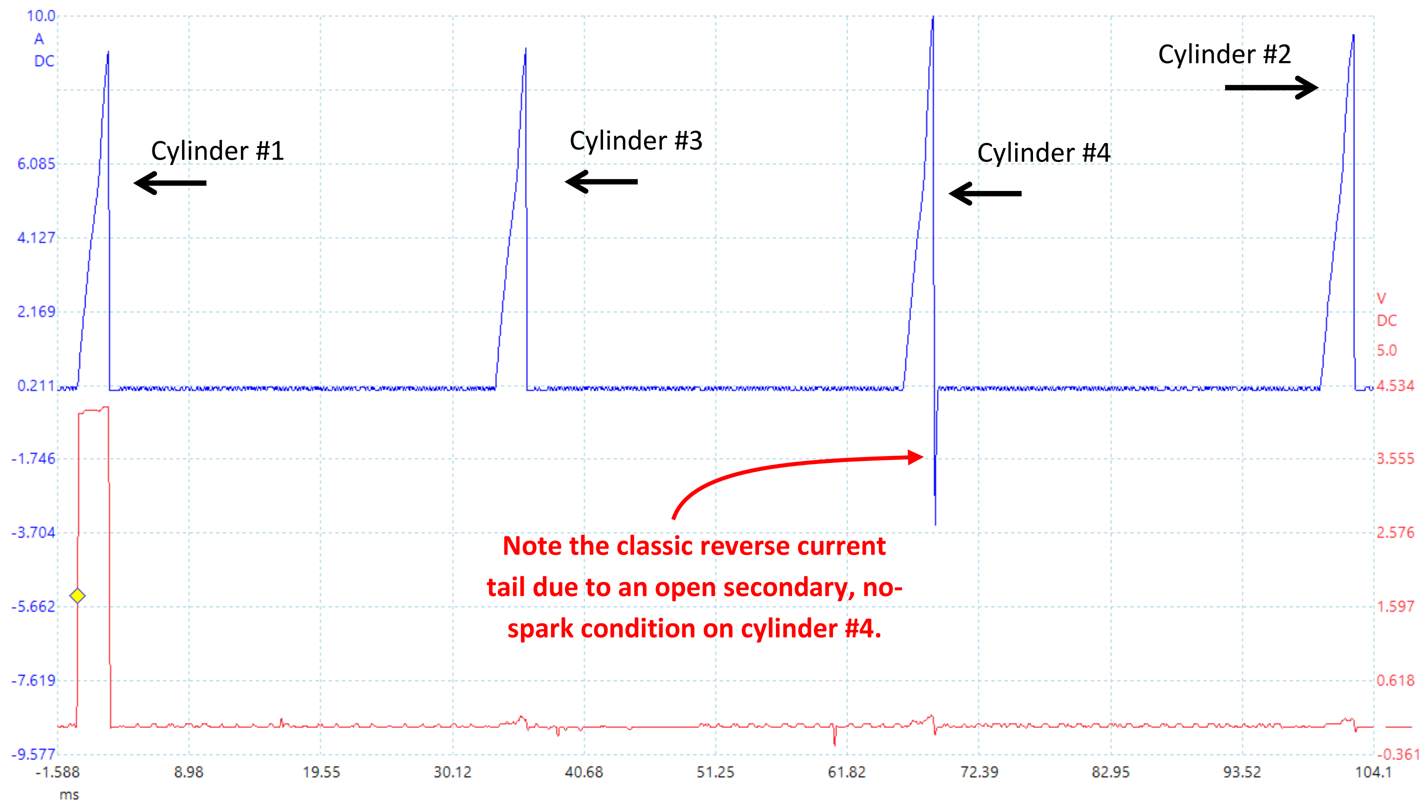
Here is a zoomed version showing the typical abnormality in the ignition coil current waveform for a shorted secondary:



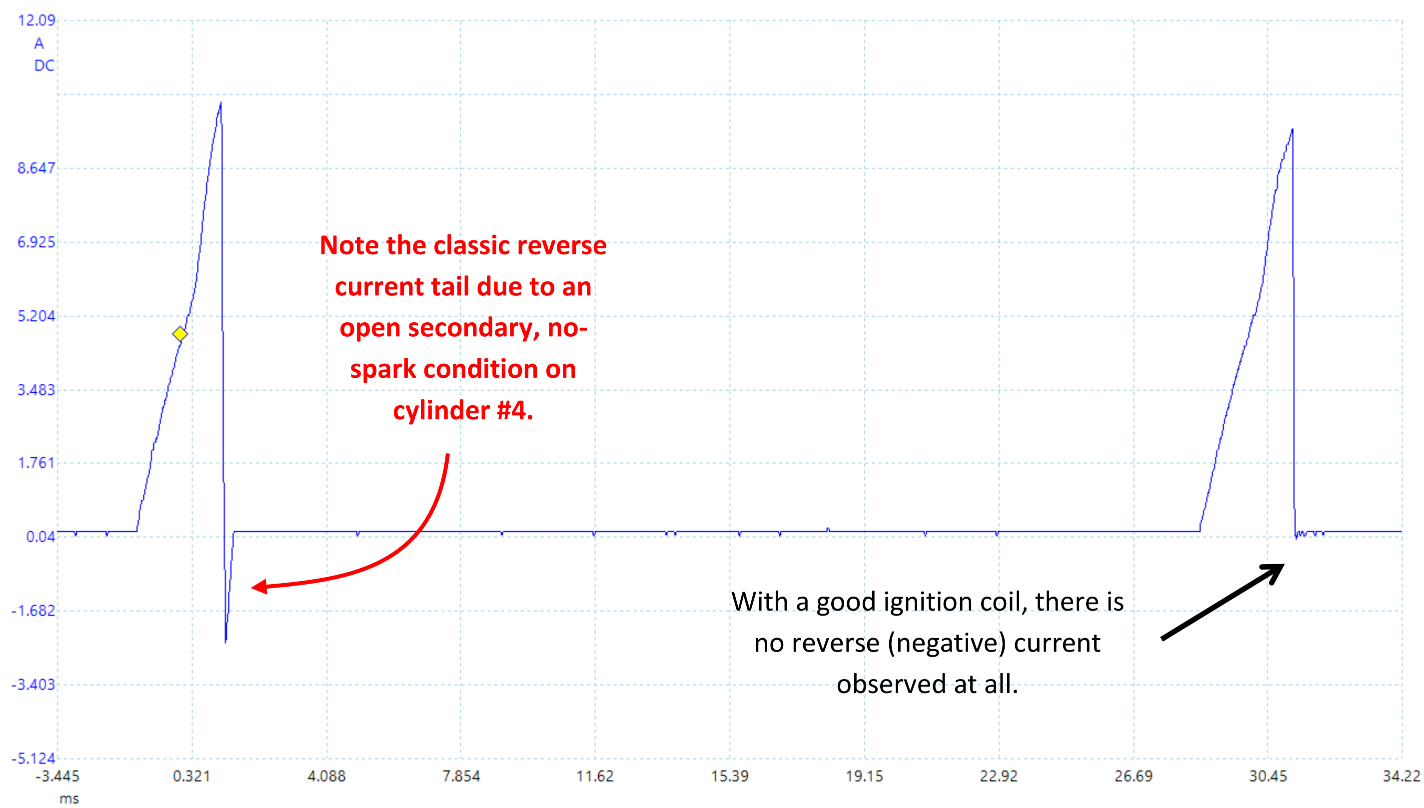


Next, I looked at the failure mode of an open secondary (which could be caused by an open secondary in the ignition coil, an open circuit in the plug, or poor connection between the coil and the plug). To create an open secondary, I connected a spare ignition coil on cylinder #4 and left its output open (no plug installed) as shown below:

Open Coil on Cylinder #4 – Plug Removed. With the plug removed, the energy stored in the ignition coil has no place to go on the secondary and a portion of it is reflected back to the input of the ignition coil and shows up as a small reverse current pulse as shown below:

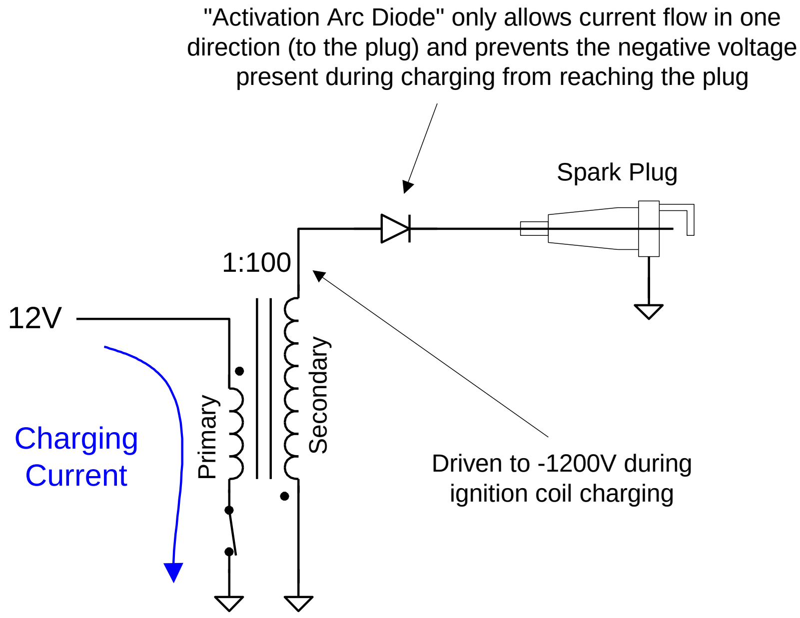


Zoom in on an Open



Appendix – How the ignition coil works and why the waveforms look as they do.

If you are curious why the current waveform has the shape it does (a ramp), here is a simplified explanation using a generic ignition coil circuit.



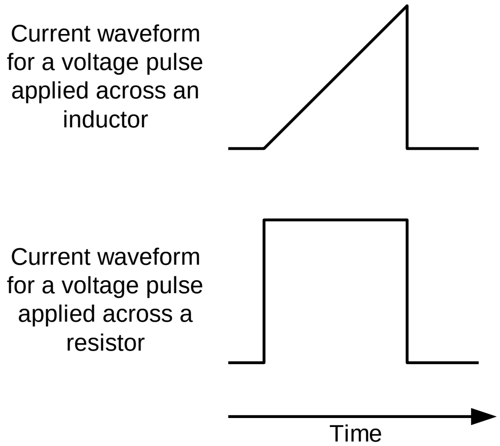
At the heart of the ignition coil is a transformer (two separate coils of wire wrapped on a common iron core). During the charging phase, current from the battery flows through the primary winding, storing energy in the magnetic field within the transformer core. During charging, the voltage on the primary winding is reflected through to the secondary winding and increased by the turns-ratio of the transformer. This results in a large (12V times 100 = 1200V) negative voltage on the secondary. To ensure that this voltage doesn't produce an undesired spark when the ignition coil starts charging, an "Activation Arc Diode" is included in the circuit. A diode only allows current to pass in the direction of the arrow, and prevents this negative voltage from reaching the spark plug. As a result, during charging, there is no current flow in the secondary winding and the electrical circuit is equivalent to an inductor being charged by a constant voltage (the battery voltage). If you have studied electronics, you may know that the current through an inductor is given by the integral of the voltage (V) across the inductor scaled by the reciprocal of the inductance value (L):

$$I = \frac{1}{L}\int V dt$$

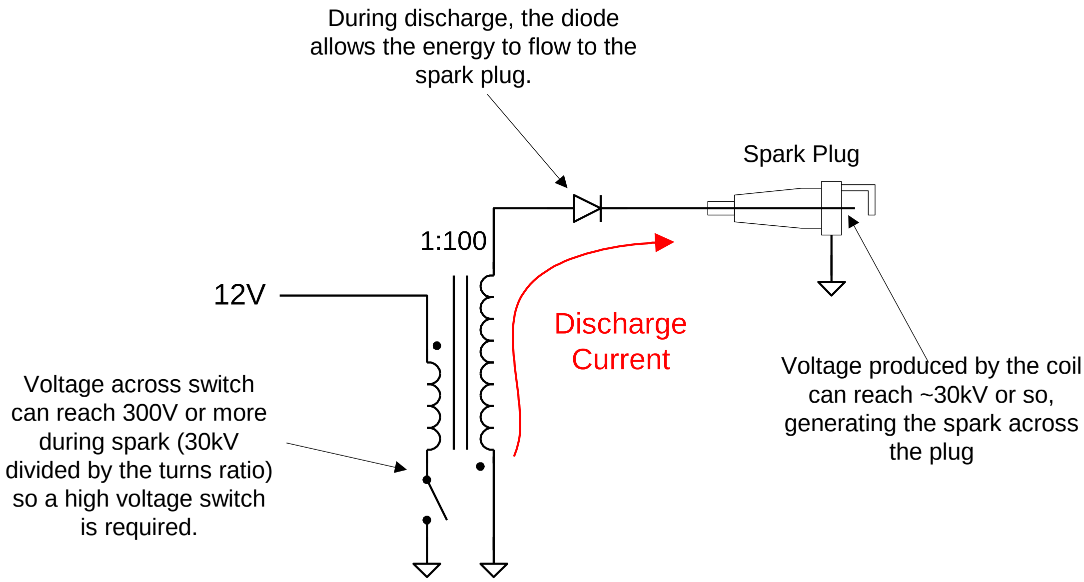
For a constant voltage, the integral can be solved for the following equation, showing that the current through the inductor is a linear ramp (increasing linearly with time, t). The slope of the ramp is steeper with a higher voltage, V, applied across the inductor.

$$I = \frac{1}{L}Vt$$

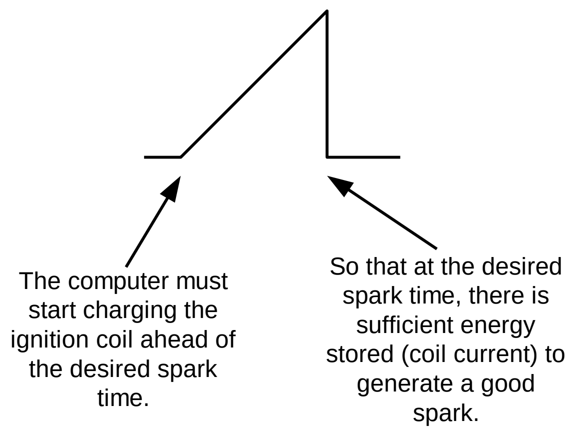
Shown graphically below, a pulse of voltage placed across a resistor results in a square pulse of current (the current is simply given by Ohm's Law, I = V/R). In contrast, a pulse of voltage across an inductor results in a linear ramp in current. Intuitively, the ramp is a result of the fact that current flow in the winding generates a magnetic field in the core. The magnetic field then induces a current back into the winding which "fights" or counters the applied voltage and slows the increase in current through the inductor resulting in the slow ramp in current rather than an instant jump in current as observed across a resistor.



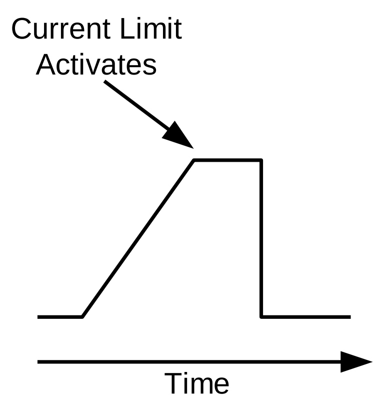
Once the engine computer sends the signal to open the ignition coil switch, there is no path for the current to flow on the primary side and all of the energy stored in the transformer is discharged through the secondary winding to the spark plug (with voltage multiplied up by the turns ratio of the transformer):



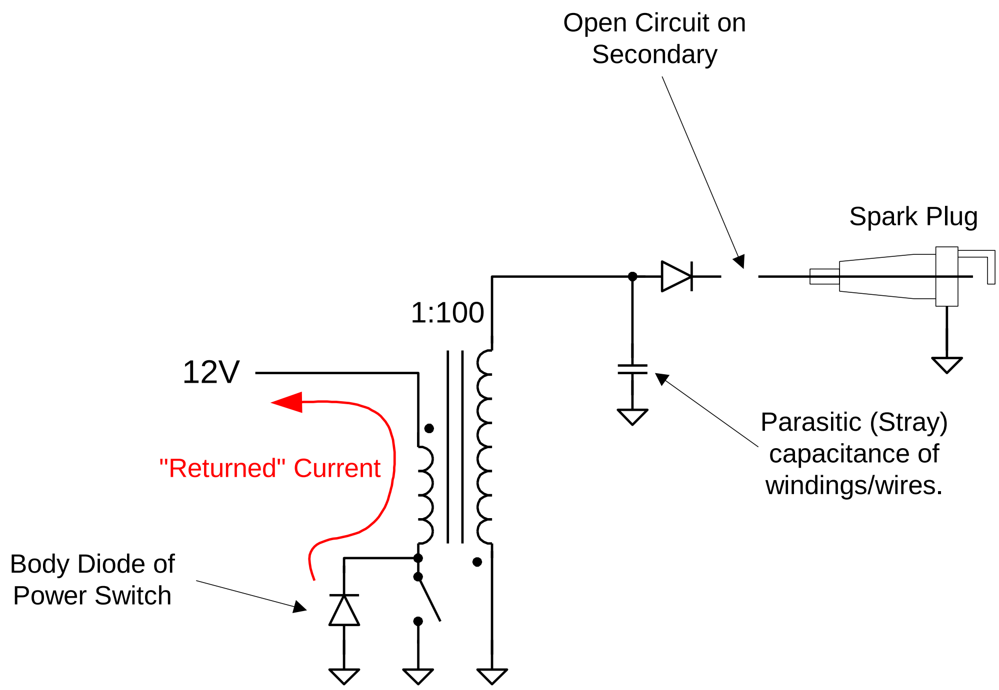
Notice that the computer has to start charging each ignition coil the correct amount of time before the desired spark (based on the desired spark timing) in order for sufficient current to have built up in the coil to ensure enough energy is stored to generate a good spark. The ramp rate of the current is determined by the coil characteristics, and therefore the engine computer has to start charging each ignition coil early enough to ensure time for the ramp to reach a sufficient level of current. However, the computer also can't start the charging too early so as to not generate too much current in the ignition coil.



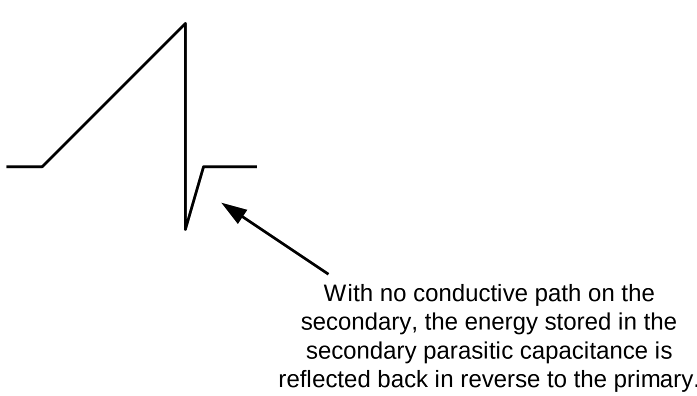
To ease this tradeoff, some vehicles have a current limit circuit built into the ignition coil charger which actively stops the current from rising beyond a certain value. This allows the ignition coil charging to be started at an earlier point, but still prevents the current from rising to too high a value. The disadvantage of this approach is that it generates more wasted power and causes heating, both in the current limiting circuit and in the ignition coil. Current limiting was not observed in the 2007 Accord ignition coil waveforms under normal operating conditions, so it appears that this vehicle has a so-called "charge and fire" approach and does not rely on a current limit in normal operation.



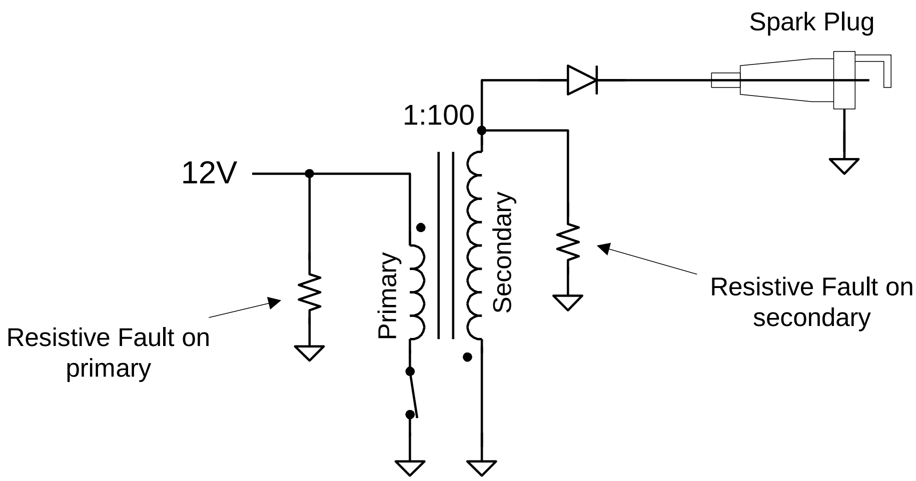
What happens when the secondary is open? In this case, the energy stored in the transformer has no place to go so it charges up the parasitic capacitance on the secondary of the transformer. This forms an LC resonant circuit. As the secondary voltage rings negative, this is reflected as a negative voltage at the power switch in the primary. The power switch (typically an IGBT) has a body diode which then begins to conduct, returning the current in reverse to the 12V power bus.



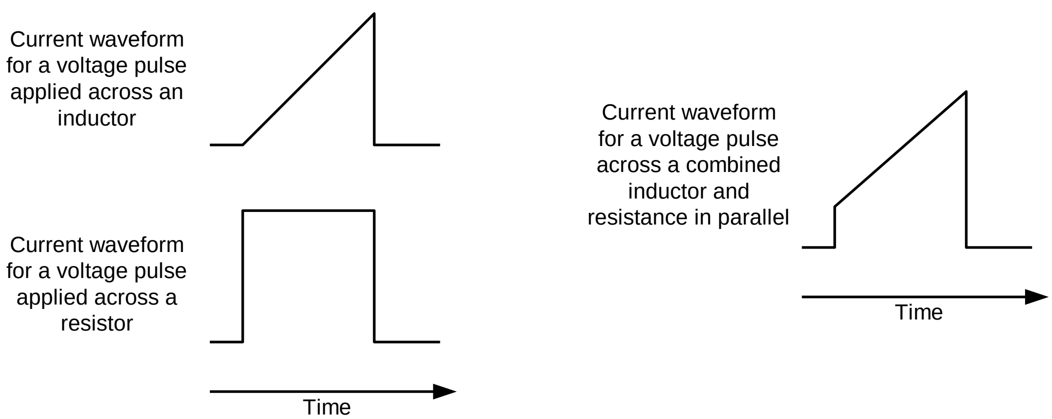
This produces the characteristics negative "tail" in the ignition coil waveform where part of the energy stored in the transformer is returned to the input of the ignition coil:



What happens when there is a resistive short on the primary or secondary? A resistive short in parallel with the primary or secondary can look similar since the resistive fault on the secondary is reflected through the transformer and acts like a resistive short on the primary as well.



A resistive short (assuming it is not a complete – zero ohm – short) results in the combination of two currents into the ignition coil, one charging the inductor and the other supplying the resistive short. This results in a combination of the square pulsed of current (resistor) and ramped current (transformer, or inductance) producing the common "step-plus-ramp" appearance of a shorted coil as shown below:



In case you are interested, here is a simple electrical model of an ignition coil using the freely available LTspice software: