Investigating GM's Compression Sense Ignition

By Jim Garrido

This combustion chamber detective uses ignition signatures to deduce engine phasing and cam position. We'll show you how it gathers the clues.

Several General Motors vehicles are equipped with a 2.2L engine called ECOTEC. This four-cylinder, four-valves-per-cylinder, all-aluminum power plant was first installed in some Saturn models, beginning with the 2000 L-series. Saturn VUE and ION models followed. It was the optional engine in the 2002 Pontiac Sunfire and Grand Am, Oldsmobile Alero and Chevrolet Cavalier and Malibu, and standard equipment starting in 2003. The ECOTEC is also used in the Saab 9.3.

The ECOTEC engine uses a speed density-based fuel injection system, along with a waste-spark electronic ignition system. The waste-spark ignition is part of a unique Compression Sense Ignition (CSI) system that allows the powertrain control module (PCM) to determine proper engine phasing (cam position) without the use of a separate camshaft position sensor mounted near a rotating engine member. This article will explain how the CSI system operates. We'll also document new misfire diagnostic techniques that are made possible by the system's unique design.

Construction

The CSI system is a modular design, with nearly all the major ignition system components housed in a single cassette (Fig. 1, page 44). The cassette is mounted directly over the spark plugs, with only connector springs and insulating boots to transfer the ignition energy to the plugs. The cassette houses two ignition coils. Each simultaneously sends ignition energy to two paired cylinders—one cylinder on its exhaust stroke and the other on its compression stroke. Cylinders 1 and 4 are paired as running mates on one coil and cylinders 2 and 3 are paired on the other coil.

The cassette has an integrally mounted lead-frame and CSI signal plates, which serve to create the four CSI input signal capacitors. The CSI signal plate output node is connected through the cassette cover to the electronic ignition (EI) module by a dual female plastic connector cavity called an *interconnect*. The EI module houses the CSI signal processing compression sense time out (CSTO) chip, as well as

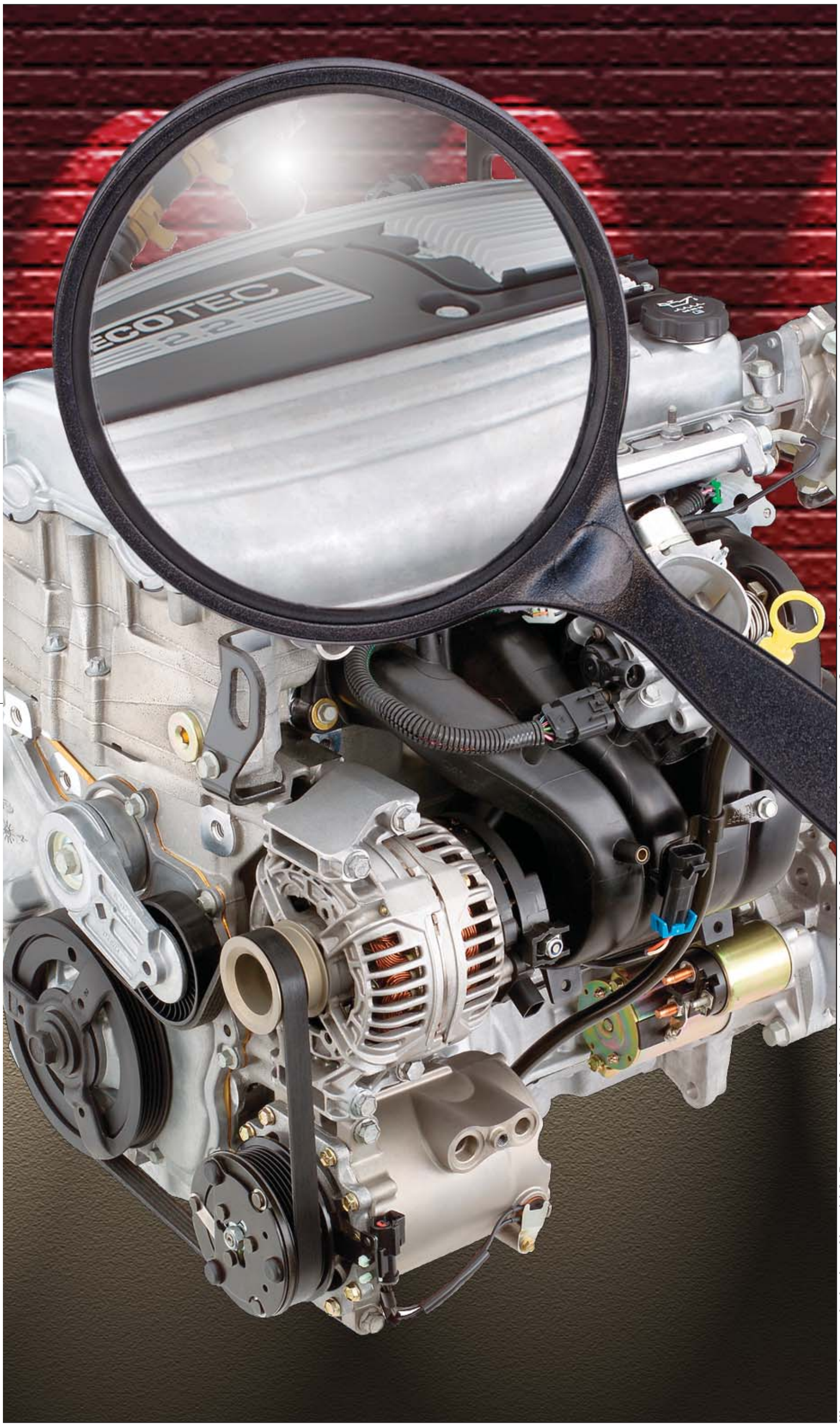


Illustration and design: Harold A. Perry; magnifying glass photo: Karl Seyfert; engine photo courtesy General Motors

the usual ignition primary drivers and current-limiting electronics.

Before explaining how the CSI signal is acquired and processed to form the CAMOUT (engine phase) signal to the PCM, it's necessary to understand the operating characteristics of a typical waste spark ignition system. These operating characteristics are important because they directly influence the information contained in the CSI signal.

Spark Polarities

Fig. 2 on page 44 illustrates the 1/4 ignition coil firing events. One spark plug in the pair of DIS running mates always fires from the center electrode to the side electrode, while the other fires from the side electrode to the center electrode. One cylinder's firing voltage rises in a negative direction, relative to engine ground, on the way to its final spark plug gap breakdown voltage. It then breaks quickly in a positive direction, back toward ground until the spark line is established. The running mate cylinder's firing voltage rises in a positive direction, relative to engine ground. It then quickly breaks over in a negative direction, back toward engine ground until the spark line is established. The polarity characteristics of the spark breakover events are one part of the information reflected in the CSI signal.

Compression Sense?

As a DIS ignition coil releases its stored energy, an electric field is created in both secondary circuits of the paired cylinders. This growing electric field simultaneously creates a voltage potential across both spark plug electrode sets. Over a period of 5 to 10 microseconds, this voltage level becomes high enough to reach the spark plug gap *breakdown* voltage level. Each spark plug gap breakdown level is determined by the impedance value of the individual spark plug gaps. At the breakdown point, the air gap between the spark plugs' electrodes will ionize and quickly conduct current, break over and establish an arc across the electrodes.

One of the important characteristics of this event is the *voltage level* at which any spark plug gap impedance will reach its breakdown voltage level. The greater the spark plug gap impedance, the greater the voltage level that must be reached for the plug gap to break down. The greater the voltage level required in order to reach breakdown, the greater the required *time* to reach this voltage level.

The spark plug gap impedance is affected by several factors. The greatest variable is the pressure in the cylinder when the spark is generated by the coil. A cylinder on its exhaust stroke has less in-cylinder pressure than a cylinder on its compression stroke. Remember, a DIS coil releases its energy to two cylinders simultaneously—to one cylinder on its exhaust stroke, to the other on its compression stroke. However, due to the pressure-related uneven plug gap impedances, both spark plug gaps will not break down at the same instant. Under most engine operating conditions, the spark plug gap in the cylinder on the exhaust stroke will break down before the spark plug gap in the cylinder on the compression stroke. The order of the spark plug gap breakover events is reflected in the CSI signal.

The CSI Sensor

The ECOTEC engine's CSI sensor detects the two secondary ignition event characteristics of breakover: *polarity* and *order*. This is accomplished by creating virtual capacitors between the secondary coils and the EI module electronics (Fig. 3, page 46). These capacitors act as a *capacitive probe* of the ignition secondary circuits and bring the secondary event characteristics into the ignition module to be processed.

One side of these capacitor plates is connected to the ignition secondary outputs. The other side is connected to one end of a sensing resistor network inside the EI module. The other end of this sensing resistor network is connected to ground. As current flows on the capacitor plates, a voltage is created on this sensing resistor. The voltage pattern measured across this resistor is reflected in the information contained in the CSI signal.

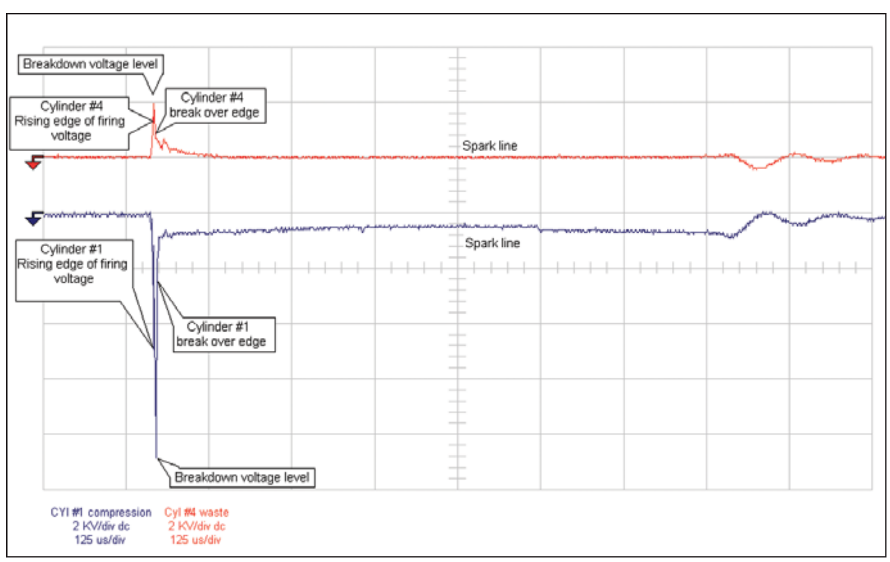
This measuring resistor, since it's combined with a capacitor, also serves to create a first-order *high-pass filter network*. This high-pass filter tends to reject the signal created by the rise of the secondary firing voltages and allows only the faster falling edge of each plug gap breakover voltage to pass through it for measurement.

The ignition firing voltages are shown in Fig. 4 on page 48, magnified by a time factor of 50 to get a closer look at the firing line characteristics as they're reflected in the CSI signal. When the 1/4 coil fires as cylinder 1 is up on its compression stroke, the No. 4 spark plug will fire *first* on its respective waste stroke. This cylinder 4 waste firing event will create a high-speed transient breakover voltage change from the positive peak breakdown firing voltage back toward zero volts. This breakover transient voltage is passed across the CSI measuring resistor in the form of a rapid voltage change in a negative direction. Then, a few microseconds later, as cylinder 1 fires on compression, there will be a high-speed transient breakover voltage change from the negative peak breakdown firing voltage back toward zero volts. This breakover transient voltage is passed across the CSI measuring resistor in the form of a rapid voltage change in a positive direction.

Conversely, as cylinder 4 (Fig. 5) is up on its compression stroke, the No. 1 spark plug will fire first on its respective waste stroke. This cylinder 1 waste firing event will create a high-speed transient breakover voltage change from the negative peak breakdown firing voltage back toward zero volts. This breakover


Photo courtesy General Motors

Fig. 1



Illustrations: Jim Garrido

Fig. 2

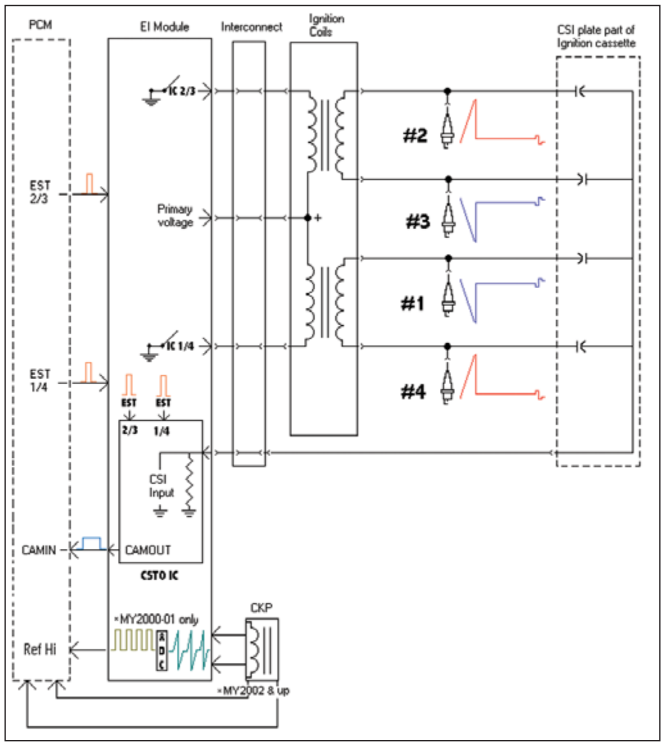


Fig. 3

transient voltage is passed across the CSI measuring resistor in the form of a rapid voltage change in a positive direction. Then, a few microseconds later, as cylinder 4 fires on compression, there will be a high-speed transient breakover voltage change from the positive peak firing breakdown voltage back toward zero volts. This breakover transient voltage is passed across the CSI measuring resistor in the form of a rapid voltage change in a negative direction.

The 2/3 coil firing event characteristics are also picked up by the CSI sensor in the same manner as above. As shown in Figs. 4 and 5, the firing voltage for cylinder 3, like cylinder 1, rises in a negative direction, and then breaks over in a positive-going direction. The firing voltage for cylinder 2, like cylinder 4, rises in a positive direction, then breaks over in a negative-going direction. The CSI signal reflects the polarity and timing (and thus the amplitude) of each cylinder's spark plug breakover voltage event.

We've examined the various pieces of information contained in the CSI signal, as well as the method in which the signal is acquired. Let's pull it all together and see how it's processed into a CAMOUT signal.

The CSTO

The EI module houses the CSI input signal logic electronics, called the *compression sense time out* chip (CSTO), shown in Fig. 3. The CSTO electronics are responsible for interpreting the CSI input signal and creating a 5V square wave output, called a CAMOUT signal.

The CSTO chip logic works as follows: The first electronic spark timing (EST) rise of either cylinder pair awakens the CSTO detection circuitry, at which time the CSTO chip looks for the CSI input voltage signal across its measuring resistor. The CSTO chip then recognizes the signal polarity and breakover order characteristics of the CSI sensor input. The CSTO will then decide whether to output a CAMOUT high or CAMOUT low signal to the PCM. If the CSTO does not receive an EST signal, the CAMOUT state will default and remain in its previously generated state—either high or low.

As illustrated in Fig. 4, when the 1/4 coil fires as cylinder 1 is on compression, the event generates a negative-going CSI signal voltage across the measuring resistor. This is followed a few microseconds later by a positive-going CSI signal voltage. This negative-then-positive CSI signal excursion causes the CSTO chip inside the EI module to output a 5V CAMOUT high signal.

As illustrated in Fig. 5, when the 1/4 coil fires as cylinder 4 is on compression, the event will generate a positive-going CSI signal voltage across the measuring resistor. Then, a few microseconds later, a negative-going CSI signal voltage is generated across the measuring resistor. This positive-then-negative CSI signal excursion causes the CSTO to output a CAMOUT low signal.

The pattern is repeated when the 2/3 coil fires while cylinder 3 is on compression. A negative-to-positive CSI signal is generated, which causes the CAMOUT signal to switch high. When the 2/3 coil fires while cylinder 2 is on compression, a positive-to-negative CSI signal is generated, which causes the CAMOUT to be switched low.

PCM Logic

This system utilizes a variable-reluctance CKP sensor mounted in the engine block near the integral crankshaft target wheel. The crankshaft has seven machined target notches, six of which are evenly spaced. The seventh crank notch is positioned about 55° ATDC of cylinders 1 and 4 and is used by the PCM as a sync pulse.

On 2000-01 ECOTEC engines, the CKP signal is fed to the electronic ignition module, which then outputs a reference pulse to the PCM, reflecting all of the CKP pulses. On 2002 and later models, the CKP signal is fed directly to the PCM. The PCM uses the CKP sync pulse notch to identify when the 2/3 coil is due up next to be charged. The engine always starts firing the 2/3 coil first upon cranking. Charging of the 2/3 coil always begins near the second crank notch. Charging of the 1/4 coil always begins near the fifth crank notch. You can actually see evidence of the coil firing events as feedback onto both the CAMOUT signal and CKP or REF HI signal. Notice the small triangular humps in the matching areas of both the signals shown in Fig. 6. The firing order is the typical 1-3-4-2.

Once the ignition process has started, the PCM looks for the sequence of CAMOUT signals from the EI module to determine engine phasing. The PCM accomplishes this by sampling the CAMOUT state (high or low) near the third crank notch, coincident after the 2/3 coil fired near the second notch, then sampling it again on the sixth notch coincident after the 1/4 coil fired near the fifth crank notch.

After two crankshaft revolutions, all four cylinders will have fired and four samples of the CAMOUT will have been taken in order to generate the four CAM ID samples. Two of the cylinders on compression (1 and 3) generate a high CAMOUT signal and two cylinders on compression (2 and 4) generate a low CAMOUT signal. This means the duty cycle of the CAMOUT signal will be 50% after two crankshaft revolutions.

These sequences of high and low CAMOUT signals are read by the PCM as a series of four data bits—a 1-bit if the CAM signal is high and a 0-bit if the CAM signal is low. The bits are in a 1001 order if cylinder 3 came up on compression first (3-4-2-1), or 0110 if cylinder 2 came up on compression first (2-1-3-4), upon initiation of ignition during cranking. The Tech 2 scan tool can display this series of bits as a Parameter ID (PID) called Calculated Compression Output (CCO). The Tech 2 PID will actually read eight bits, but only the lower four bits are used. The first four bits in the sequence always remain displayed as zeros.

In-cylinder pressures affect spark plug breakdown voltage levels and the timing of the breakover events. Under certain engine operating conditions, the in-cylinder pressures for the waste spark ignition running mates can be nearly equal. During deceleration, the pressure of the compressing cylinder can be as low as or lower than that of the cylinder on its waste stroke. This condition would, of course, render the CSI signal information invalid. For this reason, the PCM considers the CAMOUT signal valid only during certain MAP sensor ranges.

CSI Diagnosis

Let's look at the misfire diagnostic information the CSI signal provides. Considering the fact that the required firing amplitude is primarily determined by the level of compression, it only makes sense that cylinder sealing as well as engine breathing issues will affect the CAMOUT signal. The ability of the ignition system components to fire the

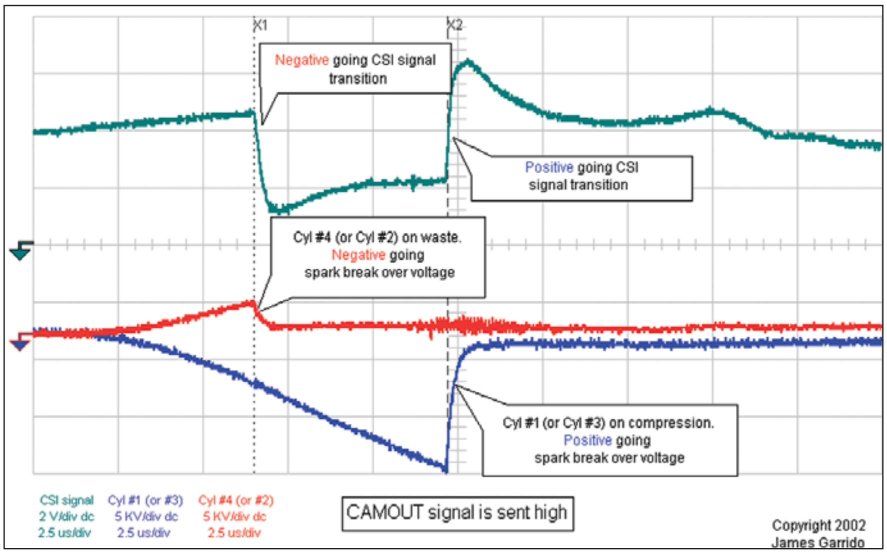


Fig. 4

cylinders also will affect the CAMOUT signal. While compression is present, the air/fuel ratio has less of an effect on firing voltage level, and will not affect the CAMOUT signal.

An extensive amount of failure mode effects analysis as well as live case studies were conducted to compile the misfire reference chart shown in Fig. 7. The chart lists the information the CSI system signals provide, regardless of whether you're using the Tech 2 scan tool or an aftermarket scan tool and a dual-trace oscilloscope. The chart lists the normal CCO PID output as read on the Tech 2, as well as the expected defect bit to be generated, listed in red below it. Each defect CCO bit pattern is to be used with the current cylinder misfire ID PID, also listed on the misfire data table of the Tech 2.

When starting up the Tech 2 scan tool, be sure to choose the "Saturn" vehicle line choice, regardless of whether the vehicle is indeed a Saturn. If you don't, the CCO bit PID will not be displayed. If you do not own a Tech 2, you can use any other aftermarket scan tool that provides a current cylinder misfire PID. If a Tech 2 is not available, use the current cylinder misfire ID PID on your scanner and your dual-trace scope

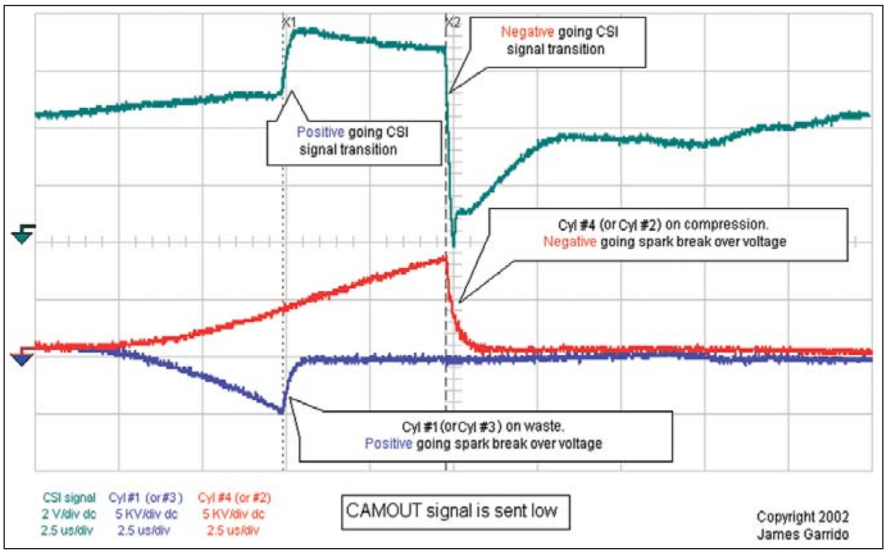


Fig. 5

on the CAMOUT signal and CKP or REF HI signals to provide all the CCO bit pattern information you'll need to use this chart.

The chart lists the expected duty cycle (D/C) of the CAMOUT signal, as well as the affected cylinder. The affected cylinder is identified via the CKP or REF HI signal count and the rise and fall of the CAMOUT signal. For the sake of brevity, the 30 corresponding diagnostic charts are not reproduced here. Refer to your service information source for these charts.

Cylinder 1 is misfiring in Charts 1 and 2. The cylinder 1 on compression bit position will generate an abnormally low CAMOUT state, which results in a 25% positive duty cycle. The signal rises coincident with cylinder 3 firing on compression and falls coincident with cylinder 4 firing on compression. This signal output combination is due to a defect causing the cylinder 1 compression firing event to occur before cylinder 4 fires on waste. The system will not have the required negative-to-positive CSI signal transition the CSTO needs to see in order to send the CAMOUT high signal.

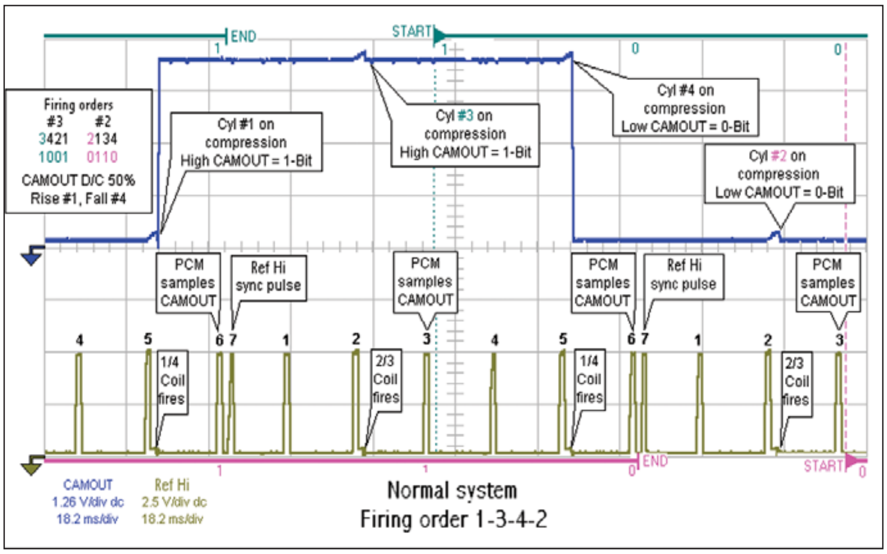


Fig. 6

If cylinder 1 were registering steady misfires at idle, use Chart 1 and inspect for defects such as extremely low compression, intake valvetrain issues resulting in a reduction in cylinder density, a badly arcing plug boot or a shorted/fouled spark plug gap. If cylinder 1 were misfiring randomly or only under load, we would use Chart 2 and inspect for leaking secondary components like a torn plug boot, a cracked spark plug or an externally arcing coil.

If cylinder 4 were registering steady misfires at idle, use Chart 3 and inspect for defects such as an open spark plug connector spring or exhaust valvetrain issues resulting in a reduction in flow out of that cylinder. An excessively large spark plug gap may also be responsible. If misfire is occurring randomly or only under load, use Chart 4 and inspect for defects such as an internally arcing or defective coil.

If both cylinders 1 and 4 are misfiring steadily at an even rate at all engine speeds and the CAMOUT signal displays 25% positive duty cycle, use Chart 5. In your waveforms you'd also notice that the normally characteristic bump in the CAMOUT waveform caused by the feedback of the coil firing is missing. This means that the primary circuit never charged and discharged any energy. Under these conditions, check for an open connection in the dual female interconnects between the EI module and the ignition cassette. Once the interconnect is removed, check for proper primary coil resistance. If both of those components are good, the EI module is bad. Lack of an EST signal from the PCM would not generate this 25% D/C CAMOUT. If both cylinders 1 and 4 are misfiring only under load, use Chart 6 to look for a defective ignition coil.

Master Misfire Chart

Scan Tool		Scope			
Normal values					
CCO PID 3421 2134 1001 • 0110	Current misfire ID PID Cyl #	CAM-OUT D/C 50%	Rise Fall Cyl# 1 4	Misfire is constant Chart #	Misfires under load Chart #
3421 2134 1000 • 0010	Cyl #1	25%	3 4	1	2
	Cyl#4	25%	3 4	3	4
	Cyls #1/4	25%	3 4	5	6
3421 2134 1101 • 0111	Cyl #1	75%	1 2	7	8
	Cyl#4	75%	1 2	9	10
	Cyls #1/4	75%	1 2	11	12
3421 2134 0001 • 0100	Cyl #3	25%	1 3	13	14
	Cyl #2	25%	1 3	15	16
	Cyls #2/3	25%	1 3	17	18
3421 2134 1011 • 1110	Cyl #3	75%	2 4	19	20
	Cyl #2	75%	2 4	21	22
	Cyls #2/3	75%	2 4	23	24
3421 2134 1100 • 0011	Cyls #1/4	50%	3 2	25	26
3421 2134 1001 • 0110	Cyls #2/3	50%	1 4	27	28
1001 • 0110	Cyls 1, 2, 3, or 4 in any combination	50%	1 4	29	30

Fig. 7

If both cylinders 1 and 4 are misfiring constantly at all engine speeds and the CAMOUT signal is 50%, use Chart 25. Again, you should notice that the normal characteristic bump in the CAMOUT waveform caused by the feedback of the coil firing is missing. Another strange aspect of this type of defect is that the 50% duty cycle of the CAMOUT is shifted 180° relative to the REF HI signal. Instead of the CAMOUT rising coincident with the cylinder 1 firing event and falling on cylinder 4, it rises on the cylinder 3 firing event and falls on cylinder 2. This happens because the CSTO did not see an EST rise from the PCM and the CSTO never armed its CSI signal-detection circuitry. Under this condition, the CAMOUT state will default and stay in its last generated state—either high or low.

The misfire diagnostics for cylinders 2 and 3 are symmetrical and identical to cylinders 1 and 4, except for one type of defect. If the 2/3 EST signal is missing, the CAMOUT will be 50% and rise coincident with the cylinder 1 firing event and fall on cylinder 4, just like a normal signal. Using Chart 27, either scope the EST 5V square wave or use a DMM and look at the duty cycle or average voltage. M

The author would like to thank Joel F. Downey, CSI lead project engineer at Delphi Automotive, for his considerable help in preparing this article.

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