2009 MY OBD System Operation

Summary for Hybrid Electric Vehicles

Table of Contents

Introduction Hybrid Electric Vehicles

HEV Powertrain Description

A hybrid electric vehicle is powered by a conventional engine with an electric motor added for enhanced fuel economy and reduced emissions. The electric motor can also be used to boost power and enhance performance (like an extra "charge"). Daily recharging plug-ins aren't needed. This type of vehicle is well suited for the environmentally aware driver who wants better fuel economy and fewer pollutants, but doesn't want the hassle of plug-ins.

A vehicle can be "more" of a hybrid than another. There are two levels of "hybridization," mild and full.

Full hybrids have all of the functions and capabilities of a mild hybrid, plus more advanced features. With both, the engine turns off when it is not needed, reducing fuel waste, and instantly restarts when the need for power is detected. In addition, both hybrids provide electric assist, in that the gasoline engine gets a boost of electric power from the battery pack. This provides additional acceleration performance when needed, without additional use of fuel. However, a full hybrid usually has a substantially higher powered battery than a mild hybrid.

A full hybrid also gives you regenerative braking (meaning vehicle energy that would otherwise would be wasted, is collected during braking to recharge the battery) while a mild hybrid has only mild regenerative braking. And only a full hybrid provides an electric launch. In full hybrid systems only, the electric motor can power the vehicle, even while the engine is off. The electric motor can be used to drive in pure electric mode even when accelerating from a complete stop. An easy way to tell the difference between a mild and a full hybrid is that a full hybrid gets better mpg in the city than on the highway.

Benefits of Hybrid Electric Vehicles

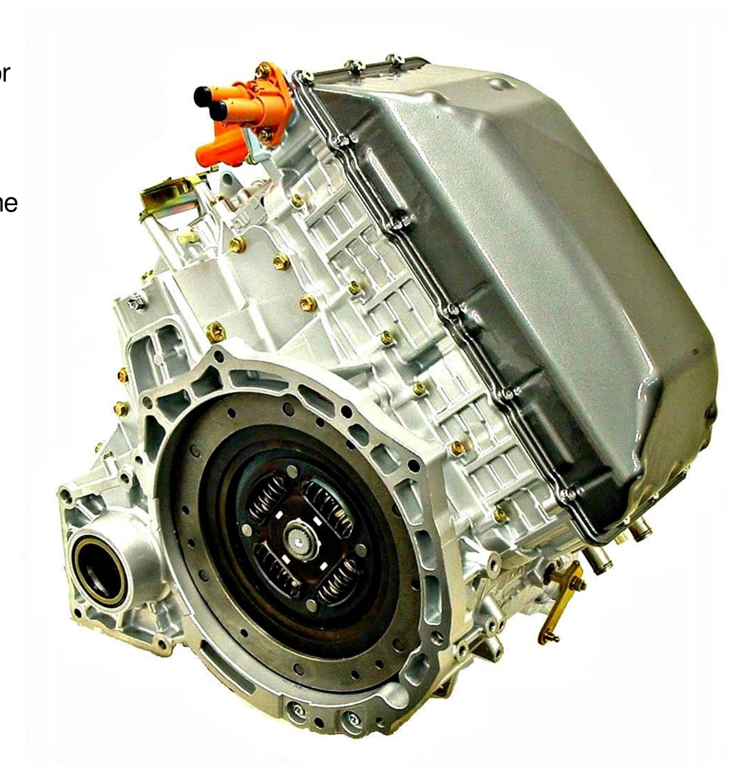
- Reduces emissions by increasing average engine efficiency.
- Engine shuts down, when the vehicle is stopped.
- Electric motor boosts acceleration performance.
- Regenerative brakes recapture energy, to recharge the battery.
- Improved fuel economy stretches a tank of gas further, saves you money, and helps you conserve our limited petroleum resources.
- Driving performance is optimized because both the gas engine and electric motor are working for you.
- No battery plug-ins required.
- An HEV offers all the conveniences of conventional vehicles: spacious seating, storage room, creature comforts, and extended driving range.
- The Ford Escape HEV will be delivered, sold, and serviced at local Ford Dealers.

Key Powertrain Components

Engine

- 2.5L I-4 Gasoline Engine
- Electronic Throttle Control
- Atkinson Cycle to improve efficiency by reducing pumping losses
- For Otto Cycle, expansion ratio equals compression ratio
- Atkinson Cycle expansion ratio greater than compression ratio
- Leaves intake valve open longer during compression stroke pushing air back into intake manifold
- Operates with less vacuum and greater throttle opening to maintain air charge

Transaxle



- 36 kW Permanent Magnet AC Generator Motor
- 65 kW Permanent Magnet AC Traction Motor
- Power Electronics / Voltage Inverter
- Planetary gear set and final drive gears
- Connected to front 2-wheel or all-wheel driveline

Battery

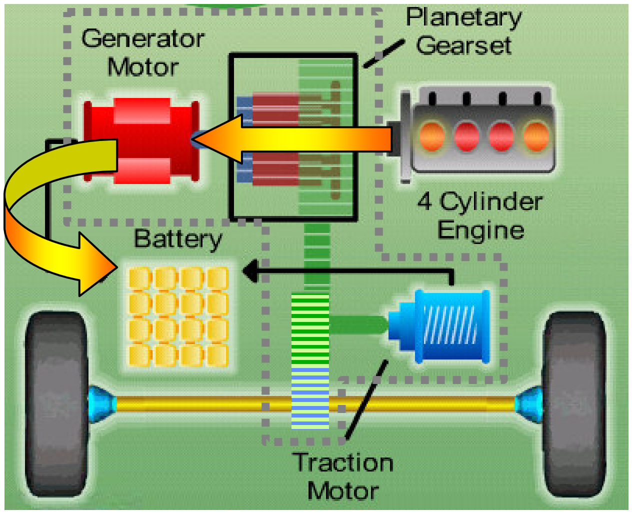
- Ni Metal Hydride
- 39 kW power rating (new)
- Nominal 330V DC operation
- 5.5 Amp-hrs capacity

Nickel-metal hydride batteries (NiMH) have a much longer life cycle than lead acid batteries. In addition to electric vehicles and HEVs, they are often used in consumer electronics, computers and medical equipment.

Propulsion Modes

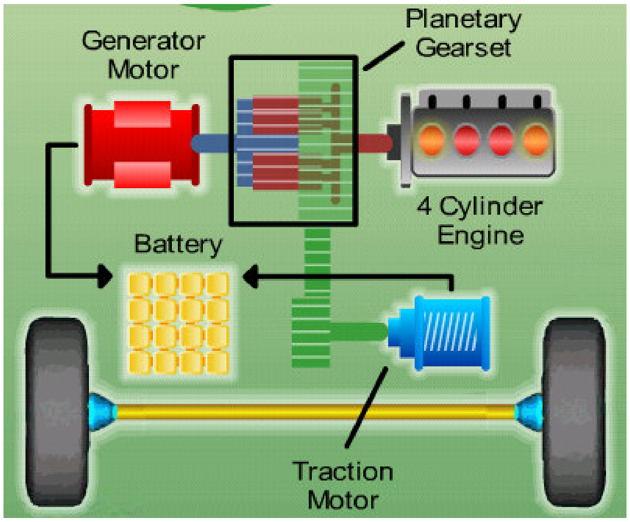
Series Mode

- Used only when vehicle is not moving and the engine is running
- Engine may be running for battery charging, cabin or battery temperature control, or catalyst warm-up.



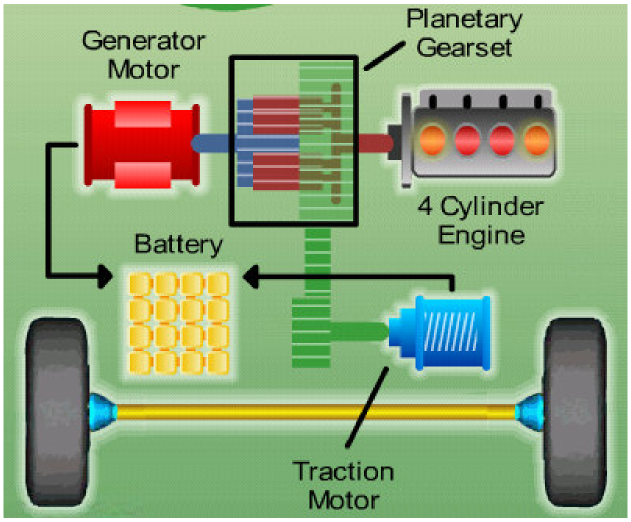
Positive Split Mode

- Engine is ON and driving the generator motor to produce electricity
- Power from the engine is split between the direct path to the road and the path through the generator motor
- Generator power can flow to the battery or to the traction motor
- The traction motor can operate as a motor or a generator to make up the difference between the engine power and the desired power
- This is the preferred mode whenever the battery needs to be charged or when at moderate loads and low vehicle speeds



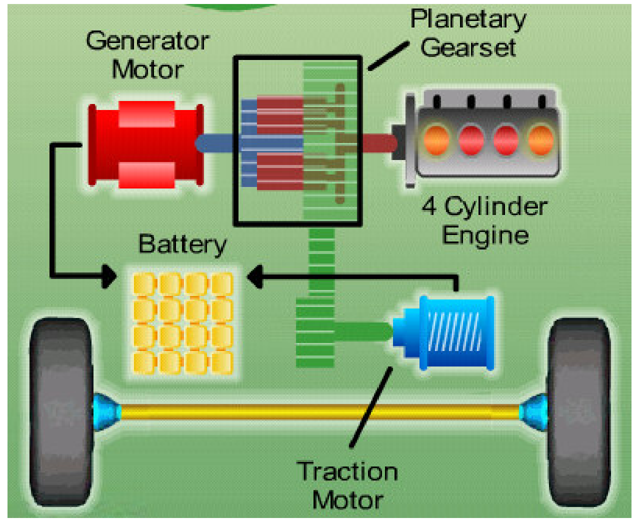
Negative Split Mode

- The engine is on and the generator motor consumes electrical energy to reduce engine speed
- The traction motor can operate as a motor or a generator to make up the difference between the engine power and the desired power
- Typical highway mode
- Occurs when the engine needs to be on, the system can not be operated in parallel mode and the battery is charged near its upper limit



Electric Mode

- The vehicle is propelled by stored electrical energy only
- The engine is turned off
- The tractive torque supplied from the traction motor
- Preferred mode whenever the desired power is low enough such that it can be produced more efficiently by electrical system than engine
- Preferred mode in reverse because the engine can not deliver reverse torque
- Separate electric pump maintains power assisted steering



City & Highway Traffic Scenarios

Stopped

- The engine will be off unless it needs to be on for reasons other than tractive power (Max A/C, vacuum, catalyst temp, heat, purge, low SOC)

Launching

- At low speed or low power demand, the launch mode will be electric, unless the engine needs to be on for other reasons.
- At moderate speed or high desired power, the engine will come on.

Entering highway or Passing

- At high acceleration demand, the engine power will be boosted with battery power through the traction motor to provide quick V-6 like response.

Cruising

- At light load, the system may operate in parallel, positive split or negative split mode depending on the battery charge.
- At heavy load (due to high speeds, weight, towing or grade), the system will be limited to engine only performance (no battery support).
- Limited regenerative braking will be used.

Exiting highway

- Provides an opportunity for regenerative braking.

Braking

- At high speed, the engine torque is ramped down, the traction motor regenerates to a limit and the foundation brakes are applied as necessary (at the traction motor or battery regen limits).
- At moderate and low speed, the engine will be turned off.

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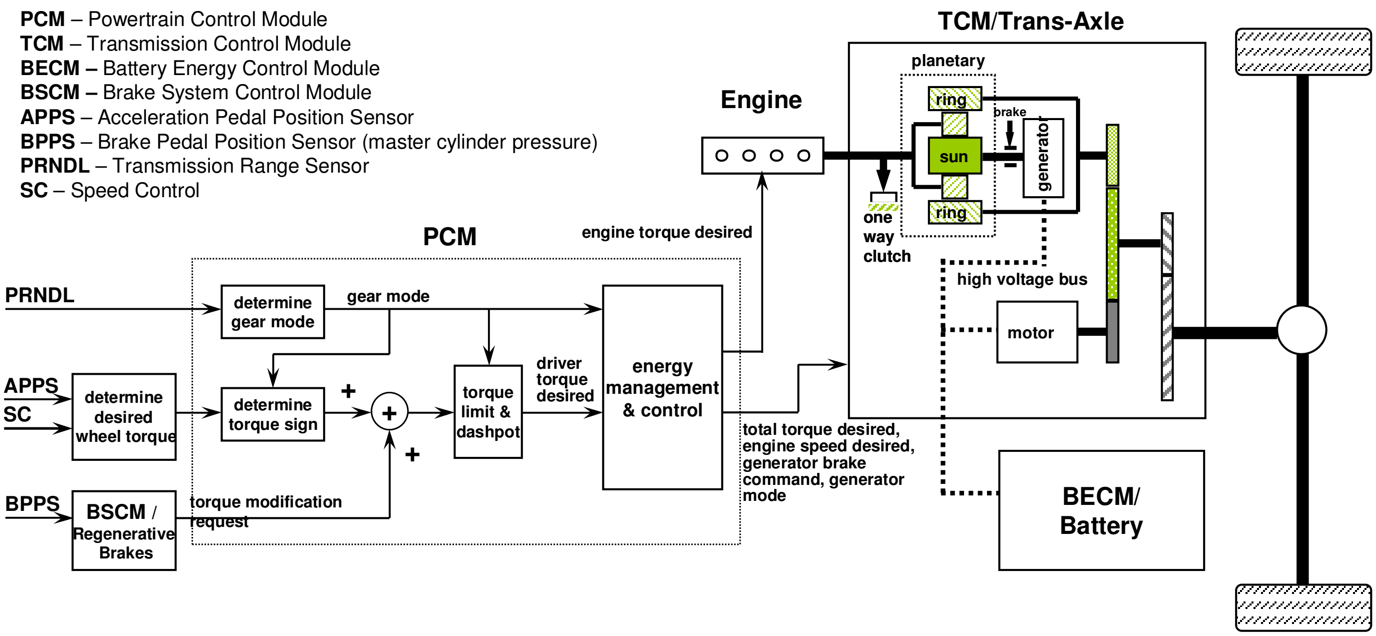
Escape HEV Powertrain Control System



The Hybrid Electric Vehicle Control System uses four modules to control hybrid electric powertrain functions:

> The Powertrain Control Module control overall vehicle system functions as well as engine operation.
>
> The Transmission Control Module controls the transaxle as well as generator and motor functions.
>
> The Battery Energy Control Module controls the high voltage battery pack.
>
> The Brake System Control Module controls the regenerative braking functions.

All these modules use CAN communication for all diagnostic functions and normal-mode communications.

The Powertrain Control Module (PCM) is a stand-alone OBD-II control module and meets all J1979 requirements. These include generic PIDs, freeze frame storage, pending and confirmed DTC retrieval and clearing, Mode 06 test data, Mode 08 evap system test and Mode 09 VIN, CALID and CVN. The OBD-II monitors for the engine are similar to the monitors used by a conventional gasoline vehicle. The basic difference between a conventional gasoline engine and the hybrid engine is that the engine often shuts down while in electric mode. This sometimes requires active intervention by the diagnostic executive to ensure that all OBD-II monitor can complete.

The Transmission Control Module (TCM) is a stand-alone OBD-II control module and meets all J1979 requirements. These include generic PIDs, freeze frame storage, pending and confirmed DTC retrieval and clearing, and Mode 09 CALID and CVN. Some of the OBD-II monitors for transmission are similar to the monitors used by a conventional transmission; however, many of the monitors are unique to the hybrid generator and motor sensors and controls. The TCM is housed within the transmission case and is not serviceable with the exception of reflashing memory.

The Battery Energy Control Module (BECM) is not a stand-alone OBD-II control module. The battery module sends fault information to the PCM. The PCM stores and reports freeze frame and DTCs for the BECM. The BECM is housed within the battery pack and is not serviceable with the exception of reflashing memory. As a result, the BECM supports J1979 Mode 09 CALID and CVN.

The Brake System Control Module (BSCM) is not an OBD-II control module because there are no regenerative braking faults that affect emissions.

Catalyst Efficiency Monitor

The Catalyst Efficiency Monitor uses an oxygen sensor after the catalyst to infer the hydrocarbon efficiency based on oxygen storage capacity of the ceria and precious metals in the washcoat. Under normal, closed-loop fuel conditions, high efficiency catalysts have significant oxygen storage. This makes the switching frequency of the rear HO2S very slow and reduces the amplitude. As catalyst efficiency deteriorates due to thermal and/or chemical deterioration, its ability to store oxygen declines and the post-catalyst HO2S signal begins to switch more rapidly with increasing amplitude. The predominant failure mode for high mileage catalysts is chemical deterioration (phosphorus deposition on the front brick of the catalyst), not thermal deterioration.

Index Ratio Method Using a Wide Range HO2S Sensor (UEGO)

The switching HO2S control system compares the HO2S signals before and after the catalyst to assess catalyst oxygen storage. The front HO2S signal from UEGO control system is used to control to a target A/F ratio and does not have "switches" As a result, a new method of catalyst monitor is utilized.

The UEGO catalyst monitor is an active/intrusive monitor. The monitor performs a calibratable 10-20 second test during steady state rpm, load and engine air mass operating conditions at normal vehicle speeds. During the test, the fuel control system remains in closed loop, UEGO control with fixed system gains. In order to assess catalyst oxygen storage, the UEGO catalyst monitor is enabled during part-throttle, closed-loop fuel conditions after the engine is warmed-up and inferred catalyst temperature is within limits. While the catalyst monitoring entry conditions are being met, the rear HO2S signal length is continually being calculated. When the required total calibrated time has been accumulated, the total voltage signal length of the rear HO2S is divided by a calibrated threshold rear HO2S signal length to compute a catalyst index ratio. The threshold rear HO2S signal is calibrated as a function of air mass using a with a catalyst with no precious metal. This catalyst defines the worst case signal length because it has no oxygen storage. If the monitored catalyst has sufficient oxygen storage, little activity is observed on the rear HO2S voltage signal. An index ratio near 0.0 indicates high oxygen storage capacity, hence high HC/NOx efficiency. As catalyst oxygen storage degrades, the rear HO2S voltage signal activity increases. An index ratio near, 1.0 indicates low oxygen storage capacity, hence low HC/NOx efficiency. If the actual index ratio exceeds the calibrated threshold ratio, the catalyst is considered failed.

General Catalyst Monitor Operation

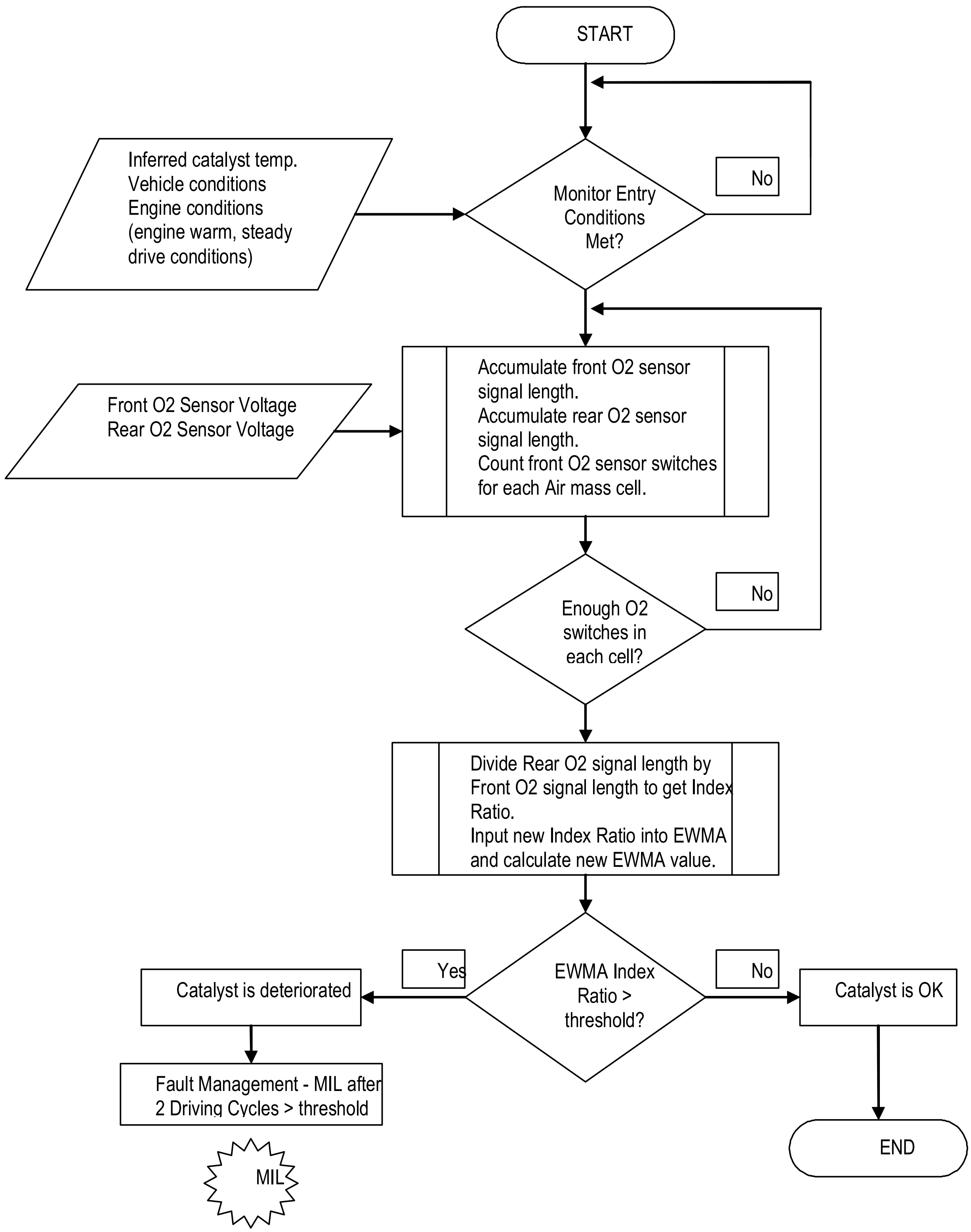
Rear HO2S sensors can be located in various ways to monitor different kinds of exhaust systems. In-line engines and many V-engines are monitored by individual bank. A rear HO2S sensor is used along with the front, fuel-control HO2S sensor for each bank. Two sensors are used on an in-line engine; four sensors are used on a V-engine. Some V-engines have exhaust banks that combine into a single underbody catalyst. These systems are referred to as Y-pipe systems. They use only one rear HO2S sensor along with the two front, fuel-control HO2S sensors. Y-pipe system use three sensors in all. For Y-pipe systems which utilize switching front O2 sensors, the two front HO2S sensor signals are combined by the software to infer what the HO2S signal would have been in front of the monitored catalyst. The inferred front HO2S signal and the actual single, rear HO2S signal is then used to calculate the switch ratio.

Most vehicles monitor less than 100% of the catalyst volume – often the first catalyst brick of the catalyst system. Partial volume monitoring is done on LEV and LEV-II vehicles in order to meet the 1.75 * emission-standard threshold for NMHC and NOx. The rationale for this practice is that the catalysts nearest the engine deteriorate first, allowing the catalyst monitor to be more sensitive and illuminate the MIL properly at lower emission standards.

Many applications that utilize partial-volume monitoring place the rear HO2S sensor after the first light-off catalyst can or, after the second catalyst can in a three-can per bank system. (A few applications placed the HO2S in the middle of the catalyst can, between the first and second bricks.)

All vehicles employ an Exponentially Weighted Moving Average (EWMA) algorithm to improve the robustness of the FTP catalyst monitor. During normal customer driving, a malfunction will illuminate the MIL, on average, in 3 to 6 driving cycles. If KAM is reset (battery disconnected), a malfunction will illuminate the MIL in 2 driving cycles. See the section on EWMA for additional information.

Index Ratio Catalyst Monitor



CATALYST MONITOR OPERATION:	
DTCs	P0420 Bank 1
Monitor execution	once per driving cycle
Monitor Sequence	HO2S response test complete and no DTCs (P0133/P0153) prior to calculating switch ratio, no SAIR pump stuck on DTCs (P0412/P1414), no evap leak check DTCs (P0442/P0456), no EGR stuck open DTCs (P0402)
Sensors OK	ECT, IAT, TP, VSS, CKP
Monitoring Duration	Approximately 10 to 20 seconds for wide range O2 control sensors.

TYPICAL WIDE RANGE O2 SENSOR INDEX RATIO CATALYST MONITOR ENTRY CONDITIONS:		
Entry condition	Minimum	Maximum
Time since engine start-up (70 ^{o}F start)	5 seconds	
Engine Coolant Temp	150 ^{o}F	230 ^{o}F
Intake Air Temp	20 ^{o}F	180 ^{o}F
Time since entering closed loop fuel	30 sec	
Inferred Rear HO2S sensor Temperature	800 ^{o}F	
EGR flow (Note: an EGR fault disables EGR)	0%	16%
Throttle Position	Part Throttle	Part Throttle
Rate of Change of Throttle Position		0.244 volts / 0.050 s
Vehicle Speed	35 mph	80 mph
Fuel Level	15%	
Air Mass	1.5 lb/min	3.5 lb/min
Engine RPM	1,000 rpm	2,500 rpm
Engine Load	20%	65%
(Note: Engine rpm, load and air mass values can vary as a function of the power-to-weight ratio of the engine, transmission and axle gearing and tire size.)		

TYPICAL MALFUNCTION THRESHOLDS:
Rear-to-front O2 sensor switch/index-ratio > 0.60 (bank monitor)

J1979 CATALYST MONITOR MODE $06 DATA			
Monitor ID	Test ID	Description for CAN	
$21	$80	Bank 1 index-ratio and max. limit	unitless

** NOTE: In this document, a monitor or sensor is considered OK if there are no DTCs stored for that component or system at the time the monitor is running.

Misfire Monitor

The HEV uses the Low Data Rate misfire monitor. The LDR system is capable of meeting "full-range" misfire monitoring requirements on 4-cylinder engines. The software allows for detection of any misfires that occur 6 engine revolutions after initially cranking the engine. This meets the new OBD-II requirement to identify misfires within 2 engine revolutions after exceeding the warm drive, idle rpm.

Low Data Rate System

The LDR Misfire Monitor uses a low-data-rate crankshaft position signal, (i.e. one position reference signal at 10 deg BTDC for each cylinder event). The PCM calculates crankshaft rotational velocity for each cylinder from this crankshaft position signal. The acceleration for each cylinder can then be calculated using successive velocity values. The changes in overall engine rpm are removed by subtracting the median engine acceleration over a complete engine cycle. The crankshaft acceleration is then processed by two algorithms. The first is optimized for detection of sporadic and single cylinder patterns of misfire; the second is optimized for multi-cylinder patterns. The resulting deviant cylinder acceleration values are used in evaluating misfire in the "General Misfire Algorithm Processing" section below.

Generic Misfire Algorithm Processing

The acceleration that a piston undergoes during a normal firing event is directly related to the amount of torque that cylinder produces. The calculated piston/cylinder acceleration value(s) are compared to a misfire threshold that is continuously adjusted based on inferred engine torque. Deviant accelerations exceeding the threshold are conditionally labeled as misfires.

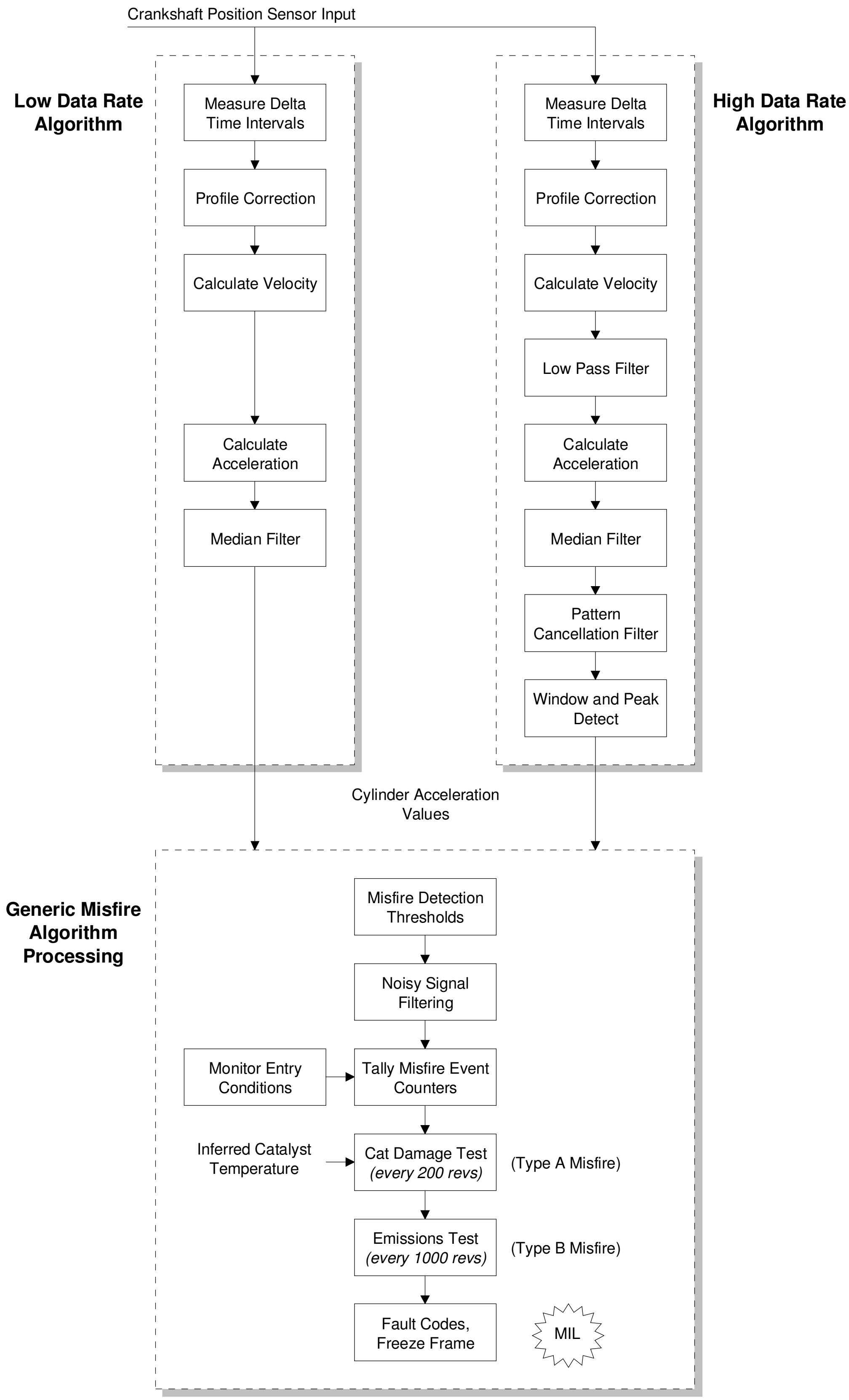
The calculated deviant acceleration value(s) are also evaluated for noise. Normally, misfire results in a non-symmetrical loss of cylinder acceleration. Mechanical noise, such as rough roads or high rpm/light load conditions, will produce symmetrical acceleration variations. Cylinder events that indicate excessive deviant accelerations of this type are considered noise. Noise-free deviant acceleration exceeding a given threshold is labeled a misfire.

The number of misfires is counted over a continuous 200 revolution and 1000 revolution period. (The revolution counters are not reset if the misfire monitor is temporarily disabled such as for negative torque mode, etc.) At the end of the evaluation period, the total misfire rate and the misfire rate for each individual cylinder is computed. The misfire rate evaluated every 200 revolution period (Type A) and compared to a threshold value obtained from an engine speed/load table. This misfire threshold is designed to prevent damage to the catalyst due to sustained excessive temperature (1650°F for Pt/Pd/Rh advanced washcoat and 1800°F for Pd-only high tech washcoat). If the misfire threshold is exceeded and the catalyst temperature model calculates a catalyst mid-bed temperature that exceeds the catalyst damage threshold, the MIL blinks at a 1 Hz rate while the misfire is present. If the misfire occurs again on a subsequent driving cycle, the MIL is illuminated.

If a single cylinder is determined to be consistently misfiring in excess of the catalyst damage criteria, the fuel injector to that cylinder will be shut off for 30 seconds to prevent catalyst damage. Up to two cylinders may be disabled at the same time on 6 and 8 cylinder engines and one cylinder is disabled on 4 cylinder engines. This fuel shut-off feature is used on all engines starting in the 2005 MY. After 30 seconds, the injector is re-enabled. If misfire on that cylinder is again detected after 200 revs (about 5 to 10 seconds), the fuel injector will be shut off again and the process will repeat until the misfire is no longer present. Note that ignition coil primary circuit failures (see CCM section) will trigger the same type of fuel injector disablement.

The misfire rate is also evaluated every 1000 rev period and compared to a single (Type B) threshold value to indicate an emission-threshold malfunction, which can be either a single 1000 rev exceedence from startup or four subsequent 1000 rev exceedences on a drive cycle after start-up. Some vehicles will set a P0316 DTC if the Type B malfunction threshold is exceeded during the first 1,000 revs after engine startup. This DTC is normally stored in addition to the normal P03xx DTC that indicates the misfiring cylinder(s). If misfire is detected but cannot be attributed to a specific cylinder, a P0300 is stored. This may occur on some vehicles at higher engine speeds, for example, above 3,500 rpm.

Low Data Rate and High Data Rate Systems



Profile Correction

"Profile correction" software is used to "learn" and correct for mechanical inaccuracies in the crankshaft position wheel tooth spacing. Since the sum of all the angles between crankshaft teeth must equal 360^o, a correction factor can be calculated for each misfire sample interval that makes all the angles between individual teeth equal. . The LDR misfire system will learn one profile correction factor per cylinder (ex. 4 correction factors for a 4 cylinder engine), while the HDR system will learn 36 or 40 correction factors depending on the number of crankshaft wheel teeth (ex. 36 for V6/V8 engines, 40 for V10 engines).

The corrections are calculated from several engine cycles of misfire sample interval data. The "mature" correction factors are the average of a selected number of samples. In order to assure the accuracy of these corrections, a tolerance is placed on the incoming values such that an individual correction factor must be repeatable within the tolerance during learning. This is to reduce the possibility of learning corrections on rough road conditions which could limit misfire detection capability and to help isolate misfire diagnoses from other crankshaft velocity disturbances.

To prevent any fueling or combustion differences from affecting the correction factors, learning is done during decel-fuel cutout. This can be done during closed-throttle, non-braking, de-fueled decelerations in the 60 to 40 mph range after exceeding 60 mph (likely to correspond to a freeway exit condition). In order to minimize the learning time for the correction factors, a more aggressive decel-fuel cutout strategy may be employed when the conditions for learning are present and are typically learned in a single 60 to 40 MPH deceleration, but can be learned during up to 3 such decelerations, or over a higher number of shorter duration decelerations..

For Hybrid Electric Vehicles profile is learned by using the electric drive to spin the crankshaft on the first engine shutdown during which time profile is calculated.

Since inaccuracies in the wheel tooth spacing can produce a false indication of misfire, the misfire monitor is not active until the corrections are learned. In the event of battery disconnection or loss of Keep Alive Memory the correction factors are lost and must be relearned. If the software is unable to learn a profile after three 60 to 40 mph decels, a P0315 DTC is set.

Misfire Monitor Operation:	
DTCs	P0300 to P0304 (general and specific cylinder misfire) P0315 (unable to learn profile) P0316 (misfire during first 1,000 revs after start-up)
Monitor execution	Continuous, misfire rate calculated every 200 or 1000 revs
Monitor Sequence	None
Sensors OK	CKP, CMP, MAF, ECT/CHT
Monitoring Duration	Entire driving cycle (see disablement conditions below)

Typical misfire monitor entry conditions:		
Entry condition	Minimum	Maximum
Time since engine start-up	0 seconds	0 seconds
Engine Coolant Temperature	20 ^oF	250 ^oF
RPM Range (Full-Range Misfire certified, with 2 rev delay)	2 revs after exceeding 150 rpm below "drive" idle rpm	5700 rpm
Profile correction factors learned in KAM	Yes	
Fuel tank level	15%	

Typical misfire temporary disablement conditions:
Temporary disablement conditions:
Closed throttle decel (negative torque, engine being driven)
Fuel shut-off due to vehicle-speed limiting or engine-rpm limiting mode
High rate of change of torque (heavy throttle tip-in or tip out)

Typical misfire monitor malfunction thresholds:
Type A (catalyst damaging misfire rate): misfire rate is an rpm/load table ranging from 20% at idle to 5% at high rpm and loads
Type B (emission threshold rate): 1.0%

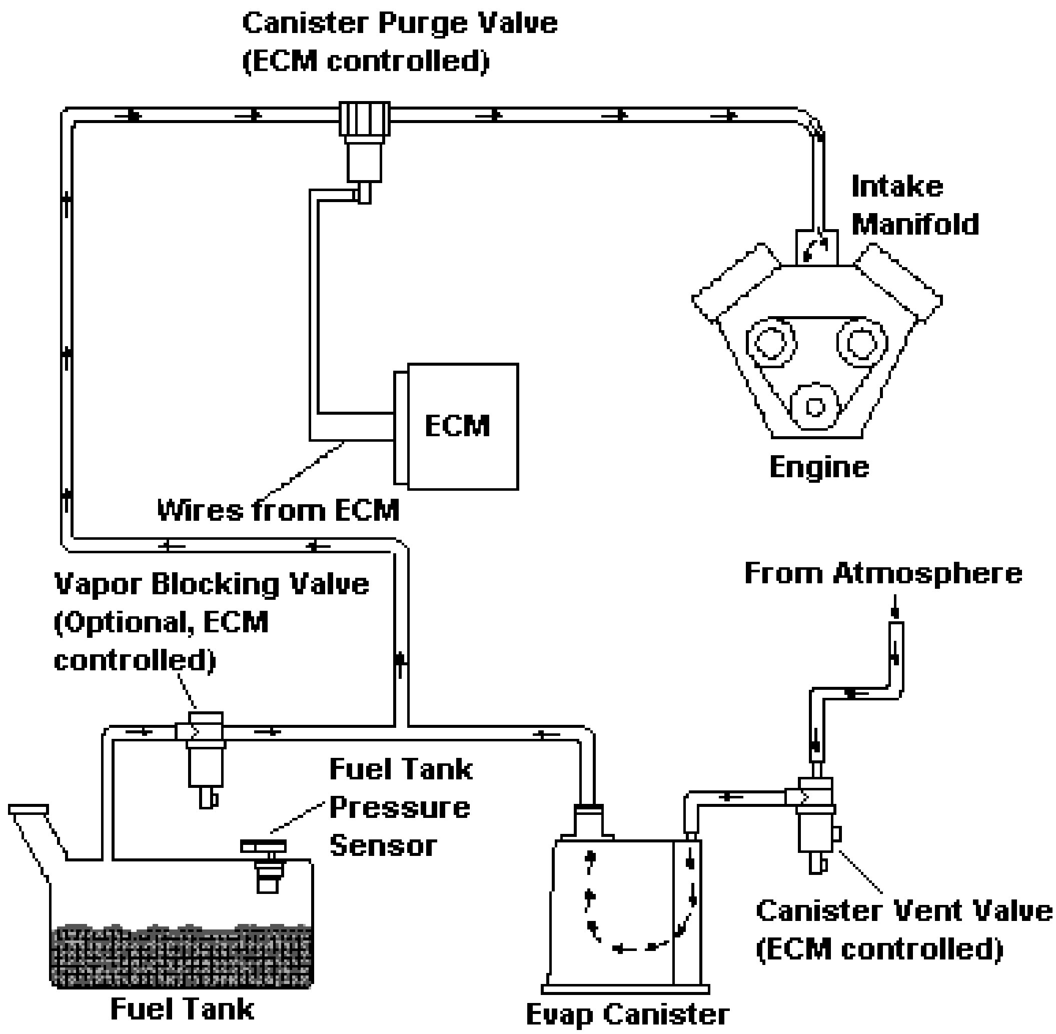
J1979 Misfire Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
A1	$80	Total engine misfire and catalyst damage misfire rate (updated every 200 revolutions)	percent
A1	$81	Total engine misfire and emission threshold misfire rate (updated every 1,000 revolutions)	percent
A1	$82	Highest catalyst-damage misfire and catalyst damage threshold misfire rate (updated when DTC set or clears)	percent
A1	$83	Highest emission-threshold misfire and emission threshold misfire rate (updated when DTC set or clears)	percent
A1	$84	Inferred catalyst mid-bed temperature	^{o}C
A2 – AD	$0B	EWMA misfire counts for last 10 driving cycles	events
A2 – AD	$0C	Misfire counts for last/current driving cycle	events
A2 – AD	$80	Cylinder X misfire rate and catalyst damage misfire rate (updated every 200 revolutions)	percent
A2 – AD	$81	Cylinder X misfire rate and emission threshold misfire rate (updated every 1,000 revolutions)	percent

Profile Correction Operation	
DTCs	P0315 - unable to learn profile
Monitor Execution	Once per profile learning sequence.
Monitor Sequence:	Profile must be learned before misfire monitor is active.
Sensors OK:	CKP, CMP, CKP/CMP in synch
Monitoring Duration;	10 cumulative seconds in conditions

Typical profile learning entry conditions:		
Entry condition	Minimum	Maximum
Engine in decel-fuel cutout mode for 4 engine cycles		
Brakes applied	N/A	N/A
Engine RPM	800 rpm	1750 rpm
Change in RPM		600 rpm/background loop
Vehicle Speed	0 mph	30 mph
Learning tolerance		1.5%
Battery temperature	-15 degrees C	
Battery Voltage	216 V	
Battery power discharge limit	12 Kw	

EVAP System Monitor - 0.040” dia. vacuum leak check

Vehicles that meet enhanced evaporative requirements utilize a vacuum-based evaporative system integrity check. The evap system integrity check uses a Fuel Tank Pressure Transducer (FTPT), a Canister Vent Solenoid (CVS) and Fuel Level Input (FLI) along with a Canister Purge Valve (CPV) to find 0.040” diameter or larger evap system leaks. Federal vehicles can utilize a 0.040" leak check rather than the 0.020" leak check required for California vehicles. Additionally, some programs may elect to run a 0.090" / 0.020" detection configuration and turn the 0.040" leak test off as provided for in the regulations. In the case of heavy duty gasoline engines (> 14,000 lbs), the regulations require 0.150" leak detection only



The evap system integrity test is done under conditions that minimize vapor generation and fuel tank pressure changes due to fuel slosh since these could result in false MIL illumination. The check is run after a 6 hour cold engine soak (engine-off timer), during steady highway speeds at ambient air temperatures (inferred by IAT) between 40 and 100 ^{o}F.

A check for refueling events is done at engine start. A refuel flag is set in KAM if the fuel level at start-up is at least 20% of total tank capacity greater than fuel fill at engine-off. It stays set until the evap monitor completes Phase 0 of the test as described below. Note that on some vehicles, a refueling check may also be done continuously, with the engine running to detect refueling events that occur when the driver does not turn off the vehicle while refueling (in-flight refueling).

The evap system integrity test is done in four phases.

(Phase 0 - initial vacuum pulldown):

First, the Canister Vent Solenoid is closed to seal the entire evap system, and then the Canister Purge Valve (CPV) is opened to pull an 8" H_2O vacuum. If the initial vacuum could not be achieved, a large system leak is indicated (P0455). This could be caused by a fuel cap that was not installed properly, a stuck open Capless Fuel Fill valve, a large hole, an overfilled fuel tank, disconnected/kinked vapor lines, a Canister Vent Solenoid that is stuck open, a CPV that is stuck closed, or a disconnected/blocked vapor line between the CPV and the FTPT.

Note: 2009 Model Year and beyond implementations require 2 or 3 gross leak failures in-a-row prior to setting a P0455 DTC.

If the initial vacuum could not be achieved after a refueling event, a gross leak, fuel cap off (P0457) is indicated and the recorded minimum fuel tank pressure during pulldown is stored in KAM. A "Check Fuel Cap" light may also be illuminated. On vehicles with capless fuel fill, a message instructing the customer to check the Capless Fuel Fill valve will appear in conjunction with a P0457 DTC. Depending on calibration, the MIL may be illuminated in two or three trips with a P0457 failure.

If the initial vacuum is excessive, a vacuum malfunction is indicated (P1450). This could be caused by kinked vapor lines or a stuck open CPV. If a P0455, P0457, or P1450 code is generated, the evap test does not continue with subsequent phases of the small leak check, phases 1-4.

Note: Not all vehicles will have the P0457 test or the Check Fuel Cap light implemented. These vehicles will continue to generate only a P0455. After the customer properly secures the fuel cap, the P0457, Check Fuel Cap and/or MIL will be cleared as soon as normal purging vacuum exceeds the P0457 vacuum level stored in KAM.

Phase 1 - Vacuum stabilization

If the target vacuum is achieved, the CPV is closed and vacuum is allowed to stabilize for a fixed time. If the pressure in the tank immediately rises, the stabilization time is bypassed and Phase 2 of the test is entered.

Some software has incorporated a "leaking" CPV test, which will also set a P1450 (excessive vacuum) DTC. This test is intended to identify a CPV that does not seal properly, but is not fully stuck open. If more than 1 " H_2O of additional vacuum is developed in Phase 1, the evap monitor will bypass Phase 2 and go directly to Phase 3 and open the canister vent solenoid to release the vacuum. Then, it will proceed to Phase 4, close the canister vent solenoid and measure the vacuum that develops. If the vacuum exceeds approximately 4 " H_2O, a P1450 DTC will be set.

Phase 2 - Vacuum hold and decay

Next, the vacuum is held for a calibrated time and the vacuum level is again recorded at the end of this time period. The starting and ending vacuum levels are checked to determine if the change in vacuum exceeds the vacuum bleed up criteria. Fuel Level Input and ambient air temperature are used to adjust the vacuum bleed-up criteria for the appropriate fuel tank vapor volume. Steady state conditions must be maintained throughout this bleed up portion of the test. The monitor will abort if there is an excessive change in load, fuel tank pressure or fuel level input since these are all indicators of impending or actual fuel slosh. If the monitor aborts, it will attempt to run again (up to 20 or more times). If the vacuum bleed-up criteria is not exceeded, the small leak test is considered a pass. If the vacuum bleed-up criteria is exceeded on three successive monitoring events, a 0.040 " dia. leak is likely and a final vapor generation check is done to verify the leak, phases 3-4. Excessive vapor generation can cause a false MIL.

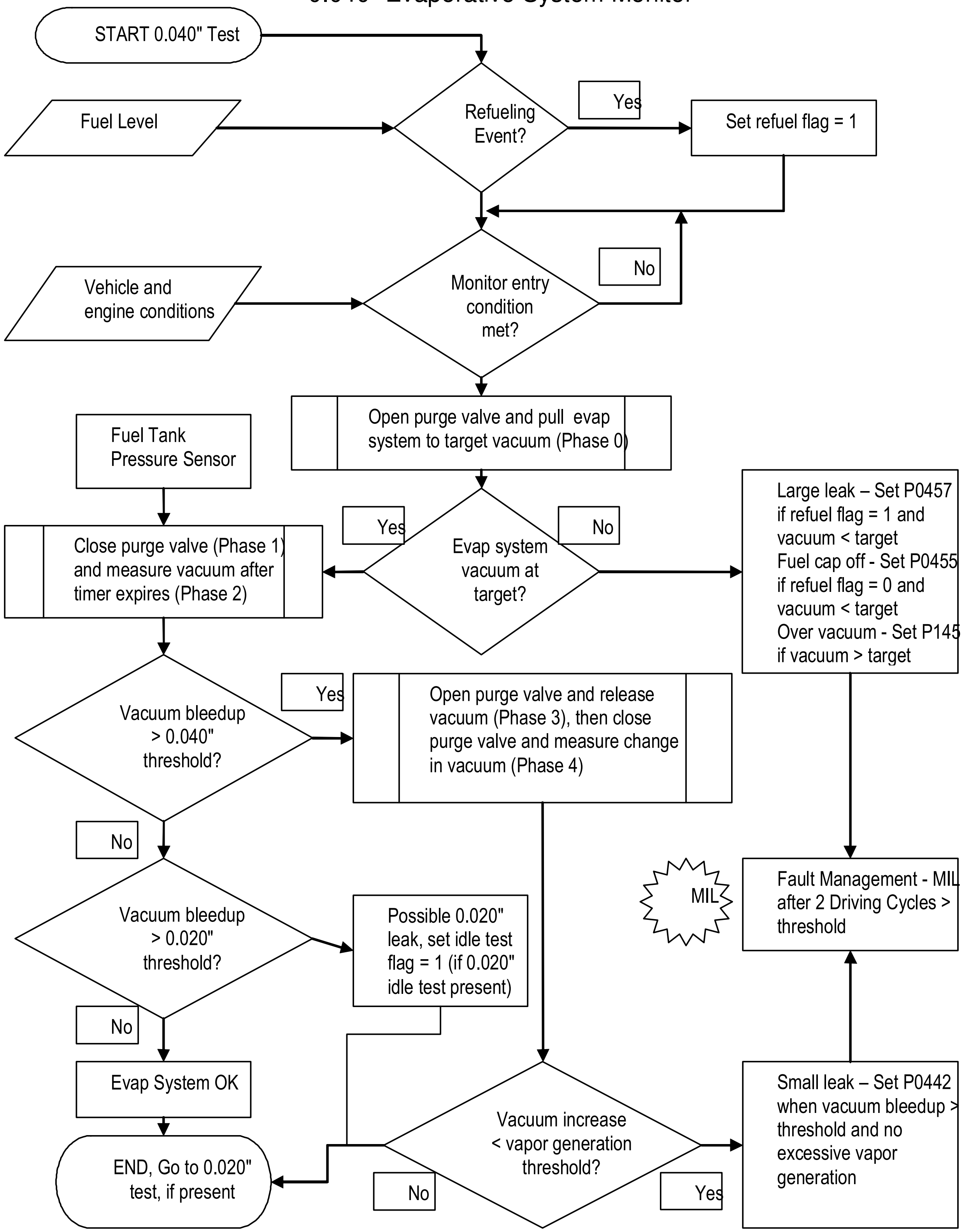
Phase 3 - Vacuum release

This stage of the vapor generation check is done by opening the CVS and releasing any vacuum. The system will remain vented to atmosphere for approximately 30 - 60 seconds and then proceed to phase 4.

Phase 4 - Vapor generation

This stage of the vapor generation check is done by closing the CVS and monitoring the pressure rise in the evaporative system. If the pressure rise due to vapor generation is below the threshold limit for absolute pressure and change in pressure, a P0442 DTC is stored.

0.040" Evaporative System Monitor



0.040" EVAP Monitor Operation:	
DTCs	P0455 (gross leak), P1450 (excessive vacuum), P0457 (gross leak, cap off), P0442 (0.040" leak)
Monitor execution	once per driving cycle
Monitor Sequence	HO2S monitor completed and OK
Sensors/Components OK	MAF, IAT, VSS, ECT, CKP, TP, FTP, CPV, CVS
Monitoring Duration	360 seconds (see disablement conditions below)

Typical 0.040" EVAP monitor entry conditions, Phases 0 through 4:		
Entry condition	Minimum	Maximum
Engine off (soak) time	3.5 hours	
Time since engine start-up	330 seconds	5400 seconds
Intake Air Temp	40 ^oF	95 - 100 ^oF
BARO (<8,000 ft altitude)	22.0 " Hg	
Engine Load	5%	65%
Vehicle Speed	40 mph	90 mph
Purge Duty Cycle	75%	100%
Purge Flow	0.08 lbm/min	0.10 lbm/min
Fuel Fill Level	15%	85%
Fuel Tank Pressure Range	- 17.819 H_2O	16.06 H_2O

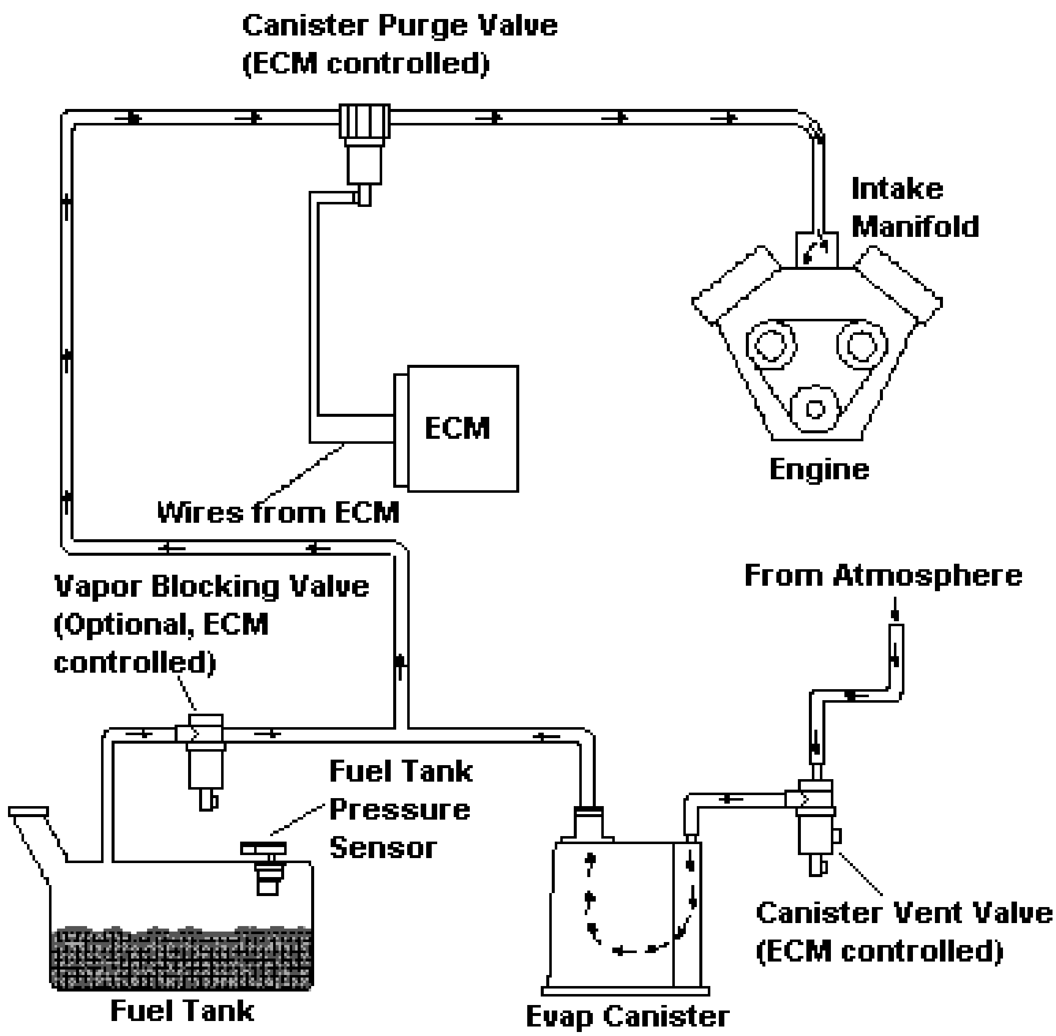
Typical 0.040" EVAP abort (fuel slosh) conditions for Phase 2:
Change in load: > 25%
Change in tank pressure: > 0.8 " H_2O
Change in fuel fill level: > 100%
Number of aborts: > 255

Typical 0.040 EVAP monitor malfunction thresholds:
P1450 (Excessive vacuum): < -8.0 in H_2O over a 20 second evaluation time or > -64. in H_2O vapor generation P0455 (Gross leak): > -8.0 in H_2O over a 50 second evaluation time. P0457 (Gross leak, cap off): > -8.0 in H_2O over a 75 second evaluation time after a refueling event. P0442 (0.040" leak): > 3.75 in H_2O bleed-up over a 20 second evaluation time. (Note: bleed-up and evaluation times vary as a function of fuel fill level and ambient air temperature) P0442 vapor generation limit: < 1.15 in H_2O over a 150 second evaluation time

J1979 Evaporative System Mode $06 Data			
Test ID	Comp ID	Description	Units
$3A	$80	Phase 0 end pressure result and test limits (data for P1450 – excessive vacuum)	Pa
$3A	$81	Phase 4 vapor generation minimum change in pressure and test limits (data for P1450, CPV stuck open)	Pa
$3A	$82	Phase 0 end pressure result and test limits (data for P0455/P0457 – gross leak/cap off)	Pa
$3B	$80	Phase 2 0.040” cruise leak check vacuum bleed-up and test limits (data for P0442 – 0.040" leak)	Pa
Note: Default values (0.0 Pa) will be displayed for all the above TIDs if the evap monitor has never completed. Each TID is associated with a particular DTC. The TID for the appropriate DTC will be updated based on the current or last driving cycle, default values will be displayed for any phases that have not completed.			

EVAP System Monitor - 0.020" dia. Engine Off Natural Vacuum leak check

Some vehicles that meet enhanced evaporative requirements utilize an engine off natural vacuum (EONV) evaporative system integrity check that tests for 0.020" dia. leaks while the engine is off and the ignition key is off. The evap system integrity check uses a Fuel Tank Pressure Transducer (FTPT), a Canister Vent Solenoid (CVS) and Fuel Level Input (FLI) to find 0.020" diameter evap system leaks.



The Ideal Gas Law (PV=mRT) defines a proportional relationship between the Pressure and Temperature of a gas that is contained in a fixed Volume. Therefore, if a sealed container experiences a drop in temperature it will also experience a drop in pressure. In a vehicle, this happens when a sealed evaporative system cools after the engine has been run, or if it experiences a drop in temperature due to external environmental effects. This natural vacuum can be used to perform the leak check, hence the name Engine Off Natural Vacuum (EONV). Condensation of fuel vapor during cooling can add to the vacuum produced by the Ideal Gas Law.

In contrast to the vacuum produced by drops in temperature, an additional factor can be heat transfer to the evaporative system from the exhaust system immediately after key-off. Heat transfer from the exhaust at key-off aided by fuel vaporization may produce a positive pressure shortly after key-off, which can also be used for leak detection.

The EONV system is used to perform only the 0.020" leak check while 0.040" dia. leaks and larger (including fuel cap off) will continue to be detected by the conventional vacuum leak monitor performed during engine running conditions.

Ford's EONV implementation for California and Green State applications uses a Motorola Star-12 microprocessor in the PCM to process the required inputs and outputs while the rest of the PCM is not powered and the ignition key is off. The Star-12 microprocessor draws substantially less battery current than the PCM; therefore, powering only the Star-12 during engine-off conditions extends vehicle battery life and allows the EONV monitor to run more often. The PCM is the only difference between California/Green State and Federal vehicles.

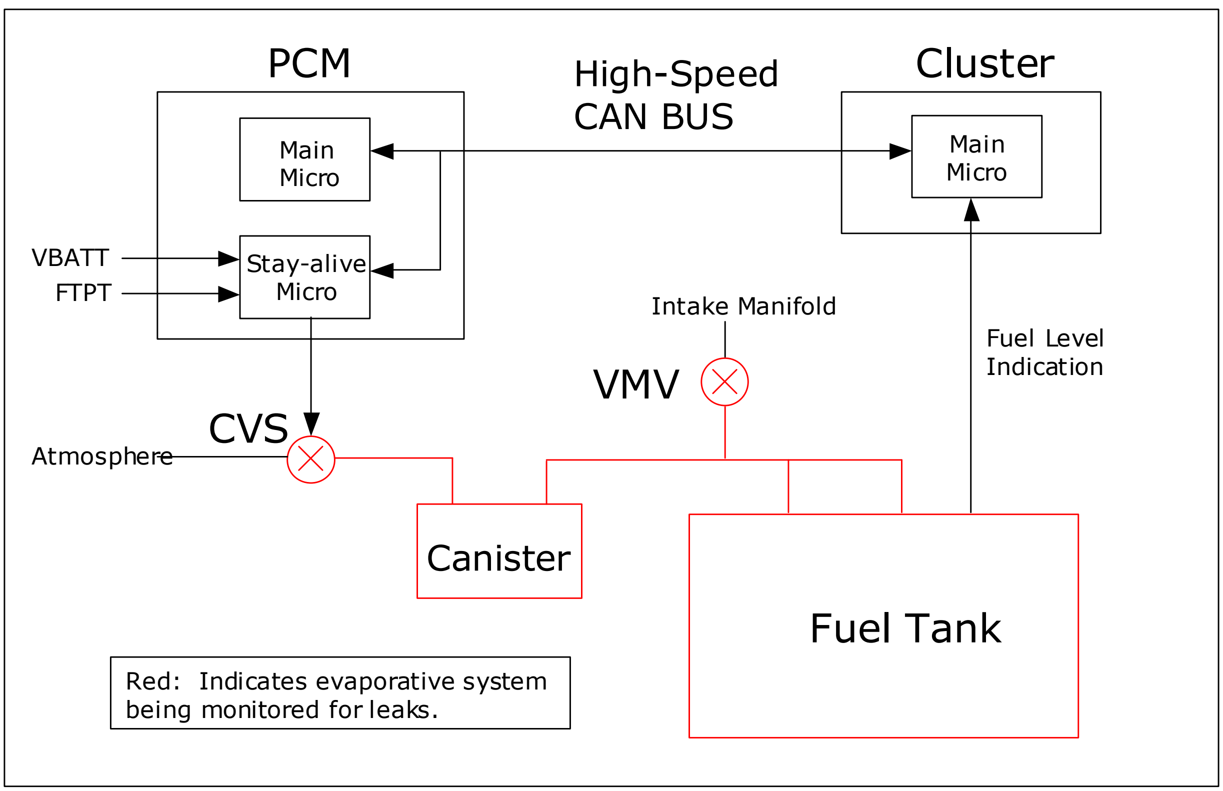
Inputs to EONV Microprocessor

- Fuel Tank Pressure
- Battery Voltage

Outputs from EONV Microprocessor

- Canister Vent Solenoid
- 0.020" leak data

MY2005 EONV System Hardware Design



Phase 0- Stabilization Phase

The purpose of the Stabilization Phase is to allow tank pressure to stabilize after vehicle shutdown (i.e. ignition in the OFF position). During this phase, the Canister Vent Solenoid (CVS) is open, thus allowing the pressure in the fuel tank to stabilize at atmospheric pressure. The duration of the Stabilization Phase is approximately 2 minutes. A fuel volatility check is performed just prior to its completion.

The fuel volatility check measures tank pressure and will abort the test if more than 1.5 "H_20 is observed in the tank. Because the CVS is open during this test, it would take a good deal of fuel vaporization to produce this level of pressure on a vented system. As an example, this condition may occur when a customer performs a long drive with highly volatile, winter fuel on a 100-deg F day. Note: This feature is not used in most applications.

If the fuel volatility check passes, a Fuel Tank Pressure Transducer (FTPT) offset correction factor is learned as the last step of this phase. This correction factor is applied to pressure measurements in the next phase to improve FTPT accuracy.

Phase 1 – First Test Phase

At the start of this phase, the CVS is commanded shut, thus sealing up the entire evaporative system. If the system is sufficiently sealed, a positive pressure or vacuum will occur during depending on whether the tank temperature change is positive or negative. Other effects such as fuel vaporization and condensation within the fuel tank will also determine the polarity of the pressure. As the leak size increases, the ability to develop a positive pressure or vacuum diminishes. With a 0.020" leak, there may be no measurable positive pressure or vacuum at all depending on test conditions.

During this phase, tank pressure is continuously measured and compared to calibrated detection thresholds (both positive pressure and vacuum) that are based on fuel level and ambient temperature. If either the pressure or vacuum threshold is exceeded, the test will be considered a pass, and the monitor will proceed to "Phase 4 – Test Complete". If a positive plateau occurs in tank pressure without exceeding the pass threshold, the monitor will progress to "Phase 2 – Transition Phase". If a vacuum occurs, the monitor will remain in Phase 1 until the test times out after 45 minutes have elapsed since key-off, or the pass threshold for vacuum is exceeded. In either case, the monitor will transition to "Phase 4 – Test Complete."

Phase 2- Transition Phase

This phase will occur if a positive pressure plateau occurred in Phase 1 without the positive pass threshold being exceeded. At the start of the Transition Phase, the CVS is opened and the evaporative system is allowed to stabilize. The Transition Phase lasts approximately 2 minutes, and a new FTPT offset correction is learned just prior to its completion. The monitor will then progress to "Phase 3 – Second Test Phase".

Note: This phase is termed the Transition Phase because there is a chance that a vacuum will be seen in the next phase if a positive pressure plateau occurred in Phase 1. The reason for this is that a positive plateau may be coincident with vapor temperature starting to decrease, which is favorable for developing a vacuum in the fuel tank. This is not always the case, and it is possible to see a positive pressure in Phase 3 as well.

Phase 3- Second Test Phase

Upon completion of the Transition Phase, the CVS is commanded shut and the FTPT is monitored for any positive pressure or vacuum that develops. As with "Phase 1 – First Test Phase", if either the positive pressure or vacuum pass threshold is exceeded, the test is considered a pass and proceeds to "Phase 4 – Test Complete". Also, if the test times out after 45 minutes have elapsed since key-off, the test will be considered a fail (i.e. leak detected) and will also proceed to "Phase 4 – Test Complete".

Phase 4 – Test Complete

In this phase, the EONV test is considered complete for this key-off cycle. The resultant peak pressure and peak vacuum are stored along with total test time and other information. This information is sent to the main microprocessor via CAN at the next engine start. During this phase, the CVS is commanded open and the electrical components performing the EONV test are shutdown to prevent any further power consumption.

Test Aborts

During the EONV test, several parameters are monitored to abort the EONV test under certain conditions. The primary abort conditions are instantaneous changes in tank pressure and fuel level. They are used to detect refuel events and rapidly open the CVS upon detection of them. A list of abort conditions is given below.

Post-2009 Model Year Fault Filtering

To increase the IUMP (rate-based) numerator once per monitor completion, the fault filtering logic for EONV was revised. The logic incorporates several important CARB requirements. These are:

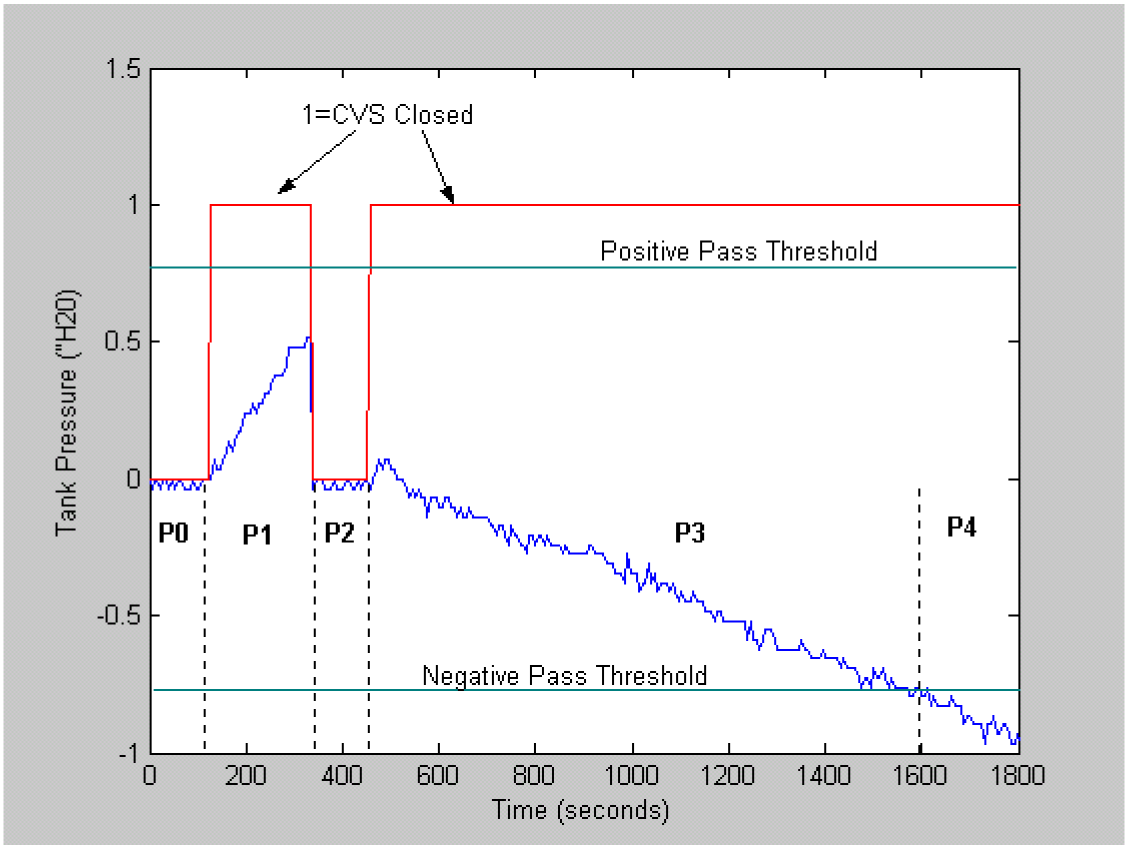
- Fast Initial Response (FIR): The first 4 tests after a battery disconnect or code clear will process unfiltered data to quickly indicate a fault. The FIR will use a 2-trip MIL. This will help the service technician determine that a fault has been fixed.

- Step-change Logic (SCL): The logic will detect an abrupt change from a no-fault condition to a fault condition. The SCL will be active after the 4th EONV test and will also use a 2-trip MIL. This will illuminate the MIL when a fault is instantaneously induced.

- Normal EWMA (NORM): This is the normal mode of operation and uses an Exponentially Weighted Moving Average (EWMA) to filter the EONV test data. It is employed after the 4th EONV test and will illuminate a MIL during the drive cycle where the EWMA value exceeds the fault threshold. (1 trip MIL). The recommended filter/time constant will produce filtering comparable to a previously-described 5-test average.

If there is a failure using any of the fault filtering logic shown above, a P0456 DTC will be set.

Phases of EONV Test



P0 = Phase 0, Stabilization Phase – With CVS open, Tank Pressure is allowed to stabilize. A fuel volatility test is performed and FTPT offset correction is learned if volatility test passes.

P1 = Phase 1, First Test Phase – CVS is closed and pressure peaks below positive pass threshold sending test to Phase 2. If the positive pass threshold were exceeded, the test would have completed and a pass would have been recorded.

P2 = Phase 2, Transition Phase – CVS is opened and a second stabilization phase occurs. A second FTPT offset is learned during this time.

P3 = Phase 3, Second Test Phase – CVS is closed again and a vacuum develops that eventually exceeds the negative pass threshold. When this occurs the test proceeds to Phase 4, test complete.

P4 = Phase 4, Test Compete – CVS opens (not pictured in above data file), results are recorded, and stay-alive electronics shutdown.

0.020" EONV EVAP Monitor Operation:	
DTCs	P0456 (0.020" leak) P260F (Evaporative System Monitoring Processor Performance)
Monitor execution	Once per key-off when entry conditions are met during drive. Monitor will run up to 2 times per day, or 90 cumulative minutes per day (whichever comes first)
Monitor Sequence	none
Sensors/Components OK	EONV Processor, Canister Vent Solenoid, Fuel Tank Pressure Sensor, Fuel Level Input, Vapor Management Valve, CAN communication link
Monitoring Duration	45 minutes in key-off state if fault present. Tests will likely complete quicker if no fault is present.

Typical 0.020" EONV EVAP monitor entry conditions:		
Entry conditions seen just prior to engine off	Minimum	Maximum
Engine off (soak) time	3.5 hrs	
Time since engine start-up	15 minutes	90 minutes
Ambient Temperature at start-up	40 °F	105 °F
Battery Voltage	11 volts	
Number of completed tests in 24hr cycle		2
Cumulative test time in 24hr cycle		90 minutes
Fuel level	15%	85%
ECU time since power-up	180 seconds	
Flex fuel inference complete	Learned	
Summation of air mass since start ensures that vehicle has been operated off idle.		
Ratio of drive time to (drive + soak) time. (This allows for the driver to key-off for a short time without losing the initial soak condition.)	0.5	

Typical 0.020" EONV EVAP key-off abort conditions:
Tank pressure at key-off > 0.8 " H_20 during stabilization phase (indicates excessive vapor)
Tank pressure not stabilized for tank pressure offset determination
Rapid change in tank pressure > 0.5"H_20 (used for refuel/slosh detection)
Rapid change in fuel level > 5% (used for refuel/slosh detection)
Battery voltage < 11 Volts
Rapid change in battery voltage > 1 Volt
Loss of CAN network
Canister Vent Solenoid fault detected
Driver turns key-on

Typical 0.020 EONV EVAP monitor malfunction thresholds:
P0456 (0.020" leak): < 0.60 in H_2O pressure build and < 0.35 in H_2O vacuum build over a 45 minute maximum evaluation time Note: EONV monitor can be calibrated to illuminate the MIL after two malfunctions (an average of four key-off EONV tests, eight runs in all) or after a single malfunction (an average of five key-off EONV tests, five runs in all), or using EWMA with Fast Initial Response and Step Change Logic. Most new 2006 MY and later vehicles will use the five-run approach, most new 2009 MY and later use the EWMA approach.

J1979 EONV EVAP monitor Mode $06 Data			
Monitor ID	Comp ID	Description for CAN	Units
$3C	$81	EONV Positive Pressure Test Result and Limits	Pa
$3C	$82	EONV Negative Pressure (Vacuum) Test Result and Limits	Pa
$3C	$83	Normalized Average of Four EONV Tests Results and Limits (where 0 = pass, 1 = fail)	unitless
Note: Default values (0.0) will be displayed for all the above TIDs if the evap monitor has never completed. The appropriate TID will be updated based on the current or last driving cycle, default values will be displayed for any phases that have not completed.			

EVAP System Monitor Component Checks

Additional malfunctions that are identified as part of the evaporative system integrity check are as follows:

The **Canister Purge Valve (CPV)** output circuit is checked for opens and shorts (P0443)

Note that a stuck closed CPV generates a P0455, a leaking or stuck open CPV generates a P1450.

Canister Purge Valve Check Operation:	
DTCs	P0443 – Evaporative Emission System Purge Control Valve "A" Circuit
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to obtain smart driver status

Typical Canister Purge Valve check malfunction thresholds:
P0443 (CPV): open/shorted at 0 or 100% duty cycle

The **Canister Vent Solenoid** output circuit is checked for opens and shorts (P0446), a stuck closed CVS generates a P1450, a leaking or stuck open CVS generates a P0455.

Canister Vent Solenoid Check Operation:	
DTCs	P0446 – Canister Vent Solenoid Circuit
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to obtain smart driver status

Typical Canister Vent Solenoid check malfunction thresholds:
P0446 (Canister Vent Solenoid Circuit): open/shorted

The **Evap Switching Valve** (EVAPSV) output circuit is checked for opens and shorts (P2418).

Evap Switching Valve Check Operation:	
DTCs	P2418 - Evap Switching Valve Circuit
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to obtain smart driver status

Evap Switching Valve check malfunction thresholds:
P2418 (Evap Switching Valve Circuit): open/shorted

The **Fuel Tank Pressure Sensor** input circuit is checked for out of range values (P0452 short, P0453 open), noisy readings (P0454 noisy) and an offset (P0451 offset).

Note that carryover 2004 MY software and 2003 MY and earlier software will set P0451 for the noisy sensor test.

Note that an open power input circuit or stuck check valve generates a P1450.

Fuel Tank Pressure Sensor Transfer Function		
FTP volts = [Vref * (0.14167 * Tank Pressure) + 2.6250] / 5.00		
Volts	A/D Counts in PCM	Fuel Tank Pressure, Inches H_2O
0.100	20	-17.82
0.500	102	-15.0
1.208	247	-10.0
2.625	464	0
3.475.	712	6.0
4.750	973	15.0
4.90	1004	16.06

Fuel Tank Pressure Sensor Check Operation:	
DTCs	P0452 – Fuel Tank Pressure Sensor Circuit Low P0453 – Fuel Tank Pressure Sensor Circuit High P0454 – Fuel Tank Pressure Sensor Intermittent/Erratic (noisy)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds for electrical malfunctions, 16.7 minutes for noisy sensor test

Typical Fuel Tank Pressure Sensor check malfunction thresholds:
P0452 (Fuel Tank Pressure Sensor Circuit Low): < -17.82 in H_2O
P0453 (Fuel Tank Pressure Sensor Circuit High): > 16.06 in H_2O
P0454 (Fuel Tank Pressure Sensor Circuit Noisy): > 14 in H_2O change between samples, sampled every 10 seconds, more than 100 fault occurrences

Fuel Tank Pressures Sensor Offset Check Operation	
DTCs	P0451 – Fuel Tank Pressure Sensor Range/Performance (offset)
Monitor execution	once per driving cycle
Monitor Sequence	No P0443 or P1450 DTCs
Sensors OK	not applicable
Monitoring Duration	< 1 second

Typical Fuel Tank Pressure Sensor Offset Check Entry Conditions:		
Entry condition	Minimum	Maximum
Ignition key on, engine off, engine rpm		0 rpm
Purge Duty Cycle		0%
Engine off (soak) time	2 hours	
Battery Voltage	11.0 Volts	

Typical Fuel Tank Pressure Sensor Offset Check Malfunction Thresholds:
Fuel tank pressure at key on, engine off is 0.0 in H_2O +/- 2.0 in H_2O

The **Fuel Level Input** is checked for out of range values (opens/ shorts). The FLI input can be hardwired to the PCM or be obtained from the serial data link, typically from the instrument cluster. If the FLI signal is open or shorted, a P0460 is set. Some software will be able to discriminate between an open and short and set the appropriate DCT (P0462 circuit low and P0463 circuit high).

Finally, the Fuel Level Input is checked for noisy readings. If the FLI input changes from an in-range to out-of-range value repeatedly, a P0461 DTC is set.

Fuel Level Input Check Operation:	
DTCs	P0460 – Fuel Level Input Circuit P0461 – Fuel Level Input Circuit Noisy P0462 – Fuel Level Input Circuit Low P0463 – Fuel Level Input Circuit High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	30 seconds for electrical malfunctions, Fuel Level Stuck test (P0460) can take up to 120 miles to complete

Typical Fuel Level Input check malfunction thresholds:
P0460 or P0462 (Fuel Level Input Circuit Low): < 5 ohms
P0460 or P0463 (Fuel Level Input Circuit High): > 200 ohms
P0461 (Fuel Level Input Noisy): > 100 circuit low or circuit high exceedences, sampled every 0.100 seconds

The FLI signal is also checked to determine if it is stuck. The PCM calculates the amount of fuel being consumed by accumulating fuel pulse width. (Fuel consumed and fuel gauge reading range are both stored in KAM and reset after a refueling event or DTC storage.) If the there is an insufficient corresponding change in fuel tank level, a P0460 DTC is set.

Different malfunction criteria are applied based on the range in which the fuel level sensor is stuck.

In the range between 15% and 85%, a 30% difference between fuel consumed and fuel used is typical. The actual value is based on the fuel economy of the vehicle and fuel tank capacity.

In the range below 15%, a 40% difference between fuel consumed and fuel used is typical. The actual value is based on reserve fuel in the fuel tank and the fuel economy of the vehicle.

In the range above 85%, a 60% difference between fuel consumed and fuel used is typical. The actual value is based on the overfill capacity of the fuel tank and the fuel economy of the vehicle. Note that some vehicles can be overfilled by over 6 gallons.

Fuel Level Input Stuck Check Operation:	
DTCs	P0460 – Fuel Level Input Circuit Stuck
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	Between 15 and 85%, monitoring can take from100 to 120 miles to complete

Typical Fuel Level Input Stuck check malfunction thresholds:
P0460 (Fuel Level Input Stuck):
Fuel level stuck at greater than 85%: > 40% difference in calculated fuel tank capacity consumed versus change in fuel level input reading
Fuel level stuck at less than 85%: > 40% difference in calculated fuel tank capacity consumed versus change in fuel level input reading
Fuel level stuck between 15% and 85%: > 60% difference in calculated fuel tank capacity consumed versus change in fuel level input reading

Evap Switching Valve (EVAPSV) Diagnostics

The Evap Switching Valve (EVAPSV) is included on HEV applications for 2009 Model Year. It is very similar to the Fuel Tank Isolation Valve (FTIV) used in previous model years. The Evap Switching Valve is also known as a Vapor Blocking Valve (VBV). The purpose of the EVAPSV is to isolate the fuel tank from the rest of the evaporative system so that the Canister Purge Valve (CPV) can purge more aggressively with minimal risk of purge vapor slugs being ingested into the intake.

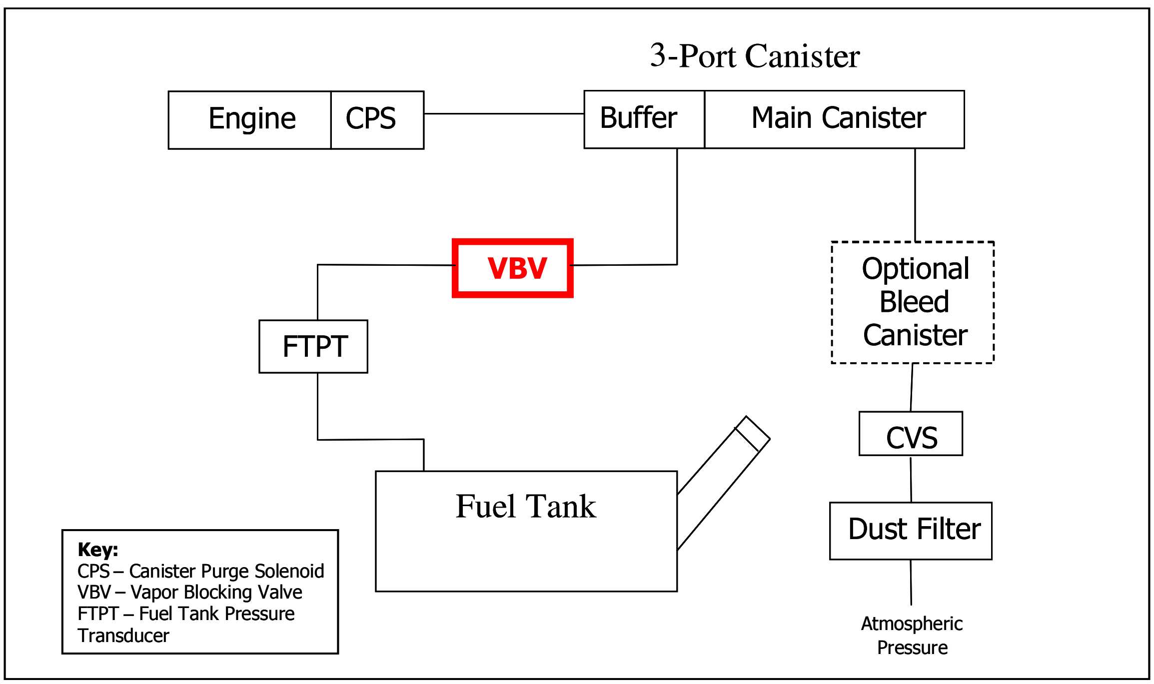
The EVAPSV is normally closed during engine operation, but may vent during a drive to relieve positive pressure. The exact pressure points at which the valve opens and closes are vehicle dependent. When the vehicle is in a key-off state, the EVAPSV is not powered and the valve is open.

The VBV circuit and functional diagnostics will set the following DTCs:

P2418 – EVAPSV circuit fault
P2450 – EVAPSV stuck open fault

The EVAPSV circuit diagnostics are very similar to that of the Canister Purge Valve (CPV) and Canister Vent Solenoid (CVS). See Evap System Monitor Component Checks below.

A diagram of an evaporative system with an EVAPSV (shown as a VBV) is shown below:



The Evaporative System monitor performs a functional check of the EVAPSV in Phase 3 of the evap monitor cruise tests if the 0.040" leak test passes. At the end of Phase 2, tank pressure will be in the range of -8 to -5 "H20 and the EVAPSV will be open. At the beginning of Phase 3, the EVAPSV is commanded closed and the CVS is commanded open. If the EVAPSV fails to close, there will be a rapid pressure loss in the fuel tank. If this pressure loss exceeds a calibrated threshold, a P2450 DTC is set. (Requires 2 or 3 failures in a row during a driving cycle (calibratable)). If the fault is present on a second driving cycle, the MIL will be illuminated.

EVAP Switching Valve (EVAPSV) Monitor Operation:	
DTC	P2450
Monitor execution	once per driving cycle
Monitor Sequence	Runs after evap 0.040" cruise test
Sensors/Components OK	MAF, IAT, VSS, ECT, CKP, TP, FTP, CPV, CVS
Monitoring Duration	30 seconds (see disablement conditions below)

Typical EVAP Switching Valve (EVAPSV) monitor entry conditions:		
Entry condition	Minimum	Maximum
0.040" Cruise Test completes		

Typical EVAP Switching Valve (EVAPSV) abort conditions:
Change in fuel fill level: > 15%

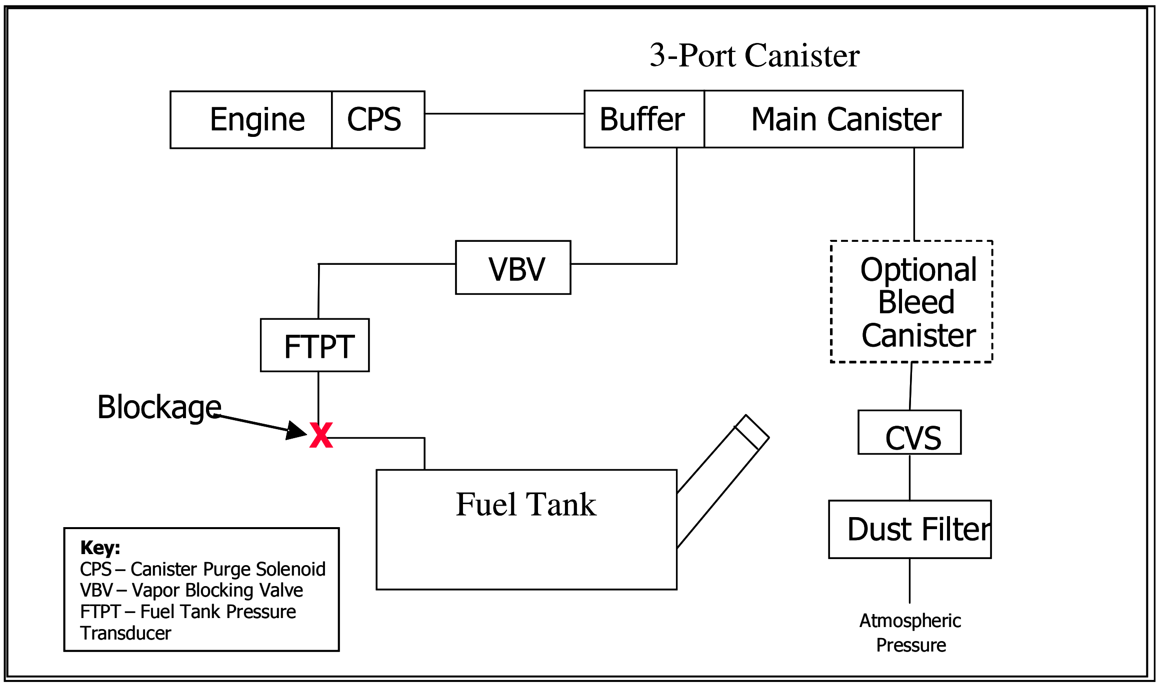
Typical EVAP Switching Valve (EVAPSV) malfunction thresholds:
P2418: Presence of short, open, or intermittent fault for more than 5 seconds P2450: Pressure loss > 3" $H_2 0$ during phase 3.

J1979 Evaporative System Mode $06 Data			
Test ID	Comp ID	Description	Units
$3D	$82	Vapor blocking valve performance	Pa
Note: Default values (0.0 Pa) will be displayed for all the above TIDs if the evap monitor has never completed. Each TID is associated with a particular DTC. The TID for the appropriate DTC will be updated based on the current or last driving cycle, default values will be displayed for any phases that have not completed.			

Blocked Purge Line Diagnostics

If an in-line Fuel Tank Pressure Transducer is used, it is possible for a blockage to occur between the Fuel Tank Pressure Transducer (FTPT) and fuel tank. If this occurs, the evap monitor would run and pass all leak check diagnostics even if there is a leak at the fuel cap. (The blockage will make the system look sealed despite the leak.). The blocked line diagnostic looks for a rapid drop in pressure during Phase 0 of the cruise test. This rapid pressure drop occurs because the Canister Purge Valve (CPV) applies a vacuum to just the canister and evap lines. Upon seeing an excessively fast pressure drop in Phase 0, the evap monitor will invoke a special execution of Phase 3 & 4 where a CPV pressure pulse is applied to the evap system. This pressure pulse is at a very low flow and short duration (0.5 -1.0 seconds) to avoid drivability issues. If this intrusive test fails, the Phase 0 test and the intrusive test are repeated 2 or 3 times prior to setting a P144A DTC.

Diagram of an evaporative system with a blockage is shown below:



EVAP Blocked Line Monitor Operation:	
DTC	P144A
Monitor execution	once per driving cycle
Monitor Sequence	Runs during Phase 0 of evap 0.040" cruise test. Performs an intrusive test in Phases 3 & 4 to confirm a fault.
Sensors/Components OK	MAF, IAT, VSS, ECT, CKP, TP, FTP, CPV, CVS
Monitoring Duration	30 seconds (see disablement conditions below)

Typical Blocked Line monitor entry conditions:		
Entry condition	Minimum	Maximum
General 0.040" Cruise Test conditions apply		
Air mass high enough for intrusive portion of test	0.05 (lb/min)	
Manifold vacuum high enough for intrusive portion of test	2 "Hg	
Not in open loop fueling		
CPV purging		

Typical EVAP Blocked Line abort conditions:
All items cited under entry conditions apply.

Typical EVAP Blocked Line malfunction thresholds:
P144A: Phase 0 portion of test delta pressure < -5 "H_20/sec P144A: Phase 3 & 4 (intrusive test) pressure response < -2 "H_20

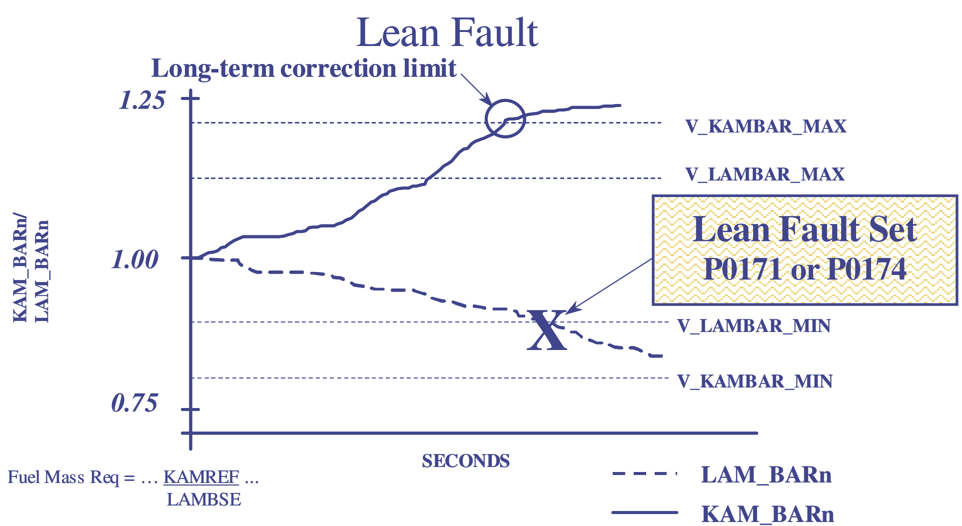
J1979 Evaporative System Mode $06 Data			
Test ID	Comp ID	Description	Units
$3D	$80	Blocked Evap System Line - Screening test	Pa/sec
$3D	$81	Blocked Evap System Line - Fault confirmation test	Pa
Note: Default values (0.0) will be displayed for all the above TIDs if the evap monitor has never completed. Each TID is associated with a particular DTC. The TID for the appropriate DTC will be updated based on the current or last driving cycle, default values will be displayed for any phases that have not completed.			

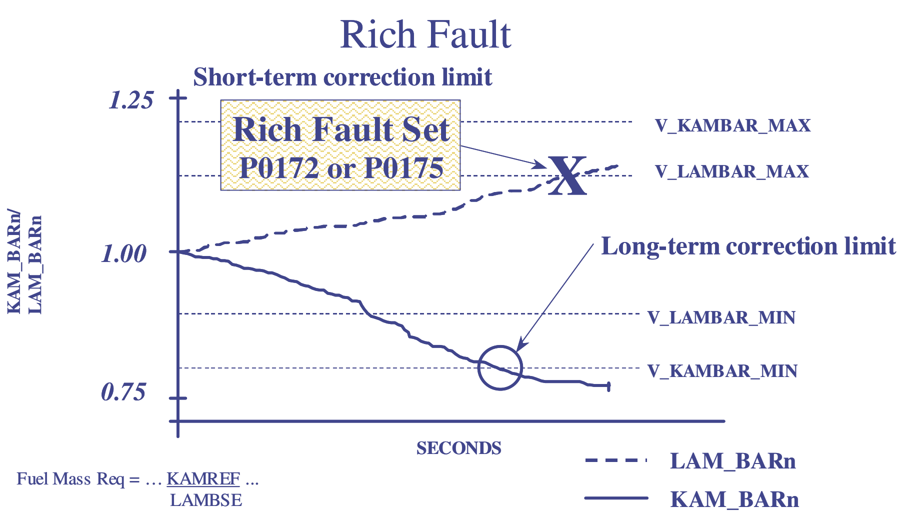
Fuel System Monitor

As fuel system components age or otherwise change over the life of the vehicle, the adaptive fuel strategy learns deviations from stoichiometry while running in closed loop fuel. These learned corrections are stored in Keep Alive Memory as long term fuel trim corrections. They may be stored into an 8x10 rpm/load table or they may be stored as a function of air mass. As components continue to change beyond normal limits or if a malfunction occurs, the long-term fuel trim values will reach a calibratable rich or lean limit where the adaptive fuel strategy is no longer allowed to compensate for additional fuel system changes. Long term fuel trim corrections at their limits, in conjunction with a calibratable deviation in short term fuel trim, indicate a rich or lean fuel system malfunction.

Note that in the PCM, both long and short-term fuel trim are multipliers in the fuel pulse width equation. Scan tools normally display fuel trim as percent adders. If there were no correction required, a scan tool would display 0% even though the PCM was actually using a multiplier of 1.0 in the fuel pulse width equation.

$$\textbf{Fuel Mass} = \frac{\textbf{Air Mass * Long-term Fuel Trim}}{\textbf{Short-term Fuel Trim * 14.64}}$$





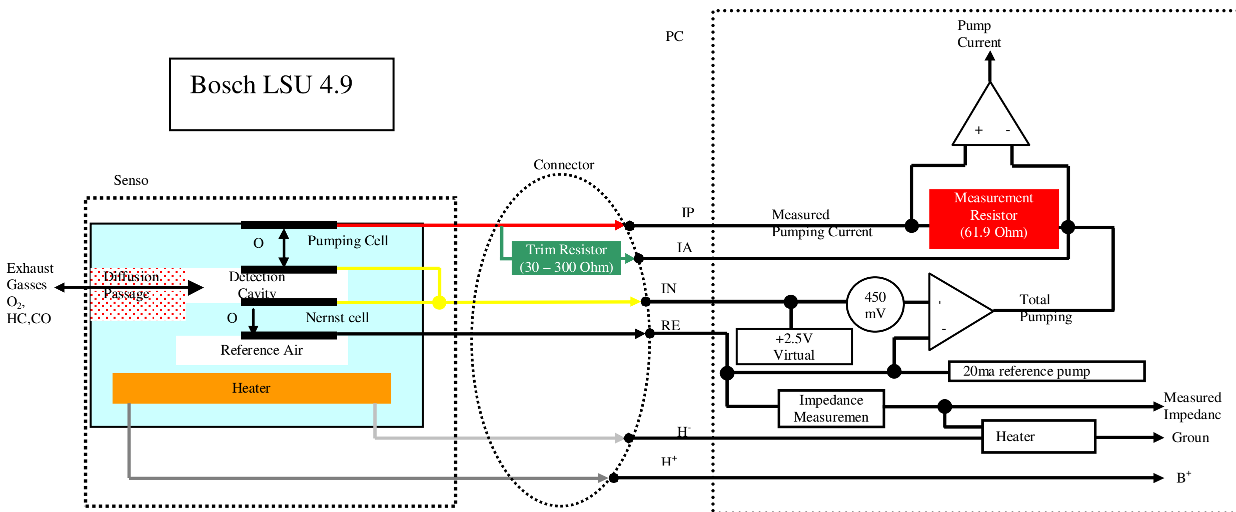
Fuel Monitor Operation:	
DTCs	P0171 Bank 1 Lean P0172 Bank 1 Rich
Monitor execution	continuous while in closed loop fuel
Monitor Sequence	none
Sensors OK	Fuel Rail Pressure (if available), IAT, CHT/ECT, MAF, TP
Monitoring Duration	2 seconds to register malfunction

Typical fuel monitor entry conditions:		
Entry condition	Minimum	Maximum
Engine Coolant Temp	160 ^{o}F	230 ^{o}F
RPM Range	1000	4000
Air Mass Range	0.4 lb/min	
Purge Duty Cycle	0%	0%

Typical fuel monitor malfunction thresholds:
Long Term Fuel Trim correction cell currently being utilized in conjunction with Short Term Fuel Trim: Lean malfunction: LONGFT > 29%, SHRTFT > 1% Rich malfunction: LONGFT < 20%, SHRTFT < -1%

Front UEGO Signal

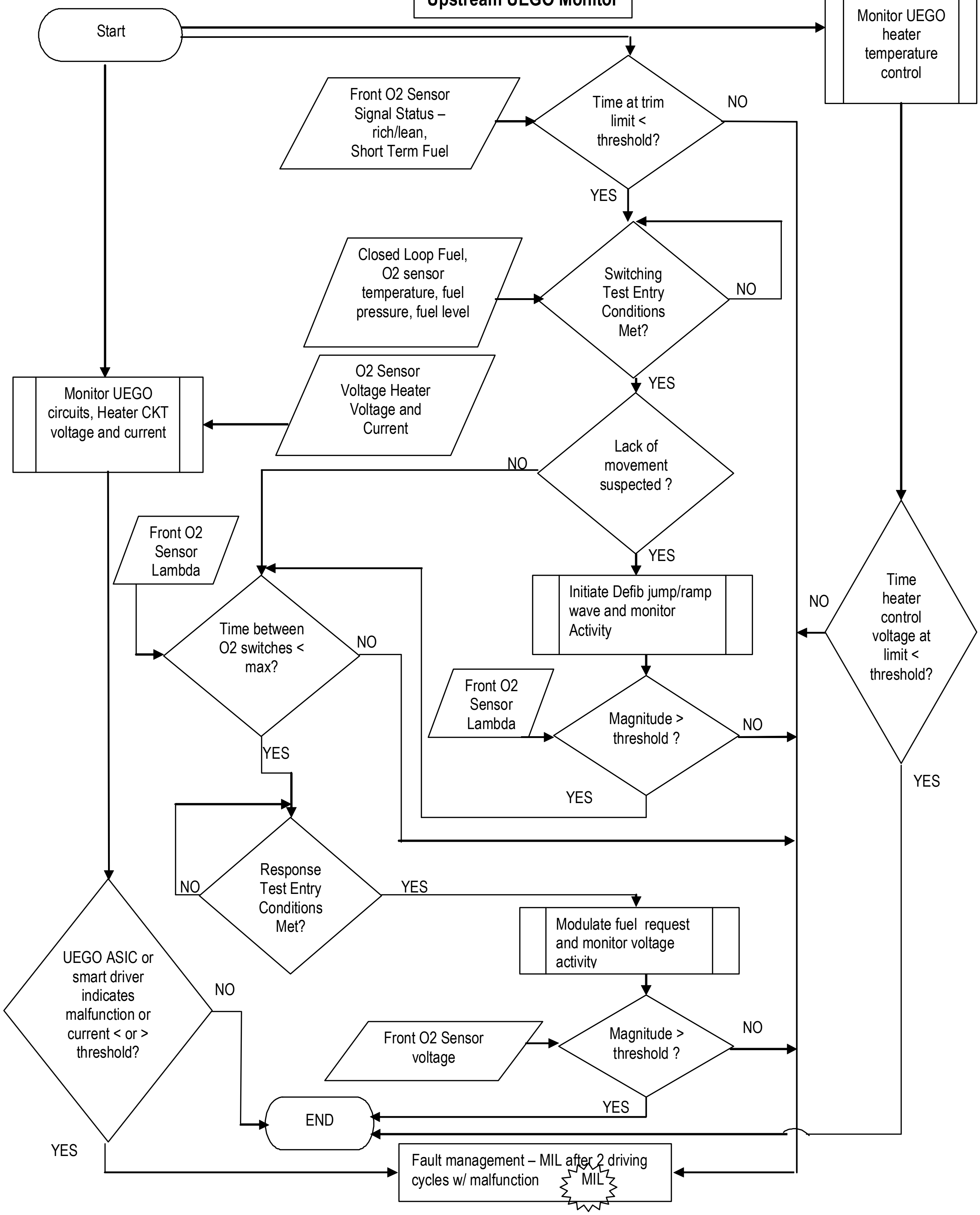
The UEGO sensor infers an air fuel ratio relative to the stoichiometric (chemically balanced) air fuel ratio by balancing the amount of oxygen pumped in or out of a measurement chamber. As the exhaust gasses get richer or leaner, the amount of oxygen that must be pumped in or out to maintain a stoichiometric air fuel ratio in the measurement chamber varies in proportion to the air fuel ratio. By measuring the current required to pump the oxygen in or out, the air fuel ratio (lambda) can be estimated. Note that the measured air fuel ratio is actually the output from the UEGO ASIC pumping current controller and not a signal that comes directly from the sensor.



Bosch UEGO sensor interface:

- IP – primary pumping current that flows through the sensing resistor
- IA – current flow through trim resistor in parallel with sense resistor.
- VM – Virtual ground, approximately 2.5 volts above PCM ground.
- RE – Nernst cell voltage, 450mv from VM. Also carries current for pumped reference.
- H+ – Heater voltage – to battery.
- H- – Heater ground side – Duty cycle on/off to control sensor temperature.

Upstream UEGO Monitor



The primary component of a UEGO sensor is the diffusion passage that controls the flow of exhaust gasses into a detection cavity, a Nernst cell (essentially an EGO sensor inside the UEGO sensor) that measures the air fuel ratio in the detection cavity. A control circuitry in the ASIC chip (mounted in the PCM) controls the pumping current (IP) to keep the detection cavity near stoichiometry by holding the Nernst cell at 450 mV. This Nernst cell voltage (RE, VS) is 450mV from the virtual ground (VM, COM), which is approximately 2.5V (Bosch UEGO) or 3.6V (NTK UEGO) above the PCM ground. For the Nernst cell to generate a voltage when the detection cavity is rich, it needs an oxygen differential across the cell. In older UEGO (and HEGO) sensor designs, this was provided by a reference chamber that was connected to outside air through the wire harness that was subject to contamination and "Characteristic Shift Down (CSD)". The new UEGO sensor uses a pumped reference chamber, which is sealed from the outside to eliminate the potential for contamination. The necessary oxygen is supplied by supplying a 20 mA pumping current across the Nernst cell to pump small amounts of oxygen from the detection cavity to the reference chamber. The pumping cell pumps oxygen ions in and out of the detection cavity from and to the exhaust gasses in response to the changes in the Nernst cell voltage. The pumping current flows through the sense resistor and the voltage drop across the sense resistor is measured and amplified. Offset volts are sent out of the ASIC to one of the PCM's A/D inputs. The PCM measures the voltage supplied by the ASIC, determines the pumping current, and converts the pumping current to measured lambda. In general, the circuitry that measures the pumping current is used to estimate the air fuel ratio in the exhaust system.

The UEGO sensor also has a trim (IA) or label resistor (RL). The biggest source of part to part variability in the measured air fuel ratio is difference in the diffusion passage. This source of variation is simply the piece-to-piece differences from the manufacturing process. To compensate for this source of error, each sensor is tested at the factory and a trim or label resistor is installed in the connector. The value of this resistor is chosen to correlate with the measured difference between a particular sensor and a nominal sensor. For NTK UEGO, the variation in the Ip signal value is corrected for by a compensation coefficient (CC), and then processed by the PCM. The value of CC (Ip rank) is determined by the value of RL. The PCM must command the ASIC to read the value of RL, so CC can be determined. After measuring the value of the label resistor, the PCM software will multiply the measured pumping current (Ip) by a compensation coefficient and determine a corrected pumping current that is used to calculate the measured exhaust air fuel ratio. During each power up, the PCM will briefly turn the UEGO heater power off, measure the output voltage from the voltage divider several times, average it, and estimate the resistance of the label resistor. The PCM will do this estimation multiple times, and if all samples are consistently within one resistor "rank", then the RL compensation coefficient determination is completed and the resistor "rank" compensation coefficient value will be stored in keep alive memory. On the other hand, if the several readings are not consistently within one rank for some amount of time, then the PCM A/D input is considered not reliable/RL erratic, and a trim circuit erratic malfunction (P164A, P164B) will be set. Conversely, if the estimated resistance is too high, then the software in the PCM will indicate RL circuit shorted to ground or open, and a trim circuit low malfunction (P2627, P2630) will be set. If the estimated resistance is too low, then the software will indicate RL circuit shorted to power, and a trim circuit high malfunction (P2628, P2631) will be set. Once a trim circuit malfunction is detected, then the compensation coefficient of the label resistor "rank" stored in KAM will be used.

The time spent at the limits of the short term fuel trim and the time when the measured lambda is nearly 1.0 are monitored after vehicle startup when closed loop fuel has been requested, during closed loop fuel conditions, or when open loop fuel has been requested due to UEGO sensor fault. Excessive time with short term fuel trim at its limits (up to +/- 40%), or no rich / lean activity seen since startup indicates a "lack of switch" malfunction. Also, excessive time without measured lambda deviating from 1.0, in spite of attempts to force activity (defib) in the measured lambda, indicates a "lack of movement" malfunction. Since “lack of switching” malfunctions can be caused by UEGO sensor malfunctions or by shifts in the fuel system, DTCs are stored that provide additional information for the “lack of switching” malfunction. Different DTCs indicate whether the sensor always indicates lean (P2195, P2197), or always indicates rich (P2196, P2198). "Lack of movement" malfunction, (Bosch UEGO application only), typically indicating a disconnected wire (pumping current, IP), results in P0134, P0154 DTCs.

UEGO equipped vehicles will also monitor the circuitry between the PCM and the UEGO sensor via the wire diagnostics capability included on the UEGO ASIC chip. The wire diagnostics will detect wires (IP, IA, VM/COM, RE/VS) shorted to battery, or ground, and in most cases will detect open circuits (IP, VM/COM, RE/VS). The diagnostic bits are transmitted to the PCM via SPI (serial peripheral interface). The SPI communication is validated continuously, and if a SPI communication failure is detected, fault code(s) P064D and/or P064E will be set. The ASIC is also capable of detecting internal circuitry failure; in which case, an ASIC failure DTC (P1646, P1647) along with the SPI communication failure DTC (P064D, P064E) will be set.

UEGO "Lack of Switching" Operation:	
DTCs	P2195 - Lack of switching, sensor indicates lean, Bank 1 P2196 - Lack of switching, sensor indicates rich, Bank 1
Monitor execution	continuous, from startup and while in closed loop fuel or open loop fuel due to UEGO sensor fault
Monitor Sequence	None
Sensors OK	ECT, IAT, MAF, VSS, TP, ETC, FRP, DPFE EGR, VCT, VMV/EVMV, CVS, FTP, CKP, CMP, ignition coils, injectors, no misfire DTCs, no system failures affecting fuel, no EVAP gross leak failure, UEGO heaters OK, no "lack of movement" malfunction, no UEGO circuit malfunction
Monitoring Duration	30 seconds to register a malfunction

Typical UEGO "Lack of Switching" entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop or Open Loop Requested due to UEGO sensor fault		
No fuel flow entering thru PCV during cold start when flashing off fuel in oil (for O2 Sensor Stuck Rich DTCs only)		
Inferred Ambient Temperature	-40 ^{o}F	
Time within entry conditions	10 seconds	
Fuel Tank Pressure		10 in H_2O
Fuel Level	15%	
Battery Voltage	11.0 Volts	18.0 Volts

Typical UEGO "Lack of Switching" malfunction thresholds:
> 30 seconds since reaching the short term fuel trim limits while closed loop fuel or < 0.5 seconds rich or < 0.5 seconds lean since startup for > 30 seconds in test conditions while open loop fuel is requested due to UEGO sensor fault.

UEGO "Lack of Movement" Operation:	
DTCs	P0134 - Lack of movement, Bank 1
Monitor execution	continuous, from startup and while in closed loop fuel or open loop fuel due to UEGO sensor fault
Monitor Sequence	None
Sensors OK	ignition coils, injectors, no misfire DTCs, no system failures affecting fuel, UEGO heaters OK, no "lack of switching" malfunction, no UEGO circuit malfunction
Monitoring Duration	40 seconds to register a malfunction

Typical UEGO "Lack of Movement" entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop or Open Loop Requested due to UEGO sensor fault		
Inferred Ambient Temperature	-40 °F	
Battery Voltage	11.0 Volts	18.0 Volts

Typical UEGO "Lack of Movement" malfunction thresholds:
> 40 seconds in test conditions without lambda movement during "defib" while in closed loop fuel or < 0.2 seconds without lambda movement since startup for > 40 seconds in test conditions while open loop fuel is requested due to UEGO sensor fault.

UEGO "Wire Diagnostic" Operation:	
DTCs	P0130 – O2 circuit (Bank 1, Sensor 1). Note: This DTC will set for open IP (NTK), RE/VS, VM/COM, short to ground IP (Bosch), RE, VM, IA, short to battery IP (Bosch), RE, VM, IA. P0131 – O2 circuit low voltage (Bank 1, Sensor 1). Note: This DTC will set for short to ground IP (NTK), VS, COM. P0132 – O2 circuit high voltage (Bank 1, Sensor 1). Note: This DTC will set for short to battery IP (NTK), VS, COM. P164A – O2 sensor positive current trim circuit performance (Bank 1, Sensor 1). Note: This DTC will set for an erratic RL. P1646 – Linear O2 sensor control chip, Bank 1 P064D – Internal control module O2 sensor processor performance (Bank 1)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	UEGO heaters OK
Monitoring Duration	10 seconds to register a malfunction

Typical UEGO "Wire Diagnostic" entry conditions:		
Entry condition	Minimum	Maximum
Fault reported by UEGO ASIC		
Battery Voltage	11.0 Volts	18.0 Volts

Typical UEGO "Wire Diagnostic" malfunction thresholds:
UEGO ASIC indicated malfunction > 10 seconds to set a code when circuit failure is present.

The UEGO is also tested functionally. The response rate is evaluated by entering a special 0.5Hz-1.5 Hz. square wave, fuel control routine. This routine drives the air/fuel ratio around stoichiometry at a calibratable frequency and magnitude, producing predictable oxygen sensor signal amplitude. A slow sensor will show reduced amplitude, measured as a line length. Oxygen sensor signal line length below a minimum threshold indicates a slow sensor malfunction (P0133 Bank 1, P0153 Bank 2). If the calibrated frequency was not obtained while running the test because of excessive purge vapors, etc., the test will be run again until the correct frequency is obtained.

UEGO "Response Rate" Operation:	
DTCs	P0133 (slow response Bank 1), P0153 (slow response Bank 2)
Monitor execution	once per driving cycle
Monitor Sequence	> 30 seconds time in lack of movement test, > 30 seconds time in lack of switch test,
Sensors OK	ECT, IAT, MAF, VSS, TP, ETC, FRP, DPFE EGR, VCT, VMV/EVMV, CVS, FTP, CKP, CMP, ignition coils, injectors, no misfire DTCs, no system failures affecting fuel, no EVAP gross leak failure, UEGO heaters OK, no "lack of switching" malfunction, no "lack of movement" malfunction, no UEGO circuit malfunction, no UEGO FAOS monitor malfunction
Monitoring Duration	4-12 seconds

Typical UEGO "Response Rate" entry conditions:		
Entry condition	Minimum	Maximum
Flex Fuel Composition not changing		
Not in Phase 0 of Evaporative System Monitor		
No Purge System reset		
Purge intrusive test not running		
Not performing CSER spark retard		
Engine Coolant Temp	140 ^{o}F	240 ^{o}F
Intake Air Temp		140 ^{o}F
Time since entering closed loop fuel	10 seconds	
Inferred Catalyst Midbed Temperature		1600 ^{o}F
Fuel Level	15%	
Short Term Fuel Trim Range	-5%	5%
Short Term Fuel Trim Absolute Change while in monitor		15%
Engine Load	11%	65%
Maximum change in engine load while in monitor		0.25
Vehicle Speed	35 mph	80 mph
Maximum change in vehicle speed while in monitor		3 mph
Engine RPM	1000 rpm	3000 rpm
Maximum change in engine rpm while in monitor		150 rpm
Commanded versus actual lambda range while in monitor	0.85	1.15
Air mass stability criteria met while in monitor		
Battery Voltage	11.0 Volts	18.0 Volts

Typical UEGO "Response Rate" malfunction thresholds:
Line length (Voltage amplitude): < 15 units

J1979 Front UEGO Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
$01	$84	UEGO11 voltage length	unitless
$05	$84	UEGO21 voltage length	unitless

FAOSC (Rear Fuel Trim) Monitor

As the front UEGO sensor ages and gets exposed to contaminants, it can develop a rich or lean bias in its transfer function. The rear bias control (also called FAOSC – Fore/Aft Oxygen Sensor Control) system is designed to compensate for any of these bias shifts (offsets) using the downstream HO2S sensor. The "FAOS" monitor looks for any bias shifts at the stoichiometric point of the front UEGO sensor lambda curve. If the UEGO has developed a bias beyond the point for which it can be compensated for, lean (P2096, P2098) or rich (P2097, P2099) fault codes will be set.

UEGO "FAOS Monitor" Operation:	
DTCs	P2096 – Post catalyst fuel trim system too lean (Bank 1) P2097 – Post catalyst fuel trim system too rich (Bank 1)
Monitor execution	Continuous while in closed loop fuel
Monitor Sequence	> 30 seconds time in lack of movement test, > 30 seconds time in lack of switch test
Sensors OK	ECT, IAT, MAF, VSS, TP, ETC, FRP, DPFE EGR, VCT, VMV/EVMV, CVS, FTP, CKP, CMP, ignition coils, injectors, no misfire DTCs, no system failures affecting fuel, no EVAP gross leak failure, UEGO heaters OK, rear HO2S heaters OK, no "lack of switching" malfunction, no "lack of movement" malfunction, no UEGO circuit malfunction, no rear stream 2 HO2S circuit malfunction, no rear stream 2 HO2S functional DTCs, no rear stream 2 HO2S response rate malfunction.
Monitoring Duration	5 seconds to register a malfunction

Typical UEGO "FAOS Monitor" entry conditions:		
Entry condition	Minimum	Maximum
Engine Coolant Temp	150 °F	235 °F
Time since entering closed loop fuel	5 seconds	
Fuel Level	15%	
Short Term Fuel Trim Range	-16.66%	18%
Short Term Fuel Trim Absolute Change		17%
Air mass change for transient rejection		2 lbm/min
Learning conditions stability time (based on air mass)	15 seconds	
Stream1 UEGO response test not running		
Intrusive UEGO catalyst monitor not running		
Battery Voltage	11.0 Volts	18.0 Volts

Typical UEGO "FAOS Monitor" malfunction thresholds:
>= 5 seconds since reaching the FAOSC lean or rich limits while system bias maturity is met.

UEGO Heaters

The UEGO heater is controlled as a function of the measured impedance to keep the sensor at a near constant temperature (Bosch: 780 deg C, NTK: 800 deg C). The impedance of the Nernst cell decreases as the sensor temperature increases. This impedance is measured by periodically applying a small current across the Nernst cell and measuring the change in the voltage. The output voltage is then sent to an A/D input on the PCM. After a cold start, the UEGO heater ramps up to the maximum duty cycle to heat the sensor. After a few seconds, the measured impedance will start to decrease and when the target value is crossed, the heater goes into closed loop heater control to maintain the sensor at a near constant temperature.

The "UEGO Heater Temperature Control Monitor" tracks the time at the maximum duty cycle during the open loop sensor warm up phase. If the measured impedance does not come down to the target value to allow the system to transition from open loop heater control to closed loop heater control within a specified time, then a fault code is set. This monitor also sets a malfunction when the closed loop heater control reaches a maximum or minimum value for a period of time indicating that the controller is no longer able to maintain the target temperature, however, if the inferred exhaust temperature is high enough that the sensor will be above the target temperature even with no heat, then this monitor is disabled.

The UEGO heaters are also monitored for proper voltage and current. A UEGO heater voltage fault is determined by turning the heater on and off and looking for corresponding voltage change in the heater output driver circuit in the PCM.

A separate current-monitoring circuit monitors heater current once per driving cycle. This monitor normally runs in closed loop heater control after all the exhaust gas sensor functional tests are completed, however, it can also run intrusively. When the UEGO sensor indicates cold, but the heater is inferred to have been adequately warm, the current monitor is forced to run intrusively prior to the completion of the heater temperature control monitor. The heater current is actually sampled three times. If the current value for two of the three samples falls below or above a calibratable threshold, the heater is assumed to be degraded or malfunctioning. (Multiple samples are taken for protection against noise on the heater current circuit.)

UEGO Heater Monitor Operation:	
DTCs	P0030 Heater Temperature Control Failure, Bank 1 P0135 O2 Heater Circuit, Bank 1 P0053 O2 Heater Resistance, Bank 1
Monitor execution	once per driving cycle for heater current monitor, continuous for voltage monitoring and heater temperature control monitoring
Monitor Sequence	Heater current monitor: Stream 1 UEGO response test complete, Stream 2 and 3 HO2S functional tests complete, Stream 1 UEGO heater voltage check complete. Heater temperature control monitor: intrusive heater current monitor completed.
Sensors OK	Heater current monitor: no HO2S/UEGO heater circuit malfunction, Heater temperature control monitor: no UEGO circuit malfunction, no UEGO heater circuit malfunction, no UEGO heater current monitor DTCs.
Monitoring Duration	< 10 seconds for heater voltage check, < 5 seconds for heater current check, >= 30 seconds for the heater temperature control monitor to register a malfunction

Typical UEGO heater monitor entry conditions:		
Entry condition	Minimum	Maximum
Inferred UEGO unheated tip temperature (heater voltage check only)	75 ^{o}F	1562 ^{o}F
Inferred UEGO heated tip temperature (heater current check only)	1346 ^{o}F	1526 ^{o}F
UEGO heater-on time (heater current check only)	30 seconds	
Engine RPM (heater current check only)		5000 rpm
Inferred UEGO unheated tip temperature (heater control monitor only)	75 ^{o}F	1000 ^{o}F
Battery Voltage	11.0 Volts	18.0 Volts

Typical UEGO heater check malfunction thresholds:
Smart driver status indicated malfunction (heater voltage check) Number monitor retries allowed for malfunction > = 30 (heater voltage check) Heater current outside limits: < 1.0 amps or > 3 amps (intrusive test) or < 0.55 amps or > 3 amps (Bosch UEGO) Heater temperature control monitor: > = 30 seconds to register a malfunction while the heater control integrator is at its maximum or minimum limit

J1979 UEGO Heater Mode $06 Data			
Monitor ID	Test ID	Description for CAN	Units
$01	$81	HO2S11 Heater Current	Amps
$05	$81	HO2S21 Heater Current	Amps

Rear HO2S Monitor

Rear HO2S Signal

A functional test of the rear HO2S sensors is done during normal vehicle operation. The peak rich and lean voltages are continuously monitored. Voltages that exceed the calibratable rich and lean thresholds indicate a functional sensor. If the voltages have not exceeded the thresholds after a long period of vehicle operation, the air/fuel ratio may be forced rich or lean in an attempt to get the rear sensor to switch. This situation normally occurs only with a green catalyst (< 500 miles). If the sensor does not exceed the rich and lean peak thresholds, a malfunction is indicated.

2005 MY and beyond vehicles will monitor the rear HO2S signal for high voltage, in excess of 1.1 volts and store a unique DTC. (P0138, P0158). An over voltage condition is caused by a HO2S heater or battery power short to the HO2S signal line.

Some Partial Zero Emission Vehicles (PZEV Focus) may utilize three sets of HO2S sensors. The front sensors (HO2S11/HO2S21) are the primary fuel control sensors. The next sensors downstream in the exhaust are utilized to monitor the light-off catalyst (HO2S12/HO2S22). The last sensors downstream in the exhaust (HO2S13/Ho2S23) are utilized for very long term fuel trim in order to optimize catalyst efficiency (Fore Aft Oxygen Sensor Control). Ford's first PZEV vehicle uses a 4-cylinder engine so only the Bank 1 DTCs are utilized.

Rear HO2S Functional Check Operation:	
DTCs Sensor 2	P0136 HO2S12 No activity or P2270 HO2S12 Signal Stuck Lean P2271 HO2S12 Signal Stuck Rich
Monitor execution	once per driving cycle for activity test
Monitor Sequence	> 30 seconds time in lack of movement test (UEGO only), > 30 seconds time in lack of switch test, front HO2S/UEGO response test complete
Sensors OK	ECT, IAT, MAF, VSS, TP, ETC, FRP, DPFE EGR, VCT, VMV/EVMV, CVS, FTP, CKP, CMP, ignition coils, injectors, no misfire DTCs, no system failures affecting fuel, no EVAP gross leak failure, UEGO/HO2S (front and rear) heaters OK, no "lack of switching" malfunction, no "lack of movement" malfunction (UEGO only), no UEGO/HO2S (front and rear) circuit malfunction, no UEGO FAOS monitor malfunction, no front HO2S/UEGO response rate malfunction
Monitoring Duration	continuous until monitor completed

Typical Rear HO2S functional check entry conditions:		
Entry condition	Minimum	Maximum
Stream 1 HO2S not in CSD recovery mode		
Flex Fuel Composition not changing		
Not in Phase 0 of Evaporative System Monitor		
No Purge System reset		
Purge intrusive test not running		
Not performing CSER spark retard		
Engine Coolant Temp	140 ^{o}F	240 ^{o}F
Intake Air Temp		140 ^{o}F
Time since entering closed loop fuel	10 seconds	
Inferred Catalyst Midbed Temperature		1600 ^{o}F
Heater-on Inferred Sensor(s) 2/3 HO2S Temperature Range	400 ^{o}F	1400 ^{o}F
Sensor(s) 2/3 HO2S heater-on time	90 seconds	
Short Term Fuel Trim Range	-9%	11%
Fuel Level (forced excursion only)	15%	
Inferred exhaust temperature range	400 ^{o}F	1400 ^{o}F
Throttle position	Part throttle	
Engine RPM (forced excursion only)	1000 rpm	2000 rpm
Battery Voltage	11.0 Volts	18.0 Volts

Typical Rear HO2S functional check malfunction thresholds:
Does not exceed rich and lean threshold envelope: Rich < 0.42 volts Lean > 0.48 volts

J1979 Rear HO2S Functional Check Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
$02	$01	HO2S12 sensor switch-point voltage	volts
$06	$01	HO2S22 sensor switch-point voltage	volts
$03	$01	HO2S13 sensor switch-point voltage	volts
$07	$01	HO2S23 sensor switch-point voltage	volts

Rear HO2S “Over Voltage Test” Operation:	
DTCs	P0138 HO2S12 Over voltage
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	rear HO2S heaters OK
Monitoring Duration	10 seconds to register a malfunction

Typical HO2S “Over Voltage Test” entry conditions:		
Entry condition	Minimum	Maximum
Inferred Stream 2 HO2S Temperature	400 °F	
Battery Voltage	11.0 Volts	18.0 Volts

Typical HO2S “Over Voltage Test” malfunction thresholds:
> 1.1 volts for 10 seconds for over voltage test

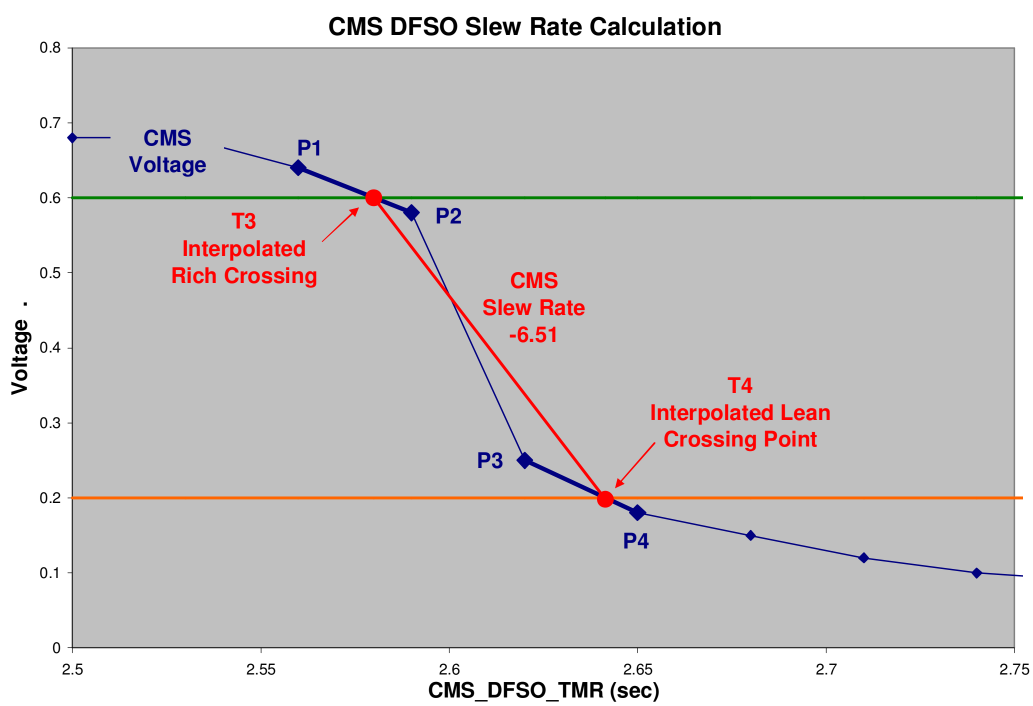
Rear HO2S Decel Fuel Shut Off Response Test

The catalyst monitor tracks and uses the length of the rear HO2S signal. The rear HO2S is also known as the Catalyst Monitor Sensor (CMS). As the catalyst ages, air/fuel fluctuations begin to break through the catalyst and the length of this signal increases. Eventually the length of the CMS signal becomes long enough to identify a failure for the catalyst monitor.

When an HO2S sensor degrades, it's response to air/fuel fluctuations slows down. The effect of a slow rear HO2S sensor on the catalyst monitor is to reduce the length of the signal. A slow CMS sensor, therefore, may cause the catalyst monitor to incorrectly pass a failed catalyst. The purpose of the Rear DFSO Response diagnostic is to ensure the catalyst monitor has a valid CMS sensor with which to perform the catalyst monitor diagnostic. The monitor is set to trigger at the level of degradation that will cause the catalyst monitor to falsely pass a malfunction threshold catalyst.

The OBD-II regulations require this monitor to utilize Decel Fuel Shut Off (DFSO). Ford plans to aggressively use DFSO starting in the 2009 MY on many applications to improve fuel economy. The DFSO rear O2 response test will be phased in coincident with this feature.

The main part of the test is the measured rich to lean response rate. It is determined by a "slew" rate calculation which determines the rich to lean slope of the sensor during a Decel Fuel Shut Off (DFSO) event which occurs during closed pedal at vehicle speeds higher than 28 mph. The calculation for the slew rate (mV/sec) is illustrated below.



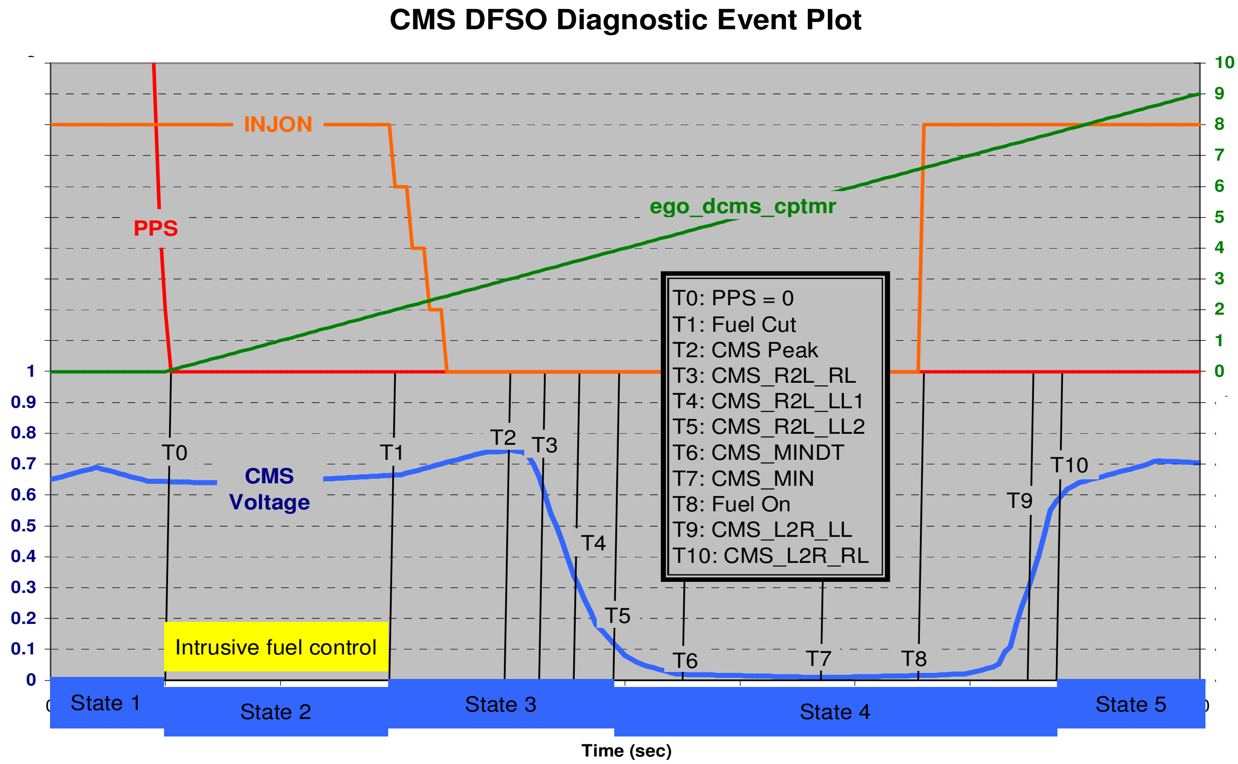
Linear interpolation is performed to calculate the Slew Rate.

1. Interpolate between points P1 and P2 to determine the time at which the rich limit threshold of 0.6 volts was crossed.

2. Interpolate between points P3 and P4 to determine the time at which the lean limit threshold of 0.2 volts was crossed.

3. Use the Interpolated times and the thresholds to calculate the slope or "slew rate" of the CMS sensor from 0.6 to 0.2 volts.

Diagnostic Data Acquisition Event Plot is a schematic of what happens when the pedal is closed and the engine enters DFSO.



The top half of the graph shows the following signals:

Closed pedal timer (ego_dcms_cptmr).

PPS (Pedal Position Sensor)

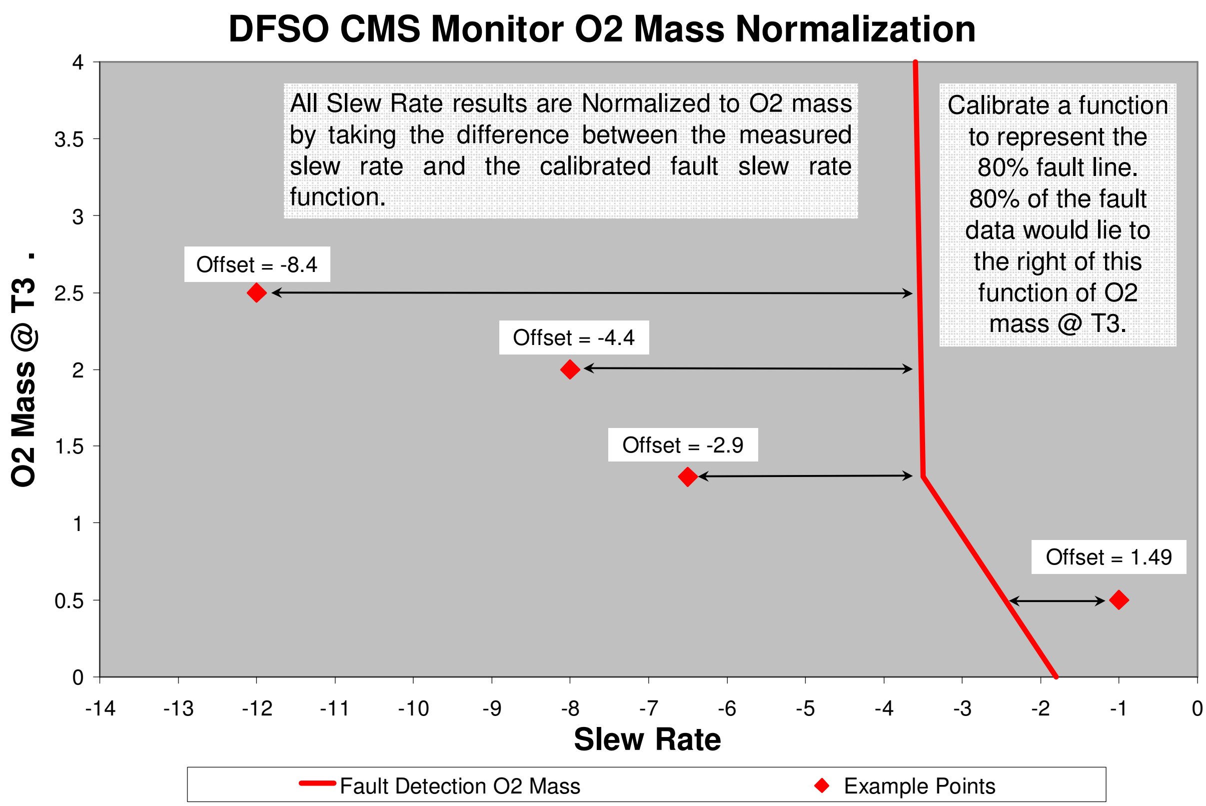
INJON (# of fuel injectors turned on)

The bottom half of the graph shows a CMS signal with black lines and a "Tx" number representing all of the points of interest where the monitor captures data.

The monitor measures the CMS Rich to Lean slew rate during a DFSO event. The CMS voltage must be rich prior to the injector cut for a valid measurement event. Each fuel cut can only yield 1 valid event. The monitor will complete after 3 valid events. Additional valid event results will be stored and applied over the next drive cycle if necessary for monitor completion.

The slope or slew rate of the CMS sensor going from rich to lean is a negative number with the units of mVolts/sec. The measured slew rate changes as an O2 sensor degrades, but it will also change as a function of catalyst oxygen storage/age; therefore, the slew rate is normalized using an offset based on catalyst oxygen storage/age. The catalyst oxygen storage/age is calculated by integrating the level of oxygen mass in the exhaust stream from the time the injectors turn off to the time where the slew rate calculation begins. The fault line (red line in the chart below) is calibrated to 80% of the fault distribution for various levels of oxygen storage/catalyst age. As shown below, the integrated oxygen mass becomes smaller with catalyst age.

The final output of the monitor = the measured slew rate – normalized fault line, therefore, any positive number will represent a fault. For the step change logic the fault threshold will represent 50% of the failed distribution (~ 0.3).



The delayed response part of the test indicates that the sensor is stuck in range. The code sets if the sensor can't get above a calibrated rich or lean voltage prior to a calibrated time out period. This time out must happen three times in a row to set the fault. If it happens once or twice and then the response monitor completes, the counter will be reset and the sensor will have to fail 3 times in a row to again set the DTC.

Due to the fact that intrusively driving the CMS sensor rich will cause drivability and emission concerns, there are other several condition counters that have to fail prior to intrusively forcing the sensor to go rich. The sequence of events to get to the rich failure is shown below:

- Initially, in order to avoid excess emissions, the monitor will only run if the CMS voltage is rich (> 0.6 volts) or CMS sensor is transitioning from lean to rich (large positive slope . 0.2).
  - Successive failures are counted up; when the count exceeds 5 to 10 failures the monitor will now intrusively force rich fuel to run the test.
- In order to avoid a drivability issues as a result of a lean shifted bank, the first phase of intrusive control has a short time out (1 to 2 seconds).
  - Successive failures are counted up; when the count exceeds 3 failures the monitor will now intrusively force rich fuel to failure or a rich sensor.
- All controllable measures have failed to force the sensor to switch, so the strategy will drive rich until the sensor switches or the failure time out is exceeded (5 to 10 seconds).
  - Successive failures are counted up; when the count exceeds 3 failures the monitor will now set a fault (P013E for bank 1 or P014A for bank 2).

If the sensor is stuck rich (can't get lean) the fault procedure is:

- While the injectors remain off, the sensor must get lean (<0.1 volts) prior to the failure time which must be set to account for a green catalyst (5 to 10 seconds).
  - Successive failures are counted up; when the count exceeds 3 failures the monitor will now set a fault (P013E for bank 1 or P014A for bank 2).

EWMA Fault Filtering

The EWMA logic incorporates several important CARB requirements. These are:

- Fast Initial Response (FIR): The first 4 tests after a battery disconnect or code clear will process unfiltered data to quickly indicate a fault. The FIR will use a 2-trip MIL. This will help the service technician determine that a fault has been fixed.

- Step-change Logic (SCL): The logic will detect an abrupt change from a no-fault condition to a fault condition. The SCL will be active after the 4th DCMS monitor cycle and will also use a 2-trip MIL. This will illuminate the MIL when a fault is instantaneously induced.

- Normal EWMA (NORM): This is the normal mode of operation and uses an Exponentially Weighted Moving Average (EWMA) to filter the EONV test data. It is employed after the 4th EONV test and will illuminate a MIL during the drive cycle where the EWMA value exceeds the fault threshold. (1 trip MIL).

Rear O2 **DFSO Response Monitor Operation:**	
DTCs	P013A - O2 Sensor Slow Response - Rich to Lean (Bank 1 Sensor 2) P013E - O2 Sensor Delayed Response - Rich to Lean (Bank 1 Sensor 2) (sensor stuck in range)
Monitor execution	Once per driving cycle, after 3 DFSO events.
Monitor Sequence	> 30 seconds time in lack of movement test (UEGO only), > 30 seconds time in lack of switch test, front HO2S/UEGO response test complete, HO2S 2 and 3 functional tests complete, HO2S/UEGO heater voltage and current checks complete, FAOS monitor system bias maturity met (UEGO applications only)
Sensors OK	ECT, IAT, MAF, VSS, TP, ETC, FRP, EGR, VCT, VMV/EVMV, CVS, FTP, CKP, CMP, ignition coils, injectors, no misfire DTCs, no system failures affecting fuel, no EVAP gross leak failure, UEGO heaters OK, rear HO2S heaters OK, no "lack of switching" malfunction, no "lack of movement" malfunction, no UEGO circuit malfunction, no rear stream 2 HO2S circuit malfunction, no rear stream 2 HO2S functional DTCs, Not performing CSER spark retard. Flex fuel composition not changing. No intrusive EGO monitors running.
Monitoring Duration	3 DFSO events, 450 seconds on the FTP.

Typical DFSO Response Monitor entry conditions:		
Entry condition	Minimum	Maximum
Air Mass	0.2	2
Vehicle Speed		90
Inlet Air Temp		140
Engine Coolant Temp	140 ^{o}F	240 ^{o}F
Catalyst Temperature (Inferred)	800 ^{o}F	1600 ^{o}F
Rear Ego Tip Temperature (Inferred)	800 ^{o}F	
Fuel Level	15%	
Fuel In Control	-5%	5%
Adaptive Fuel Within Limits	-5%	5%
Battery Voltage	11.0 Volts	18.0 Volts
Rich Voltage on downstream CMS sensor(s)	0.6 Volts	
Rich Voltage on upstream HEGO / UEGO sensor(s)	0.45 Volts (HEGO)	1 (UEGO)

Typical DFSO response rate malfunction thresholds:		
Rich to lean slew rate thresholds:		
	Normal Threshold	= > 0.0 mV/sec
	Fast Initial Response Threshold	= > 0.0 mV/sec
	Step Change Threshold	= > 0.3 mV/sec
Note that the thresholds use a normalized offset and the threshold is set at "zero".		

Typical DFSO delayed response malfunction thresholds:
Successive failures are counted up (5 to 10 faults). Monitor will now intrusively force rich fuel to run the test.
Intrusive controls will time out based on drivability (1 to 2 sec).
Successive drivability failures are counted up (3 faults).
Intrusive controls will now time out at a slower time (5 to 10 sec) and count a fault. After 3 faults are counted, a DTC is set.

J1979 DFSO response rate Mode $06 Data			
Monitor ID	Test ID	Description for CAN	
$02	$85	HO2S12 Fuel Shut off Rich to Lean Response Rate	mV/sec
$02	$86	HO2S12 Fuel Shut off Rich to Lean Response Time	msec
$06	$85	HO2S22 Fuel Shut off Rich to Lean Response Rate	mV/sec
$06	$86	HO2S22 Fuel Shut off Rich to Lean Response Time	msec

Rear HO2S Heaters,

The HO2S heaters are monitored for proper voltage and current. A HO2S heater voltage fault is determined by turning the heater on and off and looking for corresponding voltage change in the heater output driver circuit in the PCM.

A separate current-monitoring circuit monitors heater current once per driving cycle. The heater current is actually sampled three times. If the current value for two of the three samples falls below a calibratable threshold, the heater is assumed to be degraded or malfunctioning. (Multiple samples are taken for protection against noise on the heater current circuit.)

HO2S Heater Monitor Operation:	
DTCs Sensor 2	P0141 O2 Heater Circuit, Bank 1 P0054 O2 Heater Resistance, Bank 1 P0147 O2 Heater Circuit, Bank 1 P0055 HO2s Heater Resistance, Bank 1
Monitor execution	once per driving cycle for heater current, continuous for voltage monitoring
Monitor Sequence	Heater current monitor: Stream 1 HO2S/UEGO response test complete, Stream 2 and 3 HO2S functional tests complete, HO2S/UEGO heater voltage check complete
Sensors OK	Heater current monitor: no HO2S/UEGO heater voltage DTCs
Monitoring Duration	< 10 seconds for heater voltage check, < 5 seconds for heater current check

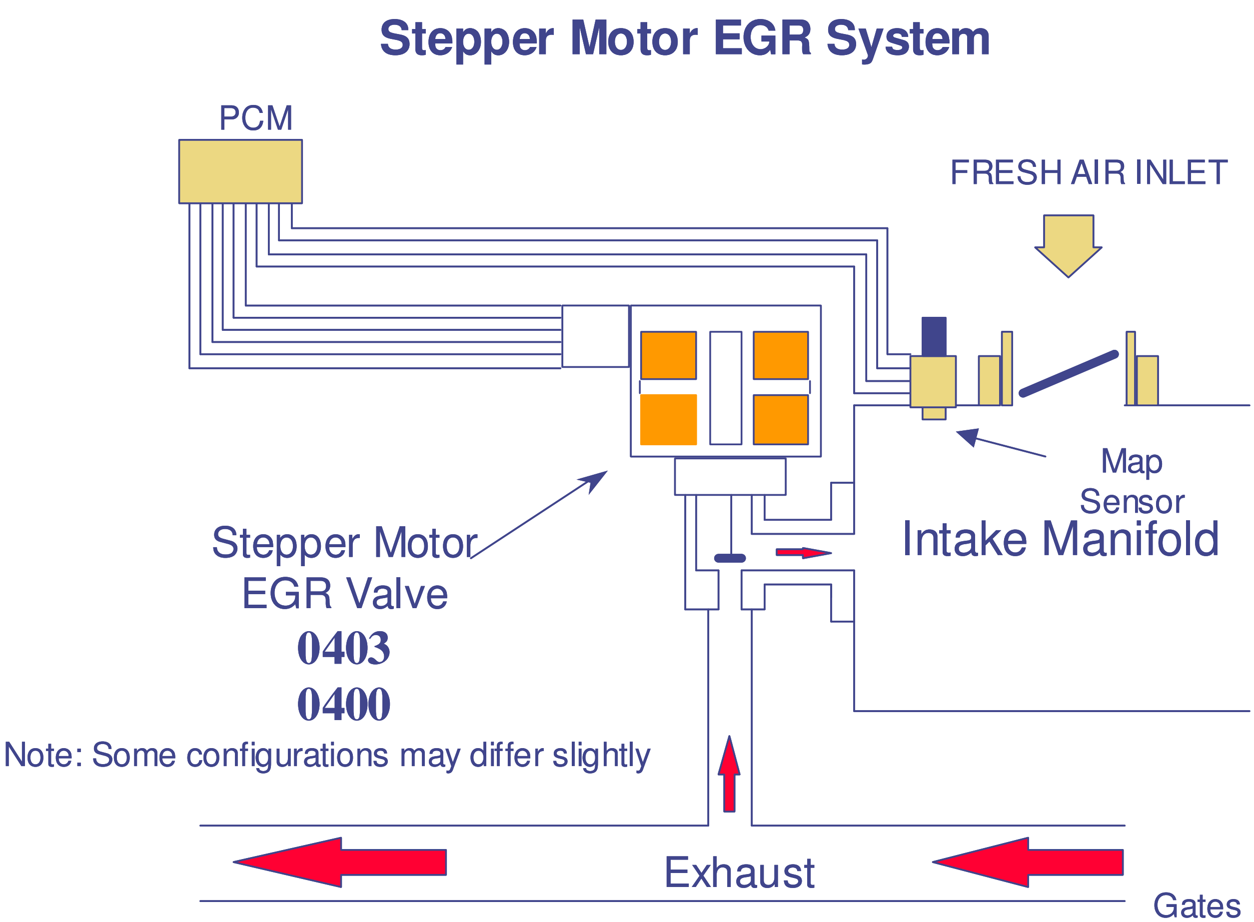
Typical HO2S heater monitor entry conditions:		
Entry condition	Minimum	Maximum
Inferred HO2S 2/3 Temperature (heater voltage check only)	400 ^oF	1400 ^oF
Inferred HO2S 2 Temperature (heater current check only)	250 ^oF	1400 ^oF
Inferred HO2S 3 Temperature (heater current check only)	250 ^oF	1400 ^oF
HO2S 1/2/3 heater-on time (heater current check only)	30 seconds	
Engine RPM (heater current check only)		5000 rpm
Battery Voltage (heater voltage check only)	11.0	18.0 Volts

Typical HO2S heater check malfunction thresholds:	
Smart driver status indicated malfunction	
Number monitor retries allowed for malfunction > = 30	
Heater current outside limits:	< 0.220 amps or > 3 amps, (NTK)
	< 0.400 amps or > 3 amps, (Bosch)
	< 0.465 amps or > 3 amps, (NTK Fast Light Off)
	< 0.230 amps or > 3 amps, (Bosch Fast Light Off)

J1979 HO2S Heater Mode $06 Data			
Monitor ID	Test ID	Description for CAN	Units
$02	$81	HO2S12 Heater Current	Amps
$06	$81	HO2S22 Heater Current	Amps
$03	$81	HO2S13 Heater Current	Amps
$07	$81	HO2S23 Heater Current	Amps

Stepper Motor EGR System Monitor – Non-intrusive Monitor

The Electric Stepper Motor EGR System uses an electric stepper motor to directly actuate an EGR valve rather than using engine vacuum and a diaphragm on the EGR valve. The EGR valve is controlled by commanding from 0 to 52 discreet increments or “steps” to get the EGR valve from a fully closed to fully open position. The position of the EGR valve determines the EGR flow. Control of the EGR valve is achieved by a non-feedback, open loop control strategy. Because there is no EGR valve position feedback, monitoring for proper EGR flow requires the addition of a MAP sensor.



The Non-Intrusive Stepper Motor EGR Monitor consists of an electrical and functional test that checks the stepper motor and the EGR system for proper flow.

The stepper motor electrical test is a continuous check of the four electric stepper motor coils and circuits to the PCM. A malfunction is indicated if an open circuit, short to power, or short to ground has occurred in one or more of the stepper motor coils for a calibrated period of time. If a malfunction has been detected, the EGR system will be disabled, and additional monitoring will be suspended for the remainder of the driving cycle, until the next engine start-up.

EGR Stepper Monitor Electrical Check Operation:	
DTCs	P0403
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	4 seconds to register a malfunction

Stepper motor electrical check entry conditions:
Battery voltage > 11.0 volts

Typical EGR electrical check malfunction thresholds:
“Smart” Coil Output Driver status indicates open or short to ground, or short to power

EGR flow is monitored using an analog Manifold Absolute Pressure Sensor (MAP). If a malfunction has been detected in the MAP sensor, the EGR monitor will not perform the EGR flow test.

The MAP sensor is checked for opens, shorts, or out-of-range values by monitoring the analog-to-digital (A/D) input voltage.

MAP Sensor Check Operation	
DTCs	P0107 (low voltage), P0108 (high voltage)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

MAP electrical check entry conditions:
Battery voltage > 11.0 volts

Typical MAP sensor check malfunction thresholds:
Voltage < 0.024 volts or voltage > 4.96 volts

The MAP sensor is also checked for rational values. The value of inferred MAP is checked against the actual value of MAP at idle and non-idle engine operating conditions.

MAP Sensor Rationality Check Operation	
DTCs	P0106
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	10 seconds to register a malfunction

Typical MAP Rationality check entry conditions:		
Entry Conditions	Minimum	Maximum
Change in load		5%
Engine rpm	500 rpm	1800 rpm

Typical MAP Rationality check malfunction thresholds:
Difference between inferred MAP and actual MAP > 8 in Hg

The MAP sensor is also checked for intermittent MAP faults.

MAP Sensor Intermittent Check Operation	
DTCs	P0109 (non-MIL)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	2 seconds to register a malfunction

Typical MAP Intermittent check malfunction thresholds:
Voltage < 0.024 volts or voltage > 4.96 volts

After the vehicle has warmed up and normal EGR rates are being commanded by the PCM, the EGR flow test is performed. The flow test is performed once per drive-cycle after the remaining entry conditions required to initiate the test are satisfied.

The EGR flow test is done by observing the behavior of two different values of MAP - the analog MAP sensor reading, and inferred MAP, (MAP calculated from the Mass Air Flow Sensor, throttle position, rpm, BARO, etc.). The calculation of inferred MAP is not compensated for EGR flow and, therefore, does not account for the effects of EGR flow whereas measured MAP does respond to the effects of EGR flow. The amount of EGR flow can therefore be calculated by looking at the difference between measured MAP and inferred MAP.

Measured MAP can be thought of as consisting of three contributors: fresh air drawn into the intake manifold, EGR flow, and a noise/variability term. The following equation describes this:

Pmap = **P**maf + **P**egr + **P**noise

Where: **P**map = pressure in manifold measured by the MAP sensor

Pmaf = fresh air pressure without EGR flow, inferred from the MAF sensor, also known as inferred MAP

Pegr = EGR flow pressure due to EGR flow

Pnoise = any discrepancy between measured MAP and inferred MAP, without EGR

Pmaf (inferred MAP) is determined by the amount of fresh air drawn into manifold as measured by the Mass Air Flow (MAF) sensor. Inferred MAP is determined during the engine mapping process with no EGR, as a function of rpm and load

Pegr , the pressure due to EGR contribution can be modeled in the following equation:

Pegr = K * (Actual EGR / Desired EGR) * Desired EGR

Where: K = converts EGR pressure to a percent EGR flow rate

By rearranging the equation:

Actual EGR / Desired EGR = **P**egr / (K * Desired EGR)

The ratio of actual to desired EGR will eventually be calculated by the EGR monitor and will reflect how accurately EGR is being delivered to the engine.

Some differences will always exist between measured MAP and inferred MAP due to hardware variations. Within steady engine operating conditions without EGR, it is reasonable to model any differences between inferred and measured MAP as an offset and slope that is a function of load. The offset and slope are learned at various loads. This correction can be represented as:

MAP correction = **P**noise = M * LOAD + B

Where: B = offset between measured MAP and inferred MAP

M = slope which accounts for the difference between measured MAP and inferred MAP as a function of load

The terms B and M are learned and compensate for differences between measured MAP and inferred MAP.

Rearranging and substituting in the equations above results in the following system model:

Actual EGR / Desired EGR = (measured MAP – inferred MAP – MAP correction) / (K * Desired EGR)

The Actual EGR / Desired EGR is called the "degradation index". A value near one indicates the system is functioning properly whereas a value near zero reflects severe flow degradation.

When the entry conditions for the flow test have been satisfied, a calibrated number of samples of the difference between measured MAP and inferred MAP are taken at low, medium and high load regions, with and without EGR, to learn the MAP correction terms and then calculate the degradation index. When the number of samples in each load region is complete, a degradation index value from zero to one is computed. A value near one indicates the system is functioning properly whereas a value near zero reflects EGR severe flow degradation.

The degradation index is compared to a calibrated threshold to determine if a low flow malfunction has occurred.

Once the EGR monitor has been completed, the counter for the number of samples in each load region is reset to zero. If an EGR flow malfunction has occurred, the P0400 DTC flow malfunction is registered.

Note: BARO is inferred at engine startup using the KOEO MAP sensor reading. It is updated during high, part-throttle, engine operation.

This monitor employs an Exponentially Weighted Moving Average (EWMA) algorithm to improve the robustness threshold of the degradation index. During normal customer driving, a malfunction will illuminate the MIL, on average, in 3 to 6 driving cycles. If KAM is reset (battery disconnected), a malfunction will illuminate the MIL in 2 driving cycles. See the section on EWMA for additional information.

EGR Flow Check Operation:	
DTCs	P0400
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	CPS, ECT, IAT, MAF, MAP (P0106/7/8), TP, BARO not available yet
Monitoring Duration	200 seconds (600 data samples)

Typical EGR flow check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM	1050 rpm	3700 rpm
Inferred Ambient Air Temperature	32 ^{o}F	200 ^{o}F
Engine Coolant Temperature	140 ^{o}F	240 ^{o}F
Engine RPM Steady (change/0.100 sec)		100 rpm
MAP Steady (change/0.100 sec)		0.2 in Hg
Engine Load Steady (change/0.100 sec)		2 %
BARO	22.5 "Hg	
Samples for slope calculation (a sample/0.1sec)	600 samples	

Typical EGR flow check malfunction thresholds:
< 0.25 degradation index

J1979 Mode $06 Data			
Monitor ID	Test ID	Description for CAN	Units
$33	$82	Degradation index and min. threshold	none

I/M Readiness Indication

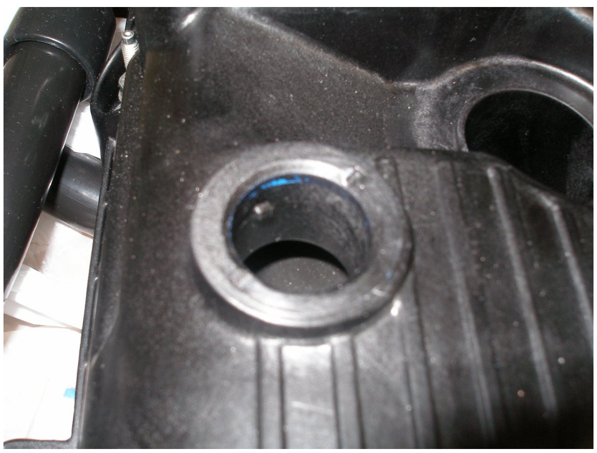
If the inferred ambient temperature is less than 20 °F, greater than 130 °F, or the altitude is greater than 8,000 feet (BARO < 22.5 "Hg), the EGR flow test cannot be reliably done. In these conditions, the EGR flow test is suspended and a timer starts to accumulate the time in these conditions. If the vehicle leaves these extreme conditions, the timer starts decrementing, and, if conditions permit, will attempt to complete the EGR flow monitor. If the timer reaches 800 seconds, the EGR flow test is disabled for the remainder of the current driving cycle and the EGR Monitor I/M Readiness bit will be set to a “ready” condition after one such driving cycle. Two such consecutive driving cycles are required for the EGR Monitor I/M Readiness bit to be set to a "ready" condition.

PCV System Monitor

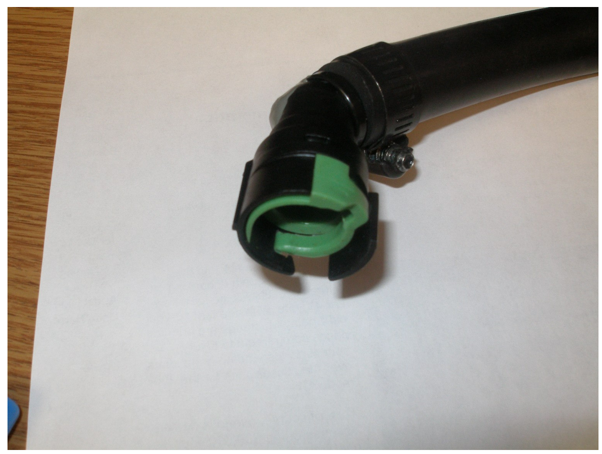
The PCV valve is installed into the rocker cover using a quarter-turn cam-lock design to prevent accidental disconnection. The PVC valve is connected to the intake manifold hose using a quick connect. Because the PCV valve has locking tabs and cannot be removed from the rocker cover without the use of special removal tools, the quick connect will be disconnected first in the event vehicle service is required. Molded plastic lines are typically used from the PCV valve to the intake manifold. The diameter of the lines and the intake manifold have been increased to 0.625" so that inadvertent disconnection of the lines after a vehicle is serviced will cause either an immediate engine stall or will not allow the engine to be restarted. In the event that the vehicle does not stall if the line between the intake manifold and PCV valve is inadvertently disconnected, the vehicle will have a large vacuum leak that will cause a Mass Air Flow equipped vehicle to run lean at idle. This will illuminate the MIL after two consecutive driving cycles and will store one or more of the following codes: Lack of O2 sensor switches, Bank 1 (P2195), Lack of O2 sensor switches Bank 2 (P2197), Fuel System Lean, Bank 1 (P0171),, Fuel System Lean, Bank 2 (P0174)

The PCV valve may incorporate a heater on some applications. A heated PCV valve is shown below. The PCV valve is designed to last for the life of the vehicle and should not require servicing or replacement.

Rocker cover with nub for quarter-turn valve



PCV hose with quick connect

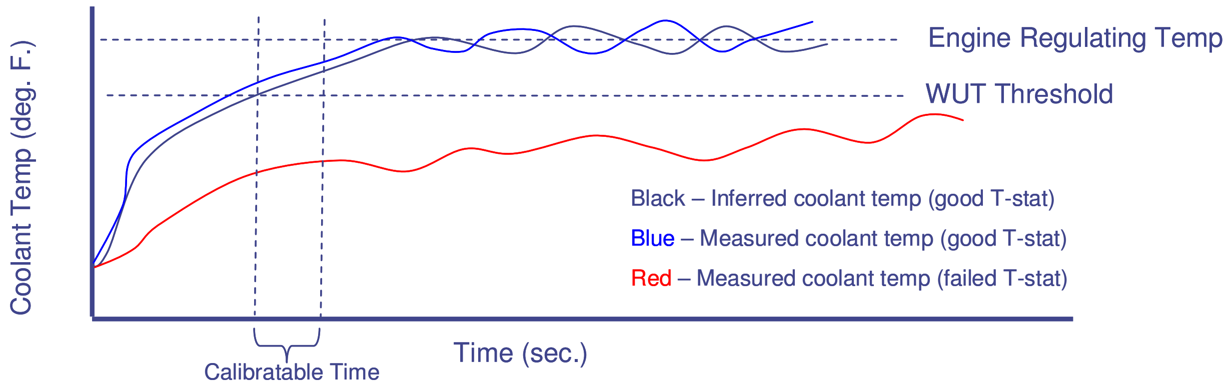


Heater quarter-turn PCV valve with heater

Assembled PCV system

Enhanced Thermostat Monitor

For the 2009 MY, the thermostat test has been enhanced to reduce the time it takes to identify a malfunctioning thermostat. The enhanced monitor includes a model which infers engine coolant temperature.



During a cold start, when the thermostat should be closed, the monitor uses a model of ECT to determine whether actual ECT should have crossed the Warm Up Temperature (WUT) threshold. Once the ECT model exceeds the WUT threshold, after a calibratable time delay, measured ECT is compared to the same WUT threshold to determine if ECT has warmed up enough. If ECT has warmed up to at least the WUT threshold, the thermostat is functioning properly. If ECT is too low, the thermostat is most likely stuck open and a P0128 is set.

The WUT threshold is normally set to 20 degrees F below the thermostat regulating temperature.

There are some circumstances that could lead to a false diagnosis of the thermostat. These are conditions where the vehicle cabin heater is extracting more heat than the engine is making. One example where this can occur is on large passenger vans which have "dual" heaters, one heater core for the driver and front passengers and another heater core for the passengers in the rear of the vehicle. At very cold ambient temperatures, even a properly functioning thermostat may never warm up to regulating temperature. Another example is a vehicle that is started and simply sits at idle with the heater on high and the defroster fan on high.

There are two features that are used to prevent a false thermostat diagnosis. For vehicles with dual heaters, the WUT threshold is reduced at cold ambient temperatures below 50 deg F. For cases where the engine is not producing sufficient heat, a timer is used to track time at idle or low load conditions (e.g. decels). If the ratio of time at idle/low load versus total engine run time exceeds 50% at the time the fault determination is made, the thermostat diagnostic does not make a fault determination for that driving cycle, i.e. "no-call".

THERMOSTAT MONITOR OPERATION	
DTC	P0128 - Coolant Thermostat (Coolant temperature below thermostat regulating temperature)
Monitor Execution	Once per driving cycle, during a cold start
Monitoring Duration	Drive cycle dependent. Monitor completes 300 seconds after inferred ECT exceeds threshold

TYPICAL THERMOSTAT MONITOR ENTRY AND COMPLETION CONDITIONS		
Entry conditions	Minimum	Maximum
Engine Coolant Temperature at start	None	125 °F
Intake Air Temperature at start (ambient temp)	20 °F	None
Inferred Percent Ethanol (flex fuel vehicles only)	Learned	N/A
Completion condition	Minimum	Maximum
Modeled ECT	160 °F	None
Time Since Modeled ECT Exceeded WUT Threshold	300 sec.	None
Time at Idle/Low Load Compared with Total Engine Run Time	None	50%

TYPICAL MALFUNCTION THRESHOLD
Engine Coolant Temperature < 160 °F (for the 180 °F thermostat)

Cold Start Emission Reduction Component Monitor

Cold Start VCT Monitor

If the VCT cam phasing is used during a cold start to improved catalyst heating, the VCT system is checked functionally by monitoring the closed loop cam position error correction. If the proper cam position cannot be maintained and the system has an advance or retard error greater than the malfunction threshold, a cold start emission reduction (CSER) VCT control malfunction is indicated (P052A/P052B (Bank 1), P052C/P052D (Bank2). This test is the same test that was used previously for monitoring the VCT system under Comprehensive Component Monitoring requirements.

CSER VCT Target Error Check Operation:]	
DTCs	P052A – Cold start camshaft position timing over-advanced (Bank 1) P052B – Cold start camshaft timing over-retarded (Bank 1) P052C – Cold start camshaft timing over-advanced (Bank 2) P052D – Cold start camshaft timing over-retarded (Bank 2)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds

Typical CSER VCT target error entry conditions:		
Entry condition	Minimum	Maximum
VCT control enabled and commanded to advance or retard cam during CSER	n/a	n/a
Time since start of CSER cam phase monitoring		60 seconds

Typical CSER VCT target error malfunction thresholds:
CSER Response/target error - VCT over-advance: 11 degrees CSER Response/target error - VCT over-retard: 11 degrees CSER Response/Stuck Pin – 10 degrees phasing commanded, and not seeing at least 2 degrees of movement.

Cold Start Emission Reduction System Monitor

The Cold Start Emission Reduction System Monitor is being introduced for the 2007 MY on vehicles that meet the LEV-II emission standards. It will eventually replace the Cold Start Emission Reduction Component Monitor. The Cold Start Emission Reduction (CSER) Monitor detects the lack of catalyst warm up resulting from a failure to apply sufficient CSER during a cold start. It does this by using the inferred catalyst temperature model to determine how closely the actual catalyst temperature follows the expected catalyst temperature during a cold start. How closely the actual temperature follows the expected temperature is reflected in a ratio which is compared with a calibratable threshold.

Temperatures Used

The actual catalyst temperature is the same inferred catalyst temperature that is used by other portions of the engine control system, including the CSER control system. The inputs to this actual temperature are measured engine speed, measured air mass, and commanded spark.

The expected catalyst temperature is calculated using the same algorithm as the actual catalyst temperature, but the inputs are different. Desired engine speed replaces measured engine speed, desired air mass replaces measured air mass, and desired cold start spark replaces commanded spark. The resulting temperature represents the catalyst temperature that is expected if CSER is functioning properly.

Ratio Calculation

A ratio is calculated to reflect how closely the actual temperature has followed the expected temperature. This ratio is the difference between the two temperatures at a certain time-since-start divided by the increase in expected temperature over the same time period. The ratio, then, provides a measure of how much loss of catalyst heating occurred over that time period.

This ratio correlates to tailpipe emissions. Therefore applying a threshold to it allows illumination of the MIL at the appropriate emissions level. The threshold is a function of ECT at engine start.

General CSER Monitor Operation

During the first 15 seconds of a cold start, the monitor checks the entry conditions, counts time in idle, and observes catalyst temperature.

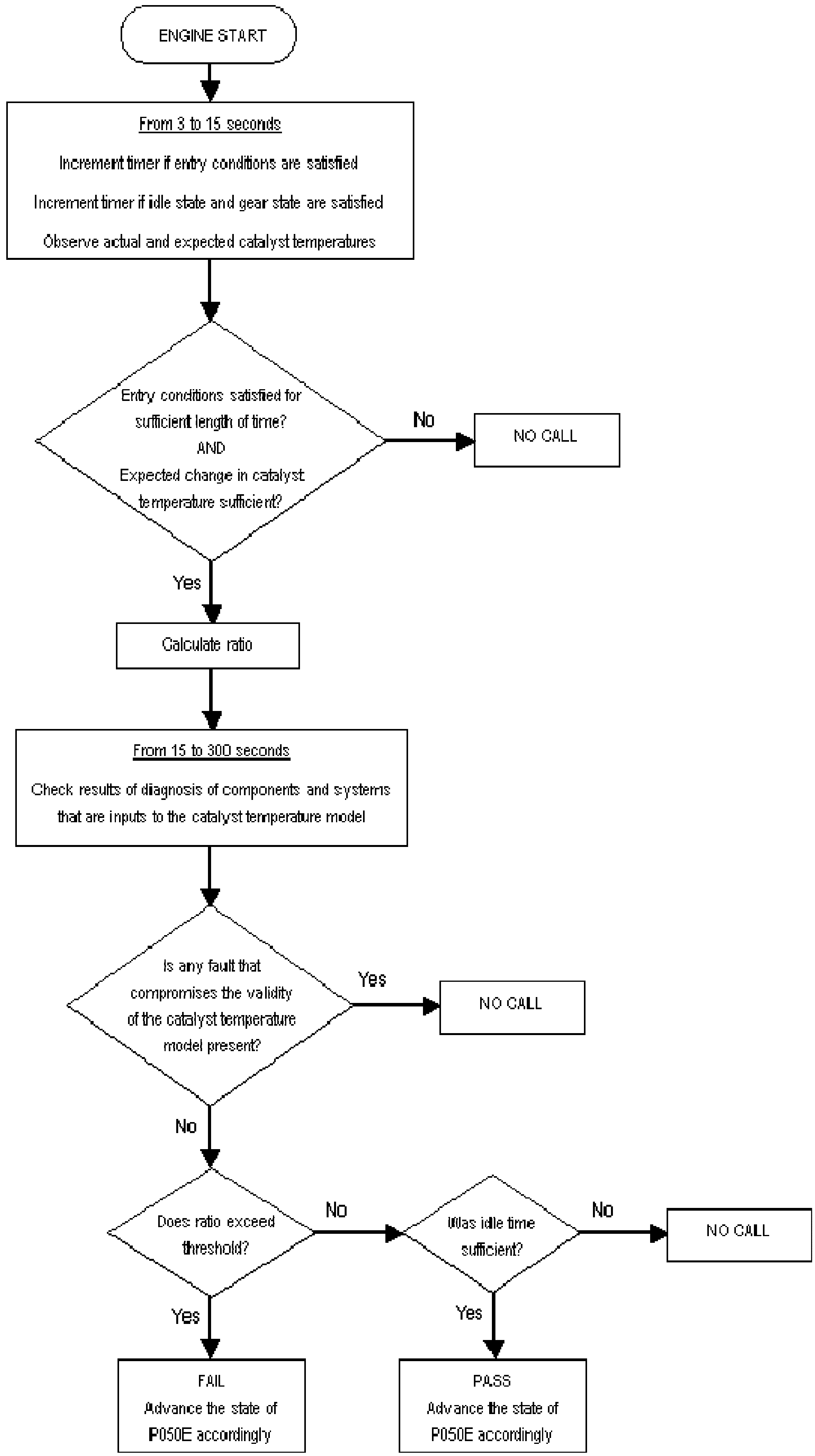
If the expected change in catalyst temperature is large enough, the monitor calculates the ratio as described above. Otherwise the monitor does not make a call.

The monitor then begins the waiting period, which lasts from the time the ratio is calculated (15 seconds after engine start) until 300 seconds after engine start. This 5-minute wait allows time to diagnose other components and systems that affect the validity of the catalyst temperature model. During this waiting period, there are no constraints on drive cycle and the monitor cannot be disabled without turning off the key.

At the end of the waiting period, if no other faults that could compromise the validity of the catalyst temperature model are found, the monitor compares the ratio to the threshold.

If the ratio exceeds the threshold, the monitor considers the test a fail, and the monitor is complete.

If the ratio falls below the threshold, the monitor determines whether the idle time was sufficient. If so, it considers the test a pass and the monitor is complete. If idle time was not sufficient, the monitor does not make a pass call and does not complete. This prevents tip-ins from resulting in false passes.


ENGINE START
From 3 to 15 seconds
Increment timer if entry conditions are satisfied
Increment timer if idle state and gear state are satisfied
Observe actual and expected catalyst temperatures
Entry conditions satisfied for sufficient length of time? AND Expected change in catalyst temperature sufficient?
No
NO CALL
Yes
Calculate ratio
From 15 to 300 seconds
Check results of diagnosis of components and systems that are inputs to the catalyst temperature model
Is any fault that compromises the validity of the catalyst temperature model present?
Yes
NO CALL
No
Does ratio exceed threshold?
No
Was idle time sufficient?
No
NO CALL
Yes
Yes
FAIL
Advance the state of P050E accordingly
PASS
Advance the state of P050E accordingly

CSER MONITOR OPERATION	
DTC	P050E: Cold Start Engine Exhaust Temperature Out Of Range
Monitor Execution	Once per driving cycle, during a cold start
Monitor Sequence	Monitor data collection takes place during first 15 seconds of cold start
Sensors OK	No fault is present in any of the sensors or systems affecting the catalyst temperature model: Mass Air Flow (P0102, P0103), Throttle Position (P0122, P0123, P0222, P0223), Misfire (P0316, P0300-P0312), Injectors (P0201-P0212), Fuel System (P0171, P0172, P0174, P0175), Secondary Air (P0412, P2258), Crank Position Sensor (P0320), Ignition Coil (P0351-P0360), Intake Air Temp (P0112, P0113), Engine Coolant Temp/Cylinder Head Temp (P0117, P0118, P1289, P1290), Variable Cam Timing (P0010, P0020, P0011, P0012, P0021, P0022), Intake Manifold Runner Control (P2008).
Monitoring Duration	Monitor completes 300 seconds after initial engine start

TYPICAL CSER MONITOR ENTRY AND COMPLETION CONDITIONS		
Entry condition	Minimum	Maximum
Barometric Pressure	22 in. Hg	
Engine Coolant Temperature at Start	35 °F	100 °F
Catalyst Temperature at Start	35 °F	125 °F
Fuel Level	15%	
No Torque Reduction by Injector Cutout		
Power Takeout Not Active		
Completion condition	Minimum	Maximum
Length of Time Entry Conditions are Satisfied	11 sec.	
Expected Change in Catalyst Temperature	50 °F	
Time in Idle	10 sec.	
Selected Gear	Neutral	Drive

TYPICAL MALFUNCTION THRESHOLD
Cold start warm-up temperature ratio > 0.3

Variable Cam Timing System Monitor

Variable Cam Timing (VCT) enables rotation of the camshaft(s) relative to the crankshaft (phase-shifting) as a function of engine operating conditions. There are four possible types of VCT with DOHC engines:

- Intake Only (phase-shifting only the intake cam);
- Exhaust Only (phase-shifting only the exhaust cam);
- Dual Equal (phase-shifting the intake and exhaust cams equally);
- Dual Independent (phase-shifting the intake and exhaust cams independently).

All four types of VCT are used primarily to increase internal residual dilution at part throttle to reduce NOx, and to improve fuel economy. This allows for elimination the external EGR system.

With Exhaust Only VCT, the exhaust camshaft is retarded at part throttle to delay exhaust valve closing for increased residual dilution and to delay exhaust valve opening for increased expansion work.

With Intake Only VCT, the intake camshaft is advanced at part throttle and WOT (at low to mid-range engine speeds) to open the intake valve earlier for increased residual dilution and close the intake valve earlier in the compression stroke for increased power. When the engine is cold, opening the intake valve earlier warms the charge which improves fuel vaporization for less HC emissions; when the engine is warm, the residual burned gasses limit peak combustion temperature to reduce NOx formation.

With Dual Equal VCT, both intake and exhaust camshafts are retarded from the default, fully advanced position to increase EGR residual and improve fuel economy by reducing intake vacuum pumping losses. The residual charge for NOx control is obtained by backflow through the late-closing exhaust valve as the piston begins its intake stroke.

The VCT system hardware consists of a control solenoid and a pulse ring on the camshaft. The PCM calculates relative cam position using the CMP input to process variable reluctance sensor pulses coming from the pulse ring mounted on the camshaft. Each pulse wheel has N + 1 teeth where N = the number of cylinders per bank. The N equally spaced teeth are used for cam phasing; the remaining tooth is used to determine cylinder # 1 position. Relative cam position is calculated by measuring the time between the rising edge of profile ignition pickup (PIP) and the falling edges of the VCT pulses.

The PCM continually calculates a cam position error value based on the difference between the desired and actual position and uses this information to calculate a commanded duty cycle for the VCT solenoid valve. When energized, engine oil is allowed to flow to the VCT unit thereby advancing and retarding cam timing. The variable cam timing unit assembly is coupled to the camshaft through a helical spline in the VCT unit chamber. When the flow of oil is shifted from one side of the chamber to the other, the differential change in oil pressure forces the piston to move linearly along the axis of the camshaft. This linear motion is translated into rotational camshaft motion through the helical spline coupling. A spring installed in the chamber is designed to hold the camshaft in the low-overlap position when oil pressure is too low (~15 psi) to maintain adequate position control. The camshaft is allowed to rotate up to 30 degrees.

Although the VCT system has been monitored under Comprehensive Component Monitoring requirements for many years, a new, emission-based VCT monitor is being introduced for the 2006 MY on vehicles that meet LEV-II emission standards. The intent of the new VCT monitoring requirements is to detect slow VCT system response that could cause emissions to increase greater than 1.5 * std. in addition to detecting functional problems (target errors).

The new logic calculates the instantaneous variance in actual cam position (the squared difference between actual cam position and commanded cam position), then calculates the long term variance using a rolling average filter (Exponentially Weighted Moving Average). Continued, slow response from the VCT system will eventually accumulate large variances.

This same logic will also detect target errors that were detected by the previous CCM monitor. If the VCT system is stuck in one place, the monitor will detect a variance which will quickly accumulate.

There are three variance indices that monitor cam variance in the retard direction, the advance direction, and for V-engines, the difference between banks. If any variance index is greater than the malfunction threshold, a VCT slow response/target error malfunction will be indicated (P0011, P0012 Bank 1, 0021, P0022 Bank 2). Target errors will tend to generate only a single over-advanced or over-retarded code while slow response will tend to generate both codes.

In addition, logic has been added to determine whether the camshaft and crankshaft are misaligned by one or more teeth. This test calculates the absolute offset between one of the camshaft teeth and the crankshaft missing tooth at idle when that can is at its stop. If the error is greater than the malfunction threshold, a cam/crank misalignment error will be indicated (P0016 Bank 1, P0018 Bank 2).

For systems that phase the cams immediately off of a cold start for reducing emissions or CSER (Cold Start Emissions Reduction) the cam position is monitored for functionality during this period of time. There are two ways to set failures.

- Error between the actual position and the expected position is calculated. If the error is greater than a specified amount, and the Error persists for a period of time, a P052x code is set designating over advanced or retarded and the bank number. The diagnostic is only executed during CSER phasing.

- The diagnostic also checks for a cam position request above a threshold for a period of time, and determines that the VCT actuator pin is stuck if the cam does not move from the locked position by a certain amount. This is also only done during CSER operation. If the locking pin is determined to be stuck then the Oil Control Solenoid (OCS) is cycled on and off for a calibratable amount to allow pressure to build in the system to unseat the locking pin. If attempts to unstick the locking pin fail, then a P052x code is set.

The in-use performance ratio numerator for the VCT monitor can be incremented only if the VCT system has been monitored for both functional and response faults. If the vehicle is operated in a manner that does not ask the VCT actuators to change position, it may not be possible to evaluate whether they are working properly. As a result, the in-use ratio numerator checks to see if the commanded VCT position changes sufficiently to detect possible target errors and with a sufficiently high rate to detect possible slow response. For each drive cycle in which both criteria are met, the VCT in-use performance numerator will be incremented.

Similar to the previous CCM monitor, the VCT solenoid output driver in the PCM is checked electrically for opens and shorts (P0010 Bank 1, P0020 Bank 2).

VCT Monitor Operation:	
DTCs	P0010 - Camshaft Position Actuator Circuit (Bank 1) P0011 - Cam Position Actuator Over Advanced (Bank 1) P0012 - Cam Position Actuator Over Retarded (Bank 1) P0016 - Crank/Cam Position Correlation (Bank 1)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	IAT, ECT, EOT, IMRC, TP, MAF, CKP, and CMP
Monitoring Duration	5 - 10 seconds for circuit faults and functional checks, 300 seconds for target error

Typical VCT response/functional monitor entry conditions:		
Entry condition	Minimum	Maximum
Engine RPM (for P0016/P0018 only)	900	4500
Engine Coolant Temperature	32 ^{o}F	
Engine Oil Temperature		280 ^{o}F
VCT control enabled and commanded to advance or retard cam **	n/a	n/a
** VCT control of advance and retard by the engine is disabled in crank mode, when engine oil is cold (< 150 ^{o}F), while learning the cam/crank offset, while the control system is "cleaning" the solenoid oil passages, throttle actuator control in failure mode, and if one of the following sensor failures occur: IAT, ECT, EOT, MAF, TP, CKP, CMP, or IMRC.		

Typical VCT monitor malfunction thresholds:
VCT solenoid circuit: Open/short fault set by the PCM driver
Cam/crank misalignment: > or = 7.5 crank degrees
Response/target error - VCT over-advance variance too high: 100 degrees squared
Response/target error - VCT over-retard variance too high: 400 degrees squared

Typical In-Use Performance monitoring thresholds:
Monitoring thresholds to increment the numerator:
Amount of cam change required for target error fault: > 160 degrees squared
Amount of rate of change required for slow response fault: > 5 degrees squared

J1979 VCT Monitor Mode $06 Data

Monitor ID	Test ID	Description for CAN	Units
$35	$80	Camshaft Advanced Position Error Bank 1	Unsigned, Angular degrees
$35	$81	Camshaft Retarded Position Error Bank 1	Unsigned, Angular degrees

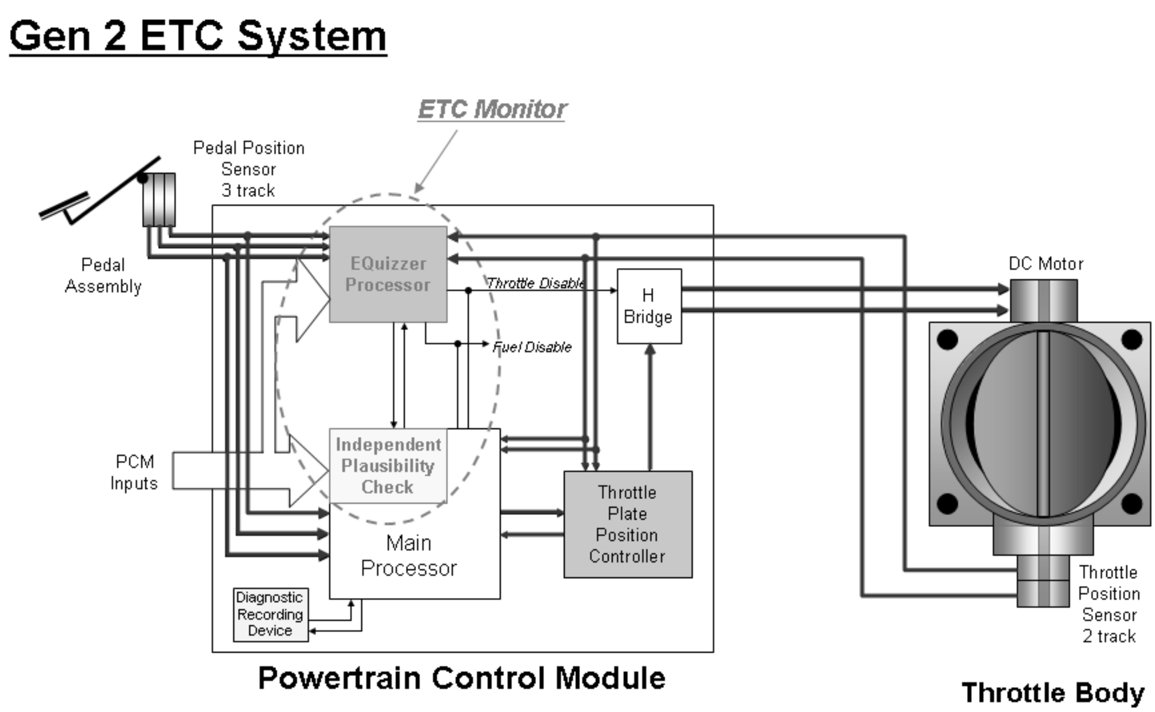
Electronic Throttle Control

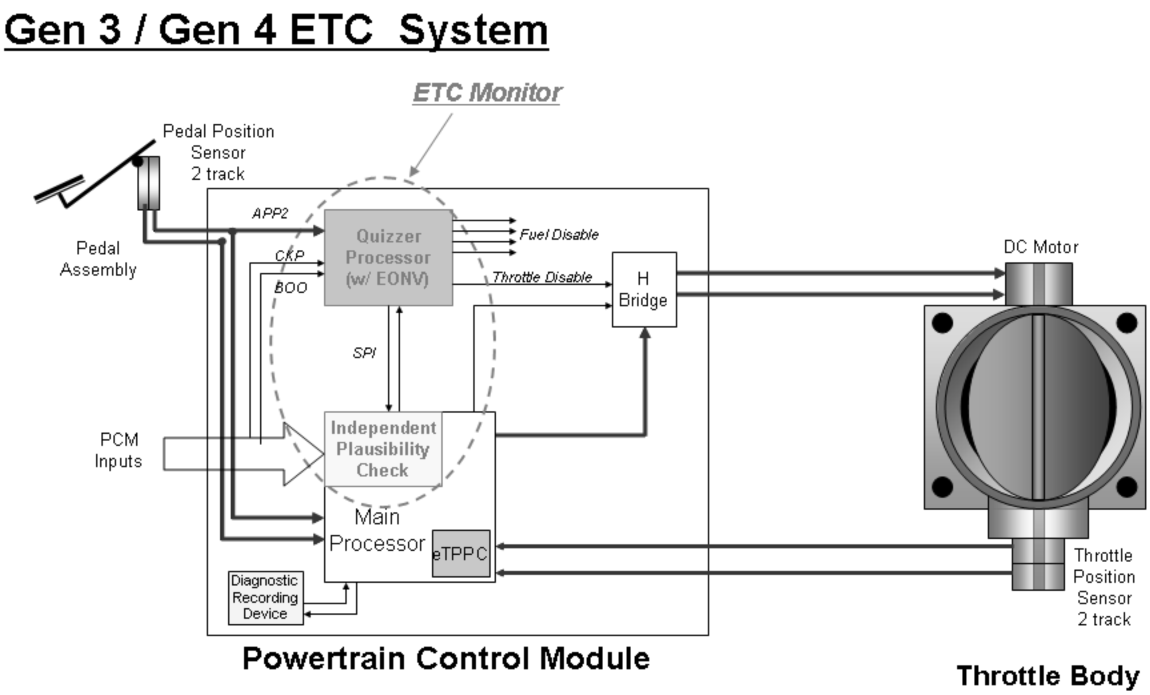
The Electronic Throttle Control (ETC) system uses a strategy that delivers engine or output shaft torque, based on driver demand, utilizing an electronically controlled throttle body. ETC strategy was developed mainly to improve fuel economy. This is possible by decoupling throttle angle (produces engine torque) from pedal position (driver demand). This allows the powertrain control strategy to optimize fuel control and transmission shift schedules while delivering the requested engine or wheel torque.

The Gen2 ETC system was first introduced in 2003MY Ford products. This system evolved into the Gen3 ETC system in 2008MY and the Gen4 ETC system in 2009MY. The Gen3 and Gen4 ETC systems made improvements over the Gen2 system by reducing complexity, improving reliability, and optimizing cost. The primary changes made for the Gen3 / Gen4 ETC systems were the following:

- Replace 3-track sensor Accelerator Pedal with 2-track sensor Accelerator Pedal.
- Introduce single plunger dual output brake switch.
- Integrate the Throttle Plate Position Controller (eTPPC) into the main processor within PCM.
- Reduce Quizzer complexity and integrate with the EONV function.

The Gen3 / Gen4 ETC systems have equivalent hardware systems with only software differences.





Because safety is a major concern with ETC systems, a complex safety monitor strategy (hardware and software) was developed. The monitor system is distributed across two processors: the main powertrain control processor and a monitoring processor called a Quizzer processor.

The primary monitoring function is performed by the Independent Plausibility Check (IPC) software, which resides on the main processor. It is responsible for determining the driver-demanded torque and comparing it to an estimate of the actual torque delivered. If the generated torque exceeds driver demand by specified amount, the IPC takes appropriate mitigating action.

Since the IPC and main controls share the same processor, they are subject to a number of potential, common-failure modes. Therefore, the Quizzer processor was added to redundantly monitor selected PCM inputs and to act as an intelligent watchdog and monitor the performance of the IPC and the main processor. If it determines that the IPC function is impaired in any way, it takes appropriate Failure Mode and Effects Management (FMEM) actions.

ETC System Failure Mode and Effects Management:	
Effect	Failure Mode
No Effect on Drivability	A loss of redundancy or loss of a non-critical input could result in a fault that does not affect drivability. The Wrench light will turn on, but the throttle control and torque control systems will function normally.
RPM Guard w/ Pedal Follower	In this mode, torque control is disabled due to the loss of a critical sensor or PCM fault. The throttle is controlled in pedal-follower mode as a function of the pedal position sensor input only. A maximum allowed RPM is determined based on pedal position (RPM Guard.) If the actual RPM exceeds this limit, spark and fuel are used to bring the RPM below the limit. The wrench light and the MIL are turned on in this mode and an ETC component causal code is set. EGR, VCT, and IMRC outputs are set to default values.
RPM Guard w/ Default Throttle	In this mode, the throttle plate control is disabled due to the loss of Throttle Position, the Throttle Plate Position Controller, or other major ETC system fault. A default command is sent to the (e)TPPC, or the H-bridge is disabled. Depending on the fault detected, the throttle plate is controlled or springs to the default (limp home) position. A maximum allowed RPM is determined based on pedal position (RPM Guard.) If the actual RPM exceeds this limit, spark and fuel are used to bring the RPM below the limit. The wrench light and the MIL are turned on in this mode and an ETC component causal code is set. EGR, VCT, and IMRC outputs are set to default values.
SLOWE / BOA (Gen3 / Gen4 only)	This mode is caused by the loss of 1 or 2 pedal position sensor inputs due to sensor, wiring, or PCM faults. For a single sensor fault, driver demand is rate limited based on input from the remaining good sensor. For a dual sensor fault, driver demand is ramped to a fixed pedal position (high idle RPM) and there is no response to the driver input. If the brake pedal is applied for either a single or dual sensor fault, the engine returns to a normal idle RPM. The wrench light is turned on in this mode, and an accelerator pedal sensor causal code is set.
	Note: The wrench light illuminates or an ETC message is displayed on the message center immediately. The MIL illuminates after 2 driving cycles.

Accelerator and Throttle Position Sensor Inputs

On-demand KOEO / KOER Sensor Check Operation:	
DTCs	P1124 – TP A out of self-test range (non-MIL) [Gen3 / Gen4 only] P1575 – APP out of self-test range (non-MIL) [Gen3 / Gen4 only]
Monitor execution	On-demand
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

Accelerator Pedal Position Sensor Check Operation:	
DTCs	P2122, P2123 – APP D circuit continuity (wrench light, non-MIL) P2127, P2128 – APP E circuit continuity (wrench light, non-MIL) P2138 – APP D/E circuit disagreement (wrench light, non-MIL) [Gen3 / Gen4 only]
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

APP sensor check malfunction thresholds:
Circuit continuity - Voltage < 0.25 volts or voltage > 4.75 volts Range/performance – disagreement between sensors > 1.1 degrees

Throttle Position Sensor Check Operation:	
DTCs	P0122, P0123 – TP A circuit continuity (MIL, wrench light) P0222, P0223 – TP B circuit continuity (MIL, wrench light) P2135 – TP A / TP B correlation (non-MIL, wrench light)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

TP sensor check malfunction thresholds:
Circuit continuity - Voltage < 0.25 volts or voltage > 4.75 volts Correlation and range/performance – disagreement between sensors > 7 degrees

Electronic Throttle Monitor

Electronic Throttle Monitor Operation:	
DTCs	U0300 – ETC software version mismatch, IPC, Quizzer or TPPC (Non-MIL, wrench light for Gen2; MIL, wrench light for Gen3 / Gen4) P0600 – Serial Communication Link (Non-MIL, wrench light for Gen2; MIL, wrench light for Gen3 / Gen4) P060A – Internal control module monitoring processor performance (Non-MIL, wrench light for Gen2; MIL, wrench light for Gen3 / Gen4) P060B – Internal control module A/D processing performance (MIL, wrench light) P060C – Internal control module main processor performance (MIL, wrench light) P060D – Internal control module accelerator pedal performance (non-MIL) [Gen3 / Gen4 only] P061B – Internal control module torque calculation performance (MIL, wrench light) P061C – Internal control module engine rpm performance (MIL, wrench light) P061D – Internal control module engine air mass performance (MIL, wrench light) P061F – Internal control module throttle actuator controller performance (MIL, wrench light for Gen2; non-MIL for Gen3 / Gen4) P062C – Internal control module vehicle speed performance (MIL, wrench light) [Gen2 only] P1674 – Internal control module software corrupted (Non-MIL, wrench light for Gen2; MIL, wrench light for Gen3 / Gen4)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

Throttle Plate Position Controller (TPPC) Outputs

The purpose of the TPPC is to control the throttle position to the desired throttle angle. The Gen2 ETC system has a separate chip embedded in the PCM. The Gen3 / Gen4 ETC systems have the eTPPC function integrated in the main PCM processor.

For the stand alone TPPC, the desired throttle angle is communicated from the main CPU via a 312.5 Hz duty cycle signal. The TPPC interprets the duty cycle signal as follows:

0% <= DC < 4% - Out of range, limp home default position.

4% <= DC < 6% - Commanded default position, closed.

6% <= DC < 7% - Commanded default position. Used for key-on, engine off.

7% <= DC < 8% - Ice Breaker Mode.

8% <= DC < 10% - Closed against hard-stop. Used to learn zero throttle angle position (hard-stop) after key-up

10% <= DC <=92% - Normal operation, between 0 degrees (hard-stop) and 82%, 10% duty cycle = 0 degrees throttle angle, 92% duty cycle = 82 degrees throttle angle.

92% < DC <= 96% - Wide Open Throttle, 82 to 86 degrees throttle angle.

96% < DC <= 100% - Out of Range, limp home default position

The desired angle is relative to the hard-stop angle. The hard-stop angle is learned during each key-up process before the main CPU requests the throttle plate to be closed against the hard-stop. The output of the (e)TPPC is a voltage request to the H-driver (also in PCM). The H driver is capable of positive or negative voltage to the Electronic Throttle Body Motor.

Throttle Plate Controller and Actuator Operation:	
DTCs	P2107 – processor test (MIL, wrench light) P2111 – throttle actuator system stuck open (MIL, wrench light) P2112 – throttle actuator system stuck closed (MIL, wrench light) P2101 – throttle actuator range/performance test (MIL, wrench light) P115E – throttle actuator airflow trim at max limit (MIL)
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	< 5 seconds to register a malfunction

Comprehensive Component Monitor - Engine

Engine Inputs

Analog inputs such as Intake Air Temperature (P0112, P0113), Cylinder Head Temperature (P1289. P1290), Mass Air Flow (P0102, P0103) and Throttle Position (P0122, P0123, P1120), Fuel Temperature (P0182, P0183), Engine Oil Temperature (P0197, P0198), Fuel Rail Pressure (p0192, P0193) are checked for opens, shorts, or rationality by monitoring the analog -to-digital (A/D) input voltage.

The ECT rationality test checks to make sure that ECT is not stuck high in a range that causes other OBD to be disabled. If after a long (6 hour) soak, ECT is very high (> 230 °F) and is also much higher than IAT at start, it is assumed that ECT is stuck high. If after a long (6 hour) soak, ECT is stuck midrange between 175 °F (typical thermostat monitor threshold temperature) and 230 °F and is also much higher than IAT at start, it is assumed that ECT is stuck mid range.

ECT Sensor Rationality Check Operation:	
DTCs	P0116 (ECT stuck high or midrange)
Monitor execution	Once per driving cycle
Monitor Sequence	None
Sensors OK	ECT, CHT, IAT
Monitoring Duration	100 seconds to register a malfunction

Typical ECT Sensor Rationality check entry conditions:		
Entry Condition	Minimum	Maximum
Engine-off time (soak time)	360 min	
Difference between ECT and IAT		50 deg
Engine Coolant Temperature	230 °F	
Engine Coolant Temperature for stuck midrange condition	160 °F	230 °F

Typical ECT Sensor Rationality check malfunction thresholds:
Catalyst, Misfire, Fuel System or HO2S Monitors have not run this drive cycle

The CHT sensor measures cylinder head metal temperature as opposed to engine coolant temperature. At lower temperatures, CHT temperature is equivalent to ECT temperature. At higher temperatures, ECT reaches a maximum temperature (dictated by coolant composition and pressure) whereas CHT continues to indicate cylinder head metal temperature. If there is a loss of coolant or air in the cooling system, the CHT sensor will still provides an accurate measure of cylinder head metal temperature. If a vehicle uses a CHT sensor, the PCM software calculates both CHT and ECT values for use by the PCM control and OBD systems.

Cylinder Head Temperature Sensor Check Operation:	
DTCs	P1289 (high input), P1290 (low input), P1299 (fail-safe cooling activated)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical CHT sensor check malfunction thresholds:
Voltage < 0.41 volts or voltage > 4.95 volts
For P1299, MIL illuminates immediately if CHT > 270 $^{o.}$ Fuel shut-off is activated to reduce engine and coolant temperature

Intake Air Temperature Sensor Check Operation:	
DTCs	P0112 (low input), P0113 (high input)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical IAT sensor check malfunction thresholds:
Voltage < 0.20 volts or voltage > 4.93 volts

ECT, IAT, EOT Temperature Sensor Transfer Function		
Volts	**A/D counts in PCM**	**Temperature, degrees F**
4.89	1001	-40
4.86	994	-31
4.81	983	-22
4.74	970	-13
4.66	954	-4
4.56	934	5
4.45	910	14
4.30	880	23
4.14	846	32
3.95	807	41
3.73	764	50
3.50	717	59
3.26	666	68
3.00	614	77
2.74	561	86
2.48	508	95
2.23	456	104
1.99	407	113
1.77	361	122
1.56	319	131
1.37	280	140
1.20	246	149
1.05	215	158
0.92	188	167
0.80	165	176
0.70	144	185
0.61	126	194
0.54	110	203
0.47	96	212
0.41	85	221
0.36	74	230
0.32	65	239
0.28	57	248
0.25	51	257
0.22	45	266
0.19	40	275
0.17	35	284
0.15	31	293
0.14	28	302

Throttle Position Sensor Check Operation:	
DTCs	P0122 (low input), P0123 (high input), P1120 (closed throttle too low)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical TP sensor check malfunction thresholds:
Voltage < 0.20 volts or voltage > 4.80 volts or voltage < 0.488

MAF Sensor Check Operation:	
DTCs	P0102 (low input), P0103 (high input)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical MAF sensor check malfunction thresholds:
Voltage < 0.244 volts and engine running or voltage > 4.785 volts engine rpm < 4,000 rpm

The MAF and TP sensors are cross-checked to determine whether the sensor readings are rational and appropriate for the current operating conditions. (P1A0C)

MAF/TP Rationality Check Operation:	
DTCs	P1A0C
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds within test entry conditions

Typical MAF/TP rationality check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM	1025 rpm	minimum of 3800 rpm
Engine Coolant Temp	40 ^{o}F	

Typical MAF/TP rationality check malfunction thresholds:
Load > 55% and TP < 0.288 volts or Load < 20% and TP > 1.953 volts

5 Volt Sensor Reference Voltage Check:	
DTCs	P0642 (low input), P0643 (high input)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical FRP sensor check malfunction thresholds:
Voltage < 3.5 volts or voltage > 6.5 volts

Miscellaneous

Loss of Keep Alive Memory (KAM) power (a separate wire feeding the PCM) results is a P1633 DTC and immediate MIL illumination on most applications.

Vehicles that require tire/axle information to be programmed into the Vehicle ID block (VID) will store a P1639 if the VID block is not programmed or corrupted.

Additional DTCs will be stored to indicate various internal PCM hardware malfunctions:

P0602 - Powertrain Control Module Programming Error indicates that the Vehicle ID block check sum test failed.

P0603 - Powertrain Control Module Keep Alive Memory (KAM) Error indicates the Keep Alive Memory check sum test failed.

P0604 - Powertrain Control Module Random Access Memory (RAM) Error indicates the Random Access Memory read/write test failed.

P0605 - Powertrain Control Module Read Only Memory (ROM) Error indicates a Read Only Memory check sum test failed.

P0607 - Powertrain Control Module Performance indicates incorrect CPU instruction set operation, or excessive CPU resets.

The PCM "engine off" or "soak" timer is tested to ensure that it is functional. The value of engine coolant temperature decays after the engine is turned off. This decay is modeled as a function of ECT, IAT and soak time. If, during a cold start, (difference between ECT and IAT is low), the actual ECT at start is much lower than the predicted ECT at start, it means that the soak timer is not functioning and a P0606 DTC is stored. (If the timer fails, it will read zero seconds and the model will predict that ECT will be the same temperature as when the engine was last turned off.)

Ignition

Power PC Ignition

New "Power PC" processors no longer use an EDIS chip for ignition signal processing. The signals are now directly processed by the PCM using a special interface chip called a Time Processing Unit or TPU. The 36-tooth crankshaft and camshaft position signals come directly into the TPU. The signals to fire the ignition coil drivers also come from the TPU.

The PowerPC ignition system is checked by monitoring three ignition signals during normal vehicle operation:

> CKP, the signal from the crankshaft 36-1-tooth wheel. The missing tooth is used to locate the cylinder pair associated with cylinder # 1 The TPU also generates the Profile Ignition Pickup (PIP) signal, a 50% duty cycle, square wave signal that has a rising edge at 10 deg BTDC.
>
> Camshaft IDentification (CMP, commonly known at CID), a signal derived from the camshaft to identify the #1 cylinder
>
> NOMI, a signal that indicates that the primary side of the coil has achieved the nominal current required for proper firing of the spark plug. This signal is received as a digital signal from the coil drivers to the TPU. The coil drivers determine if the current flow to the ignition coil reaches the required current (typically 5.5 Amps for COP, 3.0 to 4.0 Amps for DIS) within a specified time period (typically > 200 microseconds for both COP and DIS).

First, several relationships are checked on the 36-1 tooth CKP signal. The TPU looks for the proper number of teeth (35 or 39) after the missing tooth is recognized; time between teeth too low (< 30 rpm or > 9,000 rpm); or the missing tooth was not where it was expected to be. If an error occurs, the TPU shuts off fuel and the ignition coils and attempts to resynchronize itself. It takes on revolution to verify the missing tooth, and another revolution to verify cylinder #1 using the CMP input. Note that if a P0320 DTC is set on a vehicle with Electronic Throttle Control, (ETC), the ETC software will also set a P2106.

If the proper ratio of CMP events to PIP events is not being maintained (for example, 1 CMP edge for every 8 PIP edges for an 8-cylinder engine), it indicates a missing or noisy CMP signal (P0340). On applications with Variable Cam Timing (VCT), the CMP wheel has five teeth to provide the VCT system with more accurate camshaft control. The TPU checks the CMP signal for an intermittent signal. If an intermittent is detected, the VCT system is disabled and a P0344 (CMP Intermittent Bank 1) or P0349 (CMP intermittent Bank 2) is set.

Finally, the relationship between NOMI events and PIP events is evaluated. If there is not an NOMI signal for every PIP edge (commanded spark event), the PCM will look for a pattern of failed NOMI events to determine which ignition coil has failed.

CKP Ignition System Check Operation:	
DTCs	P0320 (CKP)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	< 5 seconds

Typical CKP ignition check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM for CKP	200 rpm	

Typical CKP ignition check malfunction thresholds:
EDIS: For PIP: Time between PIP edges: > 350 milliseconds Ratio of current PIP period to last two periods: < 0.75, > 1.75 PowerPC: Incorrect number of teeth after the missing tooth is recognized, Time between teeth too low (< 30 rpm or > 9,000 rpm) Missing tooth was not where it was expected to be.

CMP Ignition System Check Operation:	
DTCs	P0340 (CMP)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	< 5 seconds

Typical CMP ignition check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM for CMP	200 rpm	

Typical CMP ignition check malfunction thresholds:
EDIS: Ratio of PIP events to CMP events: 4:1, 6:1, 8:1 or 10:1 based on engine cyl. PowerPC: Ratio of PIP events to CMP events: 4:1, 6:1, 8:1 or 10:1 based on engine cyl

Coil Primary Ignition System Check Operation:	
DTCs	P0351 – P0354 (Coil primary)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	< 5 seconds

Typical Coil primary ignition check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM for coil primary	200 rpm	Minimum of 3200 rpm
Positive engine torque	Positive torque	

Typical Coil primary ignition check malfunction thresholds:
Ratio of PIP events to IDM or NOMI events 1:1

Engine Outputs

The PCM will monitor the "smart" driver fault status bit that indicates either an open circuit, short to power or short to ground.

Injector Check Operation:	
DTCs	P0201 through P0204 (opens/shorts)
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	10 seconds

Typical injector circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	
Engine Coolant Temp		240 ^{o}F
Intake Air Temp		150 ^{o}F

The engine is monitored for excessive torque generation at idle. If excessive torque is being produced, injectors are turned off in order to reduce torque. If the frequency of injector cut-off is higher than the EWMA threshold, a P2279 DTC is set.

Intake Air System Leak Check Operation:	
DTCs	P2279 Intake Air System Leak
Monitor execution	Continuous during Idle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	< 16 seconds

Typical Intake Air System Leak test entry conditions:		
Entry Condition	Minimum	Maximum
Engine Speed		Idle
Vehicle Speed		2 MPH
High Voltage Battery Temperature	0 degree F	
Inferred Ambient Temperature	20 degree F	

Typical Intake Air System Leak test malfunction thresholds:
Injectors cut off for > 0.7 frequency (EWMA)

Comprehensive Component Monitor – Battery Energy Control Module

BECM Inputs/Outputs

BECM has many inputs/outputs used to control the high voltage battery; however, none of the components are serviceable. The battery itself consists of 250 battery cells. A group of 5 cells is called a battery module; thus, there are 50 battery modules in the vehicle battery pack. The battery pack is physically split into two half-packs, a 24 module half-pack and a 26 module half-pack. Each half-pack is monitored by a microprocessor that senses voltage in each battery pack, temperature in eight placers, and monitors the half-pack for current or voltage leakage.

The BECM sends the ECM fault information over the CAN network if any of the BECM input or output components are faulty. The ECM immediately set a P0A1F DTC if a fault request was received from BECM.

Battery Energy Control Module (BECM) Check Operation:	
DTCs	P0A1F (Battery Energy Control Module)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 – 10 seconds

Battery Energy Control Module (BECM) fault check malfunction thresholds:

(1) The difference between the maximum battery voltage and the minimum battery voltage between any battery module is greater than 1.4 volts for 1 second.

(2) Both current sensors fail:
For Current Sensor #1, the current offset (calculated at power up) is > 6.5 A, or the magnitude of the current is greater than 280A for 1 second (detects shorts and opens).
For Current Sensor #2, communications are lost for 5 seconds or the magnitude of the current is greater than 350A for 5 seconds.

(3) The BECM is unable to access EEPROM data at power up.

(4) One of the two Voltage/Temperature Sensor microprocessor units reports a temperature, voltage, or leakage fault, or can not communicate with the BECM microprocessor for ten seconds.

(5) The vehicle battery pack voltage is reported as either < 5.0 or > 470.0 V for ten seconds and a battery module voltage fault exists.

(6) Both voltage reference wires for any battery half-pack (there are redundant wires) are detected as faulted for 10 seconds, or the half-pack voltage is out of range for ten seconds.

(7) Eight or more of the sixteen battery temperature sensors in the vehicle battery pack are faulted.

Comprehensive Component Monitor - Transmission

Transmission External Inputs

There are four external, hardwired inputs into the transmission.

Rapid Discharge **(RDC)** signals come from the Battery Module (TBCM), and cause the Transmission to perform a rapid discharge.

High Voltage (HV) Interlock (HVIL) is a circuit that causes a vehicle shutdown if opened.

Motor Shut Down (MSDN) and **Generator Shut Down (GSDN)** are signals from the PCM, which cause the transmission to shutdown either the Motor or the Generator.

Clean Tach Out (CTO) is a signal from the PCM, which is used to determine Engine Speed.

Rapid Discharge

The Rapid Discharge (RDC) signals are two hardwires coming from the TBCM to the transmission. The voltage on these signals should always be high (Charge) during normal operation. If one of the wires goes low (Discharge), the transmission will set a DTC (P1A0A) but not perform any action. If both of the wires go low, the transmission will set the DTC, and perform a Rapid Discharge.

Rapid Shutdown Signal Check Operation:	
DTCs	P1A0A (Rapid Shutdown Circuit request or fault)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	10 - 200 msec

Rapid Shutdown Circuit fault check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	100 msec	none

Rapid Shutdown Circuit fault check malfunction thresholds:
Voltage of Rapid Discharge Signal1 is not equal to Signal 2 for 200 msec

Rapid Shutdown Request check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
12V Battery voltage	7.5 V	17.0 V

Rapid Shutdown Request check malfunction thresholds:
Both Rapid Discharge Signals = Discharge, and HV Interlock Circuit = Charge, for > 10 msec

High Voltage Interlock

The HV Interlock (HVIL) is a circuit that goes through the Transmission, the DC/DC converter, and the Battery. If this circuit is detected to be open by the transmission, the vehicle will be shutdown.

High Voltage Interlock Open Check Operation:	
DTCs	P0A0A (High Voltage Interlock Open)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	10 - 200 msec

High Voltage Interlock Open check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	100 msec	none
12V Battery voltage	7.5 V	17.0 V

High Voltage Interlock Open check malfunction thresholds:
(1) and (2) and (3) for > 10 msec OR (1) and (4) and (5) for > 200 msec (1) HV Interlock = discharge (2) Rapid Discharge Signal 1 = discharge (3) Rapid Discharge Signal 2 = discharge (4) Rapid Discharge Signal 1 = charge (5) Rapid Discharge Signal 2 = charge

MSDN/GSDN (Motor Shutdown/Generator Shutdown)

The MSDN and GSDN are hardwires going from the PCM to the transmission. A signal can be sent from the PCM to command the transmission to shutdown the motor or the generator.

MSDN/GSDN Signal Check Operation:	
DTCs	P1A03 and P1A04 (Motor and Generator shutdown Signal Command or Signal circuit failure)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	CAN status not "Bus-off"
Monitoring Duration	520 – 528msec

Motor/Generator Shutdown Signal Command check entry conditions:		
CAN TimeOut($575)	Normal	

Motor/Generator Shutdown Signal Command check malfunction thresholds:
MSDN/GSDN Signal = Shutdown OR EQ Motor/Generator Inverter Shutdown CAN signal = Shutdown for > 528 msec

Motor/Generator Shutdown Signal Circuit Failure check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	200 msec	none
12V Battery voltage	7.5 V	17.0 V
CAN TimeOut($575)	Normal	

Motor/Generator Shutdown Signal Circuit Failure check malfunction thresholds:
MSDN/GSDN Signal = Shutdown and EQ Motor/Generator Inverter Shutdown CAN signal = Not Shutdown for > 520 msec

CTO (Clean Tach Out)

The CTO signal is sent from the PCM to the transmission. The signal is sent at 10 degrees before Top Dead Center (TDC) for each cylinder. This translates into the transmission seeing this signal every 180 degrees of engine rotation. This signal is used to calculate Engine Speed.

CTO Signal Check Operation:	
DTCs	P0727 and P0726 (CTO Circuit failure and out-of-range)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	Motor/Generator Serial Communication Status OK Motor/Generator Resolver sensor OK Motor/Generator R/D Converter OK Motor/Generator Rotor Position OK
Monitoring Duration	280 – 290 msec

CTO Input Circuit Failure and Out- of- Range check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	125 msec	none
12V Battery voltage	7.5 V	17.0 V
Motor enable signal to18V power supply	Supply	
Generator enable signal to18V power supply	Supply	
Engine Speed	600 rpm	None
CTO Signal Circuit Open/Short Status	Normal	

CTO Input Circuit Failure check malfunction thresholds:
CTO Signal = Hi for > 280 msec OR CTO Signal = Low for > 280 msec

CTO Input Circuit Out-of-Range check malfunction thresholds:
Engine Speed from CTO > 10000 rpm OR | TCM Engine Speed – PCM Engine Speed | > 1000 rpm for > 290 msec

*Resolver sensor and R/D Converter are used to detect the magnetic motor/generator pole position
Motor/Generator speed is calculated using magnetic pole position.
The TCM calculates Engine speed from Motor/Generator speed.

Transmission Temperature Inputs

Motor/Generator Coil Temperature Sensors
These temperature sensors are located on the coil windings of the stators of the motor and the generator.

Motor/Generator Coil Temperature Sensor check Operation:	
DTCs	P0A2A (Motor Coil Sensor failure) P0A2F (Motor Coil Sensor over temp) P0A36 (Generator Coil Sensor failure) P0A3B (Generator Coil Sensor over temp)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	TCM A/D Converter OK
Monitoring Duration	240 - 2400 msec

Motor/Generator Coil Temp check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	0 msec	none
12V Battery voltage	7.5 V	17.0 V

Motor/Generator Coil Temp Over Temp check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	50 msec	none
12V Battery voltage	7.5 V	17.0 V
Motor/Generator Serial Comm. Status	Normal	

Motor/Generator Coil Temp Shorted Low check malfunction thresholds:
Motor/Generator Coil Temp > 220 deg C for > 240 msec

Motor/Generator Coil Temp Sensor Shorted High check malfunction thresholds:
Motor Coil Temp
Transmission Fluid Temperature >= 10 deg C AND Generator Coil Temp >= 10 deg C AND Motor Coil Temp <= -20 deg C for > 240 msec
Generator Coil Temp
Transmission Fluid Temperature >= 10 deg C AND Motor Coil Temp >= 10 deg C AND Generator Coil Temp <= -20 deg C for > 240 msec

Motor/Generator Coil Temp Sensor In-range failure check malfunction thresholds:
Motor Coil Temp
Transmission Fluid Temperature - Generator Coil Temp < 30 deg C AND Transmission Fluid Temperature - Motor Coil Temp > 30 deg C for > 2400 msec
Generator Coil Temp
Transmission Fluid Temperature - Motor Coil Temp < 30 deg C AND Transmission Fluid Temperature - Generator Coil Temp > 30 deg C for > 2400 msec

Motor/Generator Coil Temp Over Temp check malfunction thresholds:
Motor/Generator Coil Temp over Temp
Motor/Generator Coil Temp > 180 deg C detected by Motor Control Unit /Generator Control Unit
3 times in 1 drive cycle

Transmission Fluid (Oil) Temperature Sensor

The Transmission Fluid Temperature sensor measures the temperature of the transmission fluid.

Trans Fluid Temperature check Operation:	
DTCs	P0710 (Transmission fluid temp sensor failure)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	TCM A/D Converter OK
Monitoring Duration	240 – 2400 msec

Trans Fluid Temp Circuit check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	0 msec	none
12V Battery voltage	7.5 V	17.0 V

Trans Fluid Temp Shorted Low check malfunction thresholds:
Transmission Fluid Temperature > 150 deg C for > 240 msec

Trans Fluid Temp Sensor Shorted High check malfunction thresholds:
Transmission Fluid Temperature <= -20 deg C AND Motor and Generator Coil Temp >= 10 deg C for > 240 msec

Trans Fluid Temp Sensor In-range failure check malfunction thresholds:
Transmission Fluid Temperature – Motor Coil Temp > 30 deg C AND Transmission Fluid Temperature – Generator Coil Temp > 30 deg C for > 2400 msec

Motor/Generator Inverter Temperature Sensors

These temperature sensors are located on the Motor and Generator Inverters.

Motor/Generator Inverter Temperature Check Operation:	
DTCs	P0A78 (Motor Inverter Temp Sensor failure) P0A3C (Motor Inverter Temp Sensor over temp) P0A7A (Generator Inverter Temp Sensor failure) P0A3E (Generator Inverter Temp Sensor over temp)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	Motor/Generator Serial Communication Status OK
Monitoring Duration	Continuous

Motor/Generator Inverter Temp Sensor Circuit Short check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Time after vehicle power up	210 msec	none
12V Battery voltage	7.5 V	17.0 V

Motor/Generator Inverter Temp Sensor Short check malfunction thresholds:
(1) and (2) OR (3) and (4) OR (5) and (6) (1) Motor/Generator U phase inverter temp sensor fail flag via MCU/GCU = Error (2) Motor/Generator U phase junction temp >= 205 deg C (3) Motor/Generator V phase inverter temp sensor fail flag via MCU/GCU = Error (4) Motor/Generator V phase junction temp >= 205 deg C (5) Motor/Generator W phase inverter temp sensor fail flag via MCU/GCU = Error (6) Motor/Generator W phase junction temp >= 205 deg C 2 Times in 1 Drive Cycle

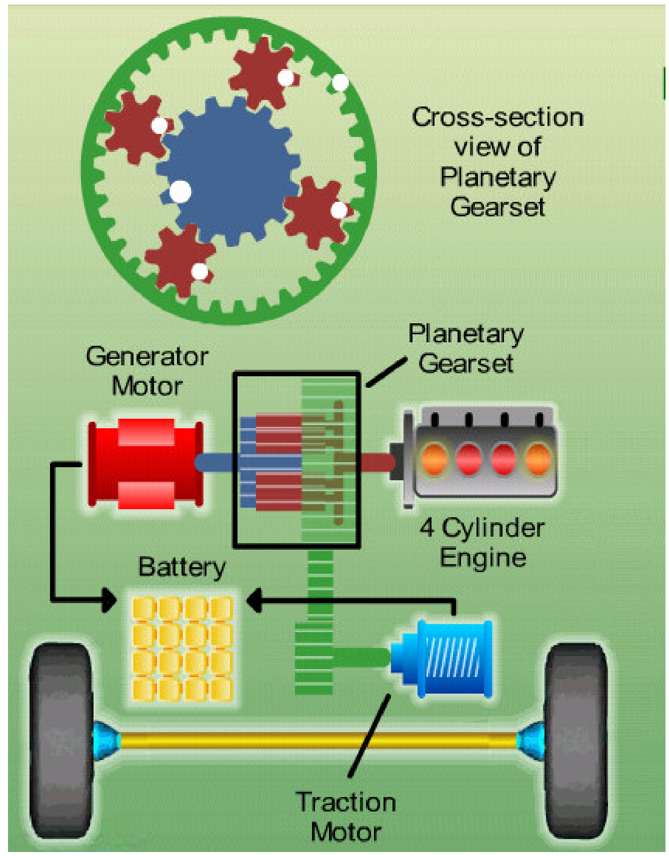
Motor/Generator Inverter Temp Sensor Open check malfunction thresholds:
(1) and (2) OR (3) and (4) OR (5) and (6) (1) Motor/Generator U phase inverter temp sensor fail flag via MCU/GCU = Error (2) Motor/Generator U phase junction temp <= -50 deg C (3) Motor/Generator V phase inverter temp sensor fail flag via MCU/GCU = Error (4) Motor/Generator V phase junction temp <= -50 deg C (5) Motor/Generator W phase inverter temp sensor fail flag via MCU/GCU = Error (6) Motor/Generator W phase junction temp <= -50 deg C 2 Times in 1 Drive Cycle

Motor/Generator Inverter Temp Over Temp check malfunction thresholds:
Motor/Generator Inverter Temperature >= 133 deg C
AND (Motor/Generator U phase inverter temp sensor fail flag via MCU/GCU = Normal
AND (Motor/Generator V phase inverter temp sensor fail flag via MCU/GCU = Normal
AND (Motor/Generator W phase inverter temp sensor fail flag via MCU/GCU = Normal
5 Times in 1 Drive Cycle

Aisin Powersplit Transaxle

Transmission Control System Architecture

The primary function of the Powersplit transaxle is to manage torque between the electric motors, engine, and driveline. The planetary gear set provides series, parallel and split paths for power distribution from the battery and engine. The torque ratio between the series path and the parallel path is fixed by the geometry of the planetary gear set. The power split between the series path and the parallel path is determined by the relative speeds (all series if vehicle speed is zero and engine is on; all parallel if generator is stopped; split otherwise)



The system behavior is similar to a CVT with the effective gear ratio between the engine and the wheels is determined by the split.

The transaxle is controlled by a standalone Transmission Control Module (TCM), The TCM communicates to the Engine Control Module (ECM), ABS Module, Traction Battery Control Module (TBCM), and Instrument Cluster using the high speed CAN communication link. The TCM incorporates a standalone OBD-II system. The TCM independently processes and stores fault codes, freeze frame, supports industry-standard PIDs as well as J1979 Mode 09 CALID and CVN. The TCM does not directly illuminate the MIL, but requests the ECM to do so. The TCM is located inside the transmission assembly. It is not serviceable with the exception of reprogramming.

Transmission Inputs

Angle Sensors

An angle sensor (resolver) is located on both the electric Motor and Generator and is used to detect the angular position of the rotor. The analog waveform generated by the resolver is converted into a digital signal by the Resolver to Digital (R/D) converter. The digital signal is used to calculate speed and angular acceleration which is used to control the electric Motor and Generator. The speed information is also used to calculate vehicle speed and is broadcasted to other modules over CAN. If a resolver open or short to power or ground is detected, or a failure with the R/D converter is detected, a P0A90 fault for the motor or a P0A92 fault for the generator will be stored.

Temperature Sensors

The Transmission Fluid Temperature Sensor (TFT) is monitored for open and short circuit faults and for in-range faults (P0710) where Trans Fluid, Motor Coil and Generator Coil temperatures do not correlate properly.

The Motor and Generator Coil Temperature Sensors are monitored for open and short circuit faults and for in-range faults where Trans Fluid, Motor Coil and Generator Coil temperatures do not correlate properly. (P0A2A – Motor Coil Sensor failure, P0A36 – Generator Coil Sensor failure). The Motor and Generator coils are also monitored for over-temperature (P0A2F, P0A3B).

The Motor and Generator Inverter Temperature Sensors are monitored for open and short circuit faults. (P0A78 – Motor Inverter Sensor failure, P0A7A – Generator Inverter Sensor failure). The Motor and Generator Inverters are also monitored for over-temperature (P0A3C, P0A3E).

Transmission Outputs

Inverter Control

Upon receiving the torque demanded by the driver from the ECM over CAN communication, the TCM calculates the required torque of the electric Motor and Generator to meet the demanded torque. The Motor/Generator Control Unit (MCU/GCU) will then control the Inverter over U, V, and W phase gate signals to regulate DC current into AC current that is fed into the stator.

The Motor and Generator gate signal lines are monitored for open circuits. A P0A78 fault for the Motor and a P0A7A fault for the Generator will be stored upon detection of a failure. The Inverter is also monitored for various faults such as over current, current sensor fault, current regulation fault, temperature sensor fault, etc. and will store a P0A78 fault for the Motor and a P0A7A fault for the Generator upon detection of a malfunction.

Transmission Control Module (TCM)

The TCM monitors itself by using various software monitoring functions. The flash ROM is checked using a checksum calculation. If the checksum is incorrect during initialization, a U2050 fault will be stored. The EEPROM is emulated in the flash ROM. If it is not possible to store information in the EEPROM emulation or if the verification fails, a P0613 fault is stored and the ECM is requested to illuminate the MIL immediately. If a RAM Read/Write error is detected during initialization, a P0613 fault code will be stored.

The Motor Control Unit (MCU) and Generator Control Unit (GCU) use similar types of RAM/ROM tests. If a fault is detected, a P0A1B fault is stored for the MCU, and a P0A1A fault is stored for the GCU.

CAN Communications error

The TCM receives information from the ECM via CAN. If the CAN link fails, the TCM no longer has torque or engine speed information available. The TCM will store a U0073 fault code if the CAN Bus is off. The TCM will store a U0100 or U0294 fault code if it doesn't receive any more CAN messages from the ECM.

The TCM receives wheel speed from the Antilock Brake System (ABS) module, A U0129 fault code will be stored if communication with the ABS module is lost. The TCM also receives information from the Traction Battery Control Module (TBCM) and a U0111 fault will be stored if the communication with the TBCM is lost.

Power Supply

If the power supply is outside of the specified 8 to 18 volt range, a fault will be stored (P0562, P0563).

PCM On Board Diagnostic Executive

The On-Board Diagnostic (OBD) Executive is a portion of the PCM strategy that manages the sequencing and execution of all diagnostic tests. It is the "traffic cop" of the diagnostic system. Each test/monitor can be viewed as an individual task, which may or may not be able to run concurrently with other tasks. The Diagnostic Executive enables/disables OBD monitors in order to accomplish the following:

- Sequence the OBD monitors such that when a test runs, each input that it relies upon has already been tested.
- Controls and co-ordinates the execution of the individual OBD system monitors: Catalyst, Misfire, EGR, O2, Fuel, AIR, EVAP and, Comprehensive Component Monitor (CCM).
- Stores freeze frame and "similar condition" data
- Manages storage and erasure of Diagnostic Trouble Codes as well as MIL illumination
- Controls and co-ordinates the execution of the On-Demand tests: Key On Engine Off (KOEO), Key On Engine Running (KOER), and the Output Test Mode (OTM).
- Performs transitions between various states of the diagnostic and powertrain control system to minimize the effects on vehicle operation.
- Interfaces with the diagnostic test tools to provide diagnostic information (I/M readiness, various J1979 test modes) and responds to special diagnostic requests (J1979 Mode 08 and 09).

The diagnostic also executive controls several overall, global OBD entry conditions.

- The Diagnostic Executive waits for 4 seconds after the PCM is powered before initiating any OBD monitoring. For the 2001 MY and beyond, this delay has been eliminated to meet the "zero startup delay" misfire monitoring requirements.
- The engine must be started to initiate a driving/monitoring cycle.
- The Diagnostic Executive suspends OBD monitoring when battery voltage falls below 11.0 volts.
- The Diagnostic Executive suspends monitoring of fuel-system related monitors (catalyst, misfire, evap, O2, AIR and fuel system) when fuel level falls below 15%

The diagnostic executive controls the setting and clearing of pending and confirmed DTCs.

- For the 2005 MY, pending DTCs will be displayed as long as the fault is present. Note that OBD-II regulations required a complete fault-free monitoring cycle to occur before erasing a pending DTC. In practice, this means that a pending DTC is erased on the next power-up after a fault-free monitoring cycle.
- For clearing comprehensive component monitoring (CCM) pending DTCs, the specific monitor must determine that no fault is present, and a 2-hour engine off soak has occurred prior to starting the vehicle. The 2-hour soak criteria for clearing CCM confirmed and pending DTCs has been utilized since the 2000 MY.

Exponentially Weighted Moving Average

Exponentially Weighted Moving Averaging is a well-documented statistical data processing technique that is used to reduce the variability on an incoming stream of data. Use of EWMA does not affect the mean of the data, however, it does affect the distribution of the data. Use of EWMA serves to “filter out” data points that exhibit excessive and unusual variability and could otherwise erroneously light the MIL.

The simplified mathematical equation for EWMA implemented in software is as follows:

New Average = [New data point * “filter constant”] + [(1 - “filter constant”) * Old Average]

This equation produces an exponential response to a step-change in the input data. The "Filter Constant" determines the time constant of the response. A large filter constant (i.e. 0.90) means that 90% of the new data point is averaged in with 10% of the old average. This produces a very fast response to a step change. Conversely, a small filter constant (i.e. 0.10) means that only 10% of the new data point is averaged in with 90% of the old average. This produces a slower response to a step change.

When EWMA is applied to a monitor, the new data point is the result from the latest monitor evaluation. A new average is calculated each time the monitor is evaluated and stored in Keep Alive Memory (KAM). This normally occurs each driving cycle. The MIL is illuminated and a DTC is stored based on the New Average store in KAM.

In order to facilitate repair verification and DDV demonstration, 2 different filter constants are used. A “fast filter constant” is used after KAM is cleared/DTCs are erased and a “normal filter constant” is used for normal customer driving. The “fast filter” is used for 2 driving cycles after KAM is cleared/DTCs are erased, and then the “normal filter” is used. The “fast filter” allows for easy repair verification and monitor demonstration in 2 driving cycles, while the normal filter is used to allow up to 6 driving cycles, on average, to properly identify a malfunction and illuminate the MIL.

In order to relate filter constants to driving cycles for MIL illumination, filter constants must be converted to time constants. The mathematical relationship is described below:

Time constant = [(1 / filter constant) - 1] * evaluation period

The evaluation period is a driving cycle. The time constant is the time it takes to achieve 68% of a step-change to an input. Two time constants achieve 95% of a step change input.

Catalyst Monitor and EGR Monitor EWMA

EWMA has been incorporated in the catalyst monitor and the non-intrusive stepper motor EGR monitor. There are 3 calibrateable parameters that determine the MIL illumination characteristics.

“Fast” filter constant, used for 2 driving cycles after DTCs are cleared or KAM is reset

“Normal” filter constant, used for all subsequent, “normal” customer driving

Number of driving cycles to use fast filter after KAM clear (normally set to 2 driving cycles)

Several examples for a typical catalyst monitor calibration are shown in the tables below. Specific calibration information can be obtained from the parameter listing provided for each strategy.

Monitor evaluation (“new data”)	EWMA Filter Calculation, “normal” filter constant set to 0.4 Malfunction threshold = .75	Weighted Average (“new average”)	Driving cycle number	Action/Comment
0.15	.15 * (0.4) + .15 * (1 - 0.4)	0.15		normal 100K system
1.0	1.0 * (0.4) + .15 * (1 - 0.4)	0.49	1	catastrophic failure
1.0	1.0 * (0.4) + .49 * (1 - 0.4)	0.69	2	
1.0	1.0 * (0.4) + .69 * (1 - 0.4)	0.82	3	exceeds threshold
1.0	1.0 * (0.4) + .82 * (1 - 0.4)	0.89	4	MIL on
0.15	.15 * (0.4) + .15 * (1 - 0.4)	0.15		normal 100K system
0.8	0.8 * (0.4) + .15 * (1 - 0.4)	0.41	1	1.5 * threshold failure
0.8	0.8 * (0.4) + .41 * (1 - 0.4)	0.57	2	
0.8	0.8 * (0.4) + .57 * (1 - 0.4)	0.66	3	
0.8	0.8 * (0.4) + .66 * (1 - 0.4)	0.72	4	
0.8	0.8 * (0.4) + .72 * (1 - 0.4)	0.75	5	exceeds threshold
0.8	0.8 * (0.4) + .75 * (1 - 0.4)	0.77	6	MIL on

Note: For the catalyst and EGR monitor, the "fast filter" is normally set to 1.0
For the catalyst monitor, the "fast filter" is normally used to 2 driving cycles, for the EGR monitor, "fast filter" is normally used for 1 driving cycle.

I/M Readiness Code

The readiness function is implemented based on the J1979 format. A battery disconnection or clearing codes using a scan tool results in the various I/M readiness bits being set to a "not-ready" condition. As each non-continuous monitor completes a full diagnostic check, the I/M readiness bit associated with that monitor is set to a "ready" condition. This may take one or two driving cycles based on whether malfunctions are detected or not. The readiness bits for comprehensive component monitoring, misfire and fuel system monitoring are considered complete once all the non-continuous monitors have been evaluated. Because the evaporative system monitor requires ambient conditions between 40 and 100 ^{o}F and BARO > 22.5 " Hg (< 8,000 ft.) to run, special logic can "bypass" the running the evap monitor for purposes of clearing the evap system I/M readiness bit due to the continued presence of these extreme conditions.

Evap bypass logic:

If the evaporative system monitor conditions are met with the exception of the 40 to 100 ^{o}F ambient temperatures or BARO range, a timer is incremented. The timer value is representative of conditions where the Evap monitor could have run (all entry conditions met except IAT and BARO) but did not run due to the presence of those extreme conditions. If the timer continuously exceeds 30 seconds during a driving cycle in which all continuous and non-continuous monitors were evaluated, the evaporative system monitor is then considered complete. If the above conditions are repeated during a second driving cycle, the I/M readiness bit for the evaporative system is set to a "ready" condition.

Power Take Off Mode

While PTO mode is engaged, the I/M readiness bits are set to a "not-ready" condition. When PTO mode is disengaged, the I/M readiness bits are restored to their previous states prior to PTO engagement. During PTO mode, only CCM circuit checks continue to be performed.

Catalyst Temperature Model

A catalyst temperature model is currently used for entry into the catalyst and oxygen sensor monitors. The catalyst temperature model uses various PCM parameters to infer exhaust/catalyst temperature. For the 1998 MY, the catalyst temperature model has been enhanced and incorporated into the Type A misfire monitoring logic. The model has been enhanced to include a misfire-induced exotherm prediction. This allows the model to predict catalyst temperature in the presence of misfire.

The catalyst damage misfire logic (Type A) for MIL illumination has been modified to require that both the catalyst damage misfire rate and the catalyst damage temperature is being exceeded prior to MIL illumination. This change is intended to prevent the detection of unserviceable, unrepeatable, burst misfire during cold engine start-up while ensuring that the MIL is properly illuminated for misfires that truly damage the catalyst.

Beginning with the 2007 MY, the catalyst temperature model is also used to generate the primary inputs to the CSER Monitor as described in that section of this document.

Serial Data Link MIL Illumination

The instrument cluster on some vehicles uses the CAN data link to receive and display various types of information from the PCM. For example, the engine coolant temperature information displayed on the instrument cluster comes from the same ECT sensor used by the PCM for all its internal calculations.

These same vehicles use the CAN data link to illuminate the MIL rather than a circuit, hard-wired to the PCM. The PCM periodically sends the instrument cluster a message that tells it to turn on the MIL, turn off the MIL or blink the MIL. If the instrument cluster fails to receive a message within a 5-second timeout period, the instrument cluster itself illuminates the MIL. If communication is restored, the instrument cluster turns off the MIL after 5 seconds. Due to its limited capabilities, the instrument cluster does not generate or store Diagnostic Trouble Codes.