



---

# **2018 MY OBD System Operation**

## **Summary for Gasoline Engines**

### Table of Contents

Introduction – OBD-II, HD OBD and EMD .....	5
Catalyst Efficiency Monitor .....	7
Misfire Monitor .....	19
EVAP System Monitor - 0.040" dia. Vacuum Leak Check .....	29
EVAP System Monitor - 0.020" dia. Engine Off Natural Vacuum .....	36
EVAP System Monitor Component Checks .....	44
Evap Switching Valve (EVAPSV) Diagnostics .....	49
Blocked Purge Line Diagnostics .....	51
Single Path Purge Check Valve Diagnostics .....	53
Dual Path Purge Check Valve Diagnostics .....	55
Fuel System Monitor .....	58
FAOSC (Rear Fuel Trim) Monitor .....	64
Air Fuel Ratio Imbalance Monitor – O <sub>2</sub> Sensor Monitor .....	66
Air Fuel Ratio Imbalance Monitor – Torque Monitor .....	69
Flex Fuel Operation .....	73
Front HO <sub>2</sub> S Monitor .....	75
Front HO <sub>2</sub> S Signal .....	75
Front HO <sub>2</sub> S Heaters .....	79
Front UEGO Monitor .....	82
Front UEGO Signal .....	82
Front UEGO Slow/Delayed Response Monitor (2010 MY+) .....	95
UEGO Heaters .....	98
Rear HO <sub>2</sub> S Monitor .....	102
Rear HO <sub>2</sub> S Signal .....	102
Rear HO <sub>2</sub> S Decel Fuel Shut Off Response Test (2009 MY+) .....	109

Rear HO2S Heaters .....	115
Stepper Motor EGR System Monitor .....	119
High Pressure Cooled EGR Monitor (HPEGR).....	124
Low Pressure Cooled EGR Monitor (LPEGR) .....	134
PCV System Monitor – Naturally Aspirated Engine with MAF Sensor .....	140
PCV System Monitor – Turbo or Naturally Aspirated with MAP Sensor ....	141
PCV System Monitor – Turbocharged Engine with MAP Sensor .....	143
Thermostat Monitor .....	147
Heavy Duty Thermostat Monitor.....	149
Time To Closed Loop Monitor .....	150
Cold Start Emission Reduction Component Monitor .....	152
Cold Start Emission Reduction System Monitor .....	156
Variable Cam Timing System Monitor .....	159
Gasoline Direct Injection .....	163
Intake Air Temperature 1 Sensor (IAT1) .....	164
Charge Air Cooler Temperature Sensor (CACT).....	165
Intake Air Temperature 2 Sensor (IAT2) .....	165
IAT1, CACT, IAT2 Key-Up Correlation Check .....	167
IAT1, CACT, IAT2 Out of Range Hot Check.....	169
Barometric Pressure Sensor (BARO).....	170
Turbocharger Boost Sensor A (TCB-A) .....	171
Intake Manifold Pressure (MAP) Sensor .....	173
BARO, TCB-A, MAP Sensor 3-Way Correlation Check at Key-Up.....	175
BARO, TCB-A and TCB-A, MAP Sensor 2-Way Correlation Check..	176
Compressor Bypass Valve(s) .....	177
Wastegate Pneumatic Solenoid Valve .....	178
Vacuum Actuated Wastegate System.....	179
Wastegate Control Pressure Sensor .....	182
Electric Turbocharger Wastegate .....	184
Boost Control .....	187
Fuel Volume Regulator.....	191
Fuel Rail Pressure Sensor .....	193
Fuel Rail Pressure Control .....	195
Fuel Rail Pressure Control (Cranking).....	196
Fuel Rail Pressure Control (CSER) .....	197
Controlled Valve Operation (CVO) .....	198
PFI/DI Fuel System .....	199
PFI/DI Electrical Failure Mode and Effects Management.....	200
High Pressure Fuel Rail Pressure Sensor (DI Fuel Rail).....	201

Fuel Rail Pressure Control .....	202
Fuel Rail Pressure Control (Cranking).....	203
Fuel Rail Pressure Control (CSER) .....	204
Low Pressure Fuel Rail Pressure Sensor (PFI Fuel Rail) .....	205
Fuel Pump Control Module .....	208
Fuel Volume Regulator.....	211
Fuel Injector (DI System).....	213
Fuel Injector (PFI System).....	213
PFI/DI Fuel Monitor.....	214
Electronic Throttle Control.....	216
Accelerator, Brake and Throttle Position Sensor Inputs.....	217
Throttle Plate Position Controller (TPPC) Outputs.....	222
Electronic Throttle Monitor.....	223
Stop Start.....	224
Stop Start Overview.....	224
Stop Start Diagnostics .....	224
Stop Start Enable Conditions: .....	225
Stop Start Disable Conditions: .....	225
Stop Start Customer Interface.....	226
Stop Start Button.....	227
Comprehensive Component Monitor - Engine .....	227
Engine Temperature Sensor Inputs.....	227
Ambient Air Temperature .....	231
IAT Rationality Test.....	235
AAT Rationality Test.....	237
Fuel Rail Pressure Sensor .....	239
Mass Air Flow Sensor.....	241
Manifold Absolute Pressure Sensor .....	242
MAF/MAP - TP Rationality Test.....	243
Miscellaneous CPU Tests .....	244
Engine Off Timer Monitor .....	245
Central Vehicle Configuration .....	248
Ignition System Tests .....	250
Knock Sensor.....	254
Engine Oil System Components.....	256
Engine Oil Pressure (EOP) Switch .....	256
Engine Oil Pressure (EOP) Sensor .....	256
Engine Oil Temperature (EOT) Sensor .....	260
Engine Outputs .....	262

Electronic Returnless Fuel System .....	263
Mechanical Returnless Fuel System (MRFS) — Single Speed.....	264
Mechanical Returnless Fuel System (MRFS) — Dual Speed .....	264
Intake Manifold Runner Control Systems.....	267
Intake Manifold Tuning Valve Systems .....	268
Engine Cooling System Outputs.....	269
Comprehensive Component Monitor - Transmission .....	275
Transmission Inputs.....	275
Transmission Outputs.....	281
6R80 (RWD) Transmission with external PCM or TCM .....	287
6F55 (FWD) Transmission.....	291
6F35 (FWD) Transmission with external PCM or TCM .....	295
6F15 (FWD) Transmission with external PCM or TCM .....	301
DPS6 (FWD) Transmission .....	307
6R140 (RWD) Transmission with PCM or external TCM .....	311
10R80 (RWD) Transmission.....	314
On Board Diagnostic Executive.....	332
Exponentially Weighted Moving Average .....	334
I/M Readiness .....	336
In-Use Monitor Performance Ratio.....	339
Catalyst Temperature Model .....	343
Serial Data Link MIL Illumination .....	343
Calculated Load Value .....	344

## **Introduction – OBD-II, HD OBD and EMD**

### **OBD-II Systems**

#### **On Board Diagnostics II - Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines certified under title 13, CCR section 1968.2**

California OBD-II applies to all California and "CAA Sec. 177 States" for gasoline engine vehicles up to 14,000 lbs. Gross Vehicle Weight Rating (GVWR) starting in the 1996 MY and all diesel engine vehicles up to 14,000 lbs. GVWR starting in the 1997 MY. Starting in the 2004 MY, Federal vehicle over 8,500 lbs. are required to phase in OBD-II. Starting in 2004 MY, gasoline-fueled Medium Duty Passenger Vehicles (MDPVs) are required to have OBD-II. By the 2006 MY, all Federal vehicles from 8,500 to 14,000 lbs. GVWR will have been phased into OBD-II.

"CAA Sec. 177 States" or "California States" are states that have adopted and placed into effect the California Air Resources Board (CARB) regulations for a vehicle class or classes in accordance with Section 177 of the Clean Air Act.. At this time, "CAA Sec. 177 States" are Massachusetts, New York, Vermont and Maine for 2004, Rhode Island, Connecticut, Pennsylvania for 2008, New Jersey, Washington, Oregon for 2009, Maryland for 2011, Delaware for 2014 and New Mexico for 2016. These States receive California-certified vehicles for passenger cars and light trucks, and medium-duty vehicles, up to 14,000 lbs. GVWR."

Federal OBD applies to all gasoline engine vehicles up to 8,500 lbs. GVWR starting in the 1996 MY and all diesel engine vehicles up to 8,500 lbs. GVWR starting in the 1997 MY. US Federal only OBD-certified vehicles through the 2016 MY may use the US Federal allowance to certify to California OBD II but then turn off/disable 0.020" evap leak detection). Starting on the 2017 MY, Federal vehicles must comply with EPA Tier 3 standards that include LD and HD standards for exhaust emissions (NMOG, NOx and PM) evaporative emission standards, reduction of sulphur in fuel, E10 test fuel and alignment of OBD requirements with CARB OBD-II regulations. For the 2017 MY EPA is referencing CARB OBD-II regulations thereby mandating 0.020" evap system leak detection requirements for all 50 states.

OBD-II system implementation and operation is described in the remainder of this document.

### **Heavy Duty OBD Systems**

#### **Heavy Duty On-Board Diagnostics - Heavy-duty engines (>14,000 GVWR) certified to HD OBD under title 13, CCR section 1971.1(d)(7.1.1) or (7.2.2) (i.e., 2010 and beyond model year diesel and gasoline engines that are subject to full HD OBD)**

Starting in the 2010 MY, California and Federal gasoline-fueled and diesel fueled on-road heavy duty engines used in vehicles over 14,000 lbs. GVWR are required to phase into HD OBD. The phase-in starts with certifying one engine family to HD OBD in the 2010 MY. (2010 MY 6.8L 3V Econoline) By the 2013 MY, all engine families must certify to the HD OBD requirements. Vehicles/engines that do not comply with HD OBD during the phase-in period must comply with EMD+.

## EMD Systems

### Engine Manufacturer Diagnostics (EMD) – Heavy duty vehicles (>14,000 GVWR) certified to EMD under title 13, CCR section 1971 (e.g., 2007-2009 model year diesel and gasoline engines)

Engine Manufacturer Diagnostics (EMD) applies to all 2007 MY and beyond California gasoline-fueled and diesel fueled on-road heavy duty engines used in vehicles over 14,000 lbs Gross Vehicle Weight Rating (GVWR). EMD systems are required to functionally monitor the fuel delivery system, exhaust gas recirculation system, particulate matter trap, as well as emission related ECM input inputs for circuit continuity and rationality, and emission-related outputs for circuit continuity and functionality. For gasoline engines, which have no PM trap, EMD requirements are very similar to current OBD-I system requirements. As such, OBD-I system philosophy will be employed, the only change being the addition of some comprehensive component monitor (CCM) rationality and functionality checks.

### Engine Manufacturer Diagnostics Enhanced (EMD+) - Heavy-duty engines (>14,000 GVWR) certified to EMD+ under title 13, CCR section 1971.1 (e.g., 2010-2012 model year diesel and gasoline engines not certified to HD OBD, 2013-2019 model year alternate fuel engines)

Starting in the 2010 MY, EMD was updated to require functional monitoring of the NOx aftertreatment system on gasoline engines. This requirement is commonly known as EMD+.

EMD+ vehicles use that same PCM, CAN serial data communication link, J1962 Data Link Connector, and PCM software as the corresponding OBD-II vehicle. The only difference is the possible removal of the fuel tank pressure sensor, canister vent solenoid, and a different PCM calibration.

The following list indicates what monitors and functions have been altered from OBD-II for EMD calibrations:

Monitor / Feature	Calibration
Catalyst Monitor	Functional catalyst monitor required starting in the 2010 MY to meet EMD+.
Misfire Monitor	Calibrated in for service, all DTCs are non-MIL. Catalyst damage misfire criteria calibrated out, emission threshold criteria set to 4%, enabled between 150 °F and 220 °F, 254 sec start-up delay.
Oxygen Sensor Monitor	Front O2 sensor "lack of switching" tests and all circuit and heater tests calibrated in, response/delay test calibrated out. Rear O2 sensor functional tests and all circuit and heater tests calibrated in, response/delay test calibrated out.
EGR/VVT Monitor	Same as OBD-II calibration except that P0402 test uses slightly higher threshold.
Fuel System Monitor	Fuel monitor and FAOSC monitor (rear fuel trim for UEGO systems) same as OBD-II calibration, A/F imbalance monitor calibrated out.
Secondary Air Monitor	Not applicable, AIR not used.
Evap System Monitor	Evap system leak check calibrated out, fuel level input circuit checks retained as non-MIL. Fuel tank pressure sensor and canister vent solenoid may be deleted.
PCV Monitor	Same hardware and function as OBD-II.
Thermostat Monitor	Thermostat monitor calibrated out.
Comprehensive Component Monitor	All circuit checks, rationality and functional tests same as OBD-II.
Communication Protocol and DLC	Same as OBD-II, all generic and enhanced scan tool modes work the same as OBD-II but reflect the EMD calibration that contains fewer supported monitors. "OBD Supported" PID indicates EMD (\$11).
MIL Control	Same as OBD-II, it takes 2 driving cycles to illuminate the MIL.

EMD system implementation and operation is a subset of OBD-II and is described in the remainder of this document.

## 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 HO<sub>2</sub>S very slow and reduces the amplitude of those. As catalyst efficiency deteriorates due to thermal and/or chemical deterioration, its ability to store oxygen declines and the post-catalyst HO<sub>2</sub>S 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 Switching HO<sub>2</sub>S Sensor

In order to assess catalyst oxygen storage, the catalyst monitor counts front HO<sub>2</sub>S switches during part-throttle, closed-loop fuel conditions after the engine is warmed-up and inferred catalyst temperature is within limits. Front switches are accumulated in up to three different air mass regions or cells. While catalyst monitoring entry conditions are being met, the front and rear HO<sub>2</sub>S signal lengths are continually being calculated. When the required number of front switches has accumulated in each cell (air mass region), the total signal length of the rear HO<sub>2</sub>S is divided by the total signal length of front HO<sub>2</sub>S to compute a catalyst index ratio. An index ratio near 0.0 indicates high oxygen storage capacity, hence high HC efficiency. An index ratio near 1.0 indicates low oxygen storage capacity, hence low HC efficiency. If the actual index ratio exceeds the threshold index ratio, the catalyst is considered failed.

If the catalyst monitor does not complete during a particular driving cycle, the already-accumulated switch/signal-length data is retained in Keep Alive Memory and is used during the next driving cycle to allow the catalyst monitor a better opportunity to complete, even under short or transient driving conditions.

If the catalyst monitor runs to completion during a driving cycle, it will be allowed to run again and collect another set of data during the same driving cycle. This would allow the catalyst monitor to complete up to a maximum of two times per driving cycle, however, the in-use performance ratio numerator for the catalyst monitor will only be allowed to increment once per driving cycle. For example, if the catalyst monitor completes twice during the current driving cycle, the catalyst monitor in-use performance numerator will be incremented once during the current driving cycle and will be incremented again for the second completion on the following driving cycle, after the catalyst monitor entry condition have been met.

### Index Ratio Method Using a Wide Range HO<sub>2</sub>S Sensor (UEGO)

The switching HO<sub>2</sub>S control system compares the HO<sub>2</sub>S signals before and after the catalyst to assess catalyst oxygen storage. The front HO<sub>2</sub>S 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 HO<sub>2</sub>S signal length is continually being calculated. When the required total calibrated time has been accumulated, the total voltage signal length of the rear HO<sub>2</sub>S is divided by a calibrated threshold rear HO<sub>2</sub>S signal length to compute a catalyst index ratio. The threshold rear HO<sub>2</sub>S signal is calibrated as a function of air mass using 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 HO<sub>2</sub>S voltage signal. An index ratio near 0.0 indicates high oxygen storage capacity, hence high HC/NO<sub>x</sub> efficiency. As catalyst oxygen storage degrades, the rear HO<sub>2</sub>S voltage signal activity increases. An index ratio near 1.0 indicates low oxygen storage capacity, hence low HC/NO<sub>x</sub> efficiency. If the actual index ratio exceeds the calibrated threshold ratio, the catalyst is considered failed.

## Integrated Air/Fuel Method

The Integrated Air/Fuel Catalyst Monitor assesses the oxygen storage capacity of a catalyst after a fuel cut event. The monitor integrates how much excess fuel is needed to drive the monitored catalyst to a rich condition starting from an oxygen-saturated, lean condition. Therefore, the monitor is a measure of how much fuel is required to force catalyst breakthrough from lean to rich. To accomplish this, the monitor runs during fuel reactivation following a Decel Fuel Shut Off (DFSO) event. The monitor completes after a calibrated number of DFSO monitoring events have occurred. The IAF catalyst monitor can be used with either a wide range O<sub>2</sub> sensor (UEGO) or a conventional switching sensor (HEGO), however, the index ratio monitor has been found to yield better results with HEGO pre-converter sensor. As a result, the direction for use of a HEGO pre-converter sensor is to use the index ratio monitor.

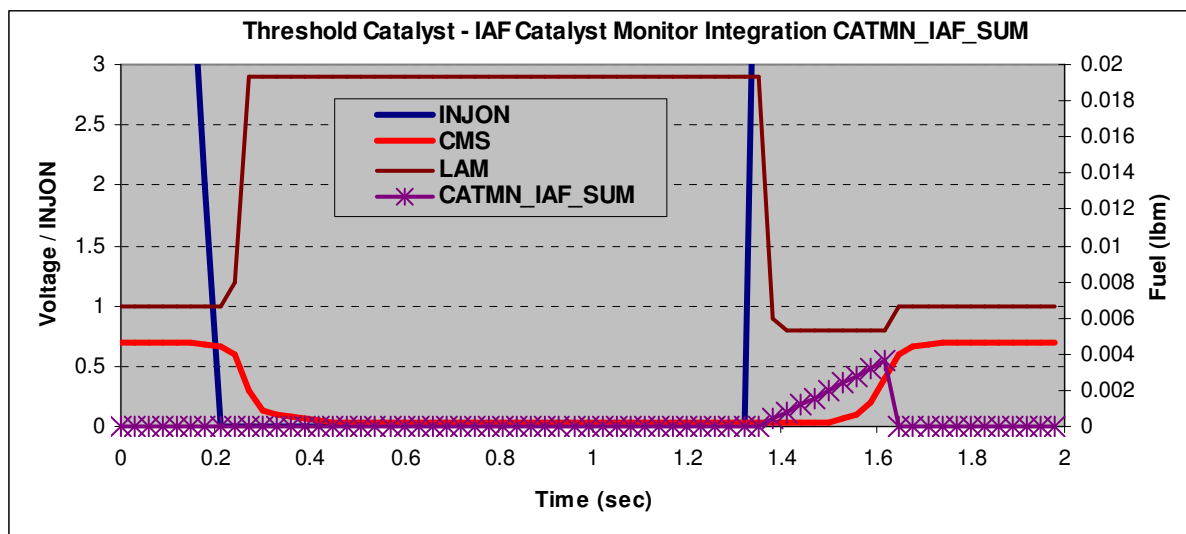
Functionally, the equation is:

$$IAF = \int \left( \frac{Fuel\_needed\_for\_stoich}{Fuel\_Measured} - Fuel\_needed\_for\_stoich \right)$$

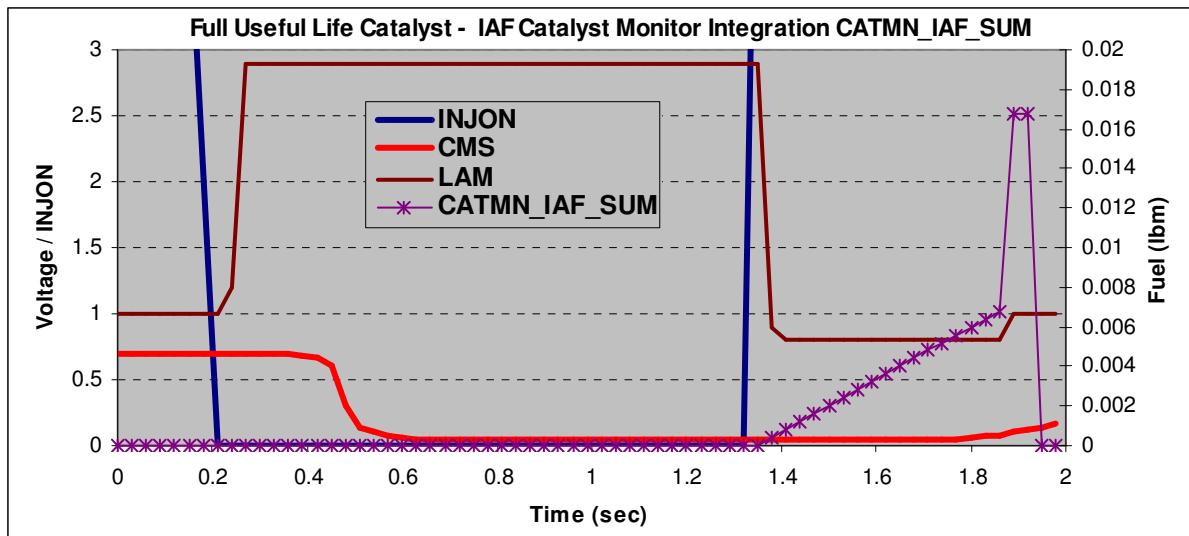
where the units are in pounds mass of fuel.

The monitor runs during reactivation fueling following an injector cut. The diagram below shows examples of one DFSO event with a threshold catalyst and with a Full Useful Life catalyst where:

- INJON = # of injectors on.
- CMS is the catalyst monitor sensor voltage. When the rear O<sub>2</sub> sensor crosses 0.45 volts (i.e. rich) the monitor will complete for the given DFSO event.
- LAM (LAMBDA) is the front O<sub>2</sub> sensor (UEGO) signal.
- CATMN\_IAF\_SUM is the integral from the equations above (Y axis on the right).



In this example, CATMN\_IAF\_SUM is small because it doesn't take much fuel to break through a low oxygen storage threshold catalyst.



In this example, CATMN\_IAF\_SUM is much larger because it takes a substantial amount of fuel to break through a high oxygen storage threshold catalyst.

Reactivation fuel is limited by the catalyst monitor to optimize fuel economy and minimize emissions. A “green” catalyst with a lot of oxygen storage capability would require a large amount of reactivation fuel to completely break through and get the rear O<sub>2</sub> sensor to switch rich. Reactivation fuel is clipped to a maximum level so that normal closed loop fuel control can be resumed when a calibrated amount of reactivation fuel has been delivered.

There are two sets of entry conditions into the IAF catalyst monitor. The high level entry conditions determine that the monitor would like to run following the next injector fuel cut event. The lower level entry conditions determine that the fuel cut-off event was suitable for monitoring and the monitor will run as soon as the injectors come back on.

1. The high level entry conditions are met when:

- There are no sensor/hardware faults
- The base monitor entry conditions have been met (ECT, IAT, cat temp, fuel level, air mass)
- Required number of DFSSO monitoring event have not yet completed

2. The lower level entry conditions are met when:

- The injectors are off
- The catalyst is believed to be saturated with oxygen (rear O<sub>2</sub> indicates lean)
- The catalyst/rear O<sub>2</sub> has been rich at least once since the last monitor event.

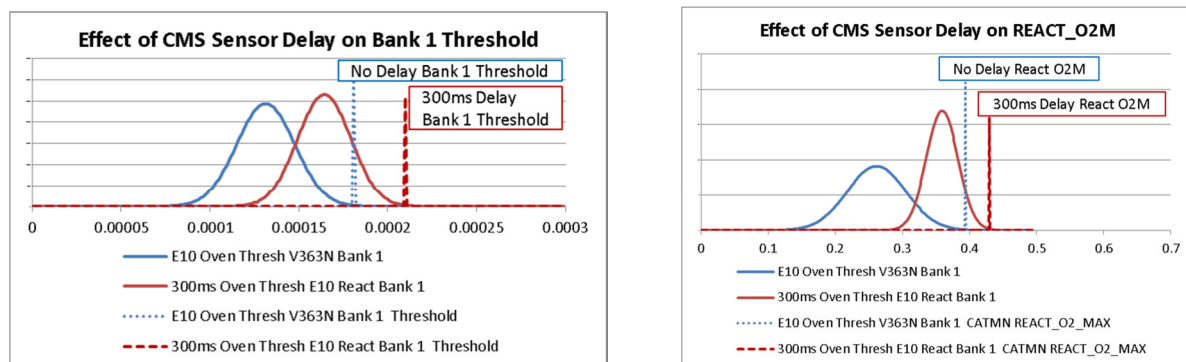
## The “Gap”

The catalyst monitor uses response of the rear O2 sensor (internally called a CMS, Catalyst Monitor Sensor) to assess the oxygen storage capacity of the catalyst. If the rear O2 sensor slows down, it will look as though the catalyst has more oxygen storage than it actually has. If the delay gets large enough, the catalyst monitor could falsely pass a deteriorated catalyst. In practice, the rear O2 sensor response rate is monitored by Rear HO2S Decel Fuel Shut Off Response Test. A slow rear O2 sensor will set a DTC P013A/P013C or P013E/P014A DTC and illuminate the MIL. The region where a slow rear O2 sensor affects the catalyst monitor results up to the point where the Rear HO2S Decel Fuel Shut Off Response Test will flag a slow sensor is commonly refer to as a “gap”. The OBD regulations require that manufacturers minimize any gap remaining between the worst performing acceptable rear O2 sensor and a sufficient sensor. In other words, the “gap” is the difference between the sensor delay that the Rear O2 sensor monitor can detect versus the sensor delay that will false pass the catalyst monitor.

On one end, the gap can be reduced by making the Rear HO2S Decel Fuel Shut Off Response Test more accurate. This can be accomplished by reducing the variability in the slew rate calculation by sampling the rear O2 signal faster and employing improved filtering and averaging techniques. The resulting slew rate is a direct measurement of sensor response. The slew rate calculation has more variability for a fast sensor versus a slow sensor. This is because you get a lot of sensor voltage samples on a slow sensor, but you only get a few on a fast sensor. This characteristic, however, provides us with an accurate slew rate for a slow sensor – the sensor of interest.

On the other end, the gap can be reduced by calibrating the catalyst monitor thresholds with a worst case, slow sensor. Although this reduces the gap, it increases the potential to falsely fail an acceptable catalyst, and it increases the amount of reactivation fuel needed to complete the catalyst monitor. This increases fuel consumption and emissions.

The example below the Full Useful Life catalyst monitor distribution shifts to the right towards the threshold catalyst distribution. This reduces the separation between acceptable and failed catalyst and increases the amount of reactivation fuel needed to complete the monitor.

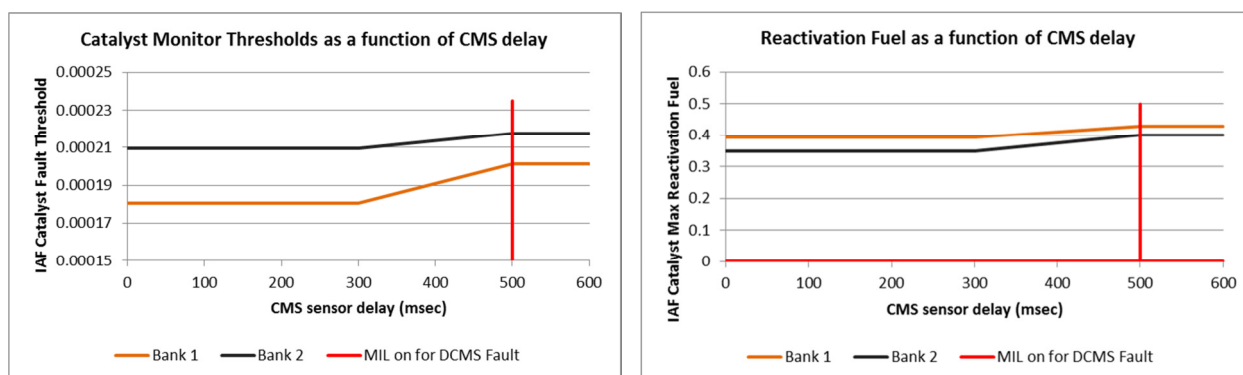


Instead of calibrating to the worst case (slow) sensor, strategy was added to adjust the catalyst monitor thresholds to account for the sensor delay. The “No-delay” CMS slew rate/slope measurement has a lot of variability however; a slow sensor has very tight slew rate/slope distribution. This characteristic was used to accurately adjust cat monitor thresholds for slow sensor, where it is the most critical.

Catalyst monitor thresholds are a function CMS slew rate/slope as shown in the chart below. In the example shown below, the following relationships were used to determine the calibration:

- The delay calibration value will be set to the fault limit of the Rear HO2S Decel Fuel Shut Off Response Test. In this example, the monitor detects and sets a MIL for a 500 msec fault level.
- The no delay calibration will be set to the CMS delay that begins to have an observable effect on catalyst monitor results. In the example above this point occurs at a 300 msec delay.
- Between 300 msec and 500 msec delay, the fault threshold will be a linear interpolation between the 300 msec and 500 msec thresholds.

Similarly, the reactivation fuel limits are a function CMS slow rate/slope as shown in the chart below.



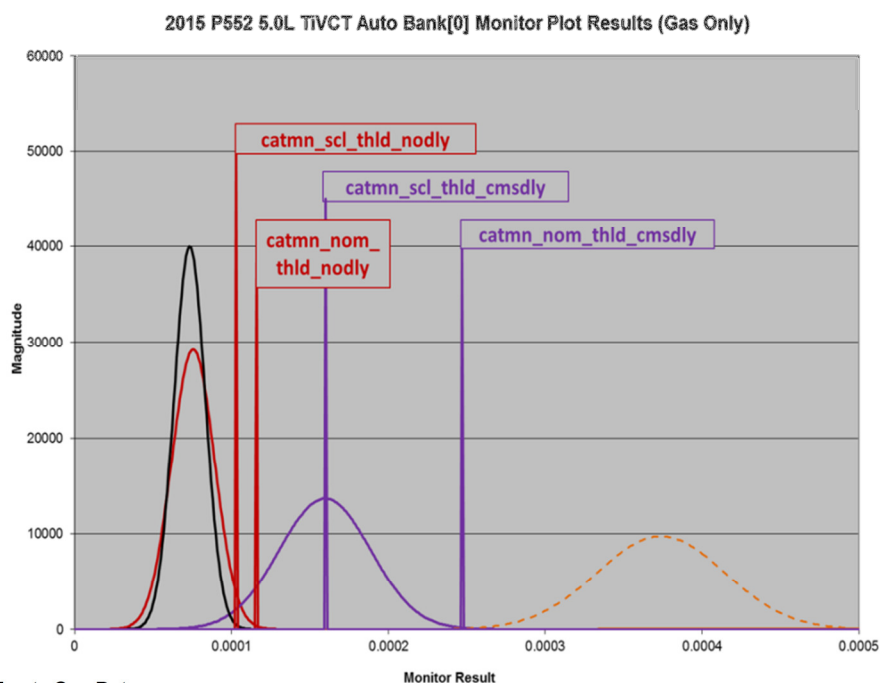
The variable thresholds apply to the normal EWMA as well as the Fast Initial Response and the Step Change Logic thresholds.

Step Change Logic thresholds:

- `catmn_scl_thld_nodly` => Set to the max of (Threshold No Delay mean or Empty Can mean + 3 sigma). The chart shows the `scl_thld_nodly` = Empty can mean + 3 sigma.
- `catmn_scl_thld_cmsdly` => Set to: max of (Threshold 500 msec Delay mean or Empty Can mean + 3 sigma). The chart shows the `scl_thld_cmsdly` = 500 msec mean

Normal EWMA and Fast Initial Response thresholds:

- `catmn_nom_thld_nodly` => Set to the max of (Threshold No Delay mean + 3 sigma, or empty can + 3 sigma)
- `catmn_nom_thld_cmsdly` => Set to the max of (Threshold 500 ms mean + 3 sigma or empty can + 3 sigma)



Black Distribution = Empty Can Data

Dark Red Distribution = Threshold Catalyst, No Delay CMS

Purple Distribution = Threshold Catalyst, 500 msec Delay CMS.

Orange dashed line Distribution = Full Useful Life Catalyst

## General Catalyst Monitor Operation

Rear HO<sub>2</sub>S 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 HO<sub>2</sub>S sensor is used along with the front, fuel-control HO<sub>2</sub>S 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 HO<sub>2</sub>S sensor along with the two front, fuel-control HO<sub>2</sub>S sensors. Y-pipe system use three sensors in all. For Y-pipe systems which utilize switching front O<sub>2</sub> sensors, the two front HO<sub>2</sub>S sensor signals are combined by the software to infer what the HO<sub>2</sub>S signal would have been in front of the monitored catalyst. The inferred front HO<sub>2</sub>S signal and the actual single, rear HO<sub>2</sub>S signal is then used to calculate the switch ratio.

Many 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-II vehicles in order to meet the 1.75 \* emission-standard threshold for NMHC and NO<sub>x</sub>. 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 HO<sub>2</sub>S 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 HO<sub>2</sub>S in the middle of the catalyst can, between the first and second bricks.)

The new Integrated Air/Fuel Catalyst Monitor can be used to monitor the entire catalyst volume, even on LEV-II vehicles.

Index ratios for ethanol (Flex fuel) vehicles vary based on the changing concentration of alcohol in the fuel. The malfunction threshold typically increases as the percent alcohol increases. For example, a malfunction threshold of 0.5 may be used at E10 (10% ethanol) and 0.9 may be used at E85 (85% ethanol). The malfunction thresholds are therefore adjusted based on the % alcohol in the fuel. (Note: Normal gasoline is allowed to contain up to 10% ethanol (E10)).

Vehicles with the Index Ratio Method Using a Switching HO<sub>2</sub>S Sensor employ an Exponentially Weighted Moving Average (EWMA) algorithm to improve the robustness of the 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) or DTCs are cleared, a malfunction will illuminate the MIL in 2 driving cycles. See the section on EWMA for additional information.

Vehicles with the Index Ratio Method Using a Wide Range HO<sub>2</sub>S Sensor (UEGO) or the Integrated Air/Fuel catalyst monitor employ an improved version of the EWMA algorithm.

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

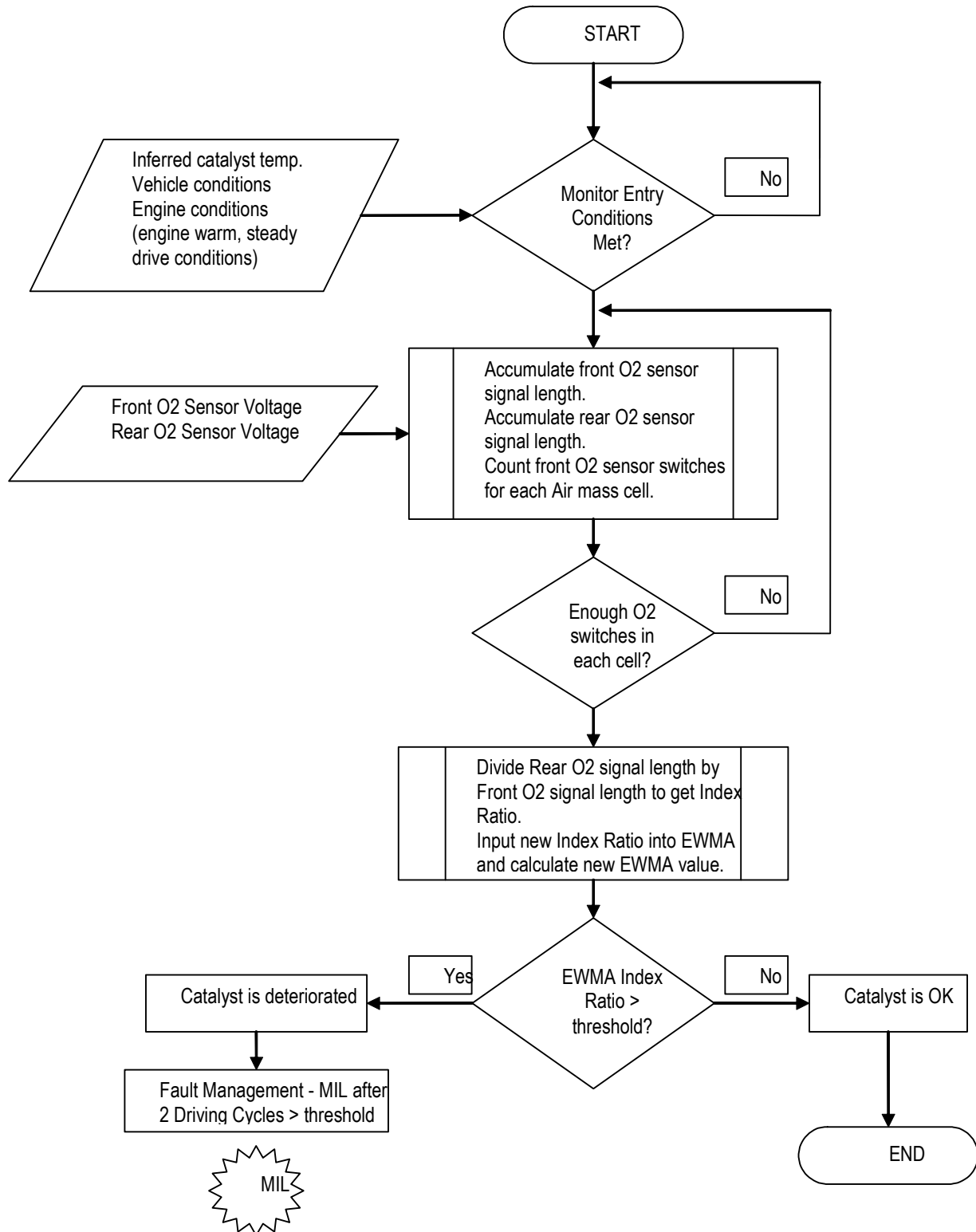
- **Fast Initial Response (FIR):** The first 4 tests after a battery disconnect or code clear will process unfiltered data to quickly indicate a fault. The FIR will use a 2-trip MIL. This will help the service technician determine that a fault has been fixed.
- **Step-change Logic (SCL):** The logic will detect an abrupt change from a no-fault condition to a fault condition. The SCL will be active after the 4<sup>th</sup> catalyst 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 catalyst monitor test data. It is employed after the 4<sup>th</sup> catalyst test and will illuminate a MIL during the drive cycle where the EWMA value exceeds the fault threshold. (1 trip MIL).

Starting in the 2010 ½ Model Year and later, the catalyst monitor will employ catalyst break-in logic. This logic will prevent the catalyst monitor from running until after a catalyst break-in period.

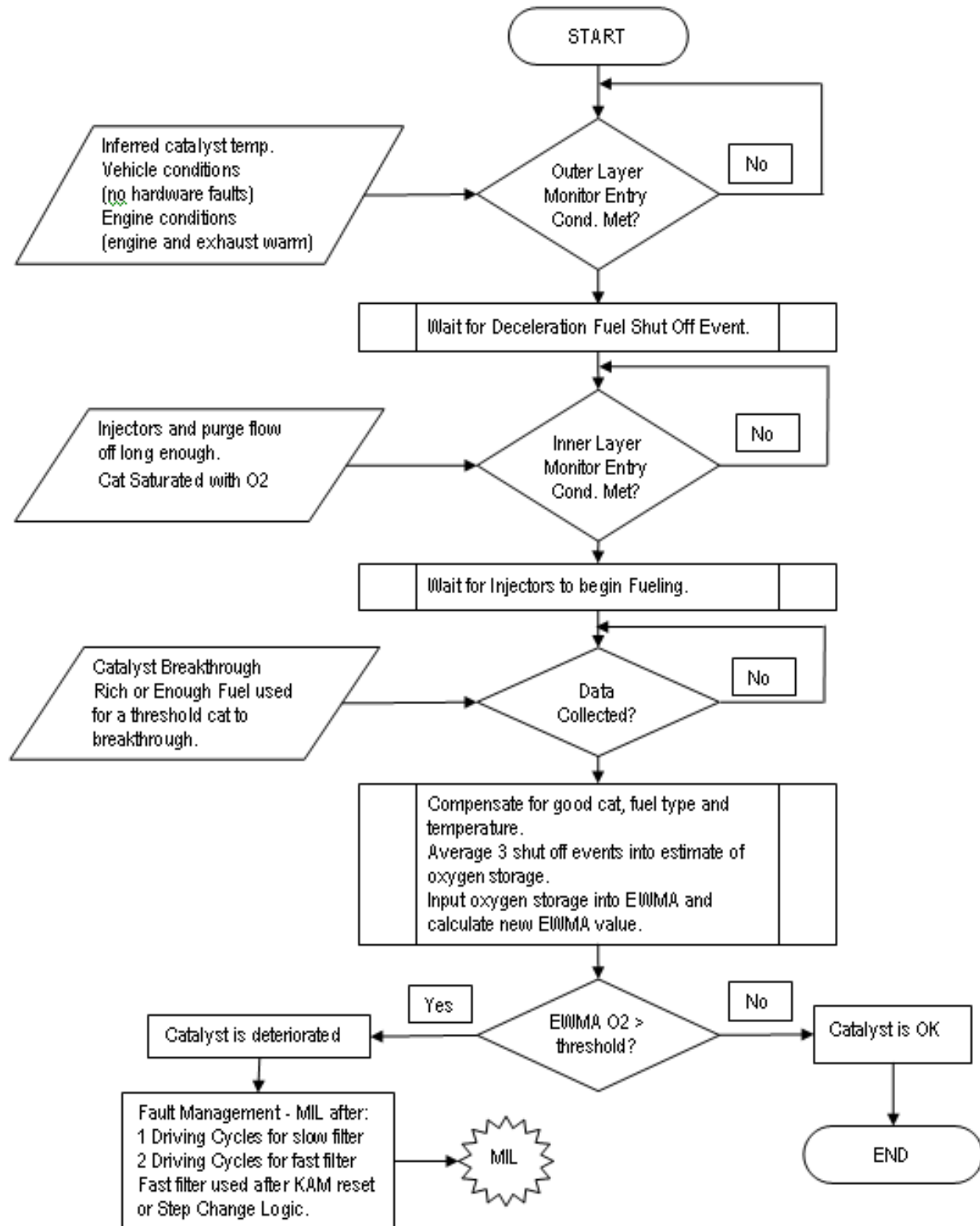
The catalyst monitor will not run on a new vehicle from the assembly plant until 60 minutes of time above a catalyst temperature (typically 800 to 1100 deg F) has been accumulated or 300 miles has elapsed.

New modules at the assembly plant will have an NVRAM flag initialized to delay the catalyst monitor. Service modules and re-flash software will have the flag set to allow that catalyst monitor to run. The flag cannot be reset to delay the catalyst monitor from running by any tool or service procedure.

## Index Ratio Catalyst Monitor



# Integrated Air Fuel Catalyst Monitor



<b>CATALYST MONITOR OPERATION:</b>	
DTCs	P0420 - Catalyst System Efficiency Below Threshold, Bank 1 (or Y-pipe), P0430 - Catalyst System Efficiency Below Threshold, Bank 2
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, MAF, no misfire DTCs (P0300, P0310), no ignition coil DTCs (P0351-P0358), no fuel monitor DTCs (P0171, P0172, P0174, P0175), no VCT DTCs (P0010-P0017, P052A, P052B, P0344, P0365, P0369-bank1) (P0018 thru P0025,P052C, P052D, P0349, P0390, P0394- bank2 ).no evap system DTCs (P0443, P0446, P0455, P0457, P1450/P0496), no ETC system DTCs (P0122, P0123, P0222, P0223, P02135) (P2101, P2107, P2111, P2112) (P0600, P060A, P060B, P060C, P061B, P061C, P061D, P1674, U0300).
Monitoring Duration	Approximately 700 seconds during appropriate FTP conditions (approximately 100 to 200 oxygen sensor switches are collected) for switching O2 control sensors  Approximately 10 to 20 seconds for wide range O2 index ratio monitor.  3 Decel Fuel Cutoff events for IAF catalyst monitor

<b>TYPICAL SWITCHING O2 SENSOR INDEX RATIO CATALYST MONITOR ENTRY CONDITIONS:</b>		
Entry condition	Minimum	Maximum
Time since engine start-up (70 °F start)	330 seconds	
Engine Coolant Temp	170 °F	230 °F
Intake Air Temp	20 °F	180 °F
Time since entering closed loop fuel	30 sec	
Inferred Rear HO2S sensor Temperature	900 °F	
EGR flow (Note: an EGR fault disables EGR)	1%	12%
Throttle Position	Part Throttle	Part Throttle
Rate of Change of Throttle Position		0.2 volts / 0.050 s
Vehicle Speed	5 mph	70 mph
Fuel Level	15%	
First Air Mass Cell	1.0 lb/min	2.0 lb/min
Engine RPM for first air mass cell	1,000 rpm	1,300 rpm
Engine Load for first air mass cell	15%	35%
Monitored catalyst mid-bed temp. (inferred) for first air mass cell	850 °F	1,200 °F
Number of front O2 switches required for first air mass cell	50	
Second Air Mass Cell	2.0 lb/min	3.0 lb/min
Engine RPM for second air mass cell	1,200 rpm	1,500 rpm
Engine Load for second air mass cell	20%	35%

Monitored catalyst mid-bed temp. (inferred) for second air mass cell	900 °F	1,250 °F
Number of front O2 switches required for second air mass cell	70	
Third Air Mass Cell	3.0 lb/min	4.0 lb/min
Engine RPM for third air mass cell	1,300 rpm	1,600 rpm
Engine Load for third air mass cell	20%	40%
Monitored catalyst mid-bed temp. (inferred) for third air mass cell	950 °F	1,300 °F
Number of front O2 switches required for third air mass cell	30	
(Note: Engine rpm and load values for each air mass cell can vary as a function of the power-to-weight ratio of the engine, transmission and axle gearing and tire size.)		

TYPICAL WIDE RANGE O2 SENSOR INDEX RATIO CATALYST MONITOR ENTRY CONDITIONS:		
Entry condition	Minimum	Maximum
Time since engine start-up (70 °F start)	330 seconds	
Engine Coolant Temp	170 °F	230 °F
Intake Air Temp	20 °F	180 °F
Time since entering closed loop fuel	30 sec	
Inferred Rear HO2S sensor Temperature	900 – 1100 °F	
EGR flow (Note: an EGR fault disables EGR)	1%	12%
Throttle Position	Part Throttle	Part Throttle
Rate of Change of Throttle Position		0.2 volts / 0.050 s
Vehicle Speed	20 mph	80 mph
Fuel Level	15%	
Air Mass	2.0 lb/min	5.0 lb/min
Engine RPM	1,000 rpm	2,000 rpm
Engine Load	20%	60%
Monitored catalyst mid-bed temp. (inferred) for first air mass cell	850 °F	1,200 °F
(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 IAF CATALYST MONITOR ENTRY CONDITIONS:		
Entry condition	Minimum	Maximum
Engine Coolant Temp	160 °F	250 °F
Intake Air Temp	20 °F	140 °F
Inferred catalyst mid-bed temperature	900 °F	1500 °F
Fuel Level	15%	
Air Mass		2.0 lb/min
Minimum inferred rear O2 sensor temperature	800 °F	
Fuel monitor learned within limits	97%	103%
Rear O2 sensor rich since last monitor attempt	0.45 volts	
Rear O2 sensor lean with injectors off (voltage needed to enter monitor)		0.1 volts
Rear O2 sensor reads rich after fuel turned back on (voltage needed to complete monitor)	0.45 volts	

TYPICAL MALFUNCTION THRESHOLDS:
Catalyst monitor index ratio > 0.75 (bank monitor)
Catalyst monitor index-ratio > 0.60 (Y-pipe monitor)
Catalyst monitor index ratio > 0.50 for E10 to > 0.90 for E85 (flex fuel vehicles)

Mode \$06 reporting for IAF Catalyst Monitor

The catalyst monitor results are converted to a ratio for Mode \$06 reporting to keep the same look and feel for the service technician. The equation for calculating the Mode \$06 monitor result is:

$$1 - (\text{Actual reactivation fuel} / \text{Good catalyst reactivation fuel})$$

Good catalyst reactivation fuel is intended to represent what the monitor would measure for a green catalyst.

J1979 CATALYST MONITOR MODE \$06 DATA			
Monitor ID	Test ID	Description	
\$21	\$81	Bank 1 Oxygen Storage Capacity and max. limit (P0420)	unitless
\$22	\$81	Bank 2 Oxygen Storage Capacity and max. limit (P0430)	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 input to the Misfire Monitor is the signal from the crankshaft position sensor and timing wheel. The signal is acquired and processed by the PCM and provided to the Misfire Monitor as individual tooth period measurements. The Monitor uses the tooth period measurements to calculate crankshaft acceleration signals for misfire detection. All misfire processing is performed in software (separate chips are no longer used except for some vehicle lines that may still be using older style PCMs.)

Two different technologies are used for misfire monitoring. They are the Low Data Rate (LDR), and High Data Rate (HDR) systems. The LDR system is capable of meeting the FTP monitoring requirements on most engines and is capable of meeting "full-range" misfire monitoring requirements on 3 and 4-cylinder engines. It is also used on 6 cylinder engines with rear mounted crank sensors. The HDR system is capable of meeting "full-range" misfire monitoring requirements on 8 and 10 cylinder engines.

All software allows for detection of any misfires that occur 6 engine revolutions after initially cranking the engine. This meets the OBD-II requirement to identify misfires within 2 engine revolutions after engine start/restart (> 150 rpm below warm idle speed) for conventional and stop-start vehicles and 2 engine revolutions after engine fueling begins for engine start/restart for hybrid vehicles.

The Monitor includes a diagnostic check on the crank sensor input. The Monitor checks the number of tooth period measurements received on each cylinder event. A P1336 will be set if the Monitor receives an invalid number of tooth period measurements. A P1336 points to noise present on the crank sensor input or a lack of synchronization between the cam and crank sensors.

### Low Data Rate System

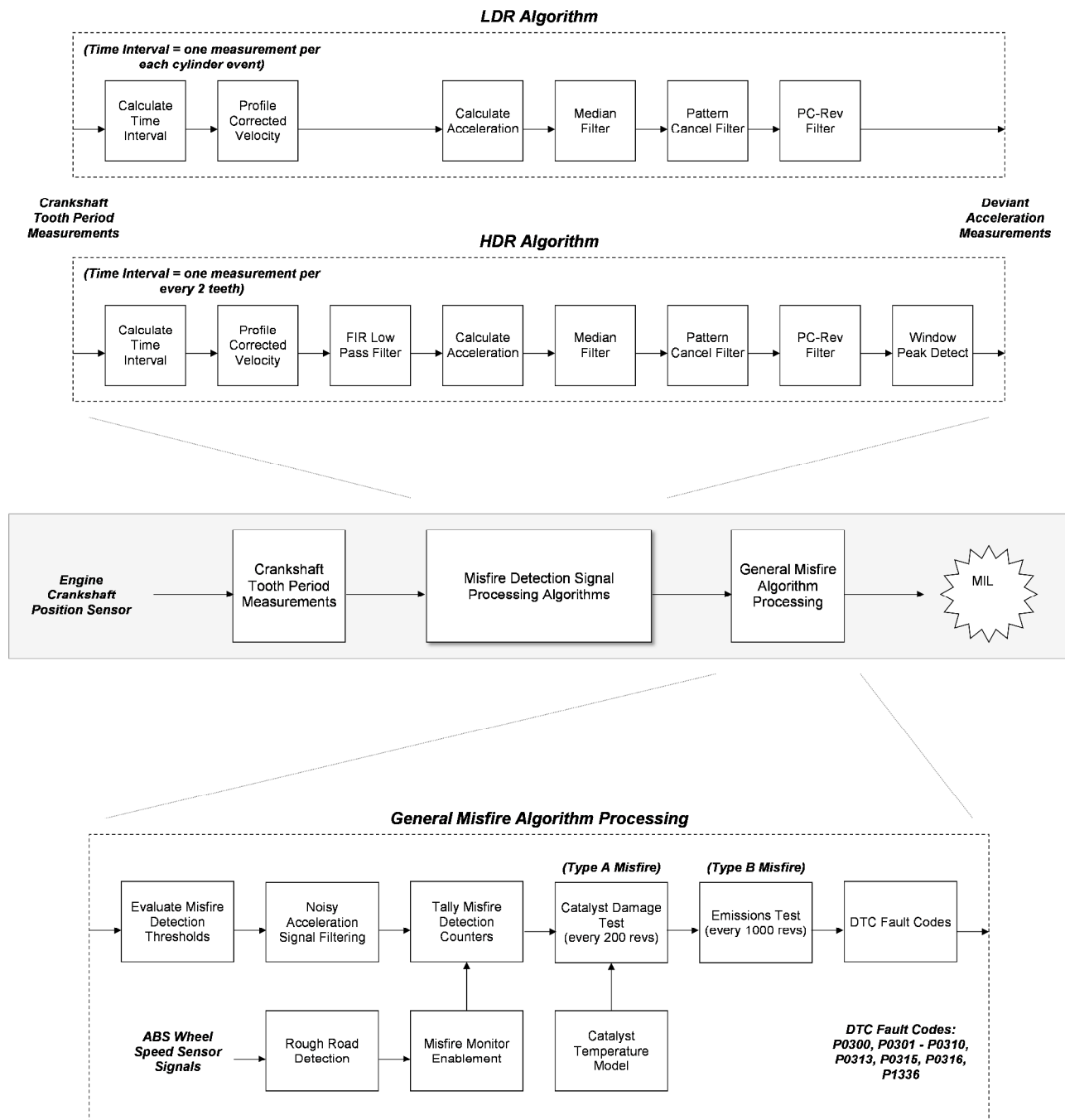
The LDR Misfire Monitor uses a low-data-rate crankshaft position signal, (i.e. one time measurement signal for each cylinder event). The PCM calculates crankshaft rotational velocity for each cylinder from this crankshaft position signal. The acceleration for each cylinder can then be calculated using 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 three algorithms. The first algorithm, called pattern cancellation, is optimized for detection of sporadic patterns of misfire. The algorithm learns the normal pattern of cylinder accelerations from the mostly good firing events and is then able to accurately detect deviations from that pattern. The second algorithm, called pattern cancellation by opposing engine revolution or "pc-rev", is optimized for single cylinder patterns. The algorithm compares the acceleration of a cylinder to its opposite cylinder on the opposing engine revolution. The algorithm learns the normal patterns that repeat every engine revolution and is then able to accurately detect deviations between the paired cylinders. The third algorithm is a non-filtered acceleration signal that is a general purpose signal for all patterns including multi-cylinder patterns. The resulting deviant cylinder acceleration values are used in evaluating misfire in the "General Misfire Algorithm Processing" section below.

### High Data Rate System

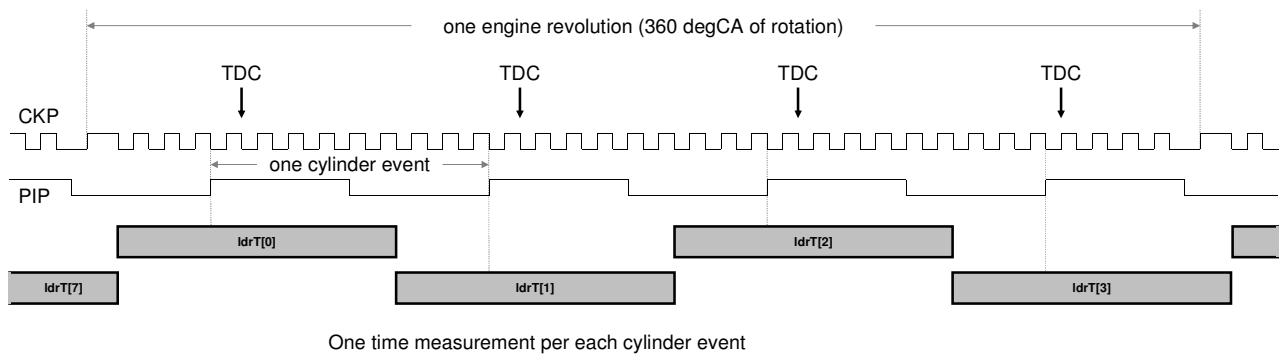
The High Data Rate (HDR) Misfire Monitor uses a high data rate crankshaft position signal, (i.e. one time measurement signal per each 2 teeth for a total of 36 measurements for one engine cycle on a 36-1 tooth wheel). This high-resolution signal is processed with a digital low pass filter. The low pass filter filters the high-resolution crankshaft velocity signal to remove some of the crankshaft torsional vibrations that degrade signal to noise. Two low pass filters are used to enhance detection capability – a "base" filter and a more aggressive filter to enhance single-cylinder capability at higher rpm. This significantly improves detection capability for continuous misfires on single cylinders up to redline. The high-resolution acceleration 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 three algorithms similar to the LDR system. The final stage is to decimate the high resolution signals by selecting the peak acceleration values from within a window location for each cylinder. The resulting deviant cylinder acceleration values are used in evaluating misfire in the "General Misfire Algorithm Processing" section below.



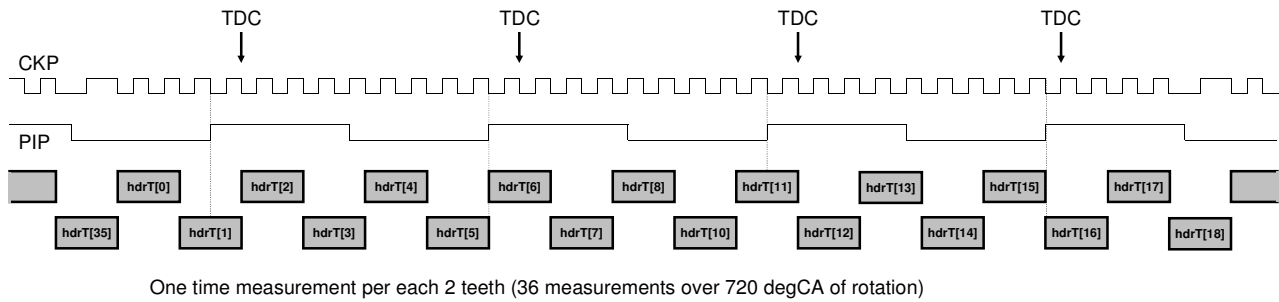
# Low Data Rate and High Data Rate Systems

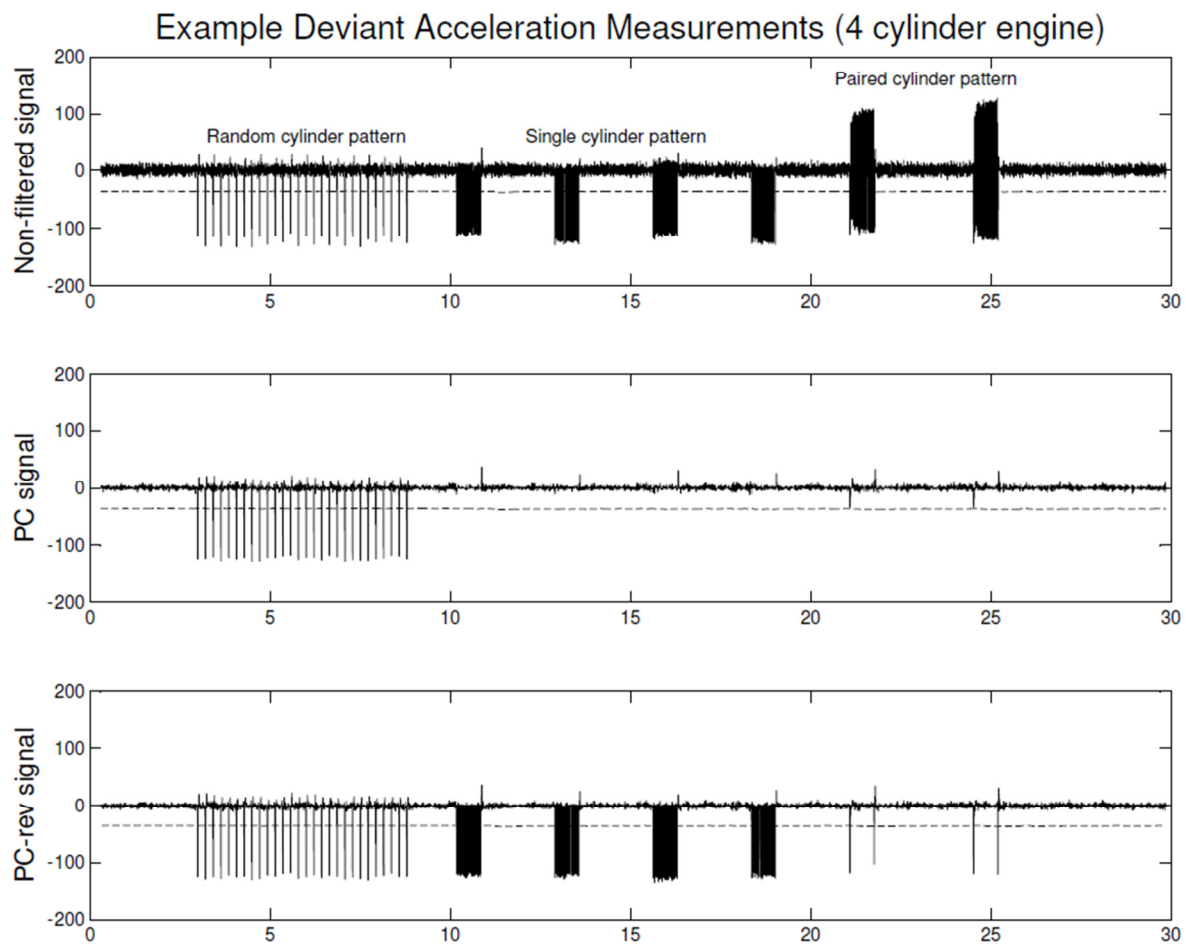


### Example LDR Tooth Period Measurements (V8 engine with 36-1 Tooth Wheel)



### Example HDR Tooth Period Measurements (V8 engine with 36-1 Tooth Wheel)





## General 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. A threshold multiplier is used during startup CSER to compensate the thresholds for the reduction in signal amplitude during spark retard conditions. Threshold adjustments may also be applied to compensate for torque reduction during gear shift events, and to compensate for changes in driveline coupling with torque converter lock status.

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 crankshaft oscillations at low rpm/high load ("lugging") conditions, will produce symmetrical, positive acceleration variations. Noise limits are calculated by applying a negative multiplier to the misfire threshold. If the noise limits are exceeded, a noisy signal condition is inferred and the misfire monitor is suspended for a brief interval. 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 is 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 (1832°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.

At high engine speed and load operating conditions the Monitor continuously evaluates the misfire rate during each 200 revolution period. If a sufficient number of misfire events have been accumulated within a 200 revolution block such that the misfire threshold is already exceeded before the end of the block has been reached, the Monitor will declare a fault immediately rather than wait for the end of the block. This improves the capability of the Monitor to prevent damage to the catalyst.

If a single cylinder (i.e. > 90% of misfires attributed to one cylinder) is determined to be consistently misfiring in excess of the catalyst damage criteria, the Monitor will initiate failure mode effects management (FMEM) to prevent catalyst damage. The fuel injector to that cylinder will be shut off for a minimum of 30 seconds. 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. Fuel control will go open loop and target lambda slightly lean (~1.05). The software may also use the throttle to limit airflow (limit boost) on GTDI engines for additional exhaust component protection. After 30 seconds, the injector is re-enabled and the system returns to normal operation. On some vehicles, the software may continue FMEM beyond 30 seconds if the engine is operating at high speed or load at the end of the 30 second period. The software will wait for a low airflow condition (~1 to 5 second tip-out) to exit from FMEM. This protects the catalyst should the misfire fault still be present when the fuel injector is turned back on. 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. If a particular cylinder cannot be determined, fuel control will still go open loop and target lambda slightly lean (~1.05) to limit catalyst temperatures.

If fuel level is below 15%, the misfire monitor continues to evaluate misfire over every 200 revolution period to determine if catalyst damaging misfire is present so that the fuel shut-off FMEM can be utilized to control catalyst temperatures. If this is the case, a P0313 DTC will be set to indicate that misfire occurred at low fuel levels. The P0313 DTC is set in place of engine misfire codes (P030x) if a misfire fault is detected with low fuel level.

The misfire rate is also evaluated every 1000 revolution period and compared to a single (Type B) threshold value to indicate an emission-threshold malfunction, which can be either a single 1000 revolution exceedence from startup or four subsequent 1000 revolution 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.

## **Rough Road Detection**

The Misfire Monitor includes a Rough Road Detection (RRD) system to eliminate false misfire indications due to rough road conditions. The RRD system uses data from ABS wheel speed sensors for estimating the severity of rough road conditions. This is a more direct measurement of rough road over other methods which are based on driveline feedback via crankshaft velocity measurements. It improves accuracy over these other methods since it eliminates interactions with actual misfire.

In the event of an RRD system failure, the RRD output will be ignored and the Misfire Monitor will remain active. An RRD system failure could be caused by a failure in any of the input signals to the algorithm. This includes the ABS wheel speed sensors, Brake Pedal sensor, or CAN bus hardware failures. Specific DTCs will indicate the source of these component failures.

A redundant check is also performed on the RRD system to verify it is not stuck high due to other unforeseen causes. If the RRD system indicates rough road during low vehicle speed conditions where it is not expected, the RRD output will be ignored and the Misfire Monitor will remain active.

## **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°, a correction factor can be calculated for each misfire sample interval that makes all the angles between individual teeth equal. The LDR misfire system learns one profile correction factor per cylinder (ex. 4 correction factors for a 4 cylinder engine), while the HDR system learns 36, 40 or 60 correction factors depending on the number of crankshaft wheel teeth (ex. 35 for some V6/V8 engines, 39 for V10 engines, 58 for some I4/V6 engines).

The corrections are calculated from several engine cycles of misfire sample interval data. The 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 bad corrections due to crankshaft velocity disturbances.

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. Two methods of learning profile correction are used:

- Neutral Profile Correction and Non Volatile Memory
- Customer Drive Cycle for Profile Correction (60-40 MPH Deceleration)

## **Neutral Profile Correction and Non-Volatile Memory**

Neutral profile learning is used at End of Line to learn profile correction via a series of one or more neutral engine rpm throttle snaps. This allows the Misfire Monitor to be activated at the Assembly Plant. A Test Tool command is required to enable this method of learning, so this method will only be performed by a Plant or Service technician. Learning profile correction factors at high-speed (3,000 rpm) neutral conditions versus during 60-40 mph decels optimizes correction factors for higher rpms where they are most needed and eliminates driveline/transmission and road noise effects. This improves signal to noise characteristics which means improved detection capability.

The profile correction factors learned at the Assembly Plant are stored into non-volatile memory. This eliminates the need for specific customer drive cycles. However, misfire profiles may need to be relearned in the Service Bay using a service procedure if major engine work is done or the PCM is replaced. (Re-learning is not required for a reflash.)

On selected vehicles, the neutral profile correction strategy is the only method used for profile correction learning. In the event of a loss of non-volatile memory contents (new PCM installed), the correction factors are lost and must be relearned. DTC P0315 is set until the misfire profile is relearned using a scan tool procedure.

The neutral profile correction strategy is available on most gasoline engine vehicles. It is not available on HEV and diesel engine vehicles.

## Customer Drive Cycle for Profile Correction (60-40 MPH Deceleration)

This method was the traditional method for profile correction learning until the introduction of Neutral Profile Correction. It is now only used as a backup method.

To prevent any fueling or combustion differences from affecting the correction factors, learning is done during deceleration fuel shut off (DFSO). This can be done during closed throttle, non-braking, defueled decelerations in the 97 to 64 km/h (60 to 40 MPH) range after exceeding 97 km/h (60 MPH) (likely to correspond to a freeway exit condition). In order to minimize the learning time for the correction factors, a more aggressive DFSO strategy may be used when the conditions for learning are present. The corrections are typically learned in a single 97 to 64 km/h (60 to 40 MPH) deceleration, but may take up to 3 such decelerations or a higher number of shorter decelerations. If the software is unable to learn a profile after three, 97 to 64 km/h (60 to 40 MPH) deceleration cycles, DTC P0315 is set.

Misfire Monitor Operation:	
DTCs	P0300 to P0310 (general and specific cylinder misfire) P1336 (noisy crank sensor, no cam/crank synchronization) P0315 (unable to learn profile) P0316 (misfire during first 1,000 revs after start-up) P0313 (misfire detected with low fuel level)
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 °F	250 °F
RPM Range (Full-Range Misfire certified, with 2 rev delay)	2 revs after exceeding 150 rpm below "drive" idle rpm	redline on tach or fuel cutoff
Profile correction factors learned in NVRAM	Yes	
Fuel tank level	15%	

**Typical misfire temporary disablement conditions:**

Temporary disablement conditions:

Closed throttle decel (negative torque, engine being driven) > -100 ft lbs

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) > -450 deg/sec or 250 deg/sec ; > -200 ft lbs/sec or > 250 ft lbs/sec

Rough Road conditions present

**Typical misfire monitor malfunction thresholds:**

Type A (catalyst damaging misfire rate): misfire rate is an rpm/load table ranging from 40% at idle to 4% at high rpm and loads

Type B (emission threshold rate): 0.9% to 1.5%

**J1979 Misfire Mode \$06 Data**

Monitor ID	Test ID	Description	
A1	\$80	Total engine misfire and catalyst damage misfire rate (updated every 200 revolutions) (P030x)	percent
A1	\$81	Total engine misfire and emission threshold misfire rate (updated every 1,000 revolutions) (P030x)	percent
A1	\$82	Highest catalyst-damage misfire and catalyst damage threshold misfire rate (updated when DTC set or clears) (P030x)	percent
A1	\$83	Highest emission-threshold misfire and emission threshold misfire rate (updated when DTC set or clears) (P030x)	percent
A1	\$84	Inferred catalyst mid-bed temperature (P030x)	°C
A2 – AD	\$0B	EWMA misfire counts for last 10 driving cycles (P030x)	events
A2 – AD	\$0C	Misfire counts for last/current driving cycle (P030x)	events
A2 – AD	\$80	Cylinder X misfire rate and catalyst damage misfire rate (updated every 200 revolutions) (P030x)	percent
A2 – AD	\$81	Cylinder X misfire rate and emission threshold misfire rate (updated every 1,000 revolutions) (P030x)	percent

The profile learning operation includes DTC P0315 if profile correction factors are not learned. On selected vehicles, this code is set immediately after a new PCM is installed until the scan tool procedure for Neutral Profile Correction is completed. On all other vehicles, this code is set if profile learning does not complete during the Customer Drive Cycle for Profile Correction.

Profile Correction Operation	
DTCs	P0315 - unable to learn profile in three 60 to 40 mph decels
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 (a maximum of three 60-40 mph defueled decels)

Typical profile learning entry conditions (Customer drive cycle):		
Entry condition	Minimum	Maximum
Engine in decel-fuel cutout mode for 4 engine cycles		
Brakes applied (Brake On/Off Switch)	No	No
Engine RPM	1300 rpm	3700 rpm
Change in RPM		600 rpm/background loop
Vehicle Speed	30 mph	75 mph
Learning tolerance		1%

Typical profile learning entry conditions (Assembly Plant or Service Bay):		
Entry condition	Minimum	Maximum
Engine in decel-fuel cutout mode for 4 engine cycles		
Park/Neutral gear		
Engine RPM	2000 rpm	3000 rpm
Learning tolerance		1%

## 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.

Starting in the 2017 MY, Federal vehicles can no longer utilize a 0.040" leak check rather than the 0.020" leak check required for California vehicles. Both California and Federal vehicles, must comply with the 0.040" and 0.020" leak check requirements.

The OBD regulations allow manufacturers to substitute a 0.090" leak requirement for the 0.040" leak check requirement based on more stringent (higher) in-use monitor performance ratio requirements. Increasing the leak size detected by the 0.040" (cruise) test allows for less restrictive entry conditions and abort conditions while also shortening monitoring times. Shortening the monitoring times allows for increased monitor completion rates, particularly in urban areas. Less restrictive entry/abort conditions include lower vehicle speed and wider manifold vacuum requirements for monitor entry, higher fuel level, vehicle speed and load delta aborts. The 2017 MY Lincoln MKS is planned as the pilot application.

In the case of heavy duty gasoline engines (> 14,000 lbs), the regulations require 0.150" leak detection only (gross leak/cap off). Heavy Duty vehicle will not set a P0442 (0.040" leak). They will set a P0455 during the initial vacuum pulldown phase to meet the 0.0150" leak detection requirement.

### 0.040"/0.090" "Cruise" Test

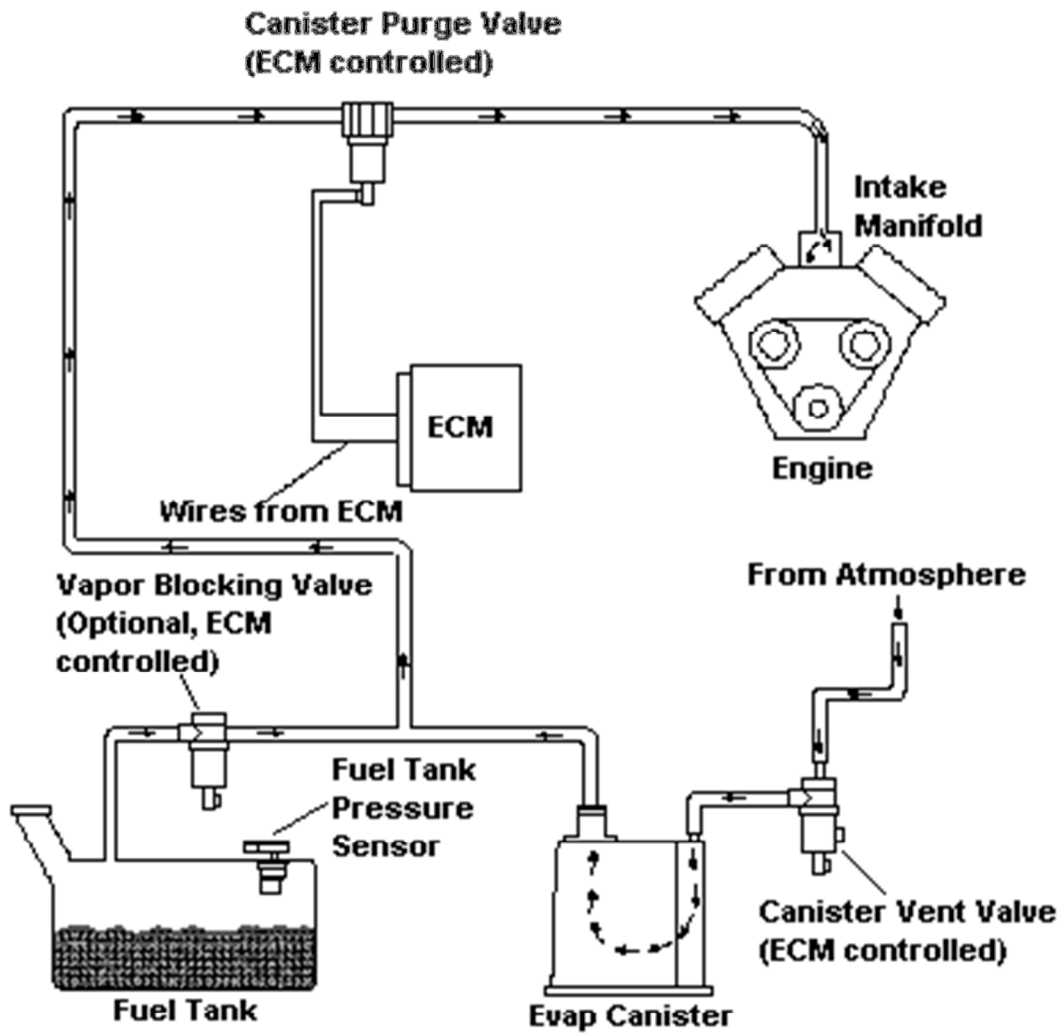
The evap system integrity test is done under conditions that minimize vapor generation and fuel tank pressure changes due to fuel slosh since these could result in false MIL illumination. The check is run after a 4 - 6 hour cold engine soak (engine-off timer), during steady highway speeds at ambient air temperatures (inferred by IAT) between 40 and 100 °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).

As a precursor to running the evap system integrity, a conditioning test is carried out to ensure that there is no excessive vacuum condition (P1450/P0496). Excessive vacuum can cause damage to the evap system if the CVS becomes coked closed during evap testing. Basically, with the purge flow commanded off, the CVS is closed and a vacuum growth or a stagnant vacuum is monitored over time. If the vacuum grows or does not dissipate then P1450/P0496 DTC sets and the evap integrity check is prohibited from running. Hence, P1450/P0496 DTC can only set outside the monitor, not inside it.

NOTE: If the 0.04" leak check monitor is ready to run but the excessive vacuum check test has not run, the leak monitor will force the excessive check to run.

Typical evap systemn layout:



Note: evap system may use in tank fuel pressure sensor or an in line fuel tank pressure sensor.

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<sub>2</sub>O 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.

On some vehicles, 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 a P0455, P0457, or P1450/P0496 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.

For the 2010 MY, a new PI controller was implemented to control the vacuum pull exactly to target. By doing so, the phase one stabilization time has been reduced.

## **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.

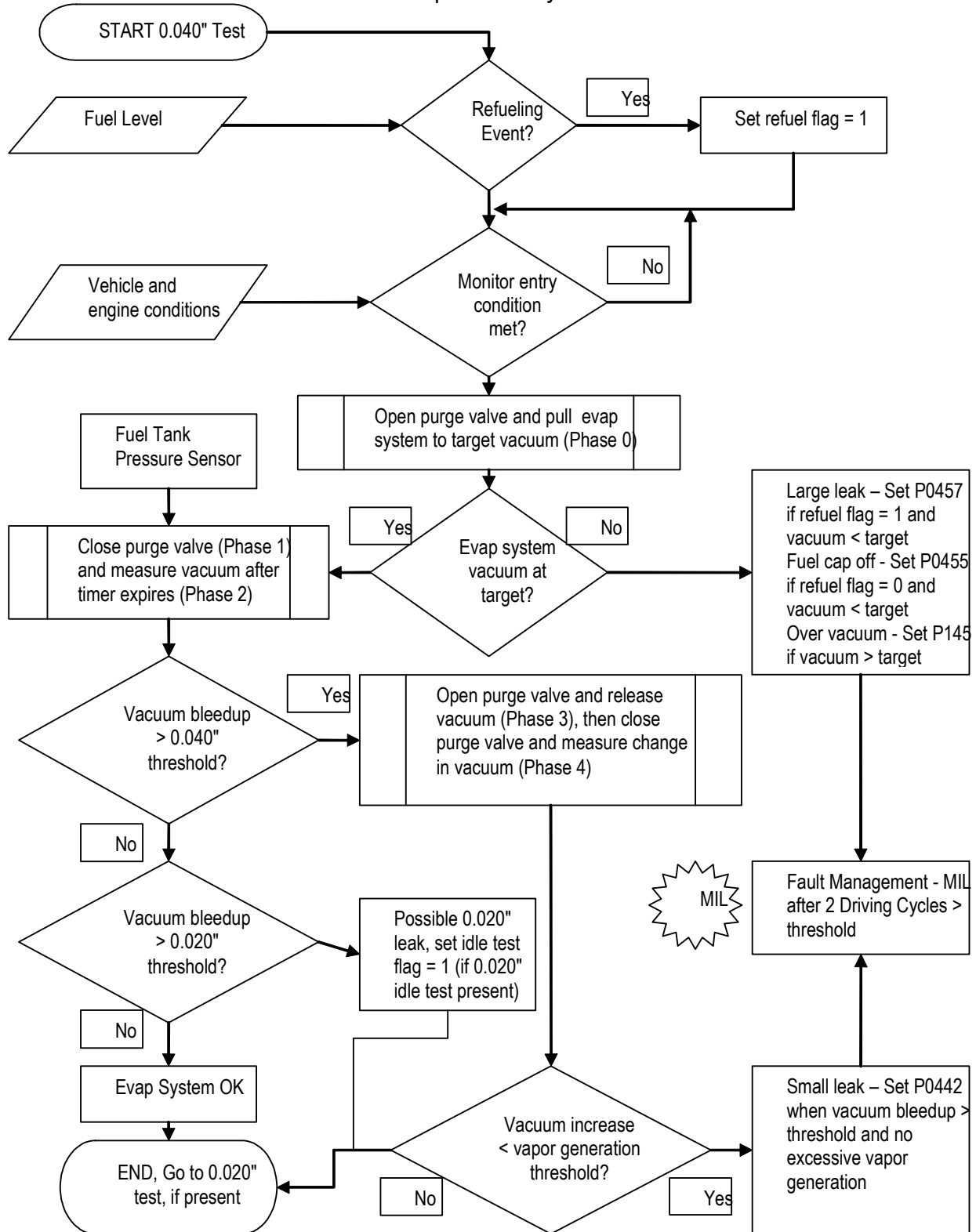
## **Phase 3 - Vacuum release**

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 - EVAP System Leak Detected (large leak) P0457 - EVAP System Leak Detected (fuel cap loose/off) P0442 - EVAP System Leak Detected (small leak) (0.040" leak), P1450 - Unable to Bleed Up Fuel Tank Vacuum (excessive vacuum) or P0496 - EVAP System High Purge Flow Note: P1450 is being replaced by P0496
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 time OR ECT at start – IAT at start $\leq 12^{\circ}\text{F}$	4 - 6 hours	
Time since engine start-up	330 seconds	1800 to 2700 seconds
Intake Air Temp	40 °F	95 - 100 °F
BARO (<8,000 ft altitude)	22.0 " Hg	
Engine Load	20%	70%
Vehicle Speed	40 mph	90 mph
Purge Duty Cycle	75%	100%
Purge Flow	0.05 lbm/min	0.10 lbm/min
Fuel Fill Level	15%	85%
Fuel Tank Pressure Range	- 17 H <sub>2</sub> O	1.5 H <sub>2</sub> O
Battery Voltage	11 volts	18 volts
Clean Canister		

**Typical 0.040" EVAP abort (fuel slosh) conditions for Phase 2:**

Change in load: > 30%
Change in tank pressure: > 1 " H <sub>2</sub> O
Change in fuel fill level: > 15%
Number of aborts: > 255
Vehicle Accel > 1 mph / sec

**Typical 0.040 EVAP monitor malfunction thresholds:**

P1450/P0496 (Excessive vacuum): < -4.0 in H<sub>2</sub>O delta vacuum from time that CVS is closed, or > -4. in H<sub>2</sub>O stagnant vapor over a 10 second evaluation time.

P0455 (Gross leak): > -8.0 in H<sub>2</sub>O over a 30 second evaluation time.

P0457 (Gross leak, cap off): > -8.0 in H<sub>2</sub>O over a 30 second evaluation time after a refueling event.

P0442 (0.040" leak): > 2.5 in H<sub>2</sub>O bleed-up over a 15 second evaluation time at 75% fuel fill. (Note: bleed-up and evaluation times vary as a function of fuel fill level and ambient air temperature)

P0442 vapor generation limit: < 2.5 in H<sub>2</sub>O over a 120 second evaluation time

**J1979 Evaporative System Mode \$06 Data prior to 2017 MY**

Test ID	Comp ID	Description	Units
\$3A	\$80	Phase 0 end pressure result and test limits (data for P1450/P0496 – excessive vacuum)	Pa
\$3A	\$81	Phase 4 vapor generation minimum change in pressure and test limits (data for P1450/P0496, 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.

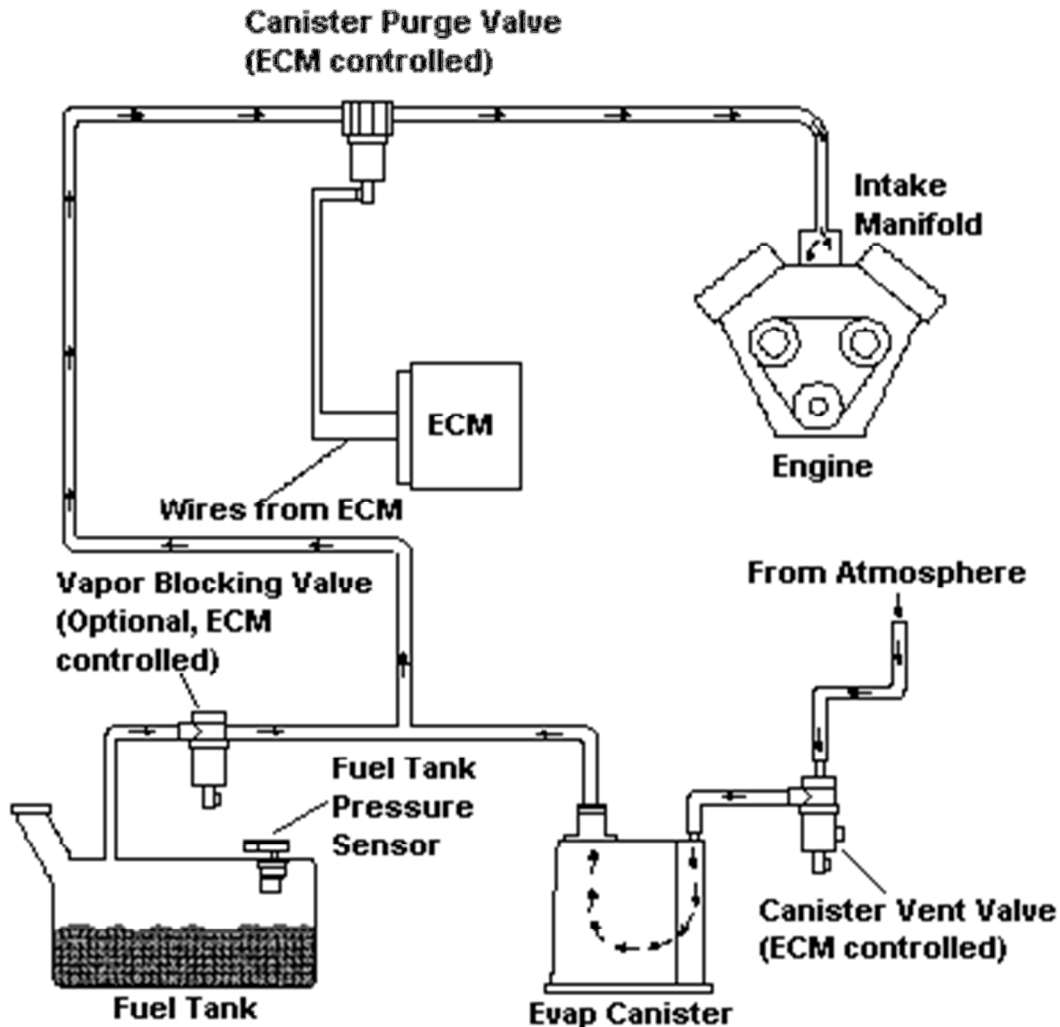
**J1979 Evaporative System Mode \$06 Data for 2017 MY and beyond**

Test ID	Comp ID	Description	Units
\$39	\$82	HD 0.150" Leak test - Phase 0 end pressure result and test limits (data for P0455/P0457 – gross leak/cap off) (P0455)	Pa
\$3A	\$83	0.090" Leak test - Phase 2 0.040"/0.090" leak check vacuum bleed-up and maximum 0.040"/0.090" leak threshold (P0442)	Pa
\$3B	\$83	0.040" Leak test - Phase 2 0.040" leak check vacuum bleed-up and maximum 0.040" leak threshold (P0442)	Pa
\$3D	\$88	Purge Flow Monitor - Excessive vacuum limit (Fail on time out) (P1450/P0496)	Pa
\$3D	\$88	Purge Flow Monitor - Excessive vacuum limit (Fail on delta pressure) (P1450/P0496)	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

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 separate, stay-alive 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 stay-alive microprocessor draws substantially less battery current than the PCM; therefore, powering only the stay-alive micro 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.

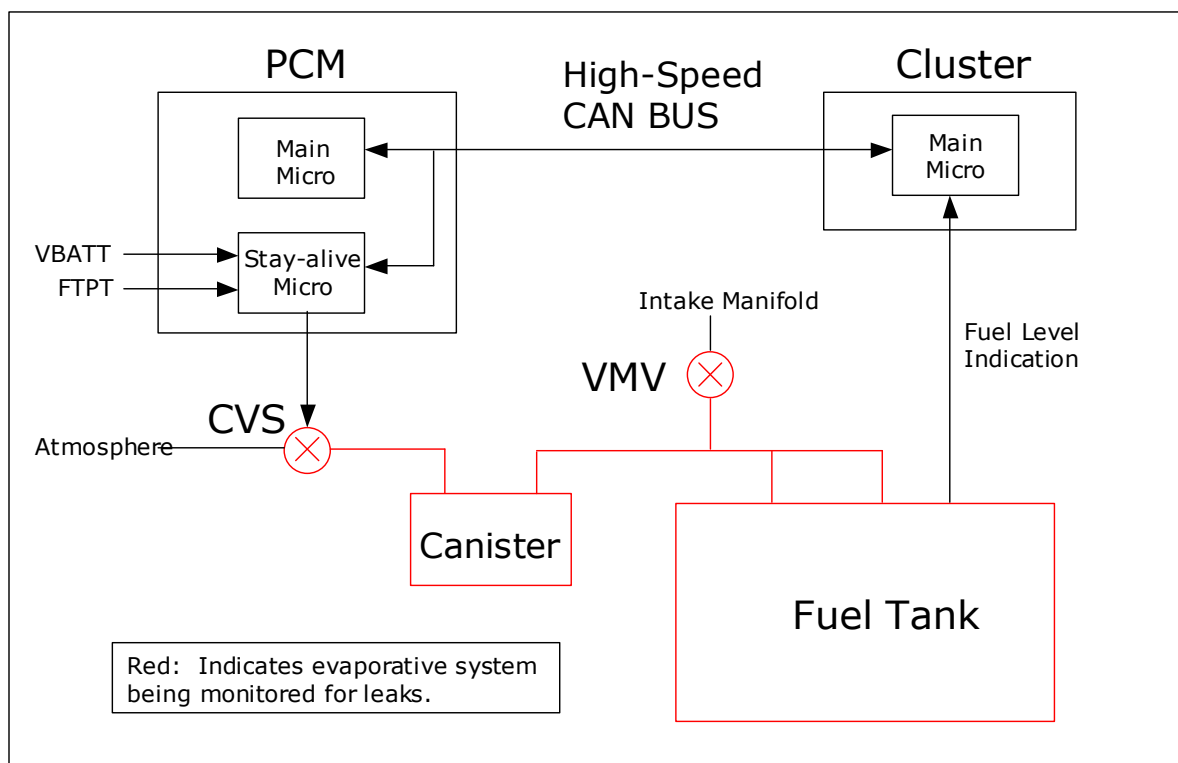
#### Inputs to EONV Microprocessor

- Fuel Tank Pressure
- Battery Voltage

#### Outputs from EONV Microprocessor

- Canister Vent Solenoid
- 0.020" leak data

## MY2005 EONV System Hardware Design



For new 2009 MY and beyond applications, EONV implementation is done in the main microprocessor. The main micro stays alive at key off in a special low power mode to run the EONV test. There is no longer a special standalone chip for EONV. The feature is called EONVM (EONV in the Main).

## **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<sub>2</sub>O 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.

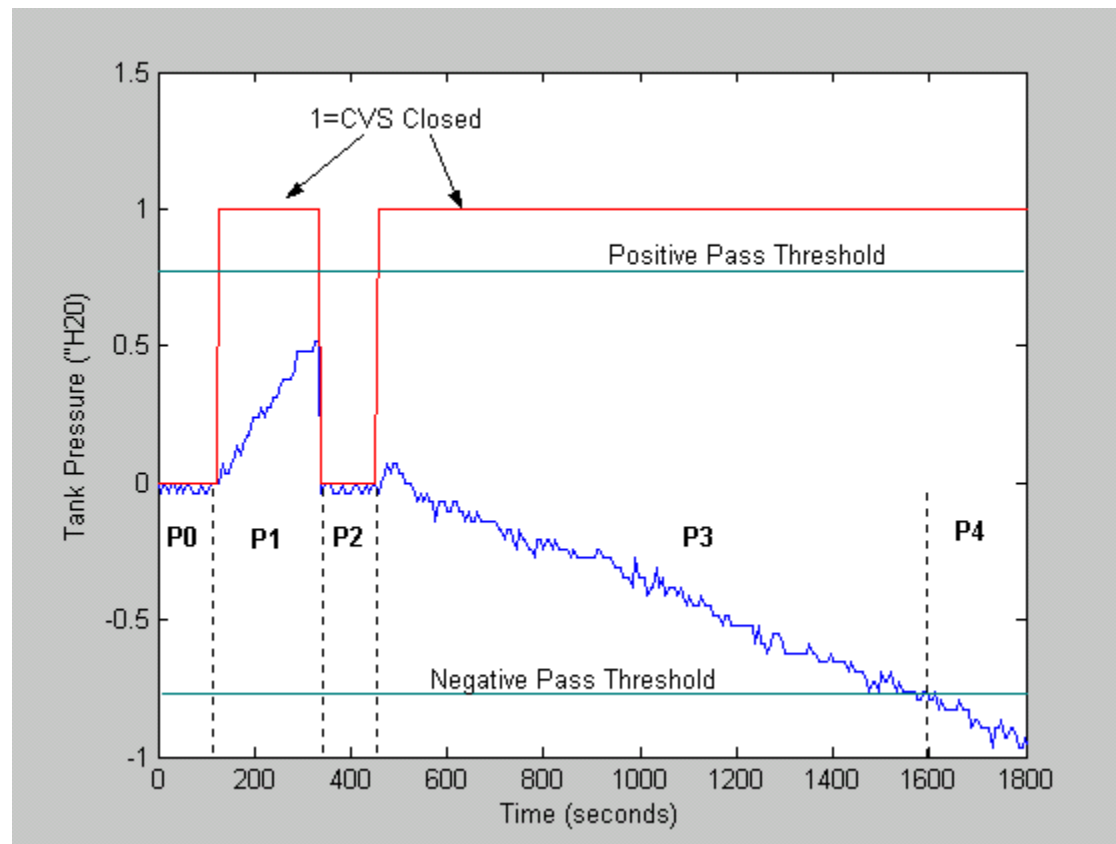
## **Post-2009 Model Year Fault Filtering**

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



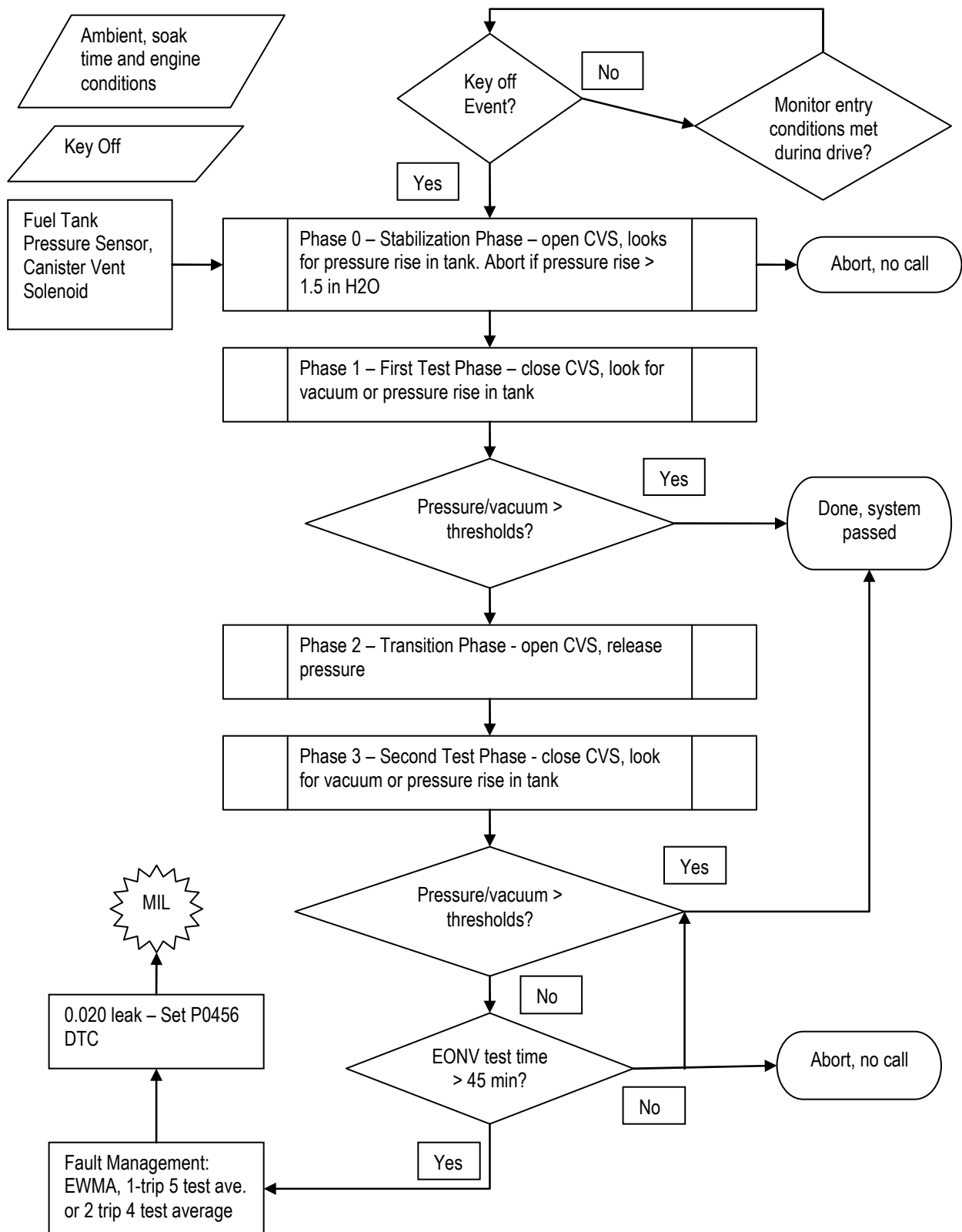
P0 = Phase 0, Stabilization Phase – With CVS open, Tank Pressure is allowed to stabilize. A fuel volatility test is performed and FTPT offset correction is learned if volatility test passes.

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 Complete – CVS opens (not pictured in above data file), results are recorded, and stay-alive electronics shutdown.



<b>0.020" EONV EVAP Monitor Operation:</b>	
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.

<b>Typical 0.020" EONV EVAP monitor entry conditions:</b>		
Entry conditions to allow EONV test (prior to key off)	Minimum	Maximum
Engine off (soak) time	3.5 - 6 hours	
OR		
Inferred soak criteria met: - (ECT at start – IAT at start )		12 °F F
Inferred soak criteria met – ECT at start	35 °F F	105 °F F
Inferred soak criteria met - minimum engine off soak time	0 sec	
Time since engine start-up to allow EONV test	20 minutes	90 minutes
Ambient Temperature at start-up	40 °F	95 °F
Battery Voltage to start EONV test	11 volts	
Number of completed EONV tests in 24hr cycle		6
Cumulative test time in 24hr cycle		90 minutes
Fuel level	15%	85%
ECU time since power-up to allow EONV test	180 seconds	
Flex fuel inference complete	Learned	
BARO (<8,000 ft altitude)	22.0 " Hg	
Summation of air mass of the combustion engine since start ensures that vehicle has been operated off idle (function of ambient temperature).	7500 to 15000 lbm/min	
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.)	0.8	

**Typical 0.020" EONV EVAP key-off abort conditions:**

Tank pressure at key-off > 1.5" H<sub>2</sub>O during stabilization phase (indicates excessive vapor)

Tank pressure not stabilized for tank pressure offset determination

Rapid change in tank pressure > 0.5"H<sub>2</sub>O (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 (only for standalone satellite micro applications)

Canister Vent Solenoid fault detected

Driver turns key-on

**Typical 0.020 EONV EVAP monitor malfunction thresholds:**

P0456 (0.020" leak): < 0.75 in H<sub>2</sub>O pressure build and

< 0.50 in H<sub>2</sub>O 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	Units
\$3C	\$81	EONV Positive Pressure Test Result and Limits (data for P0456)	Pa
\$3C	\$82	EONV Negative Pressure (Vacuum) Test Result and Limits(data for P0456)	Pa
\$3C	\$83	Normalized Average of Multiple EONV Tests Results and Limits (where 0 = pass, 1 = fail) (data for P0456)	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/P0496.

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/P0496, 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 an open power input circuit or stuck check valve generates a P1450/P0496.

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 <sub>2</sub> O
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, 10 seconds for noisy sensor test

**Typical Fuel Tank Pressure Sensor check malfunction thresholds:**

P0452 (Fuel Tank Pressure Sensor Circuit Low): < -17.82 in H<sub>2</sub>O

P0453 (Fuel Tank Pressure Sensor Circuit High): > 16.06 in H<sub>2</sub>O

P0454 (Fuel Tank Pressure Sensor Circuit Noisy): > open circuit, short circuit or > 4 in H<sub>2</sub>O change between samples, sampled every 100 msec

**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/P0496 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	4 - 6 hours	
Fuel Tank Pressure Sensor Variation during test		0.5 in H <sub>2</sub> O
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<sub>2</sub>O +/- 2.0 in H<sub>2</sub>O

The **Fuel Level Input** is checked for out of range values (opens/ shorts). The FLI input is obtained from the serial data link from the instrument cluster. If the FLI signal is open or shorted, the appropriate DTC is set (P0462 circuit low and P0463 circuit high).

Vehicles with a "saddle tank" (a tank that wraps over the axle) have two fuel level senders. The FLI input is obtained from the serial data link from the instrument cluster. If the FLI signal is open or shorted, the appropriate DTC is set (P2067 circuit low and P2068 circuit high). A "jet pump" pumps fuel from the passive side of the saddle tank (Sensor B) to the active side of the saddle tank (Sensor A) where the main fuel pump supplies the engine with fuel. This means that the active side of the fuel tank typically has a high fuel level reading because it is constantly filled by the jet pump. For purposes of computing vehicle fuel level, the two FLI readings are averaged together into one signal that represents the combined fuel level.

Finally, the Fuel Level Input is checked for noisy readings. If the FLI input continues to change > 40% between samples, a P0461 or P2066 DTC is set.

<b>Fuel Level Input Check Operation:</b>	
DTCs	P0461 – Fuel Level Sensor A Circuit Noisy P0462 – Fuel Level Sensor A Circuit Low P0463 – Fuel Level Sensor A Circuit High P2066 – Fuel Level Sensor B Circuit Noisy P2067 – Fuel Level Sensor B Circuit Low P2068 – Fuel Level Sensor B Circuit High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	30 seconds for electrical malfunctions,

<b>Typical Fuel Level Input check malfunction thresholds:</b>
P0460 or P0462 (Fuel Level Input Circuit Low): < 5 ohms (< 1 A/D count) P0460 or P0463 (Fuel Level Input Circuit High): > 200 ohms (>253 A/D counts) P0461 or P2066 (Fuel Level Input Noisy): > 40% change between samples, > 100 occurrences, sampled every 0.100 seconds

The FLI signal is also checked to determine if it is stuck. "Fuel consumed" is continuously calculated based on PCM fuel pulse width summation as a percent of fuel tank capacity. (Fuel consumed and fuel gauge reading range are both stored in KAM and reset after a refueling event or DTC storage.) If 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.

For saddle tanks that use two fuel senders, P25B0 is set for Fuel Sensor A stuck, P25B1 is set for Fuel Sensor B stuck and P25B2 is set for Fuel Sensor A or B stuck. The active side of the fuel tank typically has a high fuel level reading because it is constantly filled by the jet pump while the passive side changes as fuel is consumed. The level of the active tank will decrease after the fuel in the passive side is consumed. To help identify a stuck sensor faster, vehicles decels and accels are used to identify the absence of movement in the FLI signal when it was expected to move due to fuel slosh.

Fuel Level Input Stuck Check Operation:	
DTCs	P0460 – Fuel Level Input Circuit Stuck or P25B0 - Fuel Level Sensor "A" Stuck P25B1 - Fuel Level Sensor "B" Stuck P25B2 - Fuel Level Sensor "A" or "B" Stuck
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	Between 15 and 85%, monitoring can take from 100 to 120 miles to complete

Typical Fuel Level Input Stuck check malfunction thresholds:	
P0460/P25B0/P25B1/P25B2 (Fuel Level Input Stuck):	
Fuel level stuck at greater than 90%: > 60% difference in calculated fuel tank capacity consumed versus change in fuel level input reading	
Fuel level stuck at less than 10%: > 30% difference in calculated fuel tank capacity consumed versus change in fuel level input reading	
Fuel level stuck between 10% and 90%: > 25% difference in calculated fuel tank capacity consumed versus change in fuel level input reading	

The **Evap Monitor Microprocessor** is checked for proper microprocessor operation or loss of CAN communication with the main microprocessor (P260F). Applies only if EONV is in separate microprocessor.

Evap Monitor Microprocessor Performance:	
DTCs	P260F - Evap System Monitoring Processor Performance
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

## Evap Switching Valve (EVAPSV) Diagnostics

The Evap Switching Valve (EVAPSV) is included on HEV applications in the 2009 MY and Stop/Start applications beginning in the 2013 MY. 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.

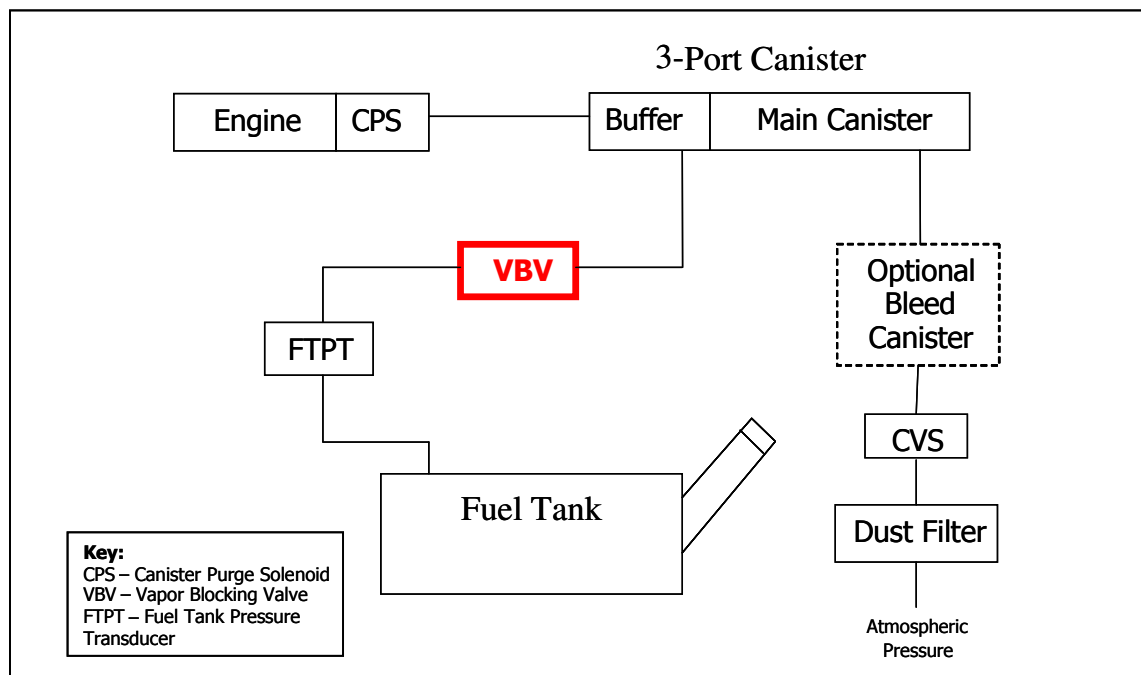
The VBV circuit and functional diagnostics will set the following DTCs:

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 (VBV) in Phase 3 of the evap monitor cruise test if the 0.040" leak test passes. At the end of Phase 2, tank pressure will be in the range of -8 to -4 "H<sub>2</sub>O and the EVAPSV will be open. At the beginning of Phase 3, the EVAPSV is commanded closed and the CVS is commanded open. When the CVS opens to atmosphere, the tank pressure decay rate is monitored for a calibrated period of time and a slope (rate) calculation is completed. The EVAPSV is then commanded open and a similar decay slope calculation is completed. The EVAPSV is then commanded open and a similar decay slope calculation is completed. A ratio of the two rate slope calculations is performed. If the calculated ratio is less than a calibrated value, a P2450 DTC is set. A low ratio indicates that the EVAPSV did not transition. (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 during Phase 3 of the evap 0.040" cruise test
Sensors/Components OK	MAF, IAT, VSS, ECT, CKP, TP, FTP, CPV, CVS
Monitoring Duration	2 to 3 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%

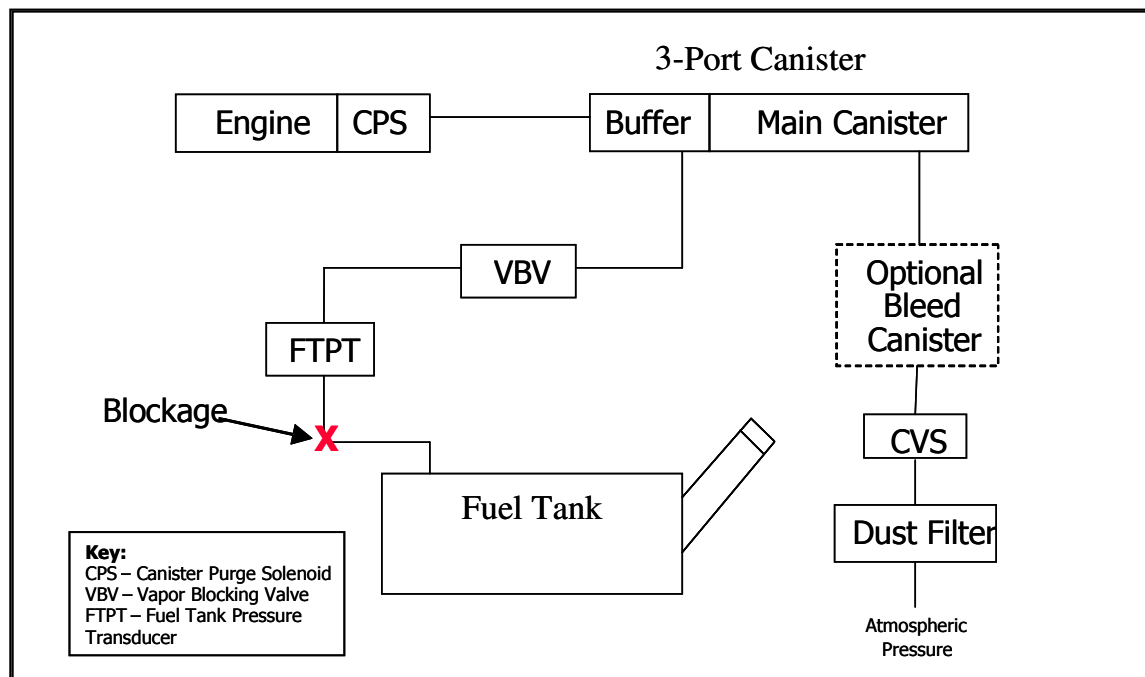
Typical EVAP Switching Valve (EVAPSV) malfunction thresholds:
P2418: Presence of short, open, or intermittent fault for more than 5 seconds
P2450: Calculated ratio < 2.75

J1979 Evaporative System Mode \$06 Data			
Test ID	Comp ID	Description	Units
\$3D	\$82	Vapor blocking valve performance (P2450)	Unitless
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.			

## Blocked Purge Line Diagnostics

If an in-line Fuel Tank Pressure Transducer (FTPT) 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 or P00FE DTC.

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



<b>EVAP Blocked Line Monitor Operation:</b>	
DTC	P144A - EVAP System Purge Vapor Line Restricted/Blocked or P00FE - EVAP System Tank Vapor Line Restricted/Blocked Note: P144A DTC is being replaced by P00FE
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)

<b>Typical Blocked Line monitor entry conditions:</b>		
Entry condition	Minimum	Maximum
General 0.040" Cruise Test conditions apply		
Air mass high enough for intrusive portion of test	1.5 (lb/min)	
Manifold vacuum high enough for intrusive portion of test	5 "Hg	
Not in open loop fueling		
CPV purging		

<b>Typical EVAP Blocked Line abort conditions:</b>
All items cited under entry conditions apply.

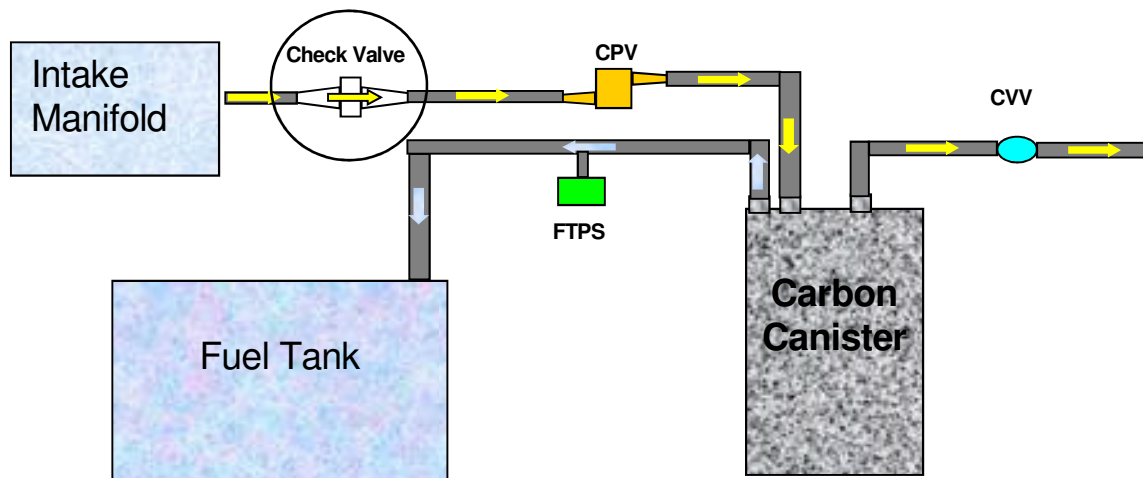
<b>Typical EVAP Blocked Line malfunction thresholds:</b>
P144A/P00FE: Phase 0 portion of test delta pressure < -5 "H <sub>2</sub> O/sec
P144A/P00FE: Phase 3 & 4 (intrusive test) pressure response < -2 "H <sub>2</sub> O

<b>J1979 Evaporative System Mode \$06 Data</b>			
Test ID	Comp ID	Description	Units
\$3D	\$80	Blocked Evap System Line - Screening test (P144A/P00FE)	Pa/sec
\$3D	\$81	Blocked Evap System Line - Fault confirmation test (P144A/P00FE)	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.			

## Single Path Purge Check Valve Diagnostics

Boosted applications use a mechanical check valve between the intake manifold and the Canister Purge Valve (CPV). The purpose of this check valve is to prevent reverse flow through the evaporative emissions system under boosted conditions. The check valve is a simple diaphragm type valve where the rubber diaphragm slides inside a cylinder and is pushed against a stop under boost closing off flow through the valve. While at atmosphere or under vacuum the valve is pulled off the stop allowing flow from the evaporative system to the intake manifold. The check valve diagnostic looks for a failed open, improperly installed, or missing valve that could result in intake manifold vapors being pushed back into the evaporative emissions system (see figure below). A failed check valve is detected if the rate of rise in Fuel Tank Pressure Sensor is greater than a calibratable threshold while the Canister Vent Valve is closed, Canister Purge Valve open, and the engine is boosted above a minimum level (under boost the system should be sealed if the check valve is operating properly). This condition will set DTC P144C/P04F0.

Figure: System schematic showing the potential for reverse flow if the check valve is failed.



<b>Evaporative System Purge Check Valve Performance Diagnostic Operation:</b>	
DTC	P144C - Evaporative Emission System Purge Check Valve Performance or P04F0 - EVAP System High Load Purge Line "A" Performance Note: P144C is being replaced by P04F0
Monitor execution	Once per driving cycle, during boosted operation
Monitor Sequence	None
Sensors/Components OK	ECT/CHT, IAT, MAP, CPV, CVV, FTPT, FLI, BARO, TIP
Monitoring Duration	5 to 10 seconds depending on level of boost

<b>Typical Evaporative System Purge Check Valve Performance Entry Conditions</b>		
Entry condition	Minimum	Maximum
Ambient temperature (IAT)	40 °F	95 °F
Battery Voltage	11.0 Volts	
Fuel level	15%	85%
Engine Coolant Temperature (CHT/ECT)	160 °F	
Atmospheric Pressure (BARO)	23" Hg	
Boost Pressure (MAP – BARO)	4 to 8" Hg	
Engine Delta Load	0.2	
Vehicle Acceleration	0.5 mph / sec	

<b>Typical Evaporative System Purge Check Valve Diagnostic malfunction thresholds:</b>
Pressure Rise Rate (delta pressure / delta time) > 0.50 " H <sub>2</sub> O/sec Threshold is a function of fuel level with a range of 0.5 to 1.0

## Dual Path Purge Check Valve Diagnostics

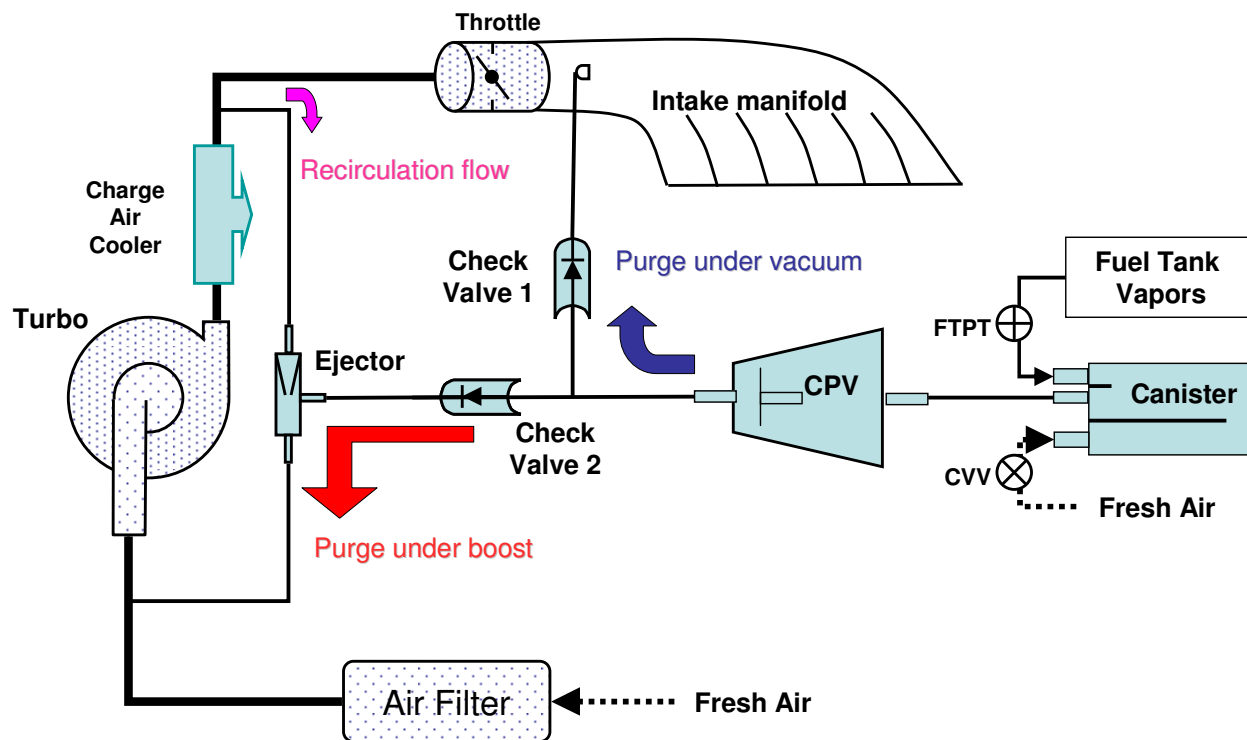
Boosted applications that have a lower power-to-weight ratio use two purge flow paths to allow purge under boost conditions in addition to normal vacuum conditions.

Dual path purge applications use a mechanical check valve 1 (CV1) between the intake manifold and the Canister Purge Valve (CPV). During non-boosted conditions, purge vapors go through check valve 1 before entering the intake. The purpose of this check valve is to prevent reverse flow through the evaporative emissions system under boosted conditions. The check valve is a simple diaphragm type valve where the rubber diaphragm slides inside a cylinder and is pushed against a stop under boost closing off flow through the valve.

A second identical check valve 2 (CV2) is used to facilitate purging during boost. During boosted conditions, a venturi device, called an ejector, is used to generate the needed vacuum for purging. The purge vapors flow through CV2, the turbo charger, and the charge air cooler before entering the intake manifold.

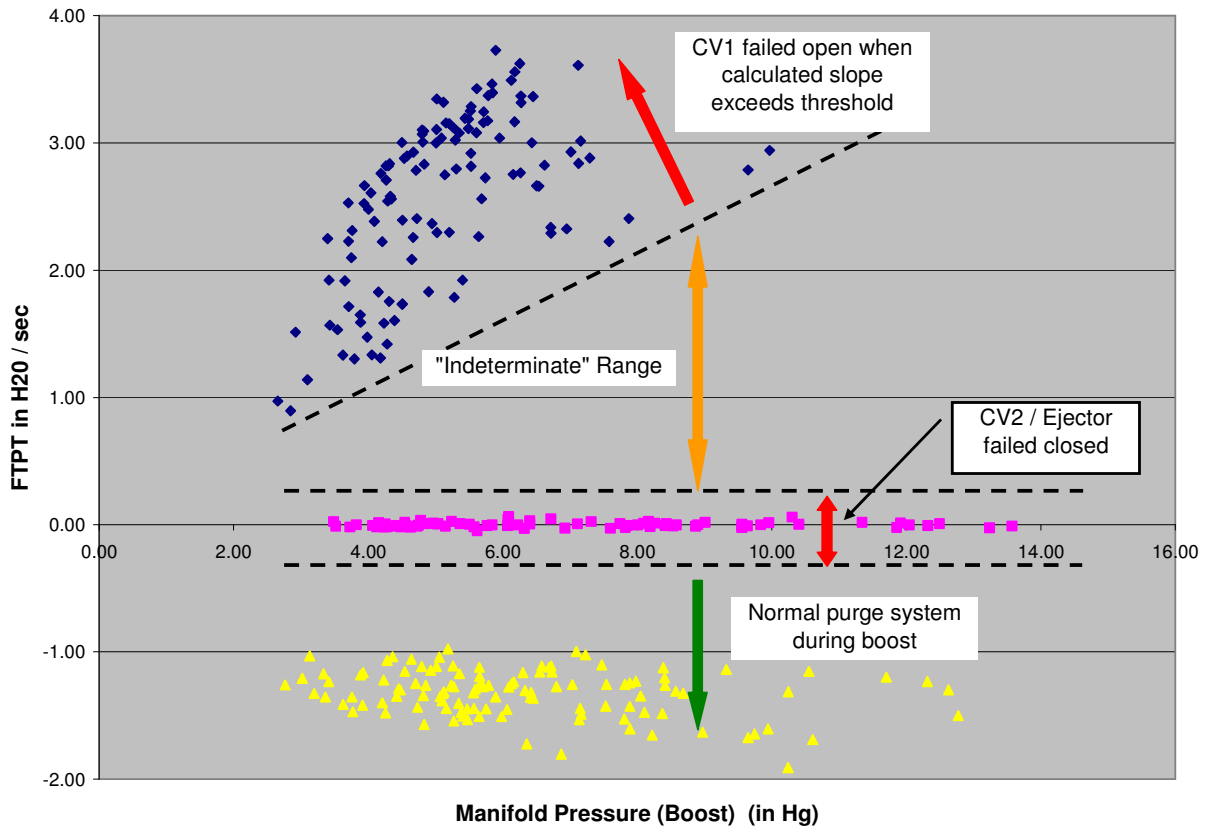
The check valve diagnostic looks for a failed open CV1, a failed closed CV2, a failed ejector, an improperly installed CV1 or CV2, or missing CV1 that could result in intake manifold vapors being pushed back into the evaporative emissions system or lack of purge under boost.

## Dual-path Purge for Turbo DI engines



A failed CV1 is detected if the rate of rise in Fuel Tank Pressure Sensor is greater than a calibratable threshold while the Canister Vent Valve is closed, Canister Purge Valve open, and the engine is boosted above a minimum level. Under boost, the system should be sealed if the check valve is operating properly. This condition will set DTC P144C/P04F0.

A failed CV2 is detected if the rate of change of ejector generated vacuum is relatively flat within a threshold window during boosted conditions. This will set DTC P144C/P04F0. Steep vacuum slopes for CV2 are indicative of good functioning valves. See the figure below for CV1/CV2 pass and fail ranges.



**Evaporative System Purge Check Valve Performance Diagnostic Operation:**

DTC	P144C - Evaporative Emission System Purge Check Valve Performance or P04F0 - EVAP System High Load Purge Line "A" Performance Note: P144C is being replaced by P04F0
Monitor execution	Once per driving cycle, during boosted operation
Monitor Sequence	None
Sensors/Components OK	ECT/CHT, IAT, MAP, CPV, CVV, FTPT, FLI, BARO, TIP, WASTEGATE
Monitoring Duration	5 to 10 seconds depending on level of boost

**Typical Evaporative System Purge Check Valve Performance Entry Conditions**

Entry condition	Minimum	Maximum
Ambient air temperature	40 ° F	105 ° F
Battery Voltage	11.0 Volts	
Fuel level	15%	90%
Engine Coolant Temperature	160 ° F	
Atmospheric Pressure (BARO)	23" Hg	
Boost Pressure (MAP – BARO)	8" Hg	

**Typical Evaporative System Purge Check Valve Diagnostic malfunction thresholds:**

CV1- Pressure Rise Rate (delta pressure / delta time) > 1 " H<sub>2</sub>O/sec

CV1- Threshold is a function of fuel level with a range of 1.5 to 2.6

CV2- Vacuum Rate (delta vacuum / delta time) >-0.4 and < 0.5 H<sub>2</sub>O/sec

CV2- Threshold is a function of fuel level with a range of 0.5 to 0.7 for the upper band and -0.4 to -0.3 for the lower band

**J1979 Evaporative System Mode \$06 Data**

Test ID	Comp ID	Description	Units
\$3D	\$89	Check valve test for dual path purge. (Check Valve 1 Failed- P144C/P04F0)	Pa/sec
\$3D	\$89	Check valve test for dual path purge. (Check Valve 2 Failed- P144C/P04F0)	Pa/sec
\$3D	\$89	Check valve test for dual path purge. (Check Valve 1 and 2 Passed - P144CP04F0)	Pa/sec

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

The adaptive fuel strategy uses O2 sensors for fuel feedback. The fuel equation includes short and long term fuel trim modifiers:

$$\text{FUEL MASS} = \frac{\text{AIR MASS} * \text{SHRTFT} * \text{LONGFT}}{\text{EQUIV\_RATIO} * 14.64}$$

Where:

Fuel Mass = desired fuel mass

Air Mass = measured air mass, from MAF sensor

SHRTFT = Short Term Fuel Trim, calculated

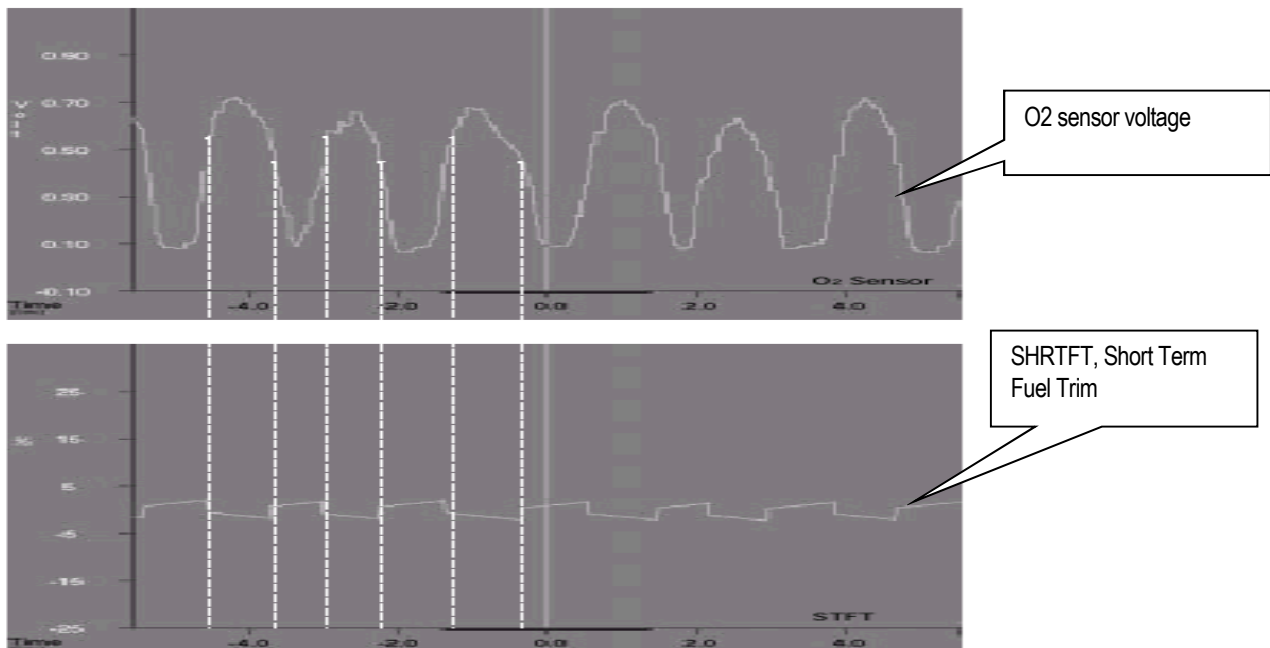
LONGFT = Long Term Fuel Trim, learned table value, stored in Keep Alive Memory

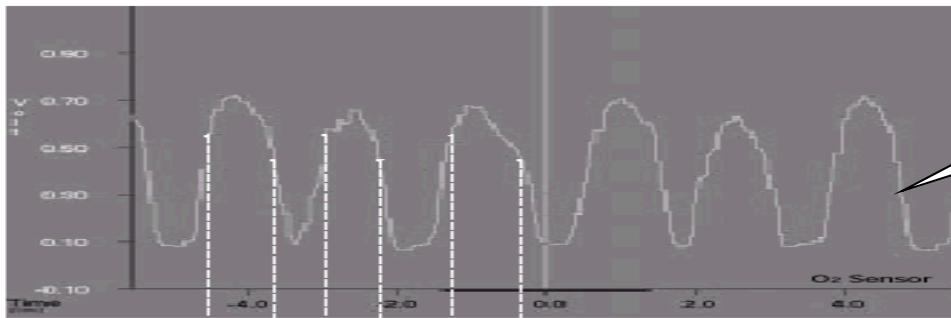
EQUIV\_RATIO = Desired equivalence ratio, 1.0 = stoich, > 1.0 is lean, < 1.0 is rich

14.64 = Stoichiometric ratio for gasoline

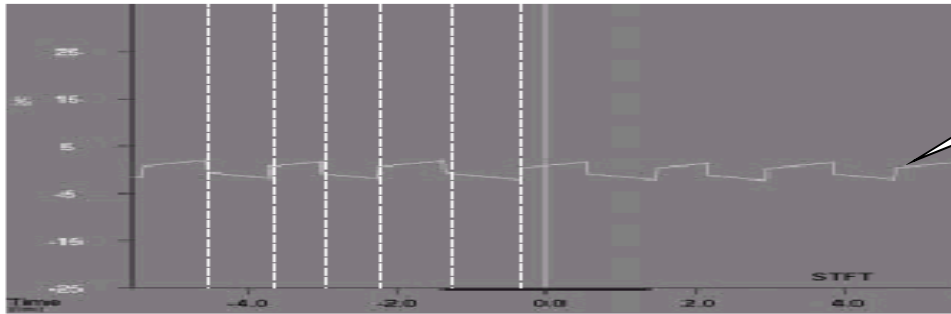
A conventional O2 sensor (not a wide-range sensor) can only indicate if the mixture is richer or leaner than stoichiometric. During closed loop operation, short term fuel trim values are calculated by the PCM using oxygen sensor inputs in order to maintain a stoichiometric air/fuel ratio. The PCM is constantly making adjustments to the short term fuel trim, which causes the oxygen sensor voltage to switch from rich to lean around the stoichiometric point. As long as the short term fuel trim is able to cause the oxygen sensor voltage to switch, a stoichiometric air/fuel ratio is maintained.

When initially entering closed loop fuel, SHRTFT starts 1.0 and begins adding or subtracting fuel in order to make the oxygen sensor switch from its current state. If the oxygen sensor signal sent to the PCM is greater than 0.45 volts, the PCM considers the mixture rich and SHRTFT shortens the injector pulse width. When the cylinder fires using the new injector pulse width, the exhaust contains more oxygen. Now when the exhaust passes the oxygen sensor, it causes the voltage to switch below 0.45 volts, the PCM considers the mixture lean, and SHRTFT lengthens the injector pulse width. This cycle continues as long as the fuel system is in closed loop operation.

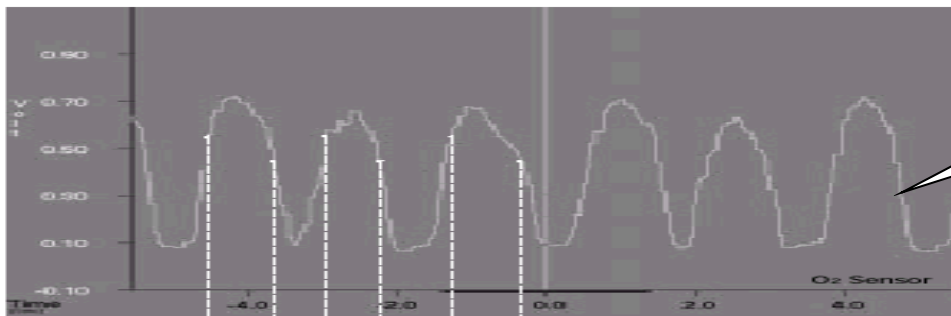




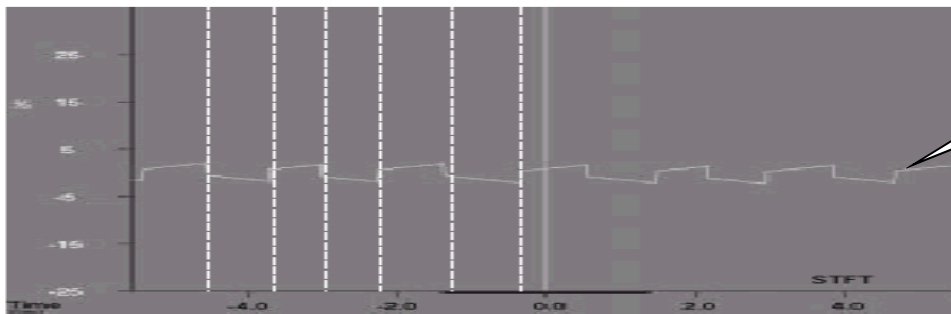
O2 sensor voltage



SHRTFT, Short Term  
Fuel Trim

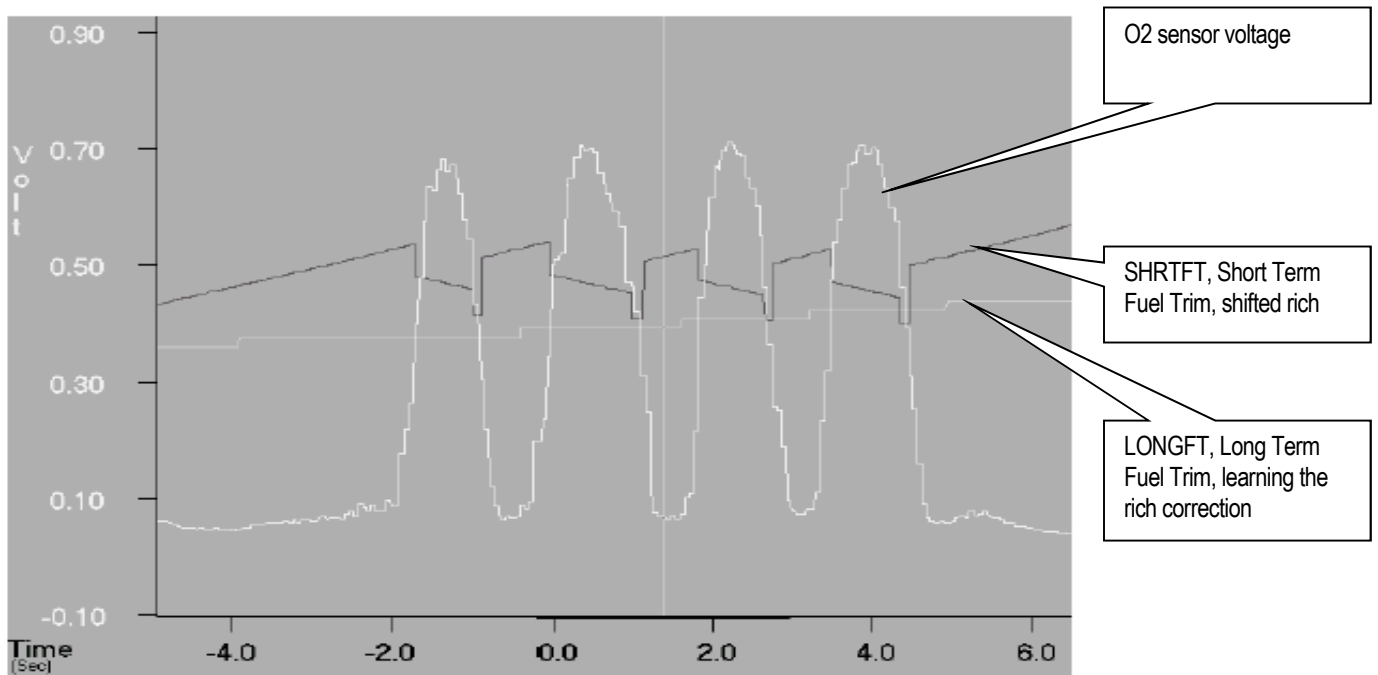
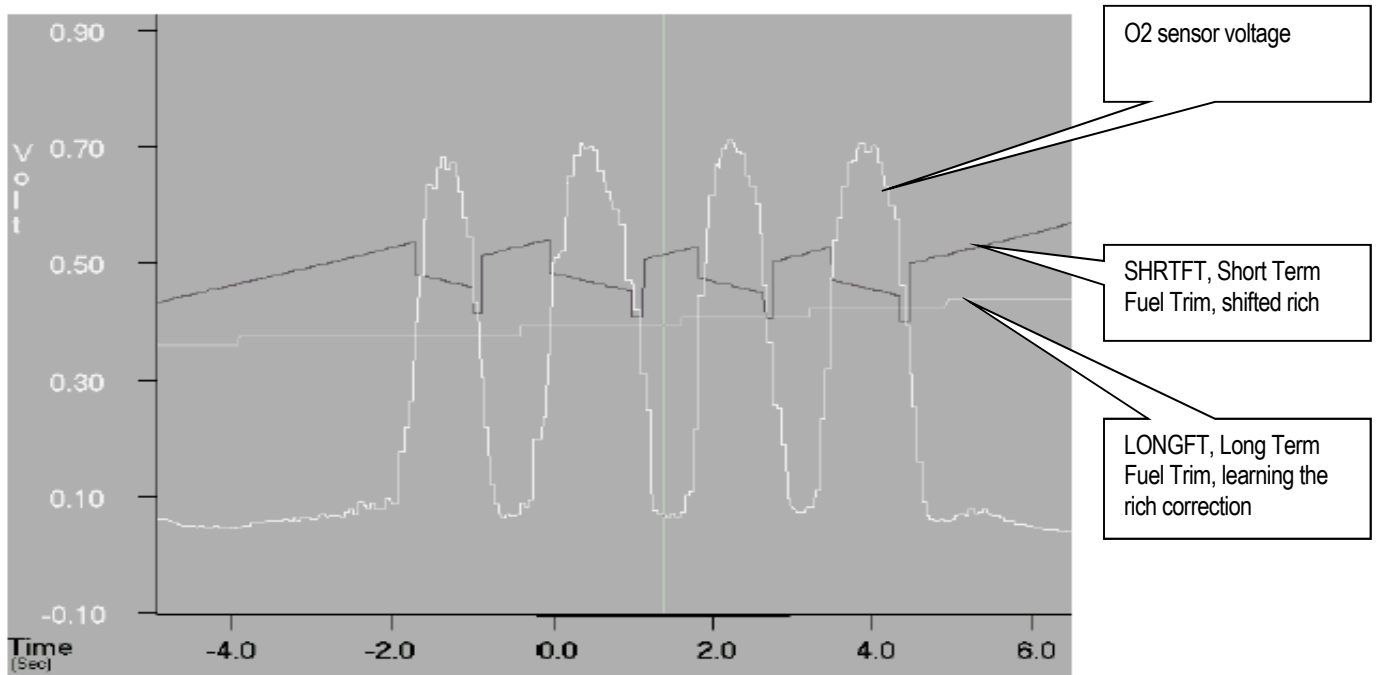


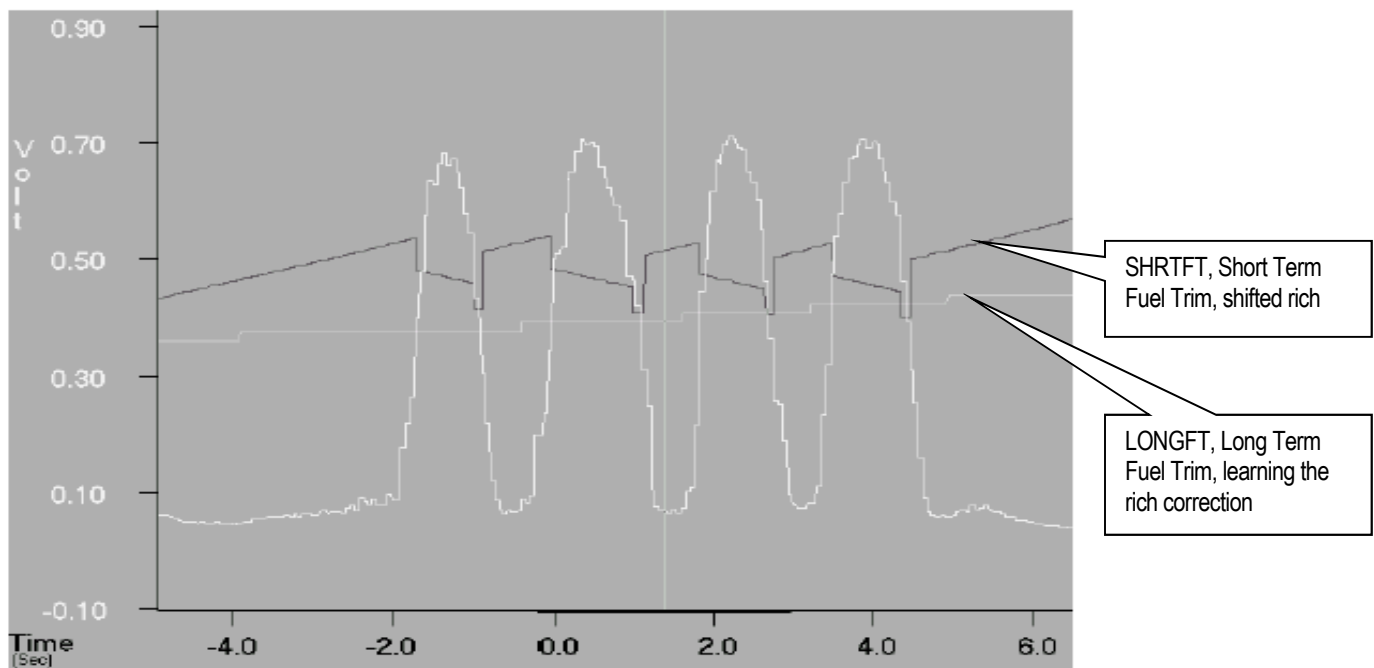
O2 sensor voltage



SHRTFT, Short Term  
Fuel Trim

As fuel, air, or engine 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. Corrections are only learned during closed loop operation, and are stored in the PCM as long term fuel trim values (LONGFT). They may be stored into an 8x10 rpm/load table or they may be stored as a function of air mass. LONGFT values are only learned when SHRTFT values cause the oxygen sensor to switch. If the average SHRTFT value remains above or below stoichiometry, the PCM “learns” a new LONGFT value, which allows the SHRTFT value to return to an average value near 1.0. LONGFT values are stored in Keep Alive Memory as a function of air mass. The LONGFT value displayed on the scan tool is the value being used for the current operating condition.

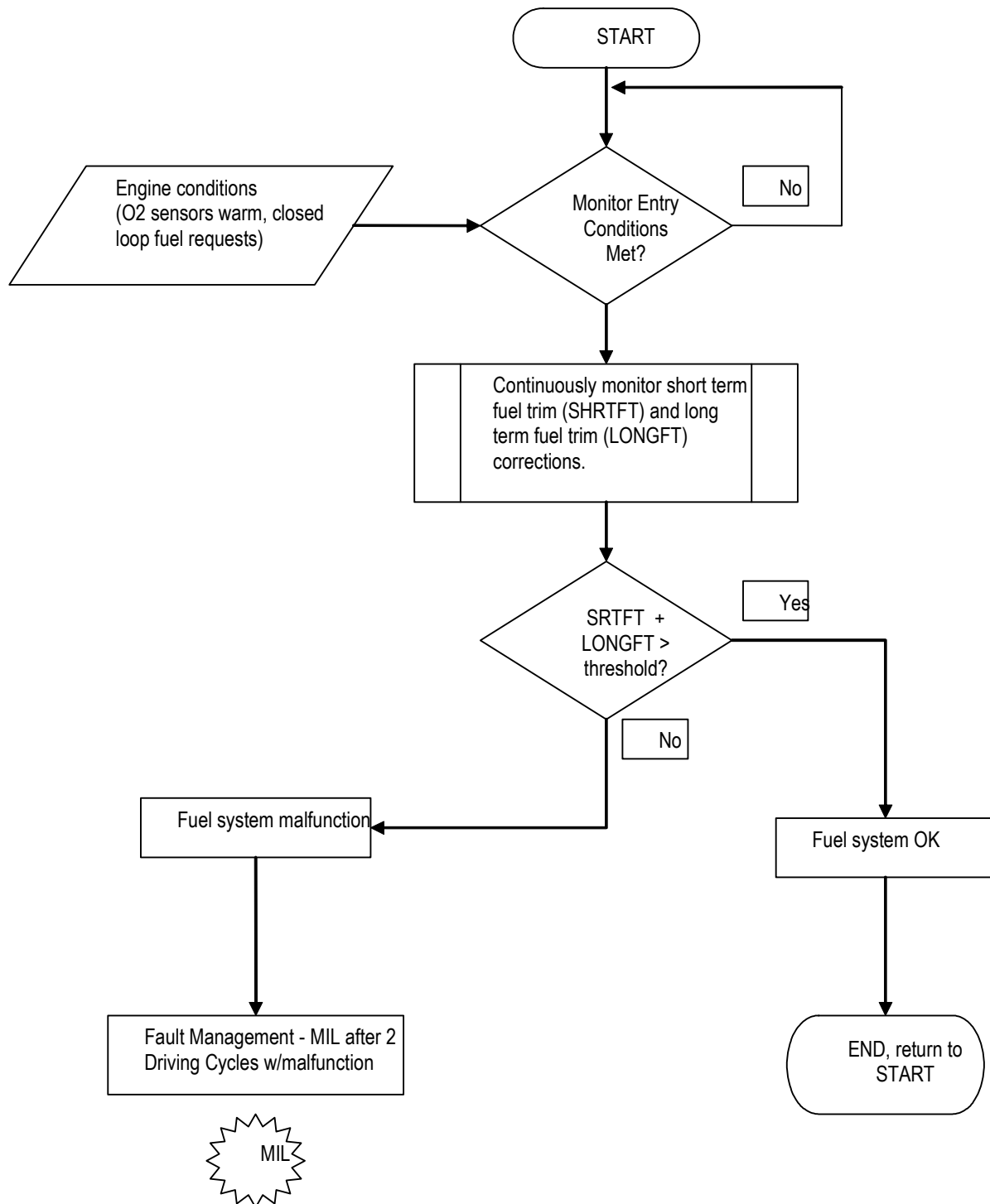




As components continue to change beyond normal limits or if a malfunction occurs, the long-term fuel trim values will reach a calibratable rich or lean limit where the adaptive fuel strategy is no longer allowed to compensate for additional fuel system changes. Long term fuel trim corrections at their 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.

## Fuel System Monitor



Fuel Monitor Operation:	
DTCs	P0171 Bank 1 Lean, P0174 Bank 2 Lean P0172 Bank 1 Rich, P0175 Bank 2 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	150 °F	250 °F
Engine load	12%	
Intake Air Temp	-30 °F	150 °F
Fuel Level	10%	
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 > 25%, SHRTFT > 1% Rich malfunction: LONGFT < 25%, SHRTFT < 1%

## 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) P2098 – Post catalyst fuel trim system too lean (Bank 2) P2099 – Post catalyst fuel trim system too rich (Bank 2)
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, MAP, VSS, TP, ETC, FRP, FVR, DPFE EGR, VCT, VMV/EVMV, CVS, CPV, EVAPSV, 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
Closed loop stoich fuel control		
Time since engine start	20 seconds	
Engine Coolant Temp	160 °F	250 °F
Time since entering closed loop fuel	20 seconds	
Fuel Level	15%	
Short Term Fuel Trim Range	-13%	18%
Air mass range	2 lbm/min	8 lbm/min
Learning conditions stability time (based on air mass)	15 seconds	
Injector fuel pulse width (not at minimum clip)	650 usec	
Inferred HO2S 2 Heated Tip Temperature	1100 °F	
No excessive movement between currently utilized long term fuel trim cells (1 = complete change from one cell to adjacent cell)		0.5
UEGO sensor within +/- 2 % from the fuel control target		
UEGO ASIC not in recalibration mode		
Stream1 UEGO response test not running		
Intrusive UEGO catalyst monitor not running		
Not performing intrusive UEGO Lack-of-Movement fuel control defib		
No air passing through during valve overlap (scavenging).		
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.
Lean malfunction: -0.083 rear bias trim limit
Rich malfunction: 0.087 rear bias trim limit

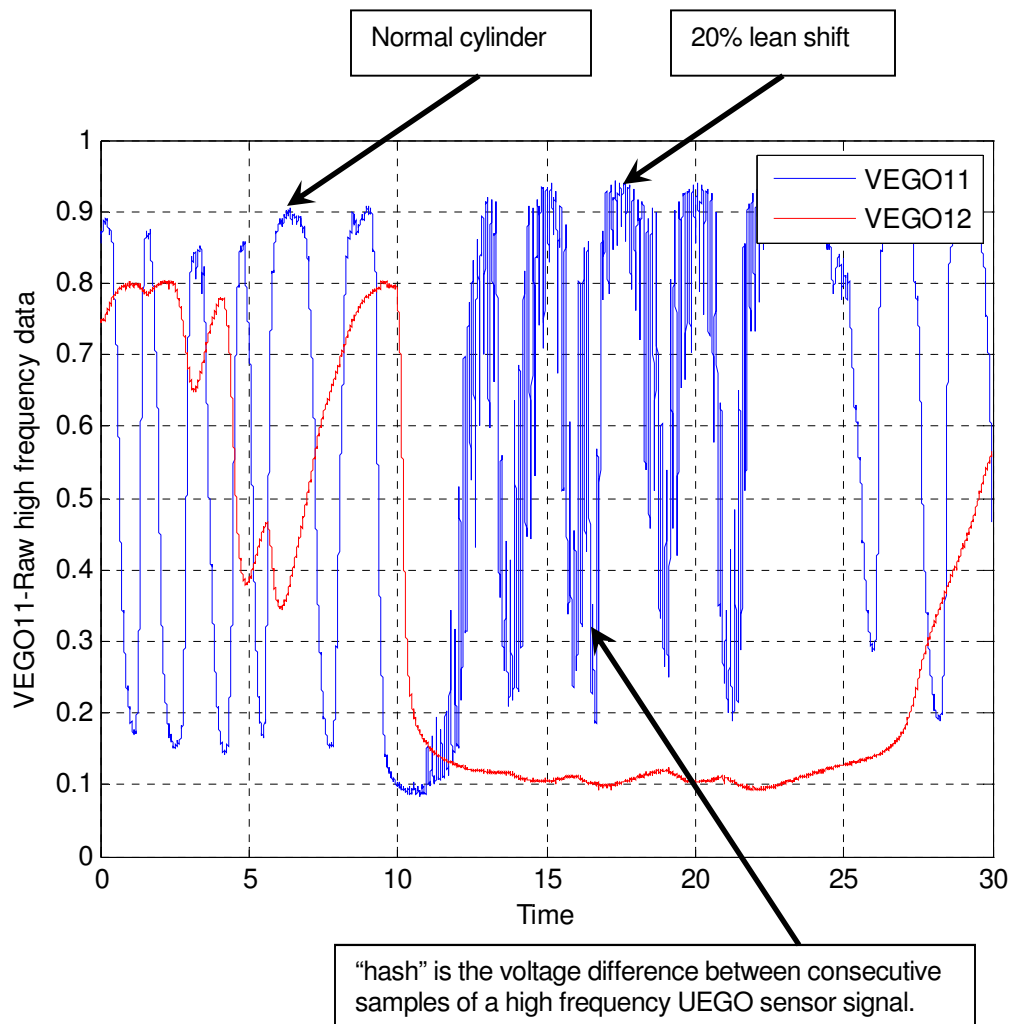
## Air Fuel Ratio Imbalance Monitor – O2 Sensor Monitor

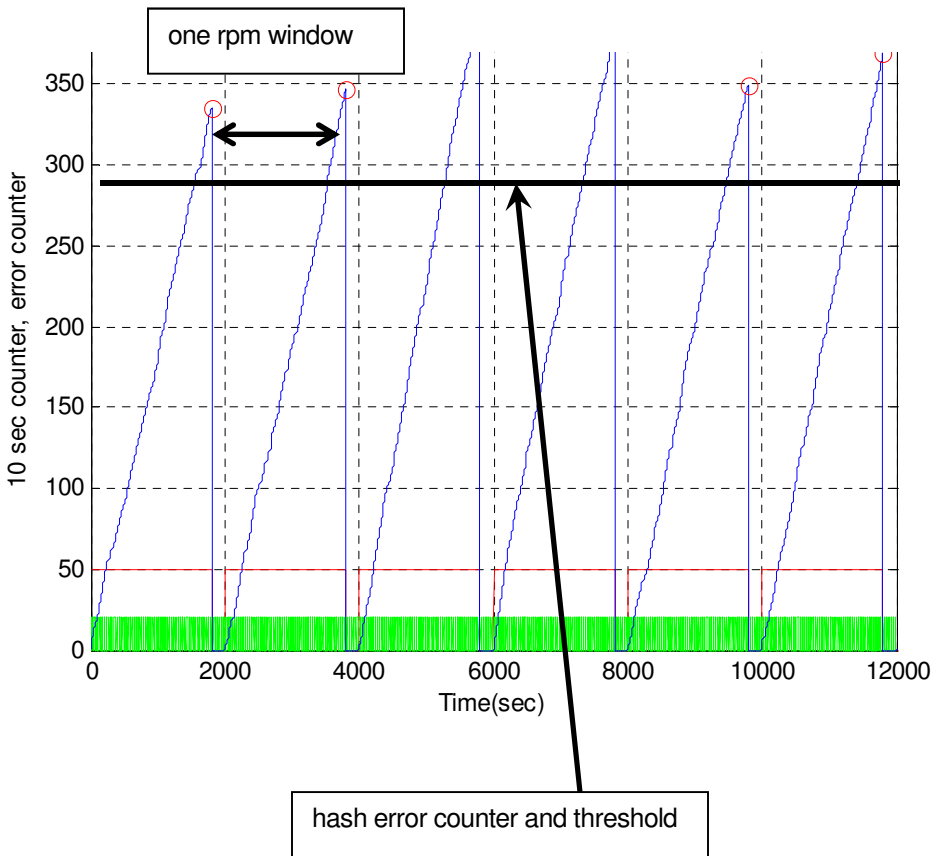
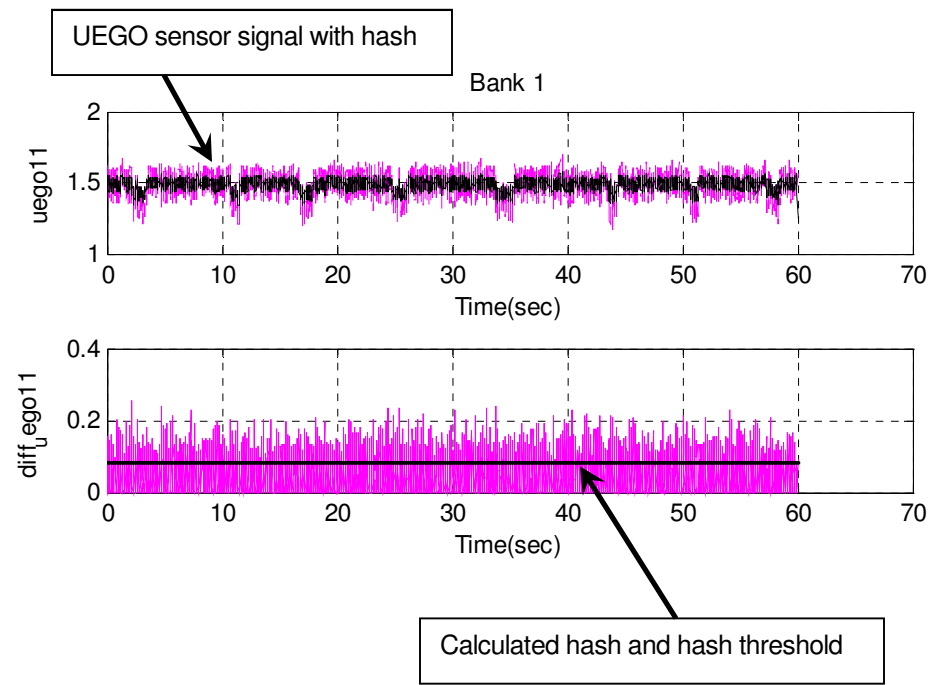
The Air Fuel Imbalance Monitor is designed to monitor the cylinder-to-cylinder air fuel imbalance per engine bank. When an Air Fuel (A/F) imbalance is present, the front UEGO signal becomes noisier. The monitor uses the high frequency component from the UEGO signal as an indicator of A/F imbalance. The UEGO signal may be either voltage or lambda, depending on the sensor ASIC being used.

"Hash" is the difference between two consecutive front UEGO voltage samples. The UEGO signal is monitored continuously and a differential or "hash" value is continuously calculated. When the hash is below a threshold, it is indicative of normal operation. If the hash exceeds the threshold, an A/F imbalance is assumed. The hash is accumulated (summed) over a calibratable period, typically 50 engine cycles. This period is referred to as a window.

Monitor completion requires each speed load cell to acquire a calibratable number of data windows. There are up to three speed load cells. Typically, each cell must acquire 30 data windows. In addition, the total number of data windows for all the cells must be larger than a calibration value that is normally set to 20% larger than the sum of the minimum number of windows for each cell. For example, if three speed load windows are used, and each requires a minimum of 30 data windows, then the calibration for the total number of windows would be set to  $3 \times 30 \times 1.2 = 108$  data windows.

When the monitor completes, an A/Fuel imbalance index is calculated. The monitor index is defined as the ratio of the failed rpm windows over the total rpm windows required to complete monitor. An index is calculated for each of the speed load cells being used. The final index for each engine bank is a weighted average of each of the three cell indices. If the monitor imbalance ratio index exceeds the threshold value, an A/F imbalance DTC is set.





Air Fuel Ratio Imbalance Operation	
DTCs	P219A – Bank 1 Air-Fuel Ratio Imbalance P219B – Bank 2 Air-Fuel Ratio Imbalance
Monitor execution	Once per driving cycle during closed loop
Monitor Sequence	Monitor runs after fuel monitor has adapted
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	Time to complete monitor ranges from 300 to 700 seconds

Air Fuel Ratio Imbalance entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop Fuel Control		
Engine Air Mass	2 lb/min	10 lb/min
Engine RPM Cell 0	1250 rpm	1700 rpm
Engine RPM Cell 1	1700 rpm	2100 rpm
Engine RPM Cell 2	2100 rpm	3400 rpm
Engine Load Cell 0	40%	70%
Engine Load Cell 1	50%	80%
Engine Load Cell 2	60%	90%
Engine Coolant Temp	150 °F	250 °F
Intake Air Temp	20 °F	150 °F
Throttle Position Rate of Change		0.122 v/100 msec
Fuel percentage from purge		40%
Fuel Level	15%	
Fuel monitor has adapted		
No purge on/off transition		
Fuel type leaning is complete (FFV only)		

Air Fuel Ratio Imbalance malfunction thresholds:	
Imbalance Ratio Bank 1 > .75	
Imbalance Ratio Bank 2 > .75	

J1979 AFIMN MONITOR MODE \$06 DATA			
Monitor ID	Test ID	Description	
\$81	\$80	Bank 1 imbalance-ratio and max. limit (P219A/P219B)	unitless
\$82	\$80	Bank 2 imbalance-ratio and max. limit (P219A/P219B)	unitless

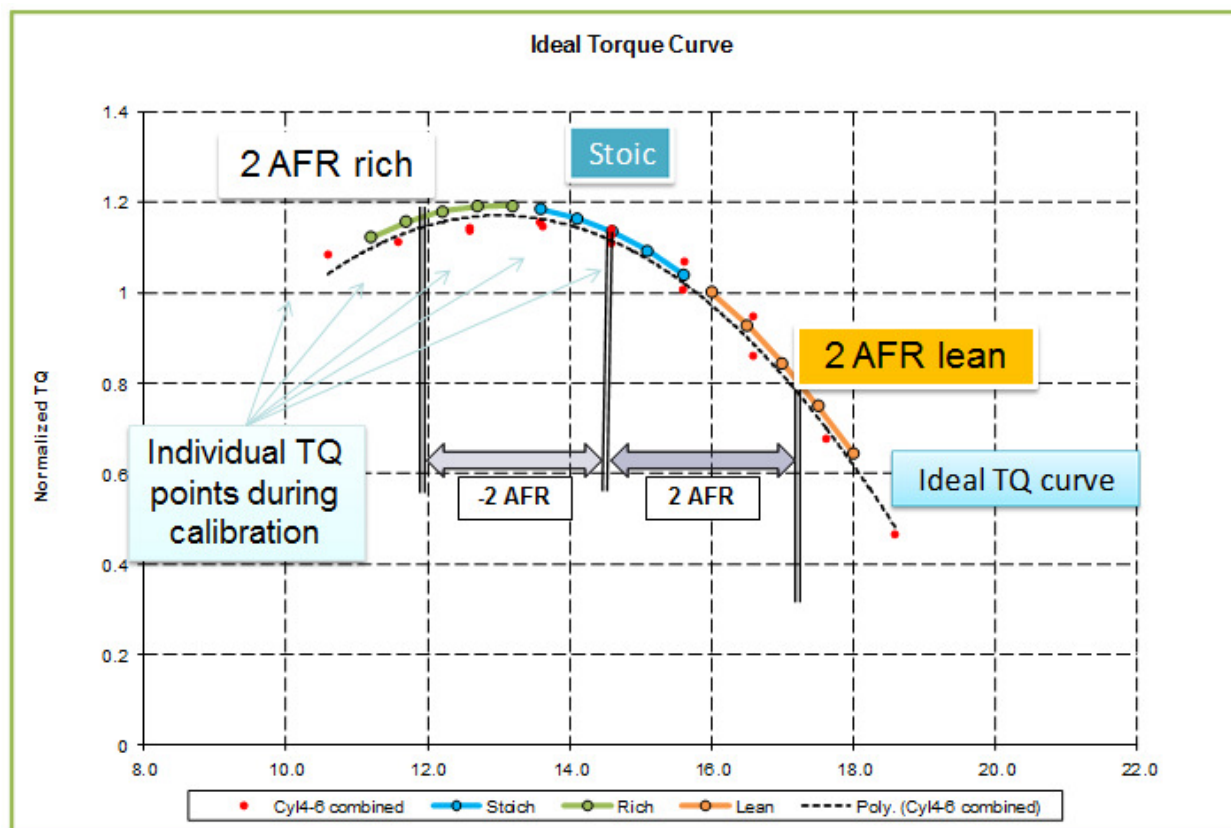
## Air Fuel Ratio Imbalance Monitor – Torque Monitor

A new, torque-based, A/F Ratio Imbalance Monitor (AFITQ) has been developed. It has an advantage over O<sub>2</sub> sensor based methods. O<sub>2</sub> sensors require optimal placement of the sensor in the exhaust manifold so that all cylinders are uniformly sampled. Optimum sensor placement is often constrained by exhaust manifold and catalyst design due to packaging.

The new torque based monitor is supplemented by the existing O<sub>2</sub> based monitor. The O<sub>2</sub> based monitor is used to detect large levels of cylinder to cylinder air fuel imbalance, while the torque based monitor is used to detect small levels of cylinder to cylinder air fuel ratio imbalance.

The AFITQ monitor uses the crankshaft position sensor (CKP) to calculate an acceleration term during each cylinder firing event (similar to the misfire monitor). The calculated acceleration value is proportional to engine torque during the firing event. The monitor will intrusively modulate each cylinder's fuel mass multiplier to generate a calibratable AFR deviation relative to the stoich point of operation.

The monitor generates 5 total torque values for each cylinder - 2 torque points richer than stoich, 2 torque points leaner than stoich and 1 point at stoich. The monitor then uses the torque curve shape defined by these 5 points versus an ideal torque curve as a reference to estimate the cylinder AFR deviation. Finally, the monitor estimates each cylinder AFR deviation from the rest of the cylinders. See the ideal torque curve below.



The AFITQ monitor is intrusive so it can affect engine operation and emissions. A fuel mass multiplier modulation table is designed to maintain stoich AFR per engine bank during the test. A positive fuel excursion on one cylinder is compensated by a negative fuel excursion on another cylinder. The fuel mass multiplier modulation table is also designed to minimize the change between AFR points in order to minimize torque/rpm disturbances for the customer.

To detect individual cylinder AFR, Ford is using an algorithm to correlate the shape of the 5 point torque curve to the ideal (calibrated) torque curve. Another algorithm identifies the individual cylinder deviation from the rest of the cylinders on the engine bank. For each cylinder, the monitor calculates the value of the AFR difference between the tested cylinder and the rest of the cylinders. This AFR deviation is converted to a value of fuel deviation where, for example, zero is no deviation, +0.15 is a 15% rich deviation and -0.15 is a 15% lean deviation.

The monitor results are based upon the torque calculation during the subsequent cylinder firing event and utilize the following entry conditions:

- Spark deviation from spark at MBT too large
- Instantaneous load variations are too large
- Closed loop fuel deviation is too far from stoich
- Cam position is not a calibrated range
- Purge flow at idle too high or not steady
- Speed/load conditions outside calibrated limits
- Vehicle speed outside calibrated limits

The AFITQ monitor is intended to run during idle, vehicle stopped, brakes on and transmission in drive. The total test duration is 18 seconds.

The initial applications for the AFITQ monitor are the 2016 MY Explorer 3.5L FWD V6 PFI and the 2016 MY Taurus/Flex 3.5L/3.7L FWD V6 PFI.

The AFITQ monitor is intended to detect very small AFR errors, in the order of +/- 2 AFR. (16% lean, 12% rich) The AFITQ monitor uses Exponentially Weighted Moving Average (EWMA) to reduce the variability of the raw cylinder data. Due to this variability, the Fast Initial Response (FIR) and Step-change Logic (SCL) are disabled. The AFITQ monitor will always operate using Normal EWMA mode. It is employed after the 4th monitor result following an OBD code clear; therefore, the monitor can illuminate the MIL following the fifth monitor result after a code clear in response to a threshold fault.

Note that the O2 sensor AFRIM monitor has also been incorporated into software to detect larger faults, e.g. faults > 25%.

Air Fuel Ratio Imbalance Operation	
DTCs	P219C Cylinder 1 Air-Fuel Ratio Imbalance P219D Cylinder 2 Air-Fuel Ratio Imbalance P219E Cylinder 3 Air-Fuel Ratio Imbalance P219F Cylinder 4 Air-Fuel Ratio Imbalance P21A0 Cylinder 5 Air-Fuel Ratio Imbalance P21A1 Cylinder 6 Air-Fuel Ratio Imbalance
Monitor execution	Once per driving cycle during idle conditions, vehicle stopped, brakes on
Monitor Sequence	Monitor runs after fuel monitor has adapted
Sensors OK	ECT, IAT, MAF, VSS, TP, ETC, FRP, DPFE EGR, VCT, VMV, CVS, FTP, CKP, CMP, ignition coils, injectors, 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, vehicle speed, AAT, PDL, fuel level, ACT,MAP, IMRC, no injector faults
Monitoring Duration	Time to complete monitor ranges from 17 to 18 seconds

Air Fuel Ratio Imbalance entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop Fuel Control		
Engine Speed	500 rpm	600 rpm
Engine Load	17%	37%
Instantaneous load change	1.5%	2%
PCV is not flashing oil		
Closed loop fuel deviation from stoic	-3.5%	3.5%
Measured AFR deviation from stoic	-5%	5%
Change of intake camshaft position at idle	-10 deg	+10 deg
Change of exhaust camshaft position at idle	-10 deg	+10 deg
Engine Coolant Temp	150 °F	250 °F
Intake Air Temp	20 °F	150 °F
Vehicle speed	0 mph	3 mph
Fuel percentage from purge		20%
Fuel Level	15%	
Fuel monitor has adapted		
No purge on/off transition		
Fuel type learning is complete (FFV only)		
Stability time within monitor	0.5 sec	

**Air Fuel Ratio Imbalance malfunction thresholds:**

Fuel deviation for Cylinder 1 < -0.12 (12% lean) or > +0.16 (16% rich)  
Fuel deviation for Cylinder 2 < -0.12 (12% lean) or > +0.16 (16% rich)  
Fuel deviation for Cylinder 3 < -0.12 (12% lean) or > +0.16 (16% rich)  
Fuel deviation for Cylinder 4 < -0.12 (12% lean) or > +0.16 (16% rich)  
Fuel deviation for Cylinder 5 < -0.12 (12% lean) or > +0.16 (16% rich)  
Fuel deviation for Cylinder 6 < -0.12 (12% lean) or > +0.16 (16% rich)

**J1979 AFIMN MONITOR MODE \$06 DATA**

Monitor ID	Test ID	Description	
\$81	\$81	Cylinder 1 fuel deviation and min/max limits	Unitless
\$81	\$82	Cylinder 2 fuel deviation and min/max limits	Unitless
\$81	\$83	Cylinder 3 fuel deviation and min/max limits	Unitless
\$82	\$84	Cylinder 4 fuel deviation and min/max limits	Unitless
\$82	\$85	Cylinder 5 fuel deviation and min/max limits	Unitless
\$82	\$86	Cylinder 6 fuel deviation and min/max limits	Unitless

## Flex Fuel Operation

Ford Motor Company is cooperating with the Department of Energy in providing customers with vehicles capable of using alcohol-blended fuels. These fuels are renewable and can lower some engine emission byproducts. The original 1993 Taurus vehicle hardware and calibration were designed for use on any combination of gasoline or methanol up to 85% methanol. Current flex fuel vehicles, however, are no longer designed for methanol, but are designed to be compatible with any combination of gasoline and ethanol, up to 85% ethanol.

This flexible fuel capability allows the vehicle to be usable in all regions of the country, even as the alcohol infrastructure is being built. Operation of a vehicle with the alcohol-blended fuels is intended to be transparent to the customer. Drivability, NVH, and other attributes are not notably different when using the alcohol-blended fuels. The higher octane of alcohol-blended fuels allows a small increase in power and performance (approximately 4%), but this is offset by the lower fuel economy (approximately 33%) due to the lower energy content. Cold starts with alcohol-blended fuels are somewhat more difficult than with gasoline due to the lower volatility of alcohol-blended fuels; 10% vaporization occurs at approximately 100 °F for gasoline vs. 160 °F for 85% ethanol. Ethanol requires approximately 37% more flow than gasoline due to a lower heating value (29.7 vs. 47.3 MJ/kg). Consequently, Flex Fuel vehicles require higher flow injectors than their gasoline counterparts. This results in a smaller fuel pulse widths with gasoline and makes the task of purging the canister more difficult during idles and decels.

In order to maintain proper fuel control, the PCM strategy needs to know the stoichiometric Air/Fuel Ratio for use in the fuel pulse width equation. On pre-2000 MY flex fuel vehicles, the percent alcohol in the fuel was determined by reading the output of the Flex fuel Sensor. The percent alcohol was stored in a register called Percent Methanol (PM). Although current alcohol-blended fuels only include ethanol, the percent methanol nomenclature has persisted. On 2000 MY and later vehicles, the Flex Fuel Sensor has been deleted and PM is inferred. The strategy to infer the correct A/F Ratio (AFR) relies on the oxygen sensor input to maintain stoichiometry after vehicle refueling occurs.

The relationship between PM and AFR is shown in the table below.

Stoich Air Fuel Ratio = $14.64 - 5.64 * PM$	
PM (percent alcohol)	Stoichiometric AFR
0.00 (100 % gasoline)	14.64
0.05	14.36
0.10 (standard gasoline)	14.08
0.15	13.79
0.20	13.51
0.25	13.23
0.30	12.95
0.35	12.67
0.40	12.38
0.45	12.10
0.50	11.82
0.55	11.54
0.60	11.26
0.65	10.97
0.70	10.69
0.75	10.41
0.80	10.13
0.85 (standard E85)	9.85
0.90	9.56
0.95	9.28
1.00 (100% ethanol)	9.00

The fuel level input is used to determine if a refueling event has occurred, either after the initial start or while the engine is running. If refueling event is detected (typically calibrated as a 10% increase in fuel level), the PCM tracks the "old" fuel being consumed by the engine. After a calibrated amount of "old" fuel has been consumed from the fuel lines, fuel rail, etc., the "new" fuel is assumed to have reached the engine. Normal long term fuel trim learning and purge control are temporarily disabled along with the evaporative system monitor and fuel system monitor to allow the composition of the fuel to be determined. The filtered value of short-term fuel trim is used during closed loop to adjust AFR in order to maintain stoichiometry. During learning, all changes in AFR are stored into the AFRMOD register. As updates are made to the AFRMOD register, the fuel composition register (PM) is updated and stored in Keep Alive Memory. Learning continues until the inference stabilizes with stabilized engine operating conditions. The PM inference and engine operating conditions are considered to have stabilized when all of the following conditions are satisfied:

- ECT indicates the engine has warmed up (typically 170 °F) or an ECT related fault is present.
- Enough "new" fuel has been consumed (typically 0.5 lb - vehicle dependant) to insure fuel is adequately mixed.
- The filtered value of short term fuel trim is in tight fuel control around stoichiometry, (typically +/- 2%) for at least 5 O2 sensor switches or AFRMOD is at a clip.
- The engine has been operated for a calibratable length of time, based on ECT temperature at start (typically 200 sec. at 40 °F and 30 sec at 200 °F) or an ECT related fault is present.
- The engine has been operating in closed loop fuel, with the brake off, within a calibratable (off-idle) air mass region (typically 2.4 to 8 lb/min) for 5 seconds, to minimize the effect of errors such as vacuum leaks.

Once the value of PM has stabilized (usually about 7 miles of driving), AFRMOD and PM are locked and deemed to be "mature." After PM is deemed "mature," normal fuel trim learning and purge control are re-enabled along with the fuel system monitor and evaporative system monitor. Any observed fueling errors from that point on are rolled into normal long term fuel trim (via adaptive fuel learning).

All remaining OBD-II monitors remain enabled unless AFR is observed to be changing. If AFR is changing, all monitors (except CCM and EGR) are disabled until the AFR stabilizes. This logic is same as was used for FFV applications that used a sensor. The AFR rate of change required to disable OBD-II monitor operation is typically 0.1 A/F (rate is based on the difference between a filtered value and the current value). For a fuel change from gasoline to E85 or vice versa, AFR typically stabilizes after 2 to 3 minutes on an FTP cycle.

If a large refueling event is detected (typically calibrated as a 40% to 50% increase in fuel level), the PCM strategy tries to assign the "new" fuel as gasoline or ethanol (E85) on the assumption that the only fuels available are either gasoline or E85. The strategy performs this fuel assignment to gasoline or ethanol (E85) only if the "old" and the "new" stabilized inferred fuel composition values are within a specified amount of each other (typically 5-10%), indicating that the fuel in the tank is the same as the fuel that was added and therefore must be either gasoline or ethanol (E85). If the "old" and "new" stabilized inferred fuel composition values are not near each other, the fuel added must be different from what was in the tank and the strategy retains the current inferred value of PM until the next refuel. By assigning the fuel to gasoline or ethanol (E85) in this manner, normal fuel system errors can be learned into normal long term fuel trim for proper fuel system error diagnosis.

After a battery disconnect or loss of Keep Alive Memory, the strategy will infer AFR immediately after going into closed loop fuel operation. A vehicle that previously had fuel system errors learned into long term fuel trim will infer incorrect values of AFR. After the value of AFR is determined, it is fixed until the next refueling event. If the next refueling event is performed with the same fuel (either E85 or gasoline), the value of AFR will not change. The fuel is then assigned to be E85 or gasoline as explained above. The long term fuel trim will again be a reliable indication of normal fuel system errors.

Only one large tank fill is required to assign the fuel as being either gasoline or ethanol, if the inferred AFR did not change significantly. If AFR did change significantly, several tank fills with the same fuel may be necessary to assign the fuel as gasoline or ethanol.

As the vast majority of vehicles are expected to be operated with gasoline, the initial value of AFR is set to gasoline. This is the starting point for the AFR after a battery disconnect and will allow for normal starting. Some vehicles may have E85 in the fuel tank after having a battery disconnect, and may not have a good start or drive away. The startability of alcohol-blended fuels at extreme cold temperatures (< 0 °F) is difficult under normal conditions; these vehicles may be required to be towed to a garage for starting if a battery disconnect occurs.

## Front HO2S Monitor

### Front HO2S Signal

The time between HO2S switches is monitored after vehicle startup when closed loop fuel has been requested, during closed loop fuel conditions and when open loop fuel has been requested due to an HO2S fault. Excessive time between switches with short term fuel trim at its limits (up to +/- 40%), or no switches since startup indicate a malfunction. Since “lack of switching” malfunctions can be caused by HO2S 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 was always indicates lean/disconnected (P2195, P2197), or always indicates rich (P2196, P2198).

Characteristic Shift Downward (CSD) is a deviation from the normal positive voltage output of the HO2S signal to negative voltage output. During a full CSD, the HO2S signal shifts downward (negative) by 1 volt. CSD occurs when the reference chamber of the HO2S becomes contaminated, causing negative HO2S voltage to be generated. Even though CSD can occur in both front and rear HO2S signals, only the front HO2S are compensated for CSD. The CSD compensation algorithm must not be in the process of driving fuel to bring the HO2S out of CSD before running some of the HO2S monitors.

2005 MY and later vehicles monitor the HO2S signal for high voltage, in excess of 1.1 volts and store a (P0132, P0152) DTC. An over voltage condition is caused by a HO2S heater or battery power short to the HO2S signal line.

HO2S “Lack of Switching” Operation:	
DTCs	P2195 - Lack of switching, sensor indicates lean, Bank 1 P2196 - Lack of switching, sensor indicates rich, Bank 1 P2197 - Lack of switching, sensor indicates lean, Bank 2 P2198 - Lack of switching, sensor indicates rich, Bank 2
Monitor execution	continuous, from startup and while in closed loop fuel or open loop fuel due to HO2S 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, front HO2S heaters OK, no front HO2S over voltage
Monitoring Duration	30 seconds to register a malfunction

Typical HO2S “Lack of Switching” entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop or Open Loop Requested due to HO2S fault		
Stream 1 HO2S not in CSD recovery mode		
No fuel flow entering thru PCV during cold start when flashing off fuel in oil (for O2 Sensor Stuck Rich DTCs only)		
No air passing through during valve overlap (scavenging).		
Inferred Ambient Temperature	-40 °F	
Time within entry conditions	10 seconds	
Fuel Tank Pressure		10 in H <sub>2</sub> O
Fuel Level	15%	
Battery Voltage	11.0 Volts	18.0 Volts

Typical HO2S “Lack of Switching” malfunction thresholds:
< 5 switches since startup for > 30 seconds in test conditions or > 30 seconds since last switch while closed loop fuel

HO2S “Over Voltage Test” Operation:	
DTCs	P0132 – O2 Sensor Circuit High Voltage, Bank 1 P0152 - O2 Sensor Circuit High Voltage, Bank 2
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	front HO2S heaters OK
Monitoring Duration	10 seconds to register a malfunction

Typical HO2S “Over Voltage Test” entry conditions:		
Entry condition	Minimum	Maximum
Inferred Stream 1 HO2S temperature	400 °F	
Battery Voltage	11.0 Volts	18.0 Volts

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

The HO2S is also tested functionally. The response rate is evaluated by entering a special 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. Oxygen sensor signal amplitude 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.

<b>HO2S Response Rate Operation:</b>	
DTCs	P0133 - O2 Sensor Circuit Slow Response Bank 1) P0153 - O2 Sensor Circuit Slow Response Bank 2)
Monitor execution	once per driving cycle
Monitor Sequence	> 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 system, no EVAP gross leak failure, no "lack of switching" malfunctions, front HO2S heaters OK no front HO2S over voltage
Monitoring Duration	6 seconds

<b>Typical HO2S response rate entry conditions:</b>		
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	150 °F	240 °F
Intake Air Temp		140 °F
Time since entering closed loop fuel	10 seconds	
Inferred Catalyst Midbed Temperature		1600 °F
Fuel Level	15%	
Short Term Fuel Trim Range	-9%	11%
Short Term Fuel Trim Absolute Change while in monitor		10%
Engine Load	20%	50%
Maximum change in engine load while in monitor		0.13
Vehicle Speed	30 mph	80 mph
Maximum change in vehicle speed while in monitor		3 mph
Engine RPM	1000 rpm	2000 rpm
Maximum change in engine rpm while in monitor		150 rpm
Battery Voltage	11.0 Volts	18.0 Volts

**Typical HO2Sresponse rate malfunction thresholds:**

Voltage amplitude: &lt; 0.5 volts

**J1979 Front HO2S Mode \$06 Data**

Monitor ID	Test ID	Description	
\$01	\$80	HO2S11 voltage amplitude and voltage threshold P0133)	Volts
\$01	\$01	H02S11 sensor switch-point voltage	Volts
\$05	\$80	HO2S21 voltage amplitude and voltage threshold P0153)	Volts
\$05	\$01	H02S21 sensor switch-point voltage	Volts

## Front 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. If the measured heater current falls below or above a calibratable threshold, the heater is assumed to be degraded or malfunctioning.

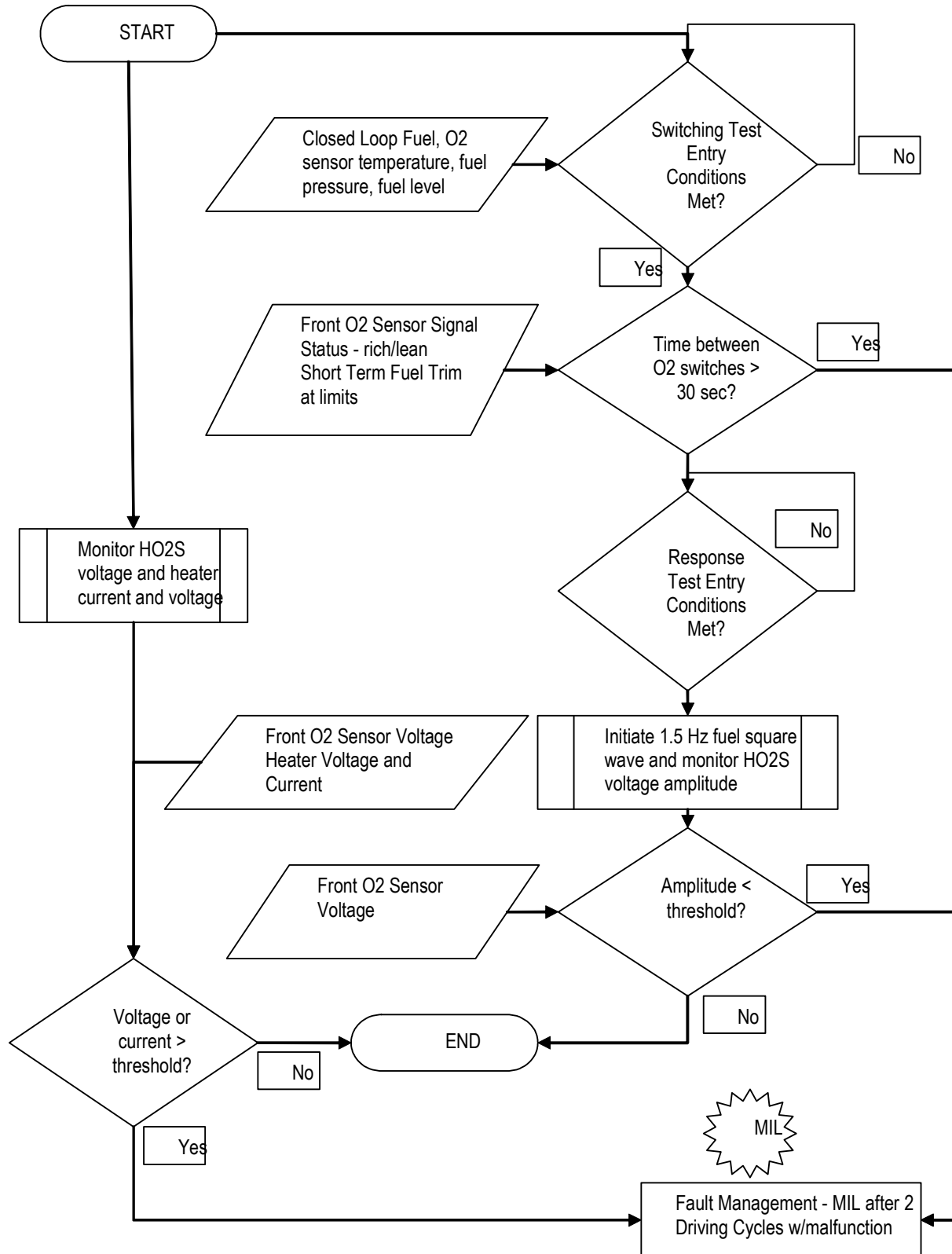
HO2S Heater Monitor Operation:	
DTCs Sensor 1	P0135 - O2 Sensor Heater Circuit, Bank 1 P0155 - O2 Sensor Heater Circuit, Bank 2 P0053 - HO2S Heater Resistance, Bank 1 P0059 - HO2S Heater Resistance, Bank 2
Monitor execution	once per driving cycle for heater current, continuous for voltage monitoring
Monitor Sequence	Heater current monitor: Stream 1 HO2S/UEGO response test complete (2010 MY and earlier), Stream 2 and 3 HO2S functional tests complete (2010 MY and earlier), 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 1 Temperature (heater voltage check only)	150 °F	1250 °F
Inferred HO2S 1 Temperature (heater current check only)	250 °F	1250 °F
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	Units
\$41	\$81	HO2S11 Heater Current (P0053)	Amps
\$45	\$81	HO2S21 Heater Current (P0059)	Amps

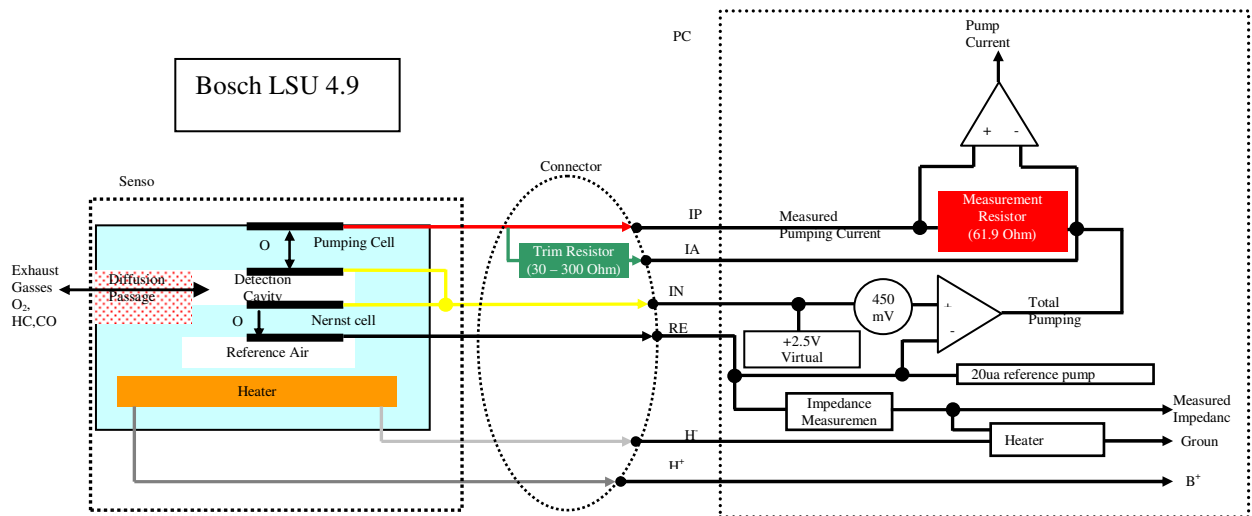
# HO2S Monitor



## Front UEGO Monitor

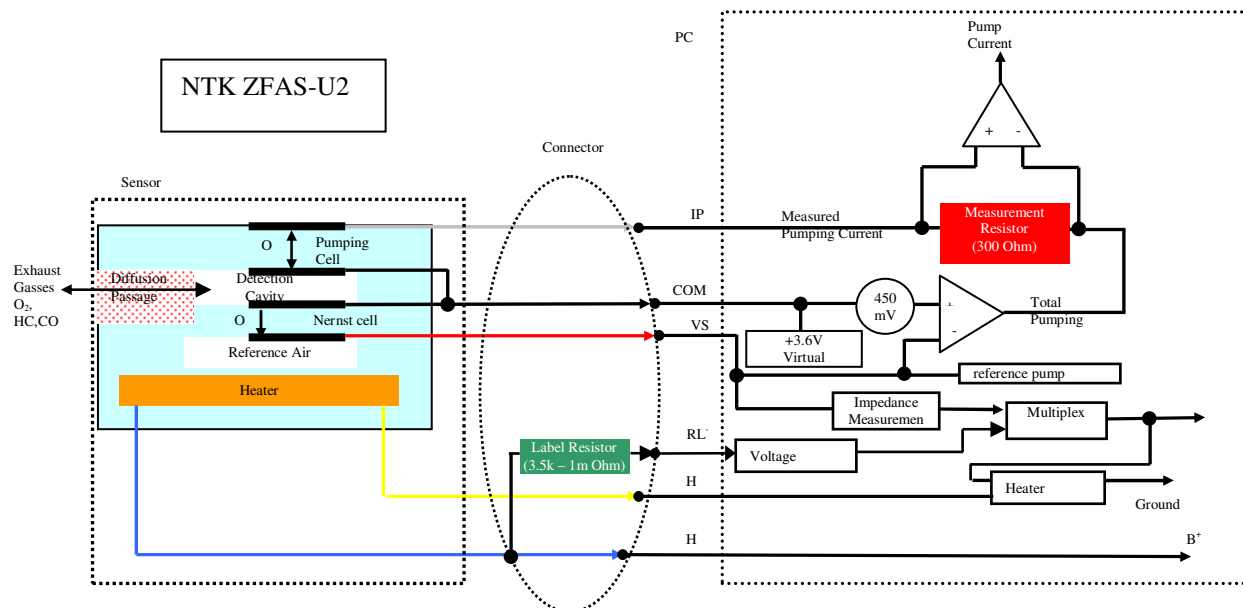
### Front UEGO Signal

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.



#### NTK UEGO sensor interface:

- IP – primary pumping current that flows through the sensing resistor
- COM – Virtual ground, approximately 3.6 volts above PCM ground.
- VS – Nernst cell voltage, 450mv from COM. Also carries current for pumped reference.
- RL – Voltage input from label resistor.
- H+ – Heater voltage – to battery.
- H- – Heater ground side – Duty cycle on/off to control sensor temperature.

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 uA 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  $I_p$  signal value is corrected for by a compensation coefficient (CC), and then processed by the PCM. The value of CC ( $I_p$  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 ( $I_p$ ) 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.

For Bosch UEGO, the trim resistor is connected in parallel to the pumping current sense resistor and the pumping current flows through both. The trim resistor adjusts the measured pumping current back to the expected nominal value at any given air fuel ratio (correcting for the sensor to sensor variations in the diffusion passage). Small trim resistors are required for sensors that require more pumping current at any particular lambda. Conversely, for sensors with lower diffusion rates than average, less pumping current is required, so a higher than average impedance trim resistor is installed. When IA circuit is open, all of the pumping current flows through the measuring resistor which increases the measured voltage. Since the pumping current is amplified, the UEGO pumping current to lambda transfer function will reflect the error. The slope of the UEGO sensor transfer function changes, which results in the wrong output of the UEGO signal (the slope of the pumping current to lambda relationship can increase or decrease). For "stoichiometric" air/fuel control applications, an open IA circuit is not monitored since the lambda error is minimal in "stoichiometric" mode. A worst case (40 ohm resistor) open IA was tested on a 2008 MY 3.5L Taurus PZEV and showed no impact on tailpipe emissions.

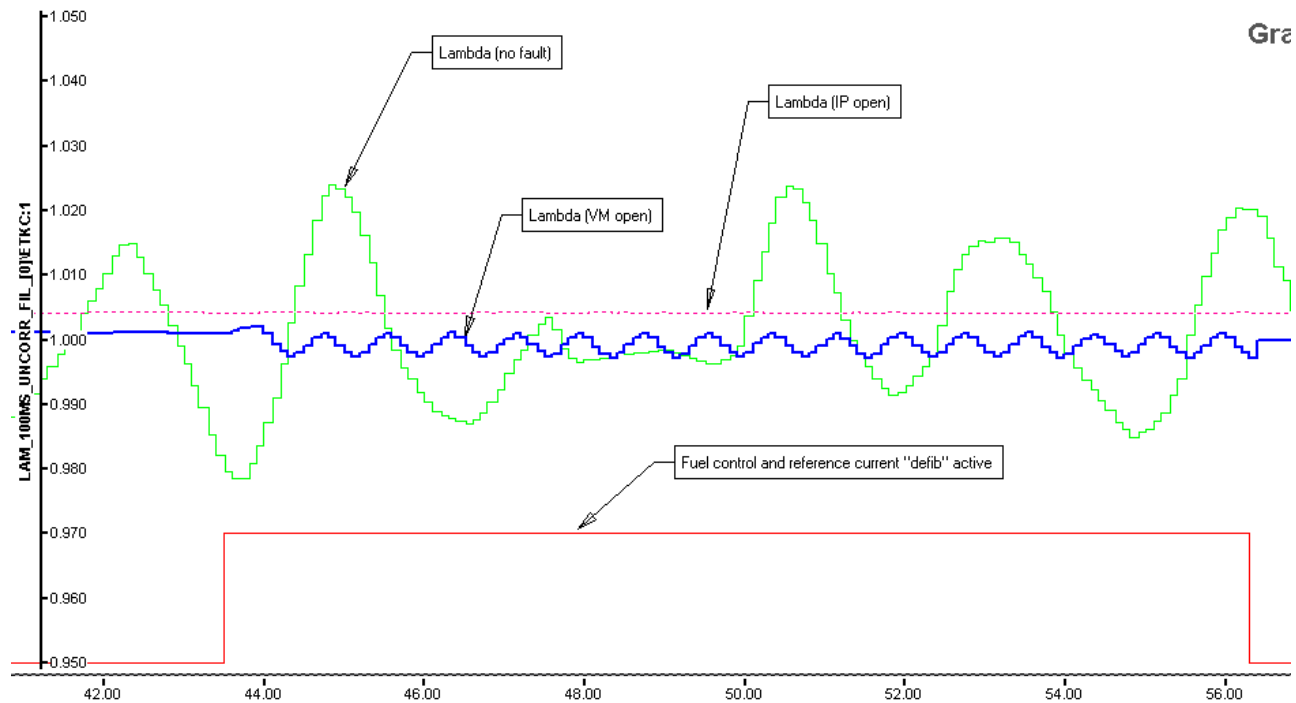
The time spent at the limits of the short term fuel trim is monitored after vehicle startup when closed loop fuel has been requested, during closed loop fuel conditions, or when open loop fuel has been requested due to UEGO sensor fault. Excessive time with short term fuel trim at its limits (up to +/- 40%), or no rich / lean activity seen since startup indicates a "lack of switch" malfunction. 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).

<b>UEGO "Lack of Switching" Operation:</b>	
DTCs	P2195 – Lack of switching, sensor indicates lean, Bank 1 P2196 – Lack of switching, sensor indicates rich, Bank 1 P2197 – Lack of switching, sensor indicates lean, Bank 2 P2198 – Lack of switching, sensor indicates rich, Bank 2
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, MAP, VSS, TP, ETC, FRP, FVR, DPFE EGR, VCT, VMV/EVMV, CVS, CPV, EVAPSV, 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

<b>Typical UEGO "Lack of Switching" entry conditions:</b>		
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 °F	
Time within entry conditions	10 seconds	
Fuel Tank Pressure		10 in H <sub>2</sub> O
Fuel Level	15%	
UEGO ASIC not in recalibration mode		
No air passing through during valve overlap (scavenging).		
Battery Voltage	11.0 Volts	18.0 Volts

<b>Typical UEGO "Lack of Switching" malfunction thresholds:</b>
Stage 1: > 30 seconds since reaching the short term fuel trim limits while closed loop fuel.
Stage 2: < 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.

The time spent when the measured lambda is nearly 1.0 is also monitored on Bosch UEGO applications using Bosch CJ125 or Conti-Siemens ATIC42 ASIC. The monitoring is conducted 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 without measured lambda deviating from 1.0, in spite of attempts to force activity (via fuel control and reference current "defib") in the measured lambda, will indicate either a "lack of movement – open Pump Current circuit" malfunction or a "lack of movement - open Reference Ground circuit" malfunction. An open Pump Current circuit (IP) is differentiated from an open Reference Ground circuit (VM) by measuring the movements in the measured lambda during the reference current defib. Change in lambda movement below a minimum threshold indicates "lack of movement- open Pump Current circuit" malfunction, which results in P2237, P2240 DTCs (replaced P0134/P0154 DTCs). Conversely, change in lambda movement greater than the minimum threshold indicates an open VM, which results in P2251, P2254 DTCs (replaced P0130/P0150 DTCs). Note that the open VM detection via reference current defib is new in 2011 MY applications.



Since the Bosch CJ125 or the Conti-Siemens ATIC42 ASIC do not have the capability to specifically detect an open RE or VM, separate diagnostics were created to monitor these failures. An open RE or VM will typically cause the impedance of the Nernst cell to increase. An open RE will cause the UEGO voltage to be greater than or less than a malfunction threshold while an open VM will cause the UEGO voltage to be within a malfunction band. Note that this open VM detection will only enable if the UEGO is unable to control the heater voltage at the desired set point; otherwise, the "lack of movement- open Reference Ground circuit" diagnostic will enable.

**UEGO “Open Circuit Diagnostic – RE, VM ” Operation (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

DTCs	<p>P2243 – O2 Sensor Reference Voltage Circuit/Open (Bank 1, Sensor 1). (replaces P0130)</p> <p>P2247 – O2 Sensor Reference Voltage Circuit/Open (Bank 2, Sensor 1). (replaces P0150)</p> <p>P2251 – O2 Sensor Negative Current Control Circuit/Open (Bank 1, Sensor 1) (replaces P0130)</p> <p>P2254 – O2 Sensor Negative Current Control Circuit/Open (Bank 2, Sensor 1) (replaces P0150)</p>
Monitor execution	continuous
Monitor Sequence	Intrusive Stream 1 UEGO heater current monitor completed
Sensors OK	UEGO heaters OK, no UEGO circuit malfunction
Monitoring Duration	10 seconds to register a malfunction

**Typical UEGO “Open Circuit Diagnostic – RE, VM ” entry conditions (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Entry condition	Minimum	Maximum
UEGO ASIC not in recalibration mode		
All injectors on (no Decel Fuel Shut Off)		
Short term fuel trim		33%
Time heater control voltage at maximum limit during open loop heater control		9 seconds (Bosch UEGO) 20 seconds (NTK UEGO)
Time heater control voltage at maximum or minimum limit during closed loop heater control		7 seconds (Bosch UEGO) 1 second (NTK UEGO)
Battery Voltage	11.0 Volts	18.0 Volts

**Typical UEGO “Open Circuit Diagnostic – RE, VM” malfunction thresholds (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Open RE circuit: UEGO voltage: > 4.7 V or < 0.2 V for 10 seconds to set a DTC.

Open VM circuit: 1.45 V < UEGO voltage < 1.55 V for 10 seconds to set a DTC (Bosch CJ125).

1.95 V < UEGO voltage < 2.05 V for 10 seconds to set a DTC (Conti-Siemens ATIC42).

**UEGO “Lack of Movement – Open Pump Current Circuit” Operation (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

DTCs	P2237 – O2 Sensor Positive Current Control Circuit/Open (Bank 1, Sensor 1) (replaces P0134)  P2240 – O2 Sensor Positive Current Control Circuit/Open (Bank 2, Sensor 1) (replaces P0154)
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 "lack of movement-open reference ground circuit" malfunction, no UEGO circuit malfunction
Monitoring Duration	10 - 20 seconds to register a malfunction

**Typical UEGO “Lack of Movement – Open Pump Current Circuit ” entry conditions  
(Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Entry condition	Minimum	Maximum
Closed Loop or Open Loop Requested due to UEGO sensor fault		
Constant lambda near stoich (~1)	0.99	1.01
Time since no lambda activity seen since start up	30 sec	
Time since no lambda activity during intrusive Stream 1 response monitor	3 sec	
Inferred Ambient Temperature	- 40 °F	
Injector fuel pulsewidth	650 usec	
UEGO ASIC not in recalibration mode		
No air passing through during valve overlap (scavenging).		
Battery Voltage	11.0 Volts	18.0 Volts

**Typical UEGO “Lack of Movement – Open Pump Current Circuit” malfunction thresholds  
(Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Stage 1: > 20 seconds in test conditions without lambda movement during fuel control and reference current "defib" while in closed loop fuel and < = 0.05 change in lambda movement.

Stage 2: < 0.2 seconds without lambda movement since startup for > 30 seconds in test conditions during reference current "defib" while open loop fuel is requested due to UEGO sensor fault and < = 0.05 change in lambda movement.

**UEGO “Lack of Movement – Open Reference Ground Circuit ” Operation (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

DTCs	P2251 – O2 Sensor Negative Current Control Circuit/Open (Bank 1, Sensor 1) (replaces P0130)  P2254 – O2 Sensor Negative Current Control Circuit/Open (Bank 2, Sensor 1) (replaces P0150)
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 "lack of movement-open pump current circuit" malfunction, no UEGO circuit malfunction
Monitoring Duration	10 - 20 seconds to register a malfunction

**Typical UEGO “Lack of Movement – Open Reference Ground Circuit ” entry conditions  
(Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Entry condition	Minimum	Maximum
Closed Loop or Open Loop Requested due to UEGO sensor fault		
Constant lambda near stoich (~1)	0.99	1.01
Time since no lambda activity seen since start up	30 sec	
Time since no lambda activity during intrusive Stream 1 response monitor	3 sec	
Injector fuel pulsewidth	650 usec	
UEGO ASIC not in recalibration mode		
No air passing through during valve overlap (scavenging).		
Battery Voltage	11.0 Volts	18.0 Volts

**Typical UEGO “Lack of Movement – Open Reference Ground Circuit” malfunction thresholds  
(Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Stage 1: > 20 seconds in test conditions without lambda movement during fuel control and reference current "defib" while in closed loop fuel and > 0.05 change in lambda movement.

Stage 2: > 20 seconds in test conditions without lambda movement during reference current "defib" while open loop fuel is requested due to UEGO sensor fault and > 0.05 change in lambda movement.

UEGO equipped vehicles 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). In particular, the NTK TIF0003 and Conti ATIC142 ASIC chips can do open circuit diagnostics. Beginning 2015 MY, applications using Conti ATIC142 ASIC can also detect open IA fault via the wire diagnostics capability included on the ASIC.

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.

- Beginning 2011 MY, the general UEGO circuit diagnostic DTCs P0130/P0150, are now replaced by more specific DTCs.
- A shorted to ground circuit (Bosch UEGO – IP, IA, RE, VM; NTK UEGO – IP, VS, COM) will set P0131/P0151 DTCs.
- A shorted to battery circuit (Bosch UEGO – IP, IA, RE, VM; NTK UEGO – IP, VS, COM) will set P0132/P0152 DTCs.
- An open Pump Current circuit (IP) will set P2237/P2240 DTCs.
- An open Reference Ground circuit (VM/COM) will set P2251/P2254 DTCs.
- An open Reference Voltage circuit (RE/VS) will set P2243/P2247 DTCs.

UEGO "Wire Diagnostic via ASIC" Operation:	
DTCs	<p>P0131 – O2 Sensor Circuit Low Voltage (Bank 1, Sensor 1). Note: Sets for short to ground on Bosch UEGO- IP, IA, RE, VM; NTK UEGO – IP, VS, COM. (replaces P0130 in Bosch UEGO applications.)</p> <p>P0151 – O2 Sensor Circuit Low Voltage (Bank 2, Sensor 1). Note: Sets for short to ground on Bosch UEGO- IP, IA, RE, VM; NTK UEGO – IP, VS, COM. (replaces P0150 in Bosch UEGO applications.)</p> <p>P0132 – O2 Sensor Circuit High Voltage (Bank 1, Sensor 1). Note: Sets for short to battery on Bosch UEGO- IP, IA, RE, VM; NTK UEGO – IP, VS, COM. (replaces P0130 in Bosch UEGO applications.)</p> <p>P0152 – O2 Sensor Circuit High Voltage (Bank 2, Sensor 1). Note: Sets for short to battery on Bosch UEGO- IP, IA, RE, VM; NTK UEGO – IP, VS, COM. (replaces P0150 in Bosch UEGO applications.)</p> <p>P2237 – O2 Sensor Positive Current Control Circuit/Open (Bank 1, Sensor 1). Note: This DTC sets for open IP. (replaces P0130 in NTK UEGO applications.)</p> <p>P2240 – O2 Sensor Positive Current Control Circuit/Open (Bank 2, Sensor 1). Note: Sets for open IP. (replaces P0150 in NTK UEGO applications.)</p> <p>P2243 – O2 Sensor Reference Voltage Circuit/Open (Bank 1, Sensor 1). Note: Sets for open VS. (replaces P0130 in NTK UEGO applications.)</p> <p>P2247 – O2 Sensor Reference Voltage Circuit/Open (Bank 2, Sensor 1). Note: Sets for open VS. (replaces P0150 in NTK UEGO applications.)</p> <p>P2251 – O2 Sensor Negative Current Control Circuit/Open (Bank 1, Sensor 1). Note: Sets for open COM. (replaces P0130 in NTK UEGO applications.)</p> <p>P2254 – O2 Sensor Negative Current Control Circuit/Open (Bank 2, Sensor 1). Note: Sets for open COM. (replaces P0150 in NTK UEGO applications.)</p>

	<p>P164A – O2 Sensor Positive Current Trim Circuit Performance (Bank 1, Sensor 1). Note: Sets for an erratic RL in NTK UEGO applications only.</p> <p>P164B – O2 Sensor Positive Current Trim Circuit Performance (Bank 2, Sensor 1). Note: Sets for an erratic RL in NTK UEGO applications only.</p> <p>P2626 - O2 Sensor Positive Current Trim Circuit Open (Bank 1, Sensor 1)</p> <p>P2629 - O2 Sensor Positive Current Trim Circuit Open (Bank 2, Sensor 1)</p> <p>P2627 – O2 Sensor Positive Current Trim circuit Low (Bank 1, Sensor 1). Note: Sets for open or short to ground RL in NTK UEGO applications only.</p> <p>P2630 – O2 Sensor Positive Current Trim Circuit Low (Bank 2, Sensor 1). Note: Sets for open or short to ground RL in NTK UEGO applications only.</p> <p>P2628 – O2 Sensor Positive Current Trim Circuit High (Bank 1, Sensor 1). Note: Sets for short to battery RL in NTK UEGO applications only.</p> <p>P2631 – O2 Sensor Positive Current Trim Circuit High (Bank 2, Sensor 1). Note: Sets for short to battery RL in NTK UEGO applications only.</p> <p>P1646 – Linear O2 Sensor Control Chip, Bank 1.</p> <p>P1647 – Linear O2 Sensor Control Chip, Bank 2.</p> <p>P064D – Internal Control Module O2 Sensor Processor Performance (Bank 1).</p> <p>P064E – Internal Control Module O2 Sensor Processor Performance (Bank 2).</p>
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	UEGO heaters OK
Monitoring Duration	10 seconds to register a malfunction

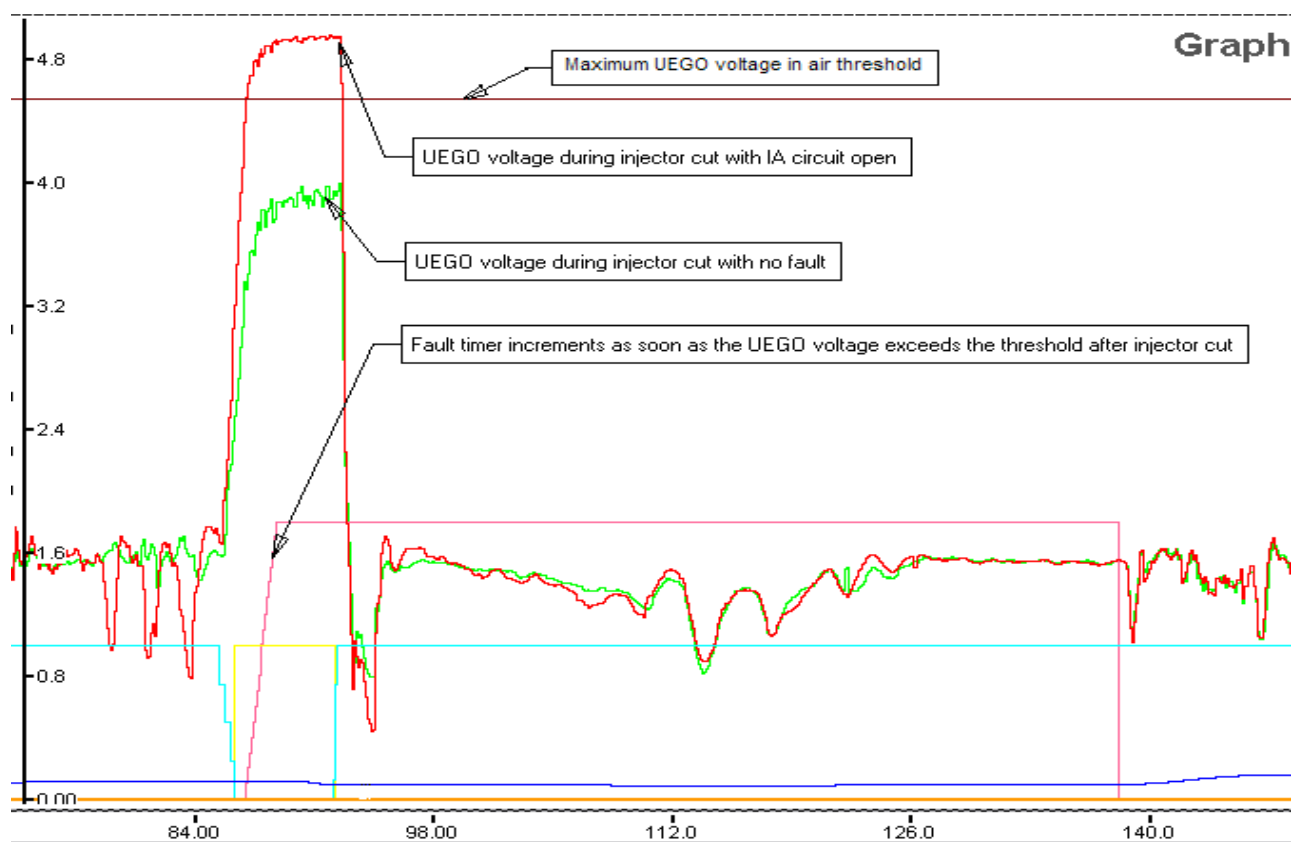
**Typical UEGO "Wire Diagnostics via ASIC" entry conditions:**

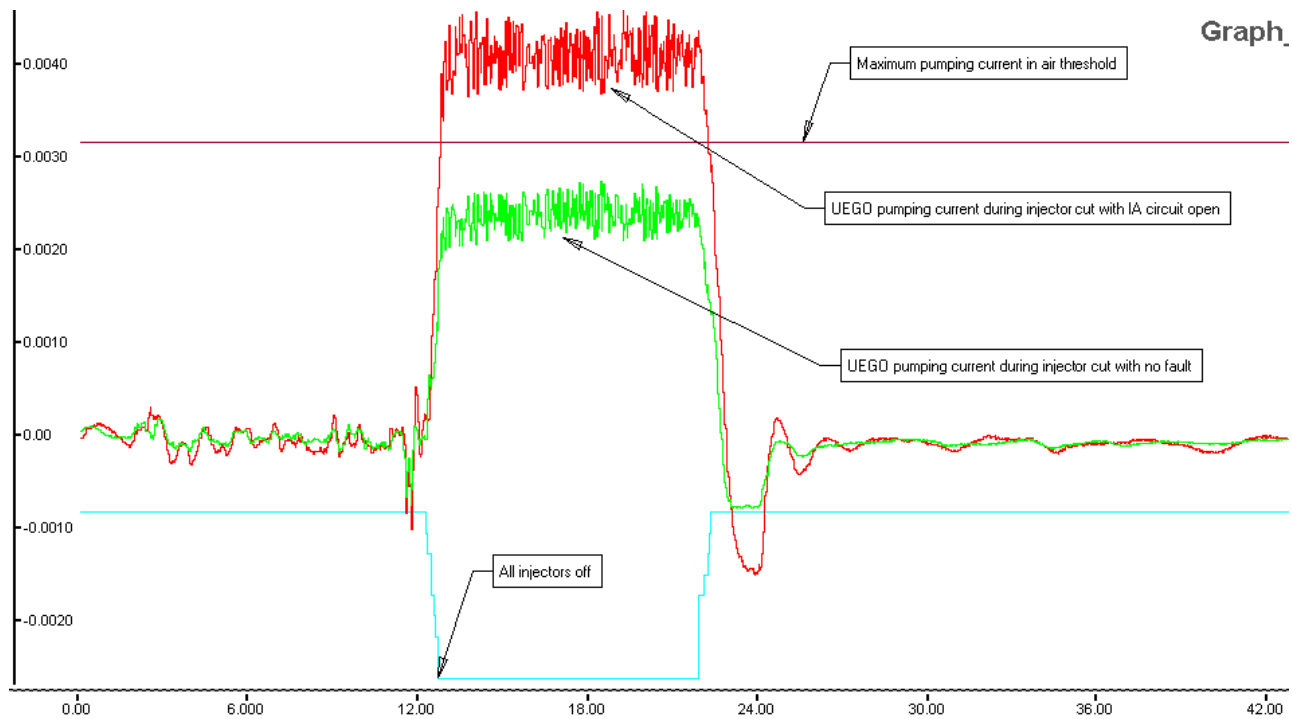
Entry condition	Minimum	Maximum
Fault reported by UEGO ASIC		
Battery Voltage	11.0 Volts	18.0 Volts

**Typical UEGO "Wire Diagnostics via ASIC " malfunction thresholds:**

UEGO ASIC indicated malfunction, DTC sets after 10 seconds when circuit failure is present.

For "Non-Stoichiometric Closed Loop (NSCL)" air/fuel control applications, a continuous open IA diagnostic is required since the lambda error is more significant in this mode. For UEGO ASICs that do not have capability to detect open IA, a separate continuous open IA diagnostic (Air Rationality Test) is created to monitor the open IA circuit fault. This diagnostic will always monitor the UEGO sensor voltage or pumping current reading during Decel Fuel Shut Off (DFSO) event. The monitor compares the UEGO sensor voltage or pumping current reading in air against the expected value for pure air. If the UEGO sensor voltage or pumping current during DFSO exceeds the maximum UEGO voltage/pumping current in air threshold, then the fault timer increments. If the fault timer exceeds the fault time threshold, then open IA DTC P2626 and/or P2629 will set. Since transient sources of fuel in the exhaust after injector cut can contribute to the UEGO sensor voltage/pumping current to read lower (rich), the air rationality monitor will not call a pass until the transient sources of fuel have been exhausted and pure air entry conditions during DFSO are met (i.e. all injectors must be off, purge must be off, no fuel must be leaking around the PCV valve, and a few transport delays must have passed to allow the last fuel transients to be exhausted leaving nothing for the sensor to see, but air). Note: Beginning 2011 MY and beyond, this diagnostics will monitor the UEGO pumping current against the expected value for pure air instead of the UEGO voltage so the monitor can be ASIC chip independent.





**UEGO “Air Rationality Test” Operation (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

DTCs	P2626 – O2 Sensor Positive Current Trim Circuit Open (Bank 1, Sensor 1) P2629 – O2 Sensor Positive Current Trim Circuit Open (Bank 2, Sensor 1)
Monitor execution	continuous, every DFSD event
Monitor Sequence	Stream 1 UEGO heater voltage check completed, > 30 seconds time in lack of movement test, > 30 seconds time in lack of switch test
Sensors OK	FTP, injectors, UEGO heaters OK, no "lack of switching" malfunction, no "lack of movement" malfunction, no purge system failure, no UEGO circuit malfunction, no UEGO FAOS monitor malfunction, no front UEGO response rate malfunction
Monitoring Duration	2 seconds to register a malfunction

**Typical UEGO "Air Rationality Test" entry conditions (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

Entry condition	Minimum	Maximum
No injectors stuck open		
No purge system failure		
Fuel Tank Pressure		10 in H <sub>2</sub> O
Closed pedal		
DFSO entry conditions met		
DFSO requested		
DFSO injectors cut		
No purge flow being requested (pass criteria only)		
No fuel flow entering thru PCV during cold start when flashing off fuel in oil (pass criteria only)		
Transport delay (pass criteria only)	2 sec	
UEGO ASIC not in recalibration mode		
Battery Voltage	11.0 Volts	18.0 Volts

**Typical UEGO “Air Rationality Test” malfunction thresholds (Bosch UEGO only using Bosch CJ125 or Conti-Siemens ATIC42 ASIC):**

UEGO voltage: > 4.55 V (max UEGO sensor voltage in air, normal range) or  
> 3.0 V (max UEGO sensor voltage in air, wide range) for >= 2 seconds in test conditions.

UEGO pumping current: > 0.00309 Amps for >= 2 seconds in test conditions.

## Front UEGO Slow/Delayed Response Monitor (2010 MY+)

The front UEGO monitor also detects malfunctions on the UEGO sensor such as reduced response or delayed response that would cause vehicle emissions to exceed 1.5x the standard (2.5x the standard for PZEV). The response rate is evaluated by entering a special 0.5 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.

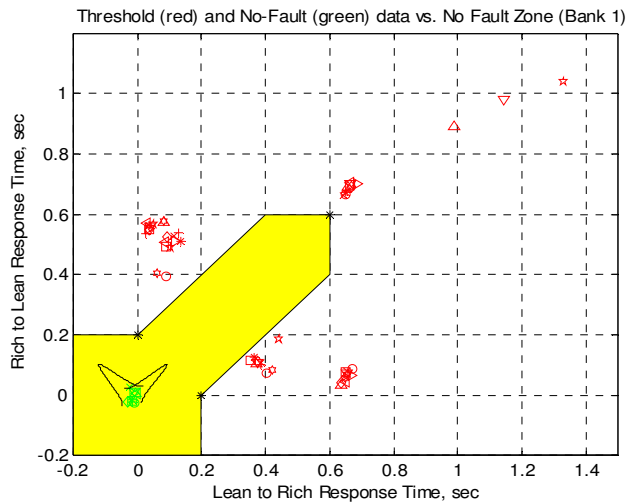
A UEGO slow or delayed sensor will show an increased response time which is compared to a no-fault polygon. Combinations of the rich to lean and lean to rich response times that fall outside the polygon indicate a sensor malfunction (P0133 Bank 1, P0153 Bank 2).

UEGO "Response Rate" Operation:	
DTCs	P0133 - O2 Sensor Circuit Slow/Delayed Response Bank 1 P0153 - O2 Sensor Circuit Slow/Delayed 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, MAP, VSS, TP, ETC, FRP, FVR, DPFE EGR, VCT, VMV/EVMV, CVS, CPV, EVAPSV, 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	12 seconds

Typical UEGO "Response Rate" entry conditions:		
Entry condition	Minimum	Maximum
Flex Fuel Composition not changing		
Not in Phase 0 of Evap Monitor, Purge intrusive test not running		
No Purge System reset		
Not performing CSER spark retard		
Not performing intrusive UEGO Lack of Movement "defib"		
No IMRC transition in progress before entering the monitor and while in monitor		
Engine Coolant Temp	150 °F	240 °F
Intake Air Temp		140 °F
Time since entering closed loop fuel	10 seconds	
Inferred Catalyst Midbed Temperature		1600 °F
Fuel Level	15%	
Short Term Fuel Trim Range	-5%	5%
Short Term Fuel Trim Absolute Change while in monitor		15%
Air Mass	1.2 lbs/min	
Engine Load	20%	70%
Maximum change in engine load while in monitor		0.25
Vehicle Speed	35 mph	80 mph
Maximum change in vehicle speed while in monitor		9 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
No excessive cam angle movement over a half cycle A/F modulation when exhaust cam position is $\geq 40$ degree or intake cam position $\geq -10$ degree to indicate an acceptable A/F disturbance due to cam angle movement.		3 degree
No excessive movement between currently utilized long term fuel trim cells (1 = complete change from one cell to adjacent cell)		0.5
UEGO ASIC not in recalibration mode		
No air passing through during valve overlap (scavenging).		
Battery Voltage	11.0 Volts	18.0 Volts

## Typical UEGO "Response Rate" malfunction thresholds:

Threshold depends on failure type (symmetric slow/delay vs. Asymmetric slow/delay)



Example shown with lean-to-rich (0.2 sec), rich-to-lean (0.2 sec), and symmetric (0.6 sec) thresholds creating the yellow no-fault zone. The completed monitor results in two measurements, a lean-to-rich response time and a rich-to-lean response time. These response time values are used as x-y pairs to make a single point and then compared to the no-fault zone. Anywhere in the yellow is a pass and outside the yellow is a failure.

## J1979 Front UEGO Mode \$06 Data

Monitor ID	Test ID	Description	
\$01	\$87	UEGO11 Rich to Lean Response Time (P0133)	seconds
\$01	\$88	UEGO11 Lean to Rich Response Time (P0133)	seconds
\$05	\$87	UEGO21 Rich to Lean Response Time (P0153)	seconds
\$05	\$88	UEGO21 Lean to Rich Response Time (P0153)	seconds

## 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: 830 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 P0030/P0050 fault code is set. This monitor also sets a malfunction when the closed loop heater controller reaches a maximum or minimum duty cycle for a period of time indicating that the controller is no longer able to maintain the target temperature. However, if the 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 (open, shorted to ground, or shorted to battery) 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 (2010 MY and earlier), 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. If the heater measured current falls below or above a calibratable threshold, the heater is assumed to be degraded or malfunctioning.

Beginning 2012MY, some PCMs do not have a separate current-monitoring circuit. For PCMs that do not have the current-monitoring circuit, a degraded or malfunctioning UEGO heater is detected by the "UEGO Heater Temperature Control Monitor".

UEGO Heater Monitor Operation:	
DTCs	P0030 – HO2S Heater Control Circuit, Bank 1 P0050 – HO2S Heater Control Circuit, Bank 2 P0135 - HO2S Heater Circuit, Bank 1 P0155 - HO2S Heater Circuit, Bank 2 P0053 - HO2S Heater Resistance, Bank 1 P0059 - HO2S Heater Resistance, Bank 2
Monitor execution	once per driving cycle for heater current monitor, continuous for voltage monitoring and UEGO heater temperature control monitoring
Monitor Sequence	Heater current monitor: Stream 1 UEGO response test completed (2010 MY and earlier), Stream 2 and 3 HO2S functional tests completed (2010 MY and earlier), Stream 1 UEGO heater voltage check completed.  UEGO heater temperature control monitor: Stream 1 UEGO heater voltage check completed, Stream 1 UEGO circuit check completed, intrusive heater current monitor completed (if applicable).
Sensors OK	Heater current monitor: no HO2S/UEGO heater circuit malfunction, no UEGO heater temperature control malfunction, no UEGO circuit malfunction  UEGO 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 UEGO 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 °F	1562 °F
Inferred UEGO heated tip temperature (heater current check only)	1346 °F	1526 °F
UEGO heater-on time (heater current check only)	30 seconds	
Engine RPM (heater current check only)		5000 rpm
Time heater control voltage at maximum limit during open loop heater control (intrusive heater current check only)		9 seconds (Bosch UEGO) 20 seconds (NTK UEGO)
Time heater control voltage at maximum or minimum limit during closed loop heater control (intrusive heater current check only)		7 seconds (Bosch UEGO) 1 second (NTK UEGO)
Inferred UEGO unheated tip temperature (heater control monitor only)	75 °F	1000 °F
UEGO ASIC not in recalibration mode		
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  $\geq 30$  (heater voltage check)

Heater current outside limits:

< 1.0 Amps or > 3 Amps (intrusive test) or < 0.55 Amps or > 3 Amps (Bosch UEGO)

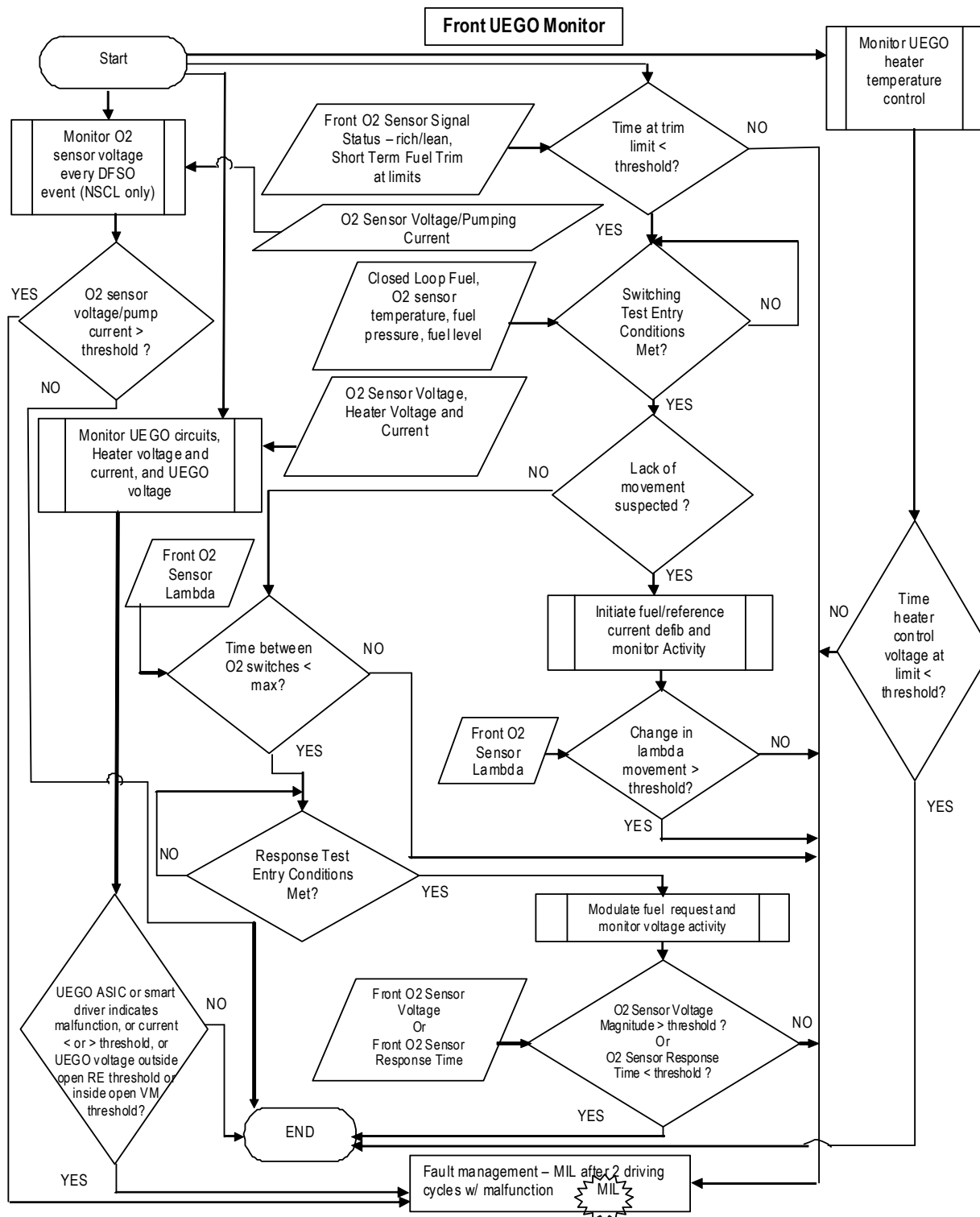
< 1.45 Amps or > 3 Amps (intrusive test) or < 1.05 Amps or > 3 Amps (NTK UEGO)

< 1.62 Amps or > 3.80 Amps (intrusive test) or < 1.12 Amps or > 3.80 Amps (Conti-Moto CBP-A2 PCM with NTK UEGO)

UEGO heater temperature control monitor:  $\geq 30$  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	Units
\$41	\$81	HO2S11 Heater Current (P0053)	Amps
\$45	\$81	HO2S21 Heater Current (P0059)	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 continuously 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.

2011 MY and beyond vehicles with Conti-Moto CBP-A2 PCM will also continuously monitor the rear HO2S signal for out of range low voltage, below -0.2 volts and store DTC P2A01, P2A04. An out of range low voltage condition is caused by swapped sensor wires (sensor signal and signal return) and sensor degradation.

Furthermore, the rear HO2S signal will also be monitored continuously for circuit open or shorted to ground beginning 2011 MY as the PCM hardware becomes capable of measuring HO2S impedance. An intrusive circuit test is invoked whenever the HO2S voltage falls into a voltage fault band. A pull-up resistor is enabled to alter the HO2S circuit characteristics. A very high HO2S internal resistance, > 500 k ohms, will indicate an open HO2S circuit while a low HO2S internal resistance, < 10 ohms, will indicate a HO2S circuit shorted to ground. Both HO2S circuit open and shorted to ground malfunction will set DTC P0137, P0157 if the fault counter exceeds the threshold.

Beginning 2015MY, Conti ATIC142 UEGO ASIC has both UEGO and rear HO2S wire diagnostics capability included on the chip. The wire diagnostics will continuously detect sensor wires open, shorted to battery, or ground.

Rear HO2S Functional Check Operation:	
DTCs Sensor 2	P0136 - HO2S12 No activity or P2270 - HO2S12 Signal Stuck Lean P2271 - HO2S12 Signal Stuck Rich P0156 - HO2S22 No activity or P2272 - HO2S22 Signal Stuck Lean P2273 - HO2S22 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 completed, Stream 2 HO2S circuit open/short to ground test time slice completed.
Sensors OK	ECT, IAT, MAF, MAP, VSS, TP, ETC, FRP, FVR, DPFE EGR, VCT, VMV/EVMV, CVS, CPV, EVAPSV, 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 rear HO2S out of range low 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	150 °F	240 °F
Intake Air Temp		140 °F
Time since entering closed loop fuel	10 seconds	
Inferred Catalyst Midbed Temperature		1600 °F
Heater-on Inferred Sensor(s) 2/3 HO2S Temperature Range	400 °F	1400 °F
Sensor(s) 2/3 HO2S heater-on time	90 seconds	
Short Term Fuel Trim Range	-9%	11%
Fuel Level (forced excursion only)	15%	
Throttle position	Part throttle	
Engine RPM (forced excursion only)	1000 rpm	2000 rpm
UEGO ASIC not in recalibration mode		
No air passing through during valve overlap (scavenging).		
Battery Voltage	11.0 Volts	18.0 Volts

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

**J1979 Rear HO2S Functional Check Mode \$06 Data**

Monitor ID	Test ID	Description	
\$02	\$01	HO2S12 sensor switch-point voltage	volts
\$06	\$01	HO2S22 sensor switch-point voltage	volts

**Rear HO2S “Over Voltage Test” Operation:**

DTCs	P0138 - HO2S12 Circuit High Voltage P0158 - HO2S22 Circuit High 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 2/3 HO2S Temperature	400 °F	
Sensor(s) 2/3 HO2S heater-on time	90 seconds	
Voltage at sensor 2 HO2S connector	11.0 Volts	
Battery Voltage	11.0 Volts	18.0 Volts

**Typical HO2S “Over Voltage Test” malfunction thresholds:**

HO2S Voltage > 1.1 volts for 10 seconds for over voltage test

**Rear HO2S “Out of Range Low Test” Operation:**

DTCs	P2A01 HO2S12 Circuit Range/Performance (Bank 1 Sensor 2) P2A04 HO2S22 Circuit Range/Performance (Bank 2 Sensor 2)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	rear HO2S heaters OK, no rear HO2S shorted to ground malfunction
Monitoring Duration	10 seconds to register a malfunction

**Typical HO2S “Out of Range Low Test” entry conditions:**

Entry condition	Minimum	Maximum
Inferred Stream 2 HO2S Temperature	400 °F	
Sensor 2 HO2S heater-on time	90 seconds	
Voltage at sensor 2 HO2S connector	11.0 Volts	
Battery Voltage	11.0 Volts	18.0 Volts

**Typical HO2S “Out of Range Low Test” malfunction thresholds:**

HO2S Voltage < -0.2 volts for 10 seconds for out of range low test

**Rear HO2S “Circuit Open/Shorted to Ground Test via HO2S Impedance Measurement” Operation:**

DTCs	P0137 HO2S12 Circuit Low Voltage (Bank 1 Sensor 2) P0157 HO2S22 Circuit Low Voltage (Bank 2 Sensor 2)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	rear HO2S heaters OK, no rear HO2S out of range low malfunction, no rear HO2S functional DTCs
Monitoring Duration	10 seconds to register a malfunction

Typical HO2S “Circuit Open/Shorted to Ground Test via HO2S Impedance Measurement” entry conditions:		
Entry condition	Minimum	Maximum
Closed Loop		
Inferred Stream 2 HO2S Temperature	680 °F	1290 °F (short to ground)
Inferred Stream 2 HO2S Element Temperature (applicable only if Stream 2 HO2S Impedance Monitor is enabled)	480 °F	
Time Stream 2 HO2S inferred element temperature within 10% of the predicted steady state temperature (applicable only if Stream 2 HO2S Impedance Monitor is enabled)	1 second	
Sensor 2 HO2S heater-on time	60 seconds	
All injectors on (no Decel Fuel Shut Off)		
Not commanding lean lambda due to torque reduction		
Not requesting enrichment due to catalyst reactivation following decel fuel shut off		
Sensor 2 HO2S voltage (open circuit voltage fault band): Conti-Moto CBP-A2 PCM	-0.05 Volts	0.05 Volts
Other PCMs	0.27 Volts	0.50 Volts
or depending on feedback circuit	1.40 Volts	1.90 Volts
Sensor 2 HO2S voltage (circuit shorted to ground voltage fault band):	-3.00 Volts	0.06 Volts
Voltage at sensor 2 HO2S connector	11.0 Volts	
Battery Voltage	11.0 Volts	18.0 Volts

Typical HO2S “Circuit Open/Shorted to Ground Test” malfunction thresholds:
HO2S Circuit Open: HO2S Impedance > 500 k ohms, fault counter > 14 (200 msec test every 500 msec check)
HO2S Circuit Shorted to ground: HO2S Impedance < 10 ohms, fault counter > 17 (100 msec test every 500 msec check)

**HO2S "Wire Diagnostics via ASIC" Operation:**

DTCs	P0137 - HO2S12 Circuit Low Voltage (Bank 1 Sensor 2) P0157 - HO2S22 Circuit Low Voltage (Bank 2 Sensor 2) P0138 - HO2S12 Circuit High Voltage P0158 - HO2S22 Circuit High Voltage
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	HO2S heaters OK
Monitoring Duration	10 seconds to register a malfunction

**Typical HO2S "Wire Diagnostics via ASIC" entry conditions:**

Entry condition	Minimum	Maximum
Fault reported by UEGO ASIC		
Battery Voltage	11.0 Volts	18.0 Volts

**Typical HO2S "Wire Diagnostics via ASIC " malfunction thresholds:**

UEGO ASIC indicated malfunction, DTC sets after 10 seconds when circuit failure is present.

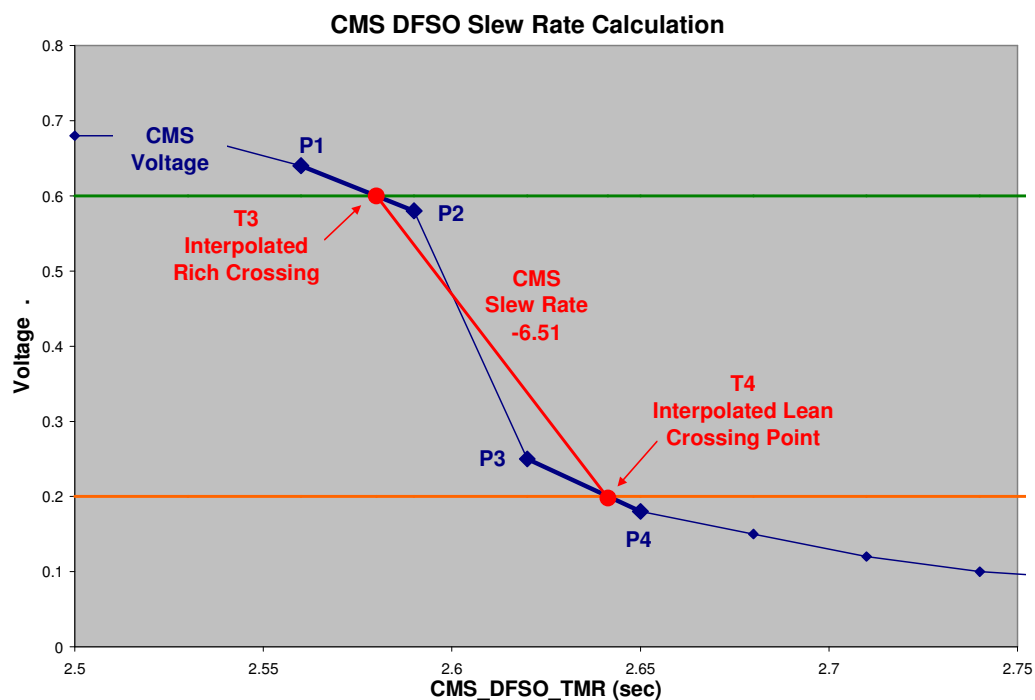
## Rear HO2S Decel Fuel Shut Off Response Test (2009 MY+)

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, its 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.

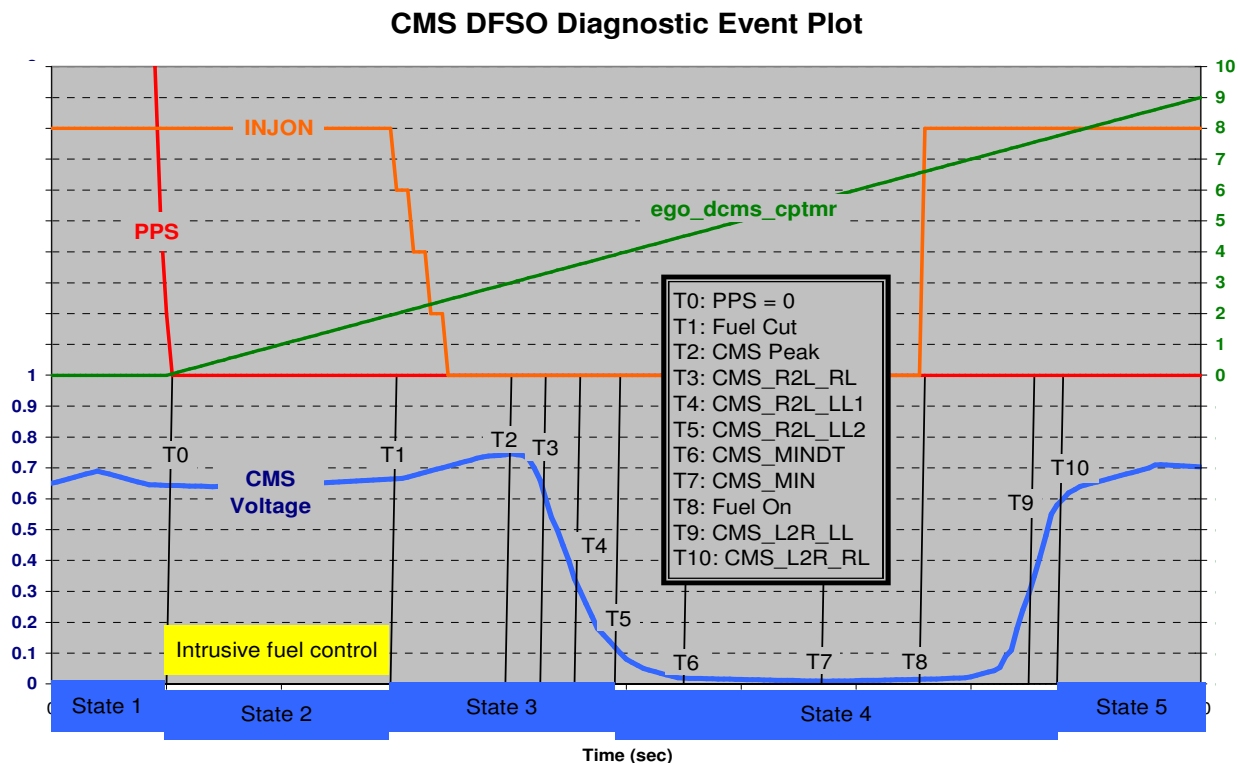
The main part of the test is the measured rich to lean response rate. It is determined by a "slew" rate calculation which determines the rich to lean slope of the sensor during a Decel Fuel Shut Off (DFSO) event which occurs during closed pedal at vehicle speeds higher than 28 mph. The calculation for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



Linear interpolation is performed to calculate the Slew Rate.

1. For 2010 MY and earlier, interpolate between points P1 and P2 to determine the time at which the rich limit threshold of 0.6 volts was crossed. For 2011MY and beyond, capture the time at T3 at which the rich limit threshold of 0.6 volts was crossed.
2. For 2010 MY and earlier, interpolate between points P3 and P4 to determine the time at which the lean limit threshold of 0.2 volts was crossed. For 2011MY and beyond, capture the time at T4 at which the lean limit threshold of 0.2 volts was crossed.
3. Use the 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)

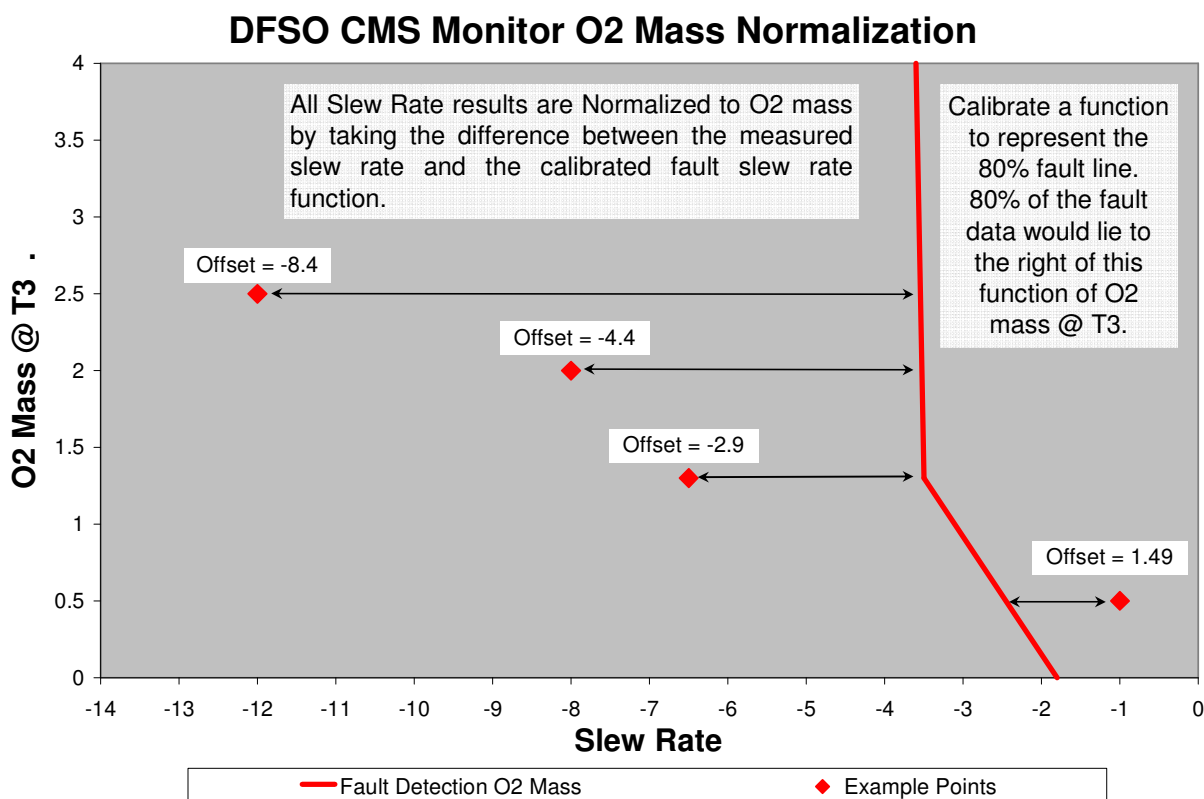
INJON (# of fuel injectors turned on)

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 4<sup>th</sup> 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 DCMS test data. It is employed after the 4<sup>th</sup> DCMS test and will illuminate a MIL during the drive cycle where the EWMA value exceeds the fault threshold. (1 trip MIL).

<b>Rear O2 DFSO Response Monitor Operation:</b>	
DTCs	P013A – O2 Sensor Slow Response – Rich to Lean (Bank 1 Sensor 2) P013C – O2 Sensor Slow Response – Rich to Lean (Bank 2 Sensor 2) P013E – O2 Sensor Delayed Response – Rich to Lean (Bank 1 Sensor 2) (sensor stuck in range) P014A – O2 Sensor Delayed Response – Rich to Lean (Bank 2 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 completed, HO2S 2 and 3 functional tests completed, HO2S/UEGO heater voltage and current checks completed, 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.

<b>Typical DFSO Response Monitor entry conditions:</b>		
Entry condition	Minimum	Maximum
Air Mass	0.5	6
Vehicle Speed		90
Inlet Air Temp		140
Engine Coolant Temp	155 °F	240 °F
Catalyst Temperature (Inferred)	800 °F	1600 °F
Rear Ego Tip Temperature (Inferred)	800 °F	
Fuel Level	15%	
Fuel In Control	-3%	3%
Adaptive Fuel Within Limits	-3%	3%
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	
\$02	\$85	HO2S12 Fuel Shut off Rich to Lean Response Rate (P013A)	mV/sec
\$02	\$86	HO2S12 Fuel Shut off Rich to Lean Response Time (P013E)	msec
\$06	\$85	HO2S22 Fuel Shut off Rich to Lean Response Rate (P013C)	mV/sec
\$06	\$86	HO2S22 Fuel Shut off Rich to Lean Response Time (P014A)	msec

## Rear HO2S Heaters

The HO2S heaters are monitored for proper voltage and current. A HO2S heater voltage fault (open, shorted to ground, or shorted to battery) is determined by turning the heater on and off and looking for corresponding voltage change in the heater output driver circuit in the PCM.

Beginning 2014MY, some applications have rear HO2S that uses impedance feedback heater controller to control impedance to a corresponding element temperature. The HO2S impedance feedback heater controller keeps the HO2S heater at constant impedance (Bosch LSF-X4: 220 ohms, NTK S2.01: 150 ohms), which corresponds to a temperature (Bosch LSF-X4: 780 deg C, NTK S2.01: 650 deg C). The impedance of the HO2S decreases as the sensor temperature increases. After a cold start, the HO2S 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 the target impedance.

The "HO2S 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 P0036/P0056 fault code is set. This monitor also sets a malfunction when the closed loop heater controller reaches a maximum or minimum duty cycle for a period of time indicating that the controller is no longer able to maintain the target impedance. However, if the exhaust temperature is high enough that the sensor will be below the target impedance even with no heat, then this monitor is disabled.

A separate current-monitoring circuit monitors heater current once per driving cycle. This monitor normally runs after the HO2S heaters have been on for some time and inferred to have been adequately warm. However, on applications that use HO2S impedance feedback heater controller, it can also run intrusively. When the HO2S impedance 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. If the current measurement falls below or above a calibratable threshold, the heater is assumed to be degraded or malfunctioning.

Beginning 2012MY, some PCMs do not have a separate heater current-monitoring circuit (without shunt resistors that can directly measure the current through the HEGO heaters). For applications that do not have a heater current-monitoring circuit and also do not use HO2S impedance feedback heater controller, the sensor heater performance is monitored by the "HO2S Impedance Monitor". The HO2S impedance monitor measures the HO2S internal impedance, validates the measurement, and then compares the validated internal impedance to an internal impedance threshold. If the validated internal impedance exceeds the threshold, then the monitor fault counter increments once. If the fault counter exceeds the total number of valid internal impedance measurements required, a HO2S heater control circuit range/performance malfunction (P00D2/P00D4) will be set.

The HO2S impedance monitor runs once per trip; however, it can also be forced to run intrusively. When the heater is inferred to have been adequately warm, but the HO2S sensor is suspected to be cold because the HO2S voltage falls inside the suspected open HO2S circuit voltage fault band or inside the suspected HO2S circuit shorted to ground voltage fault band, a HEGO sensor circuit or HEGO heater malfunction is suspected. To differentiate HO2S signal circuit failures from a degraded/malfunctioning heater or normal FAOS control, the HO2S impedance monitor is forced to run intrusively after the heater voltage test and the HO2S open/short to ground circuit diagnostics had ran and indicated no malfunction.

Any corrosion in the harness wiring, connector, or increase in the sensor heater element resistance will result in an overall increase in the heater circuit resistance, causing the HO2S impedance to increase. The impedance is dependent on the HO2S element temperature and the voltage at the connector. As the HO2S element temperature increases, the impedance decreases. Furthermore, as the voltage at the connector increases, the sensor impedance decreases. Hence, the impedance threshold for the HO2S heater impedance monitor is a function of the inferred HO2S element temperature and the voltage at the connector.

On the other hand, applications that use HO2S impedance feedback heater controller and also do not have a separate heater current-monitoring circuit, a degraded or malfunctioning HO2S heater is detected by the "HO2S Heater Temperature Control Monitor." This monitor would call the malfunction after the heater voltage test and HO2S circuit diagnostics had run first and indicated no malfunction.

HO2S Heater Monitor Operation:	
DTCs Sensor 2	P0036 – HO2S12 Heater Control Circuit, Bank 1 P0056 – HO2S22 Heater Control Circuit, Bank 2 P0141 - O2 Sensor Heater Circuit, Bank 1 P0161 - O2 Sensor Heater Circuit, Bank 2 P0054 - HO2S Heater Resistance, Bank 1 P0060 - HO2S Heater Resistance, Bank 2
DTCs Sensor 3	P00D2 - HO2S Heater Control Circuit Range/Performance (Bank 1, Sensor 2) P00D4 - HO2S Heater Control Circuit Range/Performance (Bank 2, Sensor 2) P0147 - O2 Sensor Heater Circuit, Bank 1 P0167 - O2 Sensor Heater Circuit, Bank 2 P0055 - HO2S Heater Resistance, Bank 1 P0061 - HO2S Heater Resistance, Bank 2
Monitor execution	once per driving cycle for heater current monitor and HO2S impedance monitor, continuous for voltage monitoring and HO2S heater temperature control monitoring.
Monitor Sequence	Heater current monitor: Stream 1 HO2S/UEGO response test complete (2010 MY and earlier), Stream 2 and 3 HO2S functional tests completed (2010 MY and earlier), HO2S/UEGO heater voltage check completed.  HO2S heater temperature control monitor: Stream 2 HO2S heater voltage check completed, Stream 2 HO2S circuit check completed, intrusive heater current monitor completed (if applicable).  HO2S impedance monitor: Stream 2 HO2S heater voltage check complete, Stream 2 HO2S circuit check and test time slice completed.
Sensors OK	Heater current monitor: no HO2S/UEGO heater voltage DTCs.  HO2S heater temperature control monitor: no rear HO2S circuit malfunction, no rear HO2S out of range low malfunction, no rear HO2S heater circuit malfunction, no HO2S heater current monitor DTCs.  HO2S impedance monitor: rear HO2S heaters OK, no rear HO2S out of range low malfunction, no rear HO2S functional DTCs, no rear HO2S circuit malfunction.
Monitoring Duration	< 10 seconds for heater voltage check, < 5 seconds for heater current check, >= 30 seconds for the HO2S heater temperature control monitor to register a malfunction, < 11 seconds for HO2S impedance test.

Typical HO2S heater monitor entry conditions:		
Entry condition	Minimum	Maximum
<b>Heater Voltage Test:</b>		
Inferred HO2S 2/3 Temperature	400 °F	1400 °F
Battery Voltage	11.0	18.0 Volts
<b>Heater Current Test:</b>		
Inferred HO2S 2 Temperature	250 °F	1400 °F
Inferred HO2S 3 Temperature	250 °F	1400 °F
HO2S 1/2/3 heater-on time	30 seconds	
Engine RPM		5000 rpm
Battery Voltage	11.0	18.0 Volts
<b>HO2S Heater Temperature Control Monitor:</b>		
Heater voltage test completed		
Stream 2 HO2S circuit check completed		
Intrusive heater current monitor completed (if applicable)		
Battery Voltage	11.0	18.0 Volts
<b>HO2S Impedance Monitor:</b>		
Inferred Stream 2 HO2S Temperature	680 °F	
Inferred Stream 2 HO2S Element Temperature	480 °F	1020 °F
Time Stream 2 HO2S inferred element temperature within 10% of the predicted steady state temperature	1 second	
Sensor 2 HO2S heater-on time	60 seconds	
All injectors on (no Decel Fuel Shut Off)		
Not commanding lean lambda due to torque reduction		
Not requesting enrichment due to catalyst reactivation following decel fuel shut off		
Sensor 2 HO2S voltage (open circuit voltage fault band- intrusive test only): Conti-Moto CBP-A2 PCM	-0.05 Volts	0.05 Volts
Other PCMs or depending on feedback circuit	0.27 Volts 1.30 Volts	0.50 Volts 1.90 Volts
Sensor 2 HO2S voltage (circuit shorted to ground voltage fault band- intrusive test only):	-3.00 Volts	0.06 Volts
Voltage at sensor 2 HO2S connector	11.0 Volts	
Battery Voltage	11.0 Volts	18.0 Volts

**Typical HO2S heater check malfunction thresholds:****Heater Voltage Test:**

Smart driver status indicated malfunction

Number monitor retries allowed for malfunction  $\geq 30$

**Heater Current Test:**

Heater current outside limits:

- $< 0.220$  Amps or  $> 3$  Amps, (NTK Thimble)
- $< 0.400$  Amps or  $> 3$  Amps, (Bosch Thimble)
- $< 0.550$  Amps or  $> 3$  Amps, (Bosch Planar)
- $< 0.465$  Amps or  $> 3$  Amps, (NTK Fast Light Off)
- $< 0.230$  Amps or  $> 3$  Amps, (Bosch Fast Light Off)

**HO2S Heater Temperature Control Monitor:**

$\geq 30$  seconds to register a malfunction while the heater control integrator is at its maximum or minimum limit and HO2S Impedance  $\geq 1$  k ohms (Bosch), 11,500 ohms (NTK)

**HO2S Impedance Test:**

HO2S internal impedance  $>$  table below (ohms), fault counter  $\geq 10$

Voltage at HO2S (Volts)/ HO2S inferred element temp (°F)	11	13	14	15	18
480	71734	26000	14583	9268	2856
570	25864	10522	6496	3733	1644
671	8629	4057	2905	2083	1175
730	3253	1862	1399	1066	576
770	2906	1614	1223	941	530
905	838	575	470	383	273
1020	675	473	410	359	251

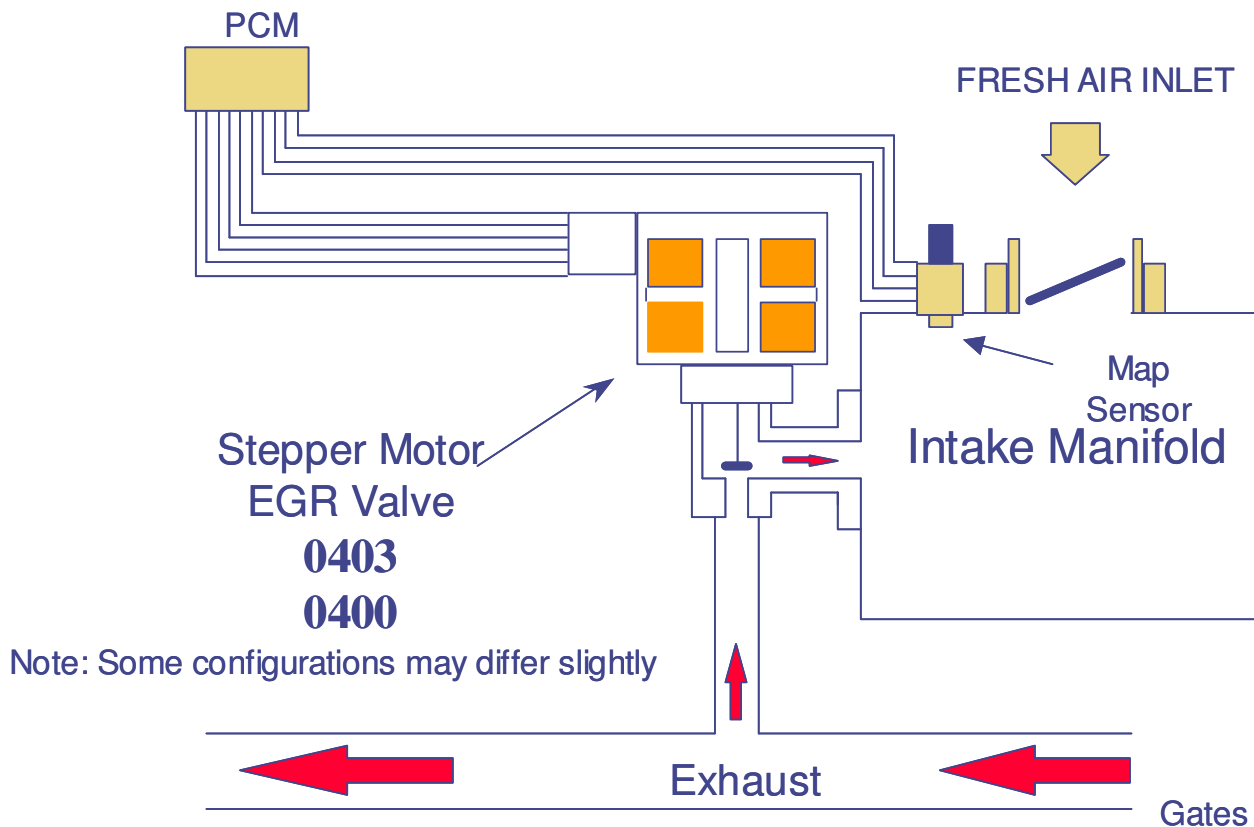
**J1979 HO2S Heater Mode \$06 Data**

Monitor ID	Test ID	Description	Units
\$42	\$81	HO2S12 Heater Current (P0054)	Amps
\$46	\$81	HO2S22 Heater Current (P0060)	Amps
\$42	\$82	O2S12 Heater Impedance (P00D2)	kOhm
\$46	\$82	O2S22 Heater Impedance (00D4)	kOhm

## Stepper Motor EGR System 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 discrete 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.

### Stepper Motor EGR System



The 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 > 10 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

When EGR is delivered into the intake manifold, intake manifold vacuum is reduced and thus manifold absolute pressure (MAP) is increased. A MAP sensor and inferred MAP are used by this monitor to determine how much EGR is flowing. A MAP sensor located in the intake manifold measures the pressure when EGR is being delivered and when EGR is not being delivered. The pressure difference between EGR-on and EGR-off is calculated and averaged. If the vehicle also has a MAF sensor fitted, then the monitor also calculates and averages an inferred MAP value in the above calculation and resulting average. After a calibrated number of EGR-on and EGR-off cycles are taken, the measured and inferred MAP values are added together and compared to a minimum threshold to determine if a flow failure (P0400) in the EGR system has occurred.

<b>EGR Flow Check Operation:</b>	
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)

<b>Typical EGR flow check entry conditions:</b>		
Entry Condition	Minimum	Maximum
Engine RPM	1400 rpm	2600 rpm
Inferred Ambient Air Temperature	32 °F	140 °F
Engine Coolant Temperature	80 °F	250 °F
Engine RPM Steady (change/0.050 sec)		100 rpm
MAP Steady (change/0.050 sec)		0.5 in Hg
Engine Load Steady (change/0.050 sec)		1.5 %
BARO	22.5 " Hg	
Intake Manifold Vacuum	9.0 "Hg	16.0 "Hg
Vehicle Speed	35 MPH	70 MPH
Engine Throttle Angle steady(absolute change)	0.0 degrees	4.0 degrees

<b>Typical EGR flow check malfunction thresholds:</b>
< 1.0 MAP differential

<b>J1979 Mode \$06 Data</b>			
Monitor ID	Test ID	Description	Units
\$31	\$82	Normalized MAP differential (range 0 – 2) (P0400)	unitless

## **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.

## High Pressure Cooled EGR Monitor (HPEGR)

Prior to the inclusion of Variable Cam Timing (VCT) systems, EGR systems were primarily used to control tailpipe NOx emissions by reducing peak combustion temperatures. Modern day engines with VCT are starting to use external EGR systems to improve vehicle fuel economy by

- Reducing pumping losses
- Reducing heat transfer losses due to lower combustion temperatures
- Potential for high load enrichment reduction
- Potential for compression ratio increase

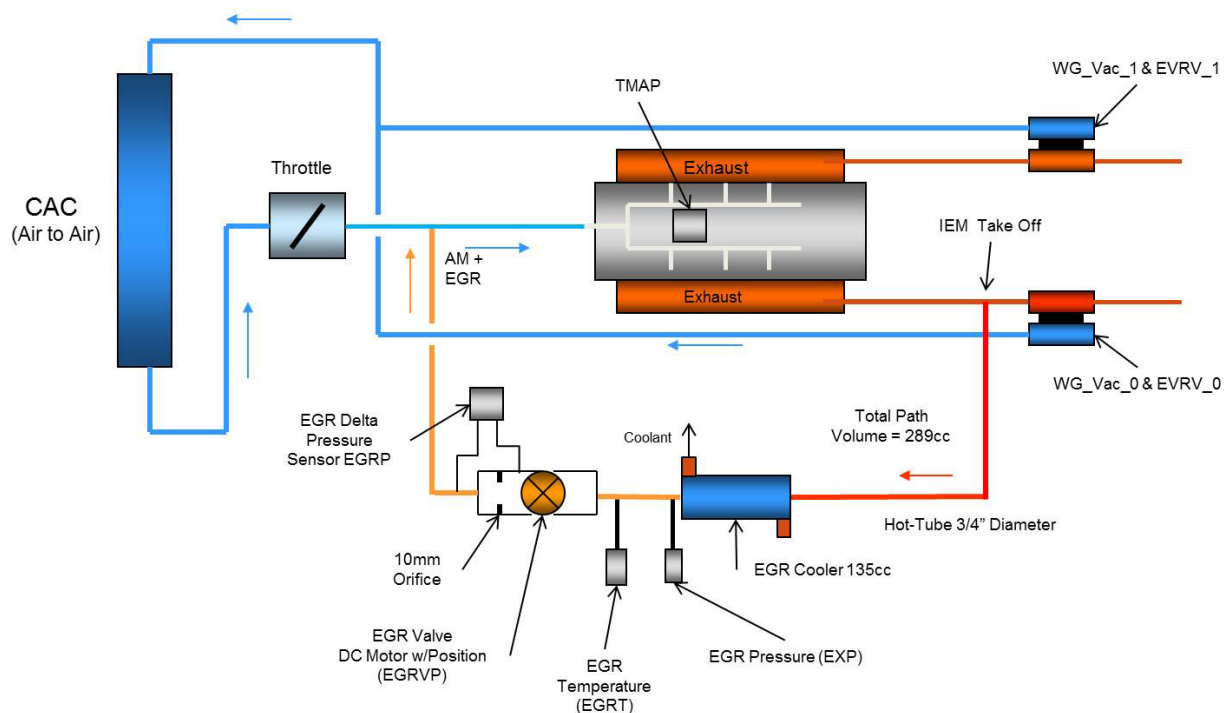
Starting in 2018 MY Ford will employ a High Pressure Cooled EGR system for fuel economy and emission reduction. This system includes the following components:

- An H-bridge motor controlled EGR valve & position sensor
- Delta PFE sensor to measure EGR flow
- EGR gas cooler (exhaust to coolant heat exchanger)
- EGR gas temperature sensor
- EGR/exhaust gas pressure sensor

High Pressure Cooled/Uncooled EGR will be used on both boosted and naturally aspirated engines:

- 2.7L GTDI 2018 MY
- 2.0L GTDI 2019 MY (uses EGR Temp Sensor post EGR valve)
- 3.3L 2018 MY

**HPEGR System Schematic**



The High Pressure Cooled EGR Monitor has a series of electrical tests and functional tests that monitors various aspects of EGR system operation.

The Exhaust Gas Recirculation Pressure sensor (EGRP) measures the pressure differential across an orifice in the EGR system.

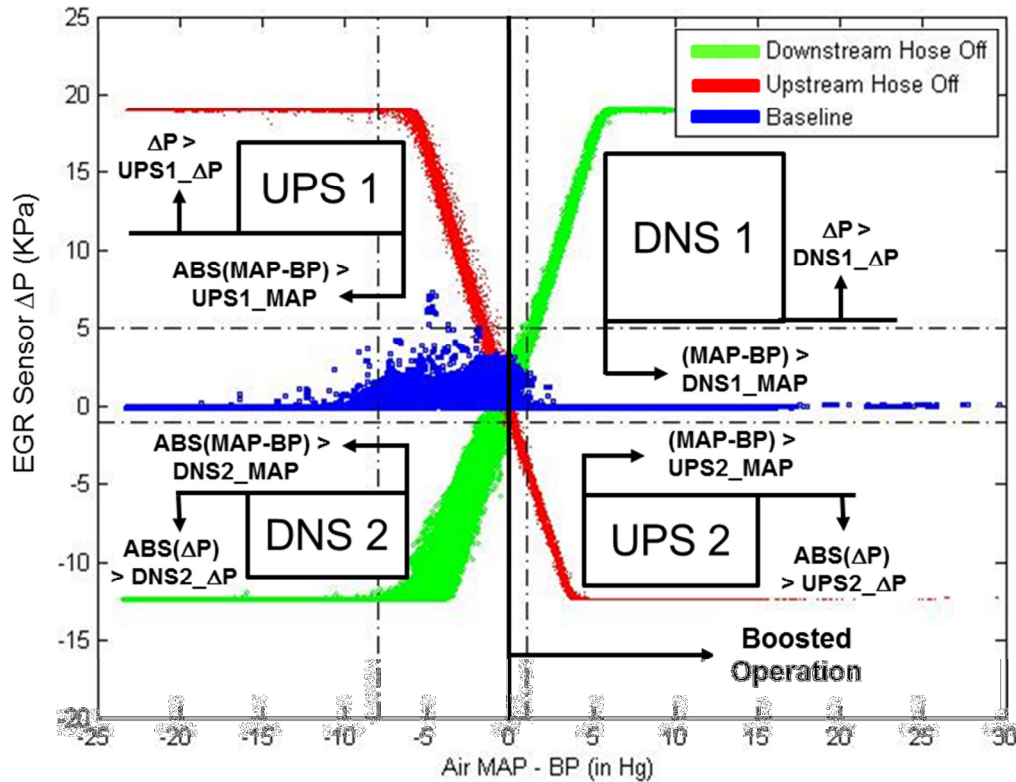
<b>EGR DPFE Electrical Check Operation:</b>	
DTCs	P044C EGR Sensor "C" Circuit Low P044D EGR Sensor "C" Circuit High
Monitor execution	Continuous, during EGR monitor
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds to register a malfunction

<b>Typical DPFE EGR electrical check entry conditions:</b>
Continuous

<b>Typical DPFE EGR electrical check malfunction thresholds:</b>
DPFE sensor outside voltage: > 4.65 volts, < 0.25 volts

<b>DPFE Sensor Transfer Function</b>	
Pressure Range: -10.989 [kPa] to +18.315 [kPa]	
$V_{out} = V_{ref} * (0.027304 * P + 0.40031)$ , P in [kPa], Vref is 5.0 volts	
Volts	Delta Pressure, kPa
0.500	-11.00
0.90	-8.07.0
1.50	-3.6750
1.90	-0.745
2.10	0.720
2.50	3.65
3.70	12.44
4.50	18.3

The EGRP sensor is a Delta Pressure Feedback EGR (DPFE) sensor measuring the pressure differential across a fixed orifice. The sensor contains two hoses on either side of the orifice and these hoses must be connected to properly measure the EGR flow. Therefore, a set of hose tests are provided to detect Upstream/Downstream hose disconnections and swapped hoses. The use of Stop/Start on some applications requires these hose tests to run during off-idle conditions because Stop/Start vehicles have limited idle opportunities. Hence, these diagnostics run continuously during both idle and off-idle operation.



The hose diagnostics execute in the vehicle operation range shown in the graph above. It shows the measured EGRP sensor delta pressure (Y-Axis) versus the full operation range of pressures seen in the intake manifold (X-Axis). The normal expected range of EGRP sensor measurements are shown in blue with both a minimum and maximum calibration range (Y-Axis dotted lines at -1 kPa and 5 kPa). When the measured EGRP pressure is outside of this calibration range then a hose fault may be present. Notice that swapped hoses will be measured as negative flow (negative delta pressure) by the EGRP resulting in a mirrored delta pressure copy of the blue samples shown above (mirrored below the minimum calibration dotted line at -1 kPa). Both the upstream (UPS) and downstream (DNS) hose disconnections are detected when the EGRP measures are in the four quadrants beyond the calibrated limits (vertical dotted lines at -8 kPa and 5 kPa in the above figure).

DPFE EGR Hose Check Operation:	
DTCs	P139A EGR Sensor "C" Hoses Reversed P139B EGR Sensor "C" Upstream Hose Off or Plugged P139C EGR Sensor "C" Downstream Hose Off or Plugged
Monitor execution	Continuous during the driving cycle
Monitor Sequence	after electrical checks completed
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P0111, P0112, P0113, P0116, P0117, P0118, P2227, P2228, P2229, P04FA, P042E, P042F, P044C, P044D, P0405, P0406, P0472, P0473
Monitoring Duration	25 to 50 seconds to register a malfunction

Typical DPFE EGR hose check entry conditions:		
Entry Conditions	Minimum	Maximum
Ambient Air Temperature	> 35 deg F	< 200 deg F
BARO	> 22.0 in Hg	
Entry conditions for hoses reversed		
EGR Valve Position (EGR commanded on)	> 0%	100%
Entry conditions for hoses off or plugged		
EGR flow near zero	>0.5 g/s	
Manifold Pressure	> -85 kPa	< 102 kPa

Typical EGR hose check malfunction thresholds:
P139A: DPFE signal < -0.5 kPa for 30 sec
P139B: DPFE Signal > 13.0 kPa for 25 sec
P139C: DPFE Signal < -4.0 kPa for 50 sec

The Exhaust Gas Recirculation Valve Control (EGRVC) actuator is used to provide a defined amount of EGR back into the intake manifold. The EGR valve actuator requires an ECU with an H-bridge output and position feedback. The EGR valve actuator is equipped with a non-contacting hall effect position sensor. This sensor is free of mechanical wear, is high-temperature capable, and provides very accurate position feedback.

<b>EGR Control Valve Electrical Check Operation:</b>	
DTCs	EGR valve position sensor tests P0405 EGR Sensor "A" Circuit Low P0406 EGR Sensor "A" Circuit High P046D EGR Sensor "A" Circuit Intermittent/Erratic EGR valve control circuit tests P042E EGR "A" Control Stuck Open P042F EGR "A" Control Stuck Closed P04FA EGR "A" Control Temperature Too High
Monitor execution	Continuous, during EGR monitor
Monitor Sequence	None
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P2227, P2228, P2229, P044C, P044D, P0405, P0406 P0071, P0072, P0073, P0106, P0107, P0108, P0111, P0112, P0113, P0116, P0117, P0118, P2227, P2228, P2229, P044C, P044D, P0472, P0473
Monitoring Duration	4 seconds to register a malfunction

<b>Typical EGR Control Valve entry conditions:</b>		
Entry Conditions	Minimum	Maximum
Battery Voltage	> 8.25 volts	
H-Bridge Voltage	> 8.25 volts	
Engine rpm	> 400 rpm	

<b>EGR Valve Position Sensor Transfer Function</b>	
$V_{out} = 0.625 * (mm) - 0.25$ . (6 mm maximum travel)	
Volts	Valve Lift (mm)
0.25 (5% of full scale)	0
0.50 (10% of full scale)	1.2
1.00 (20% of full scale)	2.0
1.50 (30% of full scale)	2.8
2.50 (50% of full scale)	4.4
3.50 (70% of full scale)	6.0
4.75 (95% of full scale)	8.0

### Typical EGR Control Valve electrical check malfunction thresholds:

P0405: EGR Valve Position signal < 5% of full scale for 4 sec

P0406: EGR Valve Position signal > 95% of full scale for 4 sec

P046D: EGR Valve Position signal > 95% or < 5% of full scale for 0.4 sec

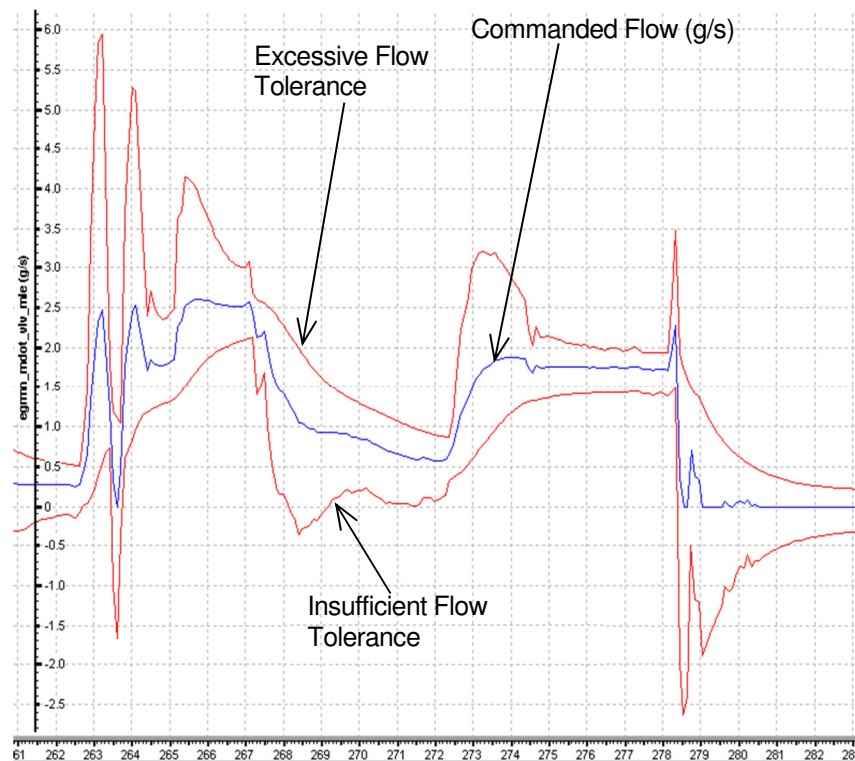
P042E: Observed actuator A position < calculated low limit minus calculated margin and observed actuator A position and observed actuator A position calculated high limit > 11 mm.

P042F: Observed actuator A position < calculated low limit minus calculated margin and observed actuator A position and observed actuator A position calculated high limit < 11 mm.

P04FA:  $2 * \text{observed position} > 5.5\text{mm}$  and  $8 * \text{estimated position} < 5.5\text{ mm}$  and observed velocity of position > 5.5 mm/s and opening by percent < 10%.

After the vehicle has warmed up and normal EGR rates are being commanded by the PCM, the low flow check and the high flow check is performed. The EGR flow diagnostics execute once-per-driving cycle and are designed to set a fault when the total mass flow error results in a tailpipe emissions increase above the CARB defined level.

This is achieved by first calculating error tolerance bands around the commanded EGR mass flow and accumulating any error between the measured mass flow and these tolerance bands. This gives separate error accumulations for both insufficient and excessive EGR mass flow. These accumulated errors are then ratio'd against an accumulation of the total commanded EGR mass flow and compared to a threshold. The threshold is set to represent the point in the drive where an unacceptable emissions level may result (calibrated to the FTP cycle emissions).



If the calculated insufficient flow rate is above a calibrated ratio when compared to actual flow rate a low flow malfunction is indicated (P0401). If the calculated excess flow rate is above a calibrated ratio when compared to actual flow rate a high flow malfunction is indicated (P0402).

<b>EGR Flow Check Operation:</b>	
DTCs	P0401 – Insufficient EGR Flow P0402 – Excessive EGR Flow
Monitor execution	once per driving cycle
Monitor Sequence	Must pass circuit (P044C, P044D) & hose tests (P139B, P139C) before a flow test fault is determined
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P2227, P2228, P2229, P044C, P044D, P0405, P0406, P139A, P139B, P139C
Monitoring Duration	70 seconds to register a malfunction

<b>Typical EGR Flow check entry conditions:</b>		
Entry Conditions	Minimum	Maximum
Ambient Air Temperature	> 35 deg F	< 200 deg F
BARO	> 22.0 in Hg	
Engine running		

<b>Typical EGR flow check malfunction thresholds:</b>	
P0401: Insufficient flow rate ratio > 0.6 after sufficient EGR flow accumulation	
P0402: Excessive flow rate ratio > 0.4 after sufficient EGR flow accumulation	

<b>J1979 Mode \$06 Data</b>			
Monitor ID	Test ID	Description for ESM DPFE	Units
\$32	\$85	Flow ratio for insufficient flow test and threshold (P0401)	Unitless
\$32	\$84	Flow ratio for excessive flow test and threshold (P0402)	Unitless

## I/M Readiness Indication

If the inferred ambient temperature is less than 32 °F, or greater than 140 °F, or the altitude is greater than 8,000 feet (BARO < 22.0 "Hg), the EGR monitor cannot be run reliably. In these conditions, 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 600 seconds, the EGR monitor 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. Starting in the 2002 MY, vehicles will require two such driving cycles for the EGR Monitor I/M Readiness bit to be set to a "ready" condition.

## EGR Cooler and Diagnostics

The High Pressure Cooled EGR Monitor is a series of electrical tests and functional tests that monitors various aspects of EGR system operation.

The Exhaust Gas Temperature sensor (EGRT) measures the gas temperature downstream of the EGR cooler and is used to determine EGR cooler effectiveness.

### EGR Temperature Sensor "B" Electrical Check Operation:

DTCs	P041C EGR Temperature Sensor "B" Circuit Low P041D EGR Temperature Sensor "B" Circuit High P041B EGR Temperature Sensor "B" Range/Performance
Monitor execution	Continuous, during EGR monitor
Monitor Sequence	None
Sensors OK	No EGR flow faults (P0401, P0402)
Monitoring Duration	5 seconds to register a malfunction

### Typical EGR Temperature Sensor "B" check entry conditions:

Continuous

### Typical EGR Temperature Sensor "B" check malfunction thresholds:

EGR Temp Sensor "B" voltage: > 4.94 volts, < 0.32 volts

### Dual Range EGR Temperature Sensor Transfer Function

#### Range Switched at 100°C +/-5°C

Volts	Cold Range Temp (°C)	Volts	Hot Range Temp (°C)
0.198	130	0.378	250
0.331	110	0.438	240
0.567	90	0.511	230
0.747	80	0.596	220
0.984	70	0.697	210
1.677	50	0.818	200
2.137	40	0.960	190
2.913	25	1.127	180
3.668	10	1.323	170
4.087	0	1.548	160
4.416	-10	2.091	140
4.648	-20	2.732	120
4.799	-30	3.069	110
4.891	-40	3.708	90

The High Pressure Cooled EGR Monitor is a series of electrical tests and functional tests that monitors various aspects of EGR system operation. The Exhaust Gas Pressure sensor (EXP) measures the exhaust pressure downstream of the EGR cooler and is used primarily for EGR cooler effectiveness.

<b>Exhaust Pressure Sensor "A" Electrical Check Operation:</b>	
DTCs	P0472 Exhaust Pressure Sensor "A" Circuit Low P0473 Exhaust Pressure Sensor "A" Circuit High P0474 Exhaust Pressure Sensor "A" Circuit Intermittent/Erratic P0471 Exhaust Pressure Sensor "A" Circuit Range/Performance
Monitor execution	Continuous, during EGR monitor
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds to register a malfunction

<b>Typical Exhaust Pressure Sensor "A" check entry conditions:</b>
Continuous

<b>Typical Exhaust Pressure Sensor "A" check malfunction thresholds:</b>
Exhaust Pressure Sensor "A" voltage: > 4.80 volts, < 0.21 volts

<b>Exhaust Pressure Sensor Transfer Function</b>	
Pressure Range: 49 [kPa] to +378 [kPa]	
$V_{out} = V_{ref} * (0.0027 * P_{exh}) + -0.0715$ Pexh in [kPa], Vref is 5.0 volts	
Volts	Pressure, kPa
0.300	49
0.982	100
1.518	140
2.053	180
2.522	215
3.058	255
3.527	290
4.70	378

<b>EGR Cooler Check Operation:</b>	
DTCs	P2457 – EGR Cooler Efficiency Below Threshold
Monitor execution	once per driving cycle
Monitor Sequence	
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P2227, P2228, P2229, P044C, P044D, P0405, P0406
Monitoring Duration	70 seconds to register a malfunction

<b>Typical EGR Cooler check entry conditions:</b>		
Entry Conditions	Minimum	Maximum
Ambient Air Temperature	> 35 deg F	< 200 deg F
BARO	> 22.0 in Hg	
Engine running		

<b>Typical EGR Cooler check malfunction thresholds:</b>
P2457: Insufficient flow rate ratio > 0.5 after sufficient EGR flow accumulation

## Low Pressure Cooled EGR Monitor (LPEGR)

Prior to the inclusion of Variable Cam Timing (VCT) systems, EGR systems were primarily used to control tailpipe NOx emissions by reducing peak combustion temperatures. Modern day engines with VCT are starting to use external EGR systems to improve vehicle fuel economy by

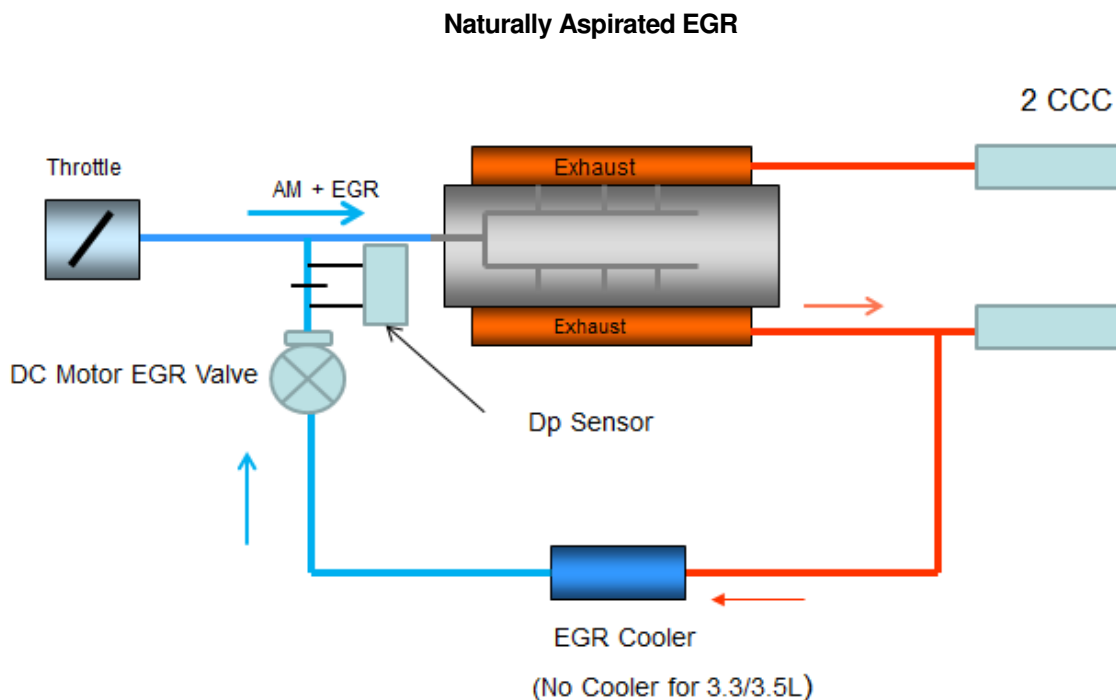
- Reducing pumping losses
- Reducing heat transfer losses due to lower combustion temperatures
- Potential for high load enrichment reduction
- Potential for compression ratio increase

Starting in 2018 MY Ford will employ a Low Pressure Cooled EGR system for fuel economy and emission reduction. This system includes the following components:

- An H-bridge motor controlled EGR valve & position sensor
- Delta PFE sensor to measure EGR flow
- EGR gas cooler (exhaust to coolant heat exchanger)

Naturally Aspirated EGR will be used on naturally aspirated engines:

- 3.3L 2018MY



The Low Pressure Cooled EGR Monitor is a series of electrical tests and functional tests that monitors various aspects of EGR system operation.

The Exhaust Gas Recirculation Pressure sensor (EGRP) measures the pressure differential across an orifice in the EGR system.

EGR DPFE Electrical Check Operation:	
DTCs	P044C EGR Sensor "C" Circuit Low P044D EGR Sensor "C" Circuit High
Monitor execution	Continuous, during EGR monitor
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds to register a malfunction

Typical DPFE EGR electrical check entry conditions:
Continuous

Typical DPFE EGR electrical check malfunction thresholds:
DPFE sensor outside voltage: > 4.65 volts, < 0.25 volts

DPFE Sensor Transfer Function	
Pressure Range: -10.989 [kPa] to +18.315 [kPa]	
$V_{out} = V_{ref} * (2.7300E-02 * P + 4.0000E-01)$ , P in [kPa] ], Vref is 5.0 volts	
Volts	Delta Pressure, kPa
0.500	-11.00
0.90	-8.07.0
1.50	-3.6750
1.90	-0.745
2.10	0.720
2.50	3.65
3.70	12.44
4.50	18.3

After the vehicle is started, the differential pressure indicated by the DPFE sensor at idle, at zero EGR flow is checked to ensure that both hoses to the DPFE sensor are connected. At idle, the differential pressure should be zero (both hoses see intake manifold pressure). If the differential pressure indicated by the sensor exceeds a maximum threshold or falls below a minimum threshold, an upstream or downstream hose malfunction is indicated (P1405, P1406).

DPFE EGR Hose Check Operation:	
DTCs	P139A EGR Sensor "C" Hoses Reversed P139B EGR Sensor "C" Upstream Hose Off or Plugged P139C EGR Sensor "C" Downstream Hose Off or Plugged
Monitor execution	once per driving cycle
Monitor Sequence	after electrical checks completed
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P2227, P2228, P2229, P044C, P044D, P0405, P0406
Monitoring Duration	25 to 50 seconds to register a malfunction

Typical DPFE EGR hose check entry conditions:		
Entry Conditions	Minimum	Maximum
Ambient Air Temperature	> 35 deg F	< 200 deg F
BARO	> 22.0 in Hg	
Entry conditions for hoses reversed		
EGR Valve Position (EGR commanded on)	> 0%	0%
Entry conditions for hoses off or plugged		
EGR flow near zero		< 0.5 g/s
Manifold Pressure	> 50 kPa	< -11 kPa

Typical EGR hose check malfunction thresholds:
P139A: DPFE signal < -0.5 kPa for 30 sec
P139B: DPFE Signal > 13.0 kPa for 25 sec
P139C: DPFE Signal < -4.0 kPa for 50 sec

The Exhaust Gas Recirculation Valve Control (EGRVC) actuator is used to provide a defined amount of EGR back into the intake manifold. The EGR valve actuator requires an ECU with an H-bridge output and position feedback. The EGR valve actuator is equipped with a non-contacting hall effect position sensor. This sensor is free of mechanical wear, is high-temperature capable, and provides very accurate position feedback.

<b>EGR Control Valve Electrical Check Operation:</b>	
DTCs	EGR valve position sensor tests P0405 EGR Sensor "A" Circuit Low P0406 EGR Sensor "A" Circuit High P046D EGR Sensor "A" Circuit Intermittent/Erratic EGR valve control circuit tests P042E EGR "A" Control Stuck Open P042F EGR "A" Control Stuck Closed P04FA EGR "A" Control Temperature Too High
Monitor execution	Continuous, during EGR monitor
Monitor Sequence	None
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P2227, P2228, P2229, P044C, P044D, P0405, P0406
Monitoring Duration	4 seconds to register a malfunction

<b>Typical DPFE EGR hose check entry conditions:</b>		
Entry Conditions	Minimum	Maximum
Battery Voltage	> 8.25 volts	
H-Bridge Voltage	> 8.25 volts	
Engine rpm	> 400 rpm	

<b>EGR Valve Position Sensor Transfer Function</b>	
$V_{out} = 0.625 * (\text{mm}) - 0.25. (\text{max. } 6 \text{ mm travel})$	
Volts	Valve Lift (mm)
0.25 (5% of full scale)	0
0.50 (10% of full scale)	1.2
1.00 (20% of full scale)	2.0
1.50 (30% of full scale)	2.8
2.50 (50% of full scale)	4.4
3.50 (70% of full scale)	6.0
4.75 (95% of full scale)	8.0

### Typical EGR Control Valve electrical check malfunction thresholds:

P0405: EGR Valve Position signal < 5% of full scale for 4 sec

P0406: EGR Valve Position signal > 95% of full scale for 4 sec

P046D: EGR Valve Position signal > 95% or < 5% of full scale for 0.4 sec

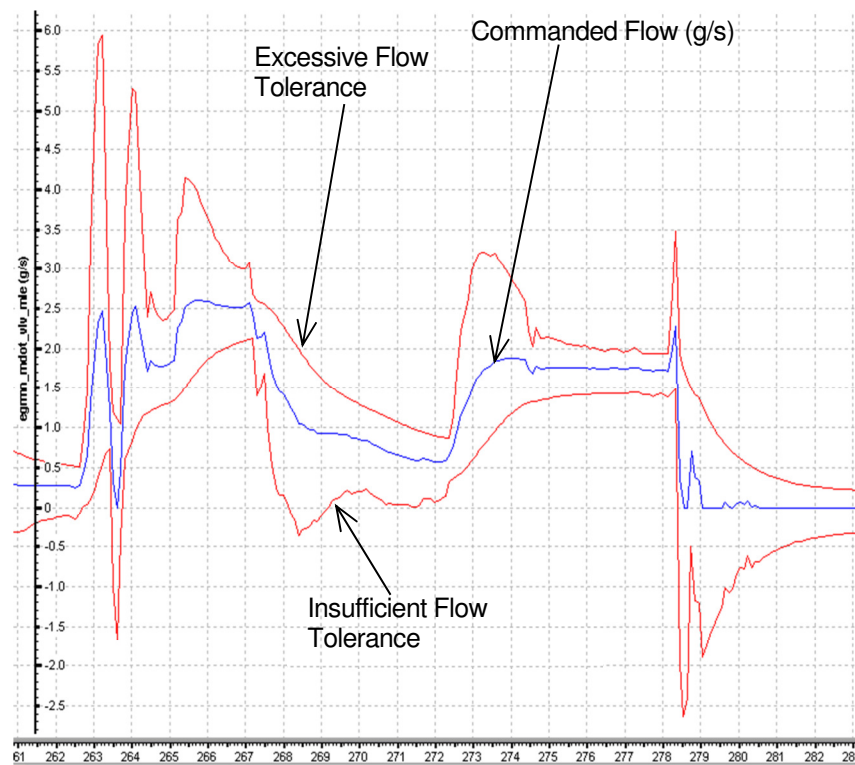
P042E: Observed actuator A position < calculated low limit minus calculated margin and observed actuator A position and observed actuator A position calculated high limit > 11 mm.

P042F: Observed actuator A position < calculated low limit minus calculated margin and observed actuator A position and observed actuator A position calculated high limit < 11 mm.

P04FA:  $2 * \text{observed position} > 5.5\text{mm}$  and  $8 * \text{estimated position} < 5.5\text{ mm}$  and observed velocity of position > 5.5 mm/s and opening by percent <10%.

After the vehicle has warmed up and normal EGR rates are being commanded by the PCM, the low flow check and the high flow check is performed. The EGR flow diagnostics execute once-per-driving cycle and are designed to set a fault when the total mass flow error results in a tailpipe emissions increase above the CARB defined level.

This is achieved by first calculating error tolerance bands around the commanded EGR mass flow and accumulating any error between the measured mass flow and these tolerance bands. This gives separate error accumulations for both insufficient and excessive EGR mass flow. These accumulated errors are then ratio'd against an accumulation of the total commanded EGR mass flow and compared to a threshold. The threshold is set to represent the point in the drive where an unacceptable emissions level may result (calibrated to the FTP cycle emissions).



If the calculated insufficient flow rate is above a calibrated ratio when compared to actual flow rate a low flow malfunction is indicated (P0401). If the calculated excess flow rate is above a calibrated ratio when compared to actual flow rate a high flow malfunction is indicated (P0402).

<b>EGR Flow Check Operation:</b>	
DTCs	P0401 – Insufficient EGR Flow P0402 – Excessive EGR Flow
Monitor execution	once per driving cycle
Monitor Sequence	done after P0402 completed
Sensors OK	P0071, P0072, P0073, P0106, P0107, P0108, P2227, P2228, P2229, P044C, P044D, P0405, P0406
Monitoring Duration	70 seconds to register a malfunction

<b>Typical EGR FLOW check entry conditions:</b>		
Entry Conditions	Minimum	Maximum
Ambient Air Temperature	> 35 deg F	< 200 deg F
BARO	> 22.0 in Hg	
Engine running		

<b>Typical EGR flow check malfunction thresholds:</b>	
P0401: Insufficient flow rate ratio > 0.5 after sufficient EGR flow accumulation	
P0402: Excessive flow rate ratio > 0.5 after sufficient EGR flow accumulation	

<b>J1979 Mode \$06 Data</b>			
Monitor ID	Test ID	Description for ESM DPFE	Units
\$32	\$86	Flow ratio for insufficient flow test and threshold (P0401)	Unitless
\$31	\$87	Flow ratio for excessive flow test and threshold (P0402)	Unitless

## I/M Readiness Indication

If the inferred ambient temperature is less than 32 °F, or greater than 140 °F, or the altitude is greater than 8,000 feet (BARO < 22.5 "Hg), the EGR monitor cannot be run reliably. In these conditions, 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 500 seconds, the EGR monitor 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. Starting in the 2002 MY, vehicles will require two such driving cycles for the EGR Monitor I/M Readiness bit to be set to a "ready" condition.

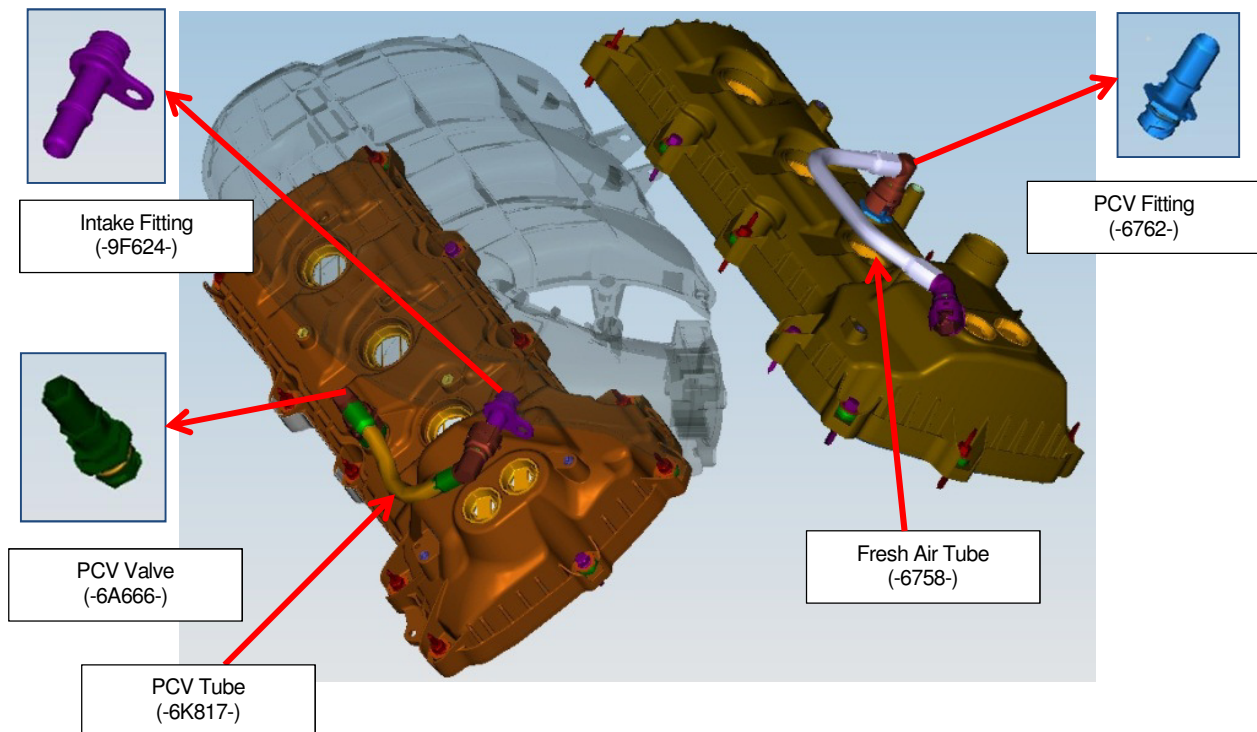
## PCV System Monitor – Naturally Aspirated Engine with MAF Sensor

The engine crankcase contains cylinder blow by vapors which consist of combustion byproducts, unburned fuel and moisture. The PCV system is designed to evacuate these crankcase vapors so that they don't contaminate the engine oil and induct them into the intake manifold so that they can be burned in the engine. The PCV hose connects the crankcase to the intake manifold through the PCV valve which is normally mounted to the rocker cover. The fresh air hose connects the Air Induction System (AIS) to the other rocker cover (on a V engine) to provide fresh, filtered clean air into the crankcase as the crankcase vapors are evacuated. The PCV valve has a spring loaded, tapered pintle and orifice that limits the amount of crankcase vapors that are inducted into the engine. The least amount of flow occurs during idle when manifold vacuum is high. As engine load increases, manifold vacuum decreases which allow more flow. At WOT there is no flow through the PCV valve. Blow by vapors will get inducted into the AIS through the fresh air tube.

The PCV valve is installed into the rocker cover using a quarter-turn cam-lock design to prevent accidental disconnection. The PCV valve is connected to the intake manifold hose using a quick connect. The PCV tube is swaged to the valve and fittings and is not removable. 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 nylon 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.

### 3.5L/3.7L TIVCT FWD PCV System Components for Taurus/Flex/MKZ/MKS/MKT

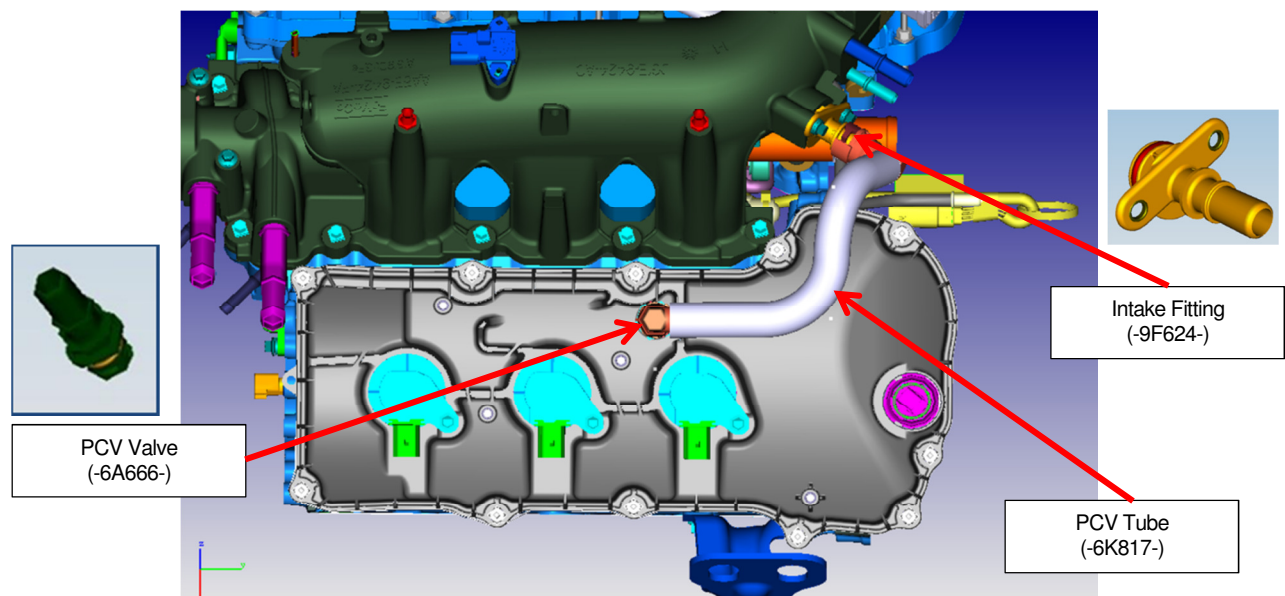


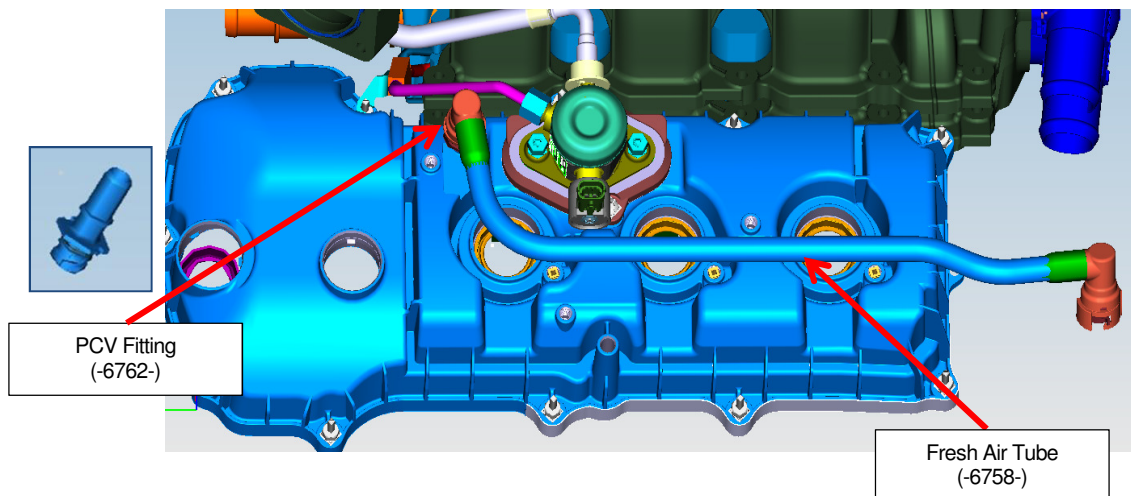
## PCV System Monitor – Turbo or Naturally Aspirated with MAP Sensor

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. The PCV tube is swedged to the valve and fittings and is not removable. 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 nylon lines are typically used from the PCV valve to the intake manifold. Disconnection causes a 10.92 mm diameter leak into the intake manifold from atmosphere. Unlike a MAF system, where an intake manifold leak will result in a lean condition, a speed density/MAP system does not have any fuel control errors with an intake leak. The only thing that happens is that idle speed increases, however, idle speed control is largely under control if an intake manifold leak exists. A persistent intake manifold leak would simply increase fuel consumption at idle and raise the engine idle speed slightly. A disconnection in the PCV inlet tube is made detectable by insuring that if it is disconnected a large (detectable) leak results. The PCV valve is semi-permanently affixed to the external oil separator or the rocker cover if an internal oil separator is used. Overcoming the torque provided by the locking tabs allows removal via a ¼ turn. It is replaceable, but needs to be "torqued out" of the assembly. Mechanically, the hose is easy to disconnect (detectable disconnection) and the PCV valve is difficult to disconnect (undetectable disconnection).

The detection method compares engine air flow rate as computed from the speed density air charge calculation with the throttle air flow rate. Should the air entering the engine exceed the air through the throttle by a threshold amount, a leak is detected.

### 2015MY 3.5L GTDI FWD PCV System Components Taurus/MKS/Flex/MKT/Explorer





PCV Monitor Operation	
DTCs	P2282 - Air Leak Between Throttle Body and Intake Valve
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	N/A
Sensors OK	No fault is present in any of the sensors or systems affecting the PCV monitor. BARO sensor, MAP sensor, throttle charge temperature sensor, throttle inlet pressure sensor, manifold charge temperature sensor, no VCT malfunction

Typical P2282 check entry conditions:		
Entry Condition	Minimum	Maximum
Throttle angle (at condition for 300 msec minimum)	N/A	4 deg
Intake Air Temp	-20 deg. F.	
Engine coolant temperature	-20 deg. F.	
Barometric pressure	20 in. Hg.	

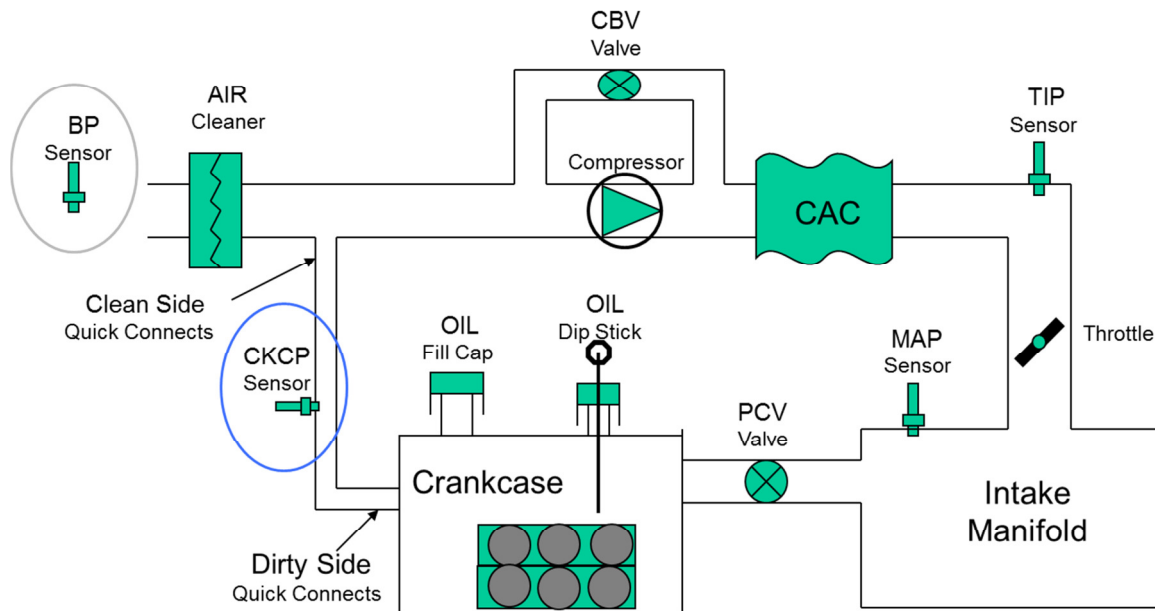
Typical P2282 malfunction thresholds:
Calculated air leak of 1 lbm/min or greater that persists for at least 5 seconds.

## PCV System Monitor – Turbocharged Engine with MAP Sensor

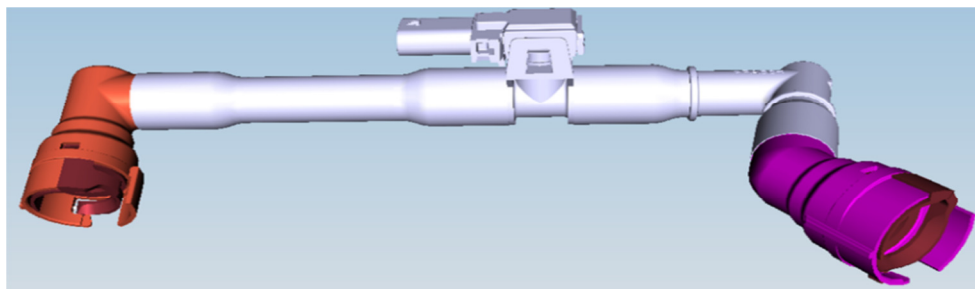
The fresh air hose connects the Air Induction System (AIS) to the rocker cover to provide fresh, filtered clean air into the crankcase as the crankcase vapors are evacuated. The PCV valve has a spring loaded, tapered pintle and orifice that limits the amount of crankcase vapors that are inducted into the engine. The least amount of flow occurs during idle when manifold vacuum is high. As engine load increases, manifold vacuum decreases which allow more flow. Under boosted conditions, there is no flow through the PCV valve. As crankcase pressure increases, blow by vapors get pushed through the fresh air tube into the Air Induction System (AIS) where they will be inducted into the engine.

Starting in the 2015 MY, Ford will be using a Crankcase Pressure Sensor (CKCP) to detect a disconnection of the fresh air hose. A disconnection of the fresh air hose would allow the discharge of crankcase vapor into the atmosphere while the engine was under boost. The diagram below shows a schematic of the PCV system. The CKCP sensor is installed in the fresh air hose. The fresh air hose has two connection points. The connection at the AIS system is called the “Clean side” connection while the connection at the rocker cover/engine is called the “dirty side” connection.

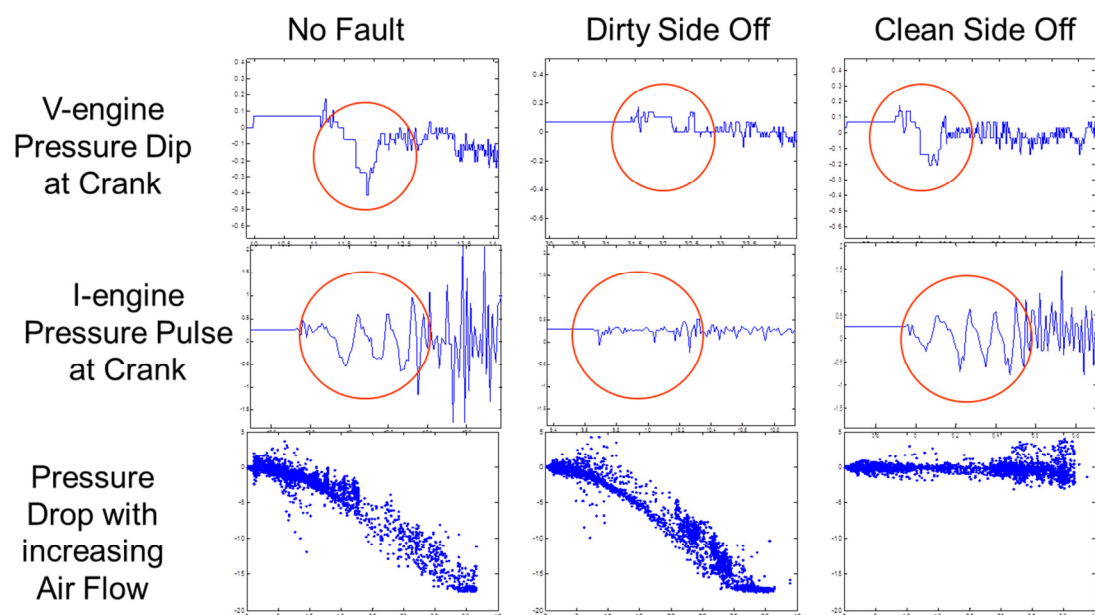
**PCV Schematic for Turbocharged Engine**



**Crankcase Pressure (CKCP) Sensor in Fresh Air Hose**



Multiple tests are used to detect fresh air hose disconnects. Dirty side disconnects are detected during engine cranking by looking for the absence of a crankcase pressure dip or pulsation. Clean side disconnects are detected during normal driving by detecting the absence of a pressure drop at higher airflows.

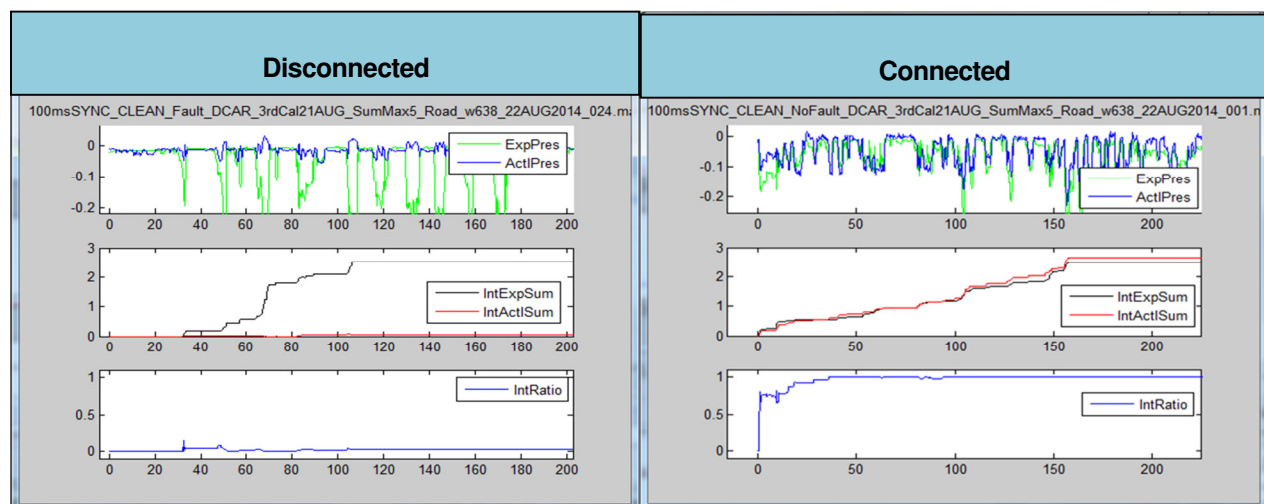


#### Clean Side Monitor:

The test looks for a lack of correlation during air flow transitions above a calibratable level. The actual and expected sensor movement is integrated during these transitions. Once a minimum amount of expected movement is achieved the ratio of integrated actual to expected movement is compared to a threshold.

When the PCV hose clean side is disconnected, the CKCP sensor response doesn't correlate to the expected pressure drop when it is connected.

The revised 2016 MY diagnostic has improved separation at low air flows (> 5 lbm/min) and completes on the OBD demonstration cycle.



## Dirty Side Monitor:

The CKCP sensor expects to read a vacuum in the crankcase during the crank and run-up period. This vacuum is the result of the PCV valve opening due to the increased intake manifold vacuum during the engine run-up. This vacuum "dip" signal (along with the pressure pulsation signal) indicates that the PCV fresh air hose is connected at the dirty/crankcase side.

Different crank throttle profiles create different crank manifold pressure pull-downs. The revised 2016 MY diagnostic starts and stops looking for dip based on feedback from MAP sensor. With a "sticky at crank" PCV valve, the CKCP sensor sees more pulsation and a slight positive (rather than dip or flat) pressure indicating operating PCV. The 2016 MY diagnostic takes into account both positive and negative pressure pulsations.

During crank and run-up and prior to entering "run" mode (i.e. low manifold vacuum) the following are calculated:

- Dip Metric: the pressure signal is corrected for any sensor offset and integrated.
- Pressure Pulse Metric: the pressure pulse signal amplitude is calculated.

The value is then compared to a threshold to determine if the PCV hose is disconnected from the crankcase. A fault will set a P04DB DTC, Crankcase Ventilation System Disconnected.

The CKCP sensor is checked for circuit/electrical faults (P051C/P051D). The CKCP sensor is also checked for in-range faults using an offset check prior to engine cranking and a rationality test after start. If the sensor offset is greater than a calibrated threshold just prior to engine cranking, a P051B DTC is set. The CKCP sensor is also checked for low readings when air flow rate is low. (There shouldn't be a high pressure drop across the air filter at low flows.), and also checked that high readings (There shouldn't be a condition where the pressure across the air filter gets higher than ambient pressure.).

CKCP Sensor Electrical Check Operation	
DTCs	P051C – Crankcase Pressure Sensor Circuit Low P051D – Crankcase Pressure Sensor Circuit High P051B – Crankcase Pressure Sensor Circuit Range/Performance
Monitor execution	Continuous for circuit checks
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

CKCP Sensor Electrical check entry conditions:		
Entry Conditions	Minimum	Maximum
Engine not cranking (for offset check only)		

Typical CKCP sensor electrical check malfunction thresholds:
P051C: Voltage < 0.44 volts P051D: Voltage > 4.56 volts, P051B: Sensor offset > 0.15" Hg OR Crankcase pressure > 5.0 " Hg or Crankcase pressure < -0.6 " Hg at air flows < 1.0 lb/min

PCV Fresh Air Disconnect Check Operation:	
DTCs	P04DB – Crankcase Ventilation System Disconnected
Monitor execution	Dirty side - once per driving cycle at crank Clean side - once per driving cycle at airflows > 5 lb/min
Monitor Sequence	none
Sensors OK	CKCP (P051B, P051C, P051D)
Monitoring Duration	up to 15 minutes to register a clean side malfunction

PCV Fresh Air Disconnect check entry conditions:		
Entry Conditions	Minimum	Maximum
Ambient temperature	20 deg F	
BARO	22.5"Hg	
Air Mass	5 lbm/min	

PCV Fresh Air Disconnect check malfunction thresholds:	
P04DB: Clean side: expected sum > 2.5 in Hg Dirty side test: dip signal or pulse signal > 0.004	

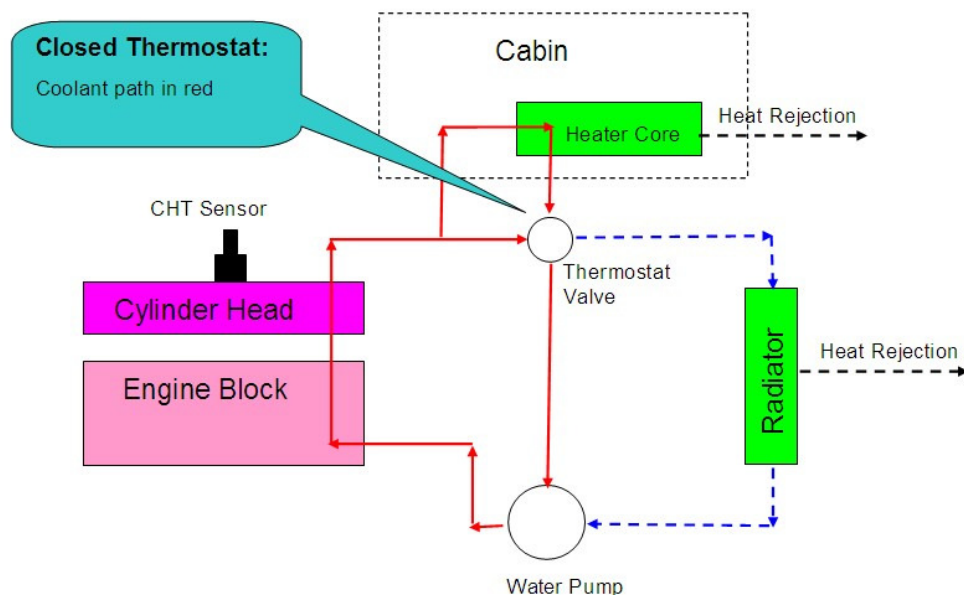
## Thermostat Monitor

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

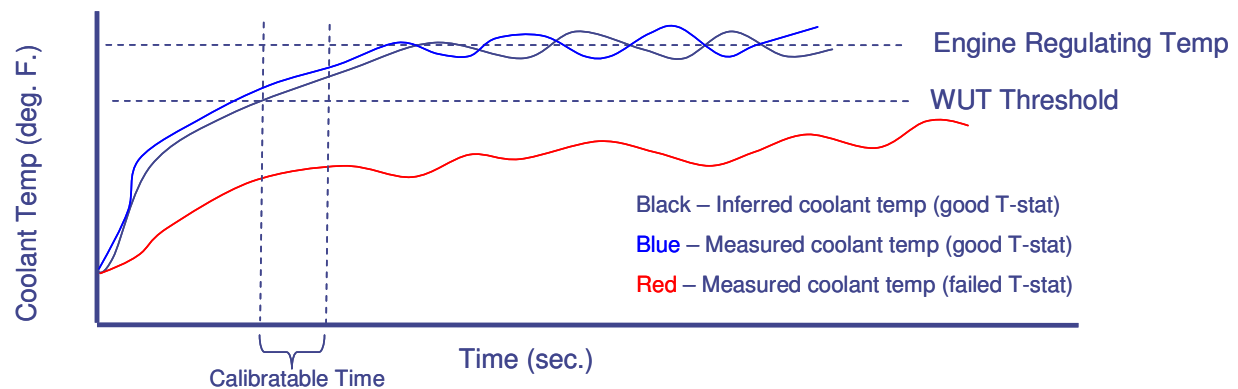
During a cold start, when the thermostat should be closed, the monitor uses a model of ECT to determine whether actual ECT should have crossed the Warm Up Temperature (WUT) threshold. . The engine coolant temperature warm-up model compensates for the following thermal characteristics:

1. Coolant heating (heat source):
  - Combustion heating (engine speed and load based).
  - Cooling system heaters (electric or fuel-fired - new for 2013 MY)
2. Coolant cooling (heat sink):
  - Due to cylinder cut-out (DFSO or powertrain limiting).
    - Injectors are cut but still pumping air through the engine. Increased cooling compared to engine shut-down.
  - Due to engine shut-down. (Stop/Start and Hybrid – new for 2013 MY).
3. Coolant flow rate:
  - Mechanical water pumps have been replaced on some applications with clutched water pumps or electric water pumps.

## Engine Cooling System



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 in less than 300 seconds, when inferred ECT exceeds threshold (at 70 deg F ambient temperature)

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	172 °F	None
Time Since Modeled ECT Exceeded WUT Threshold	3 sec.	None
Time at Idle/Low Load Compared with Total Engine Run Time	None	50%

TYPICAL MALFUNCTION THRESHOLD
Engine Coolant Temperature < 172 °F (for a typical 192 °F thermostat)

## Heavy Duty Thermostat Monitor

For the 2016 MY, the Heavy Duty OBD regulations require an enhancement to the thermostat test. As in the past, the thermostat monitor requires monitoring of the following:

- The coolant temperature does not reach the highest temperature required by the OBD-II system to enable other diagnostics;
- The coolant temperature does not reach a warmed-up temperature within 20 deg F of the manufacturer's nominal thermostat regulating temperature

For 2016 MY, the monitor becomes continuous and adds the following:

- The coolant temperature has reached regulating temperature and then drops below the thermostat malfunction threshold

The enhanced diagnostic will continue to set the P0128 DTC. The test consists of two portions:

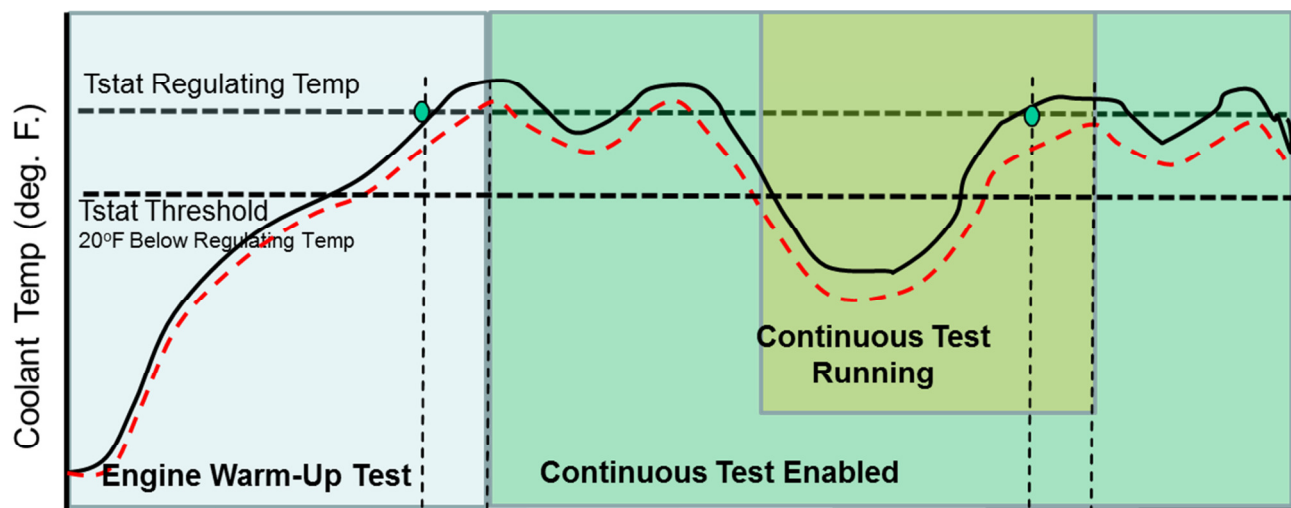
### Cold start engine warm-up test (existing monitor)

The ECT model is used to determine when the engine is expected to be fully warmed up to the thermostat regulating temperature. At that time, the measured ECT is expected to be above the thermostat malfunction threshold (within 20 deg F of thermostat regulating temperature).

### Warm engine continuous test (new HD OBD Requirement)

The continuous portion is enabled once the cold start engine warm-up test has completed and determined that no fault exists and the measured ECT has exceeded thermostat regulating temperature. Once enabled, if measured ECT drops below the thermostat fault threshold, the ECT model is reinitialized so that the cold start monitor can run again. Once the ECT model gets to thermostat regulating temperature, the measured ECT is expected to be above the thermostat malfunction threshold.

A P0128 DTC is set if measured ECT < Tstat Threshold once modeled ECT has exceeded Tstat Regulating Temperature for 3 seconds.



Black— Inferred coolant temp  
Red— Measured coolant temp

## Time To Closed Loop Monitor

For the 2015 MY, an additional monitor was added to ensure that the fuel control system entered into stoichiometric closed loop fuel control within a manufacturer specified (reasonable) amount of time. The primary determination for entering stoich closed loop control is engine coolant temperature (ECT) and load. Load is monitored via the fuel monitor, thus leaving ECT with a monitoring requirement.

Engine coolant temperature is already modelled to fulfill the thermostat monitoring requirements, however, thermostat regulating temperature is typically 192 deg F while stoich closed loop temperature is typically 50 deg F. This means that the same ECT model can be used, but with different thresholds.

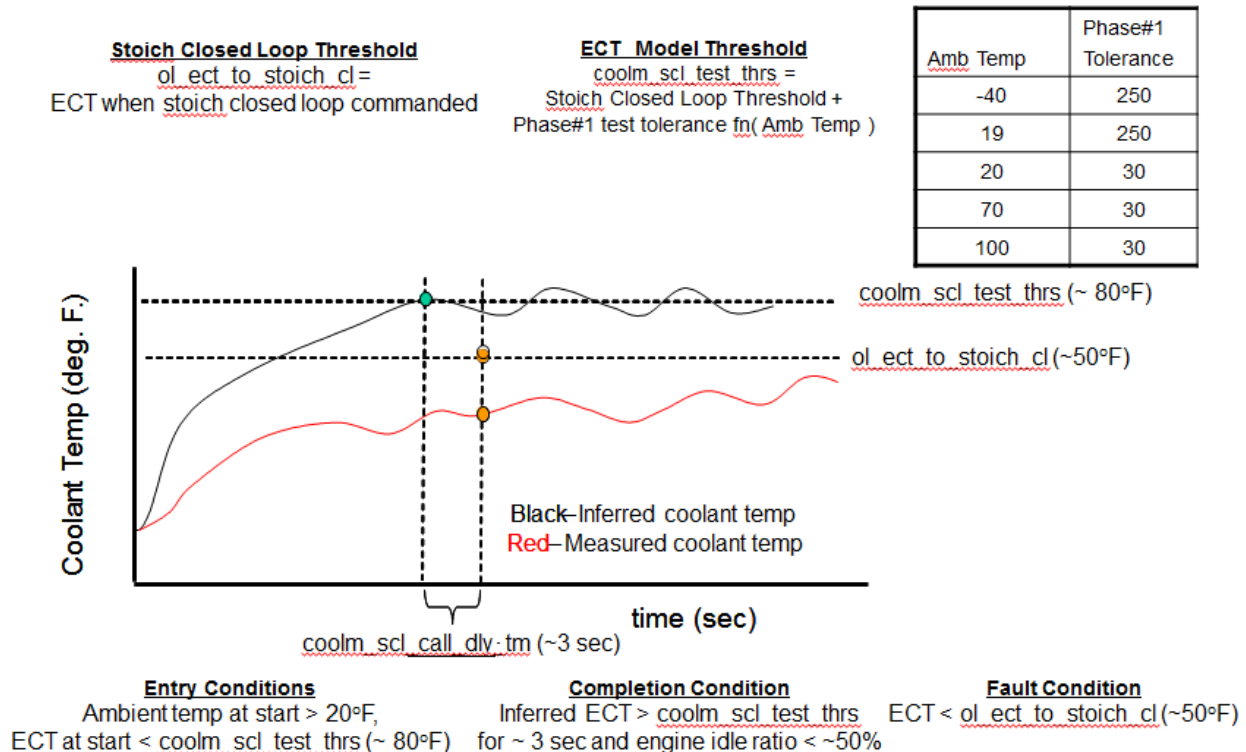
The stoich closed loop ECT threshold is a function of load - a higher ECT value is used at higher loads. The monitor software will pull the ECT value from the calibration table at the minimum load (idle) and use it as the worst case value for the stoich closed loop threshold.

The time to closed loop monitor shares the ECT model with the thermostat monitor. If the modelled ECT reaches the closed loop stoich temperature threshold and actual ECT does not achieve the same temperature (within a tolerance) after a given time interval, a P0125 DTC is set.

Similar to the thermostat test, the test is disabled under conditions where monitoring would be unreliable, e.g., high percentage of time at idle.

Because the thermostat test does not run below 20 deg F, the model accuracy is not understood at those temperatures. For Phase #1 (2015 MY-2016 MY), the time to closed loop monitor will detect faults above 20 deg F, similar to the thermostat monitor. For Phase #2 (2016 MY 2017MY+) a different algorithm is planned for ambients below 20 deg F.

### Time to Closed Loop Test using Inferred ECT Model



TIME TO CLOSED LOOP MONITOR OPERATION	
DTC	P0125 - Insufficient Coolant Temp For Closed Loop Fuel Control
Monitor Execution	Once per driving cycle, during a cold start
Monitoring Duration	Drive cycle

TYPICAL TIME TO CLOSED LOOP MONITOR ENTRY AND COMPLETION CONDITIONS		
Entry conditions	Minimum	Maximum
Engine Coolant Temperature at start	None	80 °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	80 °F	None
Time Since Modeled ECT Exceeded Threshold	3 sec.	None
Time at Idle/Low Load Compared with Total Engine Run Time	None	50%

TYPICAL TIME TO CLOSED LOOP MALFUNCTION THRESHOLD
Engine Coolant Temperature < 50 °F

## Cold Start Emission Reduction Component Monitor

The Cold Start Emission Reduction Component Monitor was introduced for the 2006 MY on vehicles that meet the LEV-II emission standards. The monitor works by validating the operation of the components of the system required to achieve the cold start emission reduction strategy, namely retarded spark timing, and elevated idle airflow or VCT cam phasing.

The spark timing monitor was replaced by the Cold Start Emission Reduction System monitor in the 2007 MY. Changes to the OBD-II regulations, however, require having both a CSER system monitor and a CSER component monitor for the 2010 MY. The 2010 MY component monitor is not the same test that was introduced for the 2006 MY; rather, it has been redesigned.

### Low Idle Airflow Monitor – Systems with Electronic Throttle Control

When the CSER strategy is enabled, the Electronic Throttle Control system will request a higher idle rpm, elevating engine airflow. Vehicles that have ETC and do not have a separate airflow test (P050A). Any fault that would not allow the engine to operate at the desired idle rpm during a cold start would be flagged by one of three ETC DTCs:

P2111 (throttle actuator control system stuck open),  
P2112 throttle actuator control system stuck closed)  
P2107 (throttle actuator control module processor/circuit test).

All three DTCs will illuminate the MIL in 2 driving cycles, and immediately illuminate the "ETC" light. These DTCS are also documented in the ETC section of this document.

For the 2009 MY, only the Fusion/Milan utilizes the CSER Component monitor with ETC.

#### Throttle Plate Controller and Actuator Operation:

DTCs	P2107 – processor test (MIL) P2111 – throttle actuator system stuck open (MIL) P2112 – throttle actuator system stuck closed (MIL)  Note: For all the above DTCs, in addition to the MIL, the ETC light will be on for the fault that caused the FMEM action.
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	60 msec for processor fault, 500 msec for stuck open/closed fault

#### Throttle Plate Controller and Actuator malfunction thresholds:

P2111 - Desired throttle angle vs. actual throttle angle > 6 degrees  
P2112 - Desired throttle angle vs. actual throttle angle < 6 degrees  
P2107 - Internal processor fault, lost communication with main CPU

## Engine Speed and Spark Timing Component Monitor (2010 MY and beyond)

### Entry Conditions and Monitor Flow

The System Monitor and 2010 Component Monitor share the same entry conditions and monitor flow. During the first 15 seconds of a cold start, the monitor checks the entry conditions, counts time in idle, observes catalyst temperature, calculates the average difference between desired and actual engine speed, and calculates the average difference between desired and commanded spark.

If the expected change in catalyst temperature is large enough, the monitor then begins the waiting period, which lasts until 300 seconds after engine start. This 5-minute wait allows time to diagnose other components and systems that affect the validity of the test. During this waiting period, there are no constraints on drive cycle and the monitor cannot be disabled without turning off the key.

If the System monitor result falls below its threshold and all of the Component monitor results are below their respective thresholds, the monitor determines whether the idle time was sufficient. If so, it considers the tests 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.

### Cold Start Engine Speed Monitor

Once the waiting period is complete, the monitor compares the average difference between desired and actual engine speeds to a calibratable threshold that is a function of ECT at start. If the magnitude of the discrepancy exceeds the threshold, P050A is set.

### Cold Start Spark Timing Monitor

Once the waiting period is complete, the monitor compares the average difference between desired and commanded spark to a calibratable threshold that is a function of ECT at start. If the magnitude of the discrepancy exceeds the threshold, P050B is set.

CSER COMPONENT MONITOR OPERATION	
Component Monitor DTCs	P050A: Cold Start Idle Air Control System Performance P050B: Cold Start Ignition Timing Performance
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 COMPONENT 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 CSER COMPONENT MONITOR MALFUNCTION THRESHOLDS
Engine speed discrepancy > 200 rpm
Spark timing discrepancy > 10 deg.

## Cold Start Variable Cam Timing Monitor (2008 MY and beyond)

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. The System 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.

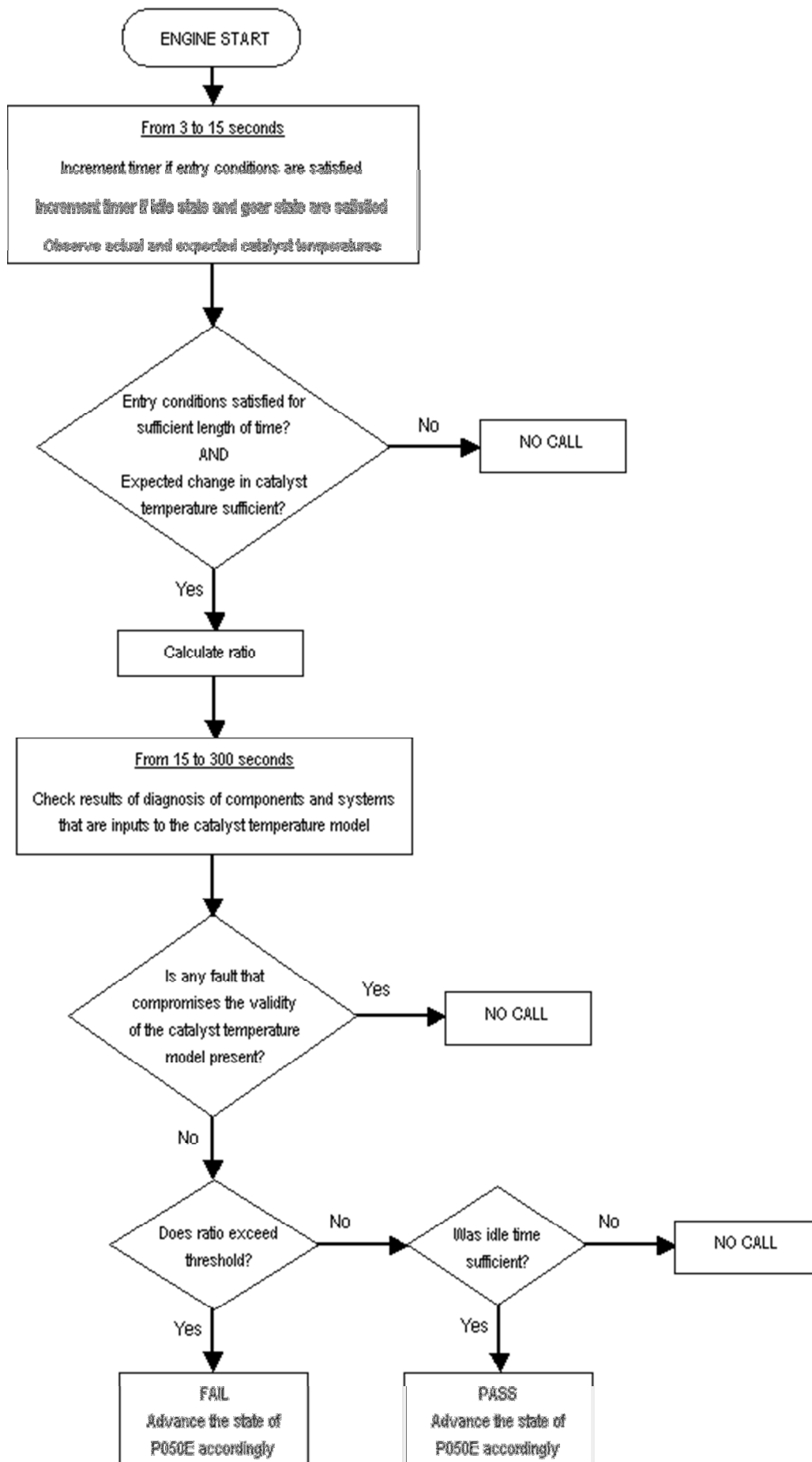
If the expected change in catalyst temperature is large enough, the monitor calculates the ratio as described above. Otherwise the monitor does not make a call.

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 and all of the component monitor results are below their respective thresholds, 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.



**CSER SYSTEM MONITOR OPERATION**

System Monitor DTC	P050E: Cold Start Engine Exhaust Temperature Too Low
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 SYSTEM 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 CSER SYSTEM MONITOR MALFUNCTION THRESHOLDS**

Cold start warm-up temperature ratio > 0.4

## 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);
- Twin 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  $1.5 * \text{std.}$  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 two variance indices, one that monitors cam variance in the retard direction and the other for the advance direction,. If either variance index is greater than the malfunction threshold, a VCT slow response/target error malfunction will be indicated (P0011, P0012, P0014, P0015 Bank 1, P0021, P0022, P0024, P0025 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. The logic calculates the instantaneous variance in actual cam position (the squared difference between actual cam position and commanded cam position), then calculates a longer term variance using a rolling average filter (Exponentially Weighted Moving Average) This is similar to the target error logic described above, but uses separate time constants and thresholds. There are two variance indices, one that monitors cam variance in the retard direction and the other for the advance direction,. If either variance index is greater than the malfunction threshold, a VCT slow response/target error malfunction will be indicated (P052A, P052B, P054A, P054B (Bank 1), P052C, P052D, P054C, P054D (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.

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. The numerator is incremented when either a pass or a fail has been indicated. A fail is determined when the variance index rolling average accumulates sufficient error such that the malfunction threshold is exceeded and a DTC is set. A pass is determined by using a separate but identical variance index rolling average filter that is used to determine a fault. The minimum amount of variance needed to set a fault is introduced. When the variance index rolling average filter accumulates sufficient error such that the malfunction threshold is exceeded, a pass is indicated. Note that the monitor continues to run even after the numerator is 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 - Intake Camshaft Position Timing - Over-Advanced (Bank 1) P0012 - Intake Camshaft Position Timing - Over-Retarded (Bank 1) P0014 - Exhaust Camshaft Position Timing - Over-Advanced (Bank 1) P0015 - Exhaust Camshaft Position Timing - Over-Retarded (Bank 1) P0016 - Crank/Cam Position Correlation (Bank 1) P0020 - Camshaft Position Actuator Circuit (Bank 2) P0021 - Intake Camshaft Position Timing - Over-Advanced (Bank 2) P0022 - Intake Camshaft Position Timing - Over-Retarded (Bank 2) P0024 - Exhaust Camshaft Position Timing - Over-Advanced (Bank 2) P0025 - Exhaust Camshaft Position Timing - Over-Retarded (Bank 2) P0018 – Crank/Cam Position Correlation (Bank 2)
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 - 900 seconds for target error

Typical VCT response/functional monitor entry conditions:		
Entry condition	Minimum	Maximum
Engine RPM (rpm to get minimum oil pressure)	400	
Engine RPM (for P0016/P0018 only)	500	4500
Engine Coolant Temperature	18 °F	
Time Since Start (function of ECT at start) (time to build oil pressure at start)	2 sec	
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, 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 occurs: IAT, ECT, EOT, MAF, TP, CKP, CMP, or IMRC or a VCT solenoid fails.		

**Typical VCT monitor malfunction thresholds:**

VCT solenoid circuit: Open/short fault set by the PCM driver

Cam/crank misalignment: > or = one tooth difference, or 16 crank degrees

Response/target error - VCT over-advance variance too high: 40 to 700 degrees squared

Response/target error - VCT over-retard variance too high: 40 to 700 degrees squared

Response/target error - Cam bank-to-bank variance too high: 40 to 700; degrees squared

**J1979 VCT Monitor Mode \$06 Data**

Monitor ID	Test ID	Description for CAN	Units
\$35	\$80	Camshaft Advanced Position Error Bank 1 (P011/P0014)	Unsigned, Angular degrees
\$35	\$81	Camshaft Retarded Position Error Bank 1 (P0012/P0015)	Unsigned, Angular degrees
\$36	\$80	Camshaft Advanced Position Error Bank 2 (P0021/P0024)	Unsigned, Angular degrees
\$36	\$81	Camshaft Retarded Position Error Bank 2 (P0022/P0025)	Unsigned, Angular degrees

## Gasoline Direct Injection

Ford is adding gasoline Direct Injection (DI) to many of its engines for improved fuel economy, performance and emissions. Most engines will also incorporate a turbocharger when they go to DI, however, some engines will not. Engines with turbo charging are designated as GTDI (Gasoline Turbo Direct Injection) and engine without turbo charging are designated GDI (Gasoline Direct Injection).

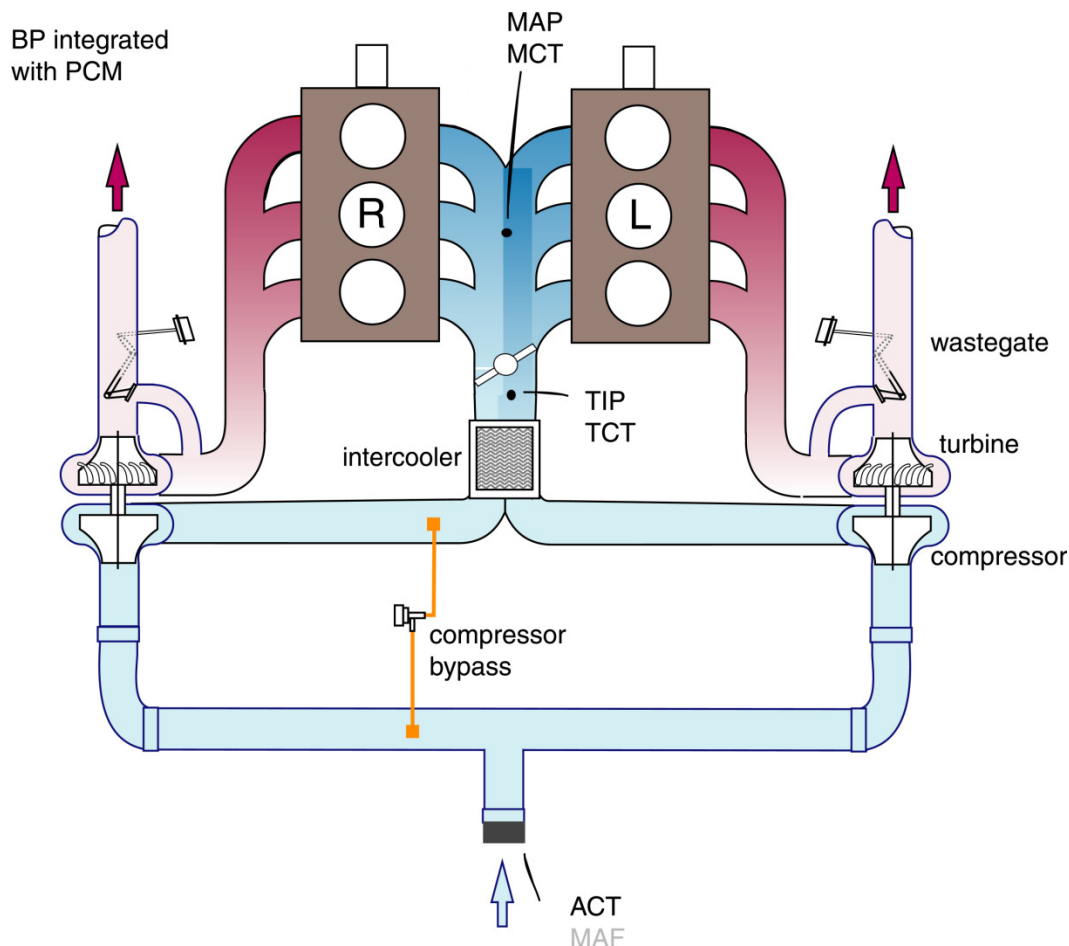
The fuel systems for both of these variants are very similar. The only difference is that the GDI engine does not have the turbo controls that consist of the Turbocharger, Wastegate Control Valve, Compressor Bypass Valve and the sensor that contains the Throttle Inlet Pressure Sensor (TCB-A) and Throttle Charge Temperature Sensor (CACT)

Ford's first GTDI engine was introduced in the 2010 MY. The 3.5 L GTDI engine was based off the 3.5L IVCT engine used in the Taurus, Edge, etc. The GTDI version was introduced in the 2010 MY Ford Flex, Lincoln MKR (CUV), Taurus and Lincoln MKS (sedan).

The PCM for the GTDI engine controls the following sensors and actuators:

Outputs/Actuators: Electronic Throttle Control, Variable Cam Timing (Intake only), Wastegate Control Valve, Compressor Bypass Valve, Ignition timing, Fuel injectors (Direct Injection), Fuel Rail Pressure Control Valve

Inputs/Sensors: MAP, Manifold Charge Temp, Throttle Inlet Pressure, Throttle Charge Temp, Intake Air Temp, BARO, Cylinder Head Temp, Cam & Throttle positions, Engine Speed, Fuel Rail Pressure, UEGO (front, control), HEGO (rear fuel trim)



For the 2011 MY, 3.5L/3.7L engine was upgraded from ICVT (Intake-only Variable Cam Timing) to TIVCT (Twin Independent Variable Cam Timing). The 3.5L GTDI engine in the F-150 is based off this upgraded engine (3.5L GTDI TIVCT). The DI and turbo controls, however, are unchanged.

For the 2011 MY, the Explorer will be available with a 2.0L GTDI engine with TIVCT. For 2012 MY, it is also available in the Edge. The DI and turbo controls are similar to the 3.5L GTDI with the exception that there is only one turbocharger.

For the 2012 MY, the Focus will be available with a 2.0L GDI engine with TIVCT. The controls are similar to the 2.0L GTDI engine. The only difference is that the GDI engine does not have the turbo controls that consist of the Turbocharger, Wastegate Control Valve, Compressor Bypass Valve and the sensor that contains the Throttle Inlet Pressure Sensor (TCB-A) and Throttle Charge Temperature Sensor (CACT)

Because GDI engine controls and OBD are a subset of the GTDI engine controls and OBD, they will all be described in this chapter.

## Intake Air Temperature 1 Sensor (IAT1)

The Intake Air Temperature 1 sensor (also called Air Charge Temperature) is used for the inference of ambient temperature for several PCM strategy features. In previous designs, the Intake Air Temperature 1 sensor was physically integrated with the Mass Air Flow (MAF) sensor. In this design, the Intake Air Temperature 1 sensor is a stand-alone sensor and is mounted near the air cleaner.

Intake Air Temperature 1 Sensor Circuit Range Check	
DTCs	P0112 Intake Air Temperature Sensor 1 Circuit Low (Bank 1) P0113 Intake Air Temperature Sensor 1 Circuit High (Bank 1)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical Intake Air Temperature 1 Sensor Circuit Range Check Malfunction Thresholds	
P0112	IAT1 voltage < 0.244 volts
P0113	IAT1 voltage > 4.96 volts

Intake Air Temperature Sensor 1 Circuit Intermittent Check	
DTCs	P0114 Intake Air Temperature Sensor 1 Intermittent/Erratic (Bank 1)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	counts intermittent events per trip

Typical Air Charge Temperature Sensor Check Malfunction Thresholds	
10 intermittent out-of-range events per driving cycle	

## Charge Air Cooler Temperature Sensor (CACT)

The Charge Air Cooler Temperature sensor (also known as Throttle Charge Temperature) refines the estimate of air flow rate through the throttle.

Throttle Charge Temperature Sensor Circuit Range Check	
DTCs	P007C Charge Air Cooler Temperature Sensor Circuit Low (Bank 1) P007D Charge Air Cooler Temperature Sensor Circuit High (Bank 1)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical Throttle Charge Temperature Sensor Circuit Range Check Malfunction Thresholds	
P007C	CACT voltage < 0.244 volts
P007D	CACT voltage > 4.96 volts

## Intake Air Temperature 2 Sensor (IAT2)

The Intake Air Temperature 2 sensor (also known as Manifold Charge Temperature) is mounted to the intake manifold and is used to compute cylinder air charge and provide input for various spark control functions. It is integrated with the intake manifold pressure sensor.

Manifold Charge Temperature Sensor Circuit Range Check	
DTCs	P0097 Intake Air Temperature Sensor 2 Circuit Low (Bank 1) P0098 Intake Air Temperature Sensor 2 Circuit High (Bank 1)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical Manifold Charge Temperature Sensor Circuit Range Malfunction Thresholds	
P0097	IAT2 voltage < 0.244 volts
P0098	IAT2 voltage > 4.96 volts

IAT1, CACT, IAT2, 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

## **IAT1, CACT, IAT2 Key-Up Correlation Check**

Once the IAT1, CACT, IAT2 are confirmed to be in-range, the key-up correlation test compares the three temperatures on key-up after a long period off key-off time (6 hours). The three-way correlation test is run only once per power-up.

After a long key-off period, the three temperature sensors are expected to report nearly the same temperature. The exception to this is when a block heater is used. Block heater use can cause these three air temperature sensors to widely differ from each other. To detect if an engine coolant heater is active we compare Cylinder Head Temperature (CHT) to Transmission Fluid Temperature (TFT). A significant temperature difference (10°F) indicates block heater activity.

The IAT, CACT, and IAT2 are mounted along the engine air intake system.

- The IAT is mounted in the engine air inlet (near air cleaner).
- The CACT is mounted near the throttle inlet.
- The IAT2 is mounted inside the intake manifold.

If the sensors all agree, no malfunction is indicated and the test is complete. Specifically, the three way check compares 3 sensor pairings. All three pairings must correlate to pass this test.

- IAT and CACT agree within a tolerance ( $\pm 30^{\circ}\text{F}$ ) and
- CACT and IAT2 agree within a tolerance ( $\pm 30^{\circ}\text{F}$ ) and
- IAT2 and IAT agree within a tolerance ( $\pm 30^{\circ}\text{F}$ ).

**Case 1** At least two correlation pairings are within tolerance ( $\pm 30^{\circ}\text{F}$ ). All sensors pass.

**Case 2** One correlation pairing is within tolerance ( $\pm 30^{\circ}\text{F}$ ). Those two sensors that correlate pass, the third sensor is flagged as faulted.

**Case 3** Zero correlation pairings are within tolerance ( $\pm 30^{\circ}\text{F}$ ). P00CE Intake Air Temperature Measurement System – Multiple Sensor Correlation

Engine Air Temperature Sensor Key-Up Correlation Check	
DTCs	P0111 Intake Air Temperature Sensor 1 Circuit Range/Performance (Bank 1) P007B Charge Air Cooler Temperature Sensor Circuit Range/Performance (Bank 1) P0096 Intake Air Temperature Sensor 2 Circuit Range/Performance (Bank 1) P00CE Intake Air Temperature Measurement System – Multiple Sensor Correlation
Monitor execution	Once per driving cycle, at start-up
Monitor Sequence	None
Sensors OK	ECT/CHT, IAT1, CACT, IAT2, TFT
Monitoring Duration	Immediate

Engine Air Temperature Sensor Key-Up Correlation Check Entry Conditions		
Entry condition	Minimum	Maximum
Engine off (soak) time	6 hours	
CHT – TFT at start (block heater inferred)		+10 °F

Typical Engine Air Temperature Sensor Key-Up Correlation Check Malfunction Thresholds
CHT at least 10°F hotter than TFT means block heater detected.

## IAT1, CACT, IAT2 Out of Range Hot Check

The IAT1, CACT, IAT2 are all checked for maximum expected temperature readings during a steady state driving condition. When parked at hot ambient temperatures or after heavy load operation, these temperatures can climb to unusually high temperatures thus the "too hot" check is not done at those conditions.

Engine Air Temperature Sensor Out of Range Hot Check	
DTCs	P0111 Intake Air Temperature Sensor 1 Circuit Range/Performance (Bank 1) P007B Charge Air Cooler Temperature Sensor Circuit Range/Performance (Bank 1) P0096 Intake Air Temperature Sensor 2 Circuit Range/Performance (Bank 1)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	ECT/CHT, IAT, VSS
Monitoring Duration	250 seconds to register a malfunction

Engine Air Temperature Sensor Out of Range Hot Check Entry Conditions		
Entry condition	Minimum	Maximum
Vehicle speed	40 mph	
Time above minimum vehicle speed (if driving req'd)	5 min	
For IAT1, Load below a maximum load threshold	1.0	

Typical Engine Air Temperature Sensor Out of Range Hot Check Malfunction Thresholds	
P0111	IAT1 > 150°F
P007B	CACT > 220°F
P0096	IAT2 > 240°F

## Barometric Pressure Sensor (BARO)

The Barometric Pressure Sensor (BARO) is used to directly measure barometric pressure and for exhaust back pressure estimation. (Exhaust back pressure influences speed density based air charge computation.) The BARO sensor is directly mounted to the PCM circuit board.

The BARO sensor has a high accuracy operating range of 60 to 115 kPa (17.7 to 34.0 "Hg) and a full operating range of 7.6 to 121.6 kPa. The voltage is electrically clipped between 0.3 and 4.8 volts.

A P2228 or P2229 DTC indicates that either the sensor is electrically faulted or the sensed barometric pressure is outside the normal operating range.

BARO Sensor Transfer Function		
$V_{out} = V_{ref} * (0.007895 * \text{Pressure (in kPa)})$		
Volts	Pressure, kPa	Pressure, Inches Hg
0.3	7.6	2.2
0.5	12.7	3.8
2.638	60	17.7
4.54	115	34.0
4.75	120.3	35.5
4.8	121.6	35.9

Barometric Pressure Sensor Range Check	
DTCs	P2228 Barometric Pressure Circuit Low P2229 Barometric Pressure Circuit High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical Barometric Pressure Sensor Range Check Malfunction Thresholds	
P2228	BP < 2.0 volts (above 15,000 ft altitude)
P2229	BP > 4.4 volts (below -1,000 ft altitude)

## Turbocharger Boost Sensor A (TCB-A)

The Turbocharger Boost Sensor A (also known as Throttle Inlet Pressure (TIP)) is the feedback sensor for turbo boost control. Boost control algorithm computes desired boost from operating conditions and adjusts the pneumatically-controlled boost pressure limit to achieve that desired boost pressure. TCB-A is also used to compute air flow rate through the throttle independently of the primary air charge computation for torque monitoring (and intake manifold leak detection).

The TCB-A sensor is physically integrated with the Charge Air Cooler Temperature Sensor. The boost sensor has a specified range of 20 to 300 kPa. The voltage is electrically clipped between 0.3 to 4.8 volts,



TCB-A and MAP Sensor Transfer Function		
$V_{out} = (V_{ref} / 5) * (0.0146428 * \text{Pressure (in kPa)} + 0.1072)$		
Volts	Pressure, kPa	Pressure, Inches Hg
0.3	13.16	3.89
0.4	20	5.91
0.986	60.0	17.72
2.157	140	41.34
3.329	220.0	64.97
4.5	300	88.59
4.8	320.49	94.64

Throttle Inlet Pressure Sensor Range Circuit Check	
DTCs	P0237 Turbocharger/Supercharger Boost Sensor A Circuit Low P0238 Turbocharger/Supercharger Boost Sensor A Circuit High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical Throttle Inlet Pressure Sensor Range Circuit Check Malfunction Thresholds	
P0237	TCB-A voltage < 0.19 volts
P0238	TCB_A voltage > 4.88 volts

Throttle Inlet Pressure Sensor Range Circuit Intermittent Check	
DTCs	P025E Turbocharger/Supercharger Boost Sensor "A" Intermittent/Erratic
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	counts intermittent events per trip

Typical Throttle Inlet Pressure Sensor Range Circuit Malfunction Thresholds	
10 intermittent out-of-range events per driving cycle	

## Intake Manifold Pressure (MAP) Sensor

The Manifold Absolute Pressure (MAP) sensor is used for the Speed Density air charge calculation.

The MAP sensor is physically integrated with the Intake Air Temperature 2 sensor. The MAP sensor has a specified range of 10 to 200 kPa. The voltage is electrically clipped between 0.3 to 4.8 volts,



TCB-A nd MAP Sensor Transfer Function		
$V_{out} = V_{ref} * (0.0044736 * \text{Pressure (in kPa)} + 0.035263)$		
Volts	Pressure, kPa	Pressure, Inches Hg
0.3	5.53	1.63
0.40	10.0	2.95
1.630	65.0	19.19
2.301	95.0	28.05
3.643	155.0	45.77
4.65	200.0	59.06
4.8	206.71	61.04

Intake Manifold Pressure Sensor Range Circuit Check	
DTCs	P0107 Manifold Absolute Pressure/BARO Sensor Low P0108 Manifold Absolute Pressure/BARO Sensor High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical Intake Manifold Pressure Sensor Range Circuit Check Malfunction Thresholds	
P0107	MAP voltage < 0.19 volts
P0108	MAP voltage > 0.4.88 volts

Intake Manifold Pressure Sensor Range Circuit Intermittent Check	
DTCs	P0109 Manifold Absolute Pressure/BARO Sensor Intermittent
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	counts intermittent events per trip

Typical Intake Manifold Pressure Sensor Range Circuit Malfunction Thresholds
10 intermittent out-of-range events per driving cycle

## BARO, TCB-A, MAP Sensor 3-Way Correlation Check at Key-Up

At key-up BARO, TCB-A, and MAP are compared. If any two agree and one does not, that sensor is declared faulted.

BP, TIP, MAP Sensor 3-Way Correlation Check at Key-Up	
DTCs	P2227 P0236 P0106 Barometric Pressure Circuit Range/Performance
Monitor execution	At key-up
Monitor Sequence	None
Sensors OK	BP, MAP, TIP
Monitoring Duration	0.2 seconds

BP, TIP, MAP Sensor 3-Way Correlation Check at Key-Up Entry Conditions		
Entry condition	Minimum	Maximum
Engine off (soak) time	10 seconds	
Battery Voltage	6.75 volts	

Typical BP, TIP, MAP Sensor 3-Way Correlation Check at Key-Up Malfunction Thresholds	
TCB-A – MAP  < 2.72"Hg	
BARO – MAP  < 2.03"Hg	
BARO – TCB-A  < 2.14"Hg	

## BARO, TCB-A and TCB-A, MAP Sensor 2-Way Correlation Check

Should a BARO, TCB-A, or MAP sensor pass the key-on test but become faulted during operation, two air pressure sensor correlation check are made.

- At low engine air flows no turbocharger boost is commanded and BARO should be very close to TCB-A.
- In certain operation regions, MAP can be estimated from TCB-A, throttle angle, and engine speed (a.k.a. speed-throttle).

These two correlations are then used to infer if any of the three air pressure sensors are faulted

BARO, TCB-A Sensor 2-Way Correlation Check Entry	
DTCs	P2227 Barometric Pressure Sensor "A" Circuit Range/Performance P0236 Turbocharger/Supercharger Boost Sensor "A" Circuit Range/Performance P0106 Barometric Pressure Circuit Range/Performance
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	BP, TIP, MAP
Monitoring Duration	10 seconds

BARO, TCB-A Sensor 2-Way Correlation Check Entry Conditions		
Entry condition	Minimum	Maximum
Low TP		4.0°
Low engine rpm		1500 rpm

Typical BARO, TCB-A Sensor 2-Way Correlation Check Entry Malfunction Thresholds	
pass	( BARO – TCB-A  < 5.5"Hg) AND ( MAP – Estimated MAP  < 3.5"Hg)
P2227	( BARO – TCB-A  > 5.5"Hg) AND ( MAP – Estimated MAP  < 1.8"Hg)
P0106	( BARO – TCB-A  < 1.8"Hg) AND ( MAP – Estimated MAP  > 3.5"Hg)
P0236	(if none of above conditions met)

## Compressor Bypass Valve(s)

The compressor bypass valve(s) is used to prevent backflow through the turbocharger compressors when the throttle is rapidly closed to avoid an undesirable audible noise. The high pressure downstream of the compressor bypasses the compressor as it travels upstream when the valve is open. In this application, two compressor bypass valves are used to establish a sufficient bypass flow rate. The compressor bypass valve(s) are checked for electrical faults.

Compressor Bypass Valve Circuit Check Operation:	
DTCs	P0034 Turbocharger/Supercharger Bypass Valve "A" Control Circuit Low P0035 Turbocharger/Supercharger Bypass Valve "A" Control Circuit High P00C1 Turbocharger/Supercharger Bypass Valve "B" Control Circuit Low P00C2 Turbocharger/Supercharger Bypass Valve "B" Control Circuit High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	5 seconds

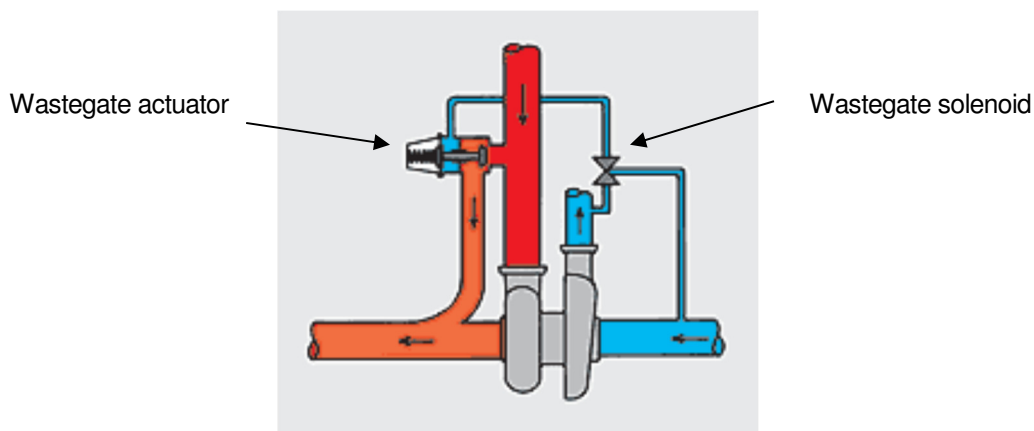
Compressor Bypass Valve Circuit malfunction thresholds:
PCM smart driver hardware detects faults for circuit short to battery, short to ground, and open circuit. Fault status reported to PCM to set appropriate DTC.

## Wastegate Pneumatic Solenoid Valve

The wastegate (one per turbocharger) allows exhaust pressure to bypass the turbocharger's turbine, to control compressor speed (on the same shaft), and thus boost pressure. The wastegate controller is actually a mechanical-pneumatic boost pressure controller. Its boost pressure limit can be increased within a limited range by altering the pressure "seen" by the pneumatic actuator. The wastegates are only controlled indirectly by the PCM via the wastegate pneumatic solenoid.

A high pressure on the wastegate actuator's diaphragm tends to open the wastegate. The solenoid valve normally connects compressor out pressure (boost) to the wastegate actuator's diaphragm, resulting in the regulation of maximum boost pressure (to a constant value). Using the wastegate vent solenoid to partially vent (reduce) that control pressure increases the regulated maximum boost.

As the compressor outlet pressure increases, a pneumatically powered actuator opens each turbocharger wastegate to limit compressor outlet pressure. The wastegate pneumatic solenoid valve modulates that feedback pressure to increase the boost pressure limit. A duty cycle of 100% vents feedback thus eliminating any wastegate controlled boost limit. A duty cycle of 0% results in the base boost limit of approximately 5 psi gauge.



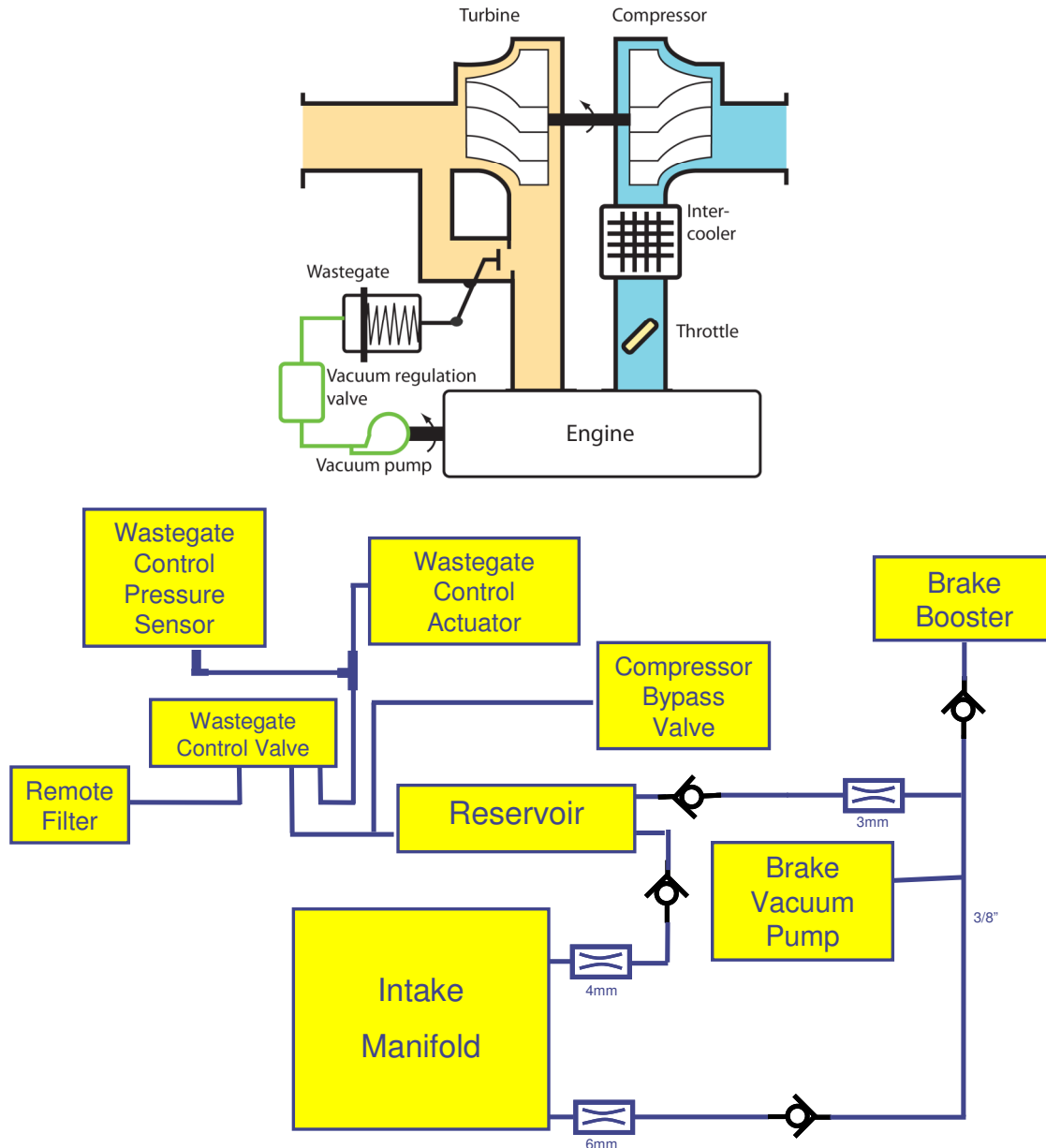
Wastegate Pneumatic Solenoid Valve Circuit Check Operation	
DTCs	P0245 Turbocharger/Supercharger Wastegate Solenoid A Low P0246 Turbocharger/Supercharger Wastegate Solenoid A High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	5 seconds

Wastegate Pneumatic Solenoid Valve Circuit malfunction thresholds:
PCM smart driver hardware detects faults for circuit short to battery, short to ground, and open circuit. Fault status reported to PCM to set appropriate DTC.

## Vacuum Actuated Wastegate System

The 3.5L GTDI was introduced with a mechanical-pneumatic boost pressure controller as described in the previous section. Boost pressure is limited mechanically via a diaphragm and spring. Boost pressure can be increased within a limited range by controlling a wastegate pneumatic solenoid.

The 2.0L GTDI was introduced with a vacuum actuated wastegate. This permits control of the wastegate position at all engine conditions. The wastegate can be opened at some part load conditions to reduce the backpressure on the engine. This reduces pumping losses and improves efficiency and fuel economy. A vacuum sensor was added to improve the accuracy and robustness of the control system.



2.0LGTDI (EcoBoost) Vacuum Schematic for Wastegate Control System

<b>Wastegate Pneumatic Solenoid Valve Circuit Check Operation</b>	
DTCs	P0245 Turbocharger/Supercharger Wastegate Solenoid A Low P0246 Turbocharger/Supercharger Wastegate Solenoid A High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	2 - 3 seconds

<b>Wastegate Pneumatic Solenoid Valve Circuit malfunction thresholds:</b>
PCM smart driver hardware detects faults for circuit short to battery, short to ground, and open circuit. Fault status reported to PCM to set appropriate DTC.

Note that the Wastegate B DTCs are only used with the Ford GT.

<b>Wastegate Pneumatic Solenoid Valve Circuit Check Operation</b>	
DTCs	P0249 Turbocharger/Supercharger Wastegate Solenoid B Low P0250 Turbocharger/Supercharger Wastegate Solenoid B High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	2 - 3 seconds

<b>Wastegate Pneumatic Solenoid Valve Circuit malfunction thresholds:</b>
PCM smart driver hardware detects faults for circuit short to battery, short to ground, and open circuit. Fault status reported to PCM to set appropriate DTC.

Under steady conditions, the control pressure error should be small. Control pressure lower than expected could indicate an air leak between wastegate canister and the wastegate solenoid, and insufficient source of vacuum, or that the wastegate solenoid is stuck off. Control pressure higher than expected could indicate that the wastegate solenoid is stuck on

<b>Wastegate Control Pressure Check Operation</b>	
DTCs	P1015 Wastegate Control Pressure Lower Than Expected P1016 Wastegate Control Pressure Lower Than Expected
Monitor execution	Continuous
Sensors OK	No P100F, P1011, P1012, P1013, P0245, P0246 DTCs
Monitor Sequence	None
Monitoring Duration	5 seconds

<b>Wastegate Control Pressure Check Entry Conditions</b>		
Entry Condition	Minimum	Maximum
Desired wastegate control pressure is stable: (desired pressure - expected pressure).		0.5 in Hg

<b>Wastegate Pneumatic Solenoid Valve Circuit malfunction thresholds:</b>
P1015 - Wastegate control pressure error > 3 in Hg
P1016 - Wastegate control pressure error > 5 in Hg

## Wastegate Control Pressure Sensor

The wastegate control pressure sensor is checked for opens, short and intermittents, P1012, P1013 and P1014.

Wastegate Control Pressure Sensor Check Operation	
DTCs	P1012 Wastegate Control Pressure Sensor Circuit Low P1013 Wastegate Control Pressure Sensor Circuit High P1014 Wastegate Control Pressure Sensor Circuit Intermittent/Erratic
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	5 seconds

Wastegate Control Pressure Sensor Transfer Function		
$V_{out} = (V_{ref} / 5) * (0.04399 * \text{Pressure (in kPa)} - 0.140)$		
Volts	Pressure, kPa	Pressure, Inches Hg
0.3	10.0	2.95
0.4	12.3	3.62
1.0	25.9	7.65
2.0	48.6	14.36
3.0	71.4	21.07
4.5	105.5	31.14
4.8	112.8	33.31

Wastegate Control Pressure Sensor Check Entry Conditions		
Entry Condition	Minimum	Maximum
none		

Wastegate Pneumatic Solenoid Valve Circuit malfunction thresholds:
P1012 – voltage < 0.20 V
P1013 – voltage > 4.93 V
P1014 – open or shorted > 10 events in a driving cycle

The wastegate control pressure sensor reading is checked at key-up using a four-way correlation check. If the wastegate control pressure sensor reading is higher or lower than the readings of the BARO, MAP, and TIP, a P100F is set. A P1011 is set if the wastegate control pressure is greater than BARO.

Wastegate Control Pressure Sensor Check Operation	
DTCs	P1011 Wastegate Control Pressure Sensor Circuit Range/Performance P100F Wastegate Control Pressure/BARO Correlation
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	No P1012, P1013, P1011, P2228, P2229, P2227, P0236, P0106 DTCs.
Monitoring Duration	5 seconds

Wastegate Control Pressure Sensor Check Entry Conditions		
Entry Condition	Minimum	Maximum
Engine off time (P100F only)	20 sec	

Wastegate Pneumatic Solenoid Valve Circuit malfunction thresholds:
P100F – pressure error exceeds 2.5 in Hg
P1011 – pressure exceeds BARO by > 3.0 in Hg

## Electric Turbocharger Wastegate

Beginning in the 2017 MY, Ford will be introducing an electrically controlled wastegate for turbocharger speed control in the 2017 MY 3.5L F150. The electric wastegate is an H-Bridge driven, motor controlled valve with a position sensor. The 3.5L will use two wastegates, one for each bank.

### Wastegate Actuator "A"

Wastegate Circuit A Check Operation	
DTCs	P0243 - Turbocharger/Supercharger Wastegate Solenoid A Low P2ABD - Turbocharger/Supercharger Wastegate Actuator "A" Driver Current/Temp Too High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	0.4 seconds

#### Wastegate Circuit A malfunction thresholds:

PCM smart driver hardware detects faults for circuit short to battery, short to ground, and open circuit. Fault status reported to PCM to set DTC.

Under steady conditions, the turbo wastegate position error should be small. Waste gate position lower than expected or higher than expected will set the appropriate DTC. Under dynamic conditions, the waste gate should follow the commanded position in a specified time.

Wastegate A Functional Check Operation	
DTCs	P25B3 Turbocharger/Supercharger Wastegate "A" Stuck Open P25B4 Turbocharger/Supercharger Wastegate "A" Stuck Closed P0244 Turbocharger/Supercharger Wastegate Actuator "A" Range/Performance
Monitor execution	Continuous
Sensors OK	No P0243, P2ABD DTCs
Monitor Sequence	None
Monitoring Duration	5.5 seconds

#### Wastegate A Functional Check malfunction thresholds:

P25B3 - Wastegate position error > 20 mm  
P25B4 - Wastegate position error > 20 mm

Wastegate position sensor circuit faults can be caused by sensor opens or shorts or out of range faults. An out of range fault can be caused by mechanical linkage over-travel faults as well as electrical faults.

### Wastegate Position Sensor A

Wastegate Position Sensor Circuit Check Operation	
DTCs	P2AB8 - Wastegate Position Sensor "A" Circuit Low P2AB9 - Wastegate Position Sensor "A" Circuit High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	4 seconds

Wastegate Position Sensor A Circuit malfunction thresholds:	
P2AB8	Wastegate Position Sensor "A" voltage < 0.50 volts
P2AB9	Wastegate Position Sensor "A" voltage > 4.50 volts

### Wastegate Actuator "B"

Wastegate Circuit B Check Operation	
DTCs	P0247 - Turbocharger/Supercharger Wastegate Solenoid B Low P2ABE - Turbocharger/Supercharger Wastegate Actuator "B" Driver Current/Temp Too High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	0.4 seconds

Wastegate Circuit B malfunction thresholds:	
PCM smart driver hardware detects faults for circuit short to battery, short to ground, and open circuit. Fault status reported to PCM to set DTC.	

Under steady conditions, the turbo wastegate position error should be small. Waste gate position lower than expected or higher than expected will set the appropriate DTC. Under dynamic conditions, the waste gate should follow the commanded position in a specified time.

<b>Wastegate B Functional Check Operation</b>	
DTCs	P25B5 Turbocharger/Supercharger Wastegate "B" Stuck Open P25B6 Turbocharger/Supercharger Wastegate "B" Stuck Closed P0248 Turbocharger/Supercharger Wastegate Actuator "B" Range/Performance
Monitor execution	Continuous
Sensors OK	No P0247, P2ABE DTCs
Monitor Sequence	None
Monitoring Duration	5.5 seconds

<b>Wastegate B Functional Check malfunction thresholds:</b>
P25B5 - Wastegate position error > 20 mm
P25B6 - Wastegate position error > 20 mm

Wastegate position sensor circuit faults can be caused by sensor opens or shorts or out of range faults. An out of range fault can be caused by mechanical linkage over-travel faults as well as electrical faults.

#### **Wastegate Position Sensor B**

<b>Wastegate Position Sensor B Circuit Check Operation</b>	
DTCs	P2ABB - Wastegate Position Sensor "B" Circuit Low P2ABC - Wastegate Position Sensor "B" Circuit High
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	4 seconds

<b>Wastegate Position Sensor B Circuit malfunction thresholds:</b>
P2ABB WGP "A" voltage < 0.50 volts
P2ABC WGP "A" voltage > 4.50 volts

## Boost Control

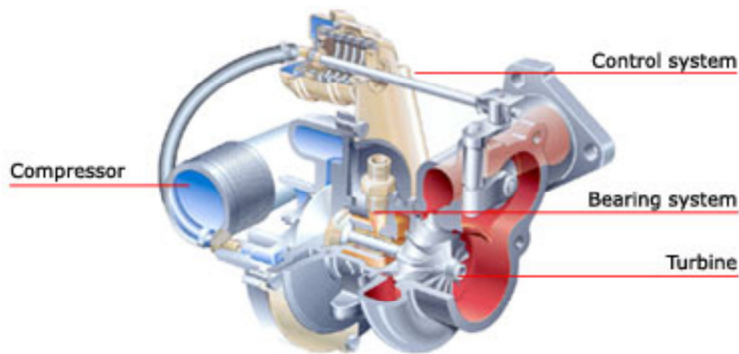
The boost control system determines a desired boost. Active control occurs when the desired boost is above base boost where base boost is defined as that boost that results when the wastegate vent solenoid is not venting (circuit off).

The following conditions may result in underboost.

- One or more wastegates stuck open
- Large conduit leak between compressor and throttle

The following conditions may result in overboost.

- One or more wastegates stuck closed
- One or more control hoses leaking/disconnected between wastegate diaphragm and wastegate vent solenoid.
- Wastegate vent solenoid stuck in vent position
- Control hoses to wastegate vent solenoid swapped.
- Hose between boost volume and wastegate vent solenoid disconnected.
- Not-yet-detected Turbocharger Boost sensor in-range failure.



The boost control system computes a desired boost based on operating conditions. Via the wastegate pneumatic solenoid valve, it varies the boost pressure limit to achieve its desired boost level (measured by the TCB-A sensor). The air charge control regulates the throttle to control the intake manifold pressure (MAP).

OverBoost Control Functional Check Operation:	
DTCs	P0234 (Turbocharger/Supercharger A Overboost Condition)
Monitor execution	continuous
Monitor Sequence	none
Sensors/Actuators OK	CBV, TCB-A, WGS, BARO
Monitoring Duration	5 seconds (up/down timer)

OverBoost Control Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
Wastegate Duty Cycle		0.05

OverBoost Control Functional Check Malfunction Thresholds:	
(Boost Pressure Desired – Boost Pressure Actual) > 4 psi	

UnderBoost Control Functional Check Operation:	
DTCs	P0299 (Turbocharger/Supercharger A Underboost Condition)
Monitor execution	continuous
Monitor Sequence	none
Sensors/Actuators OK	CBV, TCB-A, WGS, BARO
Monitoring Duration	5 seconds (up/down timer)

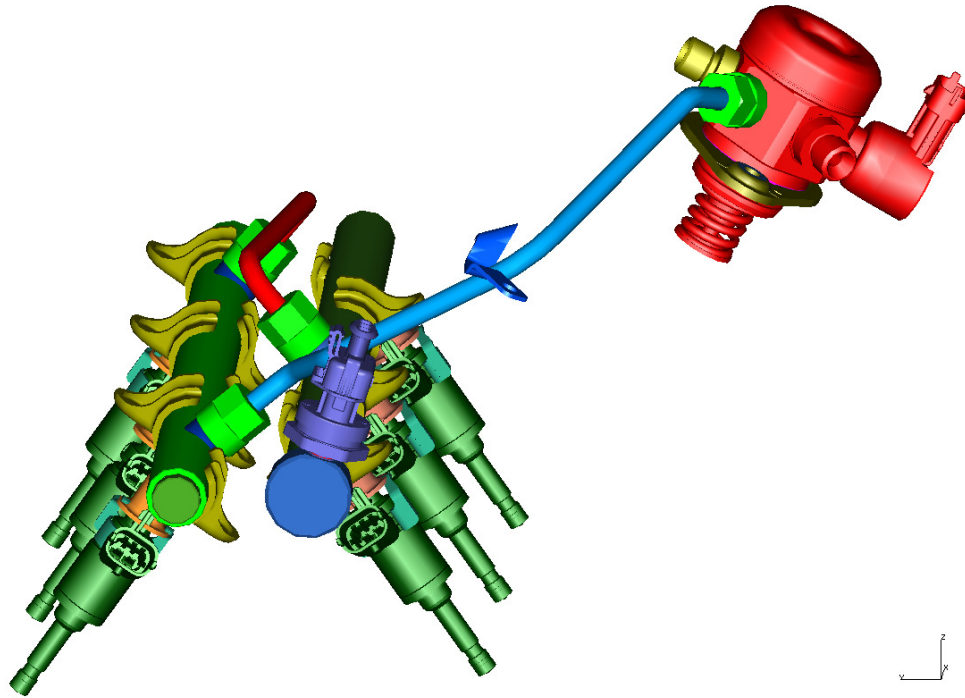
OverBoost Control Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
Wastegate Duty Cycle	0.95	

OverBoost Control Functional Check Malfunction Thresholds:	
(Boost Pressure Desired – Boost Pressure Actual) > 4 psi	

## Overview

The Gasoline Direct Injection (GDI) system is similar to a Port Fuel Injection (PFI) system with the exception of an added high-pressure pump.

- An in-tank pump supplies 65 psi fuel to the high pressure, camshaft-driven pump.
- The PCM-controlled pump produces a selectable pressure in the fuel rail(s).
- On/off injectors meter the high pressure fuel directly into the cylinders.



GDI Fuel Injectors, Rail, and High Pressure Pump

Gasoline Direct Injection (GDI) injectors spray liquid fuel, under high pressure, directly in the cylinder when activated. The high pressure fuel is supplied to the injector by a common fuel rail. The desired fuel pressure is determined by the PCM. Fuel injector pulsewidth is based on actual fuel pressure which is measured by a pressure sensor in the common rail.

Injection typically occurs in the cylinder's intake and compression stroke. Under certain conditions, multiple injections can occur per cylinder event. Since injection pressure is variable, the fuel mass injected is a function of both fuel pressure and injector pulsewidth.

A typical PFI injector is activated by applying battery voltage to it. The GDI injector driver applies a high voltage (65 volts) to initially open the injector and then controls injector current to hold it open during injection.

## Fuel Injectors

A typical PFI injector is single side controlled by the PCM. The GDI injector has two wires per injector routed to the PCM. The injector high side goes to a PCM pin (or two pins) that are common between an injector pair. The PCM contains a smart driver that monitors and compares high side and low side injector currents to diagnose numerous faults. All injector fault modes, however, are mapped into a single DTC per injector.

A higher-than-battery-voltage supply (internally generated within the PCM) is used to open the injector and modulated battery voltage holds the injector open. The injector driver IC controls three transistor switches that apply the boost voltage and then modulate injector current. Should that full voltage be unavailable, the proper injector opening current may not be generated in the time required. This fault (P062D) is detected on a per cylinder basis and reported without specifying a particular cylinder.



GDI Fuel Injector

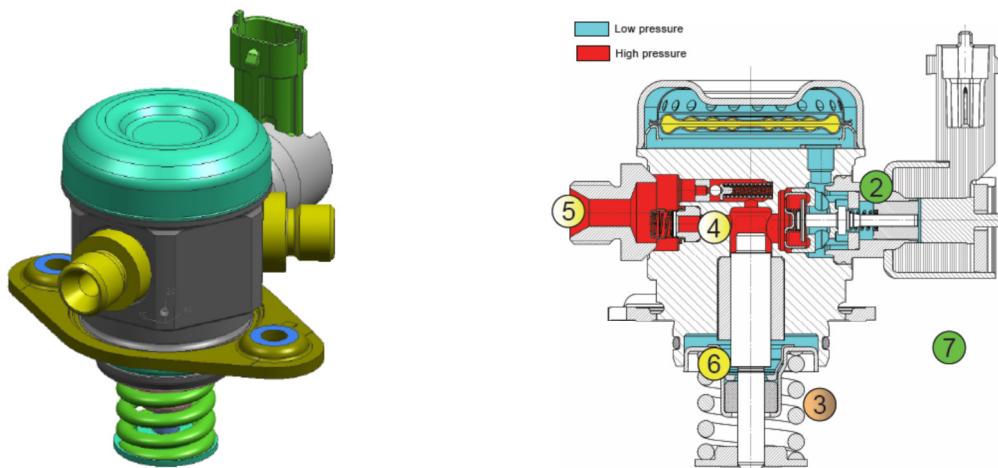
Injector Circuit Check Operation	
DTCs	P0201 through P0206 (Cylinder x Injector Circuit) P062D Fuel Injector Driver Circuit Performance
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	10 seconds

Typical Injector Circuit Check Entry Conditions		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

## Fuel Volume Regulator

The high pressure fuel pump raises Fuel Rail Pressure (FRP) to the desired level to support fuel injection requirements. Unlike Port Fuel Injection (PFI) systems, with Gasoline Direct Injection (GDI), the desired fuel rail pressure ranges widely over operating conditions.

The Fuel Volume Regulator is controlled to allow a desired fraction of the pump's full displacement (fuel volume) into the fuel rail. A fuel rail pressure control algorithm computes the required fraction of fuel pump volume to achieve the desired pressure. The high pressure fuel pump can only increase (and not reduce) fuel rail pressure. Fuel Injection is used to reduce fuel rail pressure.

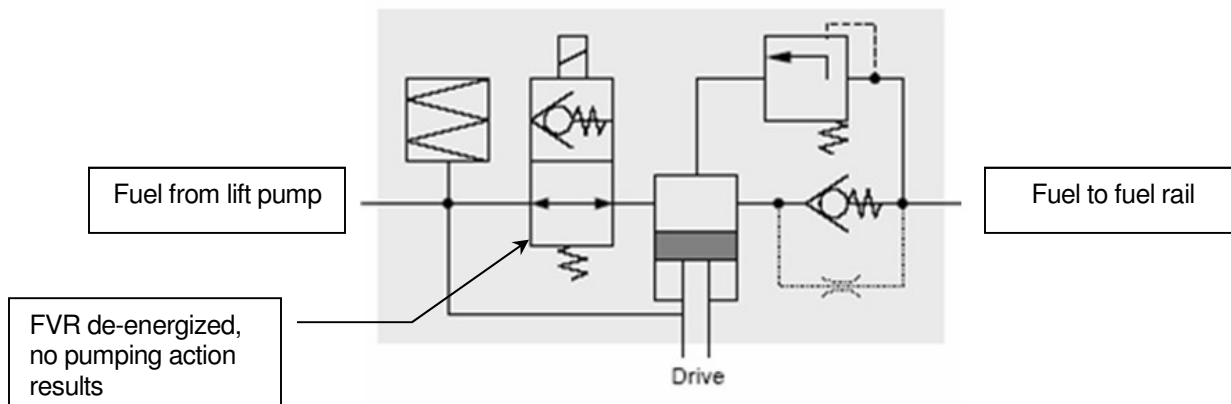


High Pressure Fuel Pump and Cutaway view

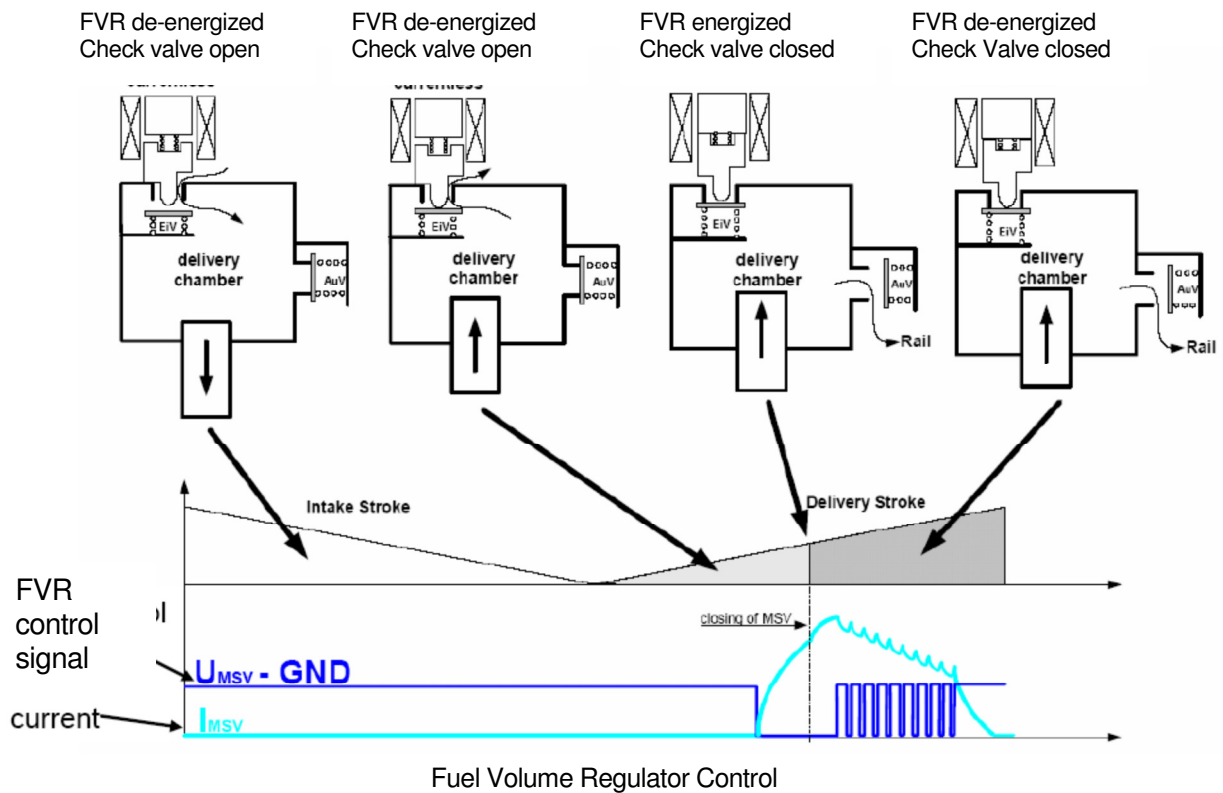
The Fuel Volume Regulator (FVR) is a solenoid valve permanently mounted to the pump assembly. It selects one of two plumbing elements upstream of the pump chamber. The next figure shows the solenoid valve in the un-powered position.)

Solenoid State	Plumbing Element Selected
Un-powered	Flow Through (i.e. Check Valve Disabled)
Energized	Check Valve

The FVR control is done synchronous to the cam position on which the pump is mounted. The synchronous FVR control must take into account that the camshaft phasing is varied during engine operation for purposes of valve control.



High Pressure Pump Plumbing Schematic



The FVR solenoid coil may overheat and fail if constant battery voltage is applied. For that reason, the PCM is equipped with protections to prevent FVR damage due certain wiring faults.

The FVR is a two wire device (high and low side control) with both wires routed to the PCM. This means that either or both wires can generate the DTC(s).

Fuel Volume Regulator Circuit Check Operation	
DTCs	P0001 Fuel Volume Regulator Control Circuit / Open P0003 Fuel Volume Regulator Control Circuit Low P0004 Fuel Volume Regulator Control Circuit High
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	none
Monitoring Duration	not applicable

## Fuel Rail Pressure Sensor

The fuel rail pressure control system uses the measured fuel rail pressure in a feedback control loop to achieve the desired fuel rail pressure. The fuel injection algorithm uses actual fuel rail pressure in its computation of fuel injector pulse width and fuel injection timing.

The Fuel Rail Pressure sensor is a gauge sensor. Its atmospheric reference hole is in the electrical connector. The fuel rail pressure sensor has a nominal range of 0 to 26 MPa (0 to 260 bar, 0 to 3770 psi). This pressure range is above the maximum intended operating pressure of 15 MPa and above the pressure relief valve setting of 19.4 MPa. The sensor voltage saturates at slightly above 0.2 and slightly below 4.8 volts.



Fuel Rail Pressure Sensor

Fuel rail pressure can develop a vacuum when the vehicle cools after running. Vacuums can be measured by the FPR gauge sensor as voltages near the 0.2 Volt limit.

FRP Sensor Transfer Function		
$\text{FRP} = -471.37 \text{ psi} + (\text{FRP\_voltage} / 5.0 \text{ volts}) * 4713.73 \text{ psi}$		
Volts	Pressure, MPa (gauge)	Pressure, psi (gauge)
4.80	27.95	4054
4.50	26	3771
3.50	19.5	2828
2.50	13.0	1885
1.50	6.5	943
0.50	0	0
0.20	-1.95	-283

FRP Open/Short Check Operation:	
DTCs	P0192 - Fuel Rail Pressure Sensor A Circuit Low P0193 - Fuel Rail Pressure Sensor A Circuit High
Monitor execution	Continuous
Monitor Sequence	none
Sensors OK	none
Monitoring Duration	5 seconds to register a malfunction

Typical FRP Sensor Check Malfunction Thresholds:	
FRP voltage < 0.20 volts   or   FRP voltage > 4.80 volts	

A fuel pressure sensor that is substantially in error results in a fuel system fault (too rich / too lean). If actual fuel rail pressure exceeds measured pressure, more fuel than that which would be expected is injected and vice versa. This fuel error would show up in the long term and short term fuel trim.

## Fuel Rail Pressure Control

Fuel rail pressure is maintained via:

- Feed-forward knowledge of pump command and injector fuel quantity and
- Feedback knowledge of sensed pressure.

A set point pressure is determined by engine operating conditions. If a pressure increase is desired, the fuel pump effective stroke is increased via FVR valve timing. Pressure decreases are analogous; however, without injection fuel rail pressure cannot be decreased. Acting alone, the pump can only increase pressure.

In theory, the PCM could exactly account for mass entering the rail via the pump and exiting the rail via the injectors, however, since both the pump timing and injector timing are constantly changing and interact, this is very difficult. Thus, the pump control performs fuel pressure control as a continuous process. It calculates average fuel mass over 720° (one engine cycle) and average fuel pressure over 240°. Control is executed at engine firing rate 240°.

For diagnostic purposes, fuel fractional pressure error is computed as a ratio of the pressure error over the desired pressure. This unitless ratio is then compared to thresholds to yield fuel pressure too low (P0087) or fuel pressure too high (P0088).

Fuel Rail Pressure Control (Normal) Functional Check Operation:	
DTCs	P0087 (Fuel Rail Pressure Too Low) P0088 (Fuel Rail Pressure Too High)
Monitor execution	continuous
Monitor Sequence	P0087 and P0088 must complete before setting P00C6 or P053F
Sensors/Actuators OK	FLI, FRP, FVR,, Lift Pump
Monitoring Duration	not applicable

Typical Fuel Rail Pressure Control (Normal) Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
High Pressure Pump Enabled	Enabled	
Fuel level	15%	
Injector Cut Off	No Injector Cut Off	
Injection Volume / (720° Pump Volume / Number of Cylinders)	0.05	0.90
Engine Coolant Temperature	20°F	250°F
CSER Mode	Not in CSER	

**Typical Fuel Rail Pressure Control (Normal) Functional Check Malfunction Thresholds:**

P0087:  $(\text{Fuel\_Pressure\_Desired} - \text{Fuel\_Pressure\_Actual}) / \text{Fuel\_Pressure\_Desired} > 0.25$

P0088:  $-(\text{Fuel\_Pressure\_Desired} - \text{Fuel\_Pressure\_Actual}) / \text{Fuel\_Pressure\_Desired} > 0.25$

**Fuel Rail Pressure Control (Cranking)**

The engine is designed to start with a minimum required fuel injection pressure. If that minimum fuel injection pressure is not achieved before the first fuel injection, a fault is set.

**Fuel Rail Pressure Control (Cranking) Functional Check Operation:**

DTCs	P00C6 (Fuel Rail Pressure Too Low – Engine Cranking)
Monitor execution	Minimum pressure met instantaneously once during cranking
Monitor Sequence	P0087 and P0088 must pass before setting P00C6 or P053F
Sensors/Actuators OK	FLI, FRP, FVR,, Lift Pump
Monitoring Duration	Minimum met instantaneously once during cranking

**Typical Fuel Rail Pressure Control (Cranking) Functional Check Entry Conditions:**

Entry Condition	Minimum	Maximum
Fuel level	15%	

**Typical Fuel Rail Pressure Control (Cranking) Functional Check Malfunction Thresholds:**

$\text{Fuel\_Pressure\_Actual} \geq \text{Fuel\_Pressure\_Desired}$

## Fuel Rail Pressure Control (CSER)

While not used in this first GTDI application, it is possible that during catalyst heating (CSER) the fuel injection timing may be unique to this mode. In future cases, a two squirt injection may be used. One of those injection squirts would occur during the compression stroke. Compression injection is only allowed within a calibrated fuel pressure "window". The P053F detection monitors the time fraction within that fuel pressure window.

### Fuel Rail Pressure Control (CSER) Functional Check Operation:

DTCs	P053F (Cold Start Fuel Pressure Control Performance)
Monitor execution	During CSER
Monitor Sequence	P0087 and P0088 must pass before setting P00C6 or P053F
Sensors/Actuators OK	FLI, FRP, FVR, Lift Pump
Monitoring Duration	Entire CSER period

### Typical Fuel Rail Pressure Control (CSER) Functional Check Entry Conditions:

Entry Condition	Minimum	Maximum
Fuel level	15%	

### Typical Fuel Rail Pressure Control (CSER) Functional Check Malfunction Thresholds:

Time in Fuel Injection Pressure Window / CSER Duration > 0.70

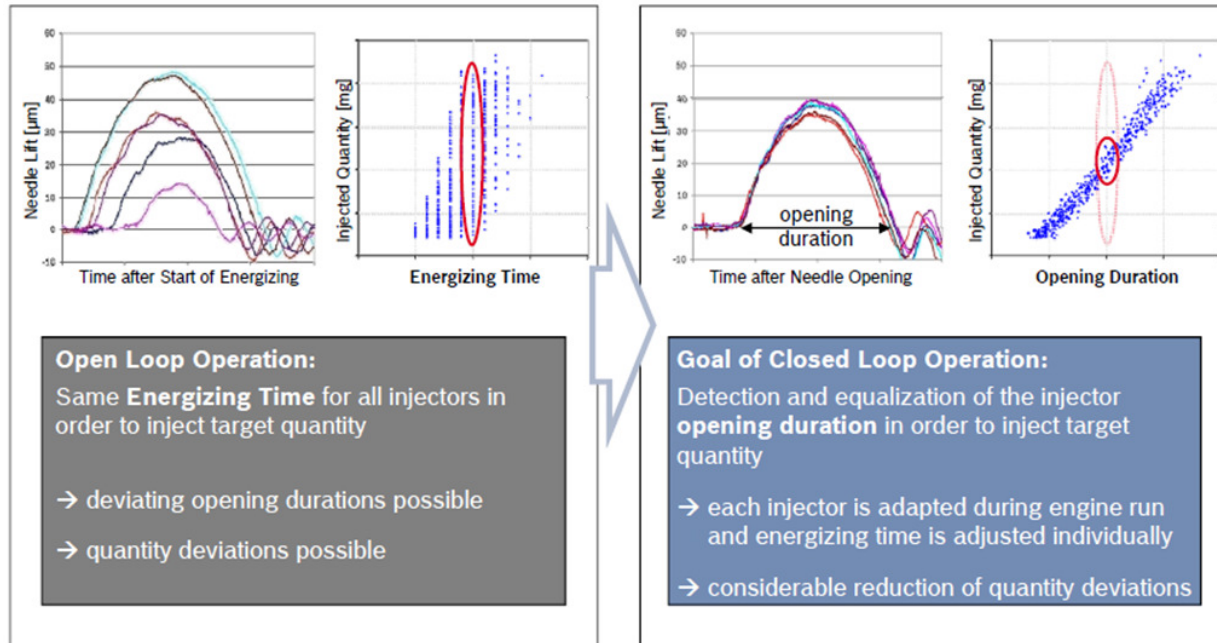
Fuel Injection Pressure Window defined as follows:

Minimum Fuel Pressure to Support Desired Injection Mode <= Fuel Pressure Actual

Fuel Pressure Actual <= Maximum Fuel Pressure to Support Desired Injection Mode

## Controlled Valve Operation (CVO)

CVO uses a current feedback circuit in the PCM to equalize the injector opening duration for all injectors to reduce deviations in fuel quantity injected. Each injector is adapted individually during engine running conditions. A DTC is set if there is a circuit fault in the PCM or the adaption is at its limits.



### CVO Functional Check Operation:

DTCs	P02EE - Cylinder 1 Injector Circuit Range/Performance P02EF - Cylinder 2 Injector Circuit Range/Performance P02F0 - Cylinder 3 Injector Circuit Range/Performance P02F1 - Cylinder 4 Injector Circuit Range/Performance P02F2 - Cylinder 5 Injector Circuit Range/Performance P02F3 - Cylinder 6 Injector Circuit Range/Performance P02F4 - Cylinder 7 Injector Circuit Range/Performance P02F5 - Cylinder 8 Injector Circuit Range/Performance
Monitor execution	Continuous
Monitor Sequence	none
Sensors/Actuators OK	FRP (P0192, P0193, P0087, P0088), FVR (P0001, P0003, P0004), INJ (P0201, P0202, P0203, P0204, P0205, P0206)
Monitoring Duration	25 seconds

### Typical CVO Functional Check Malfunction Thresholds:

Driver software indicates CVO circuit fault or unable to adapt/adaption at limits

## PFI/DI Fuel System

Port Fuel Injection/Direct Injection (PFI/DI) fuel systems will be introduced in the 2017 MY on the 3.5L GTDI F150 and 3.5L GTDI Ford GT. The benefits of using both a PFI and a DI fuel injection system on an engine are fuel economy, emissions and performance.

Fuel economy can be improved by running in PFI mode during light load conditions. In this region, the energy required to compress the fuel for use within the DI system is not utilized which equates directly into improved fuel economy. Performance can be improved by running DI as engine speeds and loads increase. By injecting the fuel directly into the cylinder, more heat from the air can be transferred to the fuel. This charge cooling effect results in an increase in torque by using DI injection. Emissions can be improved by running in PFI mode at idle. DI fuel rail pressure must be lowered at idle to avoid running at fuel pulse widths that are very small. The variability in delivered fuel at small fuel pulse widths leads to higher Particulate Matter (PM) emissions. Running in PFI mode at low loads reduces PM emissions. PFI/DI Maintenance Modes

### DI Injector Maintenance:

The DI injector can be damaged if exposed to excessive heat, which can occur by running PFI only at higher loads. To avoid damage, the DI system is commanded on sufficiently enough to cool the injector via the fuel flow.

### DI Rail Pressure Maintenance:

While running PFI only, the pressure within the DI fuel rail will increase due to thermal expansion. Higher pressures reduce the ability of the DI system to accurately meter small fuel masses when needed. The minimum pulse width of an injector is set by electrical and mechanical injector characteristics and fuel pressure. As pressure increases, the minimum fuel mass that can be delivered also increases. Pressure maintenance mode is used to ensure that the minimum requested fuel mass can be delivered, if needed. Pressure relief can be done in two ways. The first is to use the pressure bleed valve within the high pressure pump. This is a passive, mechanical valve which opens around 3,500 psi. The second is an active approach where the DI injectors are commanded on for a few engine cycles. The delivered fuel mass will lower the rail pressure and will lower the rail temperature as fuel is replenished with cooler fuel from the tank that has not be subjected to engine heat.

### DI High Pressure Pump Maintenance:

While running PFI only, the temperature of the DI pump will increase due to heat transfer from the cylinder head and due to friction, as the pump's piston is still actively moving. To avoid pump damage, the control system will turn on the DI injectors to allow fuel to flow through the pump. This cooler fuel flow replenishes the lubrication film on the piston and transfers out of the pump.

## **PFI/DI Electrical Failure Mode and Effects Management**

### **DI Injector/Circuit Failure:**

If a DI fuel injector fails, fuel injection for that cylinder (both PFI and DI) will be disabled. Some failures, such as shorts to ground on the low side, require the control system to disable a pair of DI injectors due to a common high side control circuit. In those cases, two cylinders will be disabled. The rationale for this FMEM action is because combustion without DI injection will damage the DI injector due to injector over temperature.

### **PFI Injector/Circuit Failure:**

If a PFI fuel injector fails, all PFI injectors will be disabled. The rationale for this is a control system constraint. The fuel fraction delivered by each system (PFI or DI) is calculated on a "per engine" basis, not an individual cylinder basis. Disabling one PFI injector would require a second set of fueling calculations. For simplicity sake, if any PFI failure exists, engine operation will switch to DI only.

### **DI High Pressure Fuel Pump Circuit Failure:**

If the DI high pressure fuel pump fails, the control system will run the engine using the PFI system, with the inclusion of some DI operation for DI injector maintenance. The DI system will be forced to operate at lift pump pressures but the PFI system will be fully functional. The DI injections will only be used to cool the DI injectors.

## High Pressure Fuel Rail Pressure Sensor (DI Fuel Rail)

The fuel rail pressure control system uses the measured fuel rail pressure in a feedback control loop to achieve the desired fuel rail pressure. The fuel injection algorithm uses actual fuel rail pressure in its computation of fuel injector pulse width and fuel injection timing.

The Fuel Rail Pressure sensor is a gauge sensor. Its atmospheric reference hole is in the electrical connector. The fuel rail pressure sensor has a nominal range of 0 to 26 MPa (0 to 260 bar, 0 to 3770 psi). This pressure range is above the maximum intended operating pressure of 15 MPa and above the pressure relief valve setting of 19.4 MPa. The sensor voltage saturates at slightly above 0.2 and slightly below 4.8 volts.



Fuel Rail Pressure Sensor

Fuel rail pressure can develop a vacuum when the vehicle cools after running. Vacuums can be measured by the FRP gauge sensor as voltages near the 0.2 Volt limit.

FRP Open/Short Check Operation:	
DTCs	P0192 - Fuel Rail Pressure Sensor A Circuit Low P0193 - Fuel Rail Pressure Sensor A Circuit High
Monitor execution	Continuous
Monitor Sequence	none
Sensors OK	none
Monitoring Duration	5 seconds to register a malfunction

Typical FRP Sensor Check Malfunction Thresholds:	
FRP voltage < 0.27 volts or FRP voltage > 4.76 volts	

A fuel pressure sensor that is substantially in error results in a fuel system fault (too rich / too lean). If actual fuel rail pressure exceeds measured pressure, more fuel than that which would be expected is injected and vice versa. This fuel error would show up in the long term and short term fuel trim.

FRP Sensor Transfer Function		
FRP = -471.37 psi + (FRP_voltage / 5.0 volts) * 4713.73 psi		
Volts	Pressure, MPa (gauge)	Pressure, psi (gauge)
4.76	27.69	4016
4.50	26	3771
3.50	19.5	2828
2.50	13.0	1885
1.50	6.5	943
0.50	0	0
0.27	-1.49	-217

## Fuel Rail Pressure Control

Fuel rail pressure is maintained via:

- Feed-forward knowledge of pump command and injector fuel quantity and
- Feedback knowledge of sensed pressure.

A set point pressure is determined by engine operating conditions. If a pressure increase is desired, the fuel pump effective stroke is increased via FVR valve timing. Pressure decreases are analogous; however, without injection fuel rail pressure cannot be decreased. Acting alone, the pump can only increase pressure.

In theory, the PCM could exactly account for mass entering the rail via the pump and exiting the rail via the injectors, however, since both the pump timing and injector timing are constantly changing and interact, this is very difficult. Thus, the pump control performs fuel pressure control as a continuous process. It calculates average fuel mass over 720° (one engine cycle) and average fuel pressure over 240°. Control is executed at engine firing rate 240°.

For diagnostic purposes, fuel fractional pressure error is computed as a ratio of the pressure error over the desired pressure. This unitless ratio is then compared to thresholds to yield fuel pressure too low (P0087) or fuel pressure too high (P0088).

Fuel Rail Pressure Control (Normal) Functional Check Operation:	
DTCs	P0087 (Fuel Rail Pressure Too Low) P0088 (Fuel Rail Pressure Too High)
Monitor execution	continuous
Monitor Sequence	P0087 and P0088 must complete before setting P00C6 or P053F
Sensors/Actuators OK	FLI, FRP, FVR,, Lift Pump
Monitoring Duration	not applicable

Typical Fuel Rail Pressure Control (Normal) Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
High Pressure Pump Enabled	Enabled	
Fuel level	15%	
Injector Cut Off	No Injector Cut Off	
Injection Volume / (720° Pump Volume / Number of Cylinders)	0.05	0.90
Engine Coolant Temperature	20°F	250°F
CSER Mode	Not in CSER	

Typical Fuel Rail Pressure Control (Normal) Functional Check Malfunction Thresholds:	
P0087: $(\text{Fuel\_Pressure\_Desired} - \text{Fuel\_Pressure\_Actual}) / \text{Fuel\_Pressure\_Desired} > 0.25$	
P0088: $-(\text{Fuel\_Pressure\_Desired} - \text{Fuel\_Pressure\_Actual}) / \text{Fuel\_Pressure\_Desired} > 0.25$	

## Fuel Rail Pressure Control (Cranking)

The engine is designed to start with a minimum required fuel injection pressure. If that minimum fuel injection pressure is not achieved before the first fuel injection, a fault is set.

Fuel Rail Pressure Control (Cranking) Functional Check Operation:	
DTCs	P00C6 (Fuel Rail Pressure Too Low – Engine Cranking)
Monitor execution	Minimum pressure met instantaneously once during cranking
Monitor Sequence	P0087 and P0088 must pass before setting P00C6 or P053F
Sensors/Actuators OK	FLI, FRP, FVR,, Lift Pump
Monitoring Duration	Minimum met instantaneously once during cranking

Typical Fuel Rail Pressure Control (Cranking) Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
Fuel level	15%	

Typical Fuel Rail Pressure Control (Cranking) Functional Check Malfunction Thresholds:	
Fuel_Pressure_Actual $\geq$ Fuel_Pressure_Desired	

## Fuel Rail Pressure Control (CSER)

While not used in this first GTDI application, it is possible that during catalyst heating (CSER) the fuel injection timing may be unique to this mode. In future cases, a two squirt injection may be used. One of those injection squirts would occur during the compression stroke. Compression injection is only allowed within a calibrated fuel pressure "window". The P053F detection monitors the time fraction within that fuel pressure window.

### Fuel Rail Pressure Control (CSER) Functional Check Operation:

DTCs	P053F (Cold Start Fuel Pressure Control Performance)
Monitor execution	During CSER
Monitor Sequence	P0087 and P0088 must pass before setting P00C6 or P053F
Sensors/Actuators OK	FLI, FRP, FVR, Lift Pump
Monitoring Duration	Entire CSER period

### Typical Fuel Rail Pressure Control (CSER) Functional Check Entry Conditions:

Entry Condition	Minimum	Maximum
Fuel level	15%	

### Typical Fuel Rail Pressure Control (CSER) Functional Check Malfunction Thresholds:

Time in Fuel Injection Pressure Window / CSER Duration > 0.70

Fuel Injection Pressure Window defined as follows:

Minimum Fuel Pressure to Support Desired Injection Mode  $\leq$  Fuel Pressure Actual

Fuel Pressure Actual  $\leq$  Maximum Fuel Pressure to Support Desired Injection Mode

## Low Pressure Fuel Rail Pressure Sensor (PFI Fuel Rail)

Fuel Rail Pressure Sensor B Check Operation:	
DTCs	P018C (low input), P018D (high input)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	8 seconds to register a malfunction

Typical FRP sensor check malfunction thresholds:	
Voltage < 0.049 volts or voltage > 4.88 volts	

Fuel Rail Pressure Sensor Transfer Function		
FRP volts = [ Vref * ( 4 * Fuel Pressure / 70) + 0.50 ] / 5.00		
Volts	A/D counts in PCM	Pressure, psi
4.85	993	76.125
4.50	922	70
4.00	820	61.25
3.50	717	52.5
3.00	614	43.75
2.50	512	35
2.00	410	26.25
1.50	307	17.5
1.00	205	8.75
0.50	102	0
0.15	31	-6.125

Fuel Rail Pressure Control (Normal) Functional Check Operation:	
DTCs	P008A (Fuel Rail Pressure Too Low) P008B (Fuel Rail Pressure Too High)
Monitor execution	continuous
Monitor Sequence	P018C, P018D and P018B must complete
Sensors/Actuators OK	FRP
Monitoring Duration	not applicable

Typical Fuel Rail Pressure Control (Normal) Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
High Pressure Pump Enabled	Enabled	
Fuel level	15%	

Injector Cut Off	No Injector Cut Off	
Injection Volume / (720° Pump Volume / Number of Cylinders)	0.05	0.90
Engine Coolant Temperature	20°F	250°F
CSER Mode	Not in CSER	

**Typical Fuel Rail Pressure Control (Normal) Functional Check Malfunction Thresholds:**

P008A:  $(\text{Fuel\_Pressure\_Desired} - \text{Fuel\_Pressure\_Actual}) / \text{Fuel\_Pressure\_Desired} > 0.25$

P008B:  $-(\text{Fuel\_Pressure\_Desired} - \text{Fuel\_Pressure\_Actual}) / \text{Fuel\_Pressure\_Desired} > 0.25$

The FRP range/performance test checks to make sure that fuel rail pressure can be properly controlled by the electronic returnless fuel system. Note that the FRP is referenced to manifold vacuum (via a hose) while the fuel rail pressure sensor is not referenced to manifold vacuum. It uses gage pressure. As a result, a mechanical gage in the fuel rail will display a different pressure than the FPR PID on a scan tool. The scan tool PID will read higher because of manifold vacuum.

<b>FRP Range/Performance Check Operation:</b>	
DTCs	P018D (FRP range/performance)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	FRP
Monitoring Duration	8 seconds to register a malfunction

<b>Typical FRP Sensor Range/Performance check entry conditions:</b>		
Entry Condition	Minimum	Maximum
Demand pressure reasonable	35 psig	60 psig
Fuel level	15%	

<b>Typical FRP Range/Performance check malfunction thresholds:</b>
Fuel pressure error (demand – actual pressure) > 20 psig

## Fuel Pump Control Module

The FP signal is a duty cycle command sent from the PCM to the fuel pump control module. The fuel pump control module uses the FP command to operate the fuel pump at the speed requested by the PCM or to turn the fuel pump off. A valid duty cycle to command the fuel pump on, is in the range of 15-47%. The fuel pump control module doubles the received duty cycle and provides this voltage to the fuel pump as a percent of the battery voltage. When the ignition is turned on, the fuel pump runs for about 1 second and is requested off by the PCM if engine rotation is not detected.

### FUEL PUMP DUTY CYCLE OUTPUT FROM PCM

FP Duty Cycle Command	PCM Status	Fuel Pump Control Module Actions
0-15%	Invalid off duty cycle	The fuel pump control module sends a 20% duty cycle signal on the fuel pump monitor (FPM) circuit. The fuel pump is off.
37%	Normal low speed operation.	The fuel pump control module operates the fuel pump at the speed requested. The fuel pump control module sends a 60% duty cycle signal on FPM circuit.
47%	Normal high speed operation.	The fuel pump control module operates the fuel pump at the speed requested. The fuel pump control module sends a 60% duty cycle signal on FPM circuit.
51-67%	Invalid on duty cycle.	The fuel pump control module sends a 20% duty cycle signal on the FPM circuit. The fuel pump is off.
67-83%	Valid off duty cycle	The fuel pump control module sends a 60% duty cycle signal on FPM circuit. The fuel pump is off.
83-100%	Invalid on duty cycle.	The fuel pump control module sends a 20% duty cycle signal on the FPM circuit. The fuel pump is off.

The fuel pump control module communicates diagnostic information to the PCM through the FPM circuit. This information is sent by the fuel pump control module as a duty cycle signal. The 5 duty cycle signals that may be sent are listed in the following table. Some vehicles, e.g. the 5.2L Mustang, use two fuel pump control modules to supply enough fuel to the engine. The fuel pump modules are the same, there are simply two of them ("A" and "B"). The second pump uses a different set of DTCs for the same set of faults. Both pumps are driven by the same PCM output.

## FUEL PUMP CONTROL MODULE DUTY CYCLE SIGNALS

Duty Cycle	Comments
20%	This duty cycle indicates the fuel pump control module is receiving an invalid duty cycle from the PCM.
30%	This duty cycle indicates a pump driver module (PEM) internal error. This status is applicable only to Omron Gen.II or higher modules.
40%	For vehicles with event notification signal, this duty cycle indicates the fuel pump control module is receiving an invalid event notification signal from the RCM. For vehicles without event notification signal, this duty cycle indicates the fuel pump control module is functioning normally.
60%	For vehicles with event notification signal, this duty cycle indicates the fuel pump control module is functioning normally.
80%	This duty cycle indicates the fuel pump control module is detecting a concern with the secondary circuits.

### FP A Check Operation:

DTCs	P025A – Fuel Pump A Control Circuit (opens/shorts) P025B – Invalid Fuel Pump A Control Data (20% duty cycle from FPM) P0627 – Fuel Pump A Secondary Circuit (80% duty cycle from PFM) P064A – Fuel Pump A Driver Module Internal Error (30% duty cycle from PFM) U2010B – Fuel Pump A Disabled Circuit (40% duty cycle from FPM) U0109 – Loss of Communication with Fuel Pump Module A
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	2 seconds

### Typical FP A check entry conditions:

Entry Condition	Minimum	Maximum
Battery Voltage	11 volts	

### Typical FP A check malfunction thresholds:

P025A - Smart Fuel Pump output driver in PCM/ECM indicates fault  
P025B - Fuel Pump Monitor duty cycle feedback of 20%  
P0627 – Fuel Pump Monitor duty cycle feedback of 80%  
P064A – Fuel Pump Monitor duty cycle feedback of 30%  
U210B – Fuel Pump Monitor duty cycle feedback of 40%  
U0191 - No Fuel Pump Monitor duty cycle feedback (i.e. 0% or 100% duty cycle)

<b>FP B Check Operation:</b>	
DTCs	P025A – Fuel Pump A/B Control Circuit (opens/shorts) P027B – Invalid Fuel Pump B Control Data (20% duty cycle from FPM) P2632 – Fuel Pump B Secondary Circuit (80% duty cycle from PFM) P26EA – Fuel Pump B Driver Module Internal Error (30% duty cycle from PFM) U2010C – Fuel Pump B Disabled Circuit (40% duty cycle from FPM) U016C – Loss of Communication with Fuel Pump Module B
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	2 seconds

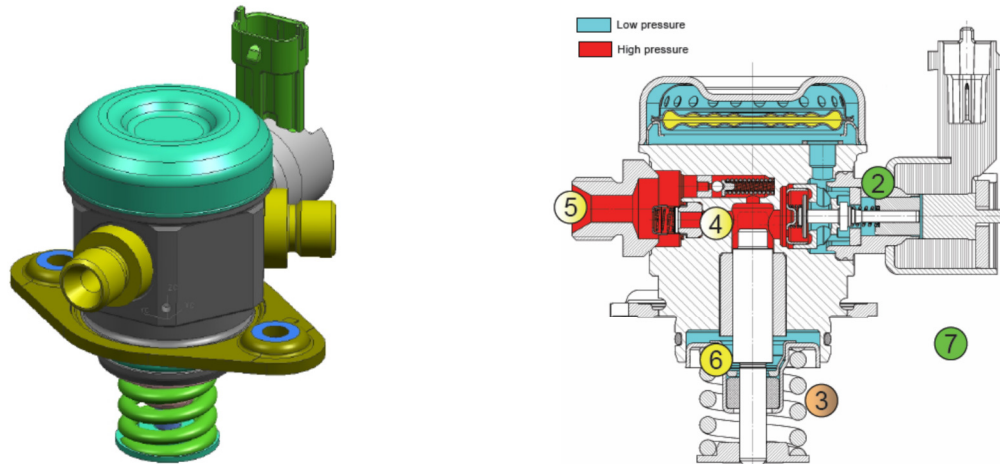
<b>Typical FP B check entry conditions:</b>		
Entry Condition	Minimum	Maximum
Battery Voltage	11 volts	

<b>Typical FP B check malfunction thresholds:</b>
P025A - Smart Fuel Pump output driver in PCM/ECM indicates fault P027B - Fuel Pump Monitor duty cycle feedback of 20% P2632 – Fuel Pump Monitor duty cycle feedback of 80% P26EA – Fuel Pump Monitor duty cycle feedback of 30% U210C – Fuel Pump Monitor duty cycle feedback of 40% U016C - No Fuel Pump Monitor duty cycle feedback (i.e. 0% or 100% duty cycle)

## Fuel Volume Regulator

The high pressure fuel pump raises Fuel Rail Pressure (FRP) to the desired level to support fuel injection requirements. Unlike Port Fuel Injection (PFI) systems, with Gasoline Direct Injection (GDI), the desired fuel rail pressure ranges widely over operating conditions.

The Fuel Volume Regulator is controlled to allow a desired fraction of the pump's full displacement (fuel volume) into the fuel rail. A fuel rail pressure control algorithm computes the required fraction of fuel pump volume to achieve the desired pressure. The high pressure fuel pump can only increase (and not reduce) fuel rail pressure. Fuel Injection is used to reduce fuel rail pressure.

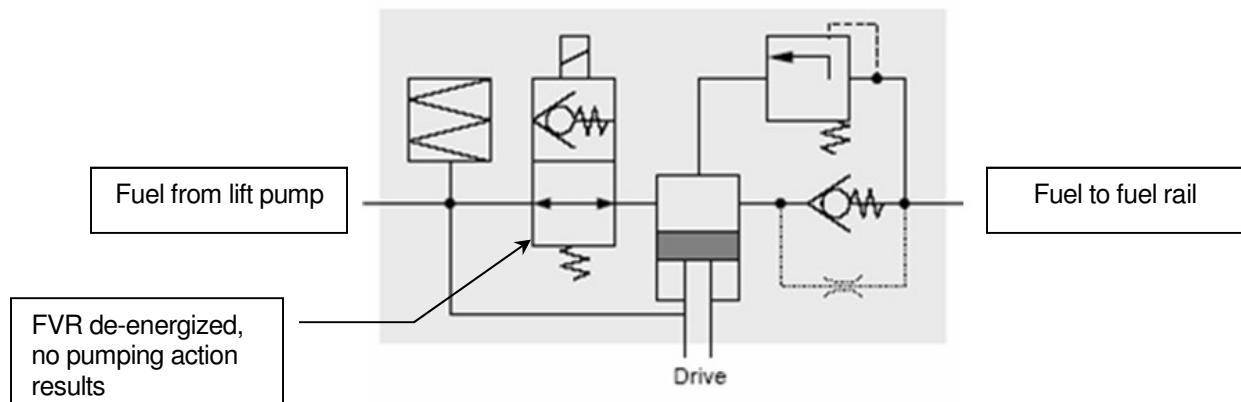


High Pressure Fuel Pump and Cutaway view

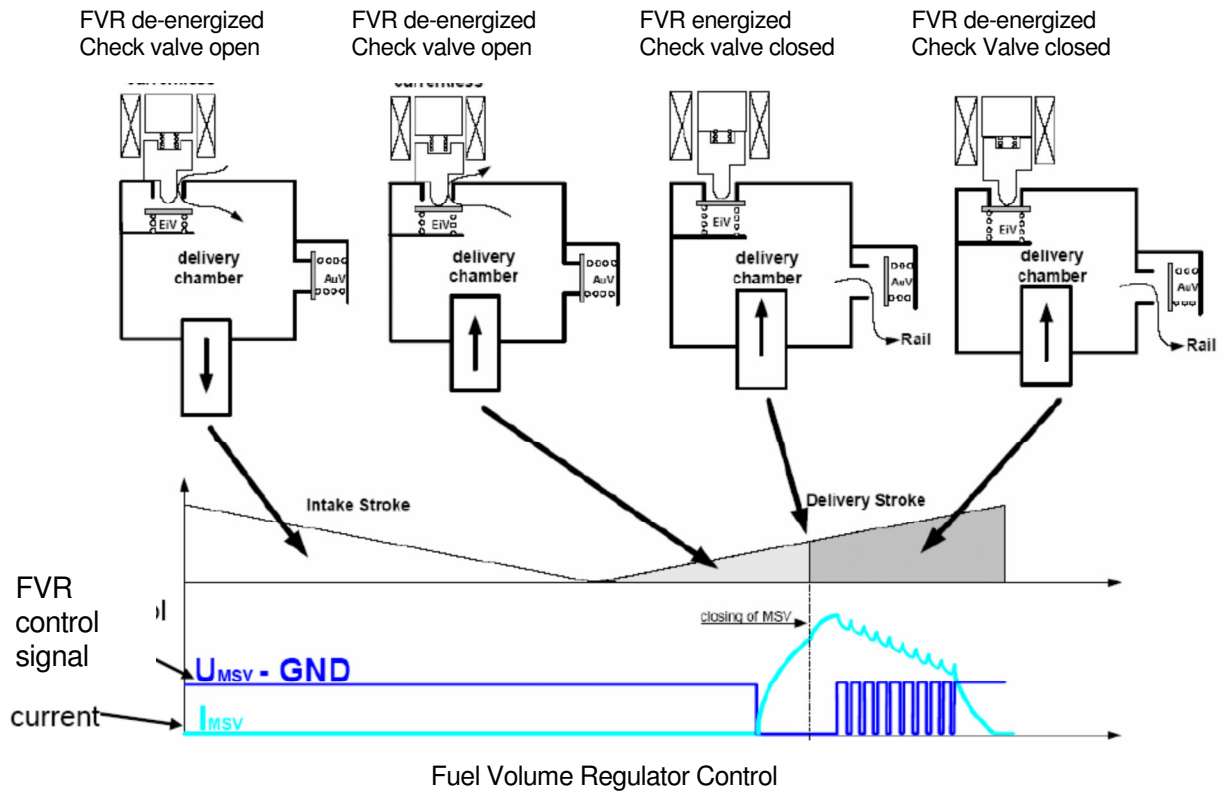
The Fuel Volume Regulator (FVR) is a solenoid valve permanently mounted to the pump assembly. It selects one of two plumbing elements upstream of the pump chamber. The next figure shows the solenoid valve in the un-powered position.)

Solenoid State	Plumbing Element Selected
Un-powered	Flow Through (i.e. Check Valve Disabled)
Energized	Check Valve

The FVR control is done synchronous to the cam position on which the pump is mounted. The synchronous FVR control must take into account that the camshaft phasing is varied during engine operation for purposes of valve control.



High Pressure Pump Plumbing Schematic



The FVR solenoid coil may overheat and fail if constant battery voltage is applied. For that reason, the PCM is equipped with protections to prevent FVR damage due certain wiring faults.

The FVR is a two wire device (high and low side control) with both wires routed to the PCM. This means that either or both wires can generate the DTC(s).

Fuel Volume Regulator Circuit Check Operation	
DTCs	P0001 Fuel Volume Regulator Control Circuit / Open P0003 Fuel Volume Regulator Control Circuit Low P0004 Fuel Volume Regulator Control Circuit High
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	none
Monitoring Duration	5 seconds

## Fuel Injector (DI System)

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

Fuel System "A" Injector Check Operation:	
DTCs	P0201 through P0208 - Cylinder X Injector "A" Circuit (opens/shorts)
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	8 seconds

Typical injector circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

## Fuel Injector (PFI System)

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

Fuel System "B" Injector Check Operation:	
DTCs	P21CF through P21D6 - Cylinder X Injector "B" Circuit (opens/shorts)
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	5 seconds

Typical injector circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

## PFI/DI Fuel Monitor

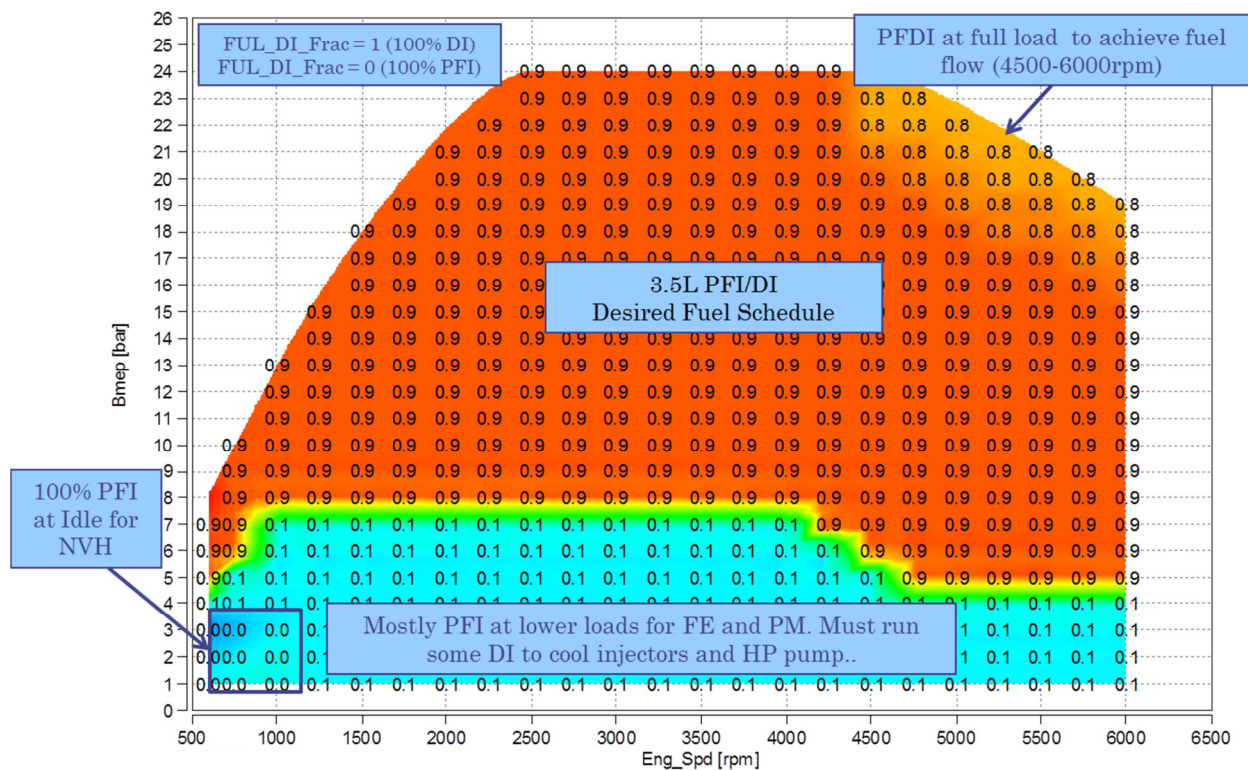
Similar to single fuel applications, the PFI/DI engines use adaptive fuel and a fuel monitor to verify the fuel metering system. Closed loop fuel corrections are learned for the PFI/DI system just as they are for a single fuel system, however, because of the multiple fuel systems, the failure mode identification is more complex.

The DI fuel injection systems can have fuel metering errors (mass/volume) from either the injectors (slope/offset) or from the pressure sensor (slope). PFI fuel injection systems can have fuel metering errors (mass/volume) from either the injectors (slope/offset) or from the pressure sensor (slope). The fuel delivery system (common mode errors) can have fuel metering errors from incorrect ethanol content estimation or from errors in air measurement.

If a fuel shift is introduced via a common mode (e.g. air metering), the software will monitor closed loop fuel adaptation, however, the errors will not change based on the amount of fuel each system is delivering.

If a fuel shift is introduced on either fuel injection system, the software will monitor closed loop fuel adaptation, but the magnitude of the error can change depending on how much fuel each system is delivering. Fuel delivery for each fuel injection system is scheduled as a function of engine rpm and load.

The "Fuel System Percentage Use" PID (\$9F) tracks percent fuel injected by fuel system A (DI injection system) and by fuel system B (PFI Injection system). Using the value of PID \$9F stored in freeze frame can help determine whether the fault is a fuel system specific fault or a common mode fault. A typical PFI/DI fuel schedule is shown below. Observing the reaction of short term and long term fuel trims (PIDs \$06 - \$09) and fuel system percentage use (PID \$9F) can help narrow down fuel system error as common mode faults of fuel injection specific faults.



**Fuel Monitor Operation:**

DTCs	Common mode faults: P0171 System Too Lean (Bank 1) P0172 System Too Rich (Bank 1) P0174 System Too Lean (Bank 2) P0175 System Too Rich (Bank 2) DI mode faults: P2BEC Fuel Control System "A" Too Lean Bank 1 P2BED Fuel Control System "A" Too Rich Bank 1 P2BEE Fuel Control System "A" Too Lean Bank 2 P2BEF Fuel Control System "A" Too Rich Bank 2 PFI mode faults: P2BF0 Fuel Control System "B" Too Lean Bank 1 P2BF1 Fuel Control System "B" Too Rich Bank 1 P2BF2 Fuel Control System "B" Too Lean Bank 2 P2BF3 Fuel Control System "B" Too Rich Bank 2
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	150 °F	250 °F
Engine load	12%	
Intake Air Temp	-30 °F	150 °F
Fuel Level	10%	
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:

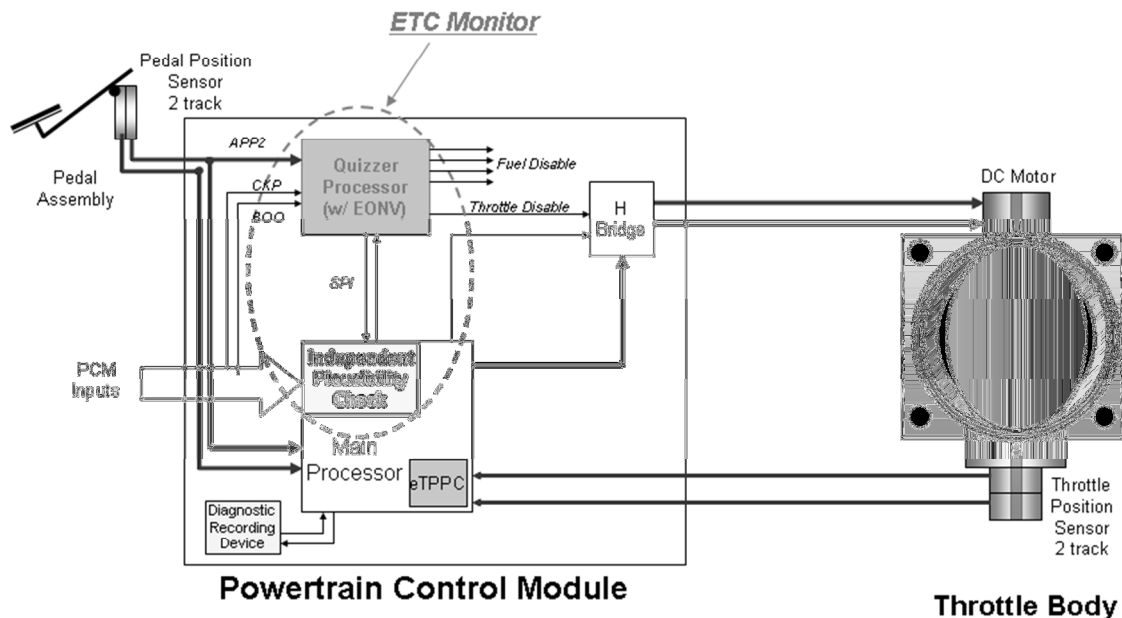
Lean malfunction: LONGFT > 25%, SHRTFT > 1%

Rich malfunction: LONGFT < 25%, SHRTFT < 1%

## Electronic Throttle Control

The Electronic Throttle Control (ETC) system uses a strategy that delivers engine 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.

### Gen 3 / Gen 4 ETC System



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.

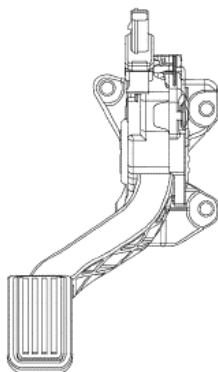
**ETC System Failure Mode and Effects Management:**

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	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.
PCM Reset (Bosch CY320 or Conti ATIC Quizzer hardware only)	If a significant processor fault is detected, the monitor will attempt to mitigate the fault by forcing a PCM reset. If the fault clears after the reset, then the vehicle will continue running. If the fault persists, then the monitor will force another reset. This will continue until the fault clears or until the PCM exceeds the maximum number of resets allowed. If this occurs, the PCM is held in reset, and the engine does not run. The maximum number of resets allowed depends on the PCM supplier and the type of fault detected. The wrench light and MIL are turned on in this mode, and the appropriate processor P-code will 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, Brake and Throttle Position Sensor Inputs****On-demand KOEO / KOER Sensor Check Operation:**

DTCs	P1124 – TP A out of self-test range (non-MIL) P1575 – APP out of self-test range (non-MIL) P1703 – Brake switch out of self-test range (non-MIL)
Monitor execution	On-demand
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

There are 2 pedal position sensors in the pedal assembly. Both signals, APP1 and APP2, have a positive slope (increasing angle, increasing voltage), but are offset and have different slope. There are 2 reference voltage circuits, 2 signal return circuits, and 2 signal circuits (a total of 6 circuits and pins) between the PCM and the APP sensor assembly. The pedal position signal is converted to pedal travel degrees (rotary angle) by the PCM.



*Typical APP Sensor*

<b>Accelerator Pedal Position Sensor Check Operation:</b>	
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)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

<b>APP sensor check malfunction thresholds:</b>
Circuit continuity - Voltage < 0.25 volts or voltage > 4.75 volts Range/performance – disagreement between sensors > 0.9 degrees For B-car architecture: Circuit continuity – Voltage < 0.6 volts or >11.4 volts for PWM input

The Brake Pedal Position (BPP) Switch (Brake On/Off) is sometimes referred to as the stop lamp switch. The BPP switch provides a signal to the PCM indicating the brakes are applied. The BPP switch is a normally open switch and is mounted on the brake pedal support. The BPP switch supplies battery positive (B+) voltage to the PCM when the brake pedal is applied. The normally closed BPS (brake pressure switch), along with the normally open BPP switch, are used for a brake rationality test within the PCM. If one or both brake pedal inputs to the PCM is not changing states as expected, a P0504 DTC is set. BPP is used by the ETC strategy (Electronic Throttle Control) for the Brake Override Accelerator (BOA) feature. Failure of the BOO switch may result in decreased drivability but it does not impact emissions or OBD.

<b>Brake On Off Switch Check Operation:</b>	
DTCs	P0504 – Brake switch A/B correlation (wrench light, non-MIL) P0572 – Brake switch circuit low (wrench light, non-MIL) P0573 – Brake switch circuit high (wrench light, non-MIL)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	> 25 brake application cycles to register a malfunction

The brake pressure switch is a normally closed switch which is typically mounted on the brake pedal support. When the brake pedal is applied, the normally closed switch opens. BPS is used for cruise control deactivation, by transmission for trailer brake control & tow haul mode, and is used in Stop/Start applications for brake pressure indication. It is not used for OBD.

<b>Brake Pressure Sensor Check Operation:</b>	
DTCs	P1561 – Brake Line Pressure Sensor Circuit (wrench light, non-MIL)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 2 seconds to register a malfunction

## Analog Throttle Position

The Electronic Throttle Body has two throttle position sensor circuits. One sensor (TP1) has a negative slope (increasing angle, decreasing voltage) and the second sensor (TP2) has a positive slope (increasing angle, increasing voltage). Two sensors are used for redundancy.

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	

## SENT Throttle Position

The 2017 MY 3.5L GTDI F150 is using a SENT Throttle Position Sensor. This is considered to be a Smart Device” by the OBD-II regulations. The analog throttle position sensor signals have been replaced by a three wires – a 5 volt reference voltage, a ground and a SENT communication line. The DTC structure is similar but not the same.

Sensor faults identified by the SENT device use the traditional P-codes, P0120 and P0124. Because of the safety related nature of throttle position faults, note that the P0124 DTC sets immediately, as soon as a fault is initially recognized and FMEM actions are taken. If the fault persists, another DTC identifying the specific fault will be set as well.

If communication is lost with the SENT device, the U0606 (lost communication) code would be set. Most likely, it means that there is a wiring issue even though it could also mean the SENT device failed or lost power/ground and is no longer communicating with the PCM. The service technician would proceed to troubleshoot the wires, but if no wiring fault could be identified, the next action would be to replace the SENT device.

SENT communication uses CRC errors to identify a communication fault. A CRC fault could be caused either by faulty wiring or by a faulty SENT microprocessor. CRC errors would also set the U0606 (lost communication) code. Similarly, the service technician would proceed to troubleshoot the wires, but if no wiring fault could be identified, the next action would be to replace the SENT device.

Two additional DTCs (U210F and U2110) to identify if the SENT communication line is shorted high or low.

Throttle Position Sensor Check Operation:	
DTCs	P0120 – Throttle/Pedal Position Sensor/Switch "A" Circuit (MIL, wrench light) U0606 – Lost Communication With Throttle/Pedal Position Sensor/Switch "A"(MIL, wrench light) P0124 - Throttle/Pedal Position Sensor/Switch "A" Intermittent (MIL, wrench light) U210F - Throttle/Pedal Position Sensor/Switch "A" Communication Circuit Low (MIL, wrench light) U2110 - Throttle/Pedal Position Sensor/Switch "A" Communication Circuit High (MIL, wrench light) P0068 - MAP / MAF - Throttle Position Correlation (MIL, wrench light)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 0.4 to 4 seconds to register a malfunction

TP sensor check malfunction thresholds:	
P0120 (TP sensor fault) – SENT device faulted > 4 seconds	
P0124 (TP intermittent) – fault present for > 0.4 seconds	
U0606 (Lost Comm with TP sensor) – wiring or SENT device fault > 4 seconds	
U210F/U2110 (SENT Comm line shorted high or low > 4 sec.	

## Throttle Plate Position Controller (TPPC) Outputs

The Electronic Throttle Body uses a DC motor to control the throttle plate. An internal spring is used to return the throttle plate to a default position. The default position is typically a throttle angle of 7 to 8 degrees from the hard stop angle. The closed throttle plate hard stop prevents the throttle from binding in the bore. This hard stop setting is not adjustable and is set to result in less airflow than the minimum engine airflow required at idle.

The purpose of the TPPC is to control the throttle position to the desired throttle angle. The current ETC systems have the eTPPC function integrated in the main PCM processor. 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 (non-MIL)
Monitor execution	Continuous
Monitor Sequence	None
Monitoring Duration	< 5 seconds to register a malfunction

## Electronic Throttle Monitor

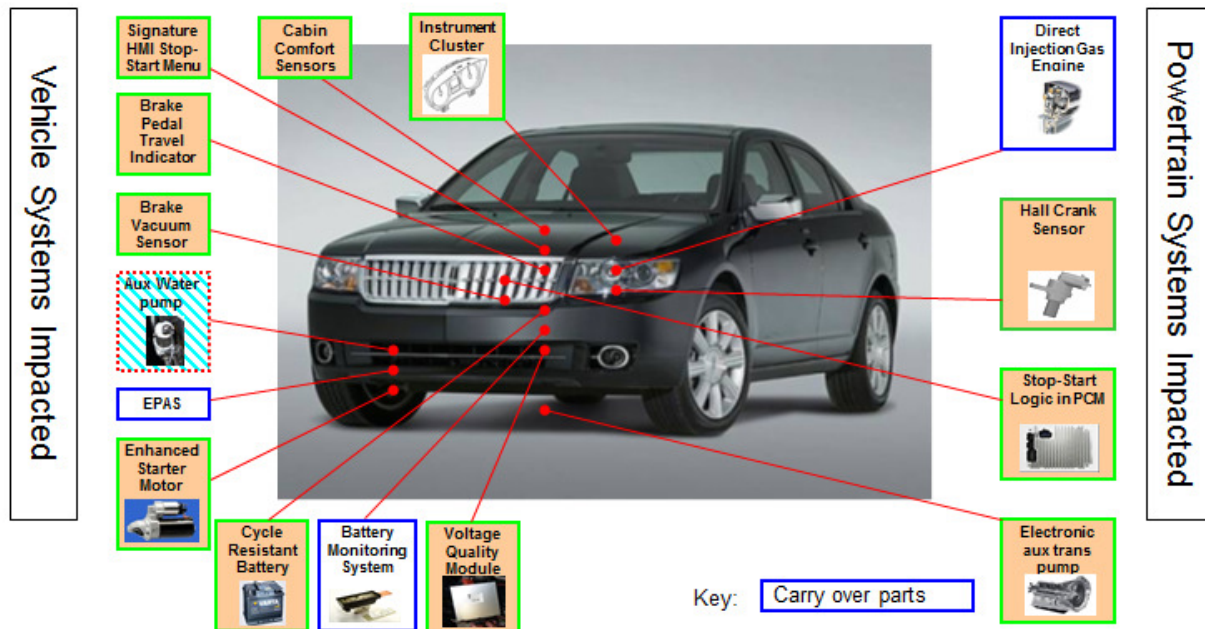
Electronic Throttle Monitor Operation:	
DTCs	<p>U0300 – ETC software version mismatch, IPC, Quizzer or TPPC (MIL, wrench light)</p> <p>P0600 – Serial Communication Link (MIL, wrench light)</p> <p>P060A – Internal control module monitoring processor performance (MIL, wrench light)</p> <p>P060B – Internal control module A/D processing performance (MIL, wrench light)</p> <p>P060C – Internal control module main processor performance (MIL, wrench light)</p> <p>P060D – Internal control module accelerator pedal performance (non-MIL, wrench)</p> <p>P061A – Internal control module torque performance (non-MIL, wrench light for cruise fault, no wrench light for torque clipping)</p> <p>P061B – Internal control module torque calculation performance (MIL, wrench light)</p> <p>P061C – Internal control module engine rpm performance (MIL, wrench light)</p> <p>P061D – Internal control module engine air mass performance (MIL, wrench light)</p> <p>P061E – Internal control module brake signal performance (non-MIL, wrench light)</p> <p>P062B – Internal control module fuel injector control performance (MIL for Conti PCM only)</p> <p>P062C – Internal control module vehicle speed performance (non-MIL, wrench light)</p> <p>P164C – Internal control module stop/start performance (non-MIL, wrench light)</p> <p>P1674 – Internal control module software corrupted (MIL, wrench light)</p> <p>P26C4 – Internal control module clutch pedal performance (non-MIL)</p> <p>U1013 – Transmission control module secure net error (non-MIL)</p>
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	< 1 seconds to register a malfunction

## Stop Start

### Stop Start Overview

The 2013 MY Fusion will incorporate Stop Start. Stop-Start will automatically turn off the engine when the vehicle is stopped, such as at traffic lights, to avoid fuel waste due to unnecessary engine idle. Upon brake pedal release, the engine will automatically restart offering normal vehicle response. The vehicle may not turn off the engine when stopped depending on customer comfort settings or vehicle conditions.

The benefits are improved fuel economy and reduced exhaust emissions. Stop Start affects many components and subsystems in the vehicle as shown in the diagram below.



### Stop Start Diagnostics

Existing diagnostics for the thermostat monitor had to be revised to accommodate stop-start. The ECT model used for the thermostat had to be revised to accommodate engine pull downs.

Diagnostics were added for new/improved hardware:

- Bi-directional crankshaft sensor
- Electric transmission fluid pump
- Auxiliary water pump
- Voltage quality module
- Brake vacuum sensor
- Stop-Start button
- Battery Monitor System
- Brake Switch

## Stop Start Enable Conditions:

Stop Start is enabled during a normal driving cycle based on the entry conditions listed in the table below:

Input	Stop-Start Inhibit Conditions	Rationale
ECT	140 deg F < ECT < 230 deg F	Combustion Stability
BARO	BARO <= 20 in Hg (Altitude <= 10,000 ft)	Minimum Air Charge
FRP at Idle	Fuel Rail Pressure (FRP) at Idle >= 45 Bar	Restart Combustion Stability
FRP w/Engine Off	FRP at engine off >= FRP at Idle with max drop of 5 Bar. If FRP at eng off drops below threshold, request pull-up	Restart Combustion Stability
Time Since Key-Start	10 seconds	Oil Stabilization and Learn Closed Throttle
Max Crank Time	Max Crank Time should be min of 5 sec below limit to allow a shutdown	To avoid a possible max crank fault
Low Fuel Level	fuel level below 15%	Avoid starts on empty fuel tank
Purge complete	Canister Purge Valve no closed before end of pre stop period	Wait for purge to complete before pulling down engine
Adaptive Fuel Complete	Adaptive fuel learning not complete	If Adaptive fuel learning is in process, wait for it to complete before pull down

## Stop Start Disable Conditions:

Stop-Start is inhibited if any of the following DTCs are set. This is intended to ensure that starting is not compromised.

**FVR** (P0001, P0003, P0004), **Low Pressure Fuel** (P008A, P008B), **Crank Fuel Pressure** (P00C6),  
**VVT** (P0010, P0011, P0012, P0013, P0014, P0015, P0016, P0017),  
**AAT** (P0072, P0073, P0074), **IAT** (P00CE), **High Pressure Fuel** (P0087, P0088),  
**IAT2** (P0096, P0097, P0098), **MAF** (P0100, P0102, P0103, P1101), **MAF/TP** (P0068),  
**MAP** (P0106, P0107, P0108, P0109), **IAT1** (P0111, P0112, P0113, P0114),  
**ECT** (P0116, P0117, P0118, P0119), **TP1** (P0122, P0123), **TP2** (P0222, P0223),  
**Fuel Monitor** (P0148, P0171, P0172), **LP FP** (P018C, P018D), **FRP** (P0192, P0193),  
**Injectors** (P0201, P0202, P0203, P0204), **Misfire** (P0300, P0301, P0302, P0303, P0304),  
**Fuel Pump** (P025A, P025B, P0230, P0231, P0232, P0627, P064A),  
**CMP A** (P0340, P0341, P0344), **Coils** (P0351, P0352, P0353, P0354),  
**CMP B** (P0365, P0366, P0369), **Idle Speed** (P0505, P0506, P0507), **Starter** (P0615, P06E9, P162F),  
**ETC** (P2100, P2101, P2107, P2111, P2112), **APP** (P2122, P2123, P2127, P2128, P2135, P2138),  
**BARO** (P2227, P2228, P2229, P2230), **PCV** (P2282),  
**Coils** (P2300, P2301, P2303, P2304, P2306, P2307, P2309, P2310)

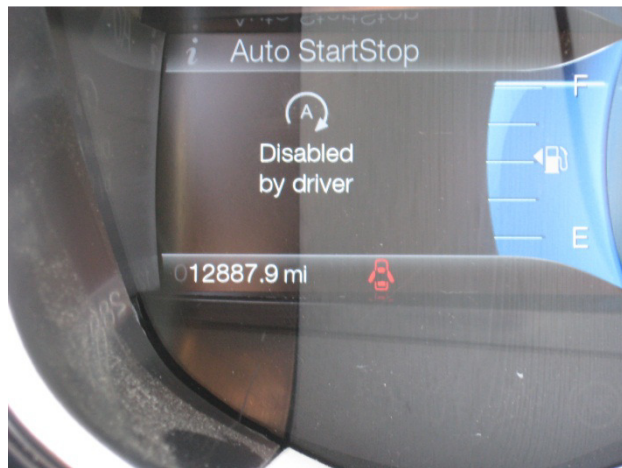
## Stop Start Customer Interface

The 2013 MY Fusion will incorporate Stop Start. Start/stop is enabled for every start as the default condition. It cannot be permanently disabled.

Auto Start/stop can be disabled (and re-enabled) by pressing the button on the console, which lights up with the word OFF next to the auto start/stop symbol. This is very similar to how other features, like traction control or back-up warning works.

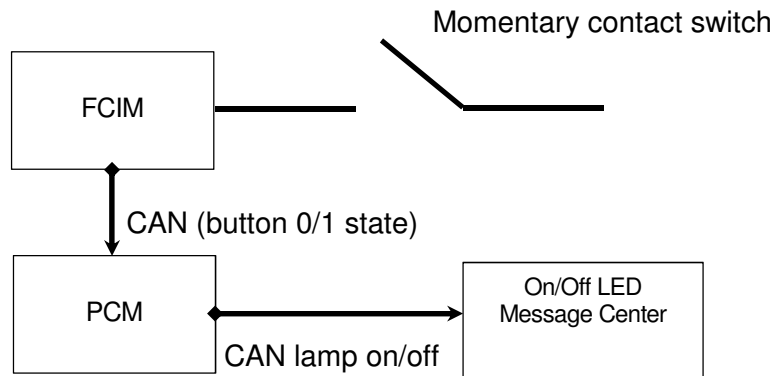


If you have the message center displaying the auto start/stop feature messages, it will tell you when you come to a stop that auto start/stop is disabled by the driver.



## Stop Start Button

The stop-start disable button is a momentary contact switch. It is normally open, CAN signal low. Closed (button being pushed) is CAN signal high. The Front Controls Interface Module reads the switch status and sends it over CAN to the PCM.



The PCM looks for a low to high transition to toggle the status of Stop-start from enabled (default state) to disabled. If there is another low to high transition, stop-start will go from disabled to enabled.

If the PCM stops receiving data from the FCIM, the PCM sets a U0256 - Lost Communication with Front Controls Interface Module "A".

If the FCIM detects that the switch is shorted to ground, it sets a B12CB -11 Start/Stop "Eco-Start" Enable Button Circuit Short To Ground. DTC sets if the button is pushed for 4 continuous seconds (8 samples) but will clear it if the fault is not detected any time after that for 500 msec

If the FCIM detects that the status indicator is shorted to ground, it sets a B12CA-11 - Start/Stop "Eco-Start" Status Indicator Circuit Short To Ground

If the FCIM detects that the status indicator is shorted to battery or open, it sets a B12CA-15 -Start/Stop "Eco-Start" Status Indicator Circuit Short To Battery or Open

If the button is stuck open, there are no low to high transitions. Since the PCM does not recognize a button push, stop-start will not be disabled if requested by the customer. All stop-start HMI will continue indicating that stop-start is enabled (e.g. Tell-Tale and IOD).

If the button is stuck closed, there are no low to high transitions. Since the PCM does not recognize a button push, stop-start will not be disabled if requested by the customer. All stop-start HMI will indicate that stop-start is enabled (e.g. Tell-Tale and IOD).

## Comprehensive Component Monitor - Engine

### Engine Temperature Sensor Inputs

Analog inputs such as Intake Air Temperature (P0112, P0113), Engine Coolant Temperature (P0117, P0118), 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.

Engine Coolant Temperature Sensor Check Operation:	
DTCs	P0117 (low input), P0118 (high input)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical ECT sensor check malfunction thresholds:	
Voltage < 0.244 volts   or   voltage > 4.96 volts	

The ECT rationality test checks to make sure that ECT is not stuck 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, 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 for stuck high	On first valid sample after key on (engine does not have to start)
Monitoring Duration for stuck midrange	5 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 (stuck high only)		50 deg
Engine Coolant Temperature for stuck high condition	230 °F	
Engine Coolant Temperature for stuck midrange condition	175 °F	230 °F

Typical ECT Sensor Rationality check malfunction thresholds:	
ECT stuck high after first valid sample   OR   ECT stuck midrange for > 5 seconds	

Currently, vehicles use either an ECT sensor or CHT sensor, not both. 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 < 0.244 volts or voltage > 4.96 volts
For P1299, MIL illuminates immediately if CHT > 270 ° Fuel shut-off is activated to reduce engine and coolant temperature

Beginning in the 2013 MY, an Exhaust Metal Temperature (EMT) sensor has been added to the 2.0L GTDI engine in some vehicles along with an ECT sensor. This EMT sensor is located in the cylinder head near the exhaust port. The signal correlates well to ECT during normal operating conditions with a properly filled and sealed coolant system. However, if the engine coolant system was damaged and coolant was low or lost, the EMT sensor will still sense the actual exhaust metal temperature while the ECT could be sitting in air instead of coolant (reading a much lower temperature). This sensor is used strictly for engine component protection via the PCM's "fail-safe" cooling algorithm with diagnostics for open and short circuit faults (P1289, P1290) along with the "fail-safe" cooling fault (P1299). This EMT sensor is actually a CHT sensor that only uses the high range resistor network, hence it uses the CHT "Hot End" transfer function shown below.

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 < 0.244 volts or voltage > 4.96 volts
For P1299, MIL illuminates immediately if CHT > 270 ° 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 < 0.244 volts   or   voltage > 4.96 volts

**Engine Oil Temperature Sensor Check Operation:**

DTCs	P0197 (low input), P0198 (high input)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

**Typical EOT sensor check malfunction thresholds:**

Voltage < 0.20 volts   or   voltage > 4.96 volts

## Ambient Air Temperature

For many years, Ambient Air Temperature was not able to be directly measure by a sensor input. Ambient Air Temperature was inferred from the Intake Air Temperature (IAT) sensor. The IAT sensor is normally located as part of the MAF sensor. Under cold start conditions (long soak, ECT < 140 deg F, no block heater), there is minimal underhood heating and the IAT sensor is a good estimate of ambient. The inferred ambient temperature is the IAT sensor value. Under normal warmed up conditions, the IAT sensor reading is normally higher than actual ambient due to the underhood heating from engine, exhaust, A/C, etc. The value of inferred ambient is updated at higher vehicle speeds under conditions where IAT reflects actual ambient. When the IAT reading is higher than the current inferred value, the ramp rate is slow due to lower confidence that the elevated temperature is the result of increasing ambient temperature. When the IAT reading is lower than the current inferred value, the ramp rate is fast since underhood effects are less likely.

Beginning in the 2013 MY some vehicles will have an Ambient Air Temperature (AAT) sensor wired to the PCM. The PCM simply reads the sensor and sends the sensor value out to the rest of the vehicles (instrument cluster, HVAC system, etc) over the CAN network. The AAT sensor is typically located as part of the driver's door mirror.

Beginning in the 2015 MY, some vehicles will begin using the AAT sensor as a measure of ambient temperature for some OBD monitors rather than inferring it from IAT as described above. This change was prompted by the replacement of the MAF sensor by a MAP sensor on some port fuel injected engines. The IAT sensor is part of the MAP sensor. It is close to the intake manifold and reflects manifold charge temperature rather than the temperature of the air passing through the MAF sensor. The higher temperature environment makes it less able to accurately infer ambient air temperature.

If utilized by the software, the ambient temperature from the AAT sensor will be used by the evaporative system monitor, the PCV system monitor and the thermostat monitor rather than the inferred ambient from the IAT sensor.

### Ambient Air Temperature Sensor Check Operation:

DTCs	P0072 - AAT Sensor Circuit Low P0073 - AAT Sensor Circuit High
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

### Typical AAT sensor check malfunction thresholds:

Voltage < 0.51 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

The Cylinder Head Temp Sensor uses a switchable input circuit to create two transfer functions for cold and hot range temperatures

CHT Temperature Sensor Transfer Function, Cold End		
Volts	A/D counts in PCM	Temperature, degrees F
4.899	1002	-40
4.861	995	-31
4.812	985	-22
4.75	972	-14
4.671	956	-4
4.572	936	4
4.452	911	14
4.309	882	22
4.14	847	32
3.95	808	40
3.737	765	48
3.508	717	58
3.26	666	68
3.00	614	77
2.738	560	87
2.478	507	96
2.226	455	105
1.985	406	114
1.759	360	122
1.551	317	132
1.362	279	141
1.193	244	149
1.043	213	159
0.91	186	168
0.794	162	176
0.693	142	186
0.604	124	194
0.528	108	203
0.462	95	204

CHT Temperature Sensor Transfer Function, Hot End		
Volts	A/D counts in PCM	Temperature, degrees F
4.235	866	168
4.119	843	168
3.993	817	176
3.858	789	185
3.714	760	194
3.563	729	203
3.408	697	212

3.244	664	221
3.076	629	230
2.908	595	239
2.740	561	248
2.575	527	257
2.411	493	266
2.252	461	275
2.099	430	284
1.953	400	294
1.813	371	303
1.680	344	312
1.556	318	320
1.439	294	329
1.329	272	338
1.228	251	347
1.133	232	356
1.046	214	366
0.965	197	375
0.891	182	383
0.822	168	392
0.760	155	401
0.701	144	408
0.648	133	415
0.599	123	422
0.555	113	428
0.513	105	433
0.476	97	438
0.441	90	442
0.409	84	447
0.380	78	450
0.353	72	454
0.328	67	457
0.306	63	460
0.285	58	463
0.265	54	465
0.248	51	468
0.231	47	470
0.216	44	472
0.202	41	474
0.190	39	475
0.178	36	477
0.167	34	478
0.156	32	480

## IAT Rationality Test

The IAT rationality test determines if the IAT sensor is producing an erroneous temperature indication within the normal range of IAT sensor input.

The IAT sensor rationality test is run only once per power-up. The IAT sensor input is compared to the CHT sensor input (ECT sensor input on some applications) at key-on after a long (6 hour) soak. If the IAT sensor input and the CHT (ECT) sensor input agree within a tolerance (+/- 30 deg F), no malfunction is indicated and the test is complete. If the IAT sensor input and the CHT (ECT) sensor input differ by more than the tolerance, the vehicle must be driven over 35 mph for 5 minutes to confirm the fault. This is intended to address noise factors like sun load that can cause the IAT sensor to indicate a much higher temperature than the CHT (ECT) sensor after a long soak. Driving the vehicle attempts to bring the IAT sensor reading within the test tolerance. If the IAT sensor input remains outside of the tolerance after the vehicle drive conditions have been met, the test indicates a malfunction and the test is complete.

In addition to the start-up rationality check, an IAT "Out of Range" check is also performed. The test continuously checks to see if IAT is greater than the "IAT Out of Range High threshold", approximately 150 deg F. In order to prevent setting false DTC during extreme ambient or vehicle soak conditions, the same count up/count down timer used for the IAT startup rationality test is used to validate the fault. If IAT is greater than 150 deg F and vehicle speed is greater than ~ 40 mph for 250 seconds then set a P0111.

Either the IAT startup rationality test or the IAT Out of Range High test can set a P0111 DTC. The logic is designed so that either fault can trigger a "two-in-a-row" P0111 MIL, however, both faults must be OK before the P0111 DTC is cleared.

Block heater detection results in a no-call.

Intake Air Temperature Sensor Range/Performance Check Operation:	
DTCs	P0111 (range/performance)
Monitor execution	Once per driving cycle, at start-up
Monitor Sequence	None
Sensors OK	ECT/CHT, IAT, VSS
Monitoring Duration	Immediate or up to 30 minutes to register a malfunction

Typical Intake Air Temperature Sensor Range/Performance Entry Conditions		
Entry condition	Minimum	Maximum
Engine off (soak) time	6 hours	
Battery Voltage	11.0 Volts	
Time since engine start (if driving req'd)		30 min
Vehicle speed (if driving req'd)	40 mph	
Time above minimum vehicle speed (if driving req'd)	5 min	
IAT - ECT at start (block heater inferred)	-30 °F	-90 °F

Typical IAT sensor check malfunction thresholds:
IAT and ECT/CHT error at start-up > +/-30 deg F

Intake Air Temperature Sensor Out of Range High Check Operation:	
DTCs	P0111 (Out of Range High)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	ECT/CHT, IAT, VSS
Monitoring Duration	250 seconds to register a malfunction

Typical Intake Air Temperature Sensor Out of Range high Entry Conditions		
Entry condition	Minimum	Maximum
Engine off (soak) time	6 hours	
Battery Voltage	11.0 Volts	
Vehicle speed	40 mph	
Time above minimum vehicle speed (if driving req'd)	5 min	

Typical IAT Sensor Out of Range High check malfunction thresholds:
IAT > 150 deg F

## AAT Rationality Test

The AAT rationality test determines if the AAT sensor is producing an erroneous temperature indication within the normal range of AAT sensor input.

The AAT sensor rationality test is run only once per power-up. The IAT sensor input is compared to the CHT sensor input (ECT sensor input on some applications) and the IAT sensor at key-on after a long (6 hour) soak. If the AAT sensor input, the CHT (ECT) sensor input and the IAT sensor input agree within a tolerance (+/- 30 deg F), no malfunction is indicated and the test is complete. If the AAT sensor input, the CHT (ECT) sensor input and IAT sensor input differ by more than the tolerance, the vehicle must be driven over 25 mph for 300 seconds to confirm the fault. This is intended to address noise factors like sun load that can cause the AAT sensor to indicate a higher temperature than the CHT (ECT) or IAT sensor after a long soak. Driving the vehicle attempts to bring the AAT sensor reading within the test tolerance. If the AAT sensor input remains outside of the tolerance after the vehicle drive conditions have been met, the test indicates a malfunction and the test is complete.

In addition to the start-up rationality check, an AAT "Out of Range" check is also performed. The test continuously checks to see if AAT is greater than the "AAT Out of Range High threshold", approximately 150 deg F. In order to prevent setting false DTC during extreme ambient or vehicle soak conditions, the same count up/count down timer used for the IAT startup rationality test is used to validate the fault. If IAT is greater than 150 deg F and vehicle speed is greater than ~ 10 mph for 300 seconds then set a P0071.

Either the IAT startup rationality test or the IAT Out of Range High test can set a P0111 DTC. The logic is designed so that either fault can trigger a "two-in-a-row" P0111 MIL, however, both faults must be OK before the P0111 DTC is cleared.

Block heater detection results in a no-call.

Ambient Air Temperature Sensor Range/Performance Check Operation:	
DTCs	P0071 - AAT Sensor Range/Performance
Monitor execution	Once per driving cycle, at start-up
Monitor Sequence	None
Sensors OK	ECT/CHT, IAT, VSS, P2610
Monitoring Duration	Immediate or up to 5 minutes to register a malfunction

Typical Ambient Air Temperature Sensor Range/Performance Entry Conditions		
Entry condition	Minimum	Maximum
Engine off (soak) time	6 hours	
Battery Voltage	11.0 Volts	
Time since engine start (if driving req'd)		30 min
Vehicle speed (if driving req'd)	25 mph	
Time above minimum vehicle speed (if driving req'd)	5 min	
IAT - ECT at start (block heater inferred)	-30 °F	-90 °F

Typical AAT sensor check malfunction thresholds:
AAT and IAT and ECT/CHT error at start-up > +/-30 deg F

Ambient Air Temperature Sensor Out of Range High Check Operation:	
DTCs	P0071 (Out of Range High)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	ECT/CHT, IAT, VSS, P2610
Monitoring Duration	300 seconds to register a malfunction

Typical Ambient Air Temperature Sensor Out of Range high Entry Conditions		
Entry condition	Minimum	Maximum
Engine off (soak) time	6 hours	
Battery Voltage	11.0 Volts	
Load		200%
Vehicle speed	10 mph	
Time above minimum vehicle speed (if driving req'd)	5 min	

Typical AAT Sensor Out of Range High check malfunction thresholds:
IAT > 150 deg F

## Fuel Rail Pressure Sensor

Fuel Rail Pressure Sensor Check Operation:	
DTCs	P0192 (low input), P0193 (high input)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	8 seconds to register a malfunction

Typical FRP sensor check malfunction thresholds:	
Voltage < 0.049 volts or voltage > 4.88 volts	

Fuel Rail Pressure Sensor Transfer Function		
FRP volts = [ Vref * ( 4 * Fuel Pressure / 70) + 0.50 ] / 5.00		
Volts	A/D counts in PCM	Pressure, psi
4.85	993	76.125
4.50	922	70
4.00	820	61.25
3.50	717	52.5
3.00	614	43.75
2.50	512	35
2.00	410	26.25
1.50	307	17.5
1.00	205	8.75
0.50	102	0
0.15	31	-6.125

The FRP range/performance test checks to make sure that fuel rail pressure can be properly controlled by the electronic returnless fuel system. The FPS sensor is also checked for in-range failures that can be caused by loss of Vref to the sensor. Note that the FRP is referenced to manifold vacuum (via a hose) while the fuel rail pressure sensor is not referenced to manifold vacuum. It uses gage pressure. As a result, a mechanical gage in the fuel rail will display a different pressure than the FPR PID on a scan tool. The scan tool PID will read higher because of manifold vacuum.

FRP Range/Performance Check Operation:	
DTCs	P0191 (FRP range/performance), P1090 (stuck in range)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	FRP
Monitoring Duration	8 seconds to register a malfunction

Typical FRP Sensor Range/Performance check entry conditions:		
Entry Condition	Minimum	Maximum
Demand pressure reasonable	35 psig	60 psig
Fuel level	15%	

Typical FRP Range/Performance check malfunction thresholds:		
Fuel pressure error (demand – actual pressure) > 20 psig		

Typical FRP Sensor Stuck check entry conditions:		
Entry Condition	Minimum	Maximum
FRP sensor input	0 psig	46 psig
FRP input not moving		1 psig / sec

Typical FRP Stuck check malfunction thresholds:		
Fuel pressure error (demand – actual pressure) > 5 psig		

## Mass Air Flow Sensor

The analog MAF sensor uses a hot wire sensing element to measure the amount of air entering the engine. Air passing over the hot wire causes it to cool. This hot wire is maintained at 200°C (392°F) above the ambient temperature as measured by a constant cold wire. The current required to maintain the temperature of the hot wire is proportional to the mass air flow. The MAF sensor then outputs an analog voltage proportional to the intake air mass.

The MAF sensor is located between the air cleaner and the throttle body or inside the air cleaner assembly. Most MAF sensors have integrated bypass technology with an integrated IAT sensor. The hot wire electronic sensing element must be replaced as an assembly. Replacing only the element may change the air flow calibration.

For the 2011 MY, some vehicles will use a digital MAF sensor, which outputs a frequency proportional to the intake air mass. The digital input low level driver software sets a flag to indicate that the frequency is out of range and a flag to indicate a high or low state. Low corresponds to 1.5 KHz and 6.6 kg/hr and high corresponds to 12 KHz and 982 kg/hr.

The Mass Air Flow sensor can produce values near zero when the engine has stalled or when the manifold empties during transient tip outs. The rpm logic is used to prevent setting a P0102 when the engine is stalling or during tip out conditions and the MAF reading is low but the sensor has not failed.

The 2017 MT Ford GT uses dual MAF sensors. This allows for a rationality test between sensors A and B.

P00BC - Mass or Volume Air Flow "A" Circuit Range/Performance - Air Flow Too Low

P00BD - Mass or Volume Air Flow "A" Circuit Range/Performance - Air Flow Too High

P00BE - Mass or Volume Air Flow "B" Circuit Range/Performance - Air Flow Too Low

P00BF - Mass or Volume Air Flow "B" Circuit Range/Performance - Air Flow Too High

MAF Sensor Check Operation:	
DTCs	Analog Sensor: P0102 (low input), P0103 (high input) Digital MAF Sensor A: P0100 (broken element), P0102 (low input), P0103 (high input), P0104 (intermittent) Digital MAF Sensor B: P010A (broken element), P010C (low input), P010D (high input), P010E (intermittent)
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	not applicable
Monitoring Duration	5 seconds to register a malfunction

Typical MAF Sensor check entry conditions:		
Entry Condition	Minimum	Maximum
P0100		
Time since last PIP edge (engine has not stalled)		
P0102		
Time since last PIP edge (engine has not stalled)		150 msec
Engine rpm	Base idle speed – 25 rpm	
Relative throttle position	1 degree	
P0103		
Engine rpm		6000 rpm

Typical MAF sensor check malfunction thresholds:	
Analog Sensor:	
P0102 - Voltage < 0.244 volts and engine running	
P0103 - Voltage > 4.785 volts engine rpm < 4,000 rpm	
Digital Sensor:	
P0100 – MAF sensor signal period > 1300 microseconds (< 0.78 kHz) for > 1 sec	
P0102 - MAF sensor signal period > 658 microseconds (< 1.5 kHz) for > 1 sec	
P0103 - MAF sensor signal period < 83 microseconds (> 0.78kHz) for > 1 sec	
P0104 – MAF sensor open/shorted > 25 occurrences	

## Manifold Absolute Pressure Sensor

The MAP (Manifold Absolute Pressure) sensor provides a voltage proportional to the absolute pressure in the intake manifold using a piezo-resistive silicon sensing element. The pressure sensor is typically mounted into a port on the engine intake manifold.

In the 2014 MY, some vehicles will be using MAP sensor in place of a MAF sensor for airflow measurement. 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 Transfer Function		
$V_{out} = (V_{ref} / 5) * 0.0409523809 * \text{Pressure (in kPa)} + -0.1095238095$		
Volts	Pressure, kPa	Pressure, Inches Hg
0.30	10.0	2.59
0.38	12.0	3.54
1.00	27.0	7.97
2.35	60.0	17.72
3.37	85.0	25.10
4.48	112.0	33.07
4.60	115.0	33.96

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 < 0.19 volts or voltage > 4.88 volts

## MAF/MAP - TP Rationality Test

The MAF or MAP and TP sensors are cross-checked to determine whether the sensor readings are rational and appropriate for the current operating conditions. (P0068) The test uses the calculated load value (LOAD) which can be computed from MAF for a mass air flow system or from MAP for a speed density system.

MAF/TP Rationality Check Operation:	
DTCs	P0068 - MAP / MAF - Throttle Position Correlation
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	3 seconds within test entry conditions

Typical MAF/TP rationality check entry conditions:		
Entry Condition	Minimum	Maximum
Engine RPM	550 rpm	minimum of 5000 rpm
Engine Coolant Temp	150 °F	

Typical MAF/TP rationality check malfunction thresholds:
Load > 60% and TP < 2.4 volts or Load < 30% and TP > 2.4 volts

## Miscellaneous CPU Tests

Loss of Keep Alive Memory (KAM) power (a separate wire feeding the PCM) results is a P1633 DTC and immediate MIL illumination. (Used for those modules that use KAM.)

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

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. (Used for those modules that use KAM.)

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.

P0610 - Powertrain Control Module indicates that one or more of the VID Block fields were configured incorrectly.

P068A - ECM/PCM Power Relay De-energized - Too Early. This fault indicates that NVRAM write did not complete successfully after the ignition key was turned off, prior to PCM shutdown.

P06B8 - Internal Control Module Non-Volatile Random Access Memory (NVRAM) Error indicates Permanent DTC check sum test failed

U0101 - Lost Communication with Transmission Control Module (for vehicles with standalone TCM)

P1934 – Lost Vehicle Speed Signal from ABS Module

## Engine Off Timer Monitor

The engine off timer is either implemented in a hardware circuit in the PCM or is obtained via a CAN message from the Body Control Module.

If the timer is implemented in the PCM, the following applies:

There are two parts to the test. The first part determines that the timer is incrementing during engine off. The test compares ECT prior to shutdown to ECT at key-on. The ECT has cooled down more than 30 deg F and the engine had warmed up to at least 160 deg F prior to shutdown, then an engine off soak has occurred. If the engine off timer indicates a value less than 30 sec, then the engine off timer is not functioning and a P2610 DTC is set.

The second part looks at the accuracy of the engine off timer itself. The timer in the satellite chip is allowed to count up for 5 minutes with the engine running and compared to a different clock in the main microprocessor. If the two timers differ by more than 15 sec (5%), a P2610 DTC is set.

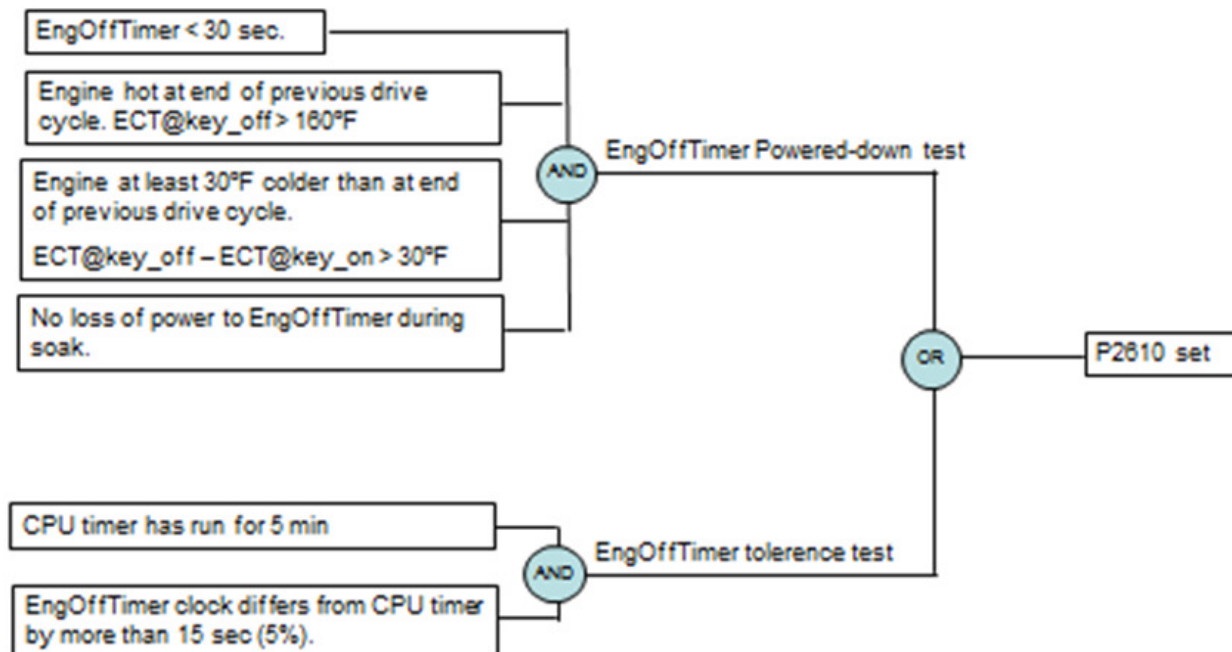
If engine off time is obtained from the BCM, the following applies. There are multiple parts to the test:

The PCM expects to get a CAN message with the engine off time from BCM shortly after start. If the engine off time is not available because of a battery disconnect, the CAN message is set to FFFFh and a U0422 is set (Invalid Data Received from BCM).

If the CAN message with engine off time is not available, a P2610 DTC is set and a U0140 is set (Lost Communication with BCM).

As above, the next part determines that the timer is incrementing during engine off. The test compares ECT prior to shutdown to ECT at key-on. The ECT has cooled down more than 30 deg F and the engine had warmed up to at least 160 deg F prior to shutdown, then an engine off soak has occurred. If the engine off timer indicates a value less than 30 sec, then the engine off timer is not functioning and a P2610 DTC is set.

The last part looks at the accuracy of the engine off timer itself. The timer in the BCM (Global Real Time) is sampled for 5 minutes with the engine running and compared to the clock in the main microprocessor. If the two timers differ by more than 15 sec (5%), a P2610 DTC is set.



Engine Off Timer Check Operation:	
DTCs	P2610
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	Immediately on startup or after 5 minutes

Typical Engine Off Timer check malfunction thresholds:	
Engine off time < 30 seconds after inferred soak	
Engine off timer accuracy off by > 15 sec.	
Engine off time CAN message missing at startup	

**5 Volt Sensor Reference Voltage A Check:**

DTCs	P0642 - Sensor Reference Voltage "A" Circuit Low P0643 - Sensor Reference Voltage "A" Circuit High
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 sec to register a malfunction

**Typical 5 Volt Sensor Reference Voltage A check entry conditions:**

Entry Condition	Minimum	Maximum
Ignition "ON"	NA	NA

**Typical 5 Volt Sensor Reference Voltage A check malfunction thresholds:**P0642

Short to ground (signal voltage): &lt; 4.75 V

P0643

Short to battery plus (signal voltage): &gt; 5.25 V

**5 Volt Sensor Reference Voltage A/B/C Check:**

DTCs	P06A6 - Sensor Reference Voltage "A" Circuit Range/Performance P06A7 - Sensor Reference Voltage "B" Circuit Range/Performance P06A8 - Sensor Reference Voltage "C" Circuit Range/Performance
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	0.5 sec to register a malfunction

**Typical 5 Volt Sensor Reference Voltage A/B/C check entry conditions:**

Entry Condition	Minimum	Maximum
Ignition "ON"	NA	NA

**Typical 5 Volt Sensor Reference Voltage A/B/C check malfunction thresholds:**P0646, P0647, P06A8 (used for Bosch Tricore modules)

Reference voltage: &lt; 4.7 V or reference voltage: &gt; 5.2 V

## Central Vehicle Configuration

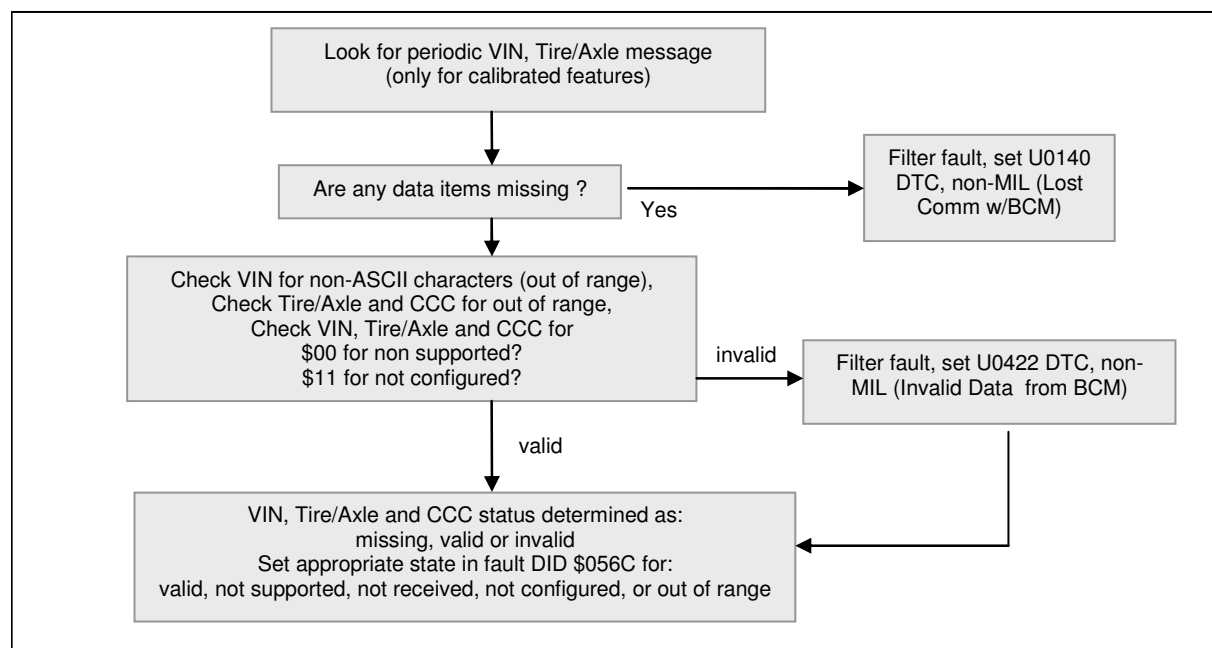
On some applications, the Body Control Module (BCM) transmits VIN, Tire Circumference, Axle Ratio and Cruise Control Configuration (CCC) over the vehicle CAN network to the ECM/PCM as well as to other modules in the vehicle that use this information. Valid data received by the ECM/PCM is stored into NVRAM. This feature is known as Central Vehicle Configuration.

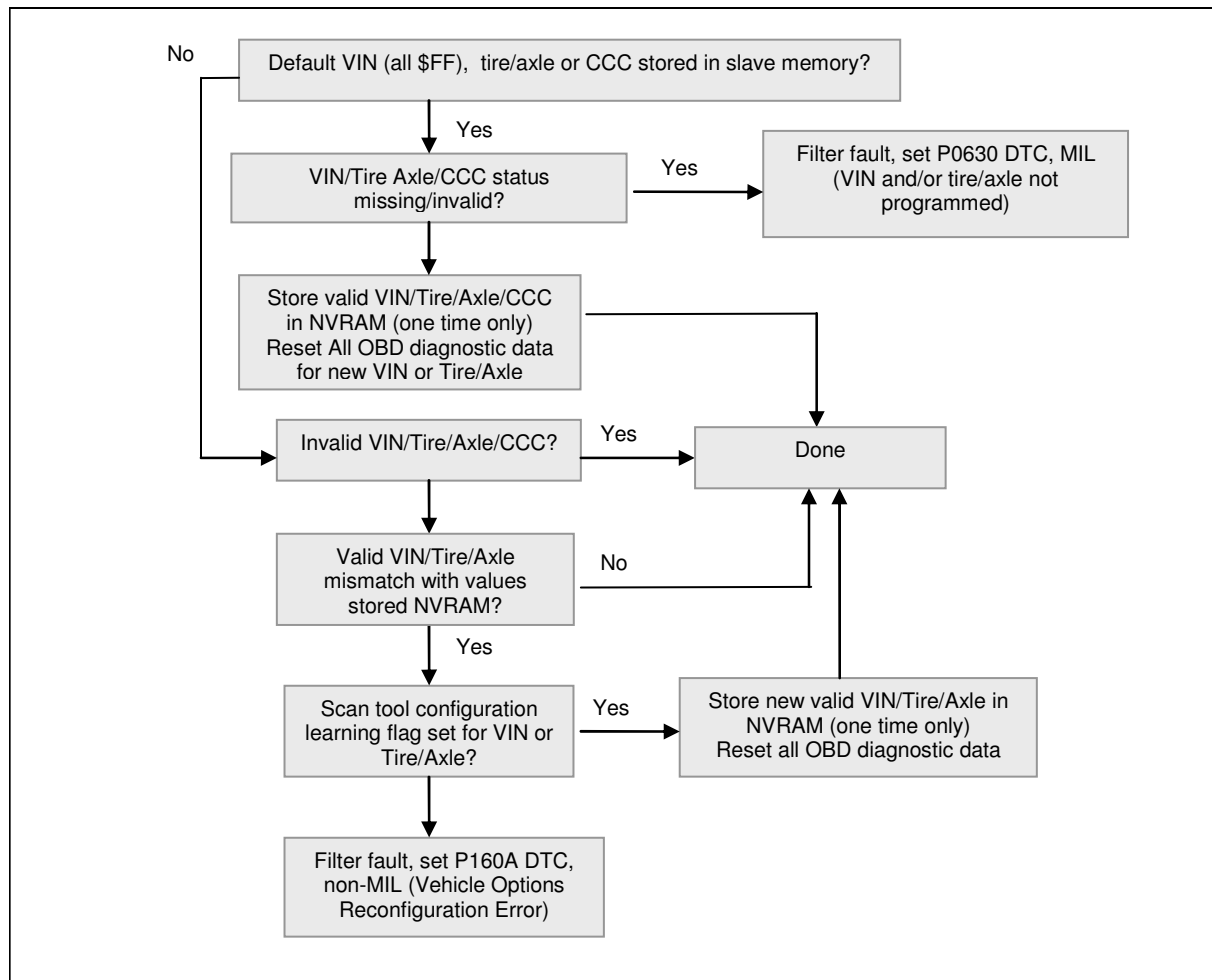
CAN messages with this data are sent every time the vehicle is started. If the CAN messages are not received after start, a U0140 (Lost Communication with BCM) DTC is set. Next, the data is checked to ensure that it is in a valid range. If the VIN, tire, axle or CCC are not in a valid range, a U0422 (Invalid Data received from BCM) DTC is set.

The system is designed to automatically accept valid VIN, tire, axle and CCC data if only the default data (\$FF) is stored. If the default VIN, tire and axle are not replaced with valid data at the vehicle assembly plant or after service, a P0630 (VIN and/or tire/axle not programmed) DTC is set and the MIL is illuminated.

Once the PCM has valid VIN, tire, axle and CCC data, and new data is received which does not match the currently stored data, the new data is not stored into NVRAM. If there is a data mismatch, a P160A (Vehicle Options Reconfiguration Error) DTC is set. The new data will not be accepted unless a service tool is used to execute a "learn" command. This allows a service technician to ensure that the vehicle uses the proper configuration data after a BCM or PCM repair. Once a "learn" command is executed, the PCM will accept the next valid VIN, tire, axle and CCC data, store it into NVRAM, and perform an OBD-II code clear which resets all diagnostic data.

The flow charts on the following pages describe the process.





## Ignition System Tests

New floating point processors no longer use an EDIS chip for ignition signal processing. The crank and cam position signals are now directly processed by the PCM/ECM microprocessor using a special interface called a Time Processing Unit or TPU, or General Purpose Time Array (GPTA), depending on the PCM/ECM. The signals to fire the ignition coil drivers also come from the microprocessor.

Historically, Ford has used a 36-1 tooth wheel for crankshaft position (40-1 on a V-10). Many engines still use a 36-1 wheel; however, some new engines are migrating to a 60-2 tooth wheel for crankshaft position. This was done to commonize ignition hardware and allow Ford to use some industry-standard PCM/ECM designs. 60-2 tooth crank wheels are being used on the 2011/2012 MY 2.0L GDI and GTDI engines, 1.6L GTDI engines and the 3.5L TIVCT GTDI engine.

Over the years, Ford ignition system have migrated away from Distributorless Ignition Systems (DIS) where a given coil pack fires two spark plugs at the same time (one spark plug fires during the compression stroke, the other spark plug fires during the exhaust stroke). All new engine now use Coil On Plug (COP) systems where there is an ignition coil and a coil driver for each spark plug, thus eliminating the need for secondary spark plug wires and improving reliability. Historically, Ford located the ignition coil drivers within the PCM/ECM, however, some new engines are migrating to coils where the driver is located on the coil itself. This eliminates the high current lines going from the PCM to the coils and again, commonizes ignition hardware to allow Ford to use some industry-standard PCM/ECM designs.

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

CKP, the signal from the crankshaft 36-1 or 60-2 tooth wheel. The missing tooth is used to locate the cylinder pair associated with cylinder # 1. The microprocessor also generates the Profile Ignition Pickup (PIP) signal, a 50% duty cycle, square wave signal that has a rising edge at 10 deg BTDC for 36-1 systems and 12 deg BTDC for 60-2 systems.

Camshaft Position (CMP), a signal derived from the camshaft to identify the #1 cylinder

Coil primary current (driver in module ignition systems). The NOMI signal 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 microprocessor. 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).

Coil driver circuit current and/or voltage (driver on coil ignition systems). The PCM/ECM coil driver IC checks for out of range current and voltage levels at the coil driver output that would indicate an open or short circuit fault. The fault could be located anywhere in the coil driver circuit: PCM/ECM, wiring harness, coil connector, or the driver circuit on the ignition coil. (Note this does not include the primary side windings. Faults in the primary side windings must be detected by the Misfire Monitor for driver on coil ignition systems).

First, several relationships are checked on the CKP signal. The microprocessor looks for the proper number of teeth (35 or 39 or 58) 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 microprocessor shuts off fuel and the ignition coils and attempts to resynchronize itself. It takes one revolution to verify the missing tooth, and another revolution to verify cylinder #1 using the CMP input. Note that if a P0320 or P0322 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 microprocessor checks the CMP signal for an intermittent signal by looking for CMP edges where they would not be expected to be. 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, for driver in module ignition systems, 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 Ignition Engine Speed Input Circuit P0322 Ignition Engine Speed Input Circuit No Signal P0339 Crankshaft Position Sensor "A" Circuit Intermittent P0335 Crankshaft Position Sensor "A" Circuit
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	500 rpm	

Typical CKP ignition check malfunction thresholds:
<p>P0320 or P0339:</p> <p>Incorrect number of teeth after the missing tooth is recognized, time between teeth too low (&lt; 30 rpm or &gt; 9,000 rpm), missing tooth was not where it was expected to be.</p> <p>P0322 or P0335:</p> <p>Camshaft indicates &gt; 1 engine revolution while crankshaft signal missing</p>

**CMP Ignition System Check Operation:**

DTCs	P0340 - Intake Cam Position Circuit, Bank 1 P0344 – Intake Cam Position Circuit Intermittent, Bank 1 P0345 - Intake Cam Position Circuit, Bank 2 P0349 – Intake Cam Position Circuit Intermittent Bank 2 P0365 - Exhaust Cam Position Circuit, Bank 1 P0369 – Intake Cam Position Circuit Intermittent, Bank 1 P0390 - Exhaust Cam Position Circuit, Bank 2 P0394 – Exhaust Cam Position Circuit Intermittent Bank 2
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:**

Ratio of PIP events to CMP events: 4:1, 6:1, 8:1 or 10:1 based on engine cyl.  
Intermittent CMP signal – CMP signal in unexpected location

**Coil Primary Ignition System Check Operation:**

DTCs	P0351 – P0360 (Coil primary)  P2300, P2303, P2306, P2309, P2312, P2315, P2318, P2321, P2324, P2327 (Coil driver short circuit low)  P2301, P2304, P2307, P2310, P2313, P2316, P2319, P2322, P2325, P2328 (Coil driver short circuit high)  P06D1 (Internal control module ignition coil control module performance)
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	< 1 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	
Battery Voltage	11 volts	16 volts

**Typical Coil primary ignition check malfunction thresholds:**

P035x (driver in module Ignition systems):

Ratio of PIP events to IDM or NOMI events 1:1

P035x, P23xx (driver on coil Ignition systems):

Coil driver circuit current and/or voltage out of range of open and short circuit limits.

P06D1 (driver on coil Ignition systems):

Missing communication from coil driver IC.

If an ignition coil primary circuit failure is detected for a single cylinder or coil pair, the fuel injector to that cylinder or cylinder pair 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. After 30 seconds, the injector is re-enabled. If an ignition coil primary circuit failure is again detected, (about 0.10 seconds), the fuel injector will be shut off again and the process will repeat until the fault is no longer present. Note that engine misfire can trigger the same type of fuel injector disablement.

## Knock Sensor

Due to the design of the knock sensor input circuitry, a short to battery, short to ground, or open circuit all result in a low knock signal voltage output. This output voltage is compared to a noise signal threshold (function of engine rpm and load) to determine knock sensor circuit high, circuit low or performance faults.

Some PCM/ECM modules use a driver circuit that will periodically and actively test the knock sensor lines for short circuit faults. In these modules, supplemental codes can be set for the short circuit condition. Some PCM/ECM modules use a standalone Knock IC. In these modules, the knock signal processing chip SPI bus is checked for proper communication between the main processor and the chip used as the interface the knock sensor.

The P130D code is associated with the "Low Speed Pre-Ignition" or "Mega Knock" strategy. Mega Knock is a phenomena present on GTDI engines during boosted operation. It is much more audible than normal engine knock and generates higher cylinder pressures that can result in the potential for engine damage. It tends to occur at lower engine speeds (< 3000 rpm) but may also occur at higher speeds. It tends to be an infrequent and random event. When it occurs, it may occur as a single event or as a burst event with multiple occurrences in rapid succession on the same cylinder. The code is set if the Mega Knock detection rate is too high.

Knock Sensor Check Operation:	
DTCs	P0325 – Knock Sensor 1 Circuit P0330 – Knock Sensor 2 Circuit P0327 – Knock Sensor 1 Circuit Low P0328 – Knock Sensor 1 Circuit High P0332 – Knock Sensor 2 Circuit Low P0333 – Knock Sensor 2 Circuit High P06B6 – Lost Comm with Knock IC Chip P130D – Engine Knock / Combustion Performance – Forced Limited Power
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Sensors OK	Not in failsafe cooling mode
Monitoring Duration	2.5 seconds

Typical Knock Sensor check entry conditions:		
Entry Condition	Minimum	Maximum
Time since engine start (function of ECT)	60 to 20 sec	
Engine Coolant Temperature	140 °F	
Engine load (circuit codes)	35%	
Engine load (Mega Knock codes)	90%	
Engine speed (circuit codes)	1500 rpm	6000 rpm
Engine speed (Mega Knock codes)	1000 rpm	4000 rpm

**Typical Knock Sensor functional check malfunction thresholds:**

P0325 & P0330 Knock signal too low (function of engine speed): < 30 to 150 A/D counts (out of 255)

P0327, P0332 (used only for PCM/ECM with corresponding diagnostic circuit)

Voltage level from active knock sensor circuit probe below limit

P0328, P0333 (used only for PCM/ECM with corresponding diagnostic circuit)

Voltage level from active knock sensor circuit probe above limit

P06B6 (used only for PCM/ECM with standalone Knock IC)

Cylinder events with missing communication from Knock IC > 200

P130D Mega Knock detection rate too high: > 10 Mega Knock events within span of several thousand combustion events.

## Engine Oil System Components

### Engine Oil Pressure (EOP) Switch

The EOP switch is widely used on many applications. The switch is utilized on applications equipped with conventional oil pump; however, selectively it is used for variable oil pump system products as well. The EOP switch is an on/off switch that turns on the 'Low Oil Pressure Lamp' on the instrument cluster whenever oil pressure is less than 6 psi (~41 kPa). No DTC for low oil pressure is set.

### Engine Oil Pressure (EOP) Sensor

The EOP sensor has been introduced in order to provide feedback for the Variable Oil Pump which is used to control oil pressure in the engine. Unlike the EOP switch, the EOP sensor provides a voltage proportional to the actual oil pressure in one of the oil galleries. The location of the EOP sensor varies, but it is usually mounted near the oil pump or the oil filter. The EOP sensor is continuously monitored for circuit faults by monitoring the input voltage. A rationality check is performed using calculated average pressures during engine off and engine running conditions. Any detected sensor fault illuminates the 'Low Oil Pressure' Warning Lamp on the instrument cluster and will initiate PTLP (Powertrain Limiting Protection) modes to protect the engine.

EOP Sensor Transfer Function		
$V_{out} = (V_{ref}) * (0.0008 * \text{Pressure (in kPa)} + 0.10)$		
Volts	Pressure, kPa	Pressure, psi
0.500	0	0
0.660	40	5.80
0.820	80	11.60
0.980	120	17.40
1.140	160	23.21
1.300	200	26.11
1.460	240	34.81
1.620	280	40.61
1.780	320	46.41
1.940	360	52.21
2.100	400	58.02
2.260	440	63.82
2.420	480	69.62
2.580	520	75.42
2.740	560	81.22
2.900	600	87.02
3.060	640	92.82
3.220	680	98.63
3.380	720	104.43
3.700	800	116.03
4.020	880	127.63
4.340	960	139.24
4.420	980	142.14
4.500	1000	145.04

<b>EOP Sensor Circuit Check Operation:</b>	
DTCs	Analog Sensor P0522: Engine Oil Pressure Sensor "A" Circuit Low P0523: Engine Oil Pressure Sensor "A" Circuit High
Monitor Execution	Continuous
Monitor Sequence	None
Sensors OK	Not applicable
Monitoring Duration	5 seconds to register a malfunction

<b>EOP Sensor Circuit Check Entry Conditions:</b>
Battery voltage > 11.0 volts

<b>Typical EOP Sensor Circuit Check Malfunction Thresholds:</b>
Voltage < 0.43 volts or voltage > 3.40 volts

## **EOP Sensor Rationality Test**

The EOP sensor is checked to determine whether the sensor reading is rational for the current operating conditions. If the sensor reading is too high when engine is not running or the difference between engine running and engine off oil pressure is too small, a DTC is set. Since the sensor stuck high test can only run when the engine is not running, monitor collects oil pressure samples whenever possible, such as when the PCM is powered up, the key is on, or after engine has shut down. The sensor stuck in-range test runs and makes the pass/fail determination once per drive cycle. Since the test requires both engine running and engine off oil pressure samples, the monitor determination is made either during engine start or after engine shut down.

<b>EOP Sensor Rationality Check Operation:</b>	
DTCs	P0521: Engine Oil Pressure Sensor "A" Range/Performance
Monitor Execution	Stuck High: Once (up to three times) per driving cycle Stuck In-range: Once per driving cycle
Monitor Sequence	None
Sensors OK	EOP
Monitoring Duration for Stuck High	Stuck High: When first valid engine-off average pressure value is available Stuck In-range: When first valid engine-off and engine-on average pressure values are available

## Engine Oil Pressure Out of Range Test

The pressure of the engine oil is monitored to ensure proper engine operation and avoid engine damage. If abnormal engine oil pressure is observed with a properly functioning EOP sensor, then an appropriate DTC (either P0524 or P055F) is set and a FMEM (Failure Mode Effective Management) action is invoked.

If the oil pressure does not increase sufficiently when the engine starts, a P0524 DTC is set. In addition, during engine operation, if the oil pressure drops below the minimum level required for internal engine protection for a calibrated period of time (normally, 5 seconds), or if the oil pressure indicated by the sensor is substantially lower than modelled oil pressure, or if there is insufficient oil pressure to operate the Variable Cam Timing system, then a P0524 is set. If oil pressure exceeds a maximum level for a calibrated period of time, (normally, 5 seconds), then a P055F is set.

Engine Oil Pressure (EOP) Check Operation:	
DTCs	P0524 - Engine Oil Pressure Too Low P055F - Engine Oil Pressure Out Of Range (Too High)
Monitor Execution	Continuous
Monitor Sequence	None
Sensors OK	EOP, EOT, ECT
Monitoring Duration	0~20 seconds to register a malfunction, depending on fault types

## Oil Pressure Control Solenoid

A conventional mechanical oil pump is connected to and driven by the crankshaft and produces oil pressure proportional to engine speed. The Variable Oil Pump (VOP) is capable of varying its output oil pressure as necessary. The Oil Pressure Control Solenoid, also known as Variable Oil Pump Control (VOPC), is a solenoid that controls the output of the Variable Oil Pump.

There are two VOP systems currently being used. They are (1) a two-stage pressure system and (2) continuous variable pressure system. The two-stage pressure system provides two pressure modes, low and high. The continuous variable pressure system directly controls output pressure based on commands from the Variable Oil Pump Control (VOPC) solenoid.

There are currently two different hardware configurations currently in use for these two systems. They are (1) Variable Displacement Oil Pump (VDOP) which controls the oil pump directly and (2) Active Oil Filter Adapter (AOFA) which controls the oil drain system.

The VDOP adjusts the pump's displacement using a moveable slide that controls the filling and draining of the oil in the reservoir via two ports in the pump. The oil pressure control solenoid controls the amount of oil filling by partially or completely opening and closing the passage. The AOFA consists of a conventional oil pump and a separate oil bypass line. The oil pressure control solenoid opens and closes a bypass line which allows oil to drain back to the sump. The VDOP can be configured to operate as both a two-stage pressure system as well as a continuous variable pressure system; however, the AOFA can only be used for a two-state pressure system. Regardless of pump and system types, the actual solenoid hardware is identical.

The Variable Oil Pump Control (VOPC) solenoid is continuously monitored for circuit faults by the smart output driver. If a fault is detected the appropriate DTC is set. In addition, a functional check is performed to determine whether the oil control solenoid is stuck.

Oil Pressure Control Solenoid Circuit Check:	
DTCs	P06DA – Engine Oil Pressure Control Circuit/Open P06DB – Engine Oil Pressure Control Circuit Low P06DC – Engine Oil Pressure Control Circuit High
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	Not applicable
Monitoring Duration	5 seconds

Typical Oil Control Solenoid Circuit Check Entry Conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

Typical Oil Control Solenoid Circuit Check Malfunction Thresholds:	
P06DA/P06DB/P06DC - Smart driver reports output circuit fault.	

Oil Pressure Control Solenoid Functional Check:	
DTC	P06DD – Engine Oil Pressure Control Performance/Stuck Off
Monitor execution	2 stage: On pressure mode (Hi/Lo) change Continuous variable: Continuous
Monitor Sequence	None
Sensors/Actuators OK	EOP, EOT
Monitoring Duration	2 stage: < 1 seconds to register a malfunction Continuous variable: 5 seconds

Typical Oil Control Solenoid Functional Check Entry Conditions:		
Entry Condition	Minimum	Maximum
Time since engine start	30 seconds	

## Engine Oil Temperature (EOT) Sensor

The Engine Oil Temperature (EOT) sensor measures the temperature of engine oil circulating through the oil gallery. Although the location of the sensor varies, usually it is located nearby the oil pump, mounted on the engine, along with the engine oil pressure sensor. The EOT sensor is checked for any circuit faults by monitoring the input voltage and checked for rationality by comparing the measure EOT value against an inferred EOT value. If any fault is detected during two contiguous trips, then the fault will be indicated.

EOP Sensor Transfer Function		
Volts	Temperature, degrees F	Temperature, degrees C
4.886	-40	-40
4.845	-31	-35
4.792	-22	-30
4.640	-4	-20
4.409	14	-10
4.084	32	0
3.664	50	10
3.173	68	20
2.650	86	30
2.142	104	40
1.685	122	50
1.299	140	60
0.994	158	70
0.757	176	80
0.577	194	90
0.441	212	100
0.339	230	110
0.262	248	120
0.205	266	130
0.161	284	140
0.143	293	145
0.128	302	150

EOT Sensor Circuit Check Operation:	
DTCs	Analog Sensor P0197: Engine Oil Temperature Sensor "A" Circuit Low P0198: Engine Oil Temperature Sensor "A" Circuit High
Monitor Execution	Continuous
Monitor Sequence	None
Sensors OK	Not applicable
Monitoring Duration	5 seconds to register a malfunction

**EOT Senor Circuit Check Entry Conditions:**

Battery voltage > 11.0 volts

**Typical EOT Sensor Circuit Check Malfunction Thresholds:**

Voltage < 0.16 volts or Voltage > 4.93 volts

**EOT Sensor Rationality Test**

The EOT sensor value is continuously compared to an inferred EOT value to determine whether the sensor reading is rational and appropriate for the current condition. If a discrepancy between the sensor value and the inferred value is observed, a P0196 DTC is set. In addition, the EOT value is checked during KOER self-test. An out of range sensor sets a P1184 DTC.

**EOT Sensor Rationality Check Operation:**

DTCs	P0196: Engine Oil Pressure Sensor "A" Range/Performance P1184: Engine Oil Temperature Sensor Out Of Self Test Range
Monitor Execution	P0196: Continuous P1184: As requested
Monitor Sequence	None
Sensors OK	ECT
Monitoring Duration	Usually 5 seconds to register a malfunction

## Engine Outputs

The Idle Air Control (IAC) system is functionally checked by monitoring the closed loop idle speed correction required to maintain the desired idle rpm. If the proper idle rpm cannot be maintained and the system has a high rpm (+200) or low rpm error (-100) greater than the malfunction threshold, an IAC malfunction is indicated. (P0507, P0506)

IAC Check Operation:	
DTCs	P0507 (functional - overspeed) P0506 (functional - underspeed)
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	15 seconds

Typical IAC functional check entry conditions:		
Entry Condition	Minimum	Maximum
Engine Coolant Temp	150 °F	
Time since engine start-up	30 seconds	
Closed loop fuel	Yes	
Throttle Position (at idle, closed throttle, no dashpot)	Closed	Closed

Typical IAC functional check malfunction thresholds:	
For underspeed error: Actual rpm 100 rpm below target, closed-loop IAC correction > 1 lb/min	
For overspeed error: Actual rpm 200 rpm above target, closed-loop IAC correction < .2 lb/min	

The PCM monitors 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 P0210 (opens/shorts)
Monitor execution	Continuous within entry conditions
Monitor Sequence	None
Monitoring Duration	5 seconds

Typical injector circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

## Electronic Returnless Fuel System

Electronic Returnless Fuel Systems (ERFS) utilize a Fuel Pump Driver Module (FPDM) to control fuel pressure. The PCM uses a Fuel Rail Pressure Sensor (FRP) for feedback. The PCM outputs a duty cycle to the FPDM to maintain the desired fuel rail pressure. During normal operation, the PCM will output a FP duty cycle from 5% to 51%. The FPDM will run the fuel pump at twice this duty cycle, e.g. if the PCM outputs a 42% duty cycle, the FPDM will run the fuel pump at 84%. If the PCM outputs a 75% duty cycle, the FPDM will turn off the fuel pump.

The FPDM returns a duty cycled diagnostic signal back to the PCM on the Fuel Pump Monitor (FPM) circuit to indicate if there are any faults in the FPDM.

If the FPDM does not output any diagnostic signal, (0 or 100% duty cycle), the PCM sets a P1233 DTC. This DTC is set if the FPDM loses power. This can also occur if the Inertia Fuel Switch is tripped.

If the FPDM outputs a 25% duty cycle, it means that the fuel pump control duty cycle is out of range. This may occur if the FPDM does not receive a valid control duty cycle signal from the PCM. The FPDM will default to 100% duty cycle on the fuel pump control output. The PCM sets a P1235 DTC.

If the FPDM outputs a 75% duty cycle, it means that the FPDM has detected an open or short on the fuel pump control circuit. The PCM sets a P1237 DTC.

If the FPDM outputs a 50% duty cycle, the FPDM is functioning normally.

Fuel Pump Driver Module Check Operation:	
DTCs	P1233 – FPDM disabled or offline P1235 – Fuel pump control out of range P1237 – Fuel pump secondary circuit
Monitor execution	Continuous, voltage > 11.0 volts
Monitor Sequence	None
Monitoring Duration	3 seconds

## Mechanical Returnless Fuel System (MRFS) — Single Speed

An output signal from the PCM is used to control the electric fuel pump. The PCM grounds the FP circuit, which is connected to the coil of the fuel pump relay. This energizes the coil and closes the contacts of the relay, sending B+ through the FP PWR circuit to the electric fuel pump. When the ignition is turned on, the electric fuel pump runs for about 1 second and is turned off by the PCM if engine rotation is not detected.

The FPM circuit is spliced into the fuel pump power (FP PWR) circuit and is used by the PCM for diagnostic purposes. With the fuel pump on and the FPM circuit high, the PCM can verify the FP PWR circuit from the fuel pump relay to the FPM splice is complete. It can also verify the fuel pump relay contacts are closed and there is a B+ supply to the fuel pump relay.

## Mechanical Returnless Fuel System (MRFS) — Dual Speed

The FP signal is a duty cycle command sent from the PCM to the fuel pump control module. The fuel pump control module uses the FP command to operate the fuel pump at the speed requested by the PCM or to turn the fuel pump off. A valid duty cycle to command the fuel pump on, is in the range of 15-47%. The fuel pump control module doubles the received duty cycle and provides this voltage to the fuel pump as a percent of the battery voltage. When the ignition is turned on, the fuel pump runs for about 1 second and is requested off by the PCM if engine rotation is not detected.

**FUEL PUMP DUTY CYCLE OUTPUT FROM PCM**

FP Duty Cycle Command	PCM Status	Fuel Pump Control Module Actions
0-15%	Invalid off duty cycle	The fuel pump control module sends a 20% duty cycle signal on the fuel pump monitor (FPM) circuit. The fuel pump is off.
37%	Normal low speed operation.	The fuel pump control module operates the fuel pump at the speed requested. The fuel pump control module sends a 60% duty cycle signal on FPM circuit.
47%	Normal high speed operation.	The fuel pump control module operates the fuel pump at the speed requested. The fuel pump control module sends a 60% duty cycle signal on FPM circuit.
51-67%	Invalid on duty cycle.	The fuel pump control module sends a 20% duty cycle signal on the FPM circuit. The fuel pump is off.
67-83%	Valid off duty cycle	The fuel pump control module sends a 60% duty cycle signal on FPM circuit. The fuel pump is off.
83-100%	Invalid on duty cycle.	The fuel pump control module sends a 20% duty cycle signal on the FPM circuit. The fuel pump is off.

The fuel pump control module communicates diagnostic information to the PCM through the FPM circuit. This information is sent by the fuel pump control module as a duty cycle signal. The 5 duty cycle signals that may be sent are listed in the following table. Some vehicles, e.g. the 5.2L Mustang, use two fuel pump control modules to supply enough fuel to the engine. The fuel pump modules are the same, there are simply two of them ("A" and "B"). The second pump uses a different set of DTCs for the same set of faults. Both pumps are driven by the same PCM output.

## FUEL PUMP CONTROL MODULE DUTY CYCLE SIGNALS

Duty Cycle	Comments
20%	This duty cycle indicates the fuel pump control module is receiving an invalid duty cycle from the PCM.
30%	This duty cycle indicates a pump driver module (PEM) internal error. This status is applicable only to Omron Gen.II or higher modules.
40%	For vehicles with event notification signal, this duty cycle indicates the fuel pump control module is receiving an invalid event notification signal from the RCM. For vehicles without event notification signal, this duty cycle indicates the fuel pump control module is functioning normally.
60%	For vehicles with event notification signal, this duty cycle indicates the fuel pump control module is functioning normally.
80%	This duty cycle indicates the fuel pump control module is detecting a concern with the secondary circuits.

### MRFS Check Operation:

DTCs	P025A – Fuel Pump A Control Circuit (opens/shorts) P025B – Invalid Fuel Pump A Control Data (20% duty cycle from FPM) P0627 – Fuel Pump A Secondary Circuit (80% duty cycle from PFM) P064A – Fuel Pump A Driver Module Internal Error (30% duty cycle from PFM) U2010B – Fuel Pump A Disabled Circuit (40% duty cycle from FPM) U0109 – Loss of Communication with Fuel Pump Module A
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	2 seconds

### Typical MRFS check entry conditions:

Entry Condition	Minimum	Maximum
Battery Voltage	11 volts	

### Typical MRFS check malfunction thresholds:

P025A - Smart Fuel Pump output driver in PCM/ECM indicates fault  
P025B - Fuel Pump Monitor duty cycle feedback of 20%  
P0627 – Fuel Pump Monitor duty cycle feedback of 80%  
P064A – Fuel Pump Monitor duty cycle feedback of 30%  
U210B – Fuel Pump Monitor duty cycle feedback of 40%  
U0191 - No Fuel Pump Monitor duty cycle feedback (i.e. 0% or 100% duty cycle)

MRFS Check Operation:	
DTCs	P025A – Fuel Pump A/B Control Circuit (opens/shorts) P027B – Invalid Fuel Pump B Control Data (20% duty cycle from FPM) P2632 – Fuel Pump B Secondary Circuit (80% duty cycle from PFM) P26EA – Fuel Pump B Driver Module Internal Error (30% duty cycle from PFM) U2010C – Fuel Pump B Disabled Circuit (40% duty cycle from FPM) U016C – Loss of Communication with Fuel Pump Module B
Monitor execution	once per driving cycle
Monitor Sequence	None
Sensors OK	
Monitoring Duration	2 seconds

Typical MRFS check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11 volts	

Typical MRFS check malfunction thresholds:
P025A - Smart Fuel Pump output driver in PCM/ECM indicates fault P027B - Fuel Pump Monitor duty cycle feedback of 20% P2632 – Fuel Pump Monitor duty cycle feedback of 80% P26EA – Fuel Pump Monitor duty cycle feedback of 30% U210C – Fuel Pump Monitor duty cycle feedback of 40% U016C - No Fuel Pump Monitor duty cycle feedback (i.e. 0% or 100% duty cycle)

There are several different styles of hardware used to control airflow within the engine air intake system. In general, the devices are defined based on whether they control in-cylinder motion (charge motion) or manifold dynamics (tuning). Systems designed to control charge motion are defined to be Intake Manifold Runner Controls. IMRC systems generally have to modify spark when the systems are active because altering the charge motion affects the burn rate within the cylinder. Systems designed to control intake manifold dynamics or tuning are defined to be Intake Manifold Tuning Valves. IMTV systems generally do not require any changes to spark or air/fuel ratio because these systems only alter the amount of airflow entering the engine.

## Intake Manifold Runner Control Systems

The Intake Manifold Runner Control (Charge Motion Control Valve) that has been used on vehicle programs with the 5.0L and 5.2L engines (Mustang and F150) since 2015 MY consists of a manifold mounted vacuum actuator and a PCM controlled electric solenoid. The linkage from the actuator attaches to the manifold butterfly plate lever for each bank. The IMRC actuator and manifold are composite/plastic with a single intake air passage for each cylinder. The passage has a butterfly valve plate that blocks most of the opening when actuated, leaving the top of the passage unblocked to generate turbulence. Vacuum holds the butterfly valve plates closed, the return spring opens the butterfly valve plates when vacuum is released. There is a monitor circuit for each bank to provide feedback to the PCM indicating butterfly valve plate position.

Below approximately 3000 rpm, the vacuum solenoid will be energized. This will allow manifold vacuum to be applied and the butterfly valve plates to remain closed. Above approximately 3000 rpm, the vacuum solenoid will be de-energized. This will allow vacuum to vent from the actuator and the butterfly valve plates to open.

IMRC System Check Operation:	
DTCs	Vacuum actuated, V engine: P2004 – IMRC stuck open, Bank 1 P2005 – IMRC stuck open, Bank 2 P2006 – IMRC stuck closed, Bank 1 P2007 – IMRC stuck closed, Bank 2 P2008 - IMRC Control Circuit P2011 – IMRC Control Circuit, Bank 2 P2016 – IMRC Position Sensor Circuit Low, Bank 1 P2021 – IMRC Position Sensor Circuit Low, Bank 2 P2017 – IMRC Position Sensor Circuit High, Bank 1 P2022 – IMRC Position Sensor Circuit High, Bank 2 P2015 – IMRC Position Sensor Over Travel, Bank 1 P2020 – IMRC Position Sensor Over Travel, Bank 2
Monitor execution	Continuous, after ECT > 40 deg F
Monitor Sequence	None
Sensors OK	
Monitoring Duration	Electrical: 5 seconds for circuit check Functional: 4 events for stuck/over travel check

Typical IMRC functional check malfunction thresholds
IMRC plates do not match commanded position / exceed operational range (functional)
IMRC position sensors open/shorted, (< 0.24 volts, > 4.7 volts)
IMRC control circuit (electrical, indicated by driver circuit)

## Intake Manifold Tuning Valve Systems

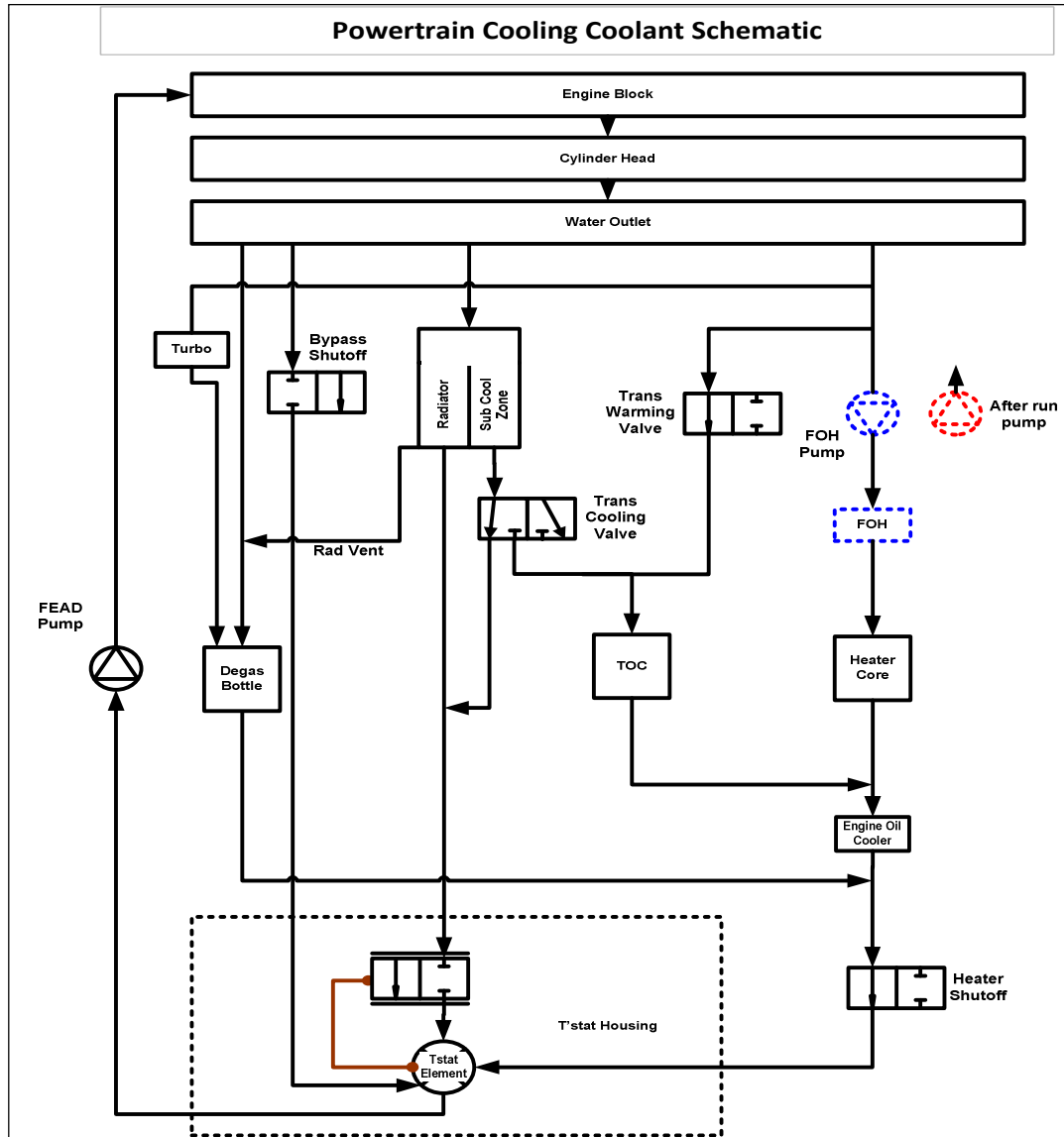
The intake manifold tuning valve (IMTV) is a motorized actuated unit mounted directly to the intake manifold. The IMTV actuator controls a shutter device attached to the actuator shaft. There is no monitor input to the PCM with this system to indicate shutter position.

The motorized IMTV unit will not be energized below approximately 2600 rpm or higher on some vehicles. The shutter will be in the closed position not allowing airflow blend to occur in the intake manifold. Above approximately 2600 rpm or higher, the motorized unit will be energized. The motorized unit will be commanded on by the PCM initially at a 100 percent duty cycle to move the shutter to the open position and then falling to approximately 50 percent to continue to hold the shutter open.

IMTV Check Operation:	
DTCs	P1549 or P0660 - IMTV output electrical check (does not illuminate MIL)
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	5 seconds

## Engine Cooling System Outputs

The engine cooling system may contain multiple control valves for improving fluid warm-up rates of both the engine and transmission. These valves are PCM controlled and primarily used for thermal control of engine metal and transmission fluid temperatures by diverting engine coolant to the appropriate component. These digital outputs include an engine coolant bypass valve, a heater core shut-off valve, an active transmission heating valve, and an active transmission cooling valve.



The Engine Coolant Bypass Valve is normally closed (de-energized) forcing all of the engine coolant through the radiator to provide maximum "cooling" of the engine and components when the thermostat is open. When opened, a portion of the engine coolant bypasses the radiator providing for coolant pressure and flow control. The Heater Core Shut Off valve has a single purpose which is to limit coolant flow for fast engine warm-up. The active transmission cooling valve will transfer engine coolant from the sub-radiator to the transmission oil cooler when energized, resulting in a heat transfer from the transmission into the engine coolant (over-temperature control of the transmission). The active transmission heating valve is used to provide hot engine coolant to the TOC to improve transmission fluid temperature control.

The Engine Coolant Radiator Bypass Valve output circuit is checked for opens and shorts (P26B7).

Engine Coolant Bypass Valve Check Operation:	
DTCs	P26B7 – Engine Coolant Bypass Valve "C" Control Circuit where "C" is defined as "Engine Coolant Radiator"
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

Typical Engine Coolant Bypass Valve check malfunction thresholds:
P26B7 - Smart driver reports output circuit fault.

The Engine Coolant Cabin Heating (Heater Core) Bypass Valve output circuit is checked for opens and shorts (P26BD).

Engine Coolant Cabin Heating Bypass Valve Check Operation:	
DTCs	P26BD – Engine Coolant Bypass Valve "D" Control Circuit where "D" is defined as "Engine Coolant Cabin Heating"
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

Typical Engine Coolant Cabin Heating Bypass Valve check malfunction thresholds:
P26BD - Smart driver reports output circuit fault.

The Active Transmission Heating Valve output circuit is checked for opens and shorts (P2681).

<b>Active Transmission Heating Valve Solenoid Check Operation:</b>	
DTCs	P2681 – Engine Coolant Bypass Valve "A" Control Circuit where "A" is defined as "Engine Coolant Auto Trans Cooler Flow"
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

<b>Typical Active Transmission Heating Valve Solenoid check malfunction thresholds:</b>
P26B7 - Smart driver reports output circuit fault.

The Active Transmission Cooling Valve output circuit is checked for opens and shorts (P26AC).

<b>Active Transmission Cooling Valve Solenoid Check Operation:</b>	
DTCs	P26AC – Engine Coolant Bypass Valve "B" Control Circuit Where "B" is defined as "Engine Coolant Auto Trans Cooling"
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

<b>Typical Active Transmission Cooling Valve Solenoid check malfunction thresholds:</b>
P26AC - Smart driver reports output circuit fault.

## Auxiliary Coolant System Pumps

Some engines will include an auxiliary coolant system pump that is PCM controlled. This is a second cooling pump in the main cooling loop. It is a low power electrically controlled pump which is used to provide engine coolant flow under conditions when the engine is not running and the main mechanical cooling pump is inactive. These auxiliary pumps can be used for two primary purposes: 1) to provide coolant flow through the cabin heat exchanger (heater core) which generates heat for the vehicle cabin (stop/start equipped vehicles), and 2) to provide coolant flow to engine components for the purposes of component protection after the engine is shut-off. On turbo equipped vehicles, engine coolant is used to cool the turbo system bearings resulting in a thermal transfer of heat into the coolant. After-run coolant flow may be required to prevent localized coolant boiling that can damage some cooling system components (particularly the degas bottle).

### Coolant Pump "A"

"A" is defined as "High Temp Loop Aux Pump - Cabin Heating" and refers to the auxiliary pump in the primary coolant loop which supplies the heater core for cabin heating. It is used on stop/start applications and HEV/PHEV applications.

The auxiliary cooling pump diagnostics include circuit checks for Open (P2600), short-to-power (P2603), short-to-ground (P2602), and a functional performance check (P2601).

Auxiliary Coolant Pump "A" Check Operation:	
DTCs	P2600 – Coolant Pump "A" Control Circuit/Open P2601 – Coolant Pump "A" Control Performance/Stuck Off P2602 – Coolant Pump "A" Control Circuit Low P2603 – Coolant Pump "A" Control Circuit High "A" is defined as "High Temp Loop Aux Pump - Cabin Heating"
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

Typical auxiliary cooling pump "A" circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

Typical auxiliary cooling pump "A" circuit check malfunction thresholds:
P2602/P2603 - Smart driver reports output circuit fault.

## Coolant Pump "B"

"B" is defined as High Temp Loop Aux Pump - Component Cooling #1" and refers to the auxiliary pump in the secondary coolant loop which supplies the CAC and turbo.

The auxiliary cooling pump diagnostics include circuit checks for Open (P261A), short-to-power (P261D), short-to-ground (P261C), and a functional performance check (P26B1).

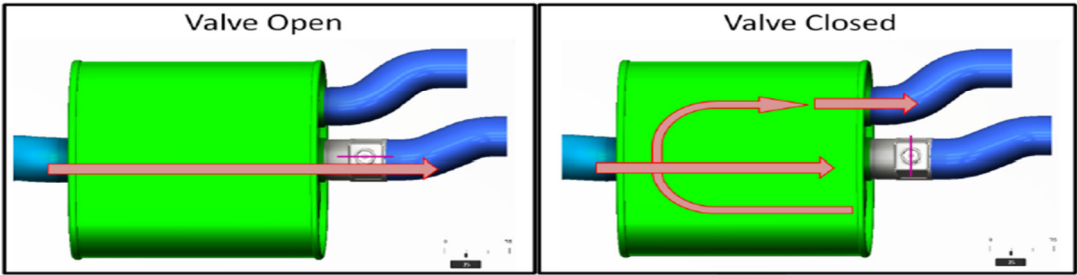
Auxiliary Coolant Pump "B" Check Operation:	
DTCs	P261A – Coolant Pump "B" Control Circuit/Open P261B1 – Coolant Pump "B" Control Performance/Stuck Off P261C – Coolant Pump "B" Control Circuit Low P261D – Coolant Pump "B" Control Circuit High "B" is defined as High Temp Loop Aux Pump - Component Cooling #1"
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

Typical auxiliary cooling pump "B" circuit check entry conditions:		
Entry Condition	Minimum	Maximum
Battery Voltage	11.0 volts	

Typical auxiliary cooling pump "B" circuit check malfunction thresholds:
P261C/P261D - Smart driver reports output circuit fault.

Exhaust Flow Control Valve - Exhaust Tuning

Exhaust flow control valves are used to control exhaust acoustics under differing vehicle operating conditions. The valve controls the exhaust flow through two flow paths within the muffler. The normal de-energized/open valve state results in normal tuned exhaust sound while the energized/closed valve provides an alternate path through the muffler with additional sound dampening. The 2016 MY Mustang GT350 and Focus RS use a PWM (pulse-width modulated) signal to control the exhaust valve position. Dual bank exhaust systems have two valves (one per bank) controlled by a single PCM output.



The actuator consists of electric motor, worm gear, position sensor and electronic control unit all integrated into a housing.



The Exhaust Flow Control Valve has no position feedback and limited component diagnostic capability. The valve can pull the PWM line down to indicate that the exhaust valve is stuck.

Exhaust Flow Control Valve Check Operation:	
DTCs	P26C5: Exhaust Flow Control Valve “A” Control Circuit/Open P26C6: Exhaust Flow Control Valve “A” Control Circuit Low P26C7: Exhaust Flow Control Valve “A” Control Circuit High P26FE: Exhaust Flow Control Valve “A” Control Performance
Monitor execution	continuous
Monitor Sequence	None
Sensors OK	not applicable
Monitoring Duration	5 seconds

Typical Exhaust Flow Control Valve check malfunction thresholds:	
P26C5, P25C6, P25C7 – Smart driver reports output circuit fault	
P26FE – Exhaust Flow Control Valve reports stuck valve (via PWM line)	

## Comprehensive Component Monitor - Transmission

### General

The MIL is illuminated for all emissions related electrical component malfunctions. For malfunctions attributable to a mechanical component (such as a clutch, gear, band, valve, etc.), some transmissions are capable of not commanding the mechanically failed component and providing the remaining maximum functionality (functionality is reassessed on each power up)- in such case a non-MIL Diagnostic Trouble Code (DTC) will be stored and, if so equipped, a Transmission Control Indicator Light (TCIL) will flash.

### Transmission Inputs

Transmission Range Sensor Check Operation:	
DTCs	P0705 Invalid pattern for digital TRS P0706 Out of range signal frequency for PWM TRS P0707 Signal out of range low for PWM TRS P0708 Open circuit for digital TRS or signal out of range high for PWM TRS
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	Up to 30 seconds for pattern recognition, 5 seconds for analog faults

Typical TRS check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Gear selector position	each position for up to 30 seconds	480 seconds

Typical TRS malfunction thresholds:	
Digital TRS:	Invalid pattern from 3 or 5 digital inputs and/or 1 analog circuit open for 5 seconds
4-bit digital TRS:	Invalid pattern for 200 ms
Dual analog TRS:	Voltage > 4.84 volts or < 0.127 volts for 200 ms or Sum of both inputs is outside the range of 5.0 volts +/- 0.29 volts for 200 ms
PWM TRS:	Frequency > 175 Hz or < 100 Hz, Duty Cycle > 90% or < 10%
Dual PWM TRS:	each signal tested for: <ul style="list-style-type: none"><li>Frequency &gt; 175 Hz or &lt; 100 Hz (HF32); &gt; 300 Hz or &lt; 200 Hz (DPS6)</li><li>Duty Cycle &gt; 90% or &lt; 10%</li></ul>
Sum of both inputs = 100% +/- 4%	

Most vehicle applications no longer have a standalone vehicle speed sensor input. The PCM sometimes obtains vehicle speed information from another module on the vehicle, i.e. ABS module. In most cases, however, vehicle speed is calculated in the PCM by using the transmission output shaft speed sensor signal and applying a conversion factor for axle ratio and tire programmed into the Vehicle ID block. A Vehicle Speed Output pin on the PCM provides the rest of the vehicle with the standard 8,000 pulses/mile signal.

Note: If the Vehicle ID block has not been programmed or has been programmed with an out-of-range (uncertified) tire/axle ratio, a P1639 DTC will be stored and the MIL will be illuminated immediately.

Vehicle Speed Sensor Functional Check Operation:	
DTCs	P0500 – VSS circuit
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	30 seconds

Typical VSS functional check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Gear selector position	drive	
Engine rpm (above converter stall speed) OR	3000 rpm	
Turbine shaft rpm (if available) OR	1500 rpm	
Output shaft rpm	650 rpm	
Vehicle speed (if available)	15 mph	
Manual Transmission Entry Conditions		
Engine load	50 %	
Engine rpm	2400 rpm	

Typical VSS functional check malfunction thresholds:
Vehicle is inferred to be moving with positive driving torque and VSS is < 1 - 5 mph for 5 seconds

**Output Shaft Speed Sensor Functional Check Operation:**

DTCs	P0720 – OSS circuit P0721 – OSS range/performance -F-21, 6HP26 P0722 – OSS no signal P0723 – OSS intermittent/erratic – 6HP26
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	TSS, Wheel Speed
Monitoring Duration	30 seconds

**Typical OSS functional check entry conditions:**

Auto Transmission Entry Conditions	Minimum	Maximum
Gear selector position	drive	
Engine rpm (above converter stall speed) OR	3000 rpm	
Primary Pulley Speed (CFT30) OR	400 rpm	
Turbine shaft rpm (if available) OR	1500 rpm	
Output shaft rpm	300 - 650 rpm	
Vehicle speed (if available)	12.5 - 15 mph	

**Typical OSS functional check malfunction thresholds:**

Circuit/no signal - vehicle is inferred to be moving with positive driving torque and OSS < 100 to 200 rpm for 5 to 30 seconds

6HP26 Circuit/no signal: open or short circuit for > 0.6 seconds

6HP Range/Performance: > 200 rpm difference between OSS and wheel speed and > 250 rpm difference between OSS and input shaft speed

F21 Range/Performance: TSS, ABS wheel speed and engine rpm correlate properly, but OSS error is greater than 15% for 10 seconds

CFT30 Range/Performance: ABS wheel speed indicates a 6.24 mph difference with OSS calculated wheel speed

6HP26 Intermittent/Erratic: > -1000 rpm instantaneous change with locked torque converter clutch

CFT30 Intermittent/Erratic: > 6000 rpm/sec change

Intermediate Shaft Speed Sensor Functional Check Operation:	
DTCs	P0791 – ISS circuit
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	
Monitoring Duration	30 seconds

Typical ISS functional check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Gear selector position	drive	
Engine rpm (above converter stall speed) OR	3000 rpm	
Turbine shaft rpm (if available) OR	1500 rpm	
Output shaft rpm	650 rpm	
Vehicle speed (if available)	15 mph	

Typical ISS functional check malfunction thresholds:
Vehicle is inferred to be moving with positive driving torque and ISS < 250 rpm for 5 seconds

<b>Turbine Shaft Speed Sensor Functional Check Operation:</b>	
DTCs	P0715 – TSS circuit / no signal P0718 – TSS erratic signal
Monitor execution	Continuous
Monitor Sequence	None
Sensors OK	OSS, Wheel Speed
Monitoring Duration	30 seconds

<b>Typical TSS functional check entry conditions:</b>		
Auto Transmission Entry Conditions	Minimum	Maximum
Gear selector position	Forward range	
Engine rpm (above converter stall speed) OR	3000 rpm	
Output shaft rpm OR	600 - 650 rpm	
Vehicle speed (if available)	12.5 - 15 mph	

<b>Typical TSS functional check malfunction thresholds:</b>
Circuit/no signal - vehicle is inferred to be moving with positive driving torque and TSS < 200 rpm for 5 – 30 seconds
Erratic signal – observe 200 turbine speed spikes > 400 rpm with no more than 1.5 seconds between spikes

Transmission Fluid Temperature Sensor Functional Check Operation:	
DTCs	P0711 – in range failure P0712 – short to ground P0713 – open circuit
Monitor execution	continuous
Monitor Sequence	none
Sensors OK	ECT substituted if TFT has malfunction TFT inferred from pressure solenoids on CFT30
Monitoring Duration	5 seconds for electrical, 600 seconds for functional check

Typical TFT Stuck Low/High check entry conditions:		
Auto Transmission Entry Conditions	Minimum	Maximum
Engine Coolant Temp (hot or cold, not midrange)	> 100 °F	< 20 °F
Time in run mode	500 – 600 sec	
Time in gear, vehicle moving, positive torque	150 sec	
Vehicle Speed	15 mph	
Time with engine off (cold start) OR	420 min	
Engine Coolant Temp AND Trans Fluid Temp (inferred cold start)		122 °F

Typical TFT malfunction thresholds:
<p>Opens/shorts: TFT voltage &lt;0.05 or &gt; 4.6 volts for 5 – 12 seconds</p> <p>TFT Stuck low/high, i.e. TFT stuck at high temperature or stuck at low temperature):</p> <p>Stores a fault code if TFT stabilizes (stops increasing if temperature &lt; 70 deg F, stops decreasing if temperature &gt; 225 deg F) before reaching the temperature region where all MIL tests are enabled (70 to 225 deg F). If TFT remains constant (+/- 2 deg F) for approximately 2.5 minutes of vehicle driving outside the 70 to 225 deg F zone a P0711 fault code will be stored. Old logic used to indicate a "pass" for a single delta, and not test until the normal operating region (70-225 deg F) was reached.</p>

## Transmission Outputs

Shift Solenoid Check Operation:	
DTCs	<p>SS A - P0750 - open circuit,  P0751 – functionally failed off  P0752 – functionally failed on  P0973 – short to ground  P0974 - shorts to power  P1714 ISIG functional (4R70 only, replaces P0751, P0752)</p> <p>SS B - P0755 - open circuit  P0756 – functionally failed off  P0757 – functionally failed on  P0976 – short to ground  P0977 - shorts to power  P1715 ISIG functional (4R70 only, replaces P0756, P0757)</p> <p>SS C - P0760 - open circuit  P0761 – functionally failed off  P0762 – functionally failed on  P0979 – short to ground  P0980 - shorts to power</p> <p>SS D P0765 - open circuit  P0766 – functionally failed off  P0767 – functionally failed on  P0982 – short to ground  P0983 - shorts to power</p> <p>SS E - P0770 - open circuit  P0771 – functionally failed off  P0772 – functionally failed on  P0985 – short to ground  P0986 - shorts to power</p>
Monitor execution	electrical - continuous, functional - during off to on solenoid transitions
Monitor Sequence	None
Sensors OK	
Monitoring Duration	0.5 to 5 seconds for electrical checks, 3 solenoid events for functional check

Typical Shift Solenoid ISIG functional check entry conditions:		
Entry Conditions	Minimum	Maximum
Transmission Fluid Temp	70 °F	225 °F
Throttle position	positive drive torque (actual TP varies)	

Typical Shift Solenoid mechanical functional check entry conditions:		
Entry Conditions (with turbine speed)	Minimum	Maximum
Gear ratio calculated	each gear	
Throttle position	positive drive torque	

Typical Shift Solenoid mechanical functional check entry conditions:		
Entry Conditions (without turbine speed)	Minimum	Maximum
Rpm drop is obtained	each shift	
Throttle position	positive drive torque	

Typical Shift Solenoid malfunction thresholds:		
Electrical circuit check: Output driver feedback circuit does not match commanded driver state for 0.5 – 5.0 seconds		
Electrical current check: Feedback current out of range for 0.5 seconds		
ISIG functional check: ISIG chip hardware circuit does not detect characteristic current dip and rise produced by solenoid movement.		
Mechanical functional check: Actual obtained gear or shift pattern indicates which shift solenoid is stuck on or off.		

Gear Ratio Check Operation:	
DTCs	P0731 incorrect gear 1 ratio P0732 incorrect gear 2 ratio P0733 incorrect gear 3 ratio P0734 incorrect gear 4 ratio P0735 incorrect gear 5 ratio P0729 incorrect gear 6 ratio P0736 incorrect reverse ratio
Monitor execution	Continuous, in each gear
Monitor Sequence	None
Sensors OK	TSS, OSS, wheel speed
Monitoring Duration	12 seconds

Typical Forward Gear Ratio check entry conditions:		
Entry Conditions	Minimum	Maximum
Gear selector position	forward range, > 8 seconds	
Engine Torque	100 NM	
Throttle position	10%	
Not shifting	> 0.5 seconds	
Engine/input Speed	550 rpm	
Output Shaft Speed	250 rpm	1350 rpm

Typical Neutral Gear Ratio check entry conditions:		
Entry Conditions	Minimum	Maximum
Gear selector position	forward range, > 1 second	
Absolute value of Engine rpm – Turbine rpm		150 rpm
Output Shaft Speed		500 rpm

Typical Gear Ratio malfunction thresholds:
Forward gear check: > 30 rpm error in commanded ratio for > 1.8 seconds that repeats 3 times

Torque Converter Clutch Check Operation:	
DTCs	P0740 – open circuit P0742 – short to ground P0744 – short to power P0741 – functionally stuck off P2758 – functionally stuck on P1740 – Inductive signature (4R70 only, replaces P0741 / P2758)
Monitor execution	electrical - continuous, mechanical - during lockup
Monitor Sequence	None
Sensors OK	TSS, OSS
Monitoring Duration	Electrical – 5 seconds, Functional - 5 lock-up events

Typical TCC ISIG functional check entry conditions:		
Entry Conditions	Minimum	Maximum
Transmission Fluid Temp	70 °F	225 °F
Engine Torque	positive drive torque	
Commanded TCC duty cycle for 0 rpm slip	60%	90%

Typical TCC mechanical functional check stuck off entry conditions:		
Entry Conditions	Minimum	Maximum
Throttle Position	steady	
Engine Torque	positive drive torque	
Transmission Fluid Temp	70 °F	225 °F
Commanded TCC duty cycle (0 rpm slip)	60%	100%
Not shifting		

Typical TCC malfunction thresholds:
Electrical circuit check: Output driver feedback circuit does not match commanded driver state for 0.5 – 5.0 seconds
Electrical current check: Feedback current out of range for 0.5 seconds
ISIG functional check: ISIG chip hardware circuit does not detect characteristic current dip and rise produced by solenoid movement.
Mechanical check, stuck off: Slip across torque converter > 100 – 200 rpm or speed ratio < 0.93
Mechanical check, stuck on: Slip across torque converter < 20 rpm with converter commanded off
Mechanical check, stuck on: engine rpm < 100 after drive engagement (engine stall)

Pressure Control Solenoid Check Operation:	
DTCs	P0960 – open circuit P0962 – short to ground P0963 – short to power
Monitor execution	Continuous
Monitor Sequence	none
Sensors OK	
Monitoring Duration	Electrical: 5 seconds, Mechanical functional: up to 30 seconds

Typical Pressure Control Solenoid mechanical functional check entry conditions:		
Entry Conditions	Minimum	Maximum
Gear ratio calculated	each gear	
Transmission Fluid Temperature	70 °F	225 °F
Throttle Position	positive drive torque	

Typical Pressure Control Solenoid malfunction thresholds:
Electrical circuit check: Output driver feedback circuit does not match commanded driver state for 0.5 – 5.0 seconds
Electrical current check: Feedback current out of range for 0.5 seconds
Mechanical functional check: Actual obtained gear pattern indicates Pressure Control solenoid fault

Inductive Signature or ADLER Chip Communication Check Operation:	
DTCs	P1636 ISIG or ADLER chip loss of communication
Monitor execution	off-to-on solenoid transitions (ISIG) continuous for ADLER (driver chip that controls shift solenoids on the 6 speed transmissions)
Monitor Sequence	none
Sensors OK	
Monitoring Duration	< 100 solenoid events (ISIG) 5 30ms loops without communication (ADLER)

Typical Inductive Signature or ADLER Chip Communication Check entry conditions:		
Entry Conditions	Minimum	Maximum
Transmission Fluid Temp	70 °F	225 °F
Solenoid commanded off duration		< 2 seconds

Typical Inductive Signature or ADLER Communication Chip malfunction thresholds:
Checksum error, chip not responding

## 6R80 (RWD) Transmission with external PCM or TCM

### Transmission Control System Architecture

Starting in 2010.5 MY 6R80 is transitioning from an internal TCM to an external PCM (gas applications) or TCM (Diesel applications). Main hardware differences:

- Transmission Range Sensor still 4 bit digital, but the transmission bulkhead connector could not accommodate 4 pins so a micro processor was added to the sensor. This processor converts the 4 bit digital signal into a Pulse Width Modulated (PWM) 125 Hz signal.
- Module temperature sensor has been deleted.

The 6R80 is a 6-speed, step ratio transmission that is controlled by an external PCM (gas engine applications) or TCM (Diesel engine applications). For Diesel the TCM communicates to the Engine Control Module (ECM), ABS Module, Instrument Cluster and Transfer Case Control Module 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 outside the transmission assembly. It is not serviceable with the exception of reprogramming.

### Transmission Inputs

#### Transmission Range Sensor

Due to transmission bulkhead connector issues the 4 bit digital TRS used by 6R80 with an internal TCM has been revised. The sensor now contains a micro processor that converts the 4 bit digital signal from into a Pulse Width Modulated (PWM) 125 Hz signal that is then output to the PCM. The sensor outputs a specific duty cycle for each bit pattern, including the invalid bit patterns. TRS is tested for invalid bit pattern (P0705 – inferred by the PCM thru the duty cycle), frequency out of range (P0706), duty cycle out of range low (P0707), duty cycle out of range high (P0708).

#### Speed Sensors

The Turbine Shaft Speed (TSS) sensor and Output Shaft Speed (OSS) sensor are Hall effect sensors.

The Turbine Shaft Speed sensor is monitored for circuit faults and rationality (P0715, P0717). If turbine shaft speed exceeds a maximum calibrated speed (7,700 rpm), a fault is stored (P0716). If engine speed and output shaft speed are high and a gear is engaged, it can be inferred that the vehicle is moving. If there is insufficient output from the TSS sensor a fault is stored (P0716).

The Output Shaft Speed sensor is monitored for circuit faults and rationality (P0720, P0722). If output shaft speed exceeds a maximum calibrated speed (7,450 rpm), a fault is stored (P0721). If output shaft speed does not correlate with turbine shaft speed and wheel speed while a gear is engaged and the vehicle is moving, a fault is stored (P0721). If the output shaft speed decreases at an erratic/unreasonable rate, a fault is stored (P0723).

#### Transmission Fluid Temperature

The Transmission Fluid Temperature Sensor is checked for open circuit, short circuit to ground, short circuit to power, and in-range failures (P0711, P0712, P0713, P0714). In-range TFT (P0711) is now the Ford standard diagnostic – the internal TCM temperature sensor is no longer available to diagnose TFT failures.

### Transmission Outputs

#### Shift Solenoids

6R80 has 5 shift solenoids:

1. SSA – a Variable Force Solenoid (VFS) that controls CB1234 (a brake clutch, grounds an element to the case, that is on in 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> gear)
2. SSB – a VFS that controls C35R (a rotating clutch on in 3<sup>rd</sup>, 5<sup>th</sup> and Reverse)
3. SSC – a VFS that controls CB26 (a brake clutch on in 2<sup>nd</sup> and 6<sup>th</sup> gear)
4. SSD – a VFS that controls either CBLR (a brake clutch on in 1<sup>st</sup> gear with engine braking and Reverse) or C456 (a rotating clutch on in 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> gear)
5. SSE – an On/Off solenoid that controls the multiplexing of SSD between CBLR and C456.

Output circuits are checked for opens, short to ground and short to power faults (codes listed in that order) by the PCM by monitoring the status of a feedback circuit from the output driver (SSA P0750, P0973, P0974; SSB P0755, P0976, P0977; SSC P0760, P0979, P0980; SSD P0765, P0982, P0983; SSE P0770).

The shift solenoids are also functionally tested for stuck on and stuck off failures. This is determined by vehicle inputs such as gear command, and achieved gear (based on turbine and output speed). In general the shift solenoid malfunction codes actually cover the entire clutch system (solenoid, valves, and the clutch itself) since using ratio there is no way to isolate the solenoid from the rest of the clutch system

For SSA thru SSD Diagnostics will isolate the fault into clutch functionally (non-electrical) failed off (SSA P0751, SSB P0756, SSC P0761, SSD P0766) and clutch functionally failed on (SSA: P0752, SSB: P0757, SSC: P0762, SSD: P0767). The On/Off solenoid (SSE) controls the multiplexing of SSD between CBLR and C456 clutches. Using ratio we can determine if the multiplex valve is in the wrong position, but cannot be sure if the failure is due to the solenoid or a stuck valve. The multiplex valve is tested for stuck in default position (P0771, includes SSE stuck off) and stuck in spring compressed position (P0772, includes SSE stuck on) failures.

#### Gear ratio errors:

If ratio errors are detected that do not match an expected pattern for a failed solenoid then gear ratio error fault codes (1<sup>st</sup> gear – P0731, 2<sup>nd</sup> gear – P0732, 3<sup>rd</sup> gear – P0733, 4<sup>th</sup> gear – P0734, 5<sup>th</sup> gear – P0735 or 6<sup>th</sup> gear – P0729) will be stored.

## Torque Converter Clutch

The Torque Converter Clutch (TCC) Solenoid output circuit is a duty-cycled output that is checked electrically for open circuit, short circuit to ground, and short circuit to power by monitoring the status of a feedback circuit from the output driver (P0740, P0742, P0744). If the TCC pressure is high and the engine torque is low, the TCC should be fully applied or have a controlled amount of slippage. If the slip exceeds a threshold, a fault is stored (P0741). If the TCC is stuck on when commanded off in multiple gears a fault code is stored (P2758).

## Pressure Control

The Pressure Control solenoid is a variable force solenoid that controls line pressure in the transmission. The Pressure Control solenoid output circuit is a duty-cycled output that is checked electrically for open, short circuit to ground or short circuit to battery by monitoring the status of a feedback circuit from the output driver (P0960, P0962, P0963).

## High Side Actuator Control Circuit

The TCM has a high side actuator supply control circuit that can be used to remove power from all 7 solenoids and the external Reverse Light Relay simultaneously. If the high side actuator control circuit is deactivated, all 7 solenoids and the external Reverse Light Relay will be electrically turned off, providing Park, Reverse, Neutral, and 3M/5M (in all forward ranges) with maximum line pressure, based on the selected transmission range. The actuator control circuit is tested for open circuits. (P0657).

ADLER (chip that controls all 7 solenoids) diagnostics:

The solenoids are controlled by an ADLER chip. The main micro sends commanded solenoid states to the ADLER, and receives back solenoid circuit fault information.

If communication with the ADLER is lost a P1636 fault code will be stored. If this failure is detected the states of the solenoids are unknown, so the control system will open the high side switch (removes power from all the solenoids), providing P, R, N and 5M with open TCC and max line pressure.

## TRID Block

The TRID block is a portion of flash memory that contains solenoid characterization data tailored to the specific transmission to improve pressure accuracy.

The TRID block is monitored for two failures:

- a) TRID block checksum error / incorrect version of the TRID (P163E)
- b) TRID block not programmed (P163F)

If the TRID block is unavailable FMEM action limits operation to 1<sup>st</sup> and 3<sup>rd</sup> gear until the issue is correct.

## **Transmission Control Module (TCM – Diesel only)**

The TCM has the same module diagnostics as a PCM – see miscellaneous CPU tests.

### **CAN Communications Error**

The TCM receives information from the ECM via the high speed CAN network. If the CAN link or network fails, the TCM no longer has torque or engine speed information available. The TCM will store a U0073 fault code and will illuminate the MIL immediately (missing engine speed) if the CAN Bus is off. The TCM will store a U0100 fault code and will illuminate the MIL immediately (missing engine speed) if it stops receiving CAN messages from the ECM. A U0401 fault codes will be stored if the ECM sends invalid/faulted information for the following CAN message items: engine torque, pedal position.

### **TCM voltage**

If the system voltage at the TCM is outside of the specified 9 to 16 volt range, a fault will be stored (P0882, P0883).

## 6F55 (FWD) Transmission

### Transmission Inputs

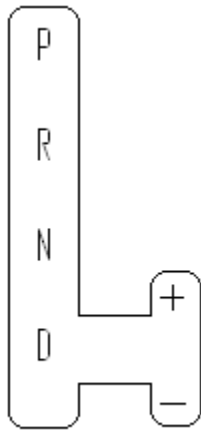
#### Transmission Range Sensor

The 6F Digital Transmission Range (DTR) sensor provides four digital inputs to the PCM. Unlike the Ford standard digital TRS that has 1 analog and 3 digital inputs, this sensor uses 4 digital inputs, and all switches open (sensor disconnect) is an invalid bit pattern. The PCM decodes these inputs to determine the driver-selected gear position (Park, Rev, Neutral, OD, Low). This input device is checked for all switches open (P0708), invalid input patterns (P0705), and a stuck in transition zone between valid positions (P0706).

#### Select Shift Transmission (SST) Up/Down

6F is picking up SST for 09 MY. This system has two new PCM inputs, an upshift switch and a downshift switch. The switches are built into the shifter (defined as an H-gate in this implementation) or Paddles located on the steering wheel (Paddle implementation):

H-gate::



Both PCM inputs are open when the shifter is on the left hand side. From Drive as the customer moves the shifter to the right both inputs transition from open to closed (the TRS continues to indicate Drive). The control system enters "Grade Assist Mode" (provides more engine braking but still follows an automatic shift schedule) at this point. If the customer never requests a shift the control system will remain in Grade Assist Mode.

The customer requests a shift by pushing the shifter up or down, which opens the appropriate switch. Once the customer requests a shift the control system transitions from Grade Assist Mode to SST. In SST the control system follows the customer's commands except for special conditions (downshifts to the lowest available gear at high pedal, downshifts at low speeds).

Diagnostics monitors for either switch closed in Park, Reverse or Neutral, and a failure will result in non-MIL P0815 (upshift switch error) or P0816 (downshift switch error) fault codes.

If either switch fails open the customer will not be able to enter Grade Mode or SST since both switches must transition from open to closed while in the Drive position to enter SST.

If either switch is detected failed Grade Assist Mode and SST are disabled and the control system defaults to Drive (normal automatic shift schedules).

Paddles:



The right paddle controls upshifts, the left paddle controls downshifts. Pulling on the appropriate paddle changes the state of the digital input.

In S the transmission will automatically shift until one of the paddles is actuated, then it will switch into “Select Shift Transmission” (SST), holding the customer selected gear until a shift request is made via the paddles, with some minor overrides like the transmission will downshift from 5<sup>th</sup> or 6<sup>th</sup> to 1<sup>st</sup> at a stop to avoid launching in a high gear if the customer forgot to downshift upon coming to a stop.

In Drive the paddles can be used to temporarily select a gear – this feature is called “Live in Drive”. The system will hold the customer selected gear indefinitely under certain operating conditions (closed pedal going down a grade or in an turn), but under normal road load conditions the system will time out after 2-3 seconds, returning to the normal automatic shift schedules.

The paddles are ignored in P, R and N.

## Speed Sensors

The Turbine Shaft Speed (TSS) sensor and Output Shaft Speed (OSS) sensor are Hall Effect inputs that are checked for rationality. The vehicle speed signal is provided from the ABS system (if present) to the PCM, or is derived from OSS. If the engine rpm is above the torque converter stall speed and engine load is high, it can be inferred that the vehicle must be moving. If there is insufficient output from the VSS sensor (if present), a malfunction is indicated (P0500). If there is insufficient output from the TSS sensor, a malfunction is indicated (P0715). If there is insufficient output from the OSS sensor, a malfunction is indicated (P0720).

## Transmission Fluid Temperature

6F has a feature called “Cold mode” (1<sup>st</sup> implemented in 5R110W in 2003 MY). If TFT is below -20 deg F, the transmission will limit operation to 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> gears (5<sup>th</sup> and 6<sup>th</sup> gears are disabled). Cold mode remains in effect until TFT rises above -20 deg F or vehicle operation (based on shift times or heat generated by driving) indicates that TFT should not be in the cold mode range, at which point normal operation is enabled.

if TFT is failed at start up the transmission will be placed in cold mode and remain there until TFT is no longer failed and above -20 deg F or the vehicle operating conditions listed above trigger an exit from cold mode.

Once out of cold mode a TFT failure will not trigger cold mode (can only go into cold mode once/power-up); this mode is the same as implemented on 5R110W in 2003.5 MY.

TFT is monitored for circuit faults (P0712, P0713) and in-range failures (P0711)

For this reason all TFT diagnostics illuminate the MIL on 6F.

## Transmission Outputs

### Shift Solenoids

6F has 5 shift solenoids:

- SSA – a Variable Force Solenoid (VFS) that controls CB1234 (a brake clutch, grounds an element to the case, that is on in 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> gear)
- SSB – a VFS that controls C35R (a rotating clutch on in 3<sup>rd</sup>, 5<sup>th</sup> and Reverse)
- SSC – a VFS that controls CB26 (a brake clutch on in 2<sup>nd</sup> and 6<sup>th</sup> gear)
- SSD – a VFS that controls either CBLR (a brake clutch on in 1<sup>st</sup> gear with engine braking and Reverse) or C456 (a rotating clutch on in 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> gear)
- SSE – an On/Off solenoid that controls the multiplexing of SSD between CBLR and C456.

Output circuits are checked for opens, short to ground and short to power faults (codes listed in that order) by the PCM by monitoring the status of a feedback circuit from the output driver (SSA P0750, P0973, P0974; SSB P0755, P0976, P0977; SSC P0760, P0979, P0980; SSD P0765, P0982, P0983; SSE P0770).

The shift solenoids are also functional tested for stuck on and stuck off failures. This is determined by vehicle inputs such as gear command, and achieved gear (based on turbine and output speed). In general the shift solenoid malfunction codes actually cover the entire clutch system (solenoid, valves, and the clutch itself since using ratio there is no way to isolate the solenoid from the rest of the clutch system), BUT due to the hydraulic controls arrangement on 6F it is possible to isolate two specific solenoid failures from clutch system faults:

- a) SSB stuck on from C35R stuck on - due to hydraulic interlock between CBLR and C35R we can isolate SSB stuck on from C35R by turning SSE on in 1<sup>st</sup> gear without engine braking (get 1<sup>st</sup> if SSB stuck on, get 3<sup>rd</sup> if C35R is stuck on)
- b) SSD stuck off. Since SSD is multiplexed (controls both CBLR and C456) we can isolate CBLR stuck off and C456 stuck off from SSD stuck off since the latter impacts both clutch systems.

For SSA thru SSD Diagnostics will isolate the fault into clutch functionally (non-electrical) failed off (SSA P0751, SSB P0756, SSC P0761, SSD P0766) and clutch functionally failed on (SSA: P0752, SSB: P0757, SSC: P0762, SSD: P0767). The On/Off solenoid (SSE) controls the multiplexing of SSD between CBLR and C456 clutches. Using ratio we can determine if the multiplex valve is in the wrong position, but cannot be sure if the failure is due to the solenoid or a stuck valve. The multiplex valve is tested for stuck in default position (P0771, includes SSE stuck off) and stuck in spring compressed position (P0772, includes SSE stuck on) failures.

### Gear ratio errors:

If ratio errors are detected that do not match an expected pattern for a failed solenoid then gear ratio error fault codes (1<sup>st</sup> gear – P0731, 2<sup>nd</sup> gear – P0732, 3<sup>rd</sup> gear – P0733, 4<sup>th</sup> gear – P0734, 5<sup>th</sup> gear – P0735 or 6<sup>th</sup> gear – P0729) will be stored.

### Torque Converter Clutch

The Torque Converter Clutch (TCC) solenoid is a Variable Force Solenoid. TCC solenoid circuit is checked electrically for open, short to ground and short to power circuit faults internally in the PCM by monitoring the status of a feedback circuit from the output driver (P0740, P0742, P0744).

The TCC solenoid is checked functionally by evaluating torque converter slip under steady state conditions when the torque converter is fully applied. If the slip exceeds the malfunction thresholds when the TCC is commanded on, a TCC malfunction is indicated (P0741). If the TCC is stuck on when commanded off in multiple gears a fault code is stored (P2758).

For 6F the TCC is controlled by a 2 valve system - TCC reg apply and TCC control valve. Normally the TCC VFS controls the positions of these valves - turning on the TCC VFS moves both valves from the release to the apply position. If the TCC control valve sticks in the apply position then there will be no flow thru the TCC (both apply and release sides exhausted) when commanded open, which will cause the converter to overheat.

A method to detect this failure was designed into the hardware - SSE pressure is routed to the TCC reg apply valve (SSE has no effect on TCC control valve). In 3rd gear or higher if TCC is open SSE can be turned on, moving the TCC reg apply valve to the apply position. If the TCC control valve is in the wrong (apply) position this will cause the TCC to apply. If the TCC applies when SSE is turned on in 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> or 6<sup>th</sup> gear while TCC is commanded open (TCC VFS pressure low) the failure will be detected, a P2783 DTC fault code stored. Even though this test only detects failures of the control valve, the FMEM actions alter the shift and TCC lock schedules to keep the TCC applied as much as possible, so this failure has been made MIL.

## Electronic Pressure Control

The EPC solenoid is a variable force solenoid that controls line pressure in the transmission. The EPC solenoid has a feedback circuit in the PCM that monitors EPC current. If the current indicates a short to ground (low pressure), a high side switch will be opened. This switch removes power from all 6 VFSs and the on/off shift solenoid, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. This solenoid is tested for open (P0960), short to ground (P0962), and short to power (P0963) malfunctions.

## High Side Switch

6F has a high side switch that can be used to remove power from all 7 solenoids simultaneously. If the high side switch is opened, all 7 solenoids will be electrically off, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. The switch is tested for open faults (switch failed closed will provide normal control). If the switch fails, a P0657 fault code will be stored.

ADLER (chip that controls all 7 solenoids) diagnostics:

The solenoids are controlled by an ADLER chip. The main micro sends commanded solenoid states to the ADLER, and receives back solenoid circuit fault information.

If communication with the ADLER is lost a P1636 fault code will be stored. If this failure is detected the states of the solenoids are unknown, so the control system will open the high side switch (removes power from all the solenoids), providing P, R, N and 5M with open TCC and max line pressure.

## TRID Block

The TRID block is a portion of flash memory that contains solenoid characterization data tailored to the specific transmission to improve pressure accuracy.

The TRID block is monitored for two failures:

- TRID block checksum error / incorrect version of the TRID (P163E)
- TRID block not programmed (P163F)

If the TRID block is unavailable FMEM action limits operation to 1<sup>st</sup> and 3<sup>rd</sup> gear until the issue is correct.

## 6F35 (FWD) Transmission with external PCM or TCM

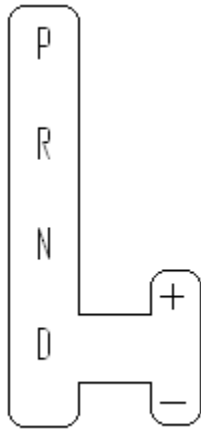
### Transmission Inputs

Transmission Range Sensor – 6F35 uses a Non-contacting Pulse Width Modulated Transmission Range Sensor (TRS) that provides a duty cycle signal for each position. This signal is transmitted at a frequency of 125 Hz. The PCM decodes the duty cycle to determine the driver-selected gear position (Park, Rev, Neutral, OD, 3, 2, 1). This input device is checked for out of range frequency, low duty cycle and high duty cycle input signals. (P0706, P0707, P0708)

### Select Shift Transmission (SST) Up/Down

6F35 is picking up SST for 10 MY. This system has two new PCM inputs, an upshift switch and a downshift switch. The switches are built into the shifter (defined as an H-gate in this implementation) or Paddles behind the steering wheel (Paddles):

H-gate::



Both PCM inputs are open when the shifter is on the left hand side. From Drive as the customer moves the shifter to the right both inputs transition from open to closed (the TRS continues to indicate Drive). The control system enters "Grade Assist Mode" (provides more engine braking but still follows an automatic shift schedule) at this point. If the customer never requests a shift the control system will remain in Grade Assist Mode.

The customer requests a shift by pushing the shifter up or down, which opens the appropriate switch. Once the customer requests a shift the control system transitions from Grade Assist Mode to SST. In SST the control system follows the customer's commands except for special conditions (downshifts to the lowest available gear at high pedal, downshifts at low speeds).

Diagnostics monitors for either switch closed in Park, Reverse or Neutral, and a failure will result in non-MIL P0815 (upshift switch error) or P0816 (downshift switch error) fault codes.

If either switch fails open the customer will not be able to enter Grade Mode or SST since both switches must transition from open to closed while in the Drive position to enter SST.

If either switch is detected failed Grade Assist Mode and SST are disabled and the control system defaults to Drive (normal automatic shift schedules).

Paddles:



The right paddle controls upshifts, the left paddle controls downshifts. Pulling on the appropriate paddle changes the state of the digital input.

In S the transmission will automatically shift until one of the paddles is actuated, then it will switch into “Select Shift Transmission” (SST), holding the customer selected gear until a shift request is made via the paddles, with some minor overrides like the transmission will downshift from 5<sup>th</sup> or 6<sup>th</sup> to 1<sup>st</sup> at a stop to avoid launching in a high gear if the customer forgot to downshift upon coming to a stop.

In Drive the paddles can be used to temporarily select a gear – this feature is called “Live in Drive”. The system will hold the customer selected gear indefinitely under certain operating conditions (closed pedal going down a grade or in a turn), but under normal road load conditions the system will time out after 2-3 seconds, returning to the normal automatic shift schedules.

The paddles are ignored in P, R and N.

## Speed Sensors

The Turbine Shaft Speed (TSS) sensor and Output Shaft Speed (OSS) sensor are Hall Effect inputs that are checked for rationality. The vehicle speed signal is provided from the ABS system (if present) to the PCM, or is derived from OSS. If the engine rpm is above the torque converter stall speed and engine load is high, it can be inferred that the vehicle must be moving. If there is insufficient output from the TSS sensor, a malfunction is indicated (P0715). If there is insufficient output from the OSS sensor, a malfunction is indicated (P0720). 6F35 applications currently use ABS vehicle speed the primary source of vehicle speed with OSS as a backup, if both sources are failed a P1934 “Vehicle Speed Signal” DTC is stored.

## Transmission Fluid Temperature

6F35 has a feature called “Cold mode” (1<sup>st</sup> implemented in 5R110W in 2003 MY). If TFT is below -20 deg F, the transmission will limit operation to 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> gears (5<sup>th</sup> and 6<sup>th</sup> gears are disabled). Cold mode remains in effect until TFT rises above -20 deg F or vehicle operation (based on shift times or heat generated by driving) indicates that TFT should not be in the cold mode range, at which point normal operation is enabled.

if TFT is failed at start up the transmission will be placed in cold mode and remain there until TFT is no longer failed and above -20 deg F or the vehicle operating conditions listed above trigger an exit from cold mode.

Once out of cold mode a TFT failure will not trigger cold mode (can only go into cold mode once/power-up); this mode is the same as implemented on 5R110W in 2003.5 MY.

TFT is monitored for circuit faults (P0712, P0713) and in-range failures (P0711)

For this reason all TFT diagnostics illuminate the MIL on 6F35.

## Transmission Outputs

### Shift Solenoids

6F has 5 shift solenoids:

- SSA – a Variable Force Solenoid (VFS) that controls CB1234 (a brake clutch, grounds an element to the case, that is on in 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> gear)
- SSB – a VFS that controls C35R (a rotating clutch on in 3<sup>rd</sup>, 5<sup>th</sup> and Reverse)
- SSC – a VFS that controls CB26 (a brake clutch on in 2<sup>nd</sup> and 6<sup>th</sup> gear)
- SSD – a VFS that controls either CBLR (a brake clutch on in 1<sup>st</sup> gear with engine braking and Reverse) or C456 (a rotating clutch on in 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> gear)
- SSE – an On/Off solenoid that controls the multiplexing of SSD between CBLR and C456.

Output circuits are checked for opens, short to ground and short to power faults (codes listed in that order) by the PCM by monitoring the status of a feedback circuit from the output driver (SSA P0750, P0973, P0974; SSB P0755, P0976, P0977; SSC P0760, P0979, P0980; SSD P0765, P0982, P0983; SSE P0770).

The shift solenoids are also functional tested for stuck on and stuck off failures. This is determined by vehicle inputs such as gear command, and achieved gear (based on turbine and output speed). In general the shift solenoid malfunction codes actually cover the entire clutch system (solenoid, valves, and the clutch itself since using ratio there is no way to isolate the solenoid from the rest of the clutch system), BUT due to the hydraulic controls arrangement on 6F it is possible to isolate two specific solenoid failures from clutch system faults:

1. SSB stuck on from C35R stuck on - due to hydraulic interlock between CBLR and C35R we can isolate SSB stuck on from C35R by turning SSE on in 1<sup>st</sup> gear without engine braking (get 1<sup>st</sup> if SSB stuck on, get 3<sup>rd</sup> if C35R is stuck on)
2. SSD stuck off. Since SSD is multiplexed (controls both CBLR and C456) we can isolate CBLR stuck off and C456 stuck off from SSD stuck off since the latter impacts both clutch systems.

For SSA thru SSD Diagnostics will isolate the fault into clutch functionally (non-electrical) failed off (SSA P0751, SSB P0756, SSC P0761, SSD P0766) and clutch functionally failed on (SSA: P0752, SSB: P0757, SSC: P0762, SSD: P0767). The On/Off solenoid (SSE) controls the multiplexing of SSD between CBLR and C456 clutches. Using ratio we can determine if the multiplex valve is in the wrong position, but cannot be sure if the failure is due to the solenoid or a stuck valve. The multiplex valve is tested for stuck in default position (P0771, includes SSE stuck off) and stuck in spring compressed position (P0772, includes SSE stuck on) failures.

### Gear ratio errors:

If ratio errors are detected that do not match an expected pattern for a failed solenoid then gear ratio error fault codes (1<sup>st</sup> gear – P0731, 2<sup>nd</sup> gear – P0732, 3<sup>rd</sup> gear – P0733, 4<sup>th</sup> gear – P0734, 5<sup>th</sup> gear – P0735 or 6<sup>th</sup> gear – P0729) will be stored.

### Torque Converter Clutch

The Torque Converter Clutch (TCC) solenoid is a Variable Force Solenoid. TCC solenoid circuit is checked electrically for open, short to ground and short to power circuit faults internally in the PCM by monitoring the status of a feedback circuit from the output driver (P0740, P0742, P0744).

The TCC solenoid is checked functionally by evaluating torque converter slip under steady state conditions when the torque converter is fully applied. If the slip exceeds the malfunction thresholds when the TCC is commanded on, a TCC malfunction is indicated (P0741). ). If the TCC is stuck on when commanded off in multiple gears a fault code is stored (P2758).

For 6F35 the TCC is controlled by a 2 valve system - TCC reg apply and TCC control valve. Normally the TCC VFS controls the positions of these valves - turning on the TCC VFS moves both valves from the release to the apply position. If the TCC control valve sticks in the apply position then there will be no flow thru the TCC (both apply and release sides exhausted) when commanded open, which will cause the converter to overheat.

A method to detect this failure was designed into the hardware - SSE pressure is routed to the TCC reg apply valve (SSE has no effect on TCC control valve). In 3rd gear or higher if TCC is open SSE can be turned on, moving the TCC reg apply valve to the apply position. If the TCC control valve is in the wrong (apply) position this will cause the TCC to apply. If the TCC applies when SSE is turned on in 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> or 6<sup>th</sup> gear while TCC is commanded open (TCC VFS pressure low) the failure will be detected, a P2783 DTC fault code stored. Even though this test only detects failures of the control valve, the FMEM actions alter the shift and TCC lock schedules to keep the TCC applied as much as possible, so this failure has been made MIL.

## Electronic Pressure Control

The EPC solenoid is a variable force solenoid that controls line pressure in the transmission. The EPC solenoid has a feedback circuit in the PCM that monitors EPC current. If the current indicates a short to ground (low pressure), a high side switch will be opened. This switch removes power from all 6 VFSs and the on/off shift solenoid, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. This solenoid is tested for open (P0960), short to ground (P0962), and short to power (P0963) malfunctions.

## High Side Switch

6F35 has a high side switch that can be used to remove power from all 7 solenoids simultaneously. If the high side switch is opened, all 7 solenoids will be electrically off, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. The switch is tested for open faults (switch failed closed will provide normal control). If the switch fails, a P0657 fault code will be stored.

ADLER (chip that controls all 7 solenoids) diagnostics:

The solenoids are controlled by an ADLER chip. The main micro sends commanded solenoid states to the ADLER, and receives back solenoid circuit fault information.

If communication with the ADLER is lost a P1636 fault code will be stored. If this failure is detected the states of the solenoids are unknown, so the control system will open the high side switch (removes power from all the solenoids), providing P, R, N and 5M with open TCC and max line pressure.

## TRID Block

The TRID block is a portion of flash memory that contains solenoid characterization data tailored to the specific transmission to improve pressure accuracy.

The TRID block is monitored for two failures:

- TRID block checksum error / incorrect version of the TRID (P163E)
- TRID block not programmed (P163F)

If the TRID block is unavailable FMEM action limits operation to 1<sup>st</sup> and 3<sup>rd</sup> gear until the issue is correct.

## Transmission Control Module (TCM only present on )

The TCM has the same module diagnostics as a PCM – see miscellaneous CPU tests.

### CAN Communications Error

The TCM receives information from the ECM via the high speed CAN network. If the CAN link or network fails, the TCM no longer has torque or engine speed information available. The TCM will store a U0073 fault code and will illuminate the MIL immediately (missing engine speed) if the CAN Bus is off. The TCM will store a U0100 fault code and will illuminate the MIL immediately (missing engine speed) if it stops receiving CAN messages from the ECM. A U0401 fault codes will be stored if the ECM sends invalid/faulted information for the following CAN message items: engine torque, pedal position.

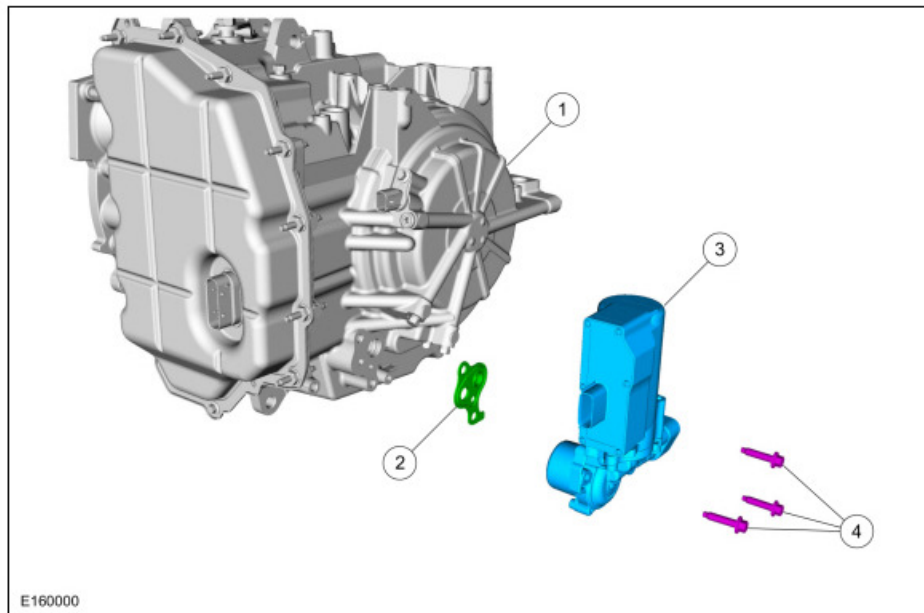
### TCM voltage

If the system voltage at the TCM is outside of the specified 9 to 16 volt range, a fault will be stored (P0882, P0883).

## Auxiliary Transmission Fluid Pump (Stop Start Applications)

For Stop Start applications, an Electronic Auxiliary Transmission Oil Pump (ePump) has been added to the transmission to allow clutches to stay engaged when the engine stops. The auxiliary pump is an electric external pump bolted to the transmission case. This allows quicker response on restarts since the transmission is ready before the main pump begins outputting pressure.

### Transmission Fluid Auxiliary Pump Components



Item	Part Number	Description
1	7005	Transmission case
2	7A136	Transmission fluid auxiliary pump-to-transmission case gasket
3	7B086	Transmission fluid auxiliary pump
4	W715302	Transmission fluid auxiliary pump-to-transmission case bolt (3 required)

The Electronic Auxiliary Transmission Oil Pump is a “smart” device – the PCM or TCM communicates with the pump via 2 Pulse Width Modulated (PWM) hardwires:

- PCM or TCM outputs a commanded pump speed to the pump using a PWM signal:

Duty Cycle	RPM of motor
0-9.9%	Reserved for diagnostics
10-19.9	Off state
20-22.9	100 rpm (pre-shipment supplier test)
23-90%	937.14 rpm to 4,000 rpm (linear range of operation)
90.1-100%	Reserved for diagnostics

- The pump outputs the fault status of the pump to the PCM or TCM using a PWM signal. The fault status is used to store the appropriate DTC in the PCM or TCM.

Duty Cycle	Indicated Operating Condition	DTC	Definition
0-10%	Out of range low	P0C2D	Electric Transmission Fluid Pump Control Module Feedback Signal Low
10-15%	Under Current, Correct Speed	P0C27	Electric/Auxiliary Transmission Fluid Pump "A" Motor Current Low
20-25%	Over Current, Correct Speed	P0C28	Electric/Auxiliary Transmission Fluid Pump "A" Motor Current High
30-34%	Over Temperature	P175A	Transmission Fluid Over Temperature Condition - Electric Transmission Fluid Pump Disabled
35-40%	Stalled	P0C2A	Electric/Auxiliary Transmission Fluid Pump "A" Motor Stalled
45-50%	Correct Current and Speed	n/a	
55-60%	Over Speed, Correct Current	P0B0D	Electric/Auxiliary Transmission Fluid Pump Motor Control Module
65-70%	Under Speed, Correct Current	P0B0D	Electric/Auxiliary Transmission Fluid Pump Motor Control Module
75-80%	Current and Speed out of Range	P0C29	Electric/Auxiliary Transmission Fluid Pump "A" Driver Circuit Performance
85-90%	No Command Signal Received from PCM	P2796	Electric Transmission Fluid Pump Control Circuit
90-100%	Out of range high	P0C2E	Electric Transmission Fluid Pump Control Module Feedback Signal High
Frequency out of range or duty cycle between valid ranges	Signal should be 120 Hz +/- 20 Hz. Should not see in-range but unused duty cycle values	P0C2C	Electric Transmission Fluid Pump Control Module Feedback Signal Range/Performance

Failures of the pump take the Stop Start system out of operation – if stopped the engine will restart, then will no longer stop for the remainder of the current drive cycle.



## 6F15 (FWD) Transmission with external PCM or TCM

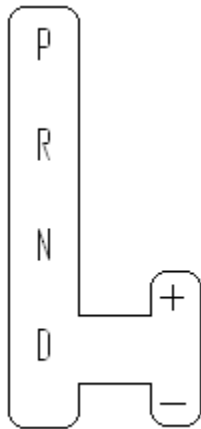
The 6F15 is a smaller version of the 6F35.

### Transmission Inputs

Transmission Range Sensor – 6F15 uses a Non-contacting Pulse Width Modulated Transmission Range Sensor (TRS) that provides a duty cycle signal for each position. This signal is transmitted at a frequency of 125 Hz. The PCM decodes the duty cycle to determine the driver-selected gear position (Park, Rev, Neutral, OD, 3, 2, 1). This input device is checked for out of range frequency, low duty cycle and high duty cycle input signals. (P0706, P0707, P0708)

### Select Shift Transmission (SST) Up/Down

6F15 is supports. This system has two PCM inputs, an upshift switch and a downshift switch. The switches are built into the shifter (defined as an H-gate in this implementation) or Paddles behind the shifter:



For the H-gate:

Both PCM inputs are open when the shifter is on the left hand side. From Drive as the customer moves the shifter to the right both inputs transition from open to closed (the TRS continues to indicate Drive). The control system enters "Grade Assist Mode" (provides more engine braking but still follows an automatic shift schedule) at this point. If the customer never requests a shift the control system will remain in Grade Assist Mode.

The customer requests a shift by pushing the shifter up or down, which opens the appropriate switch. Once the customer requests a shift the control system transitions from Grade Assist Mode to SST. In SST the control system follows the customer's commands except for special conditions (downshifts to the lowest available gear at high pedal, downshifts at low speeds).

Diagnostics monitors for either switch closed in Park, Reverse or Neutral, and a failure will result in non-MIL P0815 (upshift switch error) or P0816 (downshift switch error) fault codes.

If either switch fails open the customer will not be able to enter Grade Mode or SST since both switches must transition from open to closed while in the Drive position to enter SST.

If either switch is detected failed Grade Assist Mode and SST are disabled and the control system defaults to Drive (normal automatic shift schedules).

Paddles:



The right paddle controls upshifts, the left paddle controls downshifts. Pulling on the appropriate paddle changes the state of the digital input.

In S the transmission will automatically shift until one of the paddles is actuated, then it will switch into “Select Shift Transmission” (SST), holding the customer selected gear until a shift request is made via the paddles, with some minor overrides like the transmission will downshift from 5<sup>th</sup> or 6<sup>th</sup> to 1<sup>st</sup> at a stop to avoid launching in a high gear if the customer forgot to downshift upon coming to a stop.

In Drive the paddles can be used to temporarily select a gear – this feature is called “Live in Drive”. The system will hold the customer selected gear indefinitely under certain operating conditions (closed pedal going down a grade or in a turn), but under normal road load conditions the system will time out after 2-3 seconds, returning to the normal automatic shift schedules.

The paddles are ignored in P, R and N.

### Speed Sensors

The Turbine Shaft Speed (TSS) sensor and Output Shaft Speed (OSS) sensor are Hall Effect inputs that are checked for rationality. The vehicle speed signal is provided from the ABS system (if present) to the PCM, or is derived from OSS. If the engine rpm is above the torque converter stall speed and engine load is high, it can be inferred that the vehicle must be moving. If there is insufficient output from the TSS sensor, a malfunction is indicated (P0715). If there is insufficient output from the OSS sensor, a malfunction is indicated (P0720). 6F35 applications currently use ABS vehicle speed the primary source of vehicle speed with OSS as a backup, if both sources are failed a P1934 “Vehicle Speed Signal” DTC is stored.

### Transmission Fluid Temperature

6F15 has a feature called “Cold mode” (1<sup>st</sup> implemented in 5R110W in 2003 MY). If TFT is below -20 deg F, the transmission will limit operation to 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> gears (5<sup>th</sup> and 6<sup>th</sup> gears are disabled). Cold mode remains in effect until TFT rises above -20 deg F or vehicle operation (based on shift times or heat generated by driving) indicates that TFT should not be in the cold mode range, at which point normal operation is enabled.

if TFT is failed at start up the transmission will be placed in cold mode and remain there until TFT is no longer failed and above -20 deg F or the vehicle operating conditions listed above trigger an exit from cold mode.

Once out of cold mode a TFT failure will not trigger cold mode (can only go into cold mode once/power-up); this mode is the same as implemented on 5R110W in 2003.5 MY.

TFT is monitored for circuit faults (P0712, P0713) and in-range failures (P0711)

For this reason all TFT diagnostics illuminate the MIL on 6F35.

## Transmission Outputs

### Shift Solenoids

6F15 has 5 shift solenoids:

- SSA – a Variable Force Solenoid (VFS) that controls CB1234 (a brake clutch, grounds an element to the case, that is on in 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> gear)
- SSB – a VFS that controls C35R (a rotating clutch on in 3<sup>rd</sup>, 5<sup>th</sup> and Reverse)
- SSC – a VFS that controls CB26 (a brake clutch on in 2<sup>nd</sup> and 6<sup>th</sup> gear)
- SSD – a VFS that controls either CBLR (a brake clutch on in 1<sup>st</sup> gear with engine braking and Reverse) or C456 (a rotating clutch on in 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> gear)
- SSE – an On/Off solenoid that controls the multiplexing of SSD between CBLR and C456.

Output circuits are checked for opens, short to ground and short to power faults (codes listed in that order) by the PCM by monitoring the status of a feedback circuit from the output driver (SSA P0750, P0973, P0974; SSB P0755, P0976, P0977; SSC P0760, P0979, P0980; SSD P0765, P0982, P0983; SSE P0770).

The shift solenoids are also functional tested for stuck on and stuck off failures. This is determined by vehicle inputs such as gear command, and achieved gear (based on turbine and output speed). In general the shift solenoid malfunction codes actually cover the entire clutch system (solenoid, valves, and the clutch itself since using ratio there is no way to isolate the solenoid from the rest of the clutch system), BUT due to the hydraulic controls arrangement on 6F it is possible to isolate two specific solenoid failures from clutch system faults:

- SSB stuck on from C35R stuck on - due to hydraulic interlock between CBLR and C35R we can isolate SSB stuck on from C35R by turning SSE on in 1<sup>st</sup> gear without engine braking (get 1<sup>st</sup> if SSB stuck on, get 3<sup>rd</sup> if C35R is stuck on)
- SSD stuck off. Since SSD is multiplexed (controls both CBLR and C456) we can isolate CBLR stuck off and C456 stuck off from SSD stuck off since the latter impacts both clutch systems.

For SSA thru SSD Diagnostics will isolate the fault into clutch functionally (non-electrical) failed off (SSA P0751, SSB P0756, SSC P0761, SSD P0766) and clutch functionally failed on (SSA: P0752, SSB: P0757, SSC: P0762, SSD: P0767). The On/Off solenoid (SSE) controls the multiplexing of SSD between CBLR and C456 clutches. Using ratio we can determine if the multiplex valve is in the wrong position, but cannot be sure if the failure is due to the solenoid or a stuck valve. The multiplex valve is tested for stuck in default position (P0771, includes SSE stuck off) and stuck in spring compressed position (P0772, includes SSE stuck on) failures.

### Gear ratio errors:

If ratio errors are detected that do not match an expected pattern for a failed solenoid then gear ratio error fault codes (1<sup>st</sup> gear – P0731, 2<sup>nd</sup> gear – P0732, 3<sup>rd</sup> gear – P0733, 4<sup>th</sup> gear – P0734, 5<sup>th</sup> gear – P0735 or 6<sup>th</sup> gear – P0729) will be stored.

### Torque Converter Clutch

The Torque Converter Clutch (TCC) solenoid is a Variable Force Solenoid. TCC solenoid circuit is checked electrically for open, short to ground and short to power circuit faults internally in the PCM by monitoring the status of a feedback circuit from the output driver (P0740, P0742, P0744).

The TCC solenoid is checked functionally by evaluating torque converter slip under steady state conditions when the torque converter is fully applied. If the slip exceeds the malfunction thresholds when the TCC is commanded on, a TCC malfunction is indicated (P0741). If the TCC is stuck on when commanded off in multiple gears a fault code is stored (P2758).

For 6F15 the TCC is controlled by a 2 valve system - TCC reg apply and TCC control valve. Normally the TCC VFS controls the positions of these valves - turning on the TCC VFS moves both valves from the release to the apply position. If the TCC control valve sticks in the apply position then there will be no flow thru the TCC (both apply and release sides exhausted) when commanded open, which will cause the converter to overheat.

A method to detect this failure was designed into the hardware - SSE pressure is routed to the TCC reg apply valve (SSE has no effect on TCC control valve). In 3<sup>rd</sup> gear or higher if TCC is open SSE can be turned on, moving the TCC reg apply valve to the apply position. If the TCC control valve is in the wrong (apply) position this will cause the TCC to apply. If the TCC applies when SSE is turned on in 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> or 6<sup>th</sup> gear while TCC is commanded open (TCC VFS pressure low) the failure will be detected, a P2783 DTC fault code stored. Even though this test only detects failures of the control valve, the FMEM actions alter the shift and TCC lock schedules to keep the TCC applied as much as possible, so this failure has been made MIL.

## Electronic Pressure Control

The EPC solenoid is a variable force solenoid that controls line pressure in the transmission. The EPC solenoid has a feedback circuit in the PCM that monitors EPC current. If the current indicates a short to ground (low pressure), a high side switch will be opened. This switch removes power from all 6 VFSs and the on/off shift solenoid, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. This solenoid is tested for open (P0960), short to ground (P0962), and short to power (P0963) malfunctions.

## High Side Switch

6F15 has a high side switch that can be used to remove power from all 7 solenoids simultaneously. If the high side switch is opened, all 7 solenoids will be electrically off, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. The switch is tested for open faults (switch failed closed will provide normal control). If the switch fails, a P0657 fault code will be stored.

ADLER (chip that controls all 7 solenoids) diagnostics:

The solenoids are controlled by an ADLER chip. The main micro sends commanded solenoid states to the ADLER, and receives back solenoid circuit fault information.

If communication with the ADLER is lost a P1636 fault code will be stored. If this failure is detected the states of the solenoids are unknown, so the control system will open the high side switch (removes power from all the solenoids), providing P, R, N and 5M with open TCC and max line pressure.

## TRID Block

The TRID block is a portion of flash memory that contains solenoid characterization data tailored to the specific transmission to improve pressure accuracy.

The TRID block is monitored for two failures:

- TRID block checksum error / incorrect version of the TRID (P163E)
- TRID block not programmed (P163F)

If the TRID block is unavailable FMEM action limits operation to 1<sup>st</sup> and 3<sup>rd</sup> gear until the issue is correct.

## Transmission Control Module (TCM only present on )

The TCM has the same module diagnostics as a PCM – see miscellaneous CPU tests.

### CAN Communications Error

The TCM receives information from the ECM via the high speed CAN network. If the CAN link or network fails, the TCM no longer has torque or engine speed information available. The TCM will store a U0073 fault code and will illuminate the MIL immediately (missing engine speed) if the CAN Bus is off. The TCM will store a U0100 fault code and will illuminate the MIL immediately (missing engine speed) if it stops receiving CAN messages from the ECM. A U0401 fault codes will be stored if the ECM sends invalid/faulted information for the following CAN message items: engine torque, pedal position.

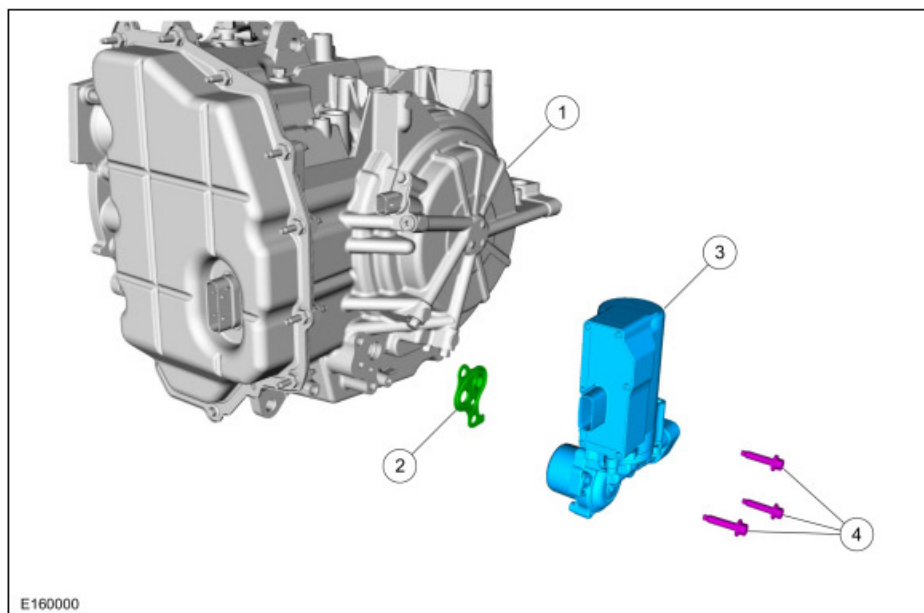
### TCM voltage

If the system voltage at the TCM is outside of the specified 9 to 16 volt range, a fault will be stored (P0882, P0883).

## Auxiliary Transmission Fluid Pump (Stop Start Applications)

For Stop Start applications, an Electronic Auxiliary Transmission Oil Pump (ePump) has been added to the transmission to allow clutches to stay engaged when the engine stops. The auxiliary pump is an electric external pump bolted to the transmission case. This allows quicker response on restarts since the transmission is ready before the main pump begins outputting pressure.

### Transmission Fluid Auxiliary Pump Components



Item	Part Number	Description
1	7005	Transmission case
2	7A136	Transmission fluid auxiliary pump-to-transmission case gasket
3	7B086	Transmission fluid auxiliary pump
4	W715302	Transmission fluid auxiliary pump-to-transmission case bolt (3 required)

The Electronic Auxiliary Transmission Oil Pump is a “smart” device – the PCM or TCM communicates with the pump via 2 Pulse Width Modulated (PWM) hardwires:

- PCM or TCM outputs a commanded pump speed to the pump using a PWM signal:

Duty Cycle	RPM of motor
0-9.9%	Reserved for diagnostics
10-19.9	Off state
20-22.9	100 rpm (pre-shipment supplier test)
23-90%	937.14 rpm to 4,000 rpm (linear range of operation)
90.1-100%	Reserved for diagnostics

- The pump outputs the fault status of the pump to the PCM or TCM using a PWM signal. The fault status is used to store the appropriate DTC in the PCM or TCM.

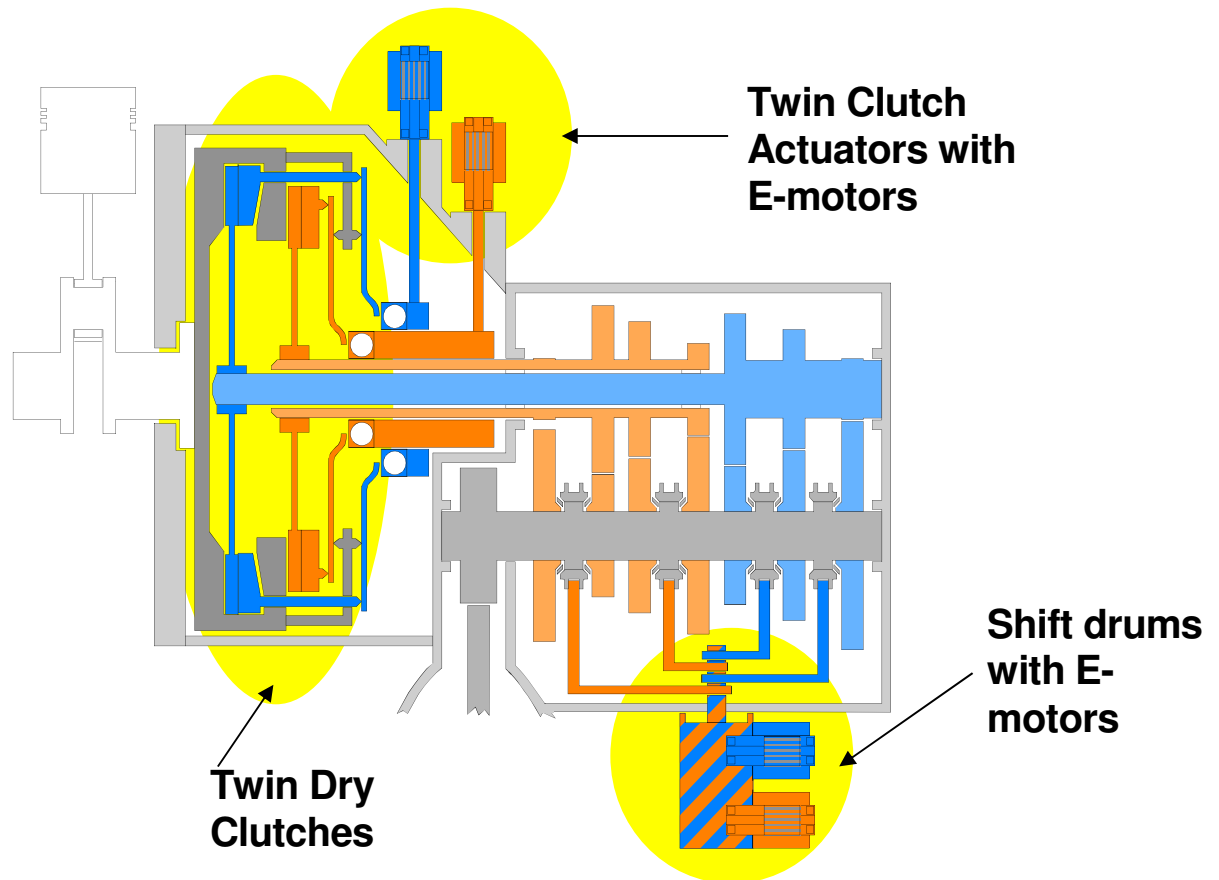
Duty Cycle	Indicated Operating Condition	DTC	Definition
0-10%	Out of range low	P0C2D	Electric Transmission Fluid Pump Control Module Feedback Signal Low
10-15%	Under Current, Correct Speed	P0C27	Electric/Auxiliary Transmission Fluid Pump "A" Motor Current Low
20-25%	Over Current, Correct Speed	P0C28	Electric/Auxiliary Transmission Fluid Pump "A" Motor Current High
30-34%	Over Temperature	P175A	Transmission Fluid Over Temperature Condition - Electric Transmission Fluid Pump Disabled
35-40%	Stalled	P0C2A	Electric/Auxiliary Transmission Fluid Pump "A" Motor Stalled
45-50%	Correct Current and Speed	n/a	
55-60%	Over Speed, Correct Current	P0B0D	Electric/Auxiliary Transmission Fluid Pump Motor Control Module
65-70%	Under Speed, Correct Current	P0B0D	Electric/Auxiliary Transmission Fluid Pump Motor Control Module
75-80%	Current and Speed out of Range	P0C29	Electric/Auxiliary Transmission Fluid Pump "A" Driver Circuit Performance
85-90%	No Command Signal Received from PCM	P2796	Electric Transmission Fluid Pump Control Circuit
90-100%	Out of range high	P0C2E	Electric Transmission Fluid Pump Control Module Feedback Signal High
Frequency out of range or duty cycle between valid ranges	Signal should be 120 Hz +/- 20 Hz. Should not see in-range but unused duty cycle values	P0C2C	Electric Transmission Fluid Pump Control Module Feedback Signal Range/Performance

Failures of the pump take the Stop Start system out of operation – if stopped the engine will restart, then will no longer stop for the remainder of the current drive cycle.

## DPS6 (FWD) Transmission

DPS6 is a fully automatic 6 speed transmission made up of manual transmission gearing, combined with electro-mechanical actuators, and conventional automatic transmission controls.

### The Gearbox & Dual-Clutch System Physical Architecture



DPS6 has 2 clutches:

1. Clutch A – on in 1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup> gear
2. Clutch B – on in Reverse, 2<sup>nd</sup>, 4<sup>th</sup> and 6<sup>th</sup> gear

Each clutch system consists of:

- Clutch
- 3 phase electric motor – rotates a screw driven fulcrum that controls clutch position (and torque). There are end stops at the full open and full closed positions
- Each motor phase has a hall position sensor that combine to provide a relative position – the system must sweep the clutch full open to full closed, then count increments on the sensors to know position. It takes many rotations of the motor to sweep the clutch from fully open to fully closed.
- Spring that returns the clutch to the full open position if the motor is turned off.

DPS6 has 2 shift drums:

1. Shift Drum A – controls the shift forks that engage 1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup> gear
2. Shift Drum B – controls the shift forks that engage Reverse, 2<sup>nd</sup>, 4<sup>th</sup> and 6<sup>th</sup> gear

Each shift drum system consists of:

- Shift drum with groove that controls the position of shift forks
- Shift forks that engage synchronizers and gears
- 3 phase electric motor that controls the position of the shift drum
- Hall sensor system that knows the position of the motor within a rotation, used to calculate the shift drum angular position (the shift drum motor rotates 61.44 times for a single revolution of the shift drum)

Relationship between shift drum angle and gears;

Angle	Shift drum 1 position	Shift drum 2 position
0 deg	End stop near 1 <sup>st</sup>	End stop near Reverse
10 deg	Centered in 1 <sup>st</sup>	Centered in Reverse
55 deg	Neutral between 1 <sup>st</sup> and 3 <sup>rd</sup>	Neutral between R and 2 <sup>nd</sup>
90 deg	Centered in 3 <sup>rd</sup>	Centered in 2 <sup>nd</sup>
135 deg	Neutral between 3 <sup>rd</sup> and 5 <sup>th</sup>	Neutral between 2 <sup>nd</sup> and 4 <sup>th</sup>
190 deg	Centered in 5 <sup>th</sup>	Centered in 4 <sup>th</sup>
200 deg	End stop near 5 <sup>th</sup>	4 <sup>th</sup> gear
235 deg		Neutral between 4 <sup>th</sup> and 6 <sup>th</sup>
280		Centered in 6 <sup>th</sup>
290		End stop near 6 <sup>th</sup>

## Transmission Inputs

### Transmission Range Sensor

DPS6 is range by wire with mechanical Park. DPS6 uses a dual PWM output (at 250 Hz) TRS where one signal is the inverse of the other and the sum of the two signals add up to 100%. Each signal is tested for frequency errors (P0706 / P2801), duty cycle out of range low (P0707 / P2802) and duty cycle out of range high (P0708 / P2803). There is also a correlation error (P2805) if the two signals do not add up to 100%.

### Speed Sensors

Input 1 Speed Sensor (I1SS) – detects input shaft 1 speed, connected to clutch 1 and the odd gears (1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup>). I1SS is tested for power supply faults (P06A6), circuit failures detected by the TCM hardware (P0715), erratic signal (P0716), and lack of signal (P0717).

Input 2 Speed Sensor (I2SS) – detects input shaft 2 speed, connected to clutch 2 and the even gears (R, 2<sup>nd</sup>, 4<sup>th</sup> and 6<sup>th</sup>). I2SS is tested for power supply faults (P06A7), circuit failures detected by the TCM hardware (P2765), erratic signal (P2766), and lack of signal (P2767).

Output Speed Sensor (OSS) – detects output speed. OSS is tested for power supply faults (P06A8), circuit failures detected by the TCM hardware (P0720), erratic signal (P0721), and lack of signal (P0722).

Note: because DPS6 is "Dry clutch" the only transmission fluid is for splash lube (no pump, no pressure control solenoids), so DPS6 does not have a temperature sensor.

## Transmission Outputs

DPS6 has four 3-phase electric motors:

1. Clutch A motor – controls clutch A torque capacity. The Clutch A system is tested for:
  - a. ATIC faults (P0805) – the ATIC is an internal TCM component that controls motor current.
  - b. Hall sensor faults (P0806) – each phase has a hall sensor that provides motor position information
  - c. Sequence faults (P0809) – as the motor rotates it generates an defined pattern from the 3 hall sensors, if the sequence of hall sensor patterns is off this code sets.
  - d. Open circuit (P0900)
  - e. Short to ground (P0902)
  - f. Short to power (P0903)
  - g. Clutch functionally stuck off (P07A2)
  - h. Clutch functionally stuck on (P07A3)
2. Clutch B motor – controls clutch B torque capacity. The Clutch B system is tested for:
  - a. ATIC faults (P087A) – the ATIC is an internal TCM component that controls motor current.
  - b. Hall sensor faults (P087B) – each phase has a hall sensor that provides motor position information
  - c. Sequence faults (P087E) – as the motor rotates it generates an defined pattern from the 3 hall sensors, if the sequence of hall sensor patterns is off this code sets.
  - d. Open circuit (P090A)
  - e. Short to ground (P090C)
  - f. Short to power (P090D)
  - g. Clutch functionally stuck off (P07A4)
  - h. Clutch functionally stuck on (P07A5)

3. Shift drum A motor – controls the shift forks that engage 1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup> gear. The system is tested for:
  - a. ATIC faults (P2831) – the ATIC is an internal TCM component that controls motor current.
  - b. Sequence faults (P2835) – as the motor rotates it generates an defined pattern from the 3 hall sensors, if the sequence of hall sensor patterns is off this code sets.
  - c. Open circuit (P285B)
  - d. Short to ground (P285D)
  - e. Short to power (P285E)
  - f. Stuck in gear (P072C, P072E, P073A)
  - g. Position error (P2832) – includes blocked motor, or any failure that results in the TCM losing confidence in the relative position of the shift drum.
4. Shift drum A motor – controls the shift forks that engage 1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup> gear. The system is tested for:
  - a. ATIC faults (P2836) – the ATIC is an internal TCM component that controls motor current.
  - b. Sequence faults (P283A) – as the motor rotates it generates an defined pattern from the 3 hall sensors, if the sequence of hall sensor patterns is off this code sets.
  - c. Open circuit (P285F)
  - d. Short to ground (P2861)
  - e. Short to power (P2862)
  - f. Stuck in gear (P072B, P072D, P072F, P073B)
  - g. Position error (P2837) – includes blocked motor, or any failure that results in the TCM losing confidence in the relative position of the shift drum.

## **Transmission Control Module (TCM)**

The TCM monitors itself by using various software monitoring functions. The TCM is monitored for:

- a. If a RAM Read/Write error is detected during initialization, a P0604 fault code will be stored
- b. the flash ROM is checked using a checksum calculation. If the checksum is incorrect during a P0605 fault will be stored
- c. CPU performance is monitored for incorrect instructions or resets, if detected a P0607 fault code is set
- d. If an error is found with NVRAM a P06B8 fault code will be stored

## **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 fault code if it doesn't receive any more CAN messages from the ECM. A U0401 fault codes will be stored if the ECM received invalid/faulted information for the following CAN message items: engine torque, pedal position.

System voltage:

the TCM monitors system voltage and stores fault codes if it is out of range low (P0882) or out of range high (P0883). These thresholds are set based on hardware capability.

## **6R140 (RWD) Transmission with PCM or external TCM**

### **Transmission Control System Architecture**

Starting in 2011 MY 6R140 replaces 5R110W in Super Duty truck applications.

The 6R140 is a 6-speed, step ratio transmission that is controlled by an external PCM (gas engine applications) or TCM (Diesel engine applications). For Diesel the TCM communicates to the Engine Control Module (ECM), ABS Module, Instrument Cluster and Transfer Case Control Module 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 outside the transmission assembly. It is not serviceable with the exception of reprogramming.

### **Transmission Inputs**

#### Transmission Range Sensor

6R140 uses a Non-contacting Pulse Width Modulated Transmission Range Sensor (TRS) that provides a duty cycle signal for each position. This signal is transmitted at a frequency of 125 Hz. The PCM / TCM decode the duty cycle to determine the driver-selected gear position (Park, Rev, Neutral, OD, 3, 2, 1). This input device is checked for frequency out of range (P0706), duty cycle out of range low (P0707) and duty cycle out of range high (P0708)

#### Speed Sensors

The Turbine Shaft Speed (TSS) sensor and Output Shaft Speed (OSS) sensor are Hall effect sensors.

The Turbine Shaft Speed sensor is monitored by a rationality test, if engine speed and output shaft speed are high and a gear is engaged, it can be inferred that the vehicle is moving. If there is insufficient output from the TSS sensor a fault is stored (P0715).

The Output Shaft Speed sensor is monitored by a rationality test. If engine speed and turbine speed are high and a gear is engaged, it can be inferred that the vehicle is moving. If there is insufficient output from the OSS sensor a fault is stored (P0720).

#### Transmission Fluid Temperature

The Transmission Fluid Temperature Sensor is checked for out of range low (P0712), out of range high (P0713), and in-range failures (P0711).

## Transmission Outputs

### Shift Solenoids

6R140 has 5 shift solenoids:

2. SSA – a Variable Force Solenoid (VFS) that controls CB1234 (a brake clutch, grounds an element to the case, that is on in 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> gear)
3. SSB – a VFS that controls C35R (a rotating clutch on in 3<sup>rd</sup>, 5<sup>th</sup> and Reverse)
4. SSC – a VFS that controls CB26 (a brake clutch on in 2<sup>nd</sup> and 6<sup>th</sup> gear)
5. SSD – a VFS that controls CBLR (a brake clutch on in 1<sup>st</sup> gear with engine braking and Reverse)
6. SSE – a VFS that controls C456 (a rotating clutch on in 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> gear)

Output circuits are checked for opens, short to ground and short to power faults (codes listed in that order) by the "smart driver" (see ADLER below) that controls the solenoids (SSA P0750, P0973, P0974; SSB P0755, P0976, P0977; SSC P0760, P0979, P0980; SSD P0765, P0982, P0983; SSE P0770, P0985, P0986).

The shift solenoids are also functional tested for stuck on and stuck off failures. This is determined by vehicle inputs such as gear command, and achieved gear (based on turbine and output speed). In general the shift solenoid malfunction codes actually cover the entire clutch system (solenoid, valves, seals and the clutch itself since using ratio there is no way to isolate the solenoid from the rest of the clutch system)

For SSA thru SSE Diagnostics will isolate the fault into clutch functionally (non-electrical) failed off (SSA P0751, SSB P0756, SSC P0761, SSD P0766, SSE P0771) and clutch functionally failed on (SSA: P0752, SSB: P0757, SSC: P0762, SSD: P0767, SSE: P0772).

### Gear ratio errors:

If ratio errors are detected that do not match an expected pattern for a failed solenoid then gear ratio error fault codes (1<sup>st</sup> gear – P0731, 2<sup>nd</sup> gear – P0732, 3<sup>rd</sup> gear – P0733, 4<sup>th</sup> gear – P0734, 5<sup>th</sup> gear – P0735 or 6<sup>th</sup> gear – P0729) will be stored.

### Torque Converter Clutch

The Torque Converter Clutch (TCC) solenoid is a Variable Force Solenoid. TCC solenoid circuit is checked electrically for open, short to ground and short to power circuit faults internally by the "smart driver" that controls the solenoids (P0740, P0742, P0744).

The TCC solenoid is checked functionally for stuck off faults by evaluating torque converter slip under steady state conditions when the torque converter is fully applied. If the slip exceeds the malfunction thresholds when the TCC is commanded on, a TCC malfunction is indicated (P0741).

The TCC solenoid is monitored functionally for stuck on faults (P2758) by monitoring for lack of clutch slip when the TCC is commanded off, but this code is non-MIL because while a stuck on TCC solenoid may cause driveability complaints and/or cause engine stalls it does not impact emissions or fuel economy.

### Electronic Pressure Control

The EPC solenoid is a variable force solenoid that controls line pressure in the transmission. The EPC solenoid is monitored for open, short to ground or short to power faults by the "smart driver" that controls the solenoid. If a short to ground (low pressure) is detected, a high side switch will be opened. This switch removes power from all 7 VFSs, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position. This solenoid is tested for open (P0960), short to ground (P0962), and short to power (P0963) malfunctions.

## Transmission Solenoid Power Control (TSPC)

6F140 PCM or TCM has a internal high side switch called TSPC that can be used to remove power from all 7 solenoids simultaneously. If the high side switch is opened, all 7 solenoids will be electrically off, providing Park, Reverse, Neutral, and 5M (in all forward ranges) with maximum line pressure based on manual lever position.

Due to current limitations TSPC is split into 2 pins / wires at the PCM / TCM. TSPC A provides power to SSA, SSC and SSE. TSPC B provides power to SSB, SSD, TCC and LPC. Each wire can be tested independently; P0657 sets for an issue with TSPC-A, P2669 sets for an issue with TPSC-B.

Although there are 2 pins and wires between the PCM / TCM and the transmission bulkhead connector the PCM / TCM contains only one TSPC internally – so the FMEM for either wire being failed is to open TSCP inside the PCM / TCM, which removes power from all 7 solenoids, providing P, R, N and 5<sup>th</sup> gear with open TCC and max line as FMEM for any TPSC faults.

ADLER (chip that controls all 7 solenoids) diagnostics:

The solenoids are controlled by an ADLER chip. The main micro sends commanded solenoid states to the ADLER, and receives back solenoid circuit fault information.

If communication with the ADLER is lost a P1636 fault code will be stored. If this failure is detected the states of the solenoids are unknown, so the control system will open the high side switch (removes power from all the solenoids), providing P, R, N and 5M with open TCC and max line pressure.

### TRID Block

The TRID block is a portion of flash memory that contains solenoid characterization data tailored to the specific transmission to improve pressure accuracy.

The TRID block is monitored for two failures:

- TRID block checksum error / incorrect version of the TRID (P163E)
- TRID block not programmed (P163F)

If the TRID block is unavailable FMEM action limits operation to 1<sup>st</sup> and 3<sup>rd</sup> gear until the issue is correct.

## Transmission Control Module (TCM – Diesel only)

The TCM has the same module diagnostics as a PCM – see miscellaneous CPU tests.

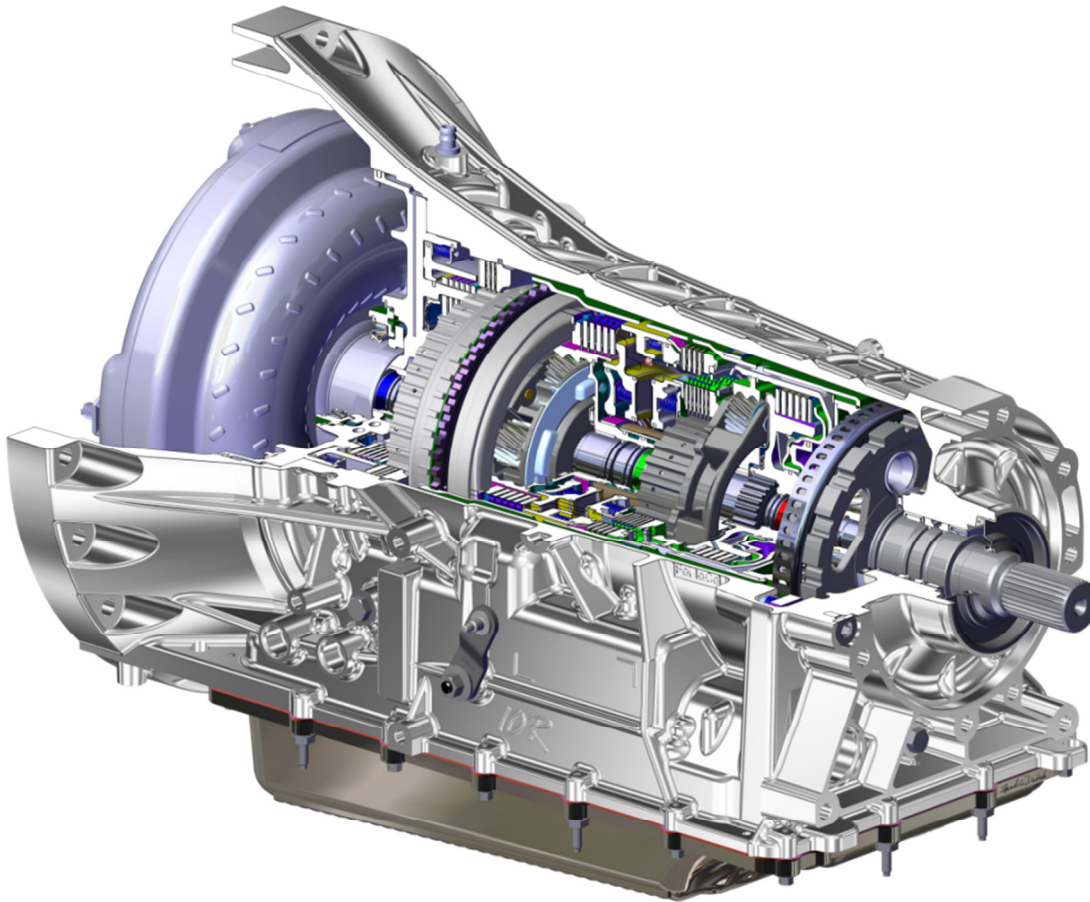
### CAN Communications Error

The TCM receives information from the ECM via the high speed CAN network. If the CAN link or network fails, the TCM no longer has torque or engine speed information available. The TCM will store a U0073 fault code and will illuminate the MIL immediately (missing engine speed) if the CAN Bus is off. The TCM will store a U0100 fault code and will illuminate the MIL immediately (missing engine speed) if it stops receiving CAN messages from the ECM. A U0401 fault codes will be stored if the ECM sends invalid/faulted information for the following CAN message items: engine torque, pedal position.

### TCM voltage

If the system voltage at the TCM is outside of the specified 9 to 16 volt range, a fault will be stored (P0882, P0883).

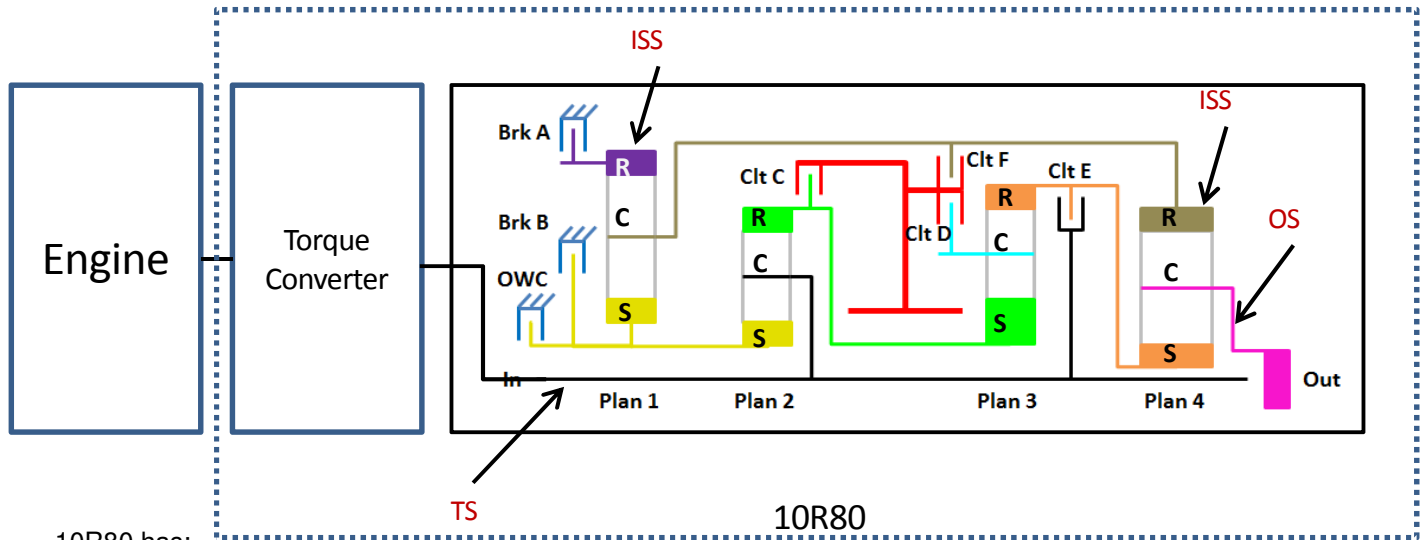
## 10R80 (RWD) Transmission



Starting in 2017 MY, 10R80 replaces 6R80 on some truck applications. 10R80 is a 10-speed, step ratio rear wheel drive transmission that is controlled by an external Control Module.

- 2017 MY 10R80 will be controlled by a Transmission Control Module (TCM).
- Starting in 2018 MY, a Powertrain Control Module (PCM) that controls both engine and transmission function will be introduced on gas engine applications
- For Diesel engine applications 10R80 will continue be controlled by a TCM.

## 10R80 Stick Diagram:



10R80 has:

- A Torque Converter with a Torque Converter bypass Clutch (TCC)
- 4 planetary gear sets – each with a Ring gear (R), Carrier (C) and Sun gear (S)
- 7 clutches (Clutches A-F plus a One Way Clutch)
- 4 speed sensors
  - Turbine Speed Sensor (TSS) – senses transmission input speed, Carrier 2 (C2)
  - Intermediate Speed Sensor A (ISSA) – senses Ring gear 1 speed (R1)
  - Intermediate Speed Sensor B (ISSB) – senses Carrier 1 / Ring 4 speed (C1 and R4 are connected, always rotate at the same speed)
  - Output Speed Sensor (OSS) – senses Carrier 4 speed (C4)

10R80 Element apply chart:

Gear	Ratio	A	B	C	D	E	F	OWC – prevents S1 from rotating backward
Park	n/a	X	X		X			B is on so S1 will not rotate
Reverse	-4.866	X	X		X		X	Holds power off, B holds power on
Neutral	n/a		X		X			
1st without engine braking	$\leq 4.696$	X			X	X		Holds power on, overruns power off
1 <sup>st</sup> with engine braking	4.696	X	X		X	X		Holds power on, B holds power off
2 <sup>nd</sup> without engine braking	$\leq 2.985$	X		X	X			Holds power on, overruns power off
2 <sup>nd</sup> with engine braking	2.985	X	X	X	X			Holds power on, B holds power off
3 <sup>rd</sup>	2.146	X		X	X	X		Overruns (S1 rotates forward)
4 <sup>th</sup>	1.769	X		X	X		X	Overruns (S1 rotates forward)
5 <sup>th</sup>	1.520	X		X		X	X	Overruns (S1 rotates forward)
6 <sup>th</sup>	1.275	X			X	X	X	Overruns (S1 rotates forward)
7 <sup>th</sup>	1.000			X	X	X	X	Overruns (S1 rotates forward)
8 <sup>th</sup>	0.854		X		X	X	X	Holds Power off, B holds power on
9 <sup>th</sup>	0.689		X	X		X	X	Holds Power off, B holds power on
10 <sup>th</sup>	0.636		X	X	X		X	Holds Power off, B holds power on

## Range by wire:

All 10R80s are range by wire – there is no manual valve. Nothing in the hydraulic controls needs to be placed in a specific position to allow Reverse or Forward gears -> all 6 clutches are under electronic control independent of customer selected range.

To support range by wire the 10R80 has picked the following hardware changes (compared to a 6 speed automatic):

- 1) Clutches are always feed by line pressure
- 2) An anti-backflow valve was added to exhaust line pressure at minimum pump out pressure
- 3) Dual Transmission Range Sensors to insure no single point faults can lead to the electronic control system misinterpreting the customer selected range.
- 4) Improved speed sensing capability
  - 4 speed sensors to improve clutch slip monitoring capability
  - All 4 speed sensors have direction sensing
  - All 4 speed sensors are 2 wire hall effect sensors - chosen to support circuit diagnostics. If a sensor is disconnected or shorted the on board diagnostics can detect the fault without requiring the vehicle be driven. This provides better isolation of speed sensor faults from non-electrical clutch faults since speed sensors are used to determine the clutch states.

10R80 will have 2 variants: mechanical shifter and shift by wire:

In 2017 MY 10R80 will have a mechanical shifter.

- Shifter is connected via a cable to the transmission
- The shifter engages and disengages Park
- The shifter position is read via dual Transmission Range Sensors (TRS A and B) to determine customer selected range (P, R, N, D, S)
- There is no manual valve – the electronics provide forward or reverse based on the TRS signals (range by wire).

In 2018 MY some applications will be shift by wire, replacing the mechanical shifter with:

- Gear Shift Module (GSM) – customer interface for selecting range (P,R,N,D S), can be push buttons or a rotary dial
- Hydraulic Controls are modified, adding a Park Servo Valve connected to the Park rod, used to engage and disengage Park.
  - Clutches B and D pressures are used to push the system out of Park
  - Once out of Park clutches A, B, C, D or F pressures can hold the system out of Park
- A Hold Out Of Park (HOOP) solenoid is added to allow the system to remain out of Park when the engine is not running.
- A mechanical override has been provided for in plant use and towing - a lever on the side of the transmission that can be bolted into one of two positions (normal control, override). In the override position the transmission is held out of park, removing control of the park system from the hydraulic controls.
- The dual Transmission Range Sensors now indicate the state of the Park system, and are not used to determine customer selected range (that comes from the GSM)

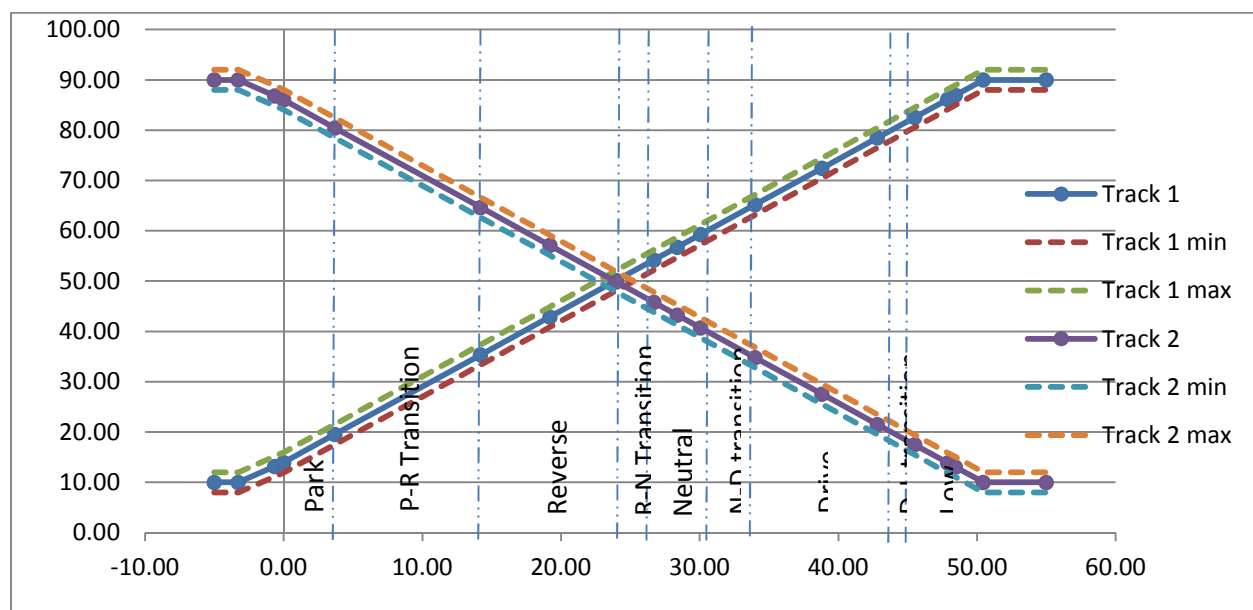
## Transmission Inputs

### Transmission Range Sensors A and B

10R80 uses a dual PWM output (at 125 Hz) TRS where:

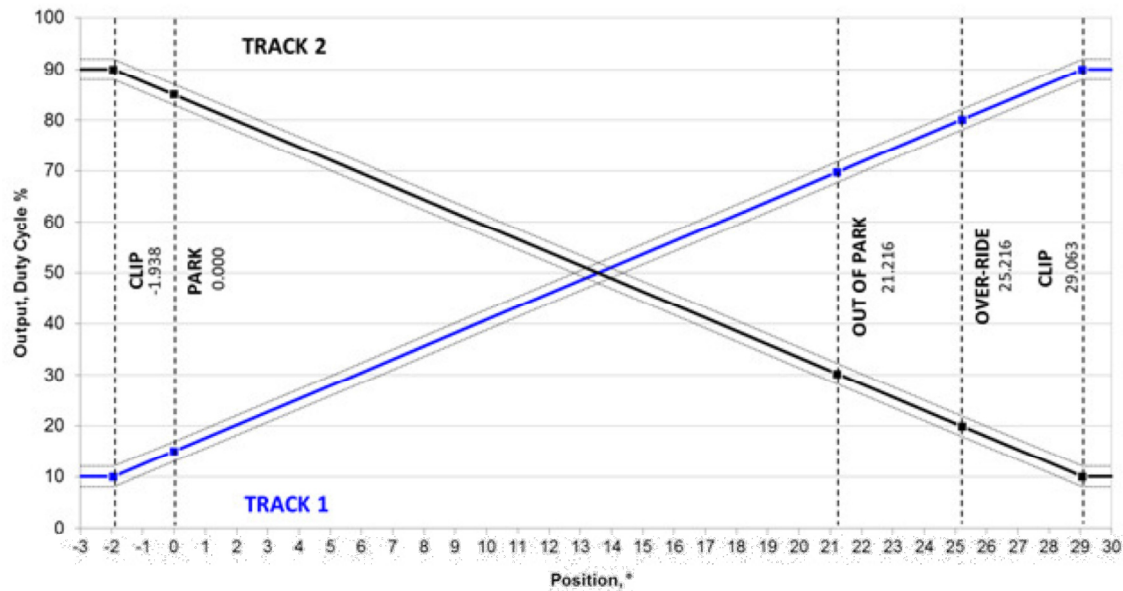
- TRSA increases as the shifter is moved from Park to Sport (mechanical shifter) or Park to out of Park (shift by wire)
- TRSB decreases as the shifter is moved from Park to Sport (mechanical shifter) or Park to out of Park (shift by wire)
- The sum of the two signals adds up to 100%.

1) 10R80 mechanical shifter variant is range by wire with mechanical Park. The dual TRS signals are used to determine customer selected range (P, R, N, D, S)



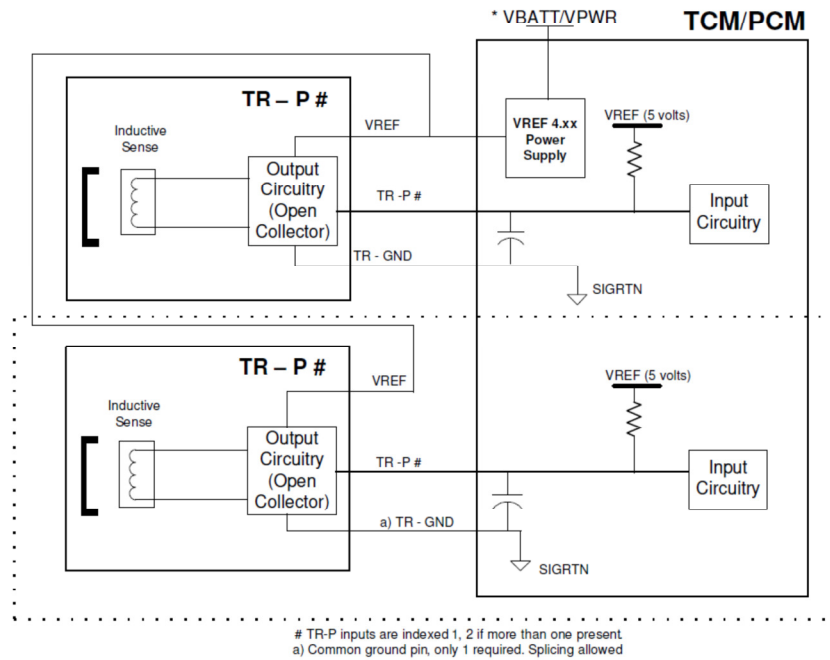
	TRSA		TRSB	
	Min	Max	Min	Max
Park	8.00	18.96	81.04	92.00
Reverse	35.50	47.90	52.10	64.50
Neutral	51.75	61.75	38.25	48.25
Drive	67.45	77.45	22.55	32.55
Sport	81.12	92.00	8.00	18.88

- 2) 10R80 shift by wire variant is range by wire with hydraulically actuated Park. The Gear Shift Module provides the customer selected range information (P,R,N,D,S), and the Transmission Range Sensors are used to determine the status of the Park system (in Park, Out of Park, Mechanically Overridden out of Park)



	TRSA		TRSB	
	Min	Max	Min	Max
Park	8.00	20.33	79.67	92
Out of Park	65.14	75.93	24.07	34.86
Mechanical override	75.93	92.00	8.00	24.07

## Actuator/Load Schematic:



For both variants the TRSs are tested for:

Fault	TRSA	TRSB
Frequency out of range (125Hz +/- 25 Hz)	P0706	P2801
Duty cycle out of range low (<8%)	P0707	P2802
Duty cycle out of range high (>92%)	P0708	P2803
Correlation error – TRS A and B duty cycles are in range but do not add up to 100% +/- 4 %	P2805	

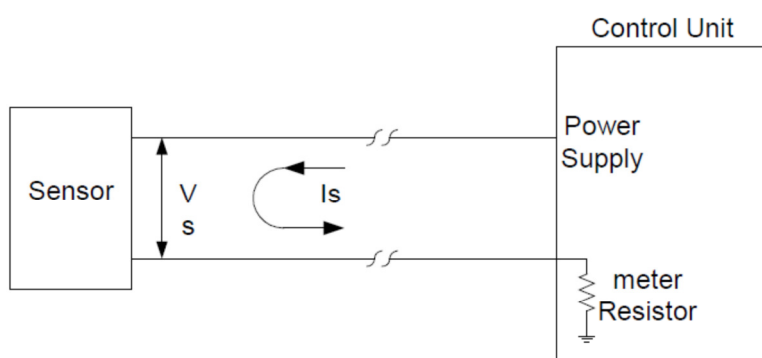
## Speed Sensors

10R80 has 4 speed sensors:

- 1) Turbine Speed Sensor (TSS) – senses the speed of the input shaft (C2)
- 2) Intermediate Speed Sensor A (ISSA) – senses the speed of R1
- 3) Intermediate Speed Sensor B (ISSB) – senses the speed of C1 and R4
- 4) Output Speed Sensor (OSS) – senses the speed of the output shaft (C4)

All 4 sensors are 2 wire hall effect sensors that detect rotational speed and direction:

- Sensor Power – provides power to the device
- Sensor ground wire - connected to the control unit node that provides a series metering resistor



**Figure 1**  
**Interface Diagram**

The 2 wire loop current is controlled by the sensor and is monitored as a voltage drop across the metering resistor. The voltage drop is a periodic rectangular wave with a frequency that is representative of the target's rotational speed and a pulse width representing the rotational direction (clockwise or counter-clockwise).

The sensors are tested for

- electrical faults (open, short to ground or short to power)
- erratic signal – spikes or dropouts of the signal
- plausibility – comparing the signal to an expected value based on current commanded gear state and the other speed sensors
- intermittent faults – sensor circuit faults or erratic behavior that happens frequently but does not last long enough to store a DTC

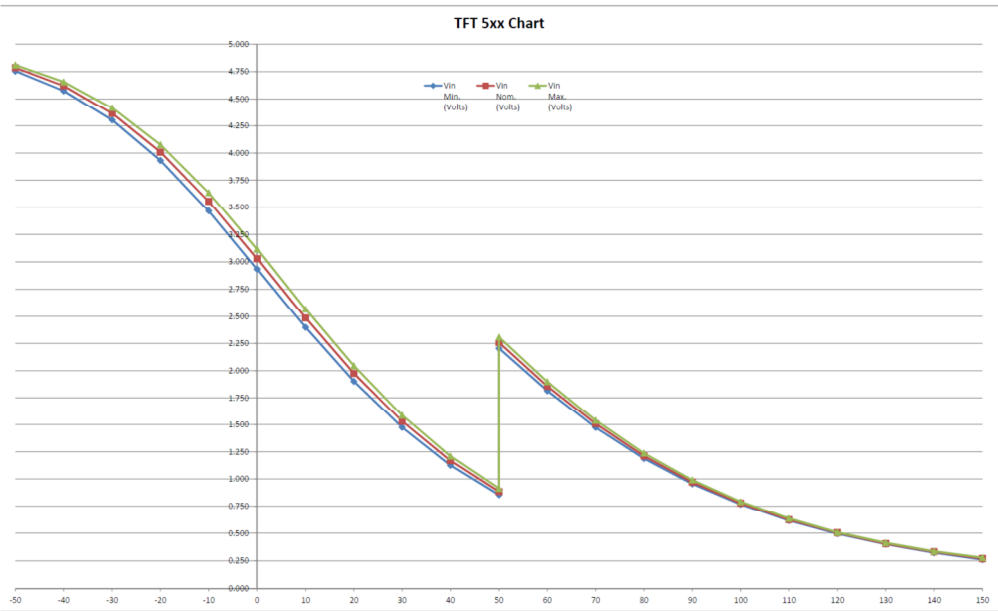
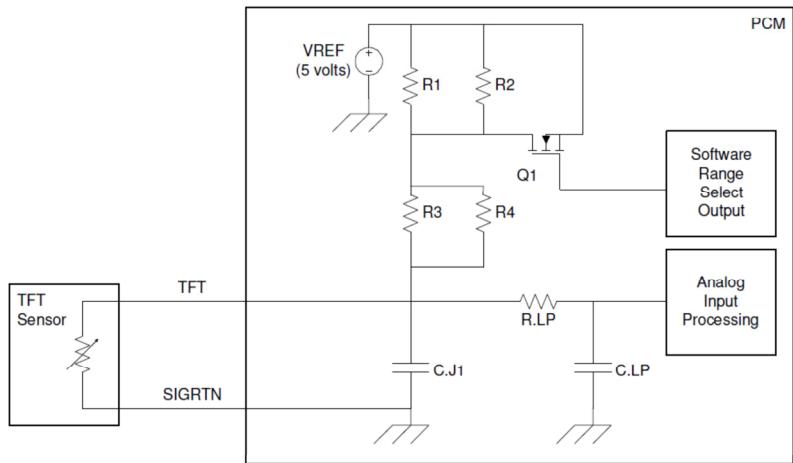
Speed sensor DTC list

	TSS	ISSA	ISSB	OSS
Open circuit	P0715	P0791	P2745	P0720
Short to ground	P07BF	P07C5	P07C7	P077C
Short to power	P07C0	P07C6	P07C8	P077D
Erratic signal / plausibility	P0716	P0792	P2746	P0721
Intermittent	P0718	P0794	P2748	P0723

# Transmission Fluid Temperature Sensor (TFT)

10R uses a Negative Temperature Coefficient (NTC) thermistor, a non-linear resistor where resistance decreases as the temperature increases. The 10R TFT sensor uses a switchable circuit in the control module, which is software controlled through an output of the microprocessor. The switchable circuit arrangement allows for more accurate reading at cold temperatures.

## Actuator/Load Schematic:



TFT is tested for:

Fault	DTC
Voltage out of range low (< 0.14v)	P0712
Voltage out of range high (> 4.90v)	P0713
In range failure	P0711

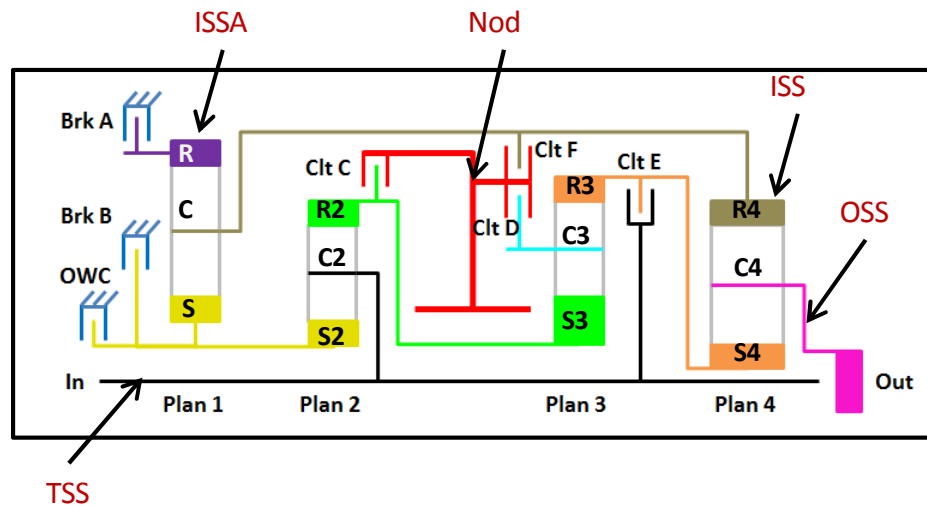
## Transmission Outputs

### Shift Solenoid Electrical faults:

Each clutch A-F has a directly proportional (0 current = 0 pressure, max current = max pressure) shift solenoid that controls pressure to that clutch. The solenoids are controlled by “smart driver” chips – when the main micro sends out the commanded state for each solenoid the smart drivers return fault information (open, short to power, short to ground).

- Open or Short to Power electrical fault - the solenoid is failed electrically off, which results in the clutch that solenoid controls being failed off.
- Short to ground - the solenoid is failed to max current, which results in the clutch the solenoid controls being failed on.

### Shift Solenoid Functional Faults:



10R has 4 planetary gear sets. Each gear set consists of a ring gear (R), a sun gear (S) and a carrier (C). The gear sets are numbered 1 thru 4. There are several connections between the gear sets:

- S1 and S2
- C1 and R4
- R2 and S3
- R3 and S4

These connections cause those elements to rotate at the same speed under all conditions (for example: S1 and S2 always rotate at the same speed).

10R has 6 clutches (A-F) plus a One Way Clutch (OWC) that works in tandem with the B clutch.

- Clutch A is a brake clutch, when on it grounds R1
- Clutch B is a brake clutch, when on it grounds S1 and S2
- Clutch C is a rotating clutch, connects R2 to the Node
- Clutch D is a rotating clutch, connects C3 to the node
- Clutch E is a rotating clutch, connects the input shaft (C2) to R3 and S4
- Clutch F is a rotating clutch, connects C1 and R4 to the node
- OWC is connected to S1 / S2 , allowing forward rotation, prevents backward rotation of S1 / S2

With 4 directional speed sensors all the gear set element speeds (ring, sun and carrier) can be calculated all the time. Using clutch slip there is no way to isolate non-electrical solenoid faults from the other clutch system failures – the shift solenoid stuck off and on DTC's cover the entire clutch system:

- Solenoid
- valves
- Clutch
- Seals
- Contamination that prevents pressure from reaching the clutch

#### Clutches A, B and E:

Clutch A, B and E slip can be calculated independent of transmission state:

- Clutch A slip = ISSA
- Clutch B slip = a function of ISSA and ISSB
- Clutch E slip is a function of TSS, ISSB and OSS

#### Clutches C, D and F:

Clutches C, D and F are called “node clutches” – these clutches work in pairs. The node is the common side of C, D and F. With the chosen sensor set the node speed cannot be sensed. If just C, D or F are on the node spins at R2, C3 or C1/R4 speed, but doesn't change the speeds of any of the other gear set elements – the state C, D or F cannot be confirmed until a 2<sup>nd</sup> node clutch is applied.

The control system can calculate the rotational speed of one side of each node clutch:

- Clutch C – R2 speed is a function of TSS, ISSA and ISSB
- Clutch D – C3 is a function of all 4 speed sensors
- Clutch F – C1 / R4 = ISSB

If C and D are on then R2 speed = C3 speed. If the speeds match we know both C and D are on. If the speeds do not match we know either Clutch C or D is slipping, but cannot determine which clutch is the cause unless all 3 node clutches are on.

Node clutch stuck off diagnostics require operation in 4<sup>th</sup>, 7<sup>th</sup> or 10<sup>th</sup> (where C, D and F are all on) to isolate a slipping clutch fault to a single node clutch.

Shift Solenoid Functional faults require operation in a gear state where the fault can be detected. As the vehicle is operated in different states the non-electrical faults can be detected.

- Shift Solenoid stuck off – these faults are detected when the clutch is commanded on and the speed sensor based slip calculation indicates the clutch is not applied. Clutch stuck off faults can be detected non-shifting if the clutch slips or during shift events if the clutch fails to apply.
- Shift Solenoid stuck on – these faults are detected when the clutch is commanded off or commanded to release during a shift. If the speed sensor based slip calculation indicates the clutch is applied when it should be slipping AND based on gear state or torque the clutch is holding significant torque (not at 0 slip due to open clutch drag) the clutch will be detected stuck on.

For example:

if clutch E is failed off at start-up the fault will be detected when the customer selects Drive. 1<sup>st</sup> gear will be commanded by the control system, and if clutch E fails to apply the transmission will be stuck in Neutral. Based on the speed signals it can be determined clutch E did not apply, the control system will release and reapply E up to 3 times, and if Clutch E slips each time a DTC is stored and function limited to gears with clutch E off.

## One Way Clutch (OWC)

The OWC is a mechanical device similar to a socket wrench. It is not a transmission output but is tested with the other clutches. The OWC locks if forces inside the transmission attempt to rotate S1 backward, grounding S1 to the case (holding S1 to 0 rpm). If forces attempt to rotate S1 forward the OWC allows the rotation. For gears that require S1 be held to 0 (Reverse, 8<sup>th</sup>, 9<sup>th</sup> and 10<sup>th</sup>) the B clutch is applied to prevent forward rotation of S1 / S2.

The speed of S1 can be calculated off ISSA and ISSB. The diagnostic simply looks for backward rotation of S1 – if this occurs then the OWC failed to lock.

### Clutch system Failure Mode Effects Management:

For shift solenoid electrical and clutch functional faults the control system simply limits function based on the state of the clutch system:

- Clutch stuck off – only command gears with that clutch off
- Clutch stuck on – only command gears with that clutch on

For example: Clutch A is on in Reverse and 1<sup>st</sup> thru 6<sup>th</sup> gear:

- If clutch A is stuck off function is limited to 7<sup>th</sup> thru 10<sup>th</sup> gear
- if clutch A is stuck on function is limited to R and 1<sup>st</sup> thru 6<sup>th</sup> gear.

Shift solenoid / clutch system related DTCs:

Component	Open circuit	Short to ground	Short to power	Stuck off	Stuck on
Shift Solenoid A	P097A	P0973	P09974	P0751	P0752
Shift Solenoid B	P097B	P0976	P0977	P0756	P0757
Shift Solenoid C	P097C	P0979	P0980	P0761	P0762
Shift Solenoid D	P097D	P0982	P0983	P0766	P0767
Shift Solenoid E	P097E	P0985	P0986	P0771	P0772
Shift Solenoid F	P097F	P2709	P2710	P2707	P2708
One Way Clutch				P1A02	

### Notes:

- Stuck off and stuck on faults cover the entire clutch system (solenoid, clutch, seals, etc.)
- OWC stuck on (preventing rotation in both directions) cannot be isolated from clutch B stuck on.

## Torque Converter Clutch (TCC)

The Torque Converter provides a fluid coupling between the engine and transmission input shaft. The fluid coupling allows the transmission to stay engaged at a stop, and provides torque multiplication during launch. At speeds where engine and transmission input speeds are nearly equal the fluid coupling is inefficient. The Torque Converter Clutch (TCC) bypasses the fluid coupling, locking engine and transmission input shaft to the same speed.

The TCC is controlled by a directly proportional solenoid. Like the shift solenoids the TCC solenoid is controlled by a “smart driver” capable of detecting open, short to ground and short to power faults.

- Open or short to power faults the TCC is failed open.
- Short to ground fault the TCC is failed “on”, to avoid engine stalls at low speed the Failure Mode Effects Management (FMEM) for a TCC short to ground will remove power from the solenoid.
- TCC and Line Pressure Control solenoids share a high side driver – anytime power is removed the transmission will be at max line pressure with open TCC.

The TCC is functionally monitored for stuck off and stuck on faults by comparing TCC slip (engine speed – turbine speed) to the commanded state of the TCC.

### TCC related DTCs

Component	Open circuit	Short to ground	Short to power	Stuck off	Stuck on
Torque Converter Clutch Solenoid	P0740	P2769	P2770	P0741	P2758

#### Notes:

- Stuck off and stuck on faults cover the entire clutch system (solenoid, clutch, seals, etc.)

### Line Pressure Control (LPC) solenoid:

Line pressure is controlled by an inversely proportional solenoid (0 current = max pressure, max current = min line pressure). The line pressure control solenoid is controlled by a “smart driver” capable of detecting open, short to ground or short to power faults.

- Open or short to power faults the transmission will be stuck at maximum line pressure. All gears and TCC lock available.
- Short to ground fault the transmission would be stuck a minimum line pressure which is not enough to provide function so the Failure Mode Effects Management for a short to ground is to remove power from the solenoid.
- TCC and LPC share a common high side driver – for a short to ground on LPC the FMEM actions will result in max line with open TCC.

Component	Open circuit	Short to ground	Short to power
Line Pressure Control Solenoid	P0960	P0962	P0963

#### Notes:

- Line pressure is not functionally monitored. Line pressure stuck low will result in shift solenoid stuck off faults, line pressure stuck high is undetectable because all the clutches apply and release correctly based on the state of the shift solenoids.

## Transmission Solenoid Power Control (TSPC):

The TCM provides 2 high side drivers that provide power to the solenoids, TSPC1 and TSPC2. For 10R the solenoids are split as follows:

- TSPC1 – shift solenoids A-F
- TSPC2 – TCC and LPC

If TSPC1 fails open the transmission will be stuck in Neutral

If TSPC2 fails open the TCC will be stuck open, line pressure at maximum, but all gears are available.

Fault	DTC
TSPC1 failed open	P0657
TSPC2 failed open	P2669

## Transmission Control Module (TCM)

In 2017 MY all 10R80 applications will use TCMs. In future years transmission controls will be integrated into the Powertrain Control Module (PCM) for gas engine applications, but diesel engine applications will continue to use a TCM.

The TCM has the same module diagnostics as an ECM or PCM – see miscellaneous CPU tests for details.

### Module DTCs

Fault	DTC
Internal Control Module Keep Alive Memory (KAM) Error	P0603
Internal Control Module Random Access Memory (RAM) Error	P0604
Internal Control Module Read Only Memory (ROM) Error	P0605
Control Module Performance	P0607
Module power relay de-energized too early	P068A
Internal Control Module Non-Volatile Random Access Memory (NVRAM) Error	P06B8
TCM Power Input Signal Intermittent	P0884
Control Module Vehicle Options Reconfiguration Error	P160A
Unable to communicate with solenoid smart driver chips	P1636

### TCM voltage

If the system voltage at the TCM is outside of the specified 10 to 17 volt range while the engine is running a fault will be stored.

Fault	DTC
System voltage out of range low	P0882
System voltage out of range high	P0883

### Ignition Switch Run Position (ISPR)

The 10R TCM ignition status 2 ways:

- CAN message from the Body Control Module
- ISPR Hardwire

The TCM will wake on CAN or ISPR high, and will remain awake if the ignition is on. Since the information is provided redundantly to the TCM the ISPR wire failing open has no impact on function. If ISPR fails short to power the TCM will not be able to power down, but otherwise provides normal function.

The TCM has a diagnostic that compares the CAN message to ISPR hardwire.

Fault	DTC
Ignition Switch Run Position Circuit Low	P2531
Ignition Switch Run Position Circuit Low	P2532

## Transmission Identification (TRID) block

During the build process transmission hardware characterization data is captured. The TRID data shows where a specific transmission's components lie within the production variability. This data is flashed onto the PCM or TCM in the vehicle assembly plant, allowing transmission controls to meet its shift quality targets on a new, unadapted vehicle. The TRID data comes with a version number and checksum.

If the TRID is invalid or missing shift quality may be adversely affected, to insure a vehicle is never released to a customer without a valid TRID the DTC's are 1 trip MIL AND the transmission will be limited one or two forward gears (1<sup>st</sup> and 3<sup>rd</sup> or just 3<sup>rd</sup> gear). This will allow the vehicle to be moved to a repair area to correct the TRID, but insure a vehicle is not released to a customer without this data.

The diagnostics can detect:

Fault	DTC
TRID version or checksum error	P163E
TRID block corrupted, not programmed	P163F

## CAN Communications Error

The 10R TCM is connected to 2 CAN networks:

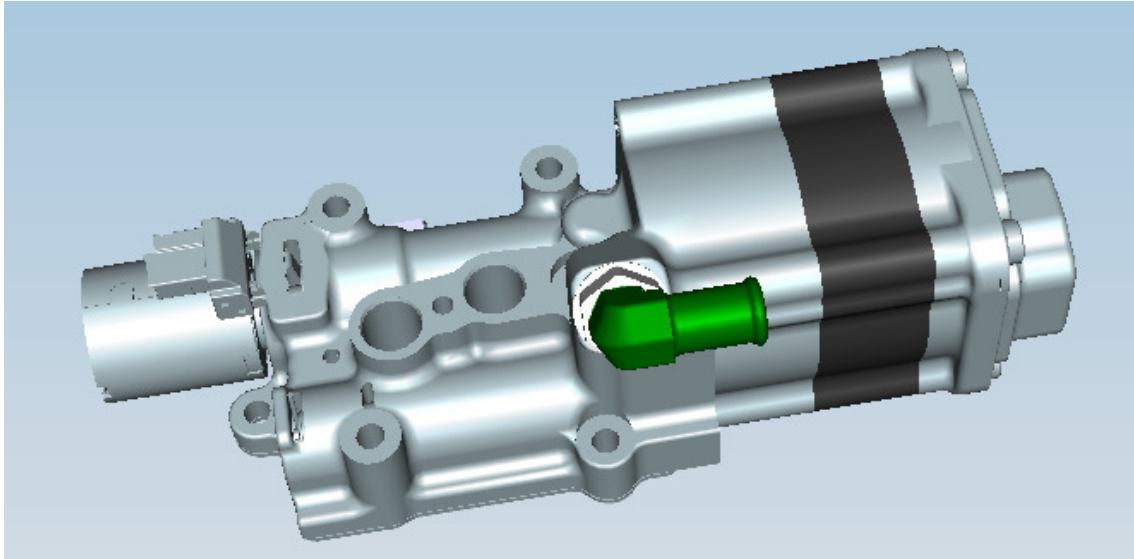
- 1) High Speed CAN network 1 (HS1) – one of 3 vehicle CAN networks (HS1, HS2, HS3) with a gateway module to move data from one vehicle CAN bus to another. The TCM receives messages from the following modules on the HS1 CAN bus:
  - Engine Control Module (ECM)
  - Body Control Module (BCM)
  - Gear Shift Module (GSM) – shift by wire applications only, starting in 18 MY TCM will receive redundant information on both CAN buses from the GSM, allowing normal control of the shift by wire system if a single CAN bus fault is present. GSM is on HS2 with messages gatewayed to HS1
  - Anti-lock Brake System Module (ABS) – on HS2, messages gatewayed to HS1
  - Instrument Panel Cluster (IPC) – gatewayed to HS1
  - Gateway Module (GWM) – moves data between different vehicle CAN buses
  - Transfer Case Control Module (TCCM) – if present, gatewayed to HS1
  - Restraints Control Module (RCM) – starting in 18 MY TCM will use data from the RCM on shift by wire applications, gatewayed to HS1
- 2) Powertrain Subnet (PT subnet) - a private CAN bus added to reduce loading on HS1. Some signals transmitted ECM to TCM on other applications are moved from HS1 to PT subnet. ECM to TCM communications require both HS1 and PT subnet up to have a full message set, there no redundancy in messages sent between ECM and TCM on HS1 and PT subnet. The TCM receives messages from the following modules on PT subnet:
  - Engine Control Module (ECM)
  - Gear Shift Module (GSM) – shift by wire applications only, starting in 18 MY TCM will receive redundant information on both CAN buses, allowing normal control of the shift by wire system if a single CAN bus fault is present

ECM – TCM CAN message traffic is split between the 2 CAN buses. The 2<sup>nd</sup> bus was added for bus loading, so there is little or no redundancy (both CAN buses must be up for normal control).

The TCM will store the following CAN related DTC's

- 1) CAN bus down (HS1 - U0073 , PT subnet – U0074)
- 2) Lost communication – CAN is up but the module is not communicating ( ECM – U0100, GSM – U0103, ABS – U0121, BCM – U0140, GWM – U0146, IPC – U0155)
- 3) Invalid data received -module is on CAN but reporting faults in key signals (ECM - U401, GSM – U0404, ABS – U0415, BCM – U0422)

## Auxiliary Transmission Fluid Pump (ATFP, also known as ePump):

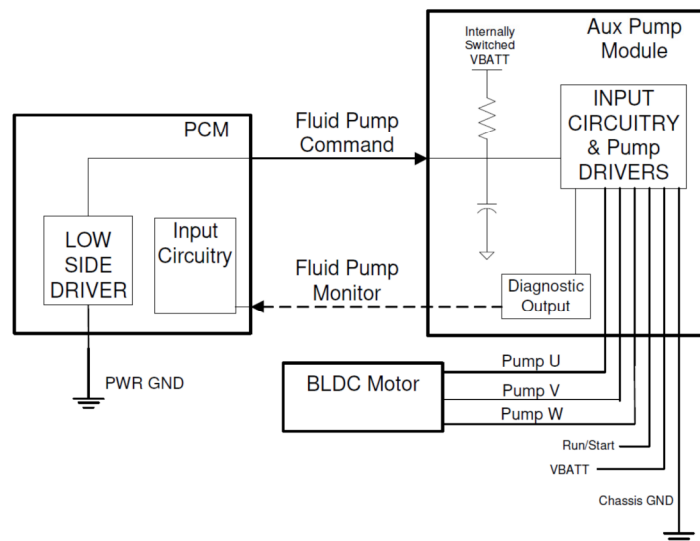


For Stop / Start purposes 10R80 comes equipped with an Auxiliary Transmission Fluid Pump (ATFP, also known as ePump), an electronic pump that can be turned on before an engine stop event, allowing the transmission to stay engaged during the stop event. This allows quick response on the engine restart because the transmission is already in gear. The ATFP does not have sufficient flow to apply clutches, but can keep clutches on when the engine stops and the main hydraulic pump stops providing pressure.

The ATFP is a smart actuator that communicates with the TCM (or PCM) via PWM hardwires:

- ATFPD – TCM or PCM commanded pump speed
- ATFPD – Diagnostics status for the ATFP

### Actuator/Load Schematic:



The TCM or PCM performs circuit diagnostics on the diagnostics hardwire (ATFPD):

Fault	DTC
Frequency out of range (expected frequency is 150 +/- 20 Hz)	P0C2C
Duty cycle out of range low (< 10%)	P0C2D
Duty cycle out of range high (> 90%)	P0C2E

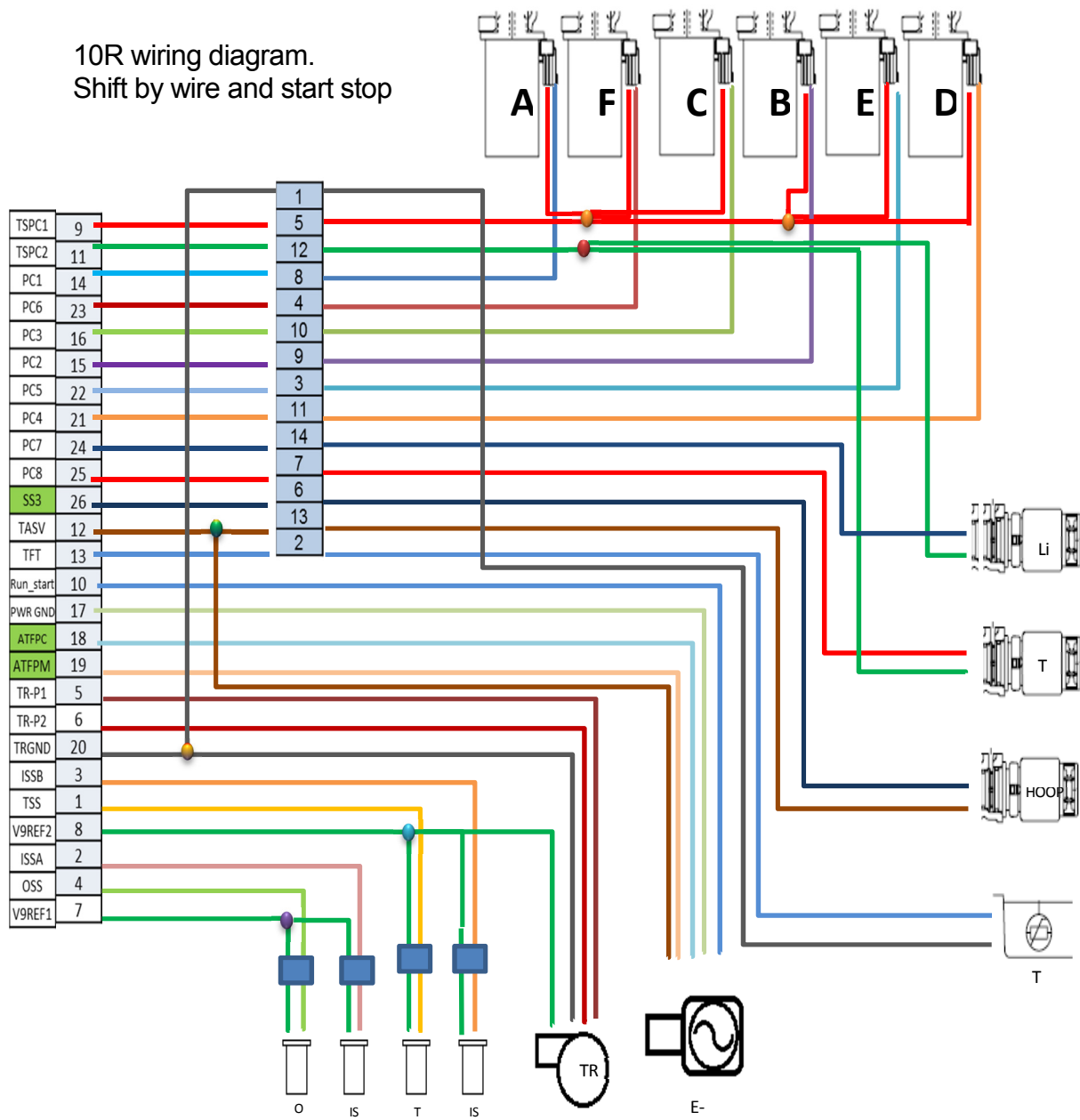
The remainder of the diagnostics are performed by the AFTP, the TCM or PCM simply stores the DTC's because the device is not on CAN so it is unable to store its own DTC's or communicate with a service tool.

AFTP detected faults are mapped to DTCs as follows:

Fault	DTC
AFTP reporting incorrect speed	P0B0D
AFTP reporting under current	P0C27
AFTP reporting over current	P0C28
AFTP reporting current and speed both out of range	P0C29
AFTP reporting pump stalled (may have lost prime)	P0C2A
AFTP reports an over temperature condition	P175A
AFTP reports it is not receiving the command PWM signal (ATFPC)	P2796

If an AFTP fault is present the stop / start system will be taken out of operation with the engine running (no more stop events while the fault is present). Failures of the diagnostics PWM can recover during a drive cycle, but most of the faults detected by the AFTP can only be detected when the pump is turned on - those faults will require a key cycle to recover.

10R wiring diagram.  
Shift by wire and start stop



## On Board Diagnostic Executive

The On-Board Diagnostic (OBD) Executive is a portion of the PCM strategy that manages the diagnostic trouble codes and operating modes for all diagnostic tests. It is the "traffic cop" of the diagnostic system. The Diagnostic Executive performs the following functions:

- Sequence the OBD monitors such that when a test runs, each input that it relies upon has already been tested. For 2008 MY and beyond ISO 14229 programs, the OBD monitors are no longer sequenced by the diagnostic executive.
- Controls and co-ordinates the execution of the individual OBD system monitors: Catalyst, Misfire, EGR, O2, Fuel, AIR, EVAP and, Comprehensive Component Monitor (CCM). For 2008 MY and beyond ISO 14229 programs, the execution of the OBD monitors is no longer controlled and coordinated by the diagnostic executive.
- 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). For 2008 MY and beyond ISO 14229 programs, the Output Test Mode is no longer supported by the diagnostic executive.
- 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 responses to special diagnostic requests (J1979 Mode 08 and 09).
- Tracks and manages indication of the driving cycle which includes the time between two key on events that include an engine start and key off.

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

- The battery voltage must fall between 11.0 and 18.0 volts to initiate monitoring cycles.
- The engine must be started to initiate the engine started, engine running, and engine off monitoring cycles.
- 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%. For 2005 MY and beyond, the execution of the fuel related OBD monitors is no longer suspended for fuel level by the diagnostic executive.

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

- A pending DTC and freeze frame data is stored after a fault is confirmed on the first monitoring cycle. If the fault recurs on the next driving cycle, a confirmed DTC is stored, freeze frame data is updated, and the MIL is illuminated. If confirmed fault free on the next driving cycle, the pending DTC and freeze frame data is erased on the next power-up.
- For the 2005 MY and later, 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. For 2008 MY and beyond ISO 14229 programs, the engine off soak is no longer used by the diagnostic executive.
- After a confirmed DTC is stored and the MIL has been illuminated, three consecutive confirmed fault-free monitoring cycles must occur before the MIL can be extinguished on the next (fourth) power-up. After 40 engine warm-ups, the DTC and freeze frame data is erased.

The diagnostic executive controls the setting and clearing of permanent DTCs.

- A permanent DTC is stored when a confirmed DTC is stored, the MIL has been illuminated, and there are not yet six permanent DTCs stored.
- After a permanent DTC is stored, three consecutive confirmed fault-free monitoring cycles must occur before the permanent DTC can be erased.
- After a permanent DTC is stored, one confirmed fault-free monitoring cycle must occur, following a DTC reset request, before the permanent DTC can be erased. For 2010MY and beyond ISO 14229 programs a driving cycle including the following criteria must also occur, following the DTC reset request, before a permanent DTC can be erased:
  - Cumulative time since engine start is greater than or equal to 600 seconds;
  - Cumulative vehicle operation at or above 25 miles per hour occurs for greater than or equal to 300 seconds (medium-duty vehicles with diesel engines certified on an engine dynamometer may use cumulative operation at or above 15% calculated load in lieu of at or above 25 miles per hour for purposes of this criteria); and
  - Continuous vehicle operation at idle (i.e., accelerator pedal released by driver and vehicle speed less than or equal to one mile per hour) for greater than or equal to 30 seconds.
- A permanent DTC can not be erased by a KAM clear (battery disconnect). Additionally, its confirmed DTC counterpart will be restored after completion of the KAM reset (battery reconnect).

## 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:

$$\text{New Average} = [\text{New data point} * \text{“filter constant”}] + [(1 - \text{“filter constant”}) * \text{Old Average}]$$

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 or DTCs are erased and a “normal filter constant” is used for normal customer driving. The “fast filter” is used for 5 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. This feature is called Fast Initial Response (FIR). The fast filter is always calibrated to 0.99 which means that the EWMA is effectively disabled because the new average is 99% of the new data point. Since the EWMA is effectively disabled, it takes two driving cycles to set the MIL. The first driving cycle with a fault will set a pending DTC; the second driving cycle will set a confirmed code and illuminate the MIL.

The other unique feature used with EWMA is called Step Change Logic (SCL). This logic detects an abrupt change from a no-fault condition to a fault condition. This is done by comparing the new data point to the EWMA old average. If the two points differ by more than a calibrated amount (i.e. the new data point is outside the normal distribution), it means that a catastrophic failure has occurred. The fast filter is then used in the same manner as for the FIR feature above. Since the EWMA is effectively disabled, it takes two driving cycles to set the MIL. The first driving cycle with a fault will set a pending DTC; the second driving cycle will set a confirmed code and illuminate the MIL. The SCL becomes active after the 4th “normal” monitoring cycle to give the EWMA a chance to stabilize.

During “normal” EWMA operation, a slower filter constant is used. The “normal filter” allows the MIL to be illuminated in 1 to 6 driving cycles. A confirmed code is set and the MIL is illuminated as soon as the EWMA crosses the malfunction threshold. There is no pending DTC because EWMA uses a 1-trip 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:

$$\text{Time constant} = [ (1 / \text{filter constant}) - 1 ] * \text{evaluation period}$$

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.

## EWMA Examples

EWMA with FIR and SCL has been incorporated in the IAF catalyst monitor, the Rear O2 response test and the EONV Evaporative system leak check monitor. There are 3 parameters that determine the MIL illumination characteristics.

“Fast” filter constant (0.99), used for 2 driving cycles after DTCs are cleared/KAM is reset (FIR) and for Step Change Logic (SCL)

“Normal” filter constant( typically 0.4), used for all subsequent, “normal” customer driving

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

Several examples for a typical catalyst monitor calibration are shown in the tables below. The first example does not show SCL in order to better illustrate the EWMA calculation and the 1-trip MIL.

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 120K system
1.0	$1.0 * (0.4) + .15 * (1 - 0.4)$	0.49	1	large failure occurs
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, MIL on
1.0	$1.0 * (0.4) + .82 * (1 - 0.4)$	0.89	4	MIL on
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	equals threshold, MIL on
0.8	$0.8 * (0.4) + .75 * (1 - 0.4)$	0.77	6	MIL on
0.8	$0.8 * (0.99) + 0 * (1 - 0.99)$	0.8	1	1.5 * threshold failure after code clear, pending DTC
0.8	$0.8 * (0.99) + .8 * (1 - 0.99)$	0.8	2	MIL on (I/M Readiness set to "ready")

Note that older implementations of EWMA for the Index ratio catalyst monitor and non-intrusive stepper motor EGR monitor incorporate Fast Initial Response but do not incorporate step change logic. For both FIR and normal EWMA usage, a pending code is set when the new EWMA average exceeds the threshold and a confirmed code is set after the second time the EWMA average exceeds the threshold. (2-trip MIL). The "normal" filter is calibrated to illuminate the MIL between 2 and 6 driving cycles.

## I/M Readiness

The readiness function is implemented based on the SAE J1979/ISO 15031-5 format. 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 and misfire monitoring are immediately considered complete since they are continuous monitors. Because the evaporative system monitor requires ambient conditions between 40 and 100 °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. The table below shows which monitors must complete for I/M readiness.

I/M Readiness bit	Bank 1	Bank 2
Catalyst monitoring	P0420	P0430
Heated catalyst monitoring	Not Supported	Not Supported
Evaporative system leak monitoring (0.020"/0.040"/0.150" monitor used for I/M readiness)  Purge flow monitoring includes blocked line test and excessive vacuum tests  Some 2018 MY LD vehicles will use 0.020" for I/M readiness, all 2019 MY LD vehicles will use 0.020" for I/M Readiness	P0442 (0.040") P0455 (0.150 for HD OBD) P0456 (0.020") P144A / P00FE (blocked line) P1450 / P0496 (excess vacuum)	
Secondary air system monitoring	P0491/P0410/P2448	P0492/P2449
Oxygen sensor monitoring		
Upstream response test	P0133	P0153
Upstream lack of movement test	P2195/P2196	P2197/P2198
Upstream heater	P0053/P0030	P0059/P0050
Downstream circuit test	P0137/P0138	P0157/P0158
Downstream functional test	P0136/P2270/P2271	P0156/P2272/P2273
Downstream heater	P0036/P0054/P00D2	P0056/P0060/P00D4
Downstream response test	P013A/P013E	P013C/P014A
Post catalyst fuel trim monitor	P2096/P0297	P2098/P2099
Oxygen sensor heater monitoring	Same as O2 sensor above	Same as O2 sensor above
EGR and/or VVT system monitoring		
Stepper Motor EGR	P0400	
High Pressure EGR	P1405/P1406/P0401/P0402	
VVT supported	P0011/P0012/P0014/P0015	P0021/P0022/P0024/P0025
Misfire monitoring	Always ready	Always ready
Fuel system monitoring	Fuel trim always ready	Fuel trim always ready
A/F ratio imbalance monitor	P219A	P219B
Comprehensive component monitoring	Always ready	Always ready



## **Evap bypass logic for new 1999 MY, 2000 MY, and beyond vehicles:**

If the evaporative system monitor conditions are met with the exception of the 40 to 100 °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.

## In-Use Monitor Performance Ratio

Manufacturers are required to implement software algorithms that track in-use performance for each of the following components: catalyst bank 1, catalyst bank 2, primary oxygen sensor bank 1, primary oxygen sensor bank 2, evaporative 0.020" leak detection system, EGR system, and secondary air system, and secondary oxygen sensor bank 1 and secondary oxygen sensor bank 2 for 2010 MY and beyond. The numerator for each component or system tracks the number of times that all conditions necessary for a specific monitor to detect a malfunction have been encountered. The denominator for each component or system tracks the number of times that the vehicle has been operated in the specified conditions.

If a vehicle utilizes Variable Valve Timing (VVT) in place of EGR, the VVT in-use data is reported in place of the EGR in-use data. If a vehicle utilizes both an EGR system and a VVT system, the PCM tracks the in-use performance data for both monitors, but reports only the data for the system with the lowest numerical ratio.

If a vehicle utilizes an evaporative system monitor that is certified to 0.040" or 0.150" requirements instead of 0.020" requirements, the PCM reports the 0.040" monitor or 0.150" monitor in-use performance data in place of the 0.020" in-use performance data.

The table below shows which monitors must complete to increment each IUMPR numerator.

Note that EVAP monitor takes longer to find a fault than to pass, therefore, it must use a "ghost monitor" that tracks whether the monitor could have found a fault, had a fault been present. To increment the IUMPR counter for EVAP, the 0.020" leak check must maintain monitoring conditions for 45 minutes after shutdown. The 0.040" leak check must maintain monitoring condition based on the longest time it takes to pull to target vacuum. If the actual monitor fails, the ghost monitor does not run and the numerator is incremented.

Note that Catalyst monitor uses EWMA. The numerator increments after the catalyst monitor completes. After a code clear, the numerator increments after catalyst monitor completes 6 times.

### Ignition Cycle Counter

Ignition cycle counter will increment after engine start  $\geq 1$  s for non-hybrid vehicle

"Engine start" is defined as the point when the engine reaches a speed 150 rpm below the normal, warmed-up idle speed (as determined in the drive position for vehicles equipped with an automatic transmission).

Ignition cycle counter will increment after propulsion system active for  $\geq 1$  s for hybrid vehicle

"Propulsion system active" is the state where the powertrain (e.g., engine, electric machine) is enabled by the driver (e.g., after ignition on for conventional vehicles, after power button pushed for some hybrid vehicles, after remote start activation) such that the vehicle is ready to be used (e.g., vehicle is ready to be driven, ready to be shifted from "park" to "drive", heating, ventilation, and air conditioning (HVAC) turned on to condition cabin prior to driving), when such an HVAC operating mode could eventually cause a fueled start of the engine). For purposes of this definition, "the state where the powertrain is enabled" does not include activations that are not driver-initiated (e.g., conditions where portions of the vehicle system wake up to perform OBD II monitoring or off-board charging).

### General Denominator Counter

General Denominator counter will increment if all the following conditions are met:

- Ambient Temperature  $\geq -7$  deg C (20 deg F)
- Barometric pressure  $\geq 752$  hPa (8,000 ft altitude)
- Time since engine start (or propulsion system active for hybrid)  $\geq 600$  s
- Time with vehicle speed greater or equal to than 40 kph (25 mph)  $\geq 300$  s

- Continuous vehicle operation at idle time (i.e., accelerator pedal released with vehicle speed  $\leq 1.6$  kph (1 mph))  $\geq 30$  s
- For hybrid vehicles, cumulative fueled engine operation  $\geq 10$  s

### **Special requirements for Denominator for VVT Monitor**

VVT Monitor requires all the conditions for the general denominator to increment and VVT system commanded on for a continuous time  $\geq 10$  s

**Conditions for interrupting Numerators are described in the individual monitor descriptions.**

**Conditions for interrupting monitor specific Denominators are as follows:**

Catalyst Monitor - In addition to faults that disable the general denominator faults on any of the following sensors or actuators:

- Oxygen sensors
- MAP/MAF sensors
- Air temperature sensors
- Canister purge solenoid
- Fuel rail pressure sensor
- Fuel volume regulator
- Crank position sensor
- Fuel injectors
- Ignition coils
- Knock sensors
- Engine coolant temperature sensors
- Fuel monitor control errors
- Torque control errors
- VVT errors"

Oxygen Sensor Monitor - In addition to faults that disable the general denominator faults on any of the following sensors or actuators:

- MAP/MAF sensors
- Air temperature sensors
- Canister purge solenoid
- Fuel rail pressure sensor
- Fuel volume regulator
- Crank position sensor
- Cam position sensors
- Fuel injectors
- Ignition coils
- Knock sensors
- Engine coolant temperature sensors
- Lambda control errors
- Torque control errors
- Throttle position sensor
- VVT errors
- Vehicle speed errors"

VVT Monitor - In addition to faults that disable the general denominator faults on any of the following sensors or actuators

- Crank position sensor
- Cam position sensors
- VVT Solenoids
- ECT Sensor
- Throttle position sensor
- MAP/MAF sensor"

Conditions for interrupting General Denominators are as follows; faults on any of the following sensors and actuators:

- Throttle position sensors
- Crank position sensor
- Vehicle speed sensor
- MAP/MAF sensor
- Intake air temperature sensor
- Engine coolant temperature sensor"

IUMPR Counter Numerator	Controlling Monitor
Catalyst Monitoring Bank 1	P0420
Catalyst Monitoring Bank 2	P0430
O2 Sensor Monitoring Bank 1	P0133
O2 Sensor Monitoring Bank 2	P0153
EGR and/or VVT System Monitoring	
EGR (if supported)	P0400/P0401
VVT (if supported)	P0011/P0012/P0014/P0015 P0021/P0022/P0024/P0025
EVAP Monitoring	
0.020" monitoring (California)	P0456
0.040" monitoring (Federal)	P0442
0.150" monitoring (HD OBD)	P0455
Secondary O2 Sensor Monitoring Bank 1	P013A/P013E
Secondary O2 Sensor Monitoring Bank 2	P013C/P014A

The data is output using Service \$09, InfoType \$08. An example for the data format is show below. The monitoring ratio is the monitor numerator divided by the monitor denominator.

Test Equipment Display	Data	Monitoring Ratio
OBDCOND – number of times OBD monitoring conditions encountered (General Denominator)	15 counts	
IGNCNTR - number of times that the engine has been started	27 counts	
CATCOMP1 - times that all conditions necessary to detect a catalyst system bank 1 malfunction have been encountered (numerator)	14 counts	0.93
CATCOND1 - times that the vehicle has been operated in the specified catalyst monitoring conditions (denominator)	15 counts	
CATCOMP2 - times that all conditions necessary to detect a catalyst system bank 2 malfunction have been encountered (numerator)	0 counts	N/A
CATCOND2 - times that the vehicle has been operated in the specified catalyst monitoring conditions (denominator)	0 counts	
O2SCOMP1 - times that all conditions necessary to detect an oxygen sensor bank 1 malfunction have been encountered (numerator)	19 counts	1.27
O2SCOND1 - times that the vehicle has been operated in the specified oxygen sensor monitoring conditions (denominator)	15 counts	
O2SCOMP2 - times that all conditions necessary to detect an oxygen sensor bank 2 malfunction have been encountered (numerator)	0 counts	N/A
O2SCOND2 - times that the vehicle has been operated in the specified oxygen sensor monitoring conditions (denominator)	0 counts	
EGRCOND - times that all conditions necessary to detect an EGR/VVT system malfunction have been encountered (numerator)	19 counts	1.27
EGRCOMP - times that the vehicle has been operated in the specified EGR/VVT system monitoring conditions (denominator)	15 counts	
AIRCOND - times that all conditions necessary to detect an AIR system malfunction have been encountered (numerator).	0 counts	N/A
AIRCOMP - number of times that the vehicle has been operated in the specified AIR system monitoring conditions (denominator).	0 counts	
EVAPCOMP - of times that all conditions necessary to detect a 0.020" (or 0.040") EVAP system leak malfunction have been encountered (numerator)	16 counts	1.33
EVAPCOND - times that the vehicle has been operated in the specified EVAP system leak malfunction monitoring conditions (denominator)	12 counts	
SO2SCOMP1 - times that all conditions necessary to detect a secondary oxygen sensor bank 1 malfunction have been encountered (numerator)	17 counts	1.13
SO2SCOND1 - times that the vehicle has been operated in the specified secondary oxygen sensor monitoring conditions (denominator)	15 counts	
SO2SCOMP2 - times that all conditions necessary to detect a secondary oxygen sensor bank 2 malfunction have been encountered (numerator)	0 counts	N/A
SO2SCOND2 - times that the vehicle has been operated in the specified secondary oxygen sensor monitoring conditions (denominator)	0 counts	

## 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.

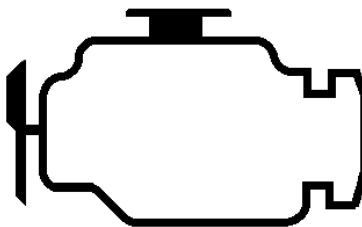
Beginning with the 2007 MY, the catalyst temperature model is also used to generate the primary inputs to the CSER Monitor as described in that section of this document.

## Serial Data Link MIL Illumination

The OBD-II diagnostic communication messages utilize an industry standard 500 kbps CAN communication link.

The instrument cluster on some vehicles uses the same 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.

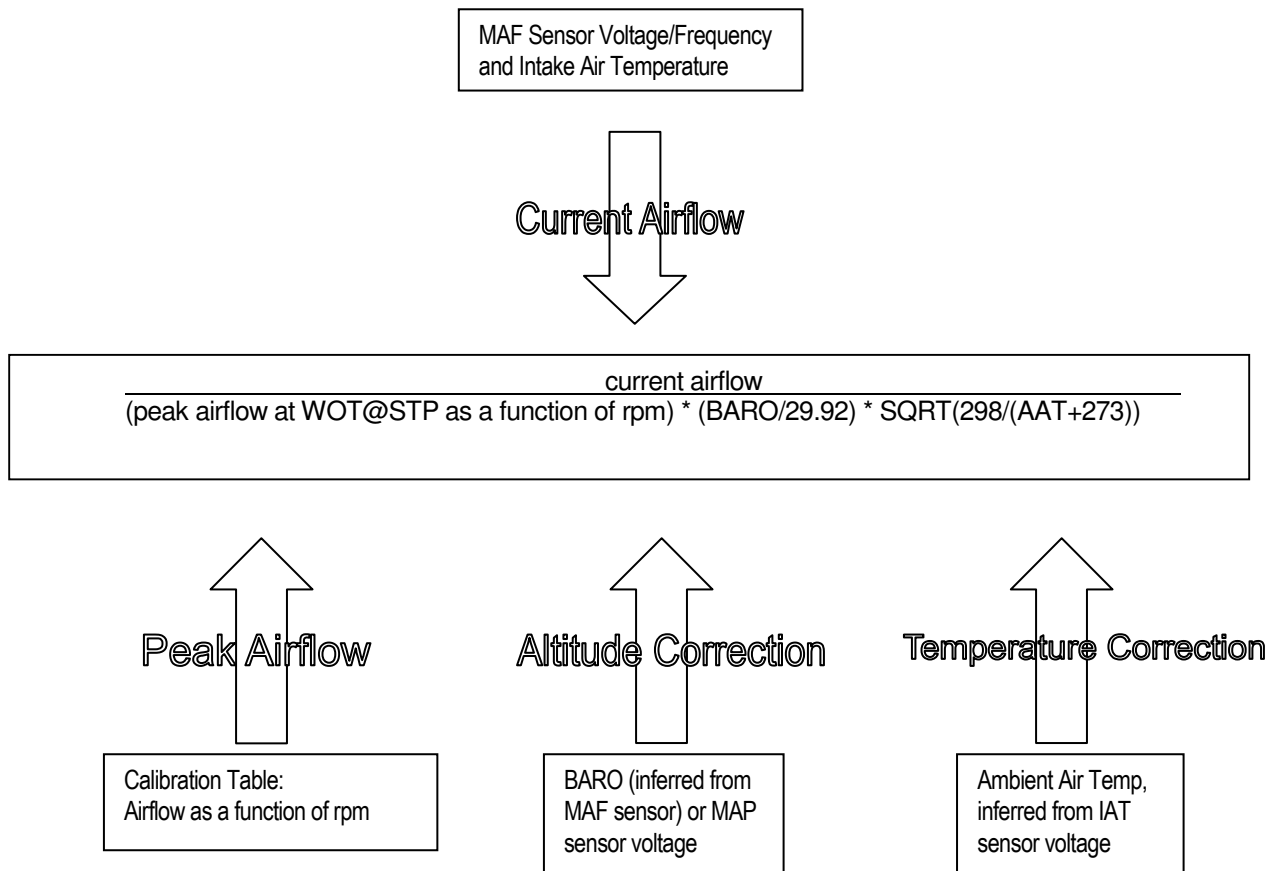


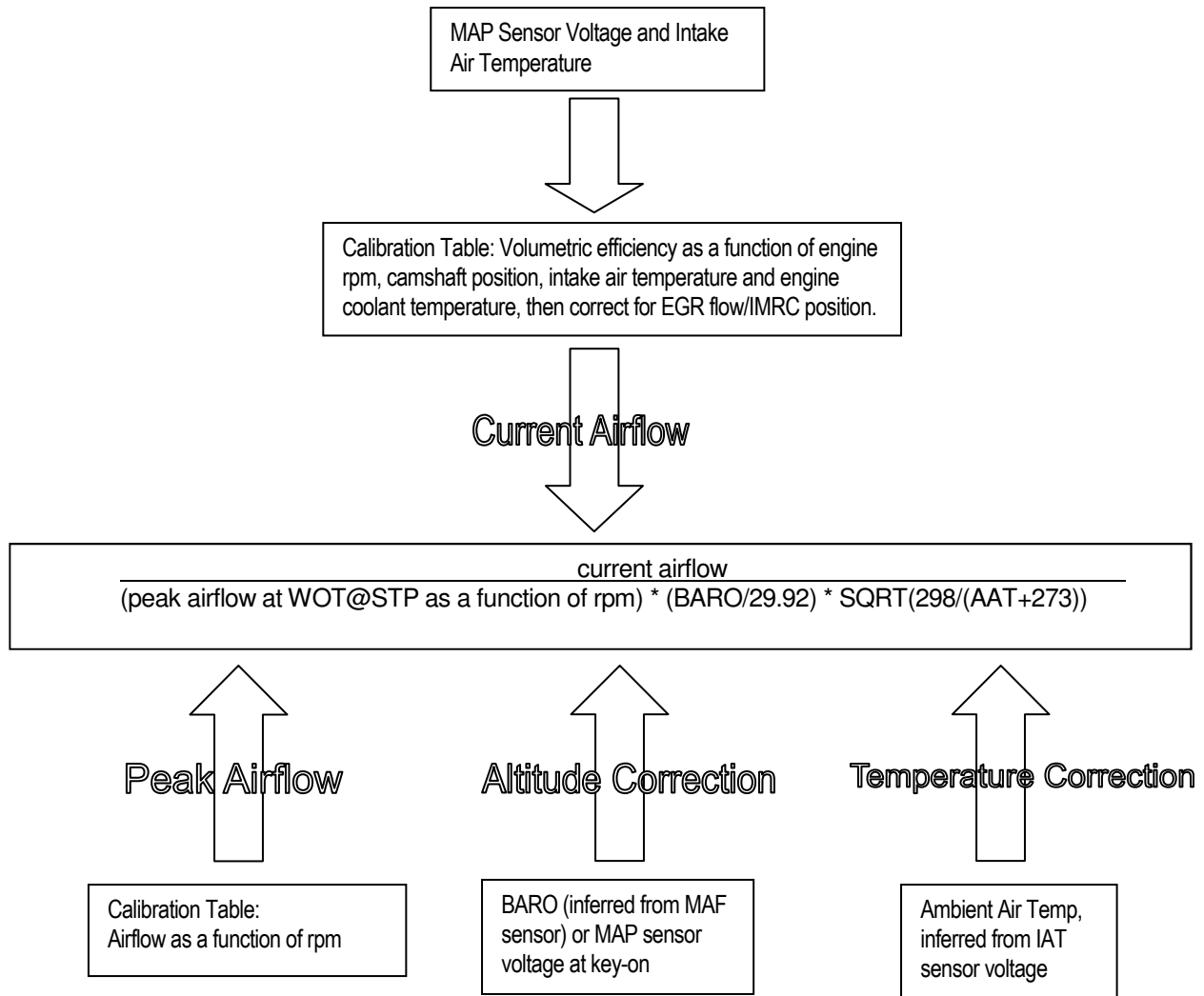
## Calculated Load Value

LOAD\_PCT (PID \$04) =

$$\frac{\text{current airflow}}{(\text{peak airflow at WOT@STP as a function of rpm}) * (\text{BARO}/29.92) * \text{SQRT}(298/(\text{AAT}+273))}$$

Where: STP = Standard Temperature and Pressure = 25 °C, 29.92 in Hg BARO,  
 SQRT = square root,  
 WOT = wide open throttle,  
 AAT = Ambient Air Temperature and is in °C





$$\frac{\text{current airflow}}{(\text{peak airflow at WOT@STP as a function of rpm}) * (\text{BARO}/29.92) * \text{SQRT}(298/(\text{AAT}+273))}$$