# 1 OBD Description

## 1.1 Catalyst Monitoring

The diagnosis of the catalyst directly determines the OSC (oxygen storage capacity) of the catalyst and compares the result with the oxygen storage capacity of a borderline catalyst (catalyst deteriorated to the malfunction criteria). The nonlinear correlation between conversion efficiency and oxygen storage capacity has been shown in various investigations.

The diagnosis is split into a quick pass check and the main catalyst check. The quick pass check is only able to diagnose a good catalyst. Malfunctions can only be detected by the main catalyst check.

### 1.1.1 System overview and catalyst diagnosis structure

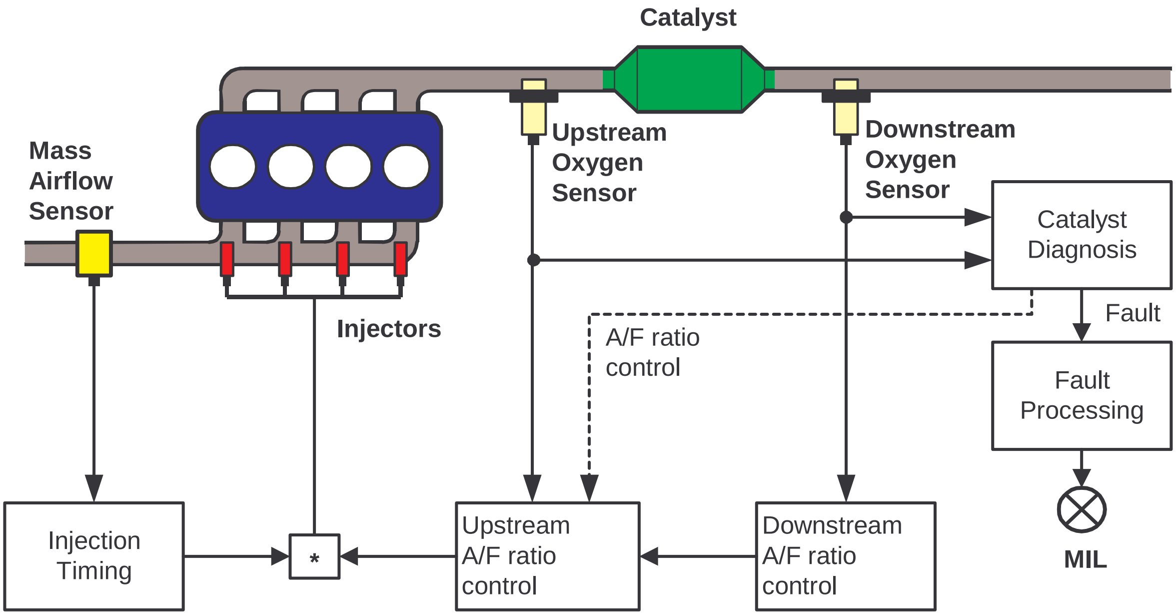


*Figure 1: System overview*

### 1.1.2 Quickpass check

During fuel cut-off oxygen is stored in the catalyst. After fuel cut-off the catalyst is flushed with a rich air-fuel mixture and the amount of removed oxygen is determined with the downstream oxygen sensor. If the amount of rich air-fuel mixture required to remove the stored oxygen exceeds a calibrated threshold, the catalyst is diagnosed as operating properly. If the quick pass check indicates an oxygen storage capacity that barely reaches that of the borderline catalyst, it doesn't explicitly mean the catalyst has deteriorated to the malfunction criteria. Such a conclusion can be drawn only with the main catalyst check.

### 1.1.3 Main Catalyst check

The main catalyst check is based on the direct measurement of the catalyst's OSC during the transition from a rich to a lean air-fuel mixture. The required set up is depicted in Figure 1. The air-fuel ratio can be precisely determined with the upstream wide band oxygen sensor. The downstream oxygen sensor delivers information about the OSC of the catalyst.

In a two-step process oxygen is first completely flushed out of the catalyst with a rich air-fuel mixture. The amount of rich air-fuel mixture is a calibrated value. In the second step a lean air-fuel mixture is flushed into the catalyst and the amount of oxygen stored is calculated[1] right up to the oxygen overflow point.

[1] $OSC(t) = \int$ air mass flow * [(normalized A/F ratio) - 1] * dt

Oxygen overflow is indicated by a drop in voltage (below a calibrated minimum) of the downstream oxygen sensor's signal.

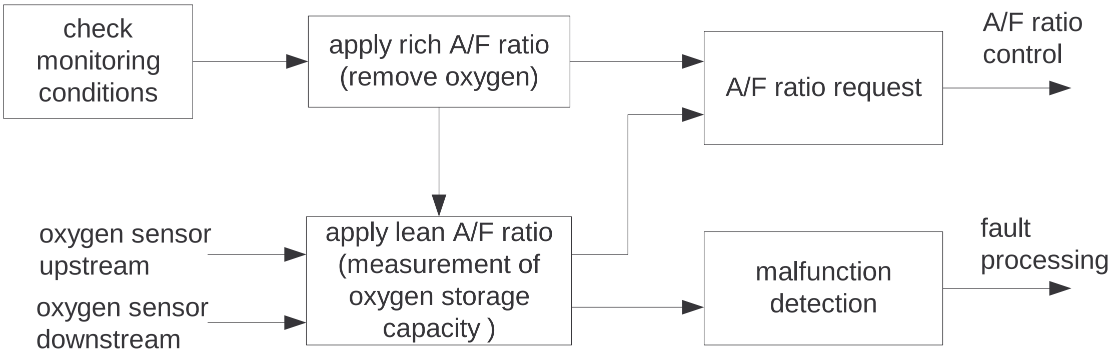


*Figure 2: Main Catalyst check - diagnosis structure*

### 1.1.4 In-use monitoring performance ratio (IUMPR)

The incrementing of the numerator, denominator, and the ratio calculation for the monitor is executed by the IUMPR kernel function. Like all monitors for whom a standardized track and report in-use performance is required, the catalyst monitor reports to the IUMPR kernel function via status flags - see description of IUMPR kernel function.

#### 1.1.4.1 Conditions for incrementing the numerator

The numerator is incremented when the catalyst monitor could have detected a malfunction. Explicitly when:

- a malfunction has been detected by the main catalyst check

or

- no malfunction has been detected by the main catalyst check **and**
  - the diagnosis of the oxygen sensor’s response rate has been performed without malfunction **and**
  - the quickpass check has not been performed

or

- no malfunction has been detected by the quickpass check **and**
  - the diagnosis of the oxygen sensor’s response rate has been performed without malfunction **and**
  - all monitoring conditions for the main catalyst check have been fulfilled such that a malfunction could have been detected. In particular these monitoring conditions are to be met till the integrated mass of exhaust gas has exceeded a calibrated minimum. The exceeded exhaust gas mass indicates that the monitor would have had enough time to be able to detect a malfunction.

If inhibiting faults (as mentioned in the monitoring conditions) are present the numerator is not incremented.

#### 1.1.4.2 Conditions for incrementing the denominator

The denominator is incremented if the monitor is not inhibited due to stored faults and if the general driving conditions have been fulfilled.

## 1.2 Misfire Detection

The misfire monitor is designed to detect combustion misfire by evaluating engine (crankshaft) speed fluctuations. The entire function for misfire detection consists of various sub-functions which together guarantee complete detection of all misfires (See Figure 3: DMD*-Method).

The diagnostic starts with the calculation of a segment duration (*tsk*) from the crankshaft signal, and correcting it with a self-learned sensor wheel adaptation (fuel-off adaptation). Engine speed fluctuation values are then calculated and again corrected by an extended adaptation (fuel-on adaptation). The misfires detected by the individual methods *Luts*, *Dluts* and *Fluts* are linked together and further processed in the fault code management. The fault code management determines appropriate fault code reporting and MIL action if required.

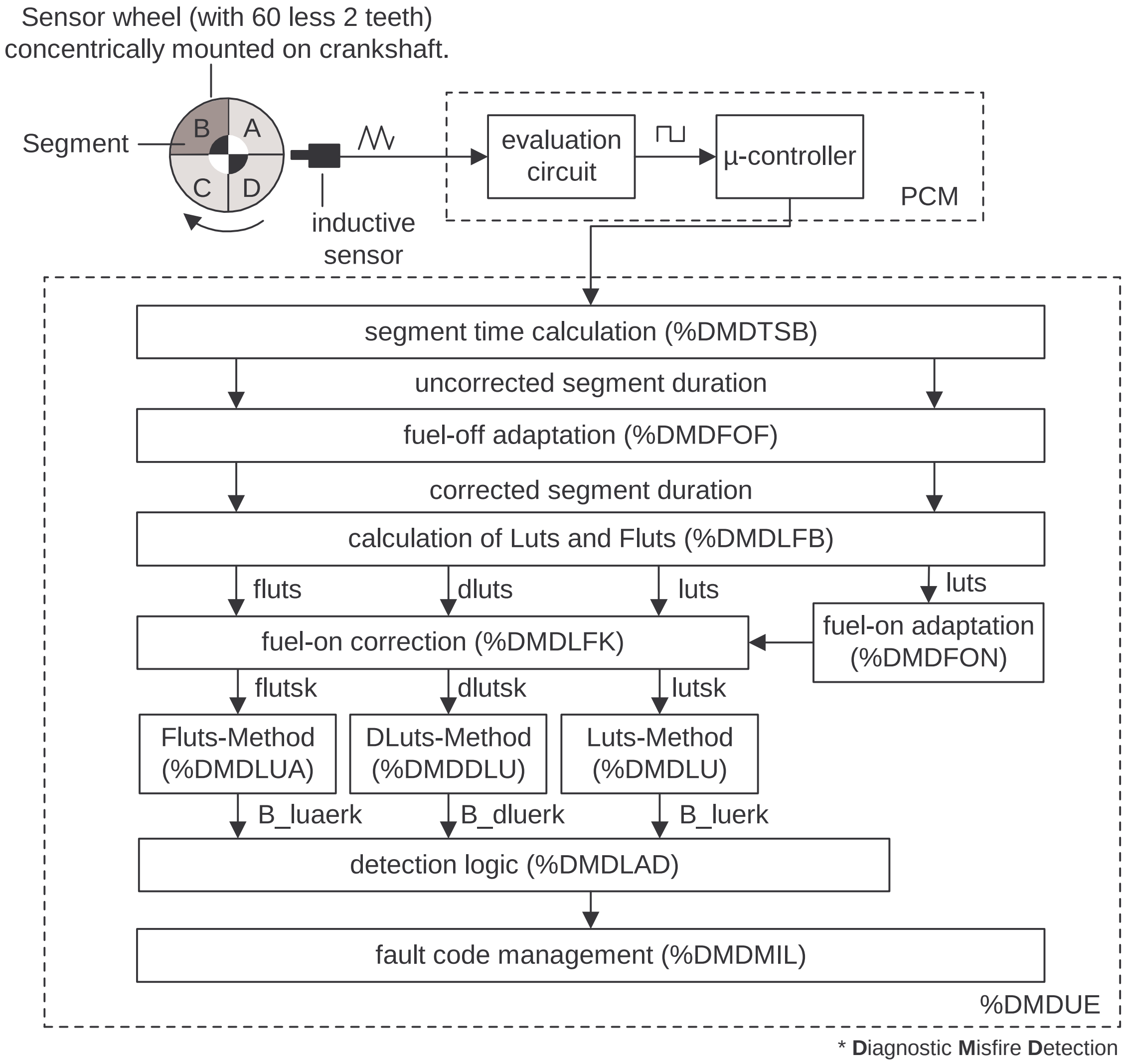


*Figure 3: DMD*-Method*

***Revised version: for US car dealers only***

### 1.2.1 Segment time formation (%DMDTSB)

The core of the method is the precise determination of the engine speed. This is realized by scanning the 60-less-2-toothed sensor wheel with an inductive sensor. The time required for a crankshaft segment to travel past the inductive sensor is referred to as the segment period ts(n) [where n is a combustion index], and its length corresponds to the interval between two ignitions. The inductive sensor's signal is processed in the PCM and used for calculating crankshaft segment periods.

#### 1.2.1.1 Correction of the Segment Time *ts(n)* (%DMDFOF, see Figure 4):

The adaptation during fuel cut-off learns systematic differences of the segment times between the individual segments and uses the determined correction values to compensate segment specific variations. After the adaptation, the segment periods are nearly identical apart from the stochastic signal noise in the steady-state case.

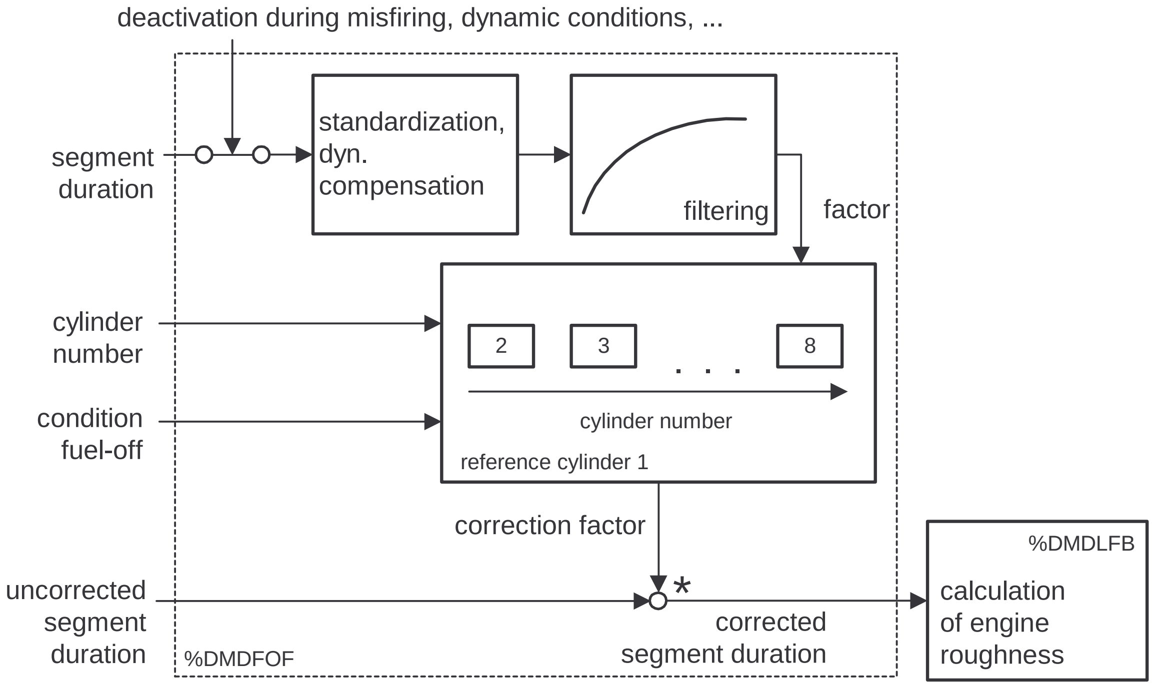


*Figure 4: Fuel-Off Adaptation - %DMDFOF*

### 1.2.2 Calculation of the engine roughness values *luts, fluts* and *dluts* (%DMDLFB):

The engine roughness *luts* (angular acceleration change) for each combustion is calculated from several temporarily consecutive segment times as follows:

$$luts(n) = \frac{tsk(n+1) - tsk(n) - tkomp(n)}{tsk(n)^3} \qquad \text{n : ignitions}$$

**Revised version: for US car dealers only**

*Dluts* is calculated by subtracting of *luts* values staggered by 360° CS: (one revolution of the crankshaft)

For *fluts* the cylinder-individual engine roughness values *luts (zyl)* are filtered by means of a recursive low

$$dluts(n) = luts(n) - luts(n + \frac{ZYLZA}{2}) \qquad \mathrm{ZYLZA: \# \ of \ cylinders}$$

$$\mathrm{n: ignitions}$$

$$fluts(zyl)(i) = (1 - FFLUTN) * \ fluts(zyl)(i-1) + FFLUTN * luts(zyl)(i)$$

$$\mathrm{i: camshaft \ revolutions}$$

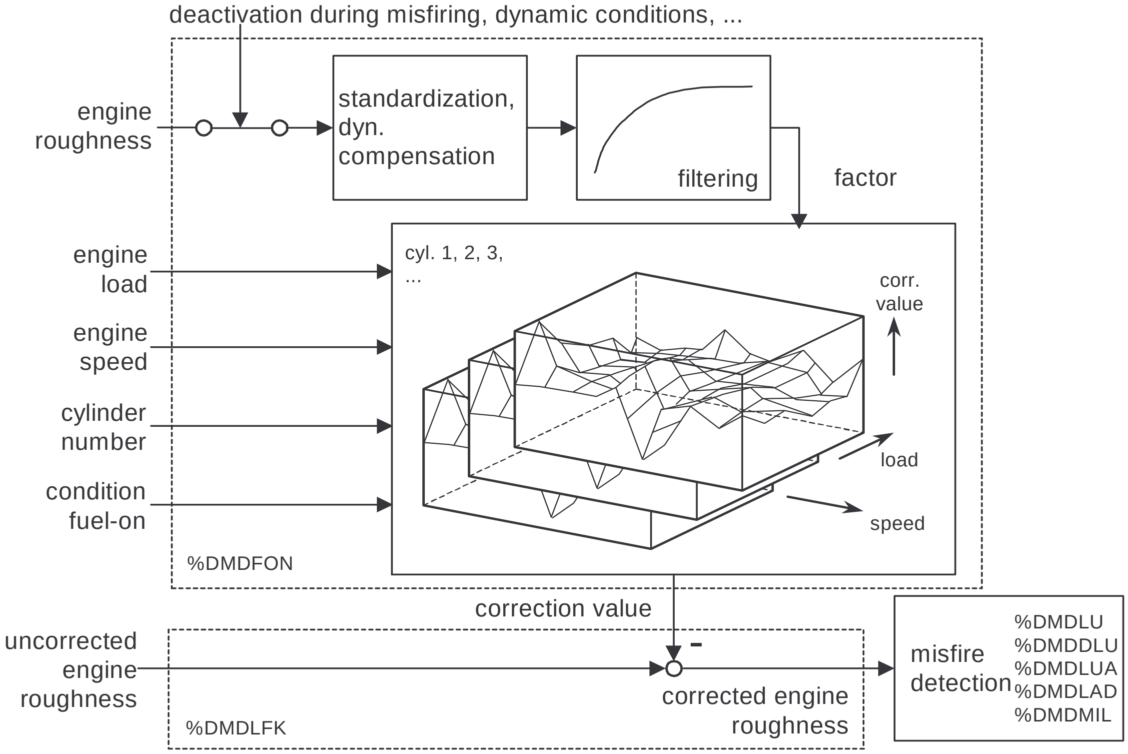
$$\mathrm{FFLUTN: filter \ constant}$$

pass (fluts(zyl)):

### 1.2.2.1 Correction of the engine roughness value *luts* (%DMDFON, see Figure 5):

The adaptation during firing operation (fuel-on adaptation) learns systematic differences of the calculated engine roughness *luts* between the individual cylinders depending on the current operating point of the engine.

*Figure 5: Fuel-on Adaptation - %DMDFON*



### 1.2.2.2 Fuel-on correction of engine roughness values *luts, fluts* & *dluts* (%DMDLFK):

The learned fuel-on adaptation values are used to correct the engine roughness values *luts, dluts* and *fluts* to improve the overall signal-to-noise ratio.

### 1.2.3 Misfire detection by *Luts*-Method (%DMDLU, see Figure 6):

The corrected engine roughness *lutsk* is compared to a load and speed dependant threshold *lurs*. When the threshold *lurs* is exceeded, misfire is detected. An example of continuous misfire in cylinder one is shown in Figure 7.

*Figure 6: Luts-Method - %DMDLU*

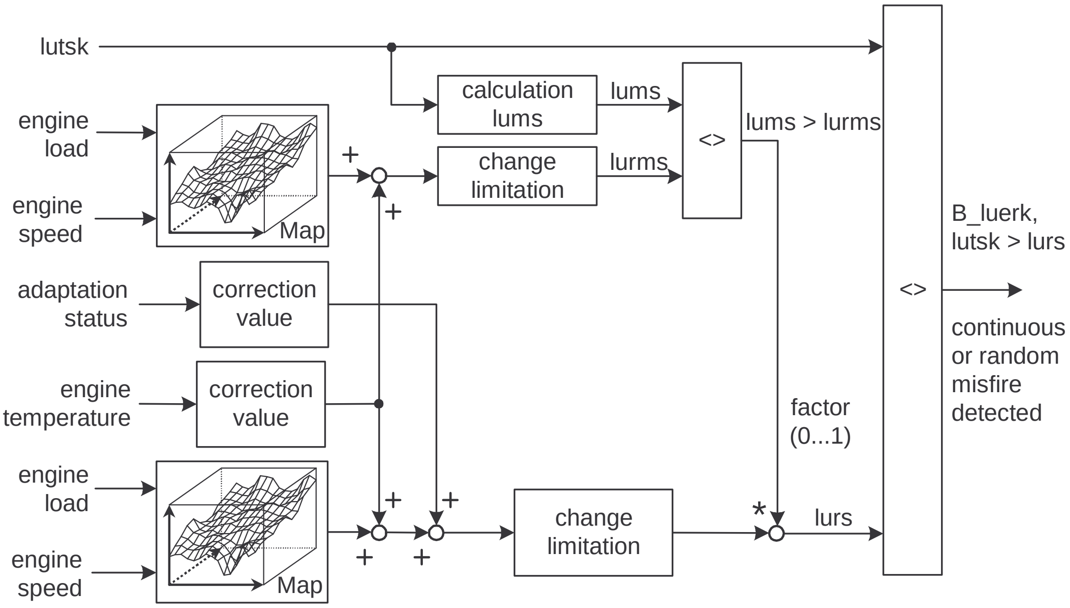


*Figure 7: An illustration of continuous Misfire*

### 1.2.4 Misfire detection by *Dluts*-Method (%DMDDLU, see Figure 8):

This function allows the detection of random and continuous misfires, as well as non-symmetrical multiple misfires. Due to the 360° CS staggered value *dlutsk* the detection quality is independent of sensor wheel inaccuracies (crankshaft-synchronous segment time fluctuations). However, symmetrical multiple misfires (which also generate crankshaft-synchronous segment time fluctuations) cannot be detected. *Dlutsk* is compared to a load and speed dependant threshold *dlurs*. Misfire is detected if the threshold is exceeded.

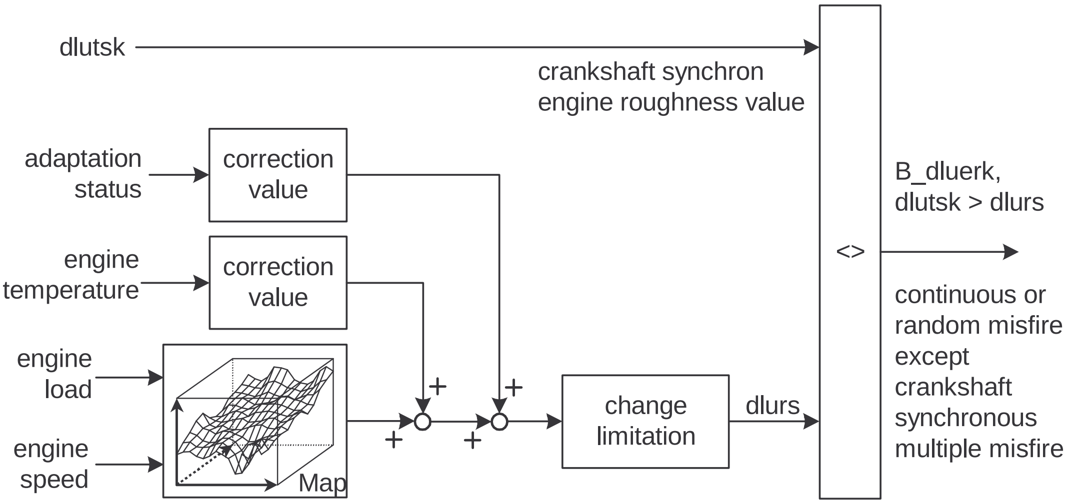


*Figure 8: Dluts-Method - %DMDDLU*

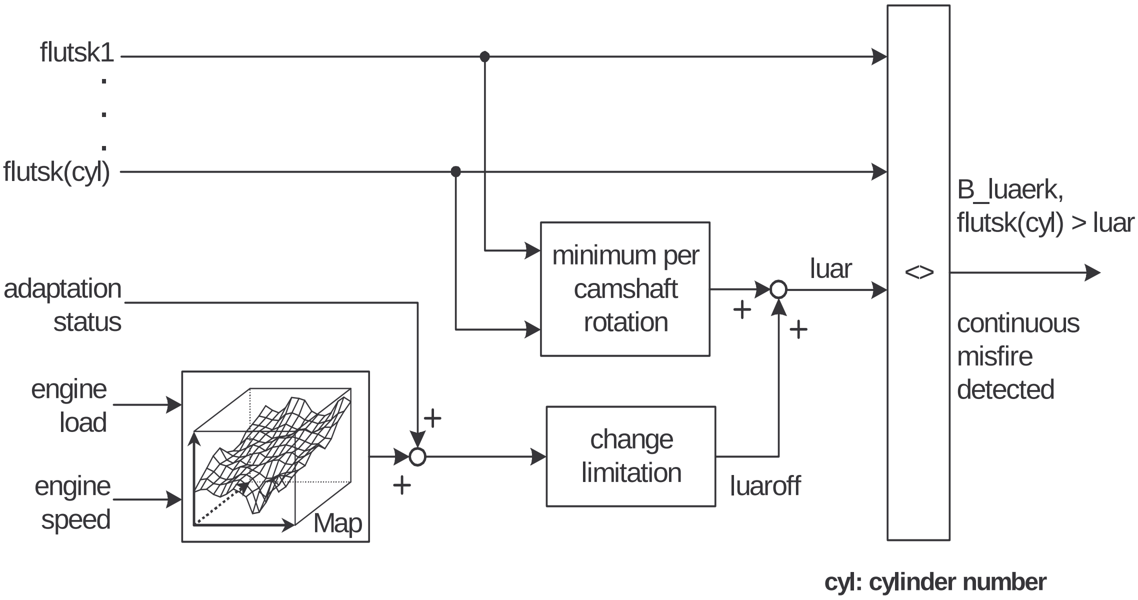


*Figure 9: Fluts-Method - %DMDLUA*

### 1.2.5 Misfire detection by *Fluts*-Method (%DMDLUA, see Figure 9):

The function allows the detection of continuous misfire at one or more cylinders. The filtered, cylinder-individual roughness values *flutsk(zyl)* are compared to an accompanying threshold or reference value *luar*. The threshold value *luar* is calculated from a load and engine speed dependent offset value, which is added to the lowest *flutsk* value per working cycle.

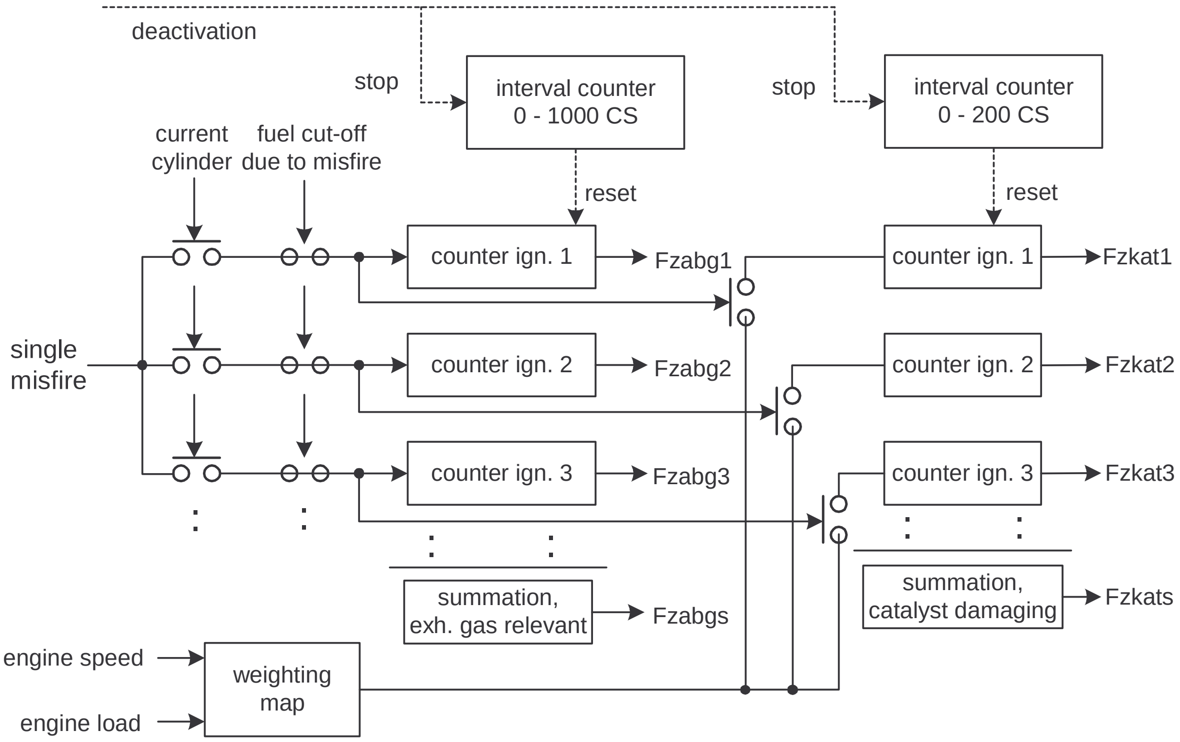
### 1.2.6 Fault handling and misfire statistics (%DMDMIL)

Each combustion, apart from those deactivated, has to be checked for misfire since misfires can be distributed arbitrarily (see Figure 10). A fault handling action will, however, only take place if specific percentage misfire levels are exceeded.

The different effects of combustion misses (increase of the exhaust emissions and catalyst damage) are handled separately.

During the fault entry a distinction is made as to whether it is an emissions relevant fault after start, during the driving cycle, or whether it is a catalyst-damaging fault. Furthermore a cylinder identification of the misfiring cylinder is performed.

*Figure 10: Fault Code Management - %DMDMIL*



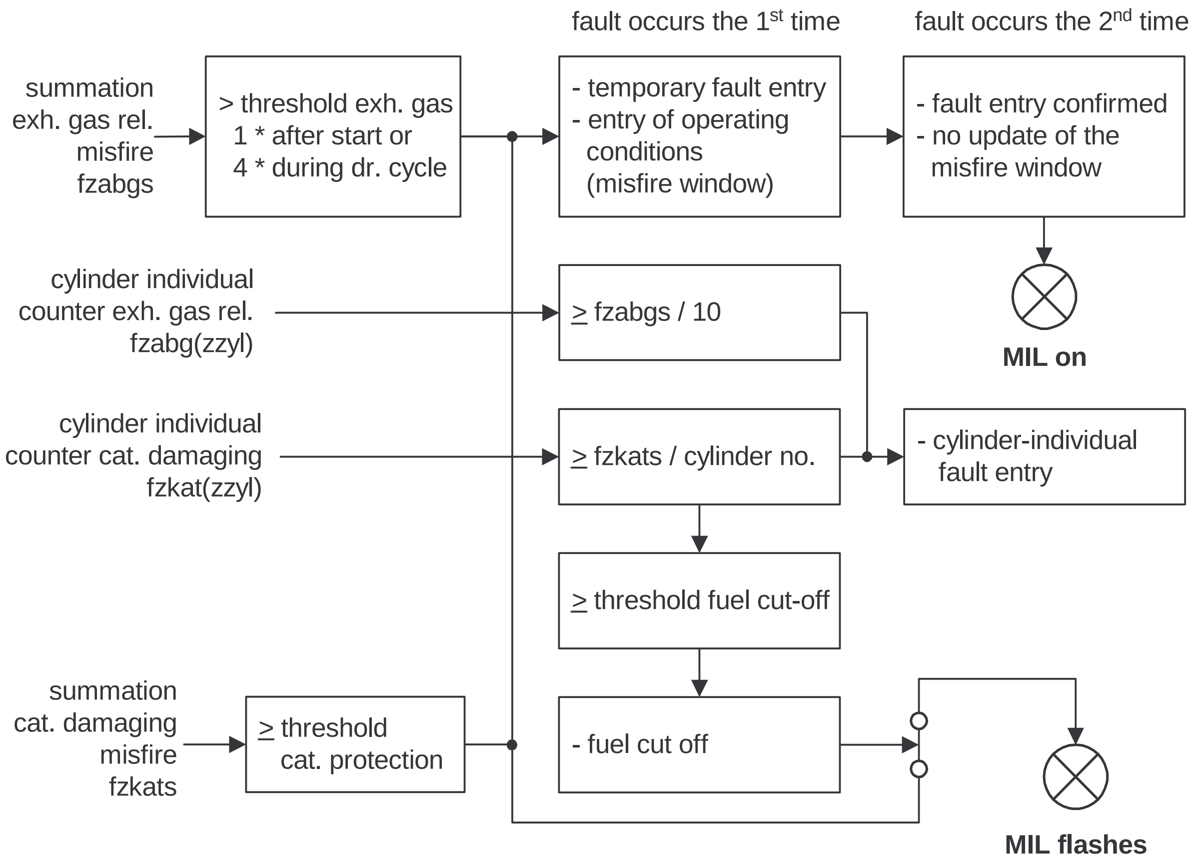


Figure 11: Fault Handling of Misfire

### 1.2.7 Emissions Relevant Misfires

Emissions relevant fault handling is accomplished by utilizing cylinder specific counters (*Fzabg1 .... Fzabg8* see Figure 10) that are incremented each time the associated cylinder misfires. The total sum of all misfires within every 1000 crankshaft revolutions (beginning from engine start) is continuously tracked with another counter *Fzabgs*. A reset of all counters is performed at the end of every 1000 crankshaft revolutions.

#### 1.2.7.1 Emissions Relevant Misfires after Engine Start

If the sum of all misfires within the first 1000 crankshaft revolutions
exceeds a calibration (the equivalence of 1.5 times emissions standards) the corresponding fault code entry and appropriate MIL action will be performed as depicted in Figure 11. A different calibrated threshold is employed if catalyst heating was active during this first interval.

#### 1.2.7.2 Emissions Relevant Misfires during Driving Cycle

If the sum of all misfires (beginning with the second 1000 crankshaft revolutions) during the driving cycle exceeds a calibration for up to 4 times, the corresponding fault code entry will be carried out as depicted in Figure 11.

### 1.2.8 Catalyst Damaging Misfires

A rapid response to misfires that could potentially damage the catalyst is necessary. The monitoring interval here (as depicted in Figure 10) is equivalent to every 200 crankshaft revolutions. Analogous to emissions relevant misfires, cylinder specific counters *Fzkat1 ... Fzkat8* and the sums total counter in bank1 *Fzkats1* and bank2 *Fzkats2* are employed as explained in Figure 10 and Figure 11 for detecting catalyst damaging misfires. The load and engine speed dependent weighting factor is higher at higher engines speeds and higher loads.

Fuel injection into cylinders that are responsible for or contribute to a catalyst damaging misfiring rate will be discontinued in order to protect the catalyst. If more than one cylinder is misfiring, both the cylinder-individual fault entry and a “multiple misfiring” entry will be carried out (see Figure 11). Each cylinder that individually has more than 10 percent of all detected misfires is identified.

Any pending fault code is erased when monitoring in the next driving cycle encounters similar conditions without detecting a malfunction.

### 1.2.9 Deactivation of the misfire detection (%DMDSTP)

Despite the already mentioned correction and adaptation methods, certain operating states exist for which deactivation of misfire detection is necessary to avoid misdetection. Misfire detection is suppressed under the following conditions:

- Engine start is immediately followed by unsteady crankshaft revolutions at low rpm. This can be wrongly diagnosed as a cylinder misfire. Hence misfire monitoring is enabled within 1 camshaft revolution after engine speed reaches 400 rpm below warmed up idle speed.
- Suppression due to deactivation of fuel injection in one or more cylinders. However, deactivation due to a failure in the power stage of an injection valve or due to the detection of a cylinder misfire, doesn’t lead to suppression of misfire detection.

Misfire detection is further deactivated

- in camshaft sensor limp home condition (misfires associated with synchronization are not counted)
- when below zero load
- when engine speed lies below a calibrated minimum
- when engine speed lies above a calibrated maximum
- during camshaft control
- when the clutch is engaged (gearshift manual transmission)
- when the canister purge diagnostic is active
- during active torque intervention (e.g ABS, traction control and gear changes)
- when a rough road is detected
- when the engine sensor’s limp home function is active
- when the throttle valve’s position has not been validated
- due to improper camshaft to crankshaft alignment
- if there are camshaft control system errors
- due to faulty engine speed sensor.

## 1.3 Evaporative Purge System Diagnostic

### 1.3.1 Evaporative System Leak Measurement

#### 1.3.1.1 General Description of Leak Measurement

The evaporative system monitoring permits the detection of leaks in the evaporative system with a diameter of 0,02 inches and up.

By means of a Diagnostic Module_Tank Leakage (DM-TL), an electrical actuated pump located at the atmospheric connection of the evaporative canister, a pressure test of the evaporative system is performed in the following order:

During the Reference Leak Measurement, the electrical actuated pump delivers through the reference restriction. The engine-management system measures the pump’s electrical current consumption in this section.

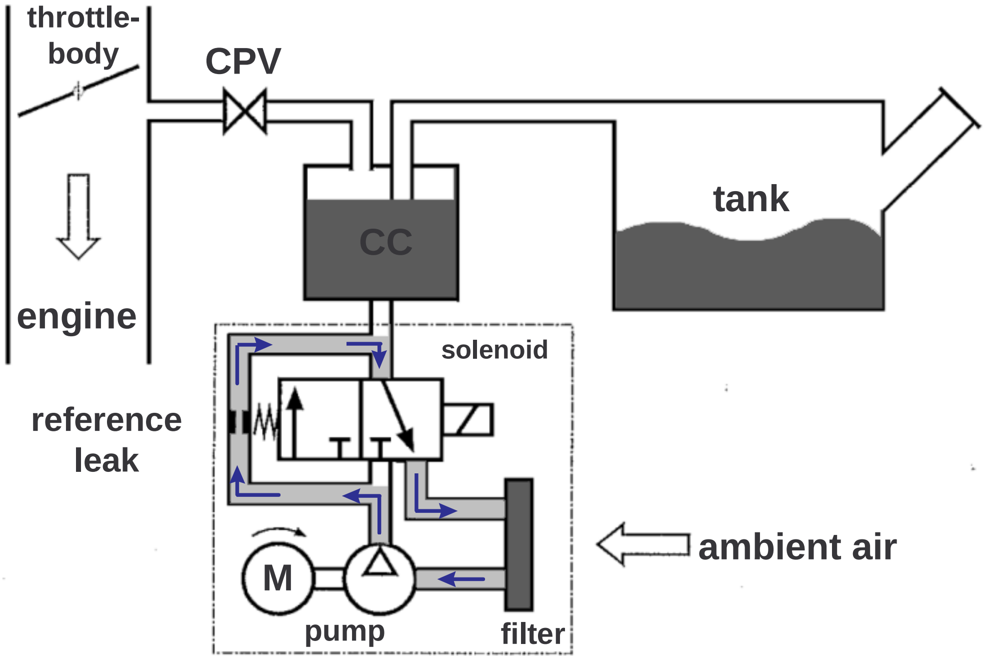


*Figure 12*

During the Leak Measurement, the electrical actuated pump delivers through the charcoal canister into the fuel-tank system. The pressure in the evaporative system may be up to 2.5 kPa depending on the fuel level in the tank. The engine-management system measures the pump’s electrical current consumption. A comparison of the currents of the reference leak measurement and the leak measurement is a measure for the leakage in the tank.

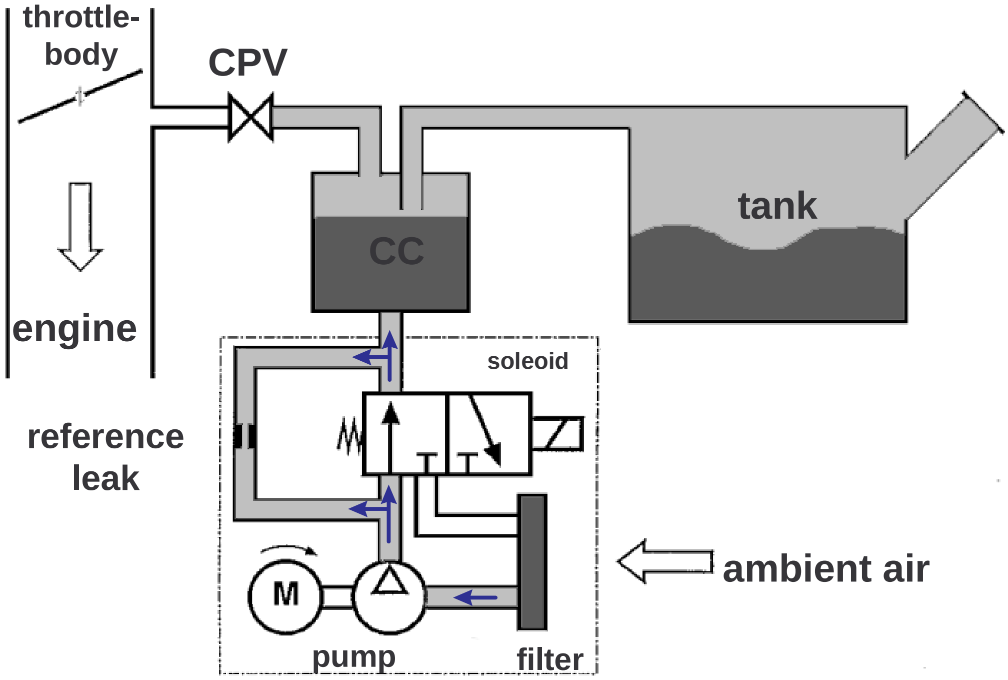


*Figure 13*

0.02 inch diagnosis:

The first step of the diagnosis is the reference measurement, the result of the pump reference current is stored. Picture in chapter a). After the solenoid switches, the venting system is pressurized. Picture in chapter b) In the rough leak measurement the rough leak threshold is reached if the leak is smaller than 0.04 inch, and then the small leak measurement phase follows. Does the DMTL current reach in the small leak time the reference current the system is tight (leak smaller than 0.02 inch), otherwise a small leak between 0.02 – 0.04 inches is detected.

0.04 inch diagnosis:

The first step of the diagnosis is also the reference measurement, the result of the pump reference is stored. Picture in chapter a). After the solenoid switches, the venting system is pressurized. Picture in chapter b). In the rough leak phase (time) the pump current must reach the rough leak threshold 1 (rough leak threshold 1 = idle current pump + K1 x (reference current – idle current). Factor K1 is between 0.16 and 0.28 depending on the characteristic current value of the pump (reference current – idle current), this value is various in every pump.
If the rough leak threshold 1 is not reached in the rough leak time, the rough leak threshold 2 must be reached in an additional time. (rough leak threshold 2 = idle current pump + K2 x (reference current – idle current) . Factor K2 between 0.60 and 0.80 depending on the characteristic current value of the pump (reference current – idle current).
If the rough leak threshold 2 is also not reached, a leak > 0.04 inches is detected.

In the diagram below is the typical current of a tight system, a 0.02 inch leak, and a leak > 0.04 inches.

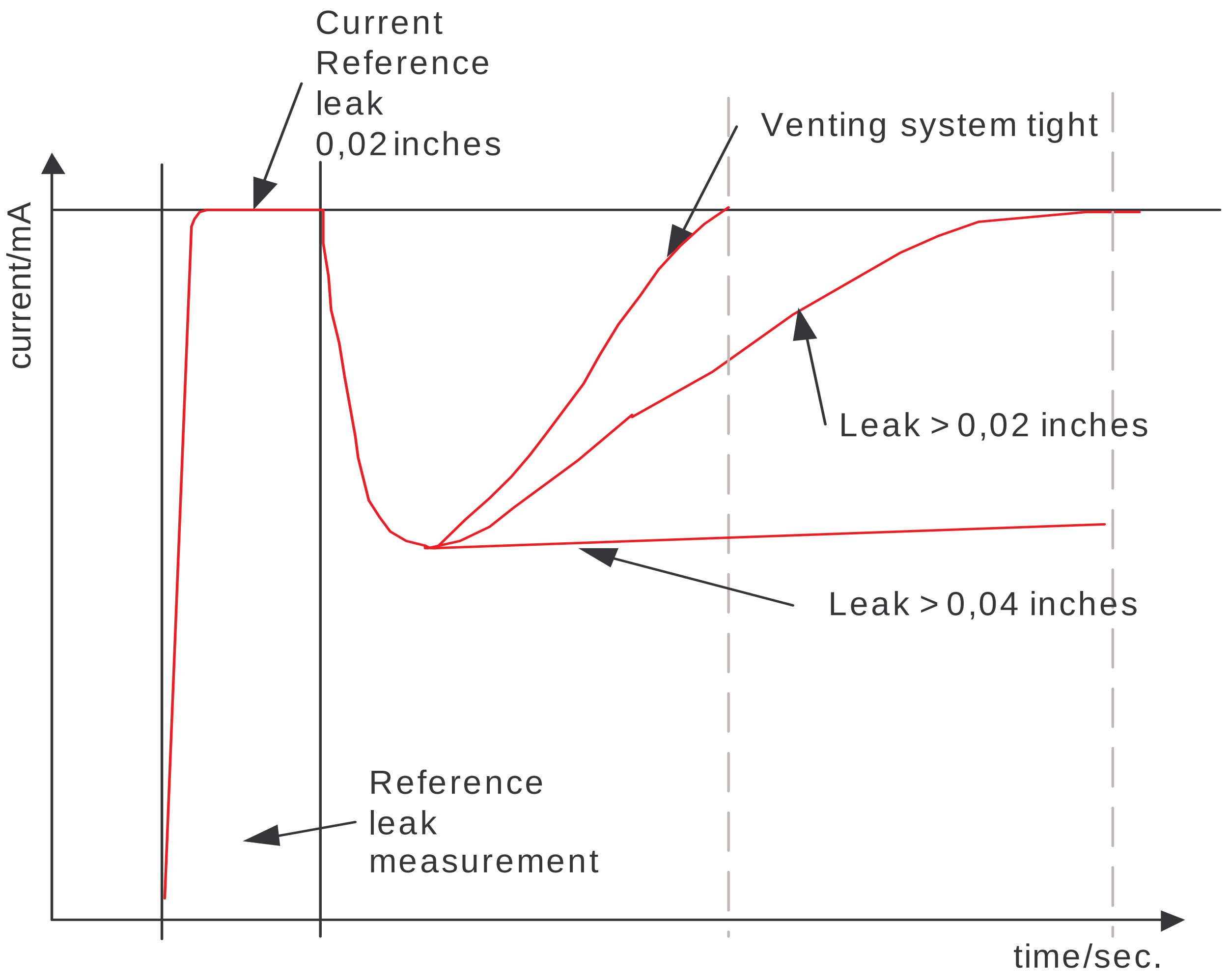


*Figure 14*

After the test the remaining pressure in the evaporative system is bled off through the charcoal canister by switching off the pump and solenoid.

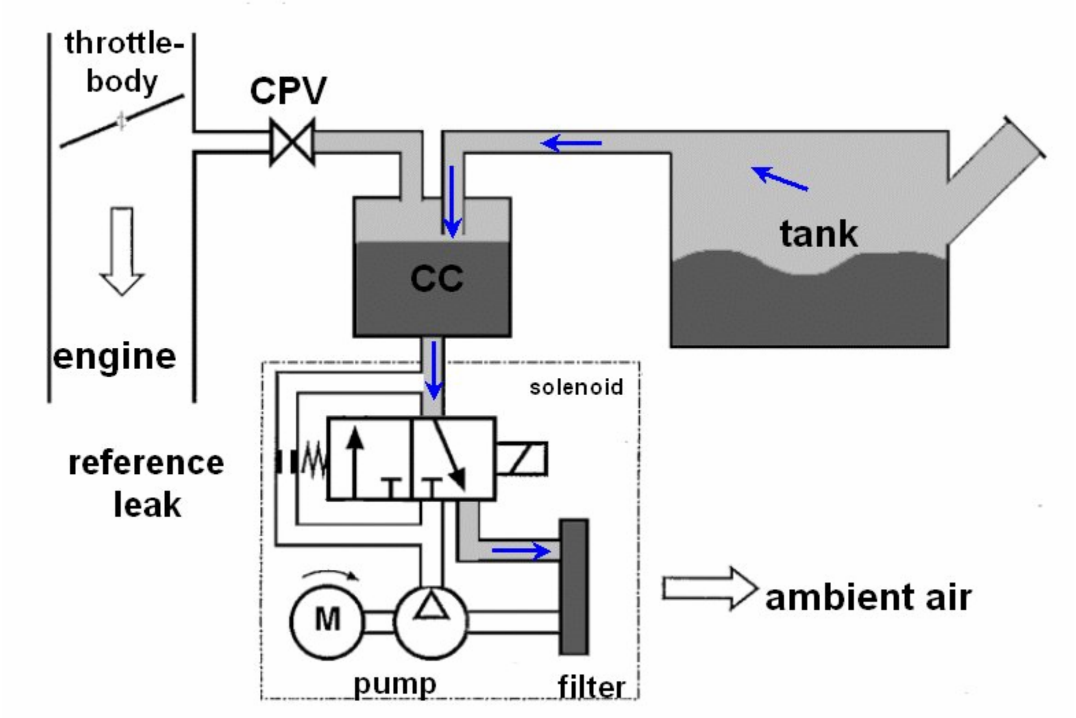
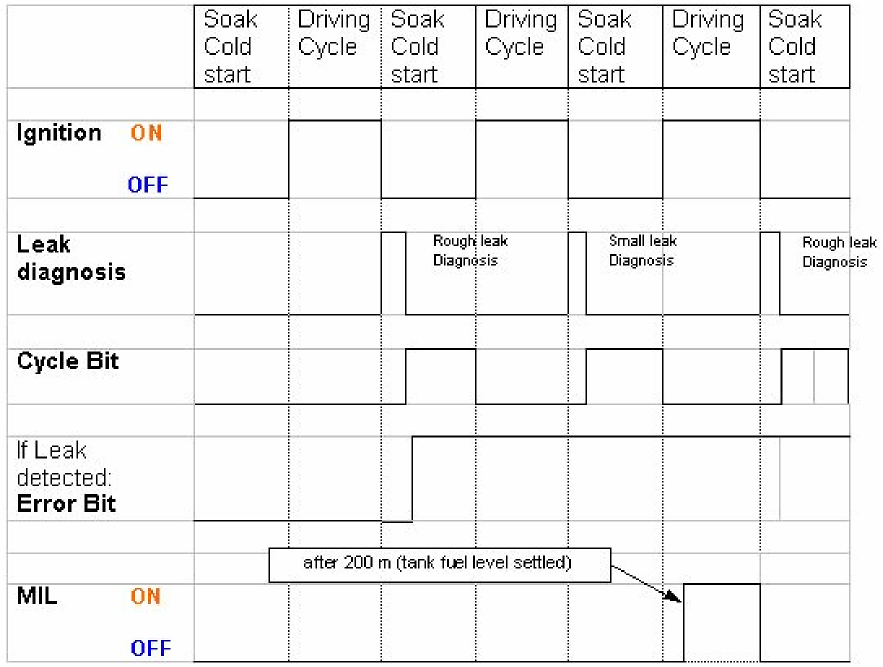


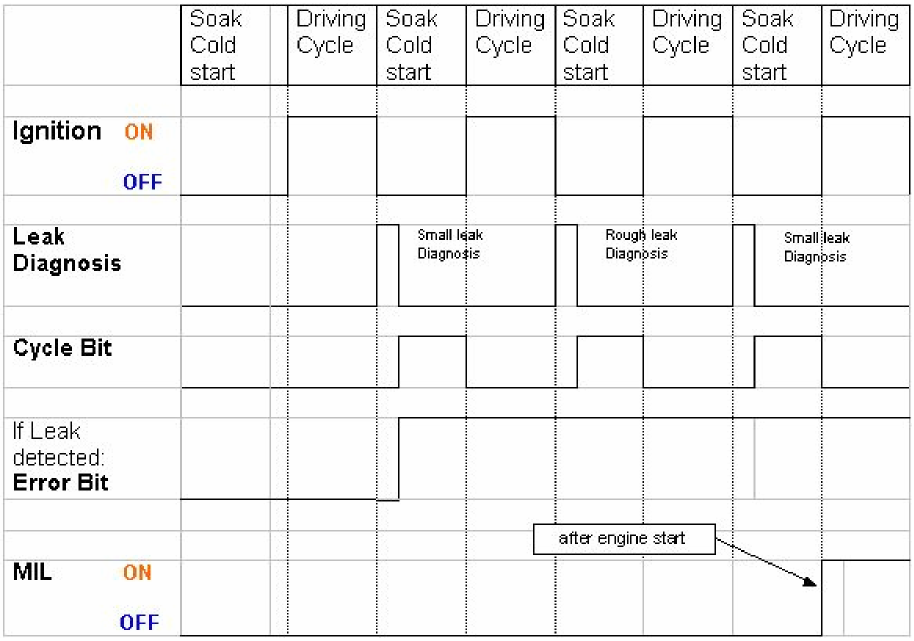
Figure 15

### 1.3.1.2 Diagnosis Frequency and MIL Illumination

#### 1.3.1.2.1 Diagnosis Frequency and MIL illumination: leak > 0.04 inches



#### 1.3.1.2.2 Diagnosis Frequency and MIL illumination: Rough leak counter ≥ threshold: leak > 0.02 inches



### 1.3.2 Evaporative Purge System – Canister Purge Valve (CPV)

The CPV is mounted directly to the engine block and is needed to purge the Activated Carbon Filter.
The purge flow from the Charcoal Filter is monitored after the fuel system adaptation is completed and the lambda controller is in closed loop operation. The diagnosis will be started during regular purging.

#### 1.3.2.1 Diagnosis of Canister Purge Valve (CPV) (under driving conditions) :

Step 1 Check of purge vapor factor (for rich or lean mixture):

Flow through the purge valve is inferred as soon as the lambda controller compensates for a rich or a lean shift. After this procedure the diagnosis is completed and the evaporative purge system resumes normal operation.

Step 2 Test of canister pressure (for a stoichiometric mixture):

In case of a stoichiometric mixture an additional check is performed by opening the purge valve during Evap leak detection. When the purge valve opens, the pressure in the tank system drops proportional to the DM-TL pump current. If ∆pump current > threshold, the purge valve is considered operational

## 1.4 Fuel Level Sensor

The diagnosis of the fuel level sensor signal, which is received via CAN bus, consists of a CAN signal check and a plausibility check.

### 1.4.1 Fuel level sensor circuit continuity check

The signal of the fuel level sensor is monitored concerning the valid range. This range depends on the used fuel level sensor.
If the fuel level sensor signal is out of the valid range, an electrical malfunction (short circuit to ground or interruption) is detected and an appropriate fault code is set.

### 1.4.2 Fuel level sensor signal rationality check (plausibility error)

The engine management system of every BMW has the capability to calculate fuel consumption. For the fuel level sensor plausibility check, this calculated consumption is compared with the difference of the fuel level signal. When the calculated fuel consumption reaches an appropriate and predetermined amount (for example five gallons), the calculated fuel consumption is compared to the change in fuel level as indicated by the fuel level sensors. If the difference is greater than the applicable threshold value, a stuck fuel level sensor fault is detected and an appropriate fault code is set.

If a fault is present, the OBD II EVAP leak monitor will run using a substitute value of 85% total fuel tank volume.
The 85% substitute value will assure that in every case the required 0.020 inch leak is detected by the OBD II system.

### 1.4.3 FLS diagnosis frequency fuel level sensor circuit continuity check

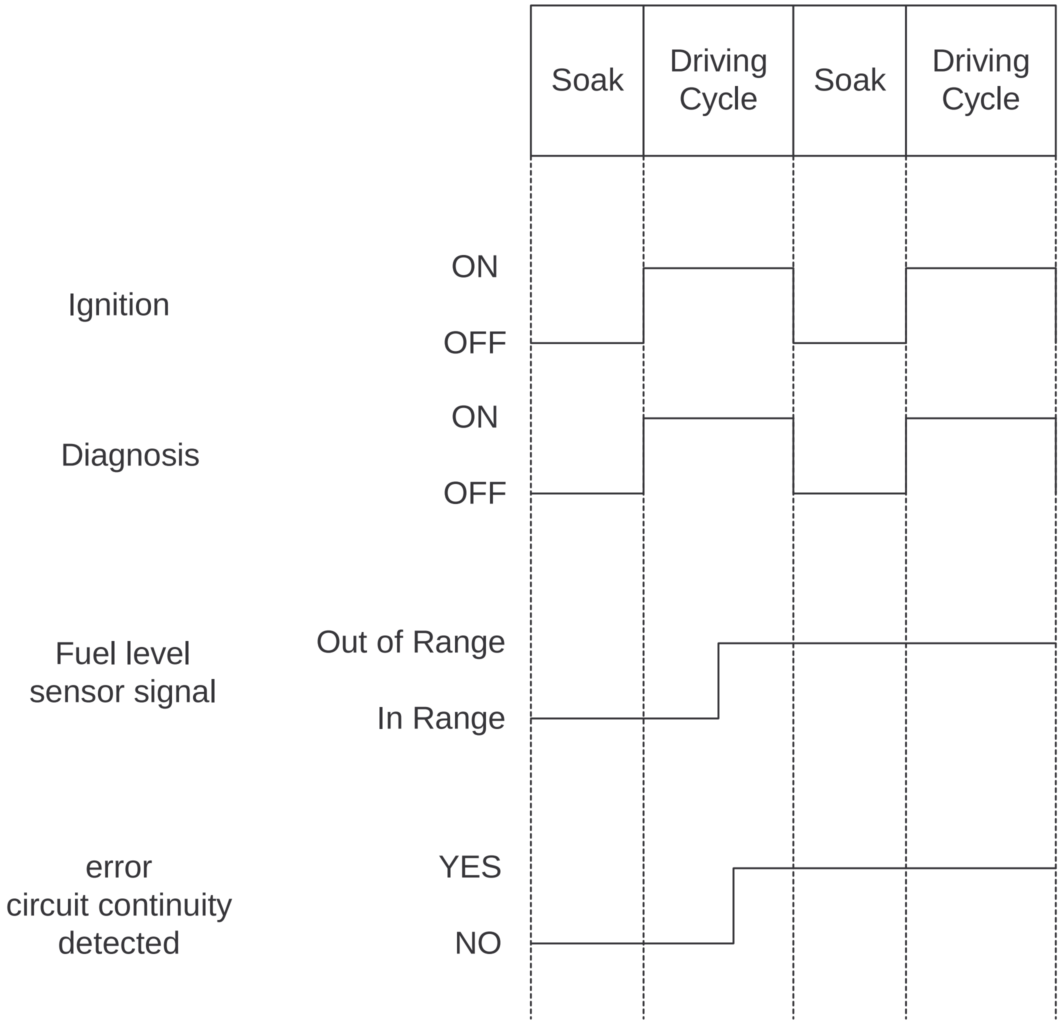


*Figure 16*

### 1.4.4 FLS diagnosis frequency fuel level sensor signal rationality check (plausibility error)

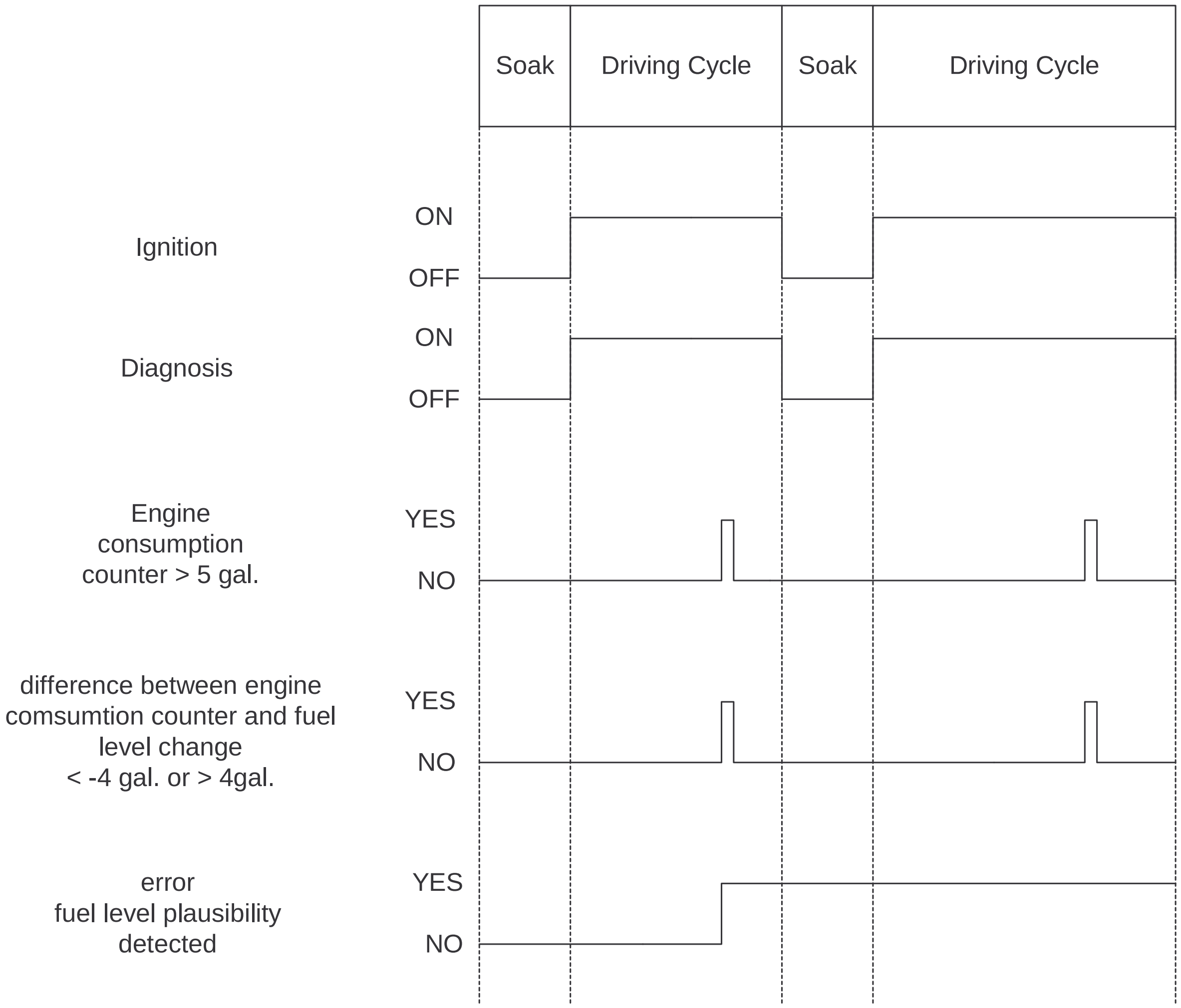


*Figure 17*

## 1.5 Positive Crankcase Ventilation System (PCV)

### 1.5.1 General description of the PCV-System:

Blowby gas with oil reaches the cylinderhead cover, where the oil will be separated and directed back to the oil sump. The cleaned blowby gases are directed via the intake system to the combustion. The pressure regulator makes sure that the high vacuum level between crankcase and ambient air will be reduced if needed.

### 1.5.2 Diagnosis of a leakage in the PCV-System:

A disconnection or leakage in the PCV-System is indicated by a rough or stalling engine and results in a reaction within the fuel system (fuel trim deviation).
In this case a fault code will be stored by the fuel system monitoring.

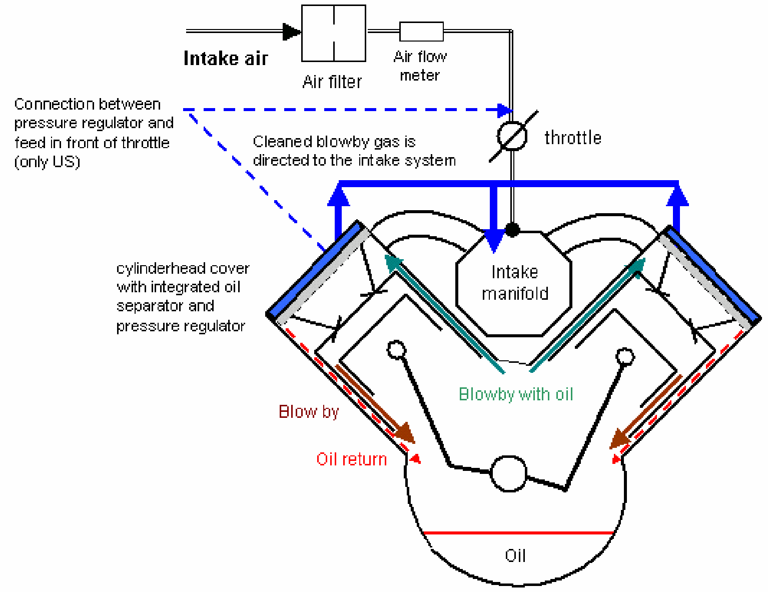
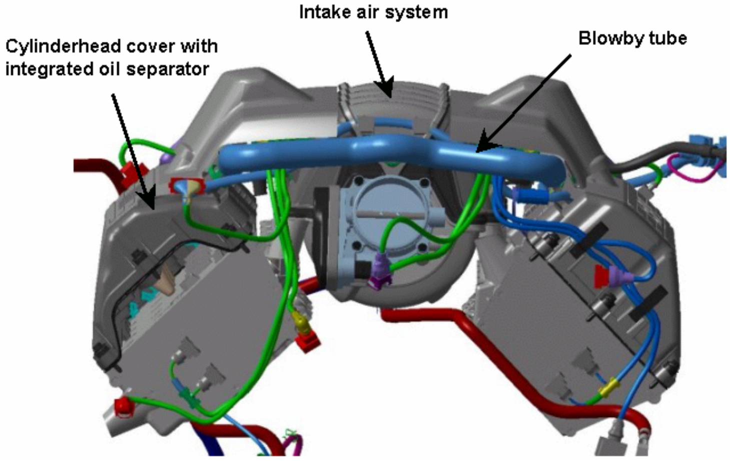


*Figure 18*

*Figure 19*



## 1.6 Diagnosis of Engine Off Time

Engine off time is determined by utilizing an externally clocked free running timer that communicates with the powertrain control module via the CAN bus. The diagnosis of this timer consists of a CAN timer signal check and a rationality check.

### 1.6.1 CAN timer signal availability check

A signal fault CUHR is set if the free running timer message (received via the CAN bus) is corrupt or missing for a calibrated period for time.

### 1.6.2 Rationality Check

Rationality check commences with the synchronization of the PCM's internally clocked timer with the externally clocked free running timer. The PCM measures and analyzes the received free running timer messages within a calibrated monitoring period of time by employing an internally clocked reference timer. Synchronization deviations within each defined monitoring period of time are analyzed.

A plausibility fault CUHR (timer too slow or too fast) is set if during a monitoring period the absolute time difference between the internal reference timer and the external free running timer exceeds a calibrated threshold for a calibrated period of time.

## 1.7 Diagnosis of Ambient Air Temperature

The diagnosis of the ambient air temperature sensor consists of a range check and a rationality check of the received temperature signal via CAN bus. Additionally the CAN signal itself is checked.

### 1.7.1 CAN Signal Check

If the ambient air temperature signal received via CAN is corrupt or missing, a malfunction is detected and a signal fault TUME is set.

### 1.7.2 Range Check

Taking into account the environmental conditions where a car is driven the ambient air temperature must lie within a valid range.
If the measured value from the ambient air temperature sensor exceeds the valid maximum temperature for a calibrated period of time, a malfunction is detected and a maximum fault TUME is set. In this case a short circuit to ground is expected.
If the measured value from the ambient air temperature sensor lies below the valid minimum temperature for a calibrated period of time, a malfunction is detected and a minimum fault TUME is set. In this case a short circuit to battery or a broken wire is expected.

### 1.7.3 Rationality Check

Depending on measured intake air temperature and other engine parameters, a substitute value for the ambient air temperature is calculated (see Figure 20).

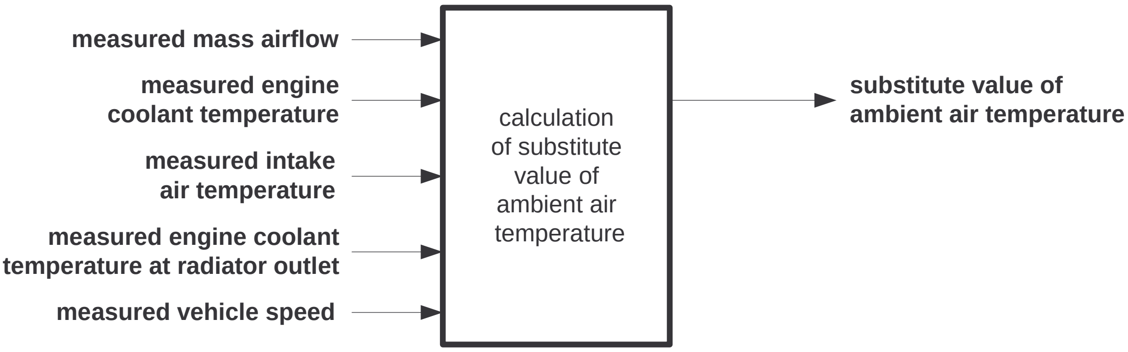


*Figure 20: calculation of substitute value of ambient air temperature*

If the difference (positive) between the measured and the calculated ambient air temperature exceeds a calibrated threshold for a calibrated period of time, a plausibility fault TUMP is set.

If the difference (negative) between the measured and the calculated ambient air temperature lies below a calibrated threshold for a calibrated period of time, a signal fault TUMP is set.

## 1.8 Diagnosis of Atmospheric Pressure Sensor

The diagnosis of the atmospheric pressure sensor consists of a circuit continuity check, a range check and a rationality check of the given output voltage of the sensor. The output voltage of the sensor can directly be calculated into the absolute atmospheric pressure.

### 1.8.1 Circuit continuity

The circuit continuity check compares the sensor signal voltage with an upper and lower limit to detect short or open circuits.

If the measured voltage from the atmospheric pressure sensor exceeds the upper calibration limit for a calibrated period of time, a short circuit to battery is detected and a maximum fault PUE is set.

If the measured voltage from the atmospheric pressure sensor lies below the lower calibration limit for a calibrated period of time, a short circuit to ground or an open circuit is detected and a minimum fault PUE is set.

### 1.8.2 Range check

Taking into account the lowest and highest driveable altitude, the pressure must lie within a valid range during all conditions.

If the measured value from the atmospheric pressure sensor lies below the valid minimum pressure for a calibrated period of time, a malfunction is detected and a minimum fault PUR is set.

If the measured value from the atmospheric pressure sensor exceeds the valid maximum pressure for a calibrated period of time, a malfunction is detected and a maximum fault PUR is set.

### 1.8.3 Rationality check

The first rationality check compares, during the current driving cycle, the change of the atmospheric pressure within a calibrated period of time. Under normal driving conditions e.g. uphill driving this change should be very slow.

If the absolute change of the measured pressure within a calibrated period of time exceeds a calibrated threshold for a calibrated period of time, a malfunction is detected and a signal fault PUR is set.

The second rationality check compares, during ignition on and engine off, the measured atmospheric pressure with the stored atmospheric pressure of the last driving cycle. After normal parking conditions (engine off) the difference between these two values should be very small. To cover special circumstances e.g. transportation from low to high altitude, the measured atmospheric pressure may additionally be compared after start of engine, with a modeled atmospheric pressure based on the mass airflow sensor. This additional check is only done if the signal change since the last driving cycle exceeds the threshold.

If

- the absolute difference between the measured and stored atmospheric pressure exceeds a calibrated threshold (during ignition on and engine off) **and**
- the absolute difference between measured atmospheric pressure and modeled atmospheric pressure exceeds a calibrated threshold (during engine running),

all for a calibrated period of time, a malfunction is detected and a plausibility fault PUR is set.

## 1.9 Diagnosis of Fuel System

This diagnosis is able to analyze up to two fuel systems, each with its own fault paths. In case of a stereo system with two fuel systems, each fuel system is monitored separately but all in the same way.
The detailed error paths of this diagnosis are not illuminating the MIL, but the general failure path FMAS. The handling of the general failure path FMAS is described in an additional document.

### 1.9.1 Fuel injection calculation

In the powertrain control module the injection time (ti) is calculated from an engine load signal (rl) provided by the mass airflow sensor, an additive correction of the fuel trim adaptation (rka), a multiplicative correction of the fuel trim adaptation (fra) and a multiplicative correction from the fuel control system (fr) as shown in Figure 21.

### 1.9.2 Fuel trim adaptation

The fuel trim adaptation has 3 self-learning integrators, which all depend on engine speed and engine load (rkat, frau, frao). The engine speed and engine load operating areas for rkat, frau and frao are shown in Figure 22.
Depending on the enable condition for each integrator, the deviation of the fuel control system from its stoichiometric A/F ratio is “learned”.

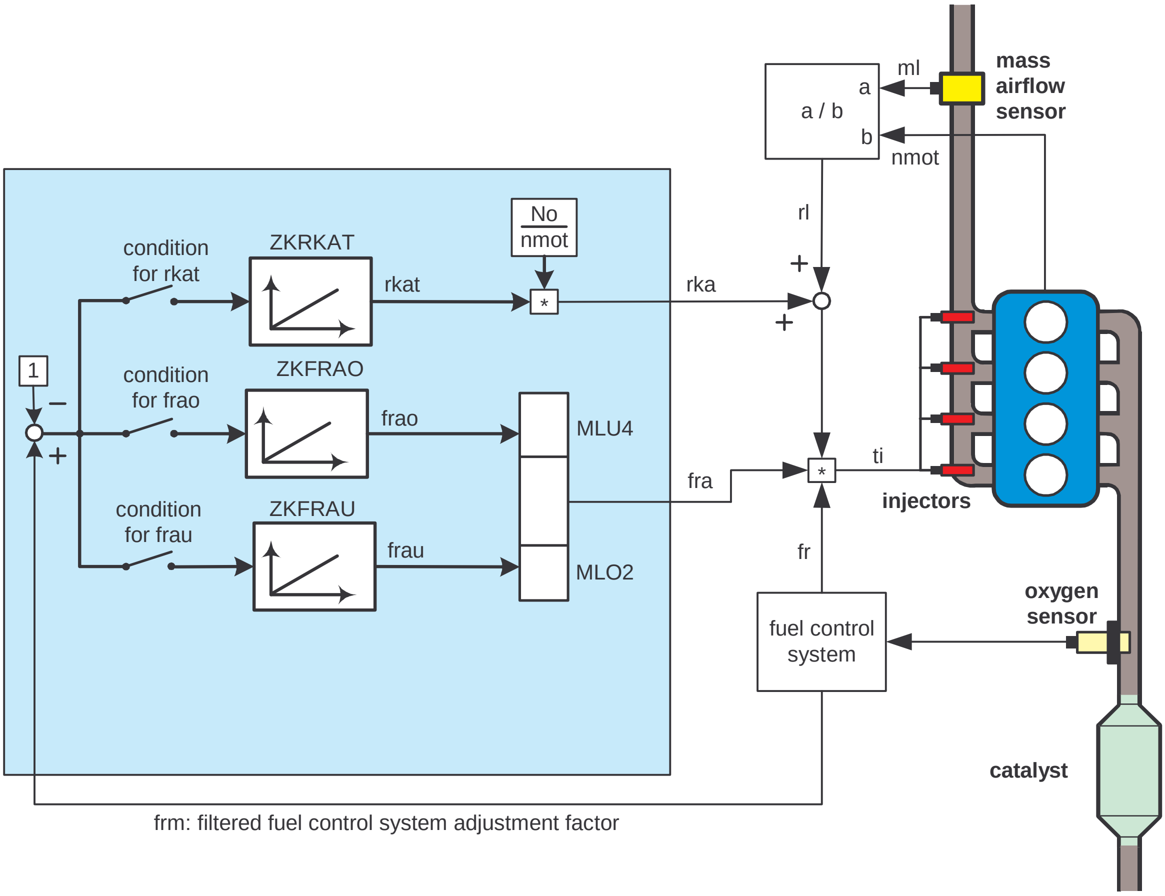


*Figure 21: Overview fuel trim adaptation and fuel injection calculation*

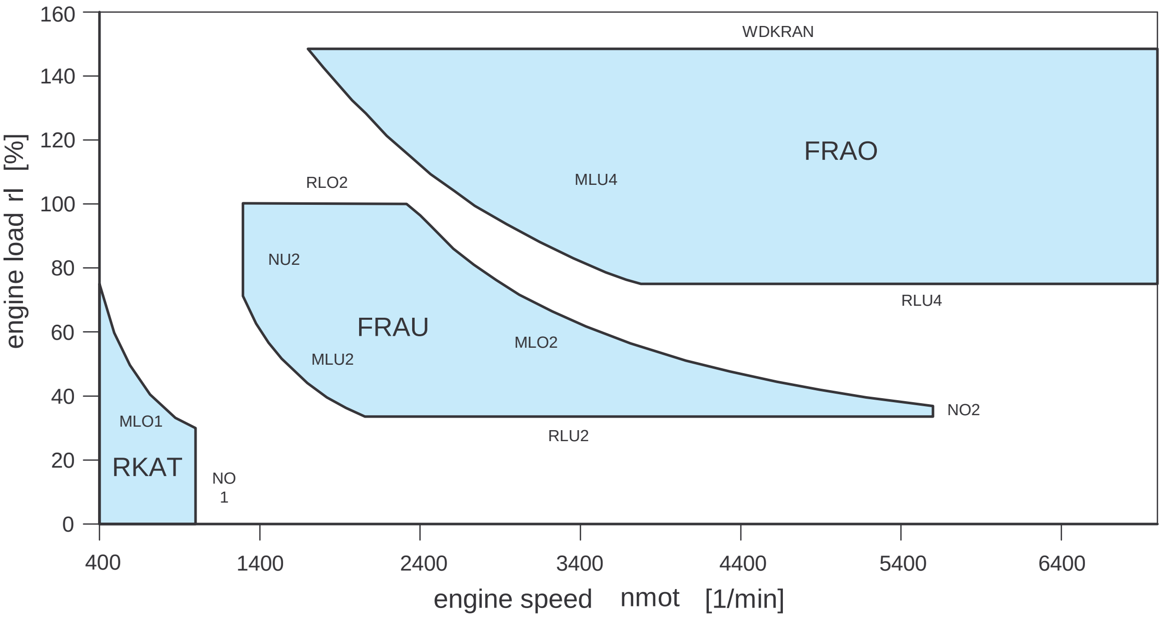


*Figure 22: Fuel trim adaptation operating areas RKAT, FRAU and FRAO*

### 1.9.3 Fuel system diagnosis

The diagnosis of the fuel system checks the output values of the fuel trim adaptation described before. Above a temperature limit the adaptation of the integrator rkat or frau or frao are enabled depending on the operating area (see Figure 22). All integrator output values are compared to their calibrated upper and lower limits. If the integrator output reaches one of the limits after the adaptation has stabilized, a malfunction is detected, the engine conditions are stored and a corresponding fault is set. To avoid misdetections, monitoring is disabled when the car is running out of fuel. For this purpose, a specific function for the detection of an empty fuel tank is performed.

### 1.9.4 Similar conditions

The fault code is erased when similar conditions have been encountered and no malfunction is detected. “Similar conditions” means engine conditions having an

- engine speed within +/- 375 rpm,
- load conditions within +/- 20 percent,
- and the same warm-up status (Due to the monitoring conditions of the engine coolant temperature only the warm-up status “warm” exists)

as the engine conditions stored at the time of fault detection.

### 1.9.5 Detection of empty fuel tank

An almost empty fuel tank can cause air bubbles in the fuel delivery system and thus causes a lean A/F ratio. First the fuel control system and then the fuel trim adaptation try to compensate this by increasing the correction factors. This can cause an erroneous MIL illumination, because the fuel trim adaptation factor could exceed a diagnostic threshold. Therefore a special precaution has to be taken in case an almost empty fuel tank is detected.

The following flowchart shows the functionality to ensure MIL illumination if the fault is detected correctly and to avoid erroneous MIL illumination in case of an almost empty fuel tank.

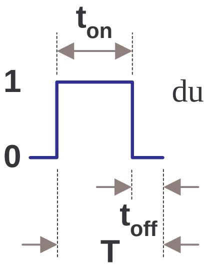
- If one of the adaptation factors exceed their diagnostic threshold and the fuel tank is detected as empty, the error flag is delayed for a certain time. Therefore the injected fuel mass is integrated and the current value is stored.
- If the integrated fuel mass exceeds a calibrated threshold and the fuel trim adaptation factor is still above its limit, the fuel system monitor is activated and a fault code is set.
- If the adaptation factor returns into the allowed working range before the integrated fuel mass exceeds its calibrated threshold, the last stored fuel mass remains unchanged for later comparison (refueling detection).
- Refueling is detected, if the difference of current fuel mass and stored fuel mass exceeds a limit or the current fuel mass exceeds a calibrated threshold.

### 1.10 Diagnosis of upstream HO2S’ Heater power stage

The CJ125 evaluation IC of the upstream heated oxygen sensor (HO2S) is equipped with an internal diagnostic circuit that monitors the HO2S’ heater power stage. The diagnosis runs continuously and is capable of detecting short circuits to ground (minimum fault), short circuits to battery (maximum fault), as well as open circuits (signal fault). The fault path is cleared only when no fault has been detected and the duty cycle of the heater did exceed a calibrated minimum.

## 1.11 Diagnosis of upstream HO2S' heater (%DHRLSU)

The wide band oxygen sensor is ready for operation at temperatures above 720°C. Internal heating is required when the exhaust gas temperature isn't sufficient to maintain the HO2S at its operating temperature. The extra power required for heating depends on the deviation from the operating temperature. The temperature can be controlled by varying the duty cycle factor of the heater - see Figure 23



$$\text{duty cycle factor} = \frac{t_{on}}{T}$$

*Figure 23: Duty cycle factor of the heater*

If the Nernst cell temperature lies below 720°C, despite maximum heater power, for a calibrated period of time a malfunction will be detected. A reliable Nernst cell temperature determination is ascertained by referencing a calibration resistor.

The HO2S' heater diagnosis consists of the calibration resistor check, the temperature check of the Nernst cell after engine start and the monitoring of the heater's output. It analyzes the fault paths of up to 2 banks, each bank with its own fault paths, handling each bank separately with the same procedure. The HO2S' heater diagnosis runs continuously.

### 1.11.1 Calibration Resistor check

The resistance of the calibration resistor mounted in the PCM is constant. If the difference between its nominal and measured values exceeds a calibrated threshold, a signal fault HSV will be set. If the signal fault HSV is present, a proper Nernst cell temperature determination will be impossible.

### 1.11.2 Temperature Check of Nernst Cell after Engine Start

The oxygen sensor's ceramic temperature is determined by measuring the internal resistance of its Nernst cell. A plausibility fault HSV will be set if after start of heating, the ceramic temperature of the sensor doesn't exceed a calibrated minimum after a calibrated period of time.

### 1.11.3 Maximum Heater Output Check

If the target temperature of the oxygen sensor's ceramic isn't reached during controlled operation, the duty cycle factor of the output function will converge towards one. A duty-cycle factor equal to one for a long period of time is implausible and prohibited.

A maximum fault HSV is set when maximum heater output doesn't achieve the targeted temperature of the oxygen sensor's ceramic within a calibrated period of time.

### 1.12 Plausibility check of the upstream HO2S (%DPLLSU)

This diagnostic function continuously checks the heated upstream oxygen sensor's (HO2S) response signal by comparing it with that of the downstream oxygen sensor or by utilizing technical parameters of the engine control system. A faulty sensor signal is implied when the characteristic lambda curve derived from the upstream HO2S's response signal (see Figure 24 below) indicates an air-fuel mixture that is leaner or richer than that expected from the nominal curve.

Four types of faults can be detected:

- The integral component of the secondary lambda controller is interpreted as an offset in the characteristic curve of the upstream oxygen sensor. A shift is acceptable (because of tolerances) only when it lies between a calibrated minimum and maximum threshold value. An offset diagnostic via the lambda controller function detects
  - a maximum fault (curve shifted to leaner region) or
  - a minimum fault (curve shifted to richer region) and

- direct comparison of the upstream HO2S' signal with that of the downstream HO2S' signal can detect
  - a plausibility fault (curve shifted to rich region) or
  - a signal fault (curve shifted to lean region).

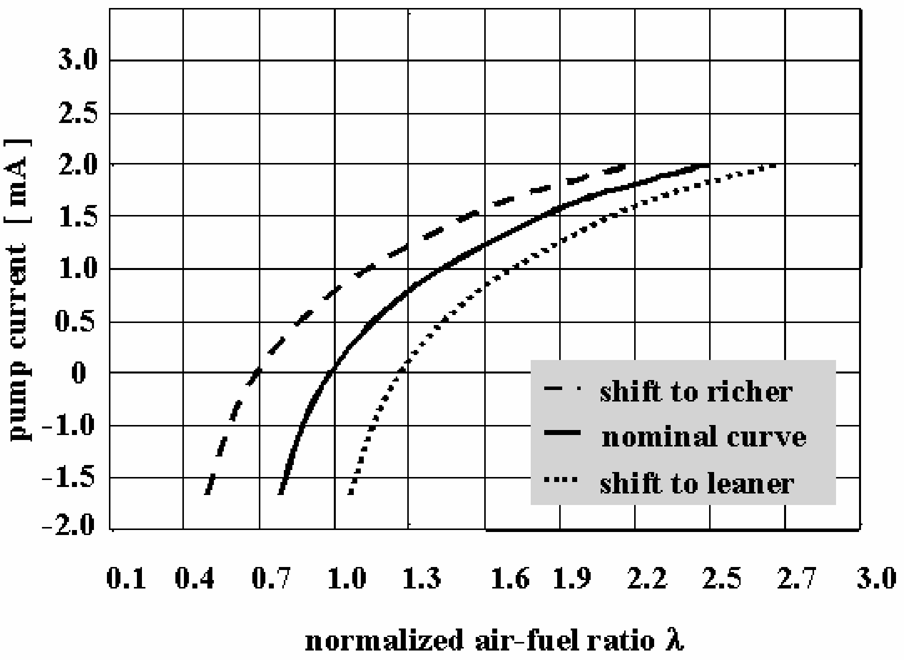


*Figure ensor's (LSU) response signal. Curves are not drawn to scale.*

### 1.12.1 Maximum Fault

A maximum fault FTDLA will be set after a calibrated delay time, if the monitoring conditions are fulfilled and the integral component of the secondary lambda controller is greater than the calibrated maximum threshold value.

### 1.12.2 Minimum Fault

A minimum fault FTDLA will be set after a calibrated delay time, if the monitoring conditions are fulfilled and the integral component of the secondary lambda controller is less than the calibrated minimum threshold value.

The fault path FTDLA is cleared only when similar conditions are fulfilled.

### 1.12.3 Plausibility fault

#### 1.12.3.1 Method A1 - shift of characteristic lambda curve to leaner region

A plausibility fault is set when the method A1 monitoring conditions are simultaneously fulfilled and the downstream and upstream HO2S both indicate a plausible rich and plausible lean mixture respectively.

#### 1.12.3.2 Method B1 - shift of characteristic lambda curve to leaner region

A plausibility fault is set if at operating points with a desired normalized A/F ratio = 1, the downstream HO2S indicates a plausible rich mixture when all the corresponding monitoring conditions are simultaneously fulfilled for a calibrated period of time i.e for a period longer than the duration of the lambda control system:

### 1.12.4 Signal Fault

#### 1.12.4.1 Method A2 - shift of characteristic lambda curve to richer region

A signal fault is set when all method A2 monitoring conditions are simultaneously fulfilled and the downstream and upstream HO2S both indicate a plausible lean and rich mixture respectively.

#### 1.12.4.2 Method B2 - shift of characteristic lambda curve to richer region

A signal fault is set if at operating points with a desired normalized A/F ratio = 1, the downstream HO2S indicates a plausible lean mixture when all the corresponding monitoring conditions are simultaneously fulfilled for a calibrated period of time i.e for a period longer than the duration of the lambda control system:

### 1.12.5 In-Use Monitor Performance Ratio (IUMPR)

The incrementing of the numerator, the denominator and the ratio calculation for the plausibility check of the upstream HO2S is executed by the IUMPR kernel function. The upstream HO2S diagnostic reports to the IUMPR kernel function via status flags - see description of IUMPR kernel function.

#### 1.12.5.1 Inhibiting faults

Inhibiting faults could be returned from the

- electrical diagnosis of the upstream oxygen sensor
- diagnosis of the upstream HO2S’ CJ125 integrated circuit
- aging diagnosis of the downstream oxygen sensor
- diagnosis of the upstream oxygen sensor’s signal voltage
- upstream oxygen sensor’s response rate diagnostic
- upstream HO2S’ heater and heater power stages diagnostics
- diagnosis of the heater’s influence on the Nernst (galvanic) cell of the HO2S
- exchanged upstream HO2S diagnosis

#### 1.12.5.2 Conditions for incrementing the denominator

As long as no inhibiting faults are present the upstream HO2S’ plausibility diagnostic instructs the IUMPR kernel function via a status flag to increment its denominator once per driving cycle if the general driving cycle conditions are fulfilled. No additional physical conditions are considered for incrementing the denominator.

#### 1.12.5.3 Conditions for incrementing the numerator

If the monitor is not inhibited due to stored faults, the numerator will be incremented once per driving cycle when the upstream HO2S diagnostic could have detected an upstream HO2S signal representing a value on a lambda characteristic curve that deviates from the nominal curve i.e shifted to the leaner or richer region. Explicitly when a faulty signal from the upstream HO2S is detected or when the upstream HO2S signal is diagnosed as lying within the expected range.

### 1.13 Monitoring of the oxygen sensor’s response rate (%DDYLSU)

Aging, contamination and improper heating of the oxygen sensor (due to heater malfunctions) lowers its response rate. A low response rate of the oxygen sensor leads to higher emissions. This diagnostic function continuously monitors the oxygen sensor’s response rate and will set a minimum fault when it falls below a calibrated minimum.

During air-fuel mixture control, a rectangular signal of a defined amplitude and period is superimposed on the targeted air-fuel ratio (lambda) signal. This results in a mean free targeted signal. If the monitoring conditions are fulfilled, the maximum and minimum of the modeled target signal at the vicinity of the oxygen sensor is compared (within each period of the rectangular signal) with the corresponding maximum and minimum of the measured and filtered signal from the oxygen sensor using the following equation:

$$\frac{\max(\mathrm{lamsam\_w}) - \min(\mathrm{lamsam\_w})}{\max(\mathrm{dfrzaf\_w}) - \min(\mathrm{dfrza\_w})}\Big|_{\mathrm{period\ i}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

A minimum fault is set after a calibrated minimum number of measurements, if the ratio (calculated with equation 1) had fallen below a calibrated threshold.

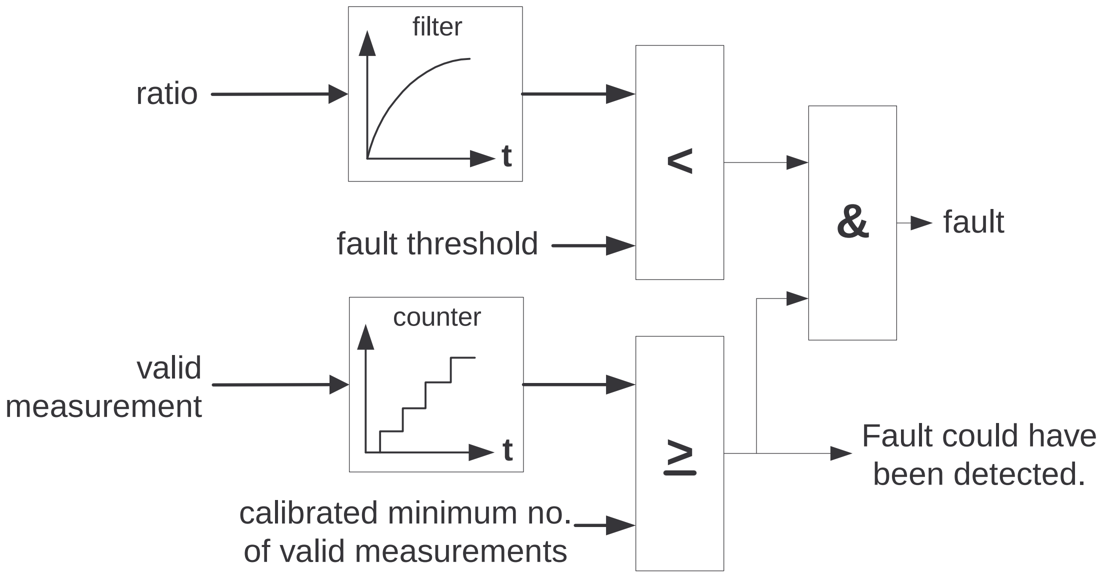


*Figure 25: Block diagram - General Description*

### 1.13.1 In-use monitor performance ratio (IUMPR)

The incrementing of the numerator, denominator, and the ratio calculation for the oxygen sensor's response rate monitor is executed by the IUMPR kernel function. Like all monitors for which a standardized track and report in-use performance is required, the oxygen sensor response rate monitor reports to the IUMPR kernel function via status flags - see description of IUMPR kernel function.

#### 1.13.1.1 Conditions for incrementing the denominator

As long as no inhibiting faults are present, the response rate monitor instructs the IUMPR kernel function via a status flag to increment its denominator once per driving cycle so long as general driving cycle conditions are fulfilled. No additional physical conditions are considered for incrementing the denominator of the oxygen sensor response rate monitor.

#### 1.13.1.2 Conditions for incrementing the numerator

The numerator is incremented once per driving cycle (see Figure 25) when the oxygen sensor's response rate monitor could have detected an oxygen sensor possessing a response rate that has deteriorated to the malfunction criteria limit. Explicitly when:

- an oxygen sensor possessing a response rate that has deteriorated to the malfunction criteria limit is detected or
- an oxygen sensor with a proper response rate is detected (calibrated minimum no. of valid measurements has been reached).

The numerator will not be incremented if inhibiting faults (as mentioned in the monitoring conditions) are present.

## 1.14 Monitoring of HO2S’ Voltage (%DULSU)

This monitor performs a rationality check of the voltage $V_A$ of the output signal of the heated wide band upstream oxygen sensor (HO2S) after amplification by the CJ125 integrated circuit - see Figure 26 below b. $V_A$ depends on the characteristics of the oxygen sensor itself and those of the peripheral circuitry of CJ125.

A rationality fault is set when $V_A$ lies outside the calibrated range V = [MIN ... MAX ] (or V = [MINL ... MAXL at low gain or low amplification). Generally, at a nearly stoichiometric air-fuel ratio the output voltage is clearly below the voltage read when the oxygen sensor lies in air. A fault could be triggered if an electrically connected oxygen sensor is not properly mounted in the exhaust system.

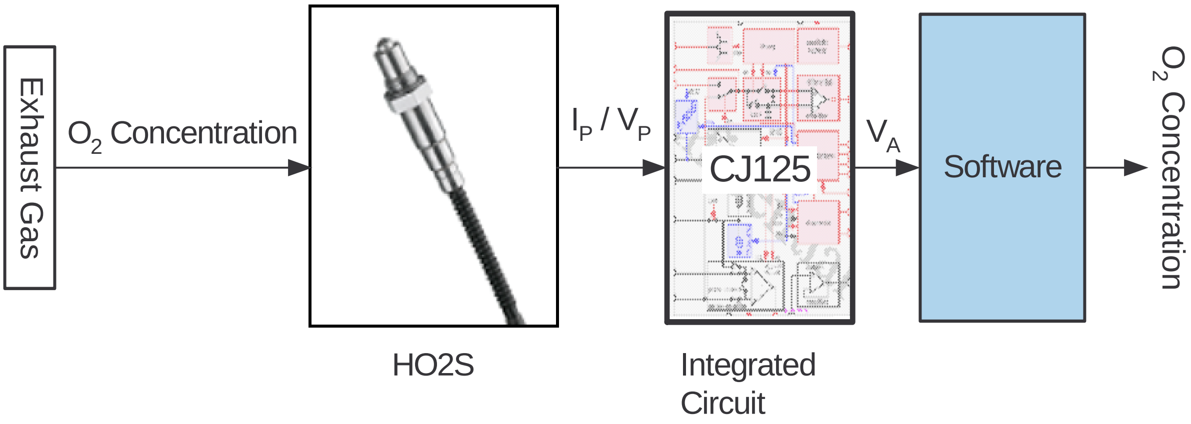


*Figure 26: Voltage diagnosis of the wide band upstream oxygen sensor (HO2S).*

### 1.14.1 In-Use monitor performance ratio (IUMPR)

The incrementing of the numerator, the denominator, the IUMPR ratio calculation, the determination of the monitor with the minimum IUMPR ratio in the oxygen sensor group (which has multiple monitors) and the preparation of the HO2S monitor’s numerator and denominator for Service $09 is executed by the IUMPR kernel function. Like all monitors for which a standardized track and report in-use monitor performance is required, the HO2S’ voltage monitor reports to the IUMPR kernel function via status flags - see description of IUMPR kernel function.

#### 1.14.1.1 Conditions for incrementing the numerator

The numerator is incremented once per driving cycle when the monitor is not inhibited due to a stored fault and the monitor could have detected a rationality fault of the voltage of the oxygen sensor’s signal. This is the case:

- when either a plausibility fault is detected or
- when a defective component could have been detected by the HO2S voltage check i.e the monitor successfully runs and terminates without detecting a fault (clearing of the fault path).

#### 1.14.1.2 Conditions for Incrementing the Denominator

The denominator is incremented once per driving cycle when the monitor is not inhibited due to a stored fault and all general driving conditions have been fulfilled. No additional physical conditions are considered for incrementing the denominator of the HO2S voltage diagnostic.

## 1.15 Diagnosis of swapped upstream Oxygen Sensors (%DLSUV)

This diagnostic function detects mistakenly exchanged upstream oxygen sensors mounted in a engine system with two banks by utilizing the A/F ratio controller function. The A/F ratio controller will not regulate the A/F mixture as intended if the oxygen sensors are exchanged – see Figure 27. Lean or rich information from any of the two upstream HO2S will result in corrective measures in the wrong bank. The fuel trim limits are quickly reached for such corrective measures lead to results that are exactly opposite to those that are desired.

If for instance A/F ratio trimming in bank1 (or bank2) results in an A/F ratio correction factor that exceeds a calibrated threshold while a parallel A/F ratio trimming in bank2 (or bank1) results in an A/F ratio correction factor that lies below a calibrated threshold, both for more than a calibrated period of time, a plausibility fault will be set after a calibrated de-bounce time. Engine operation then continues with the disablement of the A/F ratio controller function, setting of neutral adaptation values (after disablement of the mixture adaptation function) and a switchover to canister purging.

The fault code is cleared (with an ensuing release of the A/F controller functionality) after a calibrated de-bounce time, if at engine restart the corresponding fault no longer exists.

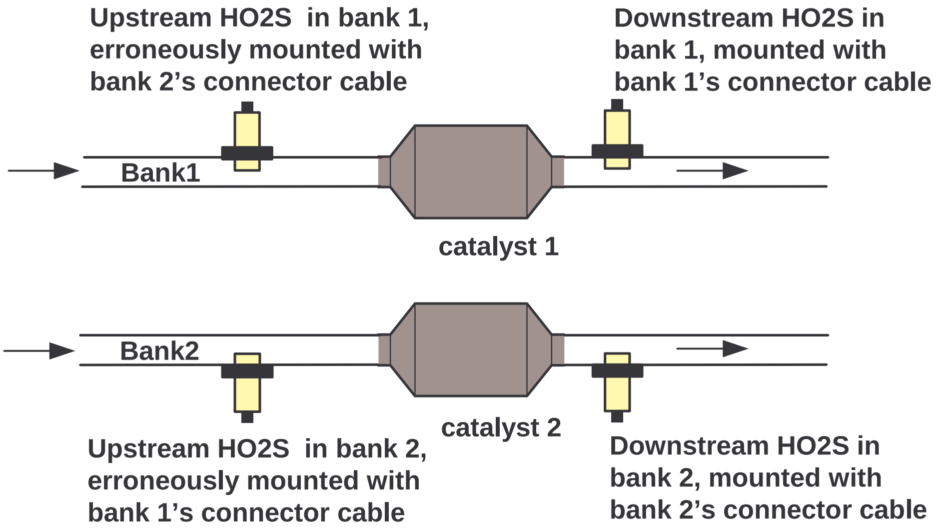


*Figure 27: Illustration of exchanged upstream oxygen sensor in a system with 2 banks*

## 1.16 Diagnosis of Evaluation IC of the upstream HO2S (%DICLSU)

The Diagnosis of the evaluation IC (CJ125) of the heated upstream oxygen sensor (HO2S) detects electrical faults of the UN (Nernst voltage), VM (virtual ground), IA (compensation) and IP (pump) signal lines - see Figure 28. These electrical faults could result from short circuits to battery, or ground and signal interruptions. Short circuits are detected by a self-diagnosis of the CJ125. Line interruptions are identified by observing the system. The diagnosis monitors communication between the CJ125 IC and the electronic control unit and also performs a rationality check of the supply voltage as well as the adaptation values of the IC's electrical compensations. The evaluation IC's diagnosis runs continuously.

### 1.16.1 Open Circuit - VM line interruption:

The pump- or limit-current of the Nernst cell no longer flows when there is a VM line interruption. This results in an extremely high resistance which remains even when the O2 sensor is sufficiently hot. The O2 sensor's ceramic temperature doesn't rise although the system reacts by increasing the heating power. A malfunction is detected and a signal fault LSUVM is set when the internal resistance of the galvanic (or Nernst) cell exceeds a calibrated threshold after a calibrated period of time.

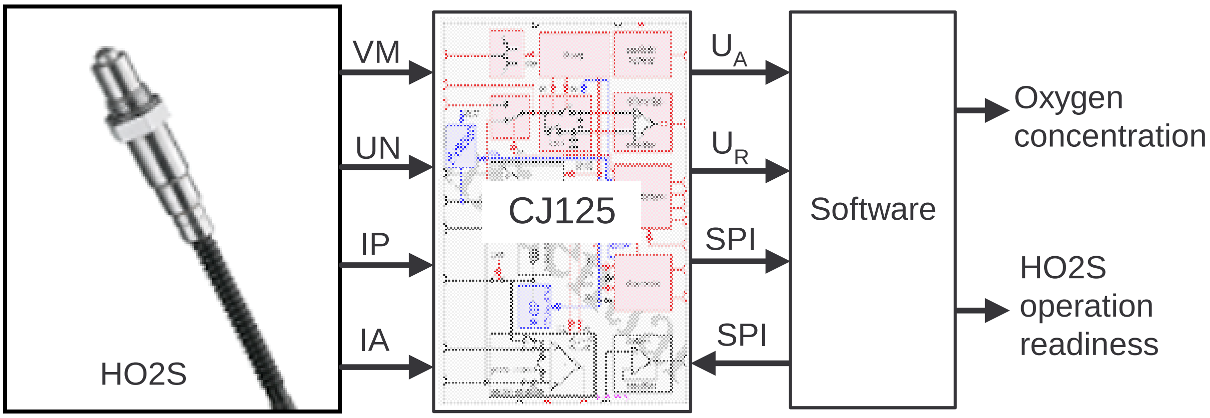


*Figure 28: Signal lines between the CJ125 IC and the HO2S. The CJ125 IC communicates with the ECU via a serial port interface (SPI).*

### 1.16.2 Open Circuit - UN line interruption:

A UN line interruption leads to an irrationally high $U_R$ signal as well as an undefined output voltage $U_A$ - see Figure 28 above. A signal fault LSUUN is set when the offset corrected voltage of the upstream HO2S lies above the upper (or below the lower) plausible output voltage $U_A$ of the CJ125 IC required for detecting a UM line interruption.

### 1.16.3 Open Circuit - IA line interruption:

An IA line interruption leads to a non-plausible large oxygen sensor voltage during fuel cut-off operation. A signal fault LSUIA is set after a calibrated delay time, if the oxygen sensor's voltage is greater than or equal to a calibrated threshold. The fault is set after an additional calibrated time if the fuel tank is empty or in an unknown state.

### 1.16.4 Open Circuit - IP line interruption:

The pump current of the HO2S, which flows through the IP line, is equivalent to the oxygen concentration in the exhaust gas. An IP line interruption means the pump current will be permanently equal to zero. The output voltage $U_A$ of the CJ125 IC will remain constant. $U_A$ no longer varies with the oxygen concentration in the exhaust gas. An IP line interruption is detectable via three methods:

- detection during fuel cut-off condition
- detection by mixture enrichment or lean-off
- detection by closed-loop control to a nominal A/F value that differs from one.

#### 1.16.4.1 Detection during fuel cut off condition

The fuel cut off condition is an operating mode with a nominal A/F ratio ∴ 1. A plausibility fault LSUIP is set when during fuel cut-off condition, the value of the oxygen sensor's voltage is less than a calibrated threshold for a calibrated period of time,

#### 1.16.4.2 Detection by mixture enrichment or lean-off

A maximum fault LSUIP is set when the absolute difference between the A/F controller's output value at the moment the HO2S' voltage springs into the calibrated range (i.e. within 1.5V) and the A/F controller's output value thereafter, exceeds the calibrated maximum allowable excursion in that calibrated range.

#### 1.16.4.3 Closed-loop control to a nominal A/F value that differs from 1

A signal fault LSUIP will be set when the monitoring conditions are fulfilled during the time required for the integrated mass air flow (measure for exhaust mass flow) to exceed a calibrated threshold.

### 1.16.5 Short circuits to ground or to battery voltage

Short circuits are detected by a self-diagnosis of the CJ125 IC. An integrated voltage comparator at each and every pin of the HO2S' CJ125 IC, detects and sets a maximum or a minimum fault LSUKS if the voltage at that pin respectively lies above a calibrated maximum or below a calibrated minimum for a calibrated period of time.

**a)** Explicitly, a maximum fault is set either when

- the HO2S' voltage at the VM pin exceeds a calibrated plausible maximum or
- the HO2S' voltage at the UN pin exceeds a calibrated plausible maximum or
- the HO2S' voltage at the IA or IP pin exceeds a calibrated plausible maximum.

**b)** Likewise, a minimum fault is set either when

- the HO2S' voltage at the VM pin lies below a calibrated plausible minimum or
- the HO2S' voltage at the UN pin lies below a calibrated plausible minimum or
- the HO2S' voltage at the IA or IP pin lies below a calibrated plausible minimum.

### 1.16.6 Monitoring of the communication between the Evaluation-IC CJ125 and the Micro-controller of the PCM

#### 1.16.6.1 Non-plausible commands counter

The CJ125 evaluation IC communicates with the main processor of the PCM via a serial port interface. They both transmit data to each other. Interference on the SPI bus leads to non-plausible signals. These non-plausible signals, which persist even when the data is re-transmitted, are tracked by incrementing an internal error counter. A signal fault ICLSU is set when the counter exceeds a calibrated threshold.

#### 1.16.6.2 Comparison of initialization and mirror register

A further communication monitor compares the old value of the initialization register, which is backed up in a mirror register, with its current value after a rewrite. A plausibility fault ICLSU is set after a calibrated period of time, if the current value of the initialization register isn’t equal to that of its mirror register.

### 1.16.7 Low supply voltage of the CJ125 IC

The CJ125 IC is specified for supply voltages > 9V. It possesses a supply voltage detection module. Low supply voltages lead to faulty diagnosis at the voltage comparators. A minimum fault ICLSU is set when the supply voltage drops below 9V. The supply voltage monitor is aborted if the monitoring conditions are not fulfilled.

### 1.16.8 Electrical trimming

Electrical trimming of the oxygen sensor is performed in order to determine and store the difference between the expected and the actual pump-current-proportional output voltage. This difference stems from hardware tolerances. Electrical trimming is carried out once after engine start and once in the idle mode during a calibrated period of time. A maximum fault ICLSU is set when after electrical trimming the adaptation value for the corresponding curve (normal and rich) exceeds a calibrated maximum.

## 1.17 Diagnosis of downstream HO2S (%DLSH)

This diagnosis runs continuously and is capable of detecting (with the exception of heater circuit faults) all electrical connection faults of the heated oxygen sensor (HO2S) located on the downstream side of the the main catalyst.

### 1.17.1 Wire Interruption or Defective Sensor Heating

The output voltage of the HO2S must be less than a calibrated maximum when the engine is running in the lean mode. It equally must lie above a calibrated minimum when running in the rich mode. Given, all general monitoring conditions are fulfilled, a signal fault will be set after a calibrated delay time if (due to wire interruption or defective sensor heating) the HO2S' operating-mode-dependent output voltage lies within a calibrated range that doesn't match the previously mentioned thresholds. The decision on whether the output voltage does lie within the faulty range must have been delayed for a calibrated amount of time in order to eliminate possible voltage spikes.
An interruption of the ground-lead of the HO2S would, at high exhaust gas temperatures, lead to a distortion of the HO2S' signal - cross talk from its heater. In such a situation a signal fault will be set only when the internal resistance of the Nernst cell lies above a calibration.

### 1.17.2 Short circuit of HO2S' signal line to battery

A short circuit of the HO2S' signal line to battery is implied (maximum fault) if the output voltage of the HO2S' evaluation circuit exceeds a calibrated threshold for a calibrated period of time. The maximum fault is set only when all general monitoring conditions have been fulfilled.

### 1.17.3 Short Circuit to Ground

A short circuit between sensor signal wire and sensor ground wire or between sensor signal wire and the car body ground is implied if the output voltage of the downstream HO2S lies below a calibrated threshold for a calibrated period of time. A minimum fault will then be set provided the following monitoring conditions are fulfilled:

- all general monitoring conditions are fulfilled
- closed loop lambda control downstream of catalyst
- the oxygen sensor remains cold after engine start
- no errors from the canister purge system
- no errors from the canister purge valve's power stage
- the engine coolant temperature lies below a calibrated threshold
- the engine coolant temperature at engine stop lies above a calibration
- the state of the fuel tank has been validated and it isn't empty nor on reserve.

A minimum fault will in any case still be set after a calibrated delay time if the state of the fuel tank is unknown.

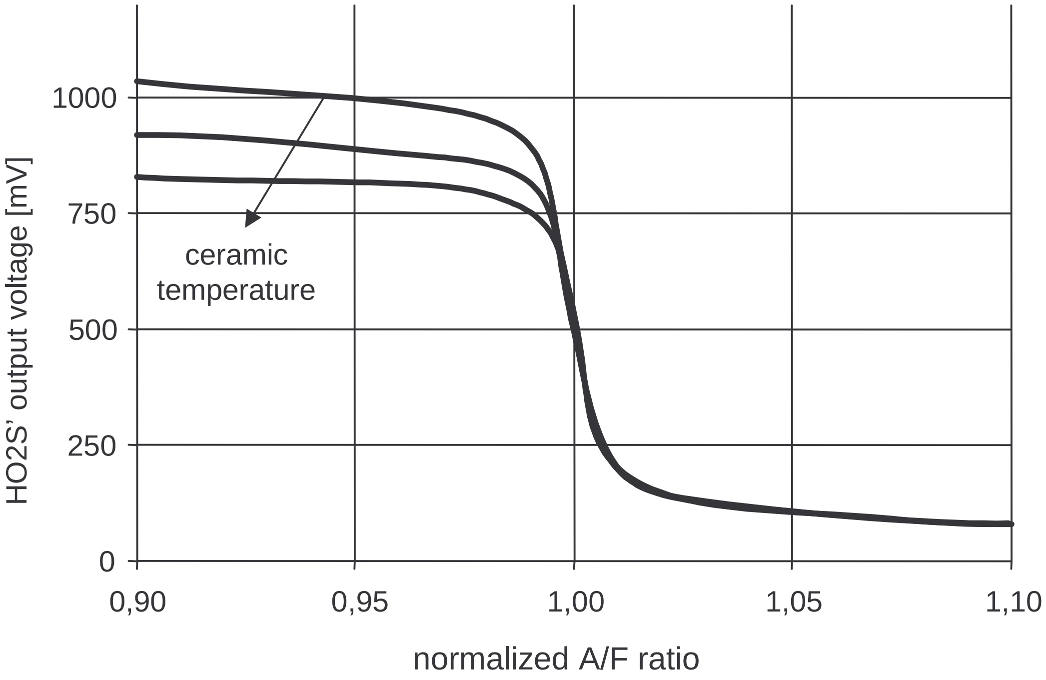


*Figure 29: Output voltage characteristics of the HO2S. The output voltage decreases with increasing temperature of the HO2S' ceramic.*

## 1.18 Diagnosis of heater of downstream HO2S (%DHLSHK)

The diagnosis of the heater of the downstream heated oxygen sensor (HO2S) runs continuously, monitoring the internal resistance of the Nernst cell as well as the switching behavior of the heater's power stage. The internal resistance of the Nernst cell depends on both the electrical power of the heater and the exhaust gas temperature.

### 1.18.1 Diagnosis of the Internal Resistance of the Nernst Cell

Typical plots of Nernst cell resistance versus exhaust gas temperature at specific heating powers are measured and stored for referencing. A plausibility fault is set after a calibrated delay time, when the measured resistance is greater than or equal to the expected reference value.

### 1.18.2 Power Stage Diagnosis

The power stage, which is periodically switched off for a defined amount of time at a defined interval, is controlled by a switch clocked at a defined frequency. The turn-on voltage of the power stage is continuously checked in order to determine whether it corresponds to that of the inverted signal of the switch's current state.

A maximum fault is set when the power stage's turn-on voltage is greater than or equal to a calibrated maximum. Likewise, a minimum fault is set when the power stage's turn-on voltage is less than or equal to a calibrated minimum.

A signal fault is set when the power stage's turn-on voltage is greater than the calibrated minimum and less than the calibrated maximum when the power stage isn't active.

## 1.19 Diagnosis of aging of downstream HO2S (%DLSAHK)

The diagnosis of the aging of the downstream HO2S consists of an oscillation check and a threshold check during fuel cut-off. It analyzes the fault paths of up to 2 banks. The faults paths of bank1 are identical to those of bank2 and the fault paths of each bank are handled separately using the same procedure. The diagnosis runs continuously.

### 1.19.1 Oscillation Check

During normal engine operation the normalized A/F ratio and hence the voltage of the HO2S oscillates about the set point value. The oscillation check triggers a test function if the measured voltage of the HO2S' signal permanently lies below or above the set point value for a calibrated period of time. The test function applies a rich A/F mixture if the voltage is below the set point value or a lean A/F mixture if the voltage is above the set point value.

If the voltage doesn't cross the set point value in the expected direction after applying a lean or rich A/F mixture, a malfunction is detected and a minimum or maximum fault LASH will be respectively set.

### 1.19.2 Threshold Check during trailing throttle Fuel Cutoff

This check determines whether the voltage of the HO2S' signal exceeds a calibrated threshold for a calibrated period of time during fuel cut-off. A malfunction is detected and a signal fault LASH is set if this is true.

## 1.20 Closed Loop Control – Enable Conditions (%LRSEB)

Closed loop lambda control is enabled (with a delay) at the start of a driving cycle and can be temporary or permanently deactivated during the driving cycle. The turn-on delay time at the start of a driving cycle is warranted by the following closed loop lambda control enable conditions which must be fulfilled:

- The upstream oxygen sensor is ready to run i.e. the upstream heated oxygen sensor's (HO2S) operating temperature of 685°C has been reached. The time required to achieve the active state depends on end of dew point and the heater's output - see section on "the diagnosis of the upstream HO2S' heater" for details. The oxygen sensor's ceramic could be damaged if it is heated with condensed water on its surface. Full heating is hence applied only after end of dew point.

  Exhaust gas temperature is determined by modelling the heat flow. The input sensors used in this temperature model are mass airflow sensor, vehicle speed sensor, ambient temperature sensor and (with a minimum influence on the model behavior) engine coolant temperature. All mentioned sensors are MIL-relevant.

- either the calibrated delay time TLRHS must have elapsed after end of engine start, when the following conditions are fulfilled:

- the engine coolant temperature must have exceeded the warm-start-calibration TMSHS and
- the intake air temperature must have exceeded the warm-start-calibration TASHS

  or the calibrated engine-coolant-temperature-dependent delay time TLRTMS must have elapsed after end of engine start.

- system voltage in range between 10,7 V and 16,1 V and sensor operating temperature above 720°C.

- no errors have been detected by the HO2S diagnostic nor by the diagnostic of the HO2S' IC

Closed loop lambda operation is disabled during the driving cycle when any of the following operating conditions, which permits only mixture enrichment by the lambda controller, is fulfilled:

the smallest possible injection time has been reached - this is typically the case at loads that lie below the idle speed load or during canister purging at low loads
when A/F mixture lean-off protection is activated - e.g temporary activation at a high frequency of transient loads to prevent fuel injection that cannot be precisely determined
the A/F ratio set-point value lies below oxygen sensor's measurable limit - in this case only A/F mixture enrichment can be executed by the lambda control (no closed loop operation) the moment the set-point value exceeds the measurable threshold.

Closed loop lambda operation is further deactivated during a driving cycle when any of the following conditions are fulfilled:
during fuel cut-off or cylinder shut-off and immediately afterwards till the oxygen sensor again starts indicating correct values (the waiting time depends on integrated mass airflow or on a calibration).
when engine load lies below a calibrated engine speed dependent minimum or when the gas pedal is not engaged at high engine speed and low load.

Closed loop lambda control is permanently deactivated during a driving cycle if any of the following errors exist:
error of catalyst damaging misfire rate
error of injection valve power stages
error of oxygen sensor and oxygen sensor heater

### 1.21 Electrical fault on upstream oxygen sensor (%DLSVE)

Lambda control can be disabled only when at least a pending fault code (service $07) has been entered in the fault code memory. Several operating conditions do exist, under which faulty components can be pinpointed only after a time delay. Lambda control must however be disabled when fault symptoms are detected. This diagnostic function detects and sets a general electrical fault. The actual fault which is accompanied by a second entry into the fault code memory is then pinpointed afterwards by the appropriate diagnostic function.

The oxygen sensor's ceramic temperature is determined by measuring the internal resistance of its Nernst cell. If the internal resistance of the Nernst cell is implausible high for a calibrated time or the ceramic temperature of the Nernst cell is not above an calibrated threshold for a calibrated time or at least one of the following errors is set

- open circuit - UN line interruption
- open circuit - VM line interruption
- maximum heater output check
- temperature check of Nernst cell after engine start

an electrical fault LSVE is set.
This diagnosis is able to analyze the failure paths of up to 2 banks, each bank with its own fault paths. The handling of the fault paths of each bank is done separately but all in the same way.

## 1.22 Diagnosis of Mass Airflow Sensor

The diagnosis of the mass airflow sensor (MAF sensor) consists of a circuit continuity check, a range check and a rationality check of the given period duration of the sensor. The period duration can directly be calculated into the mass airflow.

### 1.22.1 Circuit continuity check

To detect a circuit continuity malfunction the period duration of the mass airflow signal is compared with an upper and a lower calibration limit to identify an intermitted contact. A short circuit is identified with a period duration equal to zero.

If the period duration of the mass airflow signal from the MAF sensor equals zero for a calibrated period of time, a short circuit is detected and a signal fault HFME is set.

If the period duration of the mass airflow signal from the MAF sensor lies below the lower calibration limit for a calibrated period of time, an intermitted contact (high frequency) is detected and a minimum fault HFME is set.

If the period duration of the mass airflow signal from the MAF sensor exceeds the upper calibration limit for a calibrated period of time, an intermitted contact (low frequency) is detected and a maximum fault HFME is set.

### 1.22.2 Range check of temperature compensation signal

The built-in MAF sensor includes additionally a temperature compensation signal (drift compensation). This signal must lie within a valid range during all engine conditions.

If the period duration of the temperature compensation signal from the MAF sensor lies below the lower calibration limit for a calibrated period of time, a malfunction is detected and a minimum fault KHFME is set.

If the period duration of the temperature compensation signal from the MAF sensor exceeds the upper calibration limit for a calibrated period of time, a malfunction is detected and a maximum fault KHFME is set.

### 1.22.3 Range check

Depending on the engine design the mass airflow must lie within a valid range during all engine conditions.

If the measured mass airflow from the MAF sensor lies below the valid minimum mass airflow for a calibrated period of time, a malfunction is detected and a minimum fault HFMR is set.

If the measured mass airflow from the MAF sensor exceeds the valid maximum mass airflow for a calibrated period of time, a malfunction is detected and a maximum fault HFMR is set. The valid maximum mass airflow depends on engine speed and throttle position.

### 1.22.4 Rationality check

Depending on engine speed and throttle position, a theoretically expected maximum and minimum mass airflow is calculated at these engine conditions and compared to the actual measured mass airflow.

If the measured mass airflow from the MAF sensor lies below the theoretically expected minimum mass airflow for a calibrated period of time, a malfunction is detected and a signal fault HFMR is set.

If the measured mass airflow from the MAF sensor exceeds the theoretically expected maximum mass airflow for a calibrated period of time, a malfunction is detected and a plausibility fault HFMR is set.

## 1.23 Diagnosis of ECT Sensor

The diagnosis of the engine coolant temperature sensor (ECT sensor) consists of circuit continuity checks and several rationality checks of the coolant's temperature behavior.

### 1.23.1 Circuit continuity checks

The circuit continuity check compares the measured engine coolant temperature with an upper and a lower limit to detect short circuits.

If the measured engine coolant temperature signal exceeds the upper calibration limit for a calibrated period of time, a short circuit to ground is detected and a maximum fault TME is set.

If the measured engine coolant temperature signal lies below the lower calibration limit for a calibrated period of time, a short circuit to battery or a broken wire is detected and a minimum fault TME is set.

### 1.23.2 Rationality checks

To determine the rationality of the ECT sensor several checks are performed.

The low side check calculates a reference engine coolant temperature with the help of a temperature model. The deviation between this calculated reference temperature and the actual measured engine coolant temperature is determined. If the deviation lies beyond a calibrated range for a calibrated period of time, a malfunction is detected and a minimum fault TMR is set.

The closed-loop check monitors the time which is needed for the fuel system to reach closed-loop enable temperature. This temperature must be reached within a calibrated time otherwise a malfunction is detected and a signal fault TMR is set.

The stuck check monitors the rise or drop behavior of the coolant temperature during a change in engine operation conditions. If the engine coolant temperature change lies below a calibrated limit for a calibrated number of driving condition changes (rise and drop), a malfunction is detected and a plausibility fault TMR is set.

If a block heater is detected, the temperature model calculations are retriggered and the rationality checks are disabled for a calibrated period of time. This is done to avoid false diagnosis.

## 1.24 Diagnosis of Thermostat

Due to a missing or stuck-open thermostat the rise of the engine coolant temperature is less then normally expected. This effect will be used by the diagnosis to detect a malfunction of the thermostat as follows.

A reference engine coolant temperature (tmotref, engine coolant temperature at maximum heat radiation with a closed thermostat) is calculated with the help of a temperature model. If the monitoring conditions are enabled, the difference between this calculated reference temperature and the actual measured engine coolant temperature (tmotref - tmot) is determined.

If the difference exceeds a calibrated threshold for a calibrated period of time and the coolant temperature sensor is diagnosed without any error, a malfunction is detected and a fault code is set. If the difference remains below the calibrated threshold for the calibrated period of time mentioned above, an error from a previous warm up cycle is cleared as soon as a calibrated coolant temperature is reached.

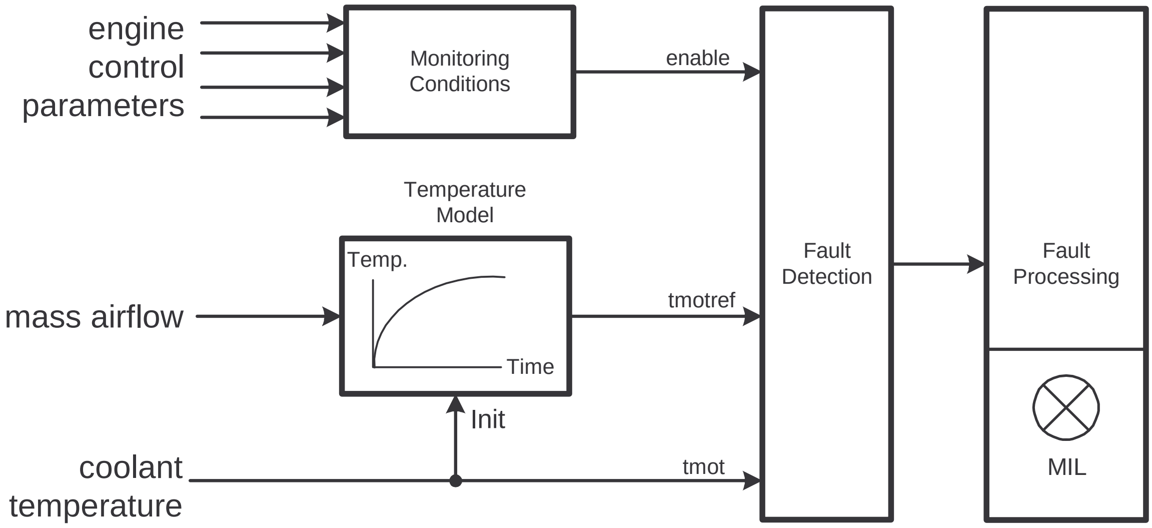


*Figure 30: Overview of thermostat diagnosis*

## 1.25 Diagnosis of Radiator Outlet ECT Sensor

The diagnosis of the radiator outlet engine coolant temperature sensor consists of circuit continuity and rationality checks.

### 1.25.1 Circuit continuity checks

The circuit continuity check compares the measured radiator outlet engine coolant temperature with an upper and a lower limit to detect short circuits.

If the measured engine coolant temperature exceeds the upper calibration limit for a calibrated period of time, a short circuit to ground is detected and a maximum fault TKA is set.

If the measured engine coolant temperature lies below the lower calibration limit for a calibrated period of time, a short circuit to battery or a broken wire is detected and a minimum fault TKA is set.

### 1.25.2 Rationality checks

To determine the rationality of the radiator outlet ECT sensor several checks are performed.

The high side check compares the measured radiator coolant temperature with the measured engine coolant temperature from the main sensor. Due to technical reasons the radiator outlet coolant temperature must be lower or at most equal to the temperature measured by the main sensor. If the engine coolant temperature difference (positive) between radiator outlet sensor and main sensor exceeds a calibrated threshold for a calibrated period of time, a malfunction is detected and a plausibility fault TKA is set.

The stuck check determines the difference between radiator outlet coolant temperature at engine start and temperature after opening of thermostat. If the radiator outlet coolant temperature change lies below a calibrated threshold, a malfunction is detected and a plausibility fault TKA is set.

### 1.26 Diagnosis of Vehicle Speed

The diagnosis of the vehicle speed consists of a range check and rationality checks.

#### 1.26.1 Range check

Taking into account the engine design a maximum valid and driveable vehicle speed is possible.

If the vehicle speed exceeds the valid calibrated maximum threshold for a calibrated period of time, a malfunction is detected and a maximum fault VFZE is set.

#### 1.26.2 Rationality check

To determine the rationality of the vehicle speed several checks are performed.

The stuck check compares the change of the vehicle speed within a calibrated time. During normal driving conditions a vehicle speed change must occur since it is not possible to drive absolutely steady.

If no change of the vehicle speed within a calibrated time for a calibrated period of time occurs, a malfunction is detected and a minimum fault VFZE is set.

The fuel cut-off check compares the vehicle speed during fuel cut-off condition. It is assumed that the vehicle must move during this condition. To cover the special fuel cut-off case when the driver has rev-up the engine at standstill the check must be debounced for a calibrated time.

If the vehicle is in fuel cut-off condition and the vehicle speed lies below a calibrated threshold for a calibrated (debouncing) time, a malfunction is detected and a minimum fault VFZNP is set.

The gear ratio check calculates, at steady engine load, the ratio of engine speed to vehicle speed. Since this calculated ratio is dependent on the gear it is compared with an expected ratio range of the current gear.

If the calculated ratio of engine speed to vehicle speed lies beyond the expected ratio range of the current gear for a calibrated period of time, a malfunction is detected and a plausibility fault VFZNP is set.

## 1.27 Diagnosis of Intake Air Temperature Sensor

The diagnosis of the intake air temperature sensor (IAT sensor) consists of circuit continuity checks and rationality checks of the intake air temperature behavior.

### 1.27.1 Circuit continuity checks

The circuit continuity check compares the measured intake air temperature with an upper and a lower calibration limit to detect out-of-range values.

If the intake air temperature signal exceeds the upper calibration limit for a calibrated period of time, a short circuit to ground is detected and a maximum fault TAE is set.

If the intake air temperature signal lies below the lower calibration limit for a calibrated period of time, a short circuit to battery or a wire interruption is detected and a minimum fault TAE is set.

### 1.27.2 Rationality checks

To determine, whether the intake air temperature is in a plausible range, several checks are performed.
The high side check monitors, depending on mass airflow and vehicle speed, whether the measured intake air temperature exceeds a maximum threshold. If the intake air temperature exceeds this threshold while the monitoring conditions are fulfilled, a malfunction is detected and a maximum fault TAR is set.
The low side check monitors the difference between the engine coolant temperature and the intake air temperature when the engine is cooled down. For a cooled down engine both temperatures must be nearly equal for a short time after start. If the difference between engine coolant and intake air temperature exceeds a calibrated threshold for a calibrated period of time, a malfunction is detected and a minimum fault TAR is set.
The fix check monitors the rise or drop behavior of the intake air temperature during a calibrated number of engine operation condition changes. If the difference of the minimum and maximum measured intake air temperature lies below a calibrated threshold for a calibrated time, a malfunction is detected and a plausibility fault TAR is set.

## 1.28 Variable Camshaft Timing (Vanos)

The BMW-Vanos is a combined hydraulic and mechanical camshaft control unit, managed by the ECU. The double Vanos allows the engine to control valvetiming continuously for both intake and exhaust camshafts. The electronically control of the Vanos positions is dependant on engine speed, load and temperature.

The function DEAVANOS is monitoring the correct mechanical function of the variable camshaft timing. The diagnosis carries out a continuous rationality check of the Vanos function.
If a malfunction is detected, an error bit will be set and sent to the modules LAYDENWS, LAYDENWSAD or LAYDENWEKW for the inlet camshaft or LAYDANWS, LAYDANWSAD or LAYDANWEKW for the exhaust camshaft. These modules produce the final information for setting the corresponding DTC.

Two parameters are monitored for all camshafts, i.e. the adapted reference position and the control deviation. The diagnostic strategy for inlet and exhaust camshaft is identical:

### 1.28.1 Vanos end position in range

This diagnosis module checks whether the camshaft position is in an expected range during the Vanos unit is in its endposition. If the camshaft position is out of this range, a min fault is set (CDKENWSAD, CDKANWSAD or CDKENWSAD2, CDKANWSAD2).

### 1.28.2 Vanos reference position offset (“one tooth off”)

This diagnosis module detects a one-tooth error in camshaft to crankshaft alignment (e.g. by a slipped chain). If the adapted camshaft reference position exceeds an adjustable limit (one chain-tooth), a min fault is set (CDKNWEKW, CDKNWAKW or CDKNWEKW2, CDKNWAKW2).

### 1.28.3 Control deviation of the camshaft position controller (Target Error and Slow Response)

In this diagnosis module the difference between the actual and target position of the Vanos units (“control deviation”) is checked. If the calculated difference between these two positions exceeds the established threshold, a counter is started. The counter is incremented twice per crank revolution (but not exceeding 10 msec-rate).
If the counter exceeds a limit (also adjustable), a plaus fault is set (CDKENWS, CDKANWS or CDKENWS1, CDKANWS2).

## 1.29 Valvetronic

### 1.29.1 Valvetronic Module

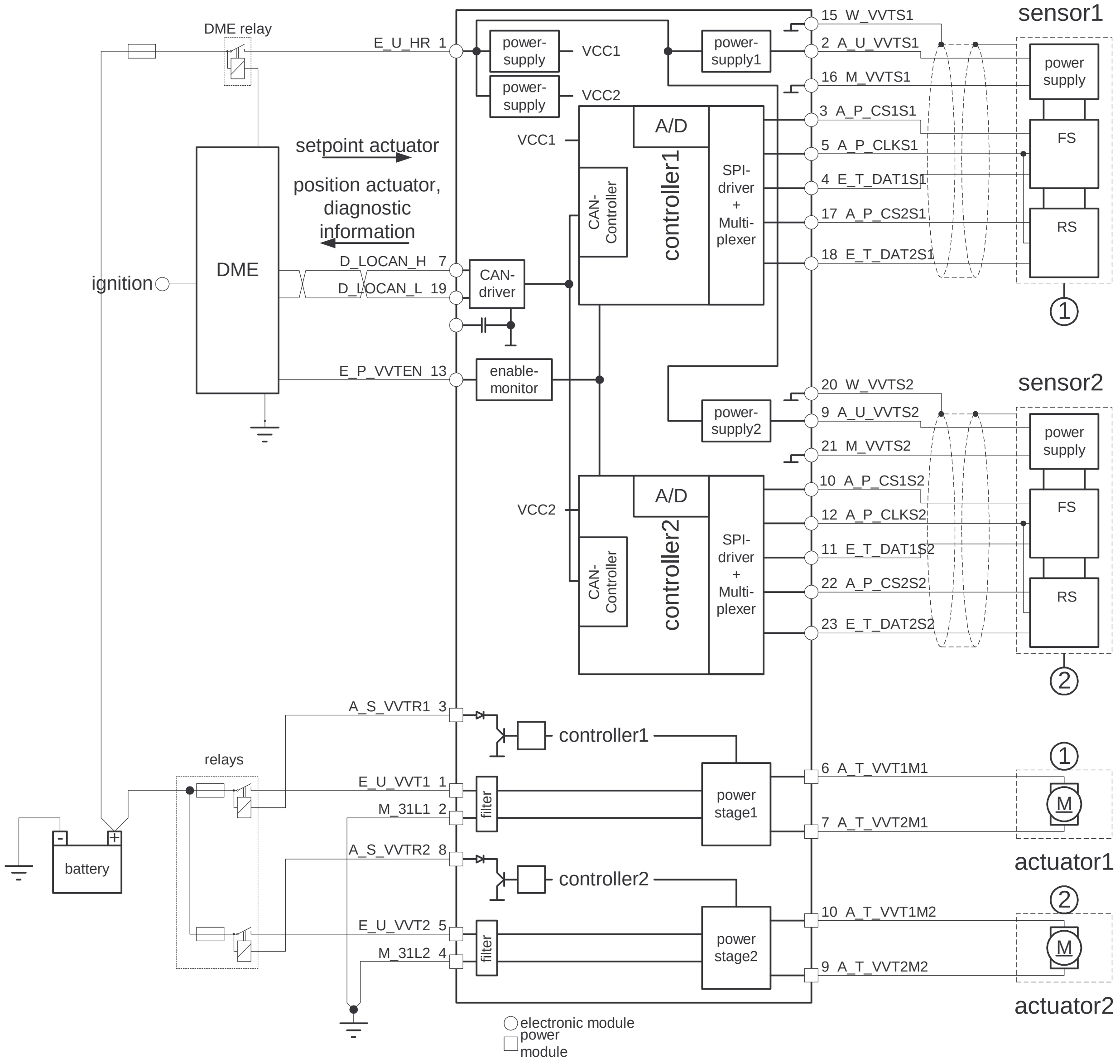


*Figure 31*

### 1.29.1.1 General description of this module:

This module is for checking the functionality of the control electronics and for the storage of data that remains permanently stored after a deactivation of the ECU. Regarding the valvetronic, this information includes: learning value for end position, diagnosis information for the manufacturer and configuration information. Five functional units are integrated into the valvetronic module to fulfill these tasks.
Function and diagnosis of these 5 integrated units:

**CAN time out:** The data transmission (rated value, actual value,..) is done via a CAN-compatible data log. Transmission errors or absent data frames are detected and a DTC is set.
**EEPROM:** This unit carries out a comparison of the checksum. As soon as a deviation of the EEPROM-data as compared to the checksum is detected, there will be the error entry Ł „invalid checksum EEPROM".
**RAM:** This unit is for the information storage during the normal operation. When an error occurs during writing of data into the test patterns during the initialization phase of the ECU, there is the error entry Ł „invalid checksum RAM".
**ROM:** This unit is for the storage of the program flow and the calibration data with storage mode flash. When an error occurs during the continuous comparison with the CRC-sum in the memory, there is the error entry Ł „invalid checksum ROM".
**Watchdog, Temp-Sensor:** An emergency switch off path that switches off the output stage in case of a faulty processor is integrated in the unit „watchdog". The temperature is applied to a thermal protection model in order to prevent output stage thermal overload. When a watchdog or temperature sensor occurs, there is the corresponding error entry Ł „watchdog, temp. sensor **on**"**Valvetronic Power Supply**

### 1.29.2.1 Description and diagnosis of this module:

The output stages of both valvetronic actuators are supplied by a relay, which is switched to the ECU. The voltage in the ECU is needed for the correction of the issued duty factor of the output stage, which is dependant to the battery voltage.
The supply voltage for the output stages is monitored permanently by the ECU and if the supply voltage gets out of the permitted range (5.7-17V), then this malfunction will be detected and the DTC will be stored. Additional to the storage of this fault code the valvetronic actuators are driven to their end positions. A further diagnosis will be carried out – see Valvetronic limp-home.
See the summary table for further details.

### 1.29.3 Valvetronic Power Stage

#### 1.29.3.1 General description of this module:

The valvetronic actuator is supplied by a power stage with integrated „Full-Bridge“-circuit in the ECU. With this „Full-Bridge“- circuit the sense of rotation of the actuator can perfectly be changed.
To avoid a damage of the power stage, a permanent monitoring of short circuit is proceeded.

Diagnosis of a malfunction within the Power Stage:

By a series connection of shunts in the high side- and low side path a short circuit will be detected. In this case the power stage will be cut off immediately and afterwards a detailed distinction of the different kinds of short circuits will be performed.

In the resistor network of the power stage circuit the voltage levels are measured and compared with the programmed thresholds (in accordance to the summary table).
Dependant to the deviation from the desired values there will be detected:

- short to ground
- short to battery
- short with each other

and the corresponding DTC will be stored (see summary table).

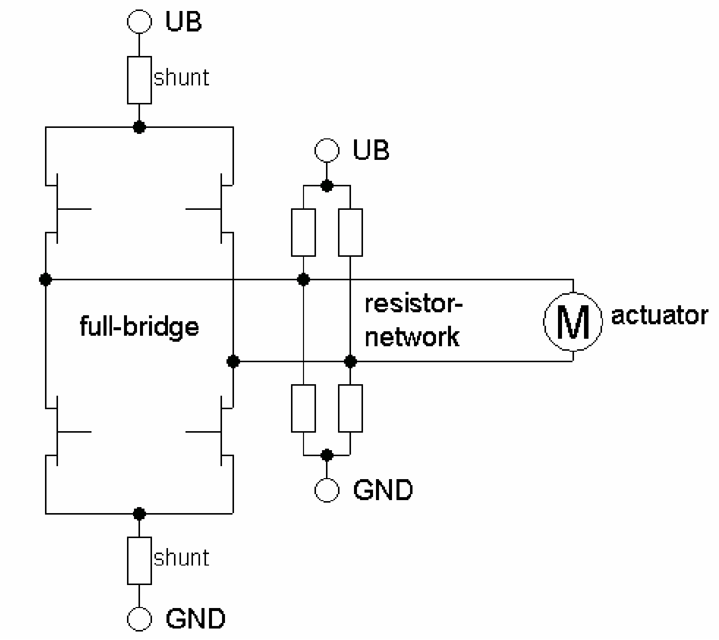


*Figure 32*

### 1.29.4 Valvetronic (limp-home)

#### 1.29.4.1 Description and diagnosis of this module:

If a malfunction of one of the valvetronic components is detected, the management tries to drive both actuators to their end positions (limp-home = full valve lift). In this case, the charge control will be managed by the throttle. If one actuator cannot reach its end position, the valvetronic tries to ensure, that the load on both banks reaches a common level. Any reduction of valvelift will lead to a reduction of the engine power. A DTC is stored, if one of both actuators was not able to reach its end position.
There will be a distinction, whether this error was detected directly by a comparison with the actuator angle or indirectly by checking the engine roughness or comparison of load or comparison of air mass flow.

This balance test is carried out for thermal protection of the catalyst. If the air charge distribution on both cylinder-banks is unequal, the fuel system runs a danger of delivering an incombustible mixture.

Valvetronic malfunction was detected and limp home mode is set. There is no information about the actuator’s end position and the engine roughness is detected as too high.

Ł P-code P1061

## 1.30 Diagnosis of Camshaft Position Sensor

### 1.30.1 Engine speed sensor and camshaft position (CMP) sensor

A ferromagnetic toothed wheel with 60 teeth, where two of which are missing (60 - 2 toothed wheel), is attached to the crankshaft. The fixed engine speed sensor scans the 58 teeth of the toothed wheel as they pass by. The passing teeth induce an alternating sinusoidal voltage which is amplified and shaped to a constant square wave for further processing. Due to the two missing teeth a gap in the square wave signal can be identified. This reference gap is allocated to a specific crankshaft position for cylinder 1 and the controller is synchronizing on it.

For a full four-stroke engine cycle two crankshaft revolutions (720° crankshaft) are necessary and the controller must use a second signal to determine if the cylinder is in compression or exhaust phase.

This second signal is provided by a fixed camshaft position (CMP) sensor and a rotating toothed wheel attached to the camshaft using the Hall effect or induction. Again the signal is amplified and shaped to a square wave as shown in Figure 33.

With both signals it is now possible to differ between compression and exhaust phase within one full four-stroke cycle.

Engine speed sensor (crankshaft) signal:

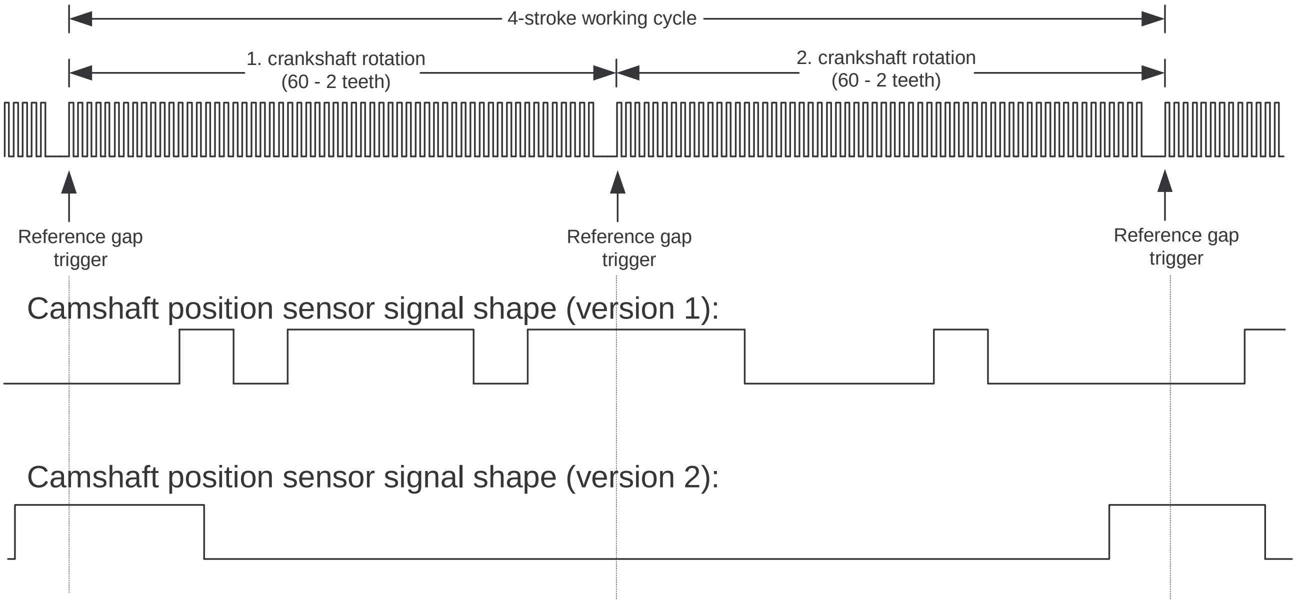


*Figure 33: Engine speed sensor and camshaft position sensor signals*

Up to four camshaft position sensors can be analyzed, each with his own fault path. In case of a system with more than one camshaft position sensor, each sensor is monitored separately but all in the same way.

### 1.30.2 Diagnosis by counting the CMP sensor signal edges

The counted number of camshaft position (CMP) sensor signal edges is stored and compared to the expected value. When the counted number of signal edges lies below or exceeds a tolerance range then a failure counter is increased by one. If the failure counter exceeds a threshold a detailed classification of the malfunction is done by analyzing the total number of counted signal edges and the sensor signal level. Depending on the result of this analysis the corresponding maximum, minimum or plausibility fault is stored.

## 1.31 Diagnosis of Throttle Position Sensor

The diagnosis of the two throttle position sensors consists in principle of a range check and a rationality check of the measured voltage values of the potentiometers.

The range check measures the voltage of sensor 1 and of sensor 2 and compares it in each case with a minimum or maximum threshold value. If the measured voltage exceeds a calibrated threshold, a malfunction is detected and a maximum fault DK1P (sensor 1) or DK2P (sensor 2) is set. Additionally a plausibility summary fault DK is set. If the measured voltage lies below a calibrated threshold, a malfunction is detected and a minimum fault DK1P (sensor 1) or DK2P (sensor 2) is set. Additionally a plausibility summary fault DK is set.

The rationality check uses the measured voltages of sensor 1 and of sensor 2 to calculate the corresponding throttle position angles. The two throttle position angles are compared to each other to get deviation (synchronism) information. If the deviation between the two throttle position angles exceeds a calibrated threshold a further check is done to define which of the throttle position sensors is defective. To exactly decide which sensor is defective a theoretical reference throttle position angle is calculated with the help of the mass airflow and compared to the measured throttle position angles. If any fault of sensor 1 or of sensor 2 is set, the checks below are also performed for the error-free sensor, regardless of the synchronism result.

If

- the deviation of sensor 1 to reference angle is greater than the deviation of sensor 2 to reference angle (checked only without sensor fault) **or**
- a fault of mass airflow sensor and intake manifold pressure sensor is set **or**
- the deviation of sensor 1 to reference angle exceeds a calibrated threshold

a malfunction of sensor 1 is detected and a plausibility fault DK1P is set.

If

- the deviation of sensor 2 to reference angle is greater than the deviation of sensor 1 to reference angle (checked only without sensor fault) **or**
- a fault of mass airflow sensor and intake manifold pressure sensor is set **or**
- the deviation of sensor 2 to reference angle exceeds a calibrated threshold

a malfunction of sensor 2 is detected and a plausibility fault DK1P is set.
Additionally a plausibility summary fault DK is set.

## 1.32 Diagnosis of Throttle Adjustment Device by DLR

The purpose of the function is to control the throttle actuator and to diagnose faults in the control loop. The position of the throttle valve is controlled by a digital position controller (DLR) which sends a PWM (Pulse Width Modulated) duty cycle factor and a flag to indicate the direction of rotation to the throttle body power stage. The throttle body power stage is designed as an integrated H-bridge with internal current limitation.

### 1.32.1 Diagnosis of non-permissible deviations between requested and actual throttle position

The position control loop is monitored for non-permissible deviations. If the deviation between the setpoint and the actual throttle blade position exceeds a calibrated value for a period of time, a throttle body malfunction is detected, the system is placed in the state “Throttle valve drive default function” and a plausibility fault DVEL is set.

### 1.32.2 Duty cycle range check

If the PWM duty cycle output of the DLR exceeds an upper calibration or is lower than a calibration value for a long period of time 2, a duty cycle malfunction and actuator current malfunction respectively is detected. The system is set to “Throttle valve drive default function” state and a maximum fault DVER is set. If the DLR output surpasses the duty cycle limits only for a shorter period of time 1, for safety reasons the system requests a fuel deactivation for a short time and a minimum fault DVER is set.

### 1.32.3 Throttle valve power stage check

The actual electrical diagnosis of the throttle valve power stage is done with the built-in controller hardware and the results are stored as error flags in a dedicated status register.

The check of these error flags is only performed if either a maximum fault DVER or a plausibility fault DVEL and therefore an impact of the controllability of the throttle valve is detected.
In case of

- error flag for ‘short circuit’ is set, the corresponding maximum fault DVEE is set
- error flag for ‘overheating’ or ‘overcurrent’ is set, the corresponding minimum fault DVEE is set
- error flag for ‘SPI bus or signal fault’ is set, the corresponding plausibility fault DVEE is set
- error flag for ‘open load’ is set, the corresponding signal fault DVEE is set

## 1.33 Diagnosis of Throttle Body

During the software adjustment phase of the powertrain control module to the mechanical throttle body characteristics, the following check is performed.

### 1.33.1 Return spring check

The return time of the wide open throttle valve to its mechanical default position, by means of the return spring, is measured and compared to a calibrated threshold value.

If the desired start position (open throttle valve) for the actual return spring check is not reached within a calibrated time, a malfunction is detected and a minimum fault DVEF is set.

If, after switch-off of the power stage, the expected mechanical default position is not reached within a calibrated time, a malfunction is detected and a maximum fault DVEF is set

## 1.34 Diagnosis of Knock Sensor

The knock sensor diagnosis is capable of detecting a leadless (circuit discontinuity) knock sensor or one that has not been mounted, knock sensor short circuits to battery or ground as well as plausibility faults. It additionally can predict a pending engine damage e.g. via increased noise level due to an enlarged piston groove. The knock sensor diagnosis runs continuously and employs the same strategy to check each an every cylinder. The knock sensor diagnosis employs two different methods to ascertain the complete detection of all knock sensor faults; monitoring of knock sensor lines with the CC196 integrated circuit and monitoring via knock-sensor- and cylinder-based reference noise signal.

### 1.34.1 Monitoring via the CC196 IC

Monitoring via CC196 has priority over the reference level diagnosis. The number of errors within one period of observation (100 working cycles) is stored in a cylinder-individual counter. A plausibility fault is set when the number of errors exceeds a calibrated threshold. The fault path is cleared only if the number of errors remains below a calibrated threshold.

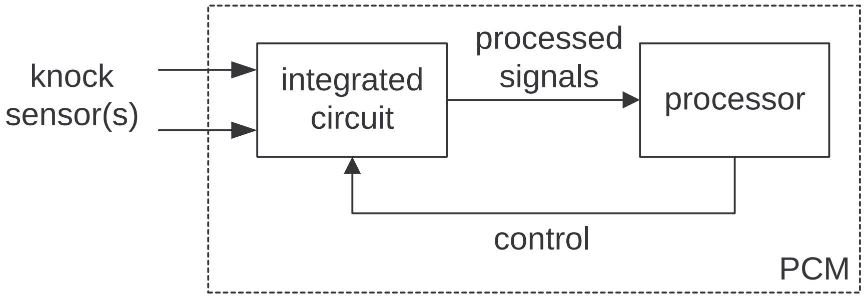
### 1.34.2 Monitoring via reference signal

A reference signal (uref) is calculated based on the knock sensor signal. This reference value represents the basic noise of the current cylinder being analyzed. When the monitoring conditions are fulfilled, uref is compared with the lower and upper calibrated engine-speed-dependent thresholds. A maximum fault is set when uref is greater than the upper calibrated threshold. Likewise, a minimum fault is set when uref is less than the lower calibrated threshold.

The fault path is cleared when the current reference level for a calibrated number of successive checks again lies within the range bounded by the upper and lower calibrated reference thresholds.

## 1.35 Diagnosis of Knock Control Circuit

The knock sensor signals are evaluated and processed in a custom made integrated circuit CC196. This circuit is controlled by the PCM's processor and the processed signals are directly accessible for knock control and diagnosis.



The knock control circuit diagnostic offers three monitoring possibilities: the pulse test, the zero test and parity check. Switching between the pulse test signal, the zero test signal and the signals from the knock sensors is accomplished via a multiplexer.

### 1.35.1 Pulse Test

A test pulse is sent to the CC196 IC and its integral is monitored within a measuring window. A maximum error is assumed if the integral of the test pulse lies below a calibrated threshold. The corresponding fault code is set as soon as a calibrated number of consecutive fault assumptions is exceeded. The fault path is cleared when the same number of consecutive test pulse measurements are performed without detecting a fault.

### 1.35.2 Zero Test

In the Zero test mode, the integral is monitored within a measuring window when all input signals are completely switched off. A minimum error is assumed if the integral of the zero test pulse lies above a calibrated threshold. The corresponding fault code is set as soon as a calibrated number of consecutive fault assumptions is exceeded. The fault path is cleared when the same number of consecutive Zero test measurements are performed without detecting a fault.

Normally when monitoring conditions are fulfilled, the Pulse Test and Zero Test are alternately performed approximately every 250 working cycles. This procedure is halted the moment any one of the 2 monitors results in a fault assumption or clearing of a fault path. The monitor that generated the fault assumption (or that resulted in the clearing of a fault path) will henceforth be performed after every 60 working cycles till that fault (or the cleared fault path) is confirmed.

### 1.35.3 Parity check

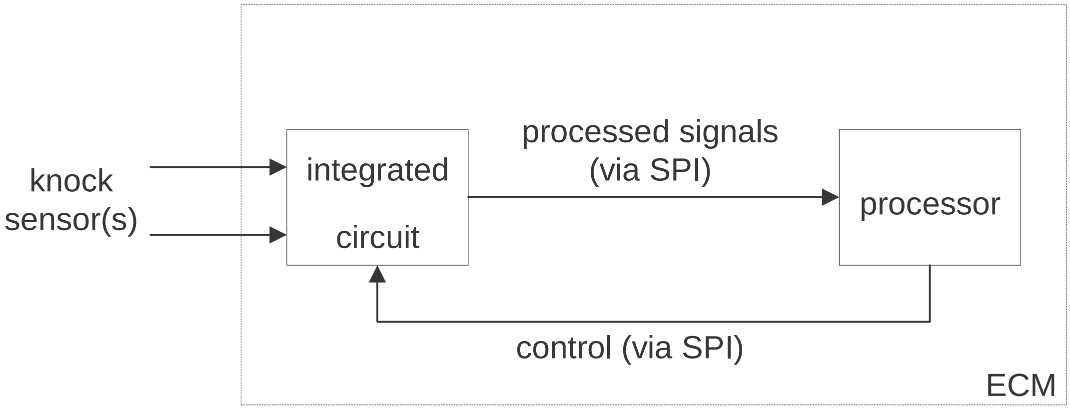
The internal random access memory (RAM) is monitored continuously. The number of errors that occur in a defined observation time frame are noted. A plausibility fault is stored when the number of errors exceeds an applicable threshold. The fault path is cleared only when the number of errors is equal to zero.

## 1.36 Diagnosis: knock control SPI Monitoring

The knock sensor signals are evaluated and processed in a custom made integrated circuit, CC196. This IC is controlled by the powertrain control module’s (PCM) processor - see diagram below. Its processed signals are directly accessible for knock control diagnosis.

The serial peripheral interface (SPI) communication is monitored continuously by evaluating the the check words (registers) of the knock sensor’s CC196 integrated circuit. The number of errors that occur in a defined observation time frame are countered. A plausibility fault is set when the number of errors exceeds a calibrated threshold. The fault path is cleared only when the number of errors is equal to zero

A plausibility fault is also stored when the Integrated Circuit (CC196) is not completely initialized. In this case only a restart resets the plausibility fault. Activation or deactivation of the diagnosis is allowed only during a reset of the PCM. This ensures a proper execution of the diagnosis.



## 1.37 Diagnosis of CAN Data Bus - TCM communication

### 1.37.1 Automatic Transmission

The diagnosis of the powertrain CAN communication between the TCM and the PCM is done by supervision of the received TCM powertrain CAN messages.
If a TCM powertrain CAN message is missing for a calibrated period of time, a timeout is detected and a signal fault CEGS is set.
If the checksum of a TCM powertrain CAN message is wrong for a calibrated period of time, a malfunction is detected and a plausibility fault CEGS is set.
If the the sequence number of a TCM powertrain CAN message is wrong for a calibrated period of time, a malfunction is detected and a minimum fault CEGS is set.

## 1.38 Diagnosis of CAN Data Bus - TCM communication

### 1.38.1 Semi-automatic transmission

The diagnosis of the powertrain CAN communication between the TCM and the PCM is done by supervision of the received TCM powertrain CAN messages.
If a TCM powertrain CAN message is missing for a calibrated period of time, a timeout is detected and a signal fault CSSG is set.
If the checksum or the sequence number of a TCM powertrain CAN message is wrong for a calibrated period of time, a malfunction is detected and a plausibility fault CSSG is set.
If the content of a TCM powertrain CAN message during the following gear shift phases

- no gear shift active
- gear shift active with engine stop request
- gear shift active without shifting
- gear shift active with torque reduction phase
- gear shift active with engine speed control phase
- gear shift active with torque increase phase

is not rational, a malfunction is detected and a plausibility CSSG is set.

## 1.39 Diagnosis of CAN Data Bus - VVT communication

The diagnosis of the local CAN communication between VVT control module and PCM is done by supervision of the received VVT local CAN messages.

If a VVT local CAN message is missing for a calibrated period of time, a timeout is detected and a signal fault CVVT is set.

If the checksum or the sequence number of a VVT local CAN message is wrong for a calibrated period of time, a malfunction is detected and a plausibility fault CVVT is set.

## 1.40 CAN Signal Timeout

The CAN signal timeout diagnosis continuously monitors the CAN-messages: ambient temperature, mileage and instrument panel status for timeout. It further performs an instrument panel alive check and controls MIL illumination.

MIL activation control distinguishes between continuous and blinking MIL illumination by evaluating the signal received via CAN.

### 1.40.1 Signal Fault

A signal fault will be set when the ambient temperature message isn't received after the calibrated turn-on delay time TDCINS or when the mileage message isn't received after the calibrated turn-on delay time TDCINS2 or when the instrument panel message isn't received after the calibrated turn-on delay time TDCINS3.

### 1.40.2 Minimum Fault

A minimum fault is set after the turn-on time TDCINS3 when the alive counter (signal from instrument panel) isn't correctly incremented or isn't incremented at all.

### 1.40.3 Plausibility Fault

A plausibility fault will be set after the calibrated turn-on delay (de-bounce) time TDCINSMIL, when during continuous MIL illumination the MIL-activation and MIL-on states are not identical. A plausibility fault is equally set during blinking MIL illumination when the MIL turn-on delay time is greater than calibration TDCIMILON or when the MIL turn-off delay time is less than the calibrated time TDCIMILOFF.

## 1.41 Diagnosis of Local CAN B

The diagnosis of the local CAN B data bus consists of several checks with their own fault codes.

If, during initialization of the CAN data bus, the CAN controller reports a CAN B initialization failure, a malfunction is detected and a minimum fault CANB is set.

If, after initialization of the CAN data bus, the CAN controller reports a CAN B failure for a calibrated period of time, a malfunction is detected and a maximum fault CANB is set.

If, after initialization of the CAN data bus, the CAN controller reports a CAN B bus-off state for a calibrated period of time, a malfunction is detected and a signal fault CANB is set.

## 1.42 Diagnosis of Powertrain CAN A and CAN C

The diagnosis of the powertrain CAN A and CAN C data bus consists of several checks with their own fault codes.

If, during initialization of the CAN data bus, the CAN controller reports a CAN A or a CAN C initialization failure, a malfunction is detected and a minimum fault CANA is set.

If, after initialization of the CAN data bus, the CAN controller reports a CAN A or a CAN C failure for a calibrated period of time, a malfunction is detected and a maximum fault CANA is set.

If, after initialization of the CAN data bus, the CAN controller reports a CAN A or a CAN C bus-off state for a calibrated period of time, a malfunction is detected and a signal fault CANA is set.

## 1.43 Identification of the communication protocol utilized by Test Groups 6BMXV04.8UL2 for communication with an SAE J1978 scan tool

The implementation and description of the diagnostic communication protocol KWP 2000 is based on the following standard:

| | |
|---|---|
| ISO 14230-4 | Road Vehicles – Diagnostic Systems |

## 1.44 Listing of DME input and output signals

| Pin # | Input | Output | Description | OBD relevant |
|---|---|---|---|---|
| 101 | x | | not contacted, JPT for prog. station clamp 15 | no |
| 103 | x | x | diagnosis (programming station) | no |
| 104 | x | | electronic ground | no |
| 105 | x | | injector nozzle ground | x |
| 106 | x | | power stage ground | x |
| 107 | x | | continuous positive clamp 30 | no |
| 108 | x | | battery voltage main relay, clamp 87 | no |
| 109 | | x | main relay (activation) | no |
| 201 | | x | heater for pre-catalyst oxygen sensor 1 | x |
| 202 | | x | heater for pre-catalyst oxygen sensor 2 | x |
| 203 | x | x | vehicle CAN-interface LOW | x |
| 204 | x | x | vehicle CAN-interface HIGH | x |
| 206 | | x | heater for post-catalyst oxygen sensor 1 | x |
| 207 | x | | pre-catalyst oxygen sensor 1 ground | x |
| 208 | x | | post-catalyst oxygen sensor 2 ground | x |
| 209 | x | | pre-catalyst oxygen sensor 2 ground | x |
| 210 | x | | post-catalyst oxygen sensor 1 ground | x |
| 212 | | x | heater for post-catalyst oxygen sensor 2 | x |
| 213 | | x | pre-catalyst continuous oxygen sensor 1 pump current | x |
| 214 | x | | post-catalyst oxygen sensor 2 | x |
| 215 | | x | pre-catalyst continuous oxygen sensor 2 pump current | x |
| 216 | x | | post-catalyst oxygen sensor 1 | x |
| 219 | x | | pre-catalyst continuous oxygen sensor 1 pumping cell | x |
| 220 | x | | pre-catalyst oxygen sensor 1 reference cell | x |
| 221 | x | | pre-catalyst continuous oxygen sensor 2 pumping cell | x |
| 222 | x | | pre-catalyst oxygen sensor 2 reference cell | x |
| 223 | | x | main relay (activation) | no |
| 302 | x | | intake manifold differential pressure sensor | no |
| 303 | x | | intake air temperature sensor 1 | x |
| 305 | x | | mass airflow sensor | x |
| 306 | | x | fuel injector 4 | x |
| 307 | | x | fuel injector 5 | x |
| 308 | | x | fuel injector 6 | x |
| 309 | | x | control of variable camshaft control: intake - 2 | x |
| 310 | | x | control of variable camshaft control: intake 1 | x |
| 311 | | x | fuel injector 7 | x |
| 312 | | x | mapped cooling system (electrically heated thermostat) | x |
| 313 | | x | fuel injector 1 | x |
| 314 | x | | electronic ground (M_HFM) | x |

| Pin # | Input | Output | Description | OBD relevant |
|---|---|---|---|---|
| 316 | x | | camshaft position sensor outlet 1 | x |
| 317 | x | | camshaft position sensor outlet 2 | x |
| 318 | | x | variable valve timing enable line | x |
| 319 | x | x | generator interface | no |
| 320 | | x | control of variable camshaft control: outlet-1 | x |
| 321 | | x | canister purge valve | x |
| 323 | | x | control of variable camshaft control: outlet-2 | x |
| 324 | | x | fuel injector 2 | x |
| 325 | | x | fuel injector 8 | x |
| 326 | | x | fuel injector 3 | x |
| 327 | x | | crankshaft sensor (engine speed sensor) | x |
| 328 | x | | NTC-water (engine temperature) | x |
| 329 | x | | camshaft position sensor intake 1 | x |
| 330 | x | | camshaft position sensor intake 2 | x |
| 331 | x | | throttle valve sensor 1 | x |
| 332 | x | | throttle valve sensor 2 | x |
| 333 | x | | knock sensor 1 b(diff-signal!) | x |
| 334 | x | | knock sensor 2 b(diff-signal!) | x |
| 335 | x | | knock sensor 3 b(diff-signal!) | x |
| 336 | x | | knock sensor 4 b(diff-signal!) | x |
| 337 | x | | digital ground (KWG) | x |
| 338 | x | | local CAN-high | x |
| 340 | | x | differential intake sysetm (DISA) motor 1 | no |
| 341 | | x | differential intake sysetm (DISA) motor 2 | no |
| 342 | | x | throttle valve control 1 | x |
| 343 | | x | throttle valve control 2 | x |
| 344 | x | | intake air temperature sensor 2 | x |
| 345 | x | | position feedback differential intake sysetm (DISA) | no |
| 346 | x | | knock sensor 1 a(diff-signal!) | x |
| 347 | x | | knock sensor 2 a(diff-signal!) | x |
| 348 | x | | knock sensor 3 a(diff-signal!) | x |
| 349 | x | | knock sensor 4 a(diff-signal!) | x |
| 350 | | x | voltage supply throttle valve position sensor (DKG1,2) | x |
| 351 | x | | local CAN-low | x |
| 352 | x | | throttle valve position sensor ground | x |
| 402 | | x | DM-TL heater | no |
| 404 | | x | electric fan 1 (pulsed) | no |
| 405 | x | | electronic ground | no |
| 406 | x | | start demand switch / cruise control accelerate | no |

| Pin # | Input | Output | Description | OBD relevant |
|---|---|---|---|---|
| 407 | x | | accelerator pedal sensor (PWG1) ground | no |
| 408 | x | | accelerator pedal sensor (PWG1) sensor | no |
| 409 | | x | voltage supply 5V accelerator pedal sensor 1 (PWG1) | no |
| 410 | | x | electric fuel pump relay | no |
| 412 | x | | accelerator pedal sensor 2 (PWG 2) ground | No |
| 413 | x | | driver demand 2 accelerator pedal sensor 2 (PWG2) | no |
| 414 | | x | voltage supply 5V accelerator pedal sensor 2 (PWG2) | no |
| 417 | | x | diagnostic connector | no |
| 418 | | x | exhaust-gas flap | no |
| 419 | | x | EBOX-fan | no |
| 420 | | x | evaporative system monitoring pump control | x |
| 422 | x | | vehicle speed (ABS) | x |
| 423 | x | | clutch switch | x |
| 424 | x | | brake lights switch | no |
| 425 | x | | oil pressure switch | no |
| 426 | x | | vehicle pin clamp 15 | no |
| 427 | x | | multiple-function steering wheel interface | no |
| 428 | x | | brake lights test switch | no |
| 429 | | x | compressor relay | no |
| 430 | | x | evaporative system leak detection pump (LDP) | x |
| 431 | | x | control of radiator shroud | (not used) |
| 432 | x | x | Diagnosis | no |
| 433 | x | x | immobilizer EWS3/4 | no |
| 436 | x | x | vehicle CAN-interface high | x |
| 437 | x | x | vehicle CAN-interface low | x |
| 438 | x | | cooling water outlet ground | no |
| 439 | x | | cooling water outlet | x |
| 440 | | x | autostart | no |
| 501 | | x | ignition cylinder x | x |
| 502 | | x | ignition cylinder x | x |
| 503 | | x | ignition cylinder x | x |
| 504 | | x | ignition cylinder x | x |
| 505 | x | | ignition ground | x |
| 506 | | x | ignition cylinder 1 | x |
| 507 | | x | ignition cylinder x | x |
| 508 | | x | ignition cylinder x | x |
| 509 | | x | ignition cylinder x | x |

## 1.45 Diagnosis of Output Stages CJ94x/CY31x/TLE6232

Depending on the state of fault information, the standard output stage diagnosis will activate a fault check or a healing cycle.

The diagram below has the following components or phases.

- Fault check

Observing a buffer and detecting if a fault is present

- Fault de-bounce

A fault is detected. A counter then triggers a test impulse to confirm the fault.

- Verification

When the same error type is again detected, the fault is verified; otherwise it is rejected.

- Healing cycle
  When a verified fault is stored in the fault code memory, a periodic healing cycle is initiated. After the healing cycle period, a test impulse is triggered. In case error flag is true on start there is no time delay to trigger the first test impulse.
- fault check 2

If there is no fault signal detected after the healing cycle, the fault is healed. If the type of fault has changed or a verified fault is detected, the healing cycle is repeated.

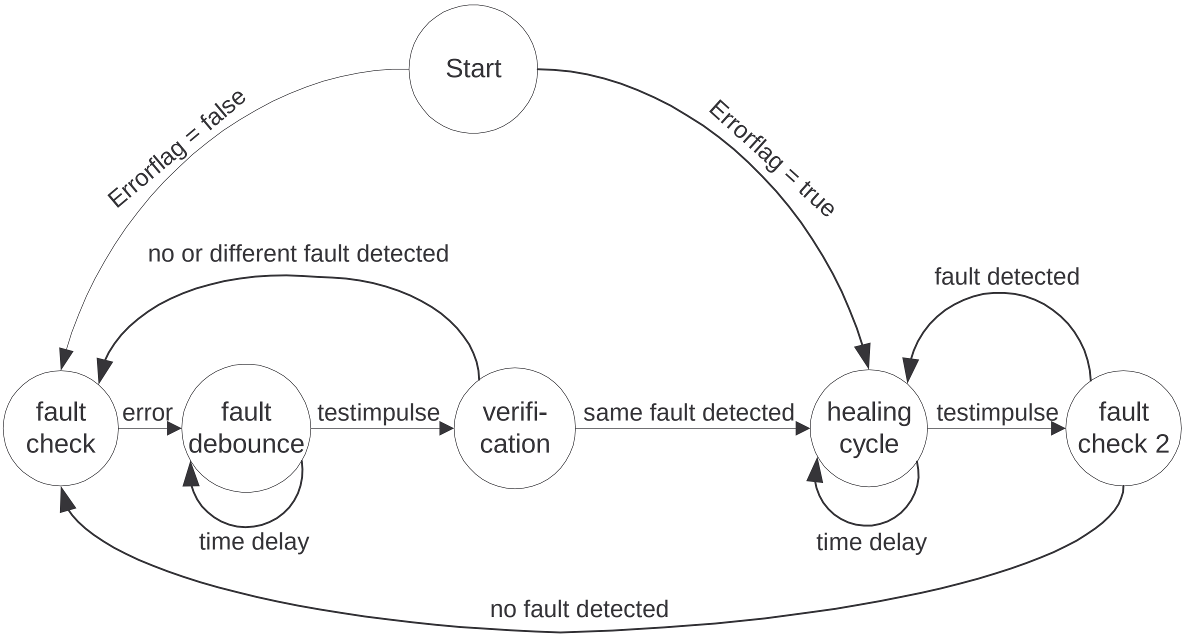


*Figure 34: Standard Diagnosis*

The Integrated Circuit CJ94x checks the output signals of several components for basic circuit functionality.

The output stage of the PCM is first checked. Depending on this output stage, the signal levels are then monitored by using a test algorithm.

The test algorithm contains several tests measuring current and voltage of the output stages. The output stage conditions turn off (high) and turn on (low) must be reached once. In case of fault detection in one condition the fault is verified. A test to detect a short circuit to battery (set max fault) is called a ”low test”. It can be performed only while the output stage is conducted. A test to detect a short circuit to ground (set min fault) or a wire interruption/break (set signal fault) is called a ”high test”. The "high test" algorithm can detect both distinctively. It can be performed only while the output stage is not conducted.

The diagnosis of the output stage IC CJ94x of the engine PCM is the basic functionality for the electrical monitoring of circuit continuity of the following components:

- Evaporation System Pump Motor (for diagnosis)
- Evaporation System Solenoid Valve
- Canister Purge Valve
- Variable Camshaft Control (inlet and outlet)
- Fuel Injection Valves
- Thermostat

## 1.46 IUMPR kernel function

The in-use monitor performance (IUMPR) kernel function represents the core of the software algorithms in the OBD II system implemented to individually track and report in-use performance, in the standardized tracking and reporting format, for every monitor of the following components/systems (subsystems A...E):

- A: catalyst
- B: primary oxygen sensor
- C: evaporative system (only 0.02 inch leak detection)
- D: EGR/VVT system and
- E: secondary air system (not available in this system).

*All monitors for which an in-use performance record is required do have an interface (a function identifier) through which they communicate with the IUMPR kernel function. It is this kernel function that does the actual tracking and preparation for reporting in the standardized format. See*
Figure 35 below. The IUMPR kernel function additionally tracks and records the ignition cycle counter, the general denominator for every driving cycle and determines the monitor with the lowest numerical ratio within each group that has multiple monitors.

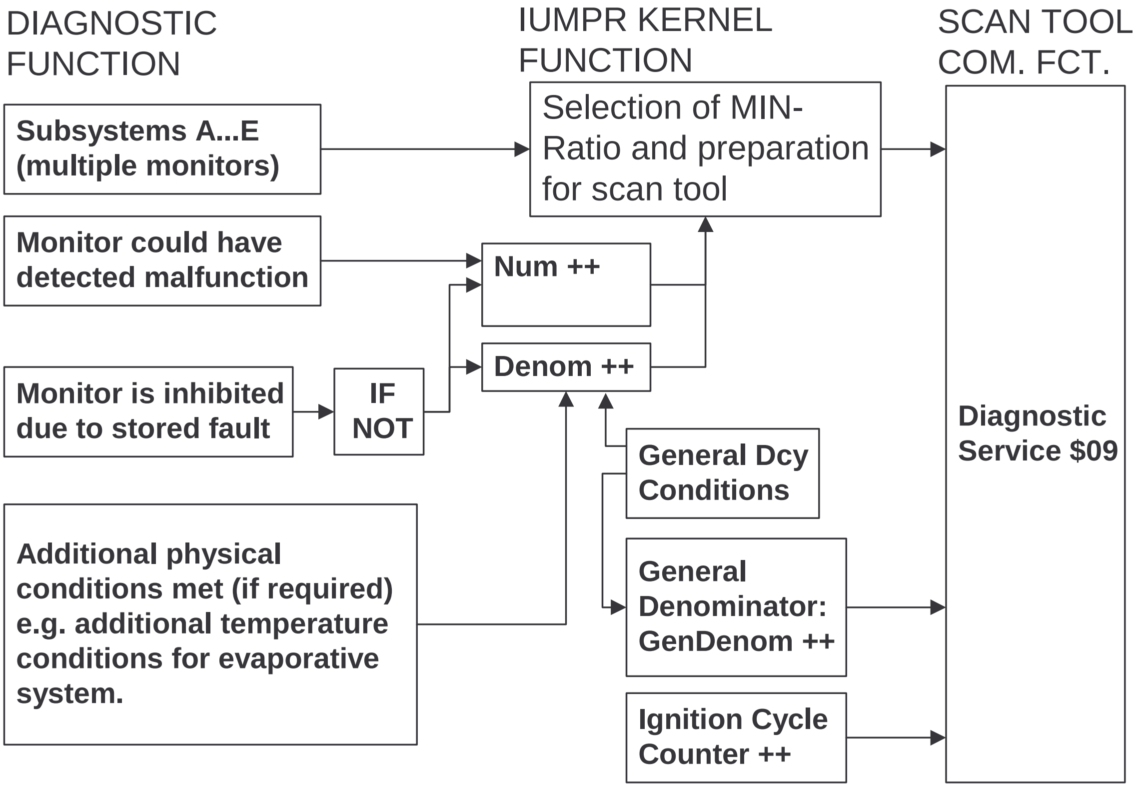


*Figure 35: Schematic view of implementation of in-use monitor performance ratio (IUMPR).*

### 1.46.1 Ignition cycle counter

The ignition cycle counter, when incremented, is incremented by an integer of one and only once per driving cycle. If the ignition cycle counter reaches the maximum value of 65,535, it rolls over and increments to zero on the next ignition cycle to avoid overflow problems.

#### 1.46.1.1 Conditions for incrementing the ignition cycle counter

- The ignition cycle counter is incremented within ten seconds if and only if the vehicle meets the engine start definition for at least two seconds plus or minus one second. The “Engine start” condition is determined via the engine speed sensor.
- Incrementing of the ignition cycle counter is disabled within ten seconds if a malfunction of the engine speed sensor has been detected and the corresponding pending fault code has been stored

### 1.46.2 General denominator

The general denominator, when incremented, is incremented by an integer of one and only once per driving cycle. If the general denominator reaches the maximum value of 65,535, it rolls over and increments to zero on the next driving cycle that meets the general denominator definition to avoid overflow problems.

#### 1.46.2.1 Conditions for incrementing general denominator

The general denominator is incremented within ten seconds if and only if the following criteria are satisfied on a single driving cycle:

- cumulative time since engine start is greater than or equal to 600 seconds while at an elevation of less than 8,000 feet above sea level and at an ambient temperature of greater than or equal to 20 degrees Fahrenheit
- cumulative vehicle operation at or above 25 miles per hour occurs for greater than or equal to 300 seconds while at an elevation of less than 8,000 feet above sea level and at an ambient temperature of greater than or equal to 20 degrees Fahrenheit
- 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 while at an elevation of less than 8,000 feet above sea level and at an ambient temperature of greater than or equal to 20 degrees Fahrenheit
- No faults from those sensors used to determine ambient temperature, ambient pressure (elevation), vehicle speed and idle condition; in flowchart referred to as “global faults”.

Incrementing of the general denominator is disabled within ten seconds if a malfunction of one of the sensors mentioned above has been detected and the corresponding pending fault code has been stored.

### 1.46.3 IUMPR - Records

The kernel function maintains a record (a collection of elements from different types of arrays as depicted in Figure 36 below) for each monitor for which in-use performance ratio tracking is required. An update of a monitor’s record is triggered or inhibited by the monitor itself. Each monitor’s function identifier addresses its corresponding record via a pointer.

Each record holds the following information about the respective monitor:

- the function identifier (interface between monitor and IUMPR kernel function)
- the associated diagnostic fault path
- the numerator
- the denominator
- IUMPR status information from the diagnostic function
- the associated component/system group (necessary for selection of minimum ratio of multiple monitors of one of the subsystems A...E).

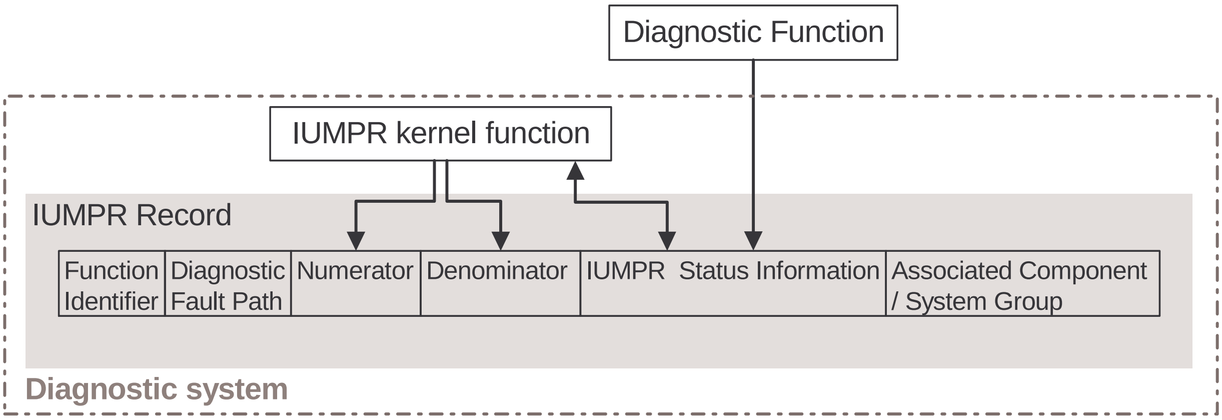


*Figure 36: IUMPR record*

| **IUMPR Status Information** |
|---|
| Fault is found / could have been found |
| Inhibition of denominator due to physical conditions if considered (e.g. for Evaportive System or Secondary Air System) |
| Inhibition of monitor due to stored fault |
| Numerator incremented is this driving cycle |
| Denominator incremented in this driving cycle |

*Figure 37: IUMPR status information of a monitor.*

### 1.46.3.1 Incrementing the numerator and denominator

A cyclic check is performed to find out if all conditions necessary for incrementing the numerator and the denominator have been fulfilled.

#### 1.46.3.1.1 Conditions for incrementing the numerator

- incrementing of the general denominator is not disabled by a fault
- no inhibition of the diagnostic function due to a fault
- diagnostic function has found or could have found a fault (includes all monitoring conditions)
- the numerator has not yet been incremented in this driving cycle.

#### 1.46.3.1.2 Conditions for incrementing the denominator

- conditions for incrementing the general denominator have been fulfilled
- incrementing of the general denominator is not disabled by a fault
- no inhibition of the diagnostic function due to fault
- Additional physical conditions met (if required)
- denominator has not yet been incremented in this driving cycle.

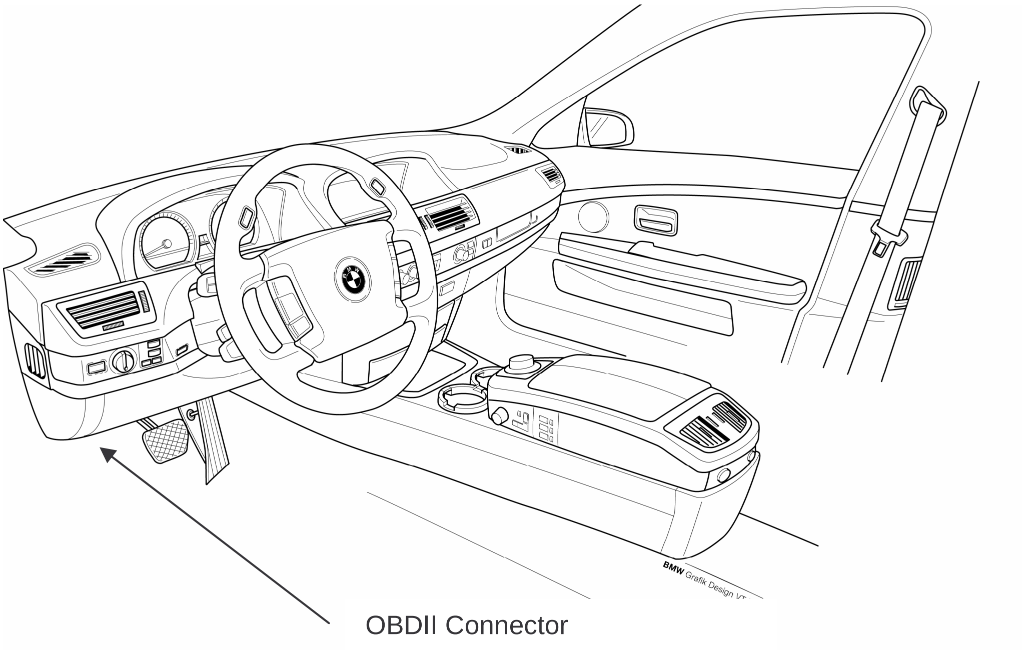
If either the numerator or denominator for a specific component reaches or exceeds the maximum value of 65,535, both numbers are divided by two before either is incremented. This helps to avoid overflow problems.

### 1.46.3.2 Minimum ratio selection (multiple monitors)

The associated component/system group identifier in a record is a pointer to the group (subsystem A...E) a monitor belongs to. IUMPR ratios are continuously calculated for all monitors. The IUMPR kernel function continuously determines the monitor with the lowest ratio in each group and provides its numerator and denominator values to Service $09 of the generic scan tool together with the ignition cycle counter and the general denominator.

## 1.47 Location of the Data Link Connector for Test Group 6BMXV04.8UL2

### 1.47.1 For models 750i, 750iL



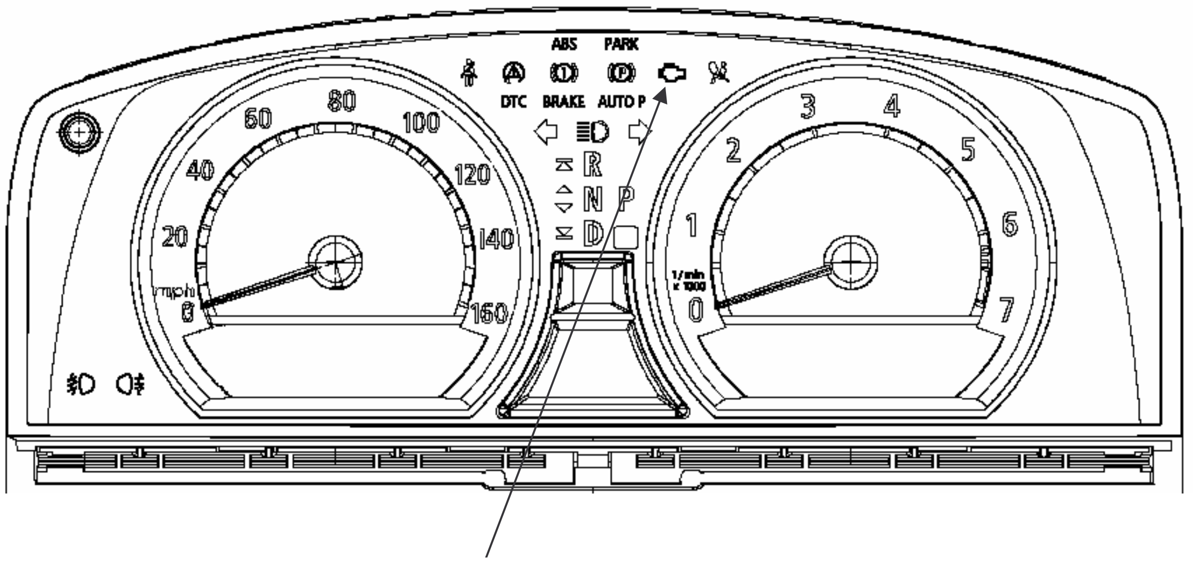
OBDII Connector

### 1.47.2 For models 550i, 650Ci, 650Ci conv

OBD-Connector

## 1.48 Drawing and Location of the Malfunction Indicator Light for Test Group 6BMXV04.8UL2

### 1.48.1 For models 750i, 750iL)



Malfunction Indicator Light (MIL)

### 1.48.2 For models 550i, 650Ci, 650Ci conv

Malfunction Indicator Light (MIL)

### 1.49 Calculated load and fuel trim determination

The calculated engine load "rl" is based on a calculated load signal balanced with the output signal delivered by the **h**ot-**f**ilm air-**m**ass sensor (HFM).

It is calculated as follows:

$$rl = \frac{mszyl}{nkw \times K\_UFAK\_MS\_RF}$$

with . . .
mszyl: calculated load signal balanced with mshfm and corrected with mste
mshfm: air mass from HFM
mste: calculated gas mass flow through canister purge valve
nkw: engine speed
K_UFAK_MS_RF: constant depending on displacement

In case of a malfunction of the HFM the balancing with mshfm is cut off. Mszyl is calculated by the throttle valve angle, the variable valve timing, the residual exhaust gas and the engine speed.

For the **determination of fuel trim** values please refer to the subsections for fuel system monitoring.