SECTION 7

OXYGEN SENSOR MONITORING
7.1 Introduction
This section is consists of two parts.

The first one deals with the UEGO sensor which is used in Lamborghini applications as primary sensor. It contains an overview about main functional aspect of UEGO sensor and its control and heating strategy.

This part demonstrates that the Lamborghini monitor strategy is able to check the UEGO sensors placed before the Catalyst and detect every functional problem, in accordance with paragraph (e) (7.2.1) of the “§1968.2. Malfunction and Diagnostic System Requirements--2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines.

The second part of this section deals with the rear $O_2$ sensor, which is used to detect catalyst failure. More in detail, heater behaviour and every relevant functional aspect of the rear $O_2$ sensor are checked, to detect every functional problem as specified in paragraph (e) (7.2.2).
7.2. Front UEGO sensor
7.2.1 Introduction and structural description
The most important characteristic of the UEGO sensor is its capability to give a signal proportional to richness or leanness of exhaust gas mixture. This capability allows the engine management system to implement a very sharp fuel control, faster than the one based upon on–off sensors especially concerning compensation of large fuelling deviations (i.e. load transients).

This characteristic comes from the structure of the UEGO sensor, which may be considered as the sum of three ceramic cells: Vs cell, Vp cell and heater cell (see pic. 7.2.1 - 1).

![UEGO sensor: TL-6***-W1](image)

**Pic. 7.2.1 - 1**

a. Vs cell

Vs cell has the same chemical composition of a on–off lambda sensor, and gives to the LIE 2010 the same signal. Its construction is made to allow Vs cell to get reference Oxygen (self generated) in its external side and to have its internal side on a very small chamber (gas detecting cavity) in the sensor. Through the ceramic structure of the sensor, when the correct temperature is reached, due to an osmotic process a constant flow of exhaust gases take place from the exhaust system to the chamber at the bottom of the tip of the sensor, and from the chamber to the exhaust gases at the top of the tip.

b. Vp Cell

Vp cell has a mechanical structure which is similar to the one of Vs cell (one side to reference air and the other to the chamber in the sensor), but works as an oxygen pump. According to the intensity and the direction of the electrical current (called Ip) which crosses the Vp cell, oxygen is pumped to or from the small chamber (in case of rich or lean mixture), till the mixture in the gas detecting cavity comes to a stoichiometric composition (Vs cell signal to 0.445V).

From the direction and the intensity of Ip we can calculate the lambda value of exhaust gases. Ip can be driven in Vp cell only when sensor temperature is high enough (Vs < 1.3V).

c. Heater

Heating process is critical for two reasons:

- the osmotic process of exhaust gases is strictly linked to the temperature, and it’s possible only if the tip temperature is over 600°C. So the heater control must measure the tip temperature through the resistance of Vs cell and must keep that temperature close to 785°C (target of the heater control strategy) to ensure the correct efficiency of the sensor.
Water condensation on the sensor (when engine is off) and in the exhaust pipes (immediately after cranking) may damage the ceramic components of the sensor, so warm up process is to be controlled to guarantee sensor durability.

For heater control, a PWM signal is managed by the LIE 2010 to modulate heating power during cranking and warmed up operation. Heater voltage may be modulated from 4 to 13V during warm up and from 7 to 13V during warmed up operation.

According with the above premise, UEGO management procedure flows as follows:

The first two steps of the above procedure are completed within the first 20 seconds from engine on, and are described in the next two chapters.

An overview of the different diagnostic phases of the first two steps may be found in Pic 7.2.1 - 2. The last step of the above procedure is performed once per trip during closed loop operation, and will be described in the third chapter.
Characteristic Voltages, UEGO and Tcat temperatures during warming up of a UEGO sensor

- Shutdown Diag on, Vp+ must be < 1 V
- Test > Dew point; Heating Ramp Diag On, Shutdown diag off
- Vp+ < 1.3 V, Heating Ramp Diag off, UEGO Temp reading on, Heater PI on, Continuous Heating Diag on
- UEGO Temp > 600°C, normal operation, Up reading and Closed Loop possible
- Continuous Elect. Diagnostic, Vp+, Vp+ and Vp-V must be among + and - V

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7.2.2 Heater management and diagnostic
Lamborghini Heating Strategy.

Sensor cycle start

- **T\text{cat}>Dew point**
  - **Yes**
  - 10V for 4 sec.
  - **No**
  - Shutdown diag module
    - **Ok**
    - **Nok**
      - Pending Fault Code Stored
  - **T\text{cat}>Dew Point**
    - **No**
    - 4 V
      - **Yes**
      - Time from key on < 6 sec
        - **Yes**
        - Engine on
          - **No**
          - Bkp 1
            - **0V**
              - **Yes**
              - Sensor cycle end
                - **No**
                - Reset Strategy
      - **No**
      - Time from key on < 6 sec
        - **Yes**
        - Engine on
          - **Yes**
          - **No**
          - Engine on
            - **Yes**
            - **No**
            - Heating ramp Diag module
              - **Ok**
              - **Nok**
                - PENDING FAULT CODE STORED
              - **Yes**
              - Rpvs reading on, PI on
                - Standard Closed loop operation, Continuous Heating Diag Strategy

Please Notice:

The sensor cycle ends 15 seconds after key off. A new trip begins when the old one is expired and key is turned on. Ip driving starts when PI on, Rpvs < 220 Ohm and engine running. Times and temperatures are calibration datas. When key is turned off, system is forced to Bkp 1 and proceeds from the 0V status.
Heater management is critical for Uego sensors, due to the fact that:

- Water condensation on the sensor and water splash phenomena during cold start and cold engine operation may be very dangerous for ceramic components at very high temperatures (operative tip temperature is over 760°C). So the heating process must guarantee that water drops which may have condensed on the tip of the sensor will evaporate at low sensor temperature (< 300°C) and that this temperature is maintained till exhaust gas temperature becomes higher than 70°C (Dew point temperature).

- Temperature level is very important to allow a correct gas exchange through the sensor, so heater PI control must be able to keep Tip temperature close to 783°C during normal operation. Tip temperature is monitored continuously and used to detect heater malfunction.

These reasons drove our design of Lamborghini Heating strategy (see diagram above).

To check heater efficiency, both electrical and functional diagnosis are performed.

**ELECTRICAL DIAGNOSIS** (Feedback analysis)
Feedback analysis is performed continuously, every time the Mosfet of the LIE 2010 is closed or opened.

![Diagram of feedback analysis process]

In Pic. 7.2.2 - 1 can be seen the representation of a transistor of the same kind which is used to drive Lambda Sensor Heater. Due to its structure, when a tension is applied by the µp the wiring side is forced down to ground; vice versa when no tension is applied by the LIE 2010 the wiring side is at high tension (Vbatt).

A hardware integrated circuit called FPGA, with a Boolean logic (EXOR for this function) checks continuously that this congruence is respected:

<table>
<thead>
<tr>
<th>µp command</th>
<th>Wiring status</th>
<th>Note</th>
<th>EXOR Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>SC to GND or open circuit</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Ok, device off</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Ok, device on</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>SC to Vbatt. Dangerous for Mosfet, µp command forced off.</td>
<td>0</td>
</tr>
</tbody>
</table>

0 means no coherence, and this condition increase the counter related to the condition of sc to ground or sc to Vbatt.

In case of sc to Vbatt, to avoid damage to the transistor, µp command is switched off.

**FUNCTIONAL DIAGNOSIS**

Functional diagnosis has a double structure.

The first part of this diagnostic system works when 12V are applied to the heater (refer to pic. 1), when we suppose not to have water splash problems (catalyst temperature is above Dew point) and a high temperature on the Tip may be reached without risk for the ceramic elements.

The second part works continuously when standard operation temperature has been reached.

- Before applying maximum heating power (Heating Ramp, once per trip). This diagnosis has been made to verify in a very short time if heater cell is integer and in good efficiency. As in a standard on – off sensor, to check heater performance the voltage of the Vs cell is monitored. If Vs...
voltage drops under 1.3 volt before a timer expire, heating power should be enough to guarantee proper operation of the sensor.
- During standard operation, to detect any performance problem and to guarantee a correct gas flow through the sensor (Continuous Heating Diag Strategy).
This strategy has been thought to ensure that the temperature of the sensor is kept always under control. This point is very important: to ensure a correct behavior of the sensor it must not only be kept hot (as a standard on – off sensor), but must be kept as close as possible to 783°C of Tip temperature.
7.2.3 Electrical Diagnostic
UEGO sensors allows sharp electrical diagnosis due to the fact that characteristic voltages from the sensor are always different from those typical of short circuit to ground or to power supply.

Electrical diagnosis concentrates on the sensor itself, so on voltage value of Vs+, Vp+ and Vp-/Vs-. In a warmed up sensor those voltage level must be among 1V and 6V.

To get a very reactive answer from the diagnostic system, two different diagnostic procedure are performed.

The first one is performed when the sensor is still cold, and exhaust gases temperature is below Dew Point (See heater strategy diagram). Its purpose is to detect if the sensor is disconnected. That’s a diagnostic procedure performed once per trip.
The second procedure starts when the sensor is recognized fully warmed up, running continuously till the engine is on. Its purpose is to detect short circuit to ground or short circuit to Vbatt / open circuit.

As shown in pict. 7.2.3 - 1, the active core of the UEGO sensor is the double tension bridge made by Vp and Vs cells.

Vs+, Vp+ and Vs- / Vp- must have a tension among 1V and 6V. Any electric malfunction force at least one of the three voltage values to exit from that range.

Pin disconnection:
- Vp+: in this situation all of the signal drops to 0.5V (stoichiometric value of the Vs cell) and a short circuit to ground is detected.
- Vs+: Internal pull up of the LIE 2010 forces Vs+ signal above 10 volts, and a short circuit to Vbatt is detected.
- Vp- / Vs-: No Ip circulation is possible, short circuit to Vbatt is detected.

Short circuit: same for all of the pins. Any voltage above 6 volts allows the system to detect a short circuit to Vbatt, any voltage below 1V allows the system to detect a short circuit to ground.
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7.2.4 Closed Loop Conditions
One of the most important characteristics of UEGO sensors is that their signal is deep enough to give information about mixture composition in a very wide range (from lambda 0.7 to 1.2).

This means that, theoretically, the only conditions for closed loop operations are a warmed up sensor with no errors. On a standard FTP driving cycle, those conditions occur after 15 – 20 sec.

Fueling needs of the engine may be monitored and corrected using UEGO signal even when the engine requires a rich mixture (full load operations at high revs). Mixture is corrected using a PI controller, which compensates differences among cars, various ambient conditions and car aging.

Actually, the only condition during which open loop is forced by the LIE 2010 is the fuel cut condition.
As stated below, the only condition to begin closed loop operation due to sensor characteristic is linked to the sensor temperature (the other condition for open loop operation, due to engine working point, is cut off operation).

For this reason the heating process is critical and must be strictly monitored.

In the table below (tab. 7.2.4 – 1) the heating process of the engine and of the sensor is described.

<table>
<thead>
<tr>
<th>Status</th>
<th>Possible malfunction</th>
<th>Pcode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust Gas Temperature Check</td>
<td>Engine coolant temperature raises but in one bank Tcat is stuck low</td>
<td>P0544 (or P0547, P11E9, P11EA according with which bank is missing), P11EB, P11EC, P11ED (functional check)</td>
</tr>
<tr>
<td></td>
<td>Engine coolant temperature raises but in both banks Tcat is stuck low</td>
<td>P0544, P0547, P11E9, P11EA</td>
</tr>
<tr>
<td></td>
<td>Engine coolant temperature does not raise</td>
<td>P0128</td>
</tr>
</tbody>
</table>

This means that Lamborghini EMS detects if the fuel system is in open loop due to Catalyst temperature / Engine temperature malfunction. No other ‘Open loop’ conditions can occur in this phase.

<table>
<thead>
<tr>
<th>Status</th>
<th>Possible malfunction</th>
<th>Pcode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Loop Operation Of UEGO Heater</td>
<td>Vs signal is higher than 1.3V after 6 seconds of heater power at 12V</td>
<td>P0135 (or P0155, P3207, P3237 according with which bank is missing)</td>
</tr>
</tbody>
</table>

This means that Lamborghini EMS detects if the fuel system is in open loop due to an Heater failure which leads to exceed the required maximum time of 6 sec for the first heating ramp.

<table>
<thead>
<tr>
<th>Status</th>
<th>Possible malfunction</th>
<th>Pcode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelling Closed Loop Control</td>
<td>RpVs &gt; 220 Ohm (open loop operation) for more than 15 secs</td>
<td>P0135 (or P0155, P3207, P3237 according with which bank is missing)</td>
</tr>
<tr>
<td>- Closed Loop Operation Of UEGO Heater – Standard Heater Monitoring</td>
<td>140 Ohm &lt; RpVs &lt; 220 Ohm (still closed loop operation) for more than 15 secs</td>
<td>P0135 (or P0155, P3207, P3237 according with which bank is missing)</td>
</tr>
<tr>
<td></td>
<td>No heater fault detected AND no fuel cut but open loop operation (RpVs &lt; 220 Ohm) for more than 60 secs cumulate during a trip</td>
<td>P0134 (or P0154, P3208, P3238 according with which bank is missing)</td>
</tr>
</tbody>
</table>

This means that Lamborghini EMS monitors closed and open loop operations continuously.

Tab. 7.2.4 - 1
More in detail:

### 7.2.4.1. Exhaust gas temperature check.

Due to combustion process, after cranking both exhaust system temperature (measured continuously through the Tcat sensors) and water temperature begin to increase. To avoid damages to the sensor due to water splash phenomena, the UEGO heater must be kept to a low power till the exhaust gas temperature reaches 70°C. This value is critical for the sensor heating process \( \Rightarrow \) closed loop operation management, and must be monitorized.

The Lamborghini engine management system has one thermocouple for each Pre-Cat, used to measure the Tcat value (see comprehensive monitoring section for details). If a malfunction causes a failure in Tcat reading which results in incoherence among the four values (P11EB, P11EC, P11ED), or among water temperature value and Tcat value (P0544, P0547, P11E9, P11EA), or a complete failure in temperature reading (neither Tcats nor Water temperature increase, P0128) a P code is generated to detect which failure occurred.

Please consider that if Tcat becomes above 70°C and then below that threshold a failure on the thermocouple is stored but closed loop condition is still allowed.

### 7.2.4.2. Open Loop Operation Of UEGO Heater

When Tcat reaches 70°C, the UEGO sensor heater may be driven to high power. Due to the fact that RpVs (\( \Rightarrow \) Uego Temperature calculation) reading is not possible until Vs value is below 1.3V, a fixed heater feed of 12V is supplied to the sensor (that is the reason why this step is called ‘open loop heater management’). In this step, Vs signal must drop below 1.3V within 6 seconds, otherwise a P0135 fault code is stored.

When Vs < 1.3V, RpVs reading is possible. RpVs is the electric resistance of a ceramic component (one of the cells of the sensor, as described in section 7.2.1) which can be used, for this purpose, as a thermoresistor to calculate UEGO Temperature.

Please find following the link among RpVs and UEGO Temperature (tab. 7.2.4 – 2).

<table>
<thead>
<tr>
<th>RpVs (Ohms)</th>
<th>10</th>
<th>40</th>
<th>60</th>
<th>70</th>
<th>85</th>
<th>100</th>
<th>110</th>
<th>130</th>
<th>150</th>
<th>180</th>
<th>210</th>
<th>240</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>UegoTemp (°C)</td>
<td>947</td>
<td>872</td>
<td>818</td>
<td>795</td>
<td>756</td>
<td>700</td>
<td>660</td>
<td>615</td>
<td>587</td>
<td>566</td>
<td>556</td>
<td>545</td>
<td>0</td>
</tr>
</tbody>
</table>

Tab. 7.2.4 – 2 Link among RpVs Value and UEGO Temperature

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7.2.4.3. Fuelling Closed Loop Control - Closed Loop Operation of UEGO Heater – Standard Heater Monitoring.

When \( V_s < 1.3V \) \( RpVs \) reading is possible and UEGO temperature can be calculated. This allows to drive the PI controller for UEGO heater, with the target to maintain 783°C of temperature.

The electrical power supplied to the sensor heater allows \( RpVs \) value to drop below 220 Ohms. In this condition, according to sensor manufacturer prescription to avoid chemical damage of the sensor, \( Ip \) may be pumped into the sensor without damage, and Closed loop operation begins.

This condition is enough to guarantee closed loop operation when no fuel cut is requested by other engine management system functions.

Due to the fact that this condition is linked to a temperature level, the heater monitoring strategy is the most appropriate to check this condition. To guarantee the maximum life of the sensor, the manufacturer considers the heater damaged if \( RpVs \) goes below the threshold of 140 Ohm. P0135 is set if \( RpVs \) drops below 140 Ohm for more than 15 sec continuously.

Furthermore, the P0134 is used to indicate sporadic open loop operation (\( RpVs \) which drops below 220 Ohm and open loop operation for more than 60 sec during a trip but continuous for less than 15 sec). This condition is typically due to a sensor problem (no wiring problem may cause fast and non repetitive changes in \( RpVs \) reading).
Summarizing the process:

- **Standard operation.** Heater control is always in closed loop, Fuelling control is in Open loop only during fuel cut.

- **RpVs** is lower than 220 Ohms, Fuelling Closed loop operation begins. P0134 is set if RpVs is above 220 Ohm for more than 60 secs per trip, even non-continuously. P0135 is set if RpVs is above 140 Ohm for more than 15 secs continuously.

- **Vs** is below 1.3V, RpVs can be read so Closed Loop Heater management begins. P0135 is set if RpVs is below 140 Ohm for more than 15 secs continuously.

- Open loop heating process begins, heating power at 12V till Vs drops below 1.3V. P0135 is set whether this step lasts more than 6 seconds.

- Exhaust temperature below Dew Point, heater power must be kept at low voltage (4V). Engine and exhaust gas heating process monitored via Pcodes P11EB, P11EC, P11ED, 0544, 0547, 11E9, 11EA 0128.

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7.2.5. Functional check - Basic theory
As it is well known, the purpose of lambda sensors is to verify the engine fuelling to allow the engine management system to get the maximum efficiency from the catalyst. This efficiency is affected by the composition of the mixture, its switching frequency from lean to rich and vice versa, and its mean lambda value.

Due to the fact that lambda sensor is the device from which the engine management system gets information to guarantee a proper composition of the mixture, a correct functional lambda diagnosis must check sensor activity (the mixture must switch from lean to rich and vice versa), the switching frequency of the mixture and the response rate of the signal from which the system reconstructs the lambda value. This signal is the Ip current.

This signal completely represents the response time of the sensor. Ip changes are driven by the LIE 2010 through the signal of Vs cell, so Ip is the slowest signal in the sensor.

Thus, Ip change $|I_{p,i+1} - I_{p,i}|$ is measured at a constant interval time. If this value exceeds a threshold value, that means a quick change in output tension, a counter is increased (hereinafter “quick output change counter” or QOCC).

Switching frequency is nominally the number of switches (to rich or to lean condition) pointed out per unit of time. In practice we just count the number of these switches during a prefixed time and we consider the test successfully overcome if this number is greater than a threshold value.

A properly working sensor has a high switching frequency and a high value of the quick output change counter, while bad sensors have a very slow quick output change counter and a slow switching frequency.
7.2.6. Algorithm for diagnosis
7.2.6.1. Algorithm for Lambda sensor Response Rate diagnosis

The following text describes the algorithm for lambda sensor response rate monitoring. As explained before, to check the Lambda sensor response rate we consider two parameters:

* the rate of change of signal output (QOCC)
* the switching frequency from lean to reach and vice versa (SW_FREQ)

To allow the monitoring strategy to start, some conditions have to be verified. In particular:

if TH2O_low < TH2O_Avv < TH2O_high then the other conditions are controlled, or else the diagnostic is definitively stopped in the current driving cycle (TH2O is the engine coolant temperature);

if RPM_low < RPM < RPM_high;

if MAP_low < MAP < MAP_high

if engine is in closed loop condition;

if TH2O > TH2O_th;

if threshold1 < time_from_cranking < time2;

if lambda_target < Lambda_targetmax + Histeresys

if lambda_target > lambda_target min - Histeresys

if |DRPM| < Threshold

if |DMAP| < Threshold

if no errors are present in the lambda sensor diagnostic lines

Then a flag DL_ON is set to true that the means that diagnostic can start.

The above variables are defined as:
TH2O_Avv = ECT at start
TH2O = engine coolant temperature;
RPM = engine revolutions
MAP= manifold absolute pressure;
DRPM= RPM derivative;
DMAP= MAP derivative;
Lambda_target= Desired Lambda value plus fuelling correction
To assure that those parameters described above are constant conditions for the engine, a time delay, specified by the constant TIMELAG, is applied before allowing the monitoring strategy to run. Note that if the diagnostic is running and one of the above conditions become false (causing DL_ON to become false too), the diagnostic is frozen. But monitoring variables are not set to zero condition. So the diagnostic can start again exactly where it was interrupted when DL_ON became false.
Therefore

if DL_ON = true;

if time from DL_ON > TIMELAG then

I_p Value is acquired at a constant interval time;

Normal lean – to – rich and rich – to – lean proportional coefficients of lambda control are switched to expanded values.

QOCC is evaluated as follow:

\[
\text{if } |I_{p,i+1} - I_{p,i}| > \text{quick_change_threshold} \\
\text{then } \text{QOCC} := \text{QOCC} + 1;
\]

Switching frequency SW_FREQ is evaluated as follows:

\[
\text{if LambdaRead}_i < \text{Lambda Rich AND last_switch was lean then} \\
SW_{\text{FREQ}} := SW_{\text{FREQ}} + 1;
\]

\[
\text{if LambdaRead}_i > \text{Lambda Lean AND last_switch was rich then} \\
SW_{\text{FREQ}} := SW_{\text{FREQ}} + 1;
\]

\[
\text{if QOCC } > \text{QOCC\_threshold} \\
\text{AND SW_FREQ } > \text{SW_FREQ\_threshold}
\]

then the Lambda sensor is judged to be working and the diagnostic stops; otherwise, the diagnostic continues until the maximum time for diagnosis is reached.

If at the end of the maximum time allowed for diagnosis it is

QOCC < QOCC\_threshold

OR SW_FREQ < SW_FREQ\_threshold

Then it means that the sensor has a non-acceptable response rate and the pending code is generated.
Verify conditions for diagnosis

Time > Thresholds

Closed loop working conditions

TH₂O > TH₂O_th

TH₂O_low < TH₂O_avr < TH₂O_high

RPM_low < RPM < RPM_high

MAP_low < MAP < MAP_high

Secondary air = off

Lambda_target < Lambda_targetmax + Histeresys

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Lambda_target > Lambda_targetmin - Histeresys

|DRPM| < Threshold and |DMAP| > Threshold

No faults in O2 sensor diagnostic lines

Conditions verified

Conditions not verified
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### 7.2.6.2 Algorithm for Symmetric/Asymmetric Test

The Symmetric/Asymmetric Test is based on the same algorithm used by Catalyst Monitoring to evaluate the maximum and minimum values of the oxygen sensor signal (see section 1.2). Purpose of the Symmetric/Asymmetric Test is to check if a malfunction affect only the lean-to-rich response rate rather than the rich-to-lean response rate or if a malfunction affect both the lean-to-rich and rich-to-lean response rate.

The test is conducted at the same time of the Response Rate Diagnosis therefore the same conditions have to be verified to allow the monitoring strategy to start.

When a maximum value is stored, the test evaluate the transient time to reach the minimum value and it compares the measured time with a threshold value TR; if the time is less than TR a rich-to-lean counter increases.

When a minimum value is stored, the test evaluate the transient time to reach the maximum value and it compares the measured time with a threshold value TR; if the time is less than TR a lean-to-rich counter increases.

After a calibrated time both the counter are compared with a threshold value TR2; if both the counter are less than TR2 a Fault for Symmetric malfunction is activated otherwise if just one counter is less than TR2 a Fault for Asymmetric malfunction is activated.
Example of functioning of Symmetric/Asymmetric Test

Pict. 7.5.2.4 – 1
Enable conditions satisfied?

**yes**

Signal is rising?

**yes**

Calculation Imax

Timer On

Calculation Imin

Timer Off

**no**

Calculation Imin

Timer On

Calculation Imax

Timer Off

**t < Thres?**

**no**

Count_LR = Count_LR + 1

**yes**

Count_RL = Count_RL + 1

**t > time for diagnosis?**

**yes**

**Diag. LR Ok**

**Diag. RL Ok**

**no**

**Diag. LR n.OK**

**Diag. RL n.OK**

**AND**

Diag. Ok

Err. Symm.

Err. Asymm.
7.2.6.3. Algorithm for Stuck signal diagnosis.

To get maximum efficiency from the catalyst converter the mixture composition must switch continuously from rich to lean condition and vice versa. The ‘rich’ and ‘lean’ condition which ensure a correct behavior of the catalyst changes among different working point of the engine (MAP and RPM couples). Lamborghini engine management system is designed to act as a status machine: according to the map reported in § 20 of this manual sheet 6 LL_status parameters and in § 20 of this manual sheet 6 LL_status parameters, it recognize itself in a ‘rich’ or ‘lean’ status (see pic. 7.2.5.1 – 1).

![Pic. 7.2.5.1 - 1](image-url)
To check continuously a proper behavior of the lambda sensor, state switch (LL_Status) is continuously monitored. Every transition from lean state to rich (LL_status from 1 to -1) and vice versa must happen in a time fixed in calibration, otherwise a stuck lean or a stuck rich pending code is generated.

From the two maps in § 20 of this manual, the Lie interpolates Lambda rich threshold and delta to lean threshold and calculates:

Lambda Lean Threshold = Lambda Rich Threshold + delta lambda to lean.

If Lambda from Lambda sensor > Lambda Lean Threshold => LL_Status = -1
If Lambda from Lambda sensor < Lambda Rich Threshold => LL_Status = 1

If LL_Status does not change for 10S. a P2197 or P2198 (P2195-P2196 , P3144-P3145, P3146-P3147) is stored.
7.4. Rear Oxygen Sensor Monitoring
7.4.1 Oxygen Sensor Heater Monitoring
7.4.1.1. Basic theory
The Lamborghini Engine management system has in its OBD II system four heated oxygen sensors, one for each Pre-Cat, after the catalyst (see figure in CATALYST MONITORING section – Basic theory).

The lambda sensor’s behavior is like that one of a voltage generator with its equivalent circuit. The impedance of this circuit is a function of temperature and is extremely high when the sensor is cold.

We adopted a pull-up circuit enclosed in the Lamborghini LIE 2010 in parallel to the sensor circuit, in order to monitor the heater circuit.

When the pull-up circuit is switched on, the output of the sensor is a function of \( O_2 \) content, temperature and aging.

Eliminating the effect of \( O_2 \) content and being aged constantly over the test, the output voltage gives an indication of temperature only.

When the sensor is cold, the impedance of the pull-up circuit is lower than the impedance of the sensor; in this case the output voltage is that of the pull-up circuit (almost 0.5 V). On the other hand, when the sensor is warm, the impedance of the sensor becomes lower than the pull-up circuit impedance; in this case the level of the output voltage generated by the sensor is in proportion to the \( O_2 \) content of the exhaust.

During engine warm-up, the heater warms the sensor quickly. If the heater does not work, the warming of the sensor is achieved only by the heat from the exhaust gases, and it is slower.

The Lamborghini Heater diagnostic looks for the time needed to heat up the sensor from engine on (that is the time to get the output voltage different from pull-up). The heater is judged operative when the time is lower than a threshold obtained from our experimental data. If greater than the threshold, it is considered to be inoperative.

Please notice that there is no difference among the two test groups under this point of view. The behavior in the warm – up phase depends only from the sensor which is the same in the two applications.
7.4.1.2 Diagnosis algorithm
The functioning of the lambda sensor heater is evaluated by the following strategy.

The monitoring is archived through a “state-machine” diagnostic with 4 steps: called A, B, C and D.

**Step A:**

The engine is “power down” - (OFF).

**Step B:**

The engine is “power up” - (ON). A timer starts. When the timer is done, the “state” switches from step B to step C.

**Step C:**

In the step C the oxygen sensor output voltage (called LBCat) is monitored for a fixed time period. If the output voltage is between two thresholds (KdgThreHi and KdgThreLo) which bound the range of the pull-up output voltage, for a period of time greater than a threshold (KdgHeaterTime), then the MIL is activated and the test is finished. Otherwise, the MIL is not activated and the test is finished successfully.

**Step D:**

Test end.
HEATER DIAGNOSIS FLOW CHART

A

Key ON

YES

ENGINE ON

NO

B

YES

Timer Elapsed

NO

YES

C

Start of Heater Diagnosis

NO

KdgThreLo< LBCat < KdgThreHi

for xtime> KdgHeaterTime

YES

D

PENDING FAULT CODE GENERATED

END OF TEST
7.4.2. Rear oxygen sensor monitoring

Functional aspects
7.4.2.1 Basic theory
The Lamborghini engine management system is equipped with a secondary oxygen sensor for each Pre-Cat for use as an OBD-II system-monitoring device to achieve compliance with the catalyst monitoring requirements.

In addition to the heater monitoring (see the chapter “Oxygen sensor Heater monitoring”); the sensor is checked when inactive, locked lean, locked rich and with a “Transient Test” The Transient test, based on the activity of the sensor, is performed as part of the diagnostic.

Purpose of the transient test is to check if the rear O2 sensor’s signal is deep enough (its amplitude is able to cover the full range of the nominal sensor characteristic which is used for catalyst monitoring) and fast enough to guarantee a correct catalyst efficiency monitoring.
7.4.2.2 Transient Test:
Algorithm for diagnosis
Rear O2 sensor’s transient test combines two aspects:

- Coherence in timing and amplitude among the shape of front UEGO sensor and rear oxygen sensors (please remember that Lamborghini uses the rear oxygen sensor for catalyst diagnosis only and that monitor is run comparing the signal of front and rear sensors).
- Switching behavior: During the rich – to – lean transition, the switching time of a healthy sensor is very short. The transition time from 0.55 to 0.25V must be shorter than 150msec.

The monitor runs during every fuel cut. In case of error detected, a fault accumulator is incremented according with which failure has been detected (Coherence or switching behavior)

At the end of every trip, if no error has been validated, the fault accumulators are reset to zero.

More in detail:

IF
Fuel cut on AND Lambda value of the front UEGO sensor above 1 (fuelling lean)
THEN
General TT countdown on (the general countdown is set to 2 sec)

IF
Rear O2 sensor signal < 0.55
THEN
Switching TT countdown on (the switching countdown is set to 150ms)

IF
Switching TT countdown = 0 AND rear O2sensor signal > 0.25V
THEN
Switching TT Fault Accum = Switching TT Fault Accum + 1

ELSE IF
General TT countdown = 0 AND rear O2sensor signal > 0.15V
THEN
General TT Fault accum = General TT Fault Accum + 1

IF
General TT Fault Accum > 5 OR Switching TT Fault Accum > 5
THEN
P0140 (P0160) fault code is stored.
ELSE
Transient test monitor enabling conditions not met.
Please notice that the coherence check is run using the comparison among front and rear sensors because those two sensor are used to run the Catalyst efficiency monitor and because this system allows Lamborghini to reduce the effect of transport time through exhaust pipes. In fact, triggering the main countdown with the front UEGO sensor signal allow to consider, in the calibration of the timer, only the transport time due to catalyst volume plus the oxygen storage effect of the catalyst itself.

In the image 7.4.2.2-1 below you can find a sample of how the strategy works. Table 7.4.2.2 – 1 describes the meaning of the flag values which appear in the graph.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Status</td>
<td>Value of the state machine which manage Cut – Off procedure</td>
<td>4 = Waiting time (condition met but injection still on)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Ramp in (fuel injection is progressively switched off to get a smooth behaviour from the engine)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = Complete fuel cut (injection off)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 = Ramp out (fuel injection is progressively switched on to get a smooth behaviour from the engine)</td>
</tr>
<tr>
<td>OBD2_TTPostState</td>
<td>Value of the state machine which manage Switching TT check</td>
<td>1 = Cut off procedure has started</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 = Complete fuel Cut</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 = Switching TT Countdown on, first (Upper) Voltage threshold of 0.55 has been crossed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 = Voltage below lower threshold of 0.25V (no error possible)</td>
</tr>
</tbody>
</table>

Table 7.4.2.2 - 1