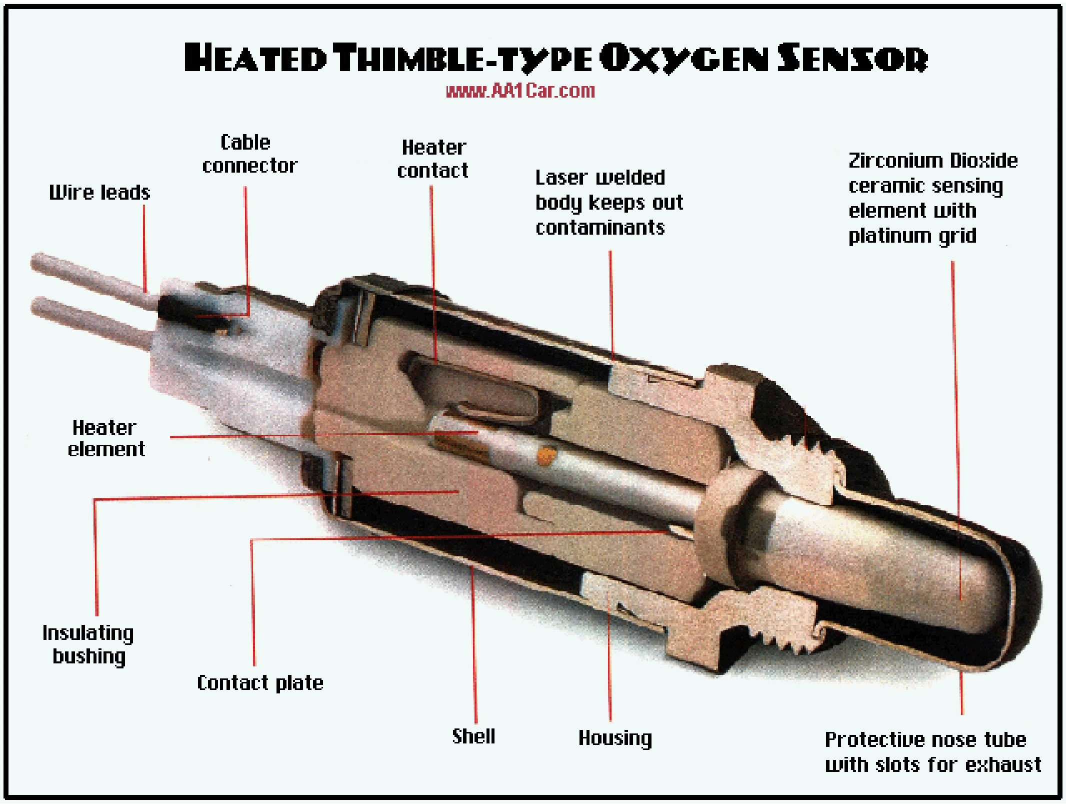
AA1Car Automotive Diagnostic Repair Help



Oxygen Sensors: How to Diagnose and Replace

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Computerized engine control systems rely on inputs from a variety of sensors to regulate engine performance, emissions and other important functions. The sensors must provide accurate information otherwise driveability problems, increased fuel consumption and emission failures can result.

> The Oxygen Sensor is one of the key sensors in this system. It is often referred to as the "O2" sensor because O2 is the chemical formula for oxygen (oxygen atoms always travel in pairs, never alone). It may also be referred to as the H2O2 for Heated Oxygen Sensor because it has an internal heater circuit to bring the sensor up to operating temperature following a cold start.

The first O2 sensor was introduced in 1976 on a Volvo 240. California vehicles got them next in 1980 when California's emission rules required lower emissions. Federal emission laws made O2 sensors virtually mandatory on all cars and light trucks built since 1981. And now that OBD-II regulations are here (1996 and newer vehicles), many vehicles are now equipped with multiple O2 sensors, some as many as four!

The O2 sensor is mounted in the exhaust manifold to monitor how much unburned oxygen is in the exhaust as the exhaust exits the engine. Monitoring oxygen levels in the exhaust is a way of gauging the fuel mixture. It tells the computer if the fuel mixture is burning rich (less oxygen) or lean (more oxygen).

A lot of factors can affect the relative richness or leanness of the fuel mixture, including air temperature, engine coolant temperature, barometric pressure, throttle position, air flow and engine load. There are other sensors to monitor these factors, too, but the O2 sensor is the master monitor for what is happening with the fuel mixture. Consequently, any problems with the O2 sensor can throw the whole system out of whack.

FUEL MIXTURE FEEDBACK CONTROL LOOP

The computer uses the oxygen sensor input to regulate the fuel mixture, which is referred to as the fuel "feedback control loop." The computer takes its cues from the O2 sensor and responds by changing the fuel mixture. This produces a corresponding change in the O2 sensor reading. This is referred to as "closed loop" operation because the computer is using the O2 sensor's input to regulate the fuel mixture. The result is a constant flip-flop back and forth from rich to lean which allows the catalytic converter to operate at peak efficiency while keeping the average overall fuel mixture in proper balance to minimize emissions. It is a complicated setup but it works.

When no signal is received from the O2 sensor, as is the case when a cold engine is first started (or the 02 sensor fails), the computer orders a fixed (unchanging) rich fuel mixture. This is referred to as "open loop" operation because no input is used from the O2 sensor to regulate the fuel mixture.

If the engine fails to go into closed loop when the O2 sensor reaches operating temperature, or drops out of closed loop because the O2 sensor signal is lost, the engine will run too rich causing an increase in fuel consumption and emissions. A bad coolant sensor can also prevent the system from going into closed loop because the computer also considers engine coolant temperature when deciding whether or not to go into closed loop.

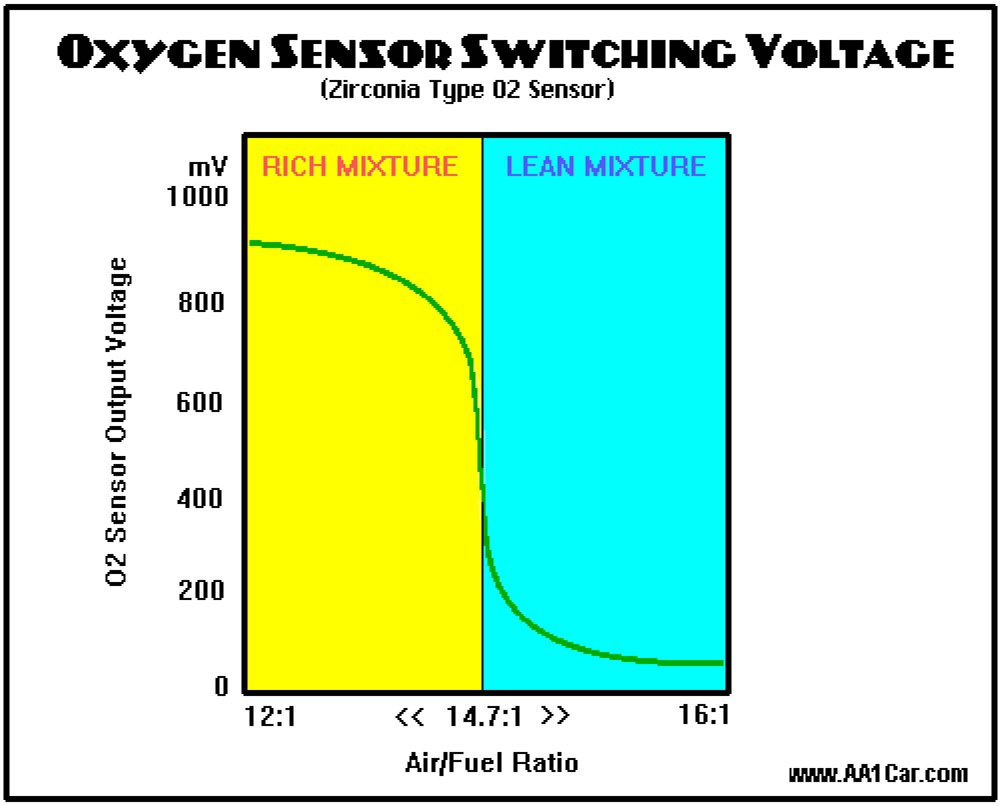
HOW AN OXYGEN SENSOR WORKS

The O2 sensor works like a miniature generator and produces its own voltage when it gets hot. Inside the vented cover on the end of the sensor that screws into the exhaust manifold is a zirconium ceramic bulb. The bulb is coated on the outside with a porous layer of platinum. Inside the bulb are two strips of platinum that serve as electrodes or contacts.

The outside of the bulb is exposed to the hot gases in the exhaust while the inside of the bulb is vented internally through the sensor body to the outside atmosphere. Older style oxygen sensors actually have a small hole in the body shell so air can enter the sensor, but newer style O2 sensors "breathe" through their wire connectors and have no vent hole. It is hard to believe, but the tiny amount of space between the insulation and wire provides enough room for air to seep into the sensor (for this reason, grease should never be used on O2 sensor connectors because it can block the flow of air). Venting the sensor through the wires rather than with a hole in the body reduces the risk of dirt or water contamination that could foul the sensor from the inside and cause it to fail.

The difference in oxygen levels between the exhaust and outside air within the sensor causes voltage to flow through the ceramic bulb. The greater the difference, the higher the voltage reading.

An oxygen sensor will typically generate up to about 0.9 volts when the fuel mixture is rich and there is little unburned oxygen in the exhaust. When the mixture is lean, the sensor output voltage will drop down to about 0.2 volts or less. When the air/fuel mixture is balanced or at the equilibrium point of about 14.7 to 1, the sensor will read around .45 volts.



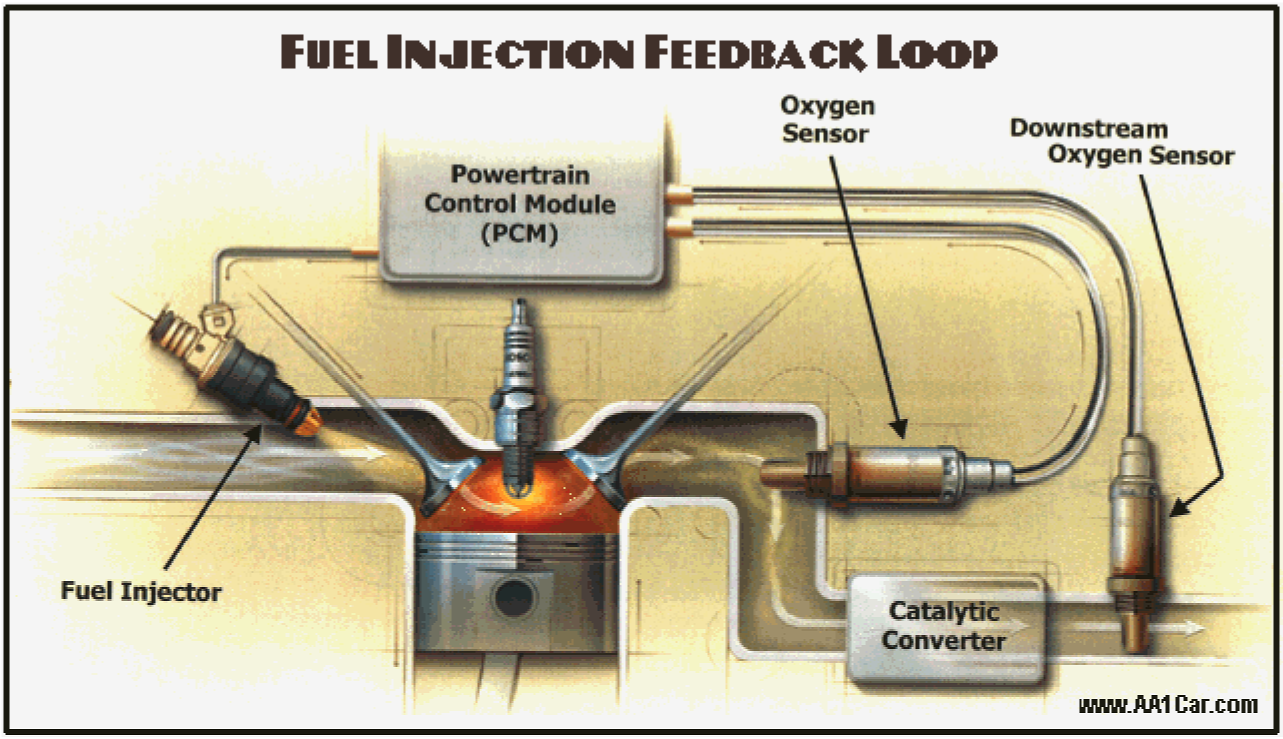
When the computer receives a rich signal (high voltage) from the O2 sensor, it leans the fuel mixture to reduce the sensor's feedback voltage. When the O2 sensor reading goes lean (low voltage), the computer reverses again making the fuel mixture go rich. This constant flip-flopping back and forth of the fuel mixture occurs with different speeds depending on the fuel system. The transition rate is slowest on engines with feedback carburetors, typically once per second at 2500 rpm. Engines with throttle body injection are somewhat faster (2 to 3 times per second at 2500 rpm), while engines with multiport injection are the fastest (5 to 7 times per second at 2500 rpm).

The oxygen sensor must be hot (about 600 degrees or higher) before it will start to generate a voltage signal, so many oxygen sensors have a small heating element inside to help them reach operating temperature more quickly. The heating element can also prevent the sensor from cooling off too much during prolonged idle, which would cause the system to revert to open loop.

Heated O2 sensors are used mostly in newer vehicles and typically have 3 or 4 wires. Older single wire O2 sensors do not have heaters. When replacing an O2 sensor, make sure it is the same type as the original (heated or unheated)

O2 SENSORS AND OBD II

Starting with a few vehicles in 1994 and 1995, and all 1996 and newer vehicles, the number of oxygen sensors per engine has doubled. A second oxygen sensor is now used downstream of the catalytic converter to monitor converter operating efficiency. On V6 or V8 engines with dual exhausts, this means up to four O2 sensors (one for each cylinder bank and one after each converter) may be used.



EFI feedback fuel control uses O2 sensor inputs to control the fuel mixture.

The OBD II system is designed to monitor the emissions performance of the engine. This includes keeping an eye on anything that might cause emissions to increase. The OBD II system compares the oxygen level readings of the O2 sensors before and after the converter to see if the converter is reducing the pollutants in the exhaust. If it sees little or no change in oxygen level readings, it means the converter is not working properly. This will cause the Malfunction Indicator Lamp (MIL) to come on.

OXYGEN SENSOR DIAGNOSIS

O2 sensors are amazingly rugged considering the operating environment they live in. But O2 sensors do wear out and eventually have to be replaced.

The performance of the O2 sensor tends to diminish with age as contaminants accumulate on the sensor tip and gradually reduce its ability to produce voltage. This kind of deterioration can be caused by a variety of substances that find their way into the exhaust such as lead, silicone, sulfur, oil ash and even some fuel additives. The sensor can also be damaged by environmental factors such as water, splash from road salt, oil and dirt.

As the sensor ages and becomes sluggish, the time it takes to react to changes in the air/fuel mixture slows down which causes emissions to go up. This happens because the flip-flopping of the fuel mixture is slowed down which reduces converter efficiency. The effect is more noticeable on engines with multiport fuel injection (MFI) than electronic carburetion or throttle body injection because the fuel ratio changes much more rapidly on MFI applications.

If the sensor dies altogether, the result can be a fixed, rich fuel mixture. Default on most fuel injected applications is mid-range after three minutes. This causes a big jump in fuel consumption as well as emissions. And if the converter overheats because of the rich mixture, it may suffer damage.

One EPA study found that 70% of the vehicles that failed an I/M 240 emissions test needed a new O2 sensor.

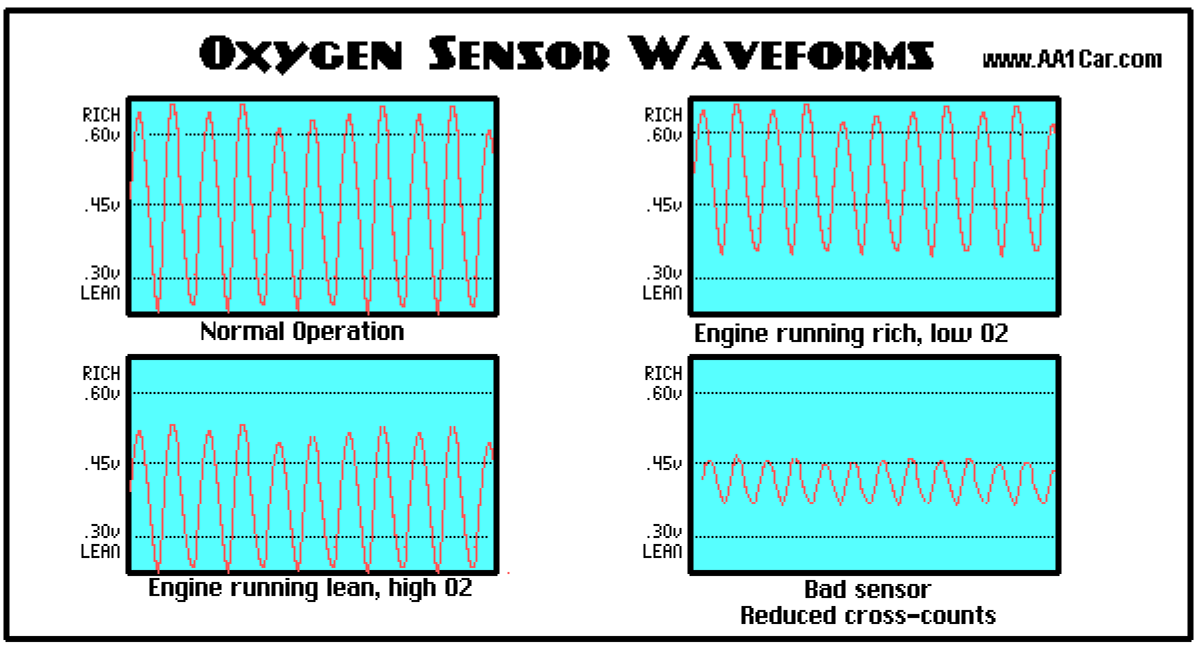
Most O2 sensor problems will cause the OBD II system to set one or more diagnostic trouble codes (DTCs) and turn on the Check Engine light. These are the OBD codes associated with O2 sensor faults:

OXYGEN SENSOR TROUBLE CODES

P0030....HO2S Heater Control Circuit Bank 1 Sensor 1
P0031....HO2S Heater Control Circuit Low Bank 1 Sensor 1
P0032....HO2S Heater Control Circuit High Bank 1 Sensor 1
P0033....Turbo Charger Bypass Valve Control Circuit
P0034....Turbo Charger Bypass Valve Control Circuit Low
P0035....Turbo Charger Bypass Valve Control Circuit High
P0036....HO2S Heater Control Circuit Bank 1 Sensor 2
P0037....HO2S Heater Control Circuit Low Bank 1 Sensor 2
P0038....HO2S Heater Control Circuit High Bank 1 Sensor 2
P0042....HO2S Heater Control Circuit Bank 1 Sensor 3
P0043....HO2S Heater Control Circuit Low Bank 1 Sensor 3
P0044....HO2S Heater Control Circuit High Bank 1 Sensor 3
P0050....HO2S Heater Control Circuit Bank 2 Sensor 1
P0051....HO2S Heater Control Circuit Low Bank 2 Sensor 1
P0052....HO2S Heater Control Circuit High Bank 2 Sensor 1
P0056....HO2S Heater Control Circuit Bank 2 Sensor 2
P0057....HO2S Heater Control Circuit Low Bank 2 Sensor 2
P0058....HO2S Heater Control Circuit High Bank 2 Sensor 2
P0062....HO2S Heater Control Circuit Bank 2 Sensor 3
P0063....HO2S Heater Control Circuit Low Bank 2 Sensor 3
P0064....HO2S Heater Control Circuit High Bank 2 Sensor 3
P0130....O2 Sensor Circuit Bank 1 Sensor 1

P0131....O2 Sensor Circuit Low Voltage Bank 1 Sensor 1
P0132....O2 Sensor Circuit High Voltage Bank 1 Sensor 1
P0133....O2 Sensor Circuit Slow Response Bank 1 Sensor 1
P0134....O2 Sensor Circuit No Activity Detected Bank 1 Sensor 1
P0135....O2 Sensor Heater Circuit Bank 1 Sensor 1
P0136....O2 Sensor Circuit Malfunction Bank 1 Sensor 2
P0137....O2 Sensor Circuit Low Voltage Bank 1 Sensor 2
P0138....O2 Sensor Circuit High Voltage Bank 1 Sensor 2
P0139....O2 Sensor Circuit Slow Response Bank 1 Sensor 2
P0140....O2 Sensor Circuit No Activity Detected Bank 1 Sensor 2
P0141....O2 Sensor Heater Circuit Bank 1 Sensor 2
P0142....O2 Sensor Circuit Malfunction Bank 1 Sensor 3
P0143....O2 Sensor Circuit Low Voltage Bank 1 Sensor 3
P0144....O2 Sensor Circuit High Voltage Bank 1 Sensor 3
P0145....O2 Sensor Circuit Slow Response Bank 1 Sensor 3
P0146....O2 Sensor Circuit No Activity Detected Bank 1 Sensor 3
P0147....O2 Sensor Heater Circuit Bank 1 Sensor 3

If an O2 sensor is marginally sluggish or is slightly biased rich or lean, it may not set a fault code. The only way to know if the O2 sensor is functioning normally is to check its responsiveness to changes in the air/fuel mixture. You can read the O2 sensor's voltage output with a scan tool or digital voltmeter, but the transitions are hard to see because the numbers jump around so much. The best way to observe O2 sensor output voltage changes is with a Digital Storage Oscilloscope (DSO). A scope will display the sensor voltage output as a wavy line that shows both it's amplitude (minimum and maximum voltage) as well as its frequency (transition rate from rich to lean).



Oxygen sensor scope patterns.

A good O2 sensor should produce an oscillating waveform at idle that makes voltage transitions from near minimum (0.1 v) to near maximum (0.9v). Making the fuel mixture artificially rich by feeding propane into the intake manifold should cause the sensor to respond almost immediately (within 100 milliseconds) and go to maximum (0.9v) output. Creating a lean mixture by opening a vacuum line should cause the sensor output to drop to its minimum (0.1v) value. If the sensor does not flip-flop back and forth quickly enough, it may indicate a need for replacement.

If the O2 sensor circuit opens, shorts or goes out of range, it may set a fault code and illuminate the Check Engine or Malfunction Indicator Lamp. If additional diagnosis reveals the sensor is defective, replacement is required. But many O2 sensors that are badly degraded continue to work well enough not to set a fault code, but not well enough to prevent an increase in emissions and fuel consumption. The absence of a fault code or warning lamp, therefore, does not mean the O2 sensor is functioning properly. The sensor may be lazy, or biased rich or lean.

A company called Lenehan Research makes a handheld O2 sensor tester that checks the response time of the O2 sensor to show if it is good or bad. The tester requires the oxygen sensor to jump from below 175mV to above 800mV in less than 100mS when the throttle is snapped. If the sensor does not respond quickly enough it fails the test. The tester also shows closed loop operation on a fast, ultra-bright, colored 10 LED display, and tests the PCM control of the fuel feedback control system.

OXYGEN SENSOR REPLACEMENT

Any O2 sensor that is defective obviously needs to be replaced. But there may also be benefits to replacing the O2 sensor periodically for preventative maintenance. Replacing an aging O2 sensor that has become sluggish can restore peak fuel efficiency, minimize exhaust emissions and prolong the life of the converter.

Unheated 1 or 2 wire wire O2 sensors on 1976 through early 1990s vehicles can be replaced every 30,000 to 50,000 miles. Heated 3 and 4-wire O2 sensors on mid-1980s through mid-1990s applications can be changed every 60,000 miles. On OBD II equipped vehicles (1996 & up), a replacement interval of 100,000 miles can be recommended.

The oxygen sensor can be removed from the exhaust manifold using a special oxygen sensor socket (which has a cutout to clear the wires), or a 22mm socket. The sensor will come out easier if the engine is slightly warm but not hot to the touch. Place the socket over the sensor and turn counterclockwise to loosen it. If it is frozen, apply penetrating oil and heat around the base of the sensor.

When installing a new "direct fit" or OEM oxygen sensor, the wiring connector on the new sensor will plug into the connector with no modifications needed. But if you are installing a "universal" oxygen sensor, the original wiring connector will have to be cut off so the wires on the new sensor can be spliced to the wires that went to the connector. With 4-wire sensors, one wire is the signal wire, one is ground, and the other two are for the heater circuit. The wires are color coded, but the colors on the universal sensor probably won't match those on the original sensor. See the chart below from the color coding used on various brands of oxygen sensors:

COLOR CODES FOR 4-WIRE OXYGEN SENSORS

	SIGNAL	GROUND	HEATER	HEATER
AC DELCO	PURPLE	TAN	BROWN	BROWN
BOSCH	BLACK	GREY	WHITE	WHITE
BWD 1	BLACK	GREY	WHITE	WHITE
BWD 2	PURPLE	GREY	WHITE	WHITE
BWD 3	PURPLE	TAN	BROWN	BROWN
DELPHI 1	PURPLE	TAN	BROWN	BROWN
DELPHI 2	BLACK	GREY	PURPLE	WHITE
DENSO	BLUE	WHITE	BLACK	BLACK
HONDA 1	WHITE	GREEN	BLACK	BLACK
HONDA 2	BLUE	WHITE	BLACK	BLACK
NTK	BLACK	GREY	WHITE	WHITE
SMP/STD	BLACK	GREY	WHITE	WHITE
TOYOTA	BLUE	WHITE	BLACK	BLACK

Refer to OEM wiring diagram to make sure wires are connected correctly

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Typical oxygen sensor wiring color codes.

Oxygen Sensor Q & A

How many oxygen sensors are on today's engines?

It depends on the model year and type of engine. On most four and straight six cylinder engines, there is usually a single oxygen sensor mounted in the exhaust manifold. On V6, V8 and V10 engines, there are usually two oxygen sensors, one in each exhaust manifold. This allows the computer to monitor the air/fuel mixture from each bank of cylinders.

On later model vehicles with OBD II (some 1993 and '94 models, and all 1995 and newer models), one or two additional oxygen sensors are also mounted in or behind the catalytic converter to monitor converter efficiency. These are referred to as the downstream O2 sensors, and thee will be one for each converter if the engine has dual exhausts with separate converters.

How are the oxygen sensors identified on a scan tool?

When displayed on a scan tool, the right and left upstream oxygen sensors are typically labeled Bank 1, Sensor 1 and Bank 2, Sensor 1. The Bank 1 sensor will always be on the same side of a V6 or V8 engine as cylinder number one.

On a scan tool, the downstream sensor on a four or straight six cylinder engine with single exhaust is typically labeled Bank 1, Sensor 2. On a V6, V8 or V10 engine, the downstream O2 sensor might be labeled Bank 1 or Bank 2, Sensor 2. If a V6, V8 or V10 engine has dual exhausts with dual converters, the downstream O2 sensors would be labeled Bank 1, Sensor 2 and Bank 2, Sensor 2. Or, the downstream oxygen sensor might be labeled Bank 1 Sensor 3 if the engine has two upstream oxygen sensors in the exhaust manifold (some do to more accurately monitor emissions).

It's important to know how the O2 sensors are identified because a diagnostic trouble code that indicates a faulty O2 sensor requires a specific sensor to be replaced. Bank 1 Sensor 1 might be the back O2 sensor on a transverse V6, or it might be the one on the front exhaust manifold. What's more, the O2 sensors on a transverse engine might be labeled differently than those on a rear-wheel drive application. There is not a lot of consistency as from one vehicle manufacturer to another as to how O2 sensors are labeled, so always refer to the OEM service literature to find out which sensor is Bank 1 Sensor 1 and which one is Bank 2 Sensor 1. This information can be difficult to find. Some OEMs clearly identify which O2 sensor is which but others do not. If in doubt, call a dealer and ask somebody in the service department.

For Oxygen Sensor Locations, Click Here.

How does a downstream O2 sensor monitor converter efficiency?

A downstream oxygen sensor in or behind the catalytic converter works exactly the same as an upstream O2 sensor in the exhaust manifold. The sensor produces a voltage that changes when the amount of unburned oxygen in the exhaust changes. If the O2 sensor is a traditional zirconia type sensor, the voltage output drops to about 0.2 volts when the fuel mixture is lean (more oxygen in the exhaust). When the fuel mixture is rich (less oxygen in the exhaust), the sensor's output jumps up to a high of about 0.9 volts. The high or low voltage signal tells the PCM the fuel mixture is rich or lean.

On some newer vehicles, a new type of Wide Ratio Air Fuel (WRAF) Sensor is used. Instead of producing a high or low voltage signal, the signal changes in direct proportion to the amount of oxygen in the exhaust. This provides a more precise measurement for better fuel control. These sensors are also called wideband oxygen sensors because they can read very lean air/fuel mixtures.

The OBD II system monitors converter efficiency by comparing the upstream and downstream oxygen sensor signals. If the converter is doing its job and is reducing the pollutants in the exhaust, the downstream oxygen sensor should show little activity (few lean-to-rich transitions, which are also called "crosscounts"). The sensor's voltage reading should also be fairly steady (not changing up or down), and average 0.45 volts or higher.

If the signal from the downstream oxygen sensor starts to mirror that from the upstream oxygen sensor(s), it means converter efficiency has dropped off and the converter isn't cleaning up the pollutants in the exhaust. The threshold for setting a diagnostic trouble code (DTC) and turning on the Malfunction Indicator Lamp (MIL) is when emissions are estimated to exceed federal limits by 1.5 times. See Troubleshooting a P0420 Catalyst Code for more info about converter problems.

If converter efficiency had declined to the point where the vehicle may be exceeding the pollution limit, the PCM will turn on the Malfunction Indicator Lamp (MIL) and set a diagnostic trouble code. At that point, additional diagnosis may be needed to confirm the failing converter. If the upstream and downstream O2 sensors are functioning properly and show a drop off in converter efficiency, the converter must be replaced to restore emissions compliance. The vehicle will not pass an OBD II emissions test if there are any converter codes in the PCM.

What's the difference between a "heated" and "unheated" oxygen sensor?

Heated oxygen sensors have an internal heater circuit that brings the sensor up to operating temperature more quickly than an unheated sensor. An oxygen sensor must be hot (about 600 to 650 degrees F) before it will generate a voltage signal. The hot exhaust from the engine will provide enough heat to bring an O2 sensor up to operating temperature, but it make take several minutes depending on ambient temperature, engine load and speed. During this time, the fuel feedback control system remains in "open loop" and does not use the O2 sensor signal to adjust the fuel mixture. This typically results in a rich fuel mixture, wasted fuel and higher emissions.

By adding an internal heater circuit to the oxygen sensor, voltage can be routed through the heater as soon as the engine starts to warm up the sensor. The heater element is a resistor that glows red hot when current passes through it. The heater will bring the sensor up to operating temperature within 20 to 60 seconds depending on the sensor, and also keep the oxygen sensor hot even when the engine is idling for a long period of time.

Heated O2 sensors typically have two-three or four wires (the extra wires are for the heater circuit). Note: Replacement O2 sensors must have the same number of wires as the original, and have the same internal resistance.

The OBD II system also monitors the heater circuit and will set a trouble code if the heater circuit inside the O2 sensor is defective. The heater is part of the sensor and cannot be replaced separately, so if the heater circuit is open or shorted and the problem is not in the external wiring or sensor connector, the O2 sensor must be replaced.

Related Engine Sensor Articles:

Wideband O2 Sensors & A/F Sensors

Oxygen Sensor Locations

Sensing Emission Problems (O2 Sensors)

Making Sense of Engine Sensors

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Powertrain control modules (PCMs)

All About Onboard Diagnostics II (OBD II)

Zeroing in on OBD II Diagnostics

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