Focus Applied Technologies
Oxygen Sensor Phase Shifting Device for Electronic Fuel Injection Systems
"O2 Shifter" Installation and Operation Manual

Rev 3.0 1-2017

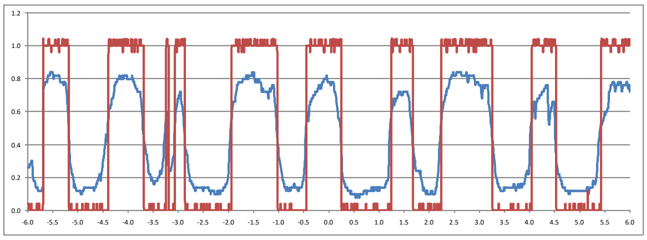
Introduction: EFI and the O2 Sensor

Modern Electronic Fuel Injection (EFI) systems with three-way exhaust catalysts are very sophisticated systems, finely tuned to provide excellent emissions, and good drivability at the expense of higher fuel consumption than is possible by operating slightly lean. In order to have the lowest possible emissions, under most conditions the engine is operated very close to stoichiometric, ie. the Air Fuel mass Ratio (AFR) is close to the chemically correct value of 14.7 for gasoline. Generally the engine is in this "low emissions" mode most of the time, the exceptions being very cold weather, immediately after cold starts, and when the throttle is opened up over about 80% for maximum torque. Under these conditions the engine is operated slightly rich, as it is "off the emissions schedule", and not subject to the strict emissions constraints of normal operation. Similarly the engine may be operated in a "lean" mode during engine breaking, ie. when in gear, with a closed throttle, and high engine revs such as during deceleration descending a long hill. In this case the fuel injection is stopped completely to reduce fuel consumption and reduce emissions, until the engine returns to idle. You may notice that modern cars do not back fire during engine breaking as older carbureted models did when descending a long grade: the carbureted vehicles inject a disproportionately rich mixture as the throttle valve is closed, but the engine is pulling vacuum on the carburetor, resulting in rich miss fires.

The key to this fine AFR control is the humble O2 sensor, pictured above. Since the 1970's gasoline fuel injections have used an exhaust gas oxygen sensor to provide feed back to the fuel injection systems control unit, usually called the Electronic Control Uint (ECU), Engine Management System (EMS) or similar. While the fuel injection is very sophisticated and had a myriad of sensors to allow proper control of the fuel injection under all operating conditions, there will always be subtle shifts in various components, and even in the fuel over time. To insure accurate fuel metering it is necessary to have a component providing feed back to the ECU in order to maintain good long term control over fueling. The O2 sensor does this by measuring the exhaust gas oxygen quantity. Exhaust gas O2 is a strong function of Air Fuel Ratio, having a higher concentration of O2 in the exhaust when operating lean, and less O2 when operating rich. Most systems use a "switching" type O2 sensor, which gives a "high" output voltage of around 0.6 to 1.0V when rich (ie. low exhaust gas O2 concentration) and a "low" voltage of 0.0 to 0.2V when lean (ie. high exhaust gas O2 concentration). Generally, when operating in "closed loop O2 control" (ie. using the O2 sensor) the ECU will lean out the AFR when the O2 sensor indicates rich operation, and richen up the mixture when the sensor indicates lean. One of the important characteristics of the sensor is it's latency: the sensor

does not respond instantaneously to changes in exhaust gas O2, in fact it may take 0.1 to 0.4 seconds for the output to “switch” to a new AFR.

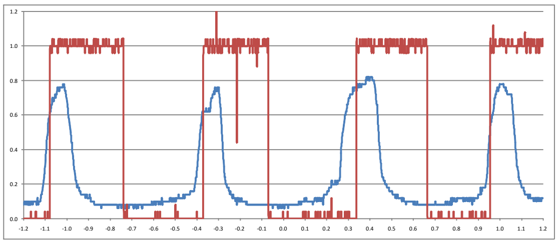
The O2 Shifter: Theory of Operation



Stock O2 signal (blue curve) and O2 Shifter signal (red) in the neutral position (no shift).

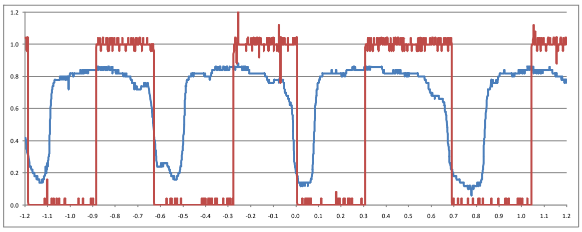
In normal operation the Air Fuel Ratio oscillates back and forth from slightly rich to slightly lean a few times per second, each time triggered by the O2 sensor. The O2 Shifter reads these “switches” on the O2 signal, and relays them to the ECU. The O2 shifter works by delaying (ie. shifting) either rich to lean, or the lean to rich transition of the O2 sensor. The O2 Shifter can also operate in “neutral” mode, applying no shift to the signal. This will not alter the AFR, and the vehicle should operate normally.

Lean Mode Operation



In “Lean Mode” the O2 shifter delays the rich to lean transition to the ECU by a user selectable duration. Receiving a rich signal, the ECU leans out the AFR, even after the O2 sensor has switched lean. The O2 shifter continues reporting a “rich” mixture for a fraction of a second or more, causing the ECU to continue operating slightly lean. After the assigned “shift” period, the O2 shifter output switches to lean, signaling the ECU to richen the mixture up. In lean mode the engine, on average, operates up to about 7.5% leaner than normal. The engine efficiency improves when operating slightly lean, so in general the vehicle mileage will improve when operating in lean mode. Extensive road and dynamometer tests have shown an approximate 8% improvement in fuel economy with a 2000ms lean shift. Generally small shifts will not be detectable: the vehicle will appear to operate exactly as always. This is due to the fact that as O2 sensors age, their latency times may become longer. The ECU is designed to make gradual changes in the AFR anticipating that the sensor’s output may, at some point, become slower. When operating with very large shifts, eg. 2.0 seconds, the vehicles drivability may be affected: you may, for example, notice slight hesitation when opening the throttle quickly from a standstill, especially when the engine is cold. This is, of course, a result of running slightly leaner than designed.

Rich Mode Operation



In “Rich Mode” the O2 shifter delays the lean to rich transition to the ECU by a user selectable duration. Receiving a lean signal, the ECU richens the AFR, even after the O2 sensor has switched rich. The O2 shifter continues reporting a “lean” mixture for a fraction of a second or more, causing the ECU to continue operating slightly rich. After the assigned “shift” period, the O2 shifter output switches to rich, signaling the ECU to lean out the mixture. In rich mode the engine, on average, operates up to about 7.5% richer than normal. Road and dynamometer tests have shown fuel consumption increases of approximately 8% when operating with a 2000ms rich shift. Again, as with lean mode operation small shifts may not be perceptible. Generally at high rich shifts you may notice slightly better engine response and acceleration when rapidly opening the throttle, especially when cold.

A Note on Testing

The changes in vehicle drivability will likely be quite subtly: we have designed the maximum shift of 2000ms to provide a good balance between drivability and efficiency. To investigate the effects on drivability you may want to perform an identical maneuver, say repeated moderately throttle openings while cruising in a high gear, at a moderate speed, in both lean and rich shift modes. Determining the effects on fuel consumption requires carefully controlled experiments: many “fuel saving” devices depend heavily on the “placebo effect” combining poorly controlled testing with a psychological bias to justify the expenditure on the device. The largest variables in fuel consumption testing are the driver and traffic conditions. Changing how you drive, or changing traffic patterns can affect fuel consumption by more than 30%. Obviously if you are trying to measure an 8% change, you need to take care to operate the vehicle as consistently as possible, and do multiple trials. Generally you should see the effect on a single full tank of fuel, if you drive consistently. Some modern cars have in-dash fuel consumption meters as shown below. We have noticed that these tend to indicate the fuel consumption accurately on vehicles we have tested, but they require several hundreds of kilometers to achieve the correct average reading.

Glossary of Abbreviations and Terms:

AFR	Air Fuel mass Ratio, (Mass of air / Mass of fuel injected), typically around 14.7:1 for gasoline engines
ECU	Electronic Control Unit, or Engine Control Unit. Controller of the EFI system, and potentially other systems, such as transmission, fans, and traction control
EFI	Electronically controlled Fuel Injection
EMS	Engine Management System, same as ECU
Latency	A delay between a physical change, and when the change is registered on the output of a sensor: O2 sensors typically have a latency of 100ms to 400ms
Lean	Engine operating with less fuel than stoich (excess O2 in exhaust), generally improves efficiency
O2	Atmospheric Oxygen, generally approximately 20% of the air is O_2
O2 Sensor	Exhaust Gas Oxygen Sensor (Switching type). Reads >05.V when rich, and <0.45V when lean
Placebo Effect	The tendency of a patient receiving fake medication to believe it is helping cure them
Rich	Engine receives more fuel than stoich, less O2 in exhaust and more power
Stoichiometric	(Stoich) Air and Fuel are chemically balanced (just enough O2 to consume fuel completely)

For more information, or to order more O2 Shifters please contact us at:
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To learn more on Oxygen Sensors please visit our technical article:
http://www.focusappliedtechnologies.com/atricles
For more information on engine and vehicle testing visit our website at:
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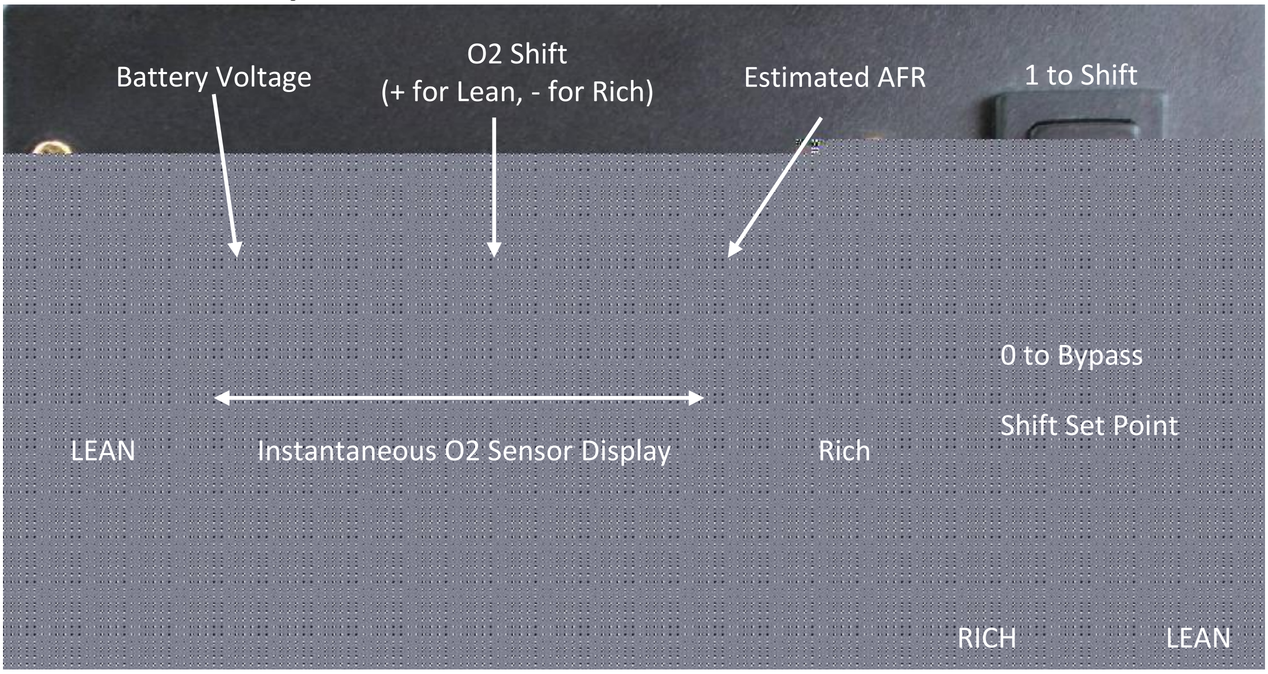
The O2 Shifter Operation



The O2 shifter comes in two forms:

- Under-hood mounted Module with Blue Tooth link
- Dash-mounted LCD Version

For both versions the connection to the vehicles wiring is the same. This manual is written for the dash-mounted version, however operation of the Blue Tooth version is identical, you just need a smart fone or similar device, and the O2 Shifter application.

The basic O2 shifter screen displays the following information:

System voltage

This is the voltage of the 12V line feeding the shifter device. Generally it will read 12.2 to 14.5 depending on the operating condition, and the condition of the battery and alternator. 14.2V means the voltage at the O2 shifter is 14.1V

O2 Signal Shift

This is the number of seconds the O2 signal is shifted: + for Lean, - for Rich shifts. +1.0 means a 1.0 second (1000ms) lean shift reducing fuel consumption by approximately 4%. -2.0 means a 2 second (2000ms) rich shift.

Average AFR

This is an estimate of the actual average Air/Fuel Ratio of the engine. This estimate is based on the actual O2 signal voltage, and the history, ie. how long it has been reading lean or rich. NOTE: *This is not a highly accurate reading of the AFR*, but it will give you an idea of whether the engine is running rich or lean on average.

Instantaneous O2 Sensor Voltage

The actual (unshifted) O2 sensor voltage is displayed on the bottom line: left is 0V or Lean, right is 1V or rich. As the O2 signal oscillates Rich/Lean the "#" mark will shift right and left respectively. During engine breaking you will notice that the "#" mark stays at the far left, indicating fuel cut out. During high throttle settings the "#" mark will go to the far right, indicating intentionally rich "open loop" operation.

The O2 shifter has 2 controls:

Bypass Switch

This rocker switch places the shifter in the active mode (ie. shifting the O2 signal) when in the "1" position. In the "0" position the O2 shifter is bypassed (the O2 signal is physically routed directly to the ECU without interference by the shifter)

Shift Adjustment Knob

The knob adjusts the amount of despaired shift, and direction. To LEAN out the engine rotate clock wise and set the desired lean shift. To RICHEN the engine rotate to the left and set the desired rich shift.

In bypass mode the battery voltage, O2 voltage and AFR are still displayed.

O2 Sensor Installation

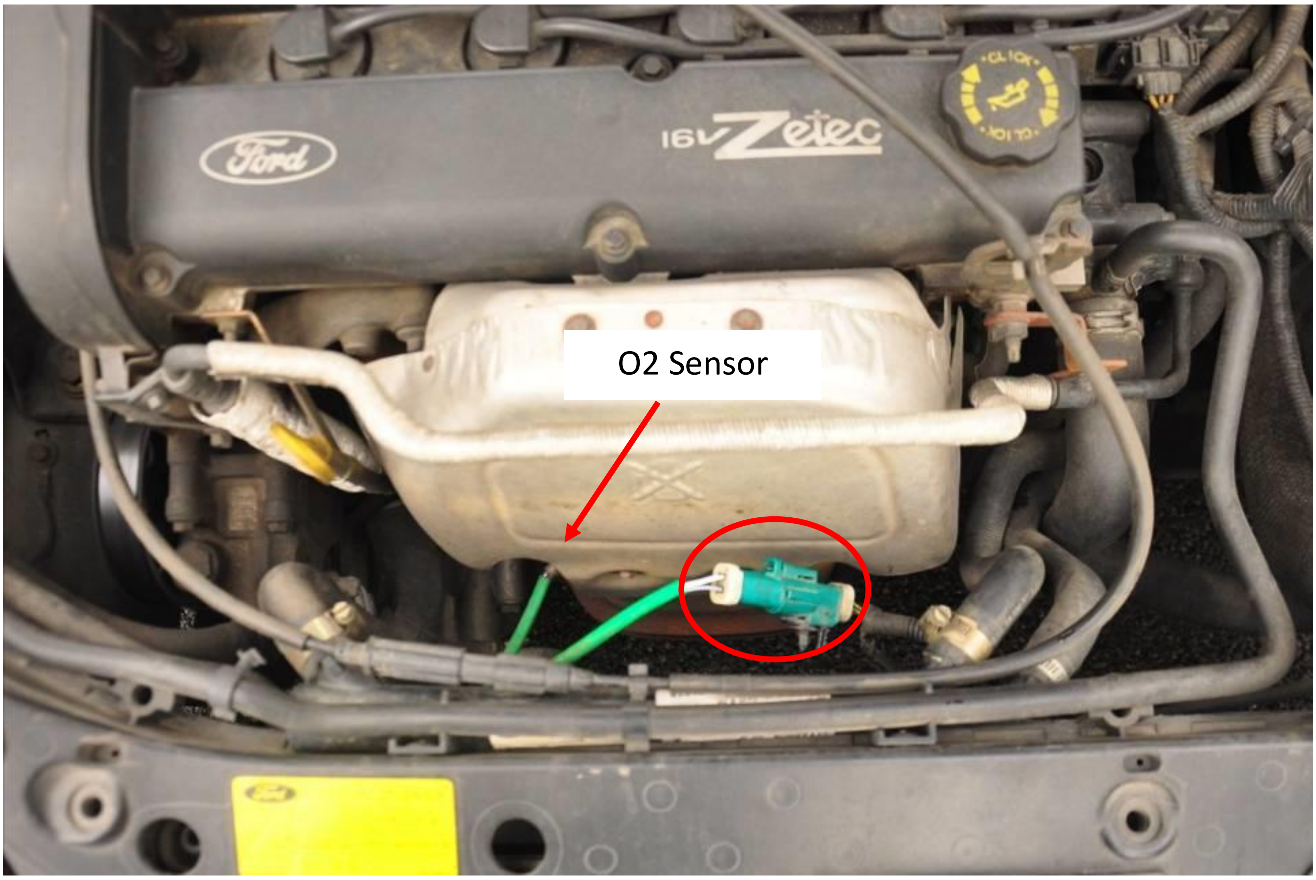
The installation process consists of the following:

1. Locating the O2 Sensor(s)
2. Unplugging the O2 Sensor connector
3. Identifying the pins of the connector
4. Connecting the O2 Shifter to the sensor and ECU
5. Testing the O2 shifter

Locating the O2 Sensors(s)

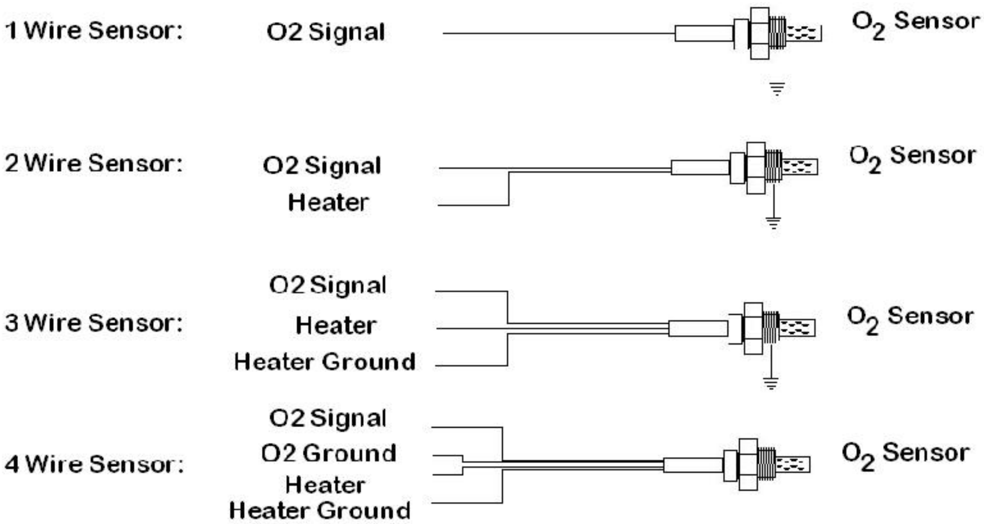
Most smaller gasoline vehicles of four or fewer cylinders have a single O2 sensor before the catalyst. Larger engines, especially "V" configuration engine, generally have two sensors located pre-catalyst. Generally these are found on the exhaust manifold(s) very near the head. Many systems have an additional O2 sensor after the catalyst, generally located under the vehicle and more difficult to access. The O2 shifter is designed to connect to the one or two pre-catalyst O2 sensor only. It has two separate channels for reading and shifting the various sensors independently.

The O2 sensor should be easily to identify as it should be the only electrical component connected directly into the exhaust manifold. If you have trouble finding it, consult you're vehicle's service manual. The O2 sensor is generally connected to the engine wiring harness via a locking connector 30 to 50cm from the sensor as circled in the foto below.



O2 Sensor Pins

The O2 sensor may have 1 to 4 wires, depending on the age of the vehicle. Typically these represent the following pins:



Unplugging the O2 Sensor connector

If you're system has two or more pins you can generally identify them via their voltage during operation and their resistance to ground.

CAUTION: Exhaust components are HOT when the engine is operating. Additionally the heater in the O2 sensor draws a lot of current and it gets HOT when connected to power. Don't get burned!

O2 Sensor Line

This wire will have high impedance (resistance) to ground. In operation when the engine is warm it should have a voltage varying between 0 and 1 Volt. If you have a 1-wire sensor this is obviously the Oxygen signal, and the sensor is grounded via the exhaust manifold.

O2 Signal Ground

On a 4-wire sensor this will appear to have high impedance (resistance) to the other wires, including the O2 sensor signal. On the engine wiring harness side this line will be run to ground full time.

Heater +

This wire is generally connected directly to 12V continuously when the engine is on. In some systems it may be possible that the heater power to the heater is toggled via the positive connection, however the typical 4-wrie O2 sensor toggles the heater on/off by connecting the heater ground to ground (internally in the ECU via a transistor) or disconnecting it. Resistance on the heater to heater ground (either one of the wires or the body of the sensor) should be 5 to 100ohms.

Heater Ground

This line is held at ground when heater current is required: ie. when the engine is first started, and any time the exhaust gas temperature is relatively low. When the engine is fully warmed up, the heater ground may be disconnected from ground by the ECU, thus it will appear to "float" up to the 12V line.

Heater to Heater Ground resistance should be 10 to 100 ohms on a working heater. If the system has less than 4 wires it is possible that the heater is grounded via the sensor's body to the exhaust manifold.
Normally oxygen sensor comes with 4 pins. Male side is to oxygen sensor, while female side is to engine control unit (ECU). Also as the heater is non-polar (ie. works when connected "backwards") the 2 heater wires are often the same color.
NOTE: Heater resistance increases with temperature. If the O2 Sensor is hot, the resistance will be higher, but not more than 1000 ohms.

The heater wires on this Ford O2 sensor (above) are both white and have a resistance of about 7 ohms. One is connected to 12V on the ECU side of the connector fueel time: that's the heater wire, the other is the heater ground.

Checking at the wiring harness we can identify the which wire is the Heater + line and the Heater Ground.

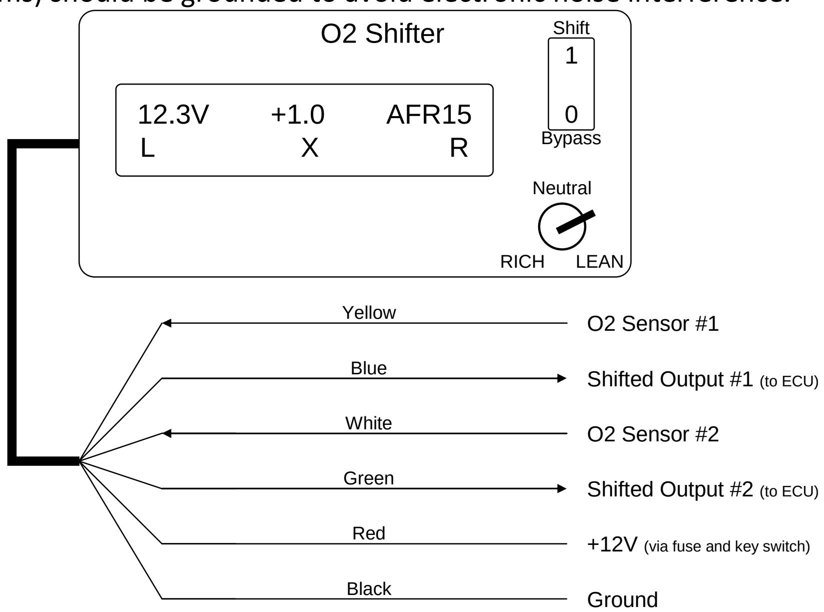
The polarity of signal line can be determined from reading the O2 sensor directly. Note: it will only work when HOT and when there is sufficient AFR to get a reading (ie. rich). The signal will be positive with respect to the signal ground.

Alternatively if you have identifies the 2 sensor wires, you can check at the wiring harness end. The signal ground will have a low resistance to ground on the vehicle as shown below.

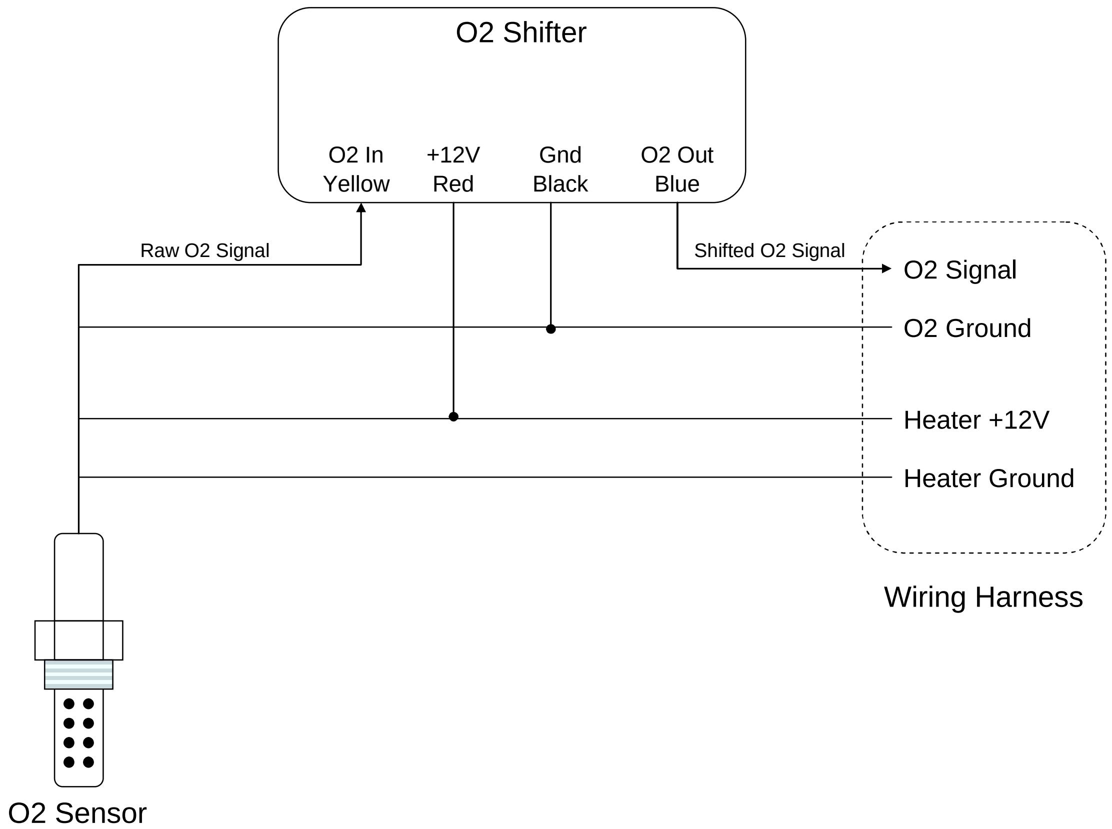
The O2 signal ground shows low resistance (3 ohms here) to the battery’s ground via the wiring harness.

Connecting the O2 Shifter to the O2 Sensor and Wiring Harness

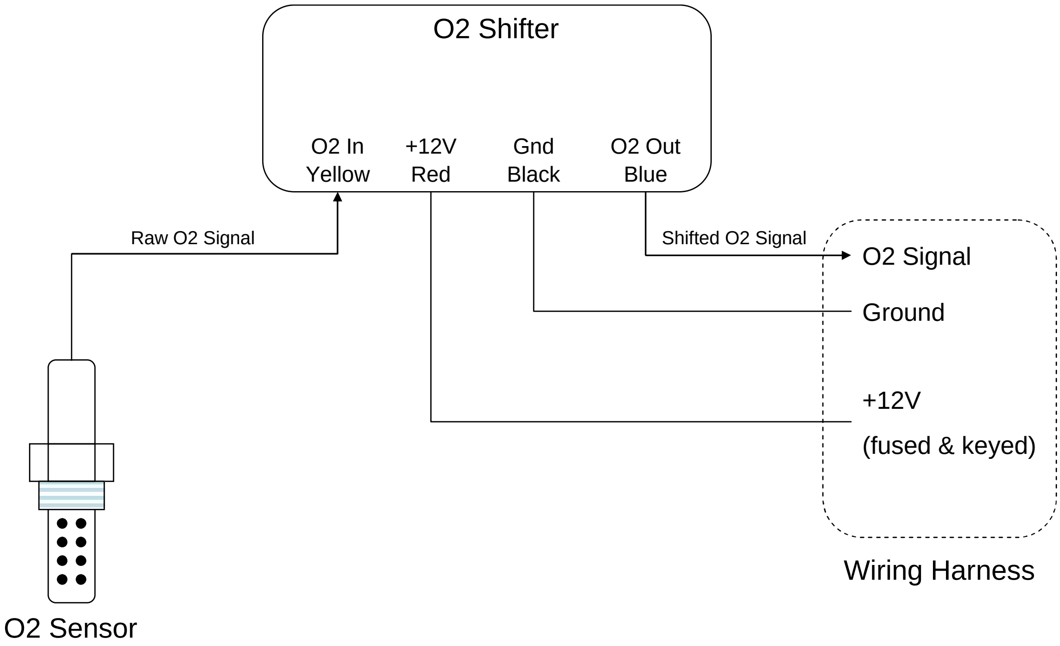
The O2 Shifter has a single shielded cable with the following wires. Unused inputs (such as O2 Sensor #2 on single sensor systems) should be grounded to avoid electronic noise interference.



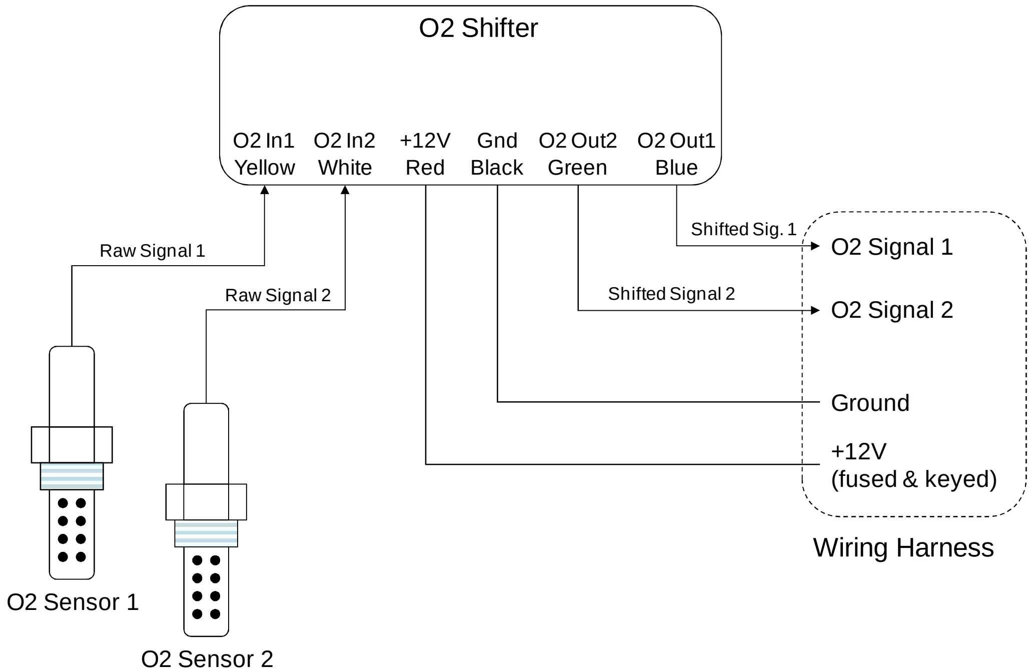
Single 4-Wire Sensor:
The O2 shifter requires a clean keyed and fused source of 12V power to the **RED** wire. On 4-wire connections this can come from the heater power line. The O2 Shifters ground line (**BLACK**) can be connected to any good ground, such as the O2 signal ground on a 4-wrie sensor. The O2 signal line (from the O2 sensor) should be run into the **YELLOW** line of the O2 shifter. The vehicles wiring harness must be disconnected form the O2 signal line of the sensor, and instead connected to the output (**BLUE**) of the O2 shifter.



Generic and Single 1-Wire Sensor:
Connect the O2 shifter to the sensor as shown below: the sensors output is fed into the **YELLOW** wire on the shifter. Connect the **BLACK** wire of the O2 shifter to a good ground, and the **RED** wire to a keyed source of fused 12V power. Disconnect the O2 sensor line from the wiring harness, and instead feed it to Shifted output from the O2 Shifter (**BLUE**). Note: This configuration can be used with any O2 sensor, regardless of the number of wires.



Two-Sensor Vehicles:



NOTE: The source of 12V power for the O2 Shifter can come from one of the O2 sensor's Heater power line, and the Shifter's ground can come from the signal ground, as shown for the single 4-wire sensor above. Keep the Sensor 1 lines (Yellow and Blue) separate from the Signal 2 lines (Orange, Green).

Testing the O2 Shifter

When the O2 Shifter is powered the display should show the battery voltage, and the O2 Shift value (in the center of the top line) should change as the knob is rotated left or right. In the middle of the range it should read 0.0V. This display should be on as long as the power is applied. If the display "blanks" intermittently, it is very likely that either the 12V line feeding it is being switched off, or the ground line is heater ground line (which is occasionally shut off by the ECU). In either event reconnect the shifter's **RED** wire to a good 12V line and the **BLACK** wire of the shifter to a good ground.

When the engine is operated the O2 signal display (on the bottom line) should follow the actual O2 Signal once the engine is warmed up (this generally requires a few minutes). Revving the engine with a high throttle, then releasing the throttle should result in rich operation (during hard acceleration) followed by lean operation (engine breaking, as the engine slows). This should cause the marker to go fully right, then fully left regardless of the O2 Shifters settings. If the display does not respond, then it is likely that the O2 sensor has not properly been connected to the O2 shifter.

If the display stays on, and responds appropriately to the O2 signal, then you should be able to use the O2 shifter. Placing the switch in the "1" position causes the shifter to modify the O2 signal according to the knob's setting. Under normal operating conditions the O2 marker will oscillate left-right a few times per second. When the O2 shifter is being used, and the knob is rotated fully right, the O2 sensor should spend more time at the extreme left (ie. lean). This indicates that the O2 shifter is telling the ECU that the engine is operating rich for longer than the sensor actually is, causing the ECU to lean out the engine. Oscillations will still occur, but slower, and with the marker staying to the left more of the time.

You're O2 shifter is now functioning. To save fuel, put the switch in the "1" position and rotate the knob clockwise. Try various settings (ie. +0.5, +.10, +1.5, +2.0) see how the vehicle feels, and monitor your fuel consumption. Switching the switch to the "0" position bypasses the O2 shifter, sending the Raw O2 signal straight to the ECU as per normal engine operation. In this mode the Shifter can still be used to monitor battery Voltage and O2 signal.

On some cars with poor drivability, running the O2 shifter in the rich mode (ie. rotating the knob counter clockwise) will cause the engine to operate slightly richer, potentially improving throttle response and drivability, especially during cold operation.

Disclaimers and Warnings:

Use of this product may cause you're vehicle to violate emissions regulations, so it is best to check you're local regulations before using it on the highway. Similarly while we have done extensive testing on a wide range of vehicles to insure that this device is safe, we can bare no liability for the use of this product on your vehicle. Use is strictly at the users own risk.

Rout all wires away from sources of heat (such as the exhaust manifold) and sharp edges to avoid chaffing. Wires should be joined professionally and insulated electrically. Cables should be tied to the frame, with sufficient slack to allow for engine motion during vehicle use.

Always observe appropriate safety precautions when working on or around engines!