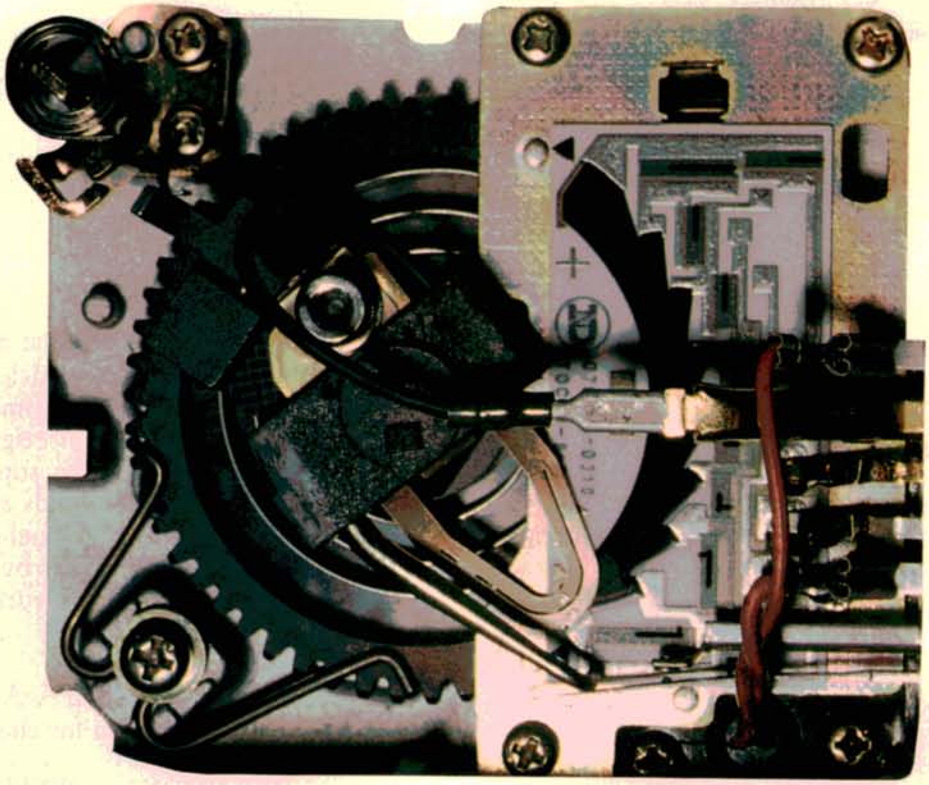

Analog Sensors

Last month we told you about reference voltage—how it's generated by the ECU—and ways to check it. This month we'd like to take a logical next step and show how analog sensors use reference voltage to provide the ECU with important information about changes going on under the hood.

What Is An Analog Voltage?

Before we look at analog sensors, it's important for us to understand analog voltage. Analog voltage is a DC voltage which varies between an upper voltage limit, and a lower voltage limit. At any given point in time, an analog voltage can exist at any point between those two extremes. Changes in the voltage signals from an analog sensor represent changes in conditions at the sensor location. Here are some examples:

- Changes in temperature (a coolant temperature sensor or air intake temperature sensor).
- Changes in the position of a component (a throttle position sensor or EGR position sensor).
- Changes in pressure (a Manifold Absolute Pressure sensor or Barometric Air Pressure sensor).
- Changes in the oxygen content of exhaust gases (an oxygen sensor).

You're already familiar with analog sensors, like the sending units for the gas gauge, and the temperature sensor used for the temperature gauge. The sensors we'll discuss use reference voltage from the computer and vary the amount of analog voltage sent back to the ECU. Since ECU reference voltage is used to operate engine analog sensors, the upper limit of analog sensor voltage is reference voltage, usually about 5.1 volts. The lower limit is set at ground, 0.1 volt.

Three Wire Sensors

There can be any number of analog sensors used, and they're known by different names depending on the manufacturer. But they all fall into three basic classifications:

- Three-Wire Sensors
- Two-Wire Sensors
- Oxygen Sensors

Now that we've simplified that part, we'll show an equally simple way to test them with one voltage check.

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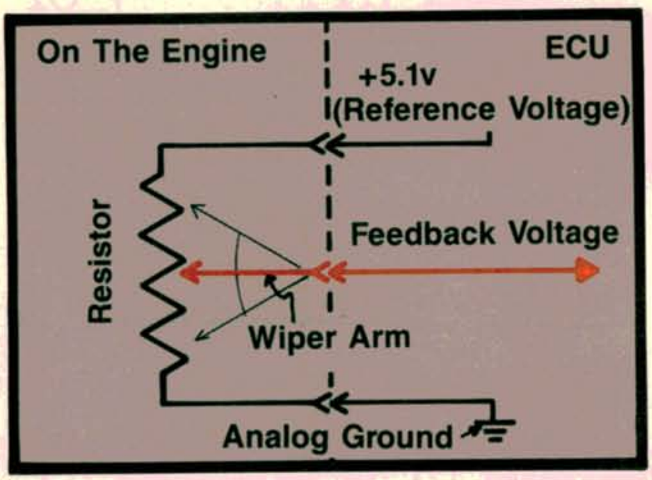
Common types of three-wire sensors include: Throttle Position Sensors (TPS), some Manifold Absolute Pressure sensors (MAP), and some Barometric Air Pressure sensors (BAP). All three-wire sensors do the same thing, and are tested the same way.

Figure 1 shows the circuit for a three-wire sensor. Three-wire sensors use this general schematic symbol for a potentiometer. A potentiometer is a variable resistor with three electrical connections. Two of the connections are fixed connections attached to opposite ends of a resistor. A third connection attaches to a sliding contact (or wiper) which moves across the resistor body.

The three-wire sensor receives the ECU reference voltage on one of the leads attached to the resistor. (The other end of the resistor is connected to ground, usually inside the ECU.)

Figure 1 Three-Wire Sensor



The wiper arm is connected to the third wire. The wiper arm is also attached to, and moves with, some moving part of the car (like a throttle shaft). As the wiper moves across the resistor, the voltage it "sees" changes as follows:

- **The closer the wiper is to the reference voltage terminal, the closer the voltage "seen" by the wire will be to reference voltage.**
- **The closer the wiper contact is to the ground side of the resistor, the closer the signal will be to ground.**
- **Voltage will gradually vary between reference voltage and ground as the wiper moves back and forth in response to the movement of the throttle shaft (or air flow meter, etc.).**

Throttle Position Sensors

If the wiper arm is connected to the throttle shaft, the amount of voltage (between about 5.1 volts and 0.1 volt) tells the ECU about the throttle's position. (Some throttle position sensors may also have additional ON/OFF switch contacts to signal wide-open throttle, idle, or both.)

MAP and BAP

Some MAP and BAP sensors are analog sensors. MAP sensors have a movable bellows or diaphragm connected to the wiper. Changes in manifold pressure move the wiper similar to the way the throttle moves the TPS.

BAP sensors work in similar fashion. They are located beneath the hood or in the passenger compartment. But instead of responding to changes in engine manifold pressure, their air pressure sensing device moves in response to changes in atmospheric pressure. BAP influence on engine performance is most noticeable at high altitudes, or when weather conditions change.

Checking Three-Wire Sensors

The quickest way to test a three wire sensor is to measure the wiper arm feedback at the ECU. This simple test checks the function of the sensor. It can also tell you a lot about the other two wires attached to the resistor, and the mechanical condition of the potentiometer. Then, if there is a problem, further checks with your DVOM can help you pinpoint the source of the trouble.

We'll use an analog meter to test analog voltage. With the meter attached to the correct return wire terminal at the ECU, exercise the component attached to the potentiometer.

Let's use our throttle position sensor as an example. With our analog meter backprobing the wiper arm terminal at the ECU, slowly open and close the throttle. Look for the following:

- **Smooth, even changes in return wire voltage as the wiper moves through its entire range.** Any skips or misses detected by the meter will probably indicate a mechanical problem at the three-wire sensor. Skips can result in driveability problems, and may be caused when the wiper contact wears through the printed circuit, usually at a point where it rides most of the time.

Another possible cause for erratic operation may be dirt or oil between the wiper arm-to-printed circuit contact points.

- **Look for voltage to change over the entire voltage range.** Do you reach a normal high voltage? Do you reach a normal low voltage?

Normal high voltage will be a little lower than reference voltage (about 4.5 volts if reference voltage is 5.1 volts), and normal low voltage should be a little higher than ground (about 0.4 volt with ground being 0.1 volt).

Typical Sensor Readings

Let's look at voltage readings from typical sensors.

Throttle Position Sensor—

Our sample TPS receives 5.1 volts of reference voltage from the ECU. It reads 0.4 to 1.0 volt with the throttle in the idle position. Voltage shouldn't drop below 0.4 volt. As the throttle is opened, the wiper moves closer to the source of reference voltage. That means reference voltage travels through less of the resistor, less voltage is dropped, and return voltage increases.

By the time we reach wide open throttle (WOT), feedback voltage rises to about 4.3 to 4.5 volts.

MAP Sensor—

Usually a MAP sensor will read a high voltage at idle, and a low voltage at high RPM. There should be a smooth change in voltage through the sensor's entire mechanical range, from high MAP to low MAP.

BAP Sensor—

BAP sensor voltage should stay fairly constant at a value similar to other cars in your area, although changes in the barometer at the local weather station will also cause gradual changes in BAP readings.

Abnormal Three-Wire Sensor Readings

Here are a few abnormal readings and things to look for when you see them:

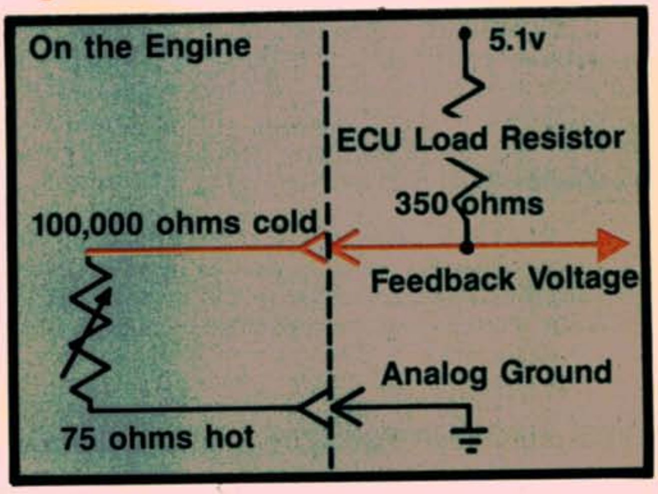
- **The feedback voltage is always the same, at a point somewhere between the high and low voltage points of normal operation**—This sounds like a mechanical failure. Check to see if the sensor is moving the wiper arm.
- **The feedback voltage is always too high**—There may be a short circuit between the wiper contact and reference voltage. Maybe the ground side of the resistor is no longer grounded. (This would show up as 5 volts on the ground terminal of the resistor.) Maybe the sensor ground circuit in the ECU is open because someone has done some careless "jumpering," and smoked the ground path inside the ECU.
- **The feedback voltage is always too low**—Maybe the sensor is not getting full reference voltage at the reference voltage terminal. The wiper arm circuit could be shorted to ground in the harness. Check resistance to ground on this circuit, this time using your digital ohmmeter (power off).

Two-Wire Sensors

Let's move on to two-wire sensors, the most common of which is the CTS or Coolant Temperature Sensor. The CTS is usually NTC, or Negative Temperature Coefficient. That means resistance goes down as the temperature of the sensor goes up. When the ECU senses that the engine is cold (high CTS resistance) it richens the fuel mixture for fast starts and smooth engine warm up.

Figure 2 shows the circuit for a typical two-wire sensor. It is a resistor symbol with an arrow drawn through it. The top of the CTS gets a portion of reference voltage from the ECU load resistor. The load resistor and the CTS form a series circuit, so they share the reference voltage.

Figure 2 CTS Two-Wire Sensor



The ECU looks at the voltage at the top of the CTS to determine engine temperature. On most imports, the ground for the CTS is connected back through the ECU's analog ground.

How the Two-Wire Sensor Works

The resistance of the two-wire sensor changes as coolant temperature changes. The ECU load resistor inside the ECU is connected to reference voltage. Its resistance stays the same. The feedback voltage (which is what the ECU reads) is taken from the connection BETWEEN the Load Resistor and the CTS.

The feedback voltage is the same as the voltage drop of the CTS.

When the engine is cold, the CTS resistance is very high, maybe even as high as 100,000 ohms. Most of the reference voltage is dropped across the higher resistance of the CTS, and little is dropped across the Load Resistor. So the feedback voltage read by the ECU is high, near 5.0 volts.

As the engine warms, the resistance of the CTS drops. The feedback voltage begins to drop as more and more of the reference voltage is dropped across the ECU Load Resistor, and less is dropped across the CTS. When the CTS resistance is equal to the resistance of the Load Resistor, feedback voltage is 2.5 volts, because the two resistors divide the voltage equally.

When the CTS reaches its normal hot resistance of about 75 ohms, most of the reference voltage is dropped across the Load Resistor which now has a higher resistance. Feedback voltage drops to 1.0 volt to indicate that the engine has reached normal operating temperature.

Analog Sensors

How to Check Two-Wire Sensors

Again, the quickest way to test a two-wire sensor is to measure the voltage at the point between the Load Resistor and the CTS, just as the ECU does. That means backprobing the voltage at the ECU connector pin. This simple test will check all the functions of a two-wire sensor. If your analog meter detects a problem at this connector, a DVOM can once again be used to look for shorts or opens in the circuit.

Another way to test the CTS circuit is to "fool" the circuit by substituting a test resistance in place of the CTS. If the test resistor has a high value, it should fool the ECU into thinking the engine is cold. Injector pulse width should increase in response to this resistance value.

Another way to trick the ECU is to short the carside CTS connectors. The effect is just the opposite here. Shorting the CTS sensor leads together makes the ECU think the engine is warm, and injector pulse width should decrease.

What Abnormal Two-Wire Sensor Readings Mean

Here's another list of possible voltage readings—this time for two-wire sensors—and suggestions for interpreting them:

- **The voltage reading is always high.** Look for an open circuited sensor, or an open ground circuit inside the ECU. Maybe somebody let out all the "smoke" with a jumper wire.

- **The voltage reading is always low.** The CTS wire may be shorted to ground. This is not an uncommon problem if the coolant sensor wires get too close to the exhaust manifold. If the problem isn't a shorted wire, the ECU Load Resistor could be open and the ECU will need to be replaced.

- **The voltage reading is always high on a warm engine.** The CTS is not getting down to its warm resistance rating. The CTS has high resistance, or an open ground circuit. (By the way, make sure the engine really is warm. Has someone removed the thermostat, or is it sticking open?)

- **The voltage reading is too low when the engine is warm.** The CTS has lost some of its resistance. Check the CTS with a digital ohmmeter at normal engine temperature and compare the reading to the shop manual specifications for sensor resistance values at that temperature.

The Oxygen Sensor Circuit

The oxygen sensor is different from the other two sensors. It also uses reference voltage, but the relationship between the O_2 sensor and the ECU is another whole story. For the time being, it's enough to remember that the oxygen sensor is a true analog sensor.

The oxygen sensor measures oxygen content of the exhaust to determine air/fuel ratio. If there is a lot of oxygen in the exhaust, the oxygen sensor sends a low voltage to indicate a lean condition. If less oxygen is present, oxygen sensor voltage increases.

Normal range of O2 sensor operation is 0.1 to 0.9 volts. Oxygen sensor voltage is processed by the input circuit at the ECU and then sent to the translator circuit so the ECU can use the information.

Oxygen sensor voltage should change faster than the other analog voltages to the ECU if the sensor is working properly, and the fuel system is in good working order. This makes testing of the O2 sensor circuit a little more difficult, Simply measuring sensor input voltage at the input terminal won't always tell you the whole story.

Checking Oxygen Sensors

Please refer to page 38 of the June 1990 issue of Import Service for a detailed set of test procedures describing oxygen sensor testing with a dual trace lab scope.

Next month, we'll look at computer switch outputs. See you then.

—By Vince Fischelli