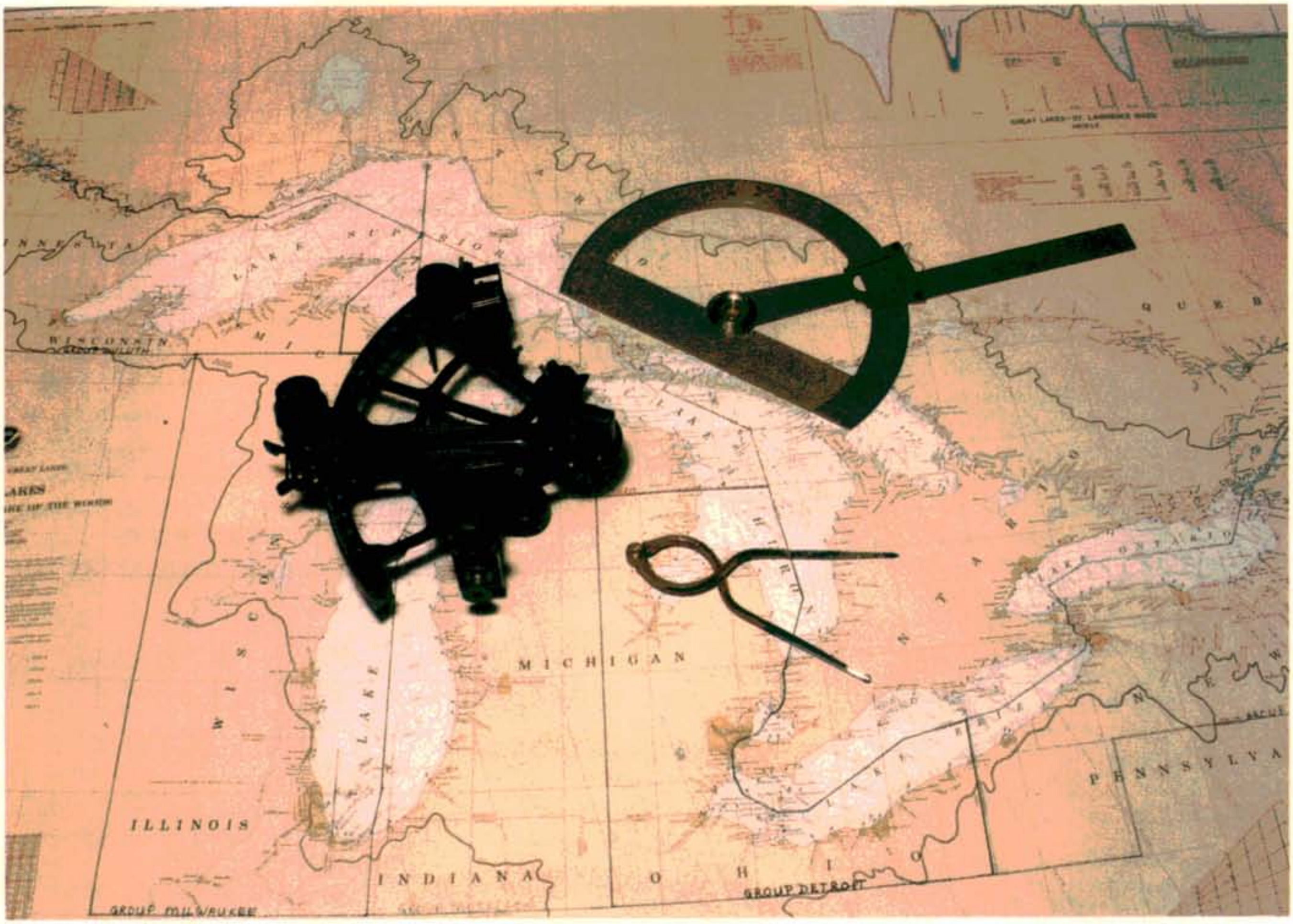


Reference Voltage and Computers

Computer Navigation

Sailors have long used the stars as an aid to navigation. When the Ancient Mariner found himself surrounded by water, his trusty sextant gave him an accurate measurement of the stars above, and helped him guide his ship safely to shore.

Modern ECUs have a similar problem. Even though they sit in darkened tin boxes that resemble oversized sardine cans, they are expected to navigate the correct course for the fuel and ignition systems on modern vehicles. And their only ''eyes'' are electrical inputs from sensors. But without a reference of its own, the ECU cannot possibly determine whether voltage signals from the sensors are accurate, or simply the result of voltage fluctuations in the electrical system.

The North Star for the ECU is called reference voltage. This article discusses reference voltage generated by the ECU and ways to check it. Next month's article will take a closer look at how specific analog sensors use reference voltage to help the ECU plot a proper course.

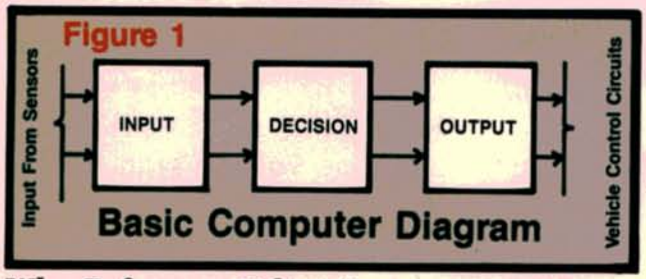
Basic ECU Block Diagram

Before we look at reference voltage, let's look at a block diagram of a basic ECU, shown in **Figure 1.**

For some of you, this will be boring, so we'll keep it short and sweet. Bear with us for a moment. The good stuff is coming.

Computer functions can be roughly summarized in three words: INPUTS, DECISIONS, and OUTPUTS.

- **Inputs**—The Input block shows how outside information (data) enters the ECU.
- **Decision**—In the Decision block, the brain of the ECU analyzes the input data, and navigates a new course of action.
- **Outputs**—The Output box executes commands from the ECU by sending electrical commands to different devices to steer a new course.



Why Reference Voltage?

The great unsung hero of the INPUT block is the ECU's reference voltage generator. Outside disturbances can blow the ECU off course. These disturbances include: vibration, temperature extremes, moisture, electrical interference, and changes in supply voltage that can interfere with analog input signals. There has to be some way to keep things on course.

Think of the reference voltage generator as a mariner looking through his sextant. By maintaining a constant voltage through all these tempests, he provides a constant reference point for comparison to analog sensor inputs.

The reference voltage is responsible for providing stable operating voltage to analog sensors. This is his main function.

Steady as She Goes

Big deal, so the ECU sends out a reference voltage. How does that help the ECU?

Let's look at an example. A constant voltage is sent out from the ECU to the Throttle Position Sensor (TPS) on one wire. As the position of the sensor changes, so does its resistance. This changes the amount of voltage returning to the ECU on the return wire. The third wire on the TPS is ground.

The TPS receives a reference voltage (roughly 5 volts), and feeds back a varying DC voltage between 0 and 5 volts to the ECU. These changes in voltage represent changes in throttle position.

Let's recap:

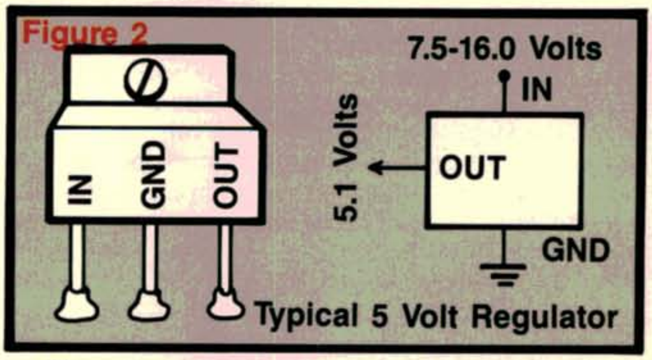
- The ECU sends out a reference voltage on one line leading to the TPS.
- The sensor sits in the middle of this series circuit running from the ECU, through the sensor, and then back to the ECU.
- The resistance of the sensor will change as the throttle position changes.
- Changes in sensor resistance change the amount of voltage passing through the sensor on its return trip to the ECU.
- The ECU looks at a chart in its transistorized brain and says, "At this return voltage, the throttle is open x-number of degrees."

However, if reference voltage is allowed to vary up and down, the return voltage will also vary. The ECU can never be sure under these changing circumstances that changes in sensor feedback (return) voltage are due entirely to conditions at the sensor, or to differences caused by changes in reference voltage itself.

What would happen to the navigator if the star viewed through the sextant kept moving?

A Typical Reference Voltage Circuit

Advances in electronic components have simplified the design of this type of circuit. One example is a three-lead reference voltage "chip." Even though this chip is connected to a supply voltage that can vary between 7.5 and 16.0 volts, it still produces a constant output reference voltage of about 5.1 volts. **See Figure 2.**



The reference voltage chip is like a small voltage regulator. It is soldered into the circuit board, and often mounted with a screw to the case of the ECU. That way, the case of the ECU becomes a heat sink to keep the chip cool. The IN lead of the chip is connected to the vehicle voltage supply through the ignition switch, and receives 7.5-16.0 volts (system voltage).

As long as the input (vehicle) voltage stays within that 7.5-16.0 volt range, the regulator chip will output a steady voltage of about 5 volts. (Just how much the output voltage varies will change according to the design characteristics of the regulator chip used, but most are designed to work within a range of 5.1 to 5.6 volts. It all depends on the chip selected by the manufacturer, based on the design of the ECU.)

It is important to remember that the design characteristics of these chips will be different for different manufacturers. Ink on paper specifications for recommended voltages can be hard to come by.

As far as the service technician is concerned, however, be it 5.1 or 5.6 volts, the reference voltage shouldn't be jumping all over the place. For reference voltage to work, it's reading on the voltmeter, like the position of the North Star, must stay constant or the ECU can't plot its course.

What Does Reference Voltage Really Do?

Reference voltage is sent to all analog sensors. By operating all these sensors at a steady reference voltage, the sensor feedback voltage to the ECU changes only as resistance values at each sensor change.

Factors Affecting Reference Voltage

The two factors which most affect the stability of the reference voltage are:

- **Temperature**
- **The amount of charging voltage (voltage at the IN terminal of the reference voltage generator.)**

As technicians, it's easier for us to keep track of charging voltage than to accurately measure small changes in temperature. As a result, careful attention to charging voltage is important when we check for a steady reference voltage.

Let's look at an example.

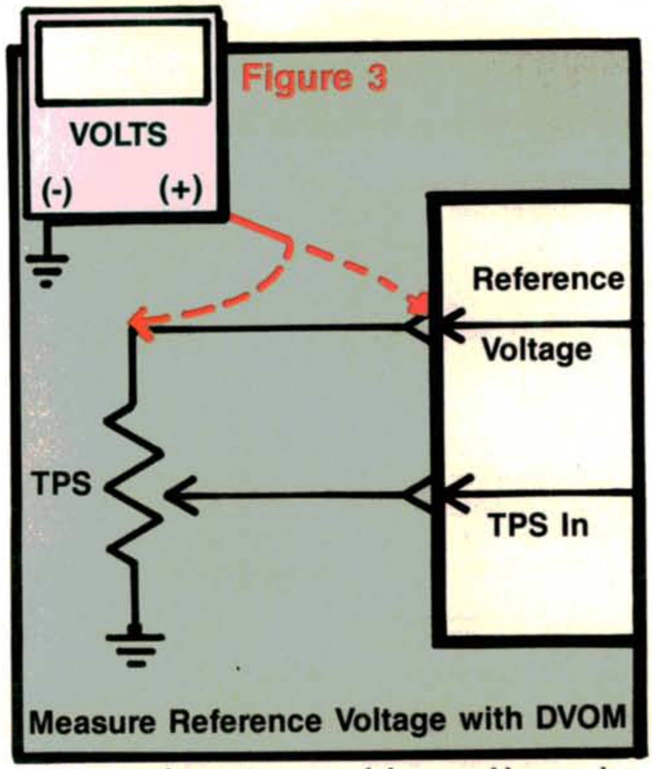
Ideally, when the charging voltage is highest (minimum electrical load combined with cold temperatures), the reference voltage should stay constant at the manufacturer's spec (let's use 5.1x volts). The x in 5.1x represents the hundredths reading on the DVOM. Readings between 5.10 and 5.19 won't usually affect the stability of the reference voltage signal.

Even with changes in temperature or charging voltage rates, the reference voltage should stay within this range.

Testing Reference Voltage

To test reference voltage, measure the voltage using a 10 megohm input impedance DVOM as shown in **Figure 3.** Depending on the vehicle, you can backprobe the ECU at the reference voltage terminal, or you may choose to sample the voltage right at the reference voltage terminal of a three-wire sensor. (It's a good idea to test at both locations, since we all know that voltage sent from the ECU can get lost along the way. Testing right at the reference voltage wire of a three-wire sensor is okay, but two-wire sensors pose a special problem. Come back next month for a detailed explanation of how different sensor types use reference voltage differently.)

For best results when making reference voltage checks, we suggest grounding the DVOM right at the battery negative terminal.



Now rev the engine up and down and keep a close eye on the DVOM reading. The reading should hold steady regardless of engine RPM and the corresponding changes in charging voltage.

Then double check. Let the engine idle and turn on all the accessory loads (high beam headlights, A/C high speed blower motor, and so forth). This will lower charging voltage, and if reference voltage remains steady, we are assured that reference voltage is constant at the low end of the charging cycle too.

Here's a hint for establishing a base reference voltage on a specific car. Check reference voltage with the ignition key in the ON position and the engine not running. Most systems will send out a normal 5.1 volt reference signal under these conditions and give you a starting point for cars of a similar type.

Bad Readings

If the reference voltage regulator circuit in the ECU is bad, the reference voltage will vary more than 0.3 volt. You can normally ignore some small variations, since your DVOM can easily show a difference in voltage from 5.15 to 5.25 volts for example. That total difference is only 0.1 volt, and that isn't enough to condemn a reference voltage circuit.

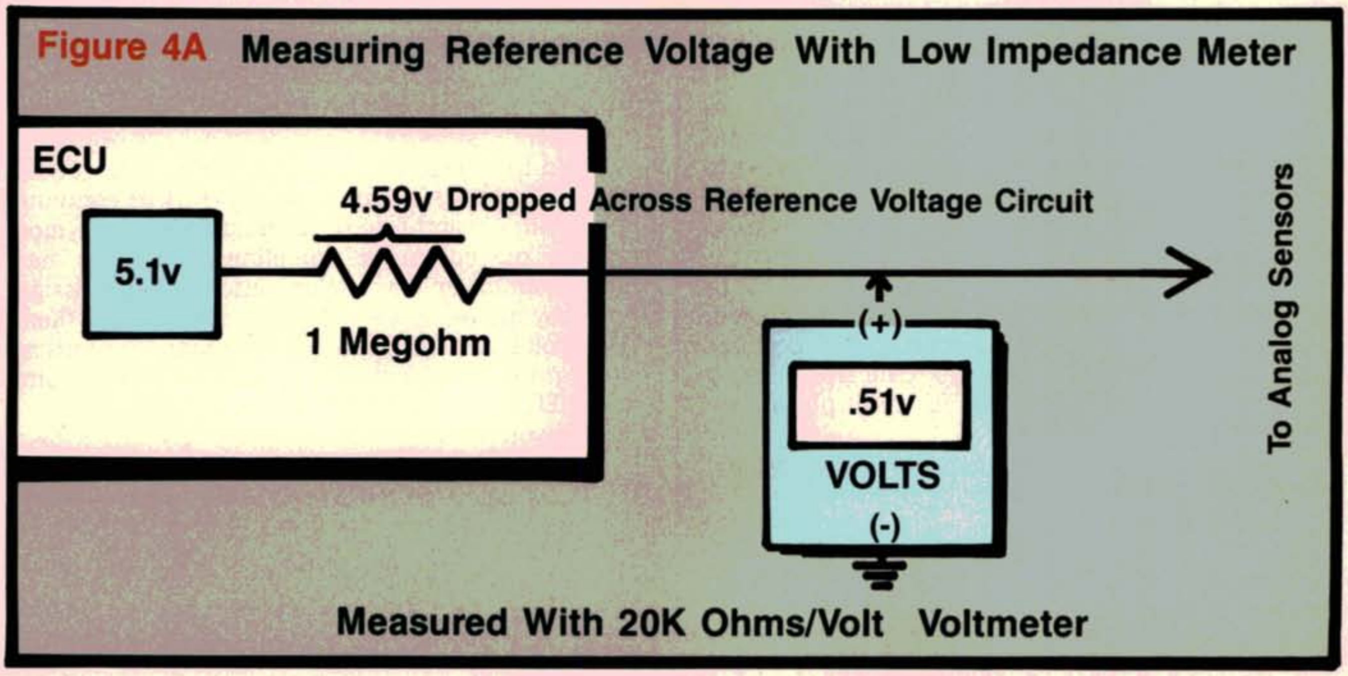
We hate to keep saying this, but experience is always going to be your best teacher when determining known good values. If practice makes perfect, then this is a good example.

Hopefully, more manufacturers will tell us how much a reference voltage can vary from low to high so we can make better diagnoses. But in the absence of these specifications, time spent testing the good ones will help you know a bad one when you see it.

The Dangers of Low Impedance Meters

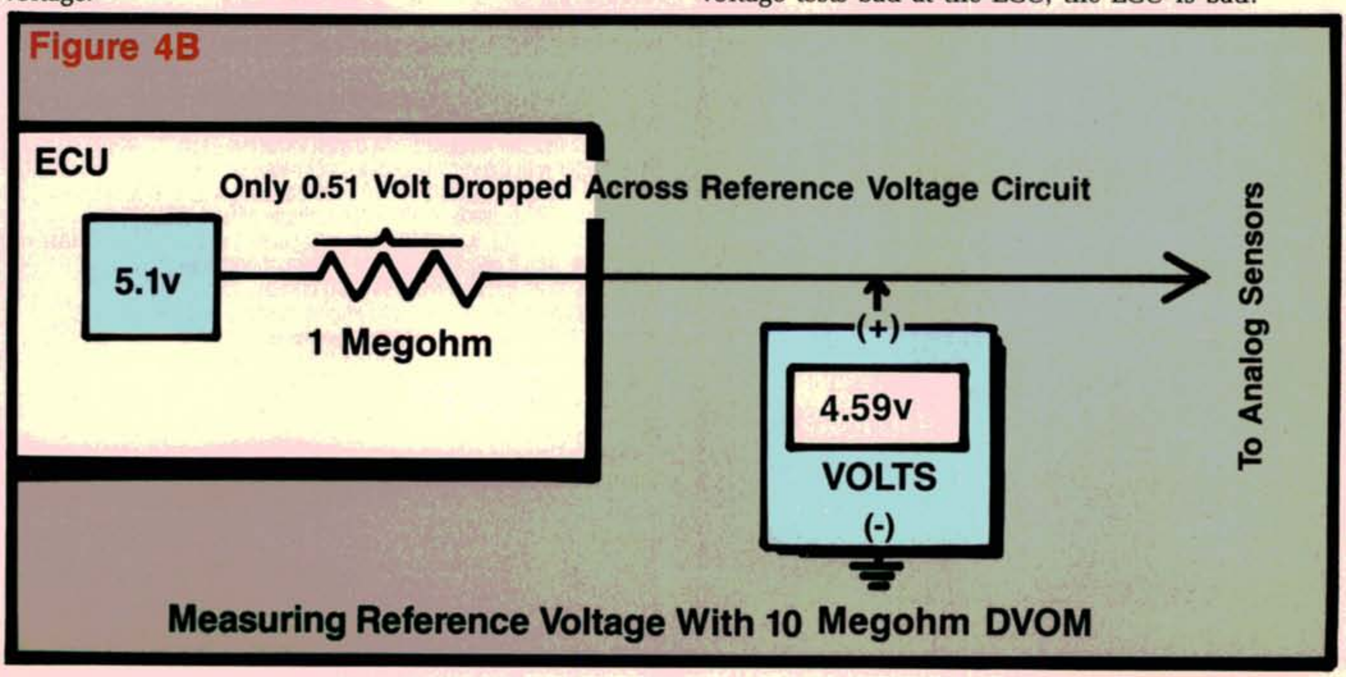
Some technicians have gotten low reference voltage readings when they used a DVOM with the wrong input impedance. Some have learned that when they read 0.51 volt with their low impedance meter, the analog voltage is actually 5.1 volts. There is an explanation for this.

In **Figure 4A**, the output impedance of the reference voltage circuit is greater than the voltmeter's 20K Ohms/Volt. The 20K Ohms/Voltmeter draws so much from the circuit that the voltage drop leaves only .51 volt for the meter to read.



In **Figure 4B**, the output impedance of the circuit is much less than the 10 megohm input impedance of the DVOM. In this case, the reference circuit drops only one tenth of the reference voltage. The DVOM reads 4.59 volts, close to the true 5.1 volts of reference voltage.

This is why it is so important that we use a DVOM with a 10 megohm input impedance, and measure reference voltage directly at the back of the ECU, or right at the analog sensor. Your DVOM is the best way to find a reference voltage problem. If the reference voltage tests bad at the ECU, the ECU is bad.



What Are the Symptoms of a Bad Reference Voltage?

Most ECUs do not directly monitor the value of reference voltage. Instead, they are programmed to set codes when reference voltage is:

- **Higher than normal**
- **Lower than normal**
- **Missing completely (no reference voltage at all)**
- **Or constantly changing**

When the reference voltage starts to bounce up and down with charging voltage, the ECU will have a hard time processing analog inputs. ECU codes related to voltage extremes may be recognized by the ECU, but we can't always depend on computer diagnostics to bail us out.

If reference voltage is zero, due to a bad ECU, or because reference voltage is shorted to ground before it reaches the sensor, the ECU will set all analog sensor codes warning of low or missing data from analog sensors. That's a good reason for multiple analog sensor codes.

Check the reference voltage first when several codes relate to analog sensors.

Just One Piece of the Puzzle

We'd like to close this article by pointing out that reference voltage is only one key part of computer operation. Over the next 12 months, look for more articles on computer operation, including next month's article on how analog sensors differ by design, how they use reference voltage, and ways to test them. Also look for an article on "Ground Side Diagnostics" since ground problems can be every bit as confusing to the ECU as an unstable reference voltage.

See you then.

—By Vince Fischelli