The Good, The Bad, & The Ugly

Part Two

Separating good, bad, or ugly electronic fuel injectors shouldn't be a hit-or-miss proposition. A solid understanding of injectors and injector circuits increases your odds.

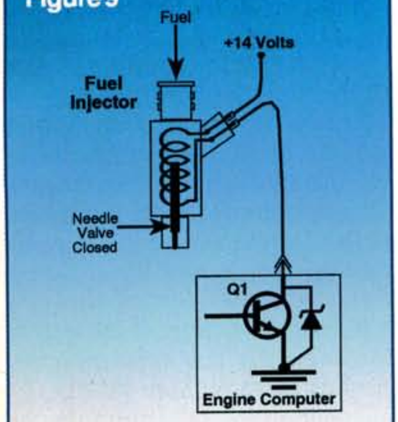
Last month's "The Good, The Bad, And The Ugly" covered basic fuel injector operation from an electrical point of view. After a short review, we'll dig into injector circuit troubleshooting procedures in this month's Part Two.

Fuel Injector Circuits

Figure 9 on the following page shows a basic injector circuit. The injector is connected directly to source voltage. The ground is supplied through the computer, so we call this a switch-to-ground circuit. There are two reasons the computer switches to ground to energize the injector.

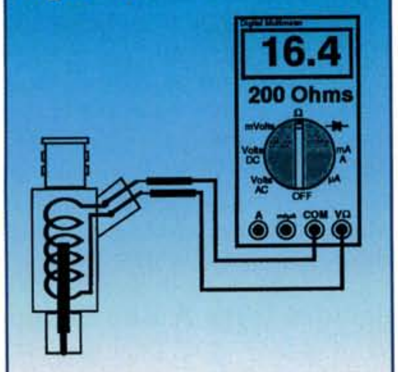
- A switch-to-ground computer driver circuit is less expensive to manufacture than a switch-to-voltage driver circuit.

Figure 9



Basic Injector Circuit

Figure 10



Checking Injector with an Ohmmeter

- A switch-to-ground driver circuit has a fail-safe mode. That is, if the wire between the ground side of the injector and the computer shorts to ground, the injector will be switched ON at all times. While this will make the engine run rich, with some luck it can still be driven to a service facility.

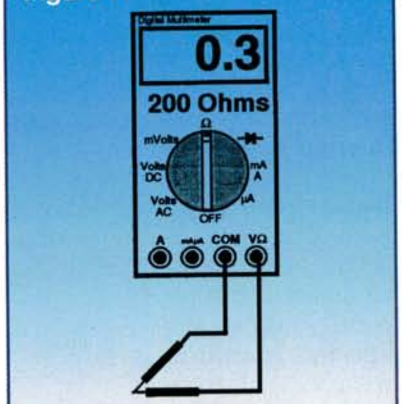
- If the short to ground occurred on the voltage supply side of the injector, it would blow the injector fuse and shut the injector OFF before the ECU could be damaged. For these reasons, most of the injector circuits you will see will be controlled from the ground side.

Checking Injectors With An Ohmmeter

The injector winding is a coil of wire that has a specific amount of resistance. By measuring the injector winding with a digital ohmmeter, it can be determined whether the injector winding is electrically intact. **Figure 10** shows a digital ohmmeter. The use of a digital ohmmeter is essential for accurate resistance checks. An analog ohmmeter can only approximate the actual resistance, while the digital meter can nail the injector winding's actual resistance to within a tenth of an ohm. That's accuracy.

The first step is to select the lowest range available on the digital ohmmeter, usually the 200 Ohm range. If the ohmmeter automatically selects the ohmmeter range, simply select the Ω symbol with the main function knob. Next, short the ohmmeter test lead probe tips together to see how much resistance is present in the ohmmeter test leads. This will also tell you whether your ohmmeter is working correctly on the lowest ohmmeter range. This ohmmeter check is shown in **Figure 11.**

Figure 11



Checking Ohmmeter for Low Resistance

Notice that the ohmmeter reads 0.3 ohms when the test leads are shorted together. This represents the resistance that the ohmmeter sees in the test leads. To accurately determine the actual resistance of any low resistance value, 0.3 must be subtracted from the reading. In the case of a 16 ohm injector, 0.3 ohms isn't going to make much difference because it is less than 2 percent of the reading. In the case of a 1.2 ohm injector, a difference of 0.3 ohms represents 25 percent of the actual reading and should be deducted from the reading.

What do you look for in the ohmmeter reading? An open circuit reading indicated by a flashing or solid "1" on the ohmmeter tells us that the injector winding is open. But make sure the ohmmeter test leads are making good contact with the injector terminals before condemning the injector.

Figure 10 shows an injector winding resistance of 16.4 ohms. We need to know the correct resistance value for the type of injector we are testing, so we can compare with the reading in **Figure 10**. Why not check all injectors on the car to get an average reading? The resistance value of injectors of the same type should not vary by more than 0.5 ohms when checked against one another. If all injectors on the car check out at approximately 16 ohms except for one that checks out at 12 ohms, you have identified an injector that has begun to lose resistance.

In this case, the injector winding may have begun to develop shorts between the individual turns of its winding. This reduces the available windings that are needed to generate the electromagnetic field and properly control the injector needle valve. A sluggish injector will open slowly and close slowly. When this happens, the oxygen sensor will signal the computer that the mixture is a little too lean (injector opening too slowly) or too rich (injector closing too slowly) and the computer will attempt to compensate.

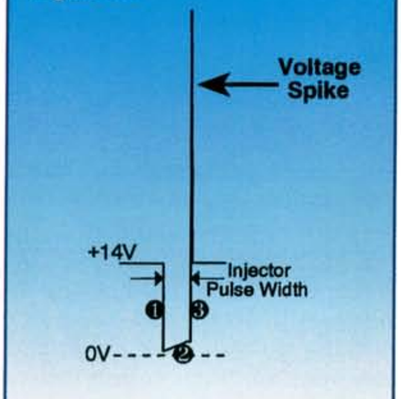
Knowing how much resistance an injector can drop before it begins to affect performance comes from experience that can only be gained by finding problems on different cars and noting the results. The type of vehicle, the type of fuel injector, the type of fuel injection system, the strategy of the computer to compensate for fuel problems, and the degree of injector damage can all affect the results.

While there is much to learn about how partially shorted injectors can affect driveability, a simple digital ohmmeter test can reveal the problem injector. If an injector checks good when cold, don't forget to check it when hot. The problem may not appear until the injector winding is hot and the wires in the winding have expanded enough for the internal short to develop.

Basic Fuel Injector Waveforms

The best test of an injector circuit is to look at the injector waveform with a dual trace lab scope. Over the past few years, several articles on dual trace scopes have appeared in *Import Service*. If you have kept the articles for reference, but are still unsure about basic scope operation, you might want to take the time to review these articles now.

Figure 12



Basic Injector Wave Form

Let's take a closer look at the basic waveform shown in **Figure 12**, which is produced by a saturation injector driver circuit in the ECU. The word *saturation* means that a maximum and constant current flows through the injector during the injector ON time. Increasing the injector current flow any further would be unnecessary because it would not open the injector any faster or farther.

The injector ON time occurs during the low portion of the waveform, which drops from 14 volts to almost 0 volts. The time duration when the signal is low is called the Injector Pulse Width and is measured in milliseconds. Observation of the ON time duration can be used to determine whether the engine is running lean or rich.

Start by determining the normal ON time duration for cold and warm engine conditions at idle and at selected higher RPMs for comparison purposes. A longer (wider) ON time means the injector is commanded rich because the oxygen sensor is sensing a lean condition.

The opposite is also true. A shorter (narrower) ON time means the injector is commanded lean because the oxygen sensor is sensing a rich condition. Just remember the injector ON time is the command the ECU generates in response to conditions sensed by the oxygen sensor, TPS, CTS and MAP sensors.

When the injector is OFF, the injector trace line should be close to the vehicle's charging system voltage (14V). Look for the injector trace to drop to almost zero volts at the beginning of the injector ON time (refer to number 1 in **Figure 12**), then ramp up slightly during the remainder of the ON time (refer to number 2 in **Figure 12**). The ramp is due to the injector winding's reactance, which opposes the sudden rise in current through the winding.

Solenoids oppose changes in current, and a fuel injector is a type of solenoid. When the injector is first commanded ON, the sudden rise of current surging through the injector is met with the maximum winding opposition (reactance) to the current rise and the greatest voltage drop across the winding occurs. As current flow continues to rise through the injector winding during ON time, the electromagnetic field develops and the reactance reduces as the current flow reaches its maximum point.

Different engine management systems and injector types may cause the ramp to have a different appearance from the ramp shown in **Figure 12**. For future reference, check the known good injector circuits on different cars that you work on to learn the exact appearance of their ON time ramp.

At the end of the ON time (number 3 in **Figure 12**) current through the injector is cut off and there is no further voltage drop across the winding. The voltage rises back toward the 14 volt source voltage. At the same instant the current stops flowing, the electromagnetic field collapses and produces the spike at the end of the ON time. The amplitude of the spike is determine by the strength of the electromagnetic field that is released back into the circuit.

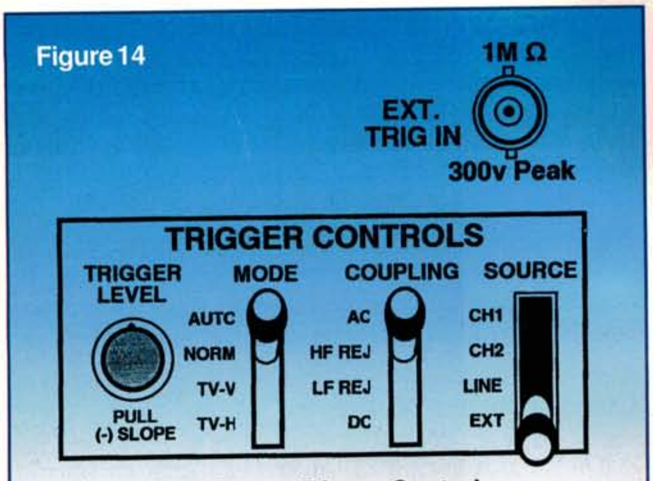
Checking Fuel Injectors With A Lab Scope

The most effective way to analyze injector circuits is with a dual-trace lab scope. And a good way to get a stable injector pattern is to set up a trigger signal. We'll use a signal from the spark plug wire connected to the EXT input on the scope, then probe the injector signal on Channel A. When properly triggered, the injector trace will stay synchronized with the engine speed. This will help to stabilize the injector pattern on the the scope for more accurate analysis of injector pulse width and spike voltage amplitude measurements.

Figure 13

A small binder clip, as shown in **Figure 13**, can be used as an inexpensive inductive pickup for the scope's trigger signal. Be sure to use the smallest binder clip that will properly grip the spark plug wire. If the binder clip is too large, it may sample a voltage signal that is too strong for the scope's EXT input. If the sample trigger signal exceeds 300V input, it could damage the EXT input circuit. Check your scope front panel for the maximum voltage level allowed at the EXT connector (It should be written next to the EXT jack).

Setting Up The Trigger



Lab Scope Trigger Controls

Figure 14 shows a sample set of scope trigger controls:

- Set the X1-X10 switch on the scope probe to X10 to attenuate the trigger signal going into the scope.
- Set the (Trigger) SOURCE switch to EXT to select the external signal as a trigger signal.
- Connect a lab scope probe to the EXT jack, then hook the end of the probe to one of the handles on the binder clip. (The EXT jack accepts a standard scope probe with a BNC connector.)

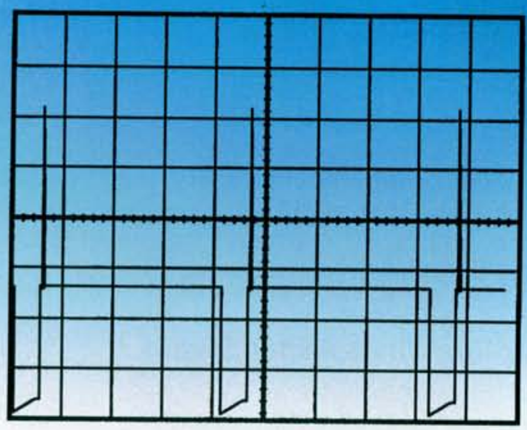
Each time the spark plug fires, a voltage is induced into the binder clip that is carried by the scope probe to the trigger input. The scope trace will begin when the selected plug fires. You may have to experiment with different spark plug wires until you find one that triggers the scope at the proper time so the injector waveform appears at the beginning of the trace.

Sampling The Injector Signal

To finish calibrating the scope:

- Select triggering on the negative SLOPE and adjust the Trigger LEVEL control knob to a mid-range position.
- To select a particular injector waveform for measurement, connect another scope probe from the Scope Channel A (Channel 1) input connector to the computer side of one injector.
- Backprobe the wiring at the injector connector or at the ECU connector.
- Set the VERTICAL Volts/Div and scope probe X1-X10 setting so that each major division is equal to 5V.

Figure 15



Injector Wave Forms

- Set the bottom graticule line at zero volts or ground.

The waveform of a saturation injector driver circuit should look very similar to **Figure 15**, depending on the scope control settings. Scope controls can be adjusted to satisfy individual tastes. Some technicians like to see several injector patterns on the scope at one time, as shown in **Figure 15**. The SWEEP RATE must be slower, like 20 ms/Div or 50 ms/Div to get this display.

Some technicians like to see only one injector pattern on the scope. To see one injector waveform per sweep, select a faster sweep rate like 10 ms/Div or 5 ms/Div. Play with these TIME/DIV settings until you get the correct pattern on the scope that will enable you to measure the time duration of the injector pulse (pulse width) and the amplitude of the voltage spike.

On some lab scopes, the trigger level does not function when EXT trigger is used. If trigger level does work in EXT position with your scope, then a slight adjustment to either side of the center position will help stabilize the trigger circuit for smooth triggering at the same point on the negative slope of the injector waveform every time.

Analyzing Injector Waveform Patterns

The following characteristics of the saturated injector waveform are illustrated in **Figure 16**:

Correct Pulse Width

The time duration of the pulse width, or injector ON time, is determined by comparing the pulse width with a major division's time duration which has been selected with the TIME/DIV control. Make sure that the Variable Control is set to the CALIBRATE position to ensure that the TIME/DIV setting is calibrated. Briefly disconnect the engine coolant temperature sensor (CTS) to trick the ECU into believing that the engine is cold. The injector pulse width should increase. Next ground the CTS wire. This tricks the ECU into believing the engine is very hot. The injector pulse width should decrease slightly. Immediately reconnect the CTS wire to avoid setting a trouble code.

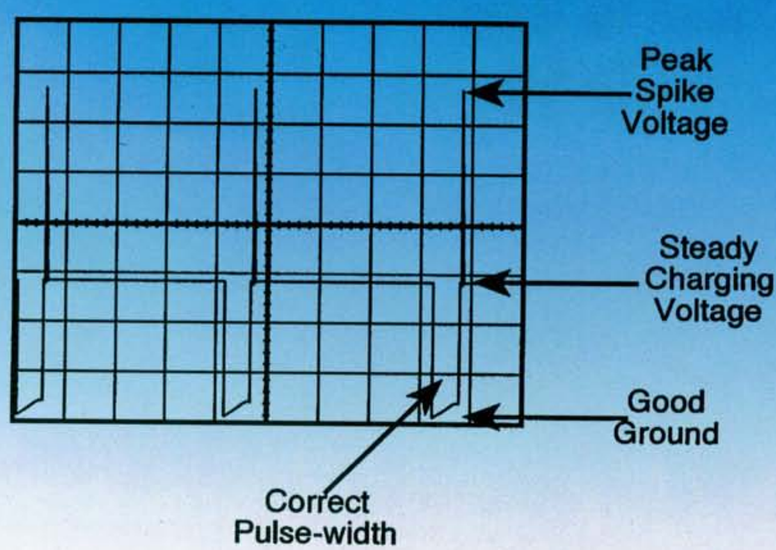
Good Ground

The injector waveform will come very close to ground during the ON time. Whether it actually reaches ground depends on the type of injector driver that is inside the ECU. If the ON time portion of the waveform is 5 volts above ground instead of nearly zero volts as shown in **Figure 16**, the ECU driver may be defective or the ECU ground may be bad.

Steady Charging Voltage

The injector trace line should hold steady at the vehicle's charging voltage when the injector is switched OFF. In **Figure 16**, this is shown at about 14V. Variations from a normal straight line at 14V during this period may indicate a noisy alt-

Figure 16



What to look for in Injector Wave Forms

ernator (ripple).

A car we repaired recently showed one injector trace line of 8V, while the rest of the injector waveforms were at the proper 14V level. An ohmmeter check showed the injector had the proper resistance when compared with the other injectors on the vehicle.

A replacement ECU fixed the problem. The ECU's injector driver for the affected injector was not turning OFF completely. ECU current continued to flow through the injector, even after the ECU was supposed to have turned the injector OFF. This caused a voltage drop across the injector winding, and produced the lower-than-normal 8V injector trace line.

Peak Spike Voltage

Last month we explained that the voltage spike at the end of the injector ON time was caused by the electromagnetic field collapsing as the injector turned OFF. The amplitude (height) of the spike is influenced by the release of energy stored in the electromagnetic field surrounding the injector winding. The spike is allowed to rise to a predetermined level for faster closing of the injector.

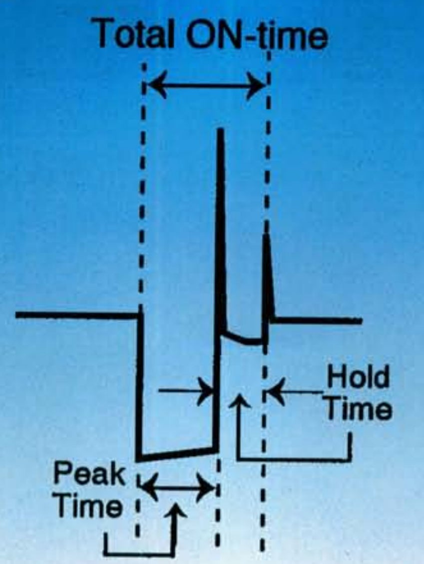
A low spike means the injector is not being assisted in closing fast enough to shut OFF the fuel. This may be due to a partially shorted injector winding (fewer winding turns produce a weaker electromagnetic field), resistance in the injector circuit that is sufficient to lower injector current (less current produces a weaker electromagnetic field), or a spike suppression diode in the ECU that is breaking down under load. Don't ignore injectors with low spike amplitude. Low spike amplitude indicates real problems that will affect driveability.

If the spike amplitude is too high, it usually means the spike suppression diode in the ECU is too weak to do its job. A new ECU should solve the problem. How do you know how much spike amplitude is normal? Check several known-good injector circuits, then write down your results for future reference.

Peak and Hold Injector Circuits

Injectors with very low resistance values of about 1.0 ohms, such as the injectors found in throttle body injection systems, are often controlled by a technique called Peak and Hold. It takes about 4 amps to open this type of injector, but only 1 amp to hold it open. In Peak and Hold injector control systems, an initial 4 amps (Peak) is used to quickly open the injector. Once the injector has been opened, the current drops to 1 amp to Hold it open. A Peak and Hold injector waveform is shown in **Figure 17**.

Figure 17



Peak and Hold Injector Wave Form

Notice the total injector waveform is divided into two time periods of "Peak" and "Hold." During the Peak period, approximately 4 amps pulls the injector open. At the end of the Peak period, the ECU reduces current flow to 1 amp to Hold the injector open for the remainder of the ON time.

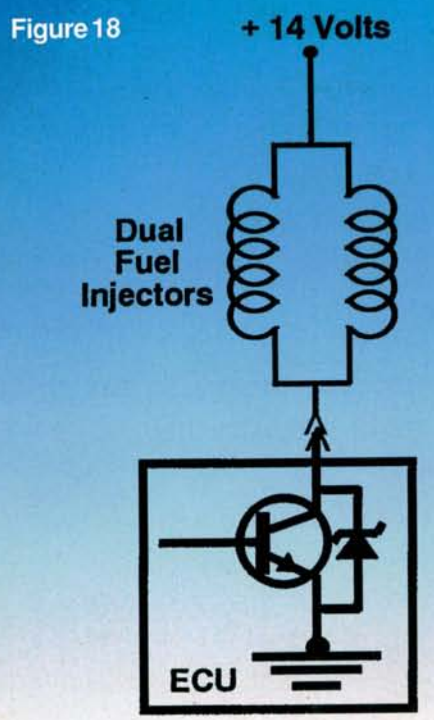
At the close of the Peak period, the drop in current causes a major reduction in the strength of the electromagnetic field. The result is a large spike at the close of the Peak period as a large percentage of the electromagnetic field dumps back into the circuit. The remaining 1 amp of current flow keeps the injector open during the remainder of the Hold period. In **Figure 17**, the remaining electromagnetic field produced by the 1 amp injector current produces the smaller voltage spike at the close of the Hold period.

Variations of the Peak and Hold injector strategy are used by different vehicle manufacturers, so not all Peak and Hold injector patterns will appear identical to the example in **Figure 17**. With practice, you will be able to quickly identify many different Peak and Hold injector circuit patterns.

Injectors Wired In Parallel

When two injectors are wired in parallel, as shown in **Figure 18**, they are controlled by a single driver inside the ECU. If one of the injectors begins to drop in resistance, more current will flow through the driver circuit. The driver senses a higher current and enters a current limiting mode to protect itself from burnout. Due to the lower-than-normal current flow, both injectors fail to get proper excitation and become sluggish.

Since most of the current will flow through the injector that has the lowest resistance (current takes the path of least resistance), the good injector in the injector pair can't work properly either. The end result is that less fuel enters the engine and the oxygen sensor signals the ECU that the engine is running lean. The ECU responds with a longer pulse width, which means the engine will begin to run



Dual Fuel Injectors

rich. How this effects driveability depends on how badly the injector is shorted and how much the ECU can compensate by increasing the injector pulse width.

This condition can be noted by observing the waveform of each injector bank. Compare the spike voltage amplitude for different banks of injectors. The injector bank with the shorted injector will have a lower spike voltage because a shorted injector will not be able to develop an electromagnetic field that is as strong as the electromagnetic field created by a good injector bank. Once you have isolated the weak injector bank, test the individual injectors in the bad bank with a digital ohmmeter to determine which one is bad.

Good, Bad, and Ugly

A successful electronic fuel injection system diagnosis depends on your ability to accurately identify and separate fuel injectors that are functioning normally from those that are malfunctioning. The preceding troubleshooting techniques should improve the odds of picking out the good, the bad, and the ugly.

—By Vince Fischelli