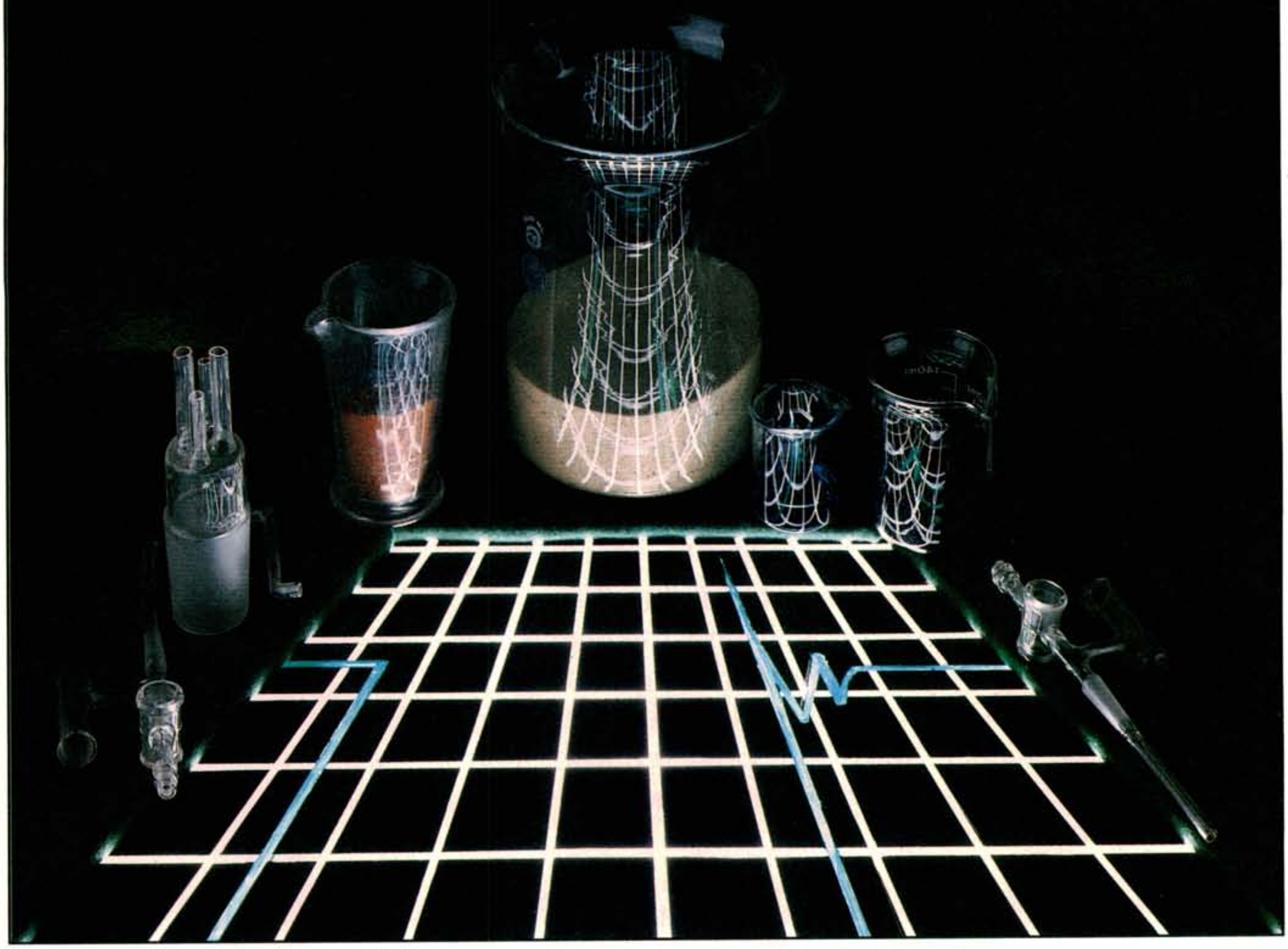
Trace Elements
Part II



Last month we tried to take some of the fear out of using an oscilloscope as a diagnostic tool. There's little doubt that some of you will still be skeptical about the merits of the scope, thinking that all this high tech stuff is a waste of your time and money.

Before we start **Part II** of our article, we'd like to take a few moments of your time to emphasize the advantages of using the scope, and also clear up a few common misconceptions about our televised voltmeter.

Common Misconceptions

1) The scope takes too long to hook up.
The scope does take a little longer to set up than your DVOM. But with practice, you should be able to make your initial adjustments, warm up the CRT, and start your tests in less than five minutes.

2) My DVOM will do anything the scope can do.
Of course you're not about to get rid of your DVOM. It's still fast and easy, and far better suited than the scope for some jobs like quick tests of battery post voltage and simple voltage drop tests in tight quarters.

But the scope will do some things your DVOM won't do. Its ability to capture a picture of an analog or digital voltage signal allows you to watch events which occur too quickly for the DVOM to capture and display.

Just as importantly, you can look at the shape of certain voltage signals. Please remember that while certain signals can be generated at the correct voltage levels they may still have an incorrect shape. The control unit or computer may fail to recognize the signal for this reason. The DVOM won't give you this information.

3) I wouldn't use a scope often enough to make having one worthwhile.

You may have us with this one. To use or not to use, that is the question. This choice is strictly up to you. But the more often you choose the scope as a diagnostic tool, the friendlier it gets.

If you're going to let the scope collect dust until you're forced to turn it on in a moment of desperation, it'll probably disappoint you. Not because it won't do the job, but because you aren't familiar enough with its capabilities to get the most out of it.

This brings us to the importance of testing known good cars and their components.

The Good, the Bad, and the Unknown

This suggestion has to do with your making an investment in time. In **Part I** of this article, we lamented the absence of good repair information about signal patterns and their frequencies. It's too bad, but it's true.

Your only option may be to test a known good car of the same model, year, and type. Getting the car may be the hard part unless you're a specialist, are working on a Saab, and have a lot filled with Saabs to "borrow" for test purposes. Once you've found a comparable car in good running order, comparison testing is fairly easy.

Here's how to do it:

• **If possible, get the two cars side by side.** Set up the scope, and sample a signal on the good running car. If there is a sensor most likely to cause your specific problem, start there. You'll want to eliminate the most probable causes for the driveability problem at hand.

Let's say you've got an intermittent ignition miss that comes and goes, and you've been unable to find the cause. We have a Saab that's doing just that, and we think our problem may be caused by the Hall effect sensor in the distributor.

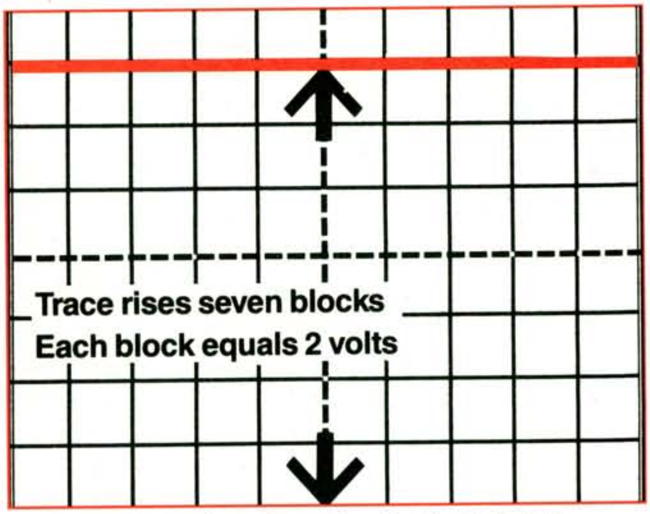
We'll use the procedures outlined in last month's article to view and measure the voltage and duration of the voltage, ground, and trigger signals at the Hall unit.

Fine tune the scope to get the best possible view of the signal on the good running car. Don't change the settings on the scope. Then test the same output on the problem car. Use an accurate tachometer, and make sure both engines are running at the same RPM, since the frequency of the signal changes with engine speed.

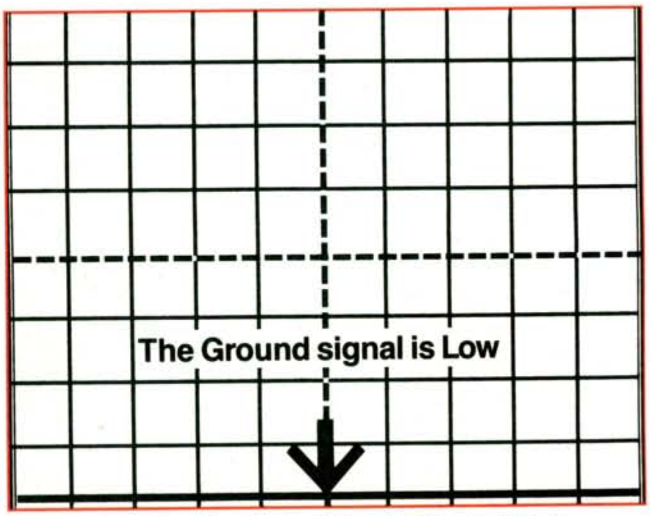
You should see the same signal on both cars. The sweep rate of the scope is calibrated to make these types of precise measurements of time. If you don't change the scope settings as you move from the known good car to the problem car, but the amplitude, time duration, or shape of the square wave is different, you've found a problem.

Maybe the signal comes and goes, or is misshapen. Comparing the signal to a known good signal will point up the differences between a good and a bad signal.

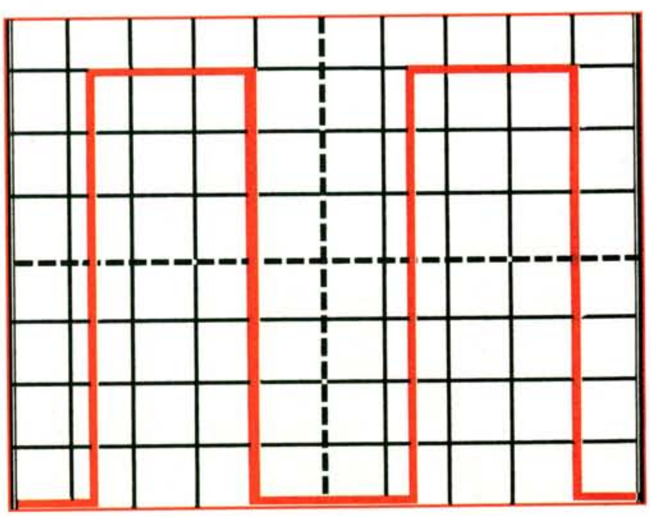
Our illustrations show you an example of the tests for voltage, ground, and the Hall effect signal.



Measuring the Voltage Signal at the Hall Unit.



Measuring the Ground Signal at the Hall Unit.



Viewing the Square Wave from the Hall Unit.

Trace Elements

In the test on the previous page, the scope is set to the 5 ms setting. To verify a similar signal on another car, leave the scope at the same setting and sample the other car for comparison.

Time and Frequency

Sometimes, the spec you get from a manufacturer will not be given in time, but in *frequency*. Once the time duration of the sensor signal is measured, it can easily be converted to frequency for purposes of comparison.

If you've made a time measurement with the scope, it can be converted to frequency with this formula:

$$\text{Frequency (Hz)} = \frac{1}{\text{Time (in seconds)}}$$

When measuring sensor signals, remember that time and frequency have a *reciprocal* relationship.

- **If the time duration increases, the frequency decreases.**
- **If the time duration decreases, the frequency increases.**

Here's a sample formula for calculating the frequency of a 25 ms signal. A millisecond is one thousandth of a second, so we need to move the decimal point three places to the left for our equation. Our 25 ms time measurement is converted to a decimal and becomes 0.025 second.

$$\text{Frequency (Hz)} = \frac{1}{0.025}$$

The frequency of this signal is 40 Hz, (it repeats itself 40 times each second). You'll need to convert the time measurement made by the scope to frequency in some cases before comparing it to a spec given in Hertz.

Going the Other Way — Hz to ms

There is another way to convert measurements when a specification is given in frequency. You can convert the frequency spec to time and then make your measurement to see if it matches up.

For instance, if the manufacturer gives a spec for a Hall sender of 150 Hz at 850 RPM, you can convert the frequency spec to time by using the following formula:

$$\text{Time (in seconds)} = \frac{1}{\text{Frequency (Hz)}}$$

Insert 150 into the formula:

$$\text{Time (in seconds)} = \frac{1}{150}$$

The time duration of the signal is 0.0066 seconds. This time, we convert seconds to milliseconds by moving the decimal point three places to the right. The time duration of this signal is 6.6 ms.

Now that we know the duration of the signal, we can set the scope to measure it. To make this time measurement an easy task, set the Time/Div control to 1 ms/Div. That means the signal will span 6.6 divisions on the graticule (reading from left to right). Again, the sweep rate of the scope, controlled by the Time/Div control is calibrated to make these precise measurements.

Always make sure the VARIABLE knob in the center of the Time/Div control is turned fully clockwise to the snap-to-lock position.

Pulse Width Modulated Signals

Now that we've spent time discussing the signal inputs, it's time to take a look at the output signals from the ECU which control a number of actuators in the car.

Actuators receive something called Pulse Width Modulated signals, abbreviated as PWM signals. Actuators can be controlled to open for a very small amount of time or a large amount of time with just a slight change in the PWM signal.

PWM signals are either High or Low to regulate an actuator's ON time.

Let's say that one terminal at each actuator is connected to battery voltage. One terminal at the actuator is hot all the time. If the PWM signal is High (usually close to battery voltage), the actuator winding doesn't get energized, and it stays closed. If the PWM signal goes to a Low voltage level, the winding in the actuator has both voltage and ground, the winding is energized, and the actuator opens.

It's the relationship between the High and Low levels of the signal which determines how long the actuator stays open. A sample signal is shown in **Figure 1** below. In our figure, the signal is High more than it is Low.

By referring to the settings on the scope, and counting the number of divisions up and down on the graticule, we can measure the amplitude, or voltage level of the signal. In this mode of operation, our oscilloscope is acting as a voltmeter.

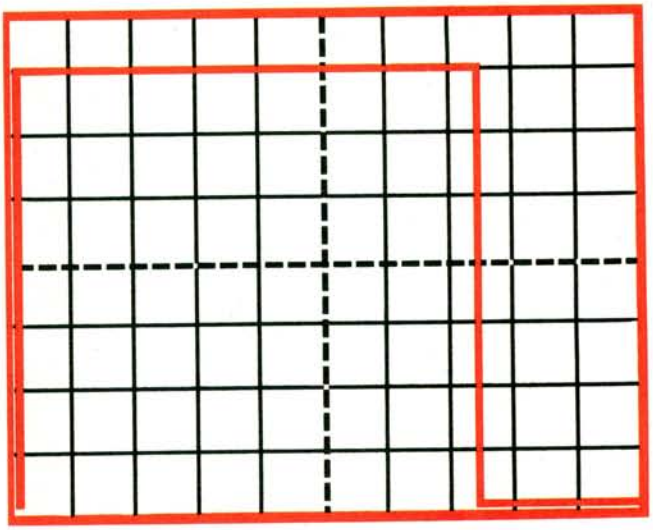


Figure 1. In this Figure, the High signal lasts longer than the Low signal.

Since the High signal is equal to charging voltage in this car, and the Low signal is close to zero volts (ground), the amplitude of the signal is approximately 14 volts.

How Long Does It Last?

We now know that we have a signal being sent to the actuator at the correct amplitude. What we don't know yet is how long the PWM signal keeps the actuator open. The scope lets us measure the time duration of the PWM signal as the total elapsed time from the beginning to the end of the signal.

This time, refer to the Time/Div setting on the scope, count the number of blocks on the graticule covered by the signal, and determine the PWM signal in either seconds or milliseconds. The PWM signal in our Figure had a time duration of 2.5 ms, or 0.0025 of a second. If we divide the number 1 by 0.0025, we see that the signal has a frequency of 400 Hz.

The signal occurs 400 times each second.

Understanding Duty Cycle

We have one last concept to master before we're through, so please stick with us for a moment longer. We know that the signal lasts for 2.5 ms, and that it occurs 400 times each second. But each PWM signal is made up of one High and one Low voltage — both occurring within that 2.5 ms interval.

For example: If the High time lasts for 2.0 ms, that leaves only 0.5 ms for the Low time. If the High part of the signal lasts for 0.5 ms, that leaves a whole 2.0 ms for the Low part of the signal.

The relationship between the High and Low signal is called the Duty Cycle. This is the percentage of time that the PWM signal is keeping the actuator ON. The total time allotted for the High and Low part of the PWM signal does not change. In this case it is always 2.5 ms.

An increase in the High time leaves less of the available time for the Low part of the signal, and vice versa.

Percent of Duty Cycle Controlling a Switch-to-Voltage

If the computer switches voltage to turn on an injector, the percent of Duty Cycle refers to the amount of time the signal stays High. In this case, one side of the injector winding is constantly grounded, and the High, or source voltage part of the signal, completes the circuit.

The PWM signal shown in **Figure 2** is running at about 40 percent duty cycle. The signal stays High for 40 percent of the available 2.5 ms pulse width interval. If the duty cycle increases, the injector stays ON for a longer time.

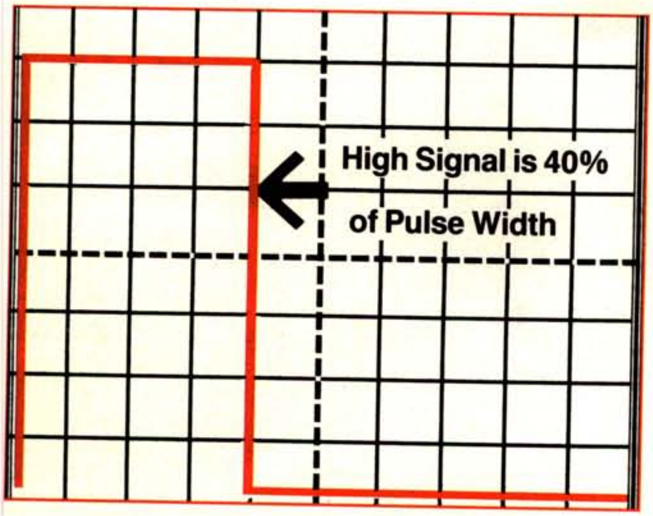


Figure 2. The High part of signal lasts 40 % of the PWM signal.

Percent of Duty Cycle Controlling a Switch-to Ground

It's common for a manufacturer to use the Low part of the signal to control the ON time of an actuator. In these systems, one wire to the actuator is hot all the time. Then the Low part of the signal is used to control actuator ON time.

The Low part of the PWM signal acts as a switch-to-ground. By moving the transition line (the vertical line in the signal) from left to right, the ECU controls the relationship between the High and Low times.

Whatever time is taken from one part of the signal is given to the other. Remember, the total elapsed time of the PWM signal doesn't change.

What DOES change is the way the time is divided between the High and Low signals. Adding the High time and Low time together will always give you 100 percent of duty. If High is 60 percent, Low is 40 percent. If the High part of the signal drops to 21 percent, then the Low part of the signal stays ON for the remaining 79 percent of the allotted time.

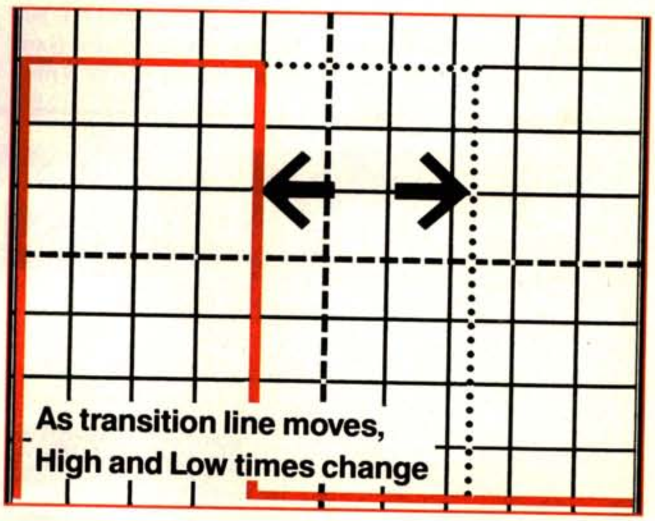


Figure 3. Movement of transition line (dotted line) changes the relationship between High and Low portions of the signal. This controls the ON time of the actuator.

Measuring Injector ON Time

Perhaps the most recognizable actuator type is the fuel injector. Injectors can be turned ON and OFF very rapidly. They can be told to stay open for a very short time to limit fuel delivery, or told to stay open longer when more fuel is needed. A slight change in the PWM signal can make a big difference in fuel delivery rates.

Percent of duty cycle can be used to measure the ON time of a fuel injector. Once again, we'll use our scope to make this measurement.

Proceed as follows:

- **Set up the scope as described in Part I of this article.**

Set the TRIGGER/SLOPE switch on the scope to the (-) negative setting. Set the AUTO/NORM switch to the NORM position.

• **Since our sample injectors have one wire hooked to source voltage, we want to measure the Low, or ground portion of the signal.**

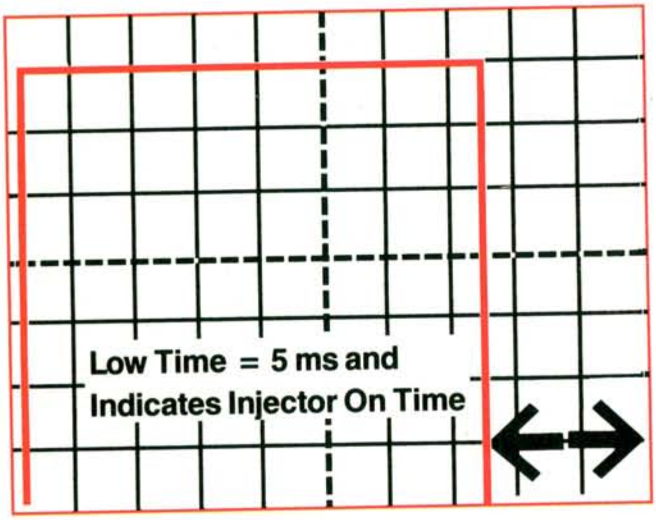


Figure 4. Checking the Time/Div setting, we see that it is set at 2 ms per division. The total ON time of our injector (Low part of the signal) is then 2.5 divisions X 2 ms/div, or 5 ms.

• **Place the tip of the probe on the ground side of the injector.** Then, with the engine running, adjust the trigger level until the injector wave form appears on the scope screen. By carefully adjusting the trigger level at idle speed, you'll make the injector wave form appear at the left side of the graticule.

• **Note the time duration of the injector ON time.** Since this is a switch-to-ground circuit, the injector is ON when the signal is Low. If the picture of the Low time is too narrow on the screen for you to accurately measure it, speed up the trace by adjusting the Time/Div knob. This will magnify the trace. Then measure its width on the screen and calculate the time.

In **Figure 4**, the low part of the signal spans 2.5 blocks on the graticule.

A Word About Injector Frequency

The injector wave form has a definite pulse width, but no definite frequency. The frequency of the injector pulse width is dependent on engine RPM. In most cases, there should be an injector pulse width every two engine revolutions.

Primary considerations when viewing injector signals are pulse width, and the correct shape of the wave form.

There are two things to look for when viewing the pulse width:

• **Correct amplitude,** or the proper range between charging voltage (High) and Low voltage (ground).

• **Shape of pattern.** Look for a crisp, sharp signal, and determine the time duration of the injector pulse width.

Keep an eye on the amplitude of the voltage spike created when the injector winding collapses as it is turned off. Compare the size of the spike to a manufacturer's spec or a known good injector. If the spike is too high, it could be warning you that the spike suppression diode in the driver circuit is open.

What Affects PWM?

If a computer gets faulty inputs from various sensors, it will have no choice but to use that information when it calculates injector ON time. Before condemning the computer, make sure that all inputs which determine pulse width are correct.

A prime example is the computer's heavy reliance on the Coolant Temperature Sensor (CTS) as an input. When coolant temperature sensor voltage is close to five volts (engine cold), the computer keeps the injector ON longer to provide enrichment. As the engine warms up, the CTS voltage drops to about one volt to tell the computer that the engine is warm, and needs less fuel.

If the CTS doesn't do its job, the computer isn't to blame for the rich fuel mixture which results. Do not condemn an engine computer until you're sure the inputs to it are correct.

Now Is the Time

Subaru recently became the last auto manufacturer to give up on carburetors. Even the entry-level Subaru Justy is now equipped with a fuel injection system. It looks like fuel injection will be the only fuel system used on cars imported to the United States for the foreseeable future.

We've given you examples of fuel injection system tests to illustrate how the scope works, but these are just a few of the many diagnostic tests that can be quickly, easily, and accurately completed using a scope. We hope this two-part article has encouraged you to start using your scope on a regular basis. If fuel injection is going to be the only game in town, your scope will at least help you learn the rules.

— By Vince Fischelli