Up Scope

PART TWO

Now that most of you have your sea legs when it comes to setting up a lab scope for automotive testing, we're ready to cast off on the second part of our cruise. In part one of "Up Scope" we kept it simple, and let you fire away at some simple problems. But the time has come to polish your scope skills.

Those of you who've been promoted to the rank of Scopeman First Class can start focusing on the fine points of scope troubleshooting. This article will concentrate on the following topics:

- **How to use the X10 setting on the scope probe.**
- **How to adjust the sweep rate for a better picture.**
- **How to identify common wave patterns.**
- **How to identify common input and output signals as an aid to troubleshooting.**

X10

Last month we said we'd give you a better explanation of the X10 setting on the scope probe. The X10 setting is a handy feature. Suppose you're scoping a circuit and find that the scope is loading down the circuit too much. Maybe you'll notice that the circuit stops operating when the scope probe makes contact at the test point. Or maybe the scope pattern will be so low in amplitude that the pattern is unusable.

Flip the switch on the probe to X10. You increase the scope's input resistance, which reduces loading of the circuit by 10 times.

If you wish to continue measuring at the same volts/division, however, you must multiply the Vertical Volts/Div setting by a factor of ten at the same time. Here's why. If the Vertical Volts/Div setting was at 5 volts with the probe switch set at X1, each major division of the vertical graticule was 5 volts. But changing the probe switch to X10 does just that to each major division—it multiplies the current setting by 10. Each major division becomes 50 volts! It now takes a 50 volt input to move the trace one full centimeter block on the scope face.

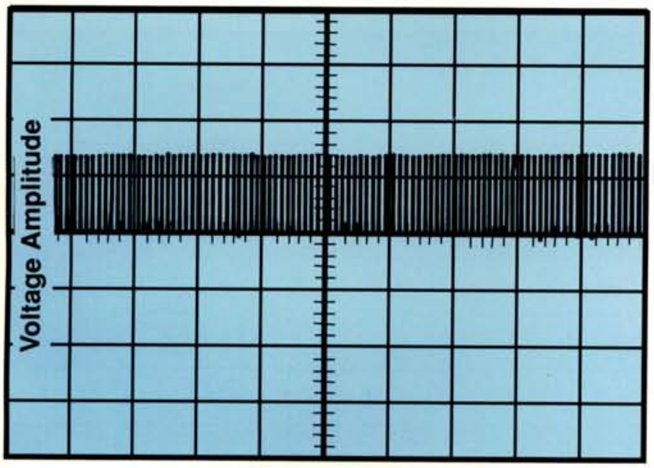
To overcome this problem, we must move the Vertical Volts/Div knob to .5 volts to compensate. Now we're back to 5 volts per division (.5 x 10 = 5 volts per major division). We have higher input resistance, but we stay on the same scale we were using before setting the probe switch to X10.

The X10 setting is also handy if we're picking up too much ignition noise while testing under the hood with the engine running. By switching to X10 we reduce the effects of noise interference by 10 times. Practice using both switch settings, being careful to adjust the Vertical Volts/Div setting each time you change the range of the probe.

Adjusting the Sweep Rate

If you remember last month's cruise, you'll also remember that we compared the Sweep Time/Div control to two cars moving down the road. As long as the two cars move at the same speed they can keep each other in clear sight, and there isn't any perception of motion. See Figure 1.

Figure 1 Time Base (Sweep Rate)



Too Slow a Sweep Rate

In Figure 1, we see a waveform that is so compressed that it's impossible to analyze. Yet the signal is standing still.

There are two reasons for this:

- **The signal is fast.**
- **The scope is locked-on to it.**

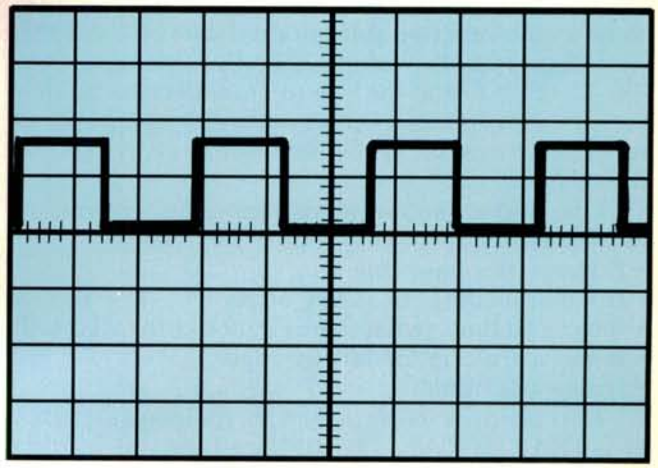
This next part is potentially confusing, so pay careful attention. The reason the signal is hard to read is that the scope sweep rate is too slow. Too much of the signal passes in front of us during each sweep. Instead of concentrating on one small part of the car next to us, we're trying to look at all of it. It's confusing.

What we want to do is speed up the sweep rate to magnify the part of the signal we want to analyze. If our sweep rate is 5ms for each one centimeter block on the screen, then we need to change the rate to 1ms (or even .5ms). The signal that was compressed into one block of the graticule is now spread out over 5 blocks. It's magnified and enlarged so we can see it better.

The faster sweep rate looks at a smaller portion of the signal, but lets us see the details a lot better.

See Figure 2.

Figure 2



That's Better

The scope stays locked-on to the signal, but the signal spreads out because the scope sweeps faster. Select the faster position of the Sweep Time/Div control to get the number of waveform receptions needed to see the enemy. It's up to you to select the final setting. No sense wasting valuable torpedoes.

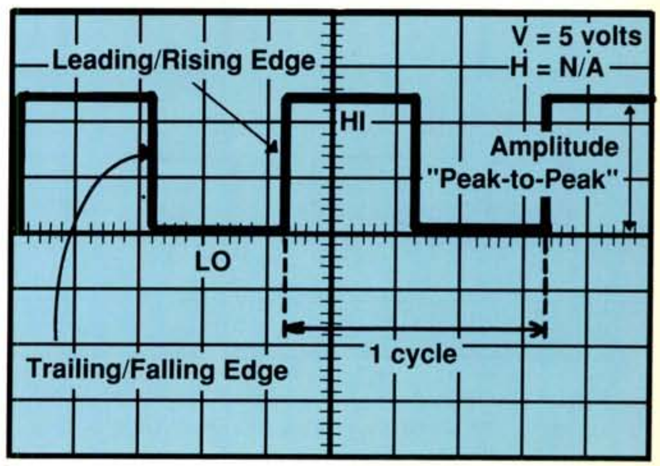
Identifying The Enemy

You insomniacs are all familiar with the late night movies where the submarine captain looks through his scope and then compares the silhouette of the enemy ship to a book of silhouettes compiled by military intelligence. The outline of each ship is distinctive, and the images help the captain tell the difference between friend and foe.

Scope patterns are like that. We need to identify both good and bad patterns. Nobody gets a medal for sinking a friendly ship.

The first pattern we want to identify is the SQUAREWAVE. The basic squarewave is shown in Figure 3.

Figure 3 Base Line



Notice the "V =" and "H =" symbols in the corner of our illustration. From now on, whenever we show a waveform that you can duplicate on a vehicle, we will give you the Vertical Volts/Div setting after the "V =" symbol, and the Sweep Time/Div setting after the "H =" symbol. That way you'll know where to set those two vital knobs to see the signal in our illustration.

The basic squarewave has the following characteristics:

- **It starts at a base line.**
- **It has a leading, or rising edge.**
- **It has a HI time. (what some might like to call dwell)**
- **It has a trailing, or falling edge.**
- **It has a LO time.**

The leading or trailing edges are sometimes referred to as TRANSITIONS. The distance from one leading edge to the next leading edge represents one complete cycle of a squarewave.

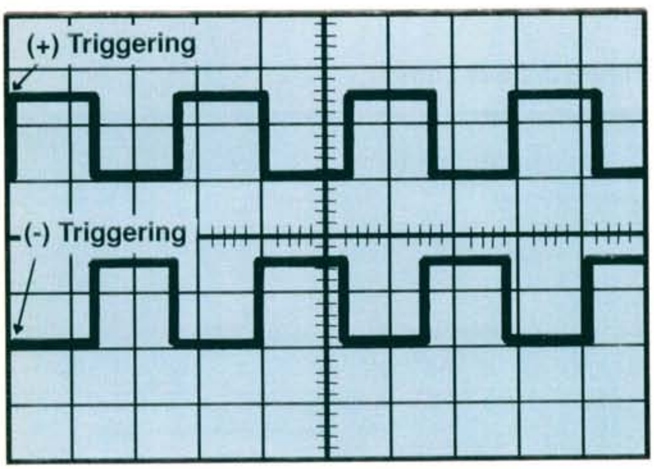
The distance from the base line to the top of the squarewave is called AMPLITUDE, or peak-to-peak, and in this case is 12.5 volts. Notice the 5v after "V =" that shows we're on the 5-volt scale. Since we're on the 5-volt scale and the trace has moved up just over two and one half blocks on the graticule, we are reading 12.6 volts, or battery voltage. There is no value given for "H =" yet, because we're not using a real vehicle. This is a test . . . only a test.

The squarewaves shown in our illustration just repeat themselves over and over again.

+/– Triggering

The plus/minus triggering feature is handy when you're having trouble getting the scope to lock-on to a signal. Sometimes, if you can't lock-on in (+) Triggering, try using the (–) Triggering position of the switch or vice versa. See Figure 4.

Figure 4



Notice in Figure 4 what happens when we lock-on to the squarewave. In the (+) Triggering position, the scope begins the sweep on the rising edge, or (+) transition of the squarewave.

In the (–) Triggering position, the scope starts the sweep on the trailing, or (–) transition of the squarewave.

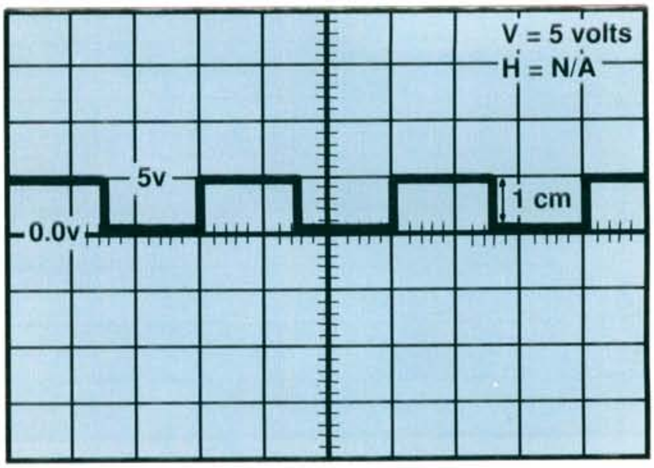
To take advantage of this control, try both settings when attempting to lock-on to a signal. One position of the switch may work better than the other, especially when looking at a signal with a lot of changes in the voltage signal.

Normal 5-Volt Squarewave

A normal 5-volt squarewave is shown in Figure 5.

Before analyzing any squarewave with the scope, we need to establish the baseline for a good ground, and know the amplitude of the signal. In our illustration, note the following:

Figure 5



- **The baseline is 0.0 volts, a good ground**. Remember the S.O.P. for ground calibrations covered last month. When analyzing a squarewave pattern, the baseline calibration must be carefully determined, or all our other readings will be inaccurate.
- **We've set the "V = " for a 5-volt signal in this case, since that is the correct range for this particular signal.**

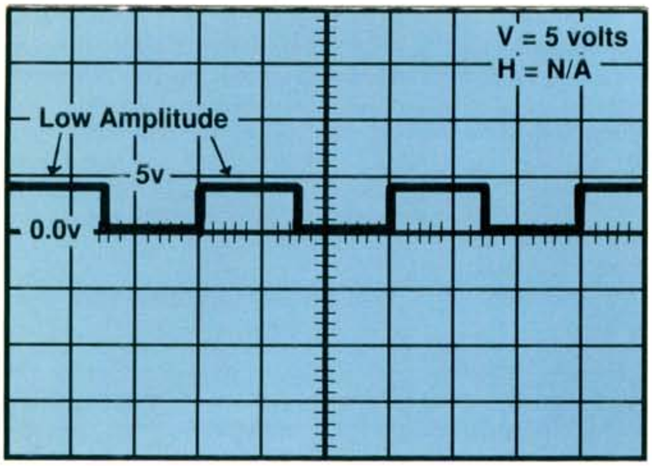
Caution: We often need to know what a good pattern should look like before deciding that the pattern on our screen is bad. Keep a notebook with drawings of known good waveform patterns and the correct Vertical Volts/Div and Sweep Time/Div settings used to see those waveforms. This notebook will become an important reference tool.

Low 5-Volt Squarewave Amplitude

When the amplitude is low, as in Figure 6, Fire One! In this case, the silhouette of this signal tells us that we are dealing with the enemy. This low amplitude signal is caused by one or all of the following:

- **Low supply voltage.** (a weak battery with key-off or low charging voltage with the engine running)

Figure 6

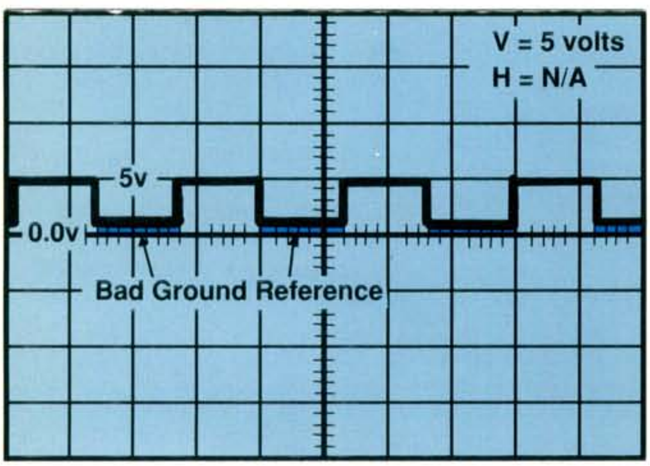


• **A damaged supply circuit supplying the 5-volt squarewave.** (caused by poor connections or damaged wiring)
• **Low resistance in the circuit receiving the squarewave.** (this low resistance loads down the circuit and pulls down the squarewave amplitude)
• **Weak semiconductor components.** (like driver transistors)
• **Moisture contamination of the circuit board.** Moisture provides a parallel path for the squarewave to follow. This extra path loads down the squarewave circuit. Circuit boards suffering from moisture contamination usually have to be replaced.

Bad Ground Reference

When DC voltage appears on the ground side of the squarewave as it does in Figure 7, Fire Two! Here are the most likely causes for this problem:

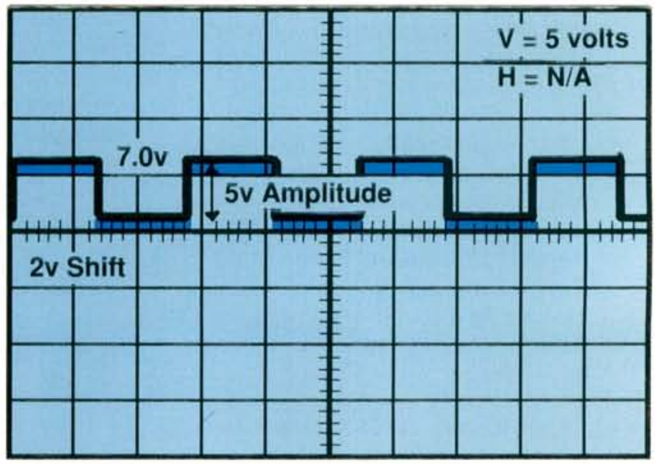
Figure 7



• **A bad vehicle ground.**
• **A bad ground on the circuit producing the squarewave.**
• **A bad ground reference caused by a defective semiconductor driver inside the ECU.**
• **Moisture contamination on a circuit board that allows voltage to "leak" into the squarewave circuit.**

Caution: Never condemn a signal until you have checked, and if necessary recalibrated the ground reference. An improperly adjusted baseline combined with a low amplitude signal could also give you a pattern like the one in Figure 8.

Figure 8



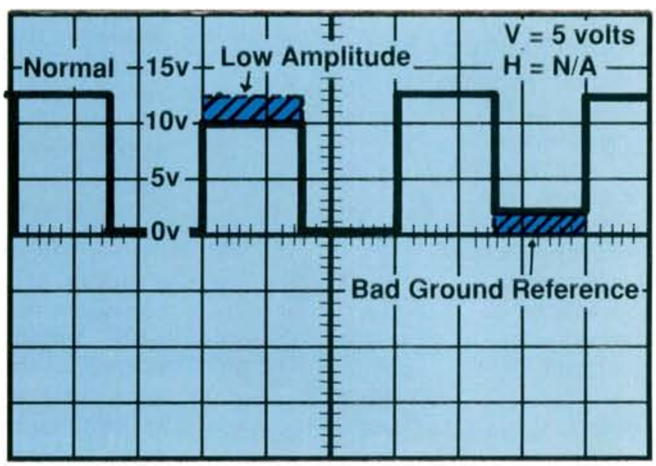
Shaded Areas Show Signal Shifted Out of Place

Shifted Voltage Levels

Figure 9 shows what happens when the entire signal randomly shifts from known good levels. Aside from a changing ground reference, this can also be caused by all the problems that would affect low amplitude or ground reference (loose vehicle ground or a bad connection?) on an intermittent basis.

Defective semiconductor components or moisture contamination are also likely causes.

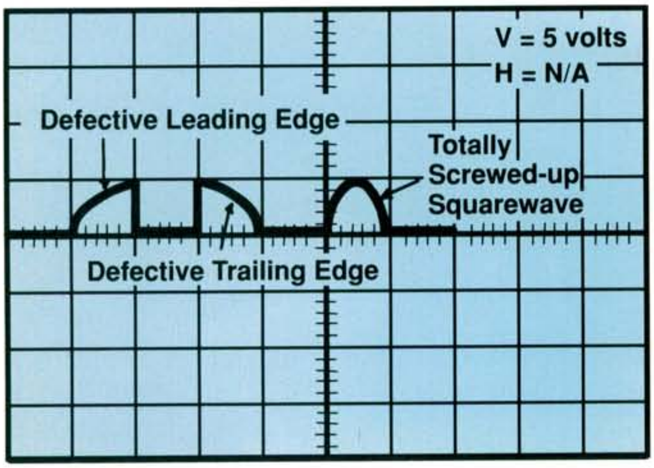
Figure 9



Signal Distortion

Figure 10 shows a squarewave with a different type of signal distortion caused by failed semiconductor components in the ECU. Here's where hands on practice and experience become vital. Since some GOOD sensors will have individual characteristics that are not strictly "by the book," we have to know a good signal from a bad one before we start.

Figure 10



We're back to looking at silhouettes. For instance, not all ships look alike, but we all know a ship when we see one. And we all know a battleship from an aircraft carrier. That's the kind of information you only get from watching ships sail by over a period of time.

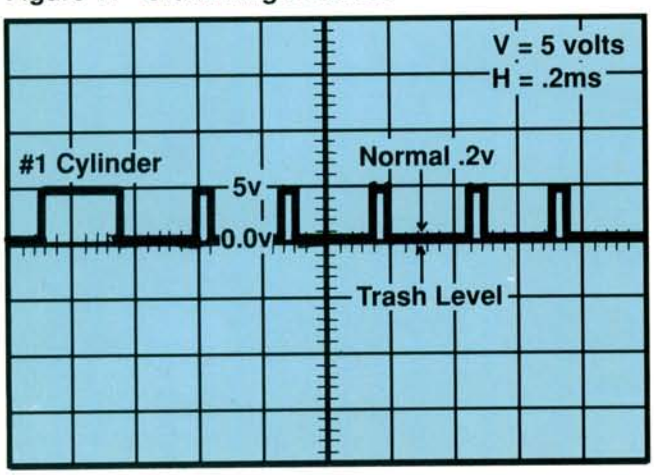
Scope signals are like that.

There won't be any substitute for practice and the lessons to be learned from practice when it comes to knowing good patterns from bad ones. We need to watch scope "traffic" long enough to tell the ships apart. As we said earlier, a notebook with "known good" patterns will become as valuable to you as your scope in the long run.

Crank Angle Sensor

Figure 11 is a signal from a crank angle sensor with the engine running at idle. The sensor on this vehicle is mounted inside the distributor and uses a slotted wheel passing between an LED and a photo diode to send its signal.

Figure 11 Crank Angle Sensor



The waveform was sampled by backprobing the sensor terminal at the ECU connector. This is a 5-volt amplitude signal. Notice the 0.2 volt "trash level" caused by noise and DC voltage at the ground reference. This is normal. It also tells you that the ECU is properly grounded to the negative post of the battery.

The amplitude is 5 volts and there are six pulses, one for each cylinder. The pulse with the longer dwell is sent by a larger opening in the trigger wheel for the number one cylinder. The remaining, shorter pulses are used by the ECU to fire the coil for the other five cylinders. Make sure you have the correct number of pulses.

If one pulse is missing, the engine will probably have a miss. This may be caused by a dirt-clogged reference slot between the LED and photo diode in the distributor. In this case, the miss will always be on the same cylinder. On the other hand, an intermittent open in the sensor will result in a random misfire.

360 Degree Sensor Input

The 360 degree sensor on our test vehicle sends a separate signal to the ECU. A ring of slots in our test car's distributor sends an engine speed signal. There are 360 slots, one for each degree in a complete circle. These slots are very thin, and send a more precise speed signal to the ECU. See Figure 12.

Figure 12 360 Degree Signal

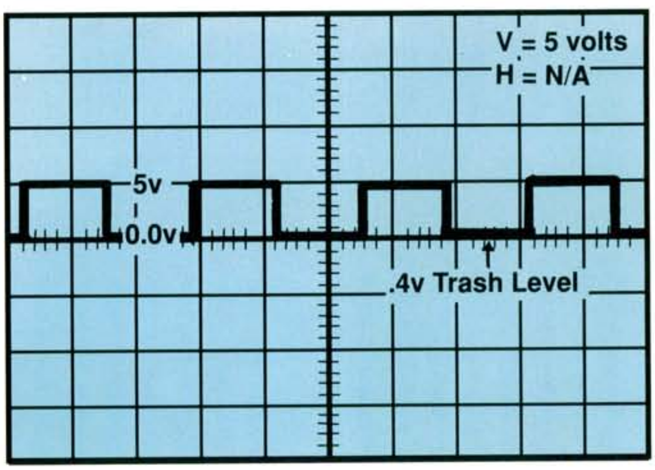


Figure 12 is also a 5-volt reference signal, although dwell should be the same for all signals from this sensor, since all the slots in the reference sensor ring are the same size. The number of signals we see on the scope will depend on engine speed, and the adjustment we make to the Sweep Time/Div setting. In this case, our best results came with the Vertical Volts/Div set at 5 volts, and the Sweep Time/Div set at .2ms.

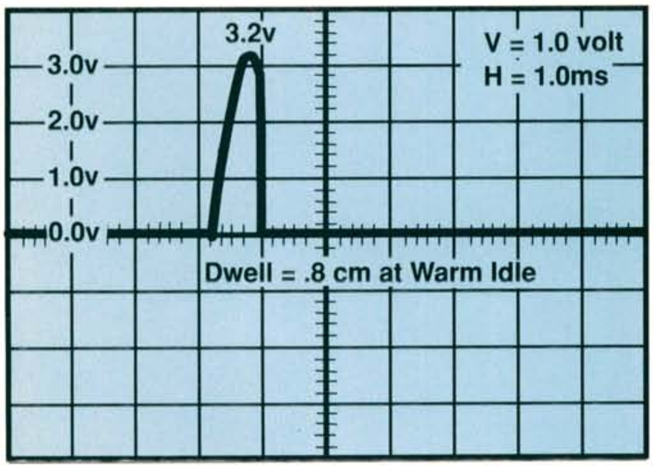
Backprobing the ECU connectors allowed us to analyze voltage amplitude, ground reference, and signal quality far from the interference of the secondary ignition wires.

The .4 volt trash level in this signal was twice the .2 volt we got from the crank angle sensor, but did not affect the car. This is one of those cases where there is no spec for this and experience is the best teacher.

Testing Under the Hood

Sometimes we have to work under the hood, however. Let's say this car is a no-start and we want to check the ignition system. Let's use our scope to check for the voltage signal from the ECU to the power transistor that controls the ground side of the ignition coil's primary circuit. In this case, a 3.0 volt signal from the ECU to the base of the power transistor turns the transistor on. The transistor acts like a switch between the primary circuit and ground. When the transistor is on, the switch is closed. See Figure 13.

Figure 13 ECU Trigger Signal to Power Transistor



On this car, we have a 3.0 to 3.2 volts signal to the base of the transistor. The nice part about this test is that we know that all the inputs to the ECU controlling this signal, and the ECU itself are working as they should to trigger the transistor. If they weren't, we wouldn't have the voltage signal in the first place. Just as importantly, we know that the connection from the ECU to the connector at the transistor is also good.

Power Transistor Output to the Ignition Coil

Next we want to see the signal on the collector terminal of the power transistor (the negative side of the coil primary). We know the signal is being sent, but is the transistor turning on to ground the primary?

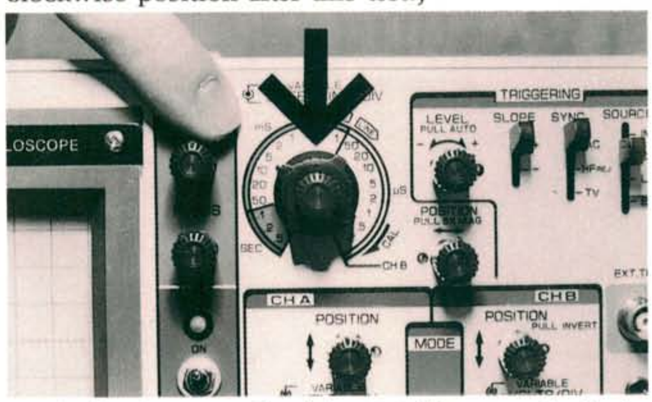
Adjust the scope as follows:

- **Set the Vertical Volts/Div to 10 Volts/Div.**
- **Set the Sweep Time/Div to 2ms/Div.**
- **Move the Vertical Position knob counterclockwise until the trace rides on the next to the bottom line on the graticule.** The signal we'll be measuring has a high amplitude, and we want more room on the screen to display it. Moving the reference line lower on the screen gives us more room above the line to display our signal.
- **Move the AC-GND-DC switch to GND** to confirm that our new line is indeed zero volts. Move the switch back to DC and continue.
- **If the car is a no-start, crank the engine with your probe on the collector terminal of the power transistor.** Or if the engine starts, but you're checking for an intermittent electrical problem, start the engine and let it idle. If things are okay, you should see a straight line representing about 12 volts.

Getting the Waveform to Appear

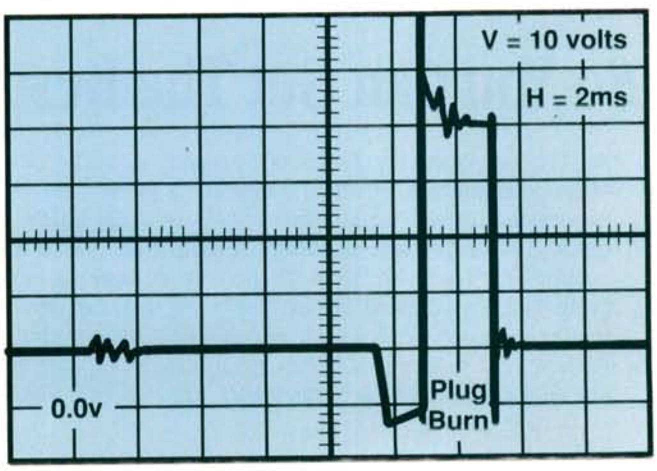
That 12-volt signal isn't telling us anything. We need a waveform to analyze. Here's a new technique to add to your scope skills.

Turn the small red knob in the center of the Sweep Time/Div in a counterclockwise direction. This moves the Sweep Time/Div off its calibrated end stop. That's okay because we don't have to keep our time base in a calibrated setting for this test. This knob is called the Attenuator. (Don't forget to return it to its fully clockwise position after this test.)



As the Attenuator knob is rotated in a counterclockwise direction, the sweep time setting is changed and the signal on the collector will appear on the screen.

Figure 14



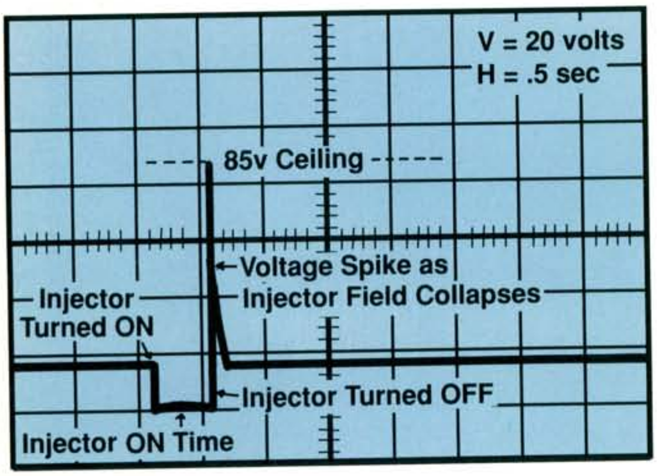
Injector Waveforms

Figure 15 shows the scope pattern from the negative side of the fuel injector. The signal shown is a common waveform on most cars. And it contains a lot of useful information about the fuel management system.

To check the ground side of the injector, proceed as follows:

- **Set the Vertical Volts/Div to 20 volts. (This is a tall waveform.)**
- **Set the Sweep Time/Div to a slow .5 seconds.**
- **When following the S.O.P. for ground calibration, start by moving the trace down two blocks below the center horizontal line on the graticule using the Vertical Position knob. (Like we said, this is a tall waveform.)**
- **Connect the scope probe to the negative side of a fuel injector, then start the engine and let it idle.**
- **Take a moment to identify the components of the waveform, noting when the injector is commanded "on" or "off."**

Figure 15 Injector Waveform



Measuring Spike Amplitude

Measuring the spike voltage amplitude of the collapsing injector field is important. Manufacturers set different upper limits for the amplitude of this spike, but most range from 65 to 95 volts. These specifications are available from some manufacturers, although this type of information may not be easy to find for some vehicles. Unfortunately, we're back to that notebook where you file away information on your own testing of known good vehicles. More silhouettes.

A spike voltage that exceeds these limits indicates the failure of a spike suppression diode in the ECU.

A spike voltage that is too low indicates resistance in the fuel injector circuit, a weak injector driver transistor or leaking spike suppression diode (also in the ECU), or low supply voltage to the "hot side" of the injector.

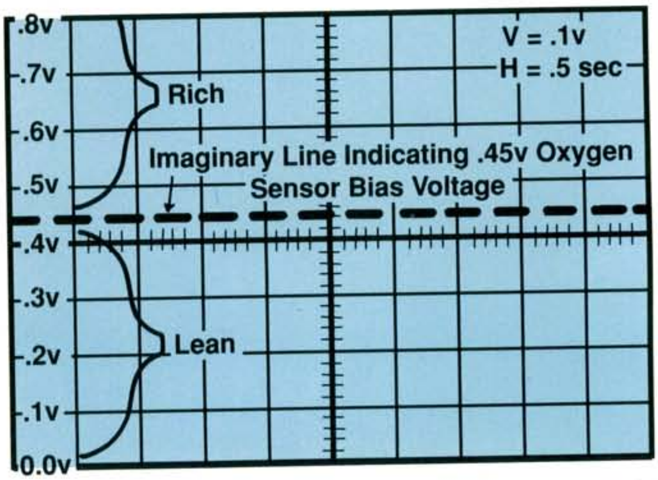
Checking the Oxygen Sensor Circuit

The scope is great for watching the activity of the oxygen sensor. When the voltage is high (.46 to .9 volts), the exhaust is rich. When the sensor voltage is low (.1 to .44 volts), the exhaust is lean. A good sensor responds instantaneously to changes in the oxygen content of the exhaust. So why not look at the oxygen sensor with a scope to see how the fuel system is working?

The scope can provide us with information about oxygen sensor activity and the fuel delivery system faster than any other diagnostic tool.

Figure 16

Graticule Values for Oxygen Sensor S.O.P.



S.O.P. to Scope the Oxygen Sensor Circuit

To check the oxygen sensor circuit, proceed as follows:

- **Set the Vertical Volt/Div scale to .1 volt per centimeter.**
- **Set the Sweep Time/Div to .5 seconds. (that's slow)**
- **The trace will form a dot that moves slowly across the screen, taking a full second to travel two major divisions of the graticule.**
- **Do the S.O.P. for ground and set the trace on the bottom horizontal graticule line. Now the readings on the graticule scale are calibrated to look like Figure 16**
- **The bottom line on the graticule is 0.0 volts. The second line up is .1 volt, and so forth, until we get to the top line which becomes .8 volt. We won't reach all the way to .9 volt, but that won't cause any serious problems. If oxygen sensor voltage gets this high, we'll still see the trace go out of sight at the top of the screen and know that we have a rich mixture.**

Evaluating Oxygen Sensor Operation

Let's get a little more specific in evaluating oxygen sensor operation. Connect the scope probe to the oxygen sensor wire going back to the ECU, or back-probe the wire at the ECU. Set the probe to X1. Run the engine until it warms and enters closed loop.

If the oxygen sensor and fuel system are working as they should, the sensor will trace out a nice sine wave pattern like the one shown in Figure 19. The sensor voltage is equally divided between a rich state (above .45 volt) and a lean state (below .45 volt). This means the system is controlling the fuel mixture at the proper 14.7 to 1 ratio.

The end result is a gently bouncing ball that travels across the screen as it follows the lean/rich cycling of the engine in response to the oxygen sensor signal.

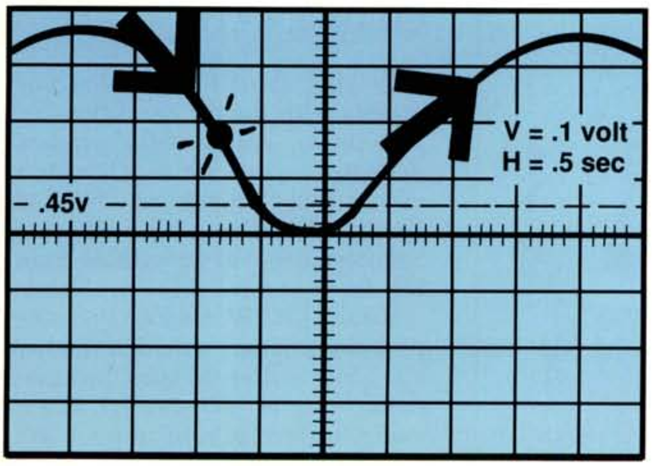
For Richer or for Leaner

The next three illustrations show how you can identify rich mixtures from lean ones using the scope, and also help you identify a system that's operating in a properly balanced closed loop.

Figure 17 shows the pattern from an overly rich mixture. The trace spends most of its time in the upper half of the screen. The ECU may be commanding a leaner mixture, but the signal stays high because the mixture stays rich.

Think of problems that can cause this rich situation, like leaking fuel injectors, a plugged air filter, or excessive fuel rail pressure.

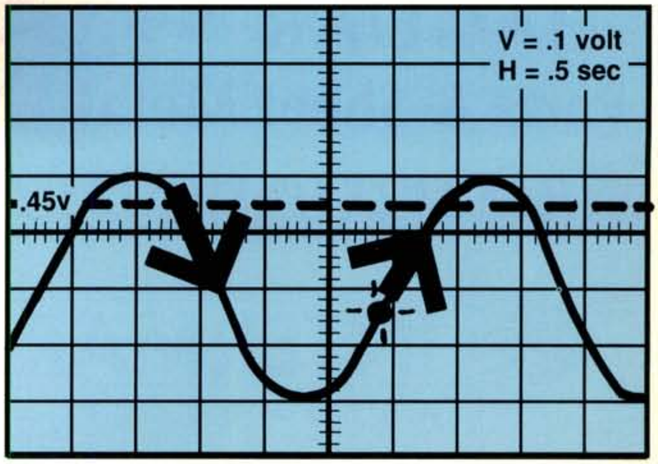
Figure 17



Rich Condition

Figure 18 shows us that when the exhaust gases are lean, the voltage stays low. Once again, assuming that the ECU itself is not damaged, the command is sent to richen the mixture. But other problems are keeping the mixture too lean. The trace spends most of its time in the lower half of the screen when the voltage signal from the sensor stays low.

Figure 18

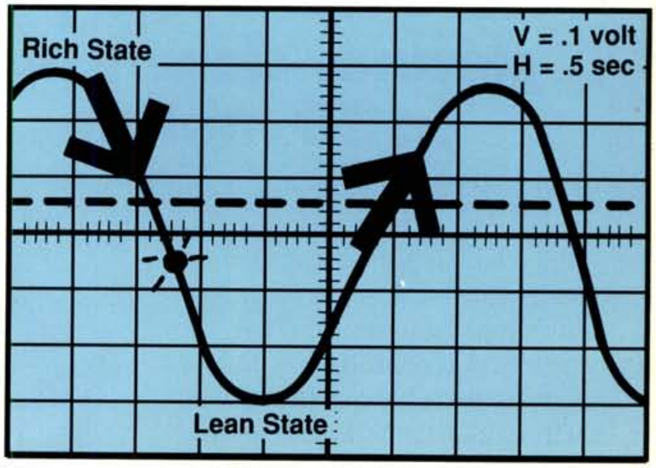


Lean Condition

Think of problems that could cause this situation, like a plugged fuel filter or a vacuum leak.

Finally, we get that nice even sine wave pattern shown in Figure 19. The trace amplitudes above and below the reference line are equal and regular. This signals an engine with a well-balanced, closed loop system, operating as it should. We have checked the closed loop operation of the entire fuel management system with a single test.

Figure 19



Balanced State

That's about it for this cruise. We hope that some of you are tempted to look at the possibilities of purchasing a lab scope. They aren't all that expensive as test equipment goes these days, with many falling in the 500 to 1000 dollar range.

The most important part to remember, is that the scope will help you see things that even your logic probe and voltmeter will miss. If the enemy is still getting away, maybe it's time to start sighting and sinking him on a regular basis.

—By Vince Fischelli