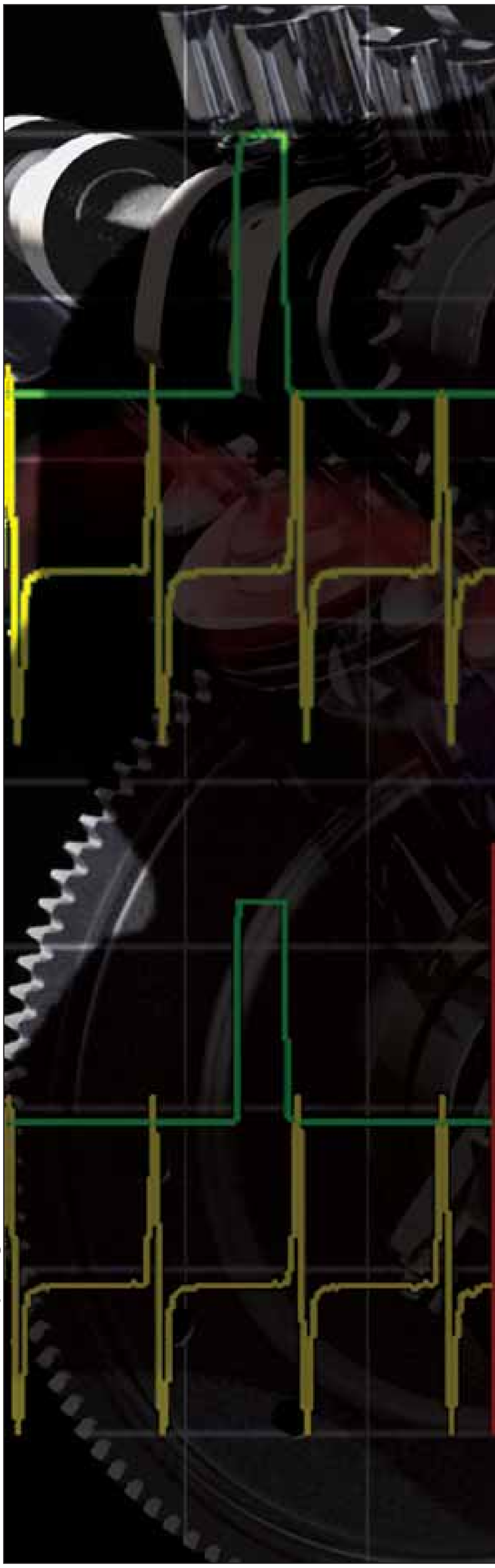
THE MECHANICS OF A WAVEFORM

By Jorge Menchu

Every time a waveform moves up or down, something in the circuit that's being tested has changed. Learning to identify the factors that shape a waveform is a powerful diagnostic skill.



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In this article I'm going to take you on a journey into the mechanics that shape a waveform. I call it Ohm's Law II. Ohm's Law II goes beyond the math of Ohm's law and considers the role of the fundamental circuit dynamics. As a result, it provides a unique pathway for waveform and circuit analysis.

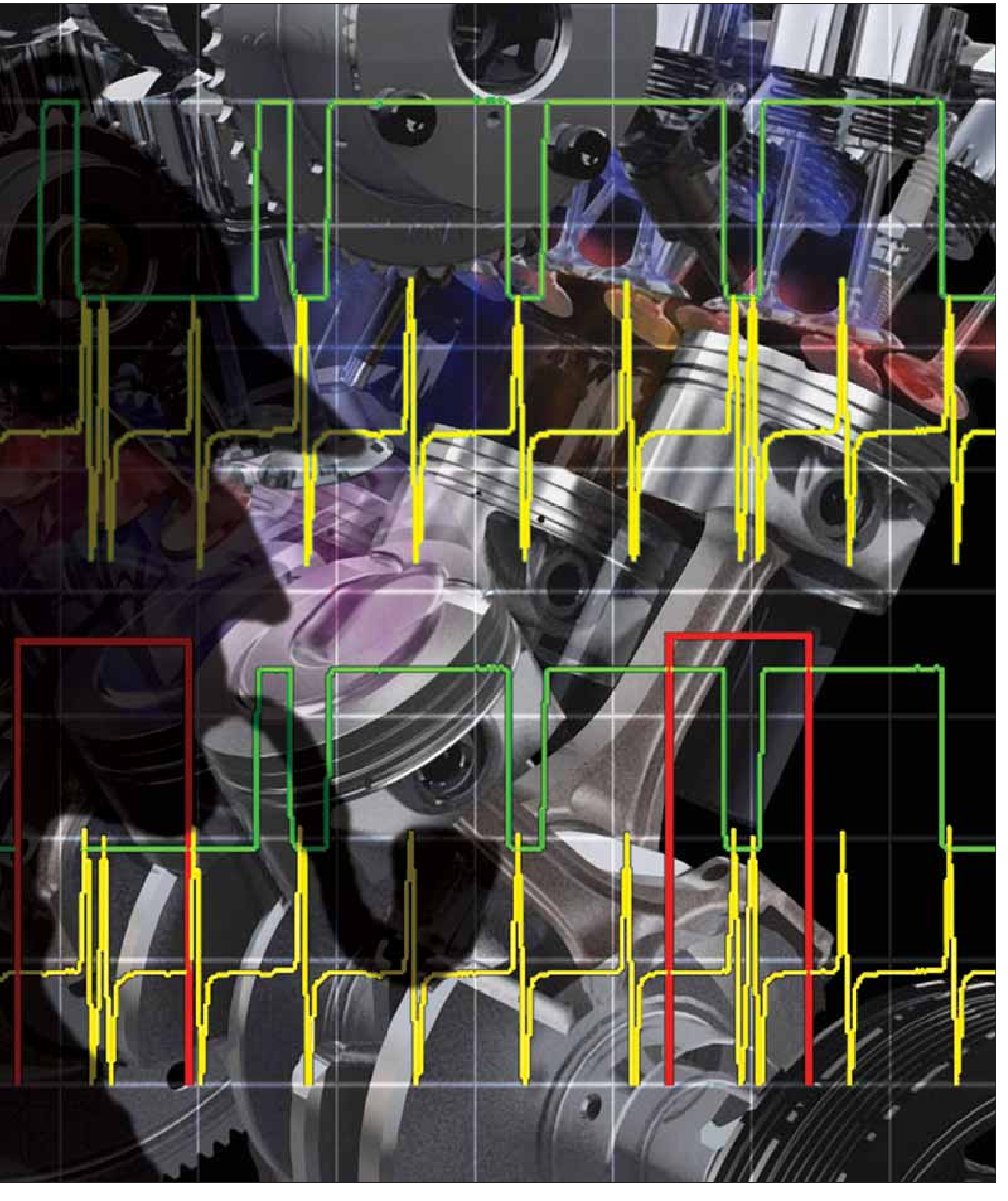
This is certainly not the most diagnostically direct method of waveform analysis, but its value is still very powerful. First, it inspires an intimate understanding of how a waveform is shaped. Second, it offers a very effective method for pinpointing the component's role in shaping the waveform or causing a glitch. Third, it will allow you to develop a greater level of confidence for a higher level of waveform analysis.

In the text that follows I'm going to reverse-engineer a waveform step by step. To simplify this process, I've developed what I call the Ohm's Law II grid (Fig. 1, page 32). The grid exposes the mechanics of shaping a waveform from a fundamental perspective. It takes into account the waveform as displayed on a lab scope, the Ohm's law variables and the test points on the circuit, then leads our analysis to the circuit components.

Before we get more deeply into this, let's define a basic circuit model for our first analysis.

A Basic Circuit Model

Often, a useful analytical process is to think in simple and generic terms. This is especially important for Ohm's Law II, since our focus is simply on voltage, current and resistance. To achieve this I have defined a basic circuit model for waveform analysis. It's a three-resistor series circuit in which each key component is defined as a generic resistor symbol (Fig. 2, page 36). R1, R2



Ohm's Law II

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	Supply Voltage	Resistance Outside (R1)	Resistance Inside (R2)	Waveform Voltage	Current
1	Same	Same	↑	↑	↓
2	Same	Same	↓	↓	↑
3	Same	↑	Same	↓	↓
4	Same	↓	Same	↑	↑
5	↑	Same	Same	↑	↑
6	↓	Same	Same	↓	↓

Fig. 1

and R3 are used to generically represent circuit components. For example, R1 could be an injector, R2 a driver and R3 the resistance of a bad circuit connection.

From a practical standpoint, test leads can be placed anywhere along a circuit as long as the test points are within the safety parameters of the test instrument. For general testing, though, an instrument's ground lead connects to the circuit ground and the signal lead is placed between the circuit load and switch. This applies to both switch-to-ground and switch-to-power circuits.

Regardless of where you place the test leads, they effectively divide the circuit into three areas, as indicated in Fig. 3 on page 36:

R1. Between the instrument signal test point and the source power.

R2. Between the two test points.

R3. Between the source ground and the test instrument ground test point.

Now you can see why I picked a three-resistor series circuit. The idea of the test points dividing the circuit makes it much easier to understand how the dynamics of the circuit work together to shape the waveform.

Anytime a waveform changes, it's the result of a change within one or more of these three circuit areas and the power source (with the exception of noise introduced into the circuit).

The Power of a Good Ground

Now let's simplify this one more step. If the instrument is connected to a known-good ground, then any change in the circuit will originate between the test points, between the red test point and the power source or in the power source itself.

This brings up an important question: *What is a good ground?* Often the answer is, "the battery." But this is not *always* the case, and it really depends on what you're testing and trying to discover in your test.

Check out the photos on page 38. Can you see the difference between the two battery connections? The system on the right is a much better ground connection because the connection is made to the battery, chassis and engine with one connection. This is especially important when the engine is running, because when the engine is running, the alternator is the ultimate source for power and ground, not the battery.

Here are some other notes about the ground:

• You can use any ground placement you want. Just make sure you understand how your choice may affect your tests.

• For sensor testing, if you want to see what the PCM sees, use the circuit ground.

• With the engine off, the battery is the ultimate ground; with the engine on, the alternator housing is the ultimate ground.

Power Up

Let's add some power and resistor values. For our circuit model we've added 12V for the power source and set R1 and R2 to be equal resistance at 1k ohms (Fig. 4 on page 36). Since both R1 and R2 are equal, we know that the voltage at the test point (between the resistors) is half the power source—that is, 6V (Fig. 5, page 38).

We now have a very simple active circuit model that we can use to discover the basic mechanics of how Ohm's law shapes a waveform: The instrument ground is on a good circuit ground. R2 is between the test points. R1 is between the signal test point and the power source (I often refer to this as upstream from the signal test point).

From the standpoint of the lab scope screen, a signal does one of only three things—stays steady, goes up or goes down. Our first step is to determine the simple actions that took place to make this happen.

We can start by identifying a change in a signal of interest and asking the appropriate question. For example, look at the fictitious (red) waveform in Fig. 6 on page 38. What caused the signal to go up? What caused it to go down?

The answers to both questions can be found in the Ohm's Law II grid shown on page 32. Each column in the grid represents an Ohm's law variable. Each row represents the action of each variable.

Here's how it works: First, ask the question, *Why did the signal go up (above 6V)?* Next, find the Waveform Voltage column in the Ohm's Law II grid and look for the up arrows which represent a rise in voltage. Rows 1, 4 and 5 each have an up arrow. Now look at the variables in each of these rows. Row 1 indicates that a rise in voltage can be caused by the resistance between the test leads going up. Row 2 indicates that the resistance between the signal test point and the power source went down. Row 5 indicates that the voltage to the circuit went up. The answer to the question of why the voltage signal went up is at least one of these three options.

Now let's consider the actual circuit components. If this were a thermistor circuit, the resistance between the test point and the power source (R1) would be a pull-up resistor inside the PCM. The resistance between the test points (R2) would be a thermistor.

It's time to play out each option and find the one that's valid:

Row 5. Did the voltage to the circuit go up? What's the likelihood that the PCM's regulated sensor voltage went up? Not likely.

Row 4. Did the pull-up resistor inside the PCM (between the test point and power source) go down in resistance? Not likely.

Row 1. Did the thermistor (between the test points) go up in resistance? Yes, very likely.

So, now our Fig. 6 waveform dips down. What made the signal drop, Row 2, 3 or 6? For our thermistor, Row 2 is the answer!

Let's put it to a real test. Fig. 7 on page 40 is an old-school peak & hold waveform. I picked this one because it has lots of great elements. Note that I also included the current waveform for reference.

In practice, here are three important steps to follow:

1. Connect to a known-good ground, or at least understand the implications of your ground test point.

2. Ask yourself, *What is between my test points?* See Fig. 8 on page 40. It's the driver, and the injector is between the signal test point and the power source.

3. Compare one signal change to the next. The signal went either up or down.

Let's reference the Ohm's Law II grid and play out the scenarios in Fig. 8.

Waveform Section A: Voltage goes down. It could be Row 2, 3 or 6.

Row 6. Did the voltage to the circuit go up? No.

Row 3. Did the resistance outside of the signal test point (R1) go up? This would be caused by the injector coil. Did it go up in resistance? No.

Row 2. Did the resistance between the test leads (R2) go down? That would be caused by the driver. Yes, the driver activated going from an open state to completing the circuit. As a result, the driver resistance went down,

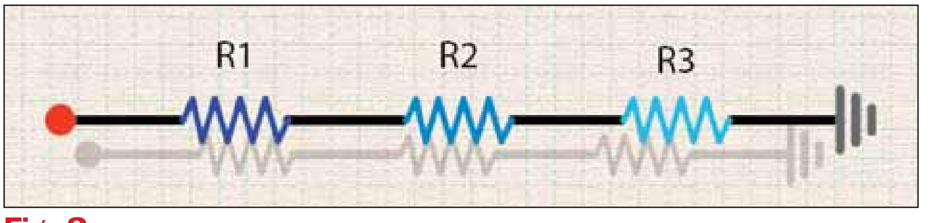

Fig. 2

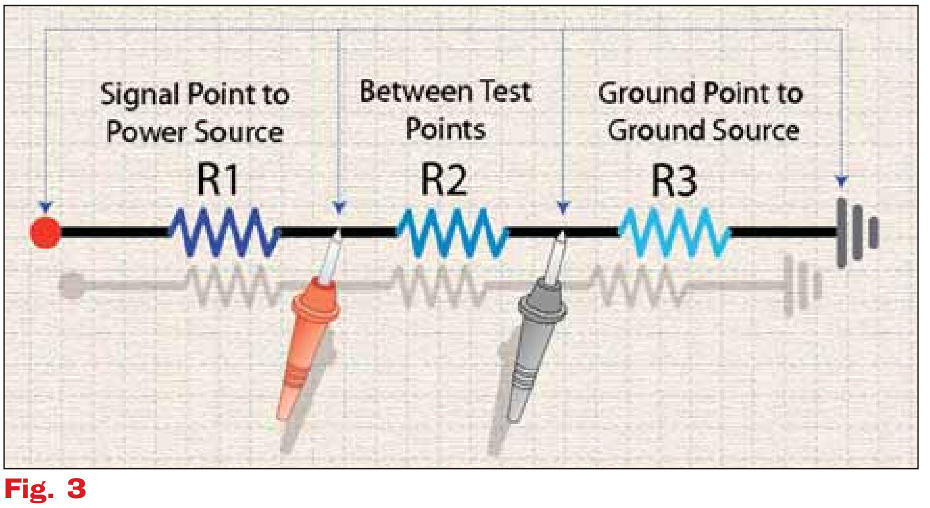

Fig. 3

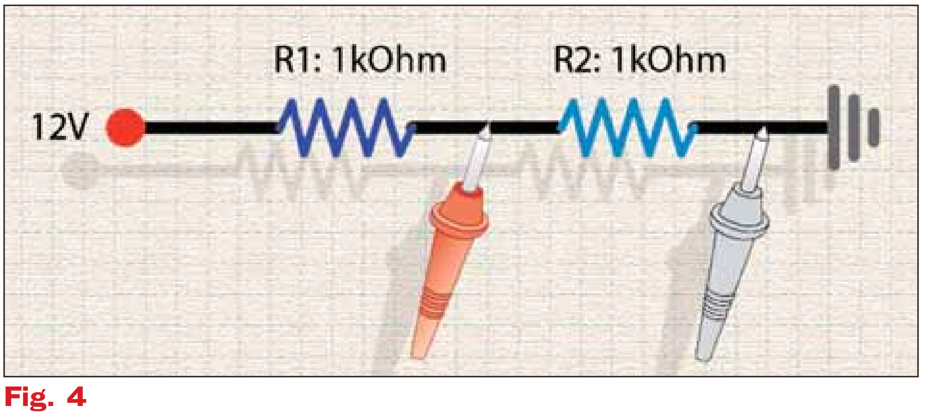

Fig. 4

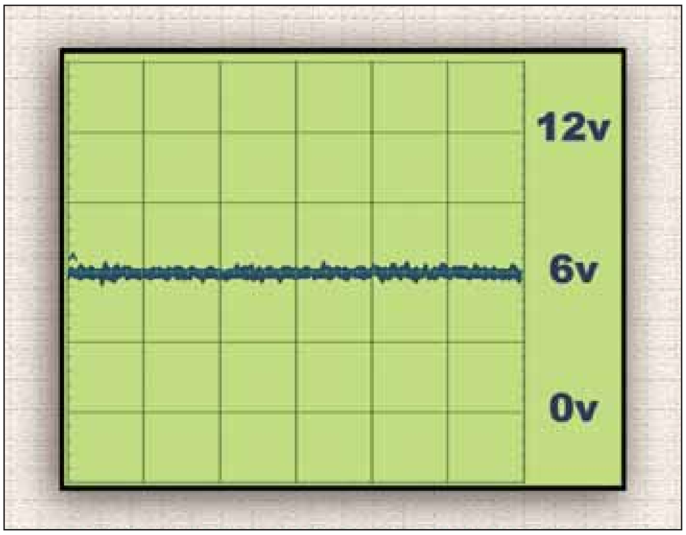

Fig. 5

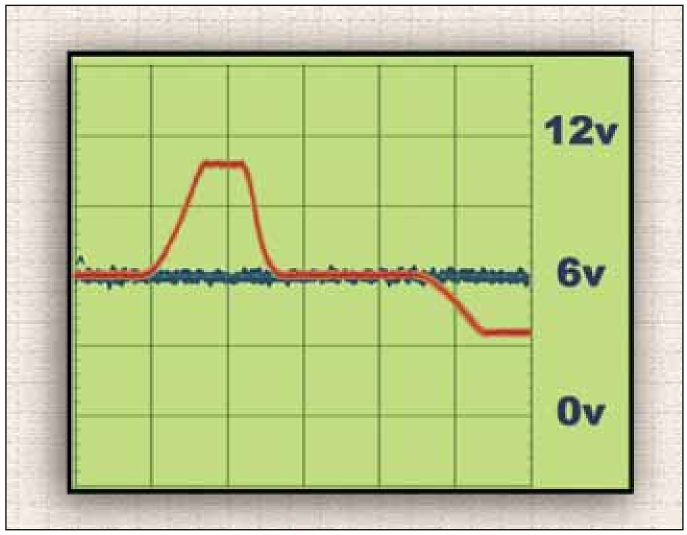

Fig. 6

signal voltage went down and current went up just as it's listed in Row 2!

Waveform Section B: Signal goes up. Close inspection of this section of the waveform shows the signal ramping up. It could be Row 1, 4 or 5.

Row 1. Did the resistance between the test leads (R2) go up? That would be caused by the driver. The circuit is activated. Maybe a little if it's getting hot? *Hmm*.

Row 5. Did the voltage go up to the circuit? No.

Row 4. Did the resistance between the signal test point and the power source (R1) go down? This would be the coil. Yes, as the coil's magnetic field builds, it allows more current through the circuit. Ohm's law says that more current across a resistance means a higher voltage drop. Resistance outside the test leads (R1) goes down, current goes up across the driver (R2) and so does displayed voltage.

Waveform Section C: Signal goes up. Since the coil field collapses, we know it's the driver opening the circuit. Therefore, the conditions correspond to Row 1; the driver is between the test leads (R2). Resistance goes up as the driver opens. Displayed voltage goes up and current goes down.

Waveform Section D: The D portion of the signal is lower than the source voltage and certainly higher than waveform section B. Therefore, we can conclude that the circuit is active as opposed to open.

Keep in mind that when we use the Ohm's Law II grid we're simply comparing one voltage state to another, asking if the signal went up or down. I chose to compare to the small ramp area marked B because it represents the active circuit as opposed to an open circuit state. So the question is, *Why did the signal go up between B and D?*

Row 4. Did the resistance between the signal test point and the power source (R1) go down? This would be caused by the coil. It would mean the coil shorted and the increase in current resulted in a larger voltage drop across the resistance between the test leads (the driver). This did not happen because we see good spikes before and after this section of the waveform, and it would take a lot of current to make that big of a voltage drop.

Row 5. Did the voltage go up to the circuit? No.

Row 1. Did the resistance between the test leads (R2) go up? This would be caused by the driver. This is a peak & hold injector circuit. "Hold" indicates current control. Since it's not a switching current control driver, it must functionally increase the resistance to lower the current. The driver resistance between test leads goes up (current control), current goes down and the displayed voltage goes up (as compared to waveform section B).

Application

In the above examples I focused on good waveforms. This process certainly can be used to determine the sources of glitches as well.

To review, here are the steps we just accomplished, with a few diagnostic steps added:

We became more aware of our test points and how they divide the circuit. Through the Ohm's Law II grid, we could see how each section of the circuit could fundamentally result in a signal change. The Ohm's Law II information then led us to focus on the components based on the test points and prompted us to ask how each component could make such a change. Then, through simple analysis, we picked the most likely answer.

In the case of glitch analysis, once a component is suspected, these are the important questions:

- Did the component fail due to weakness, age or stress?
- Did the environment influence the component? For example, heat increases resistance.
- Did the system influence the component? For example, the system may be responsible for sending a signal to the base of the transistor, activating a circuit.
- Is the glitch noise introduced into the circuit and not caused by a circuit under test component?
- Are you on a good ground, and is it the best ground for the test?

When applicable, never hesitate to break out an amp probe to see how much energy is passing through the circuit and how that energy is being used. Sometimes voltage waveforms just don't reveal enough.

In essence, this was an exercise in organizing: If we learn to do the right thing first, it makes it easier to learn to do the next right thing. Each of these steps leads to the next. As a result, whether you do it for diagnostic purposes or for learning, you efficiently develop a more intimate understanding of waveforms and how the components shape them. You get better at pinpointing unusual occurrences and learn to identify sources of component failures.

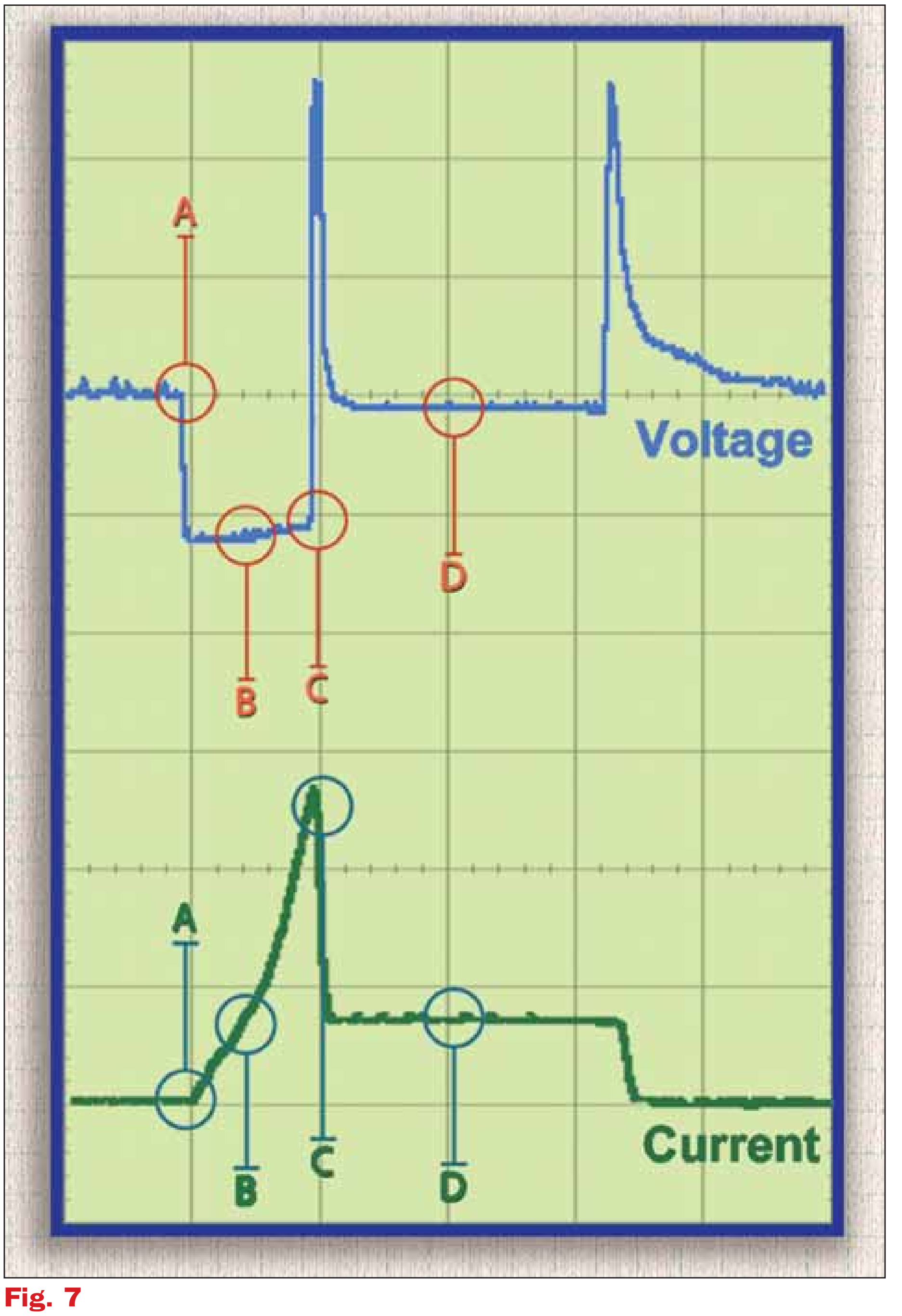

Fig. 7

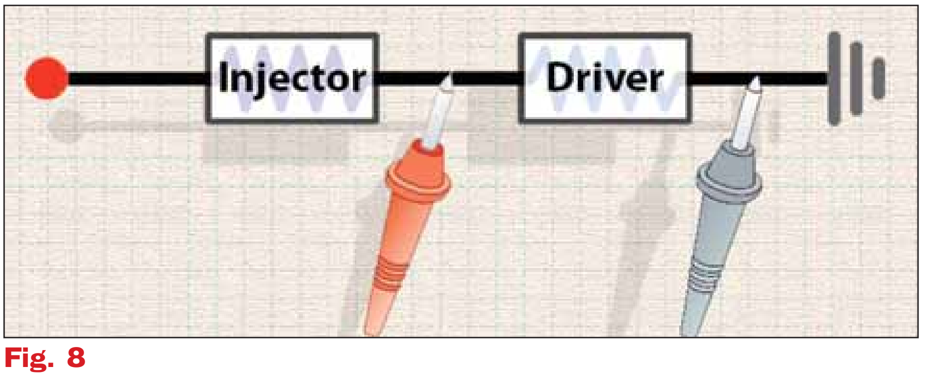

Fig. 8

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