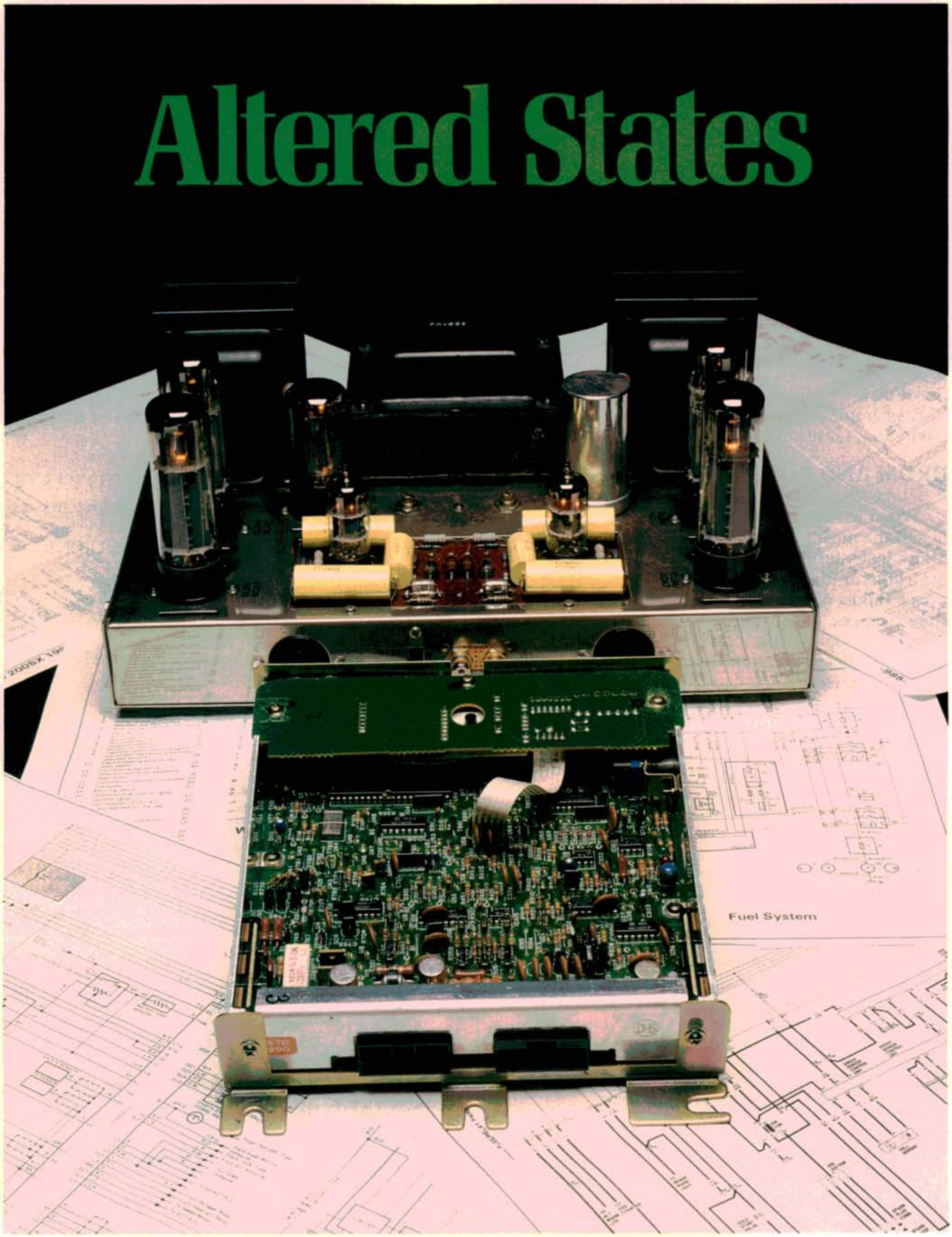
Altered States



Those of you old enough to remember Mantle, Maris, and Mays, are old enough to remember tube style television sets. You may also remember accompanying your Dad as he rummaged through a paper bag of suspect vacuum tubes down at the corner drugstore's tube tester. One by one, he'd plug them in, twist the dials, and look for the tube or tubes which had died right in the middle of the Ed Sullivan Show.

Now imagine trying to control the complicated systems on modern cars if you were forced to use this antique vacuum tube technology. You'd need an 18 wheeler just to haul the ECU along since it would be so huge. Fortunately, today's use of electronics technology is operating in an Altered State called Solid State, which allows manufacturers to miniaturize that 18 wheeler load into a box about the size of a paperback novel.

And the heart of Solid State is something called the semiconductor. Let's look at what makes a semiconductor tick. Then we can better appreciate how all semiconductors work, and find ways to test them. To understand semiconductors, however, we must first understand the difference between conductors and insulators.

Conductors and Insulators

We all know the practical differences between a conductor and an insulator. If you've ever gotten a healthy jolt from an old, ungrounded power tool, you know that it's not a lesson soon forgotten.

In bare bones scientific talk, conductors pass current flow easily, and insulators don't. As a result, we need both conductors and insulators to make the wiring harness of a vehicle. Wires, or conductors, are made of metals which easily allow electrons to pass through them. These conductive wires must be covered with an insulating plastic material to keep those electrons from taking a detour through a neighboring conductor.

But why are some materials conductive, while others aren't?

Excuse us if we go back to high school physics for a moment, but we need to look at atoms and how they're put together. Atoms are like tiny solar systems, with electrons orbiting around a nucleus, just as planets orbit around the sun. There may be any number of electrons in one or more orbits. It's the outer layer, the orbit farthest from the nucleus which concerns us here since it's the outer orbit which determines whether a material is a conductor, or an insulator.

If we look at the atoms in conductors and insulators, we see a striking difference between the two. **Figure 1** shows an atom of a typical conductor. Notice that there's only one electron orbiting in the outer ring around the nucleus.

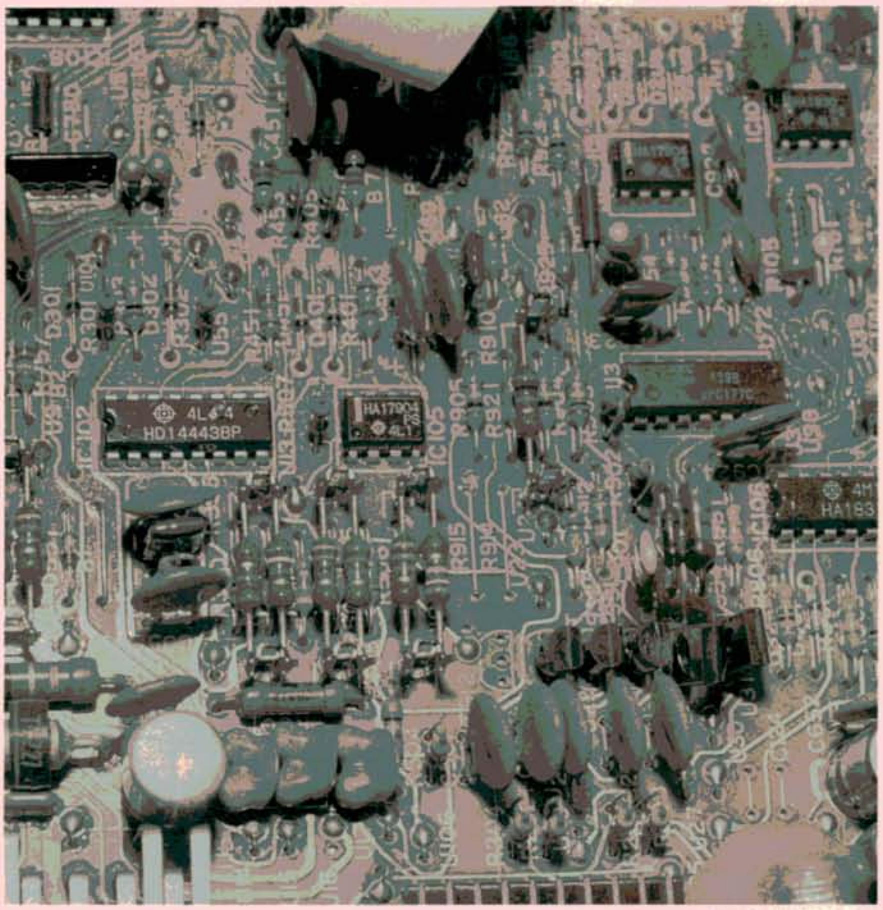
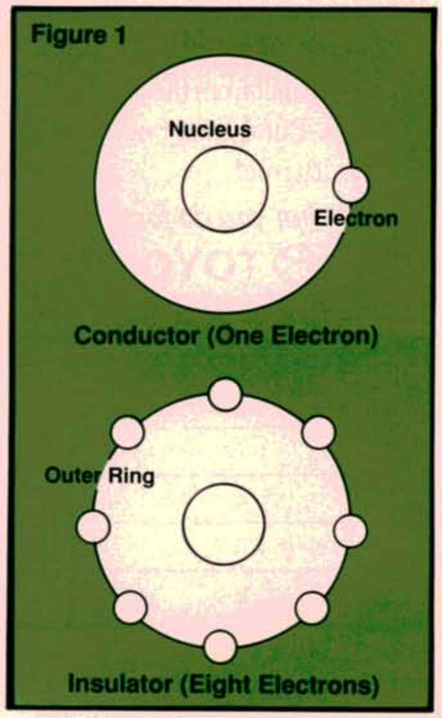


Photo of an ECU circuit showing ICs.



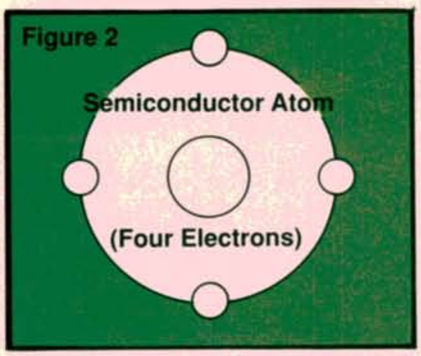
That single electron is a flighty fellow, and is loosely held in his orbit. A little jolt of electrical pressure (voltage), can send him bouncing on to the next conductor atom. If enough voltage is applied to start a chain reaction of bounding electrons through a row of similar atoms, we have Current Flow.

Insulator Atoms

Insulator atoms are much more stable characters. They have seven or eight electrons in the outer orbit. An atom with a full house of eight electrons in its outer ring is a very stable atom, and a good insulator. It takes a lot of voltage to pry any of those outer eight away from the nucleus.

Semiconductors

Between these two extremes, we have atoms with four electrons in their outer orbit. They aren't good conductors, nor are they good insulators. **Figure 2** shows us an atom which could as easily be called a "semi-insulator," but by popular demand became known as a semiconductor.



If we throw a group of these atoms into a pile, they huddle together and share the electrons in their outer orbits. This process causes them to form a crystal-like mass which has metallic properties, but poor conductivity. A semiconductor atom in the crystal mass is fooled into thinking it has a full eight electron orbit as it shares electrons with neighboring semiconductor atoms.

Doping

Engineers use a manufacturing process called "doping" to add or remove electrons from the crystal mass. It's this last part, the "doping," which is the key to making diodes, transistors, and ICs work.

If we add more electrons, we of course end up with a "more negative" semiconductor material appropriately called N-Type material. Remember, N for Negative-Type material which has additional electrons floating around looking for a home.

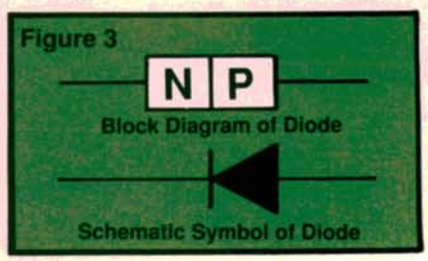
If we remove electrons, we make the material more positive, and call it P-Type (Positive) material. The missing electrons in P-Type leave "holes." Think of P-Type as a piece of Swiss cheese, full of holes. Those holes are the homes those extra electrons in N-Type are looking for.

A Common Diode

Take a piece of N-Type material and a piece of P-Type material, and fuse them together. The point where the two materials come in contact is called the "junction." This combination of the two materials forms a semiconductor.

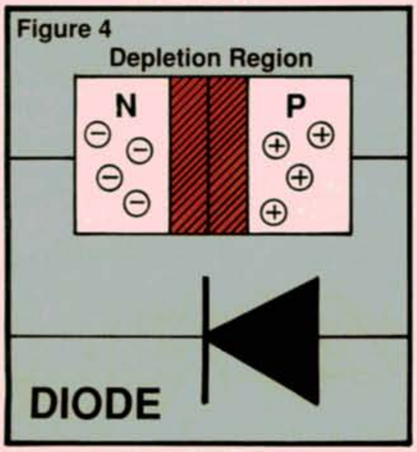
See **Figure 3.**

Our block diagram and schematic symbol show a common diode. The same principles of operation found in the diode will also apply to transistors and integrated circuits.



Neutral Zone

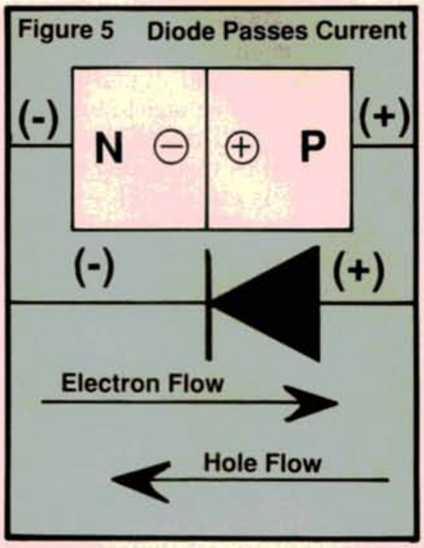
In **Figure 4**, we see that when the diode is first formed, some of those stray electrons in the N-Type material fill in the holes in the neighboring P-Type where the two pieces come together. They cancel each other out, polarity-wise. This neutral zone is called the "depletion region," and it becomes a barrier between the P and N-Type materials. The remaining electrons in the N-Type aren't strong enough to jump the gap across the depletion region and combine with the holes in the P-Type material.



Let's power up our diode, and see what happens. Hook the positive side of a voltage supply to the P-Type material, and the negative side of the voltage supply to the N-Type. This is called applying the voltage in the forward direction, or Forward Biasing the diode.

See Figure 5.

The extra electrons in the N-Type material now have enough manpower to fight their way through the depletion zone and find homes in the holes of the P-Type material. It takes a force of about 0.6 volt to overcome the depletion region in a silicon diode.



What happens if we reverse the leads and apply positive voltage to the negative side, and negative to the positive? Electrons and holes are pulled away from the junction. This makes the depletion zone even wider and leaves electrons in the N-type material homeless. The wider the depletion zone, the tougher it is for current to pass.

That's why a diode is ON in forward bias, needing a small amount of voltage to force current through, and OFF when the bias is reversed.

Remember:

- **Forward Bias turns the diode ON.**
- **Reverse Bias turns the diode OFF.**

Testing Diodes

Figure 6 shows how to test a diode using an analog ohmmeter. Analog meters are good for testing diodes since they usually have both higher voltage (to turn the diode ON) and higher test current than digital meters.

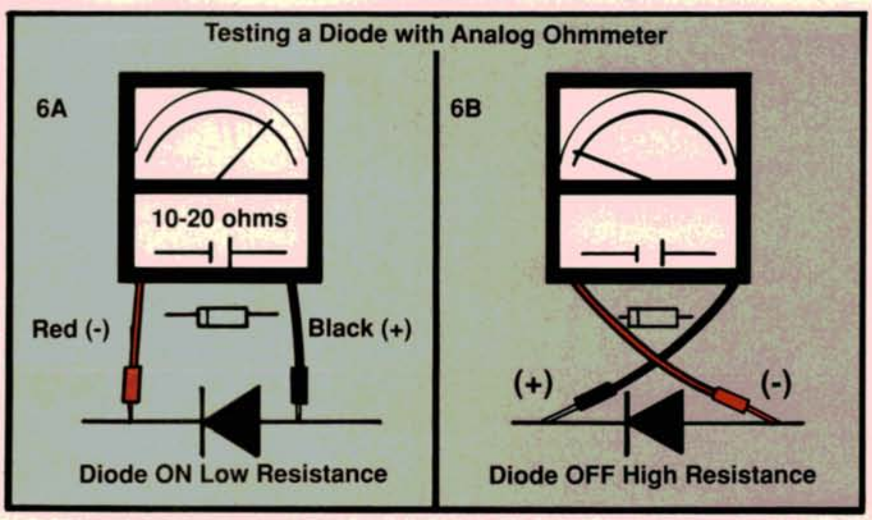
Unlike a digital meter which measures the voltage drop in a circuit to check resistance, an analog meter measures resistance by measuring the amount of current passing through the circuit. And the added strength of the analog meter's battery makes it tougher for the circuit to load down the ohmmeter battery. That's why analog meters are good for testing diodes in a circuit.

In **6A** the analog meter applies forward bias to the diode, and overcomes the depletion region. It turns ON and ohmmeter test current flows through the diode. Expect to read about 10 to 20 ohms, depending on your meter.

If we reverse the leads, we also reverse the polarity of the tester's voltage supply. The depletion region of the diode gets too wide for the tester's voltage to cross. The diode is OFF.

Our ohmmeter pointer doesn't move. It indicates full, maximum resistance on the analog meter's Rx1 scale.

Figure 6



Typical Diode Failures

If the diode can be turned ON and OFF with an analog meter, it's probably good. If the diode reads high resistance in both directions, it's open-circuited.

If the diode reads low in both directions, it's shorted.

In either case, the diode is bad.

Testing With a Digital Meter

The analog meter's ability to test diodes in a circuit can also be a liability. What if you want to test a circuit containing semiconductors without turning them ON and having them affect the overall circuit resistance? In this case, the digital meter is better since it doesn't have high enough voltage to turn the semiconductor ON.

But the digital meter has its own shortcomings when it comes to diode testing. Its low test voltage can't turn the diode ON. That's where the diode test feature of a digital meter comes in.

Diode Test

Figure 7 shows how to test a diode using a digital ohmmeter equipped with the diode test feature. Unlike the analog meter, the digital meter uses a voltage drop to measure resistance. The diode must be disconnected from the circuit for this test.

Why?

Because even though the diode test function of the digital meter supplies enough voltage to turn the diode ON, it still doesn't have as much voltage as the analog meter. If the diode is connected across a relay winding for example, the winding may load down the meter's diode test circuit so far that it doesn't have enough voltage left to turn the diode ON.

If the load causes the meter's voltage to drop below about 0.6 volt, the diode stays OFF.

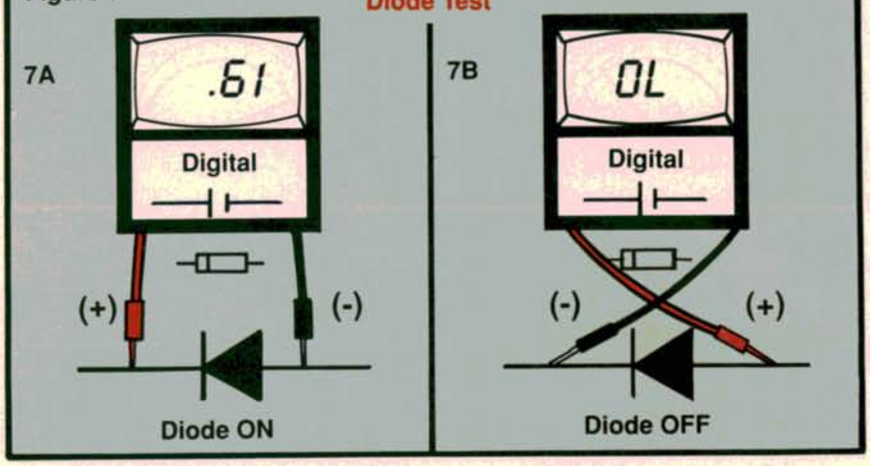
In **Figure 7A** the digital ohmmeter applies forward polarity voltage to the diode to turn it ON, and the test current flows through the diode. Expect the digital ohmmeter's diode test function to read about 0.55-0.65 volt, which is the voltage drop of the diode during this test.

In **Figure 7B** the digital ohmmeter leads are reversed, and the ohmmeter indicates a reading for an open circuit. This open circuit reading tells us that the diode has responded as it should to the reversed polarity, and turned OFF. It also tells us that the diode is not shorted.

If the diode can be turned ON and OFF with the diode test function, the diode is probably good.

If the diode reads a low voltage drop regardless of test lead polarity, we know the diode is shorted.

Figure 7 Diode Test



Testing the Diode Without Disassembling the Relay

You can test the diode in a relay without ever removing the relay cover. And that means you don't need to unsolder the diode to check it.

Step One—Measure the resistance of the relay coil with your digital ohmmeter. Since the digital meter won't turn on the diode, it won't affect the reading. In this case, the resistance of the relay coil is 73 ohms.

Step Two—Now take your analog meter. Set it to the Rx1 scale and zero it.

Check across the same relay coil terminals. Write down the reading. Then reverse the tester leads and test the same terminals again. (Remember, the diode is connected across those same leads.)

In this case, forward biasing the diode gave us a reading of 20 ohms, indicating that the diode was ON. Reversing the leads gave us a reading of 73 ohms, the coil's initial resistance reading. That's because reversing the leads turned the diode OFF and it no longer passed any current. Only the relay winding is seen by the ohmmeter.

Step Three—Know a bad diode when you see it:

If our resistance readings for a relay are identical to the relay winding resistance regardless of test lead polarity, we know that the diode is open. (All we're reading is the resistance of the coil.)

If our resistance reading is 1 or 2 ohms no matter which way we connect the probes, we know that the diode or winding is shorted. In a parallel circuit, if either the diode or relay winding is shorted the ohmmeter will read 1-2 ohms.

If the ohmmeter reads an open regardless of test lead polarity, the diode is open.

This also explains why a digital ohmmeter cannot test a diode using its 200 ohm scale. It cannot generate enough test voltage to overcome the diode's depletion region. The diode never turns ON.

Diode Applications

One of the reasons we've picked diodes as our spotlight performer in this article, is that they are so common, and so important to vehicle operation. They've been used since the first alternators replaced old style generators. In fact, without semiconductor diodes, there would be no alternators.

Other uses for diodes? Aside from alternators, diodes are used across relay winding terminals to suppress the spike voltage generated when the relay winding powers down. In this application, the diode only turns ON when the field collapses.

Spike suppression diodes are also used whenever a computer controls a relay winding. The diode protects the computer circuit from a burnout caused when a voltage spike feeds back through the computer output circuit.

See Figure 8.

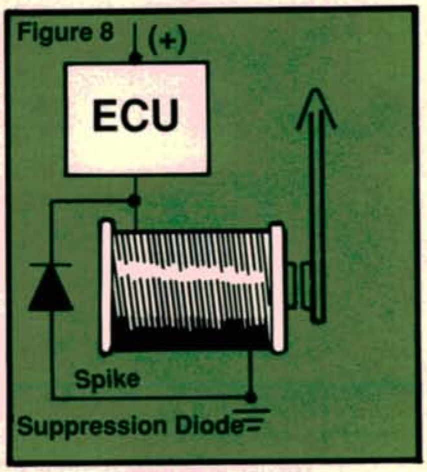


Figure 9 shows a diode in series with a fuel injector. In this case, the diode is called a polarity sensing diode. It protects the injector and ECU if the battery is connected backwards, or if jumper cables are hooked up wrong to jump start a car.

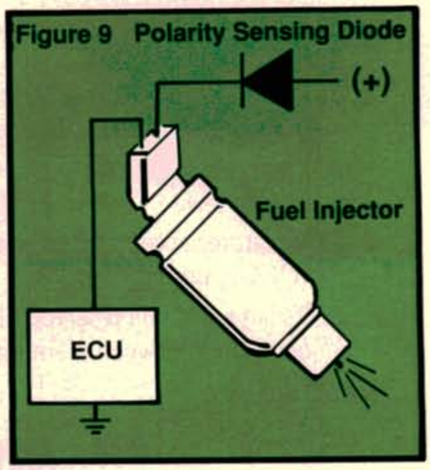
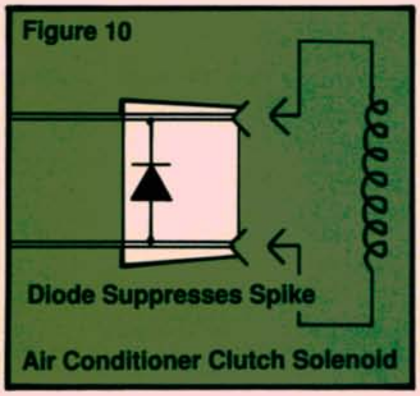


Figure 10 shows a diode across an A/C clutch solenoid. Once again, it is used to suppress the spike voltage created when the clutch winding powers down. Some cars have these wired into the harness at the connector plug for the clutch. Since the resistance of the clutch winding is only about 3-5 ohms, be sure you disconnect the connector at the clutch before checking the diode, or the low resistance in the clutch coil will make the diode look like it's shorted.



Transistors

Our next solid state component is the transistor. There are two kinds. **Figure 11** shows NPN and PNP transistors. Each has three leads: emitter, base, and collector. Checking a transistor is like checking two diodes.

Check between the emitter and the base as you would check a diode. And then check between the collector and base the same way. Notice that the difference between the NPN and PNP transistors has to do with the polarity of the semiconductor materials.

On some cars, you can remove the switch transistor in the electronic ignition and check it for shorts or opens using an analog ohmmeter.

Integrated Circuits—The Big Mystery

An ECU is an incredible advance in electronics engineering. It can make many thousands of decisions each second to control an engine's performance. The key to this rapid-fire calculation is the tiny IC, or Integrated Circuit. Some ICs contain hundreds of thousands of tiny transistors. Each one performs a vital function to allow the ECU to control the engine.

As stated earlier, an ECU using vacuum tube technology from the '60s would be so large that it would require a tractor trailer to haul it around behind the vehicle. And even if it used individual transistor technology from the 1970s, the ECU would still be so large that you'd need a small trailer to haul it around.

How to Destroy Semiconductors

Here are a few ways to destroy semiconductors. Each method has been field tested and proven effective in scorching an unlucky ECU:

1) Sliding across a car seat with an ECU in your hands. Combine this with forgetting to wear your anti-static wrist strap, and static discharge from your body will toast those tiny circuits.

2) Jump starting a car and connecting the jumper cables backwards. Say good-bye to the ECU.

3) Disconnecting the ECU connector with the key ON (or even worse with the engine running). You may want to shade your eyes from the bright flash as the spark smokes the ECU.

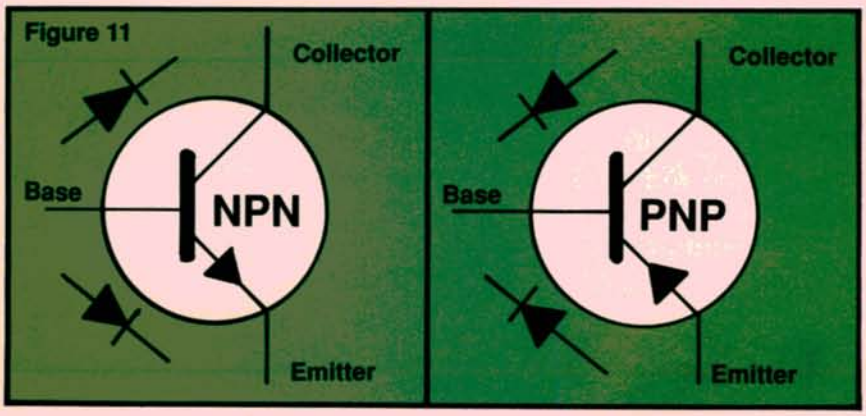
4) Disconnecting a battery cable with the engine running to see if the alternator's charging. It probably is, but now the ECU can't remember its own name, let alone what day it is.

5) Arc welding on the car with the ECU still on board. Many body shops have done extensive testing in this area. Those who persist in this activity usually buy their ECUs in bulk lots.

6) Installing an oversized fuse in an ECU power circuit because the normal size fuse blows. Need we say more?

7) Playing tick-tack-toe on the backside of the ECU connector with a jumper to bypass the ECU and get a circuit working. This can make the letters ECU stand for Entirely Cooked Unit.

New technologies bring new responsibilities for each of us. We've shown you how semiconductors work, some of the ways to test them, and several ways to destroy them. The tests are easy, and the needless destruction of semiconductor components is just as easily avoided.



—By Vince Fischelli