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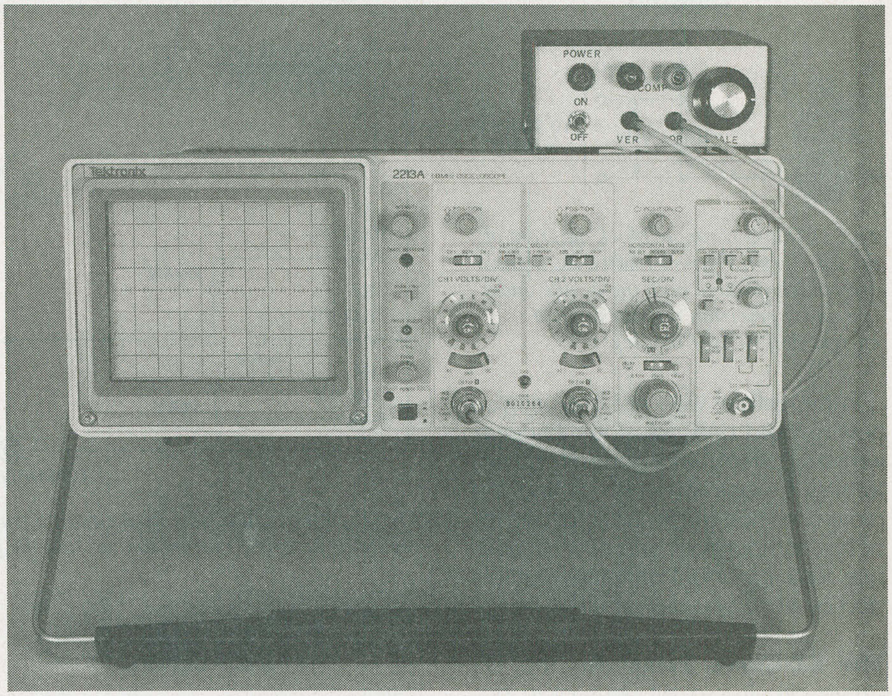
BUILD A SIGNATURE TRACER



Build an inexpensive precision component checker that will put your oscilloscope on an even footing with the newer models, replace some of your test gear, and teach you to interpret characteristic curves in the process.

BY JOHN YACONO

It has often been said that a picture is worth a thousand words. That adage is just as true in electronics as it is in any other endeavor. In fact, the importance of "seeing" how a device operates prompted the development of oscilloscopes fairly early in this "age of electronics." To further the usefulness of oscilloscopes, some models today incorporate a "component-checking" feature. That innovation allows the scope to plot the "characteristic curve" of a component.

Essentially, a characteristic curve—a plot of voltage across a device versus the current through it—is the *signature* of the component. It reveals the most intimate details of a part's operation *while it's working*. In fact, if you can generate a curve and know what to look for, you can determine all the information that you'd normally find in a databook. What's more important is that your measurements will really mean something—they'll be applicable to the device you have on hand and not just a databook pipe dream.

By comparing the measurements that you make to the component's specifications or to the curve of a definitely healthy unit that you have on hand, you can determine exactly how the part is (or isn't) working and whether it's functioning suitably. Such information is useful for both troubleshooting circuits and selecting components of reasonable quality. That is great for checking out semiconductors that test fine on your multimeter, but fail in a circuit.

Such a feature also allows you to determine the important characteristics of reactive components (impedance, resistance, reactance, component value, and Q-factor). So basically, a scope can take the place of a capacitance meter and an inductance bridge in low-budget electronic workshops.

A plain oscilloscope allows you to observe a component's operation in a circuit, but most of them (especially in the hobbyist price range) can't provide you with a characteristic curve. If you don't know precisely how a component should be acting in a circuit point-by-point, a no-frills oscilloscope will be of no help.

Test-equipment manufactures are providing more and more oscilloscopes with a component-checker feature that allows them to plot the characteristic curve. But that doesn't help those of us who are not prepared to invest in a new scope. That's where the *EZ-Curve* oscilloscope accessory described in this article comes in; it can provide any oscilloscope with the ability to generate characteristic curves. Even an old scope can be used with the accessory, as long as it has at least a 60-Hz bandwidth and X-Y mode (those are pretty meager requirements).

Among the device's features are built-in current limiting (to automatically protect sensitive components), an adjustable current scale, and a design that can easily be altered to accommodate any special requirements that you might have.

Even though it's a precise test-instrument add-on, the EZ-Curve is a trouble-free project to build. The parts required for the accessory are common and can probably be found in your junkbox or, at the very least, at your local electronics-parts store. It can be built and adjusted in one evening, so you can put it to use almost immediately.

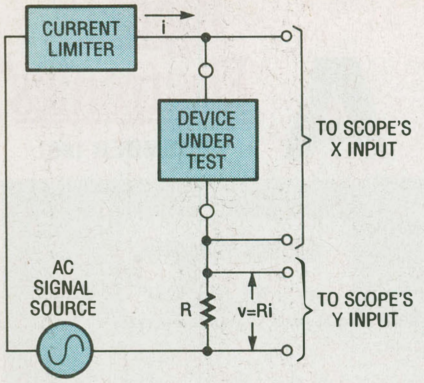


Fig. 1. This is a simple block diagram of the EZ-Curve. Current-limited AC signals are passed through both the device under test and a precision resistor to yield current and voltage readings.

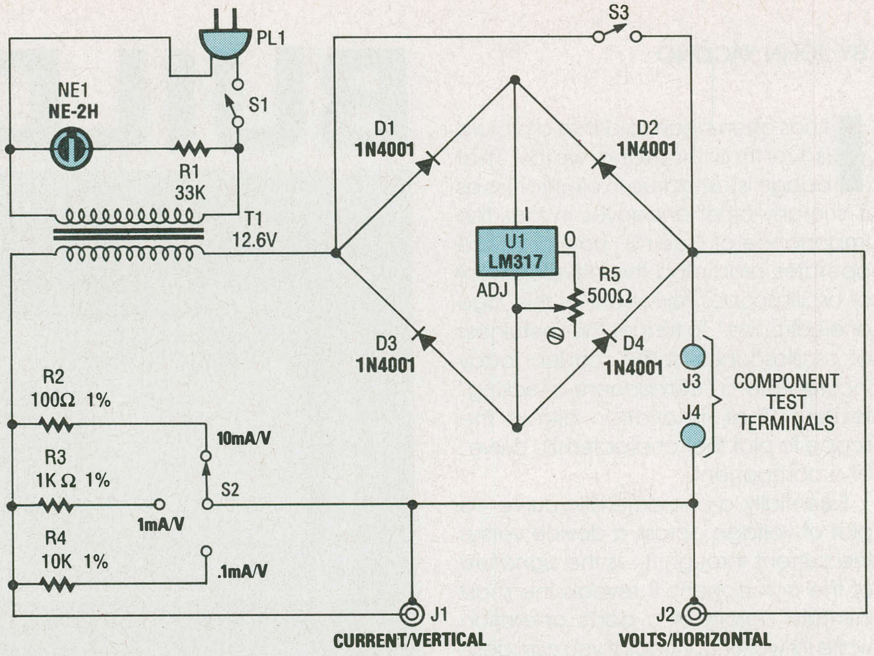


Fig. 2. In the actual EZ-Curve circuit a transformer is the signal generator, a voltage regulator acts as a current limiter, and the precision resistor is switch selectable.

In this article, we'll not only tell you how to build and adjust the EZ-curve, we'll also tell you what general characteristics to look for when testing the more common semiconductor and reactive components, and how to measure their important attributes. But let's start by discussing the circuit.

The EZ-Curve Principle. The EZ-Curve circuit is a bit unusual in appearance, so it's a good idea to first present a block diagram of it. As shown in Fig. 1, the circuit is basically an AC signal source connected in series to an active current-limiting circuit, the device under test, and a precision resistor.

As was mentioned, the current limiter is present to keep the current through the component being tested down to a safe level. An active current limiter was used instead of a simple resistor because a resistor would've limited the maximum voltage available to the device under test. That would be undesirable for testing certain components that require more voltage (such as Zener diodes).

Since everything is connected in series, the current flowing through the resistor is equal to the current through the component under test. According to Ohm's Law, the voltage across the resistor is proportional to the current through it. By connecting an oscilloscope across the resistor, you can watch the voltage and thus the current rise and fall as it flows through the component under test and the resistor. Note that we used a lower case "i" and "v" in Fig. 1 to indicate that those quantities vary with time.

You can make it easy to read the current right off the oscilloscope if you select the value of R wisely. For example, if R is 1 ohm, by Ohm's Law:

$$v = i \times 1 = i$$

so a 1-volt reading on the scope would mean 1 ampere of current is flowing through the component, a 2-volt reading indicates 2 amps, etc. The voltage across the component under test can be viewed by simply attaching an oscilloscope input across the component.

PARTS LIST FOR THE EZ-CURVE

SEMICONDUCTORS

U1—LM317 adjustable voltage regulator.
D1–D4—1N4001 rectifying diode

RESISTORS

(All fixed resistors are ¼-watt, 1% units unless otherwise noted.)
R1—33,000-ohm, 5%
R2—100-ohm
R3—1000-ohm
R4—10,000-ohm
R5—500-ohm, multi-turn potentiometer

ADDITIONAL PARTS AND MATERIALS

J1, J2—Male BNC connector
J3, J4—Banana jack
NE1—NE-2H neon indicator
S1, S3—SPST switch
S2—SP3T rotary switch
PL1—AC plug and line cord
T1—12.6-volt, 300-mA, power transformer
Perfboard material, coaxial cable, project case, wire, solder, etc.

Now let's say that you put your scope in X vs. Y mode, and you supply the X input with the voltage across the component, and the Y input with the voltage across the resistor. The signal source will supply the component with a current-limited AC sinewave, causing the scope to display the characteristic (V vs. I) curve. Why, you ask? Because the voltage across the device is presented to the X (horizontal) input, and a voltage proportional to the current controls the Y (vertical) input.

There is one catch, however: Scope inputs have a common shield—the shield of one input is electrically connected to the other via the chassis. So the shield on both inputs must be connected at the junction between the device under test and the resistor. The catch is that the polarity of the resistor will be opposite that of the component, causing the X axis to flip around; its positive side will be on the left and its negative side on the right. That is an aspect of commercial units as well as ours and can only be overcome at the expense of accuracy (and money).

Quite honestly, it wouldn't even matter if the characteristic curves came out upside down. What is important is that the user must know what to look for when viewing a curve, and we'll get into that a little later.

A Look at the Circuit. A schematic diagram of the EZ-Curve circuit is shown in Fig. 2. In that circuit, transformer T1

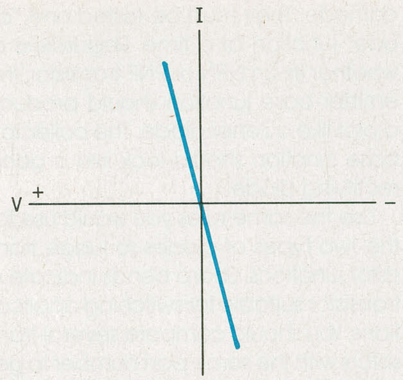


Fig. 3. Resistors produce the most boring characteristic curves. The inverse of the slope is the resistance.

acts as a very simple AC signal source. It receives its power from PL1 via the power switch S1. A neon lamp, NE1, is included in the circuit to indicate that the unit is on.

Resistors R2–R4 are precision units that take the place of R in Fig. 1. Switch S2 allows you to choose one of those resistors to get the scale you wish. For example, if you select R3, then a 1-volt reading on your scope indicates a 1-mA current flow. The voltage across that resistor is sent to the scope's Y input through BNC connector J1.

Integrated circuit U1 is the active current-limiting device. It is an LM317, which is normally used as an adjustable positive-voltage regulator, but it can be used as a current regulator when wired as shown. Multi-turn potentiometer R5 sets the maximum current level that the regulator will permit.

The LM317 is a DC device, even when used for current regulation, so diodes D1–D4 are used to steer the AC flowing through the rest of the circuit into the regulator with the right polarity. Keep in mind that only the regulator receives DC, the rest of the circuit is AC. The active current limiter can be removed from the circuit (shorted) by closing S3. That is useful for testing reactive devices, which don't require current limiting and yield a more informative curve without it.

The component that you wish to examine should be connected to the component test terminals, J3 and J4. The voltage across the component is made available to the scope's X input via J2.

Construction. Building the EZ-Curve couldn't be easier. That's because so few components are involved. We used a piece of perforated construction board and point-to-point wiring to do the job. Follow Fig. 2 as a wiring guide.

First mount all of the small components on the board, but be sure to leave enough room to mount the transformer on the board as well—leave the transformer for last, because it's easier to work on the board without T1's added weight. We used a PC-mounting potentiometer for R5 because it must be adjusted only once in the initial calibration of the unit. Therefore, you don't have to have front-panel access to that control.

We included an on/off switch (S1) and neon power-on indicator (NE1) in our prototype. If you don't have them on hand, or don't wish to go for the added expense, then it is perfectly alright to leave them out. In that case, just remember to unplug the unit when not in use.

Switch S2 must have at least three positions. Although the one in our prototype has a lot more than three, we used it because we had it on hand. You can use whatever switch you have on hand, or purchase an appropriate one.

Although shielding is not required on the connections to J1 and J2, we used lengths of shielded cable because it's easier to attach the required BNC connectors to that kind of wire. The BNC's connect to your oscilloscope inputs.

Two binding posts (J3 and J4) are used to connect the component under test to the EZ-Curve. They should be mounted for easy access on the front panel of whatever cabinet you use so that inserting a component to be tested is as simple as possible.

The size of the cabinet is determined by the overall size of the board and the height of the transformer. Since shielding is not a concern, you can use whatever kind of cabinet you like—plastic, metal, etc. The cabinet we used is best suited for front-panel mounting of the controls. However, depending on the cabinet you use, they can be mounted wherever it's most convenient.

Adjustment and Operation. The current limiter needs to be adjusted before you use the unit. If not adjusted properly you could damage the precision resistors as well as any component you try to test. Stick to the easy adjustment procedure that follows and no harm will befall you.

Start by connecting an ohmmeter across R5. Adjust that potentiometer to 125 ohms and remove the ohmmeter. Plug the circuit in and turn it on. Switch the scale control (S2) to the 1-mA/V position and make sure S3 is open. Connect J1 to an input on your scope (the scope should not be in X vs. Y mode right now). The scope should display nothing at this time.

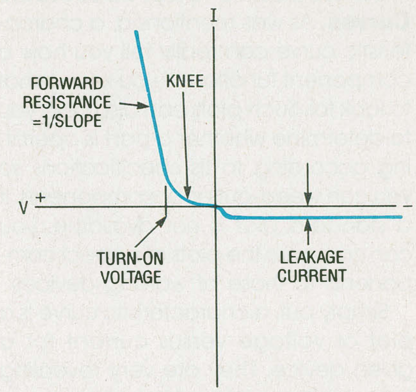


Fig. 4. A diode's curve reveals all of its important characteristics. The sharpness of the knee bend is important.

Connect (read that "short-out") the component test terminals (J3 and J4) together. You should see a slightly distorted sinewave of around 20 volts peak-to-peak. If not, carefully adjust the potentiometer, R5, being careful not to stray too much higher than 20 volts peak-to-peak.

Now switch to the 10-mA/V position and check the waveform. It should be less than or equal to 2 volts peak-to-peak. If it's higher, adjust R5 to lower the voltage. Remove the wire shorting J3 and J4 and you're all done with the adjustment procedure.

To use the unit, you should connect J1 to your scope's Y input and J2 to its X input. Before connecting a component to J3 and J4, ask yourself this unlikely question: Will the component be harmed by 10-mA? (This is usually only a concern with FET's and other semiconductors with high input impedance.) If the answer is "yes," set the scale switch to the 0.1-mA/V position and leave it there. That will limit the current to less than 2 mA, which is harmless for *any* device (and is a standard output-current limit for oscilloscope-based component checkers). However, for most semiconductors, you can use any scale that suits you.

If the component is an inductor or capacitor, close S3. That prevents the current limiter from altering the characteristic curve. As you'll soon see, that will allow you to gather the important information contained in the curve. However, this is not an important consideration when testing non-reactive components.

Non-Reactive Characteristic Curves. As was mentioned, a characteristic curve can really tell you how a component functions if you know what to look for. Such plots can also help you to determine whether a part is operating according to its specifications so you can weed-out poor components. If a standard plot is not available, you can compare the plots of suspect components to those of working devices.

Simply put, a characteristic curve is a plot of voltage versus current for a given device. They are very revealing because the relationship between current and voltage is all you need to know to use any component.

To give you more of a feel for what a characteristic curve is let's start by examining the simplest one possible: the "curve" of a resistor. As you might suspect, the characteristic curve of a resistor (its voltage to current relationship) is based on Ohm's Law:

$$V = IR$$

If you were to connect a resistor to an adjustable-voltage source, and plot the current through the resistor versus a number of different input voltages, the resulting "curve" would be a straight line. One over the slope of the line, which would be V/I, would be equal to the resistance. The steeper the slope the smaller the resistance.

Such a plot is not terribly useful (it's easier to use a multimeter), but it serves to illustrate how the EZ-curve works: If the resistor were connected to the EZ-curve, you would get a straight line. That's because the EZ-curve would apply a continuously varying (read that "sinewave") voltage to it and supply the scope with the resulting voltage and current information. If the resistor had a low value, the plot would look like the one shown in Fig. 3. (Remember the X-axis is flipped around.)

Other devices have more interesting and more informative curves. For example, a diode would generate a curve something like that shown in Fig. 4. The forward-bias portion of a good-diode curve should have a steep slope. Furthermore, the knee of the curve, where the diode begins to conduct, should be fairly sharp and close to the origin. Poor diodes will appear to have shallow slopes, wide bends, require too much forward voltage to conduct and/or breakdown too easily when reverse-biased. The last problem will manifest itself as a "tail" hanging off the end of the curve (see Fig. 5).

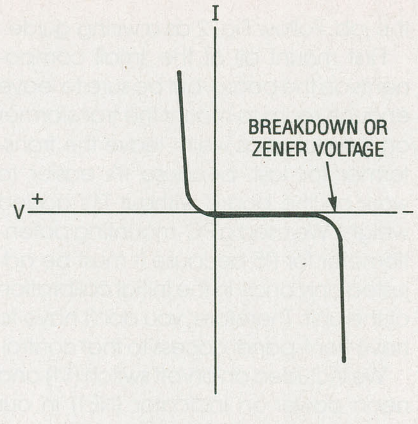


Fig. 5. Zener diodes look like diodes with a poor breakdown region when reverse biased. The breakdown voltage should be approximately the diode's specified Zener voltage.

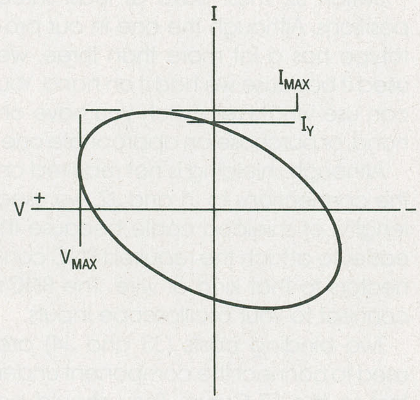


Fig. 6. This curve is typical of a reactance, whether a capacitor or inductor. The three important data points are marked here.

You can directly read the diode's reverse-leakage current and turn-on voltage from the oscilloscope trace. You can determine the forward-bias resistance of the diode by finding the slope of the forward-biased part of the curve and dividing it into 1.

Zener diodes will produce the same forward-bias curve as a normal diode, but the reverse-bias part of the trace will have a tail (like the diode in Fig. 5). Such a Zener is actually good. The tail should occur very near the specified Zener voltage, and the diode should be able to handle the rated Zener current at that voltage. Again, that can be determined directly from the plot. Unlike a regular diode, the forward-biased portion of a Zener can be ignored.

Bipolar transistors can be viewed as a pair of diodes tied together: NPN transistors are like two diodes placed anode-to-anode and PNP transistors are like diodes connected cathode-to-cathode. They must be tested one "diode" junction at a time. Regardless of whether its an NPN or PNP transistor, the emitter-base junction should produce a plot like a Zener diode. The collector-base junction should look like a good rectifying diode.

Use the same rules you would use for the two types of diodes to judge transistor junctions. Sharp bends indicate a transistor suitable for switching applications. You should compare several transistors with the same part number to get a feel of what to look for. The wide range of quality (and its absence) that you'll find among transistors purchased in bulk will probably surprise and perhaps disappoint you.

Reactive Components. As we mentioned, the device can help you determine impedance, Q-factor, and all the other attributes associated with reactive components (capacitors and inductors). You just have to take some readings off the scope and do a little simple math, as we'll explain.

Unlike the components we've already examined, the curves for reactive components look like slightly-tilted ellipses (see Fig. 6). Without getting too bogged down in theory, the ellipse-like shape is due to the fact that current and voltage in reactive devices do not change in step with one another. The slant just indicates that the component contains some DC resistance.

The important characteristics of reactive devices are impedance, Z; reactance, X; resistance, R; Q-factor, Q; and the value of the component: L for an inductor, C for a capacitor. You can determine all of these quantities by taking three measurements off the device's characteristic curve (look back at Fig. 6) and doing some very simple math. Keep in mind that since the EZ-Curve operates at 60 Hz, the values you obtain for impedance, reactance, and Q-factor are only true at 60 Hz. You will have to do a little extra math to determine those values for other operating frequencies. Of course, once the resistance and the value of L or C are determined, it is easy to determine Q, X, and Z for any desired frequency.

For our purposes, the sign of the quantities should be dropped, so as to make all your readings positive numbers. To further simplify things, the math is the same for both inductors and capacitors when determining Z, X, R, and Q. Only finding the components value,

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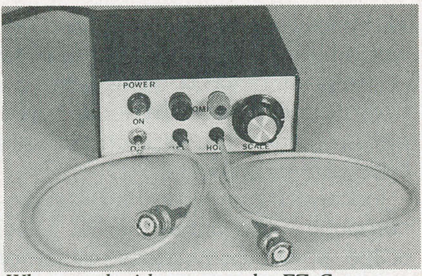

When used with a scope the EZ-Curve Signature Tracer can diagnose the condition of a variety of components.

C or L, involves using one of two different equations.

The easiest procedure to follow, which reduces the math to a minimum, is to take a reading or two, do some math to find a value, perhaps take another reading, and use your previous results to find yet another quantity. With that in mind, the first thing you should do is measure the maximum current (denoted I_{MAX}) and the maximum voltage (denoted V_{MAX}) on the scope. Note that the maximum current and voltage do not occur at the same point on the curve. From the two readings you can determine the impedance:

$$Z = V_{MAX}/I_{MAX}$$

Next, measure the current at which the curve crosses the vertical axis (I_Y). You can use that measurement and the value you got for Z to find the reactance:

$$X = Z \times I_Y/I_{MAX}$$

From the reactance and the impedance you can find the value of the component's internal resistance:

$$R = \sqrt{Z^2 - X^2}$$

From X and R you can determine the device's Q factor:

$$Q = X/R$$

You can also find the value using this equation for an inductor:

$$L = X/(180\pi)$$

or this equation for a capacitor:

$$C = 1/(180\pi X)$$

That's a lot of data from three points on a curve!

We're sure that you'll find the EZ-Curve to be a very useful device. But even if your scope already has a component checker, you now know exactly how that feature works and how to take full advantage of it. ■