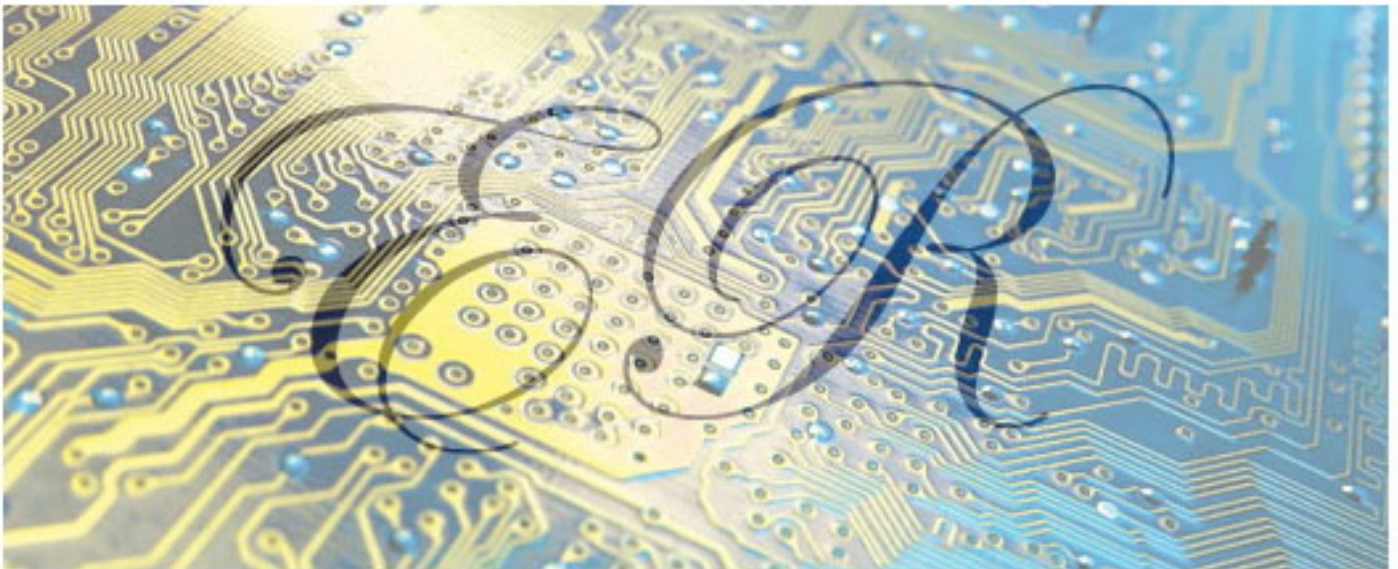


Basic Testing Of Semiconductor Devices



Electronic Repair

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Introduction

Scope of This Document

The first part of this note describes procedures for testing of diodes (signal, rectifier, and zener); bipolar (NPN or PNP, small signal and power) transistors; SCRs, and MOSFETs for catastrophic failures like shorts and opens.

In most cases, this will identify bad silicon transistors. Gain, frequency response, etc. are not addressed here. While the tests can be applied to germanium devices, these are more likely to change characteristics, it would seem, without totally failing.

It is also possible to determine the lead arrangements of identified diodes and bipolar transistors as well as breakdown voltage ratings.

Curve tracers are pieces of electronic test equipment similar to an oscilloscope. They can not only test transistors and other devices but evaluate the functional specifications as well. The chapter: "Curve Tracer Design" includes information on their basic principles of operation and provides details on some very additions to conventional scopes to add some basic curve tracer capability.

Safety Considerations

Before touching, probing, or unsoldering any component, make sure the equipment is unplugged and any large capacitors have been safely discharged.

Testing Semiconductor Devices with a VOM or DMM

VOMs and DMMs

Analog and Digital meters behave quite differently when testing nonlinear devices like diodes and transistors. It is recommended that you read through this document in its entirety.

Caution:

An analog VOM on the lowest resistance range may put out too much current for smaller devices possibly damaging them. Ironically, this is more likely with better meters like the Simpson 260 which can test to lower ohms (X1 scale). Use the next higher resistance range in this case or a DMM as these never drive the device under test with significant current. However, this can result in false readings as the current may be too low to adequately bias the junctions of some power devices or devices with built in resistors.

Testing Diode Junctions with a Multimeter

On an (analog) VOM, use the low ohms scale. A regular signal diode or rectifier should read a low resistance (typically 2/3 scale or a couple hundred ohms) in the forward direction and infinite (nearly) resistance in the reverse direction. It should not read near 0 ohms (shorted) or open in both directions. A germanium diode will result in a higher scale reading (lower resistance) due to its lower voltage drop.

For the VOM, you are measuring the resistance at a particular (low current) operating point - this is not the actual resistance that you will see in a power rectifier circuit, for example.

On a (digital) DMM, there will usually be a diode test mode. Using this, a silicon diode should read between .5 to .8 V in the forward direction and open in reverse. For a germanium diode, it will be lower, perhaps .2 to .4

V or so in the forward direction. Using the normal resistance ranges - any of them - will usually show open for any semiconductor junction since the meter does not apply enough voltage to reach the value of the forward drop. Note, however, that a defective diode may indeed indicate a resistance lower than infinity especially on the highest ohms range. So, any reading of this sort would be an indication of a bad device but the opposite is not guaranteed.

Note: For a VOM, the polarity of the probes is often reversed from what you would expect from the color coding - the red lead is negative with respect to the black one. DMMs usually have the polarity as you would expect it. Confirm this using a known diode as a reference. Also, 'calibrate' your meter with both silicon and germanium semiconductors so you will know what to expect with an unknown device.

Transistor Testing Methodology

As with diode junctions, most digital meters show infinite resistance for all 6 combinations of junction measurements since their effective resistance test voltage is less than a junction diode drop (if you accidentally get your skin involved it will show something between 200K and 2M Ohms). The best way to test transistors with a DMM is to make use of the "diode test" function which will be described after the analog test. For both methods, if you read a short circuit (0 Ohms or voltage drop of 0) or the transistor fails any of the readings, it is bad and must be replaced. This discussion is for OUT OF CIRCUIT transistors *ONLY*.

One exception to this occurs with some power transistors which have built in diodes (damper diodes reversed connected across C-E) and resistors (B-E, around 50 ohms) which will confuse these readings. If you are testing a transistor of this type - horizontal output transistors are the most common example - you will need to compare with a known good transistor or check the specifications to be sure. There are some other cases as well. So, if you

lead "A" of your multi-meter on the base and lead "B" on the emitter. You should get a reasonable low resistance reading. Depending on scale, this could be anywhere from 100 ohms to several K. The actual value is not critical as long as it is similar to the reading you got with your 'known good diode test', above. All Silicon devices will produce somewhat similar readings and all Germanium devices will result in similar but lower resistance readings.

Now move lead "B" to the collector. You should get nearly the same reading. Now try the other 4 combinations and you should get a reading of infinite Ohms (open circuit). If any of these resistances is wrong, replace the transistor. Only 2 of the 6 possible combinations should show a low resistance; none of the resistances should be near 0 Ohms (shorted).

As noted above, some types of devices include built in diodes or resistors which can confuse these measurements.

Testing with a (Digital) DMM

Set your meter to the diode test. Connect the red meter lead to the base of the transistor. Connect the black meter lead to the emitter. A good NPN transistor will read a JUNCTION DROP voltage of between .45v and .9v. A good PNP transistor will read OPEN. Leave the red meter lead on the base and move the black lead to the collector. The reading should be the same as the previous test. Reverse the meter leads in your hands and repeat the test. This time, connect the black meter lead to the base of the transistor. Connect the red meter lead to the emitter. A good PNP transistor will read a JUNCTION DROP voltage of between .45v and .9v. A good NPN transistor will read OPEN. Leave the black meter lead on the base and move the red lead to the collector. The reading should be the same as the previous test. Place one meter lead on the collector, the other on the emitter. The meter should read OPEN. Reverse your meter leads. The meter should read OPEN. This is the same for both NPN and PNP transistors.

As noted, some transistors will have built in diodes or resistors which can confuse these readings.

Testing Power Transistors

Power transistors without internal damper diodes test just about like small signal transistors using the dual diode model, high in one direction B-E or B-C. If there is a built in damper diode, it is across C-E back biased under normal operating conditions. Therefore, a reading between C-E will also test low in one direction and B-C will show a double diode drop in the reverse direction. Also, there is often a low value resistor - about 50 ohms - between B-E when there is a built in damper. This will show up as a nearly zero volt junction drop on the diode test scale of a DMM but such a reading does not indicate a bad part. Use the resistance scale to confirm.

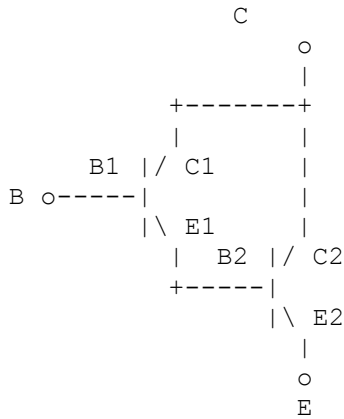
Testing Darlington Transistors

A Darlington is a special type of configuration usually consisting of 2 transistors fabricated on the same chip or at least mounted in the same package. Discrete implementations as well as Darlington's with more than 2 transistors are also possible.

In many ways, a Darlington configuration behaves like a single transistor where:

- the current gains (H_{fe}) of the individual transistors it is composed of are multiplied together and,
- the B-E voltage drops of the individual transistors it is composed of are added together.

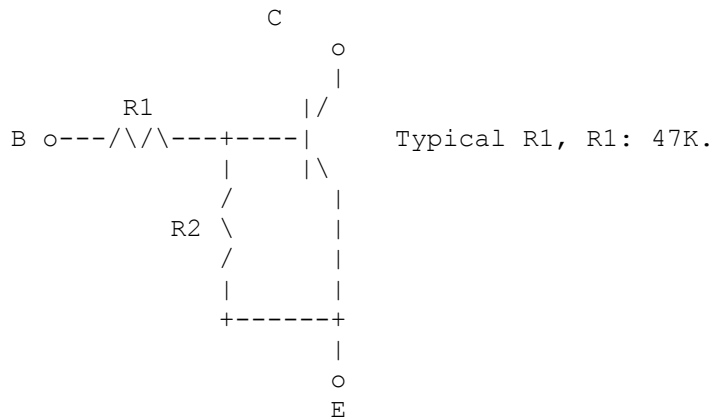
Darlington's are used where drive is limited and the high gain - typically over 1,000 - is needed. Frequency response is not usually that great, however.



Testing with a VOM or DMM is basically similar to that of normal bipolar transistors except that in the forward direction, B-E will measure higher than a normal transistor on a VOM (but not open and 1.2 to 1.4 V on a DMM's diode test range due to the pair of junctions in series. Note, 1.2 V may be too high for some DMMs and thus a good Darlington may test open - confirm that the open circuit reading on your DMM is higher than 1.4 V or check with a known good Darlington.

Testing Digital or Bias Resistor Transistors

Occasionally you may find a transistor that includes an internal bias resistor network attached to the base and emitter so that it can be driven directly from a digital (e.g., TTL) source. These may be used in consumer electronic equipment where space is critical or for no good reason other than to make it difficult to locate a suitable replacement device!

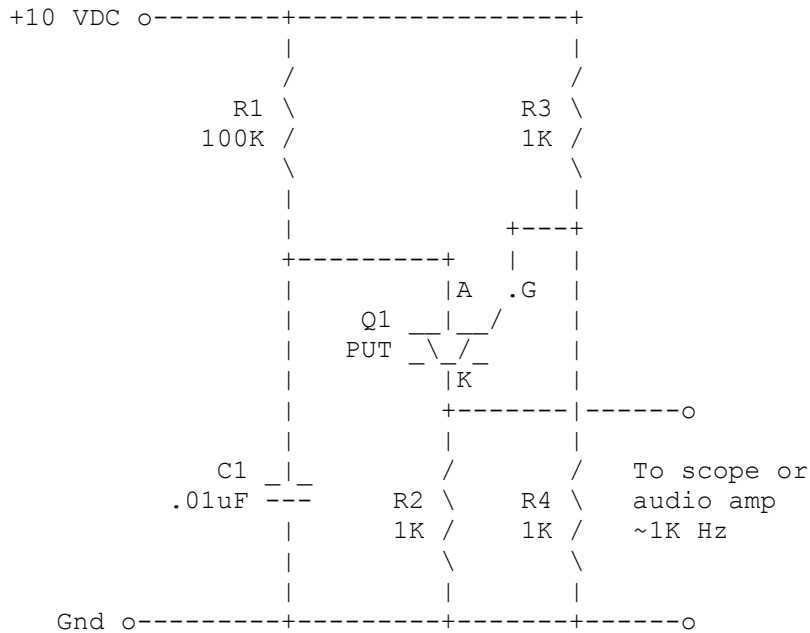


The addition of R1 makes testing with a multimeter other than for shorts more difficult. With a VOM, you should see a difference in the B-E and B-C junctions in the forward and reverse directions. However, a DMM will probably read open across all pairs of terminals.

Testing Unijunction and Programmable Unijunction Transistors

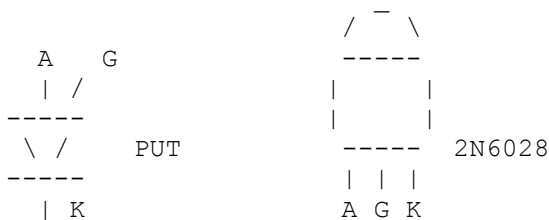
Unijunction Transistors (UJTs) and Programmable Unijunction Transistors (PUTs) are used in similar sorts of circuits though the UJT is all but extinct. They both exhibit a negative resistance characteristic and can be used easily in low to medium frequency free running relaxation oscillators and other trigger type circuits.

- The UJT goes into heavy conduction from E to B1 when E becomes more positive than a critical trigger voltage, $V_t = n * V_{bb} + .6$. (n, the 'intrinsic standoff voltage' is typically about .6). It continues to conduct until the emitter current drops below some minimum 'valley current' value. Sounds sort of like a thyristor, right? :)
- The PUT is even more like a thyristor: The PUT in that the triggering takes place when the G becomes more positive than the A (probably plus a diode drop, .6 V) so that the threshold voltage can now be set with a voltage divider feeding the anode. Then, current flows from the G to the K terminal. Note that its leads are even labeled like an SCR but it behaves sort of backwards!



A PUT is essentially an SCR with a large reverse gate breakdown voltage (G can be more positive than A by maybe 40 V) and a sensitive gate. When the voltage at A exceeds the voltage at G by a diode drop, and assuming enough voltage from A to K, the SCR turns on (conducts from A to K) and stays that way until the current drops below the holding current (typically around 100 uA, but it drops with increasing resistance in series with the gate).

Symbol and example:



If you connect your meter from A to K, it should measure open both ways. If you connect the positive lead (which may be red or black, depending on

the meter design) to A and the negative lead to K, and then momentarily short G to K it should change to a relatively low resistance reading (meter dependent). It will most likely stay latched when the G lead is returned to being open, because the meter measuring current will exceed the "holding current" of the PUT (called "valley current" in PUT specs).

If your meter has a "diode" range (in the ohms group), using that would assure there is enough open-circuit voltage to make this work, but it works this way in the half-dozen or so meters I have checked, using reasonable ohms ranges.

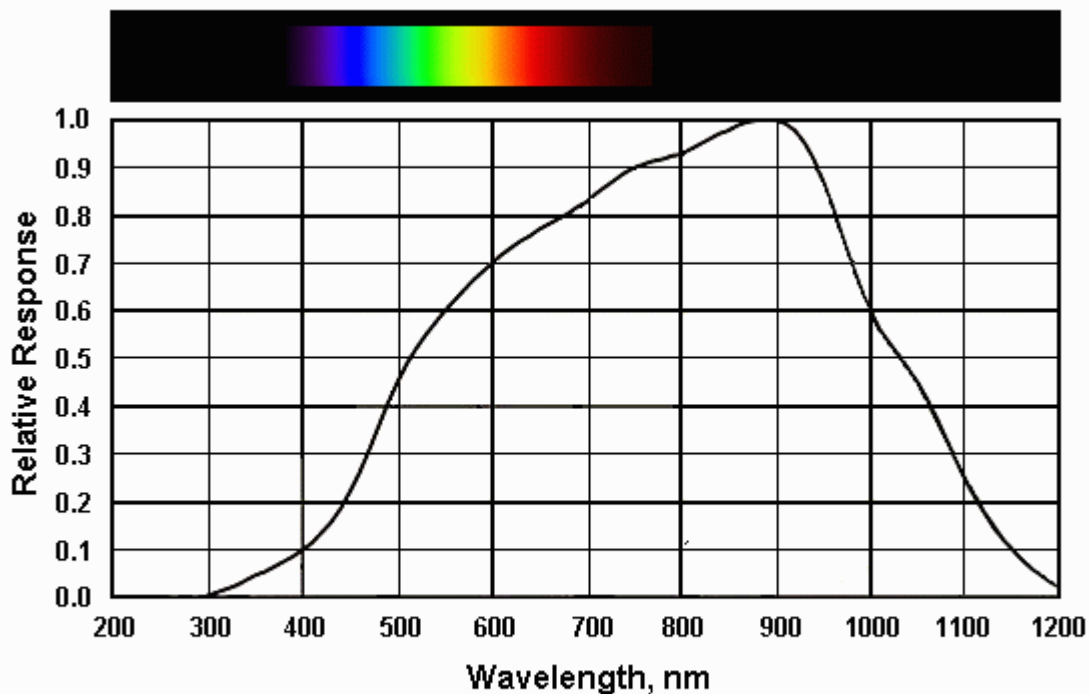
Measurements between A and G, with K open, should be similar to a silicon diode (fairly low in one direction, open in the other). Between G and K, with A open, should be open in both directions.

PUTs are pretty sensitive (less than 1 uA trigger current) so be sure to keep fingers away from the G lead.

Testing a Photodiode

Photodiodes are used in all sorts of equipment from PC mice (those with a ball) to high power lasers (for monitoring the output power). They are generally very reliable and rarely fail on their own. However, some types are susceptible to damage from ESD and other abuse.

The following assumes a silicon photodiode which is the most common type with a useful spectral range from near-UV to near-IR, typically from 400 to 1,150 nm at the 10 percent response points. See the chart



Typical Silicon Photodiode Spectral Response

The simplest electrical test is to check it like a normal diode. The results should be similar - a forward voltage drop of 0.5 to 0.7 V, and open in the reverse direction. For GaAs and other types, the forward voltage drop will differ.

To test for functionality, connect the photodiode to a multimeter set to its mA current range (1 mA full scale optimal). This is operating the photodiode in photovoltaic mode - like a solar cell. A laser pointer or helium-neon laser is the ideal light source to use for testing, but the Sun, a light bulb, a flashlight, or even an LED will work fine as well but will not provide any useful sensitivity information. For the laser source, the sensitivity should be between 0.2 and 0.5 mA/mW of laser power depending on wavelength. So, using a typical cheap Far East import red laser pointer (typically 3 mW at 650 nm), the current will be about 1 mA.

For a more accurate measurement, reverse bias the photodiode with a few volts with a current limiting resistor (for protection) and repeat the light

measurement. This is operating the photodiode in photoconductive mode, which is probably the way it is used in your equipment. The results should be similar but the response is more linear at higher current than in photovoltaic mode.

For most applications, photodiodes either work or they don't. But in some cases, performance degradation may occur from age or abuse. Substitution of a known good device is the easiest confirmation where the photodiode appears to behave properly based on the tests above, but doesn't perform properly in-circuit.

Thyristors - SCRs and Triacs

What are Thyristors

Thyristors are used to control power in numerous applications including light dimmers and motor speed controls, solid state relays, some microwave ovens, photocopiers, traction motors for electric locomotives and electric cars, power inverters for transmission of electric power over long distances, frequency converters, other DC-DC or DC-AC or AC-AC inverters, AC-DC regulated power supplies, and many other applications where efficient power control is required.

A Silicon Controlled Rectifier is one type of thyristor used where the power to be controlled is unidirectional. The Triac is a thyristor used where AC power is to be controlled. (There are exceptions in both cases but for this simple discussion these can be ignored).

Both types are normally off but may be triggered on by a low current pulse to an input called the Gate. Once triggered on, they remain on until the current flowing through the main terminals of the device drops below a hold value which is very close to zero. It is usually not possible (at least not easy) to turn thyristors off while current is flowing. However, there are

special types called Gate Turnoff Thyristors which enable this type of control as well.

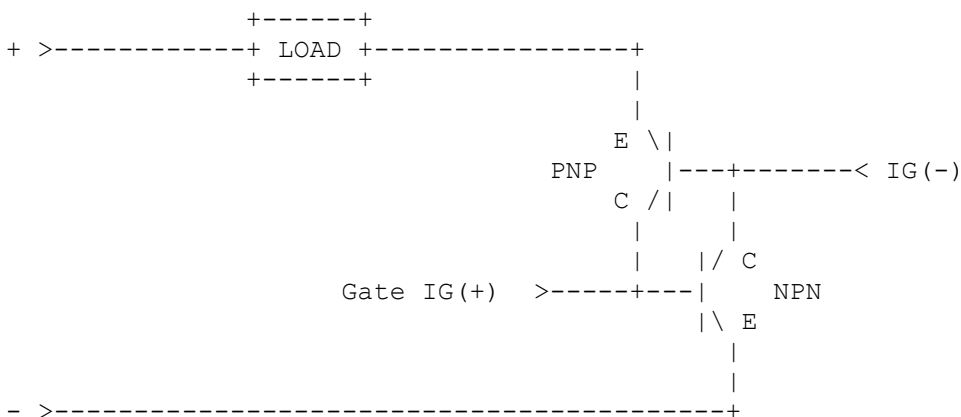
Both SCRs and Triacs are 4 layer PNPN structures.

How Does a Thyristor Work?

The usual way an SCR is described is with an analogy to a pair of cross connected transistors - one is NPN and the other is PNP. The base of the NPN is connected to the collector of the PNP and the base of the PNP is connected to the collector of the NPN.

If we connect the positive terminal of a supply to say, a light bulb, and then to the emitter of the PNP transistor and its return to the emitter of the NPN transistor, no current will flow as long as the breakdown voltage ratings of the transistor are not exceeded because there is no base current to either transistor. However, if we provide some current to the base of the NPN ($I_{G(+)}$) transistor, it will turn on and provide current to the base of the PNP transistor which will turn on providing more current to the NPN transistor. The entire structure is now in the solid on state and will stay that way even when the input to the NPN's base is removed - until the power supply goes to zero and the load current goes below the hold value.

The same scenario is true if we reverse the power supply and use the $I_{G(-)}$ input for the trigger.



A Triac works in a basically similar manner except that the polarity of the Gate can be either + or - during either half cycle of an AC cycle.

For a light dimmer or motor speed control, for example, the exact time when the thyristor is triggered relative to the zero crossings of the AC power is used to determine the power level. Trigger the thyristor early in the cycle and the load is driven at high power. Trigger the thyristor late in the cycle and there is only a small amount of power delivered to the load. The thermal or mechanical inertia is generally counted to smooth out the power and results in smooth continuous operation (i.e., a light bulb controlled by a dimmer does not flicker.)

The advantage of thyristors over simple variable resistors is that they (ideally) dissipate very little power as they are either fully on or fully off.

There are a wide variety of other types of thyristor and thyristor-like devices. In particular, are diacs and sidacs which have no gate input but simply turn on when a specified threshold voltage is exceeded across their main terminals.

For more information on thyristors, see Horowitz and Hill or any thyristor databook.

Testing SCRs and Triacs

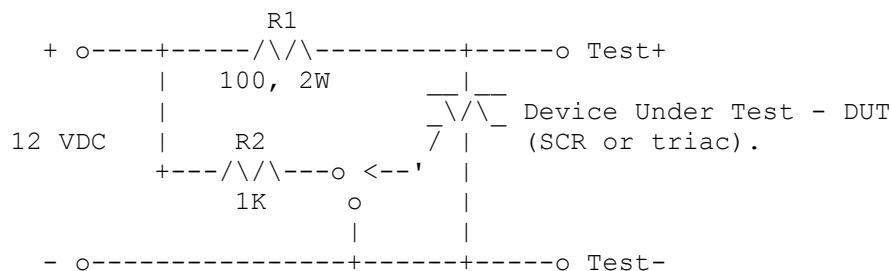
- For SCRs, the gate to cathode should test like a diode (which it is) on a multimeter. The anode to cathode and gate to anode junctions should read open in both directions.
- For triacs, the gate to main terminal 1 (MT1) should test like a diode junction in both directions. MT1 to MT2 and gate to MT2 junctions should read open in both directions. (CAUTION: I'm not sure the MT1 and MT2 designations are universal - check the datasheet to be sure!)

- For diacs and sidacs, there is no gate terminal - resistance should be infinite in both directions.

Note: Some thyristors will have a low G-K/MT1 resistance but it should not read as a short.

The real test is quite simple but will require a low voltage DC power supply and two resistors. For triacs, a negative output from the supply is desirable as well to test the triggering when the gate is negative).

R1 will be used to limit current through the device and R2 will be used to limit current to the gate. A 12 VDC supply of at least 200 mA capacity with a 100 ohm 2 W resistor for R1 and 1 K 1/4 W resistor for R2 should work for most small to medium power SCRs. Check the 'minimum gate current' and 'holding current' specs to be sure. For larger devices, R1 and/or R2 may need to be smaller.



1. Connect the supply as shown.
 2. Trigger the gate from the positive of the supply through the current limiting resistor (R2) and see that the DUT turns on stays on when the gate is disconnected.
 3. Open the circuit to the anode (with the gate connected to the cathode) and again reconnect the anode resistor. The DUT should now be off again.
- For triacs, repeat steps (2) and (3) with R2 supplied from a negative voltage.

- For diacs, testing must be at full rated voltage.

If the device passes these tests, it is behaving properly and is probably functional. However, without applying full voltage or current, there is no way of knowing if it will meet all specifications.

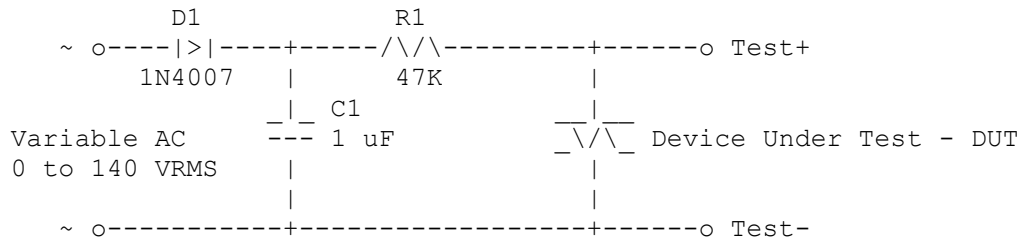
You can replace the DC supply with a low voltage power transformer (say, 12 VAC). Use a scope to monitor the voltage across the DUT or R1. Then, when the gate is connected to R2, you should see the voltage across the DUT drop to nearly zero when it switches on part way through the positive cycle. This phase will be determined by the voltage and value of R2. It should remain off for the entire negative cycle (SCRs only) with the gate connected and remain off all the time with the gate connected to the cathode.

If you have a semiconductor curve tracer you can configure a small audio transformer circuit to drive the gate. I did this with my B&K and it works well. The secondary should provide enough voltage to drive the gate of the SCR and the negative swing of the AC will cycle the scr off while the positive phase turns it on. I drive the transformer with an audio generator. Hope this offers some ideas.

Testing Diacs and Sidacs

Diacs and Sidacs are thyristors without any gate terminal. They depend on the leakage current to switch them on once the voltage across the device exceeds their specified ratings. With an ohmmeter, they can be tested only for shorts. Resistance should be infinite in both directions.

However, you can test a diac or sidac with a resistor, variable power supply (you will need at least the rating of the device), and a DMM. Hook them in series and monitor across the device. With care, your variable supply can be a Variac, 1N4007, and 1 uF, 200 V capacitor. Use a 47 K resistor to limit the current:



CAUTION: this is not isolated from the power line. Use an isolation transformer for safety. If the DUT is rated more than about 180 V, you will need to use a doubler and higher voltage capacitor but testing is otherwise similar.

As you increase the input, the voltage on the DUT will track it until the rated voltage at which point it will drop abruptly to zero and stay there until the voltage is reduced below its holding current. Repeat with the opposite polarity.

With a scope it is even easier as you can use an AC supply directly (remove D1 and C1) and observe that the DUT will turn on at the proper voltage on both polarities of the AC waveform and stay on until the voltage crosses 0.

Use an isolation transformer for safety.

Thyristors Driving Inductive Loads

"I am trying to turn on a triac which is driving an inductive load (solenoid) using a digital signal without using an opto triac. I get limited success."

From: Jeroen Stessen

It is soooo easy: just use a DC current to drive the gate of the triac. Even the polarity of the current doesn't matter, although most triacs are more sensitive for a negative input current (flowing out of the gate to a negative supply). A large triac may require some 50 mA.

There will be some applications where there is no 50 mA supply available. That's where you would want to drive with short pulses. But these pulses would have to occur around the expected instant of the zero-crossing of the load current, which is a bit tricky with an inductive load.

As an alternative you could look for a more sensitive triac, for not too large load currents there are types down to 5 mA or so. If you have 50 mA of DC to spare, go for it, it will work.

By the way, never switch an inductive load like a power transformer ON at the zero crossing of the mains voltage. That's guaranteed to drive the transformer into saturation and create the worst possible current transient. Try and switch on at maximum mains voltage, at +/- 90 degrees delay. Do not use a voltage differentiator to generate +90 degrees phase shift, as it will be too sensitive to mains disturbances. Instead, use a double integrator to give $2 * -45$ degrees and a low-pass filter. Using only 1 integrator to approach -90 degrees gives too much attenuation of the voltage, hence 2 are recommended.

Burning Up of Thyristors

From: Neill Means

Any thyristor will have a maximum change in current vs change in time di/dt . If this is exceeded, then current flowing through the thyristor will find the path of least resistance through the silicon. Unfortunately, for us, this can be thought of as a molecular sized lightning bolt streaking through the doped layers of silicon - finding the path of least resistance from individual molecule to individual molecule. This soon results in an 'avalanche' of electrons streaming through a very small path and this process feeds on itself until the thyristor dies. This whole process probably takes only microseconds to happen.

I don't know if fast blow fuses will help this situation if the current changes too rapidly. A fuse is a very analog device with mass and it seems like it would be a slow, lumbering giant compared to almost instantaneous current change.

The solution for this problem? I am guessing putting an appropriately sized inductor in series with the light bulb, but just be sure to add the correct over voltage snubbing network. The inductor will keep the current from changing too rapidly.

Additional Semiconductor Tests

Identifying Unknown Bipolar Transistors

The type (NPN or PNP) and lead arrangement of unmarked transistors can be determined using a multimeter based on similar considerations. This, again, assumes the back-to-back diode model. The collector and emitter can then be identified based on the fact that the doping for the B-E junction is always much higher than for the B-C junction. Therefore, the forward voltage drop will be very slightly higher - this will show up as a couple of mV (sometimes more) difference on a DMM's diode-test scale or a slightly higher resistance on an analog VOM.

To determine the lead arrangement, label the pins on the unknown device 1, 2, and 3. Put the positive probe (as determined above) of your multimeter on pin 1. Now, measure the resistance (VOM) or diode drop (DMM) to the other two pins. If the positive probe is on the base of a good NPN transistor, you should get low resistance readings or a low diode drop to the other two leads. The B-C resistance or diode drop will be just slightly lower than the B-E reading.

If one or both measurements to the other two pins is high, put the positive probe on pin 2 and try again. If still no cigar, try pin 3.

If this still doesn't work, you may have a PNP transistor - repeat with the negative probe as the common pin.

If none of the six combinations yields a pair of low readings - or if more than one combination results in a pair of low readings, your transistor is likely bad - or it is not a bipolar transistor!

As noted, some power transistors have built in base resistors or damper diodes and will confuse these measurements. However, the lead arrangement of these types of transistors is usually self evident (standard TO3, TOP3, or TO220 cases). There are also some transistors with series base resistors which may prove confusing. There are relatively rare, however.

Voltage ratings are more difficult and require a low current variable DC power supply with a maximum voltage output greater than the expected (or desired) breakdown rating of the transistors being tested. A fixed DC supply with a suitable potentiometer is also satisfactory. For tests up to 100 V, a 100K ohm pot would be satisfactory. Put a current limiting resistor of about 100 K ohms in series with the output. For higher voltage transistors, use an appropriate power supply and increase the value of the potentiometer (if used) and current limiting resistor. It should be possible to determine approximate values for Breakdown Voltages such as:

BV_{cbo} - collector to base, emitter open. BV_{ceo} - collector to emitter, base open. BV_{ces} - collector to emitter, base shorted to emitter. BV_{ebo} - emitter to base, collector open.

Apply your variable voltage across the appropriate leads and monitor at the transistor with your VOM or DMM. The breakover point should be easily detectable. The current limiting resistor should prevent damage to the part from power dissipated in the reverse biased junction.

This approach also works for signal, rectifier, zener diodes, and other similar devices.

Luke's Comments on Junction Voltage Drops and Doping

(From: Luke Enriquez VK3DLE)

The B-C junction voltage drop is always very slightly lower than the E-B junction drop. The drop is given by the equation:

$$V_{\text{drop}} = V_t * \ln (N_a * N_d / n_i^2)$$

where:

$$V_t = kT/q = 26 \text{ mV at } 300 \text{ degrees K}$$

n_i = intrinsic carrier concentration in a pure sample of silicon
($n_i = 1.5 * 10^{10} \text{ cm}^{-3}$ at 300 deg K for silicon)

N_d = doping density atoms/cm³ in the n-type material

N_a = doping density atoms/cm³ in the p-type material

This equation means that if the doping density at the Base-Emitter junction is higher than the Base-Collector junction, the V_{drop} of the Base-Emitter junction will be higher than that of the Base-Collector junction.

This has been confirmed below on a selection of common transistors using an El-cheapo DMM:

Transistor	B-C Voltage	B-E Voltage
TIP3055	0.640	0.642
TIP2955	0.668	0.668
BD140	0.697	0.699
2N2369A	0.682	0.710
PN3563	0.752	0.753

BC108 0.715 0.716

CAUTION: Do not hold the transistor under test in your hand. For every degree the transistor increases in temperature, the Base-Emitter Diode Drop (commonly called V_{be}) decreases by 2 mV. This is a significant amount when determining the B-E and B-C junctions.

Lance's Method for Determining C and E on an Unmarked Bipolar Transistor

(From: Lance

Using an analog (VOM - a DMM will not work), on its highest resistance range I test across the collector and the emitter one way and then change the leads around. The reading that is lower reading is the one to note (the one with the most leakage on a μA meter). Sometimes the needle only just barely moves. For a PNP the positive lead is on the emitter and for a NPN the positive lead is on the collector. Now you know the base collector and emitter, this has helped me work out how a circuit works by finding the legs of the working transistors and then repairing it. I found this in a very old mag more than fifteen years ago. If I can't remember which way is what I use a known transistor. I then find out the hard way.

Testing MOSFETs

From: Paul Mathews

1. Verify gate has infinite resistance to both drain and source.
Exception: FETs with protection circuitry may act like there is a zener shunting GS, i.e., diode drop for gate reverse bias, $\sim 20V$ breakdown in fwd bias.
2. Connect gate to source. Drain to source should act like a diode.
3. Forward bias GS with $\sim 5 V$. DS in forward bias should measure very low ohms. In reverse bias, it will still act like a diode.

The usual failure mode: GS short AND DS short. In other words, everything connected together.

From: Richard Torrens

A lot of common multimeters have a diode range: you can use this to measure a MOSFET out of circuit and get a good idea of whether it is OK. Meter negative on the source, you should get no reading (open circuit) on the drain. Not on the gate but if you measure the drain AFTER measuring the gate you will find it conducts. A finger between source and gate will bleed away the charge and the MOSFET stops conducting.

You really need a 'scope to check the drive circuit. What it does will depend on the circuit configuration, whether there is current limiting etc.

From: E. Wolsner

My way of testing a power MOSFET is indeed simple and normally sufficient:

One ohmmeter is connected to the drain and the source, measuring the resistance between drain and source, which should be very high. Another ohmmeter is connected between gate and source. This ohm-meter should have a high resistance capability (maybe 20 M ohms) and thus have a relatively high test voltage (more than 5 volts). Now this voltage, when connected with the proper polarity, will turn the mosfet on, which will be indicated by the first ohm-meter. It will show zero resistance. To turn the transistor off, you reverse the gate-source voltage, and the drain-source ohm-meter will again indicate high resistance.

Portions from: Egon Wolsner

The multimeter must be able to provide at least 5 volts output on the resistance measuring range (this usually means that a DMM will not work). If it does, here is the procedure:

First you measure the resistance between the drain and source terminals, it should be infinity. Then connect the plus to the gate and the minus to the source pin. That should turn the MOSFET on. Then you measure the resistance between the drain and source pins, which should verify that the resistance is indeed near zero. (The gate capacitance will hold the device in the on-state long enough for this test.) Turn the mosfet off by shorting the gate and source pins (for a n-channel MOSFET)

From: Bruce

You can get a pretty good idea about the condition of a MOSFET with some quick & simple bench tests. The first thing you can do with a meter is measure the parasitic substrate diode that connects the drain to the source. In an NMOS part, this diode's cathode will be at the drain, and the anode at the source. It will meter out similar to any conventional diode in both fwd / reverse directions. You can see this diode in the schematic representation of the FET in some databooks and a few schematics. The FET should show infinite resistance, gate - source and gate - drain. If it does not, then the gate oxide may be blown.

A second simple test can be done with a meter and a 9 V battery. First, short the gate to the source to discharge any stored charge there. Then put your meter on ohms and connect it across the drain - source. It should measure as an open. Briefly connect the 9 V across the gate (+) to source (-) , again, NMOS polarities, and the meter resistance should fall to a very low resistance, on the order of an ohm or less. Removing the battery will not change the reading, because in a good FET, C_{iss} will remain charged for a long time and keep the FET on. Most FETs come on at $V_{gs}=2$ volts or so.

If these two tests work, then the FET is off to a good start. Substituting a power supply and a proper load resistor for the meter, and a variable voltage (a pot across the 9v will work) for the V_{gs} supply, in the

aforementioned test, will obviously be a more realistic test, and will also let you measure V_{ds} , I_d , etc.

BEWARE ESD WITH FETS! Wear a wrist strap, keep the parts away from insulators like plastics, and make sure your soldering iron tips are grounded. If you do not have any of the black ESD foam to keep your parts in, then look around for an anti-static bag that once may have contained a computer board, SIMMs, etc.

Testing IGBT

Basic testing IGBTs (Insulated Gate Bipolar Transistors) should be similar to an enhancement mode N-channel MOSFET except that the threshold voltage may be larger than a typical MOSFET (e.g., 8 V instead of 4 V).

1. Check for shorts with an ohmmeter.
2. Put a current limited supply across C-E with an ammeter in series.
3. Apply at least 10 V G-E. The transistor should turn on.
4. Ground the gate. The transistor should turn off.

A curve tracer should be able to be configured for IGBT testing to determine more complete behavior.

Testing LEDs

Electrically, LEDs (and IR emitting diodes, strictly speaking called IREDS) behave like ordinary diodes except that their forward voltage drop is higher.

Typical values are:

IR: 1.2 V, Red: 1.85 V, Yellow: 2 V, Green: 2.15 V. The new blue LEDs will be somewhat higher (perhaps 3 V). These voltages are at reasonable forward current. Depending on the actual technology (i.e., compounds like GaAsP, GaP, GaAsP/GaP, GaAlAs, etc.), actual voltages can vary quite a

bit. For example, the forward voltage drop of red LEDs may range at least from 1.50 V to 2.10 V. Therefore, LED voltage drop is not a reliable test of color though multiple samples of similar LEDs should be very close. Obviously, if the device is good, it will also be emitting light when driven in this way if the current is high enough.

So, test for short and open with a multimeter (but it must be able to supply more than the forward voltage drop to show a non-open condition).

An LED can be weak and still pass the electrical tests so checking for output is still necessary.

Therefore, if these tests don't find a problem, drive the LED from a DC supply and appropriate current limiting resistor. For the IR types, you will need a suitable IR detector.

Testing Opto-Isolators and Photo-Interrupters

Both these classes of components are basically similar: a light source (usually an IR LED) and photodetector together in a single package.

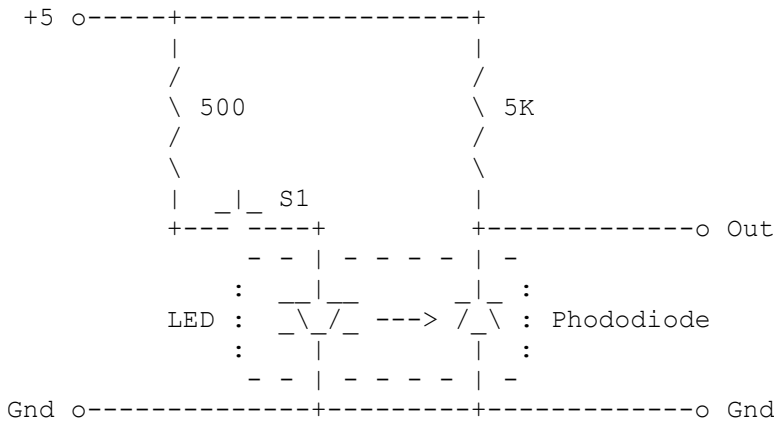
- The opto-isolator will be totally sealed with adequate separation between the two parts to provide the specified isolation voltage rating.
- The photo-interrupter (and similar devices) will provide a beam path that can be blocked or otherwise modified by external means.

For both types, the photodetector can be a photodiode, phototransistor, photothyristor, or other more complex device or circuit.

Refer to an optoelectronics databook or the catalog of a large electronics distributor for specific pinouts and specifications.

Assuming a photodiode or phototransistor type (most common), these can be tested for basic functionality pretty easily:

Wire up a test circuit as follows:



Depressing S1 should result in the Output dropping from +5 V to close to 0 V. For monitoring on a scope, drive the LED with a pulse generator and current limiting resistor instead of S1. With a photo-interrupter type, blocking or adding a reflector to the optical path (as appropriate) should result in similar behavior.

Testing Thermistors

There are two types of thermistors:

- Positive Temperature Coefficient (PTC) types have a resistance that increases with increasing temperature.
- Negative Temperature Coefficient (NTC) types have a resistance that decreases with increasing temperature.

For a small thermistor, put an ohmmeter on it and the heat it up with a blow dryer, heat gun, or the tip of a soldering iron - the resistance should change smoothly (up or down depending on whether it is PTC or NTC type). If the resistance changes erratically, or goes to infinity or zero, the device is bad. However, you will need specifications, temperature measuring sensors, etc. to really determine if it is operating correctly.

Testing Thermo-Electric (Peltier) Devices

While these are often called Thermo-Electric Coolers (TECs), they are equally good (or poor) at heating. The typical TEC uses a series connected string of thermocouple-like junctions sandwiched between a pair of ceramic plates. They are generally specified in terms of maximum temperature difference (typically between 60 to 70 °C); maximum current, voltage, and power dissipation; and physical dimensions.

Most problems will be obvious - like the entire thing was smashed by your pet elephant or melted down due to applying too much power. :) However, a hairline crack in one of the interior junctions could be undetectable without testing.

The best way to test a TEC is to apply a controlled current and monitor the voltage across the device as a function of current and measure the temperature difference between the hot and cold surfaces. Then, compare the readings with the device's specifications. If these aren't known, it may be possible to match up your device with one of similar dimensions. One major supplier is [Melcore](#).

Testing for continuity can be done with an ohmmeter but really only if the temperature of the two sides is exactly equal - otherwise there will be a voltage offset (the junctions also generates voltage when a temperature difference is present - and this can also serve as a test of sorts).

The I-V characteristics should be fairly linear over a relatively wide range of current within the device's specified operating range. However, the voltage for a given current does vary slightly with the temperature difference between the hot and cold surfaces.

Miscellaneous Information

Differences Between Ordinary, Fast Recovery, and Schottky Diodes

When the polarity reverses on a diode, it takes finite time for the charge carriers to be cleared from the area of the junction. During this time, reverse current flows. For high frequency applications - i.e., switching power supplies, horizontal deflection circuits, etc. - a normal diode would act more like a short circuit and result in poor performance or even burn out.

There are a variety of alternatives: fast, super-fast, ultra-fast (and so forth) recovery diodes, schottky diodes, and others that must be used in high frequency signal, switching, and power supply circuits:

Thus, if you find a bad diode in a piece of electronic equipment, don't assume it is just an ordinary diode because the case looks the same. Replacing a fast recovery diode with a 1N4007 will very likely just result in more confusion. A proper device must be used even for testing. In most cases, a faster part can be substituted without problems. However, there are occasional situations where the specific characteristics of a slow part (a reverse pulse due to its long recovery time or high capacitance) are depended upon for the circuit to operation properly!

From: John Popelish

Fast recovery diodes have a little gold added to the silicon (and perhaps other process changes) that make the minority carriers (holes in n type and electrons in p type sides of the junction) have shorter lifetimes, so that in addition to sweeping them out by applied voltage, the carriers spontaneously disappear. This makes the diodes turn off faster. Other tricks help the diodes to turn off with less of a snap, to reduce high frequency noise generation. These changes usually compromise other

properties of the diode, like reverse leakage, forward drop or breakdown voltage, so there are lots of different combinations of trade-offs.

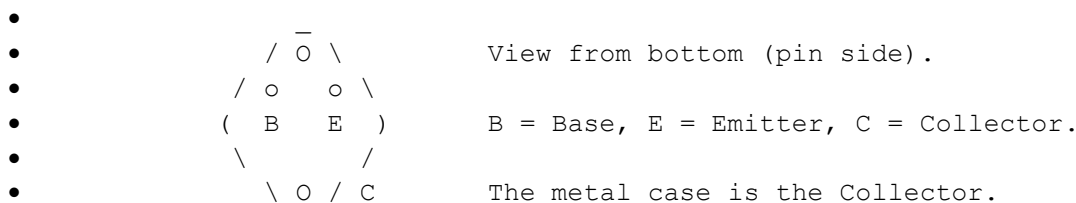
Schottky diodes are really just half diodes. A metal intimately bonded to a p type semiconductor. Holes have a zero lifetime in metal, so the minority lifetime is just about zero for schottky diodes. They also have about half a diode drop in the forward direction, and so are twice as efficient even for low frequency rectification. The trade off here is that they can only be made to handle low reverse voltages and even there, they have more reverse leakage than junction diodes.

Motorola published a diode handbook that goes into a lot more detail on these things and I recommend it.

Horizontal Output Transistor Pinouts

You will nearly always find one of two types of horizontal output transistors in TVs and monitors:

- Metal can - TO3 package:



- Plastic tab - Mostly these will be the TO3Pn (n = several suffixes) package but some B/W TVs and mono monitors or video display terminals may use HOTs in the smaller TO220 package:

This makes layout of high-frequency pairs easier because traces do not have to cross over one another, and the layout is 'cleaner' but bites you if you are unaware!

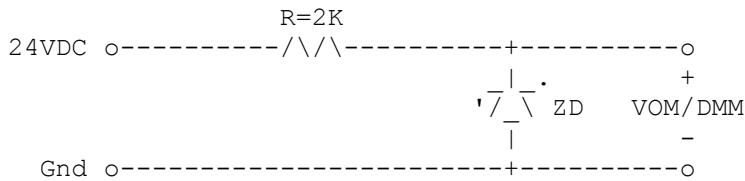
Testing Zener Diodes

The following applies to both testing of zeners for failure and determining the ratings of an unknown device. Zeners most often fail short or open with short probably more likely. However, it is also possible, though a lot less common, for the zener voltage to change (almost always to a lower voltage) and/or for the shape of the I-V curve to change dramatically (e.g., become less sharp cornered).

With a VOM, a good zener diode should read like a normal diode in the forward direction and open in the reverse direction unless the VOM applies more than the zener voltage for the device. A DMM on its diode test range may read the actual zener voltage if it is very low (e.g., a couple V) but will read open otherwise. The most common failure would be for the device to short - read 0.0 ohms in both directions. Then, it is definitely dead. :)

Some zeners are marked with a JEDEC (1N) part number, others with a couple of colored bands (e.g., for 18 V, brown/gray), or a house number or house color code.

You can easily test a zener and identify its voltage rating with a DC power supply, resistor, and multimeter. You will need a power supply (a DC wall adapter or AC wall adapter with a rectifier and filter capacitor is fine) greater than the highest zener voltage you want to test. Select a resistor that will limit current to a few mA. For example, for zeners up to about 20 V, you can use:



This same approach applies to other devices that exhibit a similar behavior such as the B-E junction of a bipolar transistor.

Testing MOVs

MOVs are used mostly for surge suppression in power strips and the front-ends of the power supplies of TVs, VCRs, and other consumer electronic equipment. They are those brightly colored things that look like Epoxy dipped capacitors. At least, that's what they look like when new. A common failure mode is for the MOV to be totally obliterated by a surge or from old age. Then testing is not needed! :)

They are supposed to be located beyond the line fuse (though possibly not always). In this case, where the line fuse blows but there is no visible damage to the MOV(s), the simplest test may be to just temporarily remove the MOV(s) and see if your problem goes away.

A multimeter can be used to test for leakage (there should be none) but the best option is to remove the device. Since the proper functioning of the equipment doesn't depend on any MOVs (in 99.9999 percent of the cases - the exception being where the MOV is used as a high voltage triggering device or something like that rather than a surge suppressor), remove the MOV(s), test the equipment, and just replace the MOV(s) if in doubt.

From: Brad Thompson

Usually, the manufacturers specify a maximum leakage current (usually one milliamperes) at a AC specified voltage. You'd need a Variac adjustable AC source, an isolation transformer (for safety), an AC voltmeter and an AC milliammeter to make the measurement.

An MOV works as follows: It's essentially a batch of metallic-oxide grains separated by insulating layers. Repeated voltage surges break down the insulating layers, lowering the overall resistance and eventually causing the device to draw too much current and trip whatever overcurrent protection is inherent in the system.

I've seen MOVs exuding tiny metallic "teardrops" through their epoxy coatings, which remained bright and shiny. These devices needed replacement!

From: Kevin Carney

This is not a valid test for breakdown voltage but these devices read a few megohms when damaged. The new replacements read open on my meter that has a 20 Megohm range of a DMM.

When is a Zener not a Zener??

If is voltage is over 6 volts, technically it's an avalanche diode. Here's an engineering text quote that explains rather well:

"The zener effect refers to removing bound electrons from outer shells by means of an electric field. In other words, as a reverse voltage is applied to a diode, an electric field appears at the junction. When this field is intense enough, outer-shell electrons are dislodged, resulting in a significant increase in reverse current.

The avalanche effect is different. In this case, when the diode is reverse biased, minority carriers are flowing. For higher reverse voltages these minority carriers can attain sufficient velocity to knock bound electrons out of there outer shells. These released electrons then attain sufficient velocity to dislodge more bound electrons, etc. The process is well named, since it is suggestive of an avalanche."

As noted, the voltage where the zener effect leaves off and the avalanche effect takes over is approximately 6 volts. More accurately, the zener effect dominates below 4 volts and the avalanche effect dominates above 6 volts and a combination of the two between 4 and 6 volts.

Now, which one is in effect significantly affects the temperature characteristics of the device.

- A zener diode (4 volts or less) has a negative temp. coefficient (as temp increases voltage drops).
- An avalanche diode (6 volts or more) has a positive temp. coefficient (as temp increases voltage increases).
- A zener/avalanche diode (4-6 volts) the effects tend to cancel each other resulting a very temp stable diode.

Introduction to Curve Tracers

Curve Tracer Design

A curve tracer is a piece of test equipment or an add-on to an oscilloscope which provides a graphical display of the V-I (or other parameters) of an electronic component. The design of a curve tracer is simple in principle (description here for bipolar transistors):

For the horizontal (collector supply) you need a variable ramp generator. If your scope has a sweep output, then you can derive it from this - if you are not interested in frequency response, an audio amplifier may be adequate with a volume control to adjust the amplitude.

For the base drive you need a programmable current source capable of putting out a series of constant currents for the base drive. Here, a counter driving a D/A set up for a current output mode. Use the trigger output or sweep output of the scope to increment the counter so that it sequences through a set of say, 10 current settings.

Then, you need some way of sensing collector current to drive the vertical channel - a small series resistor in the emitter circuit, for example.

For simple diode tests, you can just use a variable AC voltage source like a variable isolation transformer (with a current limiting resistor) across the diode. The X (horizontal) input of the scope goes across the device under test. The Y (vertical) input of the scope goes across the current limiting resistor or a separate series current sense resistor.

Then, you can jazz it up with microprocessor controlled on-screen display.

The following are circuits that are only a bit more complex than the minimal solution:

- [Simple Curve Tracer 1.](#)

- [Simple Curve Tracer 2](#).

And, here's a MAXIM application note on one that is driven from your PC's parallel port:

- [MAXIM APPNOTE 253: PC Printer Port Controls I-V Curve Tracer](#).

Curve tracers can be big expensive things (e.g., multi-\$K) or little add-ons to regular scopes. Here one company selling a curve tracer kit or assembled. I have no idea how good it is but check out [Gootee Systems](#) for more info.

Popular Electronics, May 1999, has complete plans for a "Semiconductor Tester" which can handle NPN and PNP bipolar transistors, JFETs and MOSFETs, all sorts of diodes including zeners, and a variety of other devices. This is basically a curve tracer adapter for an oscilloscope. With a little ingenuity, it can be enhanced to test virtually all the semiconductors discussed in this document.

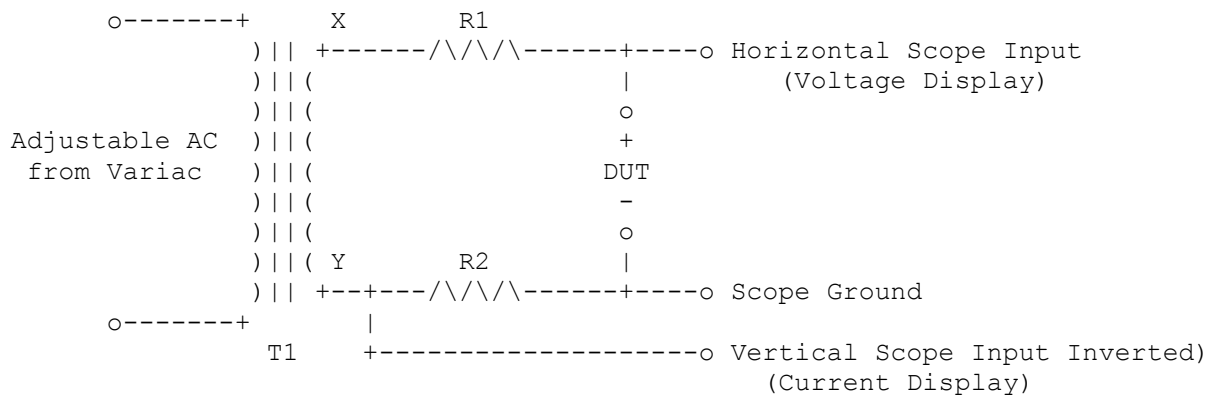
Therefore, if you want a sophisticated piece of test equipment, one of these would be suitable. Or, get yourself a used Tektronix 575 curve tracer. This will do just about everything you could possibly want (including the testing of vacuum tubes with the addition of a bit of external circuitry.)

However, to just test 2 terminal devices - or to just get a feel for device characteristics, there are much simpler, cheaper, alternatives.

Quick and Dirty Curve Tracer

I threw the following circuit together in about 10 minutes. With minor modifications, it is capable of displaying V-I curves for diodes, zeners, transistors, thyristors, resistors, capacitors, inductors, etc.

I used a 12 VAC transformer just because it was handy. You can use anything you like as long as you understand the safety implications of higher voltages and make sure the components you use can withstand the power that might be dissipated in them if the Device Under Test (DUT) is a dead short. In addition, it is bad form to blow out the DUT while testing it! A signal generator driving a small audio transformer could also be used if it is desired to test components at frequencies other than 60 (or 50) Hz.



CAUTION: turn down the intensity of the scope so the spot is just barely visible so that when there is no input, you don't end up drilling a hole in the face of the CRT!

- R1: Current limiting and phase shift control. I used 500 ohms which works well for small signal semiconductors and capacitors around 1 uF.
- R2: Current sense. I used 10 ohms and put the scope on the one of the 0.1, 0.2, or 0.5 V/cm ranges.
- T1: Small power transformer. I used the 12 VAC wall wart from an obsolete modem. This will supply a voltage of up to about 17 V peak to your DUT.

For higher power or higher voltage devices, substitute a suitable larger transformer.

Modify these (selector switches might be nice) for your needs. A Variac provides a convenient method of adjusting the voltage applied to the DUT.

- Zener diodes - the result will be exactly like the picture in your textbook. Try this with a 5 or 6 V zener to confirm that your rig is working.
- Resistors - the display should be a straight diagonal line. You should be able to compute their value from the ratio of V to I.
- Capacitors - you should see the phase shift between voltage and current resulting in an ellipse (though you will probably have to adjust the scale factors to obtain a usable display with typical capacitor values).
- Bipolar transistors - a source of (DC) base current is needed. You can be fancy or simple. For a simple source, I used a variable 0 to 15 V power supply and a current limiting resistor. Since we know that the voltage drop across the B-E junction is fairly constant at around .7 V (for silicon), the output of the supply can be calibrated in terms of base current.
- SCRs - connect a suitable resistor in series with a diode or two (or a diac) between the gate and DUT+ (so that gate current is included in the V-I curve). When the threshold current is exceeded, the device should turn on and remain on until the zero crossing. With the reverse polarity, the device should remain off. For triacs, use diodes in parallel in both directions or a diac. A triac should trigger on both polarities of the AC waveform.

In-Circuit Tester

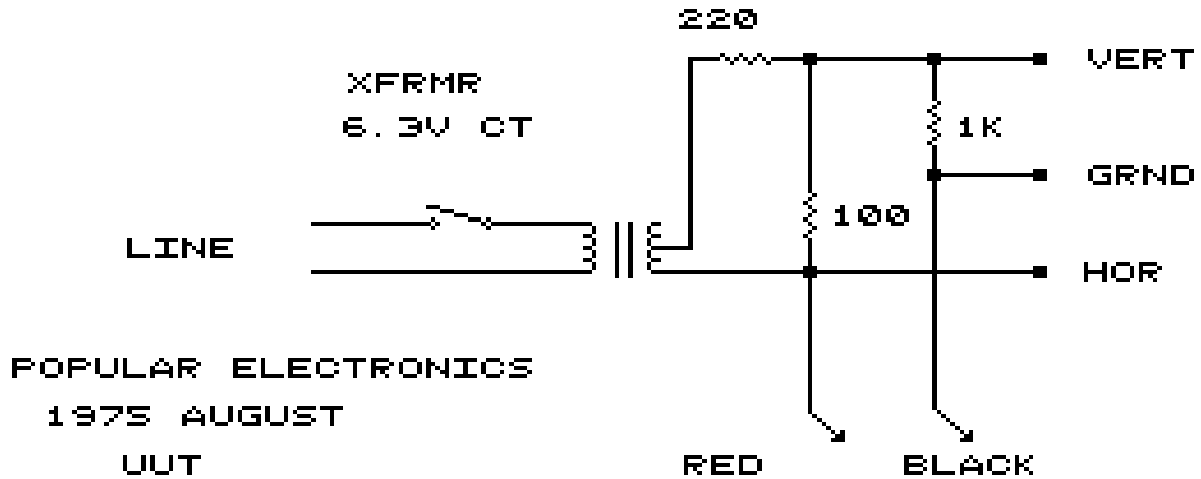
The following is along the same lines as the "Quick and Dirty Curve Tracer" but is suitable for in-circuit testing as the current and voltage are limited to safe values for most devices (less than 1 VAC and than 1 mAAC respectively).

The very complicated circuit is shown in:

SEMICONDUCTOR AND COMPONENT

CURVE DISPLAY

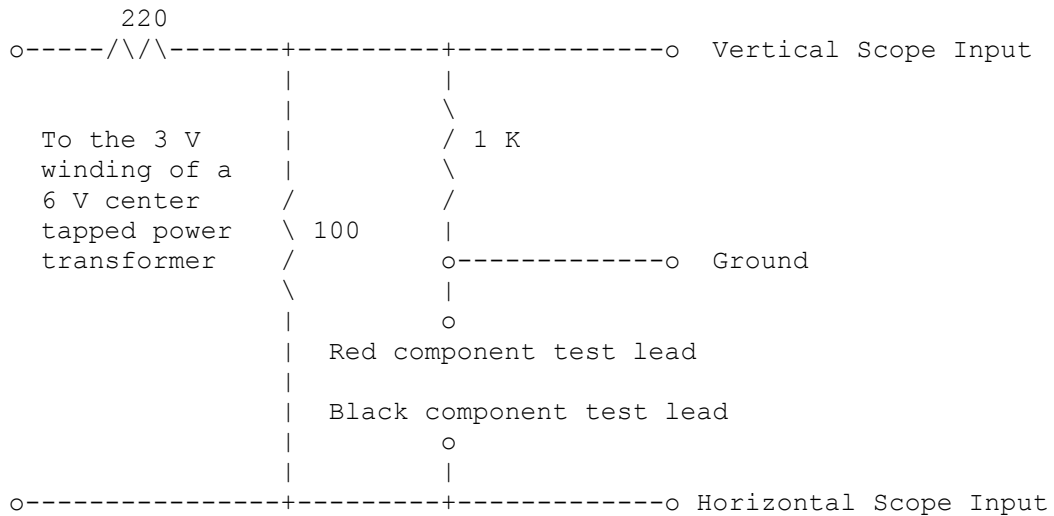
SCOPE



and below in ASCII.

CAUTION: Use at your own risk. I cannot absolutely guarantee that there won't be certain devices in use today that didn't exist in 1975 that might be unhappy with this approach.

From: Wern Thiel



In the August 1975 issue of Popular Electronics author John T. Fyre wrote in a story called "A simple On-Board Tester" about this fairly simple piece of test equipment.

The device can be used with any type of oscilloscope and consists of a 6 volt filament transformer, three 1/4 watt resistors and two test probes. Half of the filament voltage is applied to a voltage divider consisting of 220 ohm and 100 ohm resistors, yielding 1 volt ac on top of the 1 K ohm resistor. This voltage can be applied to any component or combination of components across which the test leads are placed. The current is limited to one milliampere by the 1 K ohm resistor.

The voltage across the probes is connected to the horizontal input of a scope while the voltage across the 1 K ohm resistor as a result of the current through it is connected to the vertical input.

What we see on the scope is a voltage across a component under test versus the current through the component:

Resistors: Open Horizontal line.
 10 K 10 degree.
 1 K 45 degree.
 0 Vertical line.

Capacitor: .1 uF Shallow ellipse.
 2.6 uF Circle.
 50. uF Narrow vertical.

Transformer: Ellipse depending on impedance.

Diodes (Germanium): Right angle display.

Diodes (Silicon): Right angle one side longer
(any leakage showing less sharp angle).

Transistors: Test as two diodes (B to E and B to C).

Integrated Circuits: Input for gates and counters show a certain signature
display.

Outputs display a different signature.

A short will show a vertical line.

An open will show a horizontal line

In circuit testing is done with **no** power applied to the equipment under test.

With some experience one is able to test components in and out of circuit and troubleshoot without danger of a damage to components.

Testing Vacuum Tubes (or FETs) on a Bipolar Curve Tracer

A transistor curve tracer can be easily adapted to test vacuum tubes (OK, valves for those of you on the other side of the lake) if it has an adequate voltage range for the collector (now plate) drive and independent control of base and collector polarity. All that is needed is to add a separate transformer to power the tube's filament(s) and a resistor to convert base current to voltage.

For FETs, just leave off the transformer.

From: Michael Covington

Get an old Tektronix 575 (mine cost \$25 at a hamfest). That is a transistor curve tracer that goes back to the 1950s and goes up to 200 volts.

It doesn't have FET settings, but you can control the 'base' and 'collector' polarity independently. So what you do is put a 1 K resistor from 'base' to ground, so that you can read milliamps as volts. Then put a positive-going voltage on the 'collector' and a negative-going current into the 'base'.

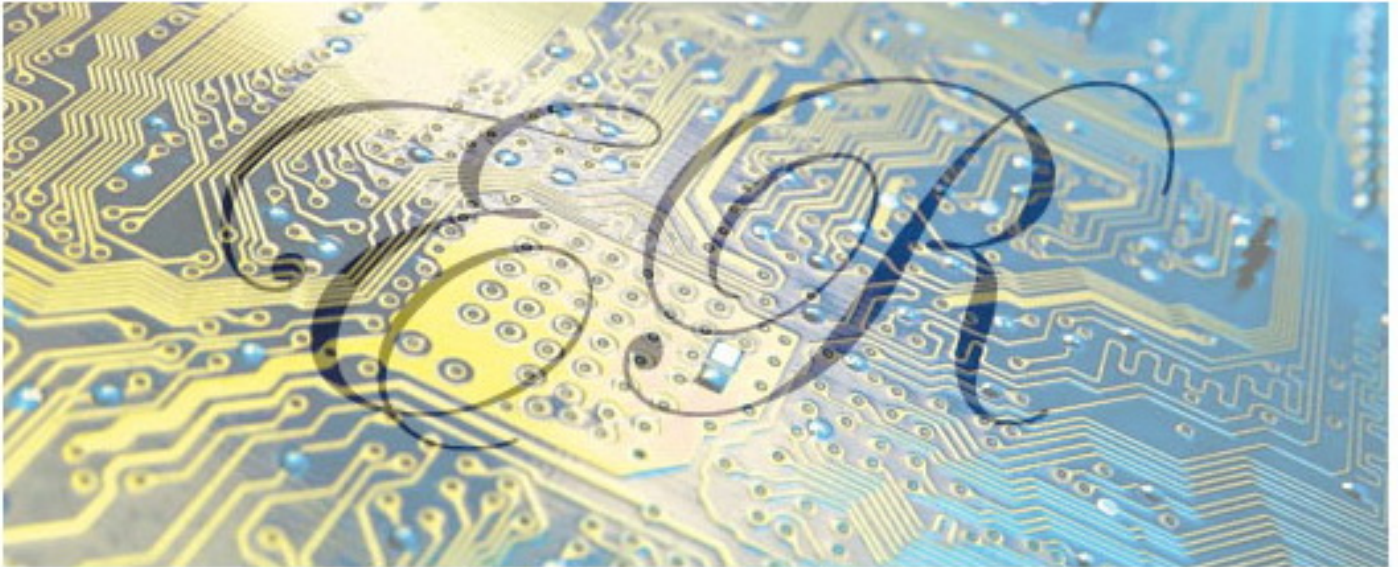
For tubes, emitter, collector, and base are cathode, plate, and grid, respectively. Naturally you also need a filament supply; I use a lab-type DC supply because it's handy and can't introduce hum.

I also test FETs that way (without the filament supply, of course). Then, emitter, collector, and base become source, drain, and gate respectively.

Thank you

Electronic Repair Company

<http://electronicrepair.weebly.com/components-testers.html>



Electronic Repair