Solid State Rectifiers Pass Or Fail

In a world where direct current reigns supreme the technician of today must have a complete working familiarity with Solid State rectifier Q & A, along with diagnostic insight.

A Text By Gary A. Minker
www.RadioWorksRFConsulting.com
561-346-8494

With the fast paced marvels of solid state technology installed in virtually every device around us today, the solid state rectifier is still the source which makes all things go. Testing these devices does not have to be rocket science. Just use common sense and some basic equipment for. While digital and analog meters are helpful, the Lissajou trace reigns supreme.

Power supply designs have transcended the brute force to switching bridge, and filters have evolved toward high frequency lower ripple modes while electronic regulators have given a new meaning to the old term "constant voltage". Rectification, and high frequency chopper conversion of the alternating current primary line supply is the first step. Many technicians associated with power supply and control circuits have third hand vague experience with the forerunners of today's silicon rectifier devices. Hot cathode tube type and mercury vapor devices introduced many technicians to the world of direct current. As a technician progressed up the industrial ladder, the mercury vapor rectifier assembly was not the only eerie purple thing to glow in the dark. The hot cathode tube and the vapor rectifier supported the theories which have given way to the selenium, Germanium, and finally silicon devices of today. Filament driven rectifiers required undesirable operating characteristics to insure proper operation (undesirable by today's standards). Vibration and extremes of cold wreaked havoc on these devices among other constraints. Lengthy warm up times made instant use impossible. Any failure to follow the proper care and feeding of these devices no doubt meant early failure, X-Ray radiation, and replacement, if not explosions. Though still in limited use today, these early devices have lead the way to the modern p/n junction and the silicon controlled rectifiers of today.

Test or replace?

Consumer level silicons of today must yield to the economic pressures which dictate a throw away style of replacement parts and entire assemblies. Unfortunately, some assemblies of Throw Away Nature only warrant repair under the most unusual of circumstances.

While typically generic in specification, these silicons are readily kept on hand in just such a situation. Professional and Industrial grades of technology mandate the sophisticated testing and repair due equipment of this caliber.

To test a suspect defective silicon, and subsequently re-install it, or to replace it, also falls under the same economic guidelines. Test bed time and diagnostic interpretation can be costly. Timely decisions can usually be made to continue testing or to simply "shotgun" the circuit with on hand parts. This decision is often influenced by the lack of sufficient parts to effectively "shotgun" the circuit. This leads back to the pressing need to efficiently and most importantly, accurately diagnose the problem and it's suspect defective devices so that only the defective devices may be replaced with parts on hand. In applications where effective, accurate testing and diagnosis of the suspect components is required, there are many avenues of support.

Pass or fail?

After the big box has blown the breaker off the wall for the N^{th} time, and the situation has become painfully obvious that the power supply problem lies in an area that must be effectively diagnosed, the suspect silicons may be more easily examined if at your earlier convenience you have developed a set of look up charts, tables and Lissajou traces outlining the assorted devices incorporated into your equipment. This preventive maintenance exercise will give the technician a greater level of understanding in normal operation of a device while allowing him to remove the suspect components and examine them based on these previously developed charts and photographs of the curve traces of the junctions within the device.

These charts or graphs should contain these parameters:

1. Forward breakdown voltage
2. Expected normal milliampere flow at a given forward voltage (both above breakdown and below breakdown)
3. Expected normal reverse bias milliamperage (below peak inverse voltage p.i.v.) yes, some diode stacks do have a resistive reverse flow.
4. Reference Lissajous traces of junction activity at repeatable parameters (curve traces)
5. Forward bias resistance or diode function test readings (ohms voltage drop)
6. Reverse bias resistance readings (ohms) ((yes, they are different))
7. Capacitance measurements of device in forward and reverse bias - see note in the following paragraph

It is important to remember that in-circuit testing of these devices is seldom reliable. Many of these tests are "bias polarity" sensitive and will not give a valid or reliable reading if performed in-circuit.

Each class of device will respond differently to these suggested graph and chart references. While all diodes will respond to the forward breakdown test, some require special test jigs or higher voltage equipment. All diodes will exhibit predictable forward milliamperage flow at a given voltage, though some require test equipment capable of generating hundreds of volts. Each device will exhibit a predictable milliamperage flow in a reverse bias condition as long as the p.i.v. (peak inverse voltage) is not exceeded. Great care must be observed where Zener or regulating silicons are in use. These devices will not conform to the usual p/n junction testing rules. High voltage diodes, packs or stacks may have a forward conduction point of 20 to 40 Volts or more. Optical (Lissajou) comparison of a junction's activity is often the best diagnostic aid. The behavioral characteristics of a junction are easily and completely observed at varying voltage and amperage ranges when displayed on a CRT or LCD screen. Figure (1)

Figure 1:

The subtle curve changes that may be glaringly obvious when displayed as an optical anomaly on an otherwise linear curve would probably go undetected when tested by any other analog means (Ohm meter). Zener devices are best tested via a curve trace/Lissajous unit, and suitable capacitor leakage test meter. The "diode test" function incorporated into many of the more modern digital meters will give a very accurate indication of the actual voltage conduction point of the junction under test for non stacked units. This reading should be repeatable from device to device. In the case where a device under test deviates from this norm, a red flag should wave vigorously. With the incredibly high resistance readings possible with modern test equipment, this category pays particular attention to resistor equalized stacked device arrays. In most cases the reverse bias milliamperage and Ohmic readings will give the proper look up chart data for these d.u.t.'s (devices under test), however in these resistor equalized cases this is an important indication of an open equalizing resistor which will certainly cause an almost immediate subsequent failure in the stack, and in the same diode position. Capacitance measurements will provide reliable and repeatable references in resistively unequalzed high voltage devices in both bias polarities. These forward and reverse readings would be distinctly different. (note) depending on the type of capacitance tester, lower voltage devices will display a shorted condition indication when tested in one or the other bias mode. Only one repeatable capacitance reading will be provided. As you will see, each type of diode device will have an anatomy of its own which can be easily used to identify good and bad components.

Equally important to these look up charts and tests is a visual inspection. All too often the engrossed technician will overlook the obvious when trying to examine a defective circuit or Diode stack. Figure (2 and 3)

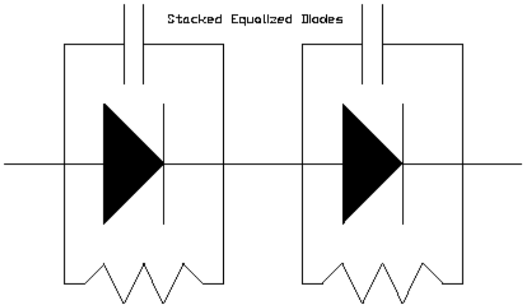
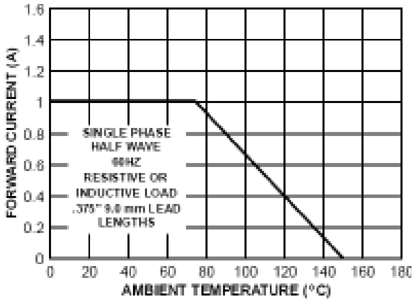
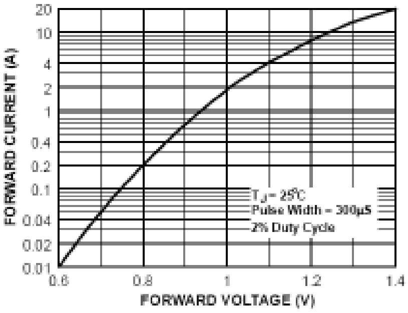


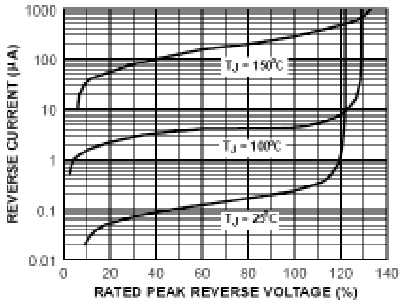
Figure 2:   Figure 3

Look up charts and graphs

The following charts are given to demonstrate the predictable behavior of a typical silicon diode model 1N4001







Crash Cart

Time is of the essence may be an old adage but in the realm of efficient diagnosis it is all too true. Nothing is slower than having to dig for each piece of test equipment. Even if it is just sitting on the shelf. Having to hook it up, power it up, and integrate it with any other support device ... All takes time that you may not have to spare. In an active service environment where the broken equipment does not always come to you, you must more importantly go to the equipment. Enter: the Crash Cart. This tremendously impressive display of gauche industrial blinking lights and numbers will typically save 45 minutes of set up time. The integration of the required test instruments within the framework of the cart makes unusual and off the wall testing possible with very little reconfiguration.

A good example is to be able to easily test an SCR though disconnected and still mounted, while simultaneously watching the gate voltage on the scope and or digital meter. Not to mention you are monitoring the gate in reference to either anode or cathode. The apparent benefit of the well equipped crash cart is only too obvious. The cart pictured in Figure (3a) is equipped with the following pieces of equipment and more. This cart is tailored to a combined audio and R.F. environment

Dual trace scope
Scope for curve trace function
Digital meter
Spectrum analyzer (audio)
Mono/stereo multiple input RMS reading voltmeter/watt meter (audio)
Frequency counter
Audio frequency generator/digital dBm meter audio

Figure 3a:

Power line disturbance monitor
Distortion analyzer, solder sucker, soldering station
SCR test adaptor capacitor/inductor test meter
Arc gap tester
Grid dip meter
Headphones
Vise
Impedance meter
Test leads (customized for ease of test on in plant studios and equipment)

As each situation dictates, other test instruments should be available.

Adaptivity

In the test environment, adaptivity is the key to intuitive diagnostics. Before the age of measurement isolation systems, (voltage, current, pressure, infrared thermal sensing and, Imaging) the test environment was predominantly referenced to ground. Those test fixtures and meters would only read a parameter from the earthen standpoint. Many of today's technicians have been engrained that this early basis for test is the most proper avenue of diagnosis. While this is very true in some respects, the adaptivity of today's new test instruments give a new twist to measurement techniques. While a good ground is important for safety, new isolated input, and battery powered test meters allow the technician the freedom to measure or view a test point not referenced to ground but from one gated or stacked level to another, as long as the voltages are within reason. Silicon controlled rectifiers and industrial Triacs are the best example of junction devices that are triggered or "fire" in more than one mode.

Isolated measurements of the elevated test points will often give the key to a trouble spot in these circuits. You can actually measure across the device and determine the voltage drop and other characteristics as compared to other brother devices.

Adaptations of circumstance motivated tests would include, directly reading the voltage drop across an active rectifier element, or hanging a battery powered, insulated scope across the same rectifier or other control silicon device, and actually observing the junction operate while looking for noise or glitch failures. Adaptive testing with the proper and safe test equipment will save much diagnostic time, especially where test equipment resources may be limited.

Small silicons

Reliable testing of most garden variety silicon devices is easily accomplished via the diode test function on many newer digital volt meters. The resulting voltage display is a true representation of the forward breakdown conduction voltage of the junction in the device under test (d.u.t.). Along with this test a quick look at the junction on the curve tracer will give a very reliable go, no go indication. Any visual anomalies that cannot be explained on the curve tracer should flag the d.u.t. Figures (4) and (5)

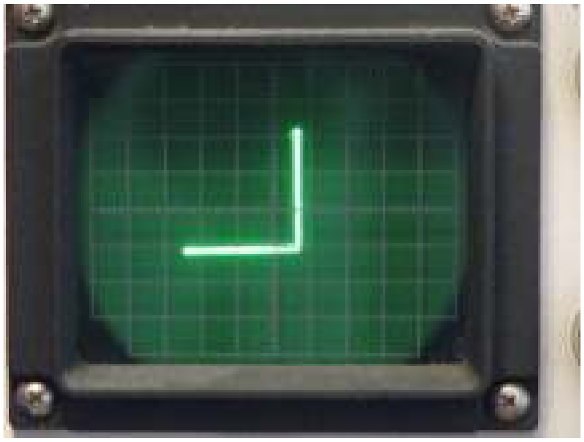


Figure 4:

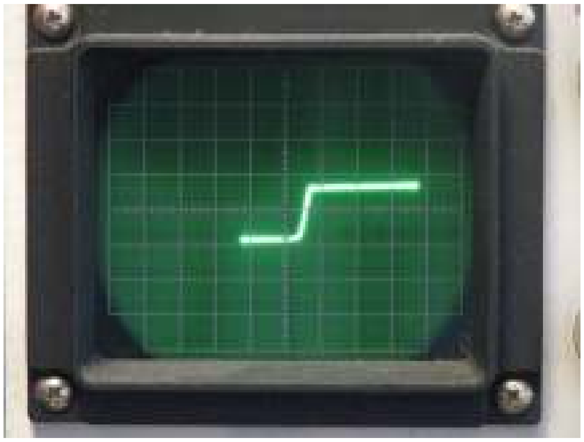


Figure 5:

Zener devices on the other hand may not be as easily tested. While the diode test function will give an indication of the one junction, and the Lissajous trace will show the forward conduction, unless the tracer is capable of generating the known reverse conduction voltage, this diode will go improperly tested especially when looking for a generic replacement without going by the numbers. Errantly installing a Zener diode in place of a normal junction device will likely cause additional damage to the already defective circuit. Any time a Zener is the known or suspect d.u.t. the forward bias conduction point should be examined in one-tenth volt increments for ratings under 30 volts. Zener's over this voltage are typically not set up for critical tolerance duty and may be tested more liberally in one volt increments.

In either test, the Zener should not show any appreciable current flow until the actual "knee" is reached, at which point the junction will cave in, and current will rise very quickly. Use caution when reverse bias testing Zener devices to insure that the dissipation limit of the d.u.t. is not exceeded.

Large Silicons

High voltage and high current silicons can require a very different test scenario. Silicons which handle voltages of 1,000 or more Volts, and which handle currents of 100 Amperes or more, will react to most usual junction tests. Diode junction tests and Lissajous traces will show most anomalies in these devices. Often, stressing these large units up to the p.i.v. mode will show any potential problems within the device. Reverse bias capacitance test comparisons may point out partially open devices when compared to the previously established look up charts. Silicons which handle voltages in excess of 2,000 Volts do not respond in the usual manners. In high voltage devices the forward conduction breakdown voltage is often greater than most digital meter diode test functions will provide, thus rendering this meter's test function useless. While standard curve tracers may give some valid indication of the condition of the numerous individual junctions strung in series within the d.u.t., this generally good optical view is only cursory at best. These devices now require the talents of the more specialized and adaptive test instruments. Figure (14). A small form high voltage device will typically be epoxy potted in order to keep the internal diodes in physical check. Failure of these units is very often typified by an obvious burn mark or crack on the exterior surface. Should this not be the case, first test for forward conduction by developing the look up chart data voltage in the terminals, and comparing the result. A device that is partially shorted either by non-visible carbonization of the internal case or by a number of shorted diodes within the string will show a definitely lower forward conduction threshold along with a correspondingly higher forward milliamperage flow at a given voltage.

Figure 14:

Partially shorted units will show good reverse milliamperage leakage but will generally fail the p.i.v. and capacitance comparison tests. Large mono block silicons are seldom equalized internally, however, the remaining tests for Capacitance, and forward bias current conduction will help to ferret out additional problems in these units. Comparison of a suspect d.u.t. to the previously completed look up charts will give a reliable indication as to the condition of the suspect device.

Stacked or composite silicons

The most common high voltage rectifier is an item of very creative electromechanical art. These large physical structures often weighing several pounds are designed to accommodate many purposes. Great use of air and fiber board dielectric facilitates not only inter-component electrical insulation, but cooling by forced clean air as well. Great numbers of these large structures are repairable. Damaged components are simply removed, and replaced with tested new parts. The basic structure of the stacked diode array consists of:

1. The support form. Always an insulative material of very high dielectric strength.
2. Diode support structure. Often conductive and serves as a heat sink to dissipate destructive thermal energy.
3. Equalizing resistors. These resistors are placed in parallel electrically with each diode to optimize or "equalize" any sudden imbalance within the stack.
4. Transient (snubber) capacitors. These capacitors are placed in parallel electrically with each diode and serve to absorb any possibly damaging spikes which may appear in the stack.

This stack or composite of components is very complex to test. The device pictured in Figure (2) and (3) consists of 15 type 1N3495 diodes

Press fit silicon devices.

The 1N3495 is a 400 volt 25 ampere cathode case device. From this information quite a bit may be surmised about the stress limits and testing criteria of this stack. Absolutely nothing needs to be known about the machine or transmitter in which this stack is operated. This ancillary information is of course, possibly helpful in understanding why this stack failed, but strictly from a test and quality assurance point, the diode information is all that is required. With a 1,000 volt rating on each equalizing capacitor noted, the information gathering is complete and testing may begin. As each diode is of the small silicon class, and no further information supports deviation, each diode may be tested first with the diode function feature of the digital meter. Figure (6)

Figure 6:

Forward bias testing shows each forward voltage drop to be in the nominal .51 volt range. Reverse bias testing will show over range which confirms the preliminary health of the diode. Switching the digital meter to an ohms scale will show the nominal value of the equalizing resistor to be 25,000 ohms. Each section may be consecutively tested, and the result noted for later comparison. Once these tests are run, the total voltage drop of the stack may be calculated along with the reverse resistance. Subsequent voltage/milliamperage tests should confirm the individual and calculated data. In the case of the stack pictured in Figure (2) sections 2 through 5 test shorted. A higher than expected service voltage was the indication of the shorted condition of the stack. Additional testing is now warranted. Having found defective sections, Lissajous curves should be done on all sections. Figure (4) shows a normal section while Figure (7) shows the shorted section as viewed on the curve tracer. Removal and further testing of the components in the suspect section will divulge the defective components. Close observation of the curve trace in Figure (8) will show a variation from the trace of Figure (4).   As discussed earlier the sharp almost 90 degree "knee" at the point of conduction in a stand alone or small silicon device shows the non linear action of the junction.

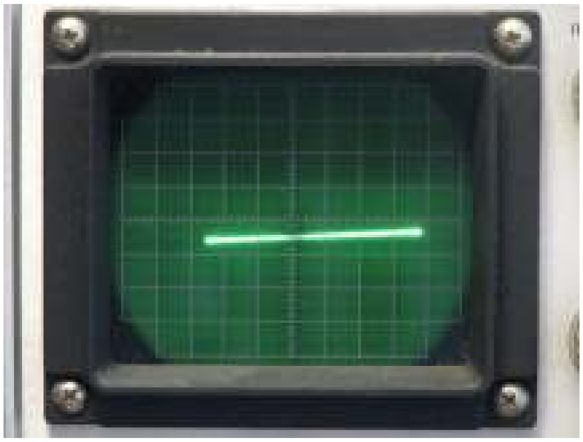


Figure 7:

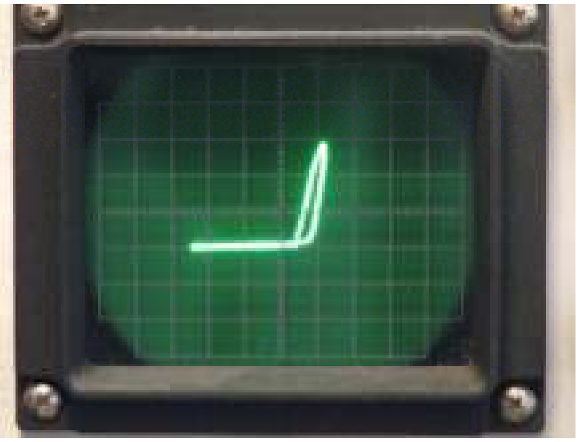


Figure 8:

Note: the trace in Figure (8) has an equalizing resistor in parallel with the diode in addition to the transient capacitor.

The obliquely angled leading vertical edge of the trace in Figure (8) is the resistive component of the trace, while the ellipse is a capacitive component of the conduction point. If the display screen is calibrated for voltage, one can measure the breakdown conduction voltage of the set up to further compare the test to published data sheets. (see Figure (9) for voltage plotting on the curve tracer) Modern data sheets are a wealth of comparative test data.

Careful comparison of each section by the curve tracer and the digital meter will provide enough data to compare each section for identical characteristics. Careful examination of Figure (10) shows an expanded trace of the effect of the capacitor in parallel with the diode. Note how the mock up emulates the actual tested part. If the diode is in good condition, the visual trace will let you determine the value of the resistive and capacitive components in the stack. Note that compared to Figure (4), the section which has the capacitor exhibits a linear ellipse at the point of conduction which grows more exaggerated as the capacitance is increased. Stacked arrays are very predictable almost to the point of forecasting a potential failure. Due to the cost of these types of stacked arrays careful documentation is warranted for future failure comparison and analysis. Figures (12) and (13) show pure resistive and capacitive traces for comparison. Testing individual diodes in an exposed stack or testing of encapsulated stacks should yield repeatable results with no deviation from device to device. Any lack of repeatable results is an indication of a defect within the device under test.

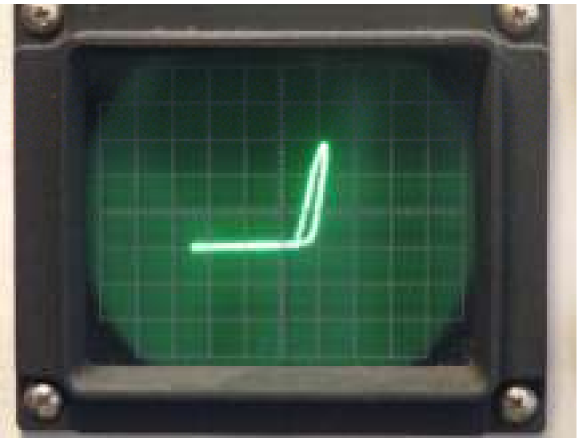


Figure 10:

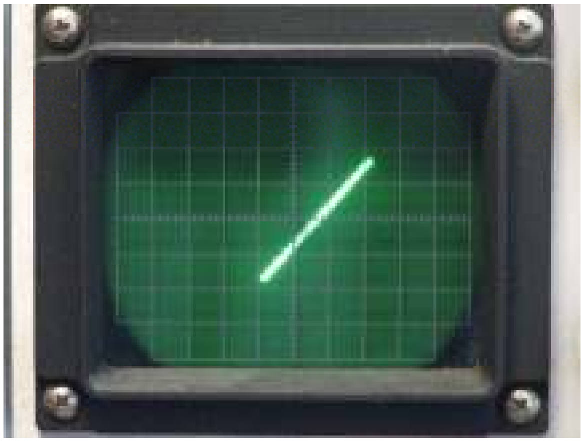


Figure 12:

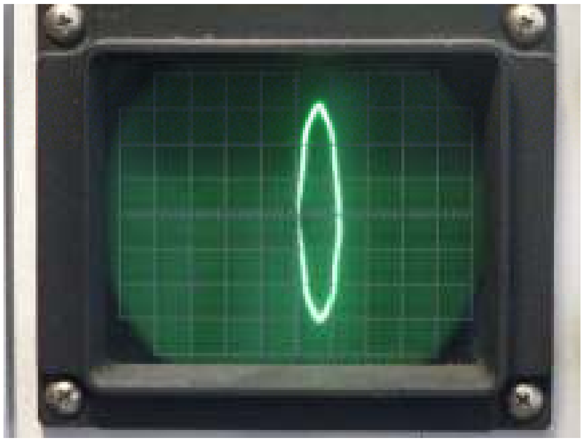


Figure 13:

Hi pot testing safety is priority # 1

High voltage stress testing of electronic components is often one of the most helpful means of sorting the most reliable parts from the trouble prone ones. With so much emphasis being placed on "clean power", the margin for damage prone semi-conductors becomes increasingly narrow. Hi pot testing is the common name given to any type of applied dynamic voltage testing which reaches the maximum design limits and should not exceed a pre-determined value of a device. In addition to the apparent mortality proofing of devices, hi pot testing serves an additional need. Safety to the technician should be foremost in the design of any electronic or mechanical system. The service and repair aspects of safety for the technician must never be compromised.

When testing components for high voltage stability or intermittent arcing problems, the frame of most large devices should be suitably isolated from the technician and must be properly grounded or isolated as the device requires. Goggles or safety glasses are recommended when stress testing any suspect device. Damaged or cracked high voltage parts will sometimes explode dangerously when stressed. Very often a large reactor or other assembly will appear normal on the outside, while being electrically defective in a non-visible area. Any hi-pot testing should be done carefully to avoid over stressing any dielectric ratings established for a particular unit.

The transformer in (Figure 11) appeared normal when viewed from one side, but was clearly visibly defective when viewed from the opposite side with a hole burned through one winding adjacent to the core frame giving a partial short to the unit frame. Physical inspections can save the technician valuable diagnostic time by being observant.

Figure 11:

Though this unit operated in this physical mode for some time before exhibiting erratic overload conditions, subsequent hi pot testing at elevated operating temperatures showed unsafe leakage to the grounded frame of the winding core. Similar Hi Pot problems can arise from arced over insulators for stud mount devices and open frame units. Dirt may set up an arc path that once started, may not trip or burn right away but will certainly do so when you least expect it and seemingly for no good reason.

Not all rules are made to be broken:

Safety around high voltage equipment, is, and rightly so, should be the number one priority.
When testing any suspect diode device, capacitor, arc gap, or reactor for any voltage parameter over 25 volts you must remember that amperage kills, not voltage.
A sweaty pair of hands in the wrong place will lead to instant cardiac arrest. Many large coil wound devices also become contaminated with corona attracted dust and other semi-conductive materials. In situations of sufficiently high voltage and humidity these dirt trails will become flash and circulating current paths and possibly energize a protective cage or mount. Because of this possibility, when working around high voltage, never stand on conductive floor coverings in proximity to high voltage devices. Static drain types of flooring should always have a non conductive kneeling mat on the standing or kneeling area. Never wear any type of jewelry, and try to keep one hand free or in your pocket. A conductive path from one hand to nowhere is better than from hand to hand or foot. When working with a partner, common sense, clear communication, and a clear procedure 'might mean the life you save may be your own.

Be Safe out there.
You may only get one chance.

Figures Page 1 of 4:

Test Set Up Figure 1

Stacked Diode Assembly Figure 2

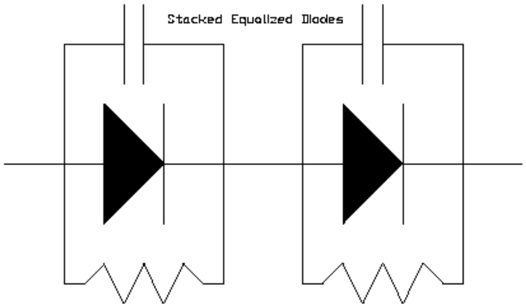
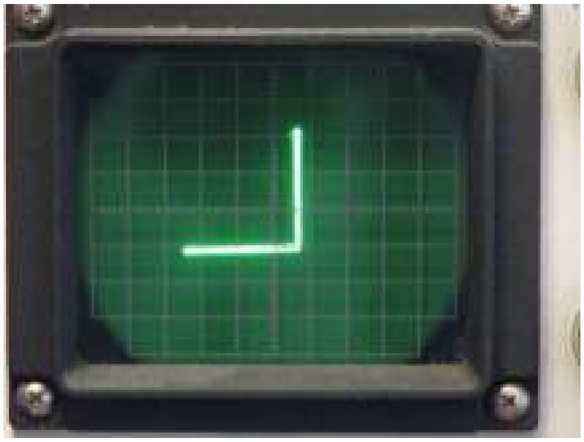


Diagram of Stacked Assembly Figure 3

The time saving crash cart, Figure 3a



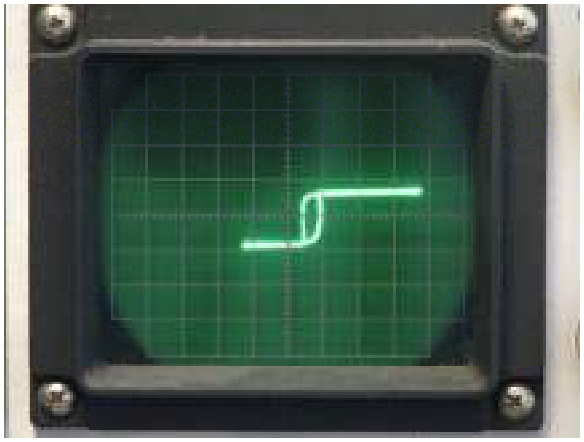
Traditional Normal Junction Figure 4

Blank

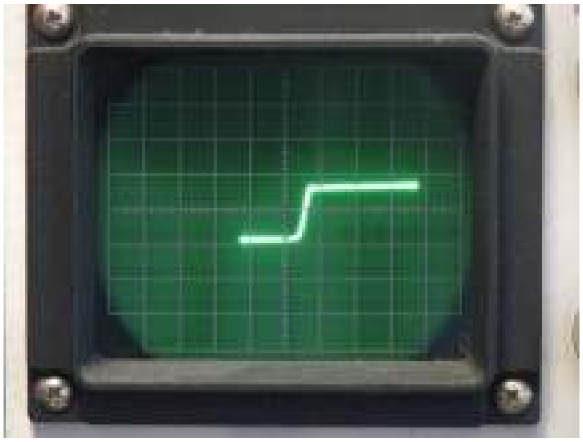
Figures 2 of 4:

Resistive Junction, Leaky, Figure 4a

Capacitive Junction, Figure 4b

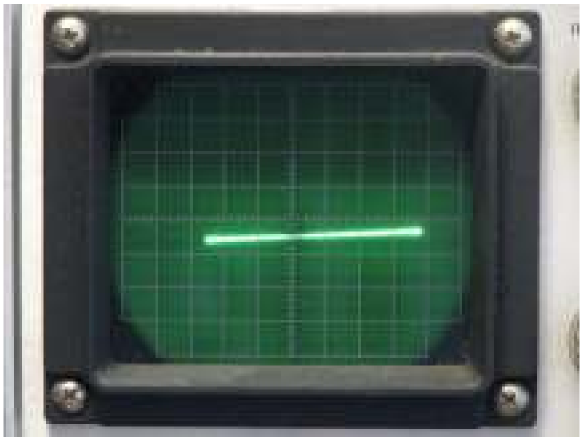


Zener with Capacitive Junction, Figure 5



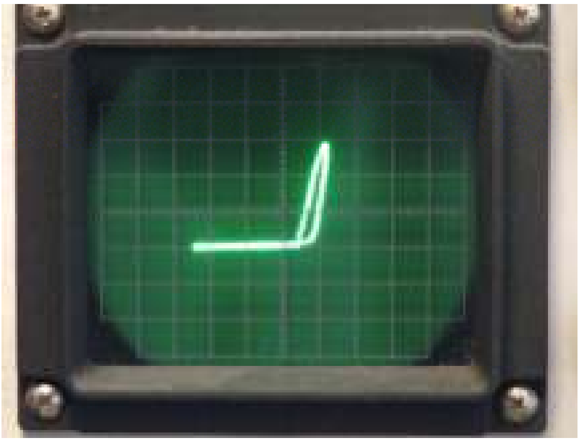
Zener with resistive Junction, Figure 5a

Diode Test Meter Function, Figure 6

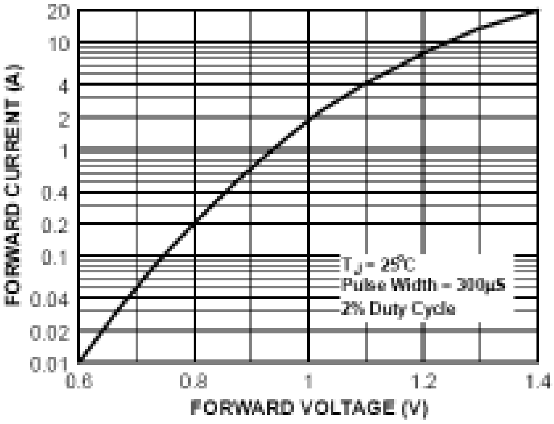


Shorted Device, Figure 7

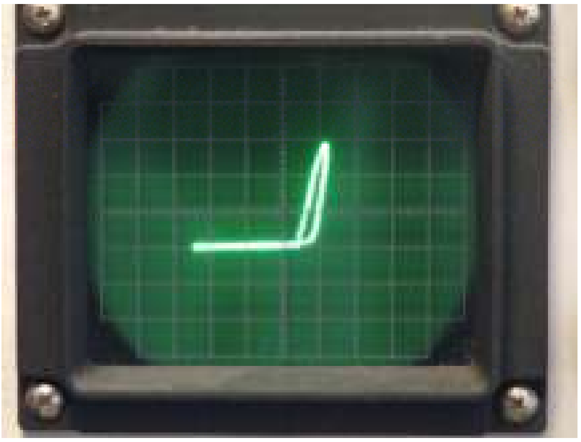
Figures 3 of 4:



Equalized Diode System, Figure 8

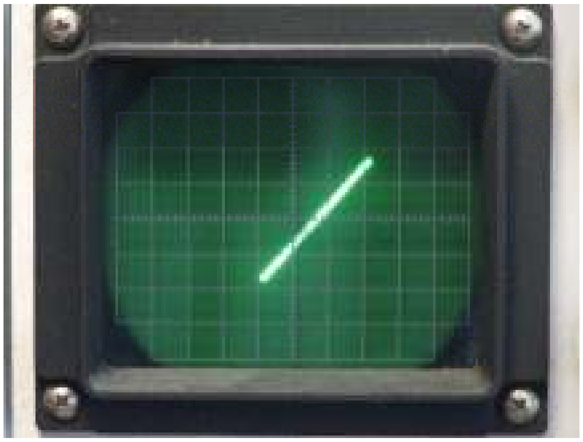


Resistive Curve For FWD Tracking, Figure 9

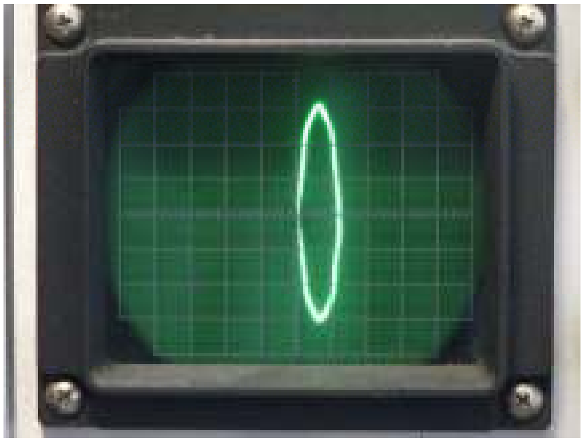


Mock up of Diode, Resistor & Capacitor. Fig 10

Deceptive View of smoked xfmr, Fig 11



Pure resistance, Figure 12



`Pure Capacitance, Figure 13

Figures 4 of 4:

A creative device for HV stack testing
Sencore LC-103 Figure 14