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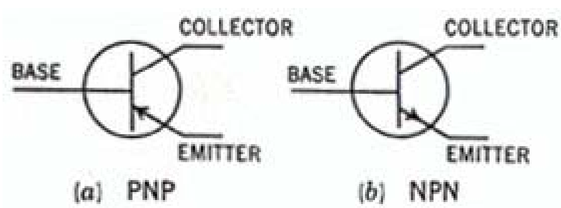
ELECTRONIC COMPONENTS

BIOPOLAR TRANSISTOR

Bipolar transistors, having 2 junctions, are 3 terminal semiconductor devices. The three terminals are emitter, collector, and base. A transistor can be either NPN or PNP. *See the schematic representations below:*



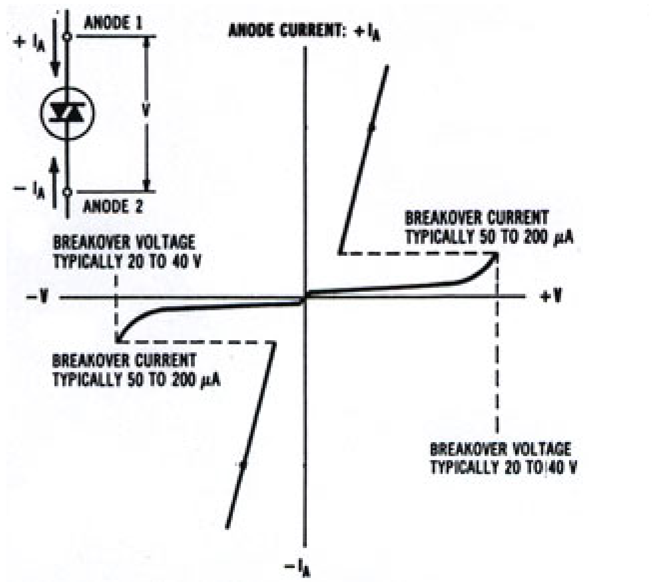
Note that the direction of the emitter arrow defines the type transistor. Biasing and power supply polarity are positive for NPN and negative for PNP transistors. The transistor is primarily used as an current amplifier. When a small current signal is applied to the base terminal, it is amplified in the collector circuit. This current amplification is referred to as H_{FE} or beta and equals Ic/Ib.

As with all semiconductors, breakdown voltage is a design limitation. There are breakdown voltages that must be taken into account for each combination of terminals. i.e. Vce, Vbe,and Vcb. However, Vce(collector-emitter voltage) with open base, designated as Vceo, is usually of most concern and defines the maximum circuit voltage.

Also as with all semiconductors there are undesireable leakage currents, notably Icbo ,collector junction leakage; and Iebo, emitter junction leakage. *A typical collector characteristic curve is shown below:*

DIAC

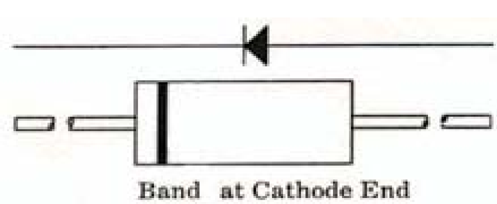
The diac is a bidirectional trigger diode which is designed specifically to trigger a triac or SCR. Basically the diac does not conduct (except for a small leakage current) until the breakover voltage is reached. At that point the diac goes into avalanche conduction also at that point the device exhibits a negative resistance characteristic, and the voltage drop across the diac snaps back, typically about 5 volts, creating a breakover current sufficient to trigger a triac or SCR. *A typical characteristic is shown below with its schematic symbol:*



Although most diacs have symmetric switching voltages,asymmetric diacs are available. Typical diacs have a power dissipations ranging from 1/2 to 1 watt.

DIODE RECTIFIER

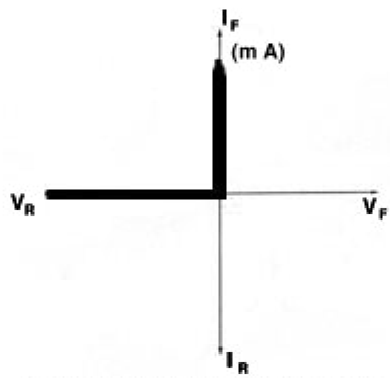
In this discussion the term diode and rectifier will be used interchangeably; however, the term diode usually implies a small signal device with current typically in the milliamp range; and a rectifier, a power device, conducting from1 to 1000 amps or even higher. Many diodes or rectifiers are identified as 1NXXXX . A semiconductor diode consists of a PN junction and has two(2) terminals, an anode(+) and a cathode(-). Current flows from anode to cathode within the diode. *A diode and schematic representation are shown below.*



An ideal diode is like a light switch in your home. When the switch is closed, the circuit is completed; and the light turns on.When the switch is open, there is no current and the light is off.

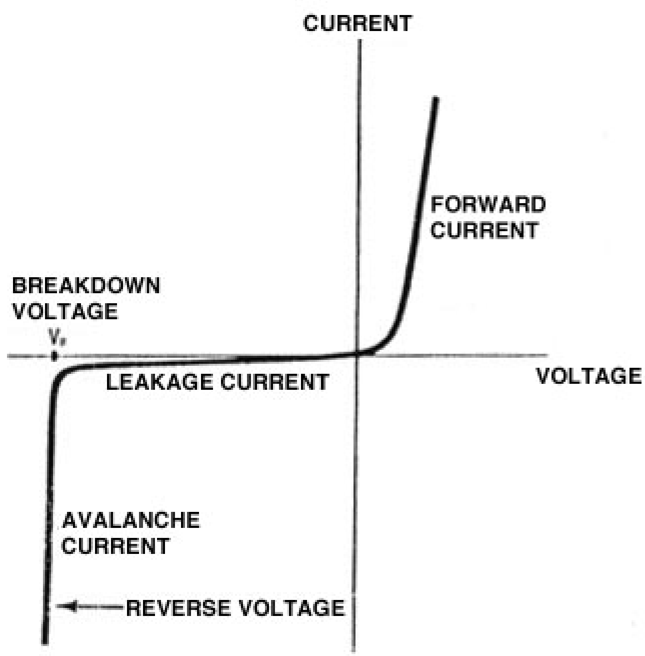
This can be shown as:

However, the diode has an additional property; it is unidirectional, i.e.current flows in only one direction(anode to cathode internally).When a forward voltage is applied, the diode conducts; and when a reverse voltage is applied, there is no conduction. A mechanical analogy is a ratchat, which allows motion in one direction only. *An ideal diode characteristic would be:*



V-I characteristics of an ideal diode

However, a typical diode characteristic is more like the following:



Forward Voltage Drop , Vf

Notice that the diode conducts a small current in the forward direction up to a threshold voltage, 0.3 for germanium and 0.7 for silicon ; after that it conducts as we might expect. The forward voltage drop, Vf, is specified at a forward current, If.

Leakage current

In the reverse direction there is a small leakage current up until the reverse breakdown voltage is reached. This leakage is undesireable, obviously the lower the better, and is specified at a voltage less the than breakdown; diodes are intended to operate below their breakdown voltage.

Current Rating

The current rating of a diode is determined primarily by the size of the diode chip, and both the material and configuration of the package, Average Current is used, not RMS current. A larger chip and package of high thermal conductivity are both conducive to a higher current rating.

Switching

The switching speed of a diode depends upon its construction and fabrication. In general the smaller the chip the faster it switches, other things being equal. The chip geometry, doping levels, and the temperature at nativity determine switching speeds . The reverse recovery time, trr, is usually the limiting parameter; trr is the time it takes a diode to switch from on to off.

DIODE ARRAYS

Multiple diode packaging or diode arrays have been an important semiconductor product. They save assembly time and improve reliability over individually packaged diodes.In general, the term diode array implies four or more diodes in a single package. The most efficient packaging scheme is typically 8 diodes or more in a dual inline package, a DIP.

Other packages are the SIP, a single inline package, the flat pack, and even a surface mount diode array. Although multiple diode arrays can incorporate different type diodes, the most popular arrays incorporate a fast, small signal diode such as the 1N4148; and the core driver arrays which employ a fast switching , higher current, 100mA diode. Of course there are various diode configurations for, say 8 or more diodes. If two independent leads are brought out for each diode, a 16 leaded DIP would be fully utilized.

On the other hand, if a common cathode or common anode connection was used internally, a 16 pin DIP would accommodate 14 diodes. Other common connections are available, and even more esoteric connections are possible, limited only by cost and one’s imagination. Many manufacturers have discontinued supplying diode arrays. The most notable are Fairchild with their FSA identification types and Motorola and their MAD and MMAD prefixing.

GERMANIUM DIODE

Early semiconductor developments used germanium as the commercial, semiconductor material. Due to its ease of processing and more stable temperature characteristics, silicon became the semiconductor of choice.

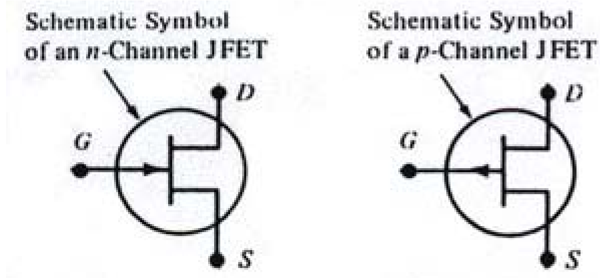
And as a consequence of that, most early germanium semiconductors were replaced with silicon. These were primarily transistors and diodes.

However, germanium diodes have the advantage of an intrinsically low forward voltage drop, typically 0.3 volts; this low forward voltage drop results in a low power loss and more efficient diode, making it superior in many ways to the silicon diode. A silicon diode forward voltage drop, by comparison, is typically 0.7 volts. This lower voltage drop with germanium becomes important in very low signal environments (signal detection from audio to FM frequencies) and in low level logic circuits. As a result germanium diodes are finding increasing application in low level digital circuits.

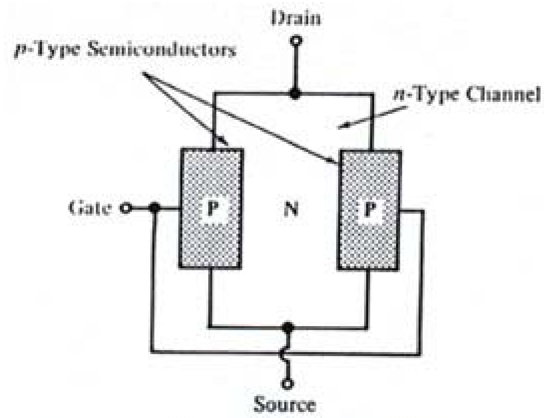
With this increased interest, certain general germanium characteristics should be understood. First and most important is that of an increased leakage current for germanium at a reverse voltage. This is mitigated to some degree by the fact that in low level circuits the reverse voltage applied to a germanium diode is also usually very low, resulting in a low reverse leakage current (leakage current is directly proportional to reverse voltage). However the leakage current is still larger than with silicon. A properly designed circuit can lessen this factor.

JUNCTION FET

The J-FET (Junction Field Effect Transistor) and the MOS-FET (Metal-Oxide-Semiconductor FET) are voltage controlled devices: that is a small change in input voltage causes a large change in output current. FET operation involves an electric field which controls the flow of a charge (current) through the device. In contrast, a bipolar transistor employs a small input current to control a large output current. The source, drain, and gate terminal of the FET are analagous to the emitter, collector, and base of a bipolar transistor . The terms n-channel and p- channel refer to the material which the drain and source are connected. *Below is the schematic symbol for the p-channel and n-channel JFET.*

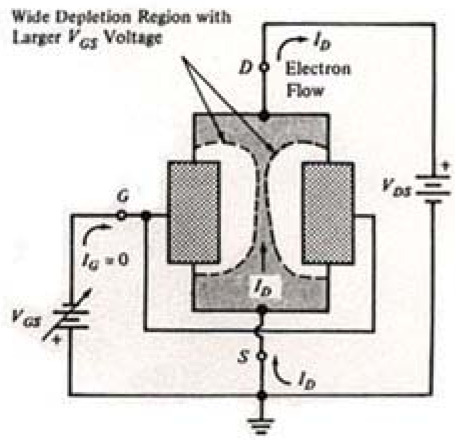


A simplified n-channel JFET construction is shown below. Note that the drain and source connections are made to the n-channel and the gate is connected to the p material. The n material provides a current path from the drain to the source. An n-channel JFET is biased so that the drain is positive in reference to the source. On the other hand , a p-channel JFET with n material gate would be biased in reverse.

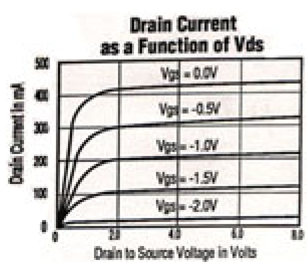


Junction FET with n-type material sandwiched between p-type materials.

As with any reversed biased PN junction, a depletion region is formed which increases as the reverse gate voltage is increased. This depletion region, being devoid of majority carriers, reduces the channel drain-source current. *See figure below:*



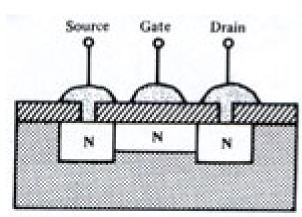
As a result, the the drain-source current is controlled by the gate voltage. Referring to the figure below, a typical JFET characteristic curve; notice the effect of the gate-source voltage on the drain-source current, Ids. Notice the near linear relationship of drain current to drain voltage from zero to about one volt after that the JFET saturates. However, as the gate voltage is increased, the drain-source current is increased.



The figure of merit, Gfs, that is the ratio of drain-source current to gate voltage is the JFET transconductance.

MOSFETS

A FET with an oxide coating between gate and channel is called a MOSFET (metal-oxide semiconductor field effect transistor) The figure below shows the oxide, insulating the gate from the channel. As a result, the MOSFET has very high input resistance, higher than the JFET ; and as with the JFET, the gate controls the main or channel current, Ids.



Notice that a postive gate voltage will induce a negative charge in the n-channel, enhancing the drain-source current, Ids; while a negative gate voltage will induce a depletion region in the n- channel, thereby reducing the drain-source current, Ids. A MOSFET so constructed is a depletion/enhancement MOSFET. A typical n-channel MOSFET curve is shown below.

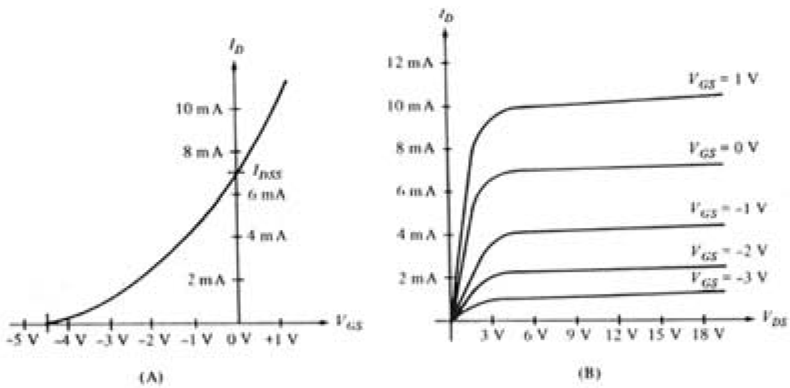
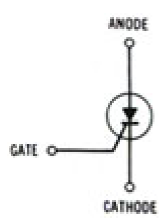


Figure (A), shows the transconductance, Gm, or effect of the gate voltage upon the drain to source current. Notice the gate-source voltage can be positive or negative. This would not be possible with a JFET. In figure (B), again notice the effect of increasing Vgs on Ids; notice also that for any given gate current, the drain-source voltage has little effect upon the drain current above 3 volts, since the MOSFET is in saturation.

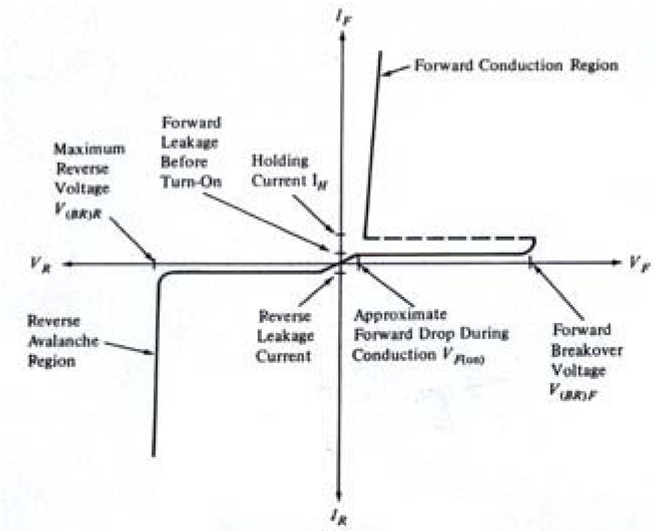
The MOSFET is also made in an enhancement-only mode, where a gate signal only induces or enhances channel current ,the gate signal never depletes the channel current. Naturally there are p-channel enhancement MOSFETS, where a negative gate voltage enhances channel conductivity; and n-channel enhancement mode MOSFETS where a positive gate voltage enhances channel conductivity. One final note, breakdown voltage in MOS devices do not depend upon p-n junction stress but rather upon the thickness and quality of the insulating oxide.When breakdown does occur, the oxide is punctured and the device is destroyed.

SCR

The Silicon Controlled Rectifier (SCR) is simply a conventional rectifier controlled by a gate signal. The main circuit is a rectifier, however the application of a forward voltage is not enough for conduction. A gate signal controls the rectifier conduction. *The schematic representation is:*



The rectifier circuit (anode-cathode) has a low forward resistance and a high reverse resistance. It is controlled from an off state (high resistance) to the on state (low resistance) by a signal applied to the third terminal, the gate. Once it is turned on it remains on even after removal of the gate signal, as long as a minimum current, the holding current, Ih, is maintained in the main or rectifier circuit. To turn off an SCR the anode-cathode current must be reduced to less than the holding current, Ih. *The characteristic curve is as shown below.*



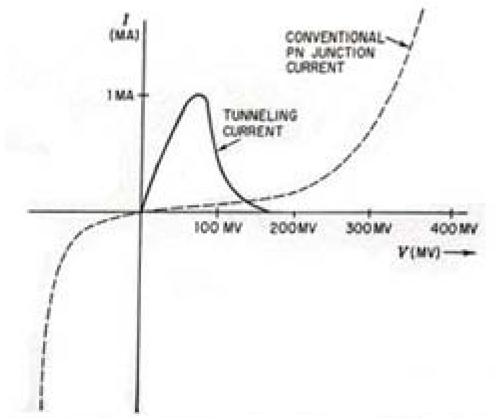
***V–I* characteristics of the SCR with gate open.**

Notice the reverse characteristics are the same as discussed previously for the rectifier or diode, having a breakover voltage with its attending avalanche current; and a leakage current for voltages less than the breakover voltage. However, in the forward direction with open gate, the SCR remains essentially in an off condition (notice though that there is a small forward leakage) up until the forward breakover voltage is reached. At that point the curve snaps back to a typical forward rectifier characteristic. The application of a small forward gate voltage switches the SCR onto its standard diode forward characteristic for voltages less than the forward breakover voltage.

Obviously, the SCR can also be switched by exceeding the forward breakover voltage, however this is usually considered a design limitation and switching is normally controlled with a gate voltage. One serious limitation of the SCR is the rate of rise of voltage with respect to time, dV/dt. A large rate of rise of circuit voltage can trigger an SCR into conduction. This is a circuit design concern. Most SCR applications are in power switching, phase control, chopper, and inverter circuits.

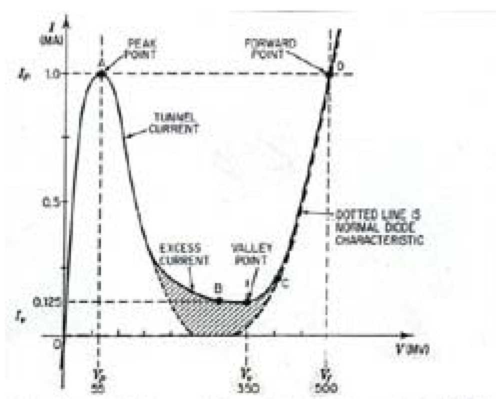
TUNEL DIODE

A tunnel diode is a semiconductor with a negative resistance region that results in very fast switching speeds , up to 5 GHz. The operation depends upon a quantum mechanic principle known as "tunneling" wherein the intrinsic voltage barrier (0.3 Volt for Germanium junctions) is reduced due to doping levels which enhance tunneling. Refering to the curves below, superimposing the tunneling characteristic upon a conventional P-N junction, we have:



Combination of tunneling current and conventional PN junction current.

Resulting in a composite characteristic which is the tunnel diode characteristic curve.

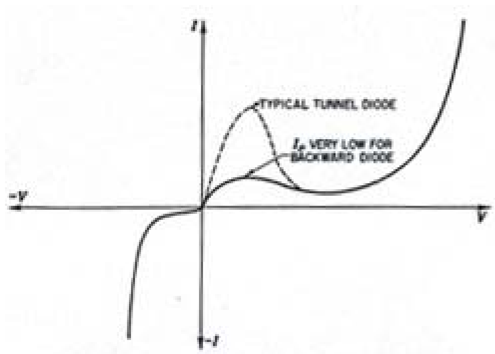


Composite characteristic representing overall operational curve of a tunnel diode.

The negative resistance region (between points A and B) is the important characteristic for the tunnel diode. In this region, as the voltage is increased, the current decreases; just the opposite of a conventional diode. The most important specifications for the tunnel diode are the Peak Voltage (Vp), Peak Current (Ip) , Valley Voltage (Vv), and Valley Current (Iv).

BACK DIODE

A Back diode is a tunnel diode with a suppressed Ip and so approximates a conventional diode characteristic See the comparison below:



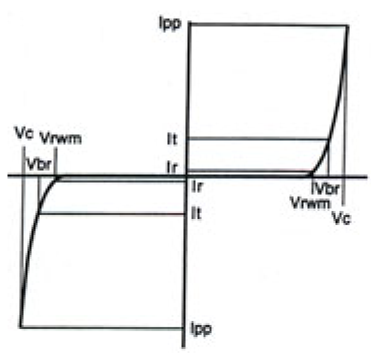
Comparison of forward characteristics of tunnel and backward diodes.

The reverse breakdown for tunnel diodes is very low, typically 200mV, and the TD conducts very heavily at the reverse breakdown voltage. Referring to the BD curve the back diode conducts to a lesser degree in a forward direction . It is the operation between these two points that makes the back diode important. Forward conduction begins at 300 mV (for germanium) and a voltage swing of only 500mV is required for full range operation.

TRANSIENT VOLTAGE SUPRESSOR

Transient Voltage Suppressors (TVS) are semiconductor devices designed to provide protection against voltage and current transients.The silicon TVS is designed to operate in the avalanche mode and uses a large junction area to absorb large transient currents. Operation in the avalanche mode insures a low impedance ; also the TVS is characterized by a fast response time. The TVS is available as unipolar or bipolar(that is it can suppress transients in one direction or in both directions.

The typical characteristic curve for a bipolar TVS is shown below:



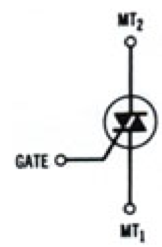
Bi-directional TVS characteristic curve

Referring to the curve:

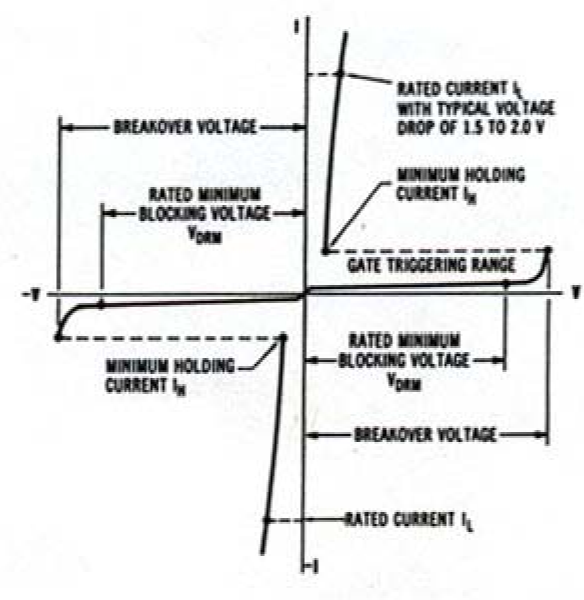
The breakdown voltage (Vbr) is the point the TVS device enters avalanche, a high conductance region. This Vbr is measured at test current It. A circuit with a TVS protection would obviously operate below the voltage, Vrwm, also referred to as the working voltage. Ir is the maximum current measured at the working voltage. The maximum peak pulse current for a TVS is Ipp. The maximum clamping voltage,Vc,is the maximum voltage across the TVS when it is subjected to Ipp.

TRIAC

The triac is a three terminal semiconductor for controlling current in either direction. Below is the schematic symbol for the triac. Notice the symbol looks like two SCRs in parallel(opposite direction) with one trigger or gate terminal.The main or power terminals are designated as MT1 and MT2 . (See the schematic representation below) When the voltage on the MT2 is positive with regard to MT1 and a positive gate voltage is applied, the left SCR conducts. When the voltage is reversed and a negative voltage is applied to the gate, the right SCR conducts. Minimum holding current, Ih, must be maintained in order to keep a triac conducting.



A triac operates in the same way as the SCR however it operates in both a forward and reverse direction. To get a quick understanding of its operation refer to its characteristic curve below and compare this to the SCR characteristic curve. It can be triggered into conduction by either a PLUS (+) or MINUS (-) gate signal.

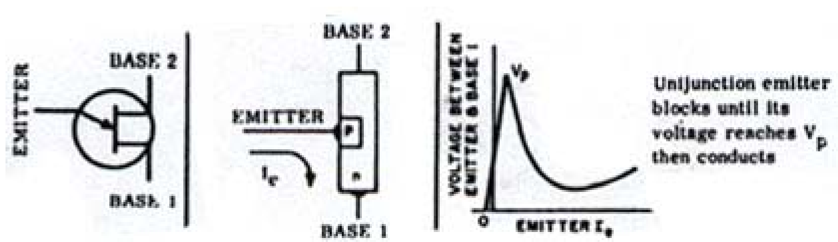


Typical triac VI characteristic curves.

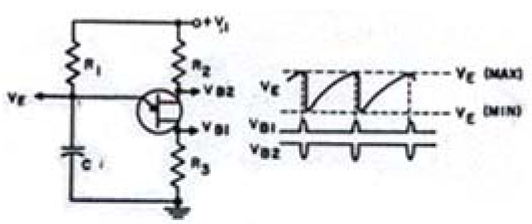
Obviously a triac can also be triggered by exceeding the breakover voltage. This is not normally employed in triac operation. The breakover voltage is usually considered a design limitation. One other major limitation, as with the SCR, is dV/dt, which is the rate of rise of voltage with respect to time. A triac can be switched into conduction by a large dV/dt. Typical applications are in phase control, inverter design, AC switching, relay replacement, etc.

UNIJUNCTION TRANSISTOR

The unijunction transistor(UJT) is a three terminal device with characteristics very different from the conventional 2 junction, bipolar transistor. It is a pulse generator with the trigger or control signal applied at the emitter . This trigger voltage is a fraction (n) of interbase voltage, Vbb.The UJT circuit symbol, junction schematic, and characteristic curve are shown below.



The emitter terminal does not inject current into the base region until its voltage reaches Vp. Once Vp is reached the base circuit conducts and a postive pulse appears at the B1 terminal and a negative pulse at B2. The UJT incorporates a negative resistance region, a low emitter current, and a high output pulse current at terminals B1 and B2, making it an ideal pulse trigger. A simple RC timer circuit using a UJT is shown below.



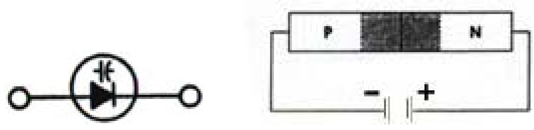
BASIC RELAXATION OSCILLATOR
WITH TYPICAL WAVEFORMS

The very basic specifications of a UJT are:

(a) Vbb(max) - The maximum interbase voltage that can be applied to the UJT
(b) Rbb-the interbase resistance of the UJT
(c) n - The intrinsic standoff ratio which defines Vp.
(d) Ip - The peakpoint emitter current

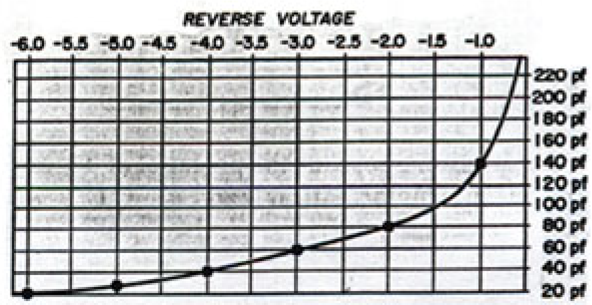
VARACTOR DIODE

The varactor diode symbol is shown below with a diagram representation.



When a reverse voltage is applid to a PN junction , the holes in the p-region are attracted to the anode terminal and electrons in the n-region are attracted to the cathode terminal creating a region where there is little current.This region ,the depletion region, is essentially devoid of carriers and behaves as the dielectric of a capacitor.

The depletion region increases as reverse voltage across it increases; and since capacitance varies inversely as dielectic thickness, the junction capacitance will decrease as the voltage across the PN junction increases. So by varying the reverse voltage across a PN junction the junction capacitance can be varied .This is shown in the typical varactor voltage-capacitance curve below.



VARACTOR VOLTAGE-CAPACITANCE CURVE

Notice the nonlinear increase in capacitance as the reverse voltage is decreased. This nonlinearity allows the varactor to be used also as a harmonic generator.

ZENER DIODE

Refer to the characteristic curve of a typical rectifier(diode) in the figure below. The forward characteristic of the curve we have previously described above in the DIODE section. It is the reverse characteristics we will discuss here.

Current-voltage characteristics of a typical P-N junction.

Notice that as the reverse voltage is increased the leakage current remains essentially constant until the breakdown voltage is reached where the current increases dramatically. This breakdown voltage is the zener voltage for zener diodes. While for the conventional rectifier or diode it is imperative to operate below this voltage; the zener diode is intended to operate at that voltage, and so finds its greatest application as a voltage regulator.

The basic parameters of a zener diode are:

(a) Obviously,the zener voltage must be specified. The most common range of zener voltage is 3.3 volts to 75 volts, however voltages out of this range are available.

(b) A tolerance of the specified voltage must be stated. While the most popular tolerances are 5% and 10%, more precision tolerances as low as 0.05 % are available . A test current (Iz) must be specified with the voltage and tolerance.

(c) The power handling capability must be specified for the zener diode. Popular power ranges are: 1/4, 1/2, 1 , 5, 10, and 50 Watts.