Power Electronic Devices

1.1) Diodes

Classification:

- General Purpose / Rectification Diodes

  Used for low speed applications. Typical reverse recovery time of the order of a few microseconds. Can be found in packages of 4 to form a bridge rectifier.
- Fast Recovery Diodes

  Used for higher speed switching applications. Reverse recovery time often less than 1µs. Soft recovery diode are fast recovery diodes which are less prone to oscillations when the voltage is reversed across them.
- Schottky Diodes

  Manufactured from a semiconductor upon which a layer of metal has been deposited. The metal replaces the p type material normally found in rectifier diodes. These are very fast (a few picoseconds) and are widely used in logic circuits e.g. LS-TTL logic as well as specialized applications in power electronics. They suffer from a large reverse leakage current which limits their use in high voltage applications.
- Zener Diodes

  Used for surge suppression and as voltage references. These diodes have a reverse breakdown voltage which is carefully controlled by the manufacture. Different diodes with different reverse breakdown voltage are available (2.7, 3.3, 4.7, 5.1, 6.3 and so on).

References:

Datasheets for 1N4004 and 1N4933 in course notes.
http://archive.chipcenter.com/eexpert/akruger/akruger004.html

1.2) Bipolar Junction Transistors

1.2.1 Structure of BJT

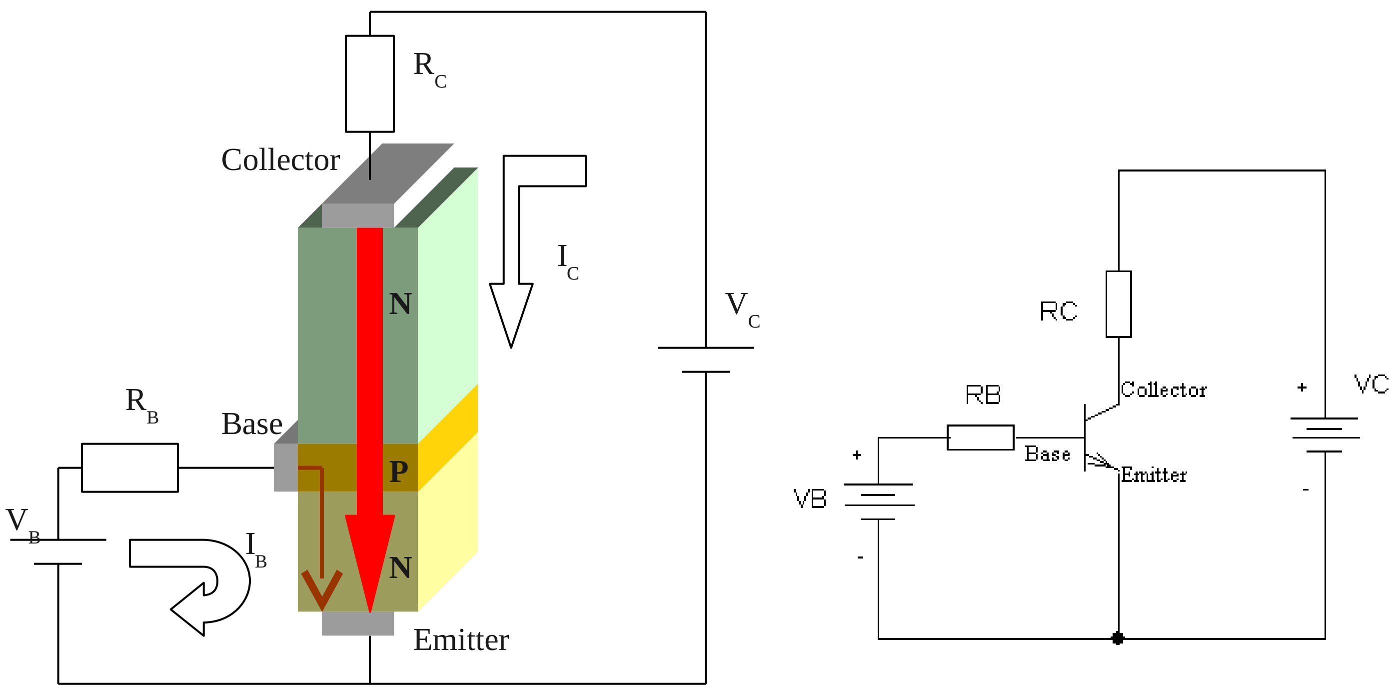


Figure 1.2.1.1

Figure 1.2.1.1 shows the normal current flows for an NPN transistor in the ON state. Current flow in from base to emitter permits a larger current flow to take place between collector and gate. Certain points are worth noting about the switching characteristics of the device (which are caused by its geometry):

- BJT's can tolerate only a small reverse base emitter voltage as the base region must be very slim to improve the gain of the device.
- A transistor is a three dimensional device and as a result it takes time for current to spread throughout the bulk of the device.
- The device is not symmetrical (and so will not work with collector and emitter swapped).
- The transistor resembles a sandwich of three conductors and so may be thought of as having built in capacitance. Figure 1.2.1.2 shows these "stray" capacitances. These greatly effect the high frequency performance of the device.

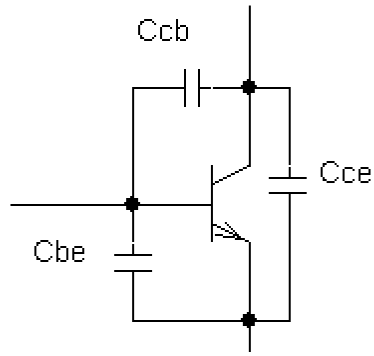


Figure 1.2.1.2

The PNP transistor compliments the NPN (and often lives in the “blindspot” of engineering students because it works backwards even though in some cases it is far more useful than its NPN counterpart). Figure 1.2.1.3 shows current flow within a PNP transistor.

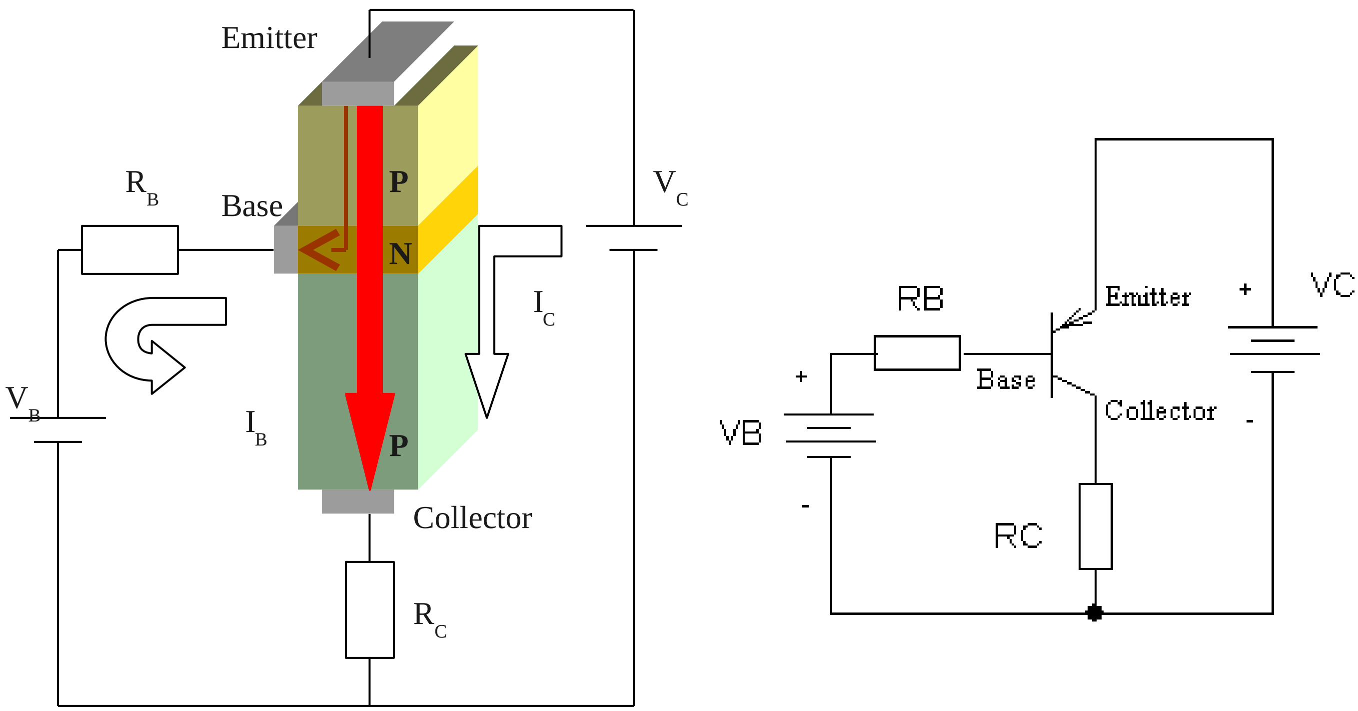


Figure 1.2.1.3

1.3) Metal-Oxide-Silicon Field Effect Transistors

1.3.1 Structure of MOSFETS.

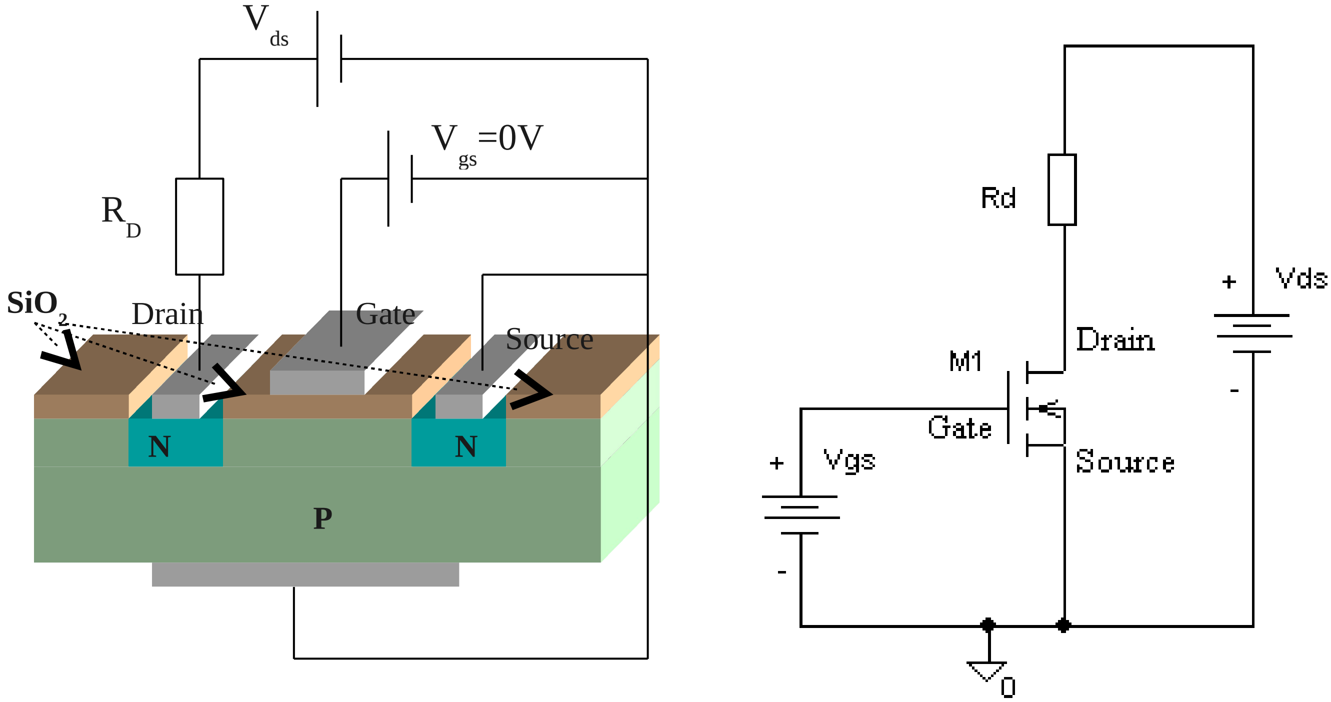


Figure 1.3.1.1

Figure 1.3.1.1 shows the structure of an N-Channel MOSFET. Points to note:

- When Vgs = 0., The drain-substrate junction is a reverse biased PN junction (i.e. no conduction takes place).
- There is a “built-in” anti-parallel PN junction (diode) between drain and source
- There is no direct electrical connection between gate and substrate.
- The insulation between gate and substrate is a very thin layer of SiO_2. This can be easily punctured if Vgs rises too high.
- Source and substrate are internally connected.

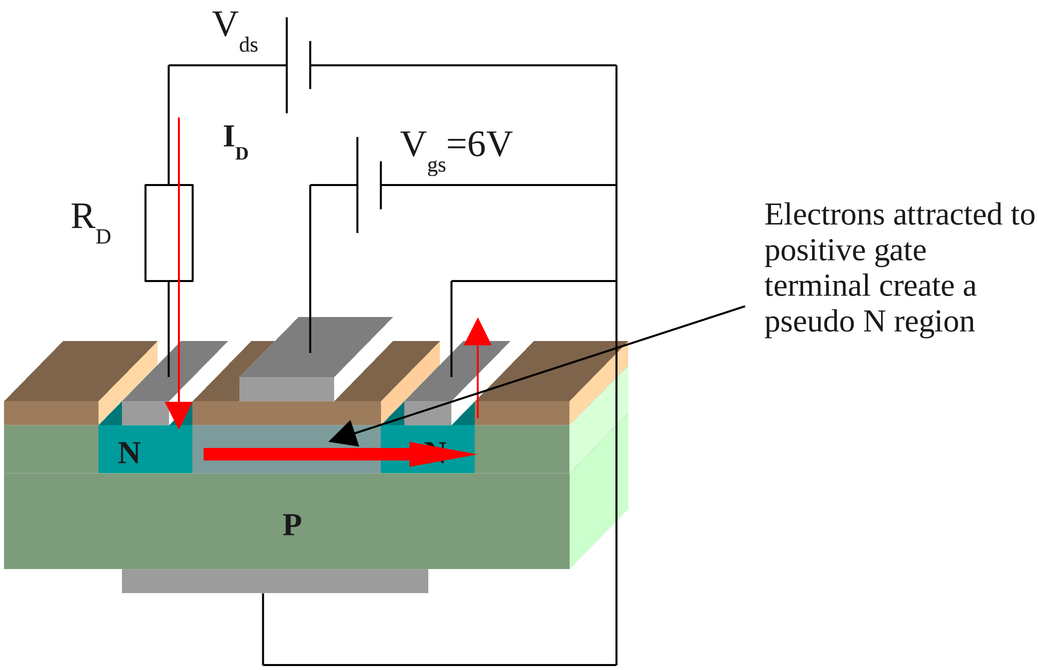


Figure 1.3.1.2

Figure 1.3.1.2 shows the effect of increasing Vgs on the device. Electronics are attracted to the region beneath the gate metal contact which creates a conductive channel between drain and source. The MOSFET therefore turns on.

P-Channel MOSFETs also exist which may be used in push-pull/bridge application. The symbol for a P-channel MOSFET is as shown in Figure 1.3.1.3.

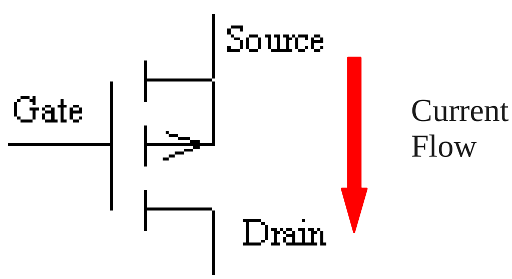


Figure 1.3.1.3

1.3.2 Switching Considerations for MOSFETS

Turning on a MOSFET is analogous to charging a capacitor between gate and source (Cgs). Rapid turn on is achieved by charging this capacitor above a certain value (which ensures that the conduction channel between drain and source is complete). The value of Vgs required to complete the channel is known as the threshold voltage and is stated in device data sheets. Figure 1.3.2.1 shows a simple test gate drive circuit.

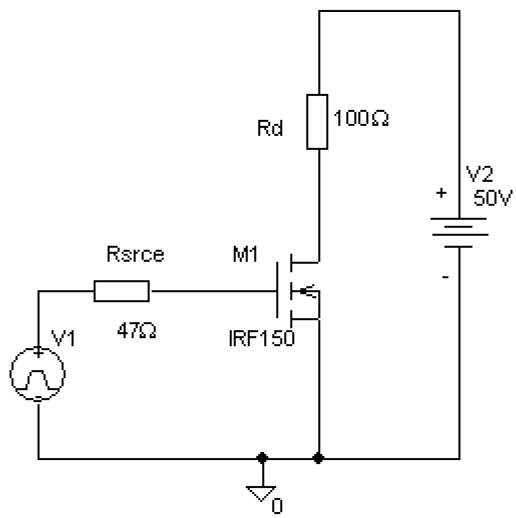


Figure 1.3.2.1

Waveforms from this circuit are shown in Figure 1.3.2.2. Note the gate current flows only for a short period i.e. just for the time it takes Cgs to charge up. Once Cgs is charged, the gate current falls to zero. Thus maintaining conduction in a MOSFET requires far less energy than as was the case for BJT’s.

Just as was the case with the BJT, MOSFET's can be accidentally turned on by large positive rates of change of Vds. This problem is potentially worse with MOSFETs as they require such little energy to control them.

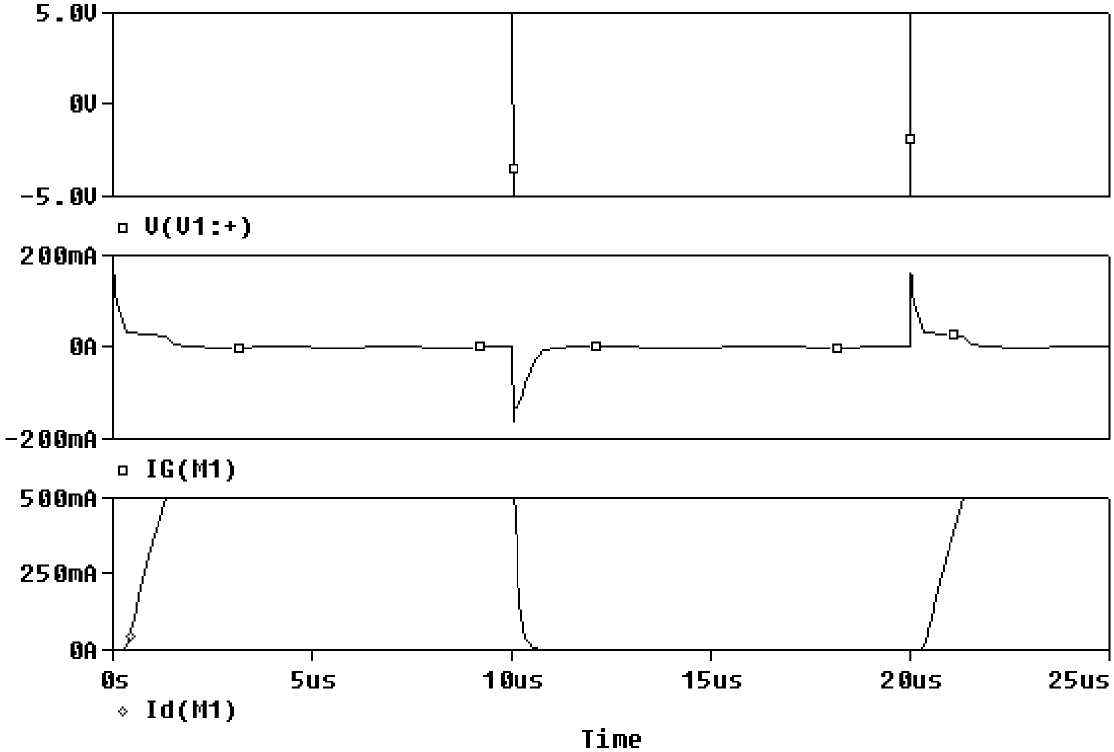

5.0V
0V
-5.0V
V(V1:+)
200mA
0A
-200mA
IG(M1)
500mA
250mA
0A
0s
5us
10us
15us
20us
25us
Id(M1)
Time

Figure 1.3.2.2

1.4) Insulated Gate Bipolar Transistors (IGBT’s).
1.4.1 Structure and operation of IGBT

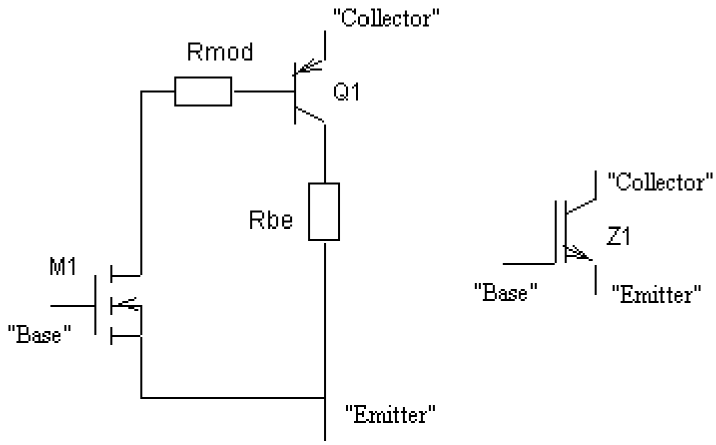


Figure 1.4.1.1

Figure 1.4.1.1 shows that an IGBT may be thought of as a composite device made up from a MOSFET, IGBT and a pair of resistors. In fact IGBT’s are manufactured as devices in their own right as shown if Figure 1.4.1.2.

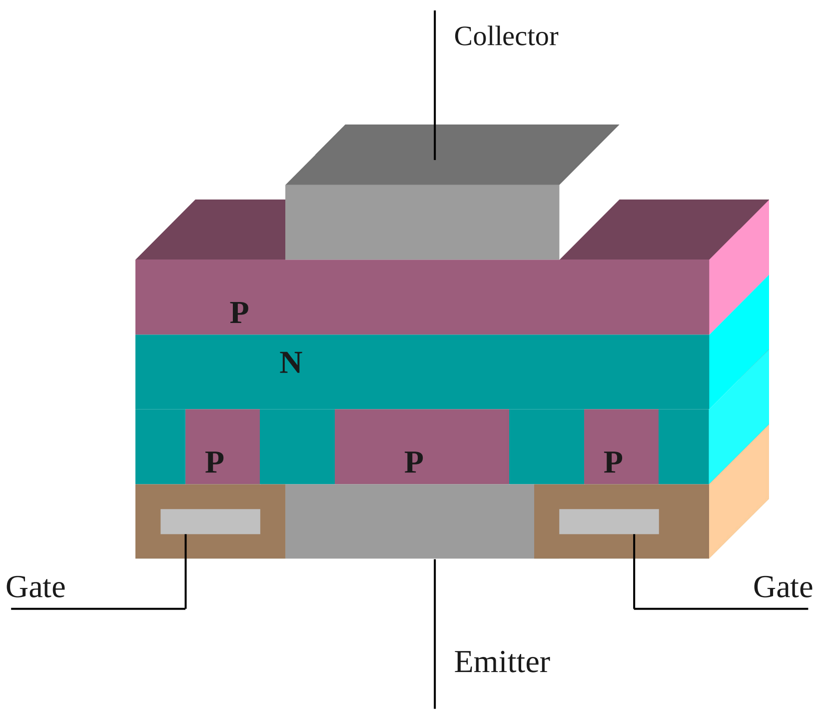


Figure 1.4.1.2.

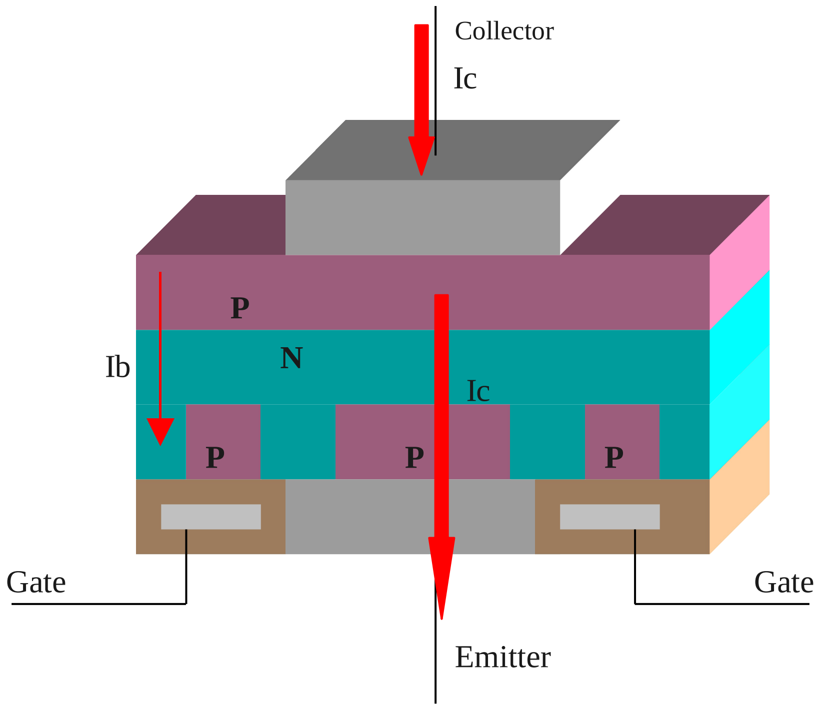


Figure 1.4.1.3

The device is turned on by switching on the rear MOSFET. This allows base current to flow in the front end PNP BJT and the overall device begins to conduct as shown in Figure 1.4.1.3

There is no complimentary device for an IGBT.

1.4.2 Switching Considerations for IGBT's.

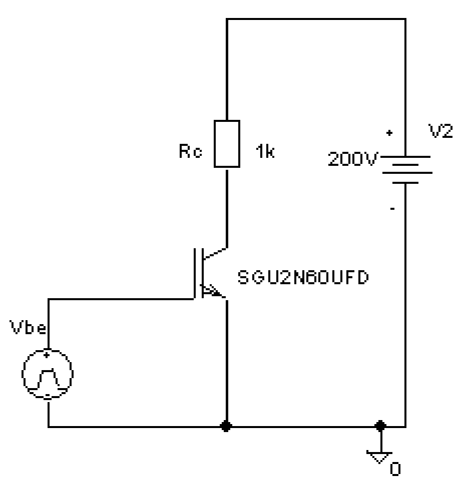


Figure 1.4.2.1

Figure 1.4.2.1 shows the test circuit used for SGU2N60UFD 600V IGBT. Vbe is a square wave which switches between –10V and +10V, Figure 1.4.2.2 shows waveforms for a positive edge of Vbe while Figure 1.4.2.3 shows those for a negative edge.

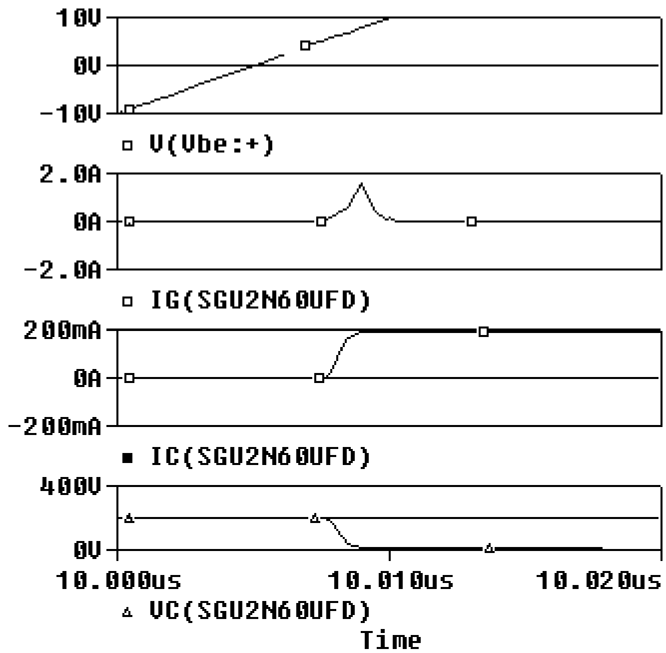


Figure 1.4.2.2

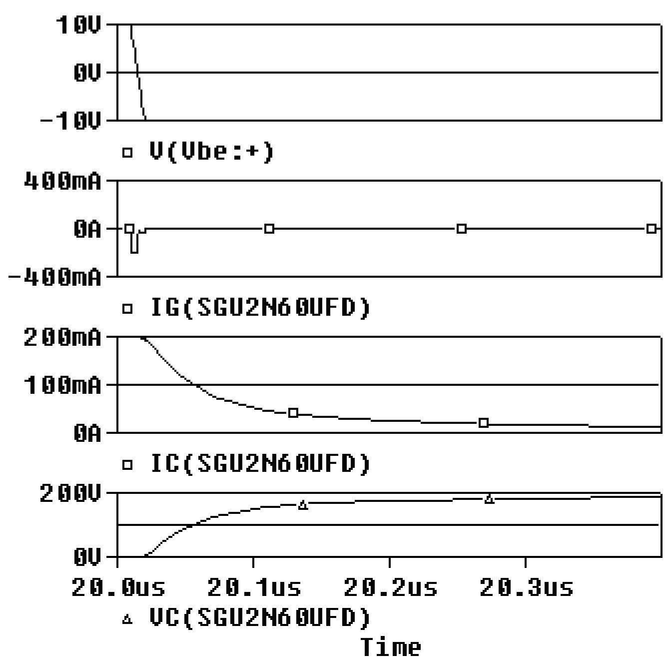


Figure 1.4.2.3

It should be noted that the IGBT takes a lot longer to turn off than on. Why do you think this is?

1.5) Thyristors

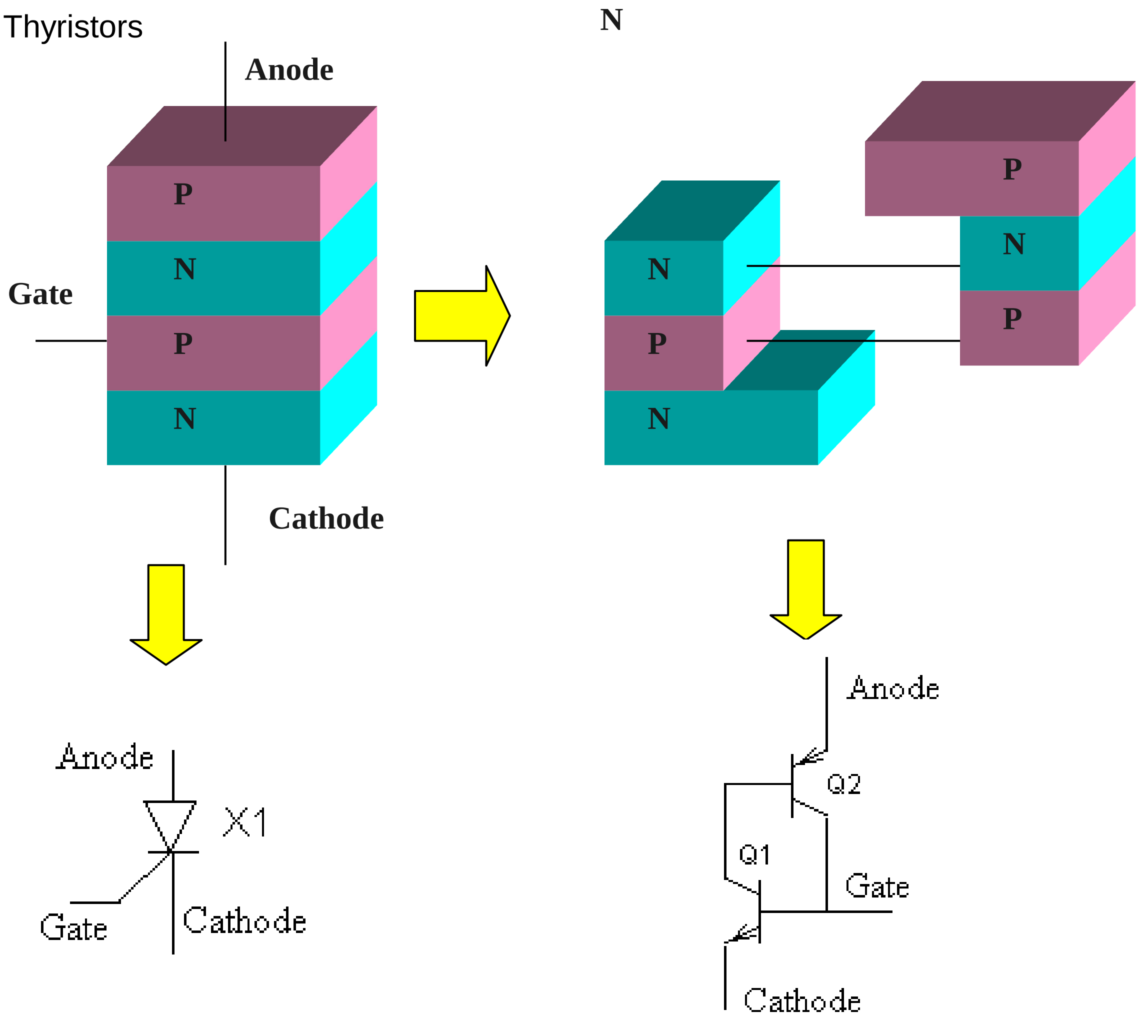
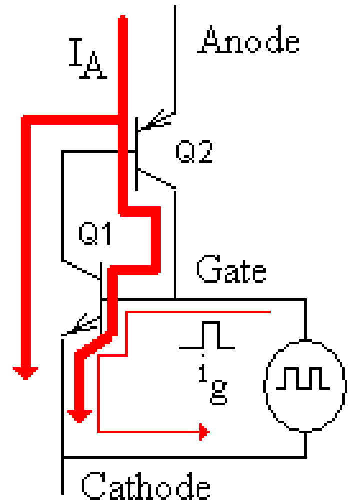


Figure 1.5.1

Figure 1.5.1 shows a schematic representation of a thyristor. It also demonstrates how thyristors may be viewed as an NPN transistor connected to a PNP transistors. Functionally, a thyristor be viewed as a controllable diode. It will conduct if it is forward biased AND a firing pulse (a short current pulse) is injected into the gate (returning via the emitter). Figure 1.5.2 illustrates this more clearly.



When set up first the Q1 is off which in turn maintains Q2 in the off state. If a small pulse of current is injected into the base of Q1, it will draw current from the base of Q2 which in turn supplies more current to the base of Q1 and the process then cascades until both transistors are fully on.
The following question then arises: How do you turn it off? There are two approaches

- Gate turn-off: If sufficient current is removed from the gate, Q1 will turn off which will also turn Q1 off. Some thyristors are designed with this in mind so that only a (relatively) small amount of current need be drawn from the gate. These are called GTO’s.
- Interrupt current flow in the device/reverse the voltage across it.

Figure 1.5.3 shows a typical application of thyristors: controlled rectification. In this case, the thyristors form part of a half controlled full-wave rectifier. Figure 1.5.4 shows the output voltage and the gate currents for each of the thyristors. This circuit achieves voltage control by removing more and more of each half cycle to achieve a lower average output voltage.

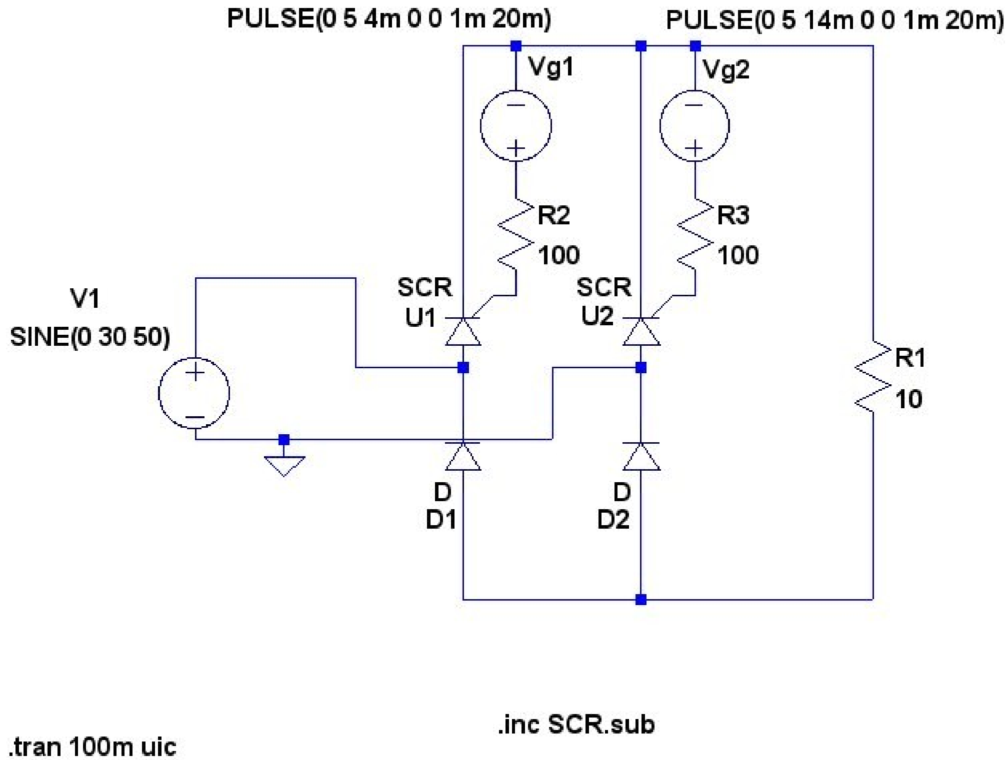
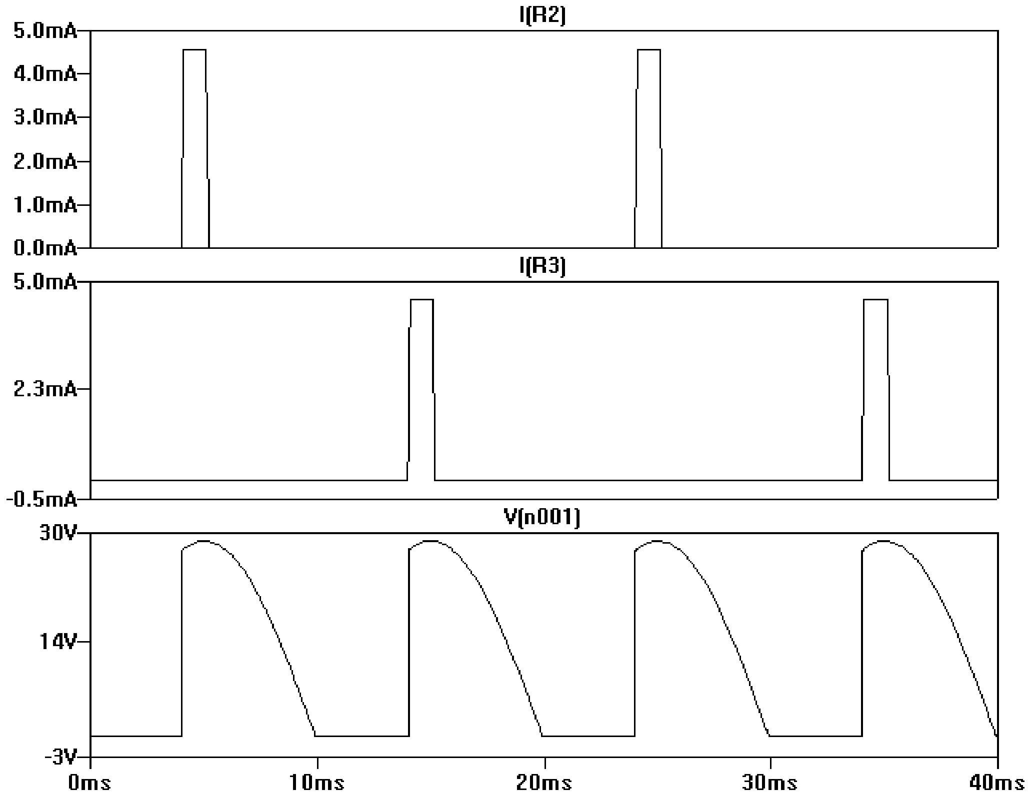

PULSE(0 5 4m 0 0 1m 20m)
PULSE(0 5 14m 0 0 1m 20m)
Vg1
Vg2
R2
100
R3
100
SCR
U1
SCR
U2
V1
SINE(0 30 50)
R1
10
D
D1
D
D2
.inc SCR.sub
.tran 100m uic

Figure 1.5.3



I(R2)
5.0mA
4.0mA
3.0mA
2.0mA
1.0mA
0.0mA
I(R3)
5.0mA
2.3mA
-0.5mA
V(n001)
30V
14V
-3V
0ms
10ms
20ms
30ms
40ms

Figure 1.5.4