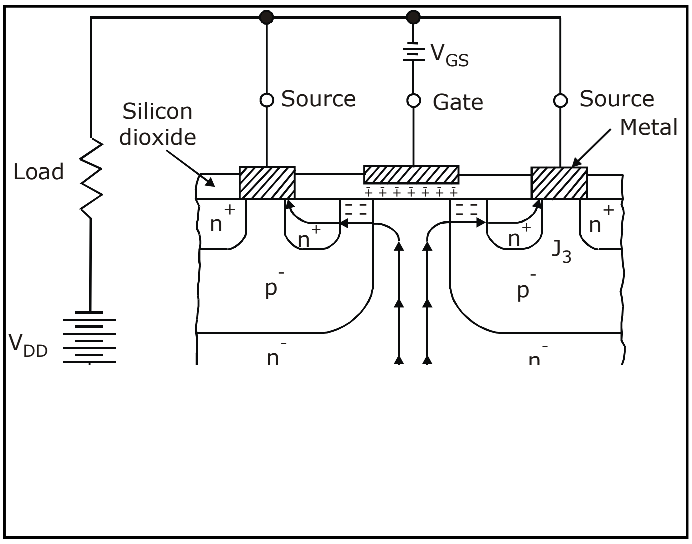
# POWER MOSFET

Power MOSFET’s are generally of enhancement type only. This MOSFET is turned ‘ON’ when a voltage is applied between gate and source. The MOSFET can be turned ‘OFF’ by removing the gate to source voltage. Thus gate has control over the conduction of the MOSFET. The turn-on and turn-off times of MOSFET’s are very small. Hence they operate at very high frequencies; hence MOSFET’s are preferred in applications such as choppers and inverters. Since only voltage drive (gate-source) is required, the drive circuits of MOSFET are very simple. The paralleling of MOSFET’s is easier due to their positive temperature coefficient. But MOSFTS’s have high on-state resistance hence for higher currents; losses in the MOSFET’s are substantially increased. Hence MOSFET’s are used for low power applications.




**Construction**

Power MOSFET’s have additional features to handle larger powers. On the $n^+$ substrate high resistivity $n^-$ layer is epitaxially grown. The thickness of $n^-$ layer determines the voltage blocking capability of the device. On the other side of $n^+$ substrate, a metal layer is deposited to form the drain terminal. Now $p^-$ regions are diffused in the epitaxially grown $n^-$ layer. Further $n^+$ regions are diffused in the $p^-$ regions as shown. $SiO_2$ layer is added, which is then etched so as to fit metallic source and gate terminals.

A power MOSFET actually consists of a parallel connection of thousands of basic MOSFET cells on the same single chip of silicon.

When gate circuit voltage is zero and $V_{DD}$ is present, $n^+ - p^-$ junctions are reverse biased and no current flows from drain to source. When gate terminal is made positive with respect to source, an electric field is established and electrons from $n^-$ channel in the $p^-$ regions. Therefore a current from drain to source is established.

Power MOSFET conduction is due to majority carriers therefore time delays caused by removal of recombination of minority carriers is removed.

Because of the drift region the ON state drop of MOSFET increases. The thickness of the drift region determines the breakdown voltage of MOSFET. As seen a parasitic BJT is formed, since emitter base is shorted to source it does not conduct.

## 2.6 Switching Characteristics

The switching model of MOSFET's is as shown in the figure 6(a). The various inter electrode capacitance of the MOSFET which cannot be ignored during high frequency switching are represented by $C_{gs}, C_{gd}$ & $C_{ds}$. The switching waveforms are as shown in figure 7. The turn on time $t_d$ is the time that is required to charge the input capacitance to the threshold voltage level. The rise time $t_r$ is the gate charging time from this threshold level to the full gate voltage $V_{gsp}$. The turn off delay time $t_{doff}$ is the time required for the input capacitance to discharge from overdriving the voltage $V_1$ to the pinch off region. The fall time is the time required for the input capacitance to discharge from pinch off region to the threshold voltage. Thus basically switching ON and OFF depend on the charging time of the input gate capacitance.

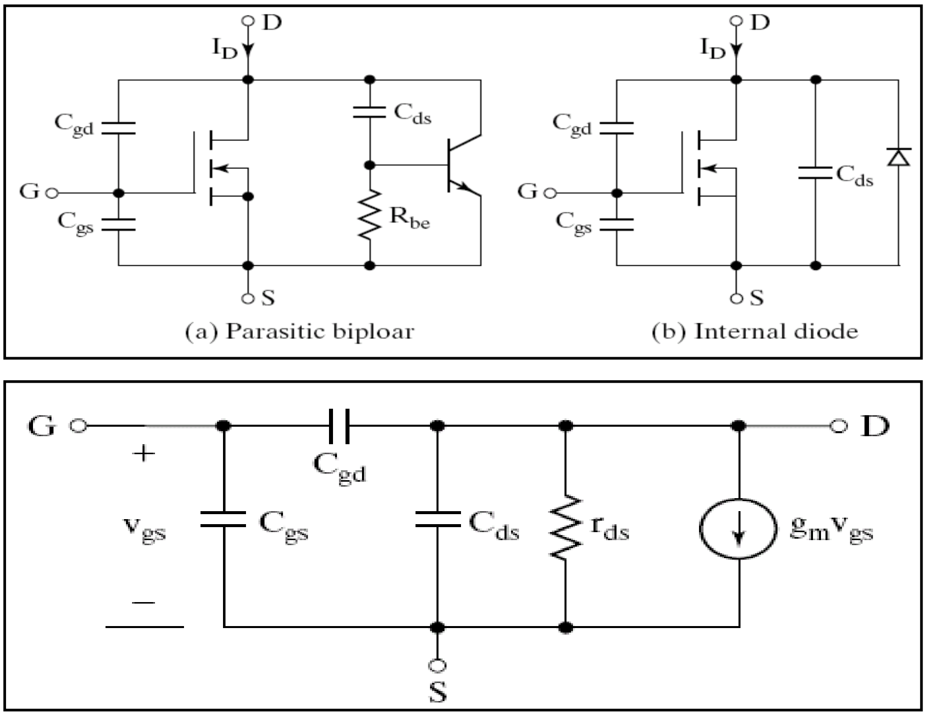



Fig.2.18: Switching model of MOSFET

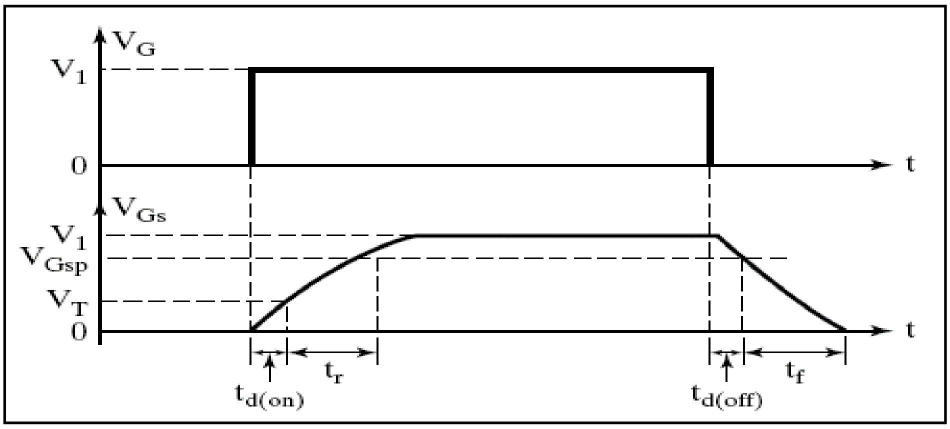



Fig2.19: Switching waveforms and times of Power MOSFET

**Gate Drive**

The turn-on time can be reduced by connecting a RC circuit as shown to charge the capacitance faster. When the gate voltage is turned on, the initial charging current of the capacitance is

$$I_G = \frac{V_G}{R_S}.$$

The steady state value of gate voltage is

$$V_{GS} = \frac{R_G V_G}{R_S + R_1 + R_G}.$$

Where $R_S$ is the internal resistance of gate drive force.

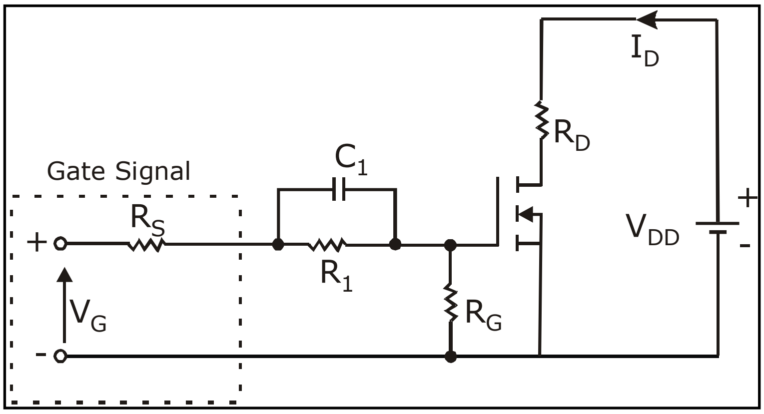



Fig.2.20: Fast turn on gate drive circuit 1

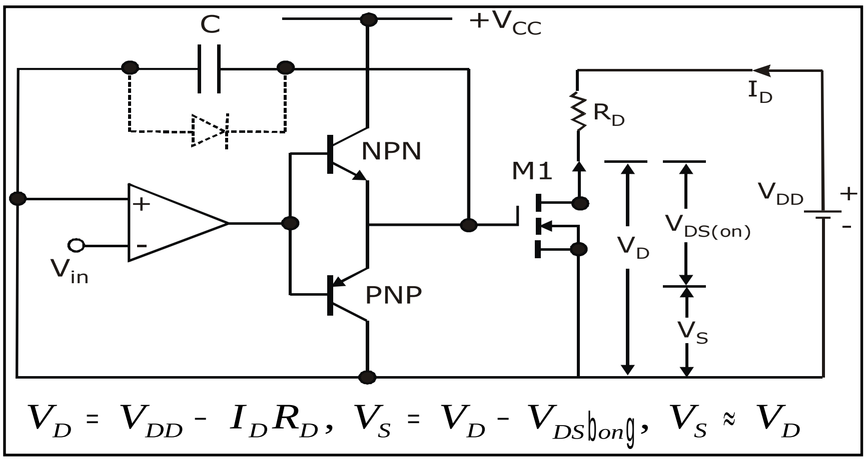



Fig.2.21: Fast turn on gate drive circuit 2

The above circuit is used in order to achieve switching speeds of the order of 100nsec or less. The above circuit as low output impedance and the ability to sink and source large currents. A totem poll arrangement that is capable of sourcing and sinking a large current is achieved by the PNP and NPN transistors. These transistors act as emitter followers and offer a low output impedance. These transistors operate in the linear region therefore minimize the delay time. The gate signal of the power MOSFET may be generated by an op-amp. Let $V_{in}$ be a negative voltage and initially assume that the MOSFET is off therefore the non-inverting terminal of the op-amp is at zero potential. The op-amp output is high therefore the NPN transistor is on and is a source of a large current since it is an emitter follower. This enables the gate-source capacitance $C_{gs}$ to quickly charge upto the gate voltage required to turn-on the power MOSFET. Thus high speeds are achieved. When $V_{in}$ becomes positive the output of op-amp becomes negative the PNP transistor turns-on and the gate-source capacitor quickly discharges through the PNP transistor. Thus the PNP transistor acts as a current sink and the MOSFET is quickly turned-off. The capacitor C helps in regulating the rate of rise and fall of the gate voltage thereby controlling the rate of rise and fall of MOSFET drain current. This can be explained as follows

- The drain-source voltage $V_{DS} = V_{DD} - I_D R_D$.
- If $I_D$ increases $V_{DS}$ reduces. Therefore the positive terminal of op-amp which is tied to the source terminal of the MOSFET feels this reduction and this reduction is transmitted to gate through the capacitor 'C' and the gate voltage reduces and the drain current is regulated by this reduction.

**Comparison of MOSFET with BJT**

- Power MOSFETS have lower switching losses but its on-resistance and conduction losses are more. A BJT has higher switching loss bit lower conduction loss. So at high frequency applications power MOSFET is the obvious choice. But at lower operating frequencies BJT is superior.
- MOSFET has positive temperature coefficient for resistance. This makes parallel operation of MOSFET's easy. If a MOSFET shares increased current initially, it heats up faster, its resistance increases and this increased resistance causes this current to shift to other devices in parallel. A BJT is a negative temperature coefficient, so current shaving resistors are necessary during parallel operation of BJT's.
- In MOSFET secondary breakdown does not occur because it have positive temperature coefficient. But BJT exhibits negative temperature coefficient which results in secondary breakdown.
- Power MOSFET's in higher voltage ratings have more conduction losses.
- Power MOSFET's have lower ratings compared to BJT's . Power MOSFET's $\rightarrow$ 500V to 140A, BJT $\rightarrow$ 1200V, 800A.