Department of Electrical Engineering
Assignment
Date: 20/04/2020

Course Details

Course Title: Power Electronics **Module:** 4rth
Instructor: Engr. Aamir aman **Total Marks:** 30

Student Details

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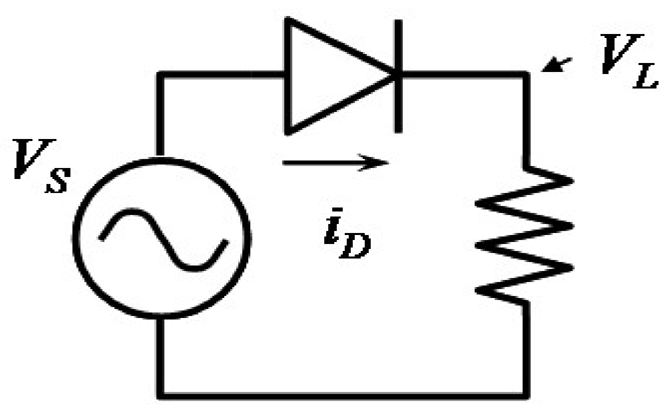
Q1.	(a)	In some applications, power semiconductor diodes are required to conduct several kilo amperes of current in the forward direction with very little power loss while blocking several kilo volts in the reverse direction. Explain the main differences of constructional features of a power diode and a signal diode. Illustrate your answer with the help of sketches to make a clear difference between the two.	Marks 10 CLO 1
Q2.	(a)	Explain operational features of the power MOSFET. Support your explanation using MOSFET operation as a switch. Also, illustrate the conditions to derive power MOSFET in the different regions of operation.	Marks 10 CLO 1
Q3.	(a)	 Consider Vs = 220Sin2wt, R = 1000kΩ and 1N4004 uncontrolled rectifier diode for the circuit shown above. Find i) V_{avg} ii) I_{oavg} iii) V_{rms} iv) I_{orms} v) Output Power	Marks 10 CLO 2

		vi) Input Power Factor vii) Conduction angle of a diode viii) Extension angle of diode ix) Comparison of both conduction angle and extension angle of diode x) Peak Inverse Voltage xi) Circuit turnoff time, t_c xii) By putting inductor of your own choice repeat all the findings and compare both circuits result and comment.	

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Answer Sheet

Q1 (a):

In some applications, power semiconductor diodes are required to conduct several kilo amperes of current in the forward direction with very little power loss while blocking several kilo volts in the reverse direction. Explain the main differences of constructional features of a power diode and a signal diode. Illustrate your answer with the help of sketches to make a clear difference between the two.

Ans:

Main differences between Power and Signal Diode:

1. Power diode is constructed with n-layer, called drift region between the p+ layer and n+ layer. In Signal diode, the drift region is not present.

2. The voltage, current, and power ratings are higher in the power diode while it is lower in the signal.

3. Power diodes operate at high speeds. Signal diode operates at higher switching speed.

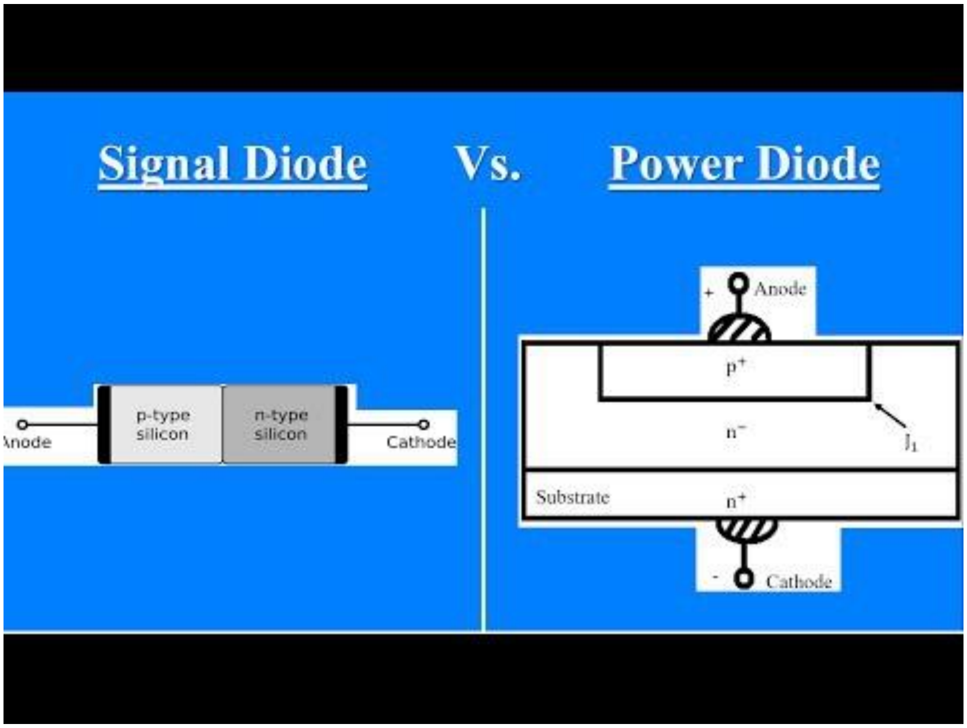
4. Signal diode have lower power rating.

5. They do not have an extra layer which is used in power diode to increase its voltage withstand capacity.

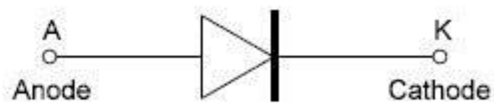
6. Power diode have large power rating with additional layer introduced to increase its voltage rating.

7. So power diode have more thickness as compared to signal diode.

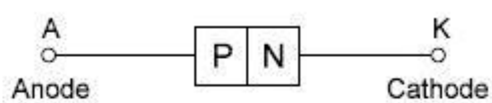
Sketches to make a clear difference between the two:



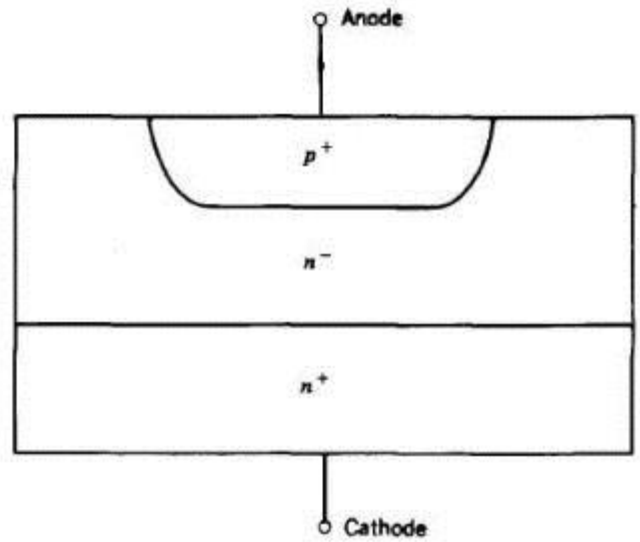
The signal diode and power diode has the same symbol.



Signal diode is a two terminal, two layer, PN junction device, two layer, PN Junction device.



Whereas , power diode is a two terminal, PN junction diode which has p^+, n^-, n^+ layers.



Signal diodes are made up of Silicon (Si) and Germanium (Ge) as well. But Power diodes are made by Silicon material only. Recently Silicon carbide (SiC) based Power diodes had entered in the market. SiC based power diodes are having very low reverse recovery time (TRR) in terms of Nano seconds.

Q2 (a):

Explain operational features of the power MOSFET. Support your explanation using MOSFET operation as a switch. Also, illustrate the conditions to derive power MOSFET in the different regions of operation.

Ans:

Operational features of the power MOSFET:

The operation of MOSFET divides into two parts:

1. Formation of the depletion layer
2. Creation of Inversion Layer

1) Formation of the depletion layer

By connecting a positive voltage to the drain with respect to the source and the gate is positive with respect to the body, the MOSFET works as forward biased. The p-layer has a large number of holes and few electrons. The holes are the majority charge carrier and electrons are minority charge carrier. Due to the positive voltage applied between the gate and the body, these electrons are attracted towards the gate and gather below the oxide layer and produce the depletion layer.

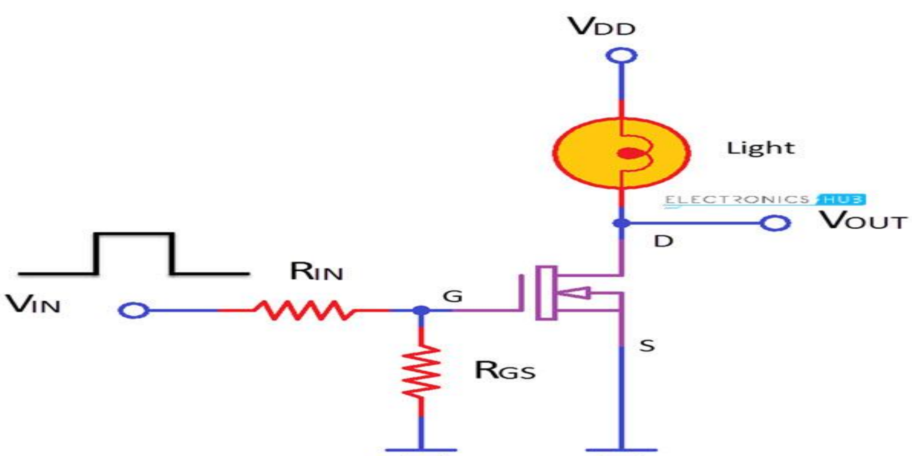
2) Creation of Inversion Layer

The number of electrons below the oxide layer will greater than the number of holes if the positive gate voltage increases further. Hence, n-type of sub layer form below the oxide layer. This process is known as the creation of the inversion layer. The process of generation of an inversion layer due to the extremely applied gate voltage is known as the field effect. This inversion layer is also known as the induced layer.

The resistance of induced layer depends on the magnitude of the gate to body voltage. Higher the gate voltage less the resistance. The resistance decreases with an increase in the gate to body voltage. But after a certain level, the resistance is not decreased even increasing the gate to body voltage. If the maximum specified value of the gate voltage exceeds then the oxide layer will breakdown.

MOSFET operation as a switch:

If you understood the working of the MOSFET and its regions of operation, you would have probably guessed how a MOSFET works as a switch. We will understand the operation of a MOSFET as a switch by considering a simple example circuit.



This is a simple circuit where an n-Channel Enhancement mode MOSFET will turn ON or OFF a light. In order to operate a MOSFET as a switch, it must be operated in cut-off and linear (or triode) region.

Assume the device is initially OFF. The voltage across Gate and Source i.e. V_{GS} is made appropriately positive (technically speaking, $V_{GS} > V_{TH}$), the MOSFET enters linear region and the switch is ON. This makes the Light to turn ON.

If the input Gate voltage is 0V (or technically $< V_{TH}$), the MOSFET enters cut-off state and turns off. This in turn will make the light to turn OFF.

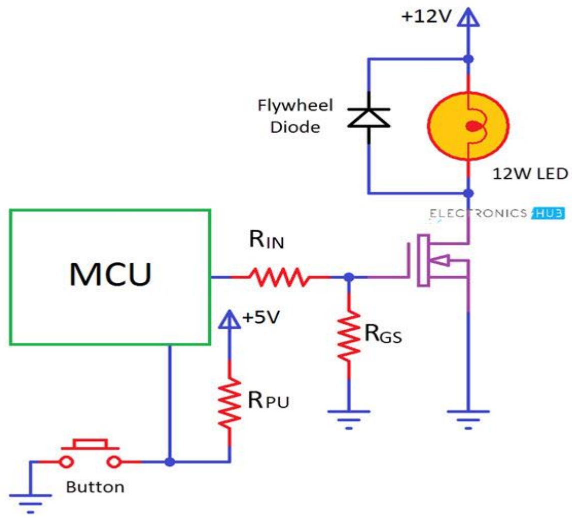
Example of MOSFET as a Switch

Consider a situation where you want to digitally control a 12W LED (12V @ 1A) using a Microcontroller. When you press a button connected to the microcontroller, the LED should turn ON. When you press the same button once again, the LED should turn OFF.

It is obvious that you cannot directly control the LED with the help of the microcontroller. You need a device that bridges the gap between the microcontroller and the LED.

This device should take in a control signal from the microcontroller (usually the voltage of this signal is in the working voltage range of the microcontroller, 5V for example) and supply power to the LED, which in this case is from a 12V supply.

The device which I am going to use is a MOSFET. The setup of the above mentioned scenario is shown in the following circuit.



When a Logic 1 (assuming a 5V Microcontroller, Logic 1 is 5V and Logic 0 is 0V) is supplied to the gate of the MOSFET, it turns ON and allows drain current to flow. As a result, the LED is turned ON.

Similarly, when a Logic 0 is given to the gate of the MOSFET, it turns OFF and in turn switches OFF the LED.

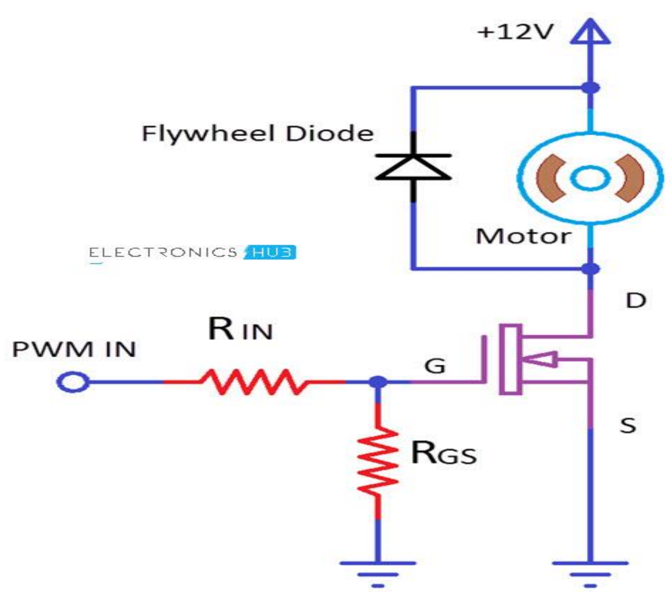
Thus, you can digitally control a high power device with the combination of Microcontroller and MOSFET.

Important Note

An important factor to consider is the power dissipation of the MOSFET. Consider a MOSFET with a Drain to Source Resistance of 0.1Ω. In the above case i.e. a 12W LED driven by a 12V supply will lead to a drain current of 1A.

Hence the power dissipated by the MOSFET is $P = I^2 * R = 1 * 0.1 = 0.1W$.

This seems to be a low value but if you drive a motor using the same MOSFET, the situation is slightly different. The starting current (also called as in-rush current) of a motor will be very high.



So, even with R_{DS} of 0.1Ω, the power dissipated during the start-up of a motor will still be significantly high, which may lead to thermal overload. Hence, R_{DS} will be a key parameter to select a MOSFET for your application.

Also, when driving a motor, the back emf is an important factor that has to be considered while designing the circuit.

One of the main advantage of driving a motor with MOSFET is that an Input PWM signal can be used to smoothly control the speed of the motor.

Conditions to derive power MOSFET in the different regions of operation:

Cut off region:

A MOS device is said to be operating when the gate-to-source voltage is less than V_{th}. Thus, for MOS to be in cut-off region, the necessary condition is –

$0 < V_{GS} < V_{th}$ - for NMOS

$0 > V_{GS} > V_{th}$ - for PMOS (as threshold voltage of PMOS is negative)

Cut-off region is also known as sub-threshold region. In this region, the dependence of current on gate voltage is exponential. The magnitude of current flowing through MOS in cut-off region is negligible as the channel is not present. The conduction happening in this region is known as sub-threshold conduction.

Linear or non-saturation region:

For an NMOS, as gate voltage increases beyond threshold voltage, channel is formed between source and drain terminals. Now, if there is voltage difference between source and drain, current will flow. The magnitude of current increases linearly with increasing drain voltage till a particular drain voltage determined by the following relations –

$V_{GS} \geq V_{th}$

$V_{DS} < V_{GS} – V_{th}$

The current is, then, represented as a linear function of gate-to-source and drain-to-source voltages. That is why, MOS is said to be operating in linear region. The linear region voltage-current relation is given as follows:

$Id(Linear) = \mu\ Cox\ W/L\ (Vgs – Vth – Vds/2)\ Vds$.

Similarly, for P-MOS transistor, condition for P-MOS to be in linear region is represented as:

$V_{GS} < V_{th}$ OR $V_{SG} > |V_{th}|$

And $V_{DS} > V_{GS} + V_{th}$ OR $V_{SD} < V_{SG} - |V_{th}|$

Saturation Region:

For an NMOS, at a particular gate and source voltage, there is a particular level of voltage for drain, beyond which, increasing drain voltage seems to have no effect on current. When a MOS operates in this region, it is said to be in saturation. The condition is given as:

$V_{GS} \geq V_{th}$

$V_{DS} > V_{GS} - V_{th}$

The current, now, is a function only of gate and source voltages:

$$Id(saturation) = \mu\ Cox\ W/L\ (Vgs - Vth - Vds/2)^2$$

Question # 3 (A)

$V_s(t) = \underset{220}{\overset{V_{peak}}{}}$ or V_m $Sin(2\omega t)$; $R = 1000\ k\Omega$

For half wave Rectefier & Sinusoidel Input voltage.

$$V_{avg} = \frac{V_{peak}}{\pi} \qquad \because V_{peak} = V_m = V_s$$

$$V_{RMS} = \frac{V_{peak}}{2}$$

1) $V_{avg} = \frac{V_{peak}}{\pi} = \frac{220}{\pi} = 70.02\ V$

2) $I_{avg} = \frac{V_{avg}}{R} = \frac{70.02}{1000k} = 70\ \mu A$

3) $V_{RMS} = \frac{V_{peak}}{2} = \frac{220}{2} = 110\ V$

4) $I_{RMS} = \frac{V_{RMS}}{R} = \frac{110}{1000k} = 110\ \mu A$

6) Input Power Factor, $Cos\theta = \frac{V_{rms}}{V_{peak}}$

$$Cos\theta = \frac{110}{220} = \frac{1}{2} = 0.5$$

7) Diode is Conducting only for 1st half therefore Conducter angle,

$$\gamma_0 = \pi$$

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5) Output Power

$P_o = I_{RMS}^2 R$

$= (110 \, \mu A)^2 \times 1000 \, k\Omega$

$P_o = 0.0121 \, W$

8) Extenstion angle of diode is Conducting upto π (First Cycle).

So, $\beta = \pi$

9) In all diode rectifier Circuit

Conduction Angle (λ) = Extenstion Angle (β)

10) Peak Inverse Value (PIV)

During negative half Cycle diode acts as open circuits and therefore all voltages appears across diode.

Thus $PIV = V_{peak} = 220 \, V$

11) Circuit turn-off tim, t_c

$\omega t_c = \pi$

$t_c = \frac{\pi}{\omega}$; assuming $f = 50 \, Hz$

$t_c = \frac{\pi}{2\pi f} = 0.01 \, sec$