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Semiconductors, Diodes, Transistors and Applications

Abdullatif Abdulkarim Zankawi

Abstract—This paper presents and reviews the Semiconductors , Diodes , Transistors to show how can we use these electronic devices in important applications.

Index Terms -- Semiconductors - Diodes - Bipolar Transistor - FET Transistor - Applications

I. INTRODUCTION

Semiconductor

• conductors Are the Materials that permit flow of electrons
• insulators Are the Materials that block flow of electrons
• Semiconductors[1] are Materials whose conductivity falls between conductors and insulators
• Semiconductors are "part-time" conductors whose conductivity can be controlled.
• Silicon is the most common material used to build semiconductor devices.
• Si is spun and grown into a crystalline structure and cut into wafers to make electronic devices.
• Atoms in a pure silicon wafer contains four electrons in outer orbit (called valence electrons).
– Germanium is another semiconductor material with four valence electrons.
• In the crystalline lattice structure of Si, the valence electrons of every Si atom are locked up in covalent bonds with the valence electrons of four neighboring Si atoms.
– In pure form, Si wafer does not contain any free charge carriers.
– An applied voltage across pure Si wafer does not yield electron flow through the wafer.
– A pure Si wafer is said to act as an insulator.
• In order to make useful semiconductor devices, materials such as phosphorus (P) and boron (B) are added to Si to change Si's conductivity.

N-Type Silicon

• Pentavalent impurities such as phosphorus, arsenic, antimony, and bismuth have 5 valence electrons.
• When phosphorus [2]impurity is added to Si, every phosphorus atom's four valence electrons are locked up in covalent bond with valence electrons of four neighboring Si atoms. However, the 5th valence electron of phosphorus atom does not find a binding electron and thus remains free to float. When a voltage is applied across the silicon phosphorus mixture, free electrons migrate toward the positive voltage end.

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* Correspondence Author (s)
Eng. Abdullatif Abdulkarim Zankawi, Kuwait Institute for International Navigation.

• When phosphorus is added to Si to yield the above effect, we say that Si is doped with phosphorus. The resulting mixture is called N-type silicon (N: negative charge carrier silicon).
• The pentavalent impurities are referred to as donor impurities.

P-Type Silicon

• Trivalent impurities e.g., boron, aluminum, indium, and gallium have 3 valence electrons.
• When boron is added to Si, every boron atom's three valence electrons are locked up in covalent bond with valence electrons of three neighboring Si atoms. However, a vacant spot "hole" is created within the covalent bond between one boron atom and a neighboring Si atom. The holes are considered to be positive charge carriers.
When a voltage is applied across the silicon-boron mixture, a hole moves toward the negative voltage end while a neighboring electron fills in its place.
• When boron is added to Si to yield the above effect, we say that Si is doped with boron. The resulting mixture is called P-type silicon (P: positive charge carrier silicon).
• The trivalent impurities are referred to as acceptor impurities.
• The hole of boron atom points towards the negative terminal.
• The electron of neighboring silicon atom points toward positive terminal.
• The electron from neighboring silicon atom falls into the boron atom filling the hole in boron atom and creating a "new" hole in the silicon atom.
• It appears as though a hole moves toward the negative terminal.

Diode

•A diode is a two lead semiconductor that acts as a one way gate to electron flow.
– Diode allows current to pass in only one direction.
•A pn-junction diode is formed by joining together n-type and p-type silicon.
•In practice,[3] as the n-type Si crystal is being grown, the process is abruptly altered to grow p-type Si crystal. Finally, a glass or plastic coating is placed around the joined crystal.
•The p-side is called anode and the n-side is called cathode.
•When the anode and cathode of a pn-junction diode are connected to external voltage such that the potential at anode is higher than the potential at cathode, the diode is said to be forward biased.
–In a forward-biased diode current is allowed to flow through the device.
•When potential at anode is smaller than the potential at cathode, the diode is said to be reverse biased. In a reverse-biased diode current is blocked.

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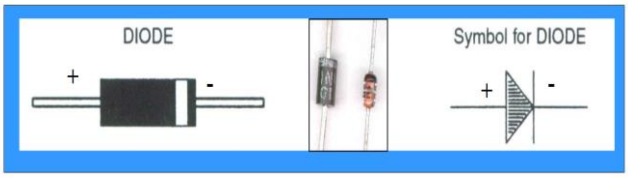
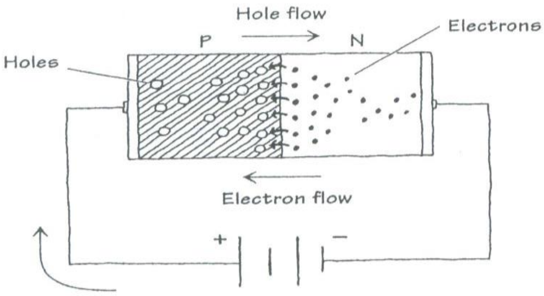
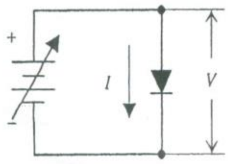


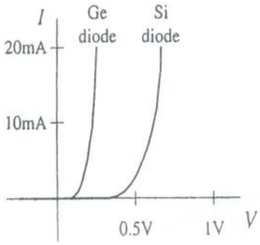
When a diode is connected to a battery as shown, electrons from the n-side and holes from the p-side are forced toward the center by the electrical field supplied by the battery. The electrons and holes combine causing the current to pass through the diode. When a diode is arranged in this way, it is said to be forward biased



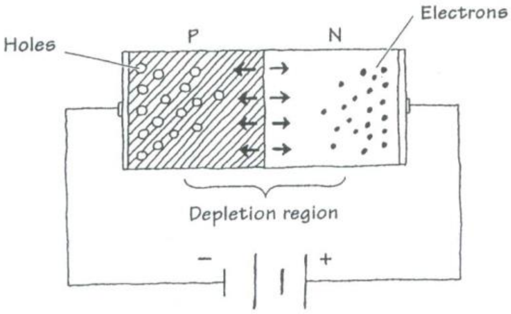
• A diode’s one-way gate feature does not work all the time.
• Typically for silicon diodes, an applied voltage of 0.6V or greater is needed,
otherwise, the diode will not conduct.
• This feature is useful in forming a voltage-sensitive switch.

• I-V characteristics for silicon and germanium diodes is shown below





When a diode is connected to a battery as shown, holes in the nside are forced to the left while electrons in the p-side are forced to the right. This results in an empty zone around the pn- junction that is free of charge carries creating a *depletion region*. This depletion region acts as an insulator preventing current from flowing through the diode. When a diode is arranged in this way, it is said to be reverse biased.



Transistor

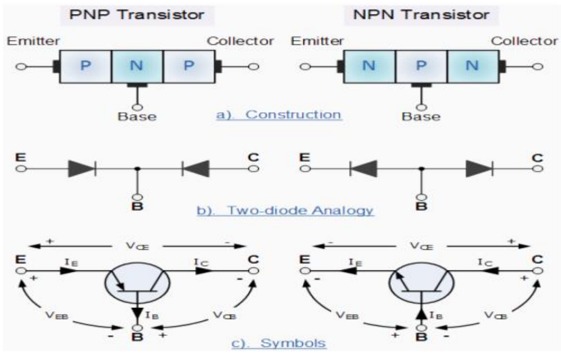
we saw that simple diodes are made up from two pieces of semiconductor material, either silicon or germanium to form a simple PN-junction and we also learnt about their properties and characteristics. If we now join together two individual signal diodes back-to-back, this will give us two PN-junctions connected together in series that share a common P or N terminal. The fusion of these two diodes produces a three layer, two junction, three terminal device forming the basis of a Bipolar Transistor, or BJT for short. Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then bipolar transistors have the ability to operate within three different regions:

• 1. Active Region - the transistor operates as an amplifier and Ic = β.Ib
• 2. Saturation - the transistor is "fully-ON" operating as a switch and Ic = I(saturation)
• 3. Cut-off - the transistor is "fully-OFF" operating as a switch and Ic = 0

Typical Bipolar Transistor

The Bipolar Transistor basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively

Bipolar Transistor Construction



The construction [4]and circuit symbols for both the NPN and PNP bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal. The direction of the arrow always points from the positive P-type region to the negative N-type region for both transistor types, exactly the same as for the standard diode symbol.

Bipolar Transistor Configurations

As the Bipolar Transistor is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor vary with each circuit arrangement.

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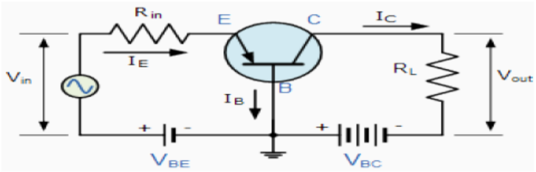
The Common Base (CB) Configuration

As its name suggests, in the Common Base or grounded base configuration, the BASE connection is common to both the input signal AND the output signal with the input signal being applied between the base and the emitter terminals. The corresponding output signal is taken from between the base and the collector terminals as shown with the base terminal grounded or connected to a fixed reference voltage point. The input current flowing into the emitter is quite large as its the sum of both the base current and collector current respectively therefore, the collector current output is less than the emitter current input resulting in a current gain for this type of circuit of "1" (unity) or less, in other words the common base configuration "attenuates" the input signal.

The Common Base Transistor Circuit



This type of amplifier configuration is a non-inverting voltage amplifier circuit, in that the signal voltages Vin and Vout are in-phase. This type of transistor arrangement is not very common due to its unusually high voltage gain characteristics. Its output characteristics represent that of a forward biased diode while the input characteristics represent that of an illuminated photo-diode. Also this type of bipolar transistor configuration has a high ratio of output to input resistance or more importantly "load" resistance (RL) to "input" resistance (Rin) giving it a value of "Resistance Gain". Then the voltage gain (Av for a common base configuration is therefore given as:

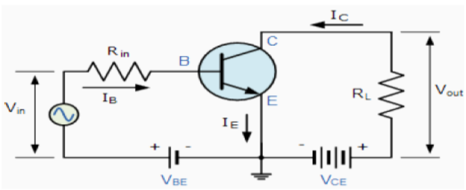
Common Base Voltage Gain

$$A_V = \frac{Vout}{Vin} = \frac{I_C \times R_L}{I_E \times R_{IN}}$$

The Common Emitter (CE) Configuration

In the Common Emitter or grounded emitter configuration, the input signal is applied[5] between the base, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers and which represents the "normal" method of bipolar transistor connection. The common emitter amplifier configuration produces the highest current and power gain of all the three bipolar transistor configurations. This is mainly because the input impedance is LOW as it is connected to a forward-biased PN-junction, while the output impedance is HIGH as it is taken from a reverse-biased PN-junction.

The Common Emitter Amplifier Circuit



In this type of configuration, the current flowing out of the transistor must be equal to the currents flowing into the transistor as the emitter current is given as Ie = Ic + Ib. Also, as the load resistance (RL) is connected in series with the collector, the current gain of the common emitter transistor configuration is quite large as it is the ratio of Ic/Ib and is given the Greek symbol of Beta, (β). As the emitter current for a common emitter configuration is defined as Ie = Ic + Ib, the ratio of Ic/Ie is called Alpha, given the Greek symbol of α.

Note: that the value of Alpha will always be less than unity.

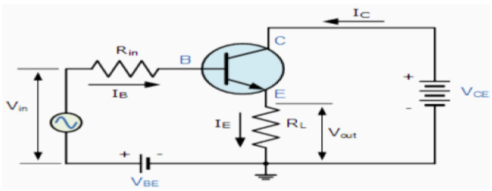
Since the electrical relationship between these three currents, Ib, Ic and Ie is determined by the physical construction of the transistor itself, any small change in the base current (Ib), will result in a much larger change in the collector current (Ic). Then, small changes in current flowing in the base will thus control the current in the emitter-collector circuit. Typically, Beta has a value between 20 and 200 for most general purpose transistors.

Then to summarise, this type of bipolar transistor configuration has a greater input impedance, current and power gain than that of the common base configuration but its voltage gain is much lower. The common emitter configuration is an inverting amplifier circuit resulting in the output signal being 180o out-of-phase with the input voltage signal.

The Common Collector (CC) Configuration

In the Common Collector or grounded collector configuration, the collector is now common through the supply. The input signal is connected directly to the base, while the output is taken from the emitter load as shown. This type of configuration is commonly known as a Voltage Follower or Emitter Follower circuit. The emitter follower configuration is very useful for impedance matching applications because of the very high input impedance, in the region of hundreds of thousands of Ohms while having a relatively low output impedance.

The Common Collector Transistor Circuit



The common emitter configuration has a current gain approximately equal to the β value of the transistor itself. In the common collector configuration the load resistance is situated in series with the emitter so its current is equal to that of the emitter current. As the emitter current is the combination of the collector AND the base current combined, the load resistance in this type of transistor configuration also has both the collector current and the input current of the base flowing through it. Then the current gain of the circuit is given as:

The Common Collector Current Gain

$$I_E = I_C + I_B$$

$$A_i = \frac{I_E}{I_B} = \frac{I_C + I_B}{I_B}$$

$$A_i = \frac{I_C}{I_B} + 1$$

$$A_i = \beta + 1$$

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This type of bipolar transistor configuration is a non-inverting circuit in that the signal voltages of Vin and Vout are in-phase. It has a voltage gain that is always less than "1" (unity). The load resistance of the common collector transistor receives both the base and collector currents giving a large current gain (as with the common emitter configuration) therefore, providing good current amplification with very little voltage gain.

Bipolar Transistor Characteristics

The static characteristics for a Bipolar Transistor can be divided into the following three main groups.

Input Characteristics:-	Common Base -	$\Delta V_{EB} / \Delta I_E$
	Common Emitter -	$\Delta V_{BE} / \Delta I_B$
Output Characteristics:-	Common Base -	$\Delta V_C / \Delta I_C$
	Common Emitter -	$\Delta V_C / \Delta I_C$
Transfer Characteristics:-	Common Base -	$\Delta I_C / \Delta I_E$
	Common Emitter -	$\Delta I_C / \Delta I_B$

with the characteristics of the different transistor configurations given in the following table:

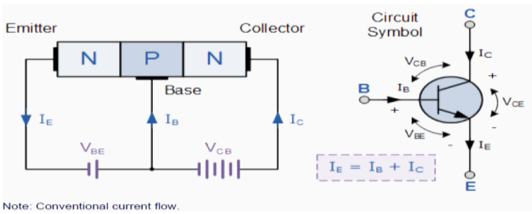
Characteristic	Common Base	Common Emitter	Common Collector
Input Impedance	Low	Medium	High
Output Impedance	Very High	High	Low
Phase Angle	0^o	180^o	0^o
Voltage Gain	High	Medium	Low
Current Gain	Low	Medium	High
Power Gain	Low	Very High	Medium

In the next tutorial about Bipolar Transistors, we will look at the NPN Transistor in more detail when used in the common emitter configuration as an amplifier as this is the most widely used configuration due to its flexibility and high gain. We will also plot the output characteristics curves commonly associated with amplifier circuits as a function of the collector current to the base current.

The NPN Transistor

In the previous tutorial we saw that the standard Bipolar Transistor or BJT, comes in two basic forms. An NPN (Negative-Positive-Negative) type and a PNP (Positive-Negative-Positive) type, with the most commonly used transistor type being the NPN Transistor. We also learnt that the transistor junctions can be biased in one of three different ways - Common Base, Common Emitter and Common Collector. In this tutorial we will look more closely at the "Common Emitter" configuration using NPN Transistors with an example of the construction of a NPN transistor along with the transistors current flow characteristics is given below.

An NPN Transistor Configuration

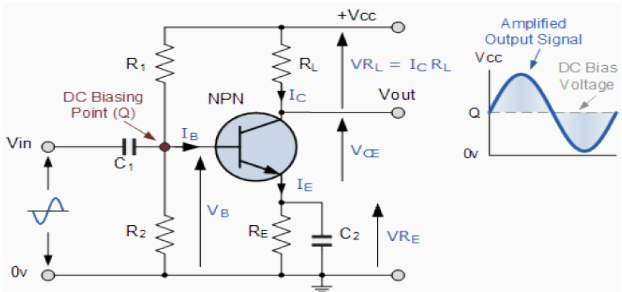


We know that the transistor is a "current" operated device (Beta model) and that a large current (Ic) flows freely through the device between the collector and the emitter terminals when the transistor is switched "fully-ON". However, this only happens when a small biasing current (Ib) is flowing into the base terminal of the transistor at the same time thus allowing the Base to act as a sort of current control input. The transistor current in an NPN transistor is the ratio of these two currents (Ic/Ib), called the *DC Current Gain* of the device and is given the symbol of hfe or nowadays Beta, (β). The value of β can be large up to 200 for standard transistors, and it is this large ratio between Ic and Ib that makes the NPN transistor a useful amplifying device when used in its active region as Ib provides the input and Ic provides the output. Note that Beta has no units as it is a ratio.

The Common Emitter Configuration.

As well as being used as a semiconductor switch to turn load currents "ON" or "OFF" by controlling the Base signal to the transistor in ether its saturation or cut-off regions, NPN Transistors can also be used in its active region to produce a circuit which will amplify any small AC signal applied to its Base terminal with the Emitter grounded. If a suitable DC "biasing" voltage is firstly applied to the transistors Base terminal thus allowing it to always operate within its linear active region, an inverting amplifier circuit called a single stage common emitter amplifier is produced. One such *Common Emitter Amplifier* configuration of an NPN transistor is called a Class A Amplifier. A "Class A Amplifier" operation is one where the transistors Base terminal is biased in such a way as to forward bias the Base-emitter junction. The result is that the transistor is always operating halfway between its cut-off and saturation regions, thereby allowing the transistor amplifier to accurately reproduce the positive and negative halves of any AC input signal superimposed upon this DC biasing voltage. Without this "Bias Voltage" only one half of the input waveform would be amplified. This common emitter amplifier configuration using an NPN transistor has many applications but is commonly used in audio circuits such as pre-amplifier and power amplifier stages. With reference to the common emitter configuration shown below, a family of curves known as the Output Characteristics Curves, relates the output collector current, (Ic) to the collector voltage, (Vce) when different values of Base current, (Ib) are applied to the transistor for transistors with the same β value. A DC "Load Line" can also be drawn onto the output characteristics curves to show all the possible operating points when different values of base current are applied. It is necessary to set the initial value of Vce correctly to allow the output voltage to vary both up and down when amplifying AC input signals and this is called setting the operating point or Quiescent Point, Q-point for short and this is shown below.

Single Stage Common Emitter Amplifier Circuit



Output Characteristics Curves for a Typical Bipolar Transistor

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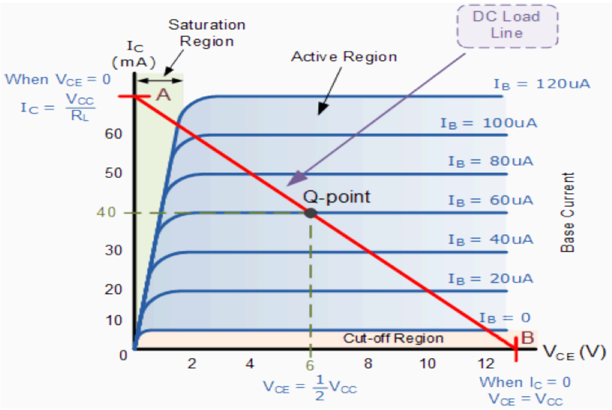


The most important factor to notice is the effect of Vce upon the collector current Ic when Vce is greater than about 1.0 volts. We can see that Ic is largely unaffected by changes in Vce above this value and instead it is almost entirely controlled by the base current, Ib. When this happens we can say then that the output circuit represents that of a "Constant Current Source". It can also be seen from the common emitter circuit above that the emitter current Ie is the sum of the collector current, Ic and the base current, Ib, added together so we can also say that " Ie = Ic + Ib " for the common emitter configuration. By using the output characteristics curves in our example above and also Ohm´s Law, the current flowing through the load resistor, (RL), is equal to the collector current, Ic entering the transistor which inturn corresponds to the supply voltage, (Vcc) minus the voltage drop between the collector and the emitter terminals, (Vce) and is given as:

$$\text{Collector Current, } I_C = \frac{V_{CC} - V_{CE}}{R_L}$$

a straight line representing the Load Line of the transistor can be drawn directly onto the graph of curves above from the point of "Saturation" (A) when Vce = 0 to the point of "Cut-off" (B) when Ic = 0 thus giving us the "Operating" or Q-point of the transistor. These two points are joined together by a straight line and any position along this straight line represents the "Active Region" of the transistor. The actual position of the load line on the characteristics curves can be calculated as follows:

$$\text{When: } (V_{CE} = 0) \quad I_C = \frac{V_{CC} - 0}{R_L}, \quad I_C = \frac{V_{CC}}{R_L}$$

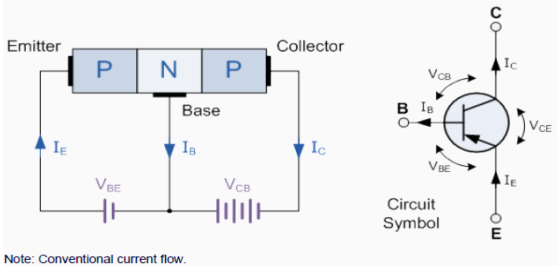
$$\text{When: } (I_C = 0) \quad 0 = \frac{V_{CC} - V_{CE}}{R_L}, \quad V_{CC} = V_{CE}$$

Then, the collector or output characteristics curves for Common Emitter NPN Transistors can be used to predict the Collector current.

The PNP Transistor

The PNP Transistor is the exact opposite to the NPN Transistor device we looked at in the previous tutorial. Basically, in this type of transistor construction the two diodes are reversed with respect to the NPN type, with the arrow, which also defines the Emitter terminal this time pointing inwards in the transistor symbol. Also, all the polarities are reversed which means that *PNP Transistors* "sink" current as opposed to the NPN transistor which "sources" current. Then, PNP Transistors use a small output base current and a negative base voltage to control a much larger emitter-collector current. The construction of a PNP transistor consists of two P-type semiconductor materials either side of the N-type material as shown below.

A PNP Transistor Configuration



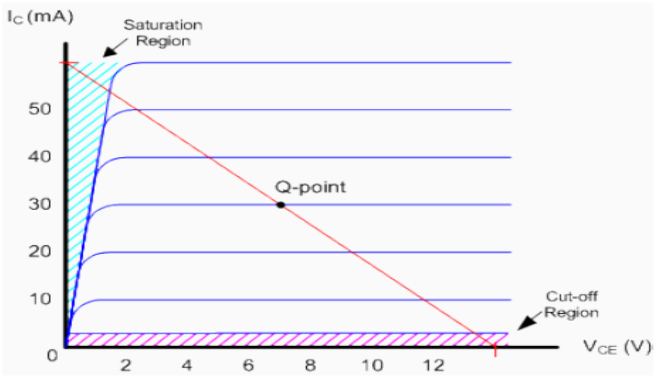
Transistor Matching

You may think what is the point of having a PNP Transistor, when there are plenty of NPN Transistors available?. Well, having two different types of transistors PNP & NPN, can be an advantage when designing amplifier circuits such as Class B Amplifiers that use "Complementary" or "Matched Pair" transistors or for reversible H-Bridge motor control circuits. A pair of corresponding NPN and PNP transistors with near identical characteristics to each other are called Complementary .

The Transistor as a Switch

When used as an AC signal amplifier[6], the transistors Base biasing voltage is applied so that it operates within its "Active" region and the linear part of the output characteristics curves are used. However, both the NPN & PNP type bipolar transistors can be made to operate as an "ON/OFF" type solid state switch for controlling high power devices such as motors, solenoids or lamps. If the circuit uses the Transistor as a Switch, then the biasing is arranged to operate in the output characteristics curves seen previously in the areas known as the "Saturation" and "Cut-off" regions as shown below.

Transistor Curves



The pink shaded area at the bottom represents the "Cut-off" region. Here the operating conditions of the transistor are zero input base current (Ib), zero output collector current (Ic) and maximum collector voltage (Vce) which results in a large depletion layer and no current flows through the device. The transistor is switched "Fully-OFF". The lighter blue area to the left represents the "Saturation" region. Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current flow and minimum collector emitter voltage which results in the depletion layer being as small as possible and maximum current flows through the device. The transistor is switched "Fully-ON". Then we can summarize this as:

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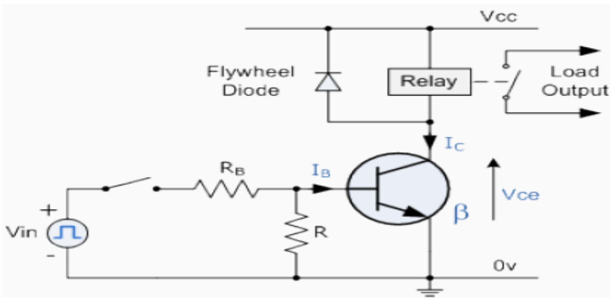
• 1. Cut-off Region - Both junctions are Reverse-biased, Base current is zero or very small resulting in zero Collector current flowing, the device is switched fully "OFF".

•

• 2. Saturation Region - Both junctions are Forward-biased, Base current is high enough to give a Collector-Emitter voltage of 0v resulting in maximum Collector current flowing, the device is switched fully "ON".

An example of an NPN Transistor as a switch being used to operate a relay is given below. With inductive loads such as relays or solenoids a flywheel diode is placed across the load to dissipate the back EMF generated by the inductive load when the transistor switches "OFF" and so protect the transistor from damage. If the load is of a very high current or voltage nature, such as motors, heaters etc, then the load current can be controlled via a suitable relay as shown.

Transistor Switching Circuit



The circuit resembles that of the Common Emitter circuit we looked at in the previous tutorials. The difference this time is that to operate the transistor as a switch the transistor needs to be turned either fully "OFF" (Cut-off) or fully "ON" (Saturated). An ideal transistor switch would have an infinite resistance when turned "OFF" resulting in zero current flow and zero resistance when turned "ON", resulting in maximum current flow. In practice when turned "OFF", small leakage currents flow through the transistor and when fully "ON" the device has a low resistance value causing

The Field Effect Transistor

In the [7]Bipolar Junction Transistor tutorials, we saw that the output Collector current is determined by the amount of current flowing into the Base terminal of the device and thereby making the Bipolar Transistor a CURRENT operated device. The Field Effect Transistor, or simply FET however, use the voltage that is applied to their input terminal to control the output current, since their operation relies on the electric field (hence the name field effect) generated by the input voltage. This then makes the Field Effect Transistor a VOLTAGE operated device.

The Field Effect Transistor is a unipolar device that has very similar properties to those of the *Bipolar Transistor* ie, high efficiency, instant operation, robust and cheap, and they can be used in most circuit applications that use the equivalent Bipolar Junction Transistors, (BJT). They can be made much smaller than an equivalent BJT transistor and along with their low power consumption and dissipation make them ideal for use in integrated circuits such as the CMOS range of chips.

We remember from the previous tutorials that there are two basic types of Bipolar Transistor construction, NPN and PNP, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made. There are also two basic types of Field Effect Transistor, N-channel and P-channel. As their name implies, Bipolar Transistors are "Bipolar" devices because they operate with both types of charge carriers, Holes and Electrons. The Field Effect Transistor on the other hand is a "Unipolar" device that depends only on the conduction of Electrons (N-channel) or Holes (P-channel).

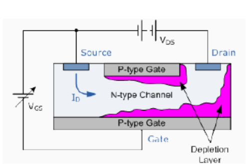
The Field Effect Transistor has one major advantage over its standard bipolar transistor cousins, in that their input impedance is very high, (Thousands of Ohms) making them very sensitive to input signals, but this high sensitivity also means that they can be easily damaged by static electricity. There are two main types of field effect transistor, the Junction Field Effect Transistor or JFET and the Insulated-gate Field Effect Transistor or IGFET), which is more commonly known as the standard Metal Oxide Semiconductor Field Effect Transistor or MOSFET for short.

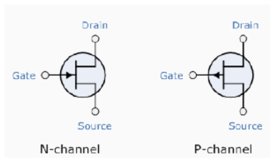
The Junction Field Effect Transistor

We saw previously that a bipolar junction transistor is constructed using two PN junctions in the main current path between the Emitter and the Collector terminals. The Field Effect Transistor has no junctions but instead has a narrow "Channel" of N-type or P-type silicon with electrical connections at either end commonly called the DRAIN and the SOURCE respectively. Both P-channel and N-channel FET's are available. Within this channel there is a third connection which is called the GATE and this can also be a P or N-type material forming a PN junction and these connections are compared below.

Bipolar Transistor	Field Effect Transistor
Emitter - (E)	Source - (S)
Base - (B)	Gate - (G)
Collector - (C)	Drain - (D)

The semiconductor "Channel" of the Junction Field Effect Transistor is a resistive path through which a voltage Vds causes a current Id to flow. A voltage gradient is thus formed down the length of the channel with this voltage becoming less positive as we go from the drain terminal to the source terminal. The PN junction therefore has a high reverse bias at the drain terminal and a lower reverse bias at the source terminal. This bias causes a "depletion layer" to be formed within the channel and whose width increases with the bias. FET's control the current flow through them between the drain and source terminals by controlling the voltage applied to the gate terminal. In an N-channel JFET this gate voltage is negative while for a P-channel JFET the gate voltage is positive. Bias arrangement for an N-channel JFET and corresponding circuit symbols.





The cross sectional diagram above shows an N-type semiconductor channel with a P-type region called the gate diffused into the N-type channel forming a reverse biased PN junction and its this junction which forms the depletion layer around the gate area. This depletion layer restricts the current flow through the channel by reducing its effective width and thus increasing the overall resistance of the channel.

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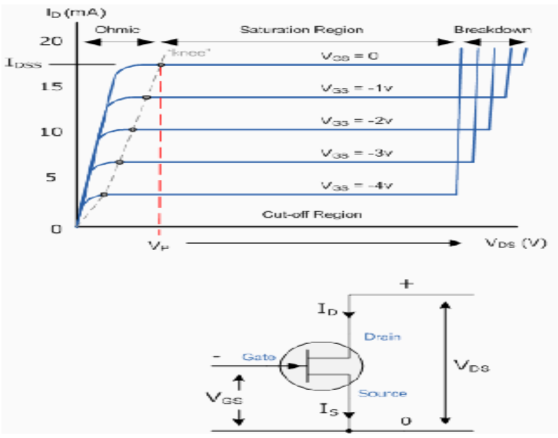
When the gate voltage Vg is equal to 0V and a small external voltage (Vds) is applied between the drain and the source maximum current (Id) will flow through the channel slightly restricted by the small depletion layer. If a negative voltage (Vgs) is now applied to the gate the size of the depletion layer begins to increase reducing the overall effective area of the channel and thus reducing the current flowing through it, a sort of "squeezing" effect. As the gate voltage (Vgs) is made more negative, the width of the channel decreases until no more current flows between the drain and the source and the FET is said to be "pinched-off". In this pinch-off region the gate voltage, Vgs controls the channel current and Vds has little or no effect. The result is that the FET acts more like a voltage controlled resistor which has zero resistance when Vgs = 0 and maximum "ON" resistance (Rds) when the gate voltage is very negative.

Output characteristic voltage-current curves of a typical junction FET.

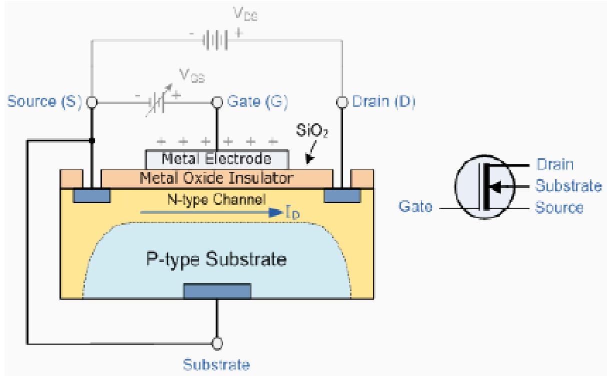


The voltage Vgs applied to the gate controls the current flowing between the drain and the source terminals. Vgs refers to the voltage applied between the gate and the source while Vds refers to the voltage applied between the drain and the source. Because a Field Effect Transistor is a VOLTAGE controlled device, "NO current flows into the gate!" then the source current (Is) flowing out of the device equals the drain current flowing into it and therefore (Id = Is).

The MOSFET

As well as the Junction Field Effect Transistor[8], there is another type of Field Effect Transistor available whose Gate input is electrically insulated from the main current carrying channel and is therefore called an Insulated Gate Field Effect Transistor. The most common type of insulated gate FET or IGFET as it is sometimes called, is the Metal Oxide Semiconductor Field Effect Transistor or MOSFET for short. The MOSFET type of field effect transistor has a "Metal Oxide" gate (usually silicon dioxide commonly known as glass), which is electrically insulated from the main semiconductor N-channel or P-channel. This isolation of the controlling gate makes the input resistance of the MOSFET extremely high in the Mega-ohms region and almost infinite. As the gate terminal is isolated from the main current carrying channel ""NO current flows into the gate"" and like the JFET, the MOSFET also acts like a voltage controlled resistor. Also like the JFET, this very high input resistance can easily accumulate large static charges resulting in the MOSFET becoming easily damaged unless carefully handled or protected.

Basic MOSFET Structure and Symbol



We also saw previously that the gate of a JFET must be biased in such a way as to forward-bias the PN junction but in a MOSFET device no such limitations applies so it is possible to bias the gate in either polarity. This makes MOSFET's specially valuable as electronic switches or to make logic gates because with no bias they are normally non-conducting and the high gate resistance means that very little control current is needed. Both the P-channel and the N-channel MOSFET is available in two basic forms, the Enhancement type and the Depletion type.

Depletion-mode MOSFET

The Depletion-mode MOSFET, which is less common than the enhancement types is normally switched "ON" without a gate bias voltage but requires a gate to source voltage (Vgs) to switch the device "OFF". Similar to the JFET types. For N-channel MOSFET's a "Positive" gate voltage widens the channel, increasing the flow of the drain current and decreasing the drain current as the gate voltage goes more negative. The opposite is also true for the P-channel types. The depletion mode MOSFET is equivalent to a "Normally Closed" switch.

Depletion-mode N-Channel MOSFET and circuit Symbols

Depletion-mode MOSFET's are constructed similar to their JFET transistor counterparts where the drain-source channel is inherently conductive with electrons and holes already present within the N-type or P-type channel. This doping of the channel produces a conducting path of low resistance between the drain and source with zero gate bias.

Enhancement-mode MOSFET

The more common Enhancement-mode MOSFET is the reverse of the depletion-mode type. Here the conducting channel is lightly doped or even undoped making it non-conductive. This results in the device being normally "OFF" when the gate bias voltage is equal to zero.

A drain current will only flow when a gate voltage (Vgs) is applied to the gate terminal. This positive voltage creates an electrical field within the channel attracting electrons towards the oxide layer and thereby reducing the overall resistance of the channel allowing current to flow. Increasing this positive gate voltage will cause an increase in the drain current, Id through the channel. Then, the Enhancement-mode device is equivalent to a "Normally Open" switch. Enhancement-mode N-Channel MOSFET and circuit Symbols

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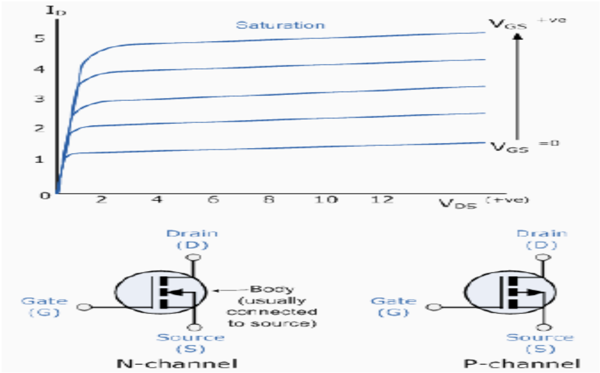
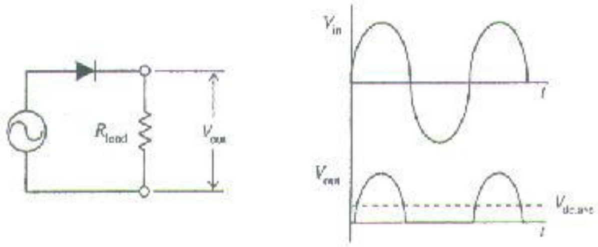


Enhancement-mode MOSFET's make excellent electronics switches due to their low "ON" resistance and extremely high "OFF" resistance and extremely high gate resistance. Enhancement-mode MOSFET's are used in integrated circuits to produce CMOS type Logic Gates and power switching circuits as they can be driven by digital logic levels.

Diode Applications:

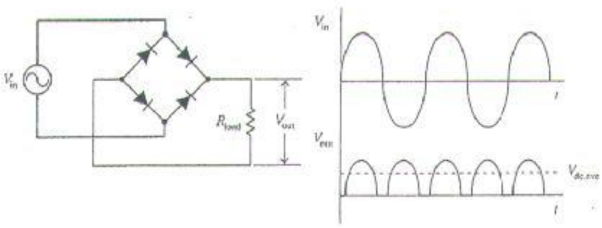
Half Wave Rectifier:

•Diode converts ac input voltage to a pulsed dc output voltage.
•Whenever the ac input becomes negative at diode's anode, the diode blocks current
flow.
– o/p voltage become zero.
•Diode introduces a 0.6V drop so o/p peak is 0.6V smaller than the i/p peak.
•The o/p frequency is same as the i/p frequency.



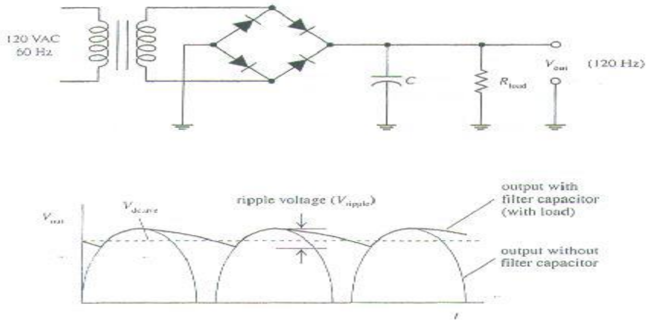
-Full Wave Rectifier

• A full-wave rectifier does not block negative swings in the i/p voltage, rather it transforms them into positive swings at the o/p.
• To gain an understanding of device operation, follow current flow through pairs of
diodes in the bridge circuit It is easily seen that one pair (D3-Rout-D2) allows current flow during the +ve half cycle of frequency.Vin while the other pair (D4-Rout-D1) allows current flow during the -ve half
cycle of Vin.
– o/p voltage peak is 1.2V below the i/p voltage peak.
– The o/p frequency is twice the i/p



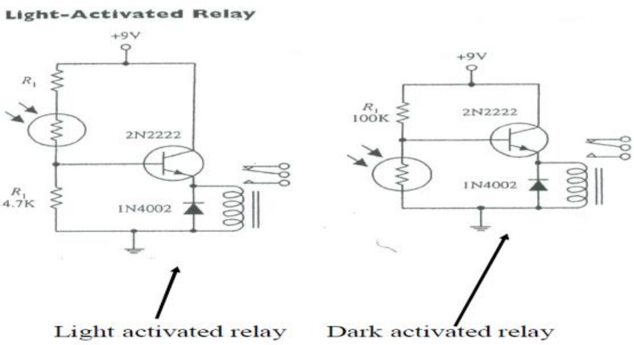
ACDC Power Supply:

•An AC2DC power supply is built using a transformer and a full-wave rectifier.
•Transformer is used to step down the voltage i/p.
•Rectifier converts AC to pulsed DC.
•A filter capacitor is used to smooth out the pulses.
•Capacitor must be large
enough to store sufficient charge so as to provide a steady current supply to the
load: $R(Load)C >>> 1/f$
f is rectified signal's
frequency (120Hz).



Photoresistor Application: Light Activated Relay

• Light-sensitive voltage divider is being used to trip a relay whenever the light intensity change.
• Light-activated circuit:
– When the photoresistor is exposed to light, its resistance decreases.
– Transistor's base current and voltage increase and if the base current and voltage are large enough, the collector-emitter pair of the transistor conducts triggering the relay.
• The value of R1 in the light-activated circuit should be around 1 KΩ but may have to be adjusted.
• Dark-activated relay works in a similar but opposite manner.
• R1 in the dark-activated circuit (100KΩ) may also have to be adjusted.
• A 6 to 9-V relay with a 500Ω coil can be used in either circuit.



Photodiode Applications: Photovoltaic Current Source

• Photodiode converts light energy directly into electric current that can be measured with meter.
• The input intensity of light and the output current are nearly linear.

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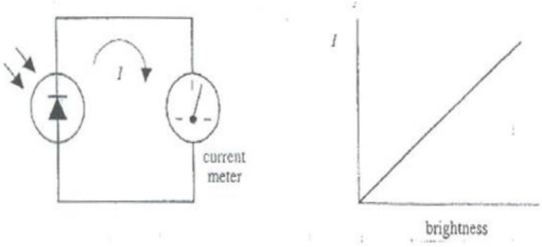
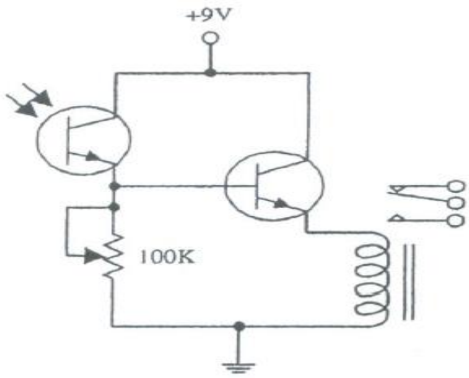


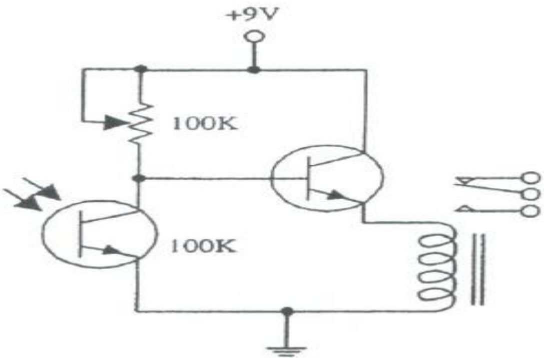
Phototransistor Applications—Light Activated Relay

• A phototransistor is used to control the base current supplied to a power-switching transistor that is used to supply current to a relay.
• When light comes in contact with the phototransistor, the phototransistor turns on, allowing current to pass from the supply into the base of the power-switching transistor.
• This allows the power-switching transistor to turns on, and current flows through the
relay, triggering it to switch states.
• The 100K pot is used to adjust the sensitivity of device by controlling current flow
through the phototransistor.



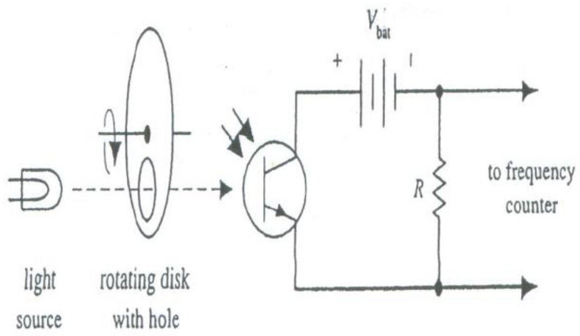
Phototransistor Application: Dark Activated Relay

• A phototransistor is used to control the base current supplied to a power-switching transistor that is used to supply current to a relay.
• When light is removed from the phototransistor, the phototransistor turns off, allowing more current to enter into the base of the power-switching transistor.
• This allows the power-switching transistor to turns on, and current flows through the relay, triggering it to switch states.
• The 100K pot is used to adjust the sensitivity of device by controlling current flow through the phototransistor.



Phototransistor Applications—Tachometer

• A phototransistor is being used as a frequency counter or tachometer.
• A rotating disk is connected to a rotating shaft. The rotating disk has one hole in it.
• For the given setup, the disk will allow light to pass through the hole once every revolution.
• The light passing through the disk triggers the phototransistor into conduction.
• A frequency counter is used to count the number of electrical pulses generated.



II. CONCLUSION

The paper has presented the Semiconductor , Diodes and Transistor and has presented the Structures , Types and the characteristics of transistors to present important applications

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