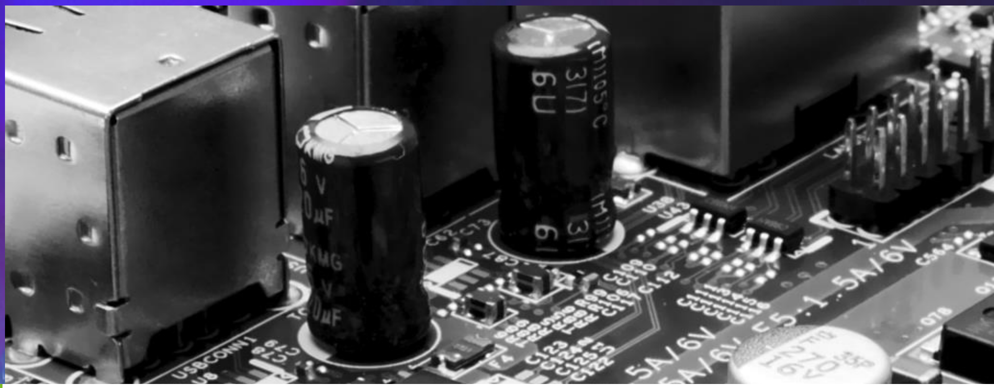

POLITEKNIK MALAYSIA
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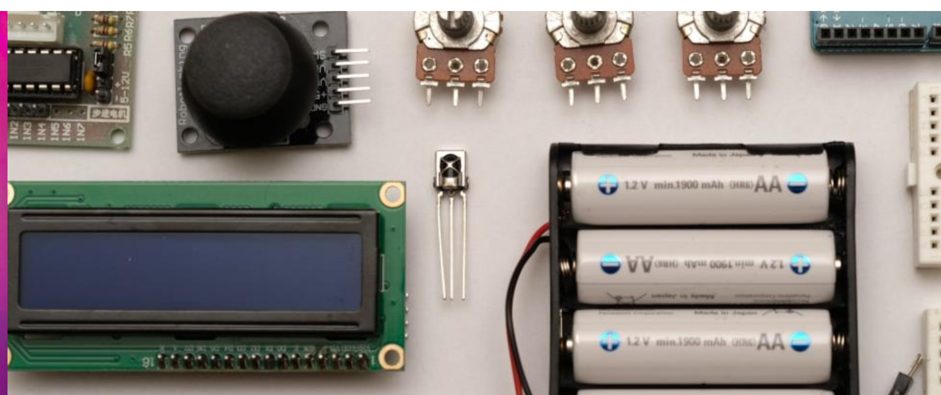
DJM20042 ELECTRONIC SYSTEM



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ELECTRONIC SYSTEM

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We hereby declare that this module is our original work. To the best of our knowledge it contains no materials previously written or published by another person. However, if there is any, due acknowledgement and credit are mentioned accordingly in the e-book.

PREFACE

The electronic system e-book covers knowledge on basic concepts of semiconductor materials, electronic devices and DC power supply. The course emphasizes on the electrical characteristics and properties of semiconductor materials, linear DC power supplies system, amplifier circuits and sinusoidal wave oscillator circuits.

The contents in this e-book are relevant to the syllabus for Diploma in Mechatronics Engineering student. There are the note, diagrams, example of problem solution and tutorial of the topic to ease for student to refer to. This e-book is very helpful for polytechnic students as a reference in their studies.

Hopefully, the student get benefits form this e-book and succeed in their life.

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AUGUST 2020

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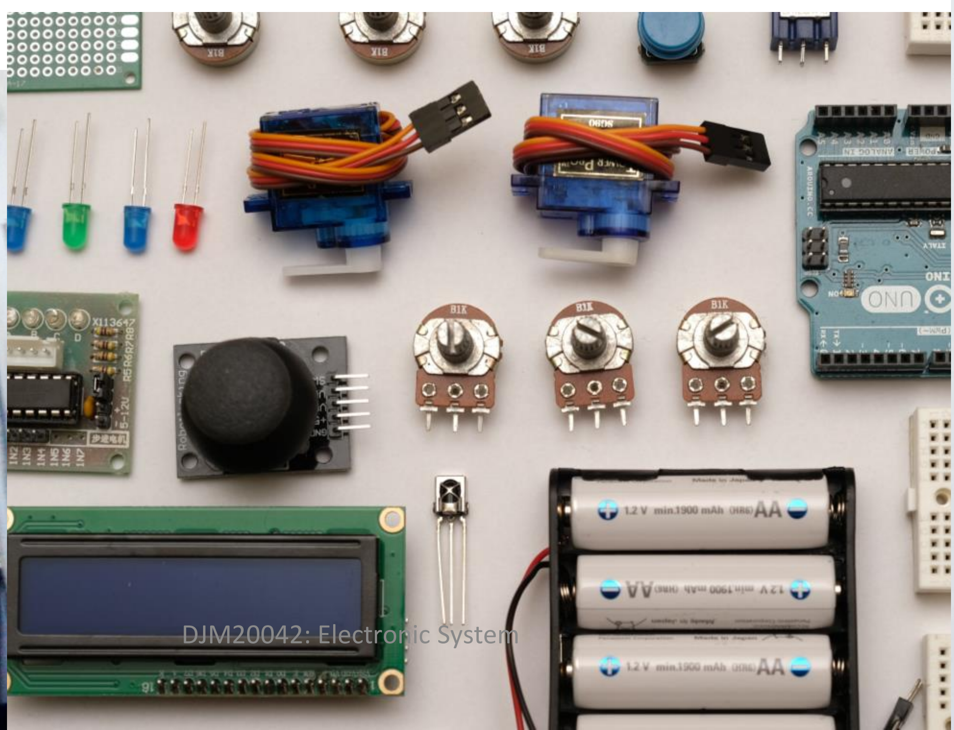
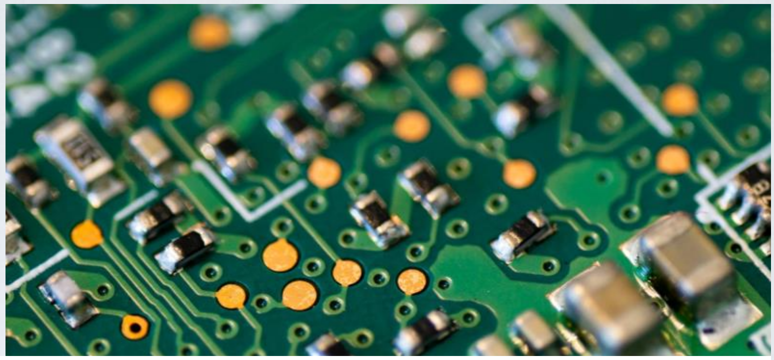




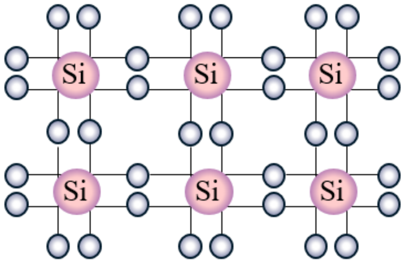
COURSE LEARNING OUTCOMES (CLO)

Upon completion of this course, students should be able to:

1. Apply the characteristics and properties of semiconductor materials. (C3,PLO 1)
2. Construct an electronic circuit based on schematic diagram. (P4,PLO5)
3. Demonstrate understanding of electronic circuit. (A3,PLO 10)

Chapter One

SEMICONDUCTOR



Chapter Outline:

1.1 Electrical Properties of Semiconductor

1.2 P-N Junction

Introduction:

Before the era of semiconductor, electronic components were made using vacuum tubes where, it is bigger, and unreliable. For the past over 50 years since semiconductor technology is introduced, we can see that the size is becoming smaller, faster speed, and low power consumption.

Electrical Properties

Semiconductor is a substance that has electrical properties in between conductor and insulator. Semiconductor's resistivity is more than conductor and less than insulator. Atom structure or atomic structure consists of nucleus (neutrally charged or no change made up with electron and proton). The outmost orbital called electron shell and contain electron. Atomic structure has different properties based on arrangement and number of their basic particles. Atomic structure containing a maximum of 7 shells. Each shell can be identified as K, L, M, N, O, P & Q. The Formulization of the maximum number of the electron (Ne) in each shell is $N_e = 2 \times n^2$; where n is the number of shell. K is the first shell and follow by L, M, N, O, P & Q.

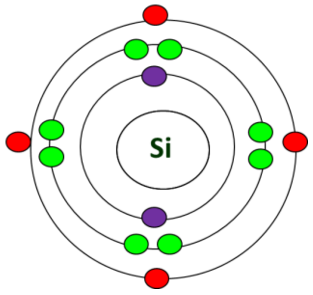


Figure 2.1: Silicon atomic structure

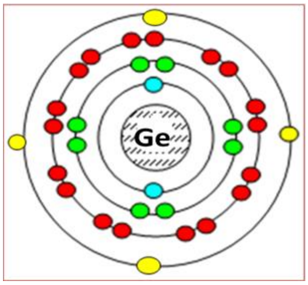


Figure 2.2: Germanium atomic structure

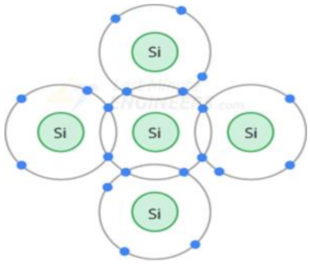


Figure 2.3: Covalent bonding

Figure 2.1 shows the atomic structure of silicon. Its containing 14 electrons in three shells, K (2 electron), L (8 electron), and M (4 electron). Figure 2.2 shows the germanium atomic structure. Its containing four shells (K, L, M, and N) and 32 of total electron.

Semiconductor has four valence electrons. Valence electrons act as a current carrier. An atom with four electron valences is considered unstable condition. They need to share with their neighbouring atoms to form a full orbital of eight electrons. The process of sharing electron valences is called Covalent Bonding as shown in Figure 2.3.

Electrical Properties

In general, semiconductor has two groups, an intrinsic or pure semiconductor and extrinsic. An intrinsic semiconductor has poor conductivity and other performance. To increase the performance of intrinsic semiconductor, adding with other materials (impurities) will be improving its performance.

Extrinsic semiconductors are produced by the process called Doping. Doping is a pure intrinsic semiconductor added with impurity atoms to increase the number of free electron. A Pentavalent has 5 valence electrons such as Arsenic, Antimony and Phosphorous are added to a pure intrinsic semiconductor. Trivalent that has 3 valence electrons such as Aluminiums, Boron and Indium can be introduced to pure intrinsic semiconductor crystal. Extrinsic semiconductors are widely used in the semiconductor devices such as diode, transistor and integrated circuits.

N-type semiconductor produced by pure semiconductor doping with pentavalent impurity. Figure 2.4 shows an example of a small amount of Antimony (pentavalent impurity) adding to Silicon (pure semiconductor crystal). Antimony has 5 valence electrons. When they enter into a silicon crystal, a free electron will be produced. Four valence electrons of Antimony will capture by silicon atoms to form a bonding. The fifth valence electron act as a free electron. This extra free electron act as a current carrier. N-type semiconductor is considered as negatively charged.

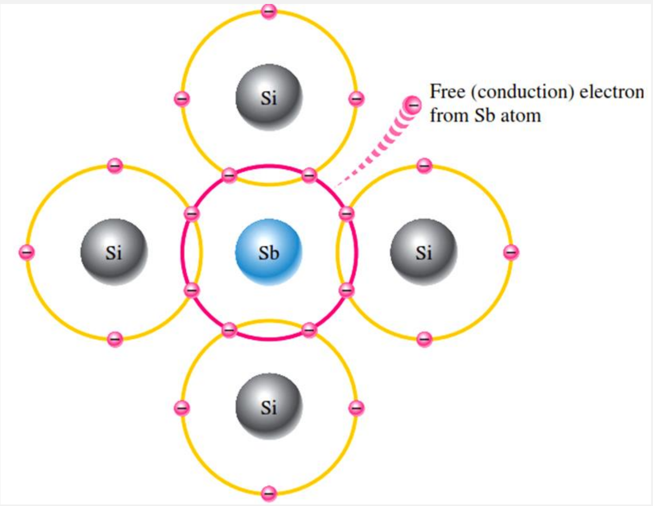


Figure 2.4: Covalent bonding https://instrumentationtools.com/n-type-p-type-semiconductors

Electrical Properties

P-type semiconductor produced by pure semiconductor doping with trivalent impurity. Figure 2.5 shows an example of a small amount of Boron (trivalent impurity) adding to Silicon (pure semiconductor crystal). Boron has 3 valence electrons. When they enter into a silicon crystal, a hole or missing electron is produced. This results in covalent bonds not being able to be formed. The hole is positively charged and is able to attract neighbouring electron to fill it.

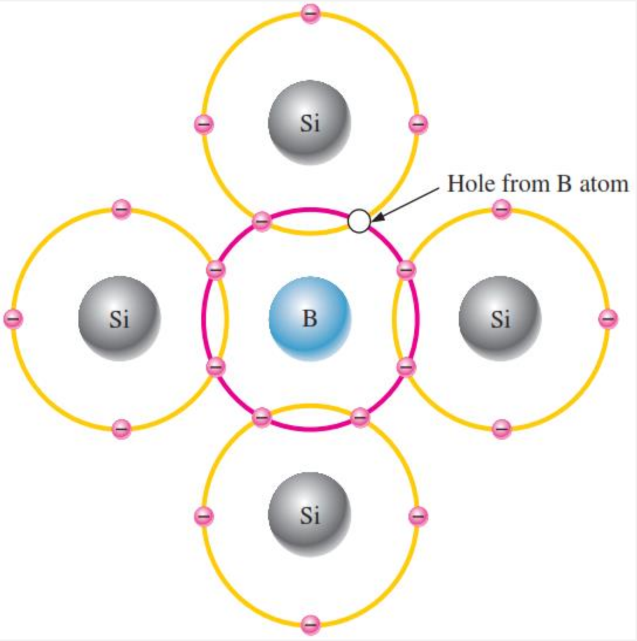


Figure 2.5: Covalent bonding https://instrumentationtools.com/n-type-p-type-semiconductors

Table 2.1: Comparison between N-type and P-type semiconductor

N-type semiconductor	P-type semiconductor
N= negative charge of electrons	P= positive charge of holes
Absorbed with Pentavalence atom (donor)	Absorbed with Trivalence atom (acceptor)
Have more electrons compare to holes	Have more holes compare to electrons
Majority current carrier is electrons	Majority of current carrier is holes

Electrical Properties

The border between p-type and n-type is called the PN junction when they are joined together. Free electrons and holes are trying to cross the PN junction. Free electrons are combined with the holes in P region. In the N region, the electrons depleted near the junction. Figure 2.6 shows the PN junction.

The PN junction becomes neutral cause of the combination of electrons and holes. This neutral region that has no current carriers is called Depletion Region. The forces between positive charges and negative charges in the depletion region resulted an electric field. The value of potential barrier or threshold voltage for Silicon is 0.7 V and Germanium is 0.3V.

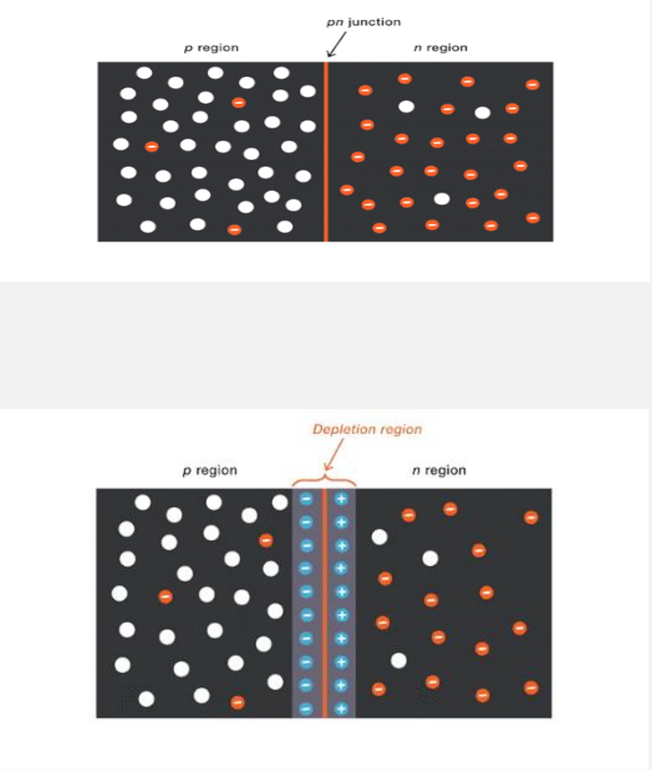


Figure 2.6: PN junction
https://www.circuitbread.com/tutorials/how-does-a-diode-work-part-1-the-pn-junction

Chapter 1: Semiconductor

Electrical Properties

When voltage applied to the circuit, electrons in N-type region will move toward to the PN junction. Resulting in the depletion region becomes thinner. When a biased voltage is greater than the potential barrier which 0.7V for silicon and 0.3 V for Germanium. Electrons cross over depletion region and combine with the holes and move to positive supply. If the biased voltage keep increased, the resistance of PN junction will decrease and current flows in the circuit will increase.

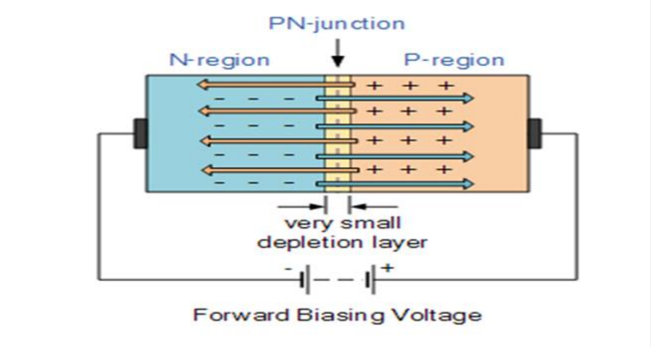


Figure 2.7: Forward biased https://www.electronics-tutorials.ws/diode/diode_3.html

When voltage is applied to the circuit, electrons in the N type region are attracted to positive supply. Holes at the P type region are attracted to the negative supply. Resulting in the depletion region become larger. If the biased voltage keeps increased, the resistance of the PN junction will increase and current cannot flows through the circuit.

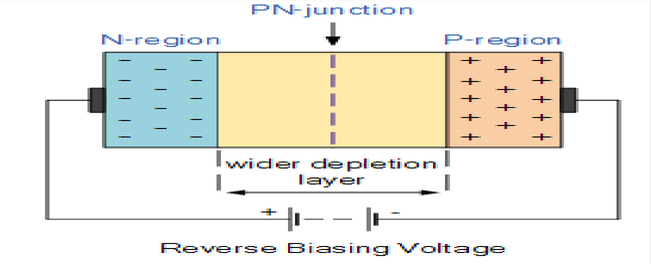


Figure 2.7: Forward biased https://www.electronics-tutorials.ws/diode/diode_3.html

Electrical Properties

Table 2.2: Comparison of biasing technique in diode

Zero biased Voltage	Forward Biased Volage	Reverse Biased Voltage
No external voltage supply is connected to the PN junction.	Positive voltage is connected to P-type, negative voltage is connected to N-type	Positive voltage is connected to N-type, negative voltage is connected to P-type.

Type of Biased Voltage	Area of Depletion Layer	Junction Resistance	Current Flow
Forward biased	Thinner	Decrease	Max
Reverse biased	Wider	Increase	Min

Leakage current or reverse current is a very small amount of current flow during Reverse biased voltage that applied to PN junction. Electrons in P-type region is drag away by the reverse-biased voltage to the joint region and pass through it (moving in the reverse direction).

The reverse-biased voltage or breakdown voltage normally is extremely high voltage (>50V depends on the type of diode). Increasing the reverse voltage result in an increase in reverse current. This is state where the covalent bonding is in unstable state. This will be causing the PN junction to overheat and fail due to the avalanche effect around the junction.

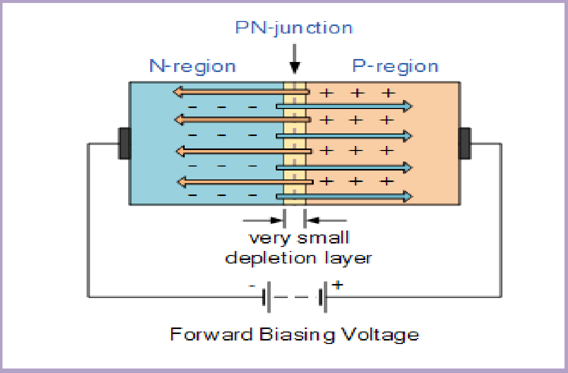
Chapter 1: Semiconductor

Exercise

1. Define semiconductor.
2. State two examples of semiconductor materials.
3. Aluminium has 13 electrons. Calculate the number of electrons in each shell.
4. Sketch the atomic structure of silicon.
5. Explain the process of covalent bonding.
6. Define the process of doping.
7. Differentiate between intrinsic and extrinsic semiconductor.
8. Explain how N-type semiconductor can be produced.
9. With a suitable diagram, explain how P-type semiconductor can be produced.
10. Differentiate between N-type and P-type semiconductor.
11. Explain the formation of the depletion region at the PN junction.
12. Sketch and describe forward biased voltage and reverse-biased voltage across a PN junction.
13. Determine the effects of PN junction when it's supplied with forwarding biased voltage.
14. Explain leakage current.
15. Explain the consequences if a high amount of reverse-biased voltage is applied to a PN junction.

Answer

1. Semiconductor is a substance that has electrical properties in between conductor and insulator
2. Germanium and silicon.
3. Shell K = 2 electrons, L = 8 electrons, M = 3 electrons.
4. Refer to subtopic silicon atomic structure
5. Doping is a pure intrinsic semiconductor added with impurity atoms to increase the number of free electrons.
6. An intrinsic semiconductor is a pure semiconductor and has poor conductivity. Extrinsic semiconductor produced by the process called Doping.
7. Refer to subtopic P-type semiconductor
8. Refer to subtopic differences between P-type and N-type semiconductor.
9. Free electrons and holes are trying to cross the PN junction. Free electrons are combined with the holes in the P region. In the N region, the electrons depleted near the junction. The PN junction becomes neutral cause of the combination of electrons and holes.
10. The positive voltage supply is connected to P-type region, negative voltage supply is connected to N-type region.



11. Effects of PN junction

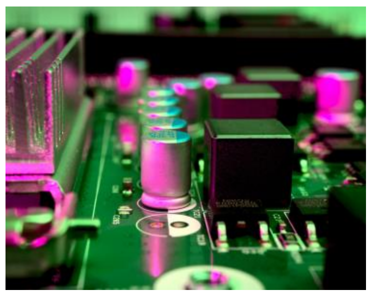
Type of Biased Voltage	Area of Depletion Layer	Junction Resistance	Current Flow
Forward Biased	Thinner	Decrease	Max
Reverse Biased	Wider	Increase	Min

Answer

12. It is a very small amount of current flow during Reverse biased voltage applied to the PN junction.
13. If the reverse-biased voltage applied to the PN junction is increased to a sufficiently high enough value, it will cause the PN junction to overheat and fail due to the avalanche effect around the junction.

Chapter Two

SEMICONDUCTOR DEVICES



Chapter Outline:

2.1 Diode I-V Curve and Characteristic

2.2 Basic Structure and Principle of Transistor

2.3 Basic Structure of Other Semiconductor Device

2.4 Differentiation of FET and BJT

Introduction:

In previous chapter, we were discussing on properties of semiconductor. In this chapter, details explanation on characteristics of semiconductor devices. Semiconductor devices technology is rapidly growing. Smaller in size, and faster in speed became new performance parameter in computing component. As we can see in microprocessor there are millions of transistor that assemble in single chip.

Diode I-V Curve & Characteristic

A diode is a semiconductor device that allows current to flow in one direction. It is created by joining P-type semiconductor and N-type semiconductor together. The direction of the arrow (anode) in a diode symbol shows the conventional current flow. Figure 4.1 shows the symbol of a diode

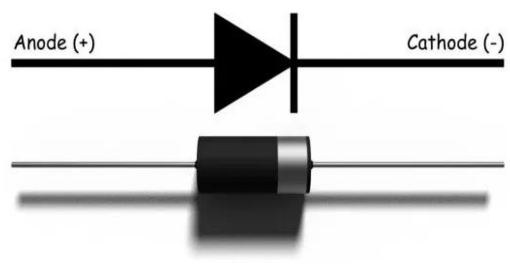


Figure 2.1: Diode symbol taken from https://www.electrical4u.com/diode-working-principle-and-types-of-diode/

A proper DC biasing is required for diode to operate. Figure 4.2 shows diode biasing. Two biasing techniques can be implemented (forward & reverse), however not all diode are capable to operate for both biasing techniques. In circuit analysis, diode can be implemented in ideal mode or conventional mode.

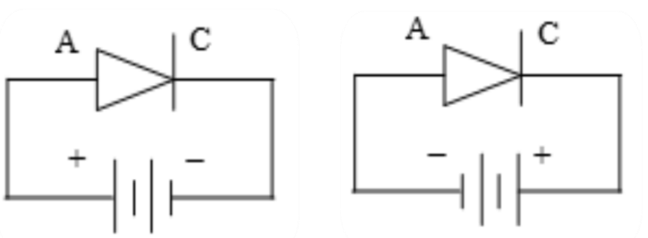


Figure 2.2: Diode biasing: (a) Forward biased; (b) Reverse biased

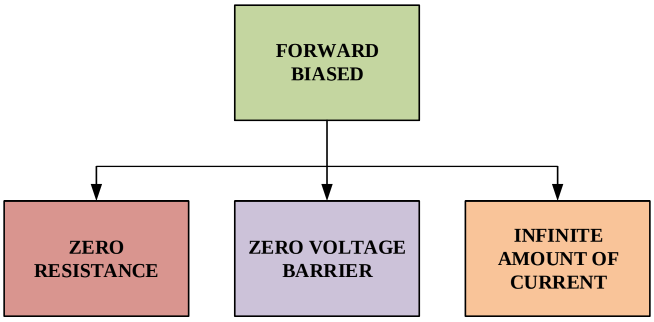


Figure 2.3: Foward biased ideal characteristic

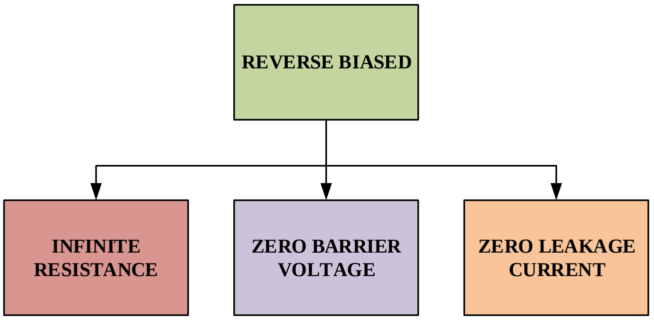
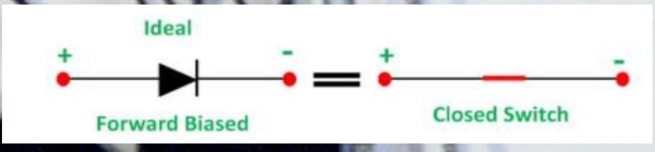
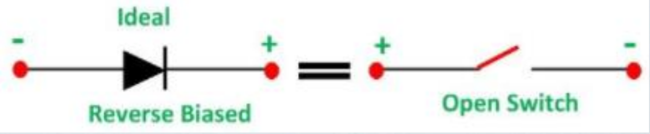


Figure 2.4: Reverse biased ideal characteristic





Diode I-V Curve & Characteristic

Figure 4.5 shows diode I-V characteristic. In general, the curve shows the variation of diode current versus voltage across it.

The curve is divided into two regions, on the right side is forward biased region, and on the left is a reverse-biased region.

<u>Knee Voltage (Threshold voltage):</u>

The minimum voltage level that forward current start increasing.

<u>Forward current (in mA scale):</u>

The current flows in diode during forward biased.

<u>Reverse current (in µA scale):</u>

The minimum current flows in diode during reverse biased.

<u>Breakdown voltage:</u>

The applied reverse voltage of P-N junction diode breakdown occurred.

<u>Burning level:</u>

When forward current and voltage exceed the maximum power of diode, so diode is reaching its burnt level.

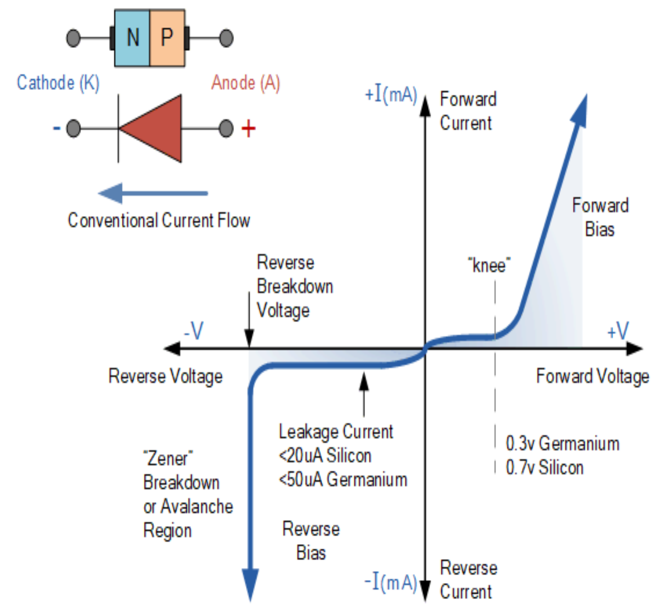


Figure 2.5: Diode I-V characteristic taken from https://www.electronics-tutorials.ws/diode/diode_3.html

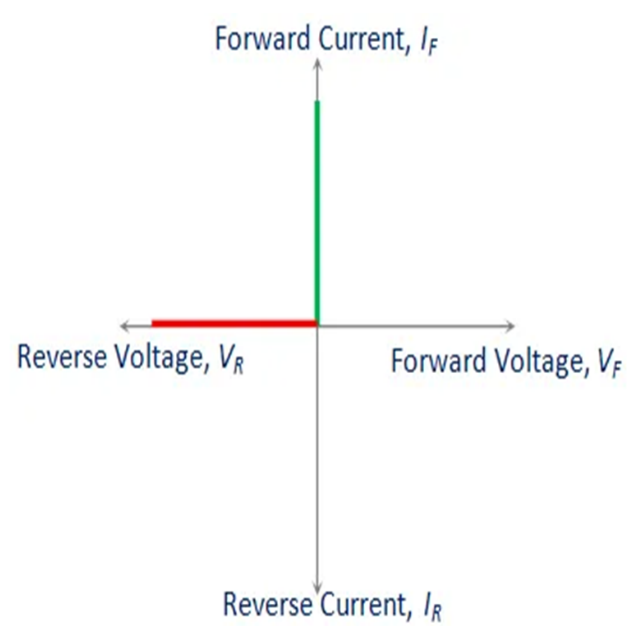


Figure 2.6: Ideal diode I-V characteristic taken https://circuitglobe.com/ideal-diode-and-real-diode.html

Diode I-V Curve & Characteristic

Zener diode is a special type of diode that is designed to operate in reverse biased. Figure 4.7 shows the Zener diode.

If Zener diode is connected in forward biased, it will be operated as normal biased. Meanwhile, it would operate as Zener mode if it connected to reverse biased and reverse voltage is higher than Zener breakdown voltage or Zener voltage. Generally, the Zener diode is used to regulate DC voltage in power supply.

Figure 4.8 shows the Zener diode I-V characteristic. Similar to normal diode I-V characteristic is divided into two regions.

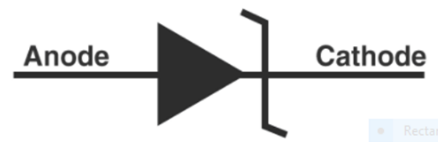


Figure 2.7: Zener Diode

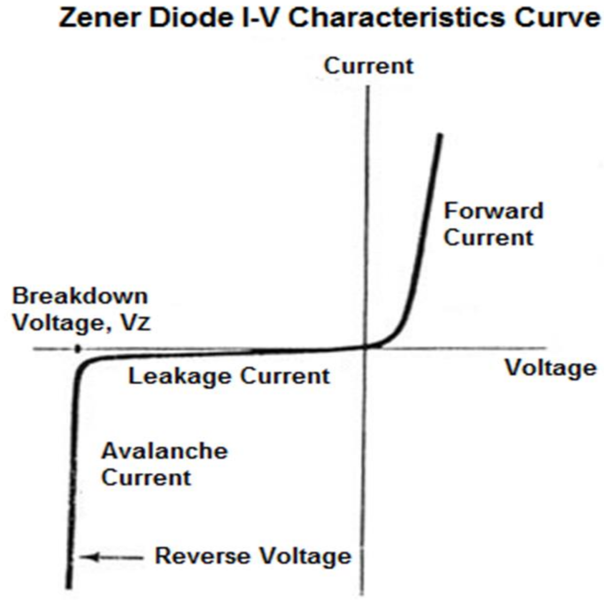
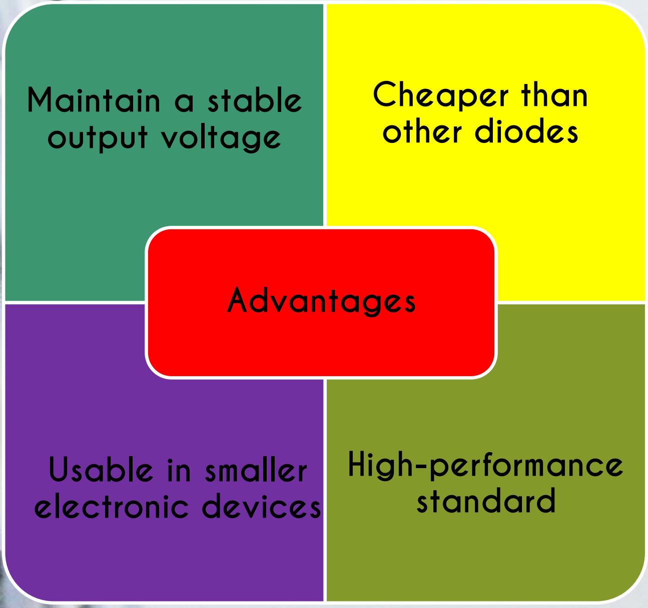
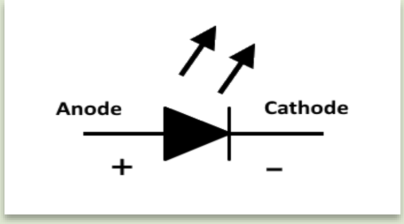
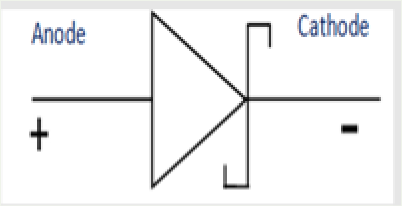
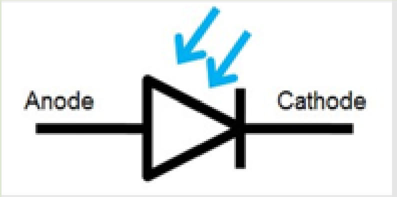
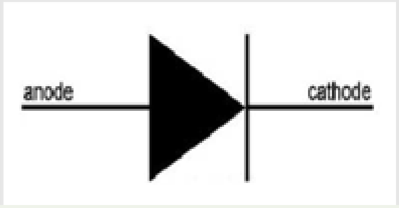
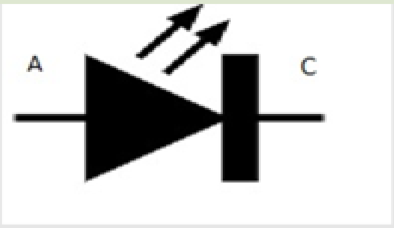


Figure 2.8: Zener diode I-V characteristic



Chapter 2: Semiconductor Devices

Diode I-V Curve & Characteristic

Diode Type	Symbol
Light Emitting Diode (LED): • Emit light when current flows through it. • When forward biased, free electrons release energy in the form of light • The emitted output light is directly proportional to the amount of forward current • Operating voltage approximately 1.2 V to 3.6 V and forward current 10 mA to 30 mA	
Schottky Diode: Used in high frequency & fast switching application	
Photo Diode: Accept light energy as input to generate electric current	
PIN Diode: Used in high voltage rectification & radio frequency application	
Laser Diode: Convert electrical energy to light energy (coherent light)	

Chapter 2: Semiconductor Devices

Bipolar Junction Transistor (BJT)

BJT is formed by two P-N junction that separated three doped semiconductor regions as shown in Figure 2.9. Each of the region are forms into transistor terminal. These terminals are called *emitter, base,* and *collector.* The emitter and collector are made up of the same type of semiconductor material. The Base terminal is a very thin layer and contains less current carrier. The most current carrier is in the emitter compare to the collector. So that, the current will flow the collector to the emitter as shown in the arrow in transistor symbol in Figure 2.10 (e). The current equation for this NPN transistor is $I_E = I_B + I_C$

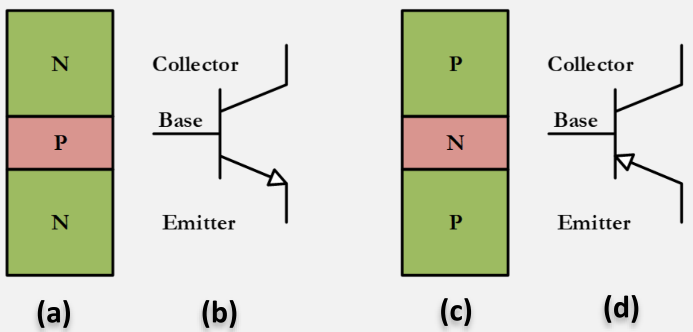


Figure 2.9: Structure and symbol of transistor

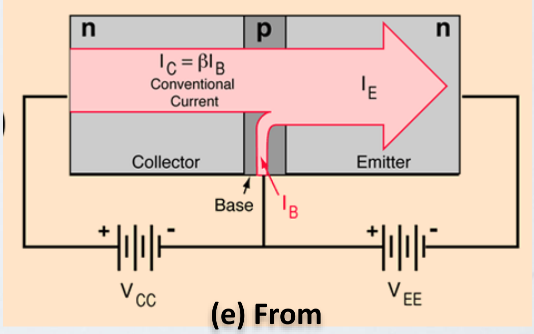


Figure 2.10: Current flow

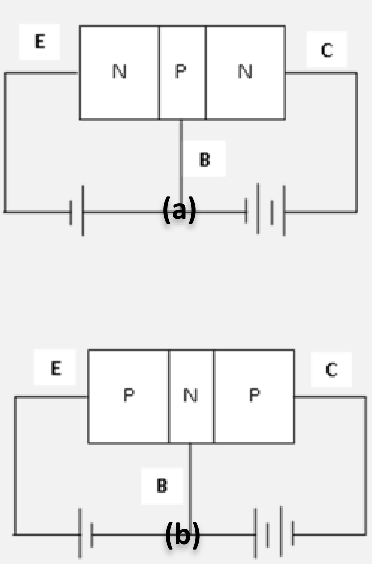


Figure 2.11: BJT biasing

A proper biasing DC voltage is required for transistor to operate. Two conditions of biased voltage are applied to the transistor; E-B (emitter-base) terminal must be forward biased and C-B (Collector-base) terminal must be reverse biased as shown in Figure 2.11

Transistor current, I_E, I_C, I_B

$I_E = I_B + I_C$

Chapter 2: Semiconductor Devices

Silicon Controlled Rectifier (SCR)

SCR is also known as thyristor and it made up with four-layer of semiconductor materials. It has three terminal anode (A), cathode (C), and gate (G). The gate terminal is used to control the operation of SCR. SCR is widely used as a switching element in power control application. Figure 2.x (a) shows the semiconductor layer of SCR and Figure 2.12 (b) shows the symbol of SCR. Figure 2.13 shows the I-V characteristic of SCR. It has similar characteristic as diode, only allows current to flow in one direction. In general, the characteristic of SCR can be divided into two regions: 1) Forward blocking state, 2) Transition state, and 3) ON state.

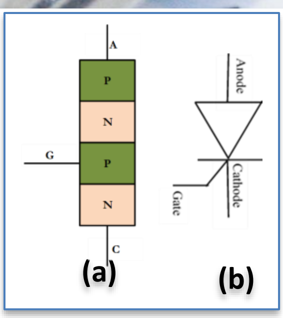


Figure 2.12: Symbol of SCR

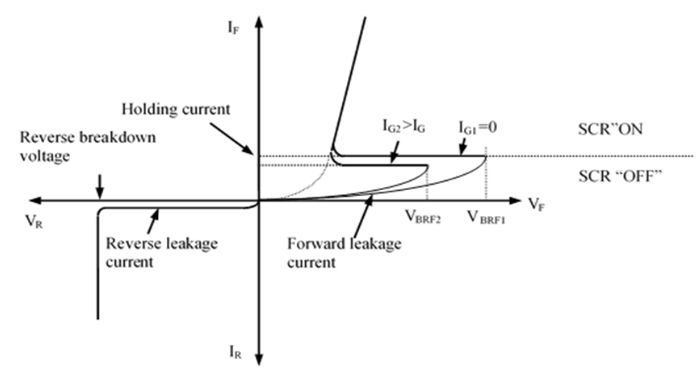


Figure 2.13: Characteristic of SCR

Forward Blocking State:

In this state, SCR is in forward biased (V_F), but the gate current, I_G = 0. Therefore, SCR is acts as an open switch with no current flow through anode accept a small leakage current. Increasing of V_F still has no affect on the SCR except the increase of small leakage current. This current is called Forward Blocking Current.

Transition State:

The increasing of V_F until at certain voltage level where forward blocking current, I_A is suddenly flow and increases quickly. V_F value at this level is called Forward breakover Voltage, (V_{BRF1}). This is where SCR is turning ON but in unstable state.

ON State

Voltage across SCR is low (less than V_{BRF1}) and applying small gate current.

Triode for Alternating Current (TRIAC)

TRIAC is a 5-layer device that allows current flows in both directions (forward and reverse). Similar characteristic with SCR and can be triggered at the gate (G) by the positive or negative trigger voltage. Similar to two SCR is connected in parallel, back-to-back opposite direction. Anode terminal of SCR1 is connected to cathode terminal of SCR2 and vice versa. This terminal is labelled as MT1 (Main terminal 1) and MT2 (Main Terminal 2). Both SCR Gate terminal is combining as one terminal. Figure 2.14 shows the construction of TRIAC and its symbol

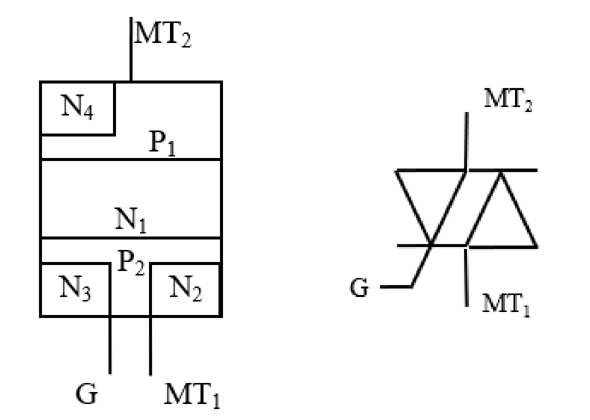


Figure 2.14: Construction of TRIAC and symbol

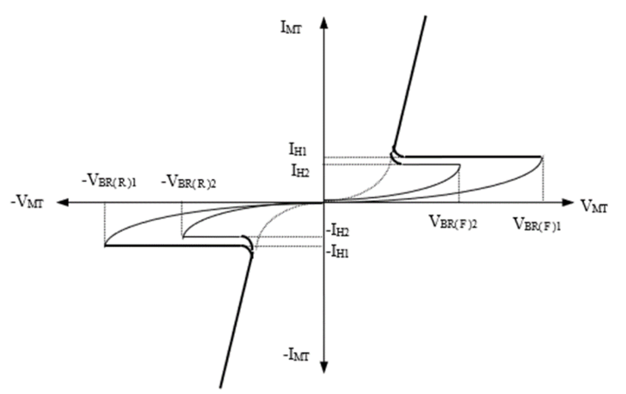


Figure 2.15: I-V characteristic of TRIAC

TRIAC characteristic curve is similar to SCR. However, in reverse biased, the curve is similar to the curve in forward biased. This shows that it can operate in both voltage direction.

Diode for Alternating Current (DIAC)

DIAC or bidirectional trigger diode is similar to the TRIAC with no gate. It is also known as 2 terminal devices and labelled as MT1 (Main Terminal 1) and MT2 (Main Terminal 2). DIAC also can be assuming as diode with 4 layers, but capable to conduct current in both directions. If MT1 is positive, then current flow through P2-N2-P1-N1. Otherwise, if MT2 is positive, current flow through N2 – P2 – N3.

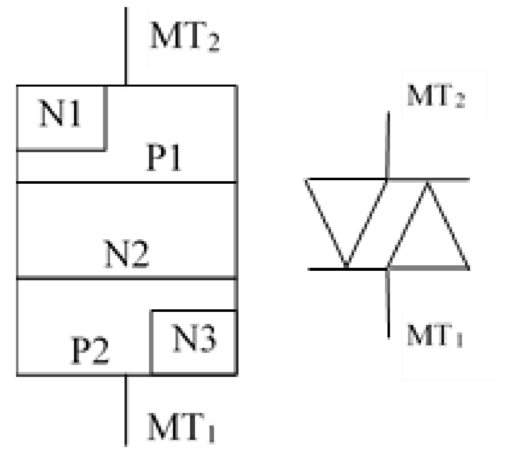


Figure 2.16: Construction of DIAC and symbol

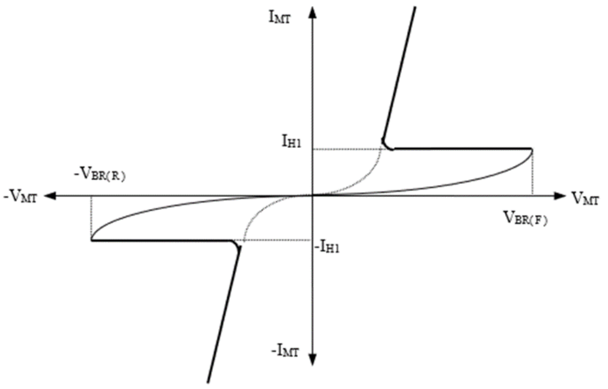


Figure 2.17: I-V characteristic of DIAC

DIAC characteristic curve is similar to the TRIAC. Differs from SCR and TRIAC, DIAC does not have a gate terminal to turn ON. DIAC is capable on conducting current in both directions.

Field Effect Transistor (FET)

FET is built from one bar N-type semiconductor. The bottom of the channel is connected to a terminal called "source" (S) and at the top is connected to a terminal called "Drain"(D). In the middle of the channel has two P-type materials forming two P-N junctions for a terminal called "Gate"(G). This is known as N-Channel FET as shown in Figure 2.18.

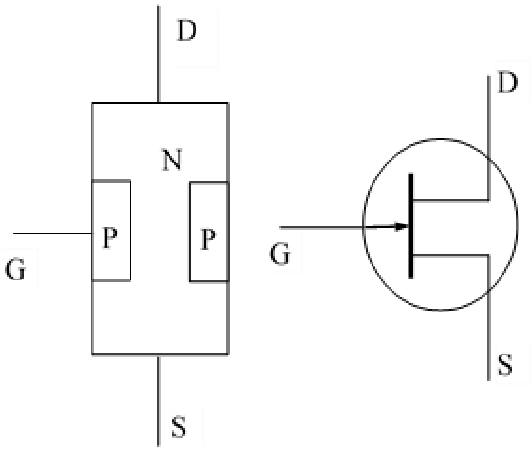


Figure 2.18: N-channel FET

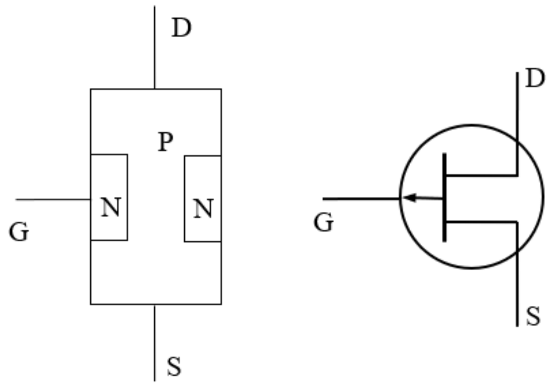


Figure 2.19: P-channel FET

Figure 2.19 shows the P-Channel FET. It constructs with one bar P-channel semiconductor. Similar to the BJT, the arrow symbol is showing the direction of the current.

Chapter 2: Semiconductor Devices

FET VS BJT

Bipolar Junction Transistor (BJT)	Field Effect Transistor (FET)
Current controlled current device	Voltage controlled current device
Bipolar transistor	Unipolar transistor
Lower switching speed	Higher switching speed
Use in low current devices	Use in high current devices
Cheaper cost	Expensive cost
Less popular of usage	More popular of usage

Metal Oxide Semiconductor FET (MOSFET)

MOSFET is the second categorized of FET. MOSFET also has3 terminals same as JFET. Source (S), Drain (D) and Gate (G). Gate is insulated by Silicon Oxide (SiO2) from the channel. Gate current becomes smaller compared to JFET. Two types:

- ❑ DE-MOSFET
- ❑ E-MOSFET

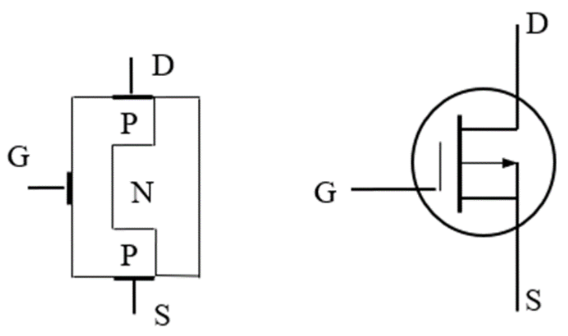


Figure 2.20: Structure of DE-MOSFET and symbol

Figure 2.21 shows the E-MOSFET structure and symbol. Differ with DE-MOSFET, E-MOSFET can be operated in enhancement mode only. E-MOSFET can operate with the high value of V_{GS}. The construction of E-MOSFET is differ from the DE-MOSFET.

Figure 2.20 shows the DE-MOSFET structure and its symbol. DE-MOSFET can be operated in depletion mode or in enhancement mode with only changing the voltage polarity between the gate and the source (VGS). When VGS is negative, DE-MOSFET operated in depletion mode. Otherwise, when VGS is positive, DE-MOSFET operated in enhancement mode.

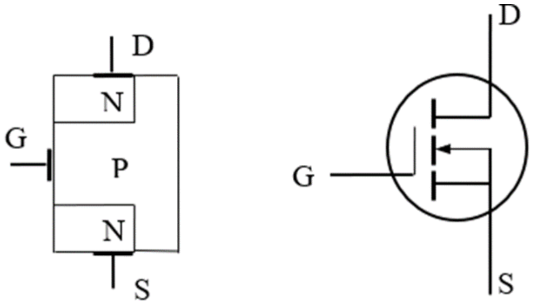


Figure 2.21 Structure and symbol of E-MOSFET

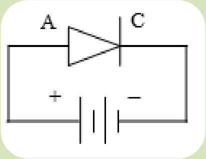
Exercise

1. State two examples of semiconductor devices.
2. Define diode.
3. Sketch diode in forward biased voltage.
4. State the characteristic of reverse-biased ideal diode.
5. Sketch IV characteristic curve of a diode.
6. Differentiate between the normal diode and Zener diode.
7. Determine three advantages of Zener diode.
8. Sketch a light emitting diode (LED).

Chapter 2: Semiconductor Devices

Answer

1. Diode, transistor etc.
2. A diode allows current to flow in one direction.
3. Diode in forward biased voltage.



4. Infinite Resistance, Zero Leakage Current, No breakdown voltage.
5. Refer sub-topic of IV characteristic curve of a diode.
6. Normal diode only conducts current in forward biased. Zener diode can conduct current during forward biased and reverse-biased,
7. Maintain a stable output voltage. Cheaper than other diodes. Usable in smaller electronic devices.
8. Light emitting diode (LED).

Chapter Three

LINEAR DC POWER SUPPLY

Chapter Outline:

3.1 What is DC Power Supply

3.2 Operation of DC Power Supply

3.3 Complete Schematic of DC Power Supply

Introduction:

Electrical power is the backbone of any electronic system, and the power supply feeds to the system. Choosing the right supply can be the critical difference between a device working at optimum levels and one that may deliver inconsistent results. In addition, conversion of alternating current (AC) to direct current (DC) power supplies, the DC-to-DC converters are also available and produce more power efficiency to the system. If a DC source is already available in your system, a DC-to-DC converter may be a better design choice than AC. DC power supplies can be categorized into either unregulated or regulated. Regulated supplies come in several options, including linear, switched and battery-based.

Chapter 3: Linear DC Power Supply

DC Power Supply

Electronic circuits are made up of diode, transistors and ICs that required DC voltage to operate. Using a battery might be the best solution, however it will be drained after being used for a certain time. Moreover, if a device load required a higher amount of voltage, more than one battery cell is needed.

Thus, the usage of battery as the main DC source is NOT ECONOMICAL. Houses and most of other building infrastructures come with 240VAC socket outlets. Therefore, converting an AC voltage to desired DC output voltage is a better solution. The equipment that converts AC to DC is called DC power supply.

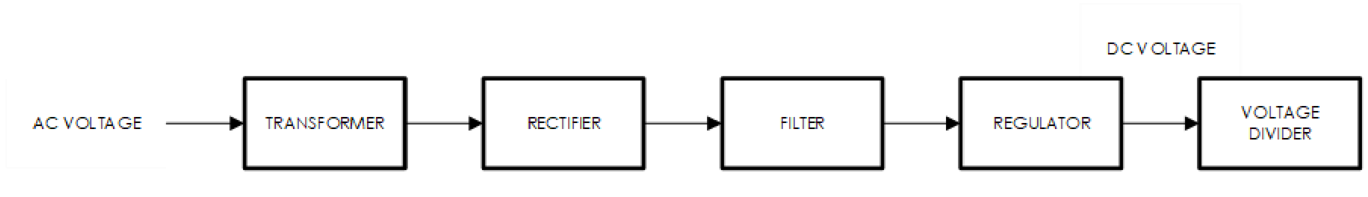


Figure 3.1: Basic power supply block diagram

Figure 3.1 shows the block diagram of DC power supply. Block diagram consists four elements, trans-former, rectifier, filter, regulator and voltage divider. Each of block has specific function.

- Transformer - Step down the AC input voltage to a desire AC output voltage
- Rectifier - Convert AC input voltage into pulse DC voltage
- Filter - Smooth the pulse DC into small ripple DC voltage
- Regulator - Eliminates ripple to a constant DC voltage
- Voltage divider - Create multiple voltage level of a constant DC output.

Operation of DC Power Supply

Figure 3.2 shows the Half-wave rectifier circuit. Half-wave rectifier is made up of a diode and a resistor it to conduct current in one direction and block current in the other direction. During the positive cycle of the input signal, diode D is in front of the bias and acts as a close switch so that current flows through it. The voltage drop at the R_L is same magnitude as the input signal (ideal diode operation). During the negative half cycle, diode is in reverse bias and act as the open switch, so that the current can't flow through it. No voltage drop at load resistor R_L since the circuit is not complete.

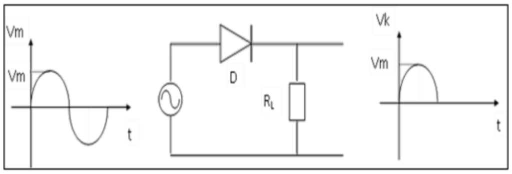


Figure 3.2: Half-wave rectifier circuit

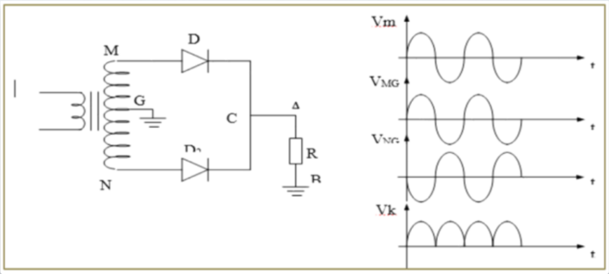


Figure 3.3: full-wave center tap rectifier circuit

Figure 3.3 shows the full-wave rectifier circuit. If AC voltage is supplied to the circuit, M and N at the secondary transformer will become +ve and -ve (exchange). During the positive cycle, the terminal M become positive , G becomes a potential (ground) and N becomes negative. D1 diode will forward biased while D2 will reverse biased. Current will flow along M, D1, C, A, B, G. A positive cycle wave will produce at the RL load. During the -ve cycle ,input voltage supply ,M terminal become negative, G will zero potential(grounded) and N become positive. Therefore, D2 diode will forward biased while D1 will reverse biased. Current will flow along N, D2, C, A, B, G. Current flow through RL during the negative cycle is similar to positive cycle

Operation of DC Power Supply

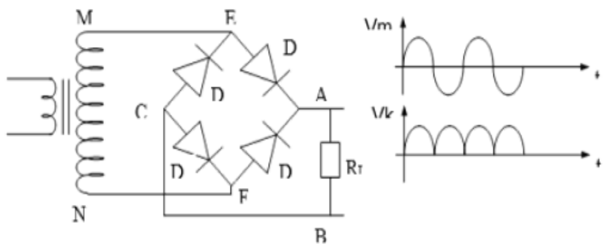


Figure 3.4: Full-wave bridge rectifier

Figure 3.4 shows the full-wave bridge rectifier circuit. The circuit is constructed using four diodes. The AC voltage is supplied to the input of transformer. Terminal M and N at the secondary transformer will become positive and negative.

During the positive cycle, M terminal becomes positive and N terminal becomes negative. Therefore, D1 and D3 are forward biased, meanwhile D2 and D4 become reverse biased. Moreover, the current will flow along M, E, A, B, C, F and N.

During negative cycle, M terminal becomes negative, and N becomes positive. Diode D_2 and D_4 are forward biased whereas D_1 and D_3 are reverse biased. The current will flow along , F, A, B, C, E, M.

Finally, we will get both output voltage during positive and negative cycle as shown in Figure 3.4. This is because there is current flowing load ,R_L for both positive and negative cycles.

Since the current will flow through 2 diodes on each cycle, therefore, the voltage drop of the diode is double compare to the half-wave rectifier (1.4V assume silicon diode and non-ideal diode is applied). So that the output voltage is

$$V_O = V_{M-N} - 1.4V$$

The output signal frequency is equal to 2 x input frequency.

Operation of DC Power Supply

In power supply, filter circuit is used to smooth the output DC voltage. There are numerous of filter types that can be used for smoothing the DC output voltage. In this chapter, we are only discussing on three common filters that are used in power supply. Those filter are:

1. Capacitor filter
2. LC filter
3. π Filter

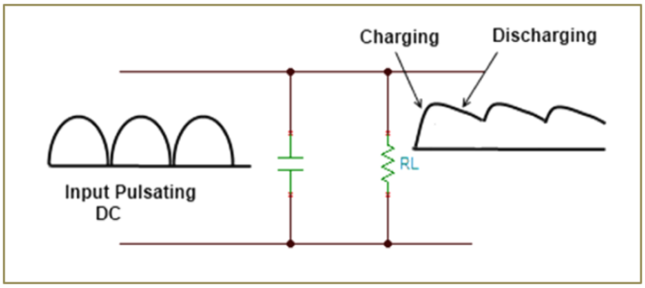


Figure 3.5: Capacitor filter

Figure 3.5 shows the capacitor filter circuit. The capacitor is connected across the load R_L. Capacitor is charging during the rise of voltage to it maximum voltage (same as input pulsating voltage). When the input voltage is decreasing, the capacitor start to discharge. This process is repeated for on every cycle. The capacitor filter its popular because of is low cost, small size, less weight and good characteristics

Figure 3.6 shows the LC filter circuit. The inductor is connected in series with the load resistor R_L. It offers high resistances to the AC components and allows DC component to flow through the load.

The capacitor across the load is connected in parallel which filters out any AC component flowing through the inductor. A smooth DC output is produced through the load.

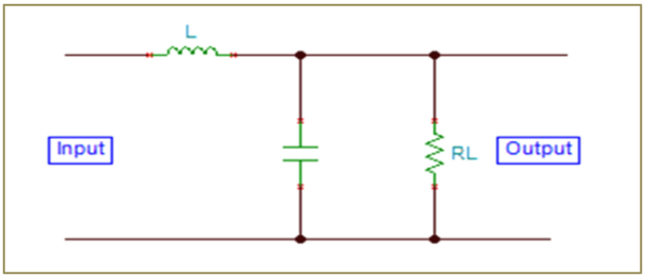


Figure 3.6: LC filter

Operation of DC Power Supply

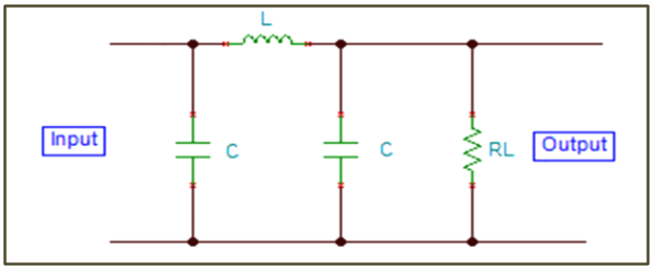


Figure 3.7: π filter

A voltage regulator provides a constant DC output voltage that is essentially independent of the input voltage, output load current, and temperature. Its input voltage comes from the filtered output of a rectifier.

Most voltage regulators fall into two broad categories: linear regulators and switching regulators. In the linear regulator category, two general types are the series regulator and the shunt regulator. These are normally available for either positive or negative output voltages. A dual regulator provides both positive and negative outputs.

In this chapter, we only discussed on:

1. Zener diode regulator
2. Serial Transistor regulator
3. Shunt Transistor regulator
4. IC regulator (LM series)

Figure 3.7 shows the π (Pie) filter circuit. The filter consists of one inductor and two capacitors connected across each end. The input capacitor C1 is selected to offer a very low reactance to the repel frequency hence major parts of filtering is done by C1. Most of the remaining repels are removed by the combining action of L and C2.

This circuit gives much better filter then the LC filter. However, C1 is still directly connected across the supply and would need high pulse of current if load current is large. This filter is used for the low current equipment's.

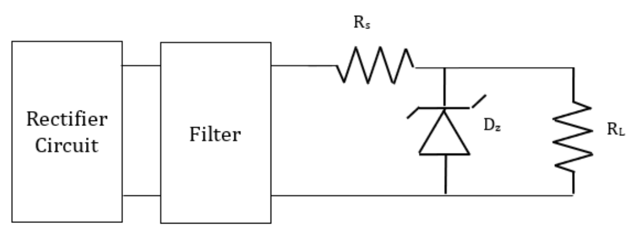


Figure 3.8: Zener voltage regulator

Figure 3.8 shows the voltage regulator using Zener diode. Zener diode is connected in reverse bias so that it can operate in breakdown region for producing constant voltage or breakdown voltage (Zener voltage)

Operation of DC Power Supply

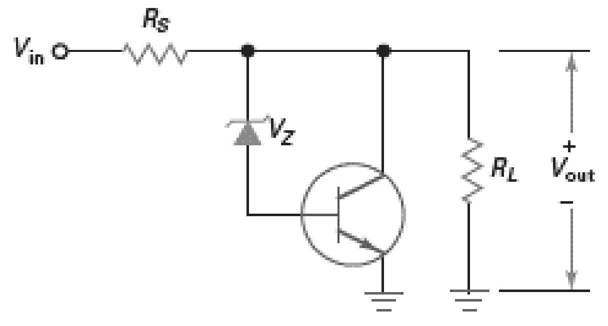


Figure 3.9: Shunt regulator

Figure 3.9 shows a shunt regulator that using the transistor. This circuit has the advantage of being able to use low-temperature-coefficient Zener voltages (between 5 and 6 V). The regulated output voltage will have approximately the same temperature coefficient as the Zener diode, but the voltage will be higher.

The disadvantage of a shunt regulator is its low efficiency, which is caused by large power losses in the series resistor and the shunt transistor. When efficiency is not important, shunt regulators may be used because they have the advantage of simplicity.

However, when efficiency is important, a series regulator may be used. The series regulator has full-load efficiencies from 50% to 70%, good enough for most applications in which the load power is less than 10W.

Figure 3.10 shows the series regulator circuit. Its relative simplicity, quiet operation, and acceptable transistor power dissipation make the series regulator the natural choice for many applications.

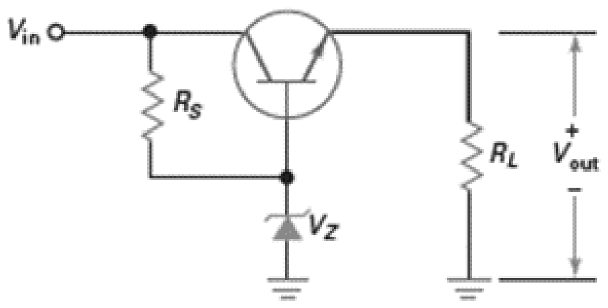


Figure 3.10: Series regulator

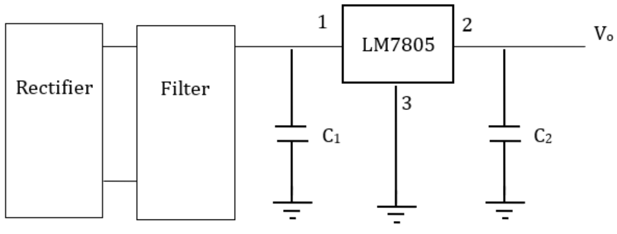


Figure 3.11: Series regulator

Schematic Diagram of Power Supply

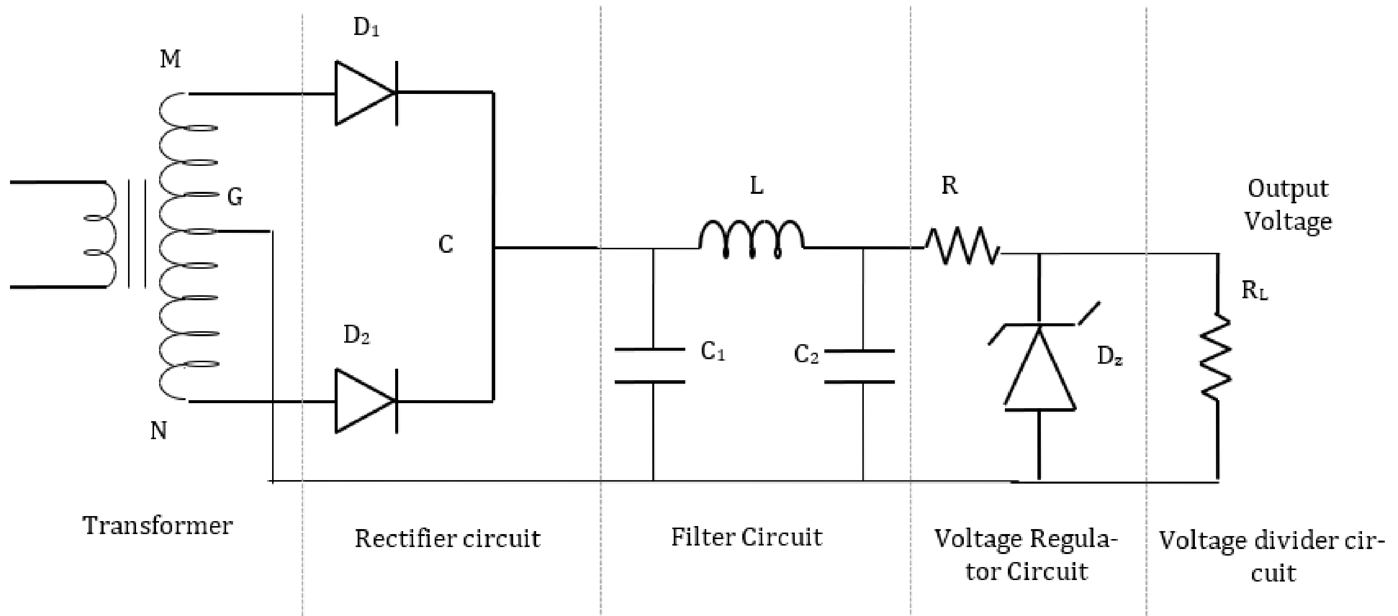


Figure 3.12: Complete diagram of DC power supply circuit

Exercise

1. State TWO (2) reasons why people need a linear DC power supply.
2. Draw the block diagram of the DC power supply.
3. Explain the factors that can determine whether the transformer is a 'step-up' or 'step-down'.
4. Sketch a complete power supply circuit that includes the following:
   i. Step-down transformer
   ii. Voltage divider circuit with 12V and 9V
   iii. RC filter circuit
   iv. Bridge rectifier circuit
   v. Diode Zener voltage regulator
5. Explain the operation of the following rectifier circuit:
   i. Half- wave rectifier
   ii. Full-wave rectifier
6. Sketch and explain each block diagram of a linear DC power supply
7. State TWO (2) functions of the transformer in DC power supply circuit.
8. "A supply voltage of 240V, 50Hz transformer is given windings ratio 6:1". Based on statement above, draw and label the transformer winding.
9. Sketch a linear DC power supply circuit using the following
   i. Input supply, Vin= 230V
   ii. Centre tap transformer step down type, with output transformer of 32V-0V-32V
   iii. Full wave rectifier (two diodes)
   iv. A filter capacitor
   v. Integrated circuit voltage regulator 78XX type (series 7824, the output of +24V).
   vi. Variable voltage divider (Fix= 24V, variable= 0V – 15V).

Chapter Four

AMPLIFIER & OSCILLATOR CIRCUIT

Chapter Outline:

4.1 Transistor Configuration Circuit and its Characteristics

4.2 DC Load Line Analysis of Common Emitter Amplifier

4.3 Other Biasing Technique for Common Emitter Amplifier

4.4 Oscillator Circuit and Its Characteristics

4.5 Comparison of Oscillator Circuit

Introduction:

The invention of the transistor in the late 40's changes the electronic technology to what we know today. Reducing of transistor size from the first invention make million of transistors can be assembled together in a single microprocessor chip. Transistor is a three terminals semiconductor device that is used as an amplifier or an electronic switch. There are two types of transistor; Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET). In this chapter, we will be studying BJTs circuit configuration, BJT amplifier and implementation of BJT in the oscillator circuit.

Transistor Configuration

Transistor is a unique semiconductor device that can be used as electronic switch or amplifier and it depends on the circuit configuration. There are three circuit configurations of transistor, common base, common collector, and common emitter. These three circuit configurations have different characteristics, such as gain, input and output impedance, etc. Choosing the right configuration depends on application requirements. Each of circuit topology has the inputs and outputs applied on different point (common terminal + input or output terminal).

Figure 4.1 shows the common base transistor configuration. Base terminal is connected to the ground and became common for this configuration. The input terminal is between emitter-base and the output terminal is collector-base.

The configuration provides a low input impedance while offering a high output impedance. Its capable to handle high voltage, but the current gain is low, and the overall power gain is also low. Figure 4.2 shows the common based DC voltage biasing.

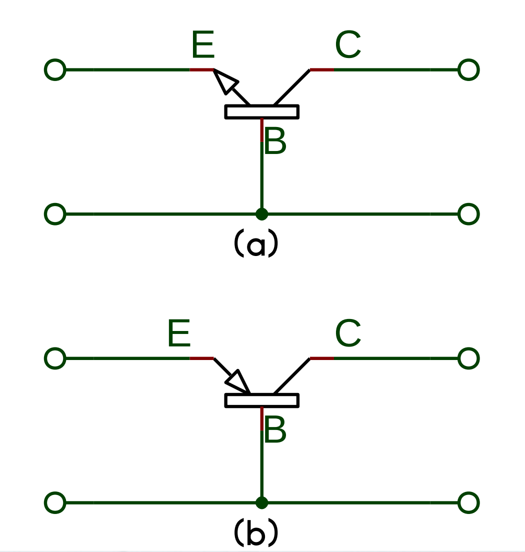


Figure 4.1: Common base transistor configuration. a) NPN, b) PNP

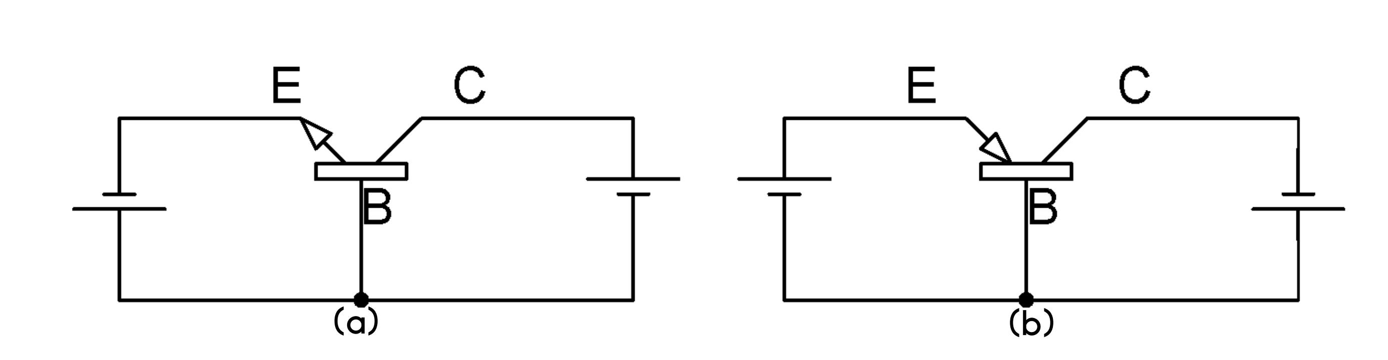


Figure 4.2: Common base biasing. a) NPN, b) PNP

Transistor Configuration

Figure 4.3 shows the common base of transistor configuration.

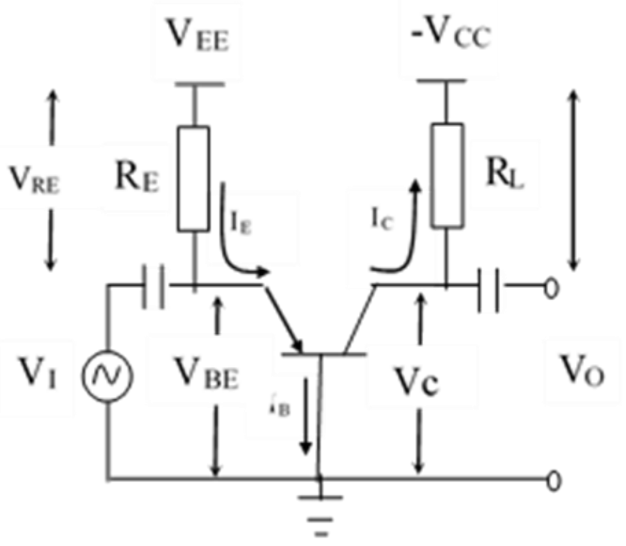


Figure 4.3: Complete circuit common base configuration

<u>Equation at emitter section:</u>

(Input section: the input waveform can be entered at this section when this circuit as an amplifier.)

$V_{EE} = V_{RE} + V_{BE}$

$V_{EE} = I_E R_E + V_{BE}$, then

$$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

<u>Equation at collector section:</u>

(Output section: The input signals that already increased is taken in this section.)

$V_{CC} = V_{RL} + V_C$

$V_{CC} = I_C R_L + V_C$, then

$$V_C = V_{CC} - I_C R_L$$

Transistor Configuration

Figure 4.4 shows the common collector transistor configuration. In this configuration, the input signal is applied to the base terminal and the output signal is taken from the emitter terminal. In this configuration, base-collector (B-C) is in forward bias and emitter-collector (E-C) is in reverse bias as shown in Figure 4.5.

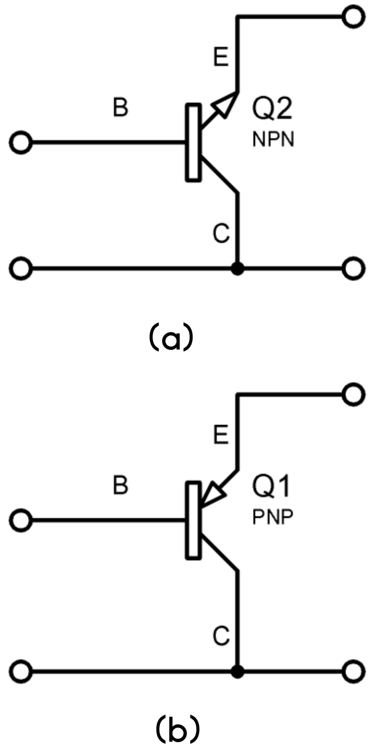


Figure 4.4: Common collector circuit configuration a) NPN, b) PNP

From Figure 4.5;

Equation at emitter section:

(Input section: the input waveform can be entered at this section when this circuit as an amplifier.)

$$V_{EE} = V_{RE} + V_{BE}$$

$V_{EE} = I_E R_E + V_{BE}$, then

$$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

Equation at collector section:

(Output section: The input signals that already increased is taken in this section.)

$$V_{CC} = V_{RL} + V_C$$

$V_{CC} = I_C R_L + V_C$, then

$$V_C = V_{CC} - I_C R_L$$

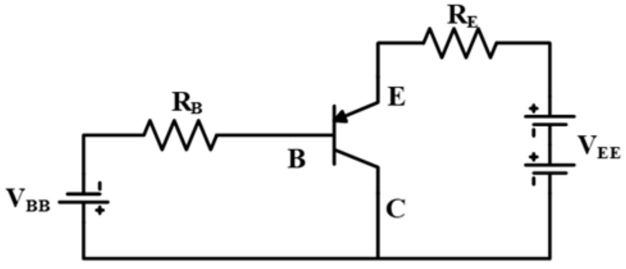


Figure 4.5: PNP circuit biasing

Transistor Configuration

Common emitter configuration is widely used in transistor to amplify signal. Figure 4.6 shows that the common emitter circuit configuration. Input signal is feeding to base terminal and output is fetching through collector termina;. Resistor R_B is connected at base terminal to limit the value of IB.

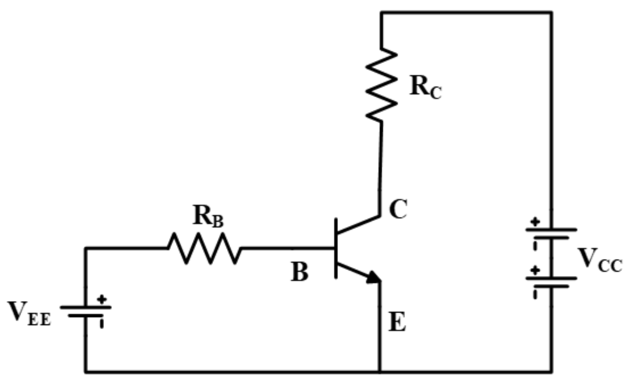


Figure 4.6: Common emitter circuit configuration

<u>Equation at emitter section:</u>
(Input section: The input waveform can be entered at this section when this circuit as an amplifier.)

$$V_{EE} = V_{RB} + V_{BE}$$
$$V_{EE} = I_B R_B + V_{BE}, \text{ then}$$
$$I_B = \frac{V_{EE} - V_{BE}}{R_B}$$

<u>Equation at collector section:</u>
(Output section: The input signals that already increased is taken in this section.)

$$V_{CC} = V_{RC} + V_{CE}$$
$$V_{CC} = I_C R_C + V_{CE},$$
$$V_{CE} = V_{CC} - I_C R_C, \text{ where,}$$
$$I_C = \beta I_B \text{ then}$$
$$V_{CE} = V_{CC} + \beta I_B R_C$$

Parameter	Common base	Common collector	Common emitter
Input resistance	low	high	low
Output resistance	high	low	high
Current gain	low	high	high
Voltage gain	high	low	high
Power gain	high	low	high
Different phase	no	no	180°

Comparison of characteristics between transistor configuration

DC Load Line

The analysis or design of a transistor amplifier requires a knowledge of both the DC and the AC responses of the system. The transistor is not a magical device that can operate without external energy. Any increase in AC voltage, current, or power is the result of an energy transfer energy from the DC bias.

The biasing is designed to ensure the transistor is operating in an active region. The active region is a region where transistor is behaves normally. This region is located between cut-off and saturated region as shown in Figure 4.7. In the active region C-E junction is reverse biased and B-E is forward biased.

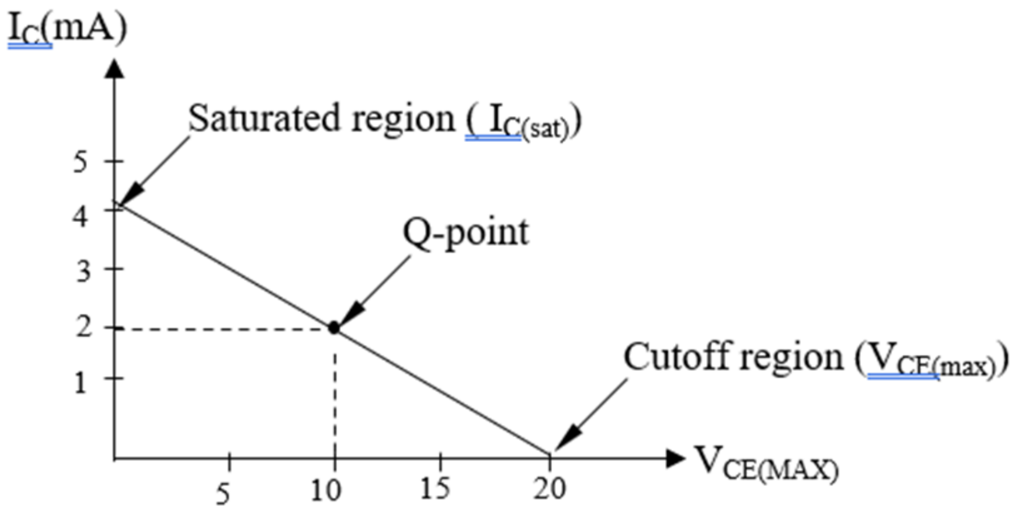


Figure 4.7: DC load line

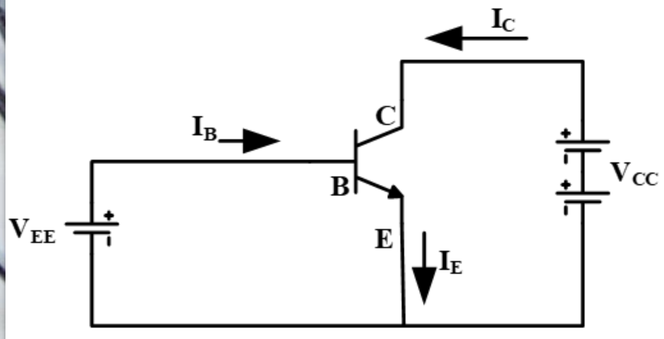


Figure 4.8: Biasing transistor circuit

Current Equation

$I_E = I_B + I_C$

DC Load Line

DC biasing establish an operating point on the characteristics that define the region that will be employed for amplification of the applied signal. The operating point is a fixed point on a characteristic called the quiescent point (abbreviated Q -point). Quiescent means quiet, still, inactive. All analyses and calculations for the DC load lineis using common emitter circuit configuration as shown in Figure 4.10.

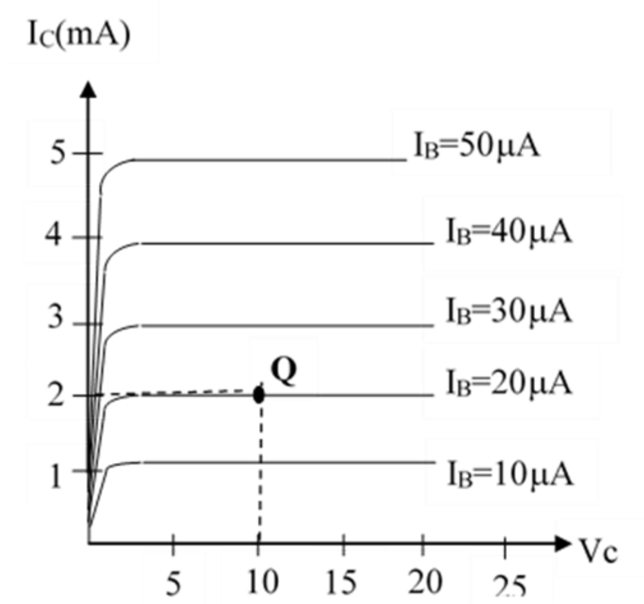


Figure 4.9: Transistor I-V curve

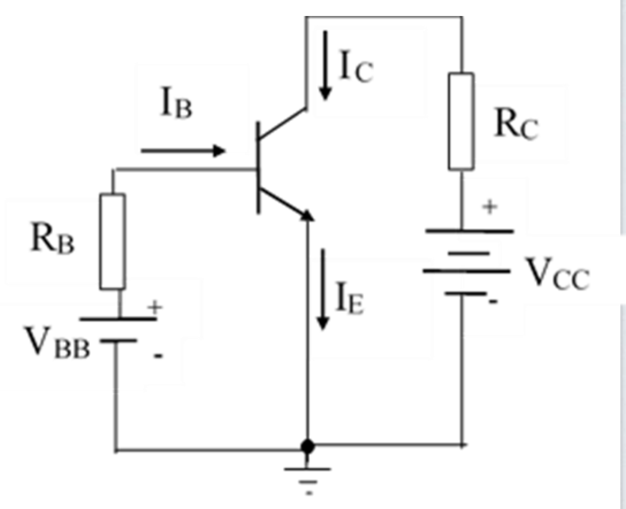


Figure 4.10: Common emitter circuit configuration

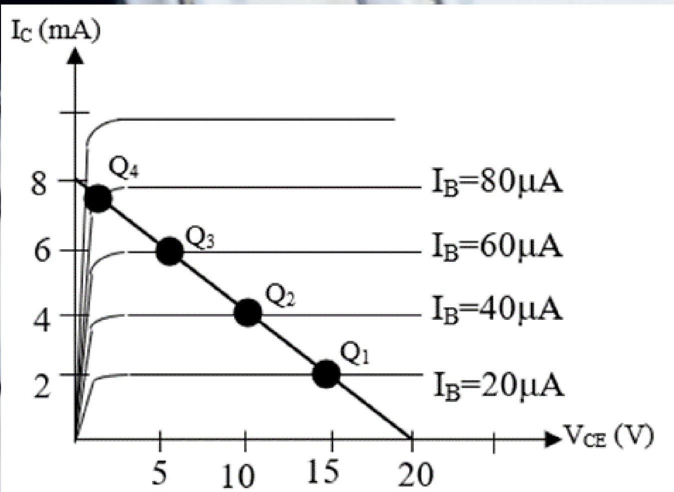


Figure 4.11: Example of operating point (Q) for different IB value

<u>Step to draw DC load line</u>

Step 1: Find $I_{C(sat)}$ and $V_{CE(max)}$

Step 2: Draw straight line

Step 3: Determine IB

Step 4: Find intersection of straight line and IB curve line

DC Load Line

Saturated and cut-off region.

Saturated Region:

$V_{CE} = 0$;

C-E Loop ,

$V_{CC} = V_{RC} + V_{CE}$

$V_{CC} = I_C R_C$, then

$$I_{C(sat)} = \frac{V_{CC}}{R_C}$$

Cutoff Region:

$I_B = 0$, then $I_C = 0$

C-E Loop,

$V_{CC} = V_{RC} + V_{CE}$

$V_{CC} = I_C R_C + V_{CE}$

Then,

$$V_{CE(max)} = V_{CC}$$

Common Emitter Amplifier

Amplification is the process of linearly increasing the amplitude of an electrical signal and is one of the major properties of a transistor (Floyd, 2012). When BJT is properly biased in the active region, B-E junction has low resistance compare to the C-E junction. This is due to the forward and reverse biased configuration. Transistor amplify AC signal because the collector current (output) is higher compared to the base current (input). Figure 4.12 shows the common emitter amplifier.

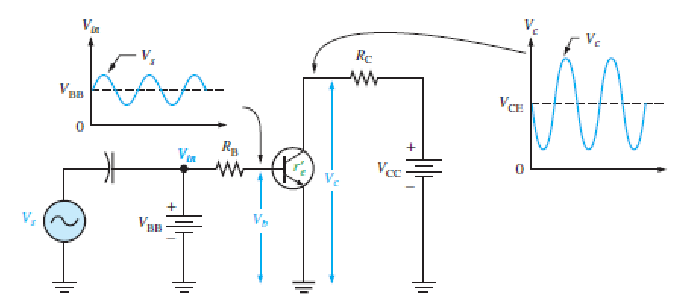


Figure 4.12: Common emitter amplifier circuit taken from (Floyd, 2012)

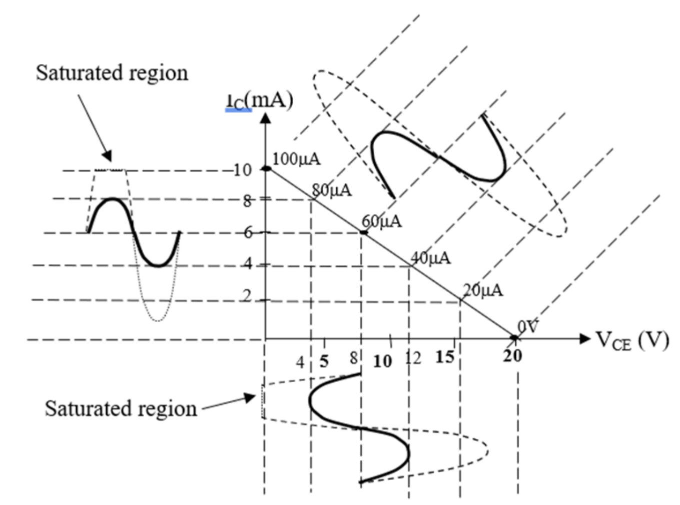
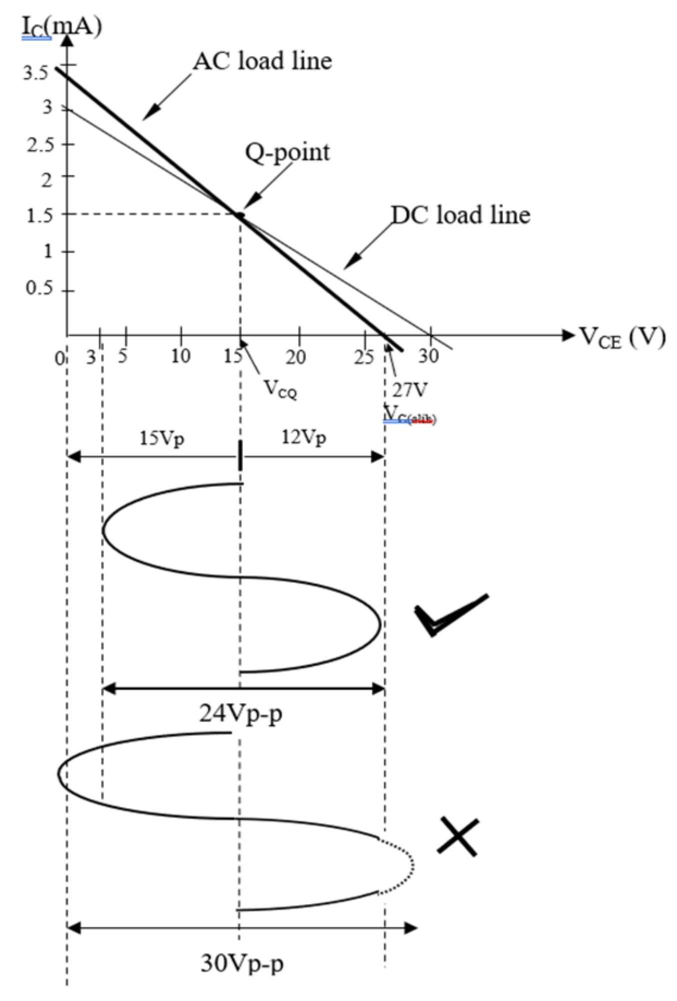


Figure 4.13: Output of AC signal



<u>Characteristic of CE Amplifier:</u>

- ❑ Q_{point} is in active region (not to low & to high)
- ❑ Signal is capped if exceeded saturation region
- ❑ Voltage Gain $A_V = \frac{V_{output}}{V_{input}}$

Oscillator

An oscillator is a circuit that produces a continuous, repeated, alternating waveform without any input. Oscillators convert unidirectional current flow from a DC source into an alternating waveform which is of the desired frequency, as decided by its circuit components. Sinusoidal oscillator operation is based on positive feedback. A portion of the output signal is fed back to the input to sustain a continuous output signal.

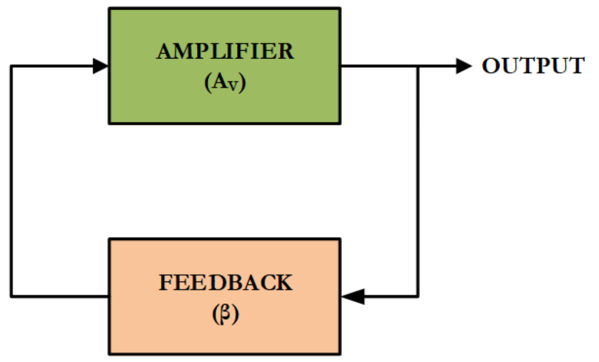


Figure 4.14: Oscillator block diagram

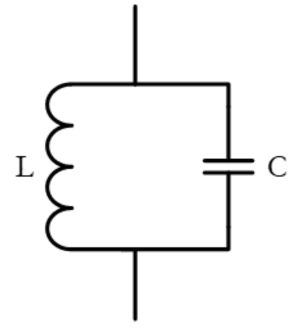


Figure 4.15: Tank circuit

Oscillator consists of *barkhausen* criterion $A_V\beta = 1$

Voltage gain (A_V) is required to be large enough to ensure *barkhausen* criterion is fulfilled. Tank circuit generates small signal voltage also known as noise.

Oscillator

Hartley Oscillator consists of a parallel LC resonator tank circuit. Oscillation Feedback is achieved by an inductive divider. In the Hartley Oscillator the tank circuit is connected between the collector and the base of transistor amplifier.

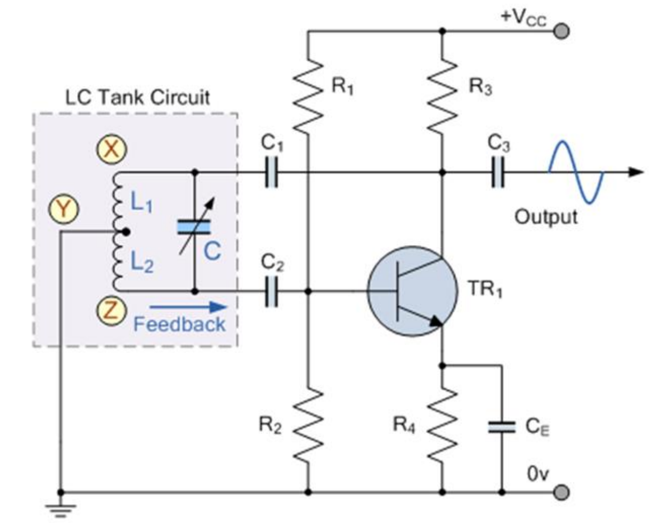


Figure 4.15: Hartley oscillator circuit taken from https://www.electronics-tutorials.ws/oscillator/hartley.html

Parameter	Equation
Resonant Frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$ $L = L_1 + L_2$
Feedback Gain	$B = \frac{L_2}{L_1}$
Voltage Gain	$A_V = \frac{L_1}{L_2}$

Oscillator

Similar to Hartley, Colpitts Oscillator consists of a parallel LC tank. Oscillation feedback is achieved by a capacitive divider. The oscillating frequency is determined by the resonance frequency of the tank circuit.

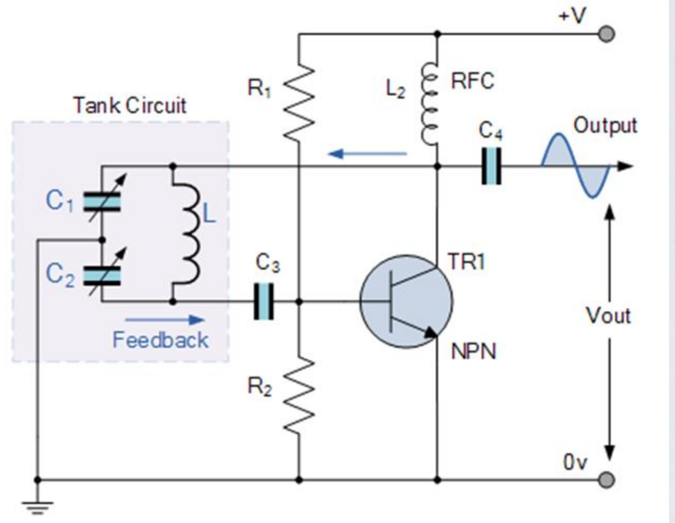
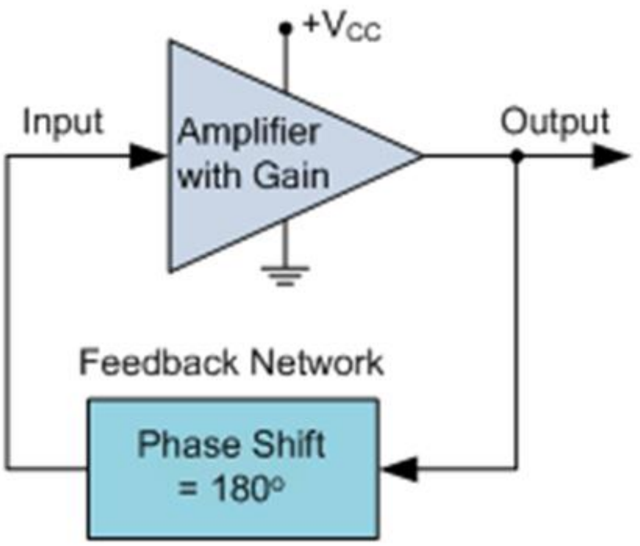


Figure 4.16: Colpitts oscillator circuit taken from https://www.electronics-tutorials.ws/oscillator/colpitts.html

Parameter	Equation
Resonant Frequency	$f_r = \frac{1}{2\pi\sqrt{LC}}$ $C = \frac{C_1 C_2}{C_1 + C_2}$
Feedback Gain	$B = \frac{C_1}{C_2}$
Voltage Gain	$A_V = \frac{C_2}{C_1}$

Oscillator

Positive feedback is required for RC oscillator to sustain its oscillations. Feedback must be provided along with the voltage gain. Input signal is shifted 180o through the feedback circuit and again it shifted 180o through an inverting amplifier. This 2 stages of shifting frequency give 360o of phase shift.



https://www.electronics-tutorials.ws/oscillator/rc_oscillator.html

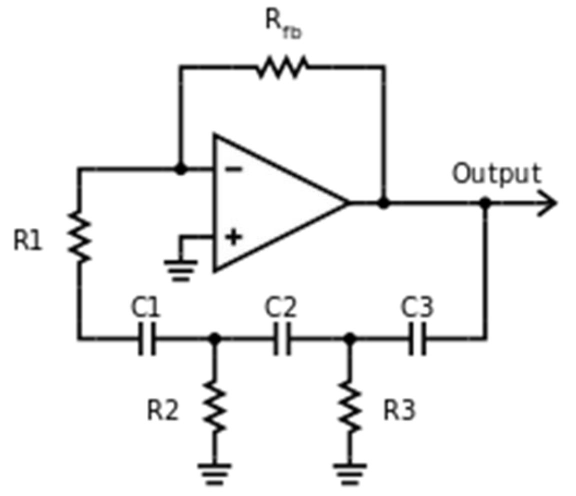
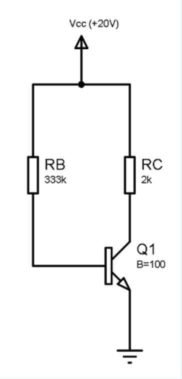


Figure 4.17: Colpitts oscillator circuit taken from https://www.electronics-tutorials.ws/oscillator/colpitts.html

Parameter	Equation
Resonant Frequency	$f_r = \frac{1}{2\pi RC}$ $C = \frac{C_1 C_2}{C_1 + C_2}$
Feedback Gain	$B = \frac{C_1}{C_2}$
Voltage Gain	$A_V = -\frac{R_{fb}}{R_1}$

Excercise

1. Draw 3 transistor configuration circuits.
2. What is a Q-point?
3. With aid of diagram, explain the effect of the transistor is operating in cut off region
4. Draw the DC load line for the transistor circuit below:



5. Define the oscillator
6. What are the criteria to circuit become an oscillator?
7. Draw the oscillator circuit below:
   i. Hartley
   ii. Colpitts
   iii. Phase shift