Lesson One: Transducer

Learning Outcomes:

After the ending of the lesson, students will be able to know

- About the definition and classifications of the transducer.
- Why the digital transducer is more advantageous over the analog transducer.
- The operating principle of a transducer
- Election Criteria of a Transducer

Transducer

A transducer is a device which transforms a nonelectrical physical quantity (i.e. temperature, sound or light) into an electrical signal (i.e. voltage, current, capacity…). In other word, it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.

BLOCK DIAGRAM OF TRANSDUCERS

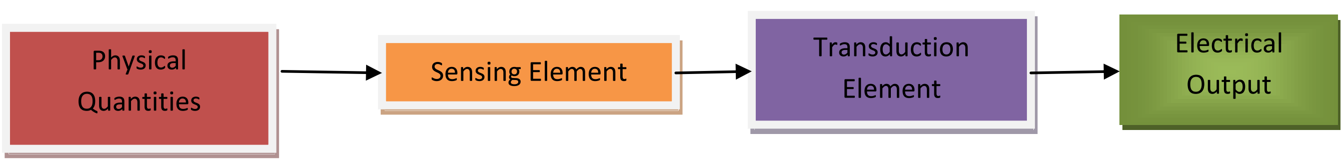


Fig. 1. Block Diagram of a transducer

- Transducer contains two parts such as the sensing element and transduction element.
- The sensing element is called as the sensor which is producing measurable response to change in physical conditions.
- The transduction element converts the sensor output to suitable electrical form.

Explain the working principle of a transducer/ What is the function of the sensing element in a transducer? / Mention the working principle of a system which is used to convert the physical quantities into electrical output.

ELECTION CRITERIA OF THETRANSDUCERS

- Operating principle: The transducers are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive, optoelectronic, piezo-electric etc.
- Sensitivity: The transducer must be sensitive enough to produce detectable output.

- Operating range: The transducer should maintain the range requirement and have a good resolution over the entire range.
- Accuracy: High accuracy is assured
- Errors: The transducer should maintain the expected input-output relationship as described by the transfer function so as to avoid errors.
- Environmental capability: It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.
- Insensitive to unwanted Signal: The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.
- Stability: The transducer must be stable.

Explain the election criteria of a transducer

Classification of Transducer

On the basis of the nature of the output signal

- Transducers are divided into two categories such as analog transducer and digital transducer.
- ***Analog Transducer:*** Analog transducers converts input signal into output signal, which is a continuous function of time. Example: Strain guage, Thermocouple etc.
- ***Digital Transducer:*** Digital transducers converts input signal into the output signal in the form of pulses e.g. it gives discrete output.

Digital transducers are becoming more popular nowadays because of advantages associated with digital measuring instruments and also due to the fact that digital signals can be transmitted over a long distance without causing much distortion due to amplitude variation and phase shift.

Why does digital transducer more advantageous than analog transducer?

On the basis of the method of applications

- Transducers are divided into two categories. Such as primary transducer and secondary transducer.
- ***Primary Transducer:*** When the input signal is directly sensed by the transducers and physical phenomenon is converted into the electrical form directly then such a transducer is called the primary transducer. For example: A THERMISTOR used for the measurement of temperature fall I this category. The THERMISTOR senses the temperature directly and causes the change in resistor with the change in temperature.

Why thermistor is called primary transducer?

- ***Secondary Transducer:*** When the input signal is sensed first by some detector or sensor and then its output being of some form other than input signal is given as input to a transducer for conversion into electrical from, them such a transducer falls in the category of secondary transducers. For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement. Then, the displacement is converted into an output voltage by an LVDT. In this case LVDT is a secondary transducer.

Why LVDT is called secondary transducer?

On the basis of methods of energy conversion used

- Transducer may be classified into active and passive transducers.
- ***Active transducer:*** The transducers which develop their output in the form of electrical voltage or current without any auxiliary source. Normally such transducers give very small outputs; therefore, use of amplifier becomes essential. For example TACHO generators used for measurements of angular velocity, thermocouples used for measurement of temperature, piezoelectric crystal used for measurement of force.
- ***Passive Transducer:*** Transducers in which electrical parameters i.e resistance, inductance or capacitance changes with the change in input signal, are called the passive transducers. These transducers require external power source for energy conversion. In such transducers electrical parameters i.e. resistance inductance or capacitance causes a change in voltage, current or frequency of the external power source. For example resistive, capacitive, and inductive transducers.

Lesson Two: Optoelectronics Transducer

Learning Outcomes:

After the ending of the lesson, students will be able to know

- About different types of optoelectronics transducer.
- The operating principle of different types of optoelectronics transducer.
- The operating principle of piezoelectric transducer.
- The advantages and limitations of piezoelectric transducer.

Photoelectric Transducer

The photoelectric transducer converts the light energy into electrical energy.

Basic principle

- Photoelectric transducers are typically made of semiconductor material called photosensitive element, which ejects the electrons when the beam of light absorbs through it.
- The discharges of electrons vary the property of the photosensitive element. Hence the current/voltage/changes of resistance induce in the devices.
- The magnitude of this change is equal to the total light absorbed by the photosensitive element.
- The absorption of light energizes the electron of the material, and hence the electrons start moving. The mobility of electrons produces one of the three effects.
  - ✓ The resistance of the material changes.
  - ✓ The output current of the semiconductor changes.
  - ✓ The output voltage of the semiconductor changes.

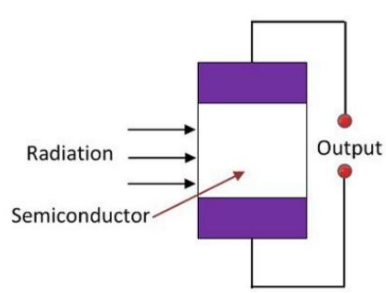


Fig.1. Photo-electric Transducer

Types of Photoelectric Transducers

- Photo-emissive cell
- Photo-conductive cell
- Photo-voltaic cell
- Photodiode
- Phototransistor

Photo-emissive cell

- It consists of the anode rode and the cathode plate. Both are coated with photoemissive material called cesium antimony.
- When the radiation of light fall on cathode plates the electrons starts flowing from anode to cathode.
- Both the anode and the cathode are sealed Photo-emissive cell in a closed, opaque evacuated tube. When the radiation of light fall on the sealed tube, the electrons starts emitting from the cathode and moves towards the anode. The anode is kept to the positive potential. Thus, the photoelectric current starts flowing through the anode. The magnitude of the current is directly proportional to the intensity of light passes through it.

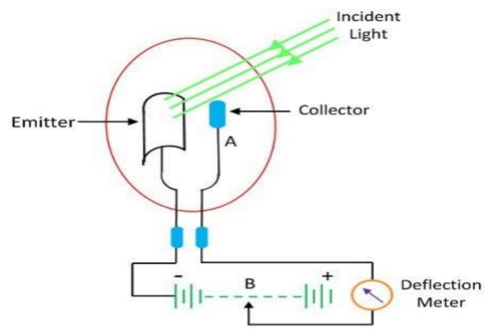
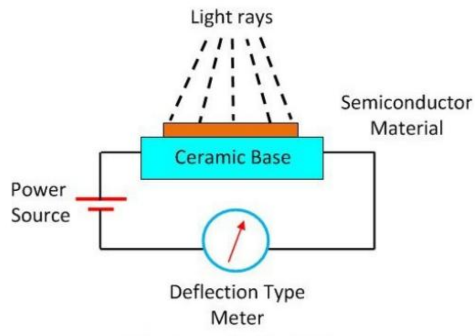


Fig.2. Photo-emissive

Photoconductive cell

- It converts the light energy into an electric current.
- Semiconductor material likes CdSe, GeSe, as a photo sensing element.
- When the beam of light falls on the semiconductor material, their conductivity increases works like a closed switch.



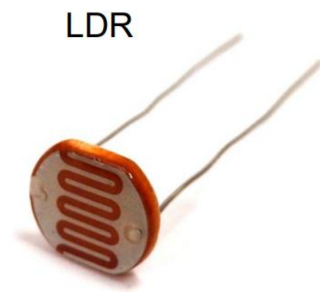


Fig.3. Photoconductive Cell

Photovoltaic cell

- It is one kind of active transducer.
- The current starts flowing into the photovoltaic cell when the load is connected to it.
- Si and Se are used as a semiconductor material.
- When the semiconductor material absorbs light, the free electrons of the material starts moving. This phenomenon is known as the photovoltaic effect.
- The movements of electrons develop the current in the cell, and the current is known as the photoelectric current.

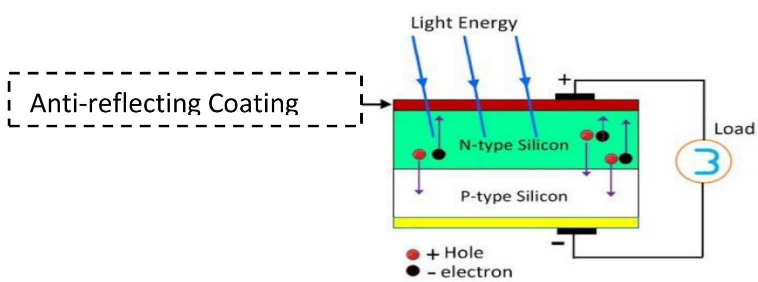


Fig.4. Photovoltaic Cell

Photodiode

- The photodiode is a semiconductor material which converts the light into the current.
- It's basically a PN junction designed to operate in reverse bias.
- The electrons of the semiconductor material start moving when the photodiode absorbs the light energy. The response time of the photodiode is very less.

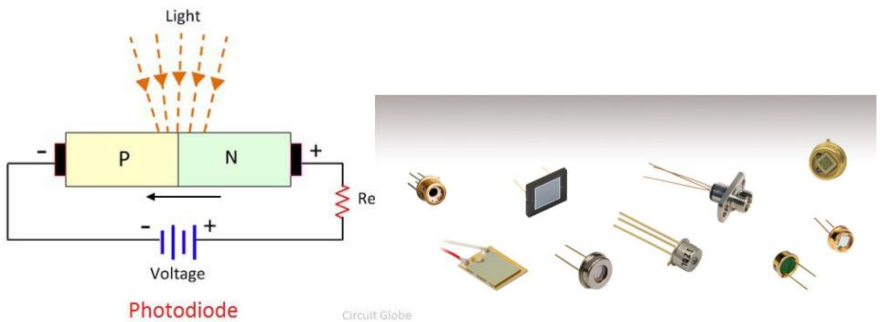


Fig.5. Photodiode

Phototransistor

- It produces both the current and voltage.
- The photovoltaic cell is a bipolar device which is made of semiconductor material.
- The semiconductor material is enclosed in an opaque container in which the light easily reaches to the photosensitive element.
- The Phototransistor element absorbs light, and the current starts flowing from base to emitter of the device. This current is converted into the voltages.

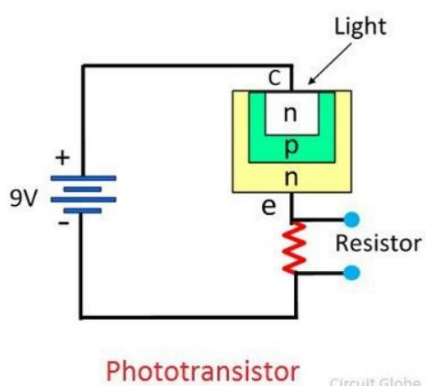
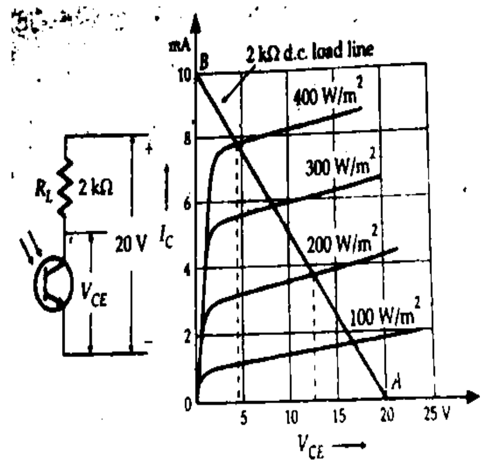


Fig.6. Phototransistor

Math Problem: A photo transistor of circuit shown in the following figure has a supply voltage of 20V and a collector load resistance of 2 Kilo-ohm. Determine the output voltage when illumination level is (a) Zero (b) 200 W/m^2 (c) 400 w/m^2



Lesson Three: Piezoelectric Transducer

Learning Outcomes:

After the ending of the lesson, students will be able to know

- The operating principle of piezoelectric transducer.
- The equivalent circuit of a piezoelectric transducer.
- The advantages and limitations of piezoelectric transducer.
- Mathematical solution procedure of piezoelectric transducer.

PIEZOELECTRIC EFFECT

There are certain materials that generate electric potential or voltage when mechanical strain is applied to them or conversely when the voltage is applied to them, they tend to change the dimensions along certain plane. This effect is called as the **PIEZOELECTRIC EFFECT**. This effect was discovered in the year 1880 by Pierre and Jacques Curie.

PIEZOELECTRIC TRANSDUCERS

- The piezoelectric transducers work on the principle of PIEZOELECTRIC EFFECT. When mechanical stress or forces are applied to some materials along certain planes, they produce electric voltage.
- This electric voltage can be measured easily by the voltage measuring instruments, which can be used to measure the stress or force.
- The voltage output obtained from the materials due to piezoelectric effect is very small and it has high impedance.
- To measure the output some amplifiers, auxiliary circuit and the connecting cables are required.

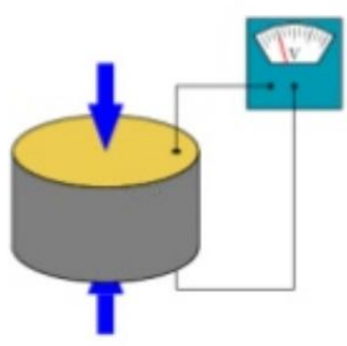


Fig. 7. Piezoelectric Transducer

Circuit Diagram of Piezoelectric Crystal

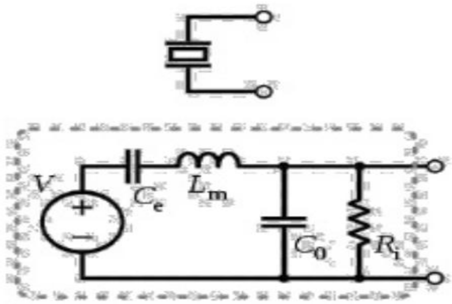


Fig.8. Circuit Diagram of Piezoelectric Crystal

Working Principle of Piezoelectric Crystal

- The figure shows a conventional piezoelectric transducer with a piezoelectric crystal inserted between a solid base and the force summing member.
- If a force is applied on the pressure port, the same force will fall on the force summing member.
- Thus a potential difference will be generated on the crystal due to its property.
- The voltage produced will be proportional to the magnitude of the applied force.

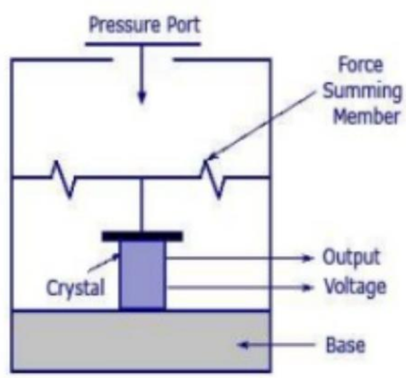


Fig.9. Piezoelectric Transducer

Advantages

- **High frequency response:** They offer very high frequency response that means the parameter changing at very high speeds can be sensed easily.

- **High transient response:** The piezoelectric transducers can detect the events of microseconds and also give the linear output.
- **Small size and Rugged Construction:** The piezoelectric transducers are small in size and have rugged construction.

Limitations

- **Low Output:** The output obtained from the piezoelectric transducers is low, so external electronic circuit has to be connected.
- **High impedance:** The piezoelectric crystals have high impedance so they have to be connected to the amplifier and the auxiliary circuit, which have the potential to cause errors in measurement. To reduce these errors amplifiers high input impedance and long cables should be used.
- **Forming into shape:** It is very difficult to give the desired shape to the crystals with sufficient strength.

Lesson Four: Pulse Width Modulation

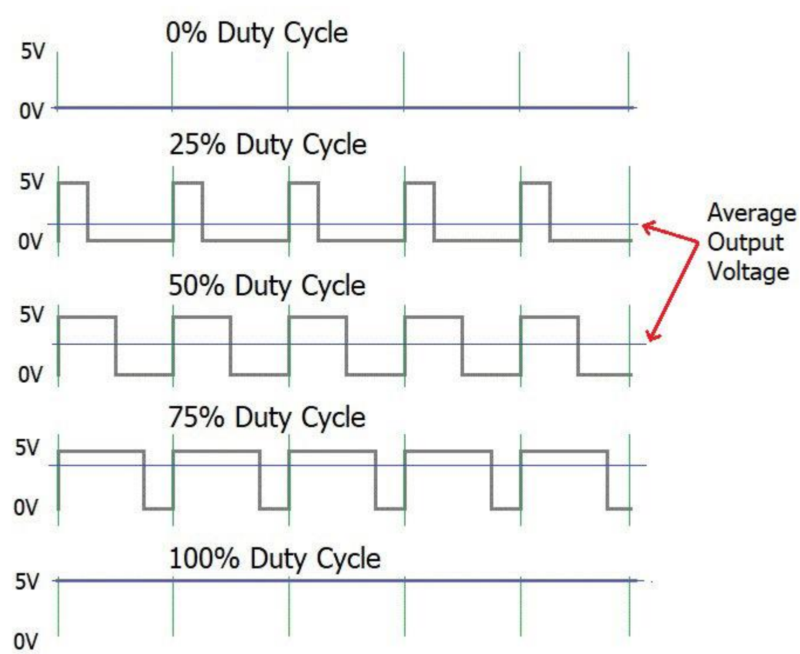
Learning Outcomes:

After the ending of the lesson, students will be able to know

- About different types of pulse width modulation techniques.
- Pulse generation process
- Effect of total harmonics distortion.
- Applications of pulse width modulation
- Advantages and disadvantages of different types of pulse width modulation.

Pulse Width Modulation

- Pulse width modulation is one kinds of switching techniques where different width of pulses is generated from an analog signal. It has two components. One is duty cycle and another is frequency.
- The duty cycle describes the amount of time the signal is in a high (on) state as a percentage of the total time of it takes to complete one cycle.
- The frequency determines how fast the PWM completes a cycle (i.e. 1000 Hz would be 1000 cycles per second), and therefore how fast it switches between high and low states.
- Although this modulation technique can be used to encode information for transmission.
- Its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors.



Different Types of Pulse Width Modulation

- SINGLE-PULSE WIDTH MODULATION
- MULTIPLE-PULSE WIDTH MODULATION
- SINUSOIDAL PULSE WIDTH MODULATION
- TRAPEZOIDAL PULSE WIDTH MODULATION
- SIXTY DEGREE SINUSOIDAL PULSE WIDTH MODULATION
- STAIRCASE PULSE WIDTH MODULATION etc.

Harmonics

Harmonics are integer multiples of a fundamental frequency. If the fundamental frequency is 5-kHz:

- 1st harmonic 1 x 5kHz
- 2nd harmonic 2 x 5kHz
- 3rd harmonic 3 x 5kHz
- 4th harmonic 4 x 5kHz etc.

Note that the 1st and 3rd harmonics are called odd harmonics and the2nd and 4th are called even harmonics.

Effect of Total Harmonic Distortion

As total harmonic distortion (THD) has an adverse effect on equipment and conductor. Higher THD offers increased heating loss, arising false triggering, and a reduced lifetime of devices. In addition, it also increases the cost and size of the filtering devices. Then again, inferior THD offers an advanced power factor, lesser pick currents, and higher efficiency. That is why it is very essential to diminish the THD of the multilevel inverter.

M. T. Islam, M. R. Islam, M. S. B. Islam and M. S. Rahman, "Improvement in Performance of Asymmetric Multilevel Inverter Used for Grid Integrated Solar Photovoltaic Systems," 2019 5th International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, Bangladesh, 2019, pp. 91-96.

SINGLE-PULSE WIDTH MODULATION

- Single pulse for half cycle generates from this techniques.
- It consists of a pulse located symmetrical about π/2 and another pulse located symmetrical about 3π/2.
- The shape of the output voltage is Quasi-Square wave.
- Great deal of harmonic content is introduced in the output voltage.
- The amplitude of harmonic content is 0.33 units.
- Very poor performance at lower voltages.

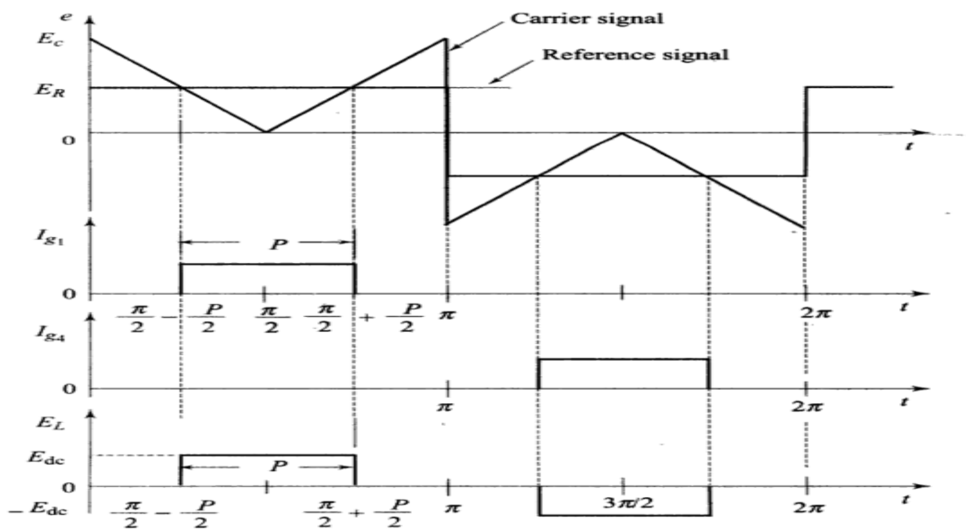


Fig.1. Single Pulse Width Modulation

MULTIPLE-PULSE WIDTH MODULATION

- It is an extension to single pulse width modulation.
- More pulses will exist in a half cycle.
- The width of every single pulse is same. Comparator Trigger pulse generator Triangular wave Square wave Trigger pulses to SCR.
- The lower order harmonics are eliminated.
- The magnitude of higher harmonics would go up.
- This has more applications than single-pulse width modulation in olden days.

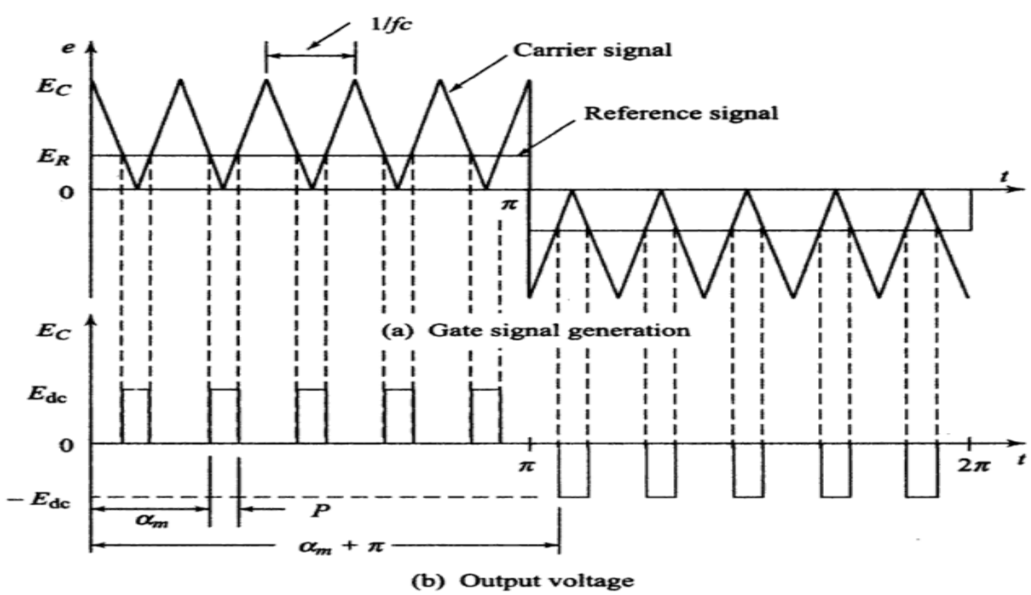


Fig.2. Multiple Pulse Width Modulation

SINUSOIDAL PULSE WIDTH MODULATION

- Pulses will have different widths.
- The width of the individual pulse will be decided according to the angular position of sine wave.
- Height of the pulse is kept as constant
- Odd multiple of 3 and even harmonics are suppressed
- Popularly accepted pulse width modulation technique.

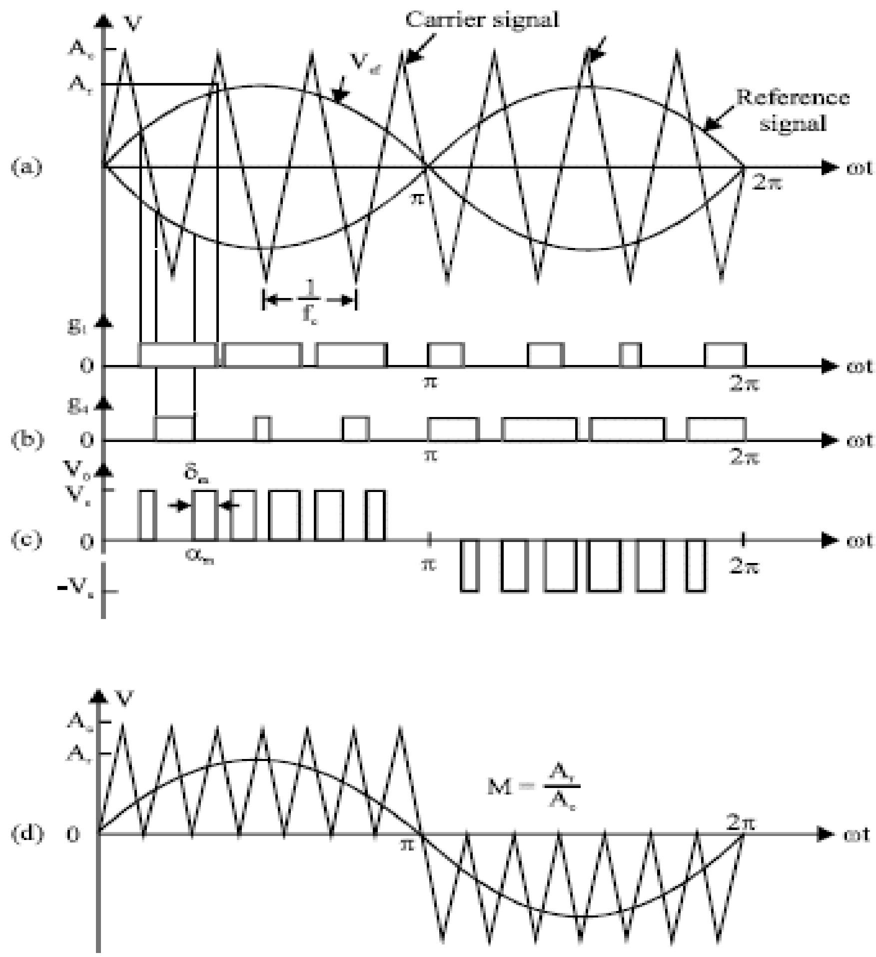


Fig.3. Sinusoidal Pulse Width Modulation Process.

Trapezoidal Pulse Width Modulation

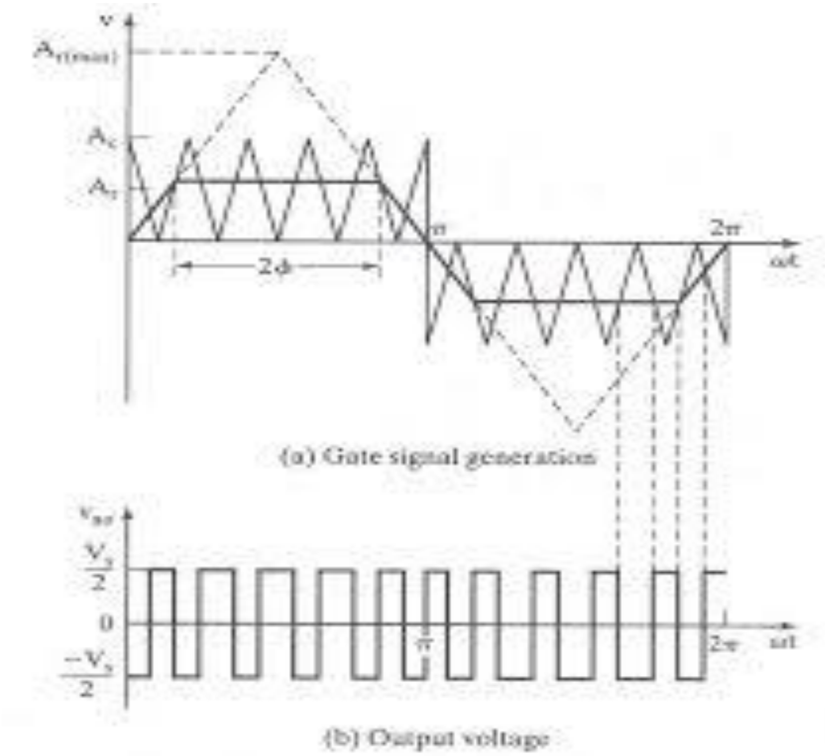


Fig.4. Trapezoidal Pulse Width Modulation

Lesson Five: Power Amplifier

Learning Outcomes:

After the ending of the lesson, students will be able to know

- About the operating principle of Class A, B, AB, C, and D power amplifier circuit
- The comparison among different power amplifier circuit.
- About crossover and amplifier distortion.
- Calculation procedure of efficiency.

Introduction

In small-signal amplifiers the main factors are:

- Amplification
- Linearity
- Gain

Since large-signal, or power, amplifiers handle relatively large voltage signals and current levels, the main factors are:

- Efficiency.
- Maximum power capability.
- Impedance matching to the output device.

Amplifier Types

- **Class A:** The amplifier conducts through the full 360 degree of the input. The Q-point is set near the middle of the load line.
- **Class B:** The amplifier conducts through 180 degree of the input. The Q-point is set at the cutoff point.
- **Class AB:** This is a compromise between the class A and B amplifiers. The amplifier conducts somewhere between 180 degree and 360 degree. The Q-point is located between the mid-point and cutoff.
- **Class C:** The amplifier conducts less than 180 of the input. The Q-point is located below the cutoff level.
- **Class D:** This is an amplifier that is biased especially for digital signals.

Comparison among different types of Amplifier Circuit

Subject	Class A	Class AB	Class B	Class C	Class D
Operating Cycle	360	180 to 360	180	Less than 180	Pulse operation
Power efficiency	25% to 50%	Between 25% and 78.5%	78.5%		Typically over 90%

Response of Different types of Power Amplifier

Class A Amplifier

- The output of a class A amplifier conducts for the full 360 degree of the cycle.
- The Q-point is set at the middle of the load line so that the AC signal can swing a full cycle.
- Remember that the DC load line indicates the maximum and minimum limits set by the DC power supply.

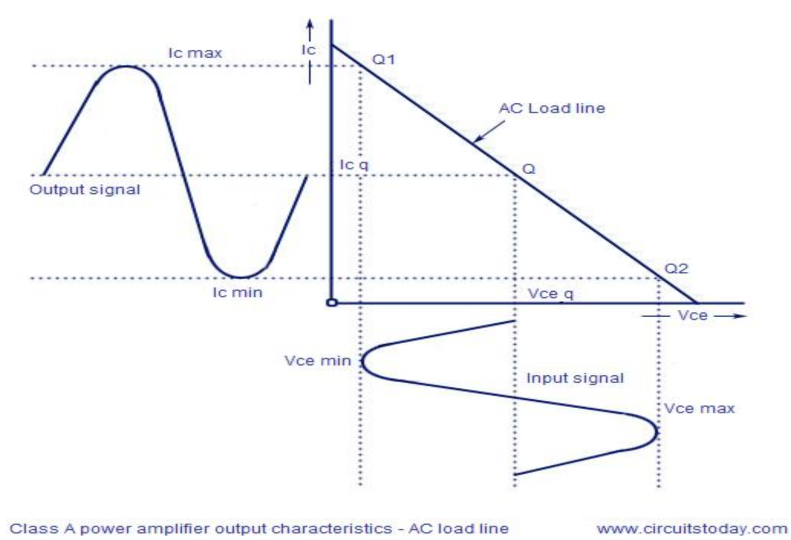


Fig.1. Response of Class A amplifier

Class B Amplifier

- A class B amplifier output only conducts for 180 degree or one-half of the AC input signal.
- The Q-point is at 0V on the load line, so that the AC signal can only swing for one-half cycle.

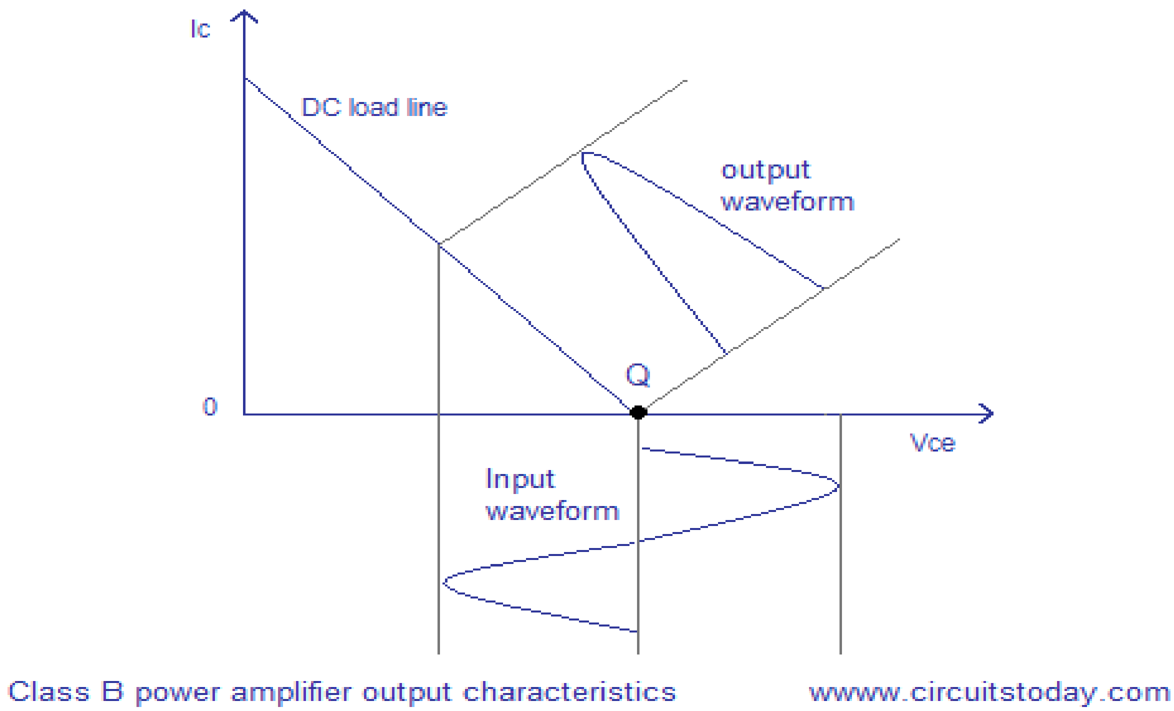


Fig.2. Response of Class B amplifier

Class AB Amplifier

- This amplifier is a compromise between the class A and class B amplifier.
- The Q-points is above that of the Class B but below the class A.
- The output conducts between 180 degrees and360 degrees of the AC input signal.

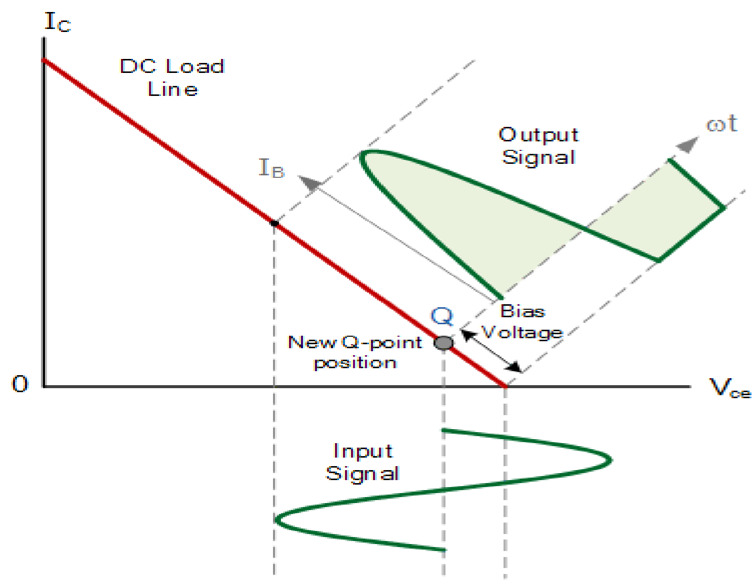


Fig.3. Response of Class AB amplifier

Class C

- The output of the class C conducts for less than 180 degree of the AC cycle.
- The Q-point is below cutoff

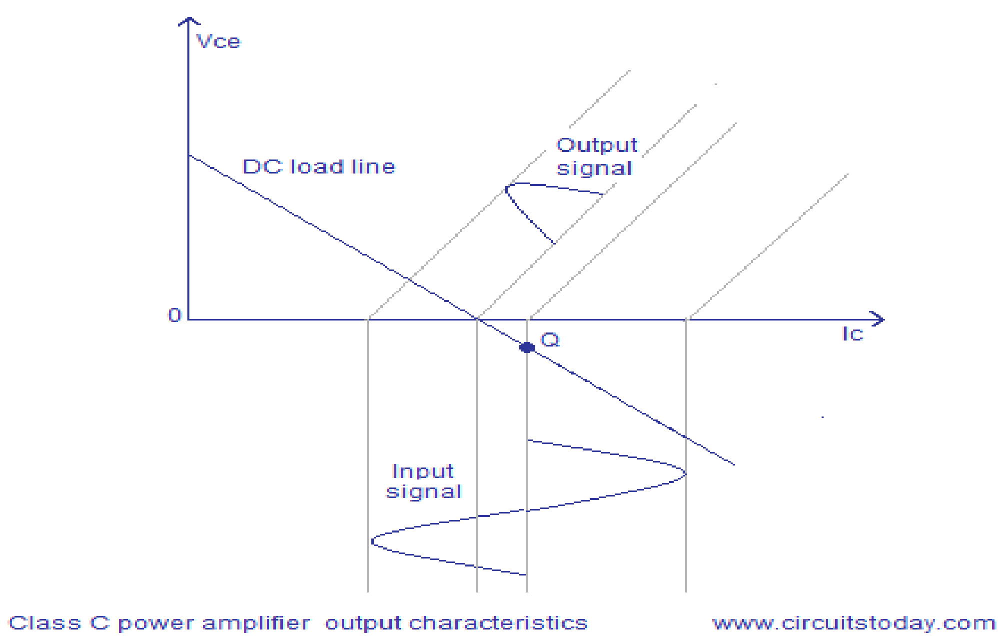


Fig.4. Response of Class C amplifier.

Transformer-Coupled Class A Amplifier

This circuit uses a transformer to couple to the load. This improves the efficiency of the Class A to 50%.

Transformer-Coupled Class A Amplifier

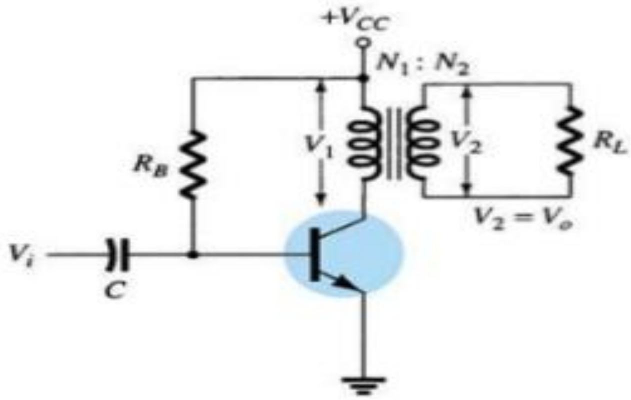
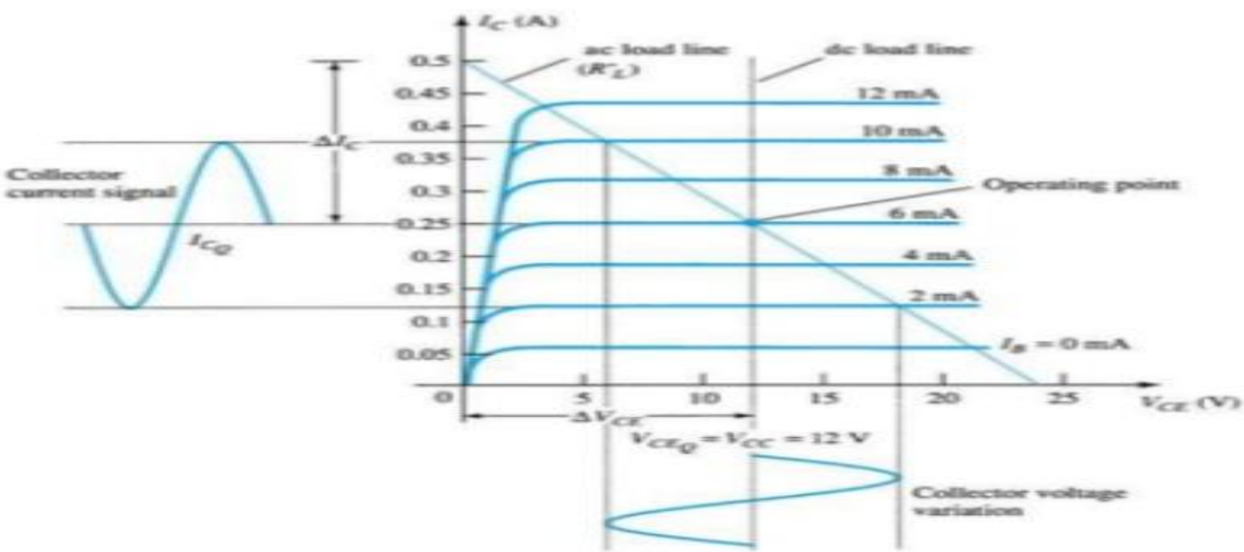


Fig.5. Transformer-Coupled Class A amplifier

DC Load Line: As in all class A amplifiers the Q-point is established close to the midpoint of the DC load line. The dc resistance is small ideally at 0Ω and a dc load line is a straight vertical line.

AC Load Line: The saturation point (I_{Cmax}) is at Vcc/R_L and the cutoff point is at V2 (the secondary voltage of the transformer). This increases the maximum output swing because the minimum and maximum values of I_C and V_{CE} are spread further apart.



Efficiency Calculation of Class A amplifier

Signal Swing and Output AC Power

The voltage swing:

$$V_{CE(p-p)} = V_{CEmax} - V_{CEmin}$$

The current swing:

$$I_{c(p-p)} = I_{C\max} - I_{C\min}$$

The AC power:

$$P_{o(ac)} = \frac{(V_{CEmax} - V_{CEmin})(I_{Cmax} - I_{Cmin})}{8} (\max imum)$$

Power input from the DC source:

$$P_{i(dc)} = V_{CC} I_{CQ}$$

Power dissipated as heat across the transistor:

$$P_Q = P_{i(dc)} - P_{o(ac)}$$

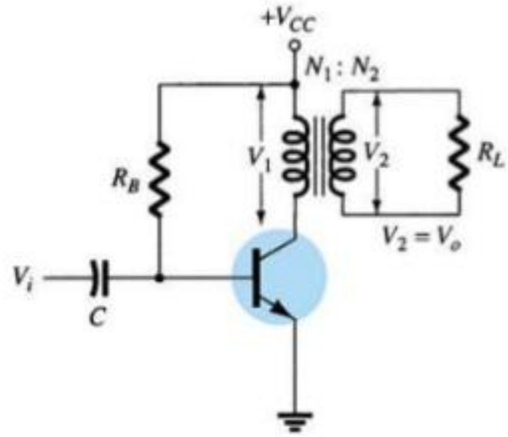
Note: The larger the input and output signal, the lower the heat dissipation.

Maximum efficiency:

$$\%\eta = 50\left(\frac{V_{CEmax} - V_{CEmin}}{V_{CEmax} + V_{CEmin}}\right)^2$$

Note: The larger V_{CEmax} and smaller V_{CEmin}, the closer the efficiency approaches the theoretical maximum of 50%.

Example: Calculate the efficiency of a transformer coupled class A amplifier for a supply of 12V and output of 6V.



Class B Amplifier

- In class B, the transistor is biased just off.
- The AC signal turns the transistor on.
- The transistor only conducts when it is turned on by one-half of the AC cycle.
- In order to get a full AC cycle out of a class B amplifier, you need two transistors: An npn transistor that provides the negative half of the AC cycle. A pnp transistor that provides the positive half.

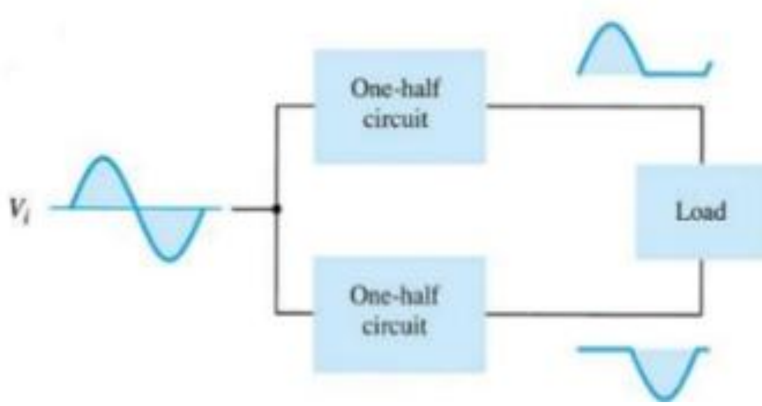


Fig.6. Operating Principle of Class B amplifier

Efficiency Calculation of Class B Amplifier

The maximum efficiency of a class B is 78.5%..

$$\%\eta = \frac{P_{o(ac)}}{P_{i(dc)}} \times 100$$

$$\text{maximum} P_{o(dc)} = \frac{V_{CC}^2}{2R_L}$$

For maximum power, $V_L = V_{CC}$

$$\text{maximum} P_{i(dc)} = V_{CC}(\text{maximum} I_{dc}) = V_{CC}\left(\frac{2V_{CC}}{\pi R_L}\right) = \frac{2V^2_{CC}}{\pi R_L}$$

Transformer-Coupled Push-Pull Class B Amplifier

- The center-tapped transformer on the input produces opposite polarity signals to the two transistor inputs. T
- The center-tapped transformer on the output combines the two halves of the AC waveform together.

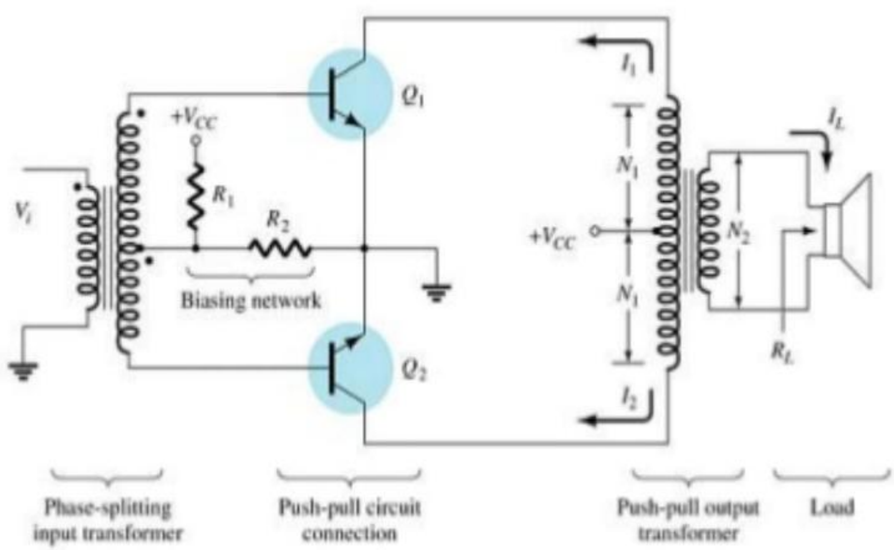


Fig.7. Circuit Diagram of Class B amplifier

Class B Amplifier Push-Pull Operation

- During the positive half-cycle of the AC input, transistor Q1 (npn) is conducting and Q2 (pnp) is off.
- During the negative half-cycle of the AC input, transistor Q2 (pnp) is conducting and Q1 (npn) is off.
- Each transistor produces one-half of an AC cycle.
- The transformer combines the two outputs to form a full AC cycle.

Crossover Distortion

If the transistors Q1 and Q2 do not turn on and off at exactly the same time, then there is a gap in the output voltage. This situation is called crossover distortion which is shown in the following figure.

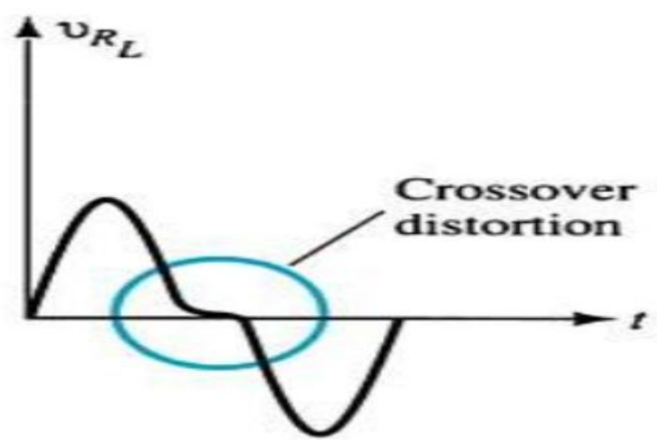


Fig.8. Problem of class B amplifier

Quasi-Complementary Push-Pull Amplifier

- A Darlington pair and a feedback pair combination perform the push-pull operation.
- This increases the output power capability.

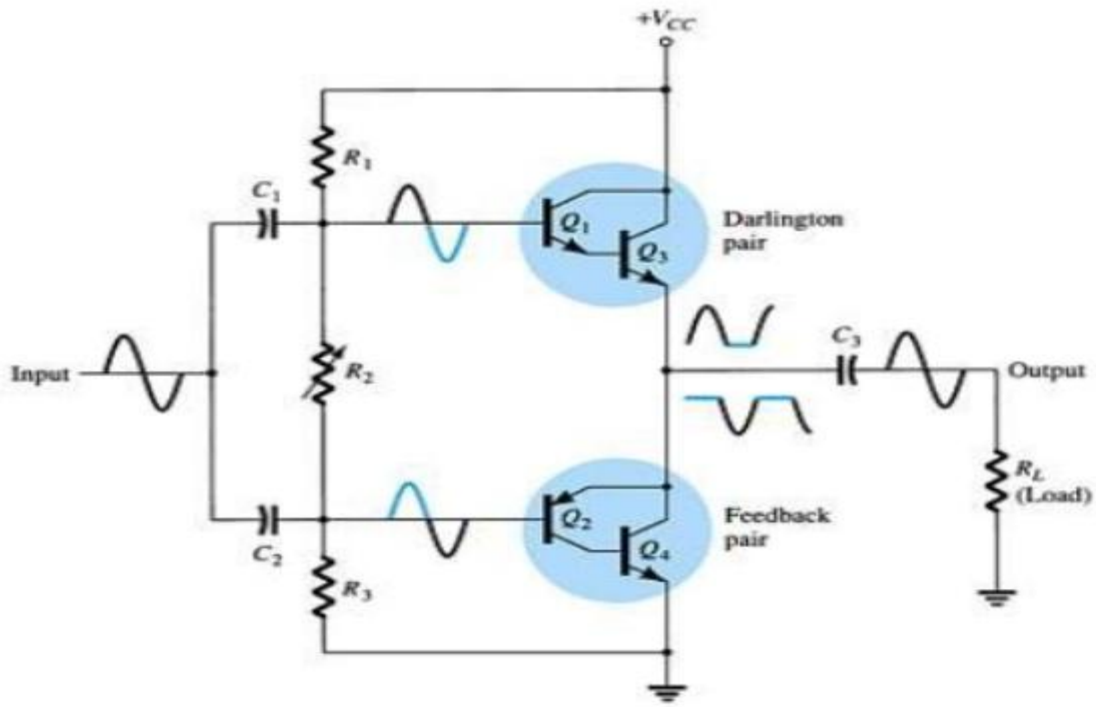


Fig.9. Quasi-Complementary Push-Pull Amplifier

Amplifier Distortion

If the output of an amplifier is not a complete AC sine wave, then it is distorting the output. The amplifier is non-linear. This distortion can be analyzed using Fourier analysis. In Fourier analysis, any distorted periodic waveform can be broken down into frequency components. These components are harmonics of the fundamental frequency.

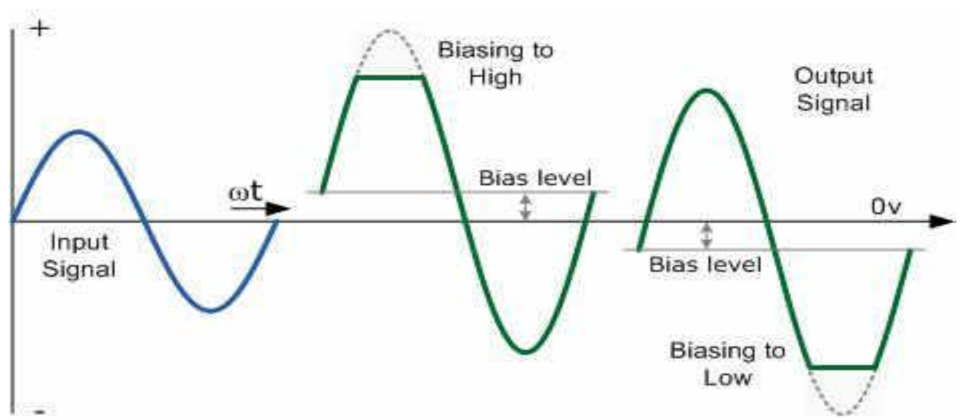


Fig.10. Amplifier Distortion

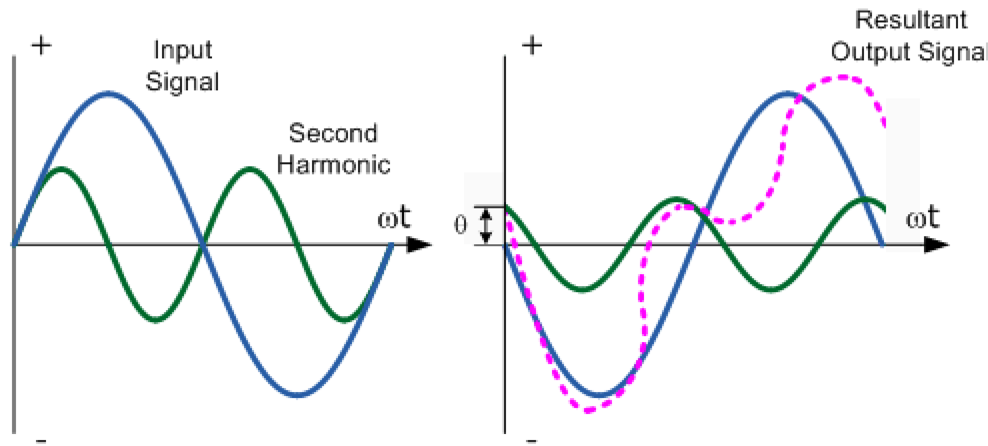


Fig.11. Amplifier Distortion

Class C Amplifiers

- A class C amplifier conducts for less than 180 degree.
- In order to produce a full sine wave output, the class C uses a tuned circuit (LC tank) to provide the full AC sine wave.
- Class C amplifiers are used extensively in radio communications circuits.

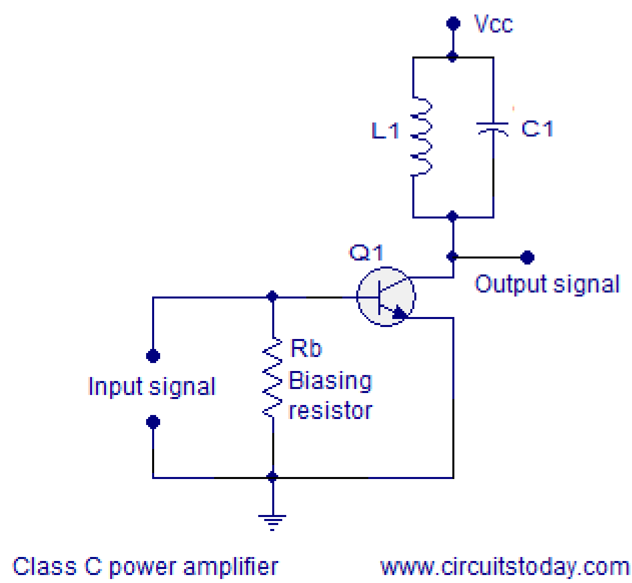


Fig.12. Class C amplifier Circuit

Class D Amplifier

- A class D amplifier amplifies pulses, and requires a pulsed input.
- There are many circuits that can convert a sinusoidal waveform to a pulse, as well as circuits that convert a pulse to a sine wave.
- This circuit has applications in digital circuitry.

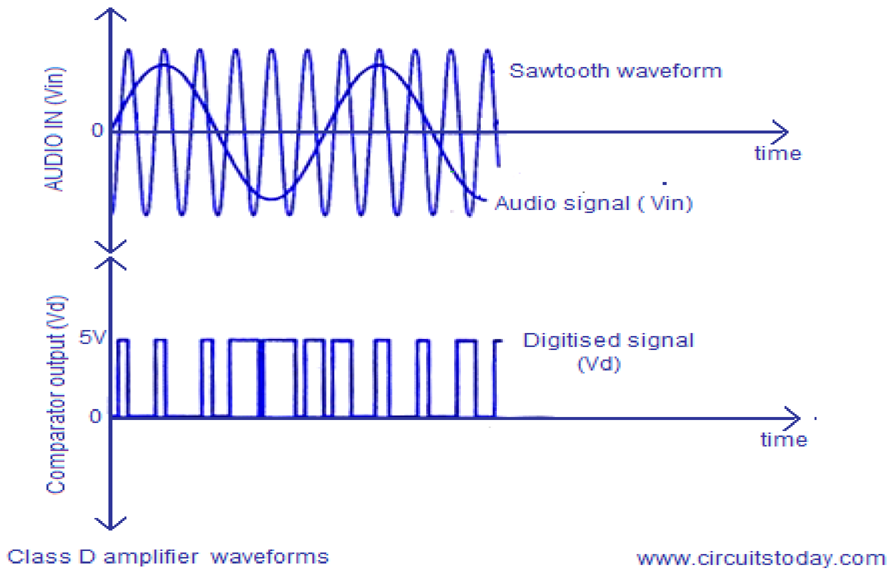


Fig.13. Operating principle of Class D amplifier