CHAPTER 1

INTRODUCTION
CHAPTER 1: INTRODUCTION

Electronics is the study and use of electrical devices that operate by controlling the flow of electrons or other electrically charged particles in devices as thermionic valves and semiconductors. The pure study of such devices is considered as the branch of physics, while the design and construction of electronic circuits to solve the practical problems is called electronic engineering.

The main use of electronic circuits is controlling, processing and distribution of information and the conversion and distribution of electromagnetic power. Both of these uses involve the creation or detection of electromagnetic fields and electric currents.

While electricity has been used for same time to transmit data over telegraph and telephones, the development of electronics truly began in the earnest with the advent of Radio. Today, electronic devises perform a much wider variety of tasks.

One way of looking at an electronic system is it divides it into the following parts-

1. **Inputs**- Electrical or mechanical sensors (or transducers), which take signals from world and convert them into current/voltage signals.
2. **Signal Processing** - These consist of electronic components connected together to manipulate, interpret and transform.

3. **Outputs** - Actuators or other devices (also transducers) that transform current/voltage signals back into useful physical form.

Television is an example of such electronic system. Its input is a broadcast signal received by an antenna or fed in through a cable. Signal processing circuits inside the T.V. extract the brightness, color and information from the signal. The output devices are a cathode ray tube that converts electronic signal into a visible image on a screen and magnet driven audio speakers.

### 1.1 Historical Background of Electronics

#### 1.1.1 Concept of Electronics

It is very difficult to say about the birth and origin of electronics. Many of the scholars have searched about this but the exact answer could not be found. Here a brief history of electronics is given.

In past the extraordinary people of Greek and India were able to send messages from one place to the other. But no one can say about there communication device. Were they using any kind of wireless devices, whose components are electronic as today's wireless devices. There is no clear idea of those technologies or no proof that whether they were using those things.
1.12 ELECTRONICS FROM START TILL PRESENT

Like the history of a nation from which its people get inspired, the history of any science inspires its future generation, so we are interested to look at the past. That is why we are enjoying all the well developed equipments provided by electronics in twenty first century. Even more than that those who spent there whole life for the inventions / discoveries, they did not do that for themselves rather they did it for whole society, the whole world. So we should tribute them. This electronic world was not just the effort of some years or decades; rather it is the result of hard work of great minds since ages. So, now it is the time to remember them. The history of electronics mainly lies in twentieth century and the three main devices invented were vacuum tubes, transistors and integrated circuits. Today the whole electronic world is dependent on these components.

History of electronics starts before twentieth century. This time is considered as pre-development era in the growth of electronic technology because before twentieth century there was almost no electronics in the daily life of a common man. Electrical engineering is regarded as the parent of electronics that’s why the study of origin of electronics is started from electrical engineering. The formal beginning of electrical engineering goes back to eighteenth century when Franklin gave the explanation of thunder and lightening. It was a big mystery that time. But the lucid explanation of Franklin gave the first idea of charge flow and its consequences.
Initially, though the concept of charge was there before Coulomb but this could not be given by any mathematical expression that could define the electrical charge in a proper way. Coulomb also invented the torsion balance and that helped him to calculate the force of interaction between the electrical charges, which is today known as coulomb's force after his name.

Thereafter the next big name was Luigi Galvani who discovered the so called bio-electricity from his famous experiment using the frog leg. He thought that electricity is one of the sources of life. That created some ideas that electricity was related to life that time. But anyway, his frog leg experiment gave some solid basis to the future researchers to develop the concept of potential difference.

The mystery of the frog leg experiment was disclosed by Allessandro Volta. He repeated Galvoni frog leg experiment using various types of electrodes. Thereafter he concluded that the spark in the frog leg experiment is not due to frog leg rather it has a different reason. He told that when the Cu and Zn electrodes are kept in acid there arises some potential difference between electrodes and the charge flows from one to the other if there is any physical connection between them through some conducting wire. That was the first electric cell made by Volta. After his name the potential difference is also known as voltage.

But it was not known why some energy in the form of potential difference is required to make the charges flow from one end to the other. The explanation came from the German scholar George Simon Ohm. He for the first time introduced the concept of resistance and conductance. In almost all
the conductors there some resistance that opposes the flow of current through them. That's why the charges cannot flow in conductors without the presence of any energy source in the form of potential difference. Then it was proved that potential difference is very important to keep the charge moving from one end to the other in a conductor. At that time chemical cells were the main source of electricity.

In the next phase started the real victory of the electrical engineering. Under the leadership of Michel Faraday. He not only gave birth to some interesting theories but himself invented some fundamental electrical machines like transformer and electric motors. Faraday was a poor child who had always aims to do something big in the scientific research. He got the opportunity from the then big name Humphrey Davy. After that Faraday never looked back. He gave many fundamental theories which are like the back bone to the electrical sciences. The concept of lines of forces was not accepted community but was later found to be the fundamental fact of electromagnetism. He first gave the knowledge of electrical power generation and made the first transformer of the world. But it was a bit strange that he himself did not have the idea that his discoveries will some day change the science of the world. Faraday's laws of electrolysis were beneficial to both the chemist and physicists of that time. That also a fundamental tool to prove that the electric charges are quantized. He also gave the concept of inductance which was also developed by another great of that time, Joseph Henry. Lenz was there to modify Faraday's second law of induction. So the electrical engineering was unstoppable and running really fast to be the most attractive science at that time.
Now, in the pre-twentieth century electronics was developing at a slow rate but after that electronics started growing at rapid rate and then it had its individual recognition. The journey starts from the invention of radio by the Italian genius Marconi and the work of Henry Hertz opened the road to further discoveries and inventions. Vacuum tube was invented in the first ten years of 20th century. It was an important device came in the electronic world. The vacuum tube at that time worked as a miraculous component for the radio devices.

Marconi's radio needs some good detectors for the receiving of the incoming radio waves. For that reason a good rectifier was needed which can convert the AC into DC. There were already many AC generating stations and AC was getting very popular. So, the engineers were planning to change AC into DC instead of producing the expensive DC. The duo to Tesla and Westinghouse brought many exciting features to the AC at all time. The invention of the induction motor by Tesla was a revolution in the use of AC.

Someone brings the breakthrough when all the great minds are in need. This happened again. The then famous engineer physicist Fleming found an alternative to the DC production. He invented the first vacuum tube using the principle known as "Edison Effect". According to the Edison effect when there is a small separation in between the two conductors connected to a source of electricity and are heated then there can be a current in the conductor. That means the vacuum in between the conductors become a good carrier. That idea was actually in the brain of Sir Ambrose Fleming. So, he tried to do something which can demonstrate the Edison Effect.
But when he tested his newly invented device he was happy to find that it can work as a rectifier, means which can change AC into DC. History was created. This was the real birth of electronics. Here starts a new chapter in the history of human being. At that time Marconi’s radio was badly needing some good detectors. This vacuum tube filled that need. It had two electrodes and that’s why it was named as diode. It was the first diode and the main motivation behind the solid state devices which after some decades take control of the whole world economics. Just after two years of Fleming’s diode De Frost in US, invented another similar device which was named as triode, because it had three electrodes besides cathode and anode there was a third electrode known as grid. The grid was controlling the flow of charges from the anode to the cathode. It was the growth of communication at that time. Because the amplifier was the important component in the radio and the other communication devices to strengthen the weak radio signal.

The computer was another main attraction that time. Due to the world wars there was a big need of computers for war related tasks like code breaking. During the first and second world war some computers were made for this purpose. But they were not efficient as many of them were using decimal system and all the prime components were made up of vacuum tubes.

The diode valves of early twentieth century were large enough to be inside the electronic devices and they had many other problems like high power consumption, low reliability and the requirement of good cooling arrangement etc, so the electrical engineers and physicist at that time tried for the developments of some alternatives which can fill up the place of troublesome vacuum tube in case of both the detectors and amplifiers. At
that time physics of solids was also on its way to bloom. Many theories like Fermi-Dirac equations had opened the wide scale research on the solids. In Bell labs the scientists were desperately looking for some alternative to the vacuum diodes and triodes for communication technology.

After the end of the horrible world war2 the world took some rest. But the scientific community who were working in the war forcefully or by the motivation of the country’s top leaders did not rest. Rather they started their original intended work places. The Scenario in the US was also not much different. After the war the economy was weak. So the industrial research was mainly focused in the economic development. Bell labs too took some leading in the development of the communication sciences. The research group in the bell labs found that the existing technology and the devices for better communication were not available at that time. So their main concern was to find some alternative for the existing amplifiers. The valve amplifiers were the main obstacle in the road of progress. So, they looked for some solid state devices. The findings of Russell Ohl had confirmed that the pure silicon when doped with some impurities as tri and penta valent materials can be used as two layers of pn junction diode. They had some foresight that the junction phenomenon may be used for the building of a new amplifier. The group led by William Shockley was investigating theses facts.

Fortune favours the brave. The auspicious day came and the science started growing at an exponential rate there after. Thanks to the genius of three young scientists of the BELL labs. They found a new concept known as “Transistor Effect”. It was for the first time discovered by Bardeon and Brattain. That is known as point contact transistor. That was mainly
contributed by Brattain and Bardeen who thought that the effects are mainly
due to some surface phenomenon. But Shockley was not dormant. He too
was working on something different which is today known as n-p-n
transistor. He gave the theory that the transistor effect was due to some bulk
phenomenon. After that he worked hard on the semiconductor theories and
gave a satisfactory explanation to the transistor effect.

The real electronics what it is called today started after the discovery of
transistor effect. Transistor opened the road for electronics and there after
electronics got its independent identity in electrical engineering. More
importantly it opened the road for computing world. Computers of various
types started hitting the market and the research work got a boost. Some
other problems were also there like assembling of the electronic computers
on a single motherboard. It was worsened when the metallic wires crossed
each other and crowded the mother board. Jack Kilbey in Texas Instruments
found a very nice solution. He suggested to throne away all the wires and
tried to connect the resistors, capacitors and transistors on the same piece of
wafer internally. Surprisingly his ideas worked and gave birth to integrated
circuit industry. At around the same time Shockley had left bell labs and
started his own company in California, whose name was Shockley
semiconductor. Some other brilliant young researchers also joined his
company there. Among them who were famous are Gorden Moore, Robert
Noyee and Jean Hoerni. A new type of transistor was invented in early
sixty’s which is known as MOSFET. MOSFET is slower than the junction
transistor but it is smaller, chipper and consumes less power.
In 1965 Gordon Moore came out with awe some paper called “Cramming more components on integrated circuits.” In that paper he described that the number of transistors used on a single chip of silicon will grow exponentially. In 1968 Rob Noyce and Moore left Fairchild to start Intel both of whom were very already in the field of microelectronics. In 1971 their company invented the first microprocessor well known as 4004 having 2300 transistors on one silicon chip. The credit mainly goes to the young engineer Ted Hoff. While working on a Japanese project, he found some problem integrated circuits and planned to have even large integrated circuits which can have the whole computer on a single chip. That microprocessor led the way to the successors like the 8080, 8085, 80486. Pentium series and the most modern microprocessor like Xenon too are very popular.

The concept of the integrated circuits was proposed in 1952 by Geoffrey W.A. Dummer, who was a British electronics expert with the Royal Radar Establishment. The semiconductor industry and the silicon integrated circuit evolved simultaneously at Texas Instruments and Fairchild Semiconductor Company. Integrated circuits were in full production at a number of firms by 1961. This growth of ICs changed the designs of equipments extensively. Then after Bipolar transistors and digital integrated circuits analog ICs, large – scale integration (LSI), and very large scale integration (VLSI) came in existence by mid 1970s. Today all the small and big electronic equipments are dependent on integrated circuits.

If we shall consider yesterday as history then there are many things which can be put in history each day. That is due to the rapid growth in the IT
industry, its concerned global market and the ultra fast research and development through out the world. Thus while considering the history of electronics we should take some time boundary to consider which is history and which is not. In this case let us take the things of the nineties as history. The domain name system and http were already in use just after their birth, but still the networking of the computers was not that spread. Only some universities of the US and Europe were mainly for the research purpose. At that time in CERN many researchers of the whole world were doing some research. So, a lot of varieties of computers were really a problem to share the research data. One of those researchers thought of the interconnection of the computers to form a common network. He tried it by using the existing protocols like the http, ftp and DNE etc. in addition to that he added a new framework which is now popularly known as www or the world wide web. The internet banks of the world, the whole information regarding anything are just now clicks away. It became possible due to that great person Tim Berners-Lee.

1.13 Conclusion

It is very difficult to explain the whole history of electronics in a limited scope because history of electronics consists of a lot of small and big incidents to come to its end or to reach till present time. Now, it can be said that Electronics which started as philosophy then physics then electrical engineering has now got its own identity and going to be even more diverse in the future. There is no doubt that the modern electronics as we see it today started from the birth of vacuum diode of Sir Ambrose Fleming on the
centenary year we should remember that great man and both his predecessors and successors. The changes of twentieth century are mainly due to electronics, there is no doubt about it. All the systems today are almost electronic.

So at last it can be said that History of electronics is as rich as electronics itself. Through ages the developments in electronics have started. The future seems to be very bright. The new fields like quantum communication and bioinformatics are going to be the leading area of studies in the future which can take the human civilization to a great height [1, 2, 3, 4, 5, 6].

1.2 General Introduction of Bipolar Junction Transistors and Amplifiers

1.21 Bipolar Junction Transistor

A bipolar junction transistor is a three-terminal device constructed of doped semiconductor material and may be used in amplifying or switching applications. As the conduction of current takes place due to both electrons and holes, they are named so. The flow of charges in Bipolar Junction Transistor is due to diffusion of charge carriers from high concentration emitter to the base of the device. [7, 8 9, 10, 11, 12, 13, 14, 15, 16, 17]
Types of Bipolar Junction Transistor

NPN

In NPN transistors electrons are majority charge carriers. Here a P-doped layer is sandwiched between two N-doped layers. These transistors are preferred because mobility of electrons is very high which results in faster operation and greater current.

Symbol:

PNP

In PNP transistors the flow of current is mainly due to holes. A N-doped layer is kept between two P-doped layers. PNP transistor is “on” when its base is pulled low relative to emitter.
. HETEROJUNCTION BIPOLAR TRANSISTOR

Normally Bipolar Junction Transistors are unable to handle signals of high frequency i.e. to several GHz. To achieve this limit heterojunction bipolar transistors are designed. These transistors are commonly used in RF systems.

1.22 APPLICATIONS

Bipolar Junction Transistors are widely used for discrete circuit designs as its wide range of types is available. Also it has high transconductance and high output resistance compared to MOSFETs. To achieve the advantage of both the Bipolar Junction Transistors and MOSFETs they are combined in an integrated circuit using a BiCMOS process of wafer fabrication. BJT's can be used in various applications, some are as follows:
• **Temperature Sensors**

Bipolar Junction Transistors can be used as temperature sensors because of its known temperature and current dependence of base emitter junction which is forward biased. The temperature can be measured by subtracting two voltages at two different bias currents in a known ratio.

• **Logarithmic Converters**

A diode can be used with BJT to compute logarithms and anti-logarithms. Because in BJT base-emitter voltage varies as the log of the base-emitter currents. In this diode performs the nonlinear functions and the transistor provides more flexibility.

1.23 **Amplifier**

*An Amplifier is a device that changes, usually increases the amplitude of the signal input to it.* The relationship of the input to the output of an amplifier is usually expressed as a function of the input frequency and is called the transfer function of the amplifier, and the magnitude of the transfer function is termed the gain.

In popular use, the term usually describes an electronic amplifier, in which the input "signal" is usually voltage or current. In audio applications, amplifiers operate loudspeakers used in PA system to make the human voice
loud or play recorded music. Amplifiers may be classified according to the input they are designed to amplify (such as guitar amplifier, to perform with an electric guitar), the device they are intended to drive (such as headphone amplifier), the frequency range of the signals (Audio, IF, RF, and VHF amplifiers, for example), whether they invert the signal (inverting amplifiers and non-inverting amplifiers), or the type of devices used in the amplification (valve or tube amplifiers FET amplifiers, etc.).

A related device that emphasizes conversion of signals of one type to another (for example, a light signal in photons to a DC signal in amperes) is a transformer, or a sensor. However, none of these amplify power.

1.24 Figures of merit

The quality of an amplifier can be characterized by a number of specifications, listed below.

- **Gain**

  The gain of an amplifier is the ratio of output to input power of amplitude, and is usually measured in decibels. (When measured in decibels it is logarithmically related to the power ratio: \( G \text{ (dB)} = 10 \log (\text{Pout}/\text{Pin}) \)). RF amplifiers are often specified in terms of the maximum power gain obtainable, while the voltage gain of the audio amplifier and instrumentation amplifiers will be more often specified (since the amplifier’s input impedance will often be much higher than the source impedance, and the load impedance higher than the amplifier’s output impedance).
For example, an audio amplifier with a gain as 20 dB will have a voltage gain of ten (but a power gain of 100 would only occur in the unlikely event the input and output impedances were identical).

- **Bandwidth**

*The bandwidth (BW) of an amplifier is the range of frequencies for which the amplifier gives “satisfactory performance”.* The satisfactory performance may be different for different applications. However, a common and well-accepted metric are the half power points (i.e. frequency where the power goes down by half its peak value) on the power vs. frequency curve. Therefore bandwidth can be defined as the difference between the lower and upper half points. This is therefore also known as the -3dB bandwidth. Bandwidths (otherwise called “frequency response”) for other tolerance are something quoted (-1 dB, -6dB etc.) or “plus or minus 1 dB” (roughly the sound level difference people can detect).

- **Efficiency**

*Efficiency is a measure of how much of the input power is usefully applied to the amplifier’s output.* Class A amplifiers are very inefficient, in the range of 10-20% with a max efficiency of 25%. Class B amplifiers have a very high efficiency but are impractical because of high levels of distortion. In practical design, the result of a tradeoff is the class AB design. Modern class AB amps are commonly between 35-55% efficient with a theoretical maximum of 78.5%. Commercially available class D switching amplifiers have reported efficiencies as high as 90%. Amplifiers of Class C-F are
usually known to be very high efficiency amplifiers. The efficiency of the amplifiers limits the amount of total power output that is usefully available. It is noticeable that more efficient amplifiers run much cooler and often do not need any cooling fans in multi-kilowatt designs. The reason for this is that the loss of efficiency produces heat as a by-product of the energy lost during the conversion of power. In more amplifiers there is less loss of energy so in turn less heat.

In RF Power amplifiers, such as cellular base stations and broadcast transmitters, specialist design techniques are used to improve efficiency. Dorthy designs, which use a second transistor, can lift efficiency from the typical 15% up to 30-35% in a narrow bandwidth. Envelop Tracking designs are able to achieve efficiencies of up to 60%, by modulating the supply voltage to the amplifier in line with the envelop of the signal.

**Linearity**

An ideal amplifier would be a totally linear device, but real amplifiers are only within certain practical limits. When the signal drive to the amplifier is increased, the output also increases until a point is reached where some part of the amplifier becomes saturated and cannot produce any more outputs; this is called clipping, and results in distortion.

Some amplifiers are designed to handle this in a controlled way which causes a reduction in gain to take place instead of excessive distortion; the result is compression effect. Which will sound much less unpleasant to the ear? For these amplifiers, the 1 dB compression point is defined as the input
power (or the output power) where the gain is 1 dB less than the small signal gain.

Linearization is an emergent field, and there are many techniques, such as feedback, predistortion, post distortion, EER, LINC, CALLUM, Cartesian feedback, etc., in order to avoid the undesired effects of the non-linearities.

• **Noise**

*This is a measure of how much noise is introduced in the amplification process.* Noise is an undesirable but inevitable product of the electronic devices and components. The merit of noise performance of a circuit is Noise Factor. Noise Factor is the ratio of input signal to that of the output signal.

• **Output Dynamic Range**

*Output dynamic range is the range, usually given in dB, between the smallest and the largest useful output levels.* The lowest useful level is limited by output noise, while the largest is limited most often by distortion. The ratio of these two is quoted as the amplifier dynamic range. More precisely, if S=maximal allowed signal and N=noise power, the dynamic range DR is DR=(S+N)/N.

• **Slew Rate**

*Slew rate is the maximum rate of change of output variable, usually quoted in volts per second (or microsecond).* Many amplifiers are ultimately slew
rate limited, which may limit the full power bandwidth to frequencies well below the amplifier's small signal frequency response.

• **Rise time**

The rise time, \( t_r \), of an amplifier is the time taken for the output to change from 10% to 90% of its final level when driven by a step input. For a Gaussian system (or a simple RC roll off), the rise time is approximated by:

\[ t_r \times BW = 0.35, \]  
where \( t_r \) is rise time in seconds and bandwidth in Hz.

• **Settling time and ringing**

Time taken for output to settle to within a certain percentage of the final value (say 0.1%). This is called the settle time, and is usually specified for oscilloscope vertical amplifier and high accuracy measured systems. Ringing refers to an output that cycle above and below its final value, leading to a delay in reaching final value quantified by the settling time above.

• **Overshoot**

In response to a step input, the overshoot is the amount the output exceeds its final, steady-state value.

• **Stability factor**

*Stability is a major concern in RF and microwave amplifiers. The degree of an amplifier's stability can be quantified by a so-called stability factor.*  
There are several different stability factors, such as the Stern stability factor.
and the stability factor, which specify a condition that must be met for the absolute stability of an amplifier in terms of its two-port parameters.

1.3 Types of Electronic Amplifiers

Many types of amplifiers are used in different type of electronic equipments. These amplifiers use active devices as vacuum tubes or transistors. The electronic equipments which use electronic amplifiers are high fidelity stereo equipments, microcomputers, television transformers and other electronic digital equipments. Many types of amplifiers are briefly given below:

1.3.1 Power Amplifiers

On the basis of the power delivered to the load or sourced by the supply circuit, the power amplifiers are named. The power amplifier is designed the last amplifier in a transmission chain and this stage of amplifier requires most attention to power efficiency. [30, 31, 32, 33, 34, 35, 36, 37]

1.3.1.1 Power Amplifier Classes

On the basis of angle of flow or conduction angle, of the input signal through the output amplifying device power amplifier circuits are classified as A, B, AB and C for analog designs, and class D and E for switching designs. The angle of flow is closely related to the amplifier efficiency. Various classes of power amplifier are discussed below:
Class A

In this class 100% of the input signal is used means that the conduction angle $\theta=360$ deg. and the device works in its linear range. Mostly all the small signal amplifiers are designed as class A. In these amplifiers efficiency is not the consideration. Class A amplifiers are simple and linear but their major drawback is that they are very inefficient. The main use of these amplifiers is in small signal stages or for low-power applications. As an example they are used in driving headphones.

If high powers are needed from class A circuit, the heat losses become significant. For this expensive power supplies and heat sinking is required. Class A amplifiers are mainly used for audio amplifiers and they provide a good sound quality. A beautiful application of class A amplifiers is the long-tailed pair, which is exceptionally linear and gives base to the many complex circuits as audio amplifiers and the operational amplifiers also. Class A amplifiers are used as medium power amplifier, low efficiency and high cost audio amplifiers. In another application they form the output stage of operational amplifiers. One major drawback of these amplifiers is low efficiency of 50% with inductive coupling and only 25% with capacitive coupling and high heat dissipation. The reason for this is defined as in the absence of input, the power consumption is the same as at high output volume.
. Class B

This class of amplifiers use 50% of input signal that is conduction angle $\Theta=180$ deg it means that the active device works in its linear range half of the time and is more or less turned off the other half. These types of amplifiers use two output devices, each of which conducts exactly for half cycle of the input signal. In these types of devices if the transition from the one active element to the other is not perfect, crossover distortion occurs. These amplifiers have theoretical efficiency of 78.5% because the amplifying element is switched off for half of the time and so power
dissipation is negligible. "Push-pull" arrangement is practical circuit using class B arrangement here opposite halves of the input signal, are amplified by complementary or quasi complementary devices and the halves are recombined at the output. This type of amplifiers give excellent efficiency but on negative point of these is that there is some mismatch at the joints of the two halves of the output wave, this is called "cross over distortion". Class B amplifiers are used in audio amplifiers and also favored in battery-operated devices as transistor radios.

GRAPHICAL REPRESENTATION OF SIGNAL WAVEFORMS FOR CLASS B AMPLIFIER
. **Class AB**

These amplifiers reduce crossover distortion by the conduction of two active elements for more than half of the time. One example is complementary emitter follower in which a bias network allows for more or less quiescent current thus providing the operating point somewhere between Class A and Class B. These amplifiers overcome the disadvantage of class B amplifiers of cross over distortion. These amplifiers have efficiency below 78.5% but they operate in more linear region.

![Graphical Representation of Signal Waveforms for Class AB Amplifier](image)

**GRAPHICAL REPRESENTATION OF SIGNAL WAVEFORMS FOR CLASS AB AMPLIFIER**
. **Class D**

These amplifiers use switching to achieve a very high power efficiency of about 90%. Losses are minimized by allowing each device to be either fully on or fully off. The analog output is created by using pulse-width modulation. The switching schemes sigma-delta modulation is more complicated to improve some performance aspects like lower distortions or better efficiency.

. **Other Classes**

For high power units class G and class H amplifiers are used. And for radio frequency applications class E and class F amplifiers are used. These classes use harmonic tuning of their output networks to achieve higher efficiency and can be considered as a subset of Class C due to their conduction angle characteristics.

Class G amplifiers uses “rail switching” to decrease power consumption and increase the efficiency of the amplifier. In this way these amplifiers are more efficient than class AB but less efficient to class D. The amplifiers of class A have different power rails at different voltages and switching takes place as the signal output approaches each. In this way the wasted power decreases and the amplifier efficiency is increased.
Graphical Representation of Signal Waveforms for Class G Amplifier

Class H is one step further modification of class G. It uses an infinitely variable supply rail. For this the supply rail is modulated such that the rails are a few volts larger than the output signal at any given time. SMPS can be used to produce tracking rails. In this configuration the output operates at its maximum efficiency and total harmonic distortions (THD) are reduced. This is achieved on the cost of complicated power supply.
GRAPHICAL REPRESENTATION OF SIGNAL WAVEFORMS FOR CLASS H AMPLIFIER

1.32 Doherty Amplifiers

For Bell labs William H. Doherty invented Doherty amplifier in 1934. This type of amplifier consists of two stages in which one is class B known as main or carrier stage connected in parallel with class C, called auxiliary or peaking stage. The amplifier works with the splitting of the input signal and combining network sums the two output signals and also corrects the phase differences between the two amplifiers. Class B amplifier efficiently operates on the signal for periods low signal levels while in this time the class C amplifier remains inactive and consumes no power. Class C amplifier operates during the high signal peaks and at this time class B
amplifier saturates. Doherty Amplifiers are used in very high-power AM transmitters, cellular-telephones and wireless-internet applications. At present time, Doherty amplifiers are widely used in cellular based stations for GHz frequencies. Doherty amplifiers provide 60% efficiency with no modulation.[7, 8 9, 10, 11, 12, 13, 14, 15, 16, 17 ]

1.33 Vacuum Tube or Valve Amplifiers

Vacuum tube amplifiers are used for low power applications while for high power applications they become cost effective. Klystron, gyrotron, traveling wave tube, and crossed- field amplifiers are specially designed to provide much greater single device power output at microwave frequencies than solid state devices.

1.34 Transistor Amplifiers

Mainly bipolar junction transistors (BJTs) and metal oxide semiconductor field effect transistors (MOSFETs) are listed as transistor amplifiers.

The most commonly used configurations for transistor-based amplifiers are common base, common collector or common emitter and For MOSFET common source, common gate or common drain configurations can be used.
Commonly these amplifiers are used in audio amplifiers in a home stereo, RF high power generation for semiconductor devices and in RF and microwave applications such as radio transmitters.

1.35 Fully Differential Amplifiers

Fully differential amplifier is a solid state integrated circuit using external feedback for control of its transfer. It has differential output pins which differs it from differential amplifier.

1.36 Video Amplifiers

Video amplifiers are designed to deal with video signals. The bandwidth of these amplifiers varies and the variation depends upon the nature of the video signal. The video signal may be for SDTV, EDTV, HDTV, 720p r 1080i/p etc. besides this the specification of bandwidth itself depends upon the kind of filter used and the point which is used for bandwidth.

1.37 Distributed Amplifier

In these amplifiers the signal is splitted with the help of a transmission line and the individual portion is amplified separately. This increases the bandwidth of the amplifier considerably. An output transmission line is used
to combine the amplified parts. In oscilloscope as the final vertical amplifier this amplifier was used.

1.38 Push – Pull Amplifier

A push-pull amplifier is a balanced amplifier employing two similar devices which can amplify the signal and working in phase opposition. This amplifier consist of two transistors in which one works as the source of current and the other as sink. One device pushes the current from the load while the other pulls it when it is necessary. The complementary symmetry push – pull amplifier is used to drive a loudspeaker.

CIRCUIT DIAGRAM REPRESENTING BASIC PUSH-PULL AMPLIFIER
The most popular form of push – pull amplifier is Quasi – complementary push – pull amplifier. This type can be achieved by connecting a Darlington pair with a feedback pair. Here the transistors of feedback pair are complementary and that of the Darlington pair are properly matched. Here a variable resistor is used to minimize the crossover distortion by adjusting the dc bias connection.

PICTORIAL REPRESENTATION OF QUASI – COMPLEMENTARY PUSH – PULL AMPLIFIER
1.39 Operational Amplifier

An operational amplifier is the circuit with very high open loop gain. It uses differential inputs and external feedback for control of its transfer function. Today operational amplifiers are implemented with valves and termed as integrated circuits.

In other words an operational amplifier may also be defined as:

An operational amplifier is a DC-coupled high gain electronic voltage amplifier with a differential input and single ended output. Operational amplifier is generally called op-amp. Op-amp amplifies the difference of input applied between its input terminal and the amplification is several millions of times larger than the input. Operational amplifier uses negative feedback to control its high gain. If positive feedback is used operational amplifier acts as comparator. The electrical characteristics of an ideal operational amplifier are given below:

1. Infinite voltage gain A.
2. Infinite input resistance \( R_i \) so that almost any signal can drive it and there is no loading on the preceding stage.
3. Zero output resistance \( R_o \) so that output can drive an infinite number of other devices.
4. Zero output voltage when input voltage is zero.
5. Infinite bandwidth so that any frequency signals from zero to infinite hertz can be amplified without attenuation.
6. Infinite common-mode rejection ratio so that the output common mode noise voltage is zero.

7. Infinite slew rate so that output voltage changes occur simultaneously with input voltage changes.

Practical operational amplifiers can be made to achieve these characteristics using negative feedback. [48, 49, 50, 51, 52, 53 54, 55]

Operational amplifiers are widely used in a vast array of consumer industrial and scientific devices. Operational amplifiers are mainly designed as microscopic components or integrated circuit cells. Features of operational amplifier are given below:

*Input offset voltage* \((V_{io})\): It is the essential voltage that must be applied between the two input terminals to null the output. For 741C precision amplifier \(V_{io}=150\mu V\) maximum.

*Input offset current* \((I_{io})\): It is the algebraic difference between the currents into the inverting and non-inverting terminals of the operational amplifier.

\[ I_{io} = I_{B1} - I_{B2} \]

\(I_{B1}\) is the current into the non-inverting terminal and \(I_{B2}\) is the current in the inverting terminal. The input offset current for 741C is 200nA maximum.
**Input Bias Current (Ib):** It is the average of the currents flowing into the inverting and non-inverting terminals of the operational amplifier.

\[
I_B = \frac{I_{B1} + I_{B2}}{2}
\]

For precision 741C this value is \(+7\)nA.

**Differential Input Resistance (Ri):** It is the resistance that can be measured at either the inverting or non-inverting input terminals with the other terminal connected to ground. For 741C this value is 2 MΩ.

**Input Capacitance (Ci):** It is the equivalent capacitance that can be measured at either the inverting or non-inverting terminal with the other terminal connected to ground.

**Common –Mode Rejection Ratio (CMRR):** The common – mode rejection ratio is defined as the ratio of the differential voltage gain \(A_d\) to the common-mode voltage gain \(A_{cm}\) i.e.,

\[
CMRR = \frac{A_d}{A_{cm}}
\]
Differential voltage gain $A_d$ is same as the large – signal voltage gain $A$, which is specified in data sheets; and the common – mode voltage gain can be determined from the formula given below:

$$A_{cm} = \frac{V_{ocm}}{V_{cm}}$$

Where, $V_{ocm}$ is output common-mode voltage
$V_{cm}$ is common-mode voltage
$A_{cm}$ is common-mode voltage gain

For 741C, CMMR is 90 dB typically.

**Large – Signal Voltage Gain ($A$):** Since the operational amplifier amplifies the difference of the voltage between the two input terminals, the voltage gain of the amplifier can be defined as the ratio of the output voltage to the differential input voltage i.e.:

$$A = \frac{V_o}{V_i}$$

It is called large signal voltage gain because the output signal is much larger than the input signal. For 741C this value is typically 200,000.

**Slew Rate (SR):** Slew rate is defined as the maximum rate of change of output voltage per unit time and is expressed per microseconds. Slew rate is one of the important factors in selecting the opamp for ac operation,
especially at high frequencies. Low slew rate of 741C is one of its drawbacks. Its value is low and is equal to 0.5V/μs this value limits its use at high frequencies.

*Gain – Bandwidth Product (GB):* Gain- Bandwidth product is the bandwidth of the operational amplifier when the voltage gain is one.

*Temperature Effects:* All parameters of operational amplifier change with temperature. Temperature drift to the input offset voltage is especially important.

*Power Supply Rejection Ratio (PSRR):* A real operational amplifier has a specified power supply rejection ratio that reflects how well the operational amplifier can reject changes its supply voltage. This ratio can be increased by using bypass capacitors.

1.40 Darlington Amplifier

A CC stage followed by another CC stage has an input resistance of about \((\beta+1)\). \((\beta+1)\) times the emitter resistance of the second stage.

\[
RB = (\beta+1) (re1 + re1 (\beta+1)(re2 + re2))
\]
If RE1 is removed the second term is about square of $\beta$ times $R_{E2}$. If collectors are connected together, the result is Darlington stage as shown in fig. given below:

A DARLINGTON AMPLIFIER

Sidney Darlington created Darlington amplifier in early 1950’s. Since then this amplifier is widely used in scientific world. It has equivalent $\beta$ of about square of $\beta$ times. This gives an extremely high current gain. Darlington BJT can be used in any of the three BJT configurations. Darlington amplifier is defined as "The combination of two transistors connected together to give very high current gain."
A Darlington pair is used to amplify weak signals so that they can be detected clearly by another circuit or a computer/microprocessor. The circuit shown in fig ‘A’ is “Darlington Pair” driver. The emitter of the first transistor feeds into the base of the second transistor, the result is that the input signal gets amplified at the output. Its main advantage is that it is a beta current multiplier; its output can be used to drive low impedance devices. [77]

1.41 RC Coupled Amplifier

RC coupled amplifier is one of the most commonly used voltage amplifiers. RC coupled amplifier gives a constant amplification over a wide range of frequency. In this amplifier the first stage is coupled to the next stage with the help of a coupling capacitor and this feeds the output of the first stage to the second one giving an amplified output. The capacitor blocks the dc voltage at the output of the first stage from appearing at the input of the second stage, but it allows the ac signal to pass through it. The quiescent operating point of the circuit can be determined by the supply voltage Vcc together with R1, R2, RL, RE. The bypass capacitor CE in shunt with RE has a very small reactance at the lowest signal frequency [81]. The fig shows the basic circuit of RC Coupled amplifier:
A TYPICAL RC COUPLED AMPLIFIER

Advantages of RC Coupled Amplifier:

1. This is the least expensive multistage amplifier.

2. It has wide frequency response.

3. It provides less frequency distortion.

4. Excellent frequency response uniform bandwidth over wide range frequencies.

5. Inexpensive it employs resistor and capacitor which are cheap.
Disadvantages of RC Coupled Amplifier:

1. The overall gain of the amplifier is comparatively small because of the loading effect of successive stages.

2. It provides poor impedance matching between the stages.

Applications of RC Coupled Amplifier:

1. RC coupled amplifier has excellent audio fidelity over a wide range of frequency, used as a audio amplifier to amplify speech or music.

2. RC coupled amplifier is used as voltage amplifiers in initial stages of public address system.

1.16 Objective of the Thesis

Objective of the thesis is to explain the circuits designed by me so that it may impart some suggestions in the electronic world. While writing the thesis it is kept in mind that all the important aspects of the electronic circuits should be explained and in my knowledge I have left no stone unturned in this work.

1.17 References:

and Simulation.


3. Transistor Museum Historic Transistor Photo Gallery BELL LABS
   PROTOTYPE DIFFUSED BASE TRIODE

4. Influence of Mobility and Lifetime Variations on Drift-field Effects in
   Silicon – junction Devices.
   (http://iee.org/ie15/16/31631/01474625).

   Peregrinus Ltd. P. 29. ISBN 0 86341 227 0.

6. Transistor Museum Historic Transistor Photo Gallery RCA TA153
   (http://semiconductormuseum.com/photogaltery//photogallery_TA153.htm)

   p. 17. [1].

8. Peter Ashburn (2003). SiGe Hetrojunction Bipolar transistors
9. Simulation of a BJT in the Common Emitter Circuit
(http://courses.ece.illinois.edu/ece110/simulation/bjt/)

10. Bipolar Transistors- The transistor as a Switch- Active Region
(http://Knol.google.com/k/max-iskram/electronic-circuits-design-for/1f4zs8p9zgq0e//12)

11. Lessons In Electric Circuits-Bipolar Junction Transistor
(http://www.fags.org/docs/electric/Semi/SEMI_4.html) (Note: this site shoes current as a flow of electrons, rather than the convention of showing it as a flow of holes, so the arrows may appear the other way around)

12. Characteristic curves

13. ECE 327: Procedures for Output Filtering Lab

14. How Do Transistor Work?

15. ENGI 242/ELEC 222: BJT Small Signal Models
(http://ux.briikdalecc.edu/fac/engtech/andy/engi242/bjt_models.pdf)
16. TRANSISTOR MUSEUM Historic Transistor Timeline
(http://semiconductormuseum.com/Historic Transistor Timeline_index.htm)

17. EncycloBEAMia_Bipolar Junction Transistor
(http://encyclobeamia.solarbotics.net/articles/bip_junct_trans.html)


32. Design and analysis of a basic class D amplifier.
(http://www.audioline.com/175006800).

33. An alternate topology called the grounded bridge amplifier-pdf.

34. Contains an explanation of different class of amplifier classes-pdf.

35. Anatomy of power amplifiers including the in formation of classes

36. Reinventing of the power amplifier-pdf

37. Class E Radio Transmitter-Tutorials, Schematics, Examples and
Construction Details
(http://www.classradio.org/index.html).

38. MAXIM Application Note 1108: Understanding Single-Ended, Pseudo-
Differential and Fully-Differential ADC Inputs.
(http://www.maxim-ic.com/appnotes.cfm/an_pk/1108)-Retrieved
November 10,2007


42. Sedra/Smith (5th Ed.) Electronic Circuits


44. The uA741 Operational Amplifier (http://ecow.engr.wise.edu/cgi-bin/get/ece/342/schowalter/notes/chapter10/theu741operationalamplifier.ppt)

45. Introduction to op-amp circuit stages, second order filters, single op-amp a simple intercom (http://www.bowdenshobby.info/opamp.htm)

46. Hyperphysics-description of common applications (http://hyperphysics.phy-satr.gsu.edu/hbase/electronic/opampvar.html)

48. Op-amp circuit collection

49. Another introduction
(http://web.trlia.com/~u8590178/begin/opamp00.htm)

50. Op-Amp for everyone
(http://focus.ti.com/lit/an/slod006b/slod006b.pdf)

51. MOS op amp design: A tutorial overview
(http://www.ee.unb.ca/Courses/EE3122/DFL/AdditionalMaterial/OpAmps/
MOS_OpAmpTutorial)

52. High Speed OpAmp Techniques
(http://cds.linear.com/docs/Application%20Note/an47fa.pdf)

53. OP Amp Applications

54. Operational Amplifier Noise Prediction(All OpAmps)
(http://www.intersil.com/data/an/an519.pdf)

55. Operational Amplifier Basics
(http://www.williamson-labs.com/480_opamp.htm)

56. History of OP-amp
57. IC Op-Amps Through the Ages
(http://www.Callvin.sdu/~pribierio/courses/engr332/Handouts/h018opamp.pdf)

58. ECE 209: Operational amplifier basics
(http://www.tedpavlic.com/teaching/osu/ece209/support/opamp_basics.pdf)

59. Joseph Neff, Visarath In, Christopher Obera and Antonio Palacios

60. Robert G. Meyer “Trade offs in Analog Circuit Design”, publisher:

61. IEEE Explore
“Large Signal Rise-Time in Junction Transistors”


63. Mourad Fakh, Yann Cooren, Amin Sallem, Mourad Loulou and Patrick
Siarry, “ÁAnalog Circuit Design Optimization through the Particle Swarm
Optimization Technique”, Analog Integrated Circuits and signal


79. Cramping more Components onto the integrated circuits by G. Moore.

80. The transistor’s Discovery and What’s Ahead by Pinto, Brinkman and Troutman.

81. Integrated Electronics by J. Milliman and C. Halkias.

82. Electrons and Holes in semiconductor by W. Shockley.

83. http://www.etedeschi.indirect.w.uk/musium/concise.history.htm