1. AMPHIERS – INTRODUCTION

Amplifiers are used extensively in electronic circuits to make an electronic signal bigger without affecting it in any other way. Generally we think of Amplifiers as audio amplifiers in the radios, CD players and stereo’s we use around the home.

An amplifier, electronic amplifier or (informally) amp is an electronic device that increases the power of a signal.

It does this by taking energy from a power supply and controlling the output to match the input signal shape but with a larger amplitude. In this sense, an amplifier modulates the output of the power supply to make the output signal stronger than the input signal. An amplifier is effectively the opposite of an attenuator: while an amplifier provides gain, an attenuator provides loss.

The first practical electronic device which could amplify was the Audion (triode) vacuum tube, invented in 1906 by Lee De Forest which led to the first amplifiers. The terms "amplifier" and "amplification" (from the Latin amplificare, 'to enlarge or expand') were first used for this new capability around 1915 when triodes became widespread. For the next 50 years vacuum tubes were the only devices which could amplify, and were used in all amplifiers until the 1960s, when transistors began to be used. Most amplifiers today use transistors, although tubes are still used.
Worksheet No.1

Exercise 1. Reading Comprehension : Answer the questions.

1. What is an amplifier?
2. How does an amplifier work?
3. What was the first „amplifier“ called?
4. When and who was it invented by?
5. When did people begin to use transistors?

Exercise 2. Complete the highlighted words to the definitions.

1. to enlarge or expand - __________________
2. an increase in wealth or resources - __________________
3. __________________ are composed of individual electronic components, such as resistors, transistors, capacitors, inductors and diodes, connected by conductive wires or traces through which electric current can flow.
4. The __________________ of a periodic variable is a measure of its change over a single period (such as time or spatial period).
5. signal that comes out of an electronic system - __________________
6. __________________ are devices that control electric current through a vacuum in a sealed container.
7. an electronic device that supplies electric energy to an electrical load - __________________
8. signal going into an electronic system - __________________

Exercise 3. Speaking

1. What amplifiers do you use daily around the home? Name the devices.
2. Do you know any famous amplifier brands? What is your favourite one?
3. What is the brand of your hi-fi audio, car, guitar, etc. amplifier?
2. SIGNAL

A signal as referred to in communication systems, signal processing, and electrical engineering "is a function that conveys information about the behavior or attributes of some phenomenon".

In the physical world, any quantity exhibiting variation in time or variation in space (such as an image) is potentially a signal that might provide information on the status of a physical system, or convey a message between observers, among other possibilities.

The IEEE (The Institute of Electrical and Electronics Engineers) Transactions on Signal Processing states that the term "signal" includes audio, video, speech, image, communication, geophysical, sonar, radar, medical and musical signals.

In electronics, a signal is an electric current or electromagnetic field used to convey data from one place to another. The simplest form of signal is a direct current (DC) that is switched on and off; this is the principle by which the early telegraph worked. More complex signals consist of an alternating-current (AC) or electromagnetic carrier that contains one or more data streams.

**input signal** - signal going into an electronic system (MP3, microphone, camera...)

**output signal** - signal that comes out of an electronic system (loudspeaker, oscilloscope, another amplifier...)

Worksheet No.2

Exercise 1. Reading Comprehension: Answer the questions.

1. What does a signal convey?
2. What does IEEE stand for?
3. What does the term signal include according to the IEEE?
4. What is the definition of a signal in electronics?
5. What does DC and AC stand for?

Exercise 2. Name the type of signal (input/output) in these devices:

a. ____________  b. ____________  c. ____________

d. ____________  e. ____________
Exercise 3. Complete the article with the words from the box.

alternating current, signal, circuits, generates, convert, direction, power supply

In actuality, the amplifier 1. ________ a completely new output signal based on the input signal. You can understand these signals as two separate 2. ________ The output circuit is generated by the amplifier's 3. ________, which draws energy from a battery or power outlet. If the amplifier is powered by household 4. ________, where the flow of charge changes directions, the power supply will 5. ________ it into direct current, where the charge always flows in the same 6. ________. The power supply also smoothes out the current to generate an absolutely even, uninterrupted 7. ________. The output circuit's load (the work it does) is moving the speaker cone.
3. TRANSISTORS

Transistors are the semiconductor devices with three terminals. The three terminals are called emitter, collector and base. Transistor is operated in three configurations called as common base, common emitter and common collector. Transistor is used for voltage and current amplification according to configurations. At base input signal of small amplitude is given and magnified output signal is collected at collector. Thus transistors help in achieving amplification of signal. By passing input current signal from region of low resistance to region of high resistance amplification is achieved in transistors.

Transistors of two types:

- Unipolar junction transistor
- Bipolar junction transistor

UNIPOLAR JUNCTION TRANSISTOR

The current condition in unipolar transistor is due to only one type of charge carriers, majority carriers.

The field-effect transistor (FET) is a transistor that uses an electric field to control the shape and hence the electrical conductivity of a channel of one type of charge carrier in a semiconductor material. FETs are also known as unipolar transistors as they involve single-carrier-type operation. The FET has several forms, but all have high input impedance. While the conductivity of a non-FET transistor is regulated by the input current (the emitter to base current) and so has a low input impedance, a FET's conductivity is regulated by a voltage applied to a terminal (the gate) which is insulated from the device. The applied gate voltage imposes an electric field into the device, this in turn attracts or repels charge carriers to or from the region between a source terminal and a drain terminal. The density of charge characters in turn influences the conductivity between the source and drain.
The FET's three terminals are:

- **Source (S)**, through which the carriers enter the channel. Conventionally, current entering the channel at S is designated by $I_S$.
- **Drain (D)**, through which the carriers leave the channel. Conventionally, current entering the channel at D is designated by $I_D$. Drain-to-source voltage is $V_{DS}$.
- **Gate (G)**, the terminal that modulates the channel conductivity. By applying voltage to G, one can control $I_D$.

**BIPOLAR JUNCTION TRANSISTOR**

In bipolar transistor the current condition is due to both types of charge carriers, holes and electrons. So it is called bipolar. It is also referred as BJT.

These two kinds of charge carriers are characteristic of the two kinds of doped semiconductor material; electrons are majority charge carriers in **n-type semiconductors**, whereas holes are majority charge carriers in **p-type semiconductors**. In contrast, unipolar transistors such as the field-effect transistors have only one kind of charge carrier.

**NPN** is one of the two types of bipolar transistors, consisting of a layer of P-doped semiconductor (the "base") between two N-doped layers.

The other type of BJT is the **PNP**, consisting of a layer of N-doped semiconductor between two layers of P-doped material.
CONSTRUCTION OF BJT:

If a p-region is sandwiched between two n-regions like shown in figure(a), then its n-p-n transistor.

a.

If a n-region is sandwiched between two p-regions like shown in figure(b), then its p-n-p transistor.

b.
PARTS OF TRANSISTORS

1. BASE- It is the middle region of the transistor. It is lightly doped and it is very thin.
2. EMITTER AND COLLECTOR- These are the other two regions of transistors. These regions are heavily doped. Emitter’s doping level is slightly greater than that of collector and collector region-area is
Worksheet No.3

Exercise 1. What types of transistors can you see in the pictures? What do the letters stand for? Write the words.

a. _______________________

![Diagram of transistor symbols](image1.png)

G = _______________________
C = _______________________
D = _______________________
E = _______________________
S = _______________________

b. _______________________

![Diagram of transistor symbols](image2.png)

B = _______________________
C = _______________________
E = _______________________
NPN = _______________________
PNP = _______________________
Exercise 2. Decide if the statements are true or false. Correct the false statements.

1. FETs are also known as bipolar transistors.
2. The carriers leave the channel through GATE.
3. In bipolar transistor the current condition is due to both types of charge carriers, holes and electrons.
4. Majority charge carriers in n-type semiconductors are holes, whereas majority charge carriers in p-type semiconductors are electrons.
5. BASE is the middle region of the transistor which is heavily doped and it is very thick.
6. If a p-region is sandwiched between two n-regions then its n-p-n transistor.
4. Classification of Amplifiers

There are many forms of electronic circuits classed as amplifiers, from Operational Amplifiers and Small Signal Amplifiers up to Large Signal and Power Amplifiers. The classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal, that is the relationship between input signal and current flowing in the load.

The type or classification of an amplifier is given in the following table.

<table>
<thead>
<tr>
<th>Type of Signal</th>
<th>Type of Configuration</th>
<th>Classification</th>
<th>Frequency of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Signal</td>
<td>Common Emitter</td>
<td>Class A Amplifier</td>
<td>Direct Current (DC)</td>
</tr>
<tr>
<td>Large Signal</td>
<td>Common Base</td>
<td>Class B Amplifier</td>
<td>Audio Frequencies (AF)</td>
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<td></td>
<td>Common Collector</td>
<td>Class AB Amplifier</td>
<td>Radio Frequencies (RF)</td>
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<td></td>
<td></td>
<td>Class C Amplifier</td>
<td>VHF, UHF and SHF Frequencies</td>
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</tbody>
</table>

Generally, amplifiers can be sub-divided into two distinct types depending upon their power or voltage gain. One type is called the **Small Signal Amplifier** which include pre-amplifiers, instrumentation amplifiers etc. Small signal amplifiers are designed to amplify very small signal voltage levels of only a few micro-volts (µV) from sensors or audio signals.

The other type are called **Large Signal Amplifiers** such as audio power amplifiers or power switching amplifiers. Large signal amplifiers are designed to amplify large input voltage signals or switch heavy load currents as you would find driving loudspeakers.

**Power Amplifiers**

The **Small Signal Amplifier** is generally referred to as a “Voltage” amplifier because they usually convert a small input voltage into a much larger output voltage. Sometimes an amplifier circuit is required to drive a motor or feed a loudspeaker and for these types of applications where high switching currents are needed **Power Amplifiers** are required.

As their name suggests, the main job of a “Power Amplifier” (also known as a large signal amplifier), is to deliver power to the load, and as we know from above, is the product of the voltage and current applied to the load with the output signal power being greater than the input signal power. In other words, a power amplifier amplifies the power of the input signal which is why these types of amplifier circuits are used in audio amplifier output stages to drive loudspeakers.

The classification of an amplifier as either a voltage or a power amplifier is made by comparing the characteristics of the input and output signals by measuring the amount of time in relation to the input signal that the current flows in the output circuit.
With the introduction to the amplifier of a Base bias voltage, different operating ranges and modes of operation can be obtained which are categorized according to their classification. These various mode of operation are better known as **Amplifier Class**.

Audio power amplifiers are classified in an alphabetical order according to their circuit configurations and mode of operation. Amplifiers are designated by different classes of operation such as class “A”, class “B”, class “C”, class “AB”, etc. These different Amplifier Classes range from a near linear output but with low efficiency to a non-linear output but with a high efficiency.

No one class of operation is “better” or “worse” than any other class with the type of operation being determined by the use of the amplifying circuit. There are typical maximum efficiencies for the various types or class of amplifier, with the most commonly used being:

- **Class A Amplifier** – has low efficiency of less than 40% but good signal reproduction and linearity.

- **Class B Amplifier** – is twice as efficient as class A amplifiers with a maximum theoretical efficiency of about 70% because the amplifying device only conducts (and uses power) for half of the input signal.

- **Class AB Amplifier** – has an efficiency rating between that of Class A and Class B but poorer signal reproduction than class A amplifiers.

- **Class C Amplifier** – is the most inefficient amplifier class as only a very small portion of the input signal is amplified therefore the output signal bears very little resemblance to the input signal. Class C amplifiers have the worst signal reproduction.

- A **wideband** amplifier has a precise amplification factor over a wide frequency range, and is often used to boost signals for relay in communications systems.
- A **narrowband** amp amplifies a specific narrow range of frequencies, to the exclusion of other frequencies.
- An **RF** amplifier amplifies signals in the radio frequency range of the electromagnetic spectrum, and is often used to increase the sensitivity of a receiver or the output power of a transmitter.

- A special type of amplifier - originally used in analog computers - is widely used in measuring instruments for signal processing, and many other uses. These are called **operational amplifiers** or **op-amps**. The "operational" name is because this type of amplifier can be used in circuits that perform mathematical algorithmic functions, or "operations" on input signals to obtain specific types of output signals.
Worksheet No.4

Exercise 1. Reading Comprehension: Answer the questions.

1. What does the classification of an amplifier depend upon?
2. What are the two types of amplifiers divided according to their power or voltage gain?
3. Which types of amplifier circuits are used in audio amplifier output stages to drive loudspeakers?
4. How are audio power amplifiers classified?
5. How are amplifiers classified according to the type of configuration?
6. What class amplifier has a maximum theoretical efficiency of about 70%?
7. How are the amplifiers which amplify a wide and narrow range of frequencies called?
8. What type of amp was originally used in analog computers?
5. Amplifier Properties

Any amplifier is said to have certain parameters. These are the particular properties that make the amplifier perform in a certain way, and so make it suitable for a given task. Typical amplifier parameters are described below.

**Gain (A)**
- a measure of the "Amplification" of an amplifier, i.e. how much it increases the amplitude of a signal
- the ratio of the output signal amplitude to the input signal amplitude
- can be calculated for voltage ($A_v$), current ($A_i$) or power ($A_p$)

When the subscript letter after the A is in lower case this refers to small signal conditions, and when the subscript is in capitals it refers to DC conditions.

The gain or amplification for the three different types of amplifiers can be described using the appropriate formula:

Voltage gain $A_v = \frac{\text{Amplitude of output voltage}}{\text{Amplitude of input voltage}}$.

\[ A_v = \frac{V_{out}}{V_{in}} \]

Current gain $A_i = \frac{\text{Amplitude of output current}}{\text{Amplitude of input current}}$.

\[ A_i = \frac{I_{out}}{I_{in}} \]

Power gain $A_p = \frac{\text{Signal power out}}{\text{Signal power in}}$.

\[ A_p = \frac{P_{out}}{P_{in}} \]

The power gain or power level of the amplifier can also be expressed in **Decibels, (dB)**. The Bel (B) is a logarithmic unit (base 10) of measurement that has no units. Since the Bel is too large a unit of measure, it is prefixed with *deci* making it **Decibels** instead with one decibel being one tenth (1/10th) of a Bel. To calculate the gain of the amplifier in Decibels or dB, we can use the following expressions.

- Voltage Gain in dB: $a_v = 20 \log A_v$
- Current Gain in dB: $a_i = 20 \log A_i$
- Power Gain in dB: $a_p = 10 \log A_p$
Output impedance ($Z_{out}$)

- **source impedance**, or **internal impedance** of an electronic device
- the opposition exhibited by its output terminals to an alternating current (AC) of a particular frequency as a result of resistance, inductance and capacitance
- can be thought of as being the impedance (or resistance) that the load sees “looking back” into the amplifier when the input is zero.
- the generalised formula for the output impedance can be given as:

\[
Z_{out} = \frac{V_{CE}}{I_C}
\]

Power output ($P_{out}$)

- the rate at which electrical energy is fed into or taken from a device or system
- is expressed, in a direct-current circuit, as the product of current and voltage and, in an alternating-current circuit, as the product of the effective values of the current and voltage and the cosine of the phase angle between them.
- is measured in watts (W)

Amplifier Efficiency ($\eta$)

- is a measure of how much of the power source is usefully applied to the amplifier's output.
- The perfect or ideal amplifier would give us an efficiency rating of 100% or at least the power “IN” would be equal to the power “OUT”. However, in reality this can never happen as some of the power is lost in the form of heat and also, the amplifier itself consumes power during the amplification process. Then the efficiency of an amplifier is given as:

\[
Efficiency \ (\eta) = \frac{\text{power delivered to the load}}{\text{d.c. power taken from the supply}} = \frac{P_{out}}{P_{in}}
\]
Worksheet No.5

Exercise 1. What do the letters denote?

\( A_v \quad V_{out} \)
\( A_i \quad Z_{out} \)
\( A_p \quad P_{out} \)
\( I_{in} \quad dB \)
\( V_{in} \quad \eta \)
\( P_{in} \quad I_{out} \)

Exercise 2. Decide which property the statements are concerning. Match.

1. is measured in watts (W) - Gain
2. is a measure of how much of the power source is usefully applied to the amplifier's output - Output
3. the ratio of the output signal amplitude to the input signal amplitude - Impedance
4. \( V_{CE}/I_C \) - Efficiency
5. a measure of the "Amplification" of an amplifier - Power output
6. can also be expressed in Decibels - Efficiency
7. \( P_{out}/P_{in} \) - Efficiency
8. the rate at which electrical energy is fed into or taken from a device or system - Efficiency
6. Operational amplifiers

As well as resistors and capacitors, Operational Amplifiers, or Op-amps as they are more commonly called, are one of the basic building blocks of Analogue Electronic Circuits.

Operational amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation.

An Operational Amplifier, or op-amp for short, is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. These feedback components determine the resulting function or “operation” of the amplifier and by virtue of the different feedback configurations whether resistive, capacitive or both, the amplifier can perform a variety of different operations, giving rise to its name of “Operational Amplifier”.

An Operational Amplifier is basically a three-terminal device which consists of two high impedance inputs, one called the Inverting Input, marked with a negative or “minus” sign, ( - ) and the other one called the Non-inverting Input, marked with a positive or “plus” sign ( + ).

The third terminal represents the Operational Amplifiers output port which can both sink and source either a voltage or a current. In a linear operational amplifier, the output signal is the amplification factor, known as the amplifiers gain ( A ) multiplied by the value of the input signal and depending on the nature of these input and output signals, there can be four different classifications of operational amplifier gain.

- Voltage – Voltage “in” and Voltage “out”
- Current – Current “in” and Current “out”
- Transconductance – Voltage “in” and Current “out”
- Transresistance – Current “in” and Voltage “out”
Op-amp Parameter and Idealised Characteristic

- **Open Loop Gain, \((A_{\text{vo}})\)**
  - **Infinite** – The main function of an operational amplifier is to amplify the input signal and the more open loop gain it has the better. Open-loop gain is the gain of the op-amp without positive or negative feedback and for such an amplifier the gain will be infinite but typical real values range from about 20,000 to 200,000.

- **Input impedance, \((Z_{\text{in}})\)**
  - **Infinite** – Input impedance is the ratio of input voltage to input current and is assumed to be infinite to prevent any current flowing from the source supply into the amplifiers input circuitry (\(I_{\text{in}} = 0\)). Real op-amps have input leakage currents from a few pico-amps to a few milli-amps.

- **Output impedance, \((Z_{\text{out}})\)**
  - **Zero** – The output impedance of the ideal operational amplifier is assumed to be zero acting as a perfect internal voltage source with no internal resistance so that it can supply as much current as necessary to the load. This internal resistance is effectively in series with the load thereby reducing the output voltage available to the load. Real op-amps have output impedances in the 100-20k\(\Omega\) range.

- **Bandwidth, \((BW)\)**
  - **Infinite** – An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies so it is therefore assumed to have an infinite bandwidth. With real op-amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifiers gain becomes unity.

- **Offset Voltage, \((V_{\text{io}})\)**
  - **Zero** – The amplifiers output will be zero when the voltage difference between the inverting and the non-inverting inputs is zero, the same or when both inputs are grounded. Real op-amps have some amount of output offset voltage.
Worksheet No.6

**Exercise 1.** Complete the statements with correct words from the text.

1. Operational amplifiers are _________ devices that have all the properties required for nearly ideal DC amplification.
2. An Operational Amplifier is fundamentally a _________ amplifying device.
3. An Operational Amplifier is basically a _________ device.
4. Op-amp consists of two high impedance inputs, one called the _________ and the other one called the _________.
5. The third terminal represents the Operational Amplifiers _________.

**Exercise 2.** Put the parameters from the box under the correct idealistic characteristic.

Avo, Z_in, Z_out, BW, V_io

<table>
<thead>
<tr>
<th>INFINITE</th>
<th>ZERO</th>
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