Design and Simulation of Single Stage Amplifier Using 2N2222A Transistor

Y. Abdullahi, B.B. Sahabi

Abstract— **An amplifier is an electronic device that amplifies the weak signal or increases the strength of a weak signal. It can either be a separate piece of equipment or an electrical circuit contained within another device. Every device or circuit, be it analog or digital requires signal amplification at one level or the other during their functioning. Considering the most basic amplifiers i.e. single-stage amplifiers which are the basic building block of all the amplifiers, be it a multi-stage amplifier or a differential amplifier. This paper presents the analysis of the parameter of a single stage signal transistor amplifier using 2N2222A transistor base on maximum rating of the transistor. A Complete Common Emitter Transistor Amplifier was design ,the battery voltage(V_{CC}), collector resistor (R_C), emitter resistor (R_E), bias resistors R_1 and R_2, additional resistor Rg between the emitter resistor and the transistor , values of capacitors (input, output and emitter) were calculated. Actual performance of the complete circuit was tested using Multisim 9 Soft ware, the resistance at which the amplifier instantaneously generates Gain, the range of the Input Voltage at which the amplifier has different Output Voltage and different Gain, the saturation point of amplifier, the cut-off frequencies, the Passband or Bandwidth (BW) of the amplifier, the relationship between additional Resistor (R_g), Input Voltage(V_{in}), frequency respond and Gain were determined and presented graphically.**

Index Terms— **Simulation, 2N2222A, Transistor, Single Stage, Amplifier.**

I. Introduction

Electronics essentially deals with study of semiconductor devices and has emerged as the most important branch of engineering (Singh, 2008)**.** Electronics devices are being used in computer based system as a set or an arrangement of element that are organized to accomplish some predefined goal by processing information (Puntambekar, 2010; Abu-Rub *et al.*, 2014).

They are capable of performing the following functions (Christopher, 2017): Rectification, Control, Amplification, Conversion of light into electricity and vice versa, etc.

Amplifiers are used extensively in electronic circuits to make an electronic signal bigger without affecting it in any other way(Pal, 2010). An amplifier 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 larger amplitude(Yan, 2015).

Amplifier can be classified basically as: Current Amplifier, Voltage Amplifier, Transconductance Amplifier,

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Transresistance Amplifier (Kularatna, 2008). Apart from the basic types, amplifiers can also be categorized by their operation, application or characteristics (Personnel, 1970; Morris, 2001; Clayton & Winder, 2003; Kumar, 2004;Elbert, 2008; Glisson, 2011; Pannenborg, 2012) as : Power Amplifiers, Operational Amplifiers (Op-Amps), Valve or Vacuum Tube Amplifiers, Klystron, Instrument Amplifiers, Distributed Amplifiers, Transistor Amplifiers, etc.

There are three terminals in a transistor: emitter, base and collector terminals. When a transistor is to be connected in a circuit, four terminals are required; two for the input and two for the output. This occurs by making one terminal of the transistor common to both input and output terminals there by the input is fed between this common terminal and one of the other two terminals while the output is obtained between the common terminal and the remaining terminal (Shashidhar & House, 2013).

Accordingly; a transistor can be connected in a circuit in the following three ways: Common Base (CB), Common Emitter(CE), and Common Collector (CC) connection. Each circuit connection has specific advantages and disadvantages (Mehta, 2008).

In this work, single stage amplifier was designed with 2N2222A transitor using Common Emitter (CE) configuration.

II. Transistor Amplifier Design

A transistor with proper circuitry can raises the strength of a weak signal and thus acts as an amplifier (Shashidhar & House, 2013) as shown in Figure 1.
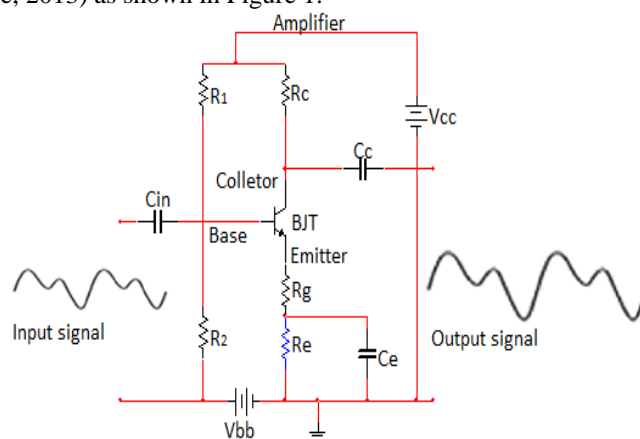

Figure 1: Common Emitter Transistor Amplifier Circuit

The weak signal is applied between emitter-base junction and output is taken across the load R_C connected in the collector circuit.

In order to achieve faithful amplification, the input circuit

should always remain forward bias. To do so, a DC voltage V_{BB} is applied in the input circuit in addition to the signal. This DC voltage is known as bias voltage and its magnitude is such that it always keeps the input circuit forward biased regardless of the polarity of the signal. A weak signal applied in the input circuit appears in the amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier. The circuit is common emitter amplifier circuit since the emitter is common to both the input circuit and the output circuit.

Rc is called the collector resistor and Re the emitter resistor. Re is actually two resistors in series one of which will be call Rg and is called the "gain" resistor since it controls the voltage gain or amplification, Rg will be important as it sets the overall gain of the amplifier (Godse & Bakshi, 2009).

R_1 and R_2 are called the bias resistors and they help to set the base current I_b by making the base emitter voltage at least V_{be} = 0.6V for silicon transistors(Joseph, Halkiadakis, Bernal, & Maiullo, 2016). The emitter resistor has the purpose of controlling "thermal runaway" which can burn up a transistor (Dailey, 2011).

The three basic rules for transistor amplifier design are (Godse & Bakshi, 2009):

1. The base-emitter voltage is always biased in the forward direction about 0.6-0.7 volts for silicon transistors for the base-emitter junction to behave like a diode and a diode has a constant voltage drop .

2. The current amplification of the transistor β to be large (typically100-300) since small changes in the base current I_b produce large changes in the collector current I_c and this is the basic idea behind transistor operation.

3. The collector current and the emitter current are to be almost the same size i.e. $I_c \approx I_e$.

Due to conservation of charge, it follows that:

$$I_e = I_b + I_c \qquad (1)$$

Since the collector current $I_c \gg I_b$ it follows that $I_c = I_e$.

To design a transistor circuit, the values of the following components are to be determined:

  i. Battery Voltage, V_{cc};
 ii. Operating Point;
iii. Collector and Emitter Resistors;
iv. Choice of the Bias Resistors R_1 and R_2;
 v. Choice of Rg;
vi. Choice of Capacitors
vii. Complete Circuit Diagram

A. Choosing Battery Voltage (V_{cc})

The battery voltage, V_{cc} is chosen such that it must be less than the maximum voltage the transistor can handle between the collector and emitter.

The Data Sheet of the Transistor (2N2222A) is as shown in Table 1 (Godse, 2009).

Table 1: Data sheet of 2N2222A Transistor

Parameter	Condition	Max	Min
Collector base voltage, V_{CBO}	Open emitter	-	75V
Collector emitter voltage, V_{CEO}	Open base	-	40V
Collector current (DC), I_C		-	800 mA
Total power dissipation, P_{tot}	$T_{amb} \leq 25^o$ C	-	500 mW
DC current gain, h_{FE}	I_C = 10mA; V_{CE} = 10V	75	-
Transition frequency, f_t	I_C = 20mA; V_{CE} = 20V	300M Hz	-
Turn off time, t_{off}	I_{Con} = 150mA; I_{Bon} = 15mA; I_{Boff} = -15mA		250 nS

The absolute maximum rating, V_{CEO} of 2N2222A Transistor is 40V. The battery voltage is chosen to be less than half the maximum V_{CEO} since this allows for an addition of AC voltage due to amplification so that the transistor does not burn out (Gates, 2001).

Based on suitability and availability, V_{cc} is chosen to be 12V.

B. Choosing an Operating Point

Operating Point is the DC values of I_c, I_b, and V_{ce} which are the steady state values(Patrick & Fardo, 2008). When an AC input voltage is applied to the amplifier, there are deviations from these values which are denoted by lower case letters i_c, i_b, and v_{ce} (Silver & Wilson, 2008). The point is to be chosen as follows:

  i. Choose an I_C such that the transistor actually does amplify;
 ii. Given the value of I_C, and gain, the base current I_B at the operating point is determined from:

$$I_b = \frac{I_c}{\beta} \qquad (2)$$

iii. The operating point collector-emitter voltage, V_{ce} is determined within the range as:

$$\frac{V_{battery}}{3} < V_{ce} < \frac{V_{battery}}{2} \qquad (3)$$

A V_{ce} somewhere in this range will allow for amplification of a maximum input voltage without distortion. For this design, $V_{battery} = 12V$; $\beta = 200$. Substituting these values gives:

$$V_{ce} = V_{battery}/3 = 12/3 = 4V$$
$$V_{ce} = \frac{V_{battery}}{3} = \frac{12}{3} = 4V$$

This is the collector emitter voltage at operating point. For

this value, the transistor might have

$I_c = 4\text{mA}$.

Therefore, $I_b = \dfrac{4 \times 10^{-5}}{200} = 0.00002 = 0.02\text{mA} = 20\mu\text{A}$
This value might be just large enough for measuring.

These value of $V_{ce} = 4\text{V}$, $I_c = 4\text{mA}$ and $I_b = 0.02\text{mA}$ when $\beta = 200$, is known as DC operating point.

C. Choosing the Collector and Emitter Resistors

The purpose of the collector resistor R_c is to set the collector current I_c as well as the emitter- collector voltage V_{ce}. In other words, R_c helps to set the transistor at the operating point of the amplifier. The purpose of the emitter resistor R_e is to prevent thermal runaway. If the emitter resistor is not present, the collector current might increase as the transistor heats up. As a result of $I_b = \dfrac{I_c}{\beta}$ there is then an increased in base current which further heats up the transistor until the transistor burns up. This effect is a cause of Amplifier instability. According to rule; chosen the voltage across R_e equal the voltage across R_c. It follows that $R_e \approx R_c$ if we follow this rule. The collector current is almost the same size as the emitter current that is $I_c \approx I_e$.), Kirchoff's loop rule says the voltage across R_e, plus the voltage across R_c, plus V_{ce} equal the battery voltage $V_{battery}$ (Kramer, 2012).

$$V_{cc} = I_c I_c + V_{ce} + I_e R_e$$
(4)

But $I_c = I_e$ and $R_c = R_e$
$$V_{cc} = 2I_c R_c + V_{ce}$$
$$R_c = \frac{V_{cc} - V_{ce}}{2I_c}$$
(5)

$$R_c = \frac{12 - 4}{2 \times 4 \times 10^{-3}} = \frac{8}{0.008} = 1000\ \Omega$$
$$\therefore R_c = R_e = 1000\ \Omega = 1\text{k}\ \Omega$$

D. The Choice of the Bias Resistors R_1 and R_2

The bias resistors R_1 and R_2 essentially work as a voltage divider for the battery voltage $V_{battery}$ (Nair & Deepa, 2013).The values of R_1 and R_2 are chosen so that the base-emitter junction is biased in the forward direction at least 0.6 volts since otherwise the transistor will not work. The bias resistors ae to be large compared with R_e and R_e so that the Voltage divider works the same way regardless of the size of I_c and I_b (Chaudhary, 2014). Disregard the rest of the circuit in the process of determining R_1 and R_2 so a simplified circuit is shown in figure 2. A current I_2 goes through resistors R_1 and R_2 and a current I_b just goes through R_1 and enters the base from the Connection with R_1

and R_2. Conservation of current allows us to conclude the current in R_1 is the sum of these currents that is $(I_2 + I_b)$ (Kramer, 2012). The voltage between the transistor base and the ground is $V_{be} = 0.6$volts plus the voltage across the emitter resistor equal to $I_2 R_2$ (Kramer, 2012).

$$I_2 R_2 = V_{be} + V_e$$
(6)

But $V_{cc} = V_{ce} + V_e$
$$V_e = V_{cc} - V_{ce}$$
$$V_e = 12 - 4 = 8V \text{ and } V_{be} = 0.6V$$

$$\therefore I_2 R_2 = 0.6 + 8 = 8.6V \text{ and } R_2 = \frac{8.6}{I_2}$$

Also $V_{cc} - I_1 I_1 - V_{be} = 0$
(7)

But $I_1 = (I_2 + I_b)$
$$\therefore R_1 = \frac{V_{cc} - V_{be}}{(I_2 + I_b)}$$
(8)

Cookbook Rule: It is a good idea to choose $I_2 \gg I_b$, Our Cookbook rule is

$I_2 = 25 \times I_b = 25 \times 0.00002 = 0.0005A$. (Neglecting $I_b \ll I_2$)

$$R_1 = \frac{12 - 0.6}{0.0005} = \frac{11.6}{0.0005} = 22800\ \Omega = 22.8\text{k}\ \Omega \text{ and } R_2 = \frac{8.6}{0.0005} = 17200\Omega = 17.2\text{k}\ \Omega$$

The values of $R_1 = 22.8$ k Ω and $R_2 = 17.2$k Ω was chosen.

E. The Choice of Rg

The input voltage\e is entirely AC since the input capacitor V_{input} blocks any DC voltage from getting to the transistor. Also, the emitter capacitor C_e will be chosen so that it effectively short circuits AC voltages around R_e. The voltage between the emitter and base is fixed at 0.6volts DC and there is no AC voltage between the emitter and base. The entire AC input voltage appears across R_g so that in terms of the AC emitter current I_e we have from Ohm's law (Avison, 2014).

$$i_e = \frac{V_{input}}{R_g}$$
(10)

The output capacitor serves to block the DC from the output voltage so the output voltage is entirely AC. The output AC voltage V_{output} is given by

$$V_{output} = i_c R_c = i_e R_c$$
(11)

Since to a good approximation $i_e \approx i_c$, the battery acts as a short or just a wire for AC so the top of the collector resistor is at the ground potential as far as AC is concerned.

$$\therefore V_{output} = \frac{R_c}{R_g} V_{input}$$
(12)

From which the AC gain g is

$$g = \frac{V_{output}}{V_{input}} = \frac{R_c}{R_g}$$
(13)

Now R_c has already been determined, the amplifier gain g must be less than β the current gain of the transistor.

$$\therefore R_g = \frac{R_c}{g}$$ Which is the chosen R_g for a particular gain, suppose we want the amplifier gain g = 25 to determine the resistor R_g.

$$R_g = \frac{1000}{25} = 40\Omega.$$ If Probably NOT found a resistor with this exact value in the lab so use one as close as possible.

F. The Values of the Capacitors

There are additionally three capacitors they do not play a role in the Basic transistor amplifier design which mainly involves setting DC voltages (Knight, Bird, & May, 2016).

The relevant part of the amplifier as far a choosing V_{input} concerned. The resistor and capacitor act as a voltage divider of the input voltage. The voltage across the resistor V_R is

$$V_R = \frac{R}{\sqrt{R^2 + \frac{1}{\omega^2 c^2}}} V_{input}$$

$$(14)$$

Where $\omega = 2\pi f$ and f is the frequency of the signal generator that provides the input voltage. The resistor $R = R_2$ and the capacitor $c = C_{input}$. If the amplifier is for audio frequencies, then the lowest f = 20Hz (U. A. B. A. P. Godse, 2010). Choose c so that $V_R = \frac{V_{input}}{2}$ at the lowest audio frequency so that at the lowest audio frequency, half the input voltage appears across the resistor. So the equation can be write as

$$v_R = \frac{V_{input}}{2} = \frac{2V_R}{V_{input}} = \frac{V_{input}}{V_{input}} = 1$$

$$\frac{V_R}{V_{input}} = \frac{1}{2}$$

$$(15)$$

$$\frac{1}{2} = \frac{R}{\sqrt{R^2 + \frac{1}{\omega^2 c^2}}}$$

$$4R^2 = R^2 + \frac{1}{\omega^2 c^2}$$

$$4R^2 \omega^2 c^2 = \omega^2 c^2 R^2 + 1$$

$$3R^2 \omega^2 c^2 = 1$$

$$= (2 \times 3.142 \times 20)^2 = 1.5795462 \times 10^4 \text{ rad/sec}$$

$$\therefore C_{input} = \frac{1}{\sqrt{3R_2^2 \omega^2}} = \frac{1}{3.7441672 \times 10^{06}} =$$

$$0.000000267 = 0.267 \times 10^{-6} = 0.267\mu F$$

. This is the value of input capacitor. The output capacitor is determined by similar reasoning since AC (but not DC) is passed along to the output which may be a speaker or another stage of amplification. Choose C_{input} in the lab as close to the above value as possible.

Choosing the output capacitor, the output capacitor can be chosen using a similar argument to finding the input capacitor value. However, in this case, the role of the output capacitor

is to make sure the DC voltage is not passed along to a second amplifier stage thus distorting the bias voltage of that stage. Also, the output voltage is developed across the output capacitor and the output voltage can be taken as half the total AC voltage across C_{output} and R_c. The voltage across the resistor V_R is

$$V_R = \frac{R}{\sqrt{R^2 + \frac{1}{\omega^2 c^2}}} V_{output}$$

$$(17)$$

But $V_R = \frac{V_{output}}{2}$

$$\frac{V_R}{V_{output}} = \frac{1}{2}$$

$$\therefore C = \frac{1}{\sqrt{3R^2 \omega^2}}$$

$$(18)$$

Where,

$$R^2 = R_c^2 = (1000)^2 \Omega, \omega^2 = (2\pi f)^2 = (2 \times 3.142 \times 20)^2 = 1.5795462 \times 10^2$$

rad/sec, and $c = C_{output}$. Substituting this value we have $C_{output} = 4.5938118 \times 10^{-6} = 4.5938118\mu F$. This is the output capacitor.

Choosing the emitter capacitor, the emitter capacitor can be a short circuit for AC around the emitter resistor. The time constant of the resistor and capacitor is $T = RC$ (Gates, 2001). Where $T = \frac{1}{f}$ and $f = 20H_z$ is the lowest AC frequency, $R = R_e$ is already known $(R = 1000\Omega)$. So the value of $C = C_e$ can be compute specifically as

From $T = RC$ $\qquad (19)$

$$C = \frac{T}{R}$$ where, $T = \frac{1}{f}$ and $f = 20H_z$,

$$R = R_e = 1000\Omega, C = C_e$$

$$\therefore C_e = \frac{T}{R_e}$$

$$(20)$$

$$C_e = \frac{0.05}{100} = 0.00005 = 50 \times 10^{-6} = 50\mu F$$

.

This is value of emitter capacitor.

G. The Complete Common Emitter Transistor Amplifier

Base of the values of $R_c = R_e = 1K$, $R_1 = 22.8K\Omega$, $R_2 = 17.2K$ Ω, $C_{input} = 0.267\mu F$, $C_{output} = 4.593811\mu F$, $C_{e3} = 50\mu F$, $V_{cc} = 12V$ since 12V is readily available in the lab and $R_g = \frac{R_c}{g}$ which is the chosen for a particular gain. The complete common emitter transistor amplifier circuit is indicated below:
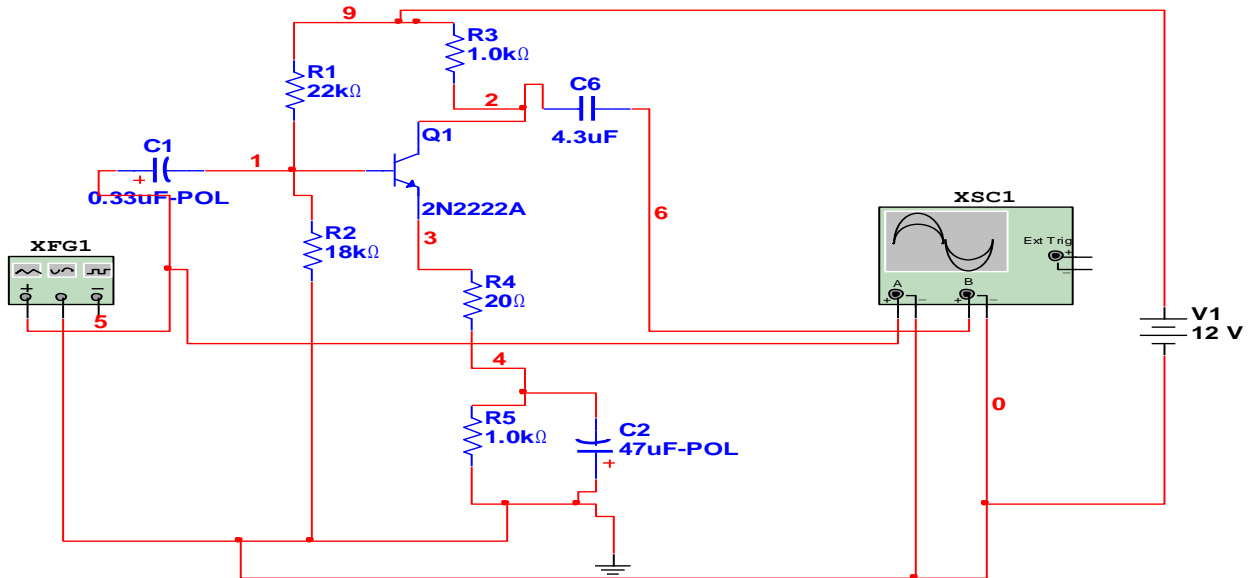
Fig .2. Complete Common Emitter Transistor Amplifier

III.   SIMULATED PERFORMANCE

Circuit simulations were performed using the Multisim 9 simulator. Function generator was used to provide the amplifier input signal for test. For all tests, the function generator amplitude was set to provide a peak-to-peak sinusoidal input to the amplifier. The amplifier input and output amplitude level was identified using Oscilloscope. Based on selected values for the implementation, the corresponding simulated gains are also indicated in the table for more detailed plots of the simulated performance are given where the simulated curves using measured component values are presented.

A.   Results and Discussions

Based on actual performance tested using Multisim 9 soft ware, the additional Resistor (R_g), Input Voltage(V_{in}), and Frequency the Gain was calculated and relationship between them was determined graphically

At constant Frequency (10KHz) and Input Voltage (20mV) varying the Resistor (R_g) the Gain was determined graphically   shown in the fig below.
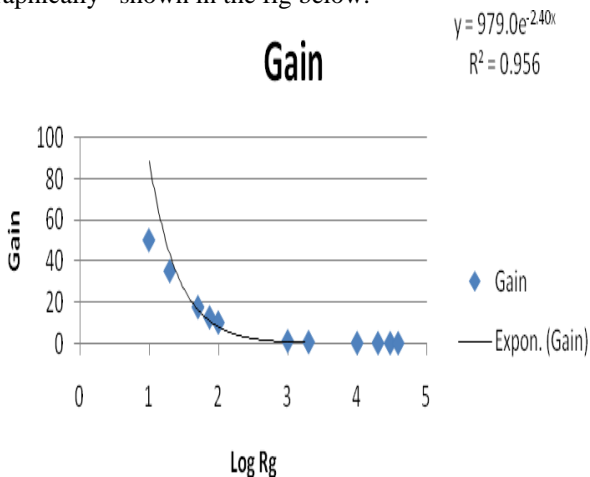

Figure3; the graph of Gain against log Resistance (R_g).
Figures, above shows the graph of Gain against log Resistance (R_g). It indicates that the resistance at which the amplifier instantaneously generates Gain can be observed by looking at the first data point that has resistance 10Ω, Gain of 50 and resistance of 40K, Gain of 0.0025 Ω , these indicate that increases in resistance would cause decreases in Gain produced by the amplifier. It can be observed from graph that the empirical relation between Gain and Resistance is   **y = 979.01e$^{-2.406x}$** this is the exponential relation which is the best among the different relation. The coefficient of determination **R² = 0.9569** which indicate that the correlation is very high. The equation can be used to estimate the Gain at any particular Resistance.

At constant Frequency (10 KHz) and Resistor R_g (30 Ω) varying Input Voltage, the Gain was determined graphically shown in fig below.
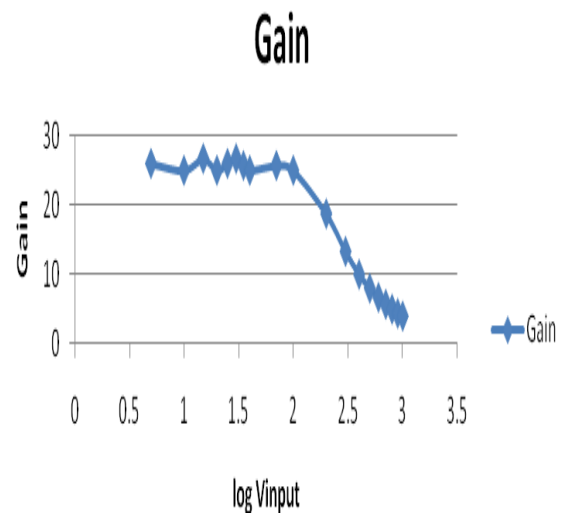

Figure4: the graph of Gain against Log of Input Voltage.
Fig above shows the graph of Gain against Log of Input Voltage. It indicated that when the input Voltage delivered into the amplifier increases this also produces a proportional amount of Output Voltage by amplifier and high Gain was also produced, From the range 0.69897 – 2 of log Input Voltage, beyond   this range Gain was gradually decreasing with increasing input Voltage, because the transistor reaches

its maximum rating power, at this point called saturation point no longer used as amplifier it became switch.

At constant Resistor Rg(30Ω) and constant Input Voltage (20mV) varying input Frequency , the Gain was determined graphically shown in below.
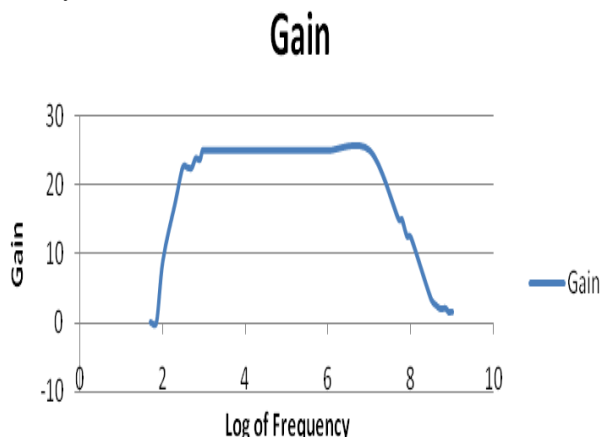

Figure5: A typical Frequency- versus-Gain curve

A typical Frequency- versus-Gain curve is shown in Fig below. While analyzing this curve, three value of frequency are important mid-frequency range ,Log 2.954242509 - Log 7, lower cut-off frequency, Log2.903089987, upper cut-off frequency, Log7.698970004 .The cut-off frequencies are also called roll-off frequencies because at these frequencies the amplifier Gain starts rolling down from its midband value or maximum value. The frequency span between these two cut-off frequencies is called the passband or bandwidth (BW) of the amplifier. All frequencies lying between lower cut- off and upper cut – off are amplified almost equally.

Conclusion

The design and implementation of a 2N2222A transistor amplifier has been presented. The amplifier was simulated using Multisim 9 soft ware. The tests verified the performance of the amplifier. It indicates the resistance at which the amplifier instantaneously generates Gain, the rang of the Input Voltage at which the amplifier has different Output Voltage and different Gain, the rang it has constant Output Voltage but Gain was gradually decreasing with increasing Input Voltage which is called saturation point. The cut-off frequencies at which the amplifier's Gain starts rolling down from its midband value or maximum value, the frequency span between these two cut-off frequencies called the passband or bandwidth (BW) of the amplifier. The relationship between additional Resistor (R_g), Input Voltage(V_{in}), frequency respond and Gain was determined graphically.

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