COMPARISON OF TRANSISTOR BIASING METHODS IN AMPLIFIER CIRCUITS

BY

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CERTIFICATION

This is to certify that CHUKWUDI CHIDUMEN BENEDICTA carried out this research under the supervision of Dr. Oboh Matthew E. of the department of physical science laboratory technology. In partial fulfillment of the award of Higher National Diploma (Physics with Electronics Option), Auchi Polytechnic Auchi.

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DEDICATION

This project is dedicated to God Almighty, the custodian of life, the epitome of great moral character and the architect of my destiny.

ACKNOWLEGDEMENT

My profound gratitude goes to God Almighty, for His grace and love towards me throughout my staying in school. It can only be God.

My thanks goes to my project supervisor, Dr. Oboh Matthew E. who ensured that this project work was a successful one. I say thank you sir.

My special thanks goes to my lovely husband Mr. Frank Onuwa Boi for his support and encouragement during this programme, also my wonderful daughter Frank Chikammadu Divine.

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ABSTRACT

The study was carried out to compare a transistor biasing method. Five methods were compared using transistor BC140 with different resistors. Stability is an important concern for the designing of amplifier. Different biasing methods were used and out of all the biasing methods, Emitter bias has the highest amplification with collector current and base current of (I_C-38mA, I_B-150mA) in practice. It may be noted here that working with a transistor below zero signal I_C=1mA is not advisable because of strongly non-linear transistor characteristics. Potential divider bias circuit provides highest stability of operation. In practice, stability factor is minimized and coming out to be equal to unity. In this research work, excellent stabilization is provided by R_E. For base bias resistor method, the stability factor is very high; therefore, there is a strong chance of thermal runaway. In a fixed bias it has poor thermal stability, due to these, this method of biasing is rarely employed.

CHAPTER ONE

2.0 INTRODUCTION

Transistors are used as amplifiers, oscillators, switching circuits etc. However, the principal use of transistor is as an amplifier (Ghandhi, 1957). An amplifier increases the magnitude of a given signal applied to its input. Most of the transistor amplifiers are required to work as linear amplifier. An amplifier is said to be linear if its output voltage is a linear function of its input voltage. Such a linear operation is ensured when zero signal operating point is selected properly, desirable in the middle of the active region and the operation is restricted in the linear region of the characteristics curves, thereby avoiding the distortion of the signal waveform (Guar *et al.,* 1973). Thus selection of zero signal operating point is of great importance and may be done by using suitable biasing arrangement i.e. by applying proper dc voltage to emitter-base junction and collector-base junction. The biasing circuit used in transistor should be such as:

i. To establish conveniently the operating point in the middle of the active region of the characteristics.
ii. To make the operating point independent of transistor parameters
iii. To stabilize the collector current against temperature variations.

Transistor is biased either with the help of battery or associating a circuit with the transistor. In a transistor amplifier circuits, biasing was done with the aid of battery V_{BB} which was operated from battery V_{CC} used in the output circuit. However, in the interest of simplicity and economy, it is desirable that a transistor circuit should have a single source of supply, the one in the output circuit (V_{CC}).

The basic function of transistor is to do amplification. The weak signal is given to the base of the transistor and amplified output is obtained in the collector circuit. One important requirement during amplification is that only the magnitude of the signal should increase and there should be no change in the signal shape. This increase in magnitude of the signal without any change in shape is known as *faithful amplification.* In order to achieve this, means are provided to ensure that input circuit (i.e. base-emitter junction) of the transistor remains forward biased and output circuit (i.e. collector-base junction) always remains reverse biased during all parts of the signal. This is known as transistor biasing.

Biasing in electronics is the method of establishing predetermined voltages or currents at various points of an electronic circuit for the purpose of establishing proper operating conditions in electronic components. Many electronic devices such as transistors and vacuum tubes, whose function is processing time-varying a.c signals, also require a steady a.c current or voltage to operate correctly a bias. The a.c signal applied to them is superposed on this point, or Q-point steady-state voltage or current at a specified terminal of an active device (a trat, is the transistor or vacuum tube) with no input signal applied. The term is also used for an alternating current (a.c) signal applied to some electronic devices which is similarly required for correct operation, such as the tape bias signal applied to magnetic recording heads used in magnetic tape recorders.

1.1 AIM AND OBJECTIVE OF THE PROJECT

1.1.1 Aim

The aim of this project is to compare transistors of common biasing methods.

1.1.2 Objectives

i. To determine the base bias or fixed current bias transistor
ii. To determine the base bias with collector feedback
iii. To determine the voltage divider bias
iv. To determine base bias collector and emitter feedback.

CHAPTER TWO

LITERATURE REVIEW

2.1 Transistor

A transistor is a semiconductor device used to amplify and switch electronic signals and electronic power. It is composed of semiconductor material with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistors terminals changes the current through another pair of terminals. Because the controlled (output) power can be higher than the controlling (input) power, a transistor can amplify a signal. Today, some transistors are packaged individually, but many more are found embedded in integrated circuits. The transistor is the fundamental building block of modern electronic devices, and is ubiquitous in modern electronic systems. Following its development in 1947 by American physicists John Bardeen, Walter Brattain, and William Shockley, the transistor revolutionized the field of electronics, and paved the way for smaller and cheaper radios, calculators, and computers, among other things. The transistor is on the list of Institute of Electrical and Electronics (IEE) milestones in electronics and the inventors were jointly awarded the 1956 Nobel Prize in Physics for their achievement (John, 2014).

2.1.1 History of Transistor

The thermionic triode, a vacuum tube invented in 1907, enabled amplified radio technology and long-distance telephony. The triode, however, was a fragile device that consumed a lot of power. In 1934, German inventor Oskar Heil patented a similar device. From November 17, 1947 to December 23, 1947, John Bardeen and Walter Brattain at AT&T's Bell Labs in the United States performed experiments and observed that when two gold point contacts were applied to a crystal of germanium, a signal was produced with the output power greater than the input (Heil *et at.,* 1935). Solid State Physics Group leader William Shockley saw the potential in this, and over the next few months worked to greatly expand the knowledge of semiconductors. The term transistor was coined by John R. Pierce as a contraction of the term transresistance. According to Lillian Hoddeson and Vicki Daitch, authors of a biography of John Bardeen, Shockley had proposed that Bell Labs first patent for a transistor should be based on the field-effect and that he be named as the inventor (Millman *et al.,* 1992). Having unearthed Lilienfeld's patents that went into obscurity years earlier, lawyers at Bell Labs advised against Shockley's proposal because the idea of a field-effect transistor that used an electronics field as a "grid" was not new. Instead, what Bardeen, Brattain, and Shockley invented in 1947 was first point-contact transistors. In acknowledgment of this accomplishment, Shockley, Bardeen, and Brattain were jointly awarded the 1956 Noble Prize in Physics "for their researches on semiconductors and their discovery of the transistor effect".

In 1948, the point-contact transistor was independently invented by German physicists Herbert Matare and Heinrich Welker while working at the Compagnie des FreinsetSignaux, a Westingouse subsidiary located in Paris. Matare had previous experience in developing crystal rectifiers from silicon and germanium in the German radar effort during World War II. Using this knowledge, he began researching the phenomenon of "interference" in 1947. By June 1948, witnessing currents flowing through point-contacts, Matare produced consistent results using samples of germanium produced by Welker, similar to what Bardeen and Brattain had accomplished earlier in December 1947. Realizing that Bell Labs scientists had already invented the transistor before them, the company rushed to get its “transistor” into production for amplified use in France’s telephone network. The first high-frequency transistor was the surface-barrier germanium transistor developed by Philco in 1953, capable of operating up to 60MHz. these were made by etching depressions into an N-type germanium base from both sides with jets of Indium (III) sulfate until it was a few ten-thousandths of an inch thick. Indium electroplated into the depressions formed the collector and emitter (Bradley, 1953). The first all-transistor car radio, which was produced in 1955 by Chrysler and Philco, used these transistors in its circuitry and also they were the first suitable for high-speed computers. The first working silicon transistor was developed at Bell Labs on January 26, 1954 by Morris Tenenbaum (Saul-Rosen, 1991). The first commercial silicon transistor was produced by Texas Instruments in 1954. This was the work of Gordon Teal, an expert in growing crystals of high purity, who had previously worked at Bell Labs. The first Metal-Oxide Semiconductor (MOS) transistor actually built was by Kahng and Atalla at Bell Labs in 1960 (Grand, 2006).

2.2 Types of Transistor

There are many different types of transistors and they each vary in their characteristics and each has their own advantages and disadvantages. Some types of transistors are used primarily for switching applications. Others can be used for both switching and amplifications. Still other transistors are in a specialty group of their own, such as phototransistors, which responds to the amount of light shining on it to produce current flow through it. Below is a list of the various types of transistors, we will go over the characteristics that make each of them vary.

2.2.1 Bipolar Junction Transistors (BJT)

These are transistors which are made up of 3 regions, the base, the collector, and the emitter. Bipolar Junction Transistors, unlike FET transistors, are current controlled devices. A small current entering in the base region of the transistor causes a much larger current flow from the emitter to the collector region. Bipolar junction transistors come in two main types, NPN and PNP.

A NPN transistor is one in which the majority current carrier are electrons. Electron flowing from the emitter to the collector forms the base of the majority of current flow through the transistor. The other type of charge carrier, holes is minority. PNP transistors are the opposite. PNP transistors, the majority current carrier are holes. Overall bipolar junction transistors are the only type of transistor which is turned on by current input (input into the base). This is because BJTs have the lowest input impedance of transistors. The low impedance (or resistance) allows current to flow through the base of the transistor. Because of this low impedance also these BJTs have the highest amplification of all transistors. The downside of BJTs is because they have low input impedance, they can cause loading in a circuit. Loading is when a device can draw significant current from a circuit, thus disturbing a circuit’s power source.

2.2.2 Field Effect Transistors (FET)

Field effect transistors are transistors which are made up of 3 regions, a gate, a source, and a drain. Unlike BJTs, FETs are voltage-controlled devices. A voltage placed at the gate controls current flow from the source to the drain of the transistor. Field Effect Transistors have very high input impedance, from several mega ohms (MΩ) of resistance to much larger values. This high input impedance causes them to have very little current run through them. (According to ohms law, current is inversely affected by the value of the impedance of the circuit. If the impedance is high, the current will be very low). So FETs draw very little current from a circuit's power source. Thus, this is ideal because they don't disturb the original circuit's power elements to which they are connected to. They won't cause the power source to be loaded down. The drawback of FETs is that they won't cause the provide the same amplification that could be gotten from BJTs. BJTS are superior in the fact that they provide greater amplification, even though FETs are better in that they cause less loading, are cheaper, and easier to manufacture. FETs come in 2 main types: Junction Field Effect Transistor (JFETs) and Metal-Oxide Semiconductors Field-Effect Transistors (MOSFETs). JFETs and MOSFETs are almost similar but MOSFETs have even higher input impedance value than JFETs. This causes even less loading in a circuit.

2.3 Types of Transistors by Function

Now we will go over the types of transistors by functions, meaning what they do or, rather are designed to do. Some transistors are used primarily for switching. Others more so for amplification. We discourse this below:

Small Signal Transistors are transistors that are used primarily to amplify low level signals but can also function well as switches. Transistors come with a value, called the transistor gain (HFE) values, which denote how greatly a transistor can amplify input signals. Typical HFE values for small signal transistors range from 10 to 500, with maximum I_C(Collector current) rating from about 80 to $600mA$. They come in NPN and PNP forms. Maximum operating frequencies range from about 1 to $300MHz$. As a design note, small signal transistors are used primarily when amplifying small signals, such as a few volts and only when using mili-amperes of current. When using larger voltage and current (larger power), using many volts or amperes of current, a power transistor should be used.

2.3.1 Small Switching Transistors

These are transistors that are used primarily as switches but which can also be used as amplifiers. Typical HFE values for small switching transistors range from 10 to 200, with maximum I_C ratings from about 1 to $1000mA$. They come in NPN and PNP forms. In terms of design, small switching transistors are used primarily as switches. Though they may be used as amplification of small signal transistors which can have amplification of up to 500. This makes small switching transistors more useful for switching, though they may be used as basic amplifiers to provide gain. When you need more gain, small transistors would work better as amplifiers.

2.3.2 Power Transistors (PT)

Power Transistors are suited for applications where a lot of power is being used (current and voltage). The collector of the transistor is connected to a metal base that acts as a heat sink to dissipate excess power. Typical power ratings range from around 10 to $300W$ with frequency ranging from about 1 to $100MHz$. Maximum I_C values range between 1 to $100A$. Power transistors come in NPN, PNP, and Darlington (NPN or PNP) forms.

2.3.3 High Frequency Transistors (HFT)

High Frequency Transistors are transistors that are used for small signals that run at high frequency for high-speed switching applications. These are transistors that are used for high frequency signals and must be able to switch on and off at very high speeds. High Frequency Transistors are used in High Frequency (HF), Very High Frequency (VHF), Ultra High Frequency (UHF), Community Antenna Television (CATV), and Master Antenna Television (MATV) amplifier and oscillator application. They have a maximum frequency ranging from about $2000MHz$ and maximum I_C current from 10 to $600mA$. They are available in both NPN and PNP forms e.g. is Phototransistors which are light-sensitive transistors. A common type of phototransistors resembles a bipolar transistor with its base lead removed and replaced with a light-sensitive area. This is why a phototransistor has only 2 terminals instead of the conventional 3 terminals. When this surface area is kept dark, the device is off. Practically, no current flows from the collector to emitter region. However, when the light-sensitive region is exposed to light, a small base current is generated that controls a much larger collector-emitter current. Just like regular transistors, phototransistors can be both bipolar of field effect transistors.

2.3.4 Field-Effect Phototransistors (Photo FETs)

These are light-sensitive field effect transistors. Unlike photobipolar transistors, photoFETs use a light to generate a gate voltage that is used to control a drain-source current. PhotoFETs are extremely sensitive to variation in light and are more fragile, than bipolar phototransistors. Unijunction transistors are three-lead transistors that act exclusively as electrically controlled switches and they are not used as amplifiers.

These transistors differs from other transistors in that general transistors usually provide the ability to act as switches and also as an amplifier. But a unijunction transistor does not provide any decent type of amplification because of the way it is constructed. It’s simply not designed to provide a sufficient voltage or current boost. The three leads of a unijunction transistor are B_1, B_2, and an emitter lead which is the lead which receives the input the input current. The basic operation of a UJT is relatively simple. When no potential difference (voltage) exists between its emitter and either of its base lead (B_1 or B_2), only a very small current flows from $B_1\ to\ B_2$. However, if a sufficiently large positive trigger voltage relative to its base lead is applied to the emitter, a larger current flows from the emitter and combines with the small B_1, B_2 current, thus giving rise to large B_1 output current. Unlike other transistors where the control leads provide little additional current, the UJT is just the opposite. Its emitter current, is the primary source of current for the transistor. The B_2 to B_1 current is only a very small amount of the total combined current. This means that unijunction transistors are not suitable for amplification purpose, but only for switching.

CHAPTER THREE

METHODOLOGY

3.1 Design of Transistor Biasing Circuits

In practice, the following steps are taken to design transistor biasing and stabilization of circuits:

Step 1. It is a common practice to take $R_E = 500 - 1000\Omega$. Greater the value of R_E, better is the stabilization. However, if R_E is very large, higher voltage drop across it leaves reduced voltage drop across the collector. Consequently, the output is decreased. Therefore, a compromise has to be made in the selection of the value of R_E.

Step 2. The zero signals current I_C is chosen according to the signal swing. However, in the initial stages of most transistor amplifiers, zero signal $I_C = 1mA$ is sufficient. The major advantages of selecting these values are:

a. The output impedance of a transistor is very high at $1mA$. This increases the voltage.
b. There is little danger of overheating as $1mA$ is quite a small collector current.

It may be noted here that working the transistor below zero signal $I_C = 1mA$ is not advisable because of strongly non-linear transistor characteristics.

Step 3. The values of resistances R_1 and R_2 are so selected that current I_1 flowing through R_1 and R_2 is at least 10 times I_B i.e. $I_1 \geq 10I_B$. When this condition is satisfied, good stabilization is achieved.

Step 4. The zero signal I_C should be a different more (say 20%) than the maximum collector current swing due to signal. For example, if collector current change is expected to be $3mA$ due to signal, and then select zero signals $I_C = 3.5mA$. It is important to note this point. Selecting zero signals I_C below this value may cut off a part of negative half-cycle of a signal. On the other hand, selecting a value much above this value (say $15mA$) may unnecessarily overheat the transistor, resulting in wastage of battery power. Moreover, a higher zero signal I_C will reduce the value of R_C (for same V_{CC}), resulting in reduced voltage gain.

3.1.1 Essentials of a Transistor Biasing Circuit

It has been discussed that transistor biasing is required for faithful amplification. The biasing network associated with the transistor should meet the following requirements:

a. It should ensure proper zero signal collectors current.
b. It should ensure that V_{CC} does not fall below $0.5\,V$ for Ge transistors and $1\,V$ for for silicon transistor at any instant.
c. It should ensure the stabilization of operating point.

3.2 Methods of Transistor Biasing

In the transistor amplifier circuits drawn so far biasing was done with the aid of a battery V_{BB} which was separate from the battery V_{CC} used in the output circuit.

However, in the interest of simplicity and economy, it is desirable that transistor circuit should have a single source of supply- the one in the output circuit (i.e. V_{CC}). The following are the most commonly used methods of obtaining transistor biasing from one source of supply (i.e.V_{CC}).

a. Base resistor method
b. Emitter bias method
c. Biasing with collector-feedback resistor
d. Voltage-divider bias
e. Base bias collector and emitter feedback.

In all these methods, the same basic principle is employed *i.e.* required value of base current (and hence I_C) is obtained from V_{CC} in the zero signal conditions. The value of collector load R_C is selected keeping in view that V_{CE} should not fall below $0.5\ V$ for germanium transistors and $1\ V$ for silicon transistors.

3.2.1 Base Resistor Method

In this method, a high resistance R_B (several hundred KΩ) is connected between the base and +ve end of supply for *npn* transistor (see fig. 1.0) and between base and negative en d of supply for *pnp* transistor. Here, the required zero signal base current is provided by V_{CC} and it flows through R_B. It is because, now base is positive with respect to emitter *i.e.* base-emitter junction is forward biased. The required value of zero signal base current I_B (and hence $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B.

3.2.1.1 Circuit Analysis

It is required to find the value of R_B so that required collector current flows in the zero signal conditions.

Let I_C be the required zero signal collector current. Therefore,

$$I_B = \frac{I_C}{\beta} \tag{3.1}$$

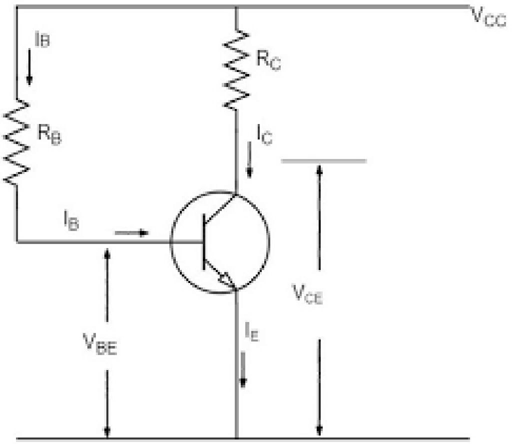

Figure 3.1.Circuit analysis for a base resistor method

Considering the closed circuit and applying Kirchhoff's law, we get

$$V_{CC} = I_B R_B + V_{BE}$$

Or

$$I_B R_B = V_{CC} - V_{BE} \tag{3.2}$$

As V_{CC} and I_B are known and V_{BE} can be seen from the transistor manual, therefore, value of R_B an be readily found from

$$R_B = \frac{V_{CC} - V_{BB}}{I_B} \tag{3.2}$$

Since V_{BE} is generally quite small as compared to V_{CC}, the former can be neglected with little error. It then follows from equation 3.2 that:

$$R_B = \frac{V_{CC}}{I_B} \qquad (3.3)$$

It may be noted that V_{CC} is a fixed known quantity and I_B is chosen at some suitable values. Hence, RB can always be found directly, and for this reason, this method is sometimes called *feed-bias method.*

To measure the stability factor, we use;

$$\text{Stability factor, } S = \frac{\beta+1}{1-\beta\ \frac{dl_B}{dl_C}} \qquad (3.4)$$

In fixed-bias method of biasing, I_B is independent of I_C so that $dl_B/dl_C = 0$. Putting the value of $dl_B/dl_C = 0$ in the above expression, we have, Stability factor, $S = \beta + 1$**.** Thus, the stability factor in a fixed bias is $(\beta + 1)$. This means that I_C changes $(\beta + 1)$ times as much as any change in I_{C0}. For instance, if $\beta = 100$, then S = 101 which means that I_C increases 101 times faster than I_{CO}. Due to the large value of S in a fixed bias, it has poor thermal stability.

Advantages:

1. This biasing circuit is very simple as only one resistance RB is required.
2. Biasing conditions can easily be set and the calculations are simple.
3. There is no loading of the source by the biasing circuit since no resistor is employed across base-emitter junction.

Disadvantages:

1. This method provides poor stabilization. It is because there is no means to stop a self-increase to collector current due to temperature rise and individual

variations. For example, if β increases due to transistor replacement, then I_C also increases by the same factor as I_B is constant.

ii. The stability factor is very high. Therefore, there are strong chances of thermal run away. Due to these disadvantages, this method of biasing is rarely employed.

3.2.2 Emitter Bias Circuit

Figure 3.2 shows the emitter bias circuit. This circuit differs from base-bias circuit in two important respects. First, it uses two separate d.c. voltages sources; on positive ($+V_{CC}$) and other negative ($-V_{CC}$). Normally, the two supply voltages will be equal. For example, if $V_{CC} = +18\,V$ (d.c.), then $V_{CC} = -18V$ (d.c.). Suddenly, there is a resistor R_E in the emitter circuit.

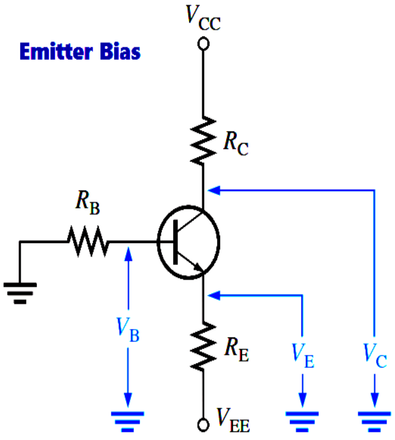

Figure 3.2. Circuit analysis for an emitter bias circuit

We shall first redraw the circuit in figure 3.2 as it usually appears on schematic diagrams. This means deleting the battery symbols as shown in Fig. 3.2. All the information is still (seeing Fig. 3.2) on the diagram except that it is in condensed form. That is a negative supply voltage $-V_{EE}$ is applied to the bottom of R_E and a positive voltage of $+V_{EE}$ to the top of R_C.

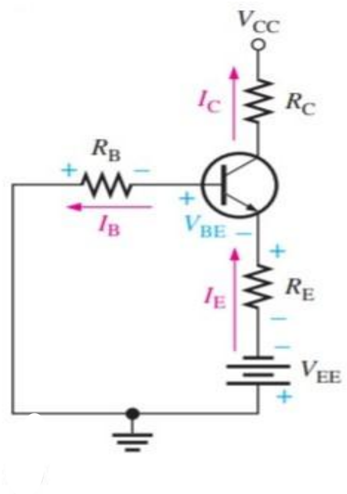

Figure 3.3. Circuit analysis for an emitter bias circuit

3.2.2.1 Circuit Analysis of Emitter Bias

Figure 3.3 shows the emitter bias circuit. We shall find the Q-point values (*i.e.* $d.c\ I_C$ and d.c. V_{CC} for this circuit.

i. Collector current (I_C). Applying Kirchhoff's voltage law to the base-emitter circuit in figure 3.2, we have,

$$-I_B R_{B-} V_{BE} - I_E R_E + V_{EE} \qquad (3.5)$$

$$\therefore V_{EE=} I_B R_B + V_{BE} + I_E R_E \qquad (3.6)$$

Now $I_C = I_E\ and\ I_C = \beta I_B \quad \therefore \quad I_B = \frac{I_E}{\beta}$ (3.7)

Putting $I_B = \frac{I_E}{\beta}$ in the above equation, we have,

$$V_{EE} = (I_E/\beta)R_B + I_E R_E + V_{BE} \qquad (3.8)$$

Or $V_{EE} - V_{BE} = I_E(\frac{R_B}{\beta} + R_E)$

$$\therefore \quad I_E = V_{EE} - \frac{V_{BE}}{R_E} + \frac{R_B}{\beta} \qquad (3.9)$$

Since $I_C = I_E$, we have,

$$I_C = V_{EE} - \frac{V_{BE}}{R_E} + \frac{R_B}{\beta} \tag{3.10}$$

ii. **Collector-emitter voltage (V_{CE}):** Fig. 3.4 shows the various voltages of the emitter bias circuit with respect to ground.

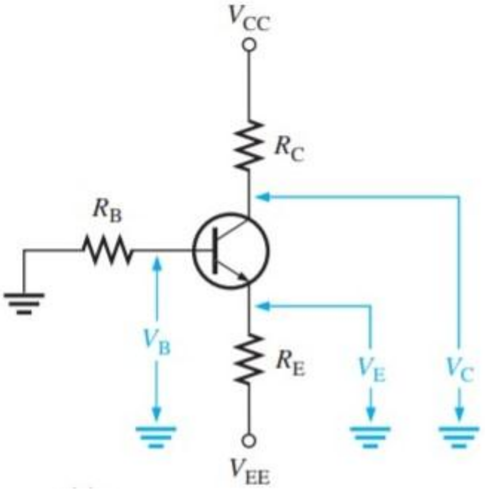

Figure 3.4. Circuit analysis for a collector emitter voltage

Emitter voltage with respect to ground is

$$V_E = -V_{EE} + I_E R_E \tag{3.11}$$

Base voltage w.r.t. ground is

$$V_B = V_E + V_{BE} \tag{3.12}$$

Collector voltage with respect to ground ground is

$$V_C = V_{CC} - R_C R_C \tag{3.13}$$

Subtracting V_E from V_C and using the approximation $I_C = I_E$, we have,

$$V_C - V_E = (V_{CC} - I_C R_C) - (-V_{EE} + I_C R_E) \tag{3.14}$$

Or $$V_{CE} = (V_{CC} + V_{EE}) - I_C(R_C + R_E) \tag{3.15}$$

Alternatively. Applying Kirchhoff's voltage law to the collector side of the emitter bias circuit in figure 3.3 (Refer back), we have,

$$V_{CC} - I_C R_C - V_{CC} - I_C x R_C + V_{EE} = 0 \qquad (3.16)$$

Or

$$V_{CE} = V_{CC} + V_{EE} - I_C(R_C + R_E) \qquad (3.17)$$

To measure the stability factor, we use,

Stability of Emitter Bias. The expression for collector current I_C for the emitter bias current is given by;

$$I_E = \frac{V_{EE} - V_{BE}}{R_E + \frac{R_B}{\beta}} \qquad (3.18)$$

$$* I_C \simeq I_E$$

3.2.3 Biasing with Collector Feedback Resistor

In this method, one end of R_B is connected to the base and the other end to the collector as shown in figure 3.5. Here, the required zero signal base current is determined not by V_{CB} but by the collector base voltage V_{CB}. It is clear that V_{CB} forward biases the base-emitter junction and hence base current I_B flows through R_B. This causes the zero signal collector current to flow in the circuit.

3.2.3.1 Circuit Analysis for Biasing Collector Feedback Resistor: The required value of R_B needed to give the zero signals current I_B can be determined as follows. Referring to figure 3.5

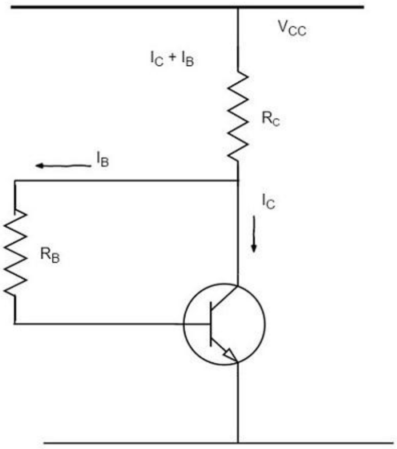

Figure 3.5. Circuit analysis for biasing collector feedback resistor

$$V_{CC} = I_C R_C + I_B R_B + V_{BE} \tag{3.19}$$

Or

$$R_B = \frac{V_{CC} - V_{BE} - I_C R_C}{I_B}$$

$$V_C = \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B}$$

Alternatively, $V_{CE} = V_{BE} + V_{CB}$

Or

$$V_{CB} = V_{CE} + V_{BE}$$

$$\therefore \quad R_B = \frac{V_{CB}}{I_B} = \frac{V_{CE} - V_{BE}}{I_B} \text{; Where} \quad I_B = \frac{I_C}{\beta} \tag{3.20}$$

It can be shown mathematically that stability factor S for this method of biasing is less than $\beta + 1$ i.e. Stability factor, $S < \beta + 1$.

Therefore, this method provides better thermal stability than the fixed bias.

$$I_C = \frac{V_{CC} - V_{BE}}{\frac{R_B}{\beta} + R_C} \tag{3.21}$$

$$V_{CE} = V_{CC} - I_C R_C \tag{3.22}$$

Advantages

1. It is a simple method as it requires only one resistance R_B.
2. This circuit provides some stabilization of the operating point as discussed below;

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

Disadvantages

1. The circuit does not provide good stabilization because stability factor is fairly high, though it is lesser than that of fixed bias. Therefore, the operating point does not change, although to lesser extent due to temperature variations and other effects.
2. This circuit provides a negative feedback which reduces the gain of the amplifier as explained here after. During the positive half-cycle of the signal, the collector current increases. The increased collector current would result in greater voltage drop across R_C. This will reduce the base current and hence collector current.

3.2.4 Voltage Divider Bias Method

This is the most widely used method of providing biasing and stabilization to a transistor. In this method, two resistances R_1 and R_2 are connected across the supply voltage V_{CC} (see figure 3.5) and provide biasing. The emitter resistance R_E provides stabilization. The name "voltage divider" comes from the voltage divider formed by R_1 and R_2. The voltage drop across R_2 forward biases the base-emitter junction.

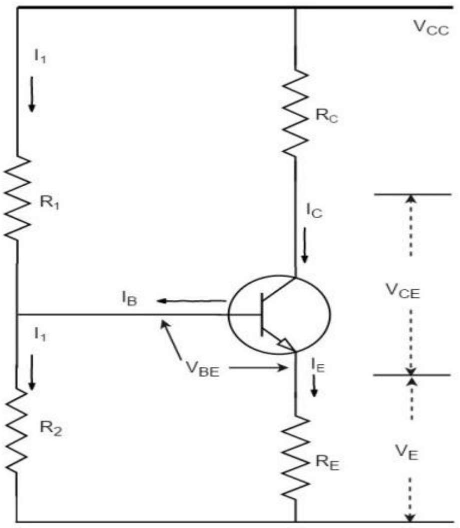

Figure 3.6. Circuit analysis for a voltage divider bias method

3.2.4.1 Current Analysis of Voltage Divider Bias Method: Suppose that the current flowing through resistance R_1 is I_1. As base current I_B is very small, therefore, it can be assumed with reasonable accuracy that current flowing through R_1 is also I_1.

i. **Collector Current I_C:**

$$V_1 = \frac{V_{CE}}{R_1+R_2} \tag{3.23}$$

∴ Voltage across resistance R_2 is

$$V_2 = \frac{V_{CE}}{R_1+R_2} \tag{3.24}$$

Applying Kirchhoff's voltage law to the base circuit of Fig. 1.6

$$V_2 = V_{BE} + V_E \tag{3.25}$$

Or $$V_2 = V_{BE} + I_E R_E \tag{3.26}$$

Or $$I_E = \frac{V_2 - V_{BE}}{R_E} \tag{3.27}$$

Since $I_E \simeq I_C$. Therefore,

$$I_C = \frac{V_2 - V_{BE}}{R_E} \quad (3.28)$$

It is clear from the above that I_C does not at all depend upon β. Though I_C depends upon V_{BE} but in practice $V_2 \gg V_{BE}$ so that I_C is practically independent of V_{BE}. Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilization is ensured. It is due to this reason that potential divider bias has become universal method for providing transistor biasing.

ii. **Collector-emitter Voltage V_{BE}:** Applying Kirchhoff's voltage law to the collector side,

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E \quad (3.29)$$

$$V_{CC} = I_C R_C + V_{CE} + I_C R_E (I_E = I_C)$$

$$V_{CC} = I_C (R_C + R_E) + V_{CE} \quad (3.30)$$

Therefore,

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

So that,

$$I_E \simeq I_C \quad (3.31)$$

3.2.4.2 Stabilization. In this circuit, excellent stabilization is provided by R_E. Consideration of equation (3.28) reveals this fact.

$$V_2 = V_{BE} + I_C R_E \quad (3.32)$$

Suppose the collector current I_C increases due to rise in temperature. This will cause the voltage drop across emitter resistance R_E to increase. As voltage drop across R_2

(*i.e.* V_2) is independent of I_C , therefore, V_{BE} decreases. This in turn causes I_B to decrease. The reduced value of I_B tends to restore I_C to the original value.

3.2.4.3 Stability Factor: It can be shown mathematically that stability factor of the circuit is given by:

$$\text{Stability Factor, } S = \frac{(\beta+1)(R_0+R_E)}{R_0+R_E+\beta R_E} \tag{3.33}$$

$$S = (\beta+1).\frac{1+\frac{R_0}{R_E}}{\beta+1+\frac{R_0}{R_E}} \tag{3.34}$$

Where $R_O = \frac{R_1 R_2}{R_1+R_2}$

If the ratio $\frac{R_O}{R_E}$ is very small, then $\frac{R_O}{R_E}$ can be neglected as compared to 1 and the stability factor becomes:

$$\text{Stability factor, } S = (\beta+1).\frac{1}{\beta+1} = 1$$

3.2.5 Base Bias Collector and Emitter Feedback

In the circuit of (figure 3.7), adding an additional resistor to the base network of the previous configuration improves stability even more with respect to variations in Beta (β) by increasing the current flowing through the base bias resistor. The current flowing through R is generally set at a value equal to about 10% of collector current I. obviously; it must also be greater than the base current required for the minimum value of Beta (β) one of the advantages of this type of self-biasing configuration is that the resistors provide both automatic biasing and feedback at the same time.

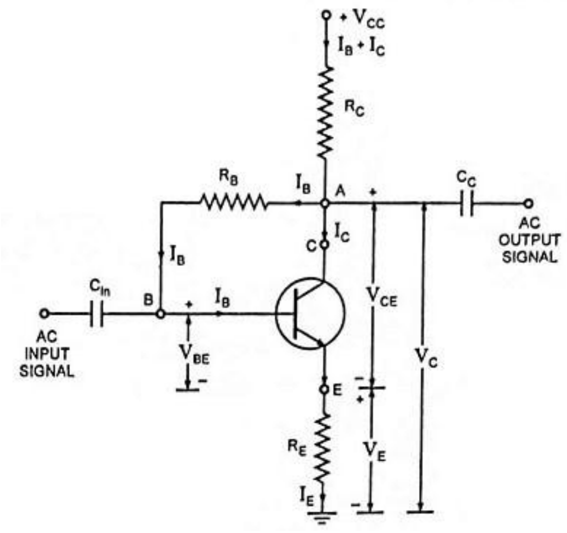

Figure 1.7. Circuit analysis for a base bias collector and emitter feedback

$$v_c = v_{cc} - R_C(I_C + I_{B1}) \tag{3.35}$$

$$V_E = 0\,V$$

$$V_B = V_{BE}$$

$$I_{RB1} = \frac{V_B}{R_{B2}}$$

$$I_C = \beta I_B \tag{3.36}$$

$$I_E = (I_C + I_B) \cong I_C \tag{3.37}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 RESULTS

4.1 Table 4.0. Basic bias or fixed current bias transistor

Transistor Type	Resistor		Voltage			Current	
	R_B	R_C	V_{CC}	V_{CE}	V_{CB}	I_C	I_B
$BC140$	$100K\Omega$	$2.2K\Omega$	$9\ V$	$9\ V$	$0.9\ V$	$3.6\ mA$	$8.2\ mA$

4.1.1 Calculation

4.1.1.1 D.C. LOADLINE: Referring to figure 3.1

$$V_{CE} = V_{CC} - I_C R_C \tag{4.1}$$

When $I_C = 0$, $V_{CE} = V_{CE} = 9\ V$. This locates the first point $B(OB = 9\ V)$ of the load line on collector-emitter voltage axis as shown in figure 4.1

When $$V_{CE} = 0,\ \ I_C = \frac{V_{CC}}{R_C} = \frac{9V}{2.2K\Omega}\text{=4mA} \tag{4.2}$$

This locates the second point A $(0A = 4mA)$ of the load line on the collector current axis. By joining points A and A, d.c load line AB is constructed.

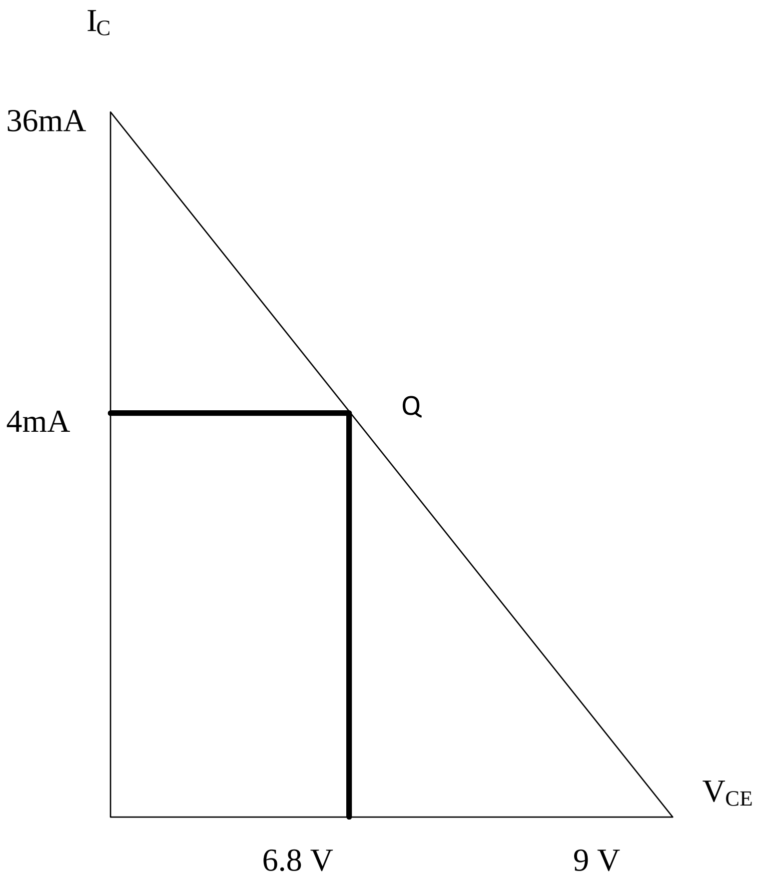

Figure 4.1. Graph of Base bias or fixed current bias transistor.

Operating Point Q

The zero signal I_C is chosen according to the signal swing, however, in the initial stages of most transistor amplifiers, zero signal $I_C = 1mA$ is sufficient because the output impedance of a transistor is very high at 1mA. This is because voltage gains.

$$V_{CE} = V_{CC} - I_C R_C \tag{4.3}$$

$$V_{CE} = 9 - (1mA * 2.2K\Omega) \tag{4.4}$$

$$V_{CE} = 9 - 2.2$$

Operating point is therefore 6.8 $V,\ 1mA$

4.2 Table 2. Emitter bias transistor

Transistor Type	Resistor			Voltage		Current	
	R_B	R_E	R_C	V_{CC}	V_{CE}	I_C	I_b
$BC140$	$100K\Omega$	$10K\Omega$	$4.7K\Omega$	$18\,V$	$-18\,V$	$38mA$	$150mA$

4.2.1 Calculation

4.2.1.1 D.C Load line: Referring to figure 3.2

$$V_{CE} = V_{CC} - I_C R_C \tag{4.5}$$

When $I_C = 0, V_{CE} = V_{CC}$ = 18V (4.6)

This locates the point $A\ (0B = 1\ V)$ of the load line on collector-emitter voltage axis as shown in figure 4.2

When $V_{CE} = 0, \quad I_C = \frac{V_{CC}}{R_C} = \frac{18V}{4.7K\Omega} = 3.8mA$ (4.7)

This locates the second point $A\ (0A = 3.8mA)$ of the load line on the collector current axis AB is constructed.

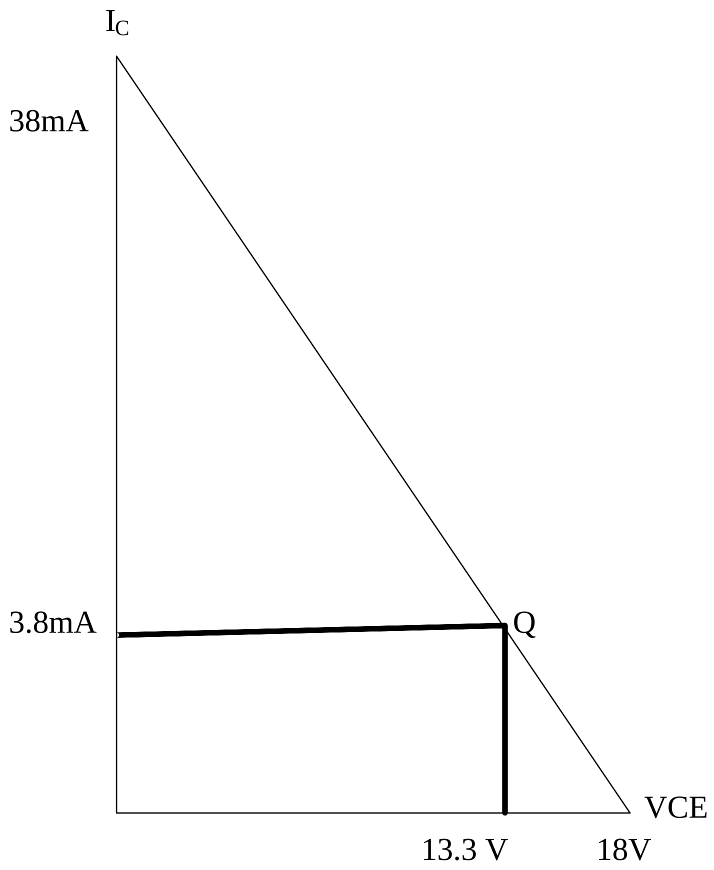

Figure 4.2. Graph of emitter bias transistor

4.3 Table 3. Biasing With Collector Feedback Resistor

Transistor Type	Resistor		Voltage		Current	
	R_B	R_C	V_{CC}	V_{CE}	I_C	I_b
$BC140$	$100K\Omega$	$4.7K\Omega$	$18\,V$	$-18\,V$	$38mA$	$150mA$

4.3.1 Calculation

4.3.1.1 D.C Load line: Referring to figure 3.3

$$V_{CE} = V_{CC} - I_C R_C \qquad (4.8)$$

When $I_C = 0, V_{CE} = V_{CC} = 18V$. This locates the first point O $(OB = 18\,V)$ of the load lone on collector-emitter voltage axis as shown in figure 4.3. When

$$V_C = 0,\ I_C = \frac{V_{CC}}{R_C} = \frac{18V}{1K\Omega} = 18mA \tag{4.9}$$

This locates the second point O $(OA = 18mA)$ of the load line on the collector current axis AB is constructed.

$$R_B = V_{CC} - V_{BE} - \beta I_B \frac{R_C}{I_B} \tag{4.10}$$

$R_B = 100m\Omega, V_{CC} = 18V, R_C = 1K\Omega, V_{BE} = 0.7V$

Or

$$100 * I_B = 18 - 0.7 - 100 * I_B * 1$$

Or

$$200I_B = 17.30$$

$$I_B = \frac{17.30}{200} = 0.09mA \tag{4.11}$$

Current collector, $I_C = \beta I_B = 100 * 0.009 = 9mA$

Collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C \tag{4.12}$$

$$V_{CE} = 18V - 9mA * 1K\Omega = 9V$$

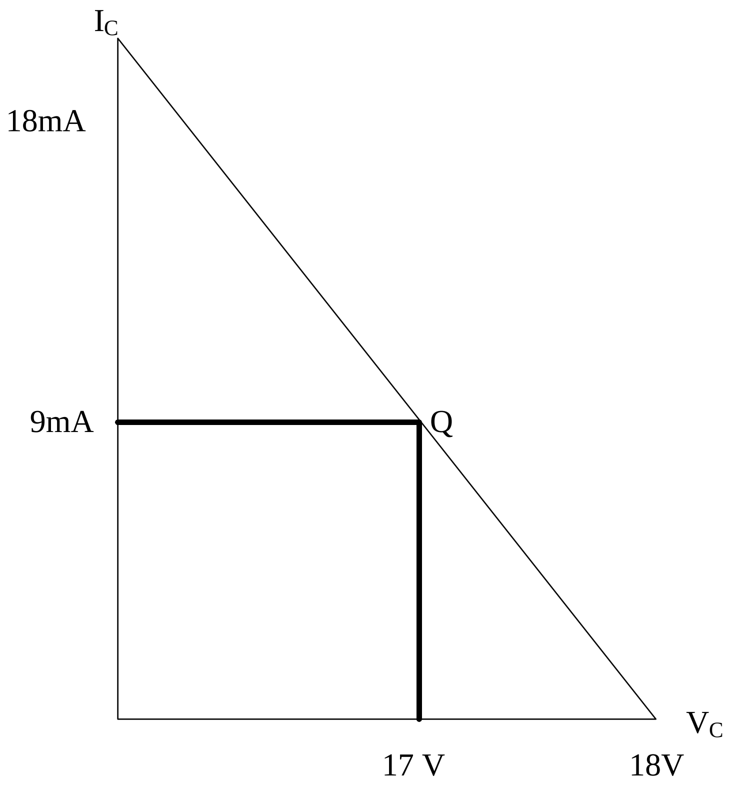

Figure 4.3. Graph of biasing with collector feedback transistor

4.4 Table 4. Voltage divider bias method

Transistor Type	Resistor			Voltage			Current	
	R_B	R_E	R_C	V_{CE}	V_{CC}	V_{EE}	I_C	I_B
$BC140$	100kΩ, 4.7kΩ	2.2kΩ	1kΩ	10 V	18 V	−18 V	$38mA$	$150mA$

4.4.1 Calculation

4.4.1.1 D.C Load Line: Referring to figure 3.4

The collector-emitter voltage V_{CE} is given by

$$V_{CE} = V_{CC} - I_C(R_C + R_E) \tag{4.13}$$

When $I_C = 0$, $V_{CE} = V_{CC} = 18\,V$. This locate the first point $B\ (OB = 18\,V)$ of the load line on the collector-emitter voltage axis. By joining points A and B, d.c load line AB is constructed as shown in figure 4.4

4.4.1.2 Operating point for silicon transistor, V_{BE}=0.7V

Voltage across 10KΩ is $V_2 = \frac{VCC}{R1} + R_2 x10 = 18x\frac{10}{10} + 4.7 = 12V$ (4.14)

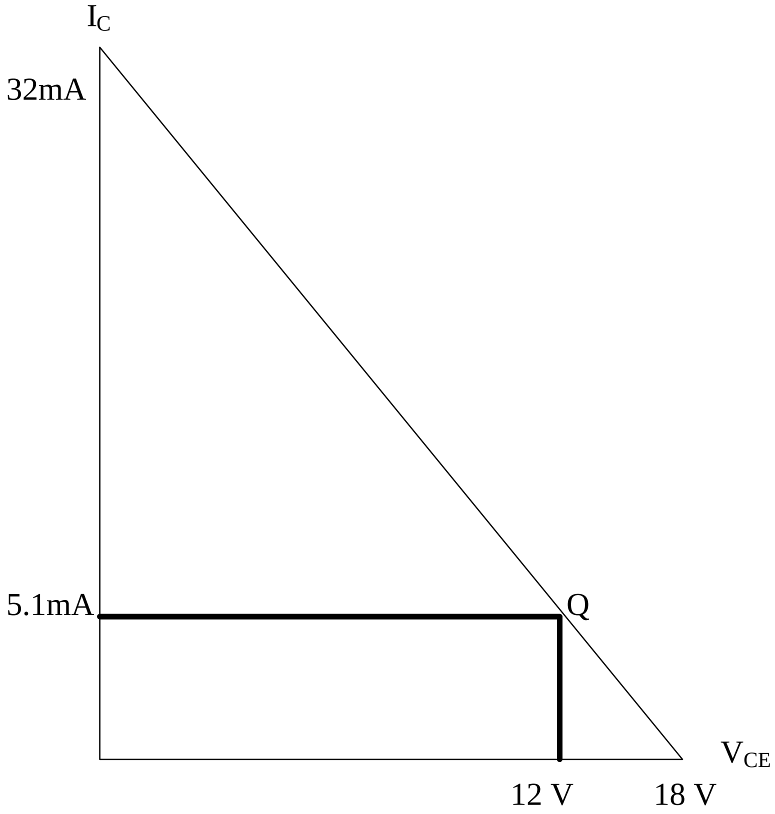

Figure 4.4. Graph of Voltage divider bias method

4.5 Table 5. Base bias collector and emitter feedback

Transistor Type	Resistor			Voltage				Current	
	R_B	R_E	R_C	V_{CE}	V_{CC}	V_C	V_E	I_C	I_B
$BC140$	4.7KΩ	10KΩ	10KΩ	8.4 V	18 V	8.4 V	9.6 V	$21mA$	$39mA$

4.5.1 Calculation

4.5.1.1 D.C Load line: Referring to Fig. 1.4

The collector-emitter voltage V_{CE} is given by

$$V_{CE} = V_{CC} - I_C(R_C + R_E) \qquad (4.14)$$

When $I_C = 0$, $V_{CE} = V_{CC} = 18V$. This locate the first point B(OB=18V) of the load lines on the collector-emitter voltage axis.

When $V_{CE} = 0, I_C = \frac{V_{CC}}{R_C} + R_C = \frac{18}{(10+10)} = 0.9mA \qquad (4.15)$

This locate the second point A $(0A = 0.9mA)$ of the load line on collector current axis. By joining points A and B, d.c load line AB is constructed as shown in figure 4.5.

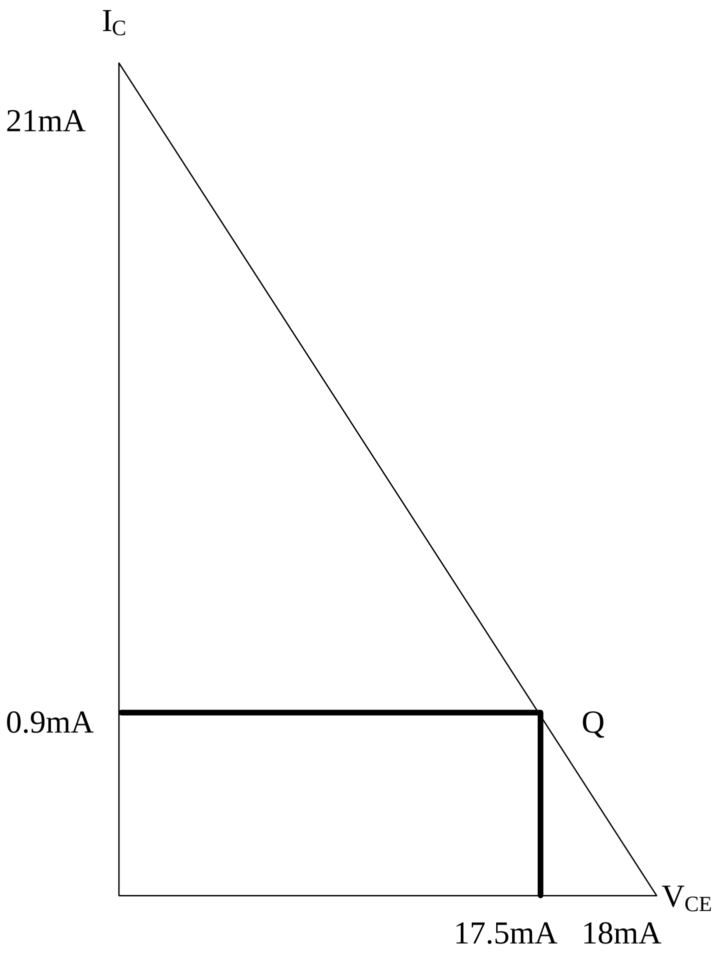

Figure 4.5. Graph of base bias collector and emitter feedback.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

Five methods were compared with transistor $BC140$ with different resistor. The base bias method has $I_C = 36mA$, $V_{BB} = 0.9\ V$ the Q-point are $(6.8\ V, 4mA)$, the second method is emitter bias method having the following $I_C = 38mA$, $I_B = 150mA$, $V_C = 18\ V$ the Q-point are $(13.3\ V, 3.8mA)$, for biasing with collector feedback the $I_C = 18mA$, $I_C = 16mA$, $V_{CC} = 18\ V$, and the Q-point $(17\ V, 9mA)$. While the voltage divider method has $I_C = 32mA$, $V_{CC} = 8\ V$ the Q-point is $(12\ V, 5.1mA)$, the last methods are Base bias collector and Emitter feedback with $I_C = 21mA$, $V_C = 18\ V$ the Q-point are $(17\ V, 0.9mA)$. Among all the five methods Emitter bias has the highest amplification of collector current $I_C = 38mA$, $I_B = 150mA$ it may be noted here that working the transistor below zero signal $I_C = 1mA$ is not advisable because of strongly non-linear transistor characteristics. Potential divider bias circuit provides highest stability to operating, in practical aspect stability factor is minimized and coming out to be equal to unity in this circuit, excellent stabilization is provided by R_E. For base bias resistor method, the stability factor is very high, therefore, there is strong chance of thermal run away, in a fixed bias it has poor thermal stability, due to these, and this method of biasing is rarely employed.

- The Q-point is the best point for operation of a transistor for a given collector current.
- The purpose of biasing is to establish a stable operating point (Q-point)

- The Linear region of a transistor is the region of operation within saturation and cutoff.
- Out of all the biasing circuit, potential divider bias circuit provides highest stability to operating point.

5.2 CONCLUSION

Five methods of transistor biasing circuits were compared, among all biasing methods "Emitter bias method" has the highest amplification of collector current ($I_C = 38mA$, $I_B = 150mA$), voltage divider become universal method for providing transistor biasing, in practical aspect stability factor is minimized and coming out to be equal to unity in this first circuit, excellent stabilization is provided.

5.3 RECOMMENDATION

1. There is little danger of overheating as 1mA is quite a small collector current. It may be noted here that working with the transistor below zero signal $I_C = 1mA$ is not advisable because of strongly non-linear transistor characteristics.
2. The zero signal I_C should be a little more (say 20%) than the maximum collector current swing due to signal. For example, if collector current change is expected to be $3mA$ due to signal, then select zero signal $I_C = 3.5mA$. It is important to note this point that selecting zero signals I_C below this value may cut off a part of negative half-cycle of a signal. On the other hand, selecting a value much above this value (say $15mA$) may unnecessarily overheat the

transistor, resulting in wastage of battery power. Moreover, a higher zero signal I_C will reduce the value of R_C (for same V_{CC}), resulting in reduced voltage gain.

3. It is a common practice to take $R_E = 500 - 1000\Omega$. Greater the value of R_E, better is the stabilization. However, if R_E is very large, higher voltage drop across it leaves reduced voltage drop across the collector load. Consequently, the output is decreased. Therefore, a compromise has to be made in the selection of the value of R_E .

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