RELIABILITY AND FAILURE ANALYSIS OF BIPOLAR JUNCTION TRANSISTOR (BJT)

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DECLARATION

I hereby declare that this project is my own work, except for certain quotations and reference that have been duly cited.

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ABSTRACT

This research is a failure analysis for bipolar junction transistor (BJT) to observe the changes of current gain, β with the increase of input voltage on transistor in different frequency in an amplifier circuit. We also observe the changes of current gain with increase of temperature effect on transistor. 2N2222A n-channel enhancement BJT transistor was used. This transistor in the amplifier circuit is to test on it when the function of transistor meets the failure. Multimeter was connected in the circuit to get the base current and collector current. These parameters are important as it use to calculate the current gain of the circuit. The values of the current are recorded from each increment of 0.1V of input voltage starting from 1.0V until the transistor meets the failure point. The process is repeated for different frequency from 2 kHz to 20 kHz. The values of the current are also recorded for every $5\,°C$ temperature increase starting from $25\,°C$ until $100\,°C$. This process is repeated for different transistor. Graph of current gain versus input voltage and current gain versus temperature are plotted. From the graph, it showed that transistor operated in higher frequency will meet the failure point at lower voltage input with increasing input voltage. It also showed that the transistor function normally within the range of $100\,°C$. Through the research, we found that the internal temperature is increasing while operating under high voltage and frequency as high electrical and thermal stresses at the semiconductor surface of transistor and cause the transistor to the failure. From the experiment, we conclude that the current gain in the amplifier circuit work well and efficient at the range of input between 1.3V and 2.6V. Failure point (β≈0) decreased in the input voltage range from 4.2V to 3.6V when frequency increased.

ABSTRAK

Kajian ini merupakan satu analisis kegagalan transistor (BJT) di mana pemerhatian nilai gandaan arus, β terhadap kesan kenaikan voltan masukan, V_{in} dengan frekuensi tinggi yang berlainan pada litar amplifier. Pemerhatian juga dilakukan terhadap nilai gandaan arus dengan kenaikan suhu pada transistor. Transistor yang digunakan ialah transistor 2N2222A iaitu transistor jenis BJT perluasan saluran-n. Transistor dalam litar amplifier diuji dari keadaan berfungsi normal sampai ia menemui kegagalan. Multimeter digital disambungkan dalam litar untuk mendapatkan arus tapak, I_b dan arus pemungut, I_c. Parameter-parameter ini penting untuk mengira gandaan arus dalam litar. Nilai-nilai arus tersebut diambil bagi setiap peningkatan 0.1V bagi voltan masukan yang bermula dari 1.0V sehingga transistor menemui titik kegagalan. Keadaan diulang bagi beberapa frekuensi tinggi bermula dari 2 kHz sehingga 20 kHz. Nilai-nilai arus juga dicatat bagi setiap peningkatan $5\,°C$ kenaikan suhu bermula dari $25\,°C$ sehingga $100\,°C$. Keaddan ini diulang bagi transistor yang berlainan. Graf gandaan arus melawan voltan masukan dan gandaan arus melawan suhu diplotkan. Melalui graf, didapati bahawa transistor yang beroperasi dalam frekuensi tinngi akan menemui titik kegagalan pada voltan masukan yang lebih awal dengan kenaikan voltan masukan. Selain itu, didapati bahawa transistor dapat berfungsi secara biasa dalam lingkungan $100\,°C$. Melalui kajian, didapati bahawa haba dalaman transistor dinaikkan apabila ia beroperasi dalam voltan dan frekuensi tinggi kerana elektrikal tinggi dan tekanan haba pada permukaan semikonduktor transistor yang mengakibatkan transistor gagal berfungsi. Melalui eksperimen, dapat disimpulkan bahawa litar amplifier dapat berjalan dengan baik dan mempunyai gandaan arus yang paling effisien dalam lingkungan 1.3V dan 2.6V. Titik kegagalan ($\beta \approx 0$) diawalkan dalam voltan masukan dari 4.2V sehingga 3.6V apabila frekuensi ditingkatkan.

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LIST OF SYMBOLS

α	Transport factor
β	Current gain
γ_E	Emitter efficiency
δ_r	Depletion layer recombination factor
A_v	Voltage gain
I	Current
I_B	Base current
I_C	Collector current
I_E	Emitter current
$I_{E,n}$	Electron diffusion current
$I_{E,p}$	Hole diffusion current
$I_{r,d}$	Base-emitter depletion layer recombination current
$I_{r,B}$	Base recombination current
I_{CBO}	Leakage current
R	Resistor
R_C	Collector resistor
R_E	Emitter resistor
V	Voltage
V_{BE}	Base-emitter voltage
V_{CB}	Collector-base voltage
V_{CE}	Collector-emitter voltage
V_{BB}	Forward biased voltage
V_{CC}	Reverse biased voltage
V_{in}	Input voltage
°C	Celsius

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In 1947, W. H. Brattain and J. Bardeen, both of Bell Labs, brought two closely spaced metallic needles into contact with the same germanium "base" wafer. The two needles served as electrodes, which were termed the *emitter* and *collector* terminals. A third, *base* terminal was also attached to the germanium crystal. Their experiments demonstrated that varying either the emitter or base dc terminal currents could cause a proportional variation in the collector voltage. Since an input (base or emitter) current could be used to control the output (collector) voltage, the gain (input-to-output transfer) of the device is equal to output voltage divided by input current.

The units of the gain defined by equation above would be ohms. Hence J. R. Pierce (also of Bell Labs) described the device as a transfer resistor and coined the term transistor. These first transistors were described as "point contact" devices. The point contact transistors were extremely difficult to produce commercially. However, in 1949 William Shockley theoretically described the bipolar junction transistor, or BJT.

The BJT truly revolutionized the electronics industry. Not only did it serve to render the vacuum tube obsolete, but the search for improved transistor manufacturing techniques laid the groundwork for the modern integrated-circuit fabrication.

In a similar fashion, the linear integrated circuit is also pushing the discrete BJT into obsolescence in many applications. However, at presençe, we find that many new electronics circuit designs are a combination of both linear integrated circuits and discrete transistors. Consequently, we need to be reasonably comfortable with both of these electronic "tools". Further, an understanding of the discrete transistor can provide us with an intuitive understanding of the operation and the limitations of linear (and digital) integrated circuits. (Stephen R. Fleeman, 1990)

1.2 PROJECT PURPOSE

The main purpose of this project is to build a simple circuit with bipolar junction transistor (BJT) and test the reliability and failure analysis of the BJT component.

1.3 PROJECT OBJECTIVES

i To build a simple BJT test circuit.
ii To analysis the current gain of a BJT at various high voltages.
iii To analysis the current gain of a BJT at various high frequencies.
iv To analysis the current gain of a BJT at various temperatures.

1.4 PROJECT SCOPE

The reliability and failure analysis will only focus on three common stresses used to accelerate device failure which is voltage frequency and temperature.

1.5 HYPOTHESIS

Each research done is based on theories learned and the theories learned are actually as a guide in doing scientific experiments and researches. Hypothesis is a tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation. In this research, the hypothesis is the higher temperature, the more active the BJT. However, after a certain temperature, the BJT would fail. Besides, The higher frequency, the BJT performance would be affected. Then, the higher voltage (or current), the easier the BJT would fail.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The transistor was invented by a team of three men at Bell Laboratories at 1947. Although this first transistor was not a bipolar junction device, it was the beginning of a technological revolution that is still continuing. All the complex electronic devices and system today are an outgrowth of early developments in semiconductor transistors.

There are two basic types of transistors in the market which are the bipolar junction transistor (BJT), and the field-effect transistor (FET). However, both transistors have many differences in their structures and characteristics. BJT is so called bipolar junction transistor is because it contains both flow of majority carriers and minority carriers while there is only flow of majority carriers in FET. Another distinct difference between the analysis of BJT and FET is that the input controlling variable for a BJT transistor is a current level, while for the FET a voltage is the controlling variable.

2.2 BIPOLAR JUNCTION TRANSISTOR

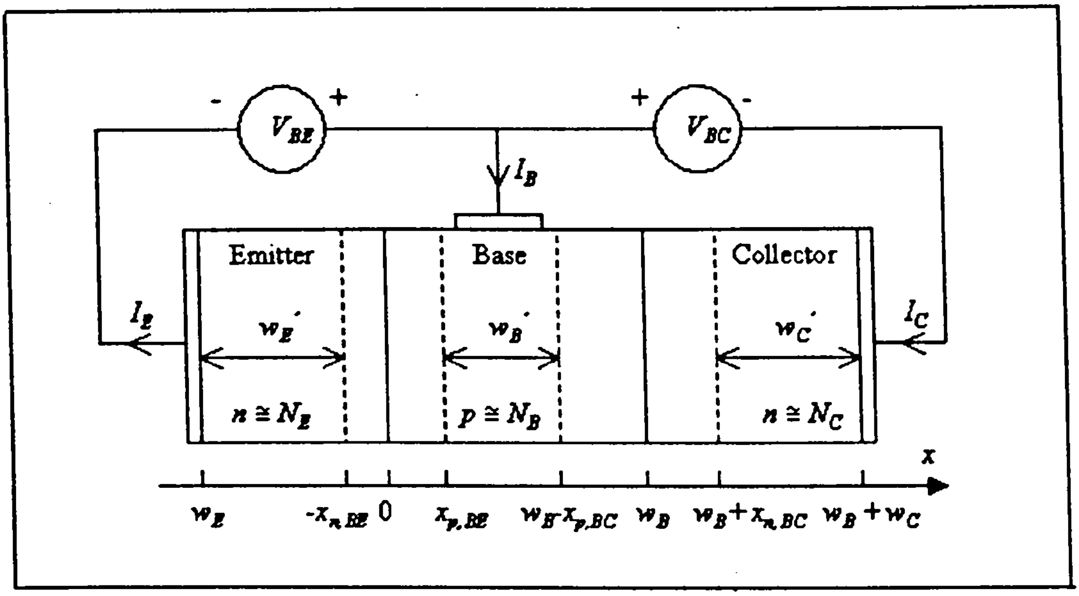

Figure 2.1 Structure and sign convention of a NPN bipolar junction transistor.

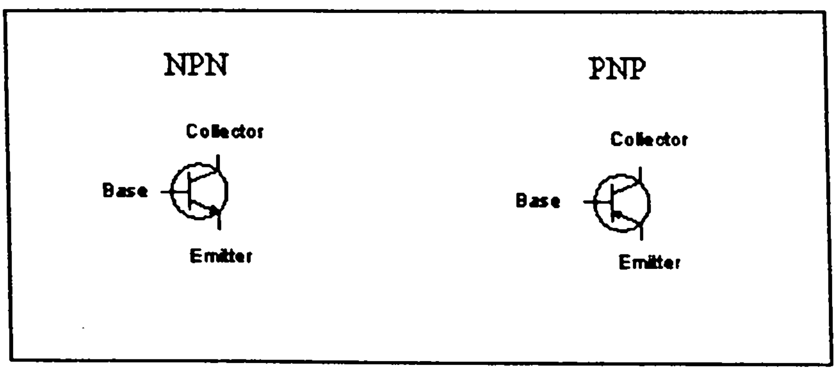

Figure 2.2 Schematic diagrams for both NPN and PNP transistors.

A bipolar junction transistor consists of two back-to-back p-n junctions, who share a thin common region with width, w_B. Contacts are made to all three regions, the two outer regions called the emitter and collector and the middle region called the base.

The device is called bipolar since its operation involves both types of mobile carriers, electrons (negative charge) and holes (positive charge). In Figure 2.2, the arrow on the emitter of NPN transistor shows that the current is easier to flow from emitter. Meanwhile, the arrow on the emitter of PNP transistor shows the direction which easier flow by positive charge (direction of current). (Cook, 1997)

2.3 OPERATION OF THE NPN BIPOLAR JUNCTION TRANSISTOR

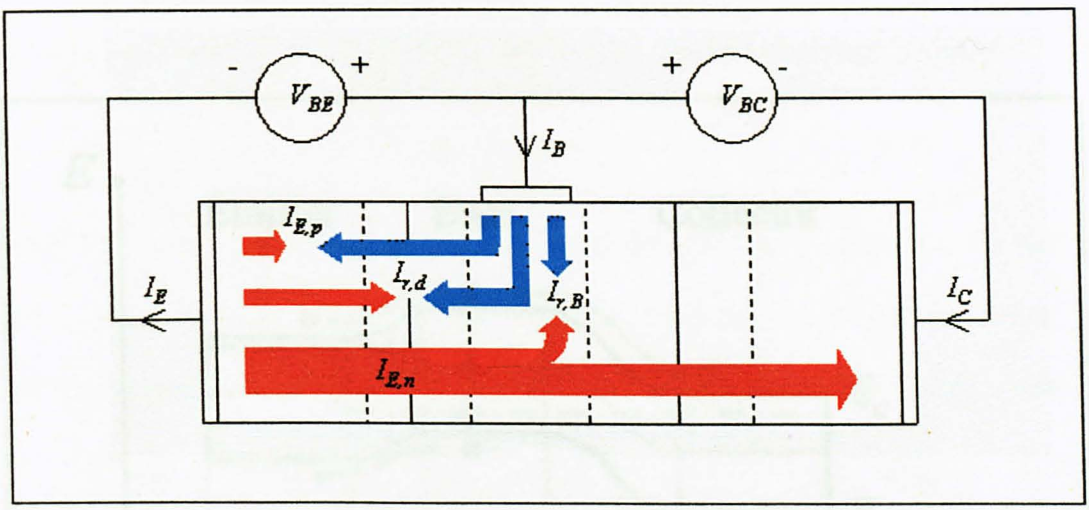

Figure 2.3 Electron and hole flow under forward active bias, $V_{BE} > 0$ and $V_{BC} = 0$.

Since the device consists of two back-to-back diodes, there are depletion regions between the quasi-neutral regions. The width of the quasi neutral regions in the emitter, base and collector are indicated with the symbols w_E', w_B' and w_C' and are calculated from:

$$w_E' = w_E - x_n, BE \tag{2.1}$$

$$w_B' = w_B - x_p, BE - x_p, BC \tag{2.2}$$

$$w_C' = w_C - x_{n}, BC \qquad (2.3)$$

The emitter current I_E, the collector current I_C, and the base current I_B (electron flows) have been indicated in Figure 2.3. By Kirchhoff's current law:

$$I_E = I_C + I_B \qquad (2.4)$$

The base-emitter voltage and the base-collector voltage are positive if a positive voltage is applied to the base contact relative to the emitter and collector respectively. (Herman, 2000)

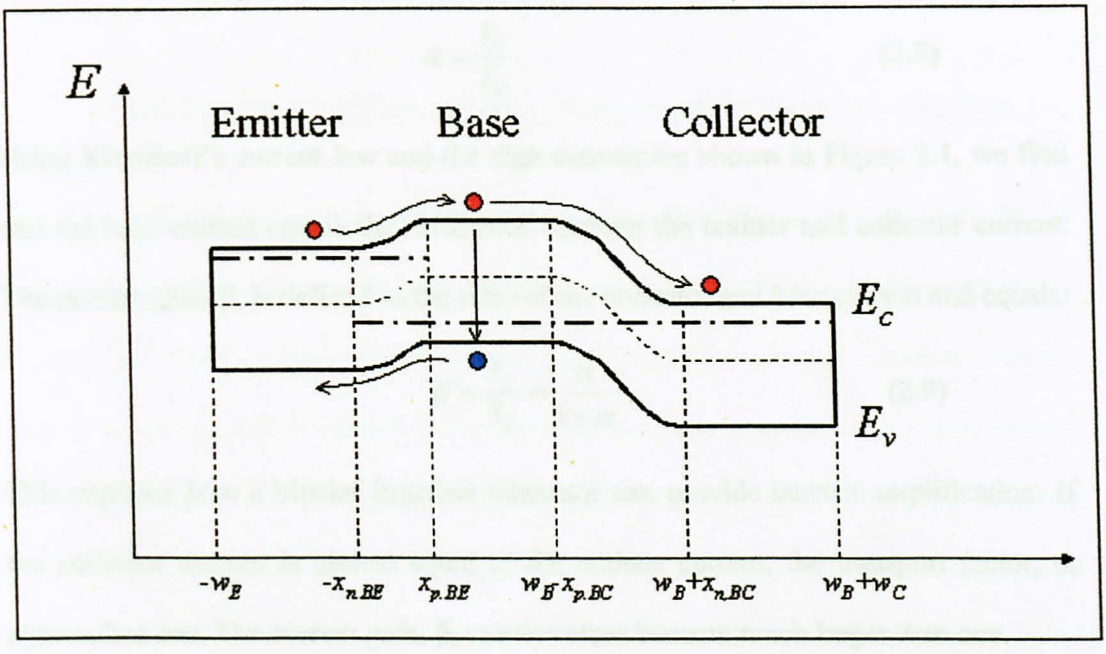

Figure 2.4 Energy band diagram of a bipolar transistor biased in the forward active mode.

The total emitter current is the sum of the electron diffusion current, $I_{E,n}$, the hole diffusion current, $I_{E,p}$ and the base-emitter depletion layer recombination current, $I_{r,d}$ (Gray and Meyer, 1993).

$$I_E = I_{E,n} + I_{E,p} + I_{r,d} \quad (2.5)$$

The total collector current is the electron diffusion current, $I_{E,n}$, minus the base recombination current, $I_{r,B}$ (Gray and Meyer, 1993).

$$I_C = I_{E,n} - I_{r,B} \quad (2.6)$$

The base current is the sum of the hole diffusion current, $I_{E,p}$, the base recombination current, $I_{r,B}$ and the base-emitter depletion layer recombination current, $I_{r,d}$ (Gray and Meyer, 1993).

$$I_B = I_{E,p} + I_{r,B} + I_{r,d} \quad (2.7)$$

The transport factor, α, is defined as the ratio of the collector and emitter current:

$$\alpha = \frac{I_C}{I_E} \quad (2.8)$$

Using Kirchhoff's current law and the sign convention shown in Figure 2.1, we find that the base current equals the difference between the emitter and collector current. The current gain, β, is defined as the ratio of the collector and base current and equals:

$$\beta = \frac{I_C}{I_E} = \frac{\alpha}{1-\alpha} \quad (2.9)$$

This explains how a bipolar junction transistor can provide current amplification. If the collector current is almost equal to the emitter current, the transport factor, α, approaches one. The current gain, β, can therefore become much larger than one.

To facilitate further analysis, we now rewrite the transport factor, α, as the product of the emitter efficiency, γ_E, the base transport factor, α_T, and the depletion layer recombination factor, δ_r.

$$\alpha = \alpha_T \gamma_E \delta_r \quad (2.10)$$

The emitter efficiency, γ_E, is defined as:

$$\gamma_E = \frac{I_{E,n}}{I_{E,n} + I_{E,p}} \tag{2.11}$$

The base transport factor, α_T, is defined as:

$$\alpha_T = \frac{I_{E,n} - I_{r,B}}{I_{E,n}} \tag{2.12}$$

The depletion layer recombination factor, δ_r, is defined as:

$$\delta_r = \frac{I_E - I_{r,d}}{I_E} \tag{2.13}$$

2.4 TEMPERATURE EFFECTS IN BIPOLAR JUNCTION TRANSISTOR

The temperature dependence of bipolar transistors depends on a multitude of parameters affecting the bipolar junction transistor characteristics in different ways. First we will discuss the temperature dependence of the current gain. Since the current gain depends on both the emitter efficiency and base transport factor, we will discuss these separately. The emitter efficiency depends on the ratio of the carrier density, diffusion constant and width of the emitter and base. As a result, it is not expected to be very temperature dependent. The carrier densities are linked to the doping densities. Barring incomplete ionization, which can be very temperature dependent, the carrier densities are independent of temperature as long as the intrinsic carrier density does not exceed the doping density in either region. The width is very unlikely to be temperature dependent and therefore also the ratio of the emitter and base width.

The ratio of the mobility is expected to be somewhat temperature dependent due to the different temperature dependence of the mobility in n-type and p-type material. The base transport is more likely to be temperature dependent since it depends on the product of the diffusion constant and carrier lifetime. The diffusion constant in turn equals the product of the thermal voltage and the minority carrier mobility in the base. The recombination lifetime depends on the thermal velocity. The result is therefore moderately dependent on temperature.

Typically the base transport reduces with temperature, primarily because the mobility and recombination lifetime are reduced with increasing temperature. Occasionally the transport factor initially increases with temperature, but then reduces again.

$$I_{CBO}(T) = [I_{CBO}(25°C)][2^{(T-25)/8}] \qquad (2.14)$$

The importance of the effects of temperature on the operation of the BJT cannot be overstated. Temperature variations can cause severe shifts in the Q-point of a BJT amplifier. This could possibly result in signal distortion. As we shall see, temperature effects cause the ac parameters of a BJT to change. Consequently, quantities such as a voltage amplifier's voltage gain and input impedance will also be affected by temperature. (Fleeman, 1990)

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