Investigations into the Effect of Magnetic Fields on the Operations of the 2BC109B Bipolar Junction Transistor

Bernard Siachingoma[1], John Madhombiro[2], Kudakwashe Munjeri[3]

[1]Geophysics Lecturer, Physics Department, Midlands State University, P/Bag 9055 Gweru, Zimbabwe

[2]Masters Student, Physics Department, Midlands State University, P/Bag 9055 Gweru, Zimbabwe

[3]Lecturer, Physics Department, University of Zimbabwe, P.O Box MP167 Mt Pleasant, Harare, Zimbabwe

Abstract: ***Transistors occupy a crucial position in technological advancement. They are used as power switching and signal amplifiers, as sensors in oscillating circuits. In this study the effects of magnetic fields on the operation of the 2BC109B bipolar junction transistor were investigated. The current-voltage (I-V) characteristics were analysed. The research showed that the performance and output characteristics of the transistor are affected by the presence of the external magnetic field and its intensity. The study confirmed amplification for low values of the magnetic field but showed that very intense fields cause failure.***

Keywords: Bipolar junction transistor, characteristics, magnetic field, amplification, failure

1. Introduction

The p-n junction forms an integral part of many commercial devices including bipolar junction transistors. Transistors are used mostly as power switching signal amplifiers. The best operating environments continue to be an aspect of concern for researchers, manufactures and users. The transistor's position occupies the cornerstone of technological advancement. Most modern gargets have irreplaceable components and their life time and reliability can be variable. The conditions that enhance as well as degrade the operation of transistors are supposed to be well known for both manufactures and users. It remains the duty for researchers to exclusively furnish finer details of how variances in the appropriate parameters affect performance.

Semi-conductor devices have made significant in-roads in many technological applications and their applications and operations are affected by many factors which can be both intrinsic and extrinsic. This study aims to establish beyond doubt how an extrinsic condition in the form of magnetic field affects the operation of the BJT transistor. After establishing the effect, it is the researchers' proposal to add onto the data sheet and specification the tolerance of the BJT to external magnetic fields it may be subjected to and operate in. While data provided by the producers is considered adequate on the transistors, specifying the I-V, C-V and temperature conditions; no information is provided on the transistor's behaviour or tolerance in magnetic fields they may possibly operate in. Apparently a possibility of both positive and negative attributes to the operations and lifetimes cannot be ruled out.

The earliest devices which acted as transistors were known as triodes and were made using vacuum tubes [1]. The development of transistors was based on an earlier solid state device using lead sulphide [1, 2]. The development of quantum mechanics helped in providing a comprehensive understanding of solids. It was Bardeen and Brattain who first managed to make a working transistor and from 1960 to 1997, the industry progressed by anticipating problems and solving them [2]. Over the decades thorough and comprehensive studies of the dynamic characteristics of the BJT are evident. The effect of the external magnetic field avail an interesting knowledge gap to be further explored. The study seeks to test the hypothesis that BJT operation especially amplification is affected by the presence of the magnetic field.

2. Theoretical Aspects

Semi-conductors are a class of elements with four valence electrons. Although Germanium and Silicon are the most common semi-conductors, Silicon is the most popular and useful semi-conductor and is expected to dominate for many years to come. BJT are fabricated junctions of either n-p-n or p-n-p[4]. Transistors can be imagined as two diodes n-p junctions sharing a common region in which minority carriers can move through as shown in figure 2.1

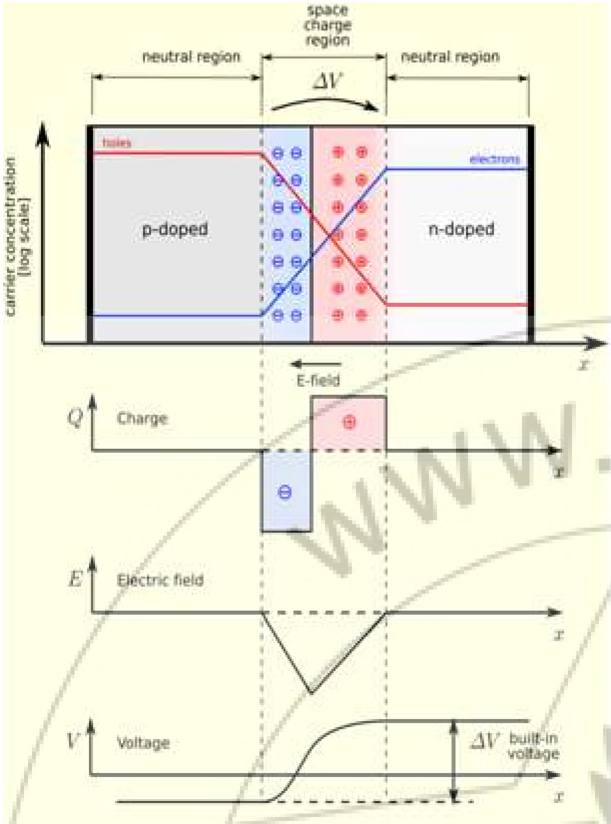

Figure 2.1: The interface of the p- n junction

The interface looks like a cluster of positive charge next to a cluster of negative charge, which creates an electric field across the junction [4, 5]. Both types of BJT function by letting a small input current control an output from collector making it a good switch and amplifier. The bipolar junction transistor makes a good amplifier. In the active mode of operation, electrons are injected from the forward biased n-type emitter into the p-type base where they diffuse to the n-type collector and are then then swept away by the electric field in the reversebiased c-b junction. The bias is shown in figure 2.2.

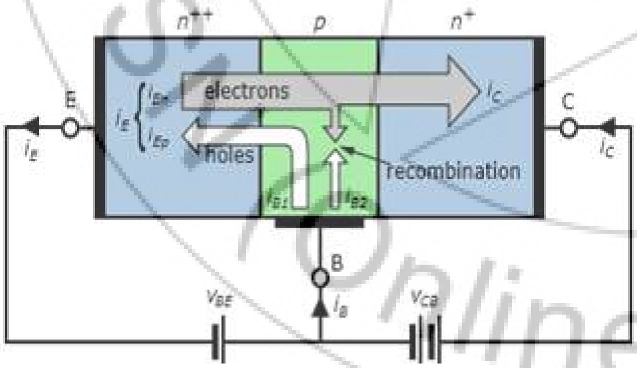

Figure 2.2: n-p -n junction forward biased [5]

Current flowing in the same direction as the force applied by the field is aided by the presence of the junction while it will be impeded in the opposite direction. The common base current gain is approximately the gain of current from emitter to collector in the forward active region.

$$\beta_F = \frac{I_c}{I_B} = \frac{\alpha_F}{1-\alpha_F} \rightarrow \alpha_F = \frac{\beta_F}{\beta_F+_1} = \frac{\Delta I_C}{\Delta I_E} \quad (2.1)$$

Thus the BJT amplifiers the output characteristic $I_C = \beta_F I_B$ With the small excitation from different environmental factors, semi-conductors conduct with both drift and diffusion components. The movement of charge carriers takes place in a current called diffusion current [6, 7]. The current in p-n diode is due to carrier generation or recombination. The Shockley equations quantify the current through the junction.

$$I = qA\left[\frac{D_n n_{p0}}{L_n} + \frac{D_p p_{n0}}{w_n}\right]\left(e^{V_a/V_t} - 1\right) \quad (2.2)$$

And the saturation current $I_s$is given by

$$I_s = qA\left[\frac{D_n n_{p0}}{w_p} + \frac{D_p p_{n0}}{w_n}\right] \quad (2.3)$$

When a semi-conductor is placed in a magnetic field, the Fermi energy levels are affected. Presence of radiation can increase number of intrinsic carriers by several orders of magnitude hence resistivity decrease [7]. The excitation of valence electrons into the conduction band can significantly increase electrical conductivity of both insulators and conductors. In a closely related scenario, application of an external magnetic field to a device with current flowing in it sets up a Hall voltage and force on charge carriers in a direction perpendicular to the field and the current. The Hall Effect affect mobility, carrier concentration hence conduction properties of semi-conductors [8]. In a semi-conductor with both positive and negative carriers, conductivity is a function of the concentration and mobility of both holes and electrons [9].

Conduction electrons trapped in the vicinity of an interface between 2 semi-conductors have been used to study quantum Hall effect. The local potential difference between the two sides produces bending of the local Fermi-level. Near the surface this Fermi-level meets with valence bands creating states liable to participate in conductivity [10]. The quantum Hall effect is a universal phenomenon quite independent of sample shape [11, 12, 13].

3. Materials and Research Methodology

The circuit diagram set up shown in Figure 3.1 was set up for this study. The variable voltage source $V_{CE}$was varied from zero to higher values, keeping I_B at fixed. Readings of V_{CE} and corresponding collector current I_C , were taken from voltmeter and family of I_C vsV_{CE} curves were plotted for different applied magnetic field strength values and base current, I_B. A set of 2BC109B transistors parameters were repeatedly measured in geomagnetic field, for equal times at room temperature (~25˚C) and I-V characteristic graphs drawn.

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

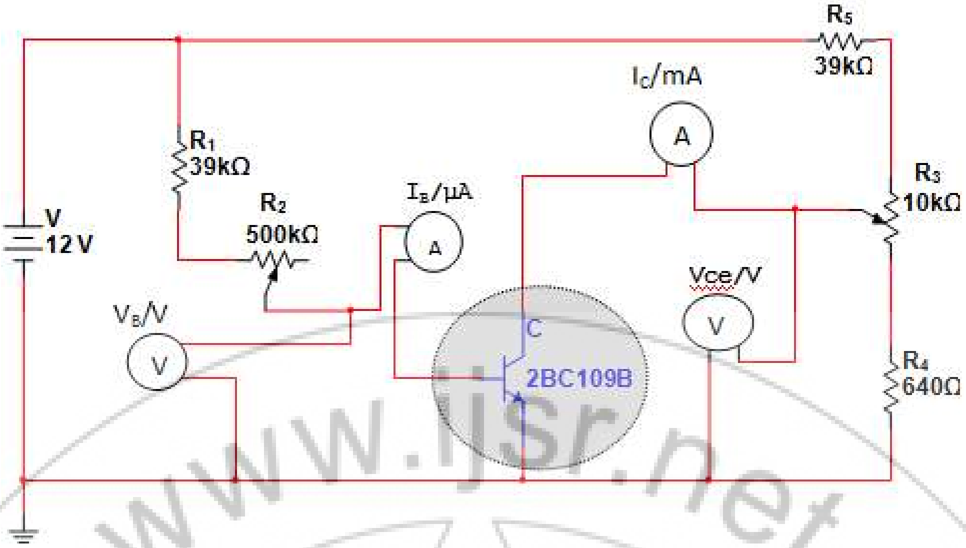

Figure 3.1: The circuit set up in the study.

The measurements of the collector currents, I_C were taken when collector emitter voltage, V_{CE} was varied from 0.7V to ~8.5V for the values of the base currents, I_B from 34µA, 44µA, 54µA, 64µA to 74µA.The measurements of I_B, I_C and V_{CE} were tabulated. The characteristic graphs were then plotted.

A hole, 10 mm in diameter and 20 mm deep was drilled at each end of a horse- shoe laminated iron core or yoke of the solenoids. A BJT, with insulated and extended legs (soldered extensions), was slotted into each hole and integrated to a separate circuit in Fig 3.1 to excite a magnetic field in the solenoids. The resultant field was repeatedly measured, averaged for each part. The whole environment acted as a heat sink to the BJTs as well, since the heat dissipated due to joule effects was conducted into the core. The solenoids circuit was completed with an ammeter registering 1.0 A DC and the BJTs' within the equivalent magnetic field of 120 mT for an average of an hour. The measurements of I_C, V_{CE} with base current I_B set at 34 µA, 44 µA, 54µA, 64 µA and 74 µA, were repeatedly taken and averaged. The transistors were given time of an hour, to recover and this was repeated for the cited ranges but now in fields of 127 mT, and 135 mT.

Figure 4.6 gives the current gain ß, at V_c=6.5V. The overall conclusions were made on the effects of the repeatedly varied fields' effects on the BJT.

4. Results and Discussions

The family of characterization graphs for the BJT which was exposed repeatedly to the magnetic field are shown in figures 4.1 to 4.5. The plotted families of the characteristic graphs showed that the fields indeed affect the performances of the BJT at constant base current. As the intensity of the field was increased, the performance was even better, shown by the active region height. However, as the magnetic field was increased at greater base currents, the cut off voltages decreased and the chances of failure increased at high field intensities.

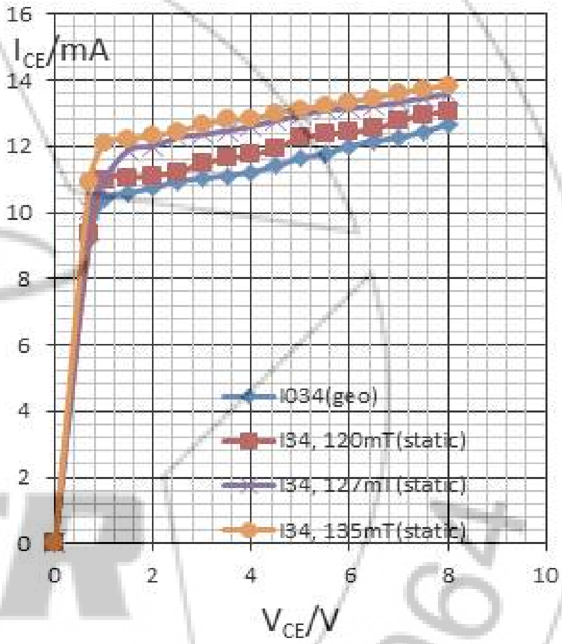

Figure 4.1: $I_C$vs V_{CE} with I_B fixed at 34 µA

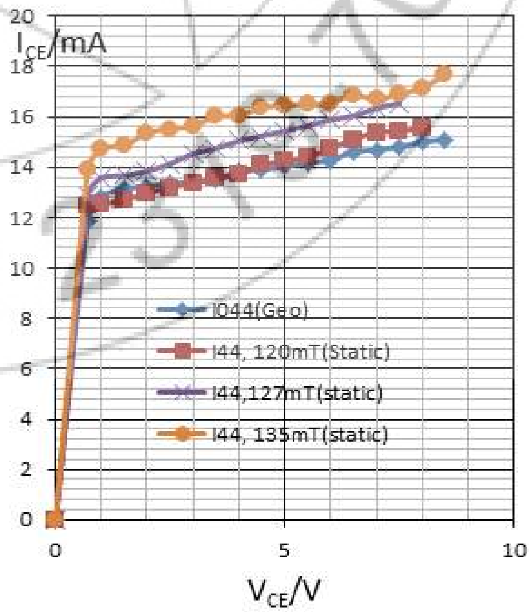

Figure 4.2:$I_C$vs V_{CE} with I_B fixed at 44 µA

The characteristics graphs rose even higher with the increase in the applied field. The cut off voltage decreased drastically as the field intensity increased as the cut-off region widens to the top. Fluctuations were registered to be much more, revealing the instability of the BJT at high fields, base current and collector voltage. Generally, the BJT responded better with the increase in the static field environments. Equation1.1 was used to calculate the gain at V_{CE}= 6.5V.

The family graphs showed that, in the active region the gain increased as the intensity of the magnetic field was increased. As the base current and the field intensities were increased, the current gain has been seen to increase as well at higher base current and higher magnetic field intensities.

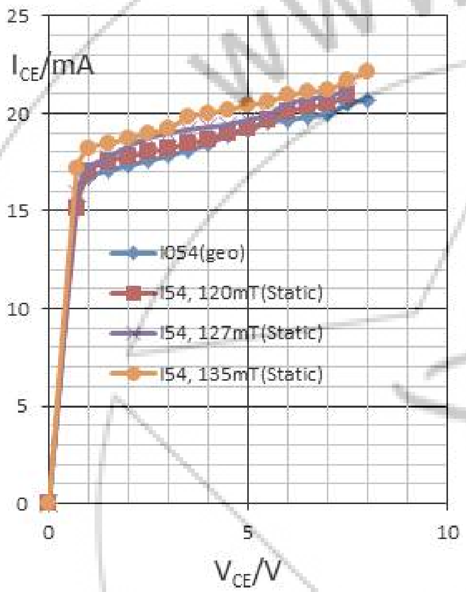

Figure 4.3: $I_C$vs V_{CE} with I_B fixed at 34 µA

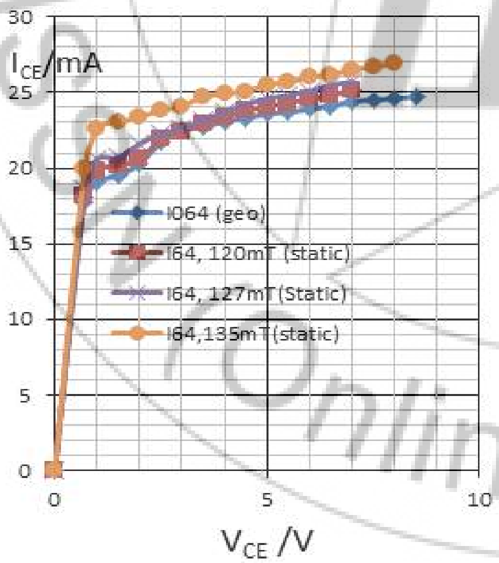

Figure 4.4: $I_C$vs V_{CE} with I_B fixed at 44 µA

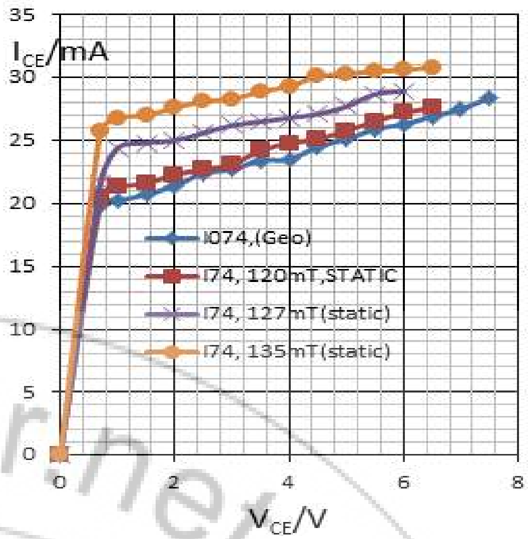

Figure 4.5: I_C vs V_{CE} with I_B fixed at 74 µA

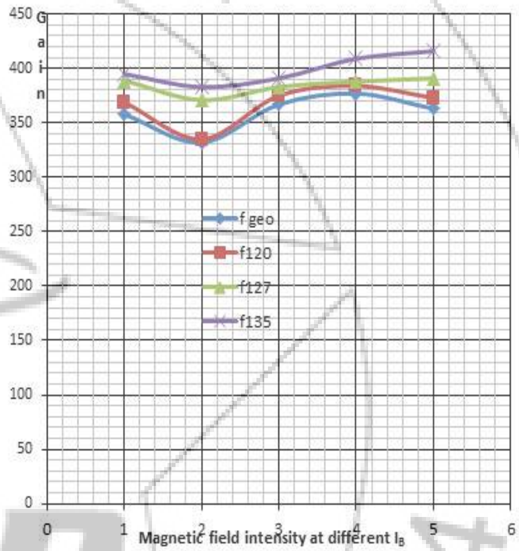

Figure 4.6: Gain vs magnetic field intensities

5. Conclusions

The position of the BJT in technological development makes this study very significant for fellow researchers, manufacturers, consumers and device reliability Physicists. The BJT` s performances, operations and stability are affected both positively and negatively by the external magnetic field. Increasing magnetic field values improved amplification. Optimum operation base current were from 34 µA to 64 µA in 135 mT, above which fluctuation chances dominated. In higher the magnetic field intensities, the cut off voltages reduced and the more the collector current fluctuations, making it more unstable. With repeated exposure to higher intensities to the field, 70% of the sampled bjts ceased, calling for its unpredictable life time. The Hall Effect excites the charge carriers to higher states of higher energy levels at the band gap. The bias field sweeps across the resultant current density at the band gap across it. The electrons can easily jump across the lowered potential barrier height. The results showed good repeatability and consistence. It recommended that further research be carried out on all types of transistors in order to include their behaviour into data sheets and Data Specification Charts.

References

[1] http://letstalkaboutscience.wordpress.com/2012/07/
[2] IEEE Journal of Solid-state circuits, vol. 32, no. 12, December 1997, p1858-1861
[3] Aisberg.E, July- August edition of Toute La Radio, No 137 p218-220
[4] Dr. Ume, Introduction to transistors and common applications in mechatronics, Lectures, ME 6405
[5] http://letstalkaboutscience.wordpress.com/
[6] Electrical Properties, Virginia.educ/borh/mse209/ chapt 19, p3-5
[7] Paper on semiconductor device modeling p5-7, www.phs.ubc.cal. quant mat/ARPES/PEOPLE/Andrea/......./lect
[8] Holbert .K.E, Radiation Effects Damage, p8- 9
[9] Claeys.C, Simoen.E, Radiation Effects in Advanced Semiconductor Materials and Devices
[10] Smeeton.T, Springer Handbook. Perspectives on Electronic and Optoelectronic Materials, Colin Humphreys, Cambridge, UK 2006 p22
[11] Rev. Mod. Phys., Vol. 71, No. 2, Centenary 1999 pS299-S305
[12] Bellissard.J, A. van Elst†, Schulz. H,2008,The Non-Commutative Geometry of the Quantum Hall Effect Baldes‡Universit´e Paul Sabatier, Toulouse, France p3-8
[13] Tony R.K., 2007, Lessons in Electric Circuits, Volume III, Semiconductors , Chapt 4

Author Profile

Bernard Siachingoma has done Masters in Geophysics. Presently he is serving as Lecturer at Midlands State University, Zimbabwe. His research interests include Geophysics. He is also a PhD Scholar.