Investigation of Temperature Effects on the Characteristics of Bipolar Junction Transistor

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ABSTRACT. Temperature rise on the electronic board can have a noticeable impact on the electronic circuit which result in some changes in the basic parameters of the circuit elements. The aim of this paper is to study and analyzes the effects of high temperature on the static and dynamic characteristics of a bipolar transistor. The research was carried out experimentally by studying and analyzing several parameters of the NPN BJT transistor type 2SC2120 at different temperatures. The obtained results showed that there is a significant increase in collector current from 0.19 A to 0.23 A and current gain from 0.14 to 0.22 by increasing the temperature from 25 °C to 130 °C. As for the threshold voltage, it was found that its value decreased from 0.6 volts to 0.4 volts. The results obtained also indicate that for the dynamic properties, the diffusion capacitance of the emitter-base junction, increased from 10.1 nF to 45.02 nF by increasing the temperature up to 130 °C. Finally, it was found that the reverse capacitance of the gate-drain junction increased from 41.4 pF to 47.3 pF under the same temperature ranges.

1. INTRODUCTION

Since the 1970, electronic components have evolved dramatically, resulting in complex, compact designs and efficient performance for designed applications [1]. The researchers conducting further studies into improving a new composite alloys to extend the life of semiconductor devices [2-4]. Many semiconductor devices can operate simultaneously on electronic circuits which can cause overheating. This trapped thermal energy or heat can reduce the efficiency of the device or cause it to malfunction. Thermal energy poses a constant threat to semiconductors, especially in critical applications. In the past, radiators and fans were often the first line of defense for handling high temperatures [5-8].

Many industries require electronic devices to perform well in harsh environments with extreme temperatures [9]. In general, when designing such devices for utilizing in abnormal temperatures, engineers must rely on testing to ensure that these devices operate correctly without any change in basic parameters [10]. Therefore, engineers may resort to cooling these devices, but in some applications this may be impossible or harm the reliability of the program [11]. Therefore, the temperature change which the device operates is considered a practical problem that must be taken into consideration by studying, analyzing [12].

Although many electronic components can withstand high temperatures, their structure may not be suitable for prolonged exposure to heat, shock, and vibration. In addition, manufacturers of high-temperature electronic components specify operating periods at specific temperatures [13]. Matching the life specifications of all components is critical to a reliable system. However, some designs constraints require new power supplies to avoid overheating, silicon limitations, and high power consumption. Several studies on the quality of connector processing at high temperatures and the strength of connectors in electrical equipment connectors have been published [14-18].

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Temperature can dramatically change the dynamic characteristics of the semiconductor devices. The thermal properties of transistors must be considered to allow the design of special applications [19]. The nonlinear bipolar junction transistor circuit with low power consumption and lower temperature associated duty of the transistors is shown in Figure 1.

![Nonlinear NPN BJT transistor circuit](image)

**Fig. 1.** Nonlinear NPN BJT transistor circuit [20].

The present paper investigates the characteristics of the NPN (BJT) under the influence of different temperature degrees over the ambient temperature in a range of (25°C, 75°C, 95°C, 115°C, 130°C). The measurements were recorded and analyzed.

## 2. METHOD

In this paper, the electrical parameters of the 2SC2120 NPN (BJT) have been experimentally tested under a wide temperature ranges of (25°C, 75°C, 95°C, 115°C and 130°C). The experiments are conducted in the electrical laboratory by using the (Tektronix 370A curve tracer system and Fluke PM6306 RCL programmable auto bridge device)[21] which allows a fast and high precision measurements of passive components in a wide range. Table 1 illustrates the basic operating parameters of the testing transistor type 2SC2120.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Collector Power Dissipation</td>
<td>$P_c$</td>
<td>0.6 W</td>
</tr>
<tr>
<td>Max. Collector-Base Voltage</td>
<td>$V_{cb}$</td>
<td>30 V</td>
</tr>
<tr>
<td>Max. Collector-Emitter Voltage</td>
<td>$V_{ce}$</td>
<td>30 V</td>
</tr>
<tr>
<td>Max. Emitter-Base Voltage</td>
<td>$V_{eb}$</td>
<td>5 V</td>
</tr>
<tr>
<td>Max. Operating Junction Temperature</td>
<td>$T_j$</td>
<td>150 °C</td>
</tr>
<tr>
<td>Min. Forward Current Transfer Ratio</td>
<td>$I_{FE}$</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1. Basic operating parameters of the testing transistor type 2SC2120[22].
3. RESULTS AND DISCUSSION

Table 2 illustrates the measurements of the output characteristic of collector current $I_C$ in dependence of the collector-emitter voltage $V_{CE}$ of the Si2SC2120 transistor in different temperature levels in case when the base current $I_B$ equals 1mA. The graph representation of the obtained results is shown in Figure 2.

<table>
<thead>
<tr>
<th>Collector -Emitter voltage $V_{CE}$ (V)</th>
<th>Collector current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 °C</td>
</tr>
<tr>
<td>1</td>
<td>0.13</td>
</tr>
<tr>
<td>2</td>
<td>0.13</td>
</tr>
<tr>
<td>4</td>
<td>0.14</td>
</tr>
<tr>
<td>6</td>
<td>0.14</td>
</tr>
<tr>
<td>8</td>
<td>0.15</td>
</tr>
<tr>
<td>10</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Fig. 2. Collector current of BJT transistor type (2SC2120) versus collector–emitter voltage at different temperature degrees.

From Figure 2, it can be clearly seen that the $I_C$ has been raised as a function of temperature level. At $V_{CE}$ = 2 V (measured at 130 °C) a value of 1.05 A can be reached compared to the value of 0.19 A (measured at 25 °C).

$R_{out}$ of a bipolar transistor at different temperatures can be calculated as follows [23]:

\[
R_{out} = \frac{\Delta V_{CE}}{\Delta I_C}
\]

(1)

In which: $\Delta V_{CE}$ represent the variations in the collector-emitter voltage and $\Delta I_C$ represent the variations in the collector current. The variations in the $R_{OUT}$ is shown in Figure 3.
Fig. 3. The output resistance versus temperature.

From Figure 3, it can be seen that the $r_{out}$ value has been decreased from $15 \, \Omega$ at $25 \, ^\circ C$ to $8.54 \, \Omega$ at $130 \, ^\circ C$. Which indicate that the temperature rise influence the output resistance of the testing transistor.

The dc current gain $h_{FE}$ can be calculated by using equation (2). The results of the dc current gain $h_{FE}$ in dependence of temperature is illustrated in Figure 4 [23].

$$h_{FE} = \frac{\Delta I_C}{\Delta I_B} \quad (2)$$

Fig. 4. The dc current gain $h_{FE}$ against gain temperature rising.

From Figure 4, it can be seen that the $h_{FE}$ has been raised from initial value of $0.13$ at $(20 \, ^\circ C)$ to $0.23$ at $(130 \, ^\circ C)$. Which means that this parameter has been increased by increasing the collector current as a result of temperature increase.

The threshold voltage measured at ambient temperature can be calculated by using the following equation [24]:

$$V_t = \frac{1}{2} h_{FE} I_C$$
Where \( V_{Th}(T) \) and \( V_{Th}(0) \) represent the threshold voltages measured at rising and ambient temperatures, respectively. The threshold voltage \( V_{Th} \) variation in dependence of temperature is illustrated in Figure 5.

\[ V_{Th}(T) = V_{Th}(0) - AT \]  

(3)

From Figure 5, it can be seen that the value of \( V_{Th} \) decreased from 0.68 V to 0.43 V, due to the increase in temperature. This makes the valence band electrons in the metal strip excited, causing them to be attracted towards the conduction band, resulting in an increment in currents.

The relation between the base current and the emitter base voltage ( \( I_B-V_{EB} \) ) value under the temperature rising from 20°C to 130 °C also has been changed as a result of the temperature rise as shown in Figure 6.

From Figure 6, it can be seen that the base current extremely increased in dependence of temperature rise in case when \( V_{EB} \) became \( \geq 0.5 \) V. Which indicates that the base current has been influenced by the temperature rising.
Table 3 Shows the temperature dependence of the diffusion capacitance (C_d) and the transfer capacitance (C_T) of both collector-base and emitter-base junction in the transistor type 2SC2120 at temperatures (25°C -130°C). The graphical representation of C_T variations in dependence of the temperature are illustrated in Figure 7 and the graphical representation of C_T variations in dependence of the temperature are illustrated in Figure 8.

Table 3. Junction capacitance values between the collector-base and the emitter-base.

<table>
<thead>
<tr>
<th>Capacitance (nF)</th>
<th>Collector - base</th>
<th>Emitter- base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 °C</td>
<td>75 °C</td>
</tr>
<tr>
<td>C_T</td>
<td>0.178</td>
<td>0.33</td>
</tr>
<tr>
<td>C_d</td>
<td>0.21</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Fig. 7. Transition junction capacitance (C_T) of the transistor type 2SC2120.

From Figure 7, It can be seen that the C_T value gradually increases from (0.2 nF to 0.67 nF) and from (0.178 nF to 0.68 nF). Which indicates that the C_d value influenced by the rising temperature.

Fig. 8. Transition junction capacitance (C_d) of the transistor type 2SC2120.
From Figure 8, it can be seen that the $C_d$ junction of the emitter-base and collector-base gradually increased from (9.7- 44.0 nF) and from (9.9 - 39.2 nF), respectively. Which indicate that this capacitance has been influenced by the temperature increasing.

4. CONCLUSION

During the rapid progress in the field of modern electronic industry, new fields have emerged specializing in some systems that are highly sensitive to temperature. For example, devices used to monitor combustion conditions, or devices used to control some processes that include in the nature of their work a high temperature rise, as well as devices used in atomic energy production reactors,[1]. These applications and factories require highly reliable operation in operating conditions with unusual temperatures, which requires reducing the temperature using a cooling system, which increases the size and cost. One solution to such problem lies in the use of electronics made of SiC. In this paper, the effects of high temperatures on the performance of NPN (BJT) type (2SC2120) was studied and analyzed. The work was conducted by the practical experiments under different temperatures. The results were recorded and analyzed. The curves in the obtained results represent the changes occurring in the basic parameters of the transistor that affect its performance such as current, voltage and output resistance.

The results obtained showed that there was an increase in collector current from 0.19 A to 0.23 A and current gain from 0.14 A to 0.22 A due to the increase in temperature from 25°C to 130°C. Also, the threshold voltage value decreased from 0.6 volts to 0.4 volts. The results obtained also demonstrated that the diffusion capacity of the emitter-base junction increased from 10.1 nF to 45.02 nF due to increasing the temperature up to 130 degrees Celsius. The reverse capacitance in the gate-drain connection increased from 41.4 pF to 47.3 pF under the same temperature conditions.

From the analyzing of the obtained results, it can be conclude that there are some variations in the basic parameters of the BJT in dependence of temperature rising. So, in the process of electronic circuits with BJT that operate in the harsh conditions, it is necessary to taking into account the changes in the performance of the transistor parameters due to high temperatures, therefore, it is better to choose the type of transistor and the temperature level that suits the aim and the environmental conditions in which the electronic device is planned to operate in order to obtain its optimal performance.
REFERENCES


