# Effect of Electromagnetic Radiation at Vs, IR, UV on The Properties of Transistor with an Exposed Device

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**Abstract**

The input and output (I-V) characteristics of exposed transistor device under VS, UV, and IR radiation effect has been studied experimentally. The results shown of input (I-V) characteristics ($V_{bi}$) increased with increasing energy of radiation.

At ( $V_{CE}$=0 V, and 5 V ) has been calculated input voltage ($V_{bi}$) and input resistant ($R_{in}$) at under every the effect of the above wavelengths and without effect, where we notice an increase in input voltage ($V_{bi}$) and input resistant ($R_{in}$) with the increase in the wavelengths used when compared it with"state without effect.

The"current gain ($\beta_{DC}$) and output resistance ($R_{out}$), which stand for the transistor's output properties, were also calculated once with the effect and once without the effect, and the results were compared, The infrared wavelength (395 nm) and the red wavelength (630–650 nm) were found to cause a drop in the gain in the current ($\beta_{DC}$), while the other wavelengths used caused an increase. Regarding the input resistance ($R_{out}$), it rises as the study's chosen wavelength is employed."

In addition, the curve of the input properties of the power transistor under the influence of electromagnetic radiation slides to the right of the properties curve without any effect, and the amount of sliding depends on the wavelength and the power of the source used, as well as the output properties slide upward for each value of the base current ($I_B$).

**Keywords:** *Radiation; Transistor; Exposed Device; Curve of properties; Visible light; Ultraviolet; Infrared; Current gain; Load line; Q-point.).*

## 1. INTRODUCTION

Even if some aspects of the harm that electromagnetic radiation causes to semiconductor devices have been covered in earlier articles [1-7]. Additionally, there is research that analyzes the impact of electro-magnetic pulse (EMP) damage mechanisms on semiconductor electronics performance. knowledge this is the most thorough and innovative study that precisely analyzes the various potential EMP effects' detrimental effects, especially on semiconductor electronics' constituent parts [8].

There is obviously a possibility that infusing external electromagnetic fields will result in the electrical system giving off unpleasant signals. The risk posed by electromagnetic pulse radiation, which could accidentally or intentionally induce, Due to their close proximity to electronic gadgets, they couple with the high-frequency ambient signal, which is often required for a microwave to garner more interest. The failure or destruction of the electronic systems would be sad and inconceivable. The electromagnetic radiation may cause long-term damage to semiconductor devices or an effect that occurs for a specific moment and disappears with the disappearance of the influencer and this effect will be the focus of our study [9- 10].

In all semiconductor electrical and optoelectronic devices, the semiconductor-semiconductor junctions play a crucial role [11-13]. And any change to the semiconductor-semiconductor junctions or to the semiconductors themselves affects how well these devices work [14]. faults brought on by the electromagnetic radiation exposure of semiconductor devices, as well as research into how radiation affects electrical characteristics. When semiconductor devices are exposed to radiation, their characteristics may deteriorate or they may stop working properly [15].

A crystal lattice can instantly develop point defects as a result of irradiation. The electrical property of semiconductors that is most vulnerable to radiation is minority carrier life. Minority carrier life-time degradation leads to modifications in device characteristics [13].

## 2. Theory.

### 2.1. The Relationship of Basic Current-Voltage.

The semiconductor parameters, such as doping and minority-carrier lifetime, are used to define the current equations since they are based on the concentration of minority-carriers in each region [16].

#### 2.1.1. Distribution of Carriers by Region

To determine the ideal transistor's current-voltage expression, Essentially, Under the forward-biased state, we suppose that holes are injected into the base from the emitter. These holes then disseminate across the base region, eventually arriving at the collector junction (C-B junction). Once we know the distribution of minority carriers (specifically, holes in the n-type base area), The current can be calculated using the minority-carrier gradient.

Furthermore, we assume that the device has uniform doping in all regions, that the hole drift current in the base region is minimal, and that the collector saturation current is zero or negligible. In the depletion zones, there is low-level injection and no generation-combination currents. and the device contains no series resistances [16].

#### 2.1.2. Base Region

The minority-carrier distribution in the neutral base region can be described by the field-free, steady-state continuity equation

$$D_P\left(\frac{d^2P_n}{dx^2}\right)-\frac{P_n-P_{no}}{\tau_P}=0, \quad \ldots\ldots\ldots\ldots\ldots(1)$$

where $D_P$ and $\tau_P$ are the diffusion constant and the minority carrier lifetime, respectively.

Eq. 1 has a general solution.

$$P_n(x)=P_{no}+C_1e^{x/L_P}+C_2e^{-x/L_P}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $L_P=\sqrt{D_P\tau_P}$ is the hole diffusion length. The boundary conditions for the active mode may be used to obtain the constants $C_1$ and $C_2$:

$$P_n(0)=P_{no}e^{qV_{BE}/KT}, \quad \ldots\ldots\ldots\ \ldots\ldots\ldots\ldots..(3a)$$

And

$$P_n(W)=0\ , \quad \ldots\ldots\ldots\ldots\ldots\ \ldots\ldots..(3b)$$

where $P_{no}$ is the equilibrium concentration of minority carriers in the base, as determined by $P_{no}={n_i}^2/N_B$ , and $N_B$ identifies the base's consistent donor concentration. (Eq. 3*a*) is first boundary condition asserts that when there is a forward bias, The exponential factor $e^{qV_{BE}/KT}$ causes the minority-carrier concentration near the edge of the emitter-base depletion zone ($x$ = 0) to rise above the equilibrium value. (Eq. 3$b$) is second boundary condition indicates that when there is a reversal bias, At the base collector depletion region's edge ($x$ = $W$), the minority carrier concentration is zero.

Eq. 3 is substituted into the general solution represented by Eq. 2 to produce

$$P_n(x) = P_{no}\left(e^{qV_{BE}/KT} - 1\right)\left[\frac{sinh\left(\frac{W-x}{L_P}\right)}{sinh\left(\frac{W}{L_P}\right)}\right] + P_{no}\left[1 - \frac{\left(sinh\frac{x}{L_P}\right)}{\left(sinh\frac{W}{L_P}\right)}\right], \ldots\ldots\ldots\ldots(4)$$

the distribution equation can be simplified as

$$P_n(x) = P_{no}e^{qV_{BE}/KT}\left(1 - \frac{x}{W}\right) = P_n(0)\left(1 - \frac{x}{W}\right), \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

The distribution approaches a straight line. The approximation is reasonable because the base region's width is intended to be substantially lower than the minority carrier's diffusion length. Fig. 1 depicts a linear minority carrier distribution in an active mode-operated transistor. Be aware that the derivation of current-voltage characteristics can be simplified by assuming a linear minority-carrier distribution. Therefore, Using the following assumption, we construct equations for the current-voltage characteristics [16].

2.1.2. Regions of the Emitter and Collector

comparable to how the distributions for the base area were obtained. In Fig. 1, the neutral emitter and collector areas' boundary conditions are

$$n_E(x = -x_E) = n_{EO}e^{qV_{BE}/KT} \quad , \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

And

$$n_C(x = x_C) = n_{CO}e^{-q|V_{BE}|/KT} = 0 \ \ldots\ldots(7)$$

where the equilibrium electron concentrations in the emitter and collector, respectively, are denoted by the letters $n_{EO}$ and $n_{CO}$ . We assume that $L_E$ and $L_C$ , the associated diffusion lengths, are significantly less than the emitter depth and the collector depth, respectively [16]. Expressions like Eq. 2 that have these boundary conditions substituted into them produce:

$$n_E(x) = n_{EO} + n_{EO}\left(e^{-qV_{BE}/KT} - 1\right)e^{\frac{x+x_E}{L_E}} \qquad x \le x_E, \ldots\ldots\ldots\ldots\ldots(8)$$

$$n_C(x) = n_{CO} - n_{CO}e^{-\frac{x-x_C}{L_C}} \qquad x \ge x_C \quad . \ldots\ldots\ldots\ldots\ldots(9)$$

2.1.3. Ideal Transistor Currents for Active Mode Operation

Once the distributions of minority carriers are determined, Calculations may be made for the different current components depicted in Fig. 1. $I_{Ep}$ at this time, is proportional to the gradient of the minority carrier concentration and is injected from the emitter at $x = 0$. For $W/L_p << 1$ , by using Eq. 5 can be expressed the hole current $I_{Ep}$:

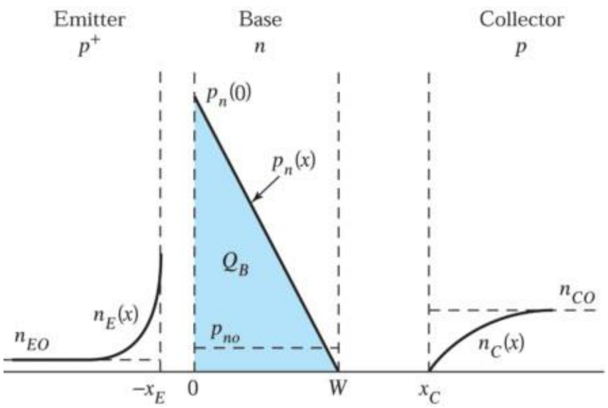
$$I_{EP} = A\left(-qD_P\frac{dP_n}{dx}\bigg|_{x \quad 0}\right) \cong \frac{qAD_PP_{no}}{W}e^{qV_{BE}/KT} . \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

In a similar vein, the collector's hole current at $x = W$ equals

$$I_{CP} = A\left(-qD_P\frac{dP_n}{dx}\bigg|_{x \quad W}\right) \cong \frac{qAD_PP_{no}}{W}e^{qV_{BE}/KT}, \ \ldots\ldots(11)$$

Take note that when $W/L_p << 1$, $I_{EP}$ and $I_{CP}$ are equal. The electron currents $I_{En}$ and $I_{Cn}$ are caused by the flow of electrons from the base to the emitter and the collector, respectively.

**Figure. 1 Minority carriers spread in various NPN transistor areas when operating in the active mode.**




$I_{En} = A\left(-qD_E \frac{dn_E}{dx}\Big|_{x\ \ -x_E}\right) \cong \frac{qAD_E P_{EO}}{L_E}\left(e^{qV_{BE}/KT}-1\right)$ , ………………….(12)

$I_{Cn} = A\left(-qD_C \frac{dn_C}{dx}\Big|_{x\ \ x_C}\right) \cong \frac{qAD_C P_{CO}}{L_C}$ , ……………………………………...(13)

where $D_E$ and $D_C$ stand for the emitter's and collector's respective diffusion constants. These equations may now be used to determine the terminal currents. The product of Equations 10 and 12 is the emitter current.

$I_E = a_{11}\left(e^{qV_{BE}/KT}-1\right) + a_{12}$, …….(14)

Where

$a_{11} = qA\left(\frac{D_P P_{no}}{W} + \frac{D_E n_{EO}}{L_E}\right)$, …………..(15)

$a_{12} = \frac{qAD_P P_{no}}{W}$, ……………..(16)

The result of the combination of equations 11 and 13 is the collector current.

$I_C = a_{21}\left(e^{qV_{BE}/KT}-1\right) + a_{22}$, ……(17)

Where

$a_{21} = \frac{qAD_P P_{no}}{W}$, …………(18)

$a_{22} = qA\left(\frac{D_P P_{no}}{W} + \frac{D_C n_{CO}}{L_C}\right)$, …….(19)

Note that $a_{12} = a_{21}$. The difference between the emitter current $I_E$ and the collector current $I_C$ is the base current for the perfect transistor. Therefore, Eq. 17 may be subtracted out of Eq. 14 to get the basic current:

$I_B = (a_{11} - a_{21})\left(e^{qV_{BE}/KT}-1\right) + (a_{12} - a_{22})$, ………………………….(20)

These talks show that the minority carrier distribution in the base area primarily controls the currents in a transistor's three terminals. Once the present components are derived [16].

2.2. Current Gain

Using the different current components mentioned above, one may express the terminal currents:

$$\left.\begin{aligned} I_E &= I_{EP} + I_{En} \\ I_C &= I_{CP} + I_{Cn} \\ I_B &= I_{BP} + I_{Bn} \end{aligned}\right\}, \quad \ldots\ldots\ldots\ldots(21)$$

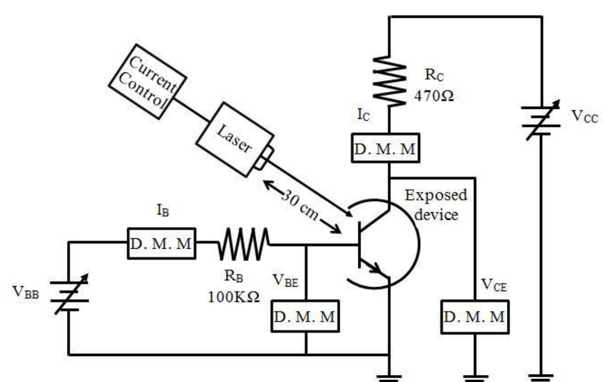
$\beta_{DC} = \frac{I_C}{I_B}$ , …………………(22)

Where $\beta_{DC}$ is called current gain [17].

**3. Results and Discussion.**

The experimental setup shown in Fig. 2 includes "a variable power supply", "a voltmeter", "an ammeter", "a 470 Ω", and "100 KΩ resistors", a 2N3773 NPN power transistor" and "electromagnetic radiation sources UV, VS, and IR".

**Figure 2: The circuit diagram of The experimental setup**




By employing various sources of electromagnetic radiation, the effects of electromagnetic radiation on the input and output characteristics of a regular transistor (2N3773) with an exposed device were explored. then compared it with no effect except for the pre-illumination of the lab space. Fig. 3 and Fig. 4 show the relationship between IB and VBE with fixed VCE at (0 V) and (5 V) respectively, Through the curves, the voltage and input resistance of the transistor (Vbi, Rin) were calculated for each wavelength of the electromagnetic radiation sources used in the study and compared with the normal case, where it was observed that there was an increase in the input voltage as well as the input resistance of the transistor power with increasing wavelength at constant power, where the power of green and blue-violet lasers is 100mW, while the rest of the sources are 5mW, and the values of these results can be compiled in Tables (1) and (2).

**Table (1) The values of the potential barrier and the transistor's input resistance under the effect of certain wavelengths when VCE = 0 volt.**

| λ(nm) | $V_{bi}(V)$ | $R_{in}(\Omega$ |
|---|---|---|
| 0 | 0.3552408 | 0.002899 |
| 395 | 0.3756374 | 0.003868 |
| 630-650 | 0.4215297 | 0.005927 |
| 850 | 0.4436261 | 0.006437 |
| 405 | 0.4929178 | 0.012352 |
| 532±10 | 0.5065156 | 0.023921 |

**Table (2) The values of the potential barrier and the transistor's input resistance under the effect of certain wavelengths when VCE = 5 volt.**

| λ(nm) | $V_{bi}(V)$ | $R_{in}(\Omega)$ |
|---|---|---|
| 0 | 0.5155556 | 0.0212 |
| 395 | 0.5182222 | 0.02779 |
| 630-650 | 0.5466667 | 0.032760291 |
| 850 | 0.5688889 | 0.088372881 |
| 405 | 0.5715556 | 0.093686441 |
| 532±10 | 0.5751111 | 0.093826271 |

The input characteristics of the transistor under the effect of the shorter wavelength are also similar to the typical scenario, without any effect of electromagnetic radiation, as shown in Figures (3) and (4). However, the curve's starting point is at a higher voltage (VBE) value, and this value rises as the electromagnetic radiation's wavelengths and strength increase. Also, it can be noted that the curves in Fig. (3) can be distinguished from each other, unlike the curves in Fig. (4), which are more close to each other.

**Figure 3. The relationship between IB and VBE with VCE constant (VCE= 0 Volt) (Input Characteristics Curves for a Transistor (2N3773) Voltage-Current)**

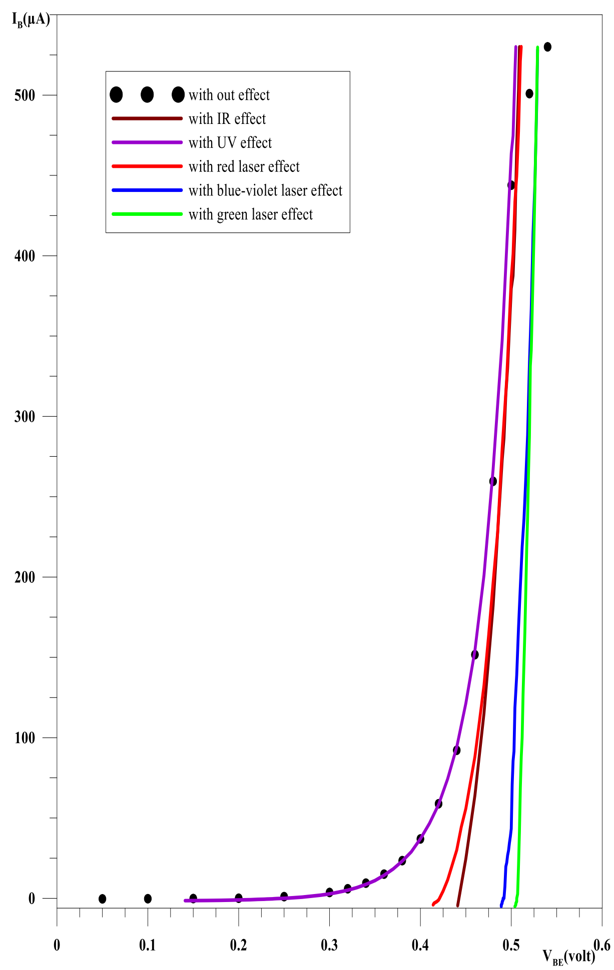


**Figure 4. The relationship between IB and VBE with VCE constant (VCE= 5 Volt) (Input Characteristics Curves for a Transistor (2N3773) Voltage-Current)**

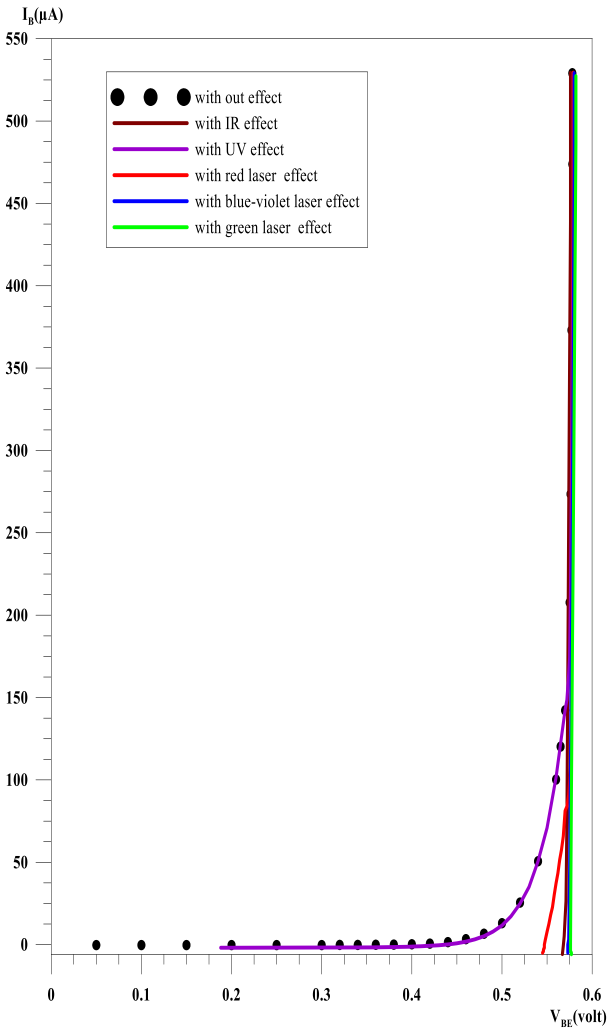



Fig. (5) to Fig. (10) represent a family of current-voltage transistor output characteristics curves at certain values of the base current (IB), i.e. (IB(□A) = 0, 20, 40, 60, 80, and 100). Where we notice that the curves that represent the relationship between (IC) and (VCE) get a shift to right under the influence of electromagnetic radiation sources when compared to the normal case, and this increase is compatible with the increase in wavelength at a certain power, which will increase the saturation current ( IC(sat)) as well as the lode line and operation point of transistor ( Q-point ).

As it is clear from the figures, the family of curves is confined between the collector current values (0 □A) and (11500 □A) for a situation where there is no impact, (500 □A) and (12000 □A), (5500 □A) and (16500 □A), (18500 □A) and (36500 □A), (54000 □A) and (78000 □A), and (106000 □A) and (132000 □A) under UV, red laser, IR, blue-violet laser, and green laser respectively.

Also, the current gain (βdc) was calculated for each effect of electromagnetic radiation, and it was found that there is an increase in the gain with increasing wavelength at a certain power, because the increase of emerge of impact radiation cussed increase IC, as a result of increasing IC increases βdc. Table (3) shows the current gain values.

**Table (3) The wave length and the current gain and the relationship between them**

| λ(nm) | $\beta_{dc}$ |
|---|---|
| 0 | 122.6 |
| 395 | 124.89 |
| 630-650 | 134.04 |
| 850 | 182.3 |
| 405 | 233.63 |
| 532±10 | 253.74 |

Now, to calculate the output resistance of the transistor, the slope was calculated for each curve of the family of curves of the output properties of the transistor under the influence of electromagnetic radiation and compared with the case without any effect, as shown in Table (4), where it was found that the resistance decreases with increasing wavelength at a certain power for the same the collector current's value (IB), and the resistance increases for the same effect at different values of the collector current.

**Table (4) The transistor's output resistance at a given IB value with and without regard to the effects of electromagnetic radiation.**

| λ(nm) | 0 | 395 | 630-650 | 850 | 405 | 532±10 |
|---|---|---|---|---|---|---|
| $I_B$(μA) | $R_{out}$(Ω) | $R_{out}$(Ω) | $R_{out}$(Ω) | $R_{out}$(Ω) | $R_{out}$(Ω) | $R_{out}$(Ω) |
| 0 | 10093.67 | 8074.935 | 6319.115 | 1776.199 | 925.6688 | 282.3902 |
| 20 | 14576.41 | 10801.59 | 7805.792 | 2075.55 | 983.4776 | 292.7143 |
| 40 | 21321.51 | 15990.02 | 12314.51 | 2129.019 | 989.5112 | 400.2882 |
| 60 | 34260.66 | 21547.54 | 18090.38 | 2789.322 | 1047.823 | 354.4842 |
| 80 | 81639.32 | 45095.83 | 32127.48 | 3099.526 | 1236.354 | 322.6119 |
| 100 | 6435006 | 48049.2 | 32552.08 | 3279.119 | 1284.555 | 405.7289 |

From Table (4), we find that the output resistance decreases with increasing radiation energy, and the reason is due to the high radiation energy increasing the number of electrons that are transmitted from the valence band to the conduction band.

**Figure 5. The family of curves representing the current-voltage output characteristics of transistors (2N3773) is unaffected.**

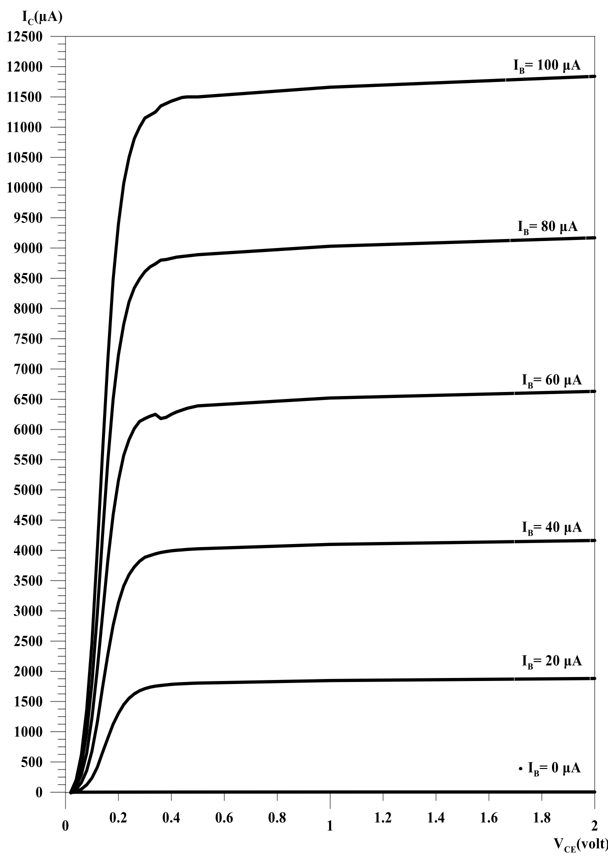


**Figure 6. The set of curves that represent the current-voltage output properties of the transistor (2N3773) under UV influence.**

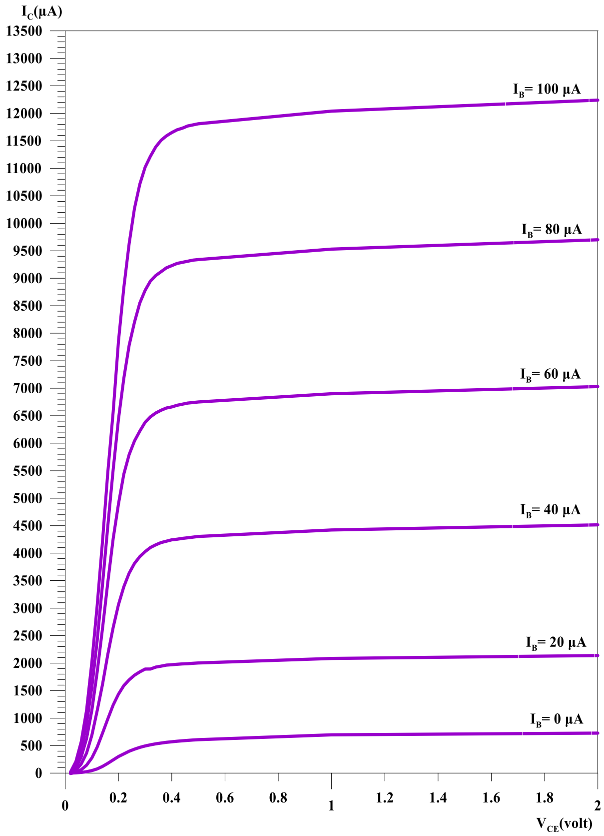



**Figure 7. The set of curves that represent the current-voltage output properties of the transistor (2N3773) under the influence of a red laser.**

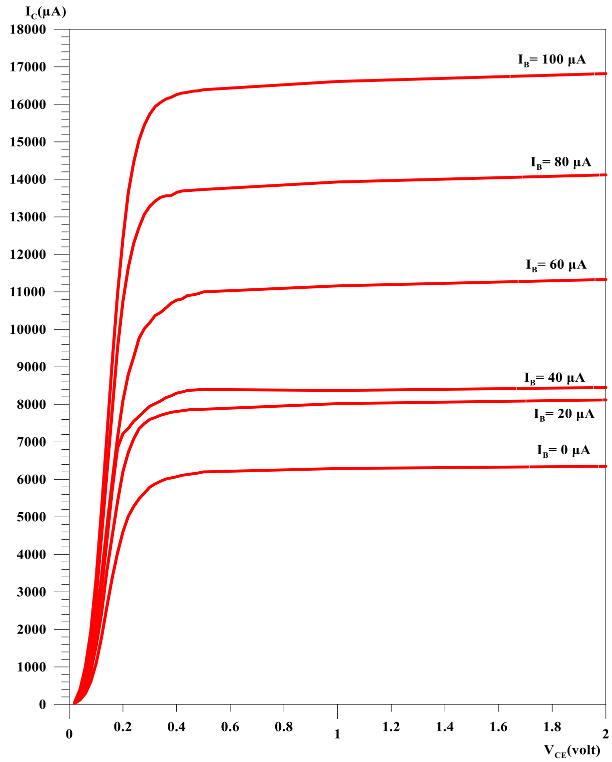


**Figure 8. The set of curves that represent the current-voltage output properties of the transistor (2N3773) under the IR effect.**

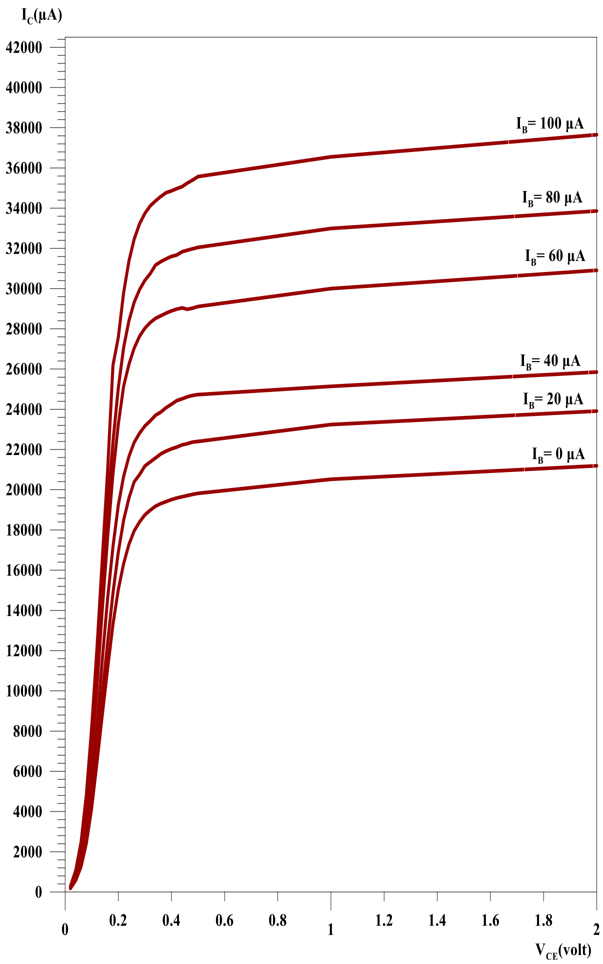



**Figure 9. The set of curves that represent the current-voltage output properties of the transistor (2N3773) under blue-violet laser action.**

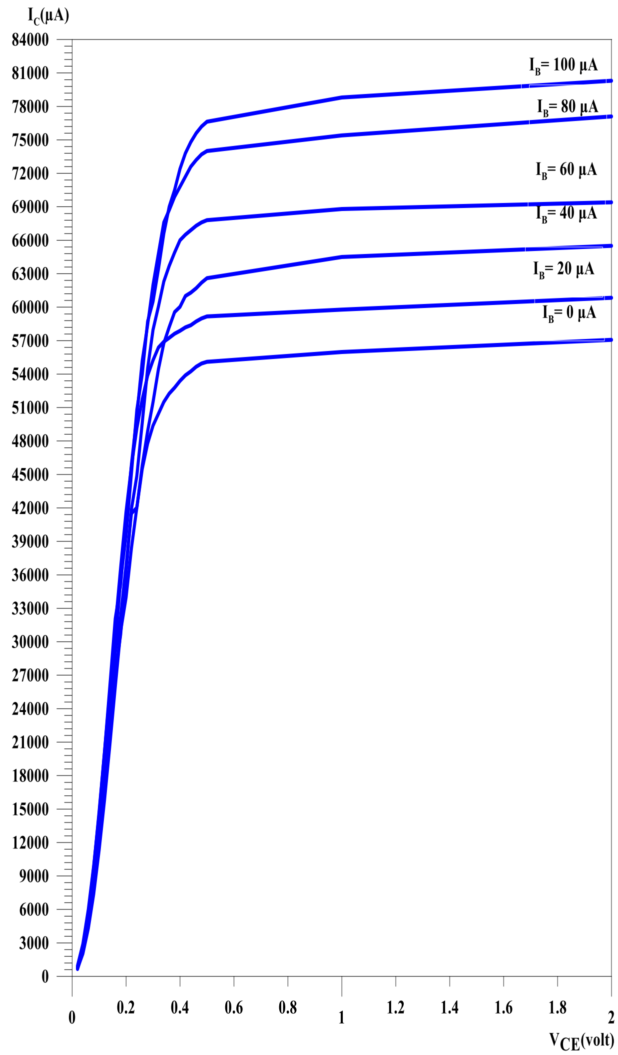
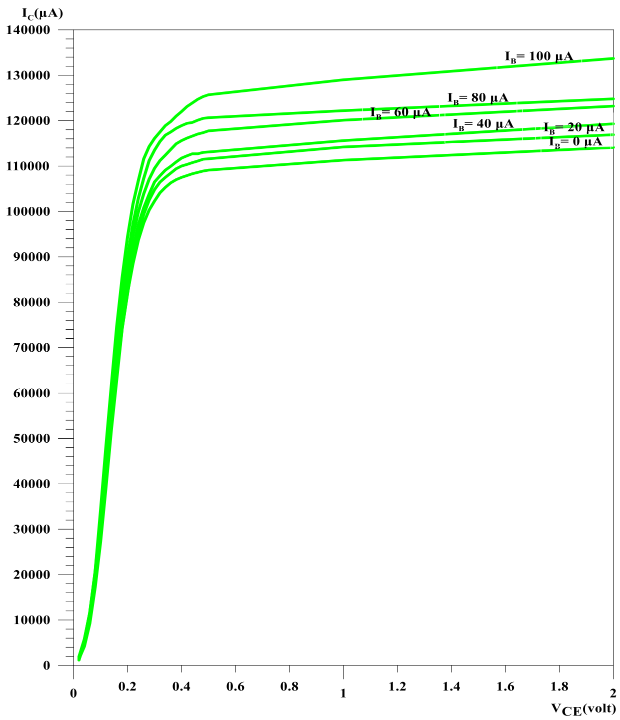


**Figure 10. The set of curves that represent the current-voltage output properties of the transistor (2N3773) under the influence of a green laser.**




## 3. Conclusions

The"effect of electromagnetic radiation on the input and output properties, can be considered a measure of electromagnetic radiation, and accordingly, "transistor (2N3773) can be used as a measure of electromagnetic radiation. Where it was observed that each parameter of the input and output parameters changes according to the wavelength used. For example, the input voltage and the input resistance increase with the increase in the wavelength used, as well as the gain of the current and the operating point (Q-point) of the transistor associated with the load line increases with the increase in the wavelength, which works to increase the saturation current, While the output impedance will decrease with increasing wavelength. "

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