Available online at: http://brsj.cepsbasra.edu.iq

ISSN –1817 –2695

Received 21-10-2018, Accepted 19-3-2019

The Electron Transport Properties of Qubit Coupled with SET: The Tuning of the Qubit Energy Levels

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Abstract

In this study, theoretical treatment is presented to study the electron transport for a system consists of two principle coupled parts, these are the key element of quantum computer which is represented by the qubit and the detector. Model calculation that includes the derivatives of the time dependent equations of motion for the system under consideration is presented. We find particular relations for the time variation of the occupation numbers of the qubit quantum dots and the single electron transistor dot as well as the current that flows from the left lead. Perfect quantum measurement can be obtained through the initialization and manipulation processes which are intended the system initialization and manipulation before the start measurement process and through the control of the parameters, the important parameters connected the electrical structure of sub device. The most important use gate voltage to tunning the qubit energy levels.

Keywords: Qubit; Single Electron Transistor(SET); Electron Transport; Quantum Computer.

1. Introduction

To construct a device for treating quantum information (quantum computer) we must firstly have physical system that can store and present information. The simplest system is a quantum system with two states that called "Two level system" or "qubit". In the quantum computing, the qubit is considered as quantum information unit it is quantum equivalent of classical bit[1]. In the classical system, the bit can be specific state or other state, but in the quantum mechanics it can be also superposition of states at the same time[2]. In other word, the qubit is quantum two level system and that can be obtained by many possible ways. As the required case is two discrete quantum levels that can be controlled practically and in the same time they can be completely isolated from unfavorable reactions [3]. There are two main options for qubit basis these are the spin freedom degree in the single quantum dot and the orbital (charge) degree of freedom in the double quantum dot. The double quantum dot provides simple and factual system with two energy levels [4,5]. The charge qubit with the single electron can be defined as a state in which one of the quantum dots or the other is occupied by single electron [6]. There is two types of coupling between the quantum dots: the electrostatically coupling which prevents two electrons to occupy the same quantum dot and the other is the quantum tunneling which allows the electron to occupy two quantum dots [7]. The single electron tunneling has been discussed using conventional current measuring method [8]. The current measurement has very few sensitivity whereas millions of electrons are required to find current with scientific concept. And Conversely, the charge detection measurement in the qubit provides direct detection to electron occupation in quantum dots and provides sensible measurement to the single electron transport. The single electron transistor in which the transport is influenced by the Coulomb interaction in the quantum dot is considered as a sensitive electrical measuring machine. There is another tool for measurement that is the quantum point contact, i. e. semiconductor point contact structure which is sensitive to the charge distribution on contacts[9]. This measurement machines provide detection for the charge in the quantum dots that coupled electrostatically with the measurement machines. The electrical measurement machine, the single electron transistor is more sensitivite than the quantum point contact which exhibits high variation in the transmission probability. It is well known that many studies discuss the qubit problem theoretically and a lot of experimental studies are still required.

The aim of our work is to study the electron transport dynamic and properties in a system consisting of charge qubit coupled to single electron transistor (see fig. (1)). In section two mathematical model is presented to derive the time dependent equations of motion for the system under consideration in order to find a special relations for the time dependence of the occupation numbers on the QDs of the qubit and the QD of the SET, also to find formula for the current that flows from the left lead passing through the left tunnel barrier to the quantum dot of the single electron transistor. All the system parameters are taken into consideration in our treatment.

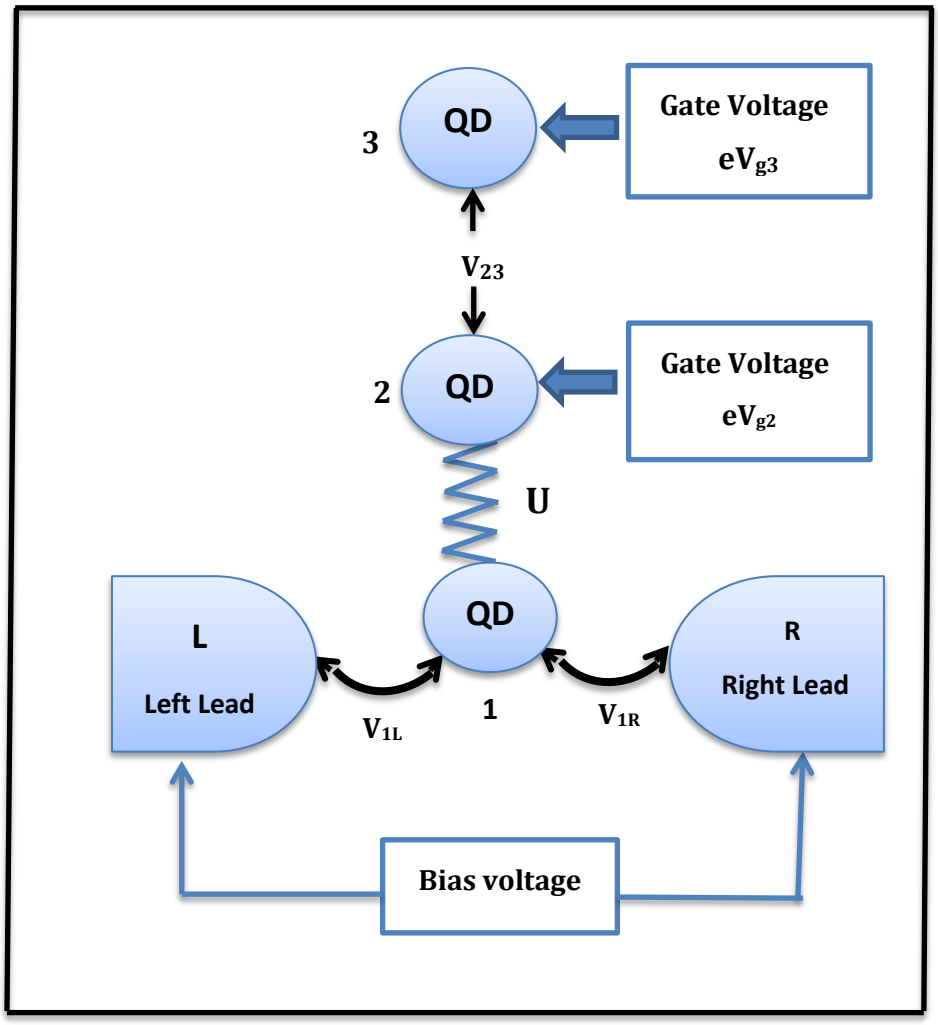

Fig. (1) represents the system used when a gate voltage is applied to the QDs of the qubit.

2. Model Calculation

The system which is studied in this paper can be described (see fig.(2)) by using the following time dependent Hamiltonian [10]:

$$H(t) = H_{SET}(t) + H_{Qubit}(t) + H'(t) \quad (1)$$

The first term in eq. (1) represents the Hamiltonian that describes the SET,

$$H_{SET}(t) = \sum_{k_L} E_{k_L} n_{k_L} + \sum_{k_R} E_{k_R} n_{k_R} + E_1 n_1(t) + \sum_{k_L} (V_{1k_L}(t)\, C_1^{+}(t)\, C_{k_L}(t) + h.c.) + \sum_{k_R} \left(V_{1k_R}(t)\, C_1^{+}(t) C_{k_R}(t)\right) + h.c.\big) \quad (2)$$

n_i represents the occupation number of the level E_i whereas $i = k_L, k_R, 1$. k_L and k_R represent the energy levels on the left and right leads ,respectively. V_{1k_R} and V_{1k_L} represent the tunnel barriers between the QD of the SET and the right and left leads ,respectively.

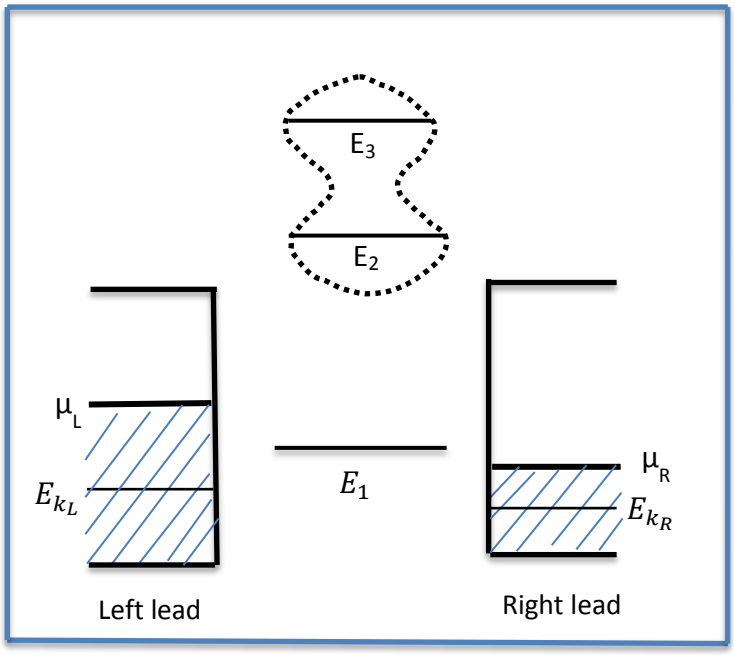

Fig. (2): Schematic representation for the energy scheme that corresponding to the system (qubit + single electron transistor) in presence of bias voltage.

The second term in equation (1) represents the Hamiltonian that describes the qubit;

$$H_{Qubit}(t) = E_2 n_2(t) + E_3 n_3(t) + (V_{23}(t) C_2^+(t) C_3(t) + h.c.) \quad (3)$$

n_2 , n_3 are the occupation numbers of the qubit QDs that corresponding to the energy levels E_2 and E_3, respectively. While V_{23} describes the tunnel barrier between QDs of the qubit, h.c. represents the harmonic conjugate. $H^{/}(t)$ in eq. (1) corresponds to the interaction between qubit and the SET,

$$H^{/}(t) = U\, n_1(t)\, n_2(t) \quad (4)$$

U represents the electrostatic coupling between these two subsystems, it is important term because it determines the current value that flowing between the leads in the SET because of electron oscillations between the qubit QDs. In general, the occupation number of the energy levels i can be written as, [11] :

$$n_i(t) = C_i^+(t) C_i \quad (5)$$

Where as $C_i^+(t)(C_i(t))$ is the creation (annihilation) operators of electrons localized on the *i*th QD, *i*=1,2,3 and on the two leads when $i = k_L$, k_R. Our main goal is to derive the equations of motion for the system under consideration. For this purpose we use Heisenberg representation to write the time evolution of the occupation numbers [12]. By using atomic units we write the following relations:

$$\frac{dC_1(t)}{dt} = -i\left[E_1 C_1(t) + \sum_{k_L} V_{1k_L} C_{k_L}(t) + \sum_{k_R} V_{1k_R} C_{1k_R}(t) + U C_1(t) n_2(t)\right] \quad (6)$$

$$\frac{d\, C_1^+(t)}{dt} = i\left[E_1\, C_1^+(t) + \sum_{k_L} V_{1k_L}^* C_{k_L}^+(t) + \sum_{k_R} V_{1k_R}^* C_{k_R}^+(t) + U C_1^+(t) n_2(t)\right] \quad (7)$$

By taking the quantum–mechanical average to both sides of equation (5), and differentiating it with respect to time, we get,

$$\frac{d}{dt}\langle n_1(t)\rangle = 2Im\left[\sum_{k_L} V_{1k_L}\langle C_1^+(t) C_{k_L}(t)\rangle + \sum_{k_R} V_{1k_R}\langle C_1^+(t) C_{k_R}(t)\rangle\right] \quad (8)$$

Eq. (8) can be simplify by finding $\frac{dC_{k_\propto}(t)}{dt}$, as follows:

$$\frac{dC_{k_\propto}(t)}{dt} = -i\left[E_{k_\propto} C_{k_\propto}(t) + V_{1k_\propto}^* C_1(t)\right] \quad (9)$$

Then by solving eq. (9) analytically one can get,

$$C_{k_\propto}(t) = C_{k_\propto}(t_0)e^{-i\,E_{k_\propto}(t-t_0)} - i\int_{t_0}^{t} dt^{/}\, V_{1k_\propto}^{*}\, e^{-i\,E_{k_\propto}(t-t^{/})}\, C_1\,(t^{/}) \qquad (10)$$

t_0 is the initial time. Then by getting use of the following equation [11],

$$\Gamma_\alpha(E) = 2\pi \sum_{k_\alpha} V_{1k_\alpha}\, V_{1k_\alpha}^{*}\, \delta\,(E - E_{k_\alpha}) \quad , \quad \alpha = L\,, R \qquad (11)$$

Whereas $\Gamma_\alpha(E)$ represents the tunnel barrier between the QD of the SET and the lead α, by using the following definitions [13],

$$V_{1k_\propto} = \nu_{k_\propto}\, V_{1\propto} \quad , \quad \mathrm{C}_{k_\propto}(\mathrm{t_0}) = \nu_{k_\propto}\, \tilde{\mathrm{C}}_{k_\propto}(\mathrm{t_0}) \qquad (12)$$

For simplicity we will not write the sign $\sim$. The lead density of states is given by[11],

$$\rho_\propto(E) = \sum_{k_\propto} \left|\nu_{k_\propto}\right|^2\, \delta(E - E_{k_\propto}) \qquad (13)$$

We also use the so- called wide band approximation [11], then $\Gamma_\alpha(E)$ will be independent on energy, so one can write the tunneling rates and the lead density of states as follows,

$$\Gamma = \Gamma_L + \Gamma_R \quad , \quad \rho_\propto(\mathrm{E}) = \rho_\propto = \frac{1}{4\beta} \qquad (14)$$

Where β is a factor related to the band width (=4β) . Eq. (7) becomes;

$$\frac{\mathrm{d}}{\mathrm{dt}}\langle\, \mathrm{n_1(t)}\,\rangle = 2\mathrm{Im}\left[\, \mathrm{I_1(t)} + \mathrm{I_2(t)} - \mathrm{i}\,\frac{\Gamma}{2}\,\langle \mathrm{n_1}\rangle\right] \qquad (15)$$

$\mathrm{I_1(t)}$, $\mathrm{I_2(t)}$ are given by the following equations,

$$I_1(t) = \frac{V_{1L}}{4\beta}\int_L e^{-i\,E_{k_L}\,(t-t_0)}\langle\, C_1^{+}\,(t) C_{k_L}(t_0)\,\rangle dE_{k_L} \qquad (16)$$

$$I_2(t) = \frac{V_{1R}}{4\beta}\int_R e^{-i\,E_{k_R}\,(t-t_0)}\langle\, C_1^{+}\,(t) C_{k_R}(t_0)\,\rangle dE_{k_R} \qquad (17)$$

Following the same procedure, we get,

$$\frac{d}{dt}\,\langle n_2(t)\rangle = 2Im\{V_{23}\langle C_2^{+}(t) C_3(t)\rangle\} \qquad (18)$$

$$\frac{d}{dt}\,\langle n_3(t)\rangle = -2Im\{V_{23}\langle C_2^{+}(t) C_3(t)\rangle\} \qquad (19)$$

In order to find the occupation numbers $n_1(t), n_2(t)$ and $n_3(t)$ we must find the equations of motion for the correlation functions. The correlation functions are

$\langle C_1^+ C_{k_L^/}(t_0)\rangle, \langle C_1^+ C_{k_R^/}(t_0)\rangle$ and $C_2^+(t)C_3(t)$, where $k_L^/$ is one of k_L values. By getting use of eq. (4) we write;

$$C_{k_\alpha}^+(t_0)C_{k_\alpha^/}(t_0) = n_{k_\alpha}(t_0)\delta_{k_\alpha k_\alpha^/} \tag{20}$$

Accordingly, we find the following equation of motion for the correlation function $\langle C_1^+ C_{k_\alpha^/}(t_0)\rangle$,

$$\frac{d}{dt}\langle C_1^+ C_{k_\alpha^/}(t_0)\rangle = \left(iE_1 - \frac{\Gamma}{2}\right)\langle C_1^+ C_{k_\alpha^/}(t_0)\rangle + iV_{1k_\alpha^/}^* n_{k_\alpha^/}(t_0)e^{iE_{k_\alpha^/}(t-t_0)} + iU\langle C_1^+ n_2(t) C_{k_\alpha^/}(t_0)\rangle \tag{21}$$

Where $n_{k_\alpha}(t_0)$ is Fermi distribution function of the lead α:

$$n_{k_\alpha}(t_0) = \mathrm{f}\left(E_{k_\alpha}, T\right) = \frac{1}{1+\exp\left(\frac{E_{k_\alpha}-\mu_\alpha}{k_B T}\right)} \tag{22}$$

μ_α represents the chemical potential for the lead α, while T represents the lead temperature and k_B is Boltzmann constant, since the system is in thermal equilibrium . Now in order to get the differential equation for the correlation function $\langle C_2^+(t)C_3(t)n_1\rangle$ we write,

$$\frac{d}{dt}\langle C_2^+(t)C_3(t)n_1\rangle = \langle C_2^+(t)C_3(t)\rangle\frac{d\langle n_1\rangle}{dt} + \frac{d\langle C_2^+(t)C_3(t)\rangle}{dt}\langle n_1\rangle \tag{23}$$

For simplification we use the following:

$$\mathrm{iUC_2^+(t)C_3(t)C_1^+(t)\{1 - C_1^+(t)C_1(t)\}C_1(t)} \quad = \mathrm{iUC_2^+(t)C_3(t)n_1}$$

to get the following equation,

$$\frac{\mathrm{d}}{\mathrm{dt}}\langle \mathrm{C_2^+(t)C_3(t)n_1}\rangle = [\mathrm{iE_2 - iE_3} + iU - \Gamma]\langle \mathrm{C_2^+(t)C_3(t)n_1}\rangle + \mathrm{iV_{23}^*}[\langle \mathrm{n_3n_1}\rangle - \langle \mathrm{n_2n_1}\rangle] - \mathrm{i(I_3 + I_4 + I_5 + I_6)} \tag{24}$$

We also derive the differential equation for $\langle n_1 n_3\rangle$ and $\langle n_1 n_2\rangle$ which take the following relations:

$$\frac{d}{dt}\langle n_3 n_1\rangle = -\Gamma\langle n_3 n_1\rangle + 2Im\{I_7 + I_8 - \mathrm{V_{23}}\langle C_2^+(t)C_3(t)n_1\rangle\} \tag{25}$$

$$\frac{d}{dt}\langle n_2 n_1\rangle = -\Gamma\langle n_2 n_1\rangle + 2Im\{I_9 + I_{10} + \mathrm{V_{23}}\langle C_2^+(t)C_3(t)n_1\rangle\} \tag{26}$$

Since I_i represents the following integrals:

$$I_3 = \frac{V_{1L}}{4\beta}\int e^{-iE_{k_L}(t-t_0)}\langle C_1^+ C_2^+ C_3 C_{k_L}(t_0)\rangle dE_{k_L}$$

$$I_4 = \frac{V_{1L}}{4\beta}\int e^{+iE_{k_L}(t-t_0)}\langle C_1^+ C_2 C_3^+ C_{k_L}(t_o)\rangle dE_{k_L}$$

$$I_5 = \frac{V_{1R}}{4\beta}\int e^{-iE_{k_R}(t-t_o)}\langle C_1^+ C_2^+ C_3 C_{k_R}(t_0)\rangle dE_{k_R}$$

$$I_6 = \frac{V_{1R}}{4\beta}\int e^{+iE_{k_R}(t-t_0)}\langle C_1^+ C_2 C_3^+ C_{k_R}(t_o)\rangle dE_{k_R} \qquad (27)$$

$$I_7 = \frac{V_{1L}}{4\beta}\int e^{-iE_{k_L}(t-t_0)}\langle C_1^+ n_3 C_{k_L}(t_0)\rangle dE_{k_L}$$

$$I_8 = \frac{V_{1R}}{4\beta}\int e^{-iE_{k_R}(t-t_0)}\langle C_1^+ n_3 C_{k_R}(t_0)\rangle dE_{k_R}$$

$$I_9 = \frac{V_{1L}}{4\beta}\int e^{-iE_{k_L}(t-t_0)}\langle C_1^+ n_2 C_{k_L}(t_0)\rangle dE_{k_L}$$

$$I_{10} = = \frac{V_{1R}}{4\beta}\int e^{-iE_R(t-t_0)}\langle C_1^+ n_2 C_{k_R}(t_0)\rangle dE_{k_R}$$

Now, to find differential equation for $\langle C_1^+(t) n_2 C_{k_\propto^/}(t_0)\rangle$ we can write,

$$\frac{d}{dt}C_1^+(t) n_2 C_{k_L^/}(t_0) = \frac{dC_1^+(t)}{dt} n_2 C_{k_L^/}(t_0) + C_1^+(t)\frac{dn_2}{dt} C_{k_L^/}(t_0) \qquad (28)$$

Then by using the following relations [12],

$$\left[C_i^+(t), C_j(t)\right] = \delta_{ij}$$

And,

$$iUC_1^+(t)C_2^+(t)C_2(t)C_3^+(t)C_3(t)C_{k_L^/}(t_0) = -iUC_1^+(t)C_2^+(t)C_3^+(t)C_2(t)C_3(t)C_{k_L^/}(t_0) = 0$$

we get,

$$\frac{d}{dt}\langle C_1^+(t) n_2 C_{k_L^/}(t_0)\rangle = \left[iE + iU - \frac{\Gamma}{2}\right]\langle C_1^+(t) n_2 C_{k_L^/}(t_0)\rangle + iV_{1k_L^/}^* e^{iE_{k_L^/}(t-t_0)}\langle n_2\rangle\langle n_{k_L^/}(t_0)\rangle$$
$$- iV_{23}\langle C_1^+(t)C_2^+(t)C_3(t)C_{k_L^/}(t_0)\rangle + iV_{23}^*\langle C_1^+(t)C_2(t)C_3^+(t)C_{k_L^/}(t_0)\rangle \qquad (29)$$

and,

$$\frac{d}{dt}\langle C_1^+(t)n_3C_{k_L'}(t_0)\rangle=\left(iE_1-\frac{\Gamma}{2}\right)\langle C_1^+(t)n_3C_{k_L'}(t_0)\rangle+\ iV_{1k_L'}^*\ e^{iE_{k_L'}(t-t_0)}\langle n_3\rangle\langle n_{k_L'}(t_0\ )\rangle$$
$$+iV_{23}\langle C_1^+(t)C_2^+(t)C_3(t)C_{k_L'}(t_0)\rangle+iV_{23}^*\langle C_1^+(t)C_2(t)C_3^+(t)C_{k_L'}(t_0)\rangle \quad (30)$$

We also get the corresponding equations to the right lead.

To obtain the differential equation for the $\langle C_1^+(t)C_2^+(t)C_3(t)C_{k_L'}(t_0)\rangle$ we used the same steps to get,

$$\frac{d}{dt}\langle C_1^+(t)C_2^+(t)C_3(t)C_{k_L'}(t_0)\rangle=iV_{1k_L'}^*e^{iE_{k_L'}(t-t_0)}\langle C_2^+(t)C_3(t)\rangle\ \langle n_{k_L'}(t_0\ )\rangle$$
$$+\ i\left(E_1+E_2-E_3+U+i\frac{\Gamma}{2}\right)\langle C_1^+(t)C_2^+(t)C_3(t)C_{k_L'}(t_0\ )\rangle$$
$$+\ iV_{23}^*\langle C_1^+(t)n_3C_{k_L'}(t_0\ )\rangle-iV_{23}^*\langle C_1^+(t)n_2C_{k_L'}(t_0\ )\rangle \quad (31)$$

Where,

$$UC_1^+(\mathrm{t})C_2^+(\mathrm{t})C_2(\mathrm{t})C_2^+(\mathrm{t})C_3(\mathrm{t})C_{k_L'}(t_0\ )=UC_1^+(\mathrm{t})C_2^+(\mathrm{t})C_3(\mathrm{t})C_{k_L'}(t_0\ )$$

In the same way we get relations for the right lead.

Following the same procedure, we also obtain,

$$\frac{d}{dt}\langle C_1^+(t)C_2(t)C_3^+(t)C_{k_L'}(t_0)\rangle=-iV_{1k_L'}^*e^{iE_{k_L'}(t-t_0)}\langle C_2(t)C_3^+(t)\rangle^*\ \langle n_{k_L'}(t_0\ )\rangle$$
$$+\ i\left(E_1+E_2+E_3+i\frac{\Gamma}{2}\right)\langle C_1^+(t)C_2(t)C_3^+(t)C_{k_L'}(t_0\ )\rangle$$
$$+iV_{23}\langle C_1^+(t)n_3C_{k_L'}(t_0\ )\rangle\ -iV_{23}\ \langle C_1^+(t)n_2C_{k_L'}(t_0\ )\rangle \quad (32)$$

and also for the correlation function $\langle C_1^+(t)C_2(t)C_3^+(t)C_{k_R'}(t_0)\rangle$.

The correlation functions needed to find the occupation numbers on the three quantum dots are $\langle C_1^+(t)C_{k_\propto'}(t_0\ )\rangle$, $\langle C_2^+(t)C_3\ (t)\rangle$, $\langle C_2^+(t)C_3\ (t)n_1\rangle$, $\langle\ n_1\ n_3\rangle$, $\langle\ n_1\ n_2\rangle$, $\langle C_1^+(t)n_2C_{k_\propto'}(t_0\ )\rangle$, $\langle C_1^+(t)n_3C_{k_\propto'}(t_0\ )\rangle$, $\langle C_1^+(t)C_2^+(t)C_3(t)C_{k_\propto'}(t_0)\rangle$and $\langle C_1^+(t)C_2(t)C_3^+(t)C_{k_\propto'}(t_0\ )\rangle$, with $\propto=R\ ,L.$

Notably the correlation functions number may increase depending on the procedure that followed in the treatment. Depending on the differential relations that we obtained, we can write formula for the current that tunnels from the left lead,

$$I_L(t) = 2Im\left[\sum_{k_L} V_{1k_L}(t)\langle C_1^+(t)C_{k_L}(t_0)\rangle^* \, e^{-iE_{k_L}(t-t_0)} - i\sum_{k_L} V_{1k_L}\int_{t_0}^{t} V_{1k_L}^*\langle C_1^+(t)C_1(t')\rangle \, e^{-iE_{k_L}(t-t')}dt'\right] \quad (33)$$

By using the definitions (11-14) we obtain,

$$I_L(t) = 2Im\left[I_1(t) - i\frac{\Gamma}{2}\langle n_1(t)\rangle\right] \quad (34)$$

3. The Results and Discussion

To study electron transport dynamics in qubit coupled with single electron transistor we solve the related equations of motion numerically by using six order Rung-Kuta method where the error is calculated in each step of time ($\Delta t = 10^{-2} a.u.$) which is found to be equal to 10^{-9} - 10^{-8} , while the step in energy integration is equal to 0.024 eV. Where the language, that used for calculation, is Fortran. The program calculates the occupation numbers n_1 (t) , n_2(t) and n_3(t) , as well as the current flows from the left lead as a function of time for all the over mentioned system parameters. The calculations are accomplished for the initial values $n_1(t_0) = 1$, $n_2(t_0) = 0$ and $n_3(t_0) = 1$, whereas $t_0(= 0)$ represents the initial time.

It is well known that the quantum dots energy levels can be tunned by applying gate voltage (see fig(1)), then the quantum dots (2 and 3) energy levels will be vary according to the following,

$$E_i \longrightarrow E_i(= 0) + eV_{gi} \qquad i = 2,3$$

In order to investigate the effect of the gate voltage on the qubit, the value of eV_{g2} is fixed at a certain value then $n_i(\infty)$ and , $I_L(\infty)$ are calculated as a function of eV_{g3} as shown in figs. (3-6) for $eV_{g2} = -1\,eV\,, -0.5eV\,, 0.5eV\,, 1eV$ for $U = 0.05$ and eV_{bias}=1.5eV. According to these figures, the behavior of $n_1(\infty), n_2(\infty), n_3(\infty)$ *and* $I_L(\infty)$ as a function of the gate voltage eV_{g3}, and for the different values of eV_{g2}, are nearly concide. The behaviour of $I_L(\infty)$ and $n_2(\infty)$ as a function of eV_{g3} is completely concide. But the value of $(eV_{g3})_{min}$ which corresponds to the maximum value of the current $I_L(\infty)$ (that corresponds to the lowest value of $n_3(\infty)$and the maximum value of $n_2(\infty)$) will be different as eV_{g2} is varied as shown in table (1) which explains the importance of the initialization and manipulation processes.

And according to these results we report the following:

1- The value of $n_2(\infty)$ is the same for different values of eV_{g2} at $(eV_{g3})_{min}$ at which the currents is maximum, this is also to $n_1(\infty)\ and\ n_2(\infty)$. The above mentioned that the ability of controlling and enhancing the charge accumulation on any quantum dot in the system by the gates voltage.

2- According to our results we write $\left|eV_{g2} - (eV_{g3})_{min}\right| = 0.25$ eV for all value of eV_{g2} as shown in figs (3-6), since the values of $(eV_{g3})_{min}$ are lying at $\left(eV_{g2} + 0.25\right)eV$ with $(eV_{bais} = 1.5\ eV)$.

3- It is concluded that at certain values of eV_{g3}, the occupation numbers are equal especially $n_2(\infty)$ and $n_3(\infty)$. One can notice that the value of eV_{g3} at which $n_2(\infty) > n_3(\infty)$ when $eV_{g2} = 1\ eV$ are $1eV < eV_{g3} < 1.5\ eV$ and when $eV_{g2} = 0.5\ eV$ we have, $0.5eV < eV_{g3} < 1\ eV$. When $eV_{g2} = -0.5\ eV$ the values of eV_{g3} are $-0.5eV < eV_{g3} < 0$ and when $eV_{g2} = -1eV$ the range is $-1\ eV < eV_{g3} < -0.5\ eV$. The above mentioned means that there is an obvious relationship between the gate voltage eV_{g2} and the gate voltage eV_{g3}.

4- The maximum value of the SET current lies at eV_{g3} values at which $n_2(\infty) > n_3(\infty)$. Notably, the above mentioned features are changed with strength of the coupling variation that used in our calculations.

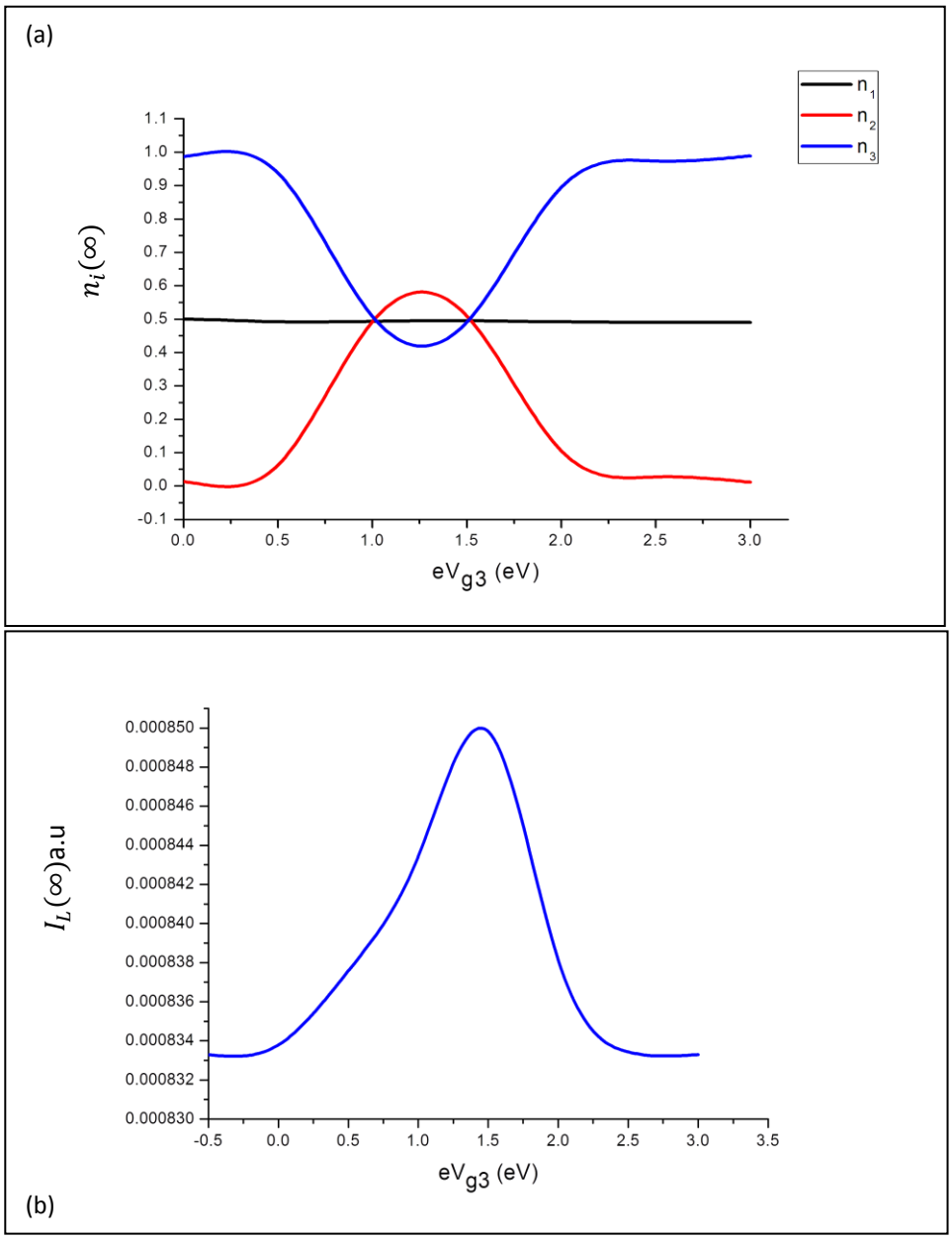

Fig. (3): (a) The occupation number $n_i(\infty)$ as a function of eV_{g3} With $i = 1, 2, 3$. (b) The current $I_L(\infty)$ as a function of eV_{g3} for the parameters:

U= 0.5 eV , eV_{bias} =1.5 eV , V_{23}= 0.1 eV

eV_{g2} = 1 eV , $V_{1\propto} = 0.3\ eV$

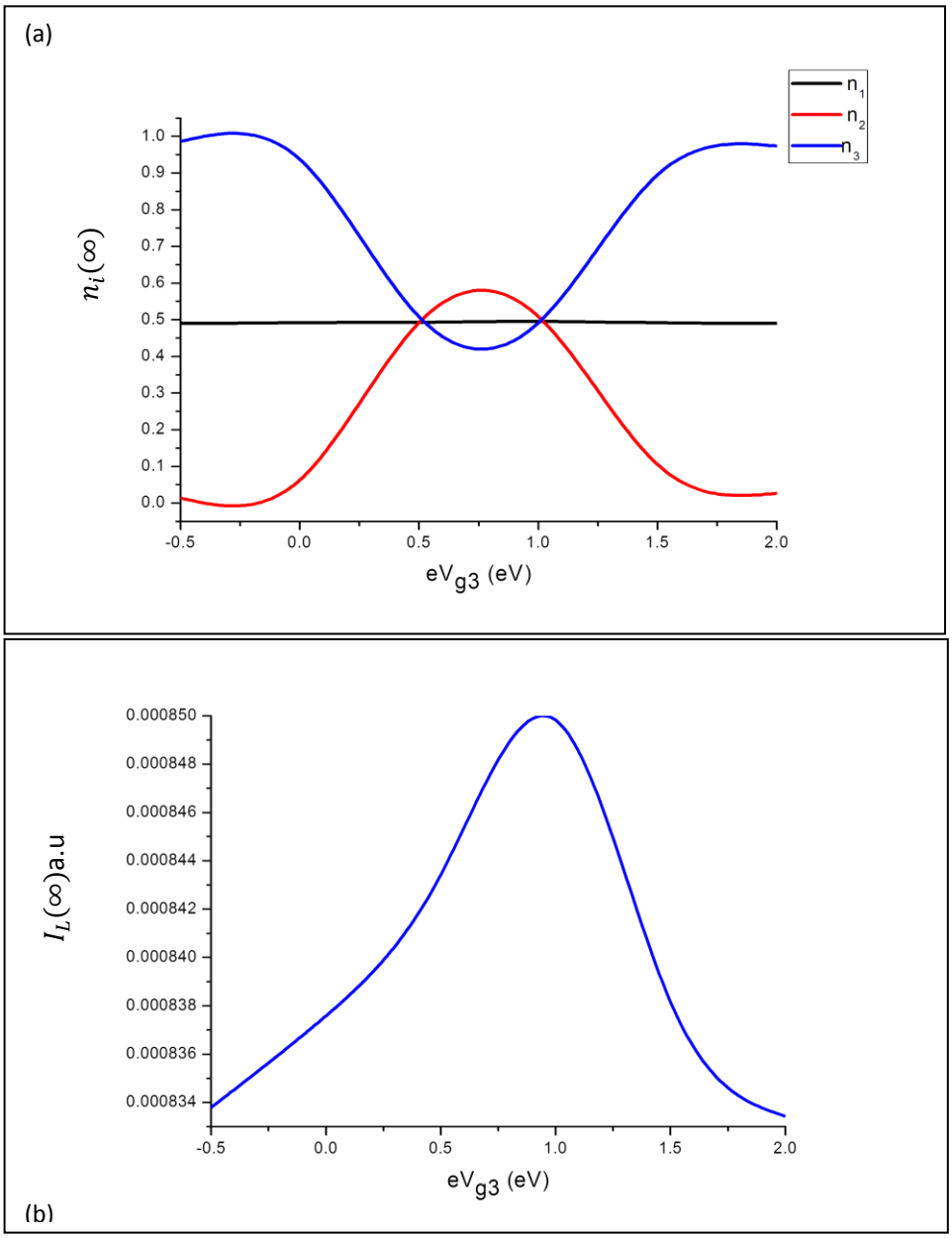

Fig. (4): (a) The occupation number $n_i(\infty)$ as a function of eV_{g3} With $i = 1, 2, 3$. (b) The current $I_L(\infty)$ as a function of eV_{g3} for the parameters:

U= 0.5 eV , eV_{bias} =1.5 eV , V_{23}= 0.1 eV

eV_{g2} = 0.5 eV , $V_{1\propto} = 0.3\ eV$

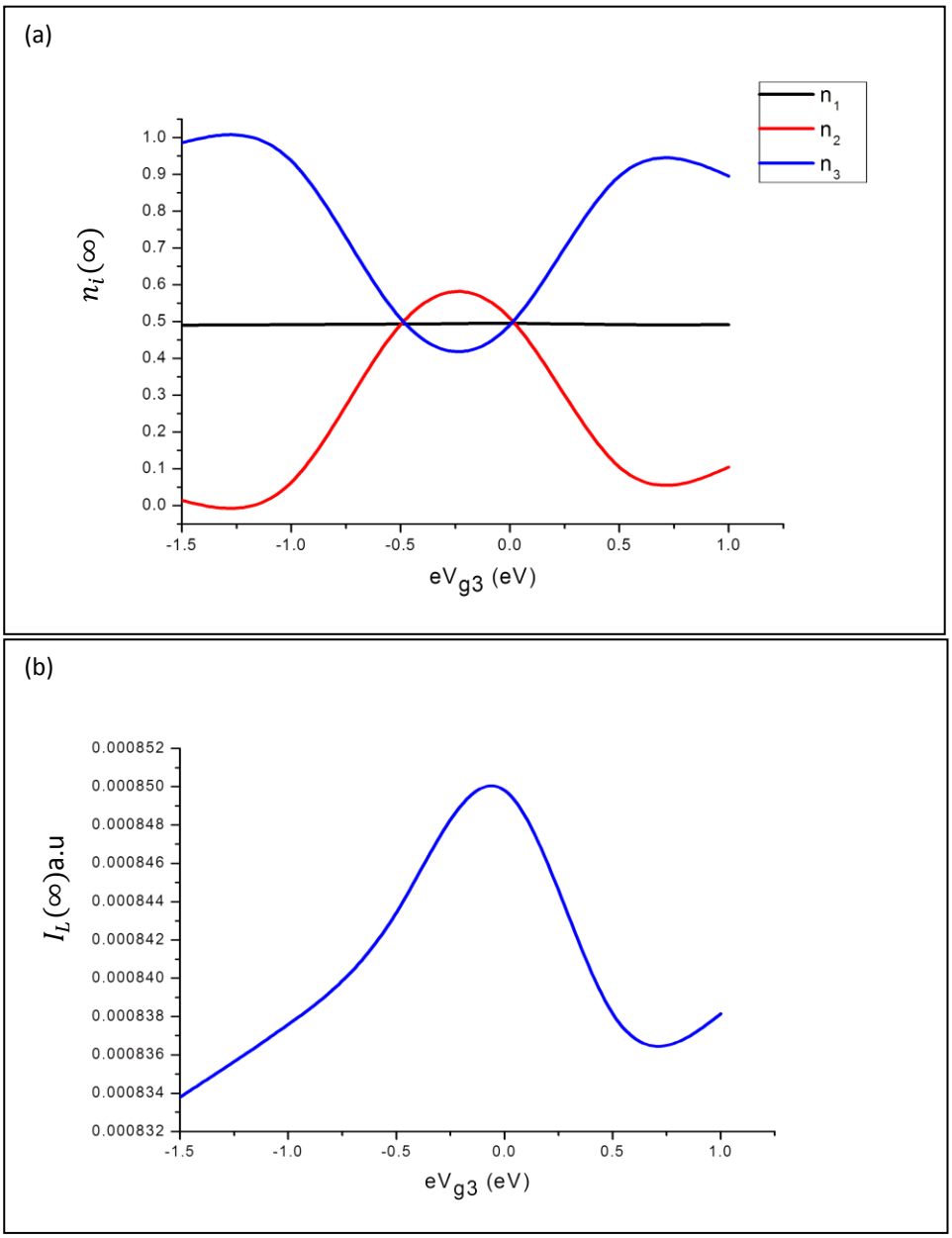

Fig. (5): (a) The occupation number $n_i(\infty)$ as a function of eV_{g3} With $i = 1, 2, 3$. (b) The current $I_L(\infty)$ as a function of eV_{g3} for the parameters:

U= 0.5 eV , eV_{bias} =1.5 eV , V_{23}= 0.1 eV

eV_{g2} = - 0.5 eV , $V_{1\propto} = 0.3\ eV$

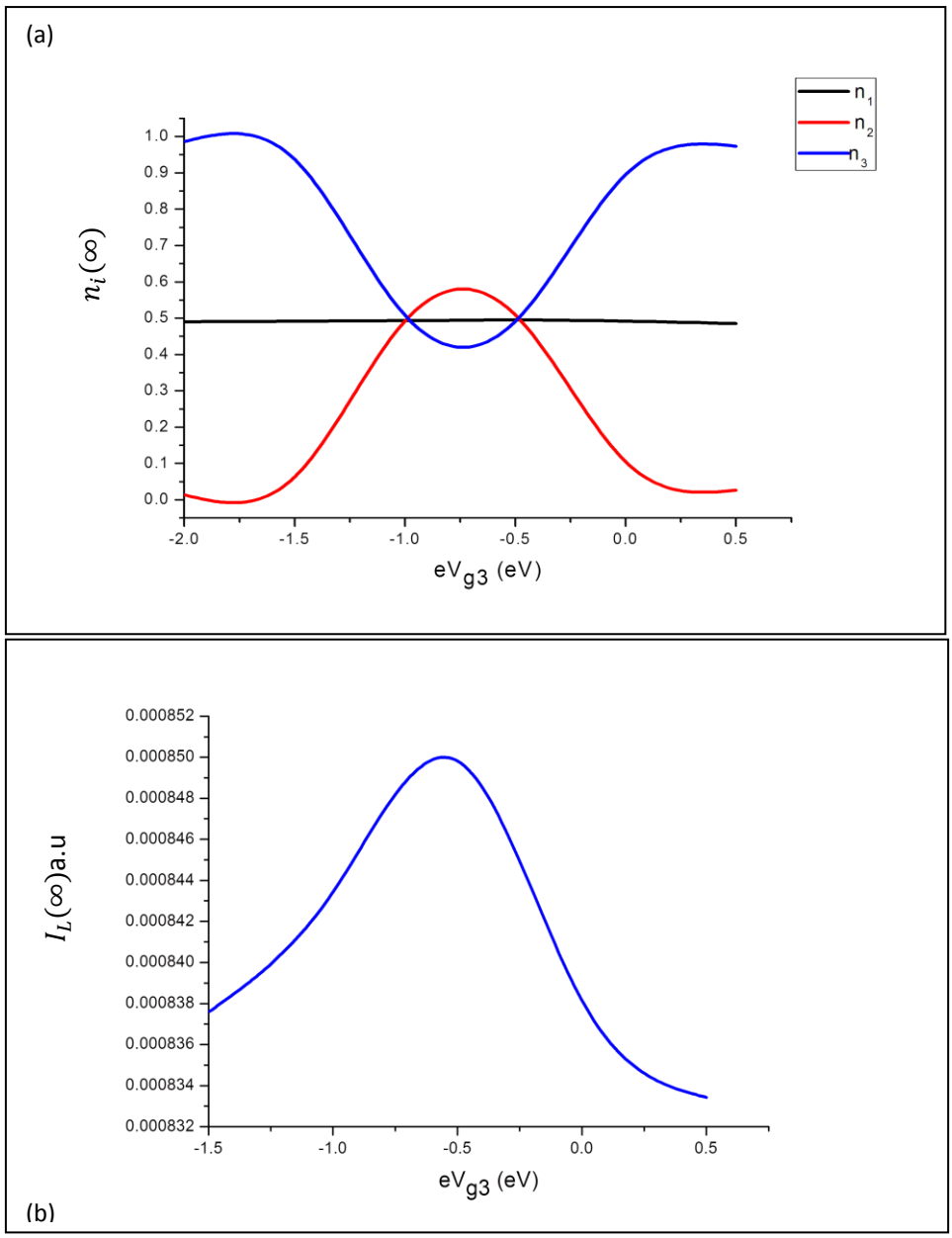

Fig. (6): (a) The occupation number $n_i(\infty)$ as a function of eV_{g3} With $i = 1, 2, 3$. (b) The current $I_L(\infty)$ as a function of eV_{g3} for the parameters:
U= 0.5 eV , eV_{bias} =1.5 eV , V_{23}= 0.1 eV
eV_{g2} = -1 eV , $V_{1\propto} = 0.3\ eV$

Table (1): The values of $(V_{g3})_{min}$ and the corresponding occupation numbers for different eV_{g2} when $\mathbf{U = 0.5eV}$, $V_{23} = 0.1\mathbf{eV}$ and $V_{1\propto} = 0.3\ \mathbf{eV}$.

$eV_{g2}(eV)$	$(eV_{g3})_{min}\ eV$	$n_1(\infty)$ $(eV_{g3})_{min}$	$n_2(\infty)$ at $(V_{g3})_{min}$	$n_3(\infty)$ at $(V_{g3})_{min}$
1.0	**1.25**	**0.49028**	**0.50797**	**0.49203**
0.5	**0.75**	**0.49028**	**0.50797**	**0.49203**
-0.5	**-0.25**	**0.49028**	**0.50797**	**0.49203**
-1.0	**-0.75**	**0.49028**	**0.50797**	**0.49203**

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خصائص نقل الالكترون لكيوبت مقترن بترانزستور الالكترون المفرد: ضبط مستويات طاقة الكيوبت

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الخلاصة

في هذا البحث تم تقديم معالجة نظرية لدراسة نقل الإلكترون لنظام مكون من جزئين أساسيين مقترنين هما مفتاح عنصر الحاسبة الكمية المتمثل بالكيوبت والكاشف. الأنموذج الحسابي تضمن اشتقاق لمعادلات الحركة المعتمدة على الزمن للنظام قيد الدراسة. وجدنا علاقات خاصة بتغير اعداد الإشغال لنقطتي الكيوبت والنقطة الكمية التابعة لترانزستور الإلكترون المفرد مع الزمن بالإضافة الى التيار الذي يسري من القطب الايسر. حصلنا على قياس كمي مضبوط خلال عمليات التهيئة والمعالجة التي يقصد بها تهيئة النظام ومعالجته قبل بدء عملية القياس وخلال التحكم بالمعاملات، المعاملات المهمة ترتبط بالتركيب الالكتروني للجهاز. من المهم ان نستخدم فولتية البوابة الذي ينفق خلال مستويات طاقة الكيوبت.

الكلمات المفتاحية: الكيوبت, ترانزستور الالكترون المفرد, نقل الالكترون, الحاسبة الكمية.