Analysis of the mutual inductive and capacitive connections and tolerances of memristor's parameter's of a memristor memory matrix

Valeri Mladenov
Dept. of Theoretical Electrical Engineering
Technical University of Sofia
Sofia, Republic of Bulgaria
E-mail: valerim@tu-sofia.bg

Stoyan Kirilov
Dept. of Theoretical Electrical Engineering
Technical University of Sofia
Sofia, Republic of Bulgaria
E-mail: s_kirilov@tu-sofia.bg

***Abstract* — In this paper the mutual inductive and capacitive connections and tolerances of memristor's parameter's of a memristor memory matrix is investigated. An equivalent circuit of three neighboring memristors of a memory matrix with complicated mutual capacitive and inductive connection is presented. Then the memristor's own parasitic capacitance and inductance are described. The mutual capacitances between the rims of the memory matrix are calculated. Two possible values of the coefficient of magnetic coupling between the memristors are used. A SIMULINK model of the circuit of three neighboring memristors is developed. The simulation is made at pulse mode with 3 GHz actuating voltages. The main result is that the parasitic parameters do not strongly affect the memristor voltage drops at frequencies up to 3 GHz. However the tolerances of the memristor parameters have stronger effect on the circuit characteristics. Finally, some concluding remarks associated with the magnetic and capacitive influence between the memristors of a memristor memory matrix are given.**

Keywords—titanium-dioxide memristor; parasitic parameters; mutual inductance; memristor characteristics

I. INTRODUCTION

One of the most important properties of the memristor is to memorize the amount of charge which has passed through it [2, 3, 14]. Many analysis and simulations on this nonlinear element have been made in last few years [4, 7, 8]. The main properties and the operation of Williams's memristor have been presented [5, 9, 12]. In the literature a few types of memristors as polymeric memristor, nitride memristors and others have been described [1, 6, 13]. Some physical relationships between the basic electrical quantities of the memristor have been shown in the literature [8, 10, 11]. The titanium-dioxide memristor matrix as an integrated circuit has mutual capacitances and inductances between the memristor cells. These parameters are dependent of the memristor chip size and the position of the cells [6, 7, 8, 10]. In the papers published no data on this topic have been found. The main purpose of this paper is to propose adequate substituting circuit with three memristors connected each other with mutual inductance and capacitance and a suitable SIMULINK model for further analysis.

In Section II an equivalent substituting circuit of the three neighboring memristors is proposed. The SIMULINK model of the memristor as a building block of the next circuit model is presented in Section III. The SIMULINK model of the whole circuit investigated and the simulation results realized are given in Section IV. The concluding remarks are presented in Section V.

II. EQUIVALENT SBSTITUTING CIRCUIT OF THREE NEIGHBOURING MEMRISTORS CONNECTED WITH MUTUAL CAPACITIVE LINKS OF A MEMRISTOR MEMORY MATRIX

The equivalent scheme of the three nearly placed on a matrix memristors with mutual inductive and capacitive connections is presented in Fig. 1. The capacitors C_1, C_2 and C_3 have value of 3.10^{-16} F and present memristor's own parasitic capacitances. The parameters L_1, L_2 and L_3 are the parasitic inductances of the memristors and have values of 9,4 nH. The coefficients of mutual inductances M_{12}, M_{13} , M_{23} are almost equal to each of inductances because of the embracement of the magnetic flux induced by the neighboring rims from the wires. Their values are 8,5 nH.

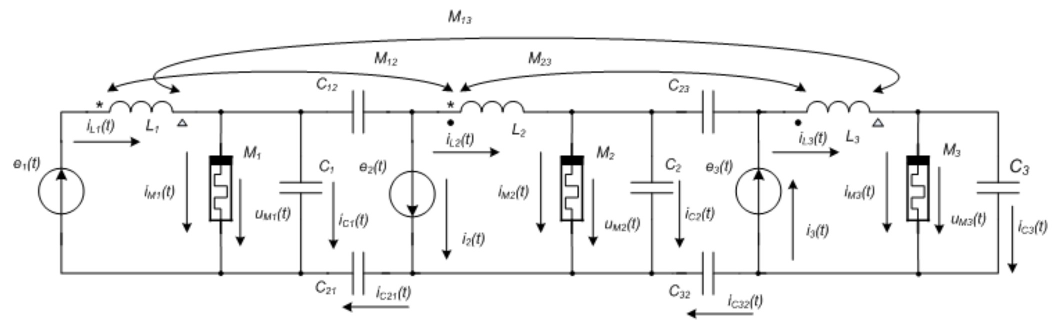

Fig. 1. Equivalent circuit of three neighboring memristors of a memory matrix with mutual capacitive connection

The mutual capacitances C_{12}, C_{21}, C_{23}, C_{32} are calculated as a capacitance of a plane capacitor. They are due to the electric influence between the nearest parallel platinum rims of the memristor memory matrix. Their values are 0,007 *pF*.

III. SYNTHESIS OF A SIMULINK MODEL OF A MEMRISTOR CELL IN THE MEMORY MATRIX

Each of the memristors in the circuit investigated is presented with linear ionic drift model. The relationship between the memristor current *i* and the voltage drop across it *u* is shown using Eq. (1):

$$i(t)=\frac{u(t)}{R_{OFF}\sqrt{\left(1-\frac{q(t_0)}{Q_D}\right)^2-\frac{2\eta}{Q_D R_{OFF}}\int u(t)dt}} \qquad (1)$$

The quantity $q(t_0)$ is the initial amount of charge memorized in the memristor cell. The resistance of the memristor in opened state is denoted with R_{OFF}. The coefficient η represents the polarization of the memristor with respect of the initial sign of the voltage applied across the element. When the memristor is forward biased the positive potential is applied to the anode of the memristor and the coefficient η is equal to 1. When the element is reverse biased the positive potential is applied to the cathode of the memristor and then the coefficient η is equal to -1. The maximal amount of charge that could be memorized in the memristor cell is denoted with Q_D:

$$Q_D=\frac{D^2}{\mu_v R_{ON}} \qquad (2)$$

The quantity *D* represents the length of the memristor, μ_v is the mobility of the charge carriers and R_{ON} is the resistance of the memristor in closed state. The SIMULINK model of the memristor cell, based on Eq. (1) is shown in Fig. 2. The coefficient η is determined automatically in the beginning of the simulation. For this purpose a short positive impulse is multiplied by the sign of the initial memristor voltage drop. After integration and determining the sign of the signal it is equalized to the coefficient η. The initial charge of the memristor is 5 % of the maximal charge of the memristor that could be accumulated in it.

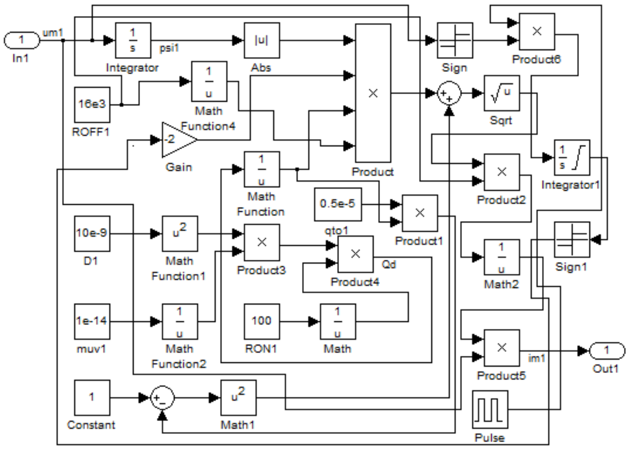

Fig. 2. SIMULINK model of a memristor cell

IV. SYNTHESIS OF A SIMULINK MODEL OF THE WHOLE MEMRISTOR CIRCUIT INVESTIGATED AND PRESENTATION OF THE SIMULATION RESULTS AT IMPULSE MODE

The SIMULINK model of the circuit investigated is presented in Fig. 3. This circuit will be used also for analysis of the equivalent scheme when the three memristors have manufacture tolerances of their basic parameters. The voltage sources produce rectangular pulse signals with frequency of 3 *GHz* and magnitude of 1 *V*. The model of the circuit presented in Fig. 1 is made with respect to the structure of the circuit and using the method for investigating of electrical circuits with the branch currents. The simulation is made using Bogachi – Shampine integration algorithm for solving the differential equations of the complicated nonlinear electrical memristor circuit.

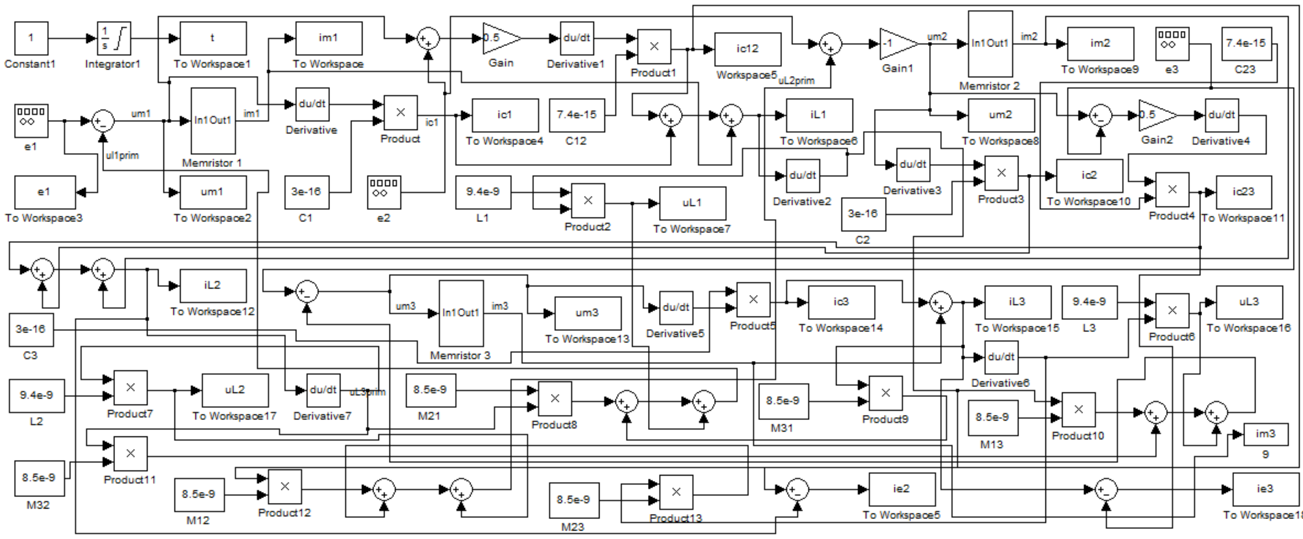

Fig. 3. SIMULINK model of the equivalent circuit of three neighboring memristors

In what follows the main results of the simulation made in MATLAB environment are presented. The time diagrams of source voltage e_1 and the memristor voltage drop over the first memristor u_{m1} are shown in Fig. 4. The diagrams of the second and third memristor voltage drops have similar form. It is obvious that there are transient processes with pseudo-periodic character. The ricochets have very high values but there are no losses of information.

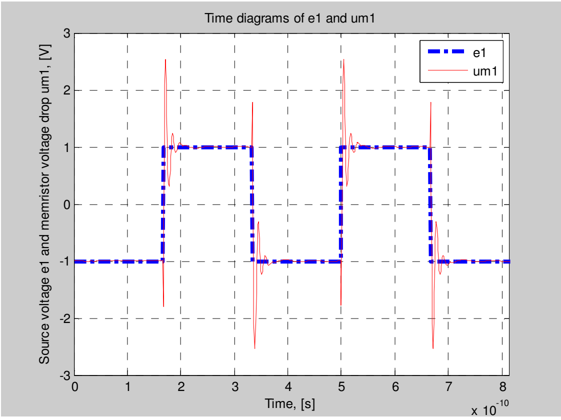

Fig. 4. Time diagrams of the source voltage $e_1(t)$ and $u_{m1}(t)$

The time diagram of memristor current i_{m3} is presented in Fig. 5. It has graphical form similar to the shape of the memristor voltage drop u_{m1}.

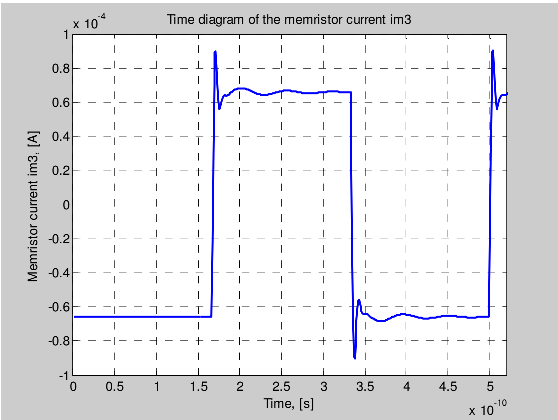

Fig. 5. Time diagram of the memristor current i_{m3}

The time diagram of the source current i_{e1} is presented in Fig. 6. It is interesting that the magnitude of the current pulses is 10 times bigger than the magnitude of the memristor current i_{m1}. That is due to the presence of capacitive currents flowing between the neighboring rims of the memristors. The time diagrams of these capacitive currents are shown in Fig. 7.

The time diagrams of the memristor current i_{m1} at different resistances R_{ON} are presented in Fig. 8. The two currents investigated almost coincide. That means that the alteration of the memristor resistance in closed state in very wide range (about 50 %) do not affect the current. But the resistance R_{ON} is one of the quantities that determine the whole amount of charge that could be memorized in the memristor cell. When the quantity Q_d decreases the memristor needs less time and current intensity to pass over from opened to closed state and vice versa.

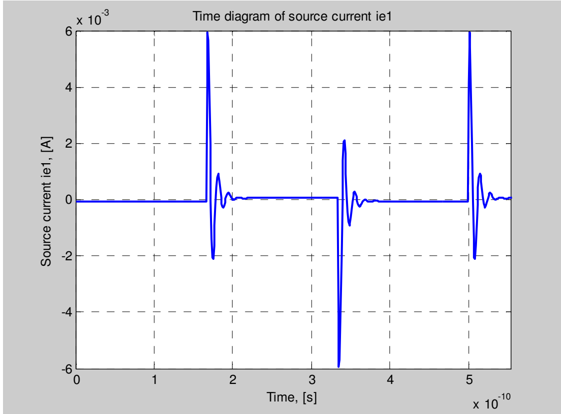

Fig. 6. Time diagram of the source current i_{e1}

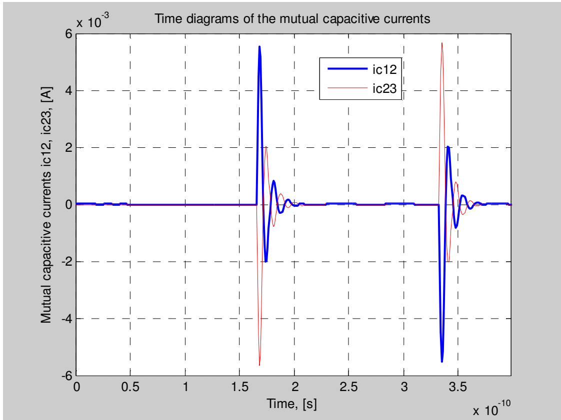

Fig. 7. Time diagrams of the mutual capacitive currents

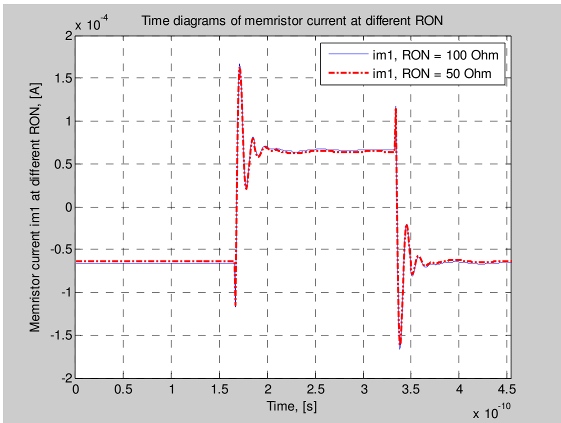

Fig. 8. Time diagrams of the memristor currents at different R_{ON}

The time diagrams of memristor current at different resistances at opened state R_{OFF} are presented in Fig. 9. It is obvious that the changes in this parameters with 50 % strongly affect the magnitude of the memristor current pulses. When the value of R_{ON} remains constant but R_{OFF} increases the ratio between R_{OFF} and R_{ON} increases too. Then the current pulses have less distortions but the switching properties of the element are decreased.

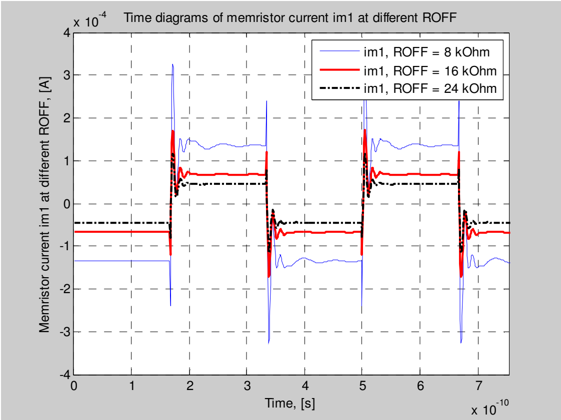

Fig. 9. Time diagram of memristor current i_{m1} at different R_{OFF}

The time diagram of whole sourse power s_1 is presented in Fig. 10. It is clear that there is a little permanent component in the power due to the active power consumed by the memristor. In some time intervals there is power pulses due to the action of the reactive parasitic elements – mainly due to the mutual capacitances and inductances.

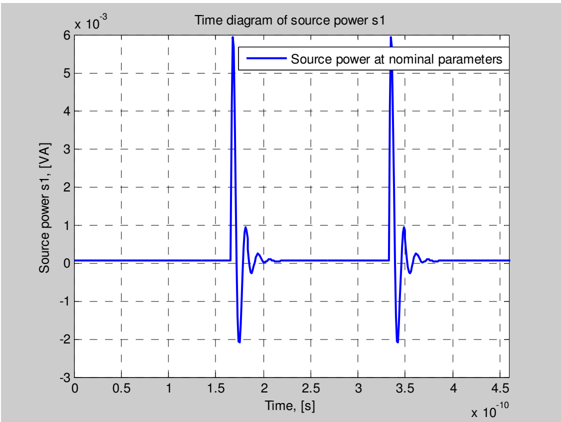

Fig. 10. Time diagram of the source power s_1

The time diagram of the power consumed by the memristor M_1 is shown in Fig. 11. In the duration of the plateaus of the pulses the power has constant value but when there is transient process the power increases rapidly.

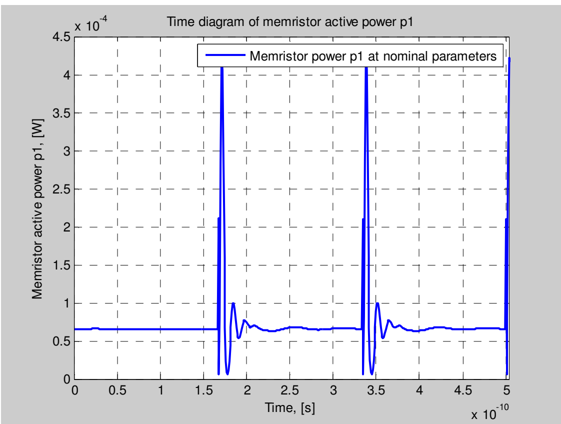

Fig. 11. Time diagrams of memristor active power p_1

V. Conclusions

From the results presented above it is obvious that the parasitic own parameters and the mutual inductances and capacitances slightly affect the parameters and the characteristics of Williams's memristor. The influence of the parasitic mutual parameters is mainly on the fronts of the pulses. The transient process has pseudo-periodic character and the first ricochet has very high magnitude. At frequencies up to 3 GHz there are no losses of information and the pulses of logical zero and logical one have its nominal values. The changes in parameters of the memristors have stronger effect on the characteristics of the circuit investigated. The changes of R_{ON} very slightly affect the current pulses. The altering of parameter R_{OFF} has effect on changing of the magnitude of current pulses and the switching properties of the memristors. The result of presented investigations is that the changes of the ionic mobility in very high interval do not affect the characteristics of the memristor circuit at high frequencies.

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