MEMCAPACITOR MODELING IN MICRO-CAP

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ABSTRACT:

The SPICE model of memcapacitor is developed and implemented in Micro-Cap 10. The model is related to the charge-controlled memcapacitor, the capacitance of which is controlled by the amount of electric charge conveyed through it. The model implementation is in the form of macro file, enabling a selection of several types of window functions for modeling the boundary effects in nano-components. Results of transient analysis clearly show basic fingerprints of the memcapacitor.

Keywords: Memcapacitor, memristor, SPICE, constitutive relation

1 INTRODUCTION

In 1971, Leon Chua introduces the so-called memristor (= memory resistor) to the modern circuit theory [1]. 37 years later, the solid-state memristor was fabricated in HP laboratories [2]. It led to a sharp rise of interest in memristive systems [3] in both the technological and the application domains. In December 2008, Chua proposes other hypothetical “mem-elements” from the nano-world, the memcapacitor and meminductor. Since all the above elements are not currently available as off-the-shelf devices, the role of modeling them increases, particularly with the aim of implementing such models in the current programs for circuit simulation.

One of the first SPICE models of memristor and memcapacitor were described in [4] and [5], respectively, starting from the general methodology given in [6]. These models were implemented in PSpice.

In this paper, the model of the memcapacitor, described in [5], was extended and implemented in Micro-Cap 10, the worldwide used circuit simulation program [7], which enables, among other things, the so-called interactive analyses. The model, described for the first time in [5] by the authors of this paper, is extended by virtue of new features, which can offer Micro-Cap 10 in comparison with OrCAD PSpice program. The model implementation is in the form of macro file, enabling a selection among Joglekar, Biolek, and user-defined window functions for modeling the so-called boundary effects in the nano-components [4], [8], [9]. The model is related to the so-called charge-controlled capacitor, the capacitance of which is controlled by the amount of electric charge conveyed through it. This charge affects the width of the dielectric. The results of transient analysis clearly show three basic fingerprints of the memcapacitor: unambiguous constitution relation [5], the hysteretic effect in the Coulomb-Volt characteristic, and the identical time instants when the voltage and charge waveforms cross zero levels.

2 SPICE-ORIENTED MEMCAPACITOR MODEL

The charge-controlled memcapacitor is characterized by the following port equation (PE) and first-order state equation (SE) [5]:

$$\text{PE: } v = D_M(x,q,t)q\,,\ \text{SE: } \dot{x} = \frac{d}{dt}x = f_q(x,q,t)\,, \quad (1)$$

where v and q are electric voltage and charge of the memcapacitor, $D_M = 1/C_M$ is an inverse memcapacitance and C_M is a memcapacitance, and x is an internal state variable of the memcapacitor. Charge-controlled memcapacitor is a special type of time-varying capacitor, (inverse) capacitance of which depends on the quantities indicated in Eq. (1).

The well-known relation between the voltage and current of the time-varying capacitor

$$v(t) = D_M(t)[C_M(0)v(0) + \int_0^t i(\xi)d\xi] = [C_M(0)v(0) + \int_0^t i(\xi)d\xi]/C_M(t)\,, \quad (2)$$

where $v(0)$ and $C_M(0)$ are initial voltage and capacitance of the memcapacitor at time $t = 0$, can be a starting point of the SPICE model, schematically described in Fig. 1.

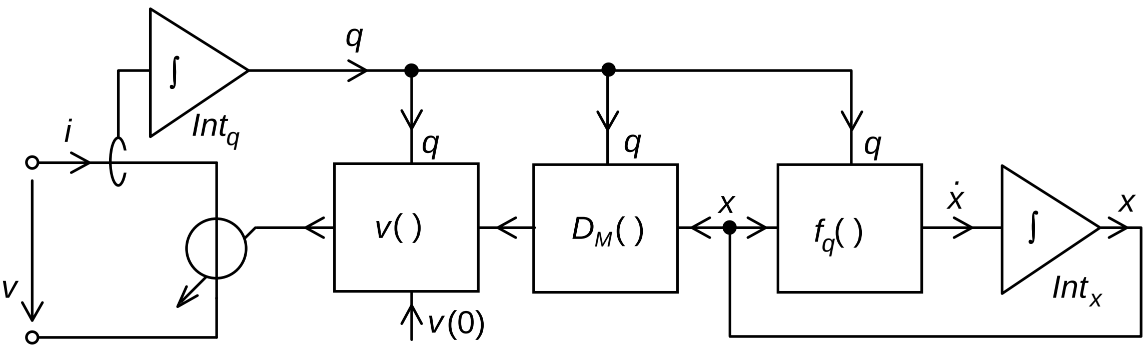


Fig. 1: Block diagram of the SPICE model of charge-controlled memcapacitor

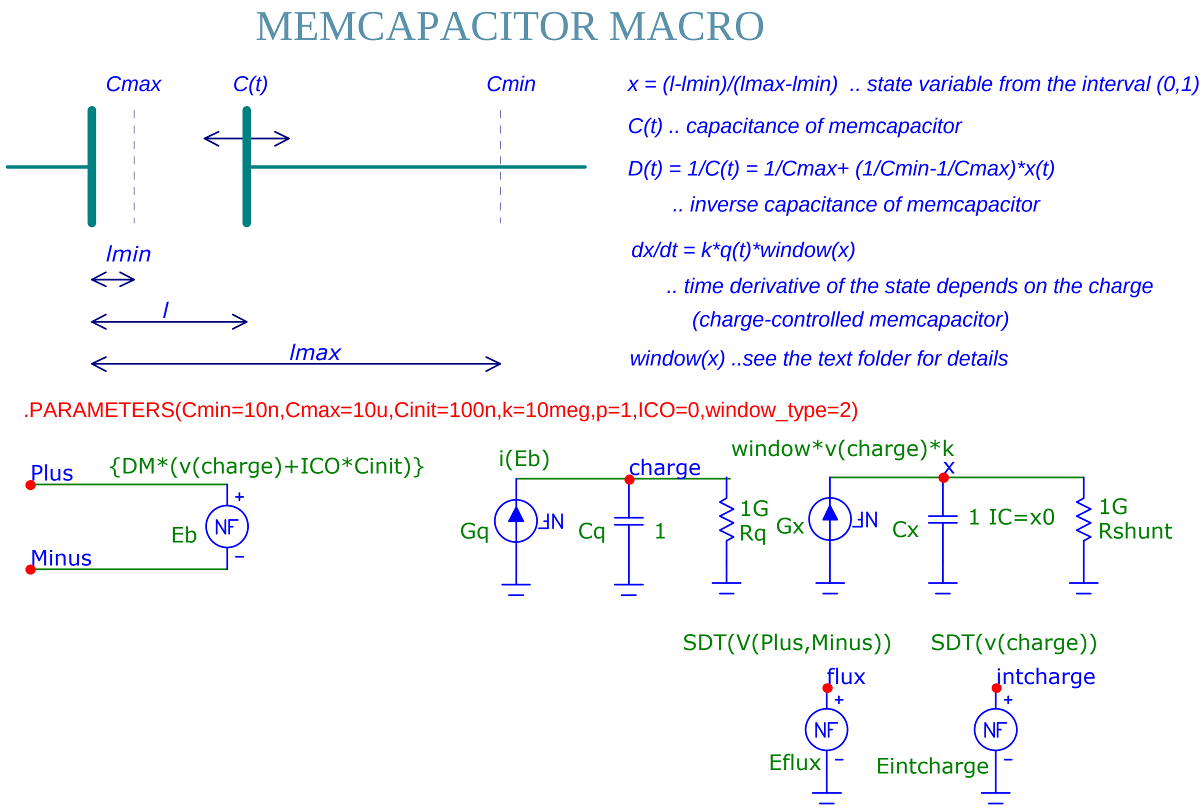
Equation (2) is modeled via a voltage source which is controlled from the block labeled as "*v*( )". The input data of this block are time-domain integral of current, i.e. charge q, the initial voltage $v(0)$, and the inverse memcapacitance as a function of charge and state x. The state variable is computed from the differential SE (1) which is modeled using the block of nonlinear function f_q and the integrator Int_x.

The above general model can be used for modeling charge-controlled memcapacitors of arbitrary nature. The contents of the blocks D_M( ) and f_q( ) depend on physical principle of concrete memcapacitor.

The following Section describes a sample example of memcapacitor which is included in the Micro-Cap 10 release [7].

3 MEMCAPACITOR MODEL IN MICRO-CAP 10

The contents of the Micro-Cap macro file of the memcapacitor is shown in Fig. 2. The schematic of a capacitor with moving right-side plate is accompanied by the basic notes how the capacitance depends on the position of this plate. The state variable x is derived from this position such that it can vary within the interval (0, 1). The state equation from [5] is considered. It contains the window function for modeling boundary conditions [4-6], [8-9].

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*The two lines below define initial state of the memcapacitor
*and the controlling law of its capacitance.
*These lines should be modified for another physical implementation of memcapacitor.
.define x0 ((1/Cinit-1/Cmax)/(1/Cmin-1/Cmax))
.define DM (1/Cmax+(1/Cmin-1/Cmax)*Xlimited)
*Window functions
.IF window_type=0
.define window sqrt(V(x)-(V(x))^2);user-defined window
;replace this sample expression by your model
.ELIF window_type=1
.define window (1-(2*Xlimited-1)^(2*p));Joglekar window
.ELIF window_type=2
.define window (1-(Xlimited-(1-sgn(V(plus,minus)))/2)^(2*p));Biolek window
.ENDIF
.define Xlimited (if(V(x)<0,0,if(V(x)>1,1,V(x))));V(x) limiter
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Fig. 2: Complete memcapacitor macro

The current source G_q together with the one-farad capacitor C_q and shunting resistor R_q for providing DC path to ground model the integrator Int_q from Fig. 1 for transforming the memcapacitor current to charge. The charge value is available in the form of the voltage at node “charge”. The current source G_x together with C_x and R_{shunt} model the integrator Int_x for evaluating the state equation (1). The auxiliary voltage sources Eflux and Eintcharge serve for computing the time-domain integrals of voltage (i.e. flux) and charge (i.e. TIQ, time-domain integral of charge). These quantities, which are important constitutive variables of the memcapacitor, can be then easily visualized in transient analysis results.

4 EXAMPLE OF ANALYSIS

Results of transient analysis of memcapacitor driven by pulse-waveform voltage source with the internal resistance of 1 mΩ are presented in Fig. 3.

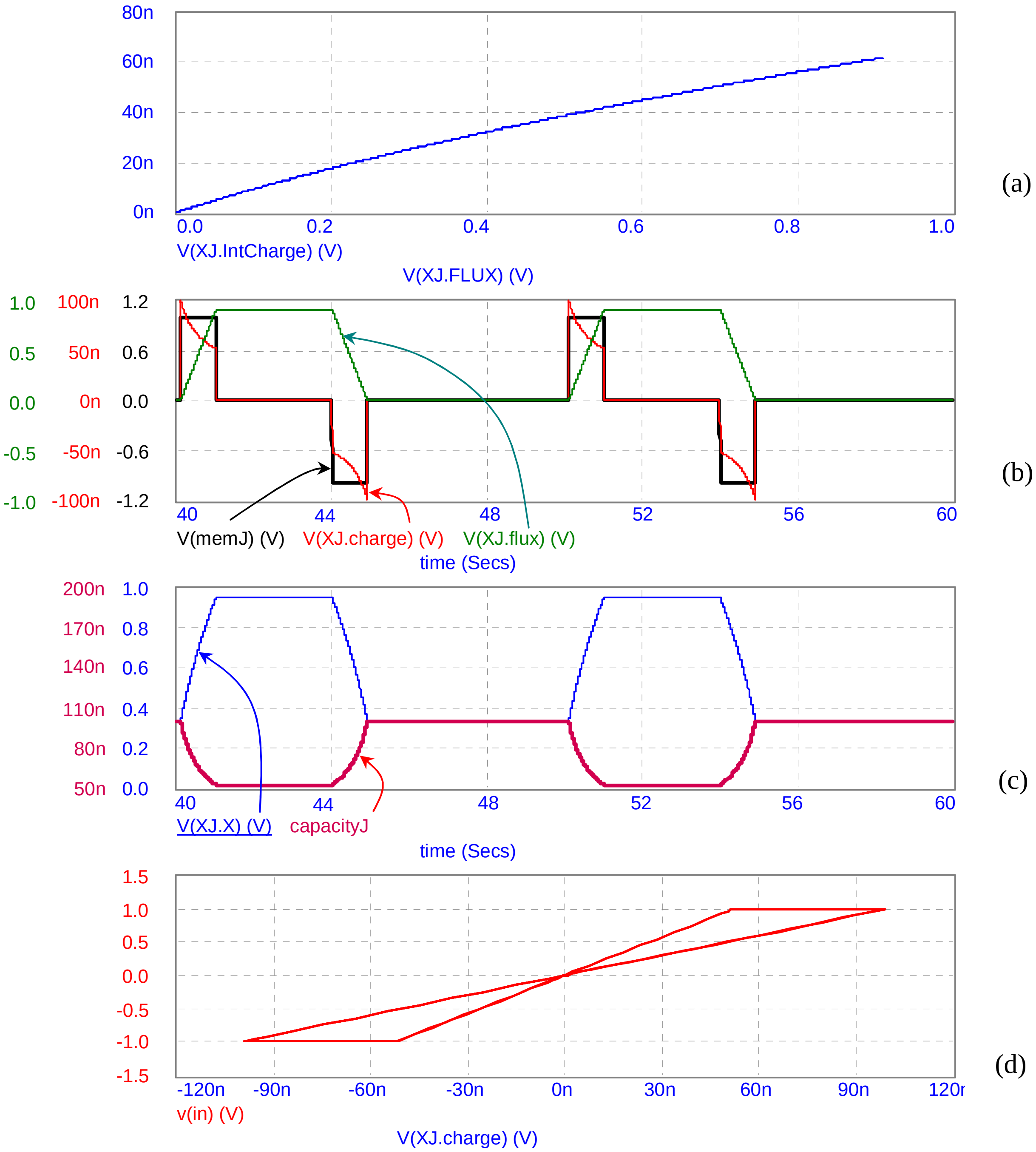

Fig. 3: Transient analysis of memcapacitor excited by pulse voltage source: (a) constitutive relation, (b) waveforms of input voltage V(memJ), charge V(XJ.charge), and flux V(XJ.flux), (c) time evolution of state variable V(XJ.X) and memcapacitance, (d) Volt-Coulomb hysteretic characteristic

The memcapacitor has the following parameters: C_{min} = 50 nF, C_{max} = 200 nF, C_{init} = 100 nF, ICO = 0, p = 10, Joglekar window. The 900 ms width and 10 ms rise/fall time bipolar ±1V pulses in Fig. 3 (b) cause the pulse waveforms of the charge which modifies the position of the plate of the memcapacitor. The corresponding variation of the memcapacity is shown in Fig. 3 (c). The following Fig. 3 (d) depicts the Volt-Coulomb characteristic with typical pinched hysteresis loop.

5 CONCLUSIONS

The memcapacitor model in Fig. 1 is quite general. Together with Eqs. (1) and (2), it can be used for modeling memcapacitor, the capacitance of which is controlled via various physical mechanisms.

6 ACKNOWLEDGMENTS

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