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Pathological Element-Based Memelement Circuits

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Abstract – This study presents the modelling of the pathological elements based memelements. More than forty years ago, Chua predicted the existence of memristor (memory+resistor) which is the fourth fundamental passive circuit element. In 2008, Hewlett Packard (HP) researchers demonstrated the physical implementation of the new element which provides the missing relationship between the magnetic flux (ϕ) and the electric charge (q). Memelements are gaining popularity among the researchers because of the some unique behaviors. Many memelements are designed using active circuit elements because of their advantages such as low energy consumption, wide band width, and compatible with nonlinear circuit element design. Pathological elements are gaining the popularity because of their capability of modelling active circuits. All presented memelements consist of transistors and active circuit elements. In this study, pathological circuit equivalents of memelements are presented.

Keywords –Memelements, pathological elements, circuit modelling.

I. Introduction

Resistors, capacitors and inductors as passive circuit elements connect the relationships between voltage-current, charge-voltage and flux-current respectively. But the connection of the flux and charge is missing until Chua's original paper [1]. Chua called the new circuit element, memristor (memory+resistor), which provides the missing relationship between flux and charge [1].

But, Chua's paper [1] didn't attract researchers' attention until 2008 [2]. Memristor is not implemented until this year because of the lack of the advanced technology. Researchers interested in the effect of the memristor on the classical designed circuits. That is why, emulator circuits were designed [3-8] because of the fact that the physical implemented memristor did not obtained easily.

All memelement circuits consist of transistors and active circuit elements. But there is no detailed mathematical studies how the memristor exhibit its hysteresis curve and how we can control or improve mathematically its voltage-current behavior depend on the material structure.

From this point, pathological elements provide unique advantages to obtain and improve the transfer function of memelements. The operational amplifier (Opamp) is realized from a nullor when one of the norator terminals is connected to the ground. The nullor element provides ability to model active devices [9-10]. Sánchez-López introduced grounded pathological elements based fully differential active device models [11]. In this study, pathological elements based memelement has been presented.

II. Pathological Elements

Various pathological elements such as voltage mirror and current mirror become important to avoid the use of the resistors in the nullor representation of building block. The nullator and narrator are one port elements and defined by V=I=0, and V, I are arbitrary, respectively. Voltage mirror is a two port network element and defined by,

$$V V_1 \square\square {}_2 \tag{13}$$

$$I_1 \square \square I_2 0 \tag{14}$$

The circuit symbol of the voltage mirror is shown in Fig.1.

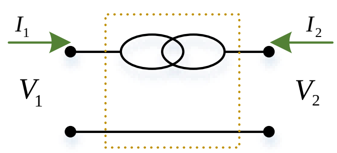
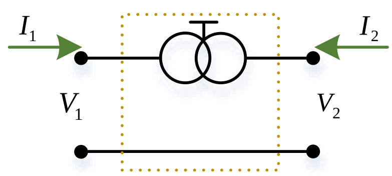


Fig.1 The voltage mirror symbol.

The all voltages and currents for current mirror are arbitrary.

$$\begin{array}{c} V\ and V \\ arearbitrary_1 \qquad {}_2 \\ I_1 \square I_2 realsoarbitrary \end{array} \tag{15}$$



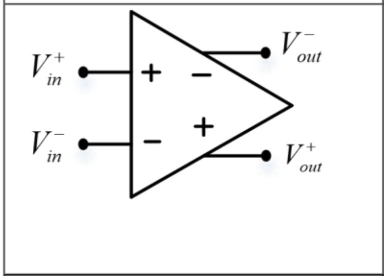
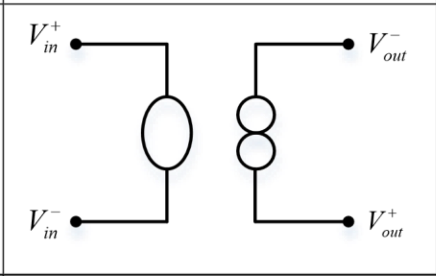
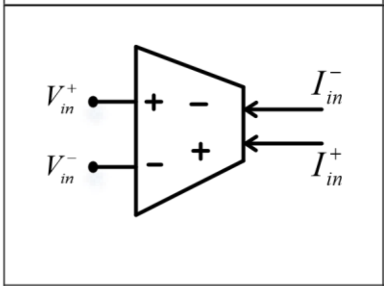
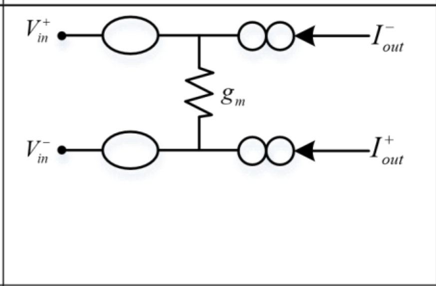
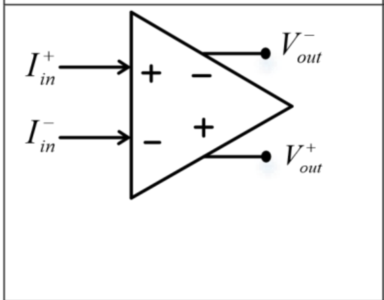
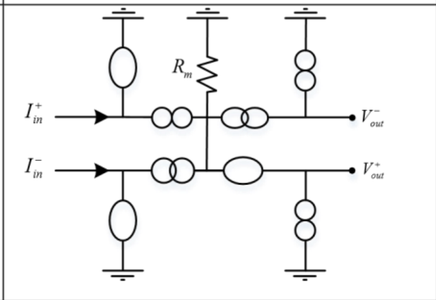
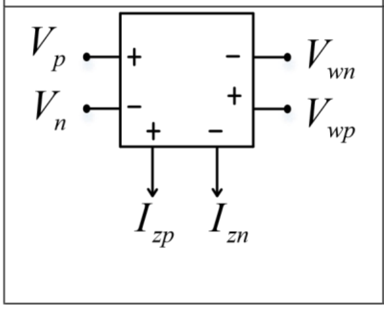
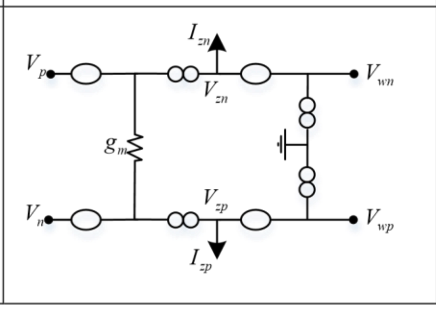
Active Device	Behavior Equation	Pathological Element-Based Model	Name
	$V_{out}^{+} - V_{out}^{-} = A_v\left(V_{in}^{+} - V_{in}^{-}\right)$		Fully-Differential Operational Amplifier **(FD-Opamp)**
	$I_{out}^{+} - I_{out}^{-} = g_m\left(V_{in}^{+} - V_{in}^{-}\right)$		Fully-Differential Operational Transconductance Amplifier **(FD OTA)**
	$\begin{bmatrix} V_{in}^{+} \\ V_{in}^{-} \\ V_{out}^{+} \\ V_{out}^{-} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ R_m & -R_m \\ -R_m & R_m \end{bmatrix} \begin{bmatrix} I_{in}^{+} \\ I_{in}^{-} \end{bmatrix}$		Fully-Differential Operational Transresistance Amplifier **(FD OTRA)**
	$\begin{bmatrix} I_{zp} \\ I_{zn} \\ V_{wp} \\ I_{wn} \end{bmatrix} = \begin{bmatrix} g_m & -g_m & 0 & 0 \\ -g_m & g_m & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_{zp} \\ V_{zn} \end{bmatrix}$		Fully-Balanced Voltage Differencing Buffered Amplifier **(FB-VDBA)**

Fig.2 The current mirror symbol. The nullor which is a two port network element is shown in Fig.3. and consists of an input nullator and an output norator. The voltage and current of a nullator and norator take zero and independently arbitrary value, respectively. *a* *c*

b *Nullator* *Norator* *d*

Fig.3 The nullor element [2].

The operational amplifier (Opamp) is realized from a nullor when one of the norator terminals is connected to the ground. The nullor element provides ability to model active devices [9-10]. Transistors which can be operated in saturation region, linear region and subthreshold region have crucial importance in all memelement circuit design. Transistors are not operated in only one region in circuit applications, sometimes operated in both saturation and linear region or other probabilities. In this situation the analyses of transistors become very hard especially operated in subthreshold region. Therefore the pathological models of transistors provide important advantage to analyses the transistor based circuit. The MOS transistor was modeled with nullor element as shown in Fig.4. Active circuit elements have elusive properties to design emulator or new circuit components. Because memristor is passive circuit elements and cannot be modeled using only passive circuit elements.

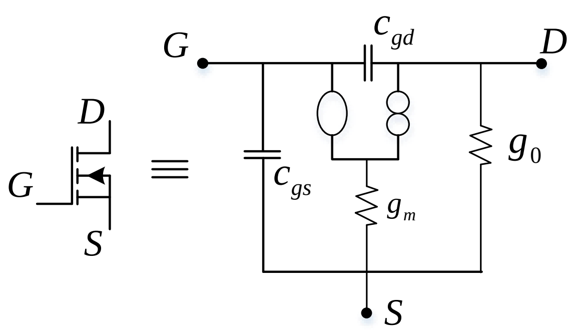


Fig.4 The MOS transistor model using nullor [12].

At this point, pathological elements occupy very important place. Sánchez-López introduced grounded pathological elements based fully differential active device models as shown in Fig.5. [11].

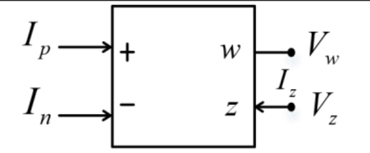
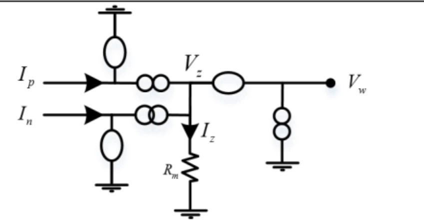
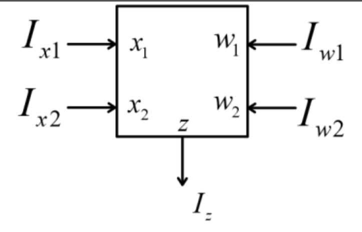
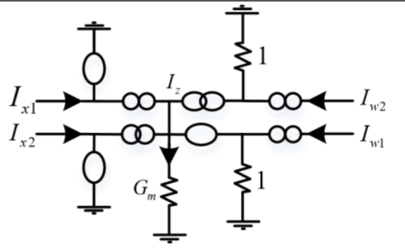
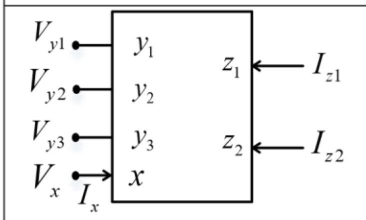
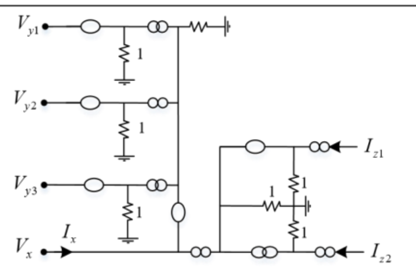
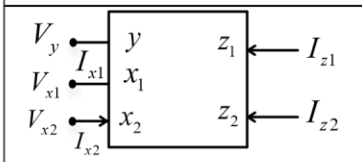
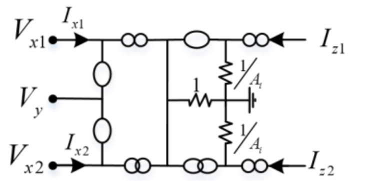
	$\begin{bmatrix} Iz \\ Vw \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 \\ 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_z \\ I_p \\ I_n \end{bmatrix}$		Current-Differencing Buffered Amplifier (**CDBA**)
	$\begin{bmatrix} I_z \\ I_{w1} \\ I_{w2} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 0 & G_m \\ 0 & 0 & -G_m \end{bmatrix} \begin{bmatrix} I_{x1} \\ I_{x2} \\ V_z \end{bmatrix}$		Current Differencing Transconductance Amplifier (**CDTA**)
	$\begin{bmatrix} V_x \\ I_{z1} \\ I_{z2} \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 1 \\ 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_{y1} \\ V_{y1} \\ V_{y3} \end{bmatrix}$		Differential Difference Current Conveyor (**DDCC±**)
	$\begin{bmatrix} V_{x1} \\ V_{x2} \\ I_{z1} \\ I_{z2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ A_i & -A_i & 0 \\ -A_i & A_i & 0 \end{bmatrix} \begin{bmatrix} I_{x1} \\ I_{x2} \\ V_y \end{bmatrix}$		Differential Current Conveyor (**DCCII±**)

Fig.5 Pathological element-based active circuit elements [11].

A. Circuit I

The memristor circuit which is based on DDCC active circuit element was designed by Yesil et al. [6], this circuit has semi-floating characteristics and strong voltage-current hysteresis curve. The schematic of the circuit is shown in Fig. 6 when rearranged using the pathological circuit elements.

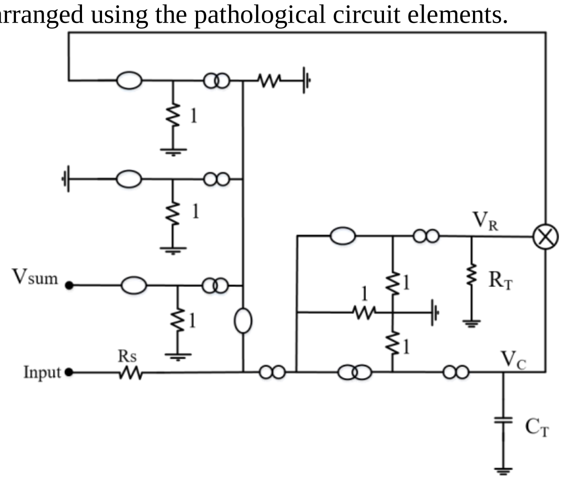
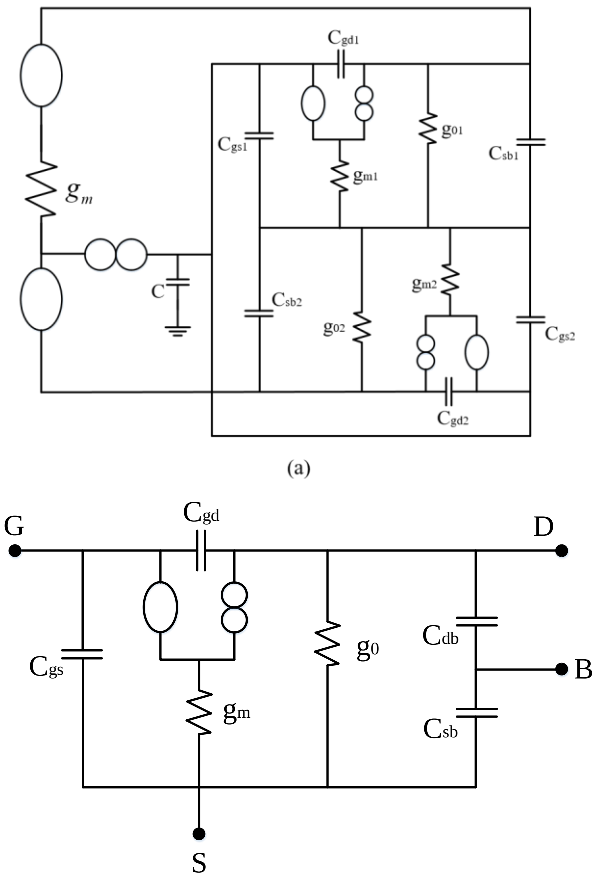


Fig. 6 DDCC based memristor emulator which is presented by Yesil and coworkers [16].

B. Circuit II

Babacan and Kacar designed fully floating memristor emulator based on OTA active circuit element [7], and its pathologic circuit element based new schematic is shown in Fig.7a. The bulk terminals were connected to the drain terminals of the transistors that is why the pathological element based MOS transistor model [12] are rearranged using bulk terminals as shown in Fig.7b. All active circuit element based circuits lack of the detailed analyses for this reason their pathological equivalent is presented. The detailed analyses are able to be done when using new forms. Because all circuits can be perform memristive effect but researchers didn’t control the memristive effect when look at the mathematical equations or transfer function. And also the active circuit element based emulators can be improved when all analyses are known.



(a)

(b)

Fig.8 a) Fully floating memristor emulator based on OTA [7] and b) Pathological element equivalents of the MOS transistor [12].

III. CONCLUSION

In this study, pathological equivalents of the memristor emulators have been referred. Memristors which have nonlinear characteristics are new passive circuit element and there are several techniques to model memristive characteristics. Especially active circuit element based memristor emulators are more successful among all emulators. Classical nodal analyses of active circuits are difficult so all presented active circuit element based memristor emulators are lack of the detailed mathematical analyses. Therefore, the detailed mathematical analyses are essential to analyse and improve the memristor and memristor based circuits. That is why pathological circuit elements become significant candidate to analyse, solve and improve the memristive elements and memristor based circuit characteristics.

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