Singapore Journal of Scientific Research 1 (2): 149-163, 2011
ISSN 2010-006x / DOI: 10.3923/sjsres.2011.149.163

Nodal Admittance Matrix and Pathological Realization of BOOA, DDA, DDOFA and DDOMA

Ahmed M. Soliman
Department of Electronics and Communications Engineering, Cairo University, Giza 12613, Egypt

ABSTRACT

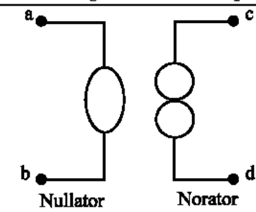
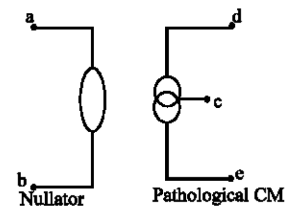
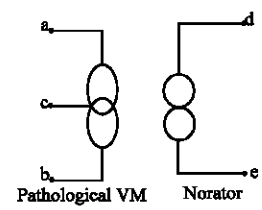
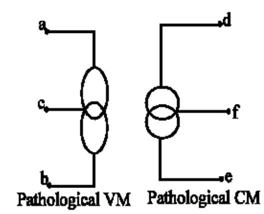
This study aimed to provide addition to the work by introducing the NAM equations as well as the pathological realizations of four important active building blocks. The four active building blocks are the Balanced Output Op Amp (BOOA), the Differential Difference Amplifier (DDA), the Differential Difference Operational Floating Amplifier (DDOFA) and the Differential Difference Operational Mirror Amplifier (DDOMA). The importance of the pathological realizations in the generation of alternative ideally equivalent realizations of an active building block is illustrated by an example on the BOOA.

Key words: Nullator, norator, voltage mirror, current mirror, operational amplifier, nodal admittance matrix, pathological realizations

INTRODUCTION

In the circuit synthesis method proposed by Haigh *et al*. (2005) and based on NAM expansion it is necessary to represent each passive and active circuit element by a NAM equation. The NAM stamp for representation of a nullor having a nullator connected between two nodes and the norator connected between two alternative nodes is derived by Haigh *et al*. (2005) based on a Voltage Controlled Current Source (VCCS) representation of the non-ideal nullor. The limit variables also called, the infinity variables is used by Haigh *et al*. (2006) to represent the nullor by a 2×2 NAM stamp. An alternative notation for the nullor elements which is defined as the bracket notation was also introduced by Haigh *et al*. (2005). Applications of the NAM model for the nullor using limit variables in circuit design was given in details by Haigh and Radmore (2006). Transformation method from symbolic transfer function to active-RC circuit by NAM expansion was demonstrated clearly by Haigh (2006). Recently the synthesis method based on NAM expansion using nullor elements (Haigh *et al*., 2005; Haigh, 2006) was extended to accommodate pathological mirror elements resulting in a generalized framework encompassing nullator, norator, pathological Voltage Mirror (VM) and pathological Current Mirror (CM) (Saad and Soliman, 2008b). Table 1 includes a summary of the NAM stamps using infinity parameters for the nullator-CM pair, VM-norator pair and VM-CM pair (Saad and Soliman, 2008b). The generalized NAM expansion method was used in the generation of gyrators (Saad and Soliman, 2008a; Awad and Soliman, 1999). NAM stamps and pathological representation of several types of active building blocks was given by Saad and Soliman (2010). Table 2 includes a summary of NAM stamps of the op amp and Current Op Amp (COA) (Soliman, 2009). Table 3 includes a summary of the NAM stamps of the current conveyor (CCII) and inverting current conveyor (ICCII) families (Saad and Soliman, 2008a; Soliman, 2009; Awad and Soliman, 1999). The generalized NAM expansion method was used

Table 1: NAM description of the four basic floating building blocks (Saad and Soliman, 2008a)

	NAM	Pathological element representation
Nullor	$\begin{array}{c} \\ c \\ d \end{array}\begin{array}{cc} a & b \\ \hline \infty_i & -\infty_i \\ -\infty_i & \infty_i \end{array}$	
Nullator CM pair	$\begin{array}{c} \\ d \\ e \\ c \end{array}\begin{array}{cc} a & b \\ \hline \infty_i & -\infty_i \\ \infty_i & -\infty_i \\ -2\infty_i & 2\infty_i \end{array}$	
VM-Norator pair	$\begin{array}{c} \\ d \\ e \end{array}\begin{array}{ccc} a & b & c \\ \hline \infty_i & \infty_i & -2\infty_i \\ -\infty_i & -\infty_i & 2\infty_i \end{array}$	
VM-CM pair	$\begin{array}{c} \\ d \\ e \\ f \end{array}\begin{array}{ccc} a & b & c \\ \hline \infty_i & \infty_i & -2\infty_i \\ \infty_i & \infty_i & -2\infty_i \\ -2\infty_i & -2\infty_i & 4\infty_i \end{array}$	

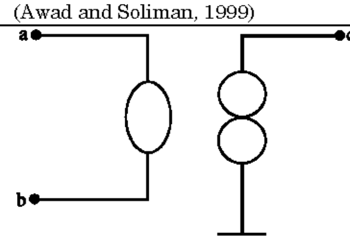
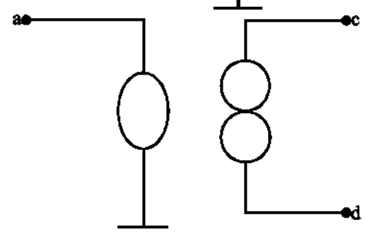
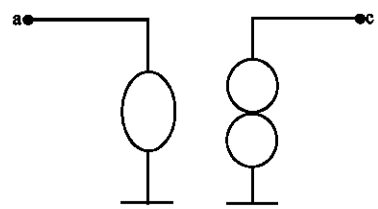
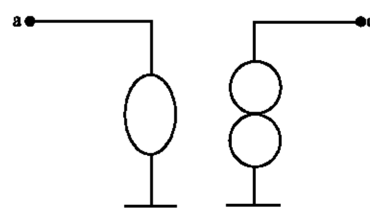
in the generation of gyrators (Saad and Soliman, 2008a). Due to the importance of the NAM in the synthesis of active RC circuits; NAM stamps of BOOA, DDA, DDOFA and DDOMA are derived in this study and their pathological realizations are also given.

BALANCED OUTPUT OP AMP (BOOA)

The fully balanced integrator introduced by Banu and Tsividis (1983) is based on using the BOOA as the active building block together with two matched MOS transistors operating in the non-saturation region and two equal capacitors. This integrator provides cancellation of the even nonlinearities introduced by the MOS transistors. Full nonlinearity cancellation using the four MOS transistor cell operating in the non-saturation region was introduced by Czarnul (1986) using also the BOOA as the active building block. The BOOA was also used in realization of a continuous time CMOS balanced filter introduced by Banu and Tsividis (1985). The BOOA was also used in the realization of the universal op amp proposed by Ramírez-Angulo and Ledesma (2006). Also most recently the BOOA has been used in the design of high-speed low-power SC circuits (Amoroso *et al*., 2010).

The symbolic representation of the BOOA is shown in Fig. 1a. In order to derive the NAM stamp of the BOOA assume that it is non-ideal and add the admittances Y_c and Y_d at the two output ports of the equivalent Voltage Controlled Voltage Source (VCVS) model as shown in Fig. 1b.

Table 2: NAM stamp of the op amp family (VOA and COA)

	NAM (Soliman, 2009)	Pathological element representation (Awad and Soliman, 1999)
VOA	$\begin{array}{c} \\ c \end{array}\begin{array}{cc} a & b \\ [\infty_i & -\infty_i] \end{array}$	
COA single input two outputs	$\begin{array}{c} \\ c \\ d \end{array}\begin{array}{c} a \\ \begin{bmatrix} \infty_i \\ -\infty_i \end{bmatrix} \end{array}$	
Single input VOA	$\begin{array}{c} \\ c \end{array}\begin{array}{c} a \\ [\infty_i] \end{array}$	
COA single input single output	$\begin{array}{c} \\ c \end{array}\begin{array}{c} a \\ [\infty_i] \end{array}$	

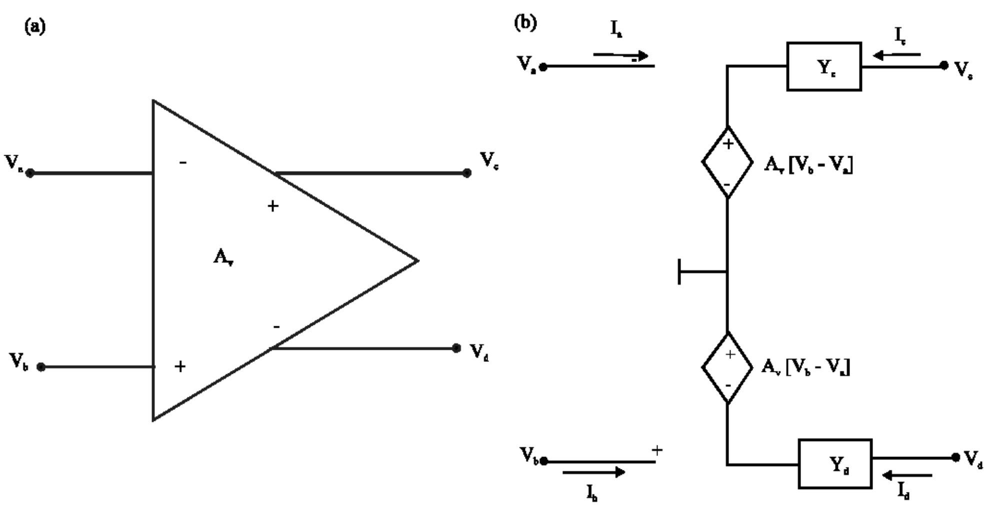
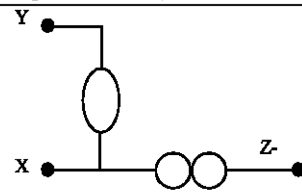
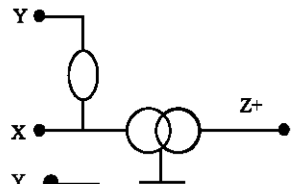
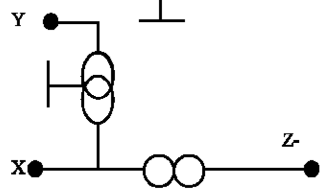
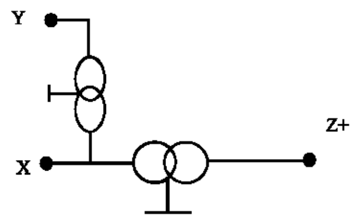


Fig. 1: (a) Symbolic representation of the BOOA and (b) Equivalent VCVS model for the non-ideal BOOA

Table 3: NAM stamp of the op amp family (VOA and COA)

	NAM (Soliman, 2009a)	Pathological element representation (Awad and Soliman, 1999)
CCII-	$\begin{array}{c} \\ X \\ Z- \end{array}\begin{array}{c} \begin{array}{cc} X & Y \end{array} \\ \begin{bmatrix} \infty_i & -\infty_i \\ -\infty_i & \infty_i \end{bmatrix} \end{array}$	
CCII+	$\begin{array}{c} \\ X \\ Z+ \end{array}\begin{array}{c} \begin{array}{cc} X & Y \end{array} \\ \begin{bmatrix} \infty_i & -\infty_i \\ \infty_i & -\infty_i \end{bmatrix} \end{array}$	
ICCII-	$\begin{array}{c} \\ X \\ Z- \end{array}\begin{array}{c} \begin{array}{cc} X & Y \end{array} \\ \begin{bmatrix} \infty_i & \infty_i \\ -\infty_i & -\infty_i \end{bmatrix} \end{array}$	
ICCII+	$\begin{array}{c} \\ X \\ Z+ \end{array}\begin{array}{c} \begin{array}{cc} X & Y \end{array} \\ \begin{bmatrix} \infty_i & \infty_i \\ \infty_i & \infty_i \end{bmatrix} \end{array}$	

The NAM equation of the non-ideal BOOA is given by:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \\ I_d \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ A_v Y_c & -A_v Y_c & Y_c & 0 \\ -A_v Y_d & A_v Y_d & 0 & Y_d \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \quad (1)$$

Setting Y_c and Y_d to their ideal values of infinity the NAM stamp of the ideal BOOA is obtained as:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \\ I_d \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ A_v \infty_1 & -A_v \infty_1 & \infty_1 & 0 \\ -A_v \infty_2 & A_v \infty_2 & 0 & \infty_2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \quad (2)$$

It is desirable to see how the ideal BOOA equations are obtained from the above NAM stamp. From Eq. 1 the following voltage matrix equation can be obtained by dividing third row by Y_c and fourth row by Y_d; thus:

$$\begin{bmatrix} \frac{I_c}{Y_c} \\ \\ \frac{I_d}{Y_d} \end{bmatrix} = \begin{bmatrix} A_v & -A_v & 1 & 0 \\ \\ -A_v & A_v & 0 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{3}$$

Setting Y_c and Y_d to their ideal values of infinity the above equation simplifies to:

$$\begin{bmatrix} 0 \\ \\ 0 \end{bmatrix} = \begin{bmatrix} A_v & -A_v & 1 & 0 \\ \\ -A_v & A_v & 0 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{4}$$

The output voltage V_c is obtained from the first equation in the above matrix as:

$$V_c = A_v\,(V_b - V_a) \tag{5a}$$

Similarly the output voltage V_d is obtained from the second equation in the above matrix as:

$$V_d = -A_v\,(V_b - V_a) \tag{5b}$$

Equation 5a and b represent the BOOA where Av is voltage gain which is very high and frequency dependent and is theoretically infinity.

DIFFERENTIAL DIFFERENCE AMPLIFIER (DDA)

The DDA was introduced by Sackinger and Guggenbiihl (1987) as a new analog building block. New CMOS realizations of the DDA and several new circuit applications were given by Zarabadi *et al.* (1992) and Huang *et al.* (1993). The symbolic representation of the DDA is shown in Fig. 2a. In order to derive the NAM stamp of the DDA assumes that it is non-ideal and has finite output admittance Y_o. Figure 2b represents the VCVS model of the non-ideal DDA, which can be represented by the following NAM equation:

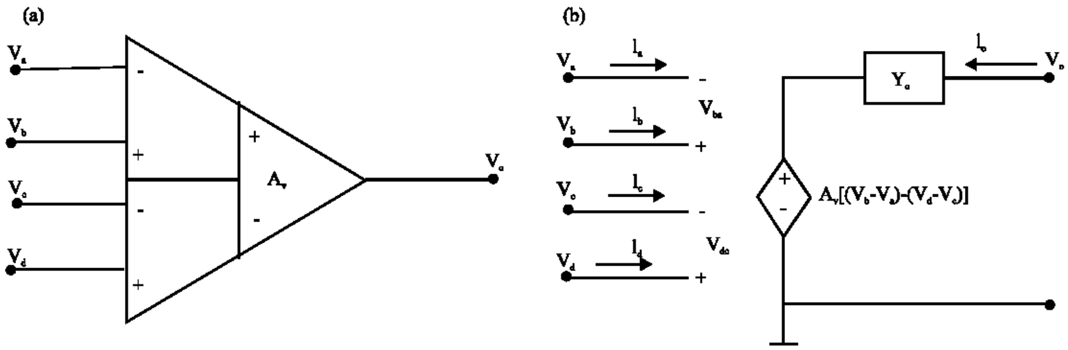


Fig. 2: (a) Symbolic representation of the DDA and (b) Equivalent VCVS model for the non-ideal DDA

$$\begin{bmatrix} I_a \\ I_b \\ I_c \\ I_d \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ A_vY_o & -A_vY_o & -A_vY_o & A_vY_o & Y_o \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_o \end{bmatrix} \tag{6}$$

From the above Equation the Y matrix of the DDA in the non-ideal case is given by:

$$Y = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ A_vY_o & -A_vY_o & -A_vY_o & A_vY_o & Y_o \end{bmatrix} \tag{7}$$

Setting Y_o to its ideal value of infinity the NAM stamp of the ideal DDA is obtained as:

$$Y = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ A_v\infty_1 & -A_v\infty_1 & -A_v\infty_1 & A_v\infty_1 & \infty_1 \end{bmatrix} \tag{8}$$

It is of interest to verify that the ideal DDA equation can be derived from the above NAM equations. The last row in the NAM Eq. 6 can be written in the form of the following voltage equation:

$$\left[\frac{I_o}{Y_o}\right] = \begin{bmatrix} A_v & -A_v & -A_v & A_v & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_o \end{bmatrix} \quad (9)$$

This voltage matrix equation can be written as:

$$\begin{matrix} & a & b & c & d & o \\ o & [A_v & -A_v & -A_v & A_v & 1] \end{matrix} \quad (10)$$

In the ideal case Y_o equal to infinity and Eq. 9 reduces to:

$$\begin{bmatrix} 0 \end{bmatrix} = \begin{bmatrix} A_v & -A_v & -A_v & A_v & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_o \end{bmatrix} \quad (11)$$

The output voltage V_o is obtained as follows:

$$V_0 = A_V \, [V_b - V_a) - (V_d - V_C)] \quad (12)$$

In the ideal case A_v equal to infinity and the above equation simplifies to:

$$V_b - V_a = V_d - V_C \quad (13)$$

The above equation represents the well-known equation defining the DDA in the ideal case with infinity gain.

DIFFERENTIAL DIFFERENCE OPERATIONAL FLOATING AMPLIFIER (DDOFA)

The DDOFA was introduced by (Mahmoud and Soliman, 1998) as a new analog building block. New CMOS realization and several new analog circuit applications were also introduced by Mahmoud and Soliman (1998). The symbol of the DDOFA is shown in Fig. 3a where G_m in the ideal case is infinity. Figure 3b represents the VCCS model of the DDOFA from which the following NAM equation is obtained:

$$\begin{bmatrix} I_e \\ I_f \end{bmatrix} = \begin{bmatrix} G_{mi} & -G_{mi} & -G_{mi} & G_{mi} \\ -G_{mi} & G_{mi} & G_{mi} & -G_{mi} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{14}$$

The above NAM equation can also be written as follows:

$$\begin{array}{c} \\ e \\ f \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} G_{mi} & -G_{mi} & -G_{mi} & G_{mi} \\ -G_{mi} & G_{mi} & G_{mi} & -G_{mi} \end{bmatrix} \end{array} \tag{15}$$

In the ideal case the NAM stamp of the DDOFA becomes:

$$\begin{array}{c} \\ e \\ f \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} \infty_i & -\infty_i & -\infty_i & \infty_i \\ -\infty_i & \infty_i & \infty_i & -\infty_i \end{bmatrix} \end{array} \tag{16}$$

It is of interest to verify that the ideal DDOFA equation can be derived from the above NAM equations, dividing both sides of Eq. 14 by G_{mi} thus:

$$\begin{bmatrix} \dfrac{I_e}{G_{mi}} \\ \dfrac{I_f}{G_{mi}} \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{17}$$

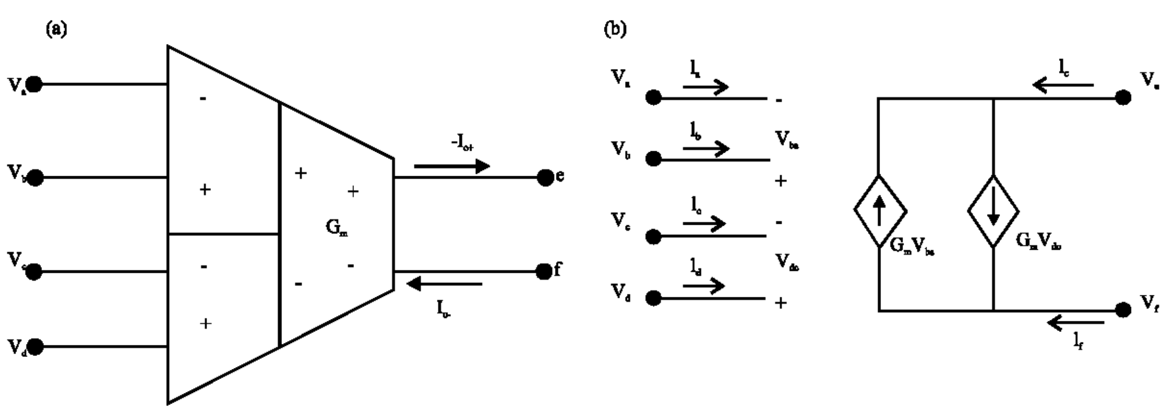


Fig. 3: (a) Symbolic representation of the DDOFA and (b) Equivalent VCCS model for the DDOFA

In the ideal case the transconductance G_{mi} approaches infinity thus:

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{18}$$

Each of the above two rows gives the same equation which represents the ideal DDOFA and given by:

$$V_b - V_a = V_d V_C \tag{19}$$

DIFFERENTIAL DIFFERENCE OPERATIONAL MIRROR AMPLIFIER (DDOMA)

The DDOMA was introduced by (Soltan and Soliman, 2009) as a new analog building block. New CMOS realization and analog circuit applications were also introduced by Soltan and Soliman (2009). The symbol of the DDOMA is shown in Fig. 4a where G_m in the ideal case is infinity. Figure 4b represents a four VCCS model of the DDOMA from which the NAM equation is obtained:

$$\begin{bmatrix} I_e \\ I_f \end{bmatrix} = \begin{bmatrix} G_{mi} & -G_{mi} & -G_{mi} & G_{mi} \\ G_{mi} & -G_{mi} & -G_{mi} & G_{mi} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{20}$$

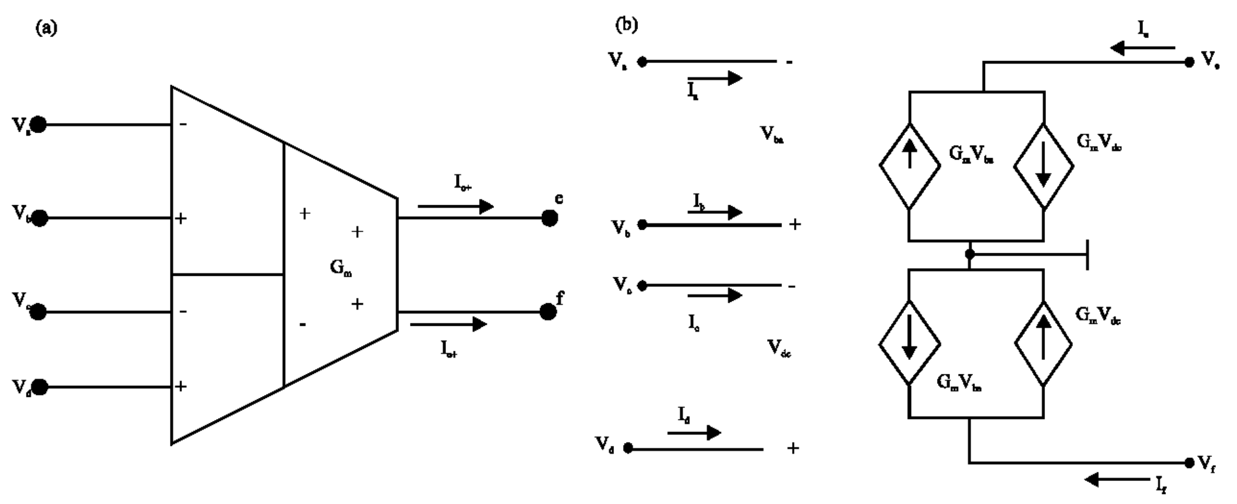


Fig. 4: (a) Symbolic representation of the DDOMA and (b) Equivalent VCCS model for the DDOMA

The above NAM equation can also be written as follows:

$$\begin{array}{c} \\ e \\ \\ f \end{array}\begin{array}{c} \begin{array}{cccc} a & b & c & d \end{array} \\ \begin{bmatrix} G_{mi} & -G_{mi} & -G_{mi} & G_{mi} \\ & & & \\ G_{mi} & -G_{mi} & -G_{mi} & G_{mi} \end{bmatrix} \end{array} \tag{21}$$

From Eq. 20 therefore:

$$\begin{bmatrix} \frac{I_e}{G_{mi}} \\ \frac{I_f}{G_{mi}} \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{22}$$

In the ideal case the transconductance G_{mi} approaches infinity thus:

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \end{bmatrix} \tag{23}$$

Each of the above two rows gives the same equation which represents the ideal DDOFA and given by:

$$V_b - V_a = V_d - V_C \tag{24}$$

The derived four new NAM stamps are very useful in computing small signal characteristics of analog circuits using Nodal Admittance (NA) analysis methods using CAD tools (Tlelo-Cuautle *et al.*, 2010a).

Most recently the derivation of NAM stamps of the Operational Trans-resistance Amplifier (OTRA) and the Current Operational Amplifier (COA) have been reported by Sanchez-Lopez *et al.* (2010).

PATHOLOGICAL REALIZATIONS

The second part of this paper includes the pathological realizations of the four active building blocks considered in this paper. The pathological realizations are very useful in the generation of alternative ideally equivalent realizations of an active building block (Carlin, 1964; Cabeza and Carlosena, 1993).

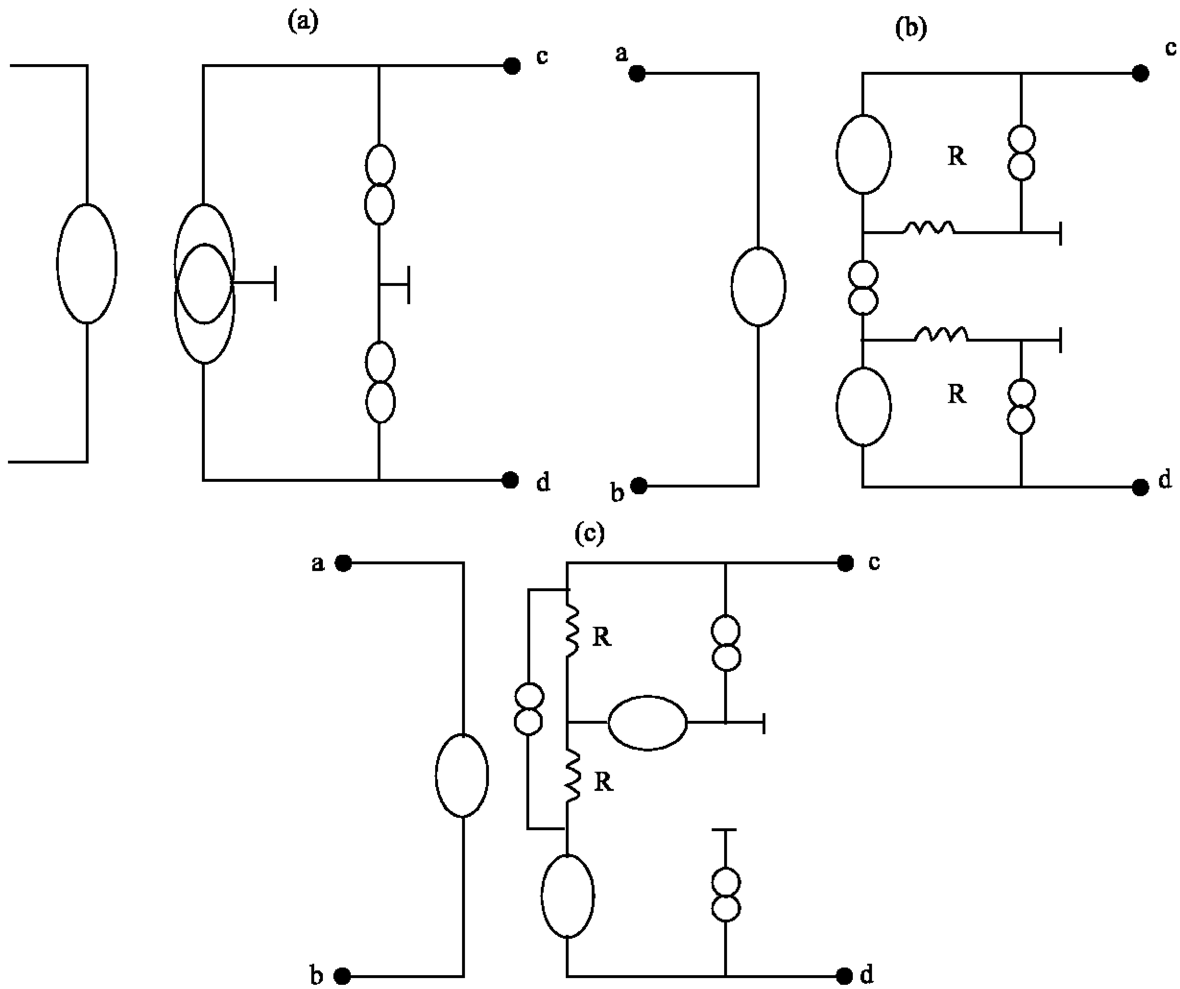


Fig. 5: (a) Pathological realization I of the BOOA and (b) Pathological realization II of the BOOA, (c) Pathological realization III of the BOOA

Three equivalent alternative pathological realizations of the BOOA are given next. The first pathological realization of the BOOA employs one nullator, one VM and two norators is shown in Fig. 5a. The second pathological realization of the BOOA employs three nullators, three norators and two grounded resistors and is shown in Fig. 5b. This realization is based on replacing the VM by its nullor equivalent circuit given by Saad and Soliman (2010) and Awad and Soliman (1999). The third pathological realization of the BOOA employs three nullators, three norators and two floating resistors and is shown in Fig. 5c. This realization is based on replacing the VM by its nullor equivalent circuit given by (Saad and Soliman, 2010; Awad and Soliman, 1999).Three alternative ideally equivalent realizations of the BOOA are shown in Fig. 6 and are obtained from Fig. 5. The circuit derived in Fig. 6a uses an OA and an inverting CCII-. The circuit derived in Fig. 6b uses a nullor, two OAs and two grounded resistors. The circuit derived in Fig. 6c uses a nullor, two OAs and two virtually grounded resistors.

The pathological realization of the DDA employs one nullator; four VM and five norator four of them are dummy and shown in Fig. 7.

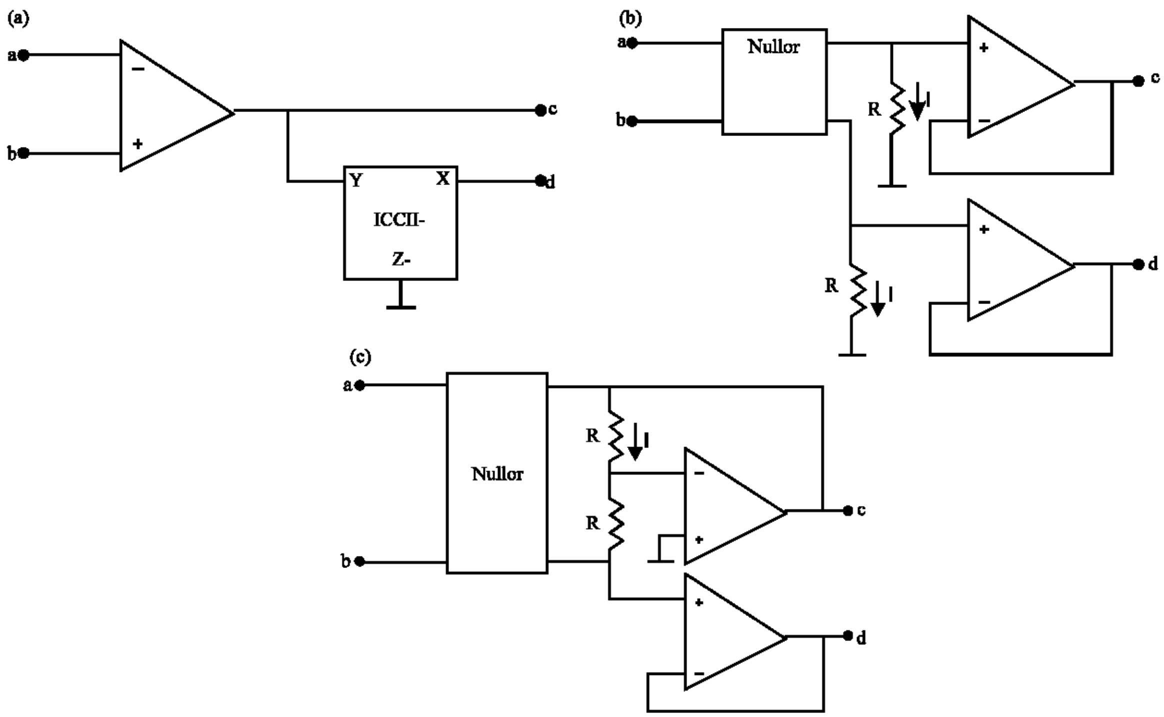


Fig. 6: (a) Realization I of the BOOA based on Fig. 5a, (b) Realization II of the BOOA based on Fig. 5b and (c) Realization III of the BOOA based on Fig. 5c

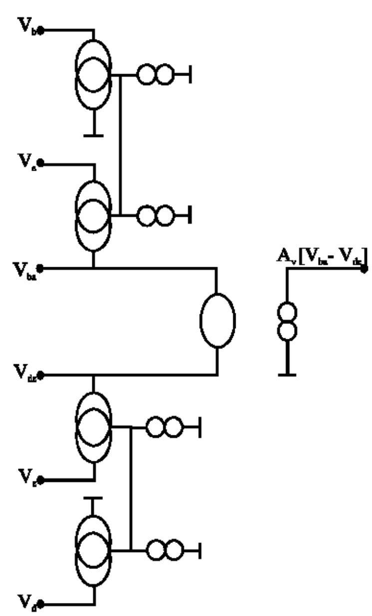


Fig. 7: Pathological realization of the DDA

The pathological realization of the DDOFA employs one nullator; four VM and five norator four of them are dummy and shown in Fig. 8.

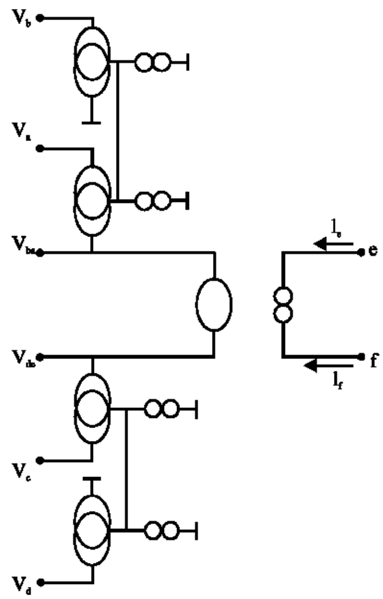


Fig. 8: Pathological realization of the DDOFA

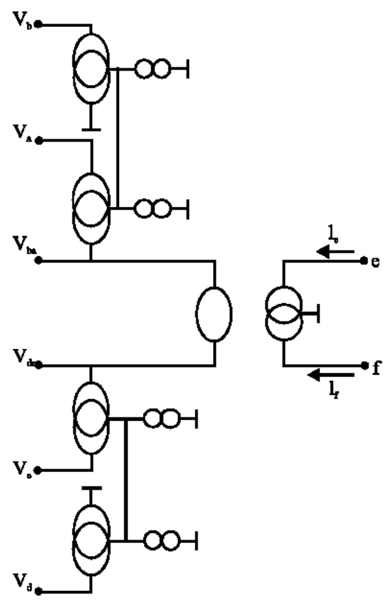


Fig. 9: Pathological realization of the DDOMA

The pathological realization of the DDOMA employs one nullator, four VM, one CM and four dummy norator and shown in Fig. 9. Alternative pathological realizations of the DDA, DDOFA and DDOMA can be derived by replacing the VMs by equivalent nullator norator realization and are not included to limit the length of this letter.

It is important to point out that for a physical realization of the circuit the total number of nullator plus the number of VM must equal to the number of norator plus the number of CM as explained by Awad and Soliman (1999).

CONCLUSIONS

The NAM stamp of the BOOA is derived from a two VCVS model assuming finite output impedance at both output terminals. Pathological representation of the BOOA using a nullator, VM and two norator is also given. The NAM stamp of the DDA is derived from a VCVS model assuming finite output impedance. Pathological representation of the DDA using a nullator, four VM and five norator four of them are added to achieve equal number of nullator plus VM and number of norator is also given. The NAM stamp of the DDOFA is derived from a two VCCS model. Pathological representation of the DDOFA using a nullator, four VM and five norator is also given. Finally the NAM stamp of the DDOMA is derived from a four VCCS model. Pathological representation of the DDOMA using a nullator, four VM, one CM and four dummy norators is also given. The NAM equations and the pathological realizations will be useful in the design automation of analogue integrated circuits (Amiri *et al.*, 2008; Chong *et al.*, 2007; Garcia-Ortega *et al.*, 2007; Masmoudi *et al.*, 2005; Tlelo-Cuautle *et al.*, 2010b).

REFERENCES

Amiri, M., N. Karimi and S.F. Jamshidi, 2008. A methodology for optimizing statistical multi-response problems using genetic local search algorithm through fuzzy goal programming. J. Applied Sci., 8: 3199-3206.

Amoroso, F.A., A. Pugliese and G. Cappuccino, 2010. Design criterion for high-speed low-power SC circuits. Int. J. Circuit Theory Appl. 10.1002/cta.687

Awad, I.A. and A.M. Soliman, 1999. Inverting second generation current conveyors: The missing building blocks, CMOS realizations and applications. Int. J. Electron., 86: 413-432.

Banu, M. and Y. Tsividis, 1983. Fully integrated active RC filters in MOS technology. IEEE J. Solid-State Circuits, 18: 664-671.

Banu, M. and Y. Tsividis, 1985. An elliptic continuous time CMOS filter with on chip automatic tuning. IEEE J. Solid-State Circuits, 20: 1114-1121.

Cabeza, R. and A. Carlosena, 1993. Nullators and norators in voltage to current mode transformations. Int. J. Circuit Theory Appl., 21: 421-424.

Carlin, H.J., 1964. Singular network elements. IEEE Trans. Circuit Theory, 11: 67-72.

Chong, K.H., I.B. Aris, M.A. Sinan and B.M. Hamiruce, 2007. Digital circuit structure design via evolutionary algorithm method. J. Applied Sci., 7: 380-385.

Czarnul, Z., 1986. Modification of Banu-Tsividis, continuous-time integrator structure. IEEE Trans. Circuits Syst., 33: 714-716.

Garcia-Ortega, J.M., E. Tlelo-Cuautle and C. Sanchez-Lopez, 2007. Design of current-mode Gm-C filters from the transformation of opamp-RC filters. J. Applied Sci., 7: 1321-1326.

Haigh, D.G. and P.M. Radmore, 2006. Admittance matrix models for the nullor using limit variables and their application to circuit design. IEEE Trans. Circuits Syst., 53: 2214-2223.

Haigh, D.G., 2006. A method of transformation from symbolic transfer function to active-RC circuit by admittance matrix expansion. IEEE Trans. Circuits Syst. I, 53: 2715-2728.

Haigh, D.G., F.Q. Tan and C. Papavassiliou, 2005. Systematic synthesis of active-RC circuit building-blocks. Analog Integrated Circuits Signal Process, 43: 297-315.

Haigh, D.G., T.J.W. Clarke and P.M. Radmore, 2006. Symbolic framework for linear active circuits based on port equivalence using limit variables. IEEE Trans. Circuits Syst., 53: 2011-2024.

Huang, S.C., M. Ismail and S.R. Zarabadi, 1993. A wide range differential difference amplifier. A basic block for analog signal processing in MOS technology. IEEE Trans. Circuits Syst. II, 40: 289-301.

Mahmoud, S.A. and A.M. Soliman, 1998. The differential difference operational floating amplifier: A new block for analog signal processing. IEEE Trans. Circuits Syst. II, 45: 148-158.

Masmoudi, D.S., N.B. El Fek, S.B. Salem, M. Fakhfakh and M. Loulou, 2005. A high frequency CCII based tunable floating inductance and current-mode band pass filter application. J. Applied Sci., 5: 1445-1451.

Ramírez-Angulo, J. and F. Ledesma, 2006. The universal Op Amp and applications in continuous time resistor-less and capacitor-less linear weighted voltage addition. IEEE Trans. Circuits Syst., 53: 404-408.

Saad, R.A. and A.M. Soliman, 2008a. Generation, modeling, and analysis of CCII based gyrators using the generalized symbolic framework for linear active circuits. Int. J. Circuit Theory Appl., 36: 289-309.

Saad, R.A. and A.M. Soliman, 2008b. Use of mirror elements in the active device synthesis by admittance matrix expansion. IEEE Trans. Circuit Syst. I-Regul. Papers, 55: 2726-2735.

Saad, R.A. and A.M. Soliman, 2010. A new approach for using the pathological mirror elements in the ideal representation of active devices. Int. J. Circuit Theory Appl., 38: 148-178.

Sackinger, E. and W. Guggenbiihl, 1987. A versatile building block: The CMOS differential difference amplifier. IEEE J. Solid-State Circuits, 22: 287-294.

Sanchez-Lopez C., F.V. Fernandez and E. Tlelo-Cuautle, 2010. Generalized admittance matrix models of OTRAs and COAs. Microelectron. J., 41: 502-505.

Soliman, A.M., 2009. Adjoint network theorem and floating elements in the NAM. J. Circuits Syst. Comput., 18: 597-616.

Soltan, A. and A.M. Soliman, 2009. A CMOS differential difference operational mirrored amplifier. AEU - Int. J. Electronics Communi., 63: 793-800.

Tlelo-Cuautle, E., C. Sanchez-Lopez and D. Moro-Frías, 2010a. Symbolic analysis of (MO)(I) CCI (II)(III)-based analog circuits. Int. J. Circuit Theory Appl., 38: 649-659.

Tlelo-Cuautle, E., I. Guerra-Gomez, M.A. Duarte-Villasenor, L.G. de la Fraga and G. Flores-Becerra *et al.*, 2010b. Applications of evolutionary algorithms in the design automation of analog integrated circuits. J. Applied Sci., 10: 1859-1872.

Zarabadi, S.R., F. Larsen and M. Ismail, 1992. A configurable op-amp/DDACMOS amplifier architecture. IEEE Trans. Circuits Syst. 39: 484-487.