On plus-type nullor

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Abstract: - It is well-known that a nullor of the negative-type is a two-port with the null transmission matrix. But there is no obviously mathematical definition for a plus-type nullor. The authors proposed a matrix definition for a nullor of the plus-type. Besides, this paper derives out the adjoint component of a plus-type nullor. A voltage-mode amplifier, an oscillator and a current-mode biquadratic filter that using plus-type nullors are transformed to their adjoint circuits as examples to demonstrate the usefulness of the new component. Simulation results are given to confirm the theoretical analysis.
Key-Words: - Nullor, Adjoint network, Circuit theory, Current-mode, Active circuit.

1 Introduction

In 1954, Tellegen proposed the concept of nullor (of the negative-type) implicitly with name of 'ideal element' [1]. In 1964, Carlin gave the name of 'nullor' [2]. Afterwards the network theory community accepted a nullor as a basic network element with the following reasons: (i) a nullor can be represent by anyone of the four kind dependent sources with infinite gain, (ii) nullors with resistors can construct any kinds of finite-gain dependent source, so they can construct any active device. (iii) the circuits with nullors are simple to analyze [3-6]. With the invention of the current mirrors, the plus-type nullor was suggested. Because two plus-type nullors can be combined to obtain a negative-type nullor, it is reasonable to regard a plus-type nullor to be more fundamental than a negative-type nullor. Speaking more precisely, a nullator and a plus-type norator (these two components together can be called a plus-type nullor) are the most fundamental elements. Because the plus-type nullor has been used in the design of active filters or sinusoidal oscillators [7-14], the adjoint circuit of plus-type nullor is needed.

A negative-type nullor is defined to be a two-port with the null transmission matrix. However, a plus-type nullor is a three-port without clearly mathematical definition but is shown symbolically. In this paper, the authors suggested a matrix definition for a plus-type nullor.

Many researchers proposed the adjoint transformation to convert voltage-mode circuits into current-mode circuits, or vice versa [15-20]. Carlosena and Moschytz suggested an adjoint transformation to replace a nullator by a negative-type norator and to replace a negative-type norator by a nullator without changing the passive elements [20]. The adjoint network of a negative-type nullor is a negative-type nullor with interchanging the input port and the output port. But the adjoint network of a plus-type nullor has not been mentioned, neither has the adjoint transformation procedure for a plus-type nullor been presented. In this paper, we derive out the adjoint component of a plus-type nullor.

Examples for the voltage-mode amplifier, oscillator and current-mode filter using plus-type nullors are converted into the current-mode amplifier, oscillator and voltage-mode filter by applying the adjoint transformation. For simulations, the adjoint network for a plus-type nullor can be achieved by a buffer, a unity-gain inverter (implemented by an Op Amp) and a negative-type nullor (implemented by three AD844 ICs).

2 Circuit Description

(i) Definition of a plus-type nullor:

A negative-type nullor is shown in Fig. 1. It is defined as a two-port network with the following equations:

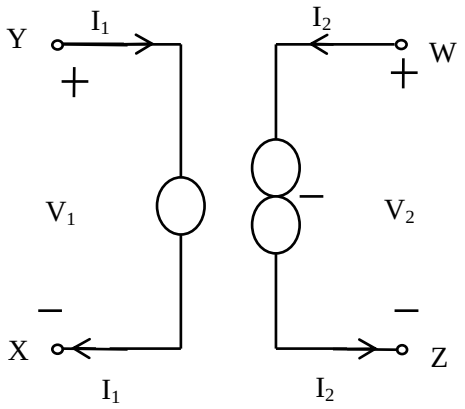
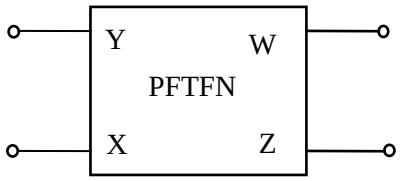


Fig. 1 The symbol of a negative-type nullor (The "-" sign may be neglected).

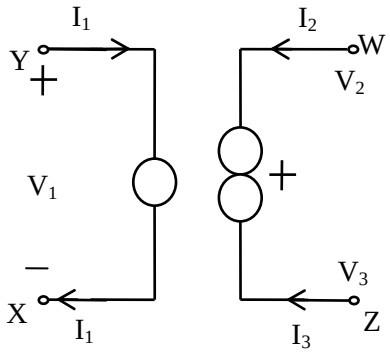
$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix} \quad (1)$$

Equation (1) implies $V_1=0$, $I_1=0$, V_2 and I_2 can be arbitrary values that determined by the feedback network [5]. A plus-type nullor (that is also called plus-type four-terminal-floating-nullor, PFTFN) is shown in Fig. 2. It is a three-port with $V_1=0$, $I_1=0$ $I_3=I_2$. But no complete mathematical port equations have been defined clearly yet.

An equivalent circuit of a plus-type nullor is shown in Fig. 3.



(a)



(b)

Fig. 2 The symbol of a plus-type nullor (PFTFN).

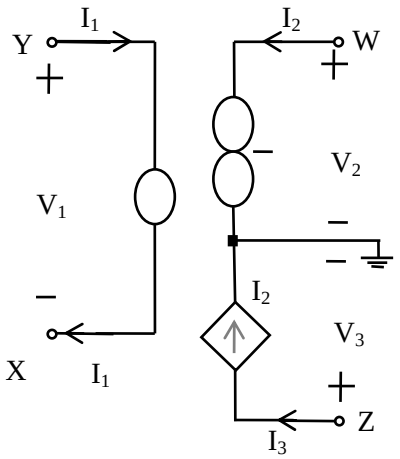


Fig. 3 An equivalent circuit of the plus-type nullor in Fig. 2.

A matrix equation is given to define the plus-type nullor. A plus-type nullor is a three-port with the following matrix equation:

$$\begin{bmatrix} V_1 \\ I_1 \\ I_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \\ V_3 \end{bmatrix} \quad (2)$$

From Fig. 3, equation (2) is obvious.

(ii) The adjoint network of a plus-type nullor:

An alternative linear network that realizes the given transfer function can be created by using the principle of adjoint network [15-20]. Consider an arbitrary linear circuit consisting of resistors, capacitors, voltage-controlled voltage sources (VCVSs), current-controlled current sources (CCCSs) and negative-type nullors. Assume that the circuit is driven by an independent current source, and that the output variable is the current flowing through some port. Then, the transfer function of the circuit is the ratio of the two currents. The adjoint of this circuit is found by replacing each element in the circuit with another element according to the list given in Fig. 4.

We can describe the adjoint transformation procedure as follows. First, replace the input current source with an open circuit and call the voltage across it the new output response variable. Second, attach new input voltage source to the output port in the original circuit. This is the new input, and the transfer function of this "adjoint circuit" is the ratio of voltages. Next, replace each CCCS with a VCVS

with the same gain. The output port of the VCVS should be connected to where the input port of the original CCCS was; the input port of the VCVS should be connected to where the output port of the original CCCS was. The resistors and capacitors are left unchanged. Finally, interchange nullators and negative-type norators. The result is an alternate circuit with exactly the same transfer function.

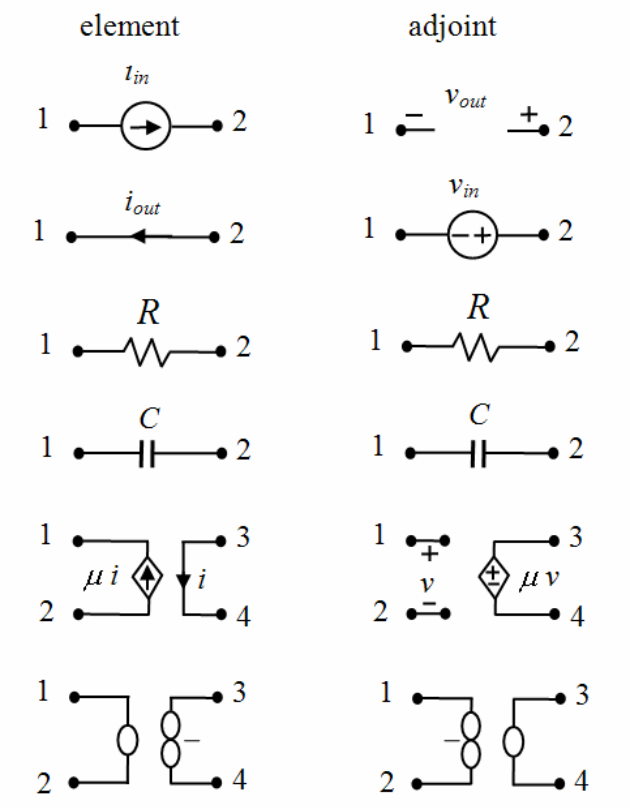


Fig. 4 Several network elements and their corresponding adjoint elements.

The circuit symbol of the plus nullor is shown in Fig. 5(a). Applying the adjoint transformation procedure to Fig. 5(a) gives the circuit in Fig. 5(b), which is a new device we call it adjoint network of plus-type nullor (ADJPN). The circuit symbol of the ADJPN is shown in Fig. 6. The terminal characteristic of the ADJPN can be described by the following matrix equation:

$$\begin{bmatrix} V_2 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_3 \\ -I_1 \\ V_1 \end{bmatrix} \qquad (3)$$

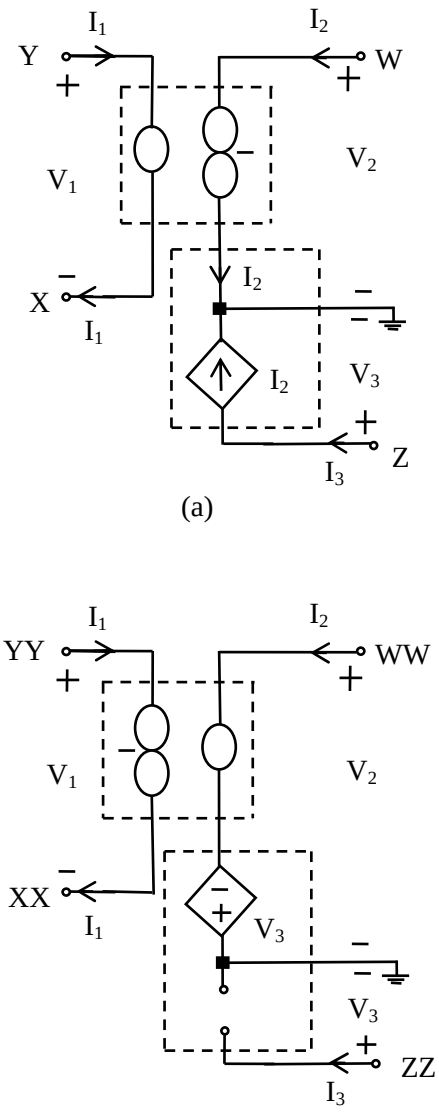
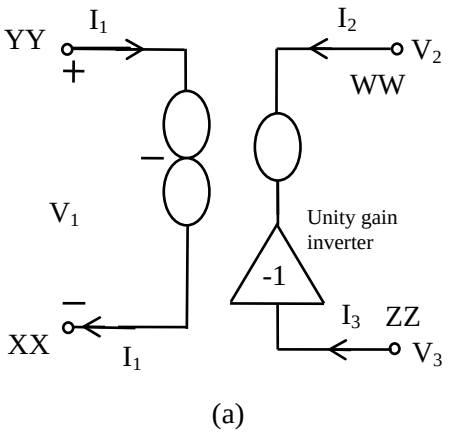
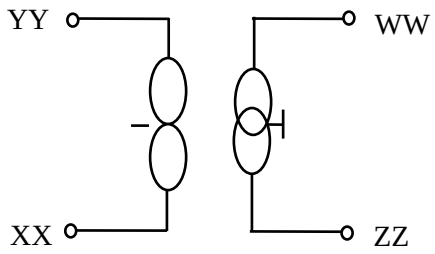


Fig. 5 (a) The plus-type nullor.
(b) The adjoint network of plus-type nullor (ADJPN).





(b)

Fig. 6 ADJPN circuit symbol.

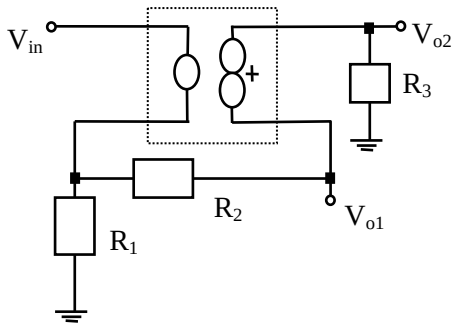
3 Applications Based on ADJPN

(i) The adjoint network of the amplifier

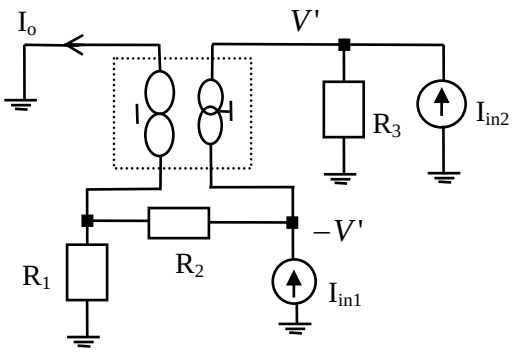
Fig. 7 shows a voltage-mode amplifier circuit based on one plus-type nullor. The circuit realizes the following voltage transfer functions:

$$\frac{V_{o1}}{V_{in}} = \frac{R_1 + R_2}{R_1} \tag{4}$$

$$\frac{V_{o2}}{V_{in}} = \frac{R_3}{R_1} \tag{5}$$



(a)



(b)

Fig. 7 (a) The plus-type nullor based amplifier.
(b) The adjoint network of (a).

Applying the adjoint network transformation method to the circuit in Fig. 7(a) gives the circuit depicted in Fig. 7(b).

From Fig. 7(b)

$$I_o = (\frac{R_1 + R_2}{R_1}) I_{in1} + \frac{R_3}{R_1} I_{in2} \tag{6}$$

(ii) The adjoint network of the oscillator

Fig. 8 shows a sinusoidal oscillator presented in [10]. The characteristic equation of the sinusoidal oscillator is:

$$Y_4(2Y_2Y_5+Y_2Y_3+Y_2Y_6+Y_3Y_6-Y_1Y_3)+Y_1Y_2Y_5=0 \tag{7}$$

Applying the adjoint network transformation method to the circuit in Fig. 8 gives the circuit depicted in Fig. 9. Note that Fig. 8 and Fig. 9 have the same characteristic equation as given in equation (7). If we select admittance $Y_1=sC_1$, $Y_2=sC_2$, and the rest conductance (G=1/R), (7) becomes

$$s^2C_1C_2G_5 + sG_4[C_2(2G_5 + G_3 + G_6) - C_1G_3] + G_3G_4G_6 = 0 \tag{8}$$

The oscillation condition and oscillation frequency are given by (for $C_1=2C_2$)

$$\frac{2}{R_5} + \frac{1}{R_6} - \frac{1}{R_3} = 0 \tag{9}$$

$$\omega_o = \frac{1}{C_2}\sqrt{\frac{R_5}{2R_3R_4R_6}} \tag{10}$$

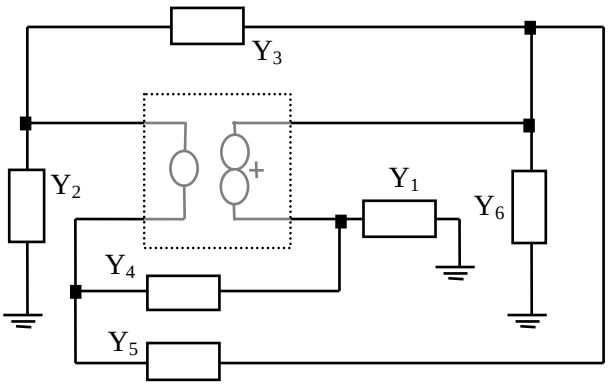


Fig. 8 The oscillator using plus-type nullor [10].

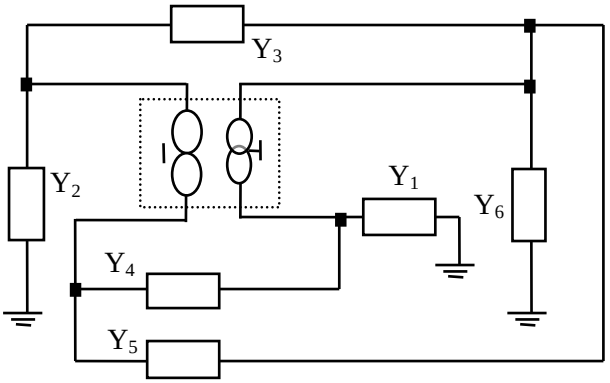


Fig. 9 The oscillator using ADJPN.

(iii) The adjoint network of the filter

Fig. 10(a) shows a current-mode universal biquadratic filter presented in [9]. The circuit realizes the following current transfer functions:

$$\frac{I_{out1}}{I_{in}} = \frac{-s^2 C_1 C_2}{s^2 C_1 C_2 + s C_2 G_1 + G_1 G_2} \tag{11}$$

$$\frac{I_{out2}}{I_{in}} = \frac{s C_2 G_1}{s^2 C_1 C_2 + s C_2 G_1 + G_1 G_2} \tag{12}$$

$$\frac{I_{out3}}{I_{in}} = \frac{-G_1 G_3}{s^2 C_1 C_2 + s C_2 G_1 + G_1 G_2} \tag{13}$$

Applying the adjoint network transformation method to the circuit in Fig. 10(a) gives the circuit depicted in Fig. 10(b), from which the output voltage can be obtained as

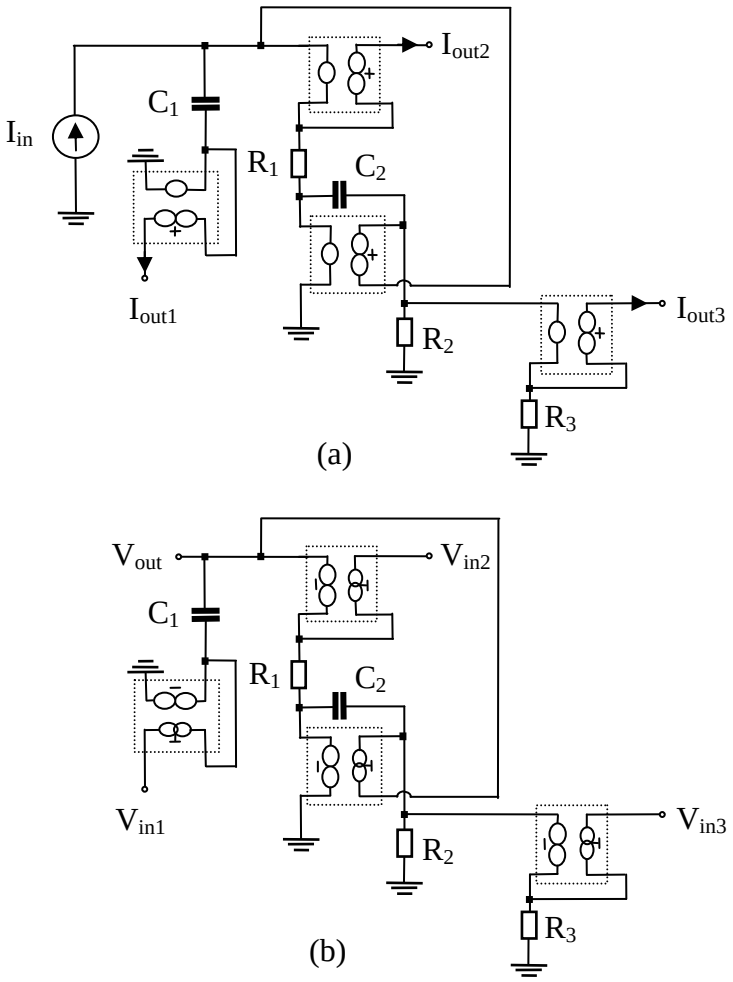


Fig. 10 (a) The current-mode universal biquad by Ozoguz and Acar [9].
(b) The adjoint circuit of (a).

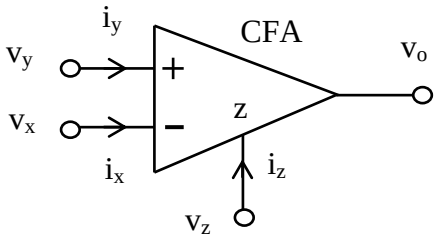
$$V_{out} = \frac{-s^2 C_1 C_2 V_{in1} + sC_2 G_1 V_{in2} - G_1 G_3 V_{in3}}{s^2 C_1 C_2 + sC_2 G_1 + G_1 G_2} \quad (14)$$

From (14), we can see that five circuit types can be obtained from Fig. 10(b):
1) if V_{in2} = V_{in3} = 0 (grounded); V_{in1} = input voltage signal, a highpass filter can be obtained;
2) if V_{in1} = V_{in3} = 0 (grounded); V_{in2} = input voltage signal, a bandpass filter can be obtained;
3) if V_{in1} = V_{in2} = 0 (grounded); V_{in3} = input voltage signal, a lowpass filters can be obtained;
4) if V_{in3} = 0 (grounded); V_{in1} = V_{in3} = input voltage signal, a notch filter can be obtained;
5) if V_{in1} = V_{in2} = V_{in3} = input voltage signal and R_3 = R_2, an allpass filter can be obtained.

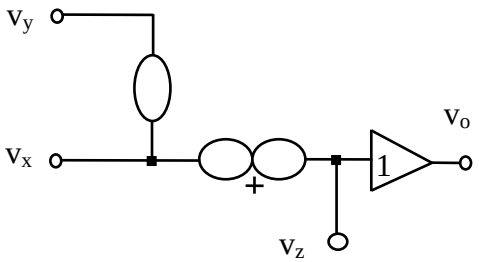
Thus, the circuit is capable of realizing all filter functions. The circuit requires the minimum number of passive components with no requirement for matching conditions. Moreover, the three input signals, V_{in1}, V_{in2} and V_{in3}, are connected to the high input impedance input nodes of the three ADJPNs, respectively.

4 Simulation Results

The circuit symbol of a current-feedback amplifier (CFA) is shown in Fig. 11(a). Its characteristic can be expressed as



(a)



(b)

Fig. 11 (a) Circuit symbol of AD844.
(b) The equivalent circuit of AD844.

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \quad \text{and } v_o = v_z \quad (15)$$

From equation (15), the CFA can also be expressed by a plus-type nullor and a voltage buffer as shown in Fig. 11(b).

In simulations or experiments, a negative-type nullor can be constructed by two AD844 ICs as shown in Fig. 12 [7]. A plus-type nullor can also be constructed by two AD844 ICs as shown in Fig. 13 [8].

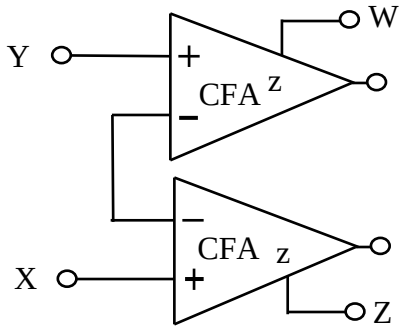


Fig.12 Two AD844 ICs form a negative-type nullor.

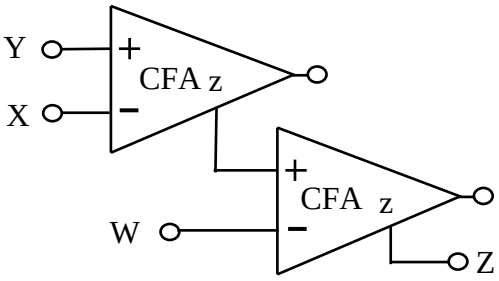


Fig. 13 Two AD844 ICs form a plus-type nullor.

The ADJPN can be obtained by using three AD844 ICs, a voltage buffer and a unity-gain inverter as shown in Fig. 14.

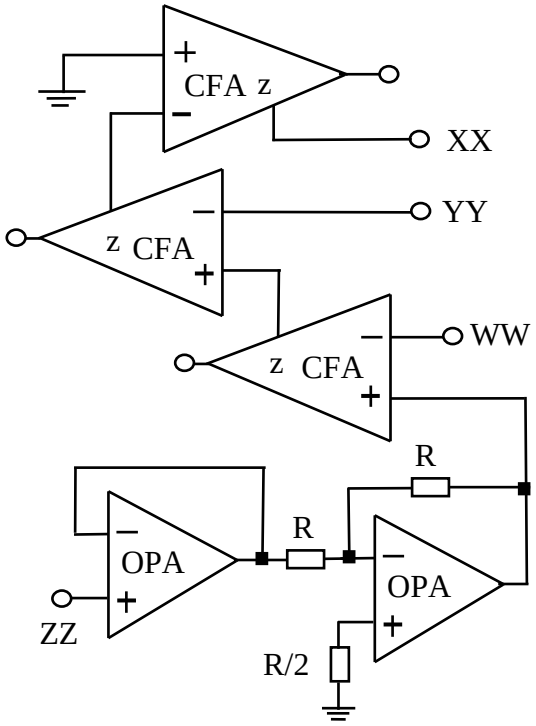


Fig. 14 The simulated circuit of ADJPN.

Hspice simulations were carried out to demonstrate the feasibility of the proposed circuit in Fig. 7(b). Fig. 14 shows the implementation of ADJPN using two HA17741 Op Amps, three AD844 ICs, R=10k Ω and ± 5 V power supply. The proposed current-mode adder was built with $R_1 = R_2 = R_3 = 10\text{k}\Omega$. The square waveform with 100 μA peak-to-peak and 0.5 kHz was applied to I_{in1}. The square waveform with 100 μA peak-to-peak and 0.5 kHz was applied to I_{in2}.The output waveform is shown in Fig. 15.

Hspice simulations were carried out to demonstrate the feasibility of the proposed oscillator circuit in Fig. 9. Fig. 16 shows the simulation result of Fig. 9 with oscillation frequency 19.6 kHz: C_1=2nF, C_2=1nF, R_3= 3.3k Ω , R_4=10k Ω , R_5=10kΩ, R_6=10kΩ.

Hspice simulations were carried out to demonstrate the feasibility of the proposed voltage-mode universal biquadratic filter in Fig. 10(b). Fig. 17 represents the simulated frequency responses for the highpass filter design with $V_{in2} = V_{in3} = 0$ (grounded), $V_{in1} = V_{in}$, C_1 = 1nF, C_2 = 10nF, R_1 = 10k Ω , $R_2 = R_3$ =1k Ω . Fig. 18 represents the simulated frequency responses for the bandpass filter design with $V_{in1} = V_{in3} = 0$ (grounded), $V_{in2} = V_{in}$, C_1 = 1nF, C_2 = 10nF, R_1 = 10kΩ, $R_2 = R_3$ =1kΩ. Fig. 19 represents the simulated frequency responses for the lowpass filter design with $V_{in1} = V_{in2} = 0$ (grounded), $V_{in3} = V_{in}$, C_1 = 1nF, C_2 = 10nF, R_1 = 10k Ω , $R_2 = R_3$ =1k Ω . Fig. 20 represents the simulated frequency responses for the notch filter design with $V_{in2} = 0$ (grounded), $V_{in1} = V_{in3} = V_{in}$, C_1 = 1nF, C_2 = 10nF, R_1 = 10kΩ, $R_2 = R_3$ =1kΩ. Fig. 21 represents the simulated frequency responses for the allpass filter design with $V_{in1} = V_{in2} = V_{in3} = V_{in}$, C_1 = 1nF, C_2 = 10nF, R_1 = 10kΩ, $R_2 = R_3$ =1kΩ.

5 Conclusion

The negative-type nullor is a two-port network with the null transmission matrix. The authors suggested a mathematical matrix definition for the plus-type nullor. Because there are many plus-type nullor-based circuits, the adjoint circuit of plus-type nullor is needed and defined in this paper. Moreover, this paper converted a voltage-mode amplifier, an oscillator and a current-mode filter with plus-type nullors into their current-mode amplifier, oscillator and voltage-mode filter counter parts by applying the adjoint transformation, respectively. For simulations, the adjoint network for a plus-type nullor (ADJPN) was achieved by a buffer, a unity-gain inverter (via Op Amp) and a negative-type nullor (using three AD844 ICs).

Acknowledgment

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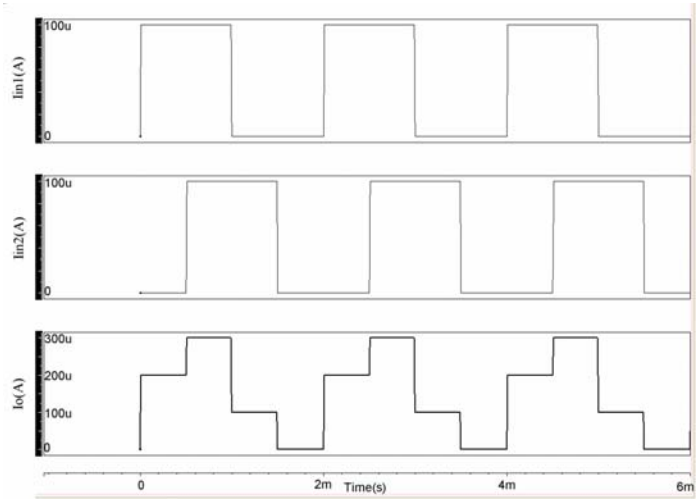

Fig. 15 The simulated input and output waveforms of Fig. 7.

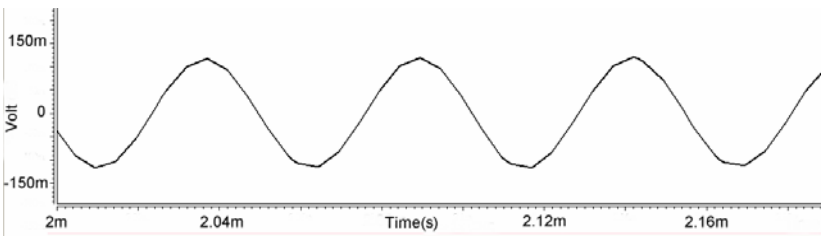

Fig. 16 The simulated sinusoidal output waveform of Fig. 9.

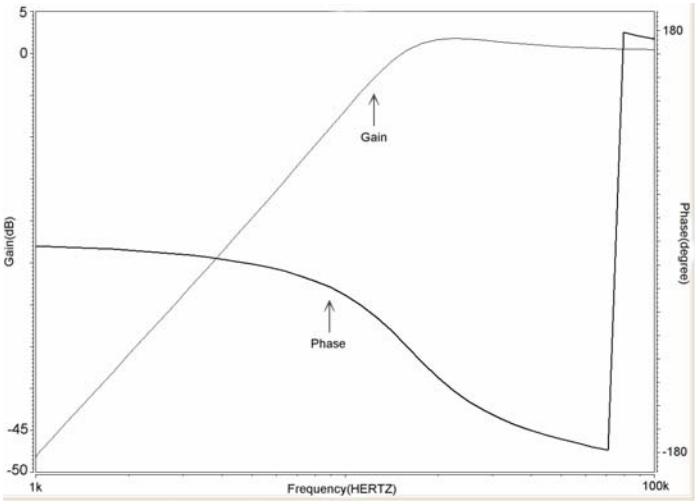

Fig. 17 Simulated frequency responses for the highpass filter design with $V_{in2} = V_{in3} = 0$ (grounded), $V_{in1} = V_{in}$.

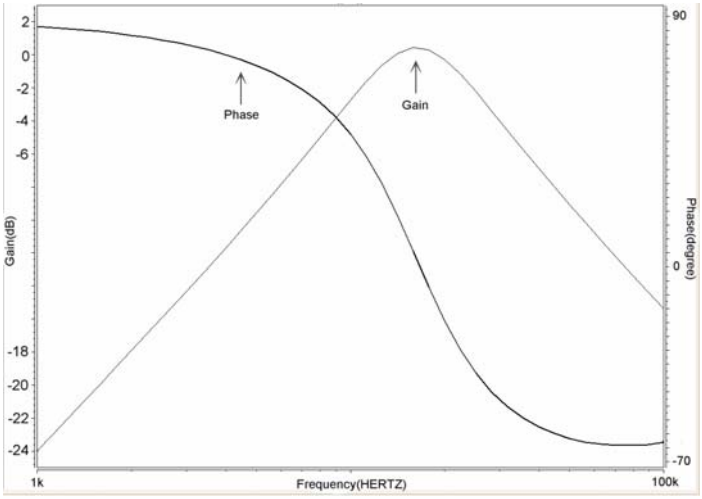

Fig. 18 Simulated frequency responses for the bandpass filter design with $V_{in1} = V_{in3} = 0$ (grounded), $V_{in2} = V_{in}$.

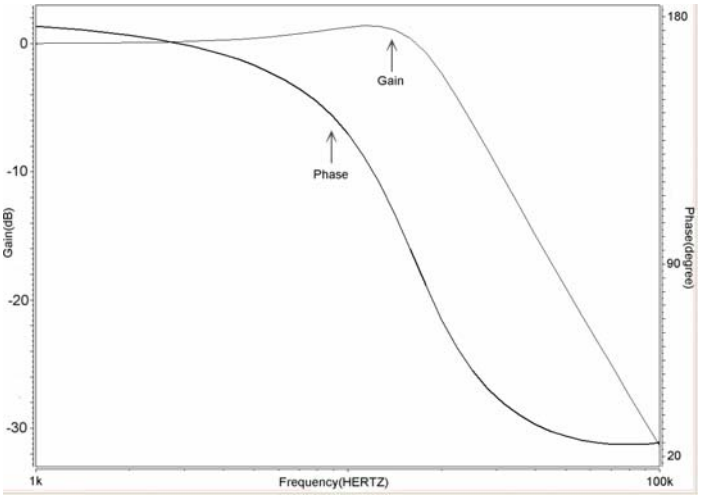

Fig. 19 Simulated frequency responses for the lowpass filter design with $V_{in1} = V_{in2} = 0$ (grounded), $V_{in3} = V_{in}$.

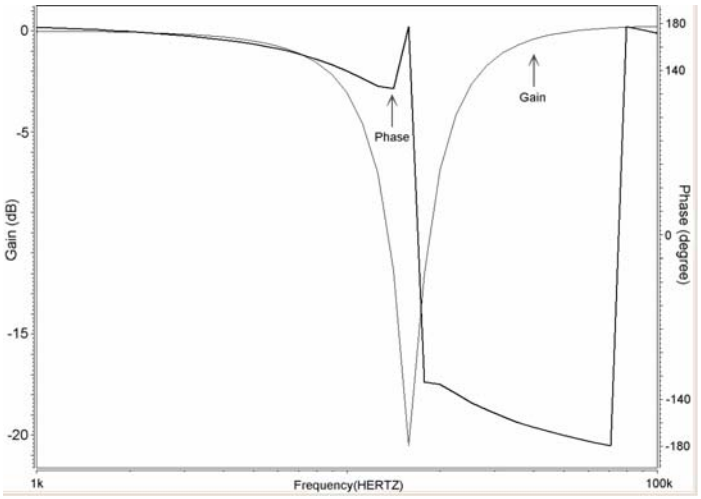

Fig. 20 Simulated frequency responses for the notch filter design with $V_{in2} = 0$ (grounded), $V_{in1} = V_{in3} = V_{in}$.

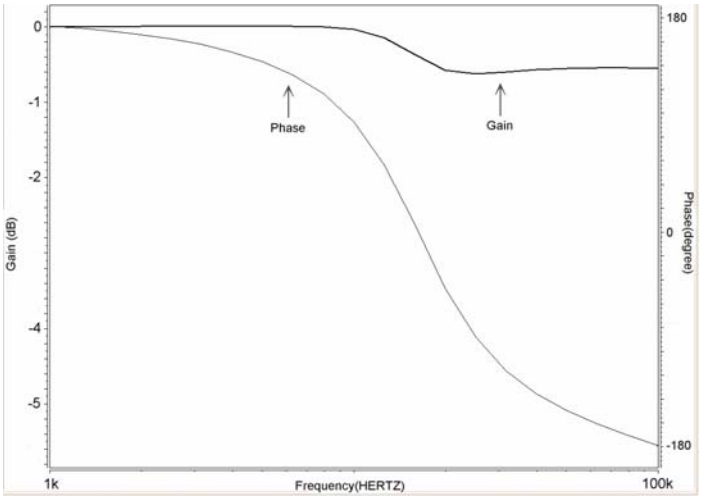

Fig. 21 Simulated frequency responses for the allpass filter design with $V_{in1} = V_{in2} = V_{in3} = V_{in}$.