# The Second Order Rejector Active Filter using Four-Terminal Floating Nullors

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*Abstract:* - The paper presents a manner of building up current-mode active filters from voltage-mode active filters, using the adjoint transformation method. The presented voltage-mode rejector active filter is built with operational amplifiers. We built the current-mode rejector active filter, using four-terminal floating nullors. Both filters have the same transfer functions. The filter response curves are also presented.

*Key-Words:* - rejector active filter, four-terminal floating nullor, operational amplifier, adjoint transformation method, transfer function, response curve

## 1 Introduction

According to the theory of the circuits, filters are electrical selective networks, which change the characteristics of amplitude and/or phase of signals in relation to the frequency. Filters are used in electronic systems, in order to send the signals from a certain frequency domain at the output. The rejector filters [1] suppress the signals from a particular frequency range, sending at the output only those signals with frequencies that are out of the range referred to. The active filters are characterized by the existence of amplification elements that provide the signals' amplification and of passive elements that ensure the selectivity [2].

The current-mode circuits enjoy significant attention because they have the advantages of greater accuracy and wider bandwidth than the similar voltage-mode circuits. The current-mode analog circuits can be built up using current-mode building blocks, such as current conveyors and four-terminal floating nullors.

The four-terminal floating nullor, having the acronym FTFN, is a constructive block more versatile than the operational amplifier or the current conveyor, combining the advantages of voltage-mode and current-mode. This explains the interest in using FTFN when building up the sinusoidal oscillators, active filters, current amplifiers, voltage-current converters and gyrators [3].

## 2 The four-terminal floating nullor

The nullor is a pathological diport, which consists of a nullator at the input and a norator at the output [4]. A nullor can model an operational amplifier if certain restrictions are imposed, such as: terminal X is considered as the inverting input terminal, the terminal Y is considered as the non-inverting input terminal and the terminal W is connected to the ground [4]. The nullor can also model a FTFN as it is presented in figure 1,a. The symbol FTFN is represented in figure 1,b [5].

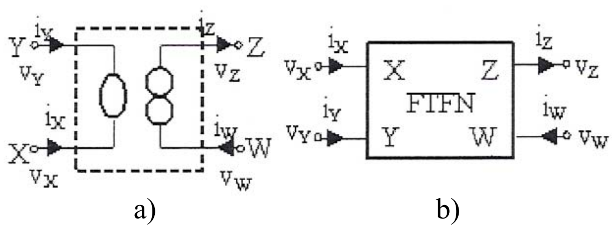



Fig. 1. FTFN representation
a) nullor (nullator-norator pair); b) symbol

The relations between the terminals' currents and voltages are synthesized in the matrix equation (1).

$$\begin{bmatrix} i_X \\ i_Y \\ v_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_W \\ v_Y \\ v_W \\ v_Z \end{bmatrix}. \quad (1)$$

From the matrix equation the following relations can be deduced [4]:

$$i_X = i_Y = 0; \quad (2)$$

$$v_X = v_Y; \quad (3)$$

$$i_Z = i_W. \quad (4)$$

The output impedances "seen" in terminals W and Z are arbitrary. A practical procedure for the building up of FTFN (figure 2) is presented in paper [6].

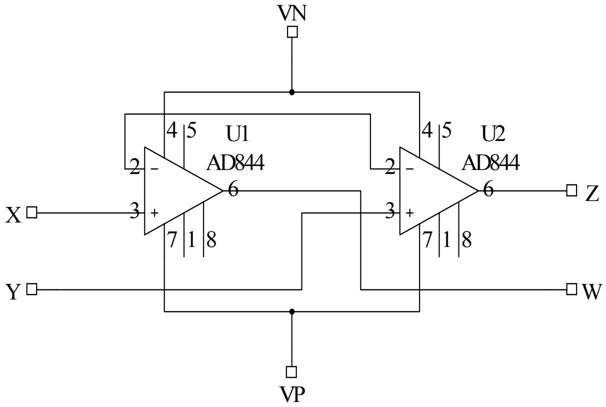



Fig. 2. FTFN built up with two circuits AD 844

## 3 Adjoint transformation method

The paper [5] describes a method of transforming voltage-mode circuits into circuits of the same type, but with a current-mode, known by the name of **the adjoint transformation method.** This method can be very easily put into practice, if the active components of the circuits are modeled through nullors. This method can be expressed by the following:

- In the pair nullator-norator that forms the nullor, the nullator must replace the norator and vice versa.
- The passive elements in the circuit remain unchanged.
- The input voltage is replaced by a short-circuit, and the current flow passing through this short-circuit becomes the output current of the new circuit.
- A current source is connected to the output port and the current provided by it is the input current of the new circuit.
- The controlled voltage sources are replaced by the controlled current source.

## 4 Rejector active filter

In figure 3, there are presented two solutions for the building up of the rejector active filter. The first solution (Fig. 3,a) is a voltage-mode filter, built with operational amplifiers [7] and second solution (Fig. 3,b) is a current-mode filter, built with four-terminal floating nullors. The current-mode filter is obtained from the voltage-mode filter using adjoint transformation method. Thus:

- The operational amplifiers are replaced by nullors.
- The adjoint transformation method is applied according to section 3.
- The new nullors are replaced by four-terminal floating nullors.

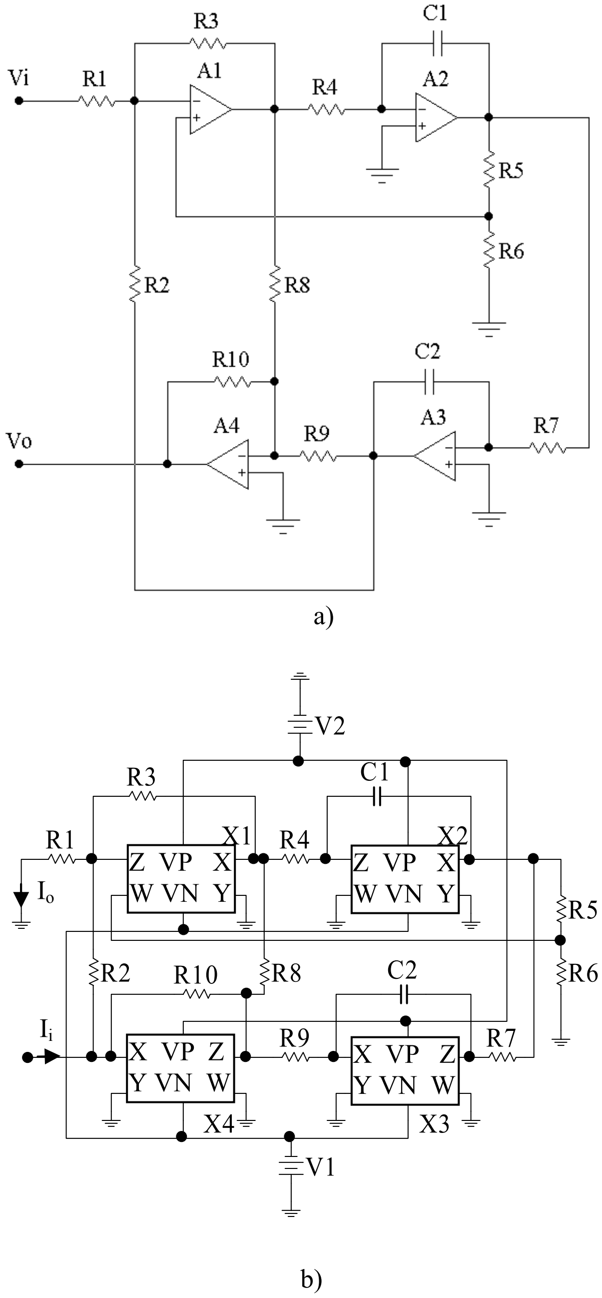



Fig.3. The rejector active filter obtained with: a)operational amplifiers; b) FTFNs

## 5 Filter analysis

The transfer function of the voltage-mode filter (Fig. 3,a) is:

$$H_1(s)=\frac{V_o(s)}{V_i(s)}, \qquad (5)$$

and the transfer function of the current-mode filter (Fig. 3,b) is:

$$H_2(s)=\frac{I_o(s)}{I_i(s)}. \qquad (6)$$

The functions $H_1(s)$ and $H_2(s)$ have the same expression (relation (7)).

$$H_1(s) = H_2(s) = A_0 \cdot \frac{\left[1+\left(\frac{s}{\omega_z}\right)^2\right]}{\left(\frac{s}{\omega_p}\right)^2 + 2\xi\left(\frac{s}{\omega_p}\right)+1}, \quad (7)$$

where:

$$\omega_z = \sqrt{\frac{R_8}{R_4 R_7 R_9 C_1 C_2}}; \quad (8)$$

$$\omega_p = \sqrt{\frac{R_3}{R_2 R_4 R_7 C_1 C_2}}; \quad (9)$$

$$Q = \frac{1}{2\xi} = \frac{R_1(R_5+R_6)}{R_1R_2+R_1R_3+R_2R_3}\sqrt{\frac{R_2R_3R_4C_1}{R_6^2R_7C_2}}; \quad (10)$$

$$A_0 = \frac{R_2R_{10}}{R_1R_9}. \quad (11)$$

Depending on the relation between $\omega_z$ and $\omega_p$ the following filters are obtained [1]:

- The second order high-pass rejector filter if

$$\omega_z < \omega_p. \quad (12)$$

- The second order low-pass rejector filter if

$$\omega_z > \omega_p. \quad (13)$$

- The second order actual rejector (notch) filter if

$$\omega_z = \omega_p. \quad (14)$$

The sensitivities of the filter parameters $\omega_z$, $\omega_p$ and Q are:

$$S_{R_4}^{\omega_z} = S_{R_7}^{\omega_z} = S_{R_9}^{\omega_z} = S_{C_1}^{\omega_z} = S_{C_2}^{\omega_z} = -S_{R_8}^{\omega_z} = -\frac{1}{2}; \quad (15)$$

$$S_{R_2}^{\omega_p} = S_{R_4}^{\omega_p} = S_{R_7}^{\omega_p} = S_{C_1}^{\omega_p} = S_{C_2}^{\omega_p} = -S_{R_9}^{\omega_p} = -\frac{1}{2}; \quad (16)$$

$$S_{R_4}^{Q} = -S_{R_7}^{Q} = S_{C_1}^{Q} = -S_{C_2}^{Q} = \frac{1}{2}; \quad (17)$$

$$-S_{R_1}^{Q} = \frac{R_1R_3}{R_1R_2+R_1R_3+R_2R_3} < 1; \quad (18)$$

$$-S_{R_2}^{Q} = \frac{R_1R_2-R_1R_3+R_2R_3}{R_1R_2+R_1R_3+R_2R_3} < 1; \quad (19)$$

$$-S_{R_3}^{Q} = \frac{-R_1R_2+R_1R_3+R_2R_3}{R_1R_2+R_1R_3+R_2R_3} < 1; \quad (20)$$

$$S_{R_5}^{Q} = -S_{R_6}^{Q} = \frac{R_5}{R_5+R_6} < 1. \quad (21)$$

From relations (15)-(21) we can see that the sensitivities are small.

## 6 Simulation results

We intend to study the three cases of rejector filters, modeling and simulating their operation with Electronics Workbench, version Multisim 9.

In order to model and simulate, we take into consideration the following values for the circuit components:

- for all versions:
$R_1=R_2=R_3=R_5=R_6=R_{10}=10$ kΩ; $R_4=R_7=3.3$ kΩ; $C_1=C_2=15$ nF;
- for the version of the high-pass rejector filter, in order to accomplish the condition (12):
$R_8=10$ kΩ; $R_9=100$ kΩ;
- for the version of the low-pass rejector filter, in order to accomplish the condition (13):
$R_8=100$ kΩ; $R_9=10$ kΩ;
- for the version of the actual rejector filter, in order to accomplish the condition (14):
$R_8=10$ kΩ; $R_9=10$ kΩ.

After the simulation, the following frequency response curves have resulted:

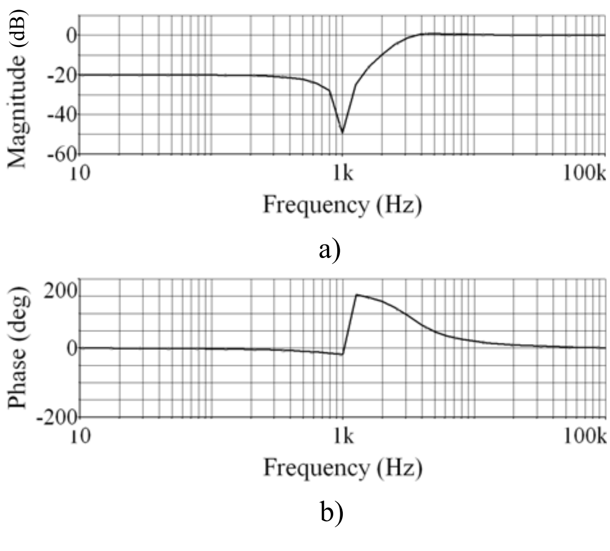
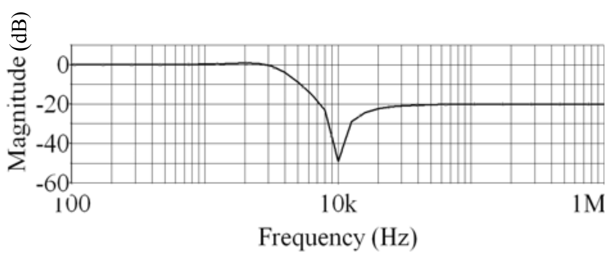
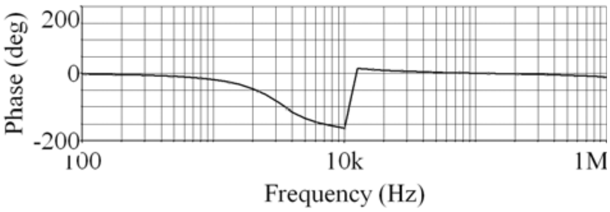



Fig. 4. Amplitude (a) and phase (b) response curves for high-pass rejector filter

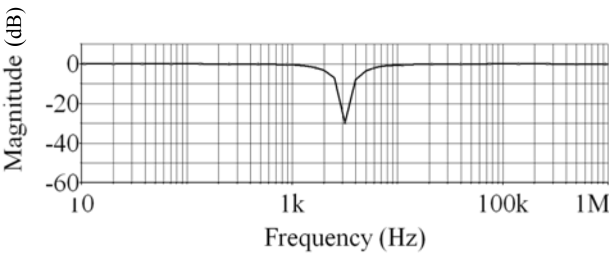



a)

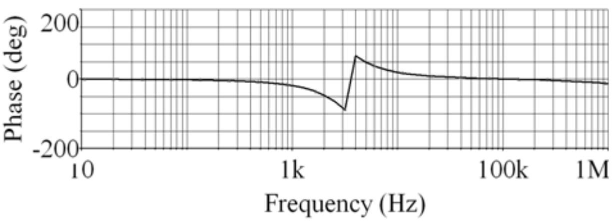



b)

Fig. 5. Amplitude (a) and phase (b) response curves for low-pass rejector filter




a)




b)

Fig. 6. Amplitude (a) and phase (b) response curves for actual rejector filter

For the above three cases the resonant frequency and the quality factor are:

- for the version of the high-pass rejector filter $f_0$=1.02 kHz and $Q = \frac{2}{3}$;
- for the version of the low-pass rejector filter $f_0$=10.2 kHz and $Q = \frac{2}{3}$;
- for the version of the actual rejector filter $f_0$=3.2 kHz and $Q = \frac{2}{3}$;

## 7 Conclusions

A current-mode second order rejector active filter, built with four FTFNs, has been described. FTFN has been obtained, using two circuits AD844. The current-mode filter has been achieved from voltage-mode filter, using the adjoint transformation method. Both circuits have the same expression of transfer functions.

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