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VERSATILE ACTIVE BIQUAD USING FTFNs

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A universal active biquad using the four-terminal floating nullors (FTFNs) is presented. The propsed circuit uses two FTFNs, three capacitors and two resistors. The proposed circuit has three input voltages and can simultaneously provide a high-impedance output current and/or an output voltage. Without changing the circuit topology, the output voltage can realise lowpass, highpass, bandpass, notch and allpass transfer functions and the output current can realise bandpass and highpass transfer functions. The proposed circuit enjoys low active and passive sensitivities and independent control of the parameters ω_o and ω_o/Q_o.

Keywords: Active filters

INTRODUCTION

The four-terminal floating nullor (FTFN) is a more flexible and versatile building block than the operational amplifier and the current-conveyor [1–4]. This explains the growing interest in using the FTFN in designing current-amplifiers, voltage-to-current converters, gyrators, floating immittances [1] and [5–7], and more recently in designing current-mode active-RC filters [3,4] and [8–10] and sinusoidal oscillators [11–13]. Higashimura [3] described a procedure for transforming voltage-mode circuits with operational amplifiers to current-mode circuits with FTFNs. Using this procedure, a current-

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mode lowpass transfer function is obtained from a Sallen-Key voltage-mode lowpass circuit. A stable grounded-capacitor first-order allpass filter using an FTFN was proposed by Higashimura [4]. Liu [8] proposed a cascadable current-mode configuration using single FTFN. This configuration can realise second-order lowpass, highpass, bandpass, notch and allpass filters. However, its active sensitivities are large and it requires a floating capacitor. Moreover, these five filters cannot be realised without changing the circuit topology to achieve a specific filter function. A current-mode configuration using two FTFNs was presented by Liu and Lee [9]. This configuration enjoys low active and passive sensitivities and can simultaneously realise lowpass/bandpass, or highpass/bandpass or bandpass/notch filters using two grounded capacitors. It can also realise an allpass filter. However, it requires a floating resistor and more importantly, its parameters ω_o and ω_o/Q_o are interdependent. Thus it is impossible to adjust any of these two parameters without disturbing the other parameter. Abuelma'atti [10] proposed a cascadable current-mode configuration using single FTFN enjoying low active and passive sensitivities. This configuration can realise second-order lowpass, highpass, bandpass, allpass and notch filters using six passive elements at most. These five filters, however, cannot be realised without changing the circuit topology to achieve a specific filter function. Moreover, the parameters ω_o and ω_o/Q_o are interdependent.

We present a new universal active biquad structure using two FTFNs, three capacitors and two resistors. The circuit has three input voltages and can simultaneously provide a high-impedance output current and/or an output voltage. Without changing the circuit topology, the output voltage can realise lowpass, highpass, bandpass, notch and allpass transfer functions and the output current can realise bandpass and highpass transfer functions. The proposed circuit enjoys low active and passive sensitivities and independent control of the parameters ω_o and ω_o/Q_o.

PROPOSED CIRCUIT

The proposed circuit is shown in Figure 1. Assuming that the port relations of the ideal FTFN, shown in Figure 2a, can be expressed as

$I_1 = I_2 = 0$, $V_2 = V_1$ and $I_{o2} = I_{o1}$, routine analysis of the circuit shown in Figure 1 yields the transfer functions expressed by

$$I_o = \frac{-sC_4G_3G_5V_1 + (s^2C_4G_5(C_2 + C_1) + sC_4G_3G_5)V_2 - s^2C_4C_1G_5V_3}{D(s)} \tag{1}$$

and

$$V_o = \frac{G_3G_5V_1 + sC_1G_5V_3 + s^2C_4C_1V_2}{D(s)} \tag{2}$$

where

$$D(s) = G_3G_5 + s(G_5(C_2 + C_1)) + s^2C_4C_1 \tag{3}$$

From (3) the parameters ω_o and ω_o/Q_o can be expressed as

$$\omega_o^2 = \frac{G_3G_5}{C_1C_4} \tag{4}$$

and

$$\frac{\omega_o}{Q_o} = \frac{G_5(C_1 + C_2)}{C_1C_4} \tag{5}$$

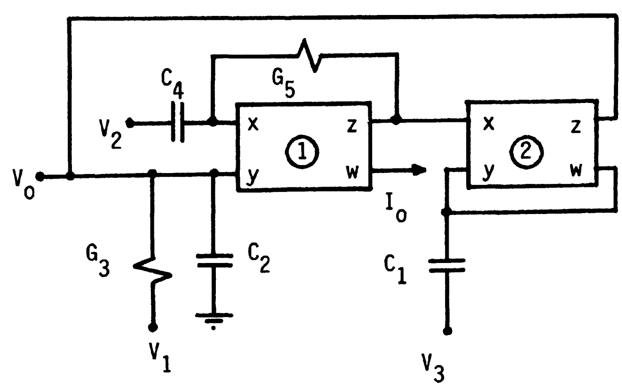

FIGURE 1 Proposed active-biquad structure.

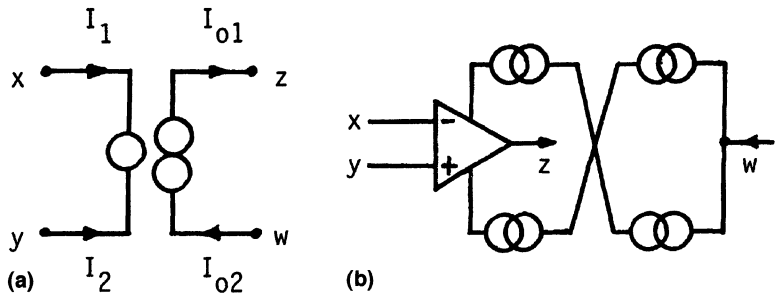

FIGURE 2 (a) Nullor model of FTFN (b) Possible implementation of the FTFN.

From (1) and (2) it can be seen that:

(i) if $V_2 = V_3 = 0$, then a lowpass response is obtained from V_o and a bandpass response is obtained from I_o,
(ii) if $V_1 = V_2 = 0$, then a bandpass response is obtained from V_o and a highpass response is obtained from I_o,
(iii) if $V_1 = V_3 = 0$, then a highpass response is obtained from V_o and no standard response is obtained from I_o,
(iv) if $V_1 = V_2$ and $V_3 = 0$, then a notch response is obtained from V_o and a highpass response is obtained from I_o,
(v) if $V_1 = V_2 = -V_3$ and $C_2 = 0$, then an allpass response is obtained from V_o and a highpass response is obtained from I_o.

From (4) and (5) it can be seen that the parameter ω_o can be adjusted by controlling the resistor $R_3 = 1/G_3$ without disturbing the parameter ω_o/Q_o. Moreover, the parameter ω_o/Q_o can be adjusted by controlling the capacitor C_2 without disturbing the parameter ω_o/Q_o. Thus the proposed circuit enjoys independent control of the parameters ω_o and ω_o/Q_o.

Taking into consideration the nonidealities of the FTFNs, assuming that the port relations of the FTFN, shown in Figure 2a, can be expressed as $I_1 = I_2 = 0$, $V_2 = \beta V_1$ and $I_{o2} = \alpha I_{o1}$ where $\beta = 1 - \varepsilon$, $(|\varepsilon| \ll 1)$, denote the voltage tracking error of the FTFN and $\alpha = 1 - \delta$, $(|\delta| \ll 1)$, denotes the current-tracking error, reanalysis of the circuit shown in Figure 1 shows that (3) can be expressed as

$$D(s) = \alpha_1\alpha_2\beta_1 G_3 G_5 + s\alpha_1\beta_1(G_5(\alpha_2 C_2 + \alpha_1\beta_2 C_1)) + s^2\alpha_1^2\beta_1\beta_2 C_4 C_1 \quad (6)$$

where β_i, α_i, $i = 1 - 2$, are the voltage- and current-tracking errors of the i th FTFN. Thus, the parameters ω_o and ω_o/Q_o can be expressed

$$\omega_o^2 = \frac{\alpha_2 G_3 G_5}{\alpha_1 \beta_2 C_1 C_4} \tag{7}$$

and

$$\frac{\omega_o}{Q_o} = \frac{G_5(\alpha_2 C_2 + \alpha_1 \beta_2 C_1)}{\alpha_1 \beta_2 C_1 C_4} \tag{8}$$

From (7) and (8) it is easy to show that the active and passive sensitivities of the parameters ω_o and Q_o are

$$S_{\alpha_1}^{\omega_o} = S_{\beta_2}^{\omega_o} = -S_{\alpha_2}^{\omega_o} = -\frac{1}{2}$$

$$S_{C_1}^{\omega_o} = S_{C_4}^{\omega_o} = -S_{G_3}^{\omega_o} = -S_{G_5}^{\omega_o} = -\frac{1}{2}$$

$$S_{G_5}^{\omega_o/Q_o} = -S_{C_4}^{\omega_o/Q_o} = 1$$

$$S_{C_2}^{\omega_o/Q_o} = S_{\alpha_2}^{\omega_o/Q_o} = -S_{\alpha_1}^{\omega_o/Q_o} = -S_{\beta_2}^{\omega_o/Q_o} = -S_{C_1}^{\omega_o/Q_o} = \frac{1}{1 + \frac{\alpha_1 \beta_2}{\alpha_2} \frac{C_1}{C_2}}$$

$$S_{C_2}^{\omega_o} = S_{\beta_1}^{\omega_o} = S_{\beta_1}^{\omega_o/Q_o} = 0$$

all of which are small.

SIMULATION RESULTS

To verify the theoretical analysis, the proposed circuit was used to realise lowpass, highpass, bandpass, notch and allpass filters. Although there are several ways to simulate the FTFNs required [1, 2, 5, 6, 11] and [14], the simulation results were obtained using the realization of the FTFN shown in Figure 2b. The FTFN consists of a 741 operational amplifier and the power-supply current-sensing technique proposed by Brinson and Faulkner [15], using the

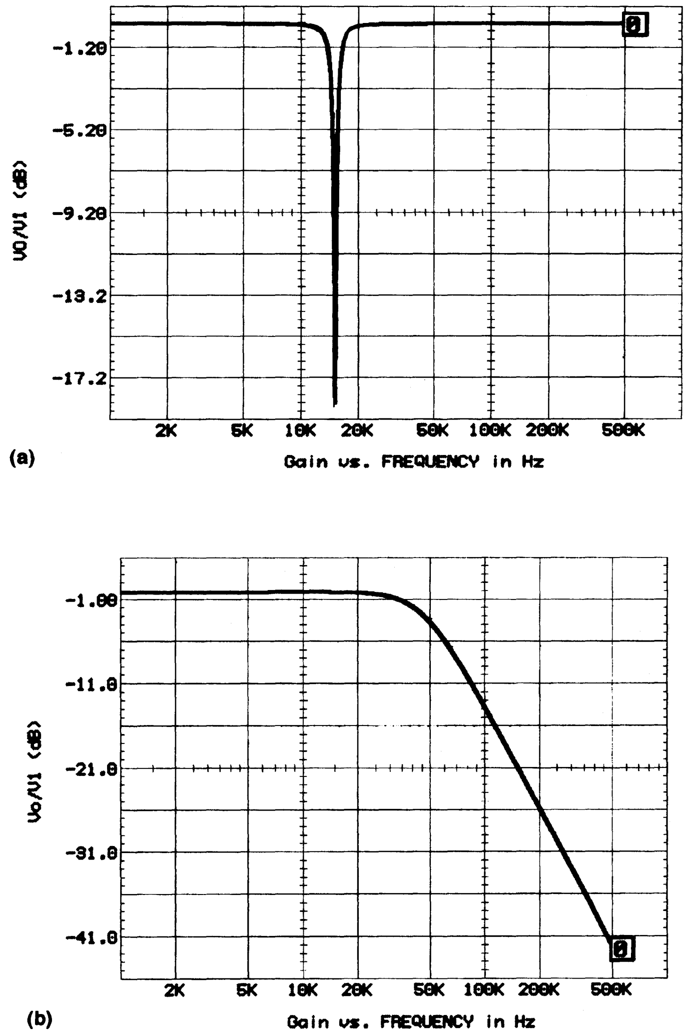

FIGURE 3 Simulation results obtained from the curcuit of Figure 1 with (a) Notch: $R_5 = 10K$, $R_3 = 1K$, $C_2 = 100PF$, $C_1 = 1nF$, $C_4 = 10nF$ (b) LPF: $R_5 = 5K$, $R_3 = 2.5K$, $C_1 = C_2 = C_4 = 1nF$ (c) BPF: $R_5 = 10K$, $R_3 = 1K$, $C_1 = 1nF$, $C_2 = 100PF$, $C_4 = 10nF$ (d)HPF:$R_5 = 5K$, $C_1 = C_2 = C_4 = 1nF$, $R_3 = 2.5K$.

QN2907 PNP and QN2222 NPN transistors. The simulation results obtained are shown in Figure 3 which agrees very well with the presented theory.

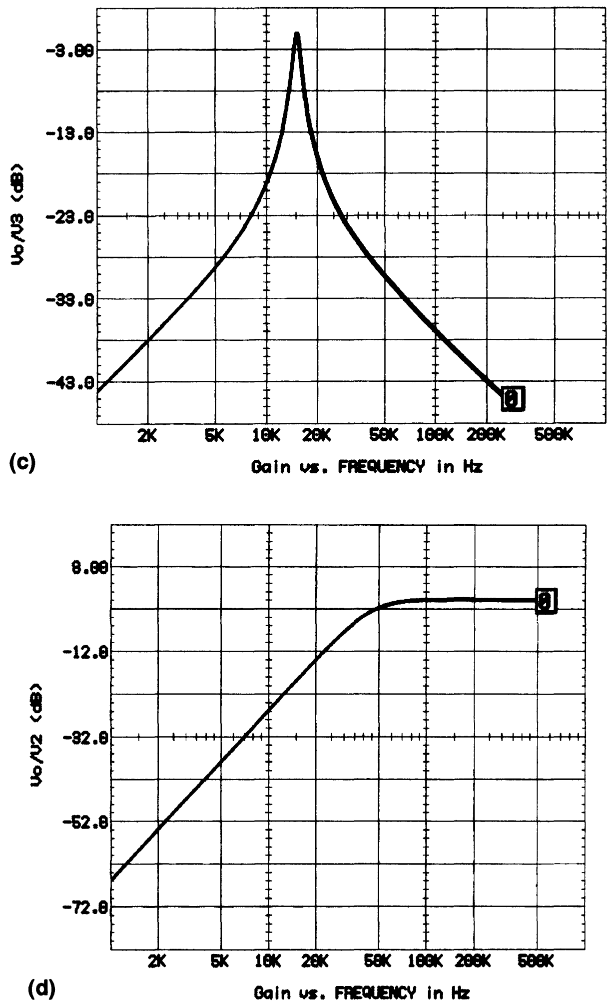

FIGURE 3 (Continued).

CONCLUSION

A universal active biquad circuit has been presented. The circuit has three input voltages, one output voltage and one high-impedance output current, and can realise lowpass, highpass, bandpass, notch and allpass transfer functions without any changes in the circuit topology. The proposed realisations enjoy the following advantages:

(i) Independent tuning of the parameters ω_o and ω_o/Q_o.
(ii) Low active and passive sensitivities.
(iii) Low active and passive component count; two FTFNs, three capacitors and two resistors only.
(iv) Simultaneous availability of output current and voltage.

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