CURRENT-MODE UNIVERSAL FILTER USING FTFNs

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A new current-mode universal filter is presented. The proposed filter uses three four-terminal floating nullors (FTFNs), three grounded capacitors, and four grounded resistors. The proposed filter has three inputs and one output and can realize lowpass, highpass, bandpass, notch, and allpass transfer functions without changing the circuit topology. The proposed filter enjoys low active and passive sensitivities and independent control of the parameters ω_0 and $\frac{\omega_0}{Q_0}$ using grounded elements.

INTRODUCTION

The four-terminal floating nullor (FTFN) is a more flexible and versatile building block than the operational amplifier and the current-conveyor [1–3]. This explains the growing interest in using the FTFN in designing current-amplifiers, voltage-to-current converters, gyrators, floating immittances [1,4–6], and more recently in designing current-mode active-RC filters [3,7–10] and sinusoidal oscillators [11,12]. In [3], a procedure is described for transforming voltage-mode circuits with operational amplifiers to current-mode circuits with FTFNs. Using this procedure, a current-mode lowpass transfer function is obtained from a Sallen-Key voltage-mode lowpass circuit. In [7], a stable grounded-capacitor, first-order allpass filter using an FTFN is presented. In [8], a cascable current-mode configuration using single FTFN is presented. This configuration can realize 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 realized without changing the circuit topology to achieve a specific filter function. In [9], a current-mode configuration using two FTFNs is presented. This configuration enjoys low active and passive sensitivities and can simultaneously realize lowpas/bandpass, or highpass/bandpass or bandpass/notch filters using two grounded capacitors. It can also realize an allpass filter. However, it requires a floating resistor and more importantly, its parameters ω_0 and ω_0/Q_0 are interdependent. Thus, it is impossible to adjust any of these two parameters without disturbing the other parameter. In [10], a cascadeable current-mode configuration using single FTFN enjoying low active and passive sensitivities is presented. This configuration can realize second-order lowpass, highpass, bandpass, allpass, and notch filters using six passive elements at most. These five filters, however, cannot be realized without changing the circuit topology to achieve a specific filter function.

Moreover, the parameters ω_0 and $\frac{\omega_0}{Q_0}$ are interdependent.

We present a new current-mode biquad filter structure using three FTFNs, three grounded capacitors and four grounded resistors. The circuit can realize second-order lowpass, highpass, bandpass, allpass, and notch filters without changing its topology. The proposed circuit enjoys the attractive features of low active and passive sensitivities and the independent control of the parameters ω_0 and ω_0/Q_0 using grounded elements.

PROPOSED CIRCUIT

The proposed circuit is shown in Fig. 1. Assuming that the port relations of the FTFN, shown in Fig. 2, can be expressed as $I_1 = I_2 = 0$, $V_2 = \beta V_1$ and $I_{O2} = \alpha I_{O1}$ where $\beta = 1 - \epsilon$, ($|\epsilon| \ll 1$), denote the voltage tracking error of the FTFN and $\alpha = 1 - \delta$, ($|\delta| \ll 1$), denotes the current-tracking error, routine analysis of the circuit shown in Fig. 1 yields the current-transfer function expressed by

$$I_0 = \frac{s^2 C_2 C_4 G_6 I_{in3} - s \frac{\beta_2}{\alpha_3} C_2 G_5 G_6 I_{in2} + \frac{\beta_2 \beta_3}{\alpha_1 \alpha_2 \alpha_3} G_3 G_5 G_6 I_{in1}}{s^2 C_2 C_4 G_6 + s \frac{\beta_1 \beta_2 \beta_3}{\alpha_1 \alpha_2 \alpha_3} C_1 G_3 G_5 + \frac{\beta_1 \beta_2 \beta_3}{\alpha_1 \alpha_2 \alpha_3} G_1 G_3 G_5} \quad (1)$$

where β_i , α_i , $i = 1 - 3$, are the voltage- and current-tracking errors of the i th FTFN.

FIGURE 1 Proposed multiple-input Single-output current-mode Universal filter

FIGURE 2 Nullor model of the FTFN

From (1) the parameters ω_0 and $\frac{\omega_0}{Q_0}$ can be expressed as

$$\omega_0^2 = \frac{\beta_1 \beta_2 \beta_3}{\alpha_1 \alpha_2 \alpha_3} \frac{G_1 G_3 G_5}{C_2 C_4 G_6} \quad (2)$$

and

$$\frac{\omega_0}{Q_0} = \frac{\beta_1 \beta_2 \beta_3}{\alpha_1 \alpha_2 \alpha_3} \frac{C_1 G_3 G_5}{C_2 C_4 G_6} \quad (3)$$

From (1), it can be seen that:

- i. the lowpass response can be realized with $I_{in2} = I_{in3} = 0$,
- ii. the highpass response can be realized with $I_{in1} = I_{in2} = 0$,
- iii. the bandpass response can be realized with $I_{in1} = I_{in3} = 0$
- iv. the notch response can be realized with $I_{in2} = 0$, and $I_{in1} = I_{in3}$
- v. the allpass response can be realized with

$$I_{in1} = I_{in2} = I_{in3} \text{ and } G_1 = G_3 = G_6, C_1 = C_2.$$

From (1), it can be seen that the lowpass gain, the highpass gain and the bandpass gain are approximately given by

$$G_{LP} \cong \frac{G_6}{G_1} \quad (4)$$

$$G_{HP} \cong 1 \quad (5)$$

and

$$G_{BP} \cong \frac{C_2 G_6}{C_1 G_3} \quad (6)$$

From (2) and (3), it can be seen that the parameter ω_0 can be adjusted by controlling the resistor $R_I = \frac{1}{G_1}$ without disturbing the parameter $\frac{\omega_0}{Q_0}$.

Moreover, the parameter $\frac{\omega_0}{Q_0}$ can be adjusted by controlling the capacitor C_I without disturbing the parameter $\frac{\omega_0}{Q_0}$. Thus, the proposed circuit enjoys independent control of the parameters ω_0 and $\frac{\omega_0}{Q_0}$.

From (2) and (3), it is easy to show that the active and passive sensitivities of the parameters ω_0 and Q_0 are

$$S_{\alpha_1}^{\omega_0} = S_{\alpha_2}^{\omega_0} = S_{\alpha_3}^{\omega_0} = -S_{\beta_1}^{\omega_0} = -S_{\beta_2}^{\omega_0} + = -S_{\beta_3}^{\omega_0} = -\frac{1}{2}$$

$$S_{C_2}^{\omega_0} = S_{C_4}^{\omega_0} = S_{G_6}^{\omega_0} = -S_{G_1}^{\omega_0} = -S_{G_3}^{\omega_0} + = -S_{G_5}^{\omega_0} = -\frac{1}{2}$$

$$S_{\alpha_1}^{Q_0} = S_{\alpha_2}^{Q_0} = S_{\alpha_3}^{Q_0} = S_{\beta_1}^{Q_0} = -S_{\beta_2}^{Q_0} + = -S_{\beta_3}^{Q_0} = \frac{1}{2}$$

$$S_{C_2}^{Q_0} = S_{C_4}^{Q_0} = S_{G_6}^{Q_0} = S_{G_3}^{Q_0} = -S_{G_5}^{Q_0} = \frac{1}{2}$$

$$S_{C_1}^{Q_0} = -1, S_{C_1}^{\omega_0} = 0,$$

all of which are small.

EXPERIMENTAL RESULTS

To verify the theoretical analysis, the proposed circuit was used to realize lowpass, highpass, bandpass, notch, and allpass filters. Although there are several ways to implement the FTFNs required [1,2,4,5,11,13], the experimental results were obtained using the two-current conveyor realization of

FIGURE 3 FTFN realization using two CCII's

the FTFN proposed in [5] and shown in Fig. 3. This realization was adopted because it provides very high impedances at the z - and w -terminals. Thus, while the FTFNs in Fig. 1 are configured as second-generation current conveyors (CCII's), these CCII's have very high impedances at ports x , y , and z . This avoids the conversion errors or the incorrect transfer functions resulting from parasitic resistances at port x of conventional CCII's. The experimental results obtained are shown in Fig. 4, which agrees very well with the presented theory.

FIGURE 4 Measured and Calculated characteristics of the LPF, HPF and BPF obtained from the circuit of Fig. 1.

$R_1 = R_3 = R_5 = R_6 = 5 \text{ K}\Omega$, $C_1 = C_2 = C_4 = 1.2 \text{ nF}$

• : Measured — : Calculated

CONCLUSION

A universal current-mode filter has been presented. The circuit has three inputs and one output and can realize lowpass, highpass, bandpass, notch, and allpass transfer functions without any changes in the circuit topology. The proposed filter enjoys the following advantages:

- i. All the passive elements are grounded
- ii. Independent tuning of the parameters ω_0 and $\frac{\omega_0}{Q_0}$.
- iii. Low active and passive sensitivities.

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