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Current-mode universal biquadratic filter with single input and four outputs using FTFNs

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A novel four terminal floating nullor (FTFN) based universal current-mode (CM) biquadratic filter configuration with single input and four outputs (SIFO) is presented**.** The circuit is based on and employs six FTFNs of the same polarity and as many passive components and realizes simultaneously lowpass (LP), highpass (HP), inverted bandpass (BP) and Notch filtering functions without any imposition of component matching conditions or cancellation constraints. The circuit can also be made to realize allpass (AP) response by tying together appropriate output filtering signals. The topology has the distinct feature of low input and high output impedances which permits easy cascading for the construction of higher order filters. The circuit enjoys low passive sensitivity figures. The resonance frequency ω_o and bandwidth ω_o/Q can be independently tuned while as resonance frequency ω_o and quality factor Q can be orthogonally adjusted. Experimental and PSPICE simulation results are given to confirm the theoretical results.

[**Keywords:** Universal filter, Biquadratic filters, Current-mode filters, Four terminal floating nullors, Filtering functions]

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The current-mode approach is playing an increasingly important role in the development of many new high performance circuits for signal processing applications owing to their advantages over the voltage-mode counterparts in terms of higher frequency operation, wider bandwidth and simpler structures. Recently, more attention has been given to the use of FTFN, a current-mode active device which is more flexible, versatile and stable element than an operational amplifier (OA) and second-generation current[1-5] conveyor (CCII) in the construction of analogue filtering circuits. Many FTFN based current-mode filters have been reported[6-16], but the one with single input and four outputs (SIFO) yielding LP, HP, BP and Notch filtering responses simultaneously in CM configuration and having low input and high output impedances has not been reported in the literature so far. Further the reported[14] low input and high output CM universal filter with single input and three outputs using four FTFNs and four passive components implements only LP, HP and inverted BP responses while Notch filtering signal is realized by connecting the corresponding nodes. The reported circuit realizes only allpass (AP) filtering signal when all the outputs are tied together. Further the resonance frequency ω_0 and bandwidth ω_0/Q in the reported circuit are devoid of independent tunability feature.

In this note, a universal cascadable current-mode filter configuration implementing four different filtering functions simultaneously is proposed. Based on and employing six FTFNs of the same polarity and as many passive components the circuit realizes LP, HP, inverted BP and Notch responses simultaneously without any component matching conditions and/or cancellation constraints. The circuit can also be made to realize AP filtering function by connecting together Notch and inverted BP responses or LP, HP and inverted BP filtering functions. The configuration has low input impedance and high output impedance which is an ideal feature for employing it in the construction of higher order filters through cascading. The topology enjoys low passive sensitivity figures. The resonance frequency ω_o and bandwidth ω_0/Q can be independently tuned while as resonance frequency ω_0 and quality factor Q can be orthogonally controlled.

Circuit analysis—The port relations of positive FTFN are characterized by $V_X = V_Y$, $I_X = I_Y = 0$ and $I_W = I_Z$. By the routine circuit analysis of the current model configuration shown in Fig. 1 yields the following equations:

$$I_{in} = -V_1 G_1 - V_2 sC_4 \qquad \ldots (1)$$

$$(V_2 - V_1)G_6 = V_3 sC_5 \qquad \ldots (2)$$

$$V_2 sC_4 = -V_3 G_3 \qquad \ldots (3)$$

$$I_{in} = -V_1 \left[\frac{s^2 C_4 C_5 G_1 + sC_4 G_3 G_6 + G_1 G_3 G_6)}{s^2 C_4 C_5 + G_3 G_6} \right] \qquad \ldots (4)$$

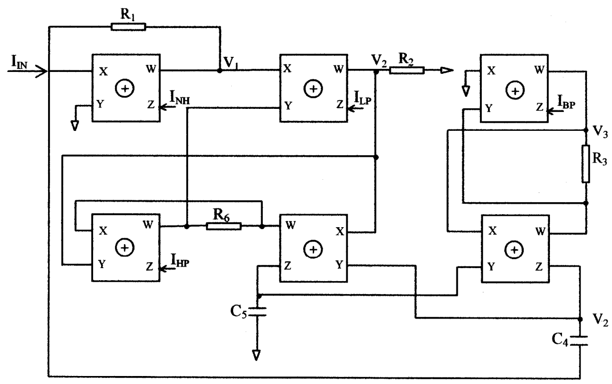

Fig. 1—Proposed CM filter configuration

$$I_{LP} = -V_2 G_2 \qquad \dots (5)$$

$$I_{HP} = -V_3 s C_5 \qquad \dots (6)$$

$$I_{BP} = -V_3 G_3 \qquad \dots (7)$$

$$I_{NH} = -V_1 G_1 \qquad \dots (8)$$

Using Eqs (2)-(5) we get lowpass transfer function as given by

$$\frac{I_{LP}}{I_{in}} = \left(\frac{G_2}{G_1}\right) \frac{G_1 G_3 G_6}{s^2 C_4 C_5 G_1 + s C_4 G_3 G_6 + G_1 G_3 G_6} \qquad \dots (9)$$

Similarly, we get highpass, bandpass and Notch transfer functions as given by:

$$\frac{I_{HP}}{I_{in}} = \left(\frac{G_6}{G_1}\right) \frac{s^2 C_4 C_5 G_1}{s^2 C_4 C_5 G_1 + s C_4 G_3 G_6 + G_1 G_3 G_6} \qquad \dots (10)$$

$$\frac{I_{BP}}{I_{in}} = -\frac{s C_4 G_3 G_6}{s^2 C_4 C_5 G_1 + s C_4 G_3 G_6 + G_1 G_3 G_6} \qquad \dots (11)$$

$$\frac{I_{NH}}{I_{in}} = \frac{G_1 (s^2 C_4 C_5 + G_3 G_6)}{s^2 C_4 C_5 G_1 + s C_4 G_3 G_6 + G_1 G_3 G_6} \qquad \dots (12)$$

By interconnecting I_{NH} and $-I_{BP}$ and treating the common node thus created as the output node, AP response can also be realized. In realizing the filtering responses it can be seen from the above equations that no component matching or cancellation constraints are imposed. The AP response can also be realized by interconnecting $I_{LP}, -I_{BP}$ and I_{HP} but it involves component matching. From Eqs (1) and (2), the passband gains for LP and HP responses are respectively given by

$$G_{LP} = \frac{G_2}{G_1} = \frac{R_1}{R_2} \qquad \dots (13)$$

$$G_{HP} = \frac{G_6}{G_1} = \frac{R_1}{R_6} \qquad \dots (14)$$

The filtering parameters ω_o, ω_0 / Q and Q are given by

$$\omega_O = \sqrt{\frac{G_3 G_6}{C_4 C_5}} \qquad \dots (15)$$

$$\frac{\omega_O}{Q} = \frac{G_3 G_6}{G_1 C_5} \qquad \dots (16)$$

$$Q = G_1 \sqrt{\frac{C_5}{G_3 G_6 C_4}} \qquad \dots (17)$$

An examination of Eqs (15) and (16) shows that ω_O can be tuned independent of ω_0 / Q by capacitor C_4 while as ω_0 / Q can be adjusted independent of ω_0 by the resistor R_1. Also one can see from Eqs (15) and (17) that ω_O and Q can be orthogonally tuned by one of the passives involved in ω_O and Q by R_1 in that order. The sensitivity figures are given by:

$$S^{\omega o}_{G3,G6} = -S^{\omega o}_{C4,C5} = \frac{1}{2}$$

$$S^{Q}_{C5} = -S^{Q}_{C4,G3,G6} = \frac{1}{2}$$

$$S^{Q}_{G1} = 1$$

which are small.

Experimental and simulation results—To evaluate the performance of the proposed circuit, experimental

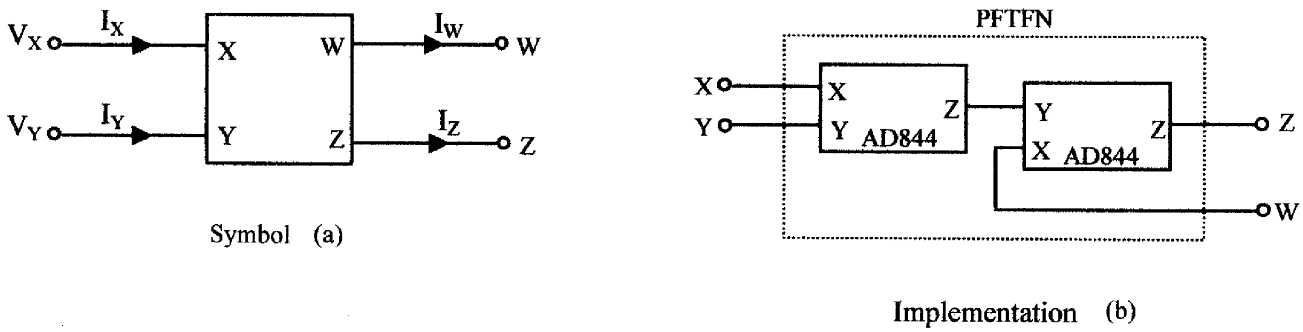

Fig. 2—Realization of positive FTFN

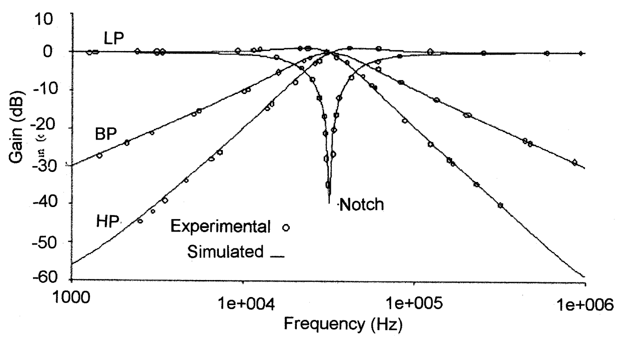

Fig. 3—Experimental and simulated, LP, BP, HP and Notch responses

and PSPICE simulation program was carried out with component values $C_4 = C_5 = 5\text{nF}$ and $R_1 = R_2 = R_3 = R_6 = 1\text{k}\Omega$. This choice leads to the resonant frequency $f_0 = 3.18 \times 10^4\,\text{Hz}$ and quality factor $Q = 1$. For experimental purpose the FTFN was constructed using commercially available current feedback op-amp IC AD844s and in PSPICE macromodals of AD844 supported by Analog Devices, Inc. were used. The FTFN with positive polarity can be implemented by cascading[17-18] two AD844 as shown in Fig. 2. The experimental and simulated responses depicted in Fig. 3 for LP, HP, BP and Notch filtering signals have been found in close conformity and agree well with the preceding theoretical analysis.

Conclusion—A new FTFN based universal current-mode biquadratic filter circuit with one input and four outputs has been presented. The circuit enjoys the following salient features:

The versatility to synthesize LP, BP, HP and Notch filtering responses simultaneously without any component matching or cancellation constraints; the configuration offers two alternatives of realizing AP filter response; very low input impedance and very high output impedance— an ideal state for using it in cascading to implement higher order filters; low passive sensitivity figures; independent tuning of the parameters ω_0 and ω_0/Q; orthogonal tuning of the parameters ω_0 and Q and employs FTFNs of the same polarity.

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