

# Voltage-mode filter with one input and six outputs using two ICCIIs

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**Abstract:** A novel voltage-mode multifunction biquadratic filter with one input and six outputs is presented. The proposed circuit uses two inverting second-generation current conveyors (ICCIIs), two grounded capacitors, and four resistors. The circuit offers realizing inverting and non-inverting lowpass, bandpass, and highpass filters, simultaneously, without component matching conditions, using grounded capacitors and low active and passive sensitivities. Experimental results are provided to demonstrate the theoretical analysis.

**Keywords:** voltage-mode circuit, filters, ICCII

**Classification:** Integrated circuits

## References

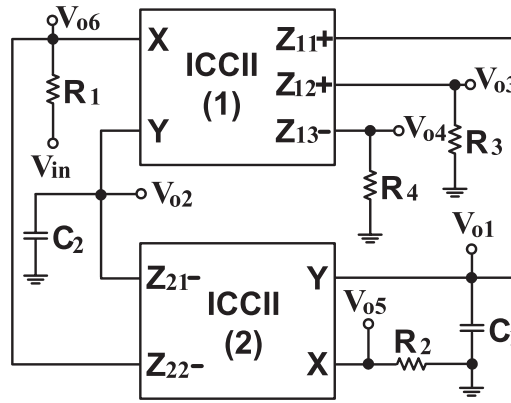
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## 1 Introduction

Multifunction biquadratic filters play an important role in the fields of engineering areas, such as a crossover network consists of a lowpass, a bandpass, and a highpass filter [1, 2]. Thus, numerous voltage-mode multifunction biquadratic filters have received significant attention in technical literature [2, 3, 4, 5, 6, 7]. However, none of these filters simultaneously realizes both inverting and non-inverting type lowpass, bandpass, and highpass responses. The inverting second-generation current conveyor (ICCI) was proposed by Awad and Soliman [8] and has been found useful in many applications [9, 10, 11, 12]. An interesting ICCI-based voltage-mode multifunction biquadratic filter with single input and six outputs employing two grounded capacitors and four resistors is proposed [13]. This filter simultaneously realizes inverting and non-inverting lowpass, bandpass, and highpass filtering responses in the same configuration. It also does not require passive element matching conditions and has low active and passive sensitivity performances. However, the X ports of the ICCIs in this circuit design are connected to capacitors and cannot absorb the parasitic capacitances at the Z or/and Y terminals of the ICCIs. Because the ICCI has a non-negligible output parasitic resistance on port X ( $R_X$ ), when the X port of ICCI is loaded by a capacitor, it leads to an improper transfer functions. Due to the effect of this parasitic resistance  $R_X$  at the X port of ICCI, the circuits with X port loaded by a capacitor do not exhibit good performance at high frequency [12, 13]. In this paper, a new voltage-mode multifunction biquadratic filter with single input and six outputs is presented. The proposed circuit employs two ICCIs, two grounded capacitors and four resistors. The inverting and non-inverting lowpass, bandpass, and highpass filtering responses can be obtained simultaneously. The proposed circuit does not require passive element matching conditions and has low active and passive sensitivity performances. With respect to the previous ICCI-based inverting and non-inverting lowpass, bandpass and highpass multifunction biquad in [13], the X ports of the ICCIs in the proposed circuit are connected to resistors. This design offers the feature of a direct incorporation of the parasitic resistance at the X ports of the ICCIs  $R_X$ , as a part of the main resistance. Moreover, the two external capacitors are grounded and can absorb the parasitic capacitances at the Z or/and Y terminals of the ICCIs.

## 2 Proposed ICCI-based multifunction biquad structure

The ICCI can be characterized by the port relations with  $I_Y = 0$ ,  $V_X = -V_Y$ ,  $I_{Z+} = I_X$  and  $I_{Z-} = -I_X$  [9, 10]. It is considered to be a special case from the differential voltage current conveyor with single Y input only [10]. The proposed configuration is shown in Fig. 1. It employs two multi-output ICCIs, two grounded capacitors and four resistors. The use of grounded capacitors is attractive from monolithic integration point of view because grounded capacitor circuits can compensate for the stray capacitances at their nodes [13]. Because each X-terminal of the ICCI in the proposed circuit of



**Fig. 1.** Proposed multifunction voltage-mode biquad configuration.

Fig. 1 is directly connected to an external resistor, the effect of parasitic resistance  $R_X$  can easily be absorbed as a part of the main resistance. Straightforwardly analyzing the filter in Fig. 1, the following six filter voltage transfer functions can be simultaneously derived as:

$$\frac{V_{o1}}{V_{in}} = \frac{-sC_2R_2}{s^2C_1C_2R_1R_2 + sC_2R_1 + 1} \quad (1)$$

$$\frac{V_{o2}}{V_{in}} = \frac{-1}{s^2C_1C_2R_1R_2 + sC_2R_1 + 1} \quad (2)$$

$$\frac{V_{o3}}{V_{in}} = -\left(\frac{R_3}{R_1}\right) \frac{s^2C_1C_2R_1R_2}{s^2C_1C_2R_1R_2 + sC_2R_1 + 1} \quad (3)$$

$$\frac{V_{o4}}{V_{in}} = \left(\frac{R_4}{R_1}\right) \frac{s^2C_1C_2R_1R_2}{s^2C_1C_2R_1R_2 + sC_2R_1 + 1} \quad (4)$$

$$\frac{V_{o5}}{V_{in}} = \frac{sC_2R_2}{s^2C_1C_2R_1R_2 + sC_2R_1 + 1} \quad (5)$$

$$\frac{V_{o6}}{V_{in}} = \frac{1}{s^2C_1C_2R_1R_2 + sC_2R_1 + 1} \quad (6)$$

Clearly, the filter simultaneously realizes second order inverting and non-inverting lowpass, bandpass, and highpass filtering responses without requiring any passive component matching condition. The resonance angular frequency ( $\omega_o$ ), the quality factor ( $Q$ ) and bandwidth ( $BW$ ) are given by

$$\omega_o = \sqrt{\frac{1}{R_1R_2C_1C_2}}, \quad Q = \sqrt{\frac{R_2C_1}{R_1C_2}}, \quad BW = \frac{\omega_o}{Q} = \frac{1}{R_1C_1} \quad (7)$$

The bandwidth can be controlled by  $R_1$ . The resonance angular frequency can be orthogonally controlled by  $R_2$ .

By taking into account the non-idealities of ICCII, the relationship of the terminal voltages and currents can be rewritten as  $V_X = -\beta V_Y$ ,  $I_{Z+} = +\alpha I_X$ , and  $I_{Z-} = -\eta I_X$ , where  $\beta = 1 - \varepsilon_v$  and  $\varepsilon_v$  ( $|\varepsilon_v| \ll 1$ ) denotes the voltage tracking error from Y terminal to X terminal of the ICCII,  $\alpha = 1 - \varepsilon_{\alpha i}$  and  $\varepsilon_{\alpha i}$  ( $|\varepsilon_{\alpha i}| \ll 1$ ) is the current tracking error from X terminal to Z+ terminal of the ICCII, and  $\eta = 1 - \varepsilon_{\eta i}$  and  $\varepsilon_{\eta i}$  ( $|\varepsilon_{\eta i}| \ll 1$ ) is the current tracking error from X terminal to Z- terminal of the ICCII. Thus, reanalysis of the proposed circuit

in Fig. 1 yields the denominator of the non-ideal voltage transfer functions as follows:

$$s^2 C_1 C_2 R_1 R_2 + \alpha_{11} \eta_{22} \beta_2 s C_2 R_1 + \alpha_{11} \eta_{21} \beta_1 \beta_2 \quad (8)$$

The filter parameters for the non-ideal  $\omega_o$  and  $Q$  are obtained as:

$$\omega_o = \sqrt{\frac{\alpha_{11} \eta_{21} \beta_1 \beta_2}{R_1 R_2 C_1 C_2}}, \quad Q = \frac{1}{\eta_{22}} \sqrt{\frac{\eta_{21} \beta_1 R_2 C_1}{\alpha_{11} \beta_2 R_1 C_2}} \quad (9)$$

The active and passive sensitivities of  $\omega_o$  and  $Q$  of the proposed filter are

$$S_{\alpha_{11}, \eta_{21}, \beta_1, \beta_2}^{\omega_o} = -S_{R_1, R_2, C_1, C_2}^{\omega_o} = \frac{1}{2} \quad (10)$$

$$S_{\eta_{11}, \beta_1}^Q = -S_{\alpha_{11}, \beta_2}^Q = S_{R_2, C_1}^Q = -S_{R_1, C_2}^Q = \frac{1}{2}, \quad S_{\eta_{22}}^Q = -1 \quad (11)$$

all of which are low and not larger than unity in absolute value.

If the  $X$ -terminal parasitic resistors  $R_{X_i}$  ( $i = 1, 2$ ) of the  $i$ th ICCII are considered, the denominator of the voltage transfer functions,  $\omega_o$  and  $Q$  can be modified as follows.

$$D(s) = s^2 C_1 C_2 R_1 (R_2 + R_{X2}) \left(1 + \frac{R_{X1}}{R_1}\right) + s C_2 R_1 + 1 \quad (12)$$

$$\omega_o = \sqrt{\frac{1}{R_1 (R_2 + R_{X2}) \left(1 + \frac{R_{X1}}{R_1}\right) C_1 C_2}} \quad (13)$$

$$Q = \sqrt{\frac{(R_2 + R_{X2}) \left(1 + \frac{R_{X1}}{R_1}\right) C_1}{R_1 C_2}} \quad (14)$$

If the conditions of  $R_2 \gg R_{X2}$  and  $1 \gg \frac{R_{X1}}{R_1}$  are satisfied, the influence of the ICCIIs parasitic resistors on the proposed filter in Fig. 1 can be ignored. Hence, the external resistors can be chosen to be much greater than the parasitic resistors at the  $X$  terminals of ICCIIs.

### 3 Experimental results

To verify the theoretical analysis, we implemented the proposed circuit in Fig. 1 by using commercially available AD844-type [14] of CFOAs with  $\pm 10$  V DC power supply. The triple-output ICCII and dual-output ICCII were

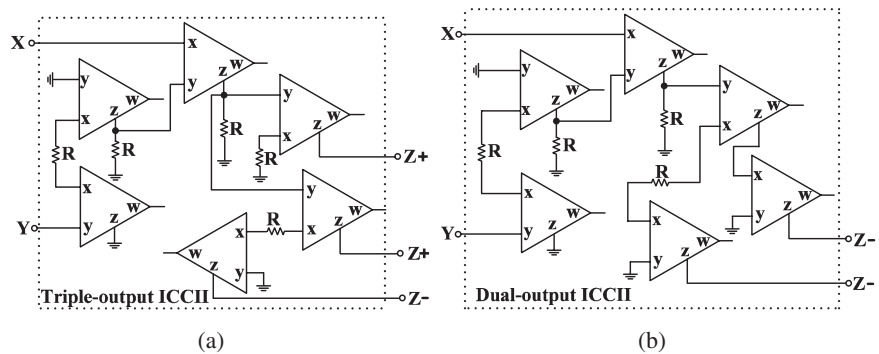
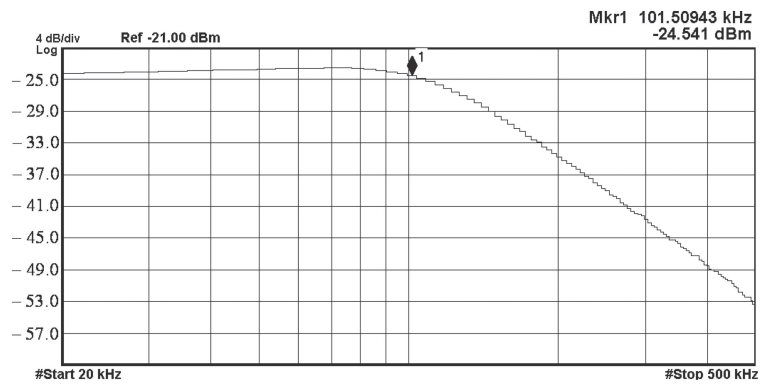


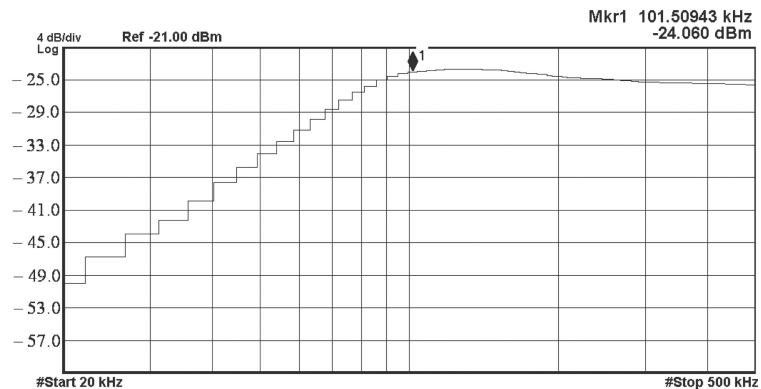
Fig. 2. Multi-output ICCII realized using AD844s.



**Fig. 3.** Experimental results of bandpass filter at  $V_{o1}$ .

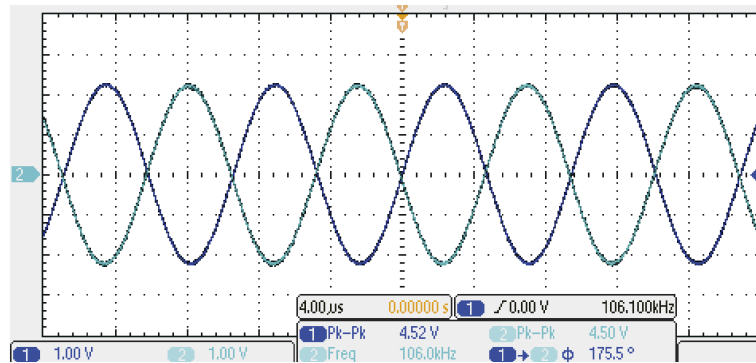


**Fig. 4.** Experimental results of bandpass filter at  $V_{o2}$ .



**Fig. 5.** Experimental results of bandpass filter at  $V_{o3}$ .

implemented by Figs. 2(a) and (b), respectively. The passive elements in the proposed filter were selected as  $R_1 = R_2 = R_3 = R_4 = 10 \text{ k}\Omega$ , and  $C_1 = C_2 = 150 \text{ pF}$  for a center frequency of  $f_o = 106.1 \text{ kHz}$ . The subsequent experimental measurements were carried out using Agilent N9000A CXA signal analyzer. Figs. 3–5 show the frequency responses of the measurement results for the inverting bandpass ( $V_{o1}$ ), inverting lowpass ( $V_{o2}$ ) and inverting high-pass ( $V_{o3}$ ) filters, respectively. The results confirm the theoretical analyses. The difference between the theoretical and measured results mainly stems from the parasitic impedance effects and non-ideal gains of AD844s. In



**Fig. 6.** The time domain input (channel 1) and output (channel 2) signal waveforms of  $V_{o6}$ .

addition, the time domain bandpass response of the proposed filter was also investigated by applying a 4.5 V peak to peak input voltage sinusoidal at frequency 106.1 kHz. Fig. 6 shows the input (channel 1) and output (channel 2) waveforms of the inverting bandpass response at  $V_{o1}$  output terminal. The obtained results show that the input dynamic of the filter extends up to amplitude of 4.5 V peak to peak without signification distortion. The phase error for the inverting bandpass response is less than 2.5%.

#### 4 Conclusion

A novel voltage-mode multifunction biquadratic filter is presented. The circuit offers several advantages, such as no requirements for component-matching conditions, the simultaneous realization of inverting and noninverting lowpass, bandpass, and highpass responses from the same configuration, the use of only grounded capacitors, and low active and passive sensitivity performances. The proposed circuit has the same advantages reported by [13] which using two ICCIIs, two grounded capacitors and four resistors. Moreover, the proposed circuit has one more important advantage of direct incorporation of the parasitic resistance at the X terminal of the ICCII as a part of the main resistance. The two external capacitors are grounded and can absorb the parasitic capacitances at the Z or/and Y terminals of the ICCIIs. Experimental results of this filter have been included.