A novel universal current-mode filter with three inputs and one high imedance output is presented. The proposed circuit uses four plus-type second-generation current-conveyors, grounded resistors and grounded capacitors. The proposed circuit enjoys low active and passive sensitivities and independent control of the parameters \( \omega_0 \) and \( Q_0 \) using grounded resistors.

**Keywords:** Current conveyors; active filters

**INTRODUCTION**

Recently, Chang, Chien and Wang, 1994, proposed a universal active current filter with three inputs and one output using current conveyors. The proposed circuit uses two plus-type first-generation current-conveyors, two minus-type second-generation current conveyors, two grounded capacitors and two grounded resistors and enjoys the following attractive features:

1. Low filter sensitivity to passive components.
2. The use of grounded capacitors which is attractive for integrated circuit implementation.

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3. The versatility to synthesize virtually any type of active filter transfer function.

However, the circuit suffers from the following disadvantages:

1. Use of different types of current conveyors.
2. Interdependent control of the parameters $\omega_0$ and $\omega_0/Q_o$. Thus, while the parameter $\omega_0$ can be adjusted without disturbing the parameter $\omega_0/Q_o$, the parameter $\omega_0/Q_o$ cannot be adjusted without disturbing the parameter $\omega_0$.
3. The sensitivity of the circuit to the voltage and current tracking errors of the current conveyors is not clear.

This paper presents a novel three-input universal current-mode biquad active filter. The proposed circuit enjoys the following attractive features:

1. Use of one type of second-generation current-conveyor.
2. Independent control of the parameters $\omega_0$ and $\omega_0/Q_o$. Thus the parameter $\omega_0$ can be adjusted without disturbing the parameter $\omega_0/Q_o$, and the parameter $\omega_0/Q_o$ can be adjusted without disturbing the parameter $\omega_0$.
3. Enjoys low active and passive sensitivities.
4. Use of grounded capacitors and grounded resistors.

**PROPOSED CIRCUIT**

The proposed circuit is shown in Figure 1. The circuit uses plus-type second-generation current-conveyors (CCII+) only. Using the standard notation, the CCII+ characteristics can be described by $i_x = \alpha i_y$, $\nu_x = \beta \nu_y$, where $\alpha = 1 - \varepsilon_i$ and $\varepsilon_i$ denotes the current-tracking error, $\beta = 1 - \varepsilon_v$ and $\varepsilon_v$ denotes the voltage-tracking error. The single output current $I_o$ can be expressed as

$$I_o = \frac{\alpha_4 \beta_4 G_2 s^2 C_1 C_2 \alpha_2 \beta_2 I_3 - s C_1 G_4 \alpha_2 \beta_2 I_2 + G_2 G_4 \alpha_1 \alpha_2 \alpha_3 \beta_3 I_1}{s^2 C_1 C_6 + s C_1 G_6 + G_2 G_5 \alpha_1 \alpha_2 \alpha_3 \beta_1 \beta_3}$$  \hspace{1cm} (1)

From (1) the parameters $\omega_0$ and $\omega_0/Q_o$ can be expressed as

$$\omega_0^2 = \frac{\alpha_1 \alpha_2 \alpha_3 \beta_1 \beta_3 G_2 G_5}{C_1 C_6}$$  \hspace{1cm} (2)
From (1) it can be seen that:

1. The lowpass response can be realised with $I_2 = I_3 = 0$
2. The highpass response can be obtained with $I_1 = I_2 = 0$
3. The bandpass response can be obtained with $I_1 = I_3 = 0$
4. The notch response can be obtained with $I_2 = 0$ and $I_1 = I_3$
5. The allpass response can be obtained with $I_1 = I_2 = I_3$, $G_4 = G_5$ and $C_3 = C_6$.

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

$$G_{LP} \approx \frac{G_7}{G_5}$$

(4)
and

\[ G_{BP} \cong \frac{G_7}{G_6} \]  \hspace{1cm} (6)

From (2) – (6) it can be seen that the parameter \( \omega_o \) can be adjusted by controlling the resistance \( R_2 = 1/G_2 \) without disturbing the parameters \( \omega_o/Q_o \), \( G_{LP} \), \( G_{HP} \) and \( G_{BP} \). Also, the highpass gain can be adjusted by controlling the resistance \( R_4 = 1/G_4 \) without disturbing the parameters \( \omega_o, \omega_o/Q_o, G_{LP} \) and \( G_{BP} \). Moreover, the parameter \( \omega_o/Q_o \) can be adjusted by controlling the resistance \( R_6 = 1/G_6 \) without disturbing the parameter \( \omega_o \). However, controlling the resistance \( R_6 \) will disturb the bandpass gain \( G_{BP} \). A possible strategy for adjusting the parameters \( \omega_o, \omega_o/Q_o, G_{LP}, G_{HP} \) and \( G_{BP} \) is, therefore, as follows: First the resistance \( R_6 = 1/G_6 \) is controlled to adjust the parameter \( \omega_o/Q_o \), then the resistor \( R_7 = 1/G_7 \) is controlled to adjust the bandpass gain \( G_{BP} \); the resistance \( R_4 = 1/G_4 \) is controlled to adjust the highpass gain \( G_{HP} \); the resistance \( R_5 = 1/G_5 \) is controlled to adjust the lowpass gain \( G_{LP} \), and finally the resistance \( R_2 = 1/G_2 \) is adjusted to control the parameter \( \omega_o \).

From (2) and (3) it is easy to show that the active and passive sensitivities of the parameters \( \omega_o \) and \( Q_o \) are

\[
S^\omega_{R_2} = S^\omega_{R_5} = S^\omega_{C_1} = S^\omega_{C_6} = -S^\omega_{\alpha_1} = -S^\omega_{\alpha_2} = -S^\omega_{\alpha_3} \]
\[= -S^\omega_{\beta_1} = -S^\omega_{\beta_2} = -S^\omega_{\beta_3} = \frac{1}{2} \]

\[
S^Q_{R_2} = S^Q_{R_5} = S^Q_{C_1} = S^Q_{C_6} = -S^Q_{\alpha_1} = -S^Q_{\alpha_2} \]
\[= -S^Q_{\alpha_3} = -S^Q_{\beta_1} = -S^Q_{\beta_2} = 0 \]

\[
S^\omega_{R_6} = 1, \quad S^\omega_{\alpha_4} = S^\omega_{\beta_4} = S^Q_{\alpha_4} = S^Q_{\beta_4} = S^\omega_{\beta_2} = S^Q_{\beta_2} = 0 \]
\[ S^\omega_{R_4} = S^Q_{R_4} = S^Q_{R_5} = S^\omega_{R_5} = 0 \]

Thus, all the active and passive sensitivities are no more than unity.
It is worth mentioning here that, another output current can be obtained when $I_1=0$. By using an additional second-generation current-conveyor and a grounded resistor as shown in the dotted box of Figure 1; this addition is, however, optional, the new output current can be expressed as

$$I_{out} = \alpha_3\alpha_4\beta_3\beta_4 \frac{G_8 G_5}{G_7 sC_1} I_o$$

(7)

Thus, when $I_o$ is realising a bandpass response, the current $I_{out}$ will realise a lowpass response. Also, when $I_o$ is realising a highpass response, the current $I_{out}$ will realise a bandpass response.

**EXPERIMENTAL RESULTS**

To verify the theoretical analysis, the proposed circuit was used to realise LP, HP, BP and notch filters using the AD844 current-conveyor.

**FIGURE 2** Measured lowpass, highpass and notch responses. $C_1 = C_3 = C_6 = 470\,\text{PF}$, $R_2 = 4\,\text{K}$, $R_4 = R_5 = R_6 = R_7 = 5\,\text{K}$. 
The results obtained with $C_1 = C_3 = C_6 = 470 \text{ pF}$, $R_2 = 4\text{K}$, $R_4 = R_5 = R_6 = R_7 = 5\text{K}$ are shown in Figure 2. These results are in good agreement with the theoretical analysis.

**CONCLUSION**

A new universal current-mode filter has been presented. The proposed filter offers the following advantages:

(i) Use only one type of current-conveyors (CCII+).
(ii) All resistors and capacitors are grounded.
(iii) Low active and passive sensitivities.
(iv) Independent control of the parameters $\omega_o$ and $\omega_o/Q_o$ using grounded resistors.
(v) High output impedance.
(vi) All the standard filter functions are realised with no component matching requirement except for all allpass realisation.

**References**

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