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Current-Mode multifunction filter employing two Differential Difference Current Conveyors

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ABSTRACT

A filtering circuit configuration using two Differential Difference Current Conveyors (DDCCs) as active elements together with three/four resistors and three/four grounded capacitors is presented. The proposed network offers the following advantages: (i) realization of current-mode lowpass, highpass, bandpass, notch and allpass filtering from the same configuration; (ii) only two active elements; (iii) low passive sensitivity; (iv) without current tracking errors; and (v) use of only grounded capacitors which is suitable for integrated circuit implementation. Four experimental results are included to certify the theoretical prediction.

Key words: ***Differential Difference Current Conveyor, sensitivity, analog circuit design, active filter***

I. INTRODUCTION

Current mode current conveyor based filters can offer wider signal bandwidths, greater linearity and larger dynamic ranges of operation [1][2]. A number of universal current-mode filters using current conveyors, four-terminal active current conveyors and differential voltage current conveys have been presented [3]~[29]. The proposed circuits have been applied in the communication, measurement, instrumentation and control system fields. The Differential Difference Current Conveyor (DDCC) is also a versatile current mode building block. It can circumvent the finite gain-bandwidth limitation of the conventional operational amplifier. Meanwhile, it has many advantages, such as: large signal bandwidth, great linearity, wide dynamic range, high input impedance and arithmetic operation capability. For the above reasons, the realizations and applications of universal filtering circuit using DDCCs have received considerable attention [30] ~ [41]. For instance, a voltage-mode canonical first-order all-pass filter using some DDCCs is presented by Muhammed A. Ibrahim, Hakan Kuntman and Oguzhan Cicekoglu [30]. The bandpass, low-pass and high-pass filter functions employing one DDCC as active elements were synthesized by Muhammed A. Ibrahim, Hakan Kuntman and Oguzhan Cicekoglu [31]. A voltage-mode biquad filter using one DDCC, two single-ended operational transconductance amplifiers and two grounded capacitors was constructed by Wen-Ta Lee and Yi-Zhen Liao [32]. The proposed circuit can realize low-pass, high-pass and band-pass filters from the same configuration. The all-pass filters using some DDCCs and the minimum number of passive elements were realized by Istanbul Cicekoglu and Pal [33]. A novel DDCC based canonic current mode Single-Resistor Controlled Oscillator, which uses a voltage controlled voltage source and a single current terminal to take out the output, was proposed by Varun Aggarwal [39]. The voltage-mode low-pass, high-pass and band-pass filters employing some DDCCs and current controlled current conveyors as active elements were constructed by Siripongdee and Mekhum [40]. Yin and Liu employed four DDCCs and two plus-type Current Followers as active elements together with some grounded capacitors and grounded resistors as passive elements to realize a current-mode universal biquad [41]. It can construct low-pass, high-pass, band-pass, notch and all-pass five filter functions. However, the shortcoming of the [40] and [41] circuits is that the required number of DDCC for universal filter is quite large. Meanwhile, the above proposed circuits have also some disadvantages, such as: (1) high sensitivity, (2) without any orthogonal control of the resonance angular frequency and the quality factor, and (3) without low-pass, high-pass, notch, allpass and band-pass filters from the same configuration.

Minimizing the number of DDCCs has the advantages of low cost and power dissipation. For the reasons, the major goal is to reduce the number of the DDCC required active components in this paper. In comparison with the recent filter proposed by Yin and Liu [41] and the other one presented by Surapong Siripongdee and Witthaya Mekhum [40], a new current-mode filtering circuit using two DDCCs, three/four resistors and three/four grounded capacitors is presented. The new proposed circuit can realize highpass, lowpass, bandpass, notch and allpass filters from the same configuration and offer the following extra advantages: use of grounded capacitors, low passive sensitivity, and without current tracking errors. Observably, this newly designed universal filter is better than any of the previously designed universal ones. Finally, experimental results which confirm the theoretical analysis are obtained.

II.CIRCUIT DESCRIPTION

The circuit symbol for a DDCC is shown in Fig.1. Using standard notation, the port relations of a DDCC can be characterized by $I_z = I_x$, $V_x = V_{y1} - V_{y2} + V_{y3}$, and $I_{y1} = I_{y2} = I_{y3} = 0$.

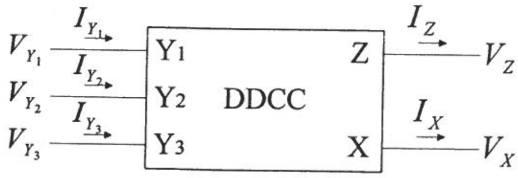

Fig.1. A DDCC symbol.

The proposed current-mode multifunction filter circuit employing two DDCCs is shown in Fig.2. From a routine analysis, the transfer function of the Fig. 2 can be derived as

$$\frac{I_o}{I_{in}} = \frac{Y_3 - Y_4}{Y_1 + Y_2} \qquad \text{-------------------------(1)}$$

where $Y_1 - Y_4$ are admittances. If $Y_2 = Y_3$ and $Y_4 = 2Y_1$, equation (1) will be

$$\frac{I_o}{I_{in}} = \frac{Y_2 - 2Y_1}{Y_1 + Y_2} \text{ ---------------------(2)}$$

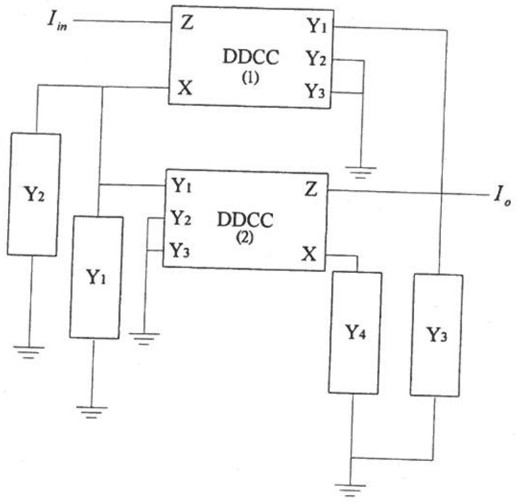

Fig-2 The proposed current-mode filters using two DDCCs.

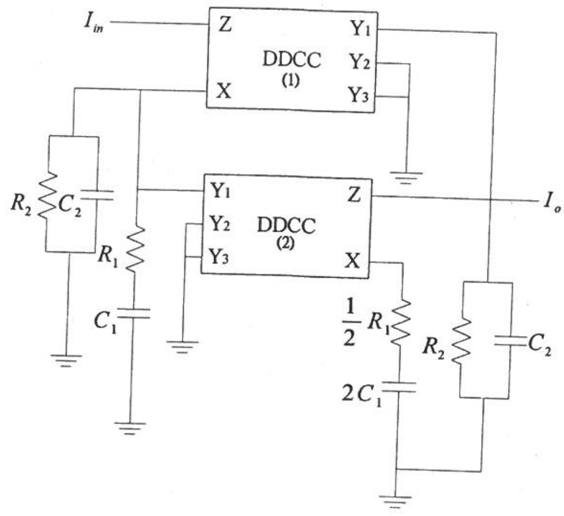

Fig-3 The proposed current–mode second-order notch/allpass filter.

If the admittances are chosen as $Y_2 = sC_2 + (1/R_2)$ and $Y_1 = 1/(R_1 + \frac{1}{sC_1})$, equation (2) will be

$$\frac{I_o}{I_{in}} = \frac{s^2 C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 - 2C_1R_2) + 1}{s^2 C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1} \text{ ---------------------(3)}$$

If $C_1R_1 + C_2R_2 = 2C_1R_2$, equation (3) will be

$$\frac{I_o}{I_{in}} = \frac{s^2 C_1C_2R_1R_2 + 1}{s^2 C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1} \text{ --------------------(4)}$$

Thus, a second-order notch filter as shown in Fig. 3 can be realized.

If $2(C_1R_1 + C_2R_2) = C_1R_2$, equation (3) will be

$$\frac{I_o}{I_{in}} = \frac{s^2 C_1C_2R_1R_2 - s(C_1R_1 + C_2R_2 + C_1R_2) + 1}{s^2 C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1} \text{ --------------------(5)}$$

Thus, a second-order allpass filter as shown in Fig. 3 can be also achieved.

Furthermore, if $Y_3 = 0$ (open-circuited), $Y_4 = Y_1 = sC_1$ and $Y_2 = G_2$, equation (1) can be expressed as

$$\frac{I_o}{I_{in}} = \frac{-sC_1}{sC_1 + G_2} \qquad \text{-----------------------(6)}$$

Thus, a highpass filter shown in Fig.4 can be obtained. If $Y_3 = 0$ (open-circuited), $Y_1 = sC_1$ and $Y_4 = Y_2 = G_2$, equation (1) can be written as

$$\frac{I_o}{I_{in}} = \frac{-G_2}{sC_1 + G_2} \qquad \text{-----------------------(7)}$$

Thus, a lowpass filter shown in Fig.5 can be obtained.

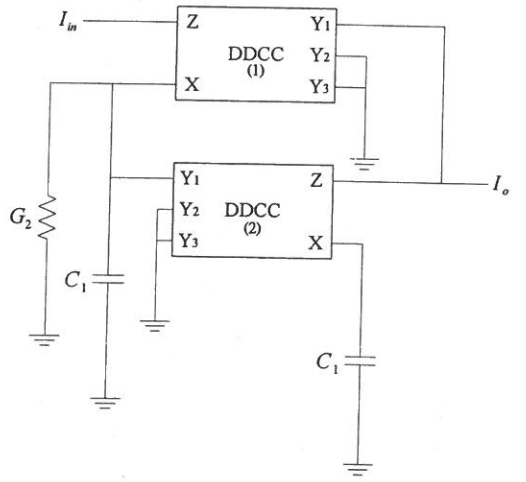

Fig-4 The proposed current–mode highpass filter.

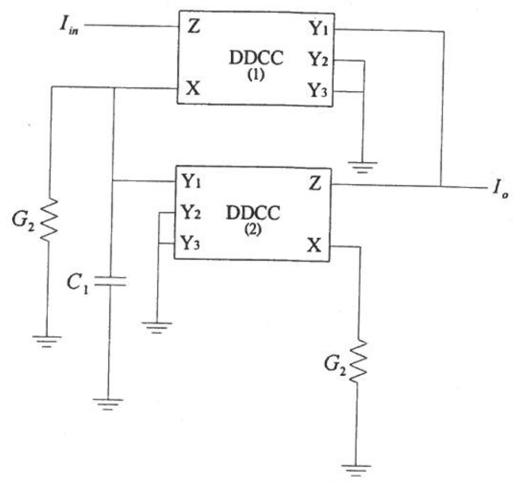

Fig-5 The proposed current–mode lowpass filter.

To realize a bandpass filter, the admittances in Fig. 2 might be chosen as follows: $Y_3 = 0$ (open-circuited), $Y_4 = Y_1 = 1/(R_1 + 1/sC_1)$ and $Y_2 = sC_2 + (1/R_2)$. Equation (1) can be expressed as

$$\frac{I_o}{I_{in}} = \frac{-sC_1R_2}{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1} \quad \text{-----------------(8)}$$

Thus, a second-order bandpass filter shown in Fig. 6 can be obtained.

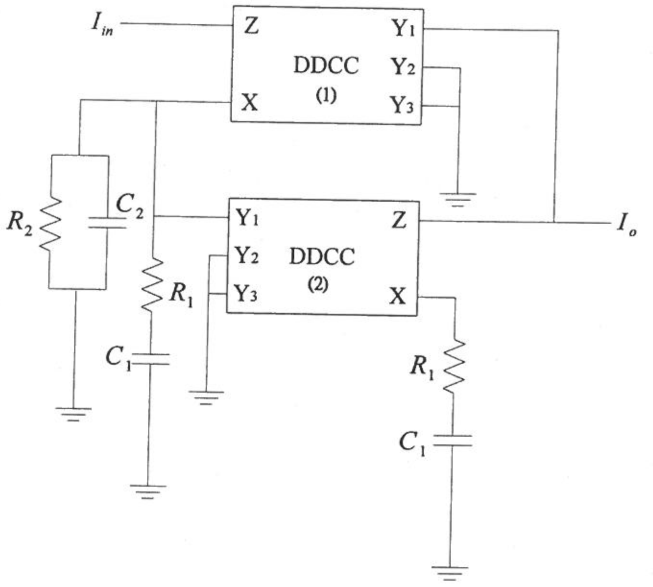

Fig-6 The proposed current–mode second-order bandpass filter.

From the mentioned above, we can see that the proposed circuit provides the following advantages: only two active components and use of only grounded capacitors. The comparison between this paper and the recent ones (Surapong Siripongdee and Witthaya Mekhum (2012) [40] and Yin and Liu (2014) [41]) is shown in the table1.

Number of DDCCs components

Paper \ Filter	Lowpass	highpass	bandpass	notch	allpass
Surapong Siripongdee and Witthaya Mekhum, (2012)	3	3	3		
Yin and Liu (2014)	4	4	4	4	4
Yin and Liu (present)	2	2	2	2	2

Table1. Comparison of the active components

From the above table, we can see that the required number of active components is indeed reduced.

III. SENSITIVITY

The resonance angular frequency ω_o and the quality factor ϑ of the current-mode bandpass filter can be expressed as

$$\omega_o = \frac{1}{(C_1C_2R_1R_2)^{1/2}} \quad \text{and} \quad \vartheta = \frac{(C_1C_2R_1R_2)^{1/2}}{C_1R_1 + C_2R_2 + C_1R_2}$$

By relating a sensitivity parameter F to the element of variation X_i

$$S_{X_i}^{F} = \frac{X_i}{F}\frac{dF}{dX_i}$$

The passive sensitivities are given by

$$S_{C_1}^{\vartheta} = \frac{1}{2}[1 - \frac{R_1 + R_2}{\Delta(C_2R_1R_2)}]$$

$$S_{C_2}^{\vartheta} = \frac{1}{2}[1 - \frac{R_2}{\Delta(C_1R_1R_2)}]$$

$$S_{R_1}^{\vartheta} = \frac{1}{2}[1 - \frac{C_1}{\Delta(C_1C_2R_2)}]$$

$$S_{R_2}^{\vartheta} = \frac{1}{2}[1 - \frac{C_1 + C_2}{\Delta(C_1C_2R_1)}]$$

$$S_{R_1}^{\omega_o} = S_{R_2}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -1/2$$

where $\Delta = (C_1R_1 + C_2R_2 + C_1R_2)$. All the passive sensitivities are quite small.

Taking into account the non-ideal DDCCs, namely $i_z = \alpha i_x$ and $v_x = \beta v_y$, where

$\alpha = 1 - \varepsilon_1$ and ε_1 ($\varepsilon_1 << 1$) denotes the current tracking error of the DDCCs, and where

$\beta = 1-\varepsilon_2$ and ε_2 ($\varepsilon_2 << 1$) denotes the voltage tracking error, the transfer function of the proposed network shown in Fig. 1 can be expressed as

$$\frac{I_o}{I_{in}} = \frac{Y_3 - \alpha_2 Y_4}{\alpha_1 (Y_1 + Y_2)} \text{------}(9)$$

The equations of the proposed notch, allpass, bandpass, highpass and lowpass filters with two non-ideal DDCCs are given by the following:

(1) notch/allpass: $$\frac{I_o}{I_{in}} = \frac{s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 - 2\alpha_2 C_1 R_2) + 1}{\alpha_1 [s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 + C_1 R_2) + 1]} \text{------------}(10)$$

(2) bandpass: $$\frac{I_o}{I_{in}} = \frac{-\alpha_2 s C_1 R_2}{\alpha_1 [s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 + C_1 R_2) + 1]} \text{----------------}(11)$$

(3) highpass: $$\frac{I_o}{I_{in}} = \frac{-\alpha_2 s C_1}{\alpha_1 (s C_1 + G_2)} \text{--}(12)$$

(4) lowpass: $$\frac{I_o}{I_{in}} = \frac{-\alpha_2 G_2}{\alpha_1 (s C_1 + G_2)} \text{---}(13)$$

where α_1 and α_2 are non-ideal factors for DDCC(1) and DDCC(2), respectively. The resultant current-mode filters will be insensitive to the current tracking error of the DDCCs.

IV. EXPERIMENTAL RESULTS

To verify the theoretical prediction of the proposed circuit, a notch, a bandpass, a highpass and a lowpass filter prototypes have been realized with discrete components. The experimental and simulation networks in Fig. 3 and Fig.6 were built with $C_1 = C_2 = 1nF$

and $R_1 = R_2 = 10k\Omega$, and Fig. 4 and Fig.5 were built with $C_1 = 1nF$ and $G_2 = 10^{-4}(\Omega)^{-1}$. The DDCC was implemented by the AD844s. The Matlab has carried out a simulation of the ideal curves of the proposed filters. The experimental results above were measured using the Hewlett Packard network/spectrum analyzer 4195A. Figure 7 shows the experimental results. The experimental results as shown confirm with the results of the theoretical analysis.

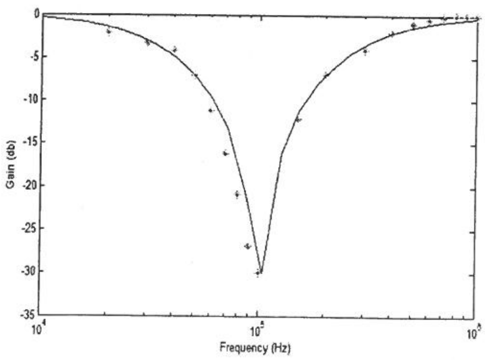

Fig-7 (a) Notch filter gain response.

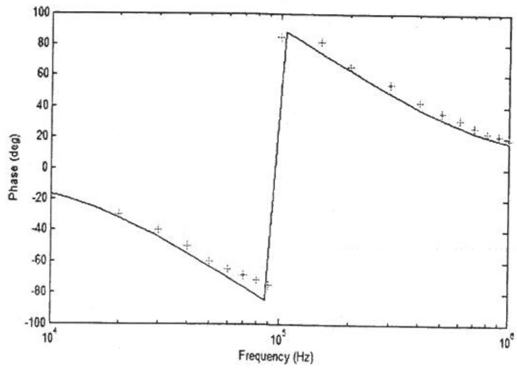

Fig-7 (b) Notch filter phase response.

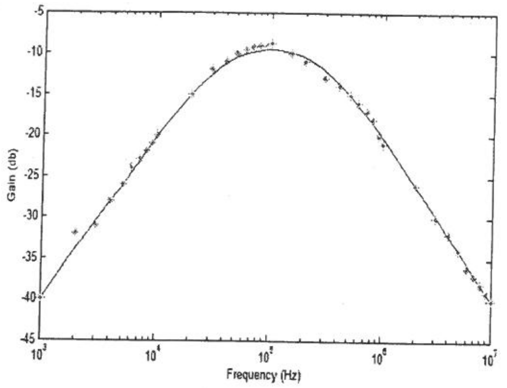

Fig-7(c): Bandpass filter gain response.

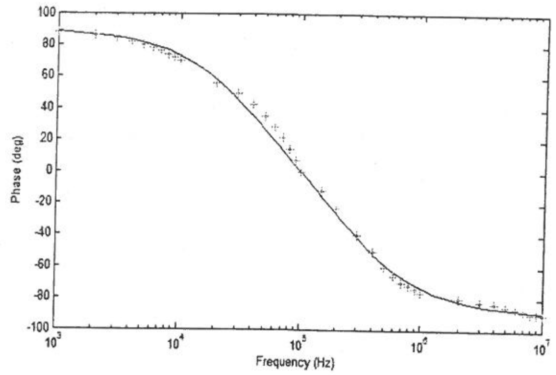

Fig-7(d): Bandpass filter phase response.

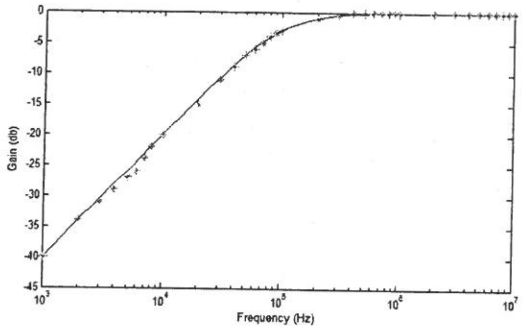

Fig-7(e):Highpass filter gain response.

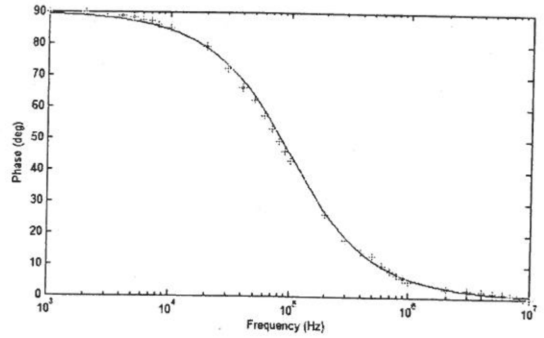

Fig-7(f): Highpass filter phase response.

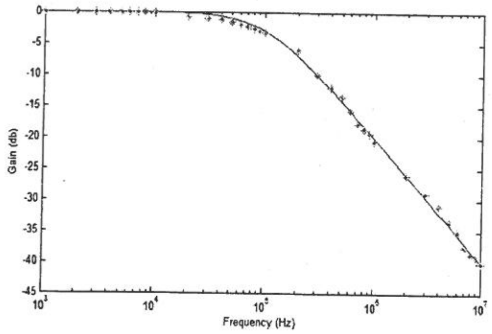

Fig-7(g): Lowpass filter gain response.

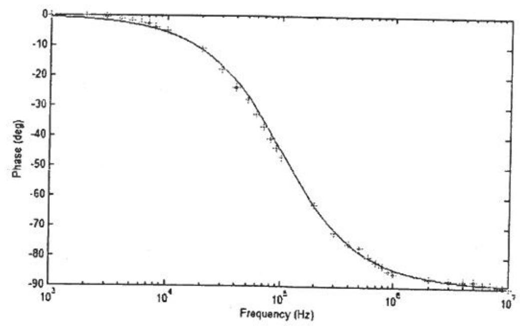

Fig-7(h): Lowpass filter phase response.

Fig-7 (a): Notch filter gain response; (b): Notch filter phase response

(c): bandpass filter gain response; (d): bandpass filter phase response

(e):Highpass filter gain response; (f): Highpass filter phase response

(g): Lowpass filter gain response; (h): Lowpass filter phase response

*: experimental result for gain; +: experimental result for phase; —: ideal curve

V. CONCLUSION

In 2012, Surapong Siripongdee and Witthaya Mekhum presented a multifunction biquadratic filter which can realize highpass, lowpass and bandpass filter functions and contain three DDCCs, two grounded resistors and two grounded capacitors. However, the notch and all-pass responses cannot be obtained in the design. In 2014, Yin and Liu proposed an universal active filter using four DDCCs, two current followers, two grounded capacitors and two/four resistors. However, the required number of DDCCs for the universal filter is quite large. In this paper, the authors have proposed a new universal filter circuit which can realize the highpass, lowpass, bandpass, notch and allpass filter transfer functions. The proposed circuit employs only two DDCCs, three/four resistors and three/four grounded capacitors. Owing to the grounded capacitor, it is suitable for integration circuit implementation. From the sensitivity analysis, it is insensitive to the current tracking errors of the DDCCs, and has low passive sensitivity characteristic. Meanwhile, the required number of active components is also indeed reduced. Finally, four experimental results confirmed the theoretical analysis. The results will be useful in analogue signal processing applications.

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使用兩個差動差分電流傳輸器合成電流式多功能濾波器

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摘　　要

本文提出一個電流式二階式濾波器。此濾波器電路只使用兩個差動差分電流傳輸器當主動元件，配合少數接地電容與電阻當被動元件。這個電流式濾波器具有以下之優點：(1).可合成低通、高通、帶通、帶拒和全通五種濾波功能之濾波器；(2).只使用兩顆主動元件；(3).低被動靈敏度；(4).無電流軌跡誤差；(5).由於所有的電容元件都接地，促使本濾波器電路更加適合於合成積體電路。最後本文以四個實驗驗證本文之理論預測。

關鍵詞：差動差分電流傳輸器，靈敏度，類比電路設計，主動濾波器