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# Implementation of Resistorless Universal Biquad Filter with Electronic Controllability

***Abstract**. A new biquad filter which simultaneously provides four filter responses, high-pass (HP), band-pass (BP), low-pass (LP) and band-reject (BR) functions is presented in this paper. Two active building blocks used in this implementation is the modified version of current controlled current conveyor transocnductance amplifier (M-CCCCTA) with two grounded capacitors. It doesn't require any external passive resistor. With this structure, it is attractive to fabricate into monolithic chip. The quality factor or bandwidth of the filter is electronically controlled without influencing the natural frequency. The input node feeding the input voltage is high impedance. Pspice simulation results of the presented filter employing the parameter models of the PR200N and NR200N bipolar transistors from AT&T are performed to verify the performances and theoretical analysis.*

***Streszczenie.**. W artykule opisano uniwersalny filtr wykorzystujący modyfikowaną wersję wzmacniacza transkonduktancyjnego CCCCTA oraz dwa uzimione kondensatory. Nie są używane zewnętrzne rezystory. Współczynnik dobroci i pasmo są dobierane elektronicznie. Przeprowadzono symulacje układów z tranzystorami bipolarnymi PR200N I NR200N. **Projekt uniwersalnego filtru bez zewnętrznych rezysto®oa) strojonego elektronicznie,**.*

**Keywords:** M-CCCCTA; Universal filter; Electronic controllability.
**Słowa kluczowe:** filtr uniwersalny, układ CCCCTA.

## Introduction

There has been a growing interest to realize the analog active filter using active building block (ABB) [1-5]. The ABB based circuits contain minimum number of passive element. Also, the circuit can be cascaded without the using of external buffer circuit. Particularly, the universal filter which simultaneously gives several filter responses in the same circuit has been continuously proposed. This filter is significant in analog signal processing system such as in the three way crossover network, telephone decoder etc. [6-7].

The voltage-mode universal filers which provide simultaneously various filter responses in the same circuit topology have been recently proposed [8-24]. Some of the proposed filters in [9, 10, 11, 22] contain excessively number of active elements (more than two ABBs). The passive resistor is required for the proposed filter in [8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24]. In [8, 10, 11, 15, 16, 18, 19, 20, 22, 23, 24], the filter parameters, natural frequency and quality factor are not electronically controlled. Also, the quality factor is not tuned independently from the natural frequency [10, 11, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]. The impedance at the input voltage node doesn't exhibit high [12, 15, 16, 19, 20].

In this paper, the resistorless universal filter which simultaneously provides HP, BP, LP and BR functions is implemented. The proposed circuit is constructed from two M-CCCCTAs and two grounded capacitors. The possibility of electronically and independently adjusting of quality factor and natural frequency is achieved.

## Theory and Principle

### Basic Characteristics of M-CCCCTA

The conventional CCCCTA is a five-terminal analogue active element. The names of the input and output terminal are represented as y, x, z and o terminals. The y-terminal is the voltage input port with high impedance. The x-terminal which contains controllable parasitic resistance ($R_x$) is the current/voltage input port. The parasitic resistance $R_x$ is electronically tuned. The high impedance z and o-terminals are the current output port. Ideally, the voltage at y-terminal is equal to voltage at x-terminal. The current at x-terminal is equal to current at z-terminal. The output current following through o-terminal is converted from the voltage at z-terminal via transconductance gain ($g_m$). Generally, the $g_m$ is electronically controllable. However, in this design, the conventional CCTA will be modified by adding the *v*-terminal and minus z-copy terminal (-$z_c$) to extend the use of CCCCTA. So, it will be called as modified CCCCTA (M-CCCCTA). In Fig. 1, the schematic circuit symbol for M-CCCCTA is illustrated. The M-CCCCTA characteristics are described as

(1) $$\begin{pmatrix} i_y \\ v_y \\ i_z \\ i_{zc} \\ i_o \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & R_x & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & g_m & -g_m \end{pmatrix} \begin{pmatrix} v_x \\ i_x \\ i_v \\ v_v \\ v_z \end{pmatrix}.$$

The M-CCCCTA implementation using BJT transistors is shown in Fig. 3. The small signal $R_x$ and $g_m$ of M-CCCCTA constructed from Fig. 3 is given as

(2) $$R_x = \frac{V_T}{I_{Bx}}; g_m = \frac{I_{Bo}}{2V_T}.$$

where $V_T$ is the thermal voltage. It should be noted from Eqs.(2) and (3) that the $R_x$ and $g_m$ is lineally controlled by $I_{B1}$ and $I_{B2}$, respectively.

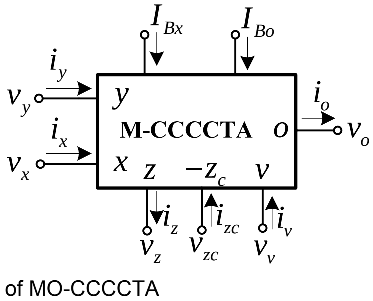


Fig.1. Symbol of MO-CCCCTA

### Proposed Voltage-Mode Filter

The filter which simultaneously obtains several filter responses with the same structure is mostly used in the analogue signal processing system. The apparent application for this filer is a three way crossover network [25] which is used to separate an audio frequency to thee ways of frequency output, low, medium and high frequency. In this active filter design, the M-CCCCTA is chosen as active element. Figure 3 shows the proposed biquad filter given simultaneously four filter responses, band-pass, band-reject, high-pass and low-pass filter. The presented second order filter structure consists of two M-CCCCTAs, two resistors and two grounded capacitors. The filer is feed voltage ($v_{in}$) as input to the high impedance port (y-terminal). Three voltage outputs, band-pass ($v_{bp}$), band-reject ($v_{br}$) and low-pass ($v_{lp}$) filter are achieved and single current output, high-pass ($i_{hp}$) filter is obtained. The voltage transfer function for band-pass filter is given as

(3) $$\frac{v_{bp}}{v_{in}}=\frac{-s\frac{g_{m2}}{C_1}}{s^2+s\frac{g_{m2}R_{x1}}{2C_1R_{x2}}+\frac{g_{m2}}{C_1C_2R_{x2}}}.$$

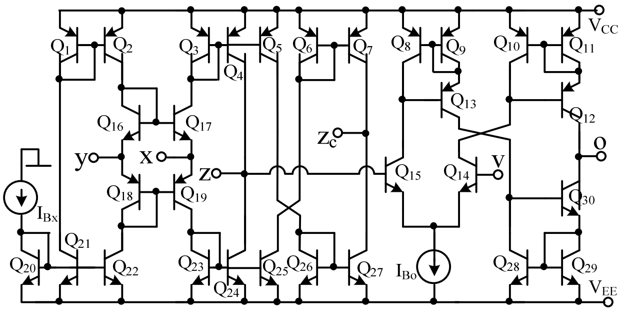


Fig.2. The BJT implementation of M-CCCCTA

The voltage gain for band-pass filter is $-2R_{x2}/R_{x1}$. The voltage transfer functions band-reject and low-pass filter are given by

(4) $$\frac{v_{br}}{v_{in}}=\frac{s^2+\frac{g_{m2}}{C_1C_2R_{x2}}}{s^2+s\frac{g_{m2}R_{x1}}{2C_1R_{x2}}+\frac{g_{m2}}{C_1C_2R_{x2}}}.$$

(5) $$\frac{v_{lp}}{v_{in}}=\frac{\frac{g_{m2}}{C_1C_2R_{x2}}}{s^2+s\frac{g_{m2}R_{x1}}{2C_1R_{x2}}+\frac{g_{m2}}{C_1C_2R_{x2}}}.$$

The voltage gain for band-reject and low-pass filter is unit. Considering for high-pass filter, the transconductance transfer function is given by

(6) $$\frac{i_{hp}}{v_{in}}=\frac{g_{m1}s^2}{s^2+s\frac{g_{m2}R_{x1}}{2C_1R_{x2}}+\frac{g_{m2}}{C_1C_2R_{x2}}}.$$

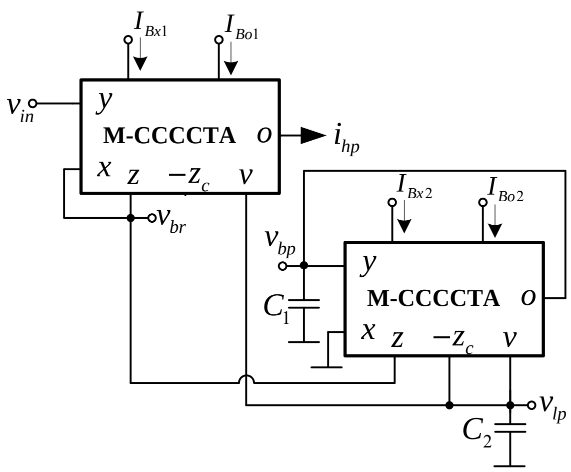


Fig.3. Proposed filter

The transconductance gain for high-pass filter is $g_{m1}$. From above transfer functions, the filter parameters, natural frequency ($\omega_0$) and quality factor (Q) are given by

(7) $$\omega_0=\sqrt{\frac{g_{m2}}{C_1C_2R_{x2}}}.$$

and

(8) $$Q=\frac{2}{R_{x1}}\sqrt{\frac{C_1R_{x2}}{C_2g_{m2}}}.$$

The equations (7) and (8) indicate that the parameter Q and bandwidth of the filter can be electronically tuned independent of the parameter $\omega_0$ via $R_{x1}$. Also, the parameter $\omega_0$ is electronically tuned via $g_{m2}$. Moreover, the gain of the high-pass filter is electronically adjusted via $g_{m1}$.

### *Sensitivity Analysis*

The sensitivities of the proposed filter are evaluated from the filter parameters, $\omega_0$ and Q as appeared in Eqs. (7) and (8). The sensitivities of the parameter $\omega_0$ to variation of $g_{m2}$, $C_1$, $C_2$ and $R_2$ is given as

(9) $$S_{g_{m2}}^{\omega_0}=\frac{1}{2};\ S_{C_1}^{\omega_0}=S_{C_2}^{\omega_0}=S_{R_{x2}}^{\omega_0}=-\frac{1}{2}.$$

The sensitivities of parameter Q to variation of $g_{m2}$, $C_1$, $C_2$, $R_1$ and $R_2$ is given as

(10) $$S_{R_{x1}}^{Q_0}=-1;\ S_{C_1}^{Q_0}=S_{R_2}^{Q_0}=\frac{1}{2};\ S_{C_2}^{Q_0}=S_{g_{m2}}^{Q_0}=-\frac{1}{2}.$$

It is evident that all the sensitivities of the proposed filter are found to be low.

### *Non-Ideal Analysis*

Taking the influent of various non-ideal port-transfer ratios of M-CCCCTA into account, the relationship of the port voltages and currents of M-CCCCTA can be rewritten as:

(11) $$\begin{pmatrix} i_y \\ v_y \\ i_z \\ i_{zc} \\ i_o \end{pmatrix}=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ \beta & R_x & 0 & 0 & 0 \\ 0 & \alpha & 0 & 0 & 0 \\ 0 & -\alpha_c & 0 & 0 & 0 \\ 0 & 0 & 0 & g_m & -g_m \end{pmatrix}\begin{pmatrix} v_x \\ i_x \\ i_v \\ v_v \\ v_z \end{pmatrix}.$$

where $\beta$ ($\beta=1-\varepsilon_v$) represents the voltage gain error from *x* to *y* terminal, $\alpha$ ($\alpha=1-\varepsilon_c$) represents the current gain error from *x* to *z* terminal and $\alpha_c$ ($\alpha=1-\varepsilon_{cz}$) represents the current gain error from *x* to $z_c$ terminal. $\varepsilon_v$ is the voltage tracking error, $\varepsilon_c$ and $\varepsilon_{cz}$ are the current tracking error where $\varepsilon_v$ <<1, $\varepsilon_c$ <<1 and $\varepsilon_{cz}$ <<1. Taking these errors into account, the voltage transfer function for band-pass filter is given as

(12) $$\frac{v_{bp}^*}{v_{in}}=\frac{-s\frac{g_{m2}\beta_1}{C_1}}{s^2+s\frac{g_{m2}R_{x1}\beta_2\alpha_2}{C_1R_{x2}\left(1+\alpha_1\right)}+\frac{g_{m2}\beta_2\alpha_{c2}}{C_1C_2R_{x2}}}.$$

The voltage gain for BP is $-(1+\alpha_1)R_{x2}/\beta_1\beta_2\alpha_2R_{x1}$. The voltage transfer functions band-reject and low-pass filter are given by

$$\frac{v_{br}^{*}}{v_{in}} = \frac{\beta_1\left(s^2 + \frac{g_{m2}\beta_2\alpha_{c2}}{C_1C_2R_{x2}}\right)}{s^2 + s\frac{g_{m2}R_{x1}\beta_2\alpha_2}{C_1R_{x2}\left(1+\alpha_1\right)} + \frac{g_{m2}\beta_2\alpha_{c2}}{C_1C_2R_{x2}}} . \quad (13)$$

$$\frac{v_{lp}^{*}}{v_{in}} = \frac{\frac{g_{m2}\beta_1\beta_2\alpha_{c2}}{C_1C_2R_{x2}}}{s^2 + s\frac{g_{m2}R_1\beta_2\alpha_2}{C_1R_{x2}\left(1+\alpha_1\right)} + \frac{g_{m2}\beta_2\alpha_{c2}}{C_1C_2R_{x2}}} . \quad (14)$$

The voltage gain for band-reject and low-pass filter is unit. Considering for high-pass filter, the transconductance transfer function is given by

$$\frac{i_{hp}^{*}}{v_{in}} = \frac{\beta_1 g_{m1} s^2}{s^2 + s\frac{g_{m2}R_{x1}\beta_2\alpha_2}{C_1R_{x2}\left(1+\alpha_1\right)} + \frac{g_{m2}\beta_2\alpha_{c2}}{C_1C_2R_{x2}}} . \quad (15)$$

The transconductance gain for high-pass filter is $g_{m1}$. From above transfer functions, the filter parameters, natural frequency ($\omega_0$) and quality factor (Q) are given by

$$\omega_0 = \sqrt{\frac{g_{m2}\beta_2\alpha_{c2}}{C_1C_2R_{x2}}} . \quad (16)$$

and

$$Q = \frac{\left(1+\alpha_1\right)\alpha_2}{R_{x1}}\sqrt{\frac{C_1R_{x2}\alpha_{c2}}{C_2 g_{m2}\beta_2}} . \quad (17)$$

**Simulation Results**

The presented biquad filter in Figure 3 has been implemented and simulated via Pspice using BJT M-CCCCTA in Figure 2. The third level parameter models of the PR200N and NR200N transistors from AT&T [26] have been used for the simulation. The filter was designed to have $f_0$ = 100kHz and Q = 2. Using calculations based on Eqs. (7) and (8), the active and passive elements were as follows: $C_1 = C_2$ = 5.6nF, $I_{Bx1} = I_{Bo1} = I_{Bo2}$ = 91.48μA and $I_{Bx2}$ = 45.74μA. The circuit was supplied with ±2.5V. The output current node for highpass was converted to be the voltage by connecting the resistor 568Ω. The simulated frequency response for $v_{lp}$, $v_{hp}$ and $v_{bp}$ is shown in Fig. 4. The simulated amplitude and phase responses of $v_{br}$ are illustrated in Fig. 5. The $f_0$ and Q obtained from the simulation are 95.72 kHz and 1.99, respectively. Figure 6 shows the simulated frequency response of band-pass filter where the Q is tuned to 1.99, 3.96 and 7.91 by changing the bias current $I_{Bx2}$ to 45.74μA, 91.48μA and 182.96μA, respectively. This result indicates that the Q is electronically tuned without affecting the $f_0$ by changing $I_{Bx2}$ as analyzed in Eq. (8). Figure 7 shows the simulated frequency response of band-pass filter where the $f_0$ is tuned to 48.64 kHz, 95.72 kHz and 185.35 kHz by simultaneously changing the bias current $I_{Bx1} = I_{Bo1} = I_{Bx2}$ to 45.74μA, 91.48μA and 182.96μA, respectively. This result indicates that the $f_0$ is electronically tuned without affecting the Q.

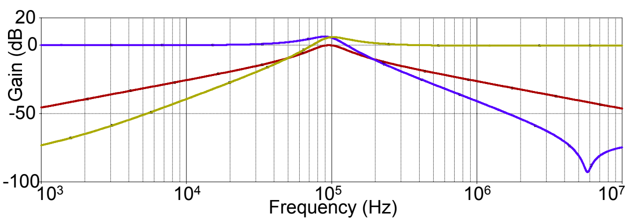


Fig.4. Simulated magnitude response of HP, LP and BP.

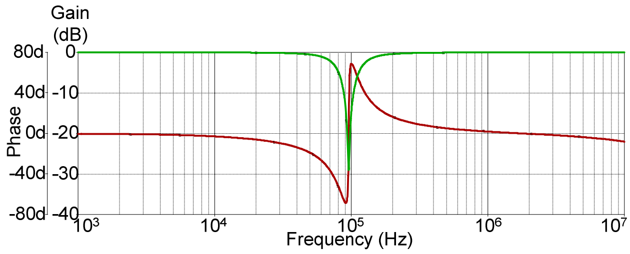


Fig.5. Simulated magnitude and gain response of BR.

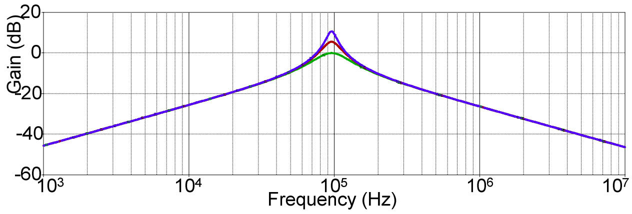


Fig.6. Varying the Q by changing the $I_{Bx2}$.

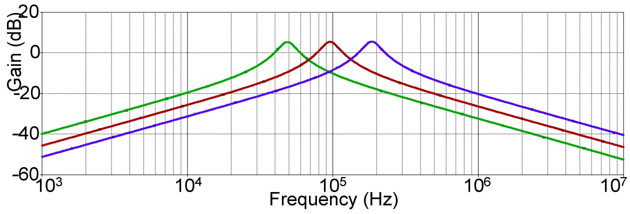


Fig.7. Varying the $f_0$ by simultaneously changing the bias current $I_{Bx1} = I_{Bo1} = I_{Bx2}$

**Conclusion**

The use of M-CCCCTA as active device to design the second order filter containing four filter responses, band-pass, band-reject, low-pass and high-pass filters is presented in this paper. The proposed circuit consists of two M-CCCCTAs and two grounded capacitors which is attractive for integrated circuit implementation. The input voltage node of the proposed filter exhibits high impedance. The tune of quality factor can be electronically done without affecting the natural frequency. Single output current response for HP and three output voltage responses, LP, BP and BR function are simultaneously obtained. The performances of the proposed circuit have been verified through Pspice and the results agree well with theoretical anticipation.

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