CCCDBA Based Voltage Mode TOW – THOMAS Biquadratic Filters

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Abstract - **This article presents a voltage-mode universal bi-quadratic filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions, based-on Current Controlled Current Differencing Buffered Amplifiers (CCCDBAs) TOW-THOMAS mode equivalent. The features of the circuit are that: the quality factor and pole frequency can be tuned orthogonally via the input bias currents: the circuit description is very simple, consisting of merely few CCCDBAs and grounded capacitors. Without any external resistors and using only grounded elements, the proposed circuit is very comfortable to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation.**

Key Words **–All pass filter, Band pass filter, Current-controlled current differencing buffered amplifier (CCCDBA), High pass filter, Low pass filter, Notch filter, Voltage-mode TOW-THOMAS-equivalent BIQUAD, Voltage mode integrator.**

I. INTRODUCTION

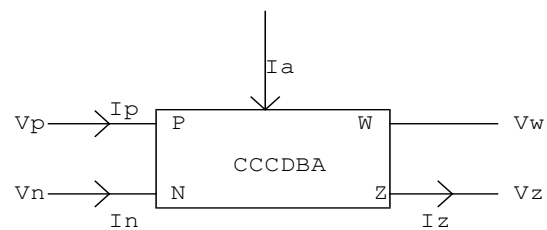Since the proposed circuits are based on CCCDBAs, a brief review of CCCDBA is given here.

Figure1. Symbolic representation of current-controlled CDBA [7],[8]

CCCDBA is a translinear based current-controlled current differencing buffered amplifier (CC-CDBA's) whose parasitic input resistances can be varied electronically. Basically, the CCDBA is a four-terminal active element. For ideal operation, it's current and voltage relations described by the matrix of equation-1 [11], [12],[13].

From the circuit operation, the current-voltage characteristics of CC-CDBA can be expressed by the following matrix.

$$\begin{bmatrix} v_p \\ v_n \\ i_z \\ v_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & R_X & 0 \\ 0 & 0 & 0 & R_X \\ 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_z \\ i_z \\ i_p \\ i_n \end{bmatrix} \quad (1)$$

II. VOLTAGE MODE TOW-THOMAS EQUIVALENT BIQUAD

A voltage-mode TOW-THOMAS-equivalent Biquad can be constructed by cascading a lossy integrator followed by lossless integrator to obtain all the five desired filter transfer functions namely:

1. Low pass Response.
2. High pass Response.
3. Band pass Response
4. Notch Response.
5. All pass Response.

Figure-2 gives the block diagram representation of voltage-mode TOW-THOMAS-equivalent BiQUAD followed by the necessary mathematical steps for deriving the current transfer functions.
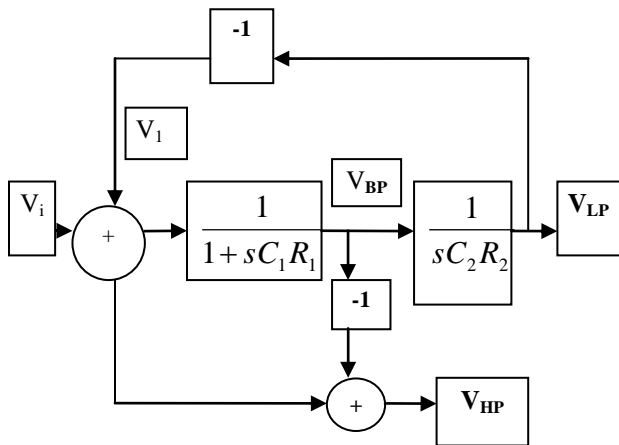

Figure2. Block Diagram Tow-Thomas-Equivalent Biquad (Tow Thomas 1969)

From the block diagrammatic representation of Figure-2 it is evident that for realization of voltage-mode TOW-THOMAS equivalent biquad we require a lossless and a lossy integrator along with a subtractor. These two building blocks have been simulated and tested [3],[5][10]. The standard second order filter transfer functions which are obtained on

simplifying the block diagram of Figure-2 are as follows:

1) Low pass Filter

$$T_{LP}(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{\dfrac{1}{C_1 C_2 R_1 R_2}}{s^2 + s\left(\dfrac{1}{C_1 R_1}\right) + \dfrac{1}{C_1 C_2 R_1 R_2}} \quad (2)$$

2) High pass Filter

$$T_{HP}(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{s^2}{s^2 + s\left(\dfrac{1}{C_1 R_1}\right) + \dfrac{1}{C_1 C_2 R_1 R_2}} \quad (3)$$

3) Band pass Filter

$$T_{BP}(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{s\left(\dfrac{1}{C_1 R_1}\right)}{s^2 + s\left(\dfrac{1}{C_1 R_1}\right) + \dfrac{1}{C_1 C_2 R_1 R_2}} \quad (4)$$

4) Notch Filter

$$T_{NOTCH}(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{s^2 + \dfrac{1}{C_1 C_2 R_1 R_2}}{s^2 + s\left(\dfrac{1}{C_1 R_1}\right) + \dfrac{1}{C_1 C_2 R_1 R_2}} \quad (5)$$

5) All pass Filter

$$T_{AP}(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{s^2 - s\left(\dfrac{1}{C_1 R_1}\right) + \dfrac{1}{C_1 C_2 R_1 R_2}}{s^2 + s\left(\dfrac{1}{C_1 R_1}\right) + \dfrac{1}{C_1 C_2 R_1 R_2}}$$

(6)

The denominator of all the five transfer functions is same and is generalized by the following equation [1]:

$$D(s) = s^2 + s\left(\frac{\omega_o}{Q_o}\right) + \omega_o^2 \quad (7)$$

Where, ω_o is the cut-off frequency and Q_o is the quality-factor.

On comparing the denominator of equation-2 to equation-6 with equation-7 we obtain the following results:

$$\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}} \quad (8)$$

$$Q_o = \sqrt{\frac{C_1 R_1}{C_2 R_2}} \quad (9)$$

For $C_1 = C_2$, and $R_1 = R_2$, the expressions for cut-off frequency and quality factor becomes,

$$\omega_0 = \frac{1}{CR} \quad \text{and, } Q_o = 1. \quad (10)$$

When the block diagram of Figure-2 was realized with the active building blocks implemented with the help of current controlled CDBA we obtain the circuit diagram as shown in Figure-3.The results thus obtained for the circuit shown in Figure-3 are as follows:

For $R_1 = R_{X4}$

$$T_{HP}(s) = \frac{V_4(s)}{V_{in}(s)} - \frac{V_8(s)}{V_{in}(s)} = \frac{s^2}{s^2 + s\left(\frac{1}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_{X4} R_{X6}}} \quad (11)$$

Where, $R_{X4} = \frac{V_T}{2I_{A3}}$ & $R_{X6} = \frac{V_T}{2I_{A5}}$ and I_{A3} & I_{A5} are the bias currents of CCCDBA2 and CCCDBA3, while V_T is the volt-equivalent of temperature given by $V_T = \frac{kT}{q}$.

$$T_{BP}(s) = \frac{V_8(s)}{V_{in}(s)} = \frac{s\left(\frac{1}{C_1 R_1}\right)\left(\frac{R_1}{R_{X4}}\right)}{s^2 + s\left(\frac{1}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_{X4} R_{X6}}} \quad (12)$$

$$T_{LP}(s) = \frac{V_{12}(s)}{V_{in}(s)} = \frac{\frac{1}{C_1 C_2 R_{X4} R_{X6}}}{s^2 + s\left(\frac{1}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_{X4} R_{X6}}} \quad (13)$$

$$T_{NOTCH}(s) = \frac{V_x(s)}{V_{in}(s)} = \frac{s^2 + \frac{1}{C_1 C_2 R_{X4} R_{X6}}}{s^2 + s\left(\frac{1}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_{X4} R_{X6}}} \quad (14)$$

Where, $V_x(s) = V_{12}(s) + V_4(s)$

$$T_{AP}(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{s^2 - \frac{s}{C_1 R_1} + \frac{1}{C_1 C_2 R_{X4} R_{X6}}}{s^2 + s\left(\frac{1}{C_1 R_1}\right) + \frac{1}{C_1 C_2 R_{X4} R_{X6}}} \quad (15)$$

Where, $V_o(s) = V_x(s) - V_8(s)$

On comparing the above equations with the standard results we obtain the following expressions for the cut-off frequency and the quality factor.

$$\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_{X4} R_{X6}}} \quad (16)$$

$$Q_O = \sqrt{\left(\frac{C_1 R_1}{C_2 R_{X6}}\right)\left(\frac{R_1}{R_{X4}}\right)} \quad (17)$$

If, the bias currents I_{A3} & I_{A5} are equal then the value of the resistances R_{X4} & R_{X5} will be also equal. On making the required changes the above expressions becomes,

$$\omega_0 = \frac{1}{R_{X4}\sqrt{C_1 C_2}} \quad (18)$$

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$$Q_O = \sqrt{\frac{C_1}{C_2}} \qquad (19)$$

Again, if C1 = C2, then we have following changes in the above expressions,

$$\omega_0 = \frac{2I_A}{V_T C} \qquad (20)$$

$$Q_O = 1 \qquad (21)$$

Note that, from equations , it is clear that the cut off frequency of the filters (LPF, HPF, and BPF) can be varied by changing the Bias current I_A [4], [9].

III.   SIMULATION RESULT

The voltage-mode TOW-THOMAS equivalent biquad as shown by the circuit representation of Figure-2 was simulated using CCCDBA in figure-3 and following results were obtained for the three responses namely low pass, high pass and band pass. The simulated result has been shown in Figure-4 which gives the value of cut-off frequency for both low pass and high pass filter to be 244.465 KHz. Also, the value of center-frequency for band pass filter comes to be 260.824 KHz and the value of bandwidth was found to be 392.555 KHz. With the value of circuit components chosen as follows: C_1 = 0.75nF, C_2 = 1.25nF, R_{x5} = 650Ω, and R_2 = 525Ω following results were calculated: cut-off frequency (f_o) = 279 KHz, Quality factor (Q_o) = 0.707, and bandwidth = 394.126 KHz. Thus, we can conclude that the simulated results are in accordance with the calculated results.
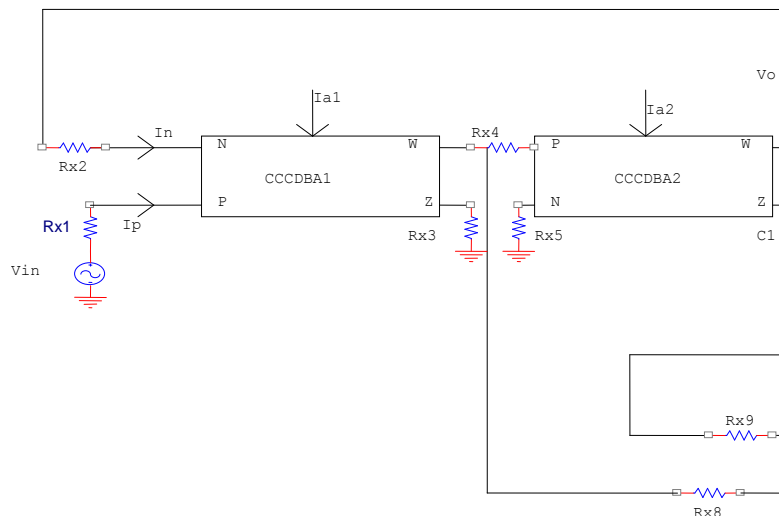

Fig.ure3. Proposed Voltage-Mode TOW-THOMAS Equivalent

IV.   CONCLUSION

In this paper TOW-THOMAS equivalent biquads were discussed, These filters can operate at frequencies of more than 10MHz and they require an operating voltage as low as 2.5V or less. The frequency of these filters can be easily and widely controlled by a single DC bias current and this provides good tunability. Finally, the circuits of all filter were implemented using CCCDBA, and the circuits were tested using SPICE and the verified results confirms the theoretical values.

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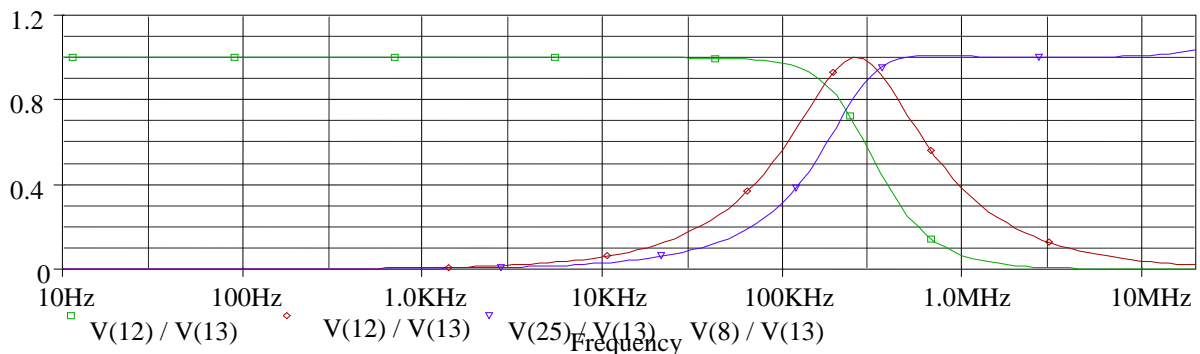
Figure-4: Simulated Response Of Voltage-Mode Tow-Thomas

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