Voltage Mode Single CDBA Based Multifunction Filter

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Abstract: A voltage mode multifunction second order filter topology employing single current differencing buffered amplifier (CDBA) has been proposed in this paper. This topology can be used to synthesize low pass (LP), band pass (BP), and high pass (HP) filter functions with appropriate admittance choices. This configuration is a suitable choice for implementing filters with high quality factor. The demonstration of the proposed configuration is done through PSPICE simulations. The CDBA block is realized using CMOS 0.18µm technology. The simulation results are found in close agreement with the theoretical results.

Keywords: CDBA, Current mode, Multifunction Filter.

1. INTRODUCTION

Electronic filters are the necessary building block of analog signal processing and find extensive applications in communication and instrumentation system. In last few decades the CDBA has emerged as a promising choice [1] for analog filter design [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18]. It is characterized by low input impedance terminals which render it free from parasitic capacitances, thereby making it a suitable choice for high frequency operations. Additionally, the CDBA provides both voltage and current outputs which further enhances the design flexibility.

Many biquadratic filters using CDBA were proposed in the literature that can be classified as single input and single output (SISO) [4], [8], [12], [13], [17] multi input single output (MISO) [9], [15], [16] and single input multi output (SIMO) [3], [5], [10], [14]. A detailed comparison of these structures is given in Table 1. For the applications having power consumption as an important design constraint, single active element based filters are the useful choice. A close study of the voltage mode structures based on single CDBA proposed in [4], [8], [9], [13] and [16] shows that

- only single filter response is provided [4], [13]
- Independent adjustment of angular frequency and Q factor is not possible [8], [13]
- filter responses are obtained by lifting of nodes for input excitation [9], [16]
- large component spread is required for obtaining high Q value [8], [9], [13], [16]
- passive component count is large [16]

In this paper a voltage mode generalized second order multifunction filter topology is proposed which employ single CDBA, two capacitors and four resistors. The proposed
generalized topology can be used to realize three filter functions namely, low pass (LP), band pass (BP), and high pass (HP), through appropriate component selections, and no component matching condition is needed. The proposed topology can be used to implement high quality factor value with moderate component spread.

The remaining paper is organized as follows: Section 2 presents the description of the proposed configuration. The sensitivity analysis is presented in section 3. The effect of non-idealities of CDBA has been dealt with in section 4. The SPICE simulation results are placed in section 5 followed by conclusion in section 6.

### Table 1: Comparison of the proposed work with the previously reported work

| Ref | No of CDBA | Type   | Standard filter Function | Mode | R+C | Independent $\omega_0$ and $Q_0$ |
|-----|------------|--------|--------------------------|------|-----|-------------------------------|
| [3] | 2          | SIMO   | LP, BP, HP               | CM   | 4+2 | YES                           |
| [4] | 1          | SISO   | BP                        | VM   | 2+2,3+3,3+2,2+3               | YES                           |
| [5] | 2          | SIMO   | LP, BP, HP               | CM   | 4+2 | YES                           |
| [8] | 1          | SISO   | LP, BP, HP               | CM   | 3+2 | YES                           |
|     |            |        |                           | VM   | 2+3 | YES                           |
|     |            |        |                           | TIM  | 2+2 | NA                            |
|     |            |        |                           | TAM  | 3+2 | YES                           |
|     |            |        |                           |      |     |                               |
| [9] | 1          | MISO   | LP, BP, HP, AP,          | VM   | 4+2 | YES                           |
| [10]| 3          | SIMO   | LP, BP, BS,              | VM   | 7+2 | YES                           |
|     | 3          |        | HP, BP, AP               | VM   | 2+7 |                               |
| [12]| 1          | SIMO   | LP, BP                   | CM   | 3+2 | YES                           |
|     | 2          | SISO   | HP                       | CM   | 3+2 | YES                           |
|     | 2          | SISO   | HP                       | CM   | 3+3 | YES                           |
| [13]| 1          | SISO   | AP                       | VM   | 3+2 | YES                           |
| [14]| 3          | SIMO   | LP, BP, BS,              | VM   | 4+2 | YES                           |
|     | 3          | SIMO   | HP, BP, AP               | VM   | 2+4 | YES                           |
| [15]| 3          | MISO   | LP, BP, HP, BS,          | CM   | 2+2 | YES                           |
| [16]| 1          | MISO   | LP, BP, HP, BS,          | VM   | 4+4 | YES                           |
| [17]| 2          | SISO   | LP, BP, HP, BS,          | CM   | 4+4 | YES                           |
|     | Proposed work | SISO | LP, BP, HP               | VM   | 4+2 | YES                           |

### 2. Circuit Description

The port characteristics of CDBA are given by matrix (1) and its circuit symbol is shown in Fig. 1.

\[
\begin{bmatrix}
I_z \\
V_w \\
V_p \\
V_n
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 1 & -1 \\
1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
V_z \\
I_w \\
I_p \\
I_n
\end{bmatrix}
\]  

(1)
The proposed filter topology is shown in Fig. 2. Using routine analysis the transfer function for the proposed circuit is obtained as

\[ \frac{V_o}{V_{in}} = \frac{K Y_1 Y_2}{D} \]  

(2)

Where, \( K = \frac{Y_1}{Y_6} \)  

(3)

\[ D = Y_1 Y_2 + Y_1 Y_3 + Y_1 Y_4 + Y_2 Y_3 + Y_2 Y_4 + Y_3 Y_4 - K Y_5 Y_6 \]  

(4)

The appropriate admittance choices would result in three required filter responses, as listed in Table 2.

Table 2: Admittance Selection for Proposed Filter Topology

| Response Type | Y_1  | Y_2  | Y_3  | Y_4  | Y_5  | Y_6  | Y_7  |
|---------------|------|------|------|------|------|------|------|
| LP            | G_1  | G_2  | G_3  | sC_1 | sC_2 | G_6  |      |
| HP            | sC_1 | sC_2 | G_3  | G_4  | G_5  | G_6  |      |
| BP            | G_1  | sC_1 | G_3  | sC_2 | G_5  | G_6  |      |

For the admittance choices available in Table 2, the transfer function for LP, HP and BP can be expressed as:

\[ \left( \frac{V_o}{V_{in}} \right)_{LP} = \frac{K_G G_1 G_2}{s^2 + \frac{sC_2}{C_1} + sC_2 + \frac{G_3 G_4 + G_3 G_4 (1 - K)}{C_2} + \frac{G_5 G_6 + G_5 G_6 (1 - K)}{C_3}} \]  

(5)

\[ \left( \frac{V_o}{V_{in}} \right)_{HP} = \frac{K_F^2}{s^2 + \frac{sC_2}{C_1} + sC_2 + \frac{G_3 G_4 + G_3 G_4 (1 - K)}{C_2} + \frac{G_5 G_6 + G_5 G_6 (1 - K)}{C_3}} \]  

(6)

\[ \left( \frac{V_o}{V_{in}} \right)_{BP} = \frac{K_S G_1}{s^2 + \frac{sC_2}{C_1} + sC_2 + \frac{G_3 G_4 + G_3 G_4 (1 - K)}{C_2} + \frac{G_5 G_6 + G_5 G_6 (1 - K)}{C_3}} \]  

(7)

From equations (5-7), the resonant angular frequency \( \omega_0 \), quality factor \( Q_0 \) and filter gain \( H_0 \) for the three filters are listed in Table 3.
Table 3: Filter Parameters

| Filter Type | $\omega_0$ | $Q_0$ | $H_0$ |
|-------------|------------|-------|-------|
| LP          | $\sqrt{G_1 G_2 G_3 (G_1 + G_2 + G_3)} / C_2 C_4$ | $\sqrt{C_2 C_4 (G_1 + G_2 + G_3 + G_4 G_5)} / (C_1 + C_3 + C_4 + C_2 C_5 (1 - K))$ | $K G G_2 / (G G_2 + G G_3 + G G_4)$ |
| HP          | $\sqrt{G_3 (G_3 + G_5)} / C_2 C_3$ | $\sqrt{C_2 C_3 (G_3 + G_5 + G_4 G_6)} / (C_1 + C_3 + C_4 + C_2 C_5 (1 - K))$ | $K$ |
| BP          | $\sqrt{G_3 (G_3 + G_5)} / C_2 C_3$ | $\sqrt{C_2 C_3 (G_3 + G_5 + G_4 G_6)} / (C_1 + C_3 + C_4 + C_2 C_5 (1 - K))$ | $G C_2 / (G_2 (G_1 + G_3 + G_4 G_5 + G_2 G_3) + C_2 C_3 (1 - K))$ |

Table 4 lists the filter parameters for all the three responses when all the conductance are set equal to $G$ except $G_6$ and all capacitors are set equal to $C$. It may be observed from the Table 4 that $\omega_0$ can be set using appropriate $G$ and $C$ values and the desired $Q_0$ can be obtained with the help of $G_6$, the $K$ determining component, thereby making tuning independent.

Table 4: Filter Parameters for Equal Component Design

| Filter Type | $\omega_0$ | $Q_0$ | $H_0$ |
|-------------|------------|-------|-------|
| LP          | $\sqrt{3} G / C$ | $\sqrt{3} / (4 - K)$ | $K / 3$ |
| HP          | $\sqrt{2} G / C$ | $\sqrt{2} / (5 - K)$ | $K$ |
| BP          | $\sqrt{2} G / C$ | $\sqrt{2} / (5 - K)$ | $K / (5 - K)$ |

3. Sensitivity Analysis

The passive sensitivities of $\omega_0$ and $Q_0$ for the LP filter configuration can be derived as

$$S^{\omega_0}_{C_4} = S^{\omega_0}_{G_1} = \frac{1}{2}, \quad S^{\omega_0}_{G_2} = \frac{1}{2} \frac{G_1 G_3}{2 (G_1 G_2 + G_1 G_3 + G_2 G_3)}, \quad S^{\omega_0}_{G_3} = \frac{1}{2} \frac{G_1 G_2}{2 (G_1 G_2 + G_1 G_3 + G_2 G_3)},$$

$$S^{\omega_0}_{G_4} = \frac{1}{2} \frac{G_3 G_2}{2 (G_3 G_2 + G_3 G_4 + G_4 G_3)}, \quad S^{\omega_0}_{G_5} = 0, \quad S^{\omega_0}_{C_2} = \frac{1}{2} \frac{C_2 (G_1 + G_2 (1 - K))}{C_2 (G_1 + G_2) + G_2 C_3 + G_2 C_3 (1 - K)},$$

Similarly the passive sensitivities of $\omega_0$ and $Q_0$ for the HP and BP filter configuration can be also be computed which have not presented here for the sake of brevity. It maybe observed that the filter configurations are insensitive to parameter variations as passive sensitivities for all the responses are less than 0.5 in magnitude.

4. Non-Ideality Analysis

In CMOS implementation of CDBA current and voltage tracking errors may exist due device mismatch. Taking these errors into consideration the terminal relationships of the CDBA get modified

$$I_x = \alpha_x I_p - \alpha_y I_n$$
\[ V_w = \beta V_z \]

where \( \alpha \) = (1 - \( \epsilon_p \)), \( \alpha_n = (1 - \epsilon_n) \) and \( \beta = (1 - \epsilon_v) \)

The terms \( \epsilon_p (|\epsilon_p|<<1) \) and \( \epsilon_n (|\epsilon_n|<<1) \) denote the current-tracking errors from p and n terminals to z terminal respectively and \( \epsilon_v (|\epsilon_v|<<1) \) is the voltage-tracking error from z to w terminal of the CDBA. The modified transfer functions of the proposed filter in the presence of current and voltage tracking errors can be expressed as:

\[
\left( \frac{V_o}{V_i} \right)_{LP} = \frac{a_0 b K}{s^2 + s \left( C_4 (G_1 + G_2) + G_3 \right) + \frac{C_2 (G_4 \cdot \epsilon_v)}{C_1}}
\]

\[
\left( \frac{V_o}{V_i} \right)_{HP} = \frac{a_0 b K_2}{s^2 + s \left( C_4 (G_1 + G_2) + G_3 \right) + \frac{C_2 (G_4 \cdot \epsilon_v)}{C_1}}
\]

\[
\left( \frac{V_o}{V_i} \right)_{BP} = \frac{a_0 b K S}{s^2 + s \left( C_4 (G_1 + G_2) + G_3 \right) + \frac{C_2 (G_4 \cdot \epsilon_v)}{C_1}}
\]

So this can be evaluated looking at Table 3 natural frequency of the filter topology is not influenced by tracking errors of the CDBA.

5. Simulation Results

The proposed multifunctional filter is verified through simulations using the CMOS implementation of the CDBA as presented in [13]. The SPICE simulations are performed using 0.18\( \mu \)m CMOS process parameters provided by MOSIS (AGILENT). Supply voltages taken are \( \pm 0.9 \) V. The LP, HP and BP filter configurations were designed with \( Q=1 \) and \( f_0 \) of 500 KHz. For all three filter response the value of resistances are taken as 10k\( \Omega \) except for \( R_6 \) having a value is 22.68k\( \Omega \) for LP and 35.86k\( \Omega \) for HP and BP it is. The values of capacitances for LP are chosen 0.055nF and for HP and BP the values of Capacitances are 0.045nF. The simulated frequency responses of all the three configurations are shown in Figs.3 (a), (b) and (c) respectively. The simulated \( f_0 \) is observed to be 493 KHz in case of LP whereas in HP and BP it is found to be 484 KHz. The simulated values are in close agreement to the theoretical frequency of 500 KHz.
Fig. 3: Phase and Gain responses of proposed (a) LP (b) HP (c) BP Filters
To show the tuning of \( f_0 \) BP responses are plotted for two different values of \( f_0 \) while keeping \( Q_0 \) fixed at 1 as depicted in Fig. 4(a). The independent tunability of \( Q_0 \) with \( R_6 \) is shown in Fig. 4(b). The center frequency \( f_0 \) is taken to be 500 KHz.

Fig. 4: The BP response depicting independent tunability of (a) \( f_0 \) (b) \( Q_0 \)
Functionality of proposed filter topology is also tested through its time domain response. As a case study the transient response of HPF is observed by applying a composite input sinusoidal signal having frequencies of 20 KHz and 700 KHz.
The transient responses along with their respective frequency spectrums for input and output signals are shown in Fig. 5(a)-(d). It may be observed from the response of Fig. 5(d) that the 700 KHz signal is passed without attenuation and 20 KHz signal is significantly attenuated.

The performance of proposed filter topology is also evaluated through well known Monte Carlo statistical analysis. The simulated standard deviation of $f_0$ is observed to be 122 Hz for BP configurationsimulated by setting the values of all passive elements in 5% tolerance. This implies that the proposed filter topology has reasonable sensitivity characteristics. The derived histogram after 50 simulation runs for BP filter is shown in Fig.6.

6. CONCLUSION

A new voltage mode single CDBA based filter topology is presented in this paper. The configuration can be used to synthesize LP, HP and BP filters with appropriate choices of admittance. The proposed configuration can be extended to obtain the current mode, transadmittance mode and transimpedance mode through appropriate input signal and
component selection. The proposed configuration is a suitable choice for high quality factor implementation. Passive sensitivities for the configuration are found low. Extensive SPICE simulations are carried out to observe the performance of the proposed configuration. The simulation and theoretical results are found in close agreement.

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