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Third order lowpass Butterworth filters using unity gain current amplifiers

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Abstract: Some new realizations of third order lowpass (LP) Butterworth filters using the current differencing buffered amplifier (CDBA) and current feedback amplifier (CFA) type unity gain cells are presented. The circuits are practically active insensitive to the decvice port tracking errors (ε). Effects of the device parasitic capacitances on the nominal design are insignificant which can be conveniently compensated. With suitable design alternate bandpass (BP) Butterworth characteristics may also be obtained.

Keywords: Butterworth filter, current amplifiers, CFA, CDBA

Classification: Integrated circuits

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1 Introduction

The design of third order Butterworth filters using various types of active devices were proposed in the past [1, 2]. Recently some such filters using voltage buffers and current amplifiers are reported [3]. With the availability of CDBA [4] and CFA [5, 6] type active building blocks, there is renewed interest on analog function circuits using these devices [7, 8, 9, 10, 11, 12, 13, 14]. These elements are essentially unity-gain current amplifiers with the provision of additional voltage follower feature. The literature describes several advantageous properties [3, 6, 15] of these elements. Albeit some second order filters [7, 8, 9, 10, 11, 12, 13, 14] are now available, a third order Butterworth filter design scheme using these devices had not yet been reported. We therefore present some new realizations of these filters wherein a CDBA based dominant pole-pair forming stage is coupled to a CFA based single-pole stage. Analyses show that the designs are practically active insensitive to the device port-mismatch errors (ε) and the parasitic device capacitances. The response is experimentally verified in a typical frequency range of 200 KHz $\ll f_o \ll$ 5 MHz, by both PSPICE simulation and hardware circuit tests wherein the CDBA element had been implemented with a pair of matched AD-844 type current feedback opamps [7].

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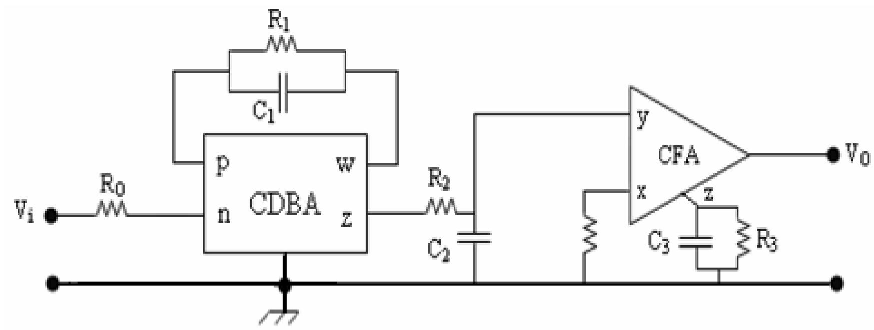
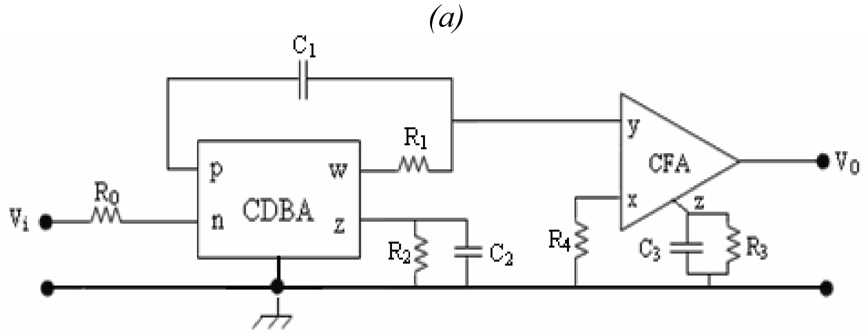
2 Analysis

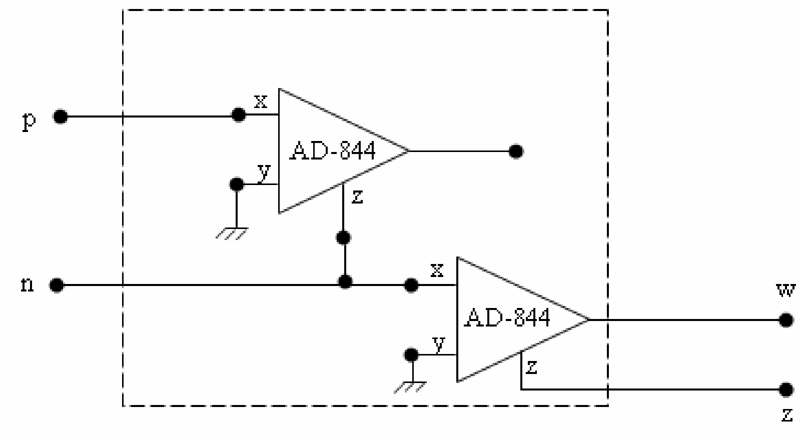
The proposed circuits are shown in Figs. 1 (a) and (b); the CDBA implementation with a pair of AD-844 current amplifier is shown in Fig. 1 (c). The port relations of the CDBA are $i_z = \alpha i_p - \beta i_n$, $v_w = \delta v_z$, $v_p = v_n = 0$, and those of CFA are $i_z = \mu i_x$, $v_x = \sigma v_y$, $v_o = m v_z$ and $i_y = 0$ where the tracking ratios are usually expressed in terms of some errors ($\varepsilon \ll 1$) [10, 11, 12, 13] as $\alpha = 1 - \varepsilon_p$, $\beta = 1 - \varepsilon_n$, $\delta = 1 - \varepsilon_w$, $\mu = 1 - \varepsilon_i$, $\sigma = 1 - \varepsilon_v$ and $m = 1 - \varepsilon_o$.



(a)



(b)



(c)

Fig. 1. Proposed configurations for third order filter (*a*) Noninverting (*b*) Inverting (*c*) CDBA implementation

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For ideal devices, the ratios are unity ($\varepsilon = 0$). Analysis of Fig. 1 yields

$$F(s) = V_o/V_i = \pm K/\{1 + d_1 s + d_2 s^2 + d_3 s^3\} \quad (1)$$

where the function is noninverting for Fig. 1 (a) and inverting for Fig. 1 (b).

The polynomial coefficients are

$$d_1 = C_2R_2 + C_3R_3 + (\lambda)_{a,b} \quad (2)$$

$$d_2 = C_1C_2R_1R_2 + C_3R_3\{C_2R_2 + (\lambda)_{a,b}\} \quad (3)$$

$$d_3 = C_1C_2C_3R_1R_2R_3 \quad (4)$$

$$K = (\acute{K})_{a,b}(R_1R_3/R_oR_4) \quad (5)$$

where suffix (a, b) relate to Fig. 1 (a) and (b) respectively; these are listed in Table I. The design becomes simple with all equal-value passive components (say R & C) if the devices are ideal; assume these are normalized to unity, then we get a maximally flat third order Butterworth function from eq. (1)

$$F(s) = \pm 1/\{1 + 2s + 2s^2 + s^3\} \quad (6)$$

However, with nonideal devices, the realizability is $(\lambda)_a = 0$ for Fig. 1 (a) in Table I which leaves a residual negative capacitance of $-C(\varepsilon_p + \varepsilon_w)$; this can be precisely compensated by connecting a small shunt grounded capacitor of same value across C_2 in Fig. 1 (a). Similarly the nominal value of R_2 in Fig. 1 (b) is reduced by an amount $R_2(\varepsilon_p + \varepsilon_w)$ which may be corrected by using a series compensating resistor of same value to R_2. We then calculated the active sensitivities using [16]

$$S_\varepsilon^{\omega_o} = S_\varepsilon^{d_1} - S_\varepsilon^{d_2}$$

$$S_\varepsilon^{Q} = S_\varepsilon^{d_3} - S_\varepsilon^{d_1} - S_\varepsilon^{d_2}$$

After some calculations we obtained $S_\varepsilon^{\omega_o} = 0$ for all the error terms $S_{\varepsilon_{p,w}}^{Q} = (\varepsilon_p + \varepsilon_w)/2 \ll 0.5$; Q-sensitivity for other errors being all zero. We next

Table I. Details of realizability design

Fig.1	λ / Ḱ	***Realizability λ=0*** Ideal ε = 0 / Nonideal ε ≠ 0	***Effect of parasitic capacitors*** đ₁	đ₂	đ₃
(a)	$R_1\{C_1 - C_2(1+\varepsilon_p + \varepsilon_w)$	$C_1 = C_2$	2+ η	2+ η +u-q	1+ η +u-q
	β δ μ σ / α δ	$C_1 = C_2(1+\varepsilon_p + \varepsilon_w)$			
(b)	$C_1[R_1 - R_2\{1-(\varepsilon_p + \varepsilon_w)\}]$	$R_1 = R_2$	2+ η +q	2(1+q)+ η +u	1+ η +q+u
	β δ μ σ m	$R_1 = R_2(1 - \varepsilon_p - \varepsilon_w)$			

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examined the effect of the device parasitic capacitances appearing internally at the z-node of CDBA (C_{z1}) and at CFA (C_{z2}), and also at the y-node (C_y) of the CFA [11, 14, 15]. Associated with these small capacitors ($C_{z1,2} \sim 3\,pF$ to $6\,pF$), there are shunt internal resistances ($r_y \sim 3\,M\Omega$ and $r_z \sim 6\,M\Omega$) which were neglected since we followed the design such that $(R/r_{y,z}) \ll 1$. Note that the p and n terminals of the CDBA are at virtual zero potential so that the parasitics there are grounded. Now for the sake of simplicity, we consider all equal unity-value passive components and thereafter write $q = C_{z1}/C$, $\eta = C_{z2}/C$ and $u = C_y/C$. The coefficients are now slightly altered as shown in Table I; note that the nominal design of $d_3 = 1$, $d_2 = d_1 = 2$ is obtainable if q, η, u $\ll 1$ which we selected in our design. It is seen that all $S^{Q,\omega_o,} \ll 1$ relative to the parasitic capacitors.

3 Experimental results

The response of the proposed circuits had been verified with both PSPICE simulation and by hardware implementation employing AD-844 type current amplifiers which were chosen matched with respect to the current gain ($\sim$ 0.99 measured) and parasitic capacitors ($C_{z1} \approx C_{z2} \approx 6.3\,pF$ measured). Satisfactory maximally flat LP Butterworth characteristic were obtained in a frequency range $200\,KHz \ll f_o \ll 5\,MHz$; typical test responses are shown in Fig. 2. A BP-type Butterworth response had also been verified after interchanging location of R_2 and C_2 in Fig. 1 (a) and that of R_1 and C_1 in Fig. 1 (b). These BP characteristics are similar to that of stagger-tuned bandpass amplifier which were designed with LC components [2, 17] in the past for broadening the flatness of the passband. It may be observed in Fig. 1 that all the equal-value capacitors used here are effectively grounded.

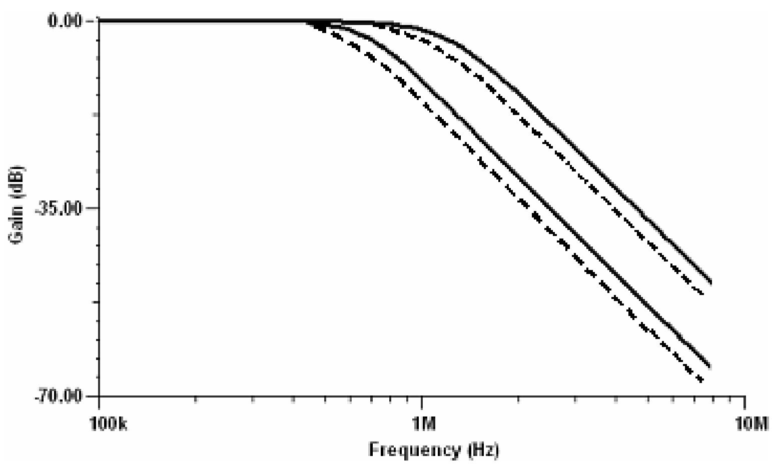

Fig. 2. Experimentally obtained third order Butterworth responses obtained for $f_o = 680.1\,KHz$ with $R = 1.5\,K\Omega$, $C = 150\,pF$ and $f_o = 1.2\,MHz$ with $R = 1.3\,K\Omega$, $C = 100\,pF$
——————— simulation
- - - - - - - - - - hardware test

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4 Conclusion

Some new third order Butterworth filter realizations using the composite CDBA-CFA unity gain devices and with equal-value passive components are presented together with satisfactory test results. The realizations are practically insensitive to device nonidealities and parasitics.

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