International Journal of Electronic and Electrical Engineering.
ISSN 0974-2174 Volume 4, Number 1 (2011), pp.33-42

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A Review on Single CFA based Multifunctional Network for Analog Signal Processing

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Abstract

This paper presents a review of multifunctional network utilizing a current feedback amplifier (CFA-AD 844) as a basic building block. The circuit implements the functions of integrator/ differentiator, high-pass, low-pass and band-pass on the same topology with the appropriate design. The circuits have been analyzed, simulated and experimentally tested. The simulation and experimental results verify the performance of the reported circuits in terms of the number of basic building blocks used and high selectivity. It has also been examined that the variation of the time constant (T) of CFA based multifunction network, the quality factor (Q) of integrators/ differentiators and filter may be measured with single component variation at extended frequency ranges (1–30 MHz).

Index Terms: Current feedback amplifier (CFA), Integrator, Differentiator, Filters.

Introduction

Current-mode active elements offer the main advantages like greater linearity, low power consumption and wider bandwidth over their voltage-mode counter parts [1-3]. Also, the design of filter circuits employing current-mode active elements may be used in phase-locked loop frequency modulation (FM), stereo demodulators, touch-tone telephone and cross over networks used in a three-way high fidelity loudspeaker [4].

Second-order active filters with infinite input impedance are of great interest because several networks of that kind can be directly connected in cascade to implement higher order filters [5-8] with no need to interpose active separating stages.

Infinite input impedance cells assure a total uncoupling between the different elementary stages. This will entail an easier determination of the passive component values of each of the elementary cells and an easier to design a global circuit. In such circuits theoretical and experimental frequency responses of the filters will generally be closer.

Frequency response of recently available Current feedback amplifier [9-12] device- AD 844 remains unchanged up to some hundred of megahertz when they are used to the design of different kind of filters. The AD844 is free from the slew rate limitations inherent in traditional op amps and other current-feedback op amps. Peak output rate of change can be over 2000 V/μs for a full 20 V output step. Settling time is typically 100 ns to 0.1%, and essentially independent of gain. The AD844 can drive 50 Ω loads to ±2.5 V with low distortion and exhibits excellent differential gain and differential phase characteristics, making it suitable for a variety of video applications with bandwidths up to 60 MHz. The literature presents different filters [13-19], integrators [20, 21] schemes using CFAs and external discrete *RC* components.

This paper presents a review of the multifunctional network that can perform the function of integrator/differentiator and filter by employing only a single CFA and few passive components [22]. Here, we have utilized the CFA (AD-844): analog device parasitic/transimpedance, for the realization of different functions. The effects of the parasitic elements in determining the quality (Q) of the integrator/differentiator had been examined. Then, we describe the design of high-quality (Q) selective filters. All of these multifunction capabilities are obtainable on the same topology after suitable choice of external RC components.

Circuit Analysis

The block diagram of the CFA is shown in Figure 1(a), and its terminal relations are given by:

$$\begin{bmatrix} V_x \\ i_y \\ i_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_Y \\ V_Z \\ i_x \end{bmatrix} \quad (1)$$

The Inverting/Non-inverting input terminal of CFA is actually the output/input of the unity gain buffer, which ideally has zero output impedance and infinite input impedance. As a result, the input impedance at the inverting terminal is zero whereas the input impedance at the non-inverting terminal is infinite. The output is therefore a linear, current-controlled source with zero output impedance.

$$V_0 = Z(s).\, i_{inv} \quad (2)$$

Where z (s) is the trans-impedance parameter (in ohms), i_{inv} is the current flowing out of the inverting input terminal.

The reported circuit [22] is shown in Figure 1(b). The circuit uses one current-feedback amplifier and five admittances. For the realization of integrator/differentiator and filter, device parasitic/ transimpedance are utilized in analysis. All of these multifunction capabilities are obtainable on the same topology by suitable choice of external RC components and there after imposing the effects of the internal device elements on the analysis. The routine analysis using the CFA port relations yields the transfer function:

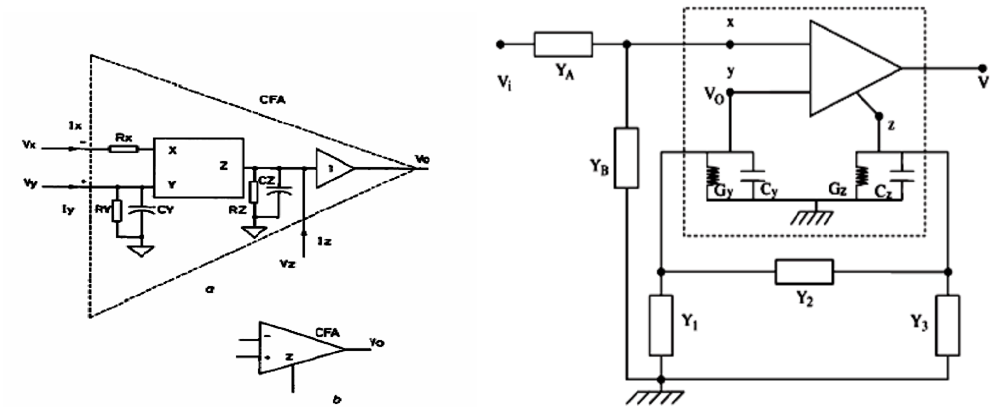


Figure 1: (a) Current feedback Amplifier Model (b) Single-CFA multifunction structure [22].

$$H(s) = \frac{Y_A}{(Y_A + Y_B) - \left[Y_1 + Y_y + Y_3 + Y_z + \left\{\frac{(Y_1 + Y_Y)(Y_3 + Y_Z)}{Y_2}\right\}\right]} \quad (3)$$

Where *Yy* and *Yz* denote the y-port parasitic input admittance and the z-port transadmittance elements of the device, respectively; both of these appear in the form of shunt RC arms, which is defined as *Ya = Ga+sCa*, where *a=y* or *a=z,* and *G* is the transconductance. The typical values for these components from the data sheet [7] are *Ry=1/Gy=2MΩ*, *Cy=3pF,Rz=1/Gz=4MΩ*, and *Cz=6pF*.

Integrator/Differentiator

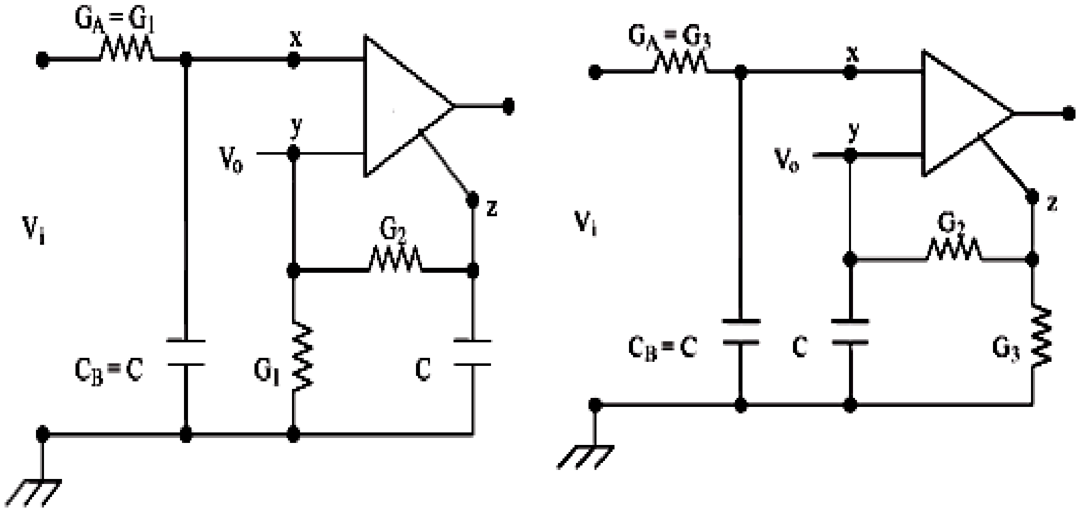
The inverting integrator is implemented by the circuit of Figure 1 by selecting $Y_A = Y_1 = G_1$, $Y_2 = G_2$, and $Y_B = Y_3 = sC$, as shown in Figure 2(a). The transfer function is:

$$-H_i(s) = \frac{G_1 G_2}{s^2 C_y (C + C_z) + s\{g_1 (C + C_z) + G_z C_y + G_2 C_T\} + G_2 G_T + g_1 G_z} \quad (4)$$

Now assuming *Yy* = *0* = *Yz* i.e. neglecting the effects of the parasitic/transadmittance elements of CFA, the equation (4) get modified as:

$$.-H_i(s) = {}^{G_2}/_{sC} = {}^{1}/_{sT_i} \quad (5)$$

The time constant is independently adjustable by R_2.



(a) With time constant $T_i = CR_2$. (b) Another integrator with the same T_i.

Figure 2: Realization of integrator.

The quality factor for integrator I:

$$q_i(\omega) = n(\omega)/m(\omega) \approx \omega_n C_T / \omega C_y \tag{6}$$

An alternate inverting integrator with a similar quality factor can also be designed by simply replacing G1 by capacitor C and C by admittance G_3 as shown in Fig. 3(b). The corresponding expressions for its transfer function:

$$-H_i(s) = \frac{G_2 G_3}{s^2 C\, C_z + s\{g_1 C_Z + G_2 C_T + g_3 C\} \quad + G_1 G_2 + g_1 g_3} \tag{7}$$

The quality factor for integrator II:

$$q_i(\omega) = n(\omega)/m(\omega) \approx \omega_m C_T / \omega C_z \tag{8}$$

For an inverting differentiator as shown in Figure 3(a), we take $Y_A = Y_1 = G_1$, $Y_B = Y_3 = G_2$, and $Y_2 = sC$, which yields:

$$-H_d(s) = \frac{G_1 sC}{s^2\left(C_y C_z + CC_T\right) + s\left(CG_T + C_y g_2 + C_z g_1\right) + g_1 g_2} \tag{9}$$

Now by ignoring *Yy* and *Yz*, the transfers function:

$$-H_d(s) = -sT_d = \; sR_2\; C \tag{10}$$

Where T_d can be adjusted independently by C.

The quality factor for differentiator:

$$q_d(\omega) \approx \frac{G_1}{T_d \omega G_T} \tag{11}$$

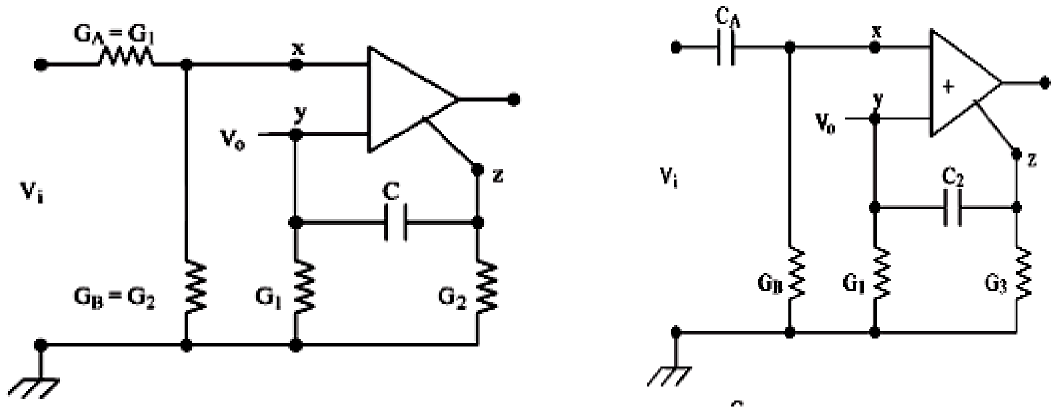


Figure 3: (a) Single CFA Differentiator (b) High Pass Filter.

Filter Design

The same circuit topology in Figure 1(a) is able to realize high-selectivity tuneable resonant filters with the appropriate choice of RC components along with the use of the device transadmittance.

A High Pass filter is designed with $Y_A = SC_A$, $Y_B = G_B$, $Y_1 = G_1$, $Y_2 = sC_2$, and $Y_3 = G_3$, as shown in Figure. 3(b).

This yield:

$$H_h(s) = Vo/Vi = -s^2 C_A C_2 / D_h(s). \tag{12}$$

Where the denominator function D_h (s):

$$D_h\ (S) = S^2\{C_y C_Z + C_2\ (C_T - C_A)\} + s[g_1 C_Z + g_3 C_Y + C_2\ (G_1 + G_3 + G_T - G_B)] + g_1 g_3 \tag{13}$$

$$Q = \frac{\omega_o C_2 (C_T - C_A)}{g_1 C_Z + g_3 C_y + C_2 (G_1 + G_3 + G_T - G_B)} \tag{14}$$

$$\omega_0 = \frac{G}{\sqrt{C_Z (C_T - C_A)}} \tag{15}$$

The Low Pass filter is shown in Figure 5 (a). The LP transfer function is given by:

$-H_l(s) = G_2G_A/D_l(s).$ (16)

Where

$$D_l\ (S) = S^2C_yC_Z + s[C_Z(G_1 + G_2 + G_Y) + g_3g_1 + C_Y\ (G_2 + G_3 + G_Z) - C_BG_2] + g_1\ g_3 + G_2\ (g_1 + g_3 - G_A) \quad (17)$$

Higher cut off frequency for the low pass filter:

$$\omega_0 = \left[\frac{g_1\, g_3\ +\ G_2\ (g_1 + g_3 - G_A)}{C_yC_Z}\right]^{1/2} \quad (18)$$

Quality factor (Selectivity) for low pass filter:

$$Q = \frac{\omega C_yC_Z}{(G_1 + G_2 + G_y)C_Z + C_Y(G_2 + G_3 + G_Z) - G_2C_B} \quad (19)$$

A Band Pass filter characteristic could be obtained by High Pass filter circuit by simply interchanging C_A and R_B, as shown in Figure 4(b). The BP transfer function is obtained as:

$-H_b(s) = (sC_2G_A)/D_b(s)$ (20)

Where

$$D_b\ (S) = S^2\{C_yC_Z + C_2\ (C_T - C_B)\} + s[g_1\, C_Z + g_3C_Y + C_2\ (G_T - G_A)] + g_1\, g_3 \quad (21)$$

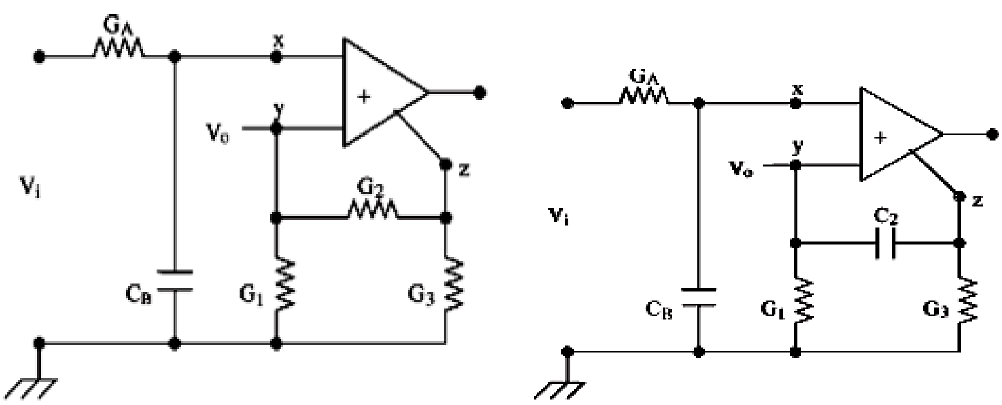


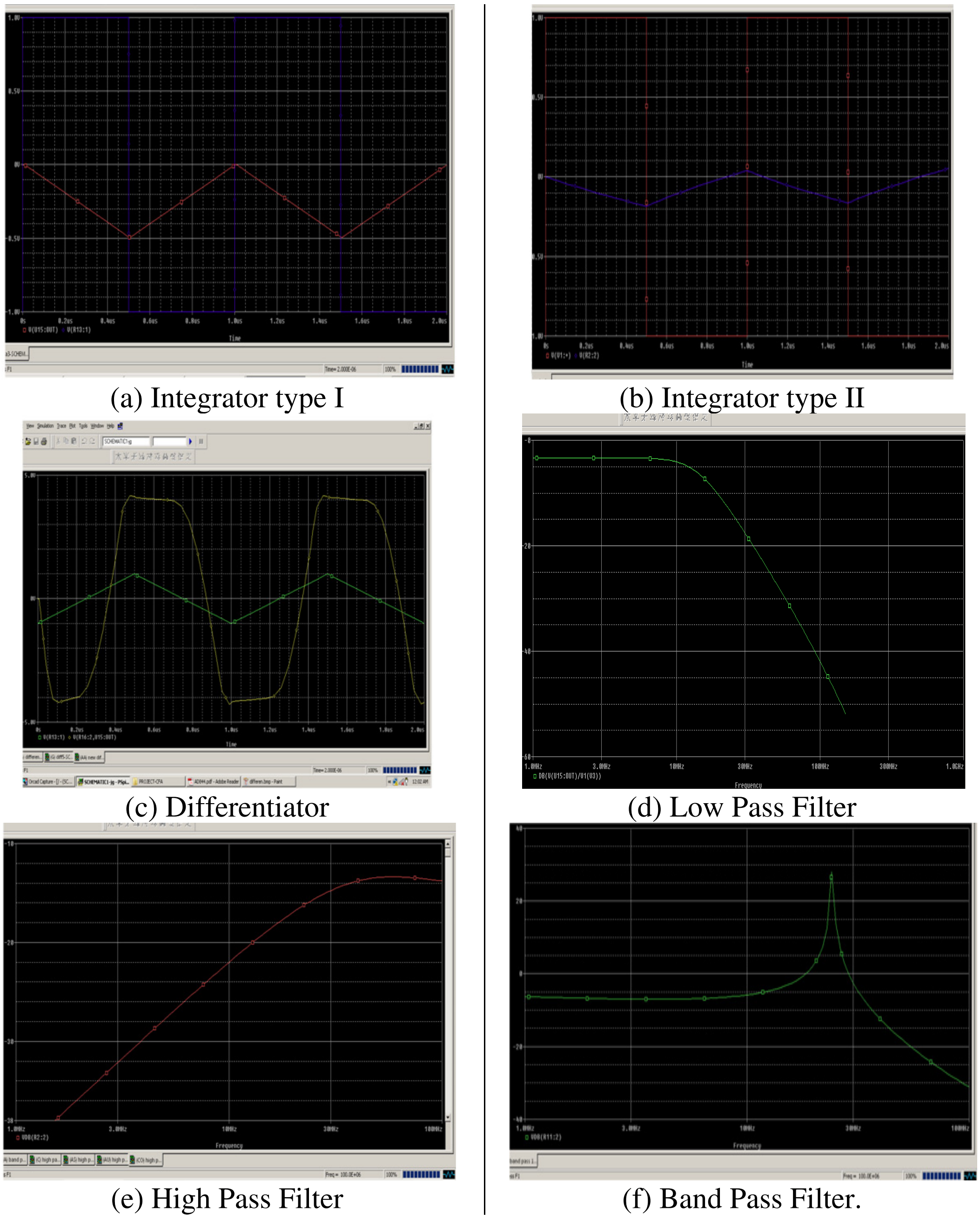
Figure 4: Design of filter. (a) Low Pass (b) Band Pass Filter.

$$Q = \frac{g_1\, g_3\, [C_ZC_Y + C_2\ (C_Z - C_B)]}{g_1\, C_Z + g_3C_Y + C_2\ (G_T - G_A)} \quad (22)$$

For narrow Band Filter Q>10 and if Q<10 Wide Band response is obtained.

Simulation and Experimental Results

All the functions of the multifunction network had experimentally been verified through hardware implementation and PSPICE macromodel simulation. The integrator/differentiator structures had been tested for time-domain response using square/triangular wave inputs, respectively. Good quality response on wave conversion up to 5 MHz was obtained, as shown in Figure 5.



(a) Integrator type I

(b) Integrator type II

(c) Differentiator

(d) Low Pass Filter

(e) High Pass Filter

(f) Band Pass Filter.

Figure 5: Pspice simulation results of different Networks.

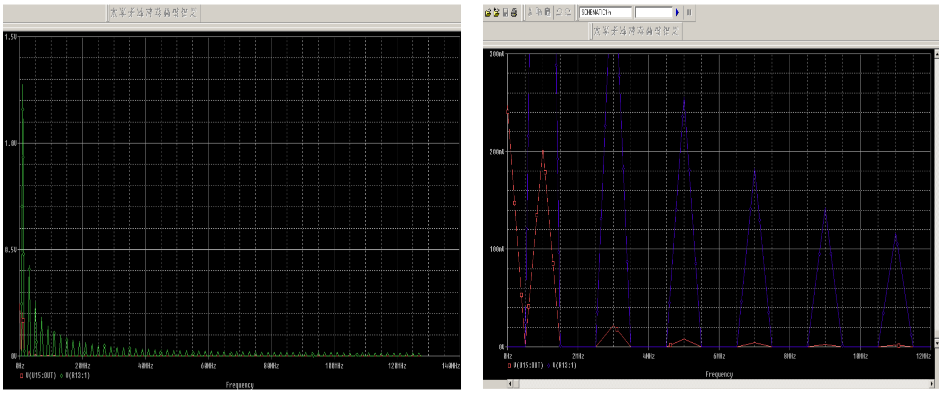
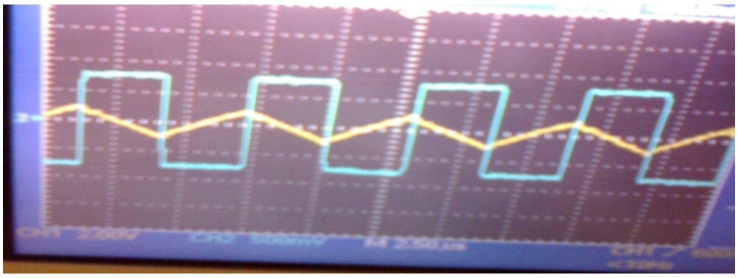
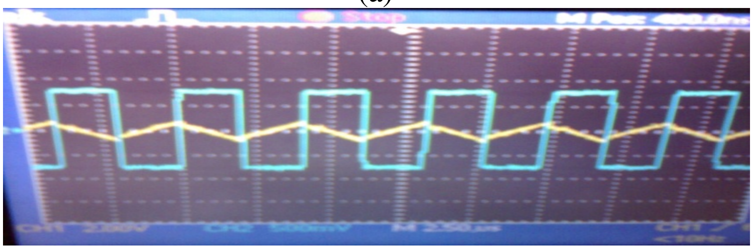


Figure 6: Fourier transforms of integrator input and output waveform.

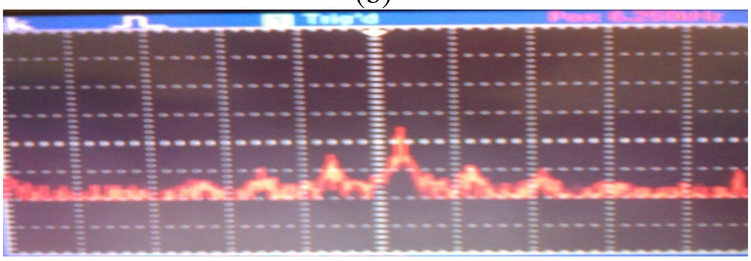
Good quality response on wave conversion and Fourier Transform up to 1 MHz is recorded by Digital oscilloscope as shown in Figure 7 (a), (b) and (c) respectively. Simulation results and hardware results are quite similar.



(a)



(b)



(c)

Figure 7: (a) Response of integrator type I, (b) Response of integrator type II, (c) Fourier transform of integrator type I.

Conclusion

Various signal processing networks like integrator, differentiator and filters, using single CFA topology are presented and reviewed. The advantages of using CFA over VFA in designing different networks are also presented. The characteristics of the integrator/differentiator realization and usable frequency range are examined and verified. The various filter transfer functions are analyzed, along with the expressions for the filter parameters ωo and Q. The simplified design equations for all the existing circuit functions are summarized. Some hardware realization results are also included.

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