Second-Order Multifunction Filter with Fully Differential Current Follower

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Abstract

This paper describes the design of a multifunction biquad filter that can provide multiple transfer functions according to the input and output current ports selected. The filter design is based on a general circuit with five passive elements (three of them are grounded) and one fully differential current follower. This versatile building block is ready to be manufactured by the ON Semiconductor Company and is expected to have impedance and transfer parameters close to the ideal ones in a wide frequency range. The functionality of the filter designed was verified by computer simulation and experimental measurement. The influence of real properties of the active element on the filter characteristics was ascertained.

1. Introduction

Analog filters are still important parts of current signal processing systems such as high-speed telecommunication, broadband multimedia or networking devices. The demands on these filters are ever stricter, particularly as far as bandwidth, dynamic range, noise properties, and power consumption are concerned.

Integrated circuits manufactured by modern sub-micron technologies operate with low supply voltages and thus their node voltages are also limited. The signal-to-noise ratio (SNR) can decrease excessively and it is more suitable to use current signals (instead of voltage signals) to carry information [1] – [3]. Of course, currents flowing through one-port elements cause voltage drops and it is necessary to set the impedance levels in the circuit such that these voltage drops have appropriate values.

We have chosen the FDCF (Fully Differential Current Follower) element as the basic active building block of the filter designed in this paper. This block has solely current inputs and outputs and will be described in the next chapter.

2. Fully differential current follower

FDCF is a very versatile active element that can be used for analog circuit design. Its schematic symbol is shown in Fig. 1.

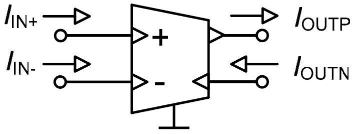

Fig. 1. Schematic symbol of FDCF

The output current I_{OUTP} flowing out of the FDCF is equal to the difference of input currents I_{IN+} and I_{IN-}. The output current I_{OUTN} has the same value but reverse direction.

2.1. FDCF with low input impedance

We as well as many other designers of analog circuits have found out that the most critical parameter of a current follower is its input impedance. Current followers based on classical transistor current mirrors [4] – [7] cannot offer a lower input impedance than several tens of ohms. The Widlar current mirror has, for example, a typical input impedance of 25 Ω and this mirror has the lowest input impedance among the classical ones. Thus for precise high-speed applications it is necessary to find a special structure that has its input impedance in the order of unity ohms even at high frequencies.

That is why the FDCF element with an original internal structure was developed at our workplace in cooperation with the Design Centre of the ON Semiconductor Company. The structure is expected to have transfer and impedance characteristics close to the ideal ones in a wide frequency range. Table 1 shows the estimated inverting and non-inverting input impedance modules that the device described should have.

Table 1. Expected values of FDCF input impedance module (inverting and non-inverting inputs to ground)

Frequency	Input impedance
1 MHz	0.49 Ω
10 MHz	2.35 Ω
100 MHz	23.32 Ω

3. Filter design

A general circuit used for the filter design is depicted in Fig. 2. It employs one FDCF, two floating resistors, one grounded resistor, and two grounded capacitors. The grounded passive elements are advantageous for integrated implementation. The circuit was designed so that it employs as much of the FDCF element properties as possible. Additionally, the general circuit has only series resistances connected to the FDCF inputs and parallel capacitances and a resistance connected to the FDCF outputs. This is useful because the real properties of the active element (internal input resistance and output capacitance) can be compensated by appropriately lowering the resistances and capacitances connected to the FDCF pins. Notice that the inverting input is not connected. This is correct because the input current into this pin should be zero. It is equivalent to a grounded voltage input where the input voltage is zero.

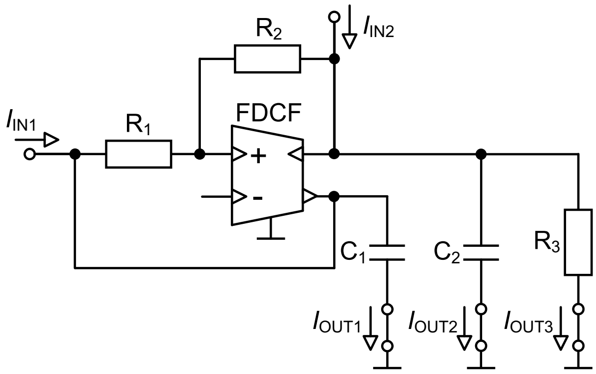

Fig. 2. Basic general circuit for the filter design

The characteristic equation (CE) of the circuit in Fig. 2 is

$$D = s^2 C_1 C_2 R_1 R_2 R_3 + sC_1 R_1 (R_2 + 2R_3) + R_3 = 0 \qquad (1)$$

We assume that the circuit chosen operates in the current mode, i.e. with current input and current output. The term multifunction filter stands in this paper for a filter that can provide multiple transfer functions simultaneously, depending on the combination of the input and output ports chosen. It has been found out by routine computer analysis that the optimal placement of current input and output ports, as regards the multifunctionality of the filter, is I_{IN1}, I_{IN2}, I_{OUT1}, I_{OUT2} and I_{OUT3} as shown in Fig. 2. A total of 5 filter variants can be obtained from the circuit in Fig. 2. They operate as low-pass (LP), band-pass (BP) and high-pass (HP) filters and their transfer functions are summarized in Table 2.

Table 2. Transfer functions of possible circuit variants

Input/Output	I_{IN1}	I_{IN2}
I_{OUT1}	---	$\frac{sC_1R_1R_3}{D}$
I_{OUT2}	$-\frac{sC_2R_2R_3}{D}$	$\frac{s^2C_1C_2R_1R_2R_3}{D}$
I_{OUT3}	$-\frac{R_2}{D}$	$\frac{sC_1R_1R_2}{D}$

The following relations are valid for the pole angular frequency ω_0 and quality factor Q of the filter.

$$\omega_0 = \sqrt{\frac{1}{C_1 C_2 R_1 R_2}}\,, \qquad (2)$$

$$Q = \frac{R_3}{R_2 + 2R_3}\sqrt{\frac{C_2 R_2}{C_1 R_1}}\,. \qquad (3)$$

4. Simulation and measurement

The functionality of the filter designed was verified by computer simulation in the PSpice environment. We used a frequency-dependent model of FDCF that has a -3 dB bandwidth of 85 MHz. The model also includes the parasitic impedances of terminals. The input resistance is 5 Ω, the output resistance is 200 kΩ, and the output capacitance is 5 pF. When manufactured, the samples of FDCF are expected to have similar or better properties.

The passive filter elements were designed for the pole frequency f_0 = 5 MHz and the Butterworth approximation (quality factor 0.707). The resulting element parameters are C_1 = 50 pF, C_2 = 225 pF, $R_1 = R_2 = R_3$ = 300.1 Ω. The simulated magnitude frequency characteristics of the filter are depicted in Figs. 3 and 4. The first graph shows the responses of the LP and BP variants with input 1 and outputs 2 and 3. The second graph shows the characteristics of the BP and HP filters with input 2 and outputs 1, 2 and 3. The simulated results are in black and the ideal characteristics in grey.

It can be seen that the characteristics are close to the ideal ones. The cut-off frequency is slightly lower than 5 MHz, which is caused by the frequency limitation and the non-zero input resistance in the FDCF model. The influences of all modeled non-idealities of FDCF on the frequency characteristics are summarized in Table 3.

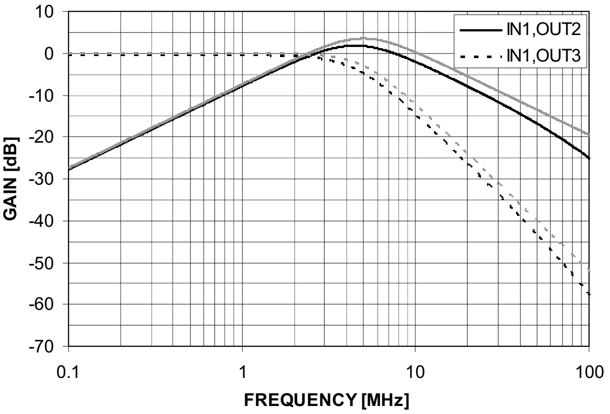

Fig. 3. Simulated (black) and ideal (grey) magnitude frequency characteristics of the designed filter with input 1 used

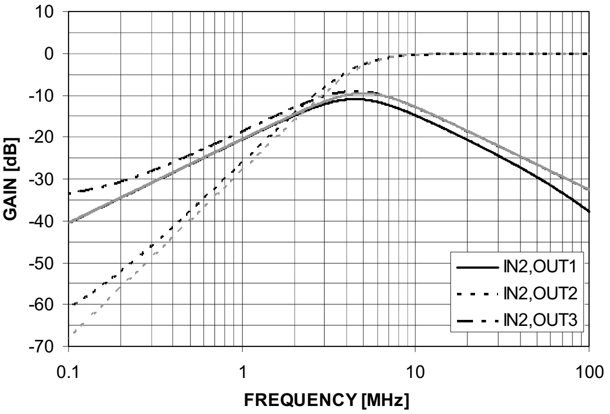

Fig. 4. Simulated (black) and ideal (grey) magnitude frequency characteristics of the designed filter with input 2 used

Table 3. Influence of real properties of FDCF on filter characteristics

FDCF non-ideality	Filter input	
	IN1 (LP and BP)	**IN2 (BP and HP)**
Higher input resistance	Gain decreases at all frequencies	Gain increases below f_0
Frequency limitation	Gain decreases above f_0	OUT1 (BP): Gain decreases above f_0 OUT2 (HP), OUT3 (BP): Gain slightly increases below f_0
Lower output resistance	Negligible influence	Negligible influence
Higher output capacitance	Gain decreases at f_0 and above f_0	OUT1 (BP): Gain decreases above f_0 OUT2 (HP), OUT3 (BP): Gain slightly increases below f_0

The filter designed was also practically constructed and its magnitude frequency characteristics were measured, see Figs. 5 and 6. FDCF was implemented by two commercially available integrated circuits. The current follower in OPA860 provides the FDCF input stage and the FDCF differential output stage is replaced by MAX435. Predistortion techniques were used to increase the pole frequency to 5 MHz, since with the element parameters computed the pole frequency was about 4.5 MHz only, which was also predicted by the computer modeling.

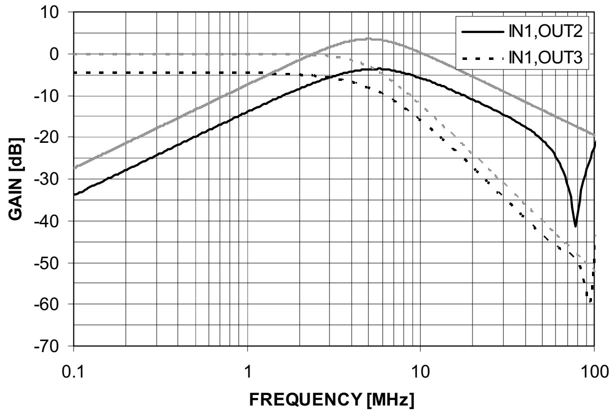

Fig. 5. Measured (black) and ideal (grey) magnitude frequency characteristics of the designed filter with input 1 used

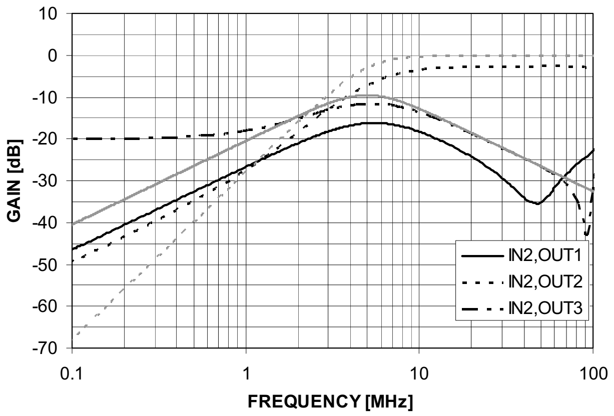

Fig. 6. Measured (black) and ideal (grey) magnitude frequency characteristics of the designed filter with input 2 used

5. Conclusions

Current-mode second-order analog filter with FDCF was designed. The filter provides three basic transfer functions (LP, BP and HP) according to the input and output ports selected. The active building block was developed at our workplace and is to be manufactured in cooperation with ON Semiconductor. The block is universal and can be used for high-frequency filter design operating mainly in the current mode. The circuit design was verified by computer modeling and the correct function of the filter at frequencies of up to 100 MHz was proved. It has been found that the most critical parameters of current followers are their input impedance and signal bandwidth. On the other hand, the output impedance (especially its resistive part) is of only negligible influence on filter operation. The filter was practically constructed and measured in the frequency domain.

6. Acknowledgement

This work was supported by the Czech Republic Grant Agency project No. 102/07/P353.

7. References

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