A New Class of MOSFET-C Multifunction Filters

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Abstract

A new class of MOSFET-C filters based on the simulation of parallel C-D impedance is presented. The core circuit is based on the Ford-Girling equivalent realization of parallel C-D impedance. Using this approach, systematic derivation of two current-mode and a voltage-mode MOSFET-C multifunction biquads are obtained. Simulation results verifying the feasibilities of the derived circuits are presented.

1. Introduction

Classically active-filter design conventionally relies on the use of highly linear, high-performance active devices such as operational transconductance amplifiers (OTA), OP-AMPs, current conveyors, these active elements are composed of large number of transistors and this increases power consumption and circuit complexity filter [1-3]. However, design using only MOSFETs offers some obvious advantages such as low power consumption, suitability to high-frequency operation and low complexity and has recently attracted some interests [4-11]. These filters classically can be called as MOSFET-C circuits. In these circuits, instead of passive resistors, transconductances of MOSFETs (g_m) operating in saturation region are used. However, this type of filters should be carefully designed due to their inherent dynamic range limitation and high harmonic distortion. Also a circuit design procedure has not been presented in the literature for these circuits.

In this paper, we present a procedure for designing MOSFET-C multifunction filters. The procedure is based on deriving MOSFET-C filters from a circuit simulating a parallel C-D (a capacitor and a FDNR (frequency dependent negative resistor) impedance. Two current-mode and one voltage-mode multifunction filters are derived. The main nonidealities of the derived filters are studied and a unified approach to alleviate this issue is presented. Simulation results verifying the proper operation of the filters are given.

2. Synthesis Procedure

In Fig. 1a, the parallel C-D impedance using a single conventional current conveyor is given. The circuit is known in the literature as Ford-Girling Equivalent Circuit [12, 13]. Although the equivalent circuit is given as a grounded equivalent, an interesting property of this circuit is that it realizes the same impedance if the terminal b is ungrounded. Therefore, this circuit actually realizes floating parallel C-D impedance.

In this paper, we propose MOSFET-C implementation shown in Fig. 1b which simulates parallel C-D impedance. This circuit is obtained by replacing the CCII- with the transistor, M_1. The resistor is also replaced with diode-connected transistor, M_2. Therefore $R=1/g_{m2}$, g_{m2} being the device transconductance. Provided that the dimension of M_1 is kept much larger than M_2, i.e. $g_{m1} >> g_{m2}$, the circuit simulates the parallel CD impedance in Fig. 1a with $C=C_1+C_2$, $D= C_1.C_2/g_{m2}$.

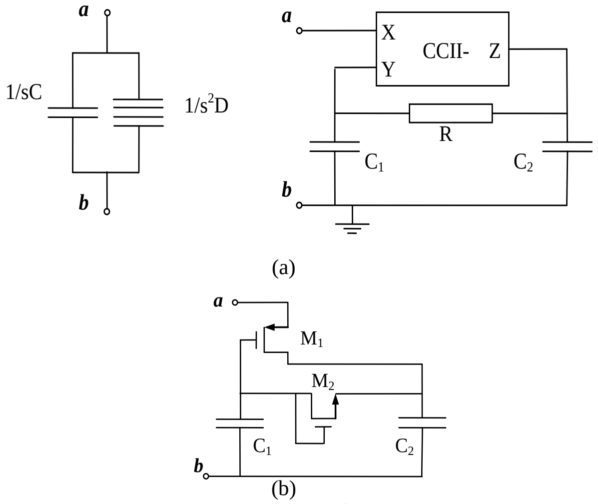


Fig. 1 a) Ford-Girling Equivalent Circuit of parallel C-D impedance [4]. b) Proposed MOSFET-C implementation of the parallel C-D impedance (biasing circuits are not shown).

A current-mode MOSFET-C filter can be realized using the prototype in Fig. 2. Routine analysis of the circuit yields

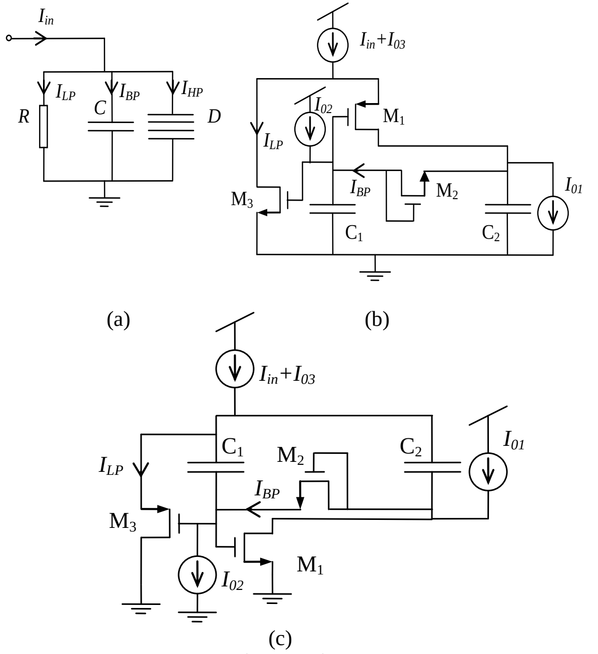
$$\frac{I_{LP}}{I_{in}} = \frac{g_{m2}g_{m3}}{s^2C_1C_2 + sg_{m2}(C_1 + C_2) + g_{m2}g_{m3}} \tag{1}$$

$$\frac{I_{BP}}{I_{in}} = \frac{sC_1g_{m2}}{s^2C_1C_2 + sg_{m2}(C_1 + C_2) + g_{m2}g_{m3}} \tag{2}$$

where g_{m2} and g_{m3} are transconductances of M_2 and M_3, respectively. Note that thanks to the configuration, intrinsic source impedance of M_1 appears in series with the high-impedance node of the input signal and does not affect in the filter transfer function. Therfore, g_{m1} indeed does not appear in the transfer functions of (1) and (2). In this circuit the resistor is replaced by the M_3 transistor to functionally performing its task. The filter simultaneously realizes second-order lowpass and bandpass characteristics with the following filter parameters:

$$\omega_0 = \sqrt{\frac{g_{m2}g_{m3}}{C_1C_2}},\; Q = \sqrt{\frac{g_{m3}C_2}{g_{m2}C_1}}\,\frac{1}{1+C_2/C_1} \qquad (3).$$

Since transistor drain currents are given by $I_{D1}=I_{01}-I_{02}$, $I_{D2}=I_{02}$, $I_{D3}=I_{03}-(I_{01}-I_{02})$ in Fig. 2b, the filter parameters are electronically controllable.



(a) (b) (c)

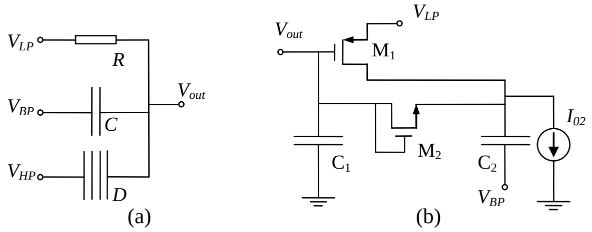
Fig. 2 a) Current mode multifunction filter prototype using FDNR. b) First proposed multifunction filter based on the MOSFET-C parallel C-D equivalent. c) Second proposed multifunction filter based on the MOSFET-C parallel C-D equivalent.

Second proposed current-mode multifunction filter is given in Fig. 2c, which is obtained by interchanging the terminals of the core C-D simulator. The circuit realizes exactly the same transfer functions given by (1) and (2) with BP transfer function in (2) with a minus sign.

In order to show the versatility of the approach, we have also presented a new voltage-mode MOSFET-C multifunction filter. The circuit is derived by using MOSFET-C simulator in the passive prototype in Fig. 3a. The prototype circuit simultaneously realizes second-order lowpass, bandpass and highpass filter functions. The MOSFET-C filter obtained is given in Fig. 3b. Routine analysis of the circuit leads to the following transfer function:

$$V_{out} = \frac{V_{LP}g_{m1}g_{m2} + V_{BP}sC_2g_{m2}}{s^2C_1C_2 + sg_{m2}(C_1+C_2) + g_{m1}g_{m2}} \qquad (4).$$

Therefore, the circuit realizes second-order lowpass functions for V_{BP}=0 (grounded) and bandpass filter function for V_{LP}=0 (grounded).



(a) (b)

Fig. 3 a) Voltage mode multifunction filter prototype using a FDNR. b) Proposed multifunction filter based on the MOSFET-C parallel C-D equivalent.

3. Modified filter Topologies

Linearity is an important issue in MOS active-only circuits since these circuits exploit the intrinsic device transconductances and capacitances. The only important source of nonlinearity in MOS active-only circuits is the nonlinear transconductance function from the gate-source voltage to the drain current. In order to overcome this problem, output currents are obtained by taking the difference of the drain currents. Thus even-order harmonics cancel out and linear operating ranges of the filters improve further.

The circuit designed in this direction is given in Fig. 4. The circuit is modified from the basic filter in Fig. 2b and its linearity is improved since output currents are obtained by taking the difference of the drain currents. For example, lowpass output, I_{LP} is obtained by taking the difference of the drain currents of M_{3a} and M_{3b}, as shown in the figure. Similarly, bandpass currents can be retrieved in differential form by adding parallel transistors to M_{a2} and M_{2b} and connecting their drain terminals.

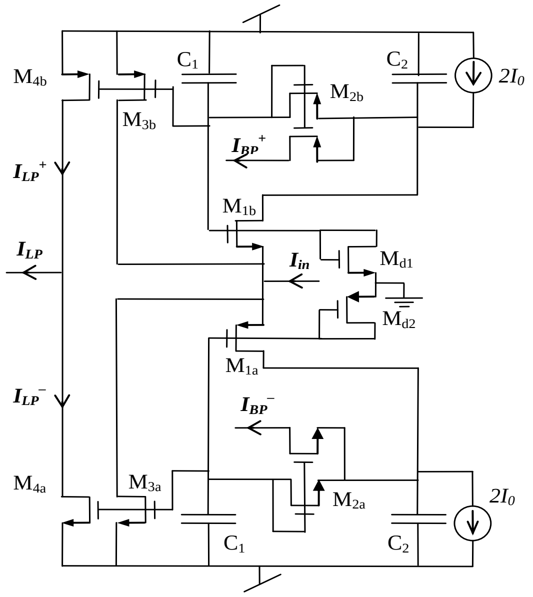


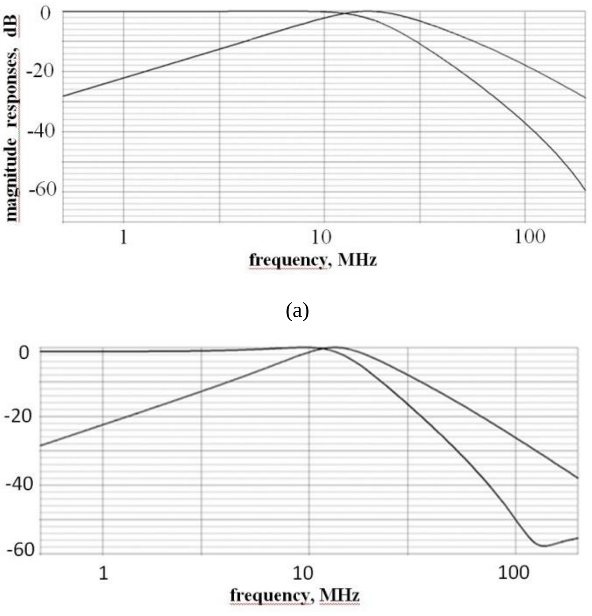
Fig. 4 Proposed current-mode MOSFET-C multifunction filter based on the R-C-D prototype.

4. Simulation Results

In order to verify theoretical analysis in Section 2, we present simulation results of the proposed filters. The circuits given Figs. 2b, 2c and 4 are all biased with ±1.65V DC power supply and the simulations were performed using pspice with AMS

0.35μm CMOS process. All the biasing current sources in Figs. 2 and 4 were realized using simple CMOS current mirrors.

The filter in Fig. 2b is designed with $I_{01}=I_{03}$=40uA, I_{02}=20uA, $C_1=C_2$=1pF. With these settings, the filter angular frequency is set to 15.9 MHz. Simulated magnitude responses corresponding to the lowpass and bandpass outputs are shown in Fig. 5a. From the simulation results, the filter center frequency and the pole quality factor are determined as 16.2 MHz and Q=0.72, respectively. Similar analysis is performed for the circuit in Fig. 2c. The results shown in Fig. 5b verify proper operation of the filter.



(a)

(b)

Fig. 5 Simulation results of the current-mode multifunction filter a) in Fig. 2b, b) in Fig. 2c.

Finally, simulation results of the modified filter in Fig. 6 is shown in Fig. 6. As expected , the filter satisfies the prescribed characteristics.

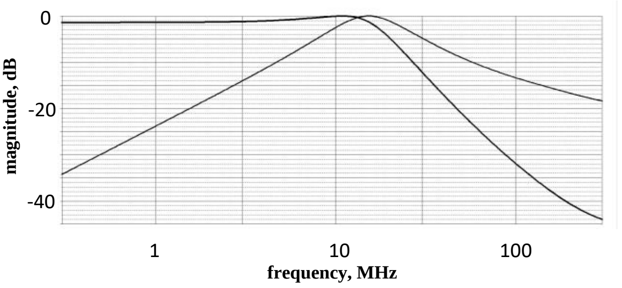


Fig. 6 Simulation results of the filter in Fig. 4.

5. Conclusion

In this paper, a class of MOSFET-C only multifunction filter is proposed. The filters avoid the use of bulky highly complex active blocks, hence have low power consumptions and low circuit complexities. This filter is based on a general parallel C-D prototype circuit and realizes simultaneously bandpass and lowpass type characteristics. In order to suppress even-order harmonics of the nonlinear drain currents and reducing harmonics at the filter outputs, the proposed filters are obtained differential form.

Detailed simulations results of the filters are also provided in order to verify the usefulness of the theoretical approach.

6. References

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