MOS-Only Current-Mode LP/BP Filter

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Abstract

In this study, a current-mode dual output low-pass (LP) and band-pass (BP) filter is presented using only six MOSFET transistors. Transconductances and gate-to-source capacitances of the MOS transistors are employed instead of passive resistors and capacitors. The proposed circuit exhibits important features such as simplicity, low-voltage/low-power operation, reduced chip area and wide frequency range compared to classical analog circuits that require active elements with large number of transistors. Simulations are performed to verify the theoretical results.

1. Introduction

Traditionally, operational-amplifiers have been used in active filter design. Since the performance of the active element determines the specifications of the filter, current-mode active elements are also widely used in the analog filter design for improved performance values [1]. Beside the performance criteria, low-voltage/power design is one of the hot research areas in analog electronics but this requires a special care and may increase the design complexity of the active elements [2]. Therefore these active elements may employ larger number of transistors; this in turn limits the high frequency performance of the filters. In addition to the restrictions of the active elements, passive elements such as resistors and capacitors have the constraints of large chip area and wide tolerances in the analog design.

In this study, we show that instead of complex active elements, only MOSFET transistors can be sufficient for analog filter design. Moreover, transconductance (g_m) and gate-to-source capacitance (C_{gs}) of the MOS transistors are employed in place of passive resistors and capacitors. For this purpose, a novel dual function (LP/BP) filter example is presented. The proposed filter circuit is easy to tune. When compared to filter circuits realized with active and passive elements [3-8], the proposed circuit employs fewer transistors including bias circuitry with very low power consumption, small layout area and also very high operating frequency. If desired, minimum dimensions can be used for the transistors to keep the power consumption and input parasitic capacitance low. Simulations are performed to verify theoretical results.

2. The Proposed Circuit

The functional core of the proposed filter consists of two transistors denoted as M_1 and M_2 as shown in Fig. 1. The filtering function is accomplished by these transistors. Note that only MOS transistors are employed without passive elements.

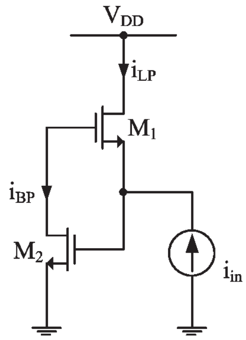

Fig. 1. The core of the proposed MOS-only filter circuit

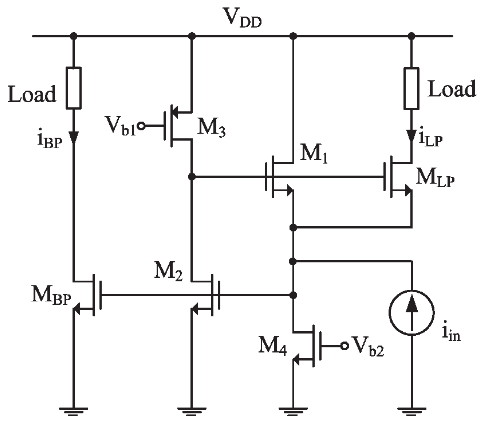

Fig. 2. The complete schematic

Fig. 2 gives the complete schematic of the proposed circuit. Transistors M_3 and M_4 are used to provide DC biasing currents for M_1 and M_2. To pick up the LP and BP currents, additional transistors, M_{lp} and M_{bp}, are connected in parallel to M_1 and M_2, as shown in Fig. 2. Note that the topology in Fig. 2 is complete circuit. The LP and BP filter functions can be easily detected using PMOS current mirrors instead of load resistors and reflected to an adequate output stage.

Small signal equivalent-circuit model of an MOS transistor operating in saturation region and the proposed filter circuit core are illustrated in Fig. 3 and Fig. 4, respectively. Using the small signal model in Fig. 4 and assuming C_{gd}, g_{ds} and g_{mb} are equal to zero; the following transfer functions are obtained for LP and BP filter operation:

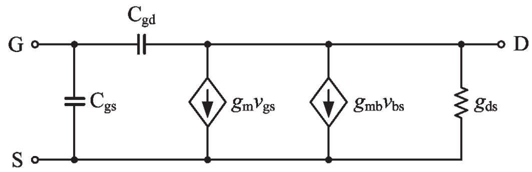

Fig. 3. Small signal model of an MOS transistor

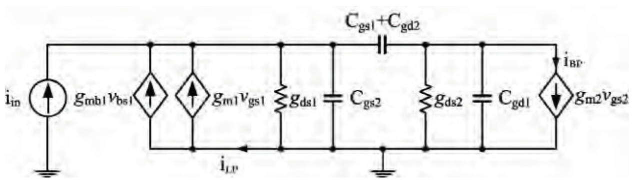

Fig. 4. Small signal equivalent circuit of the proposed filter

$$\frac{i_{LP}}{i_{in}} = -\frac{g_{m1}g_{m2}}{g_{m1}g_{m2} + g_{m2}sC_{gs1} + s^2C_{gs1}C_{gs2}} \quad (1a)$$

$$\frac{i_{BP}}{i_{in}} = \frac{g_{m2}sC_{gs1}}{g_{m1}g_{m2} + g_{m2}sC_{gs1} + s^2C_{gs1}C_{gs2}} \quad (1b)$$

Quality factor (Q) and radial pole frequency (ω_0) for LP and BP filters can be given as follows:

$$Q = \sqrt{\frac{C_{gs2}g_{m1}}{C_{gs1}g_{m2}}} \quad (2a)$$

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_{gs1}C_{gs2}}} \quad (2b)$$

When other parasitic elements, such as g_{ds1}, g_{ds2}, C_{gd1}, C_{gd2} and g_{mb1}, are taken into consideration, the following transfer functions are obtained:

$$\frac{i_{LP}}{i_{in}} = -\frac{(g_{m1} + g_{mb1})(g_{m2} + g_{ds2}) + (g_{m1} + g_{mb1})sC_{gd1}}{\Delta} \quad (3a)$$

$$\frac{i_{BP}}{i_{in}} = \frac{g_{m2}g_{ds2} + g_{m2}s(C_{gd1} + C_{gd2} + C_{gs1})}{\Delta} \quad (3b)$$

where $\Delta = a_0 + a_1 s + a_2 s^2$ and

$$a_0 = g_{ds1}g_{ds2} + (g_{m1} + g_{mb1})(g_{ds2} + g_{m2}) \quad (4a)$$

$$a_1 = g_{ds1}(C_{gd1} + C_{gd2} + C_{gs1}) + g_{ds2}(C_{gs1} + C_{gs2} + C_{gd2}) + g_{m1}C_{gd1} + g_{m2}(C_{gd2} + C_{gs1}) \quad (4b)$$

$$a_2 = C_{gd1}C_{gs2} + (C_{gs1} + C_{gd2})(C_{gd1} + C_{gs2}) \quad (4c)$$

It is important to note that under the assumptions that $C_{gs} >> C_{gd}$, $g_m >> g_{mb}$ and $g_m >> g_{ds}$, equations (3a) and (3b) can be approximated to (1a) and (1b).

3. Simulation Results

The performance of the proposed filter circuit is examined through HSpice simulations using AMS 0.35µm process parameters and 2V supply voltage. The biasing voltages, V_{b1} and V_{b2}, are chosen as 1.2V and 0.65V, respectively. The dimensions of the MOS transistors are given in Table 1.

Table 1. Aspect ratios

Transistor	Aspect ratio [µm/µm]
M_1, M_2	30/1
M_3, M_4	50/1
M_{LP}, M_{BP}	45/0.35

Simulation results are given in Fig. 5. The pole frequency of the filter is approximately 275MHz with only 200µW power consumption.

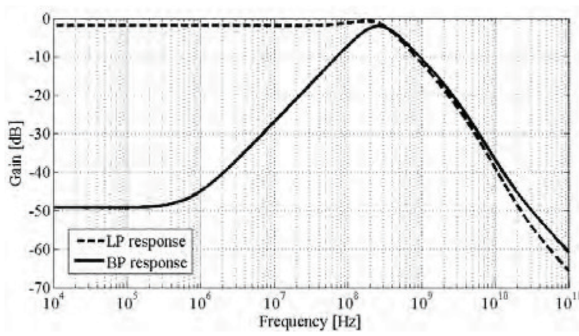

Fig. 5. Frequency-domain simulation results

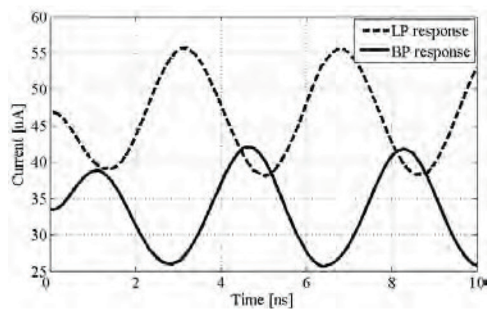

Fig. 6. Time-domain simulation results for a sinusoidal input current of 20µA peak-to-peak

Transient analysis of the proposed filter circuit is also performed. A sinusoidal input current waveform with amplitude of 20µA peak-to-peak and frequency of 275MHz is applied to the filter. Time domain LP and BP output signal waveforms are shown in Fig. 6. Note that the output signals have some DC component , if desired they can be eliminated using additional circuitry.

The total harmonic distortion (THD) of the proposed LP filter is determined by applying 275MHz sinusoidal input signal to input port with various amplitudes. THD is found less than 5% for the input currents below 50µA peak-to-peak. Simulation results are given in Fig. 7. When evaluating this graph, one should take into consideration that some higher harmonics may be filtered out.

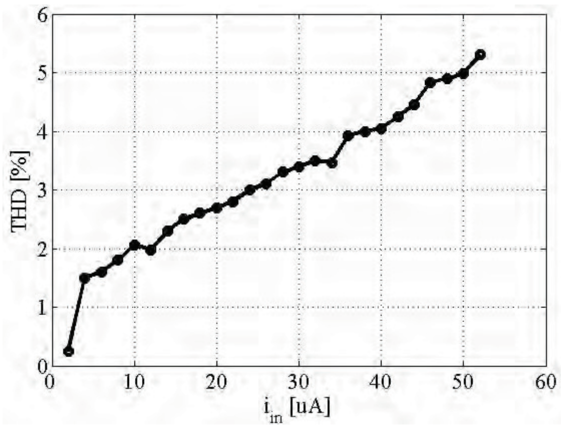

Fig. 7. Output harmonic distortion versus input current at 275MHz

4. Conclusions

In this study, a dual output current mode analog filter is presented using only six MOSFET transistors instead of an active element that includes large number of transistors. The proposed filter is also suitable for low voltage/low power operation. Theoretical values are verified with HSpice simulations.

5. References

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