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MOSFET-only multi-function biquad filter

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ABSTRACT

In this paper, using only seven MOS transistors, second order current-mode LP/BP filter is proposed. The transconductances of the MOS transistors in saturation region are used instead of passive resistors and gate-to-source capacitances are employed instead of passive capacitors. The proposed circuit exhibits important features such as simplicity, reduced chip area and wide frequency range compared to classical analog circuits that require active elements including large number of transistors. Layout of the proposed circuit is drawn using Mentor Graphics IC Station layout editor. AMS 0.35 μm process parameters are used during post-layout simulations.

1. Introduction

In the literature, many analog circuits for filtering functions are proposed using various active elements. Several decades ago operational amplifier based analog filters are proposed and they are still very popular in designing analog filters. Such filters can be found in any filter design book. Later, current-mode active elements, such as current conveyors, became increasingly popular due to their high frequency performance [1]. Researchers focused on different features, such as low voltage operation or good high frequency performance, component count etc., and they presented many other circuits [2–7]. Although these circuits provide sufficient high performance compared to classical active filters, they may not answer requirements of gigahertz-range applications. Employing large number of transistors limits their high frequency operation. Furthermore, they include passive elements requiring large chip area. Therefore, some researchers proposed analog filter circuits using only MOS transistors instead of traditional passive and active elements.

First generation transistor only filters without external passive elements were based on the distributed RC networks [8]. A MOS transistor biased in the strong inversion region operates as a distributed RC network by using the parasitic resistances and capacitances of MOS channel as passive elements [9]. The hyperbolic frequency functions of distributed RC structure was (approximately) represented as a first order RC circuit [9] and used in some filter applications [9–12]. Reference [11] states the disadvantage of this approach as follows: "The inherently distributed nature of the MOS transistor channel is not modeled in common CAD models. One can split the transistor into many small ones, with their channels in series and with common gates and substrates, ensuring that no extrinsic parasitics at intermediate nodes or artificial short channel effects are introduced".

However, some recent studies [13–16] presented a novel approach for transistor only filters. In these second generation MOSFET-only filters, the transconductance (g_m) and gate-to-source capacitance (C_{gs}) of the MOSFET operated in saturation are used instead of passive resistors and capacitors. In other words, the small signal model of the MOSFET in saturation region is very suitable for designing active filters. Such circuits exhibit important features such as; reduced number of transistors, simplicity, small chip area and wide frequency range compared to classical analog circuits that employ standard active elements having large number of transistors. In the literature, some second-generation MOSFET-only all-pass filter circuits [13,14] and second order filters [15,16] presented.

In this study, a MOSFET-only dual function (LP/BP) filter is proposed. The proposed filter circuit is easy to tune. When compared to filter circuits realized with active and passive elements [2–7], the proposed circuit employs very fewer transistors with reduced power consumption and layout area and also extended operating frequency. The presented circuit is attractive compared to [9–12] considering the device modeling difficulties [11] of MOSFET distributed RC circuits. The presented circuit has fewer number of transistors compared to [15] and improved output swing without

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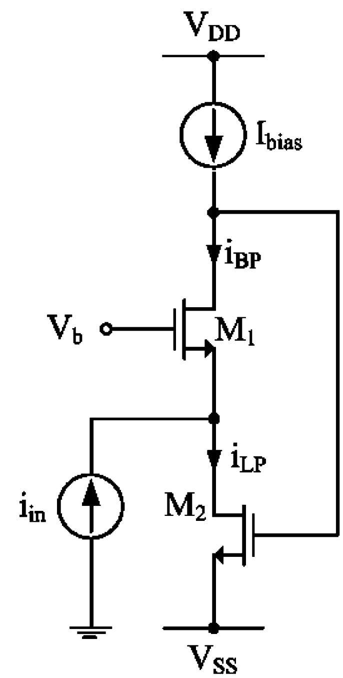

Fig. 1. The proposed filter circuit using only two MOS transistors. Transconductances (g_m) and gate-to-source capacitances (C_{gs}) of the MOSFETs M_1 and M_2 are used instead of passive resistors and capacitors, respectively.

off-set current compared to [16]. Simulations are performed to verify theoretical results. Layout of the proposed circuit is drawn using Mentor Graphics IC Station layout editor. AMS 0.35 µm process parameters are used during post-layout simulations. It is shown that with careful design it is possible to obtain satisfactory dynamic range and reasonable linearity.

2. Circuit description

The functional core of the filter consists of two transistors denoted as M_1 and M_2 as shown in Fig. 1. Note that only MOS transistors are employed without passive elements. MOS transistor gate-to-source capacitances are used as filter capacitors and transistor transconductances are used to obtain resistive dimension.

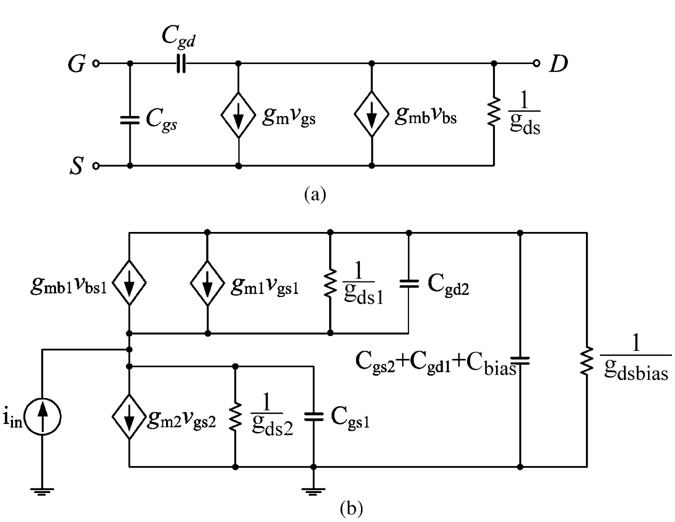

Fig. 2. (a) MOSFET small signal model. (b) The small signal equivalent circuit of the proposed filter.

Using the simplified MOSFET small signal model in Fig. 2a, the small signal equivalent circuit is obtained as shown in Fig. 2b. Moreover, for M_1, the current source $g_{mb}.v_{bs}$ representing the body effect is taken into account since there is no bulk-source connection for this transistor, on the other hand for M_2 this effect is ignored due to its source-bulk connection. In this paper, we denote all MOS parameters except g_m as parasitic elements. In the small signal model in Fig. 2b, we define two kinds of parasitics: Parasitic elements contributing to the ideal filtering function are called as useful parasitic elements (UPE), and parasitic elements disturbing the standard form of the filtering function are called as disturbing parasitic elements (DPE). UPEs modify ω_0 and Q or the gain but do not change the standard form of the filter transfer function. However, DPEs may create undesired poles or zeroes and disturb the basic form of the filter transfer function. For this circuit UPEs are g_{m1}, g_{mb1}, g_{m2}, C_{bias}, C_{gs1} and C_{gs2}. Note that at the drain node of M_1 the three parasitic capacitors, are in parallel, forming a single capacitance at the corresponding node. Therefore C_{gd1} and C_{bias} modify the natural angular frequency without creating additional poles ore zeroes. Taking only UPEs into consideration, band-pass and low-pass current signals can be given below where $C_x = C_{gs2} + C_{gd1} + C_{bias}$ represents the equivalent capacitance at the drain node of M_1 composed of three parasitic capacitors.

$$\frac{i_{BP}}{i_{in}} = -\frac{(g_{m1} + g_{mb1})sC_x}{\Delta} \tag{1}$$

$$\frac{i_{LP}}{i_{in}} = \frac{(g_{m1} + g_{mb1})g_{m2}}{\Delta} \tag{2}$$

where

$$\Delta = (g_{m1} + g_{mb1})g_{m2} + (g_{m1} + g_{mb1})sC_x + s^2 C_{gs1} C_x \tag{3}$$

For the filter circuit, DPEs are g_{ds1}, g_{ds2}, g_{dsbias} and C_{gd2}. They create zeroes in the transfer function as:

$$\frac{i_{BP}}{i_{in}} = -(g_{m1} + g_{mb1})\frac{(g_{dsbias} + g_{ds1}) + s(C_{gd2} + C_x)}{\Delta} \tag{4}$$

$$\frac{i_{LP}}{i_{in}} = \frac{g_{m2}(g_{ds1} + g_{m1} + g_{mb1}) + g_{m2} s C_{gd2}}{\Delta} \tag{5}$$

where

$$\Delta = b_0 + b_1 s + b_2 s^2 \tag{6}$$

and the coefficients b_0, b_1 and b_2 are equal to:

$$b_0 = (g_{m1} + g_{mb1})(g_{m2} + g_{dsbias}) + g_{m2} g_{ds1} + g_{ds1}(g_{dsbias} + g_{ds2}) + g_{dsbias} g_{ds2} \tag{7a}$$

$$b_1 = C_{gs1}(g_{dsbias} + g_{ds1}) + C_x(g_{ds1} + g_{ds2} + g_{m1} + g_{mb1}) + C_{gd2}(g_{ds2} + g_{m2}) \tag{7b}$$

$$b_2 = C_{gs1}(C_x + C_{gd2}) + C_{gd2} C_x \tag{7c}$$

The complete schematic is shown in Fig. 3. M_{b1} is used to supply the DC drain currents of M_1 and M_2 and therefore used for biasing purpose. The band-pass and low-pass current outputs are obtained by copying the currents of M_1 and M_2, respectively. To pick up the current of M_1 and M_2, additional transistors such as M_{b2}, M_{b3}, M_{bp} and M_{lp}, are used.

Note that the gate to source capacitances of these mirror transistors M_1, M_{bp} and M_2, M_{lp} are connected in parallel and this is taken into account by calculating ω_0 and Q of the filter. The filter structure operates in class-A mode therefore is expected to have low distortion.