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Design of a Wide-band Low-voltage CMOS Filter for Wireless Transceiver Systems

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Abstract. This paper presents a wideband low voltage tunable CMOS filter for wireless transceivers systems. The proposed filter attempts to optimize the performance of the circuit as it operates at relatively low voltage providing wide tunable range at the same time. It is constructed using Gm-C technique employing three Operational Transconductance Amplifiers (OTA) and two grounding capacitors. The filter is of second order with cutoff frequency (f_c) at 5 MHz and Quality factor of 1. The filter also exhibits independent electronic tuning of (f_c) and quality factor (Q) providing more accuracy in its frequency response. Also, its circuit can also be synthesized to produce multiple other filter frequency responses by varying inputs which can be beneficial in other applications. The OTA is the main active element in the filter operating at input supply voltage of 1 V and having open loop dc gain of 38 dB with power dissipation of 270 uW. The unit gain frequency is at 36 MHz and the phase margin angle is at 65 degrees. Simulations are done in HSPICE using CMOS 0.18μm process parameters as functional verification of the presented theory.

Keywords: transceiver, filter, tunability, low voltage

1 Introduction

Wireless technology has been evolving ever since the invention of radio. From the circuit point of view modern wireless devices can be integrated into single chip and even controlled by software. Various tradeoffs exist among power consumption, performance and cost and circuit designers are continually seeking improvement on these aspects [1-4]. The increasing use of wireless applications especially personal communication devices with different wireless standards has given additional challenge to create complex multi-mode transceiver which can process multiple wireless standards on the single hardware platform. Software Defined Radio (SDR) can be taken as an example of multi-mode transceiver which supports multi-standard reception by tuning to any carrier frequency and selection of any channel bandwidth. Its key performances are defined by software and the goal is to push the digital domain as near as possible to the antenna [5-7].

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parameters of the system. These systems needs programmable filters with wide tuning range since it deals with widely varying signal bandwidths. However, wide tuning range has to make tradeoffs with linearity and power consumption [8]. This paper proposes a LP filter tunable to a wide range while optimizing power consumption in the circuit at the same time. Also its f_c and Q factor can be tuned electronically without disturbing each other, thus providing more accurate frequency response [9]. It employs three Operational Transconductance Amplifiers (OTA) as its active element and two grounded capacitors. The proposed LP filter is constructed using Gm-C technique. Besides tunability and low power consumption, this circuit can also realize multifunction filter outputs by making alteration in input signal ports which can prove to be efficient in other applications. Circuit simulations are done in HSPICE using Metal Oxide Semiconductor Implementation Service (MOSIS) 0.18 μm SPICE datasheet process parameters

2 Wireless Transceiver Systems

Wireless transceiver is a radio communication technology where receiver and transmitter is integrated into single hardware. Modern transceiver is fully integrated as a system in chip (SOC) and is an integral part of any wireless communication system.

Table 1. Wireless Communication Standards

Standards	Frequency Bands (GHz)	Channel Bandwidth (MHz)
GSM	0.93 - 0.96	0.2
WCDMA	2.11 - 2.17	3.84
802.11a	5.25 - 5.35	20
WiMAX	2 - 11	1.25-28
GPS	1.575	-
Bluetooth	2.4 - 2.483,	1

Table.1 shows different wireless communication standards existing today with different frequency bands and channel bandwidth. A modern transceiver system should be able to have select all the frequency bands ranging from kilohertz to several gigahertz all with different communication standards. A typical example might be a modern smart phone which supports GSM/WCDMA for voice communication, GPS for location and Bluetooth for short distance multimedia files transfer. All of these applications operate at different frequency bands and require their own communication standards.

3 Design of an Analog Baseband Filer

Analog filters operate at the base band section of a transceiver and are very important in wireless system. They are required to select wanted signals within the required channel with minimum distortion. As mentioned in the introduction part analog baseband filters play a crucial role in the design of wireless transceiver system since the performance of these filters directly affects various important parameters of the system. In this paper a low voltage LP filter is designed using gm-c technique. Fig.1 shows the proposed LP filter for SDRs with wide tuning range and low power consumption. It employs three OTAs and two grounded capacitors. The transfer function of the LP filter can be derived as shown in the equation 1.

$$\frac{V_{out}}{V_{in}} = \frac{\frac{g_{m1}g_{m2}}{C_1C_2}}{S^2+S\left(\frac{g_{m3}}{C_2}\right)+\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{1}$$

The angular frequency (ω_0) and Q factor of the filter can be derived as in equation (2).

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}\ ,\ \mathrm{Q} = \omega_o\frac{C_2}{g_{m3}} \tag{2}$$

In equation (2) if g_{m3} is adjusted separately then controllable value for Q can be derived. This feature can improve the frequency response of a tunable filter since tuning cutoff frequency won't affect the Q factor and vice versa.

$$f_c = \frac{g_m}{2\pi\sqrt{C_1C_2}} \tag{3}$$

Equation (3) represents the cutoff frequency by controllable value of g_m.

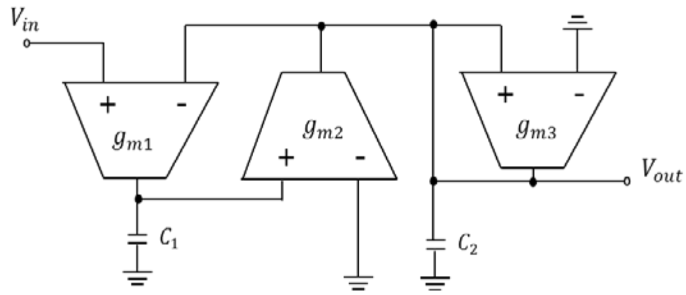

Fig. 1. Proposed structure of Low pass filter

Similarly, the sensitivity analysis of the LP filter can be derived as shown in the Table 2.

Table.2 Sensitivity of the circuit components

Parameters	$S_x^{\omega_0}$	S_x^Q
g_m	1	0
C_1	-1/2	0
C_2	-1/2	0

Here, Table.2 shows circuit sensitivity level of ω_0 and Q factor with respect to g_m and C values. The sensitivity level is quite low giving the reasonable approximation of the transfer function in the presence of component variations.

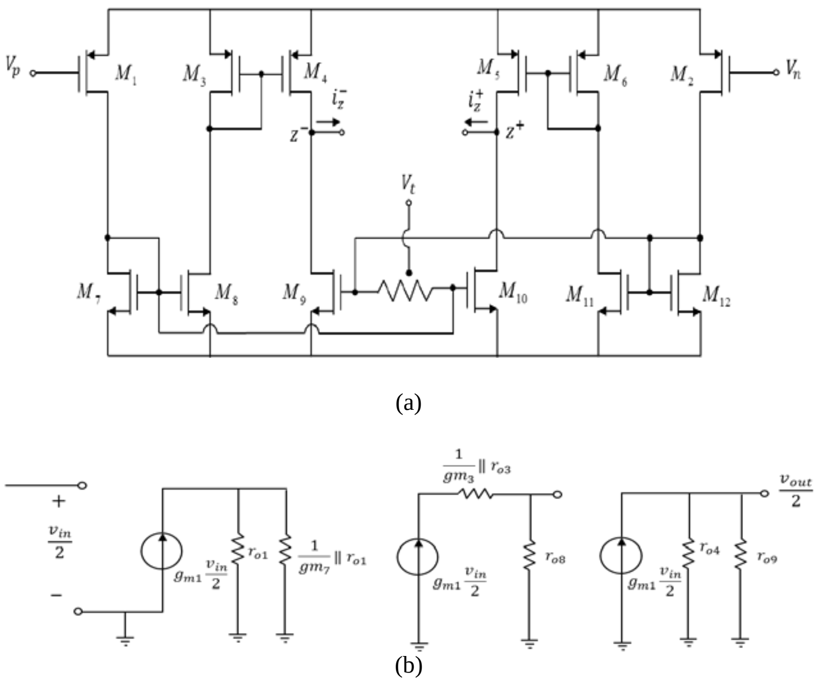

Fig.2 (a) CMOS implementation of OTA (b) Small Signal analysis of OTA

$$g_m = \sqrt{\mu C_{ox}(W/_L) I_b} \tag{4}$$

$$A_v = -g_{m1}(ro_4||ro_9) \tag{5}$$

$$f_{-3dB} = \frac{1}{2\pi R_{o1} C_L} \tag{6}$$

$$\omega_{0dB} = A_v \times f_{-3dB} \tag{7}$$

Here Fig.2 (a) represents CMOS implementation of OTA and Fig.2 (b) represents small signal analysis of OTA. Assuming all MOS transistors operating in saturation regions, the value of g_m can be expressed as equation (4), where I_b is the current flowing in the each branch of the circuit, μ is the effective carrier mobility, C_{ox} is the gate-oxide capacitance per unit area, and W/L is the ratio of effective channel width and length of an individual MOS transistor. V_p and V_n are differential inputs which goes through M_1 an M_2 respectively. The circuit in Fig.4 (a) is perfectly symmetric and can be divided into two equal circuits. Fig.4 (b) represents the small signal analysis of one half of the circuit where small signal gain (A_v), pole frequency (f_{-3dB}) and gain bandwidth (ω_{0dB}) of the amplifier can be estimated. The proposed second order low pass filter with 5 MHz cutoff frequency is simulated in HSPICE. Currents were biased in the MOS transistors to give g_m= 125 μS and capacitors C_1 and C_2 were assigned with the value of 25 pF

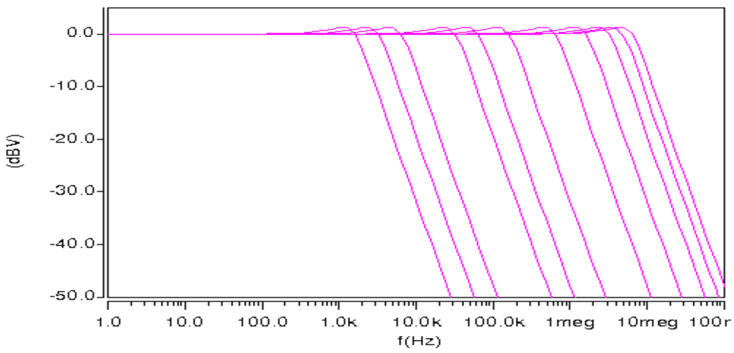

Fig. 5. Frequency tunings of designed low pass filter

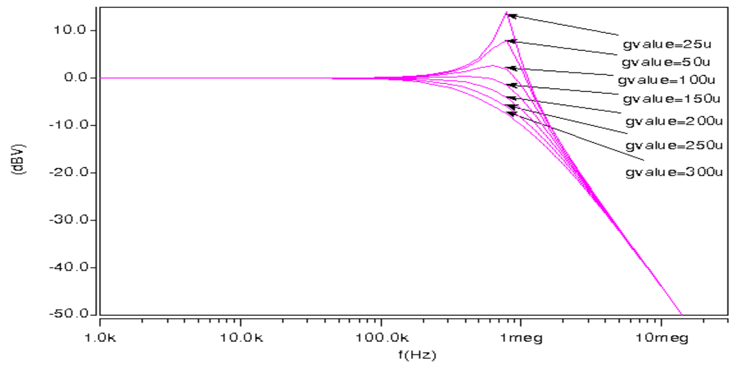

Fig. 6. Quality factor tuning of designed low pass filter

Fig.5 shows the tuning of the cutoff frequency (f_c) of the designed filter from 5 KHz to 50 MHz when g_m values were changed from 0.5 μS to 1 mS. Likewise

Fig.6 shows the tuning of and Q factor of the LP filter when g_m values were changed from 50 μS to 300 uS. Both f_c and Q factor were tuned independently as mentioned in the previous chapters.

4 Conclusion

A low voltage CMOS filter with wide tuning capability is proposed for wireless transceiver systems. The filter is designed using Gm-C technique and it main advantage is its internal circuitry which helps balancing the tradeoff between power consumption and tuning range. Operational Transconductance Amplifier (OTA) is used as an active element for the filter which could operate on 1 V of DC power supply. Also as extra features, the circuit provided electronically tuning capability of cutoff frequency and quality factor of the filter giving more accuracy in its frequency response. It was observed through the HSPICE simulation that f_c and Q factor of the LP filter could be tuned when g_m values were changed from 50 uS to 300 uS. The sensitivity analysis also showed quite low sensitivity of various circuit components to the network. It is therefore expected that the use of this architecture might optimize the power consumption in the transceiver systems.

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