Design of Power-Efficient Operational Transconductance Amplifier in the Application of Low Pass Filter Using 180 nm CMOS Technology

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Abstract. In modern transreceivers, analog base band section is very crucial which deals with channel selectivity, antialiasing and dynamic range. Nowadays OTA become a basic building block of any analog system.For better performance of RF front end a filter which is used in base band section must include many characteristics like high linearity, tunable BW, low noise etc. A second order low pass Gm-C Filter is implemented.The core of this filter is power efficient OTA. The OTA is implemented to operate at a ±1.0 V supply voltage with a power consumption of 0.42 mW. All simulations has been performed using Tanner EDA tool using CMOS technology with parameters TSMC 0.18 µm. The simulation results of this circuit show that it has a high DC gain of 76 dB and a transconductance of 360 µS.

Keywords: CMOS · OTA · LPF · DC gain and CMRR

1 Introduction

Rapidly growing, mobile and wireless communication market is highly dependant on the receiver architecture for analog baseband signal processing, there fore high frequency and low power, fully integrated filters received considerable worldwide attention. In today's Scenerio multi-standard transceivers are so much in demand and direct conversion architectures are best suited forthat purpose [1]. The RF front end module of the receiver includes a variable gain amplifier and a LPF. The range of variable gain for UWB analog front ends should be small. Therefore, the realization of voltage gain amplifier is not important. Therefore, the low-pass filter design has become the most crucial design in the analog front end [2, 3]. Analog filter based on operational transconductance amplifier (OTA) Capacitor (so-called OTA-C or gm-C) filters have attracted the attention in recent research. In comparison of traditional active RC filter, OTA-C filter has better performance. OTA-C filters offer simple in design, high-frequency capability, Electronic adjustability, suitable for monolithic integration, reducing the number of components and the potential of design automation. The low-pass filter based on Gm-C

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is the only choice when the cutoff frequency of the filter reaches in the range of GHz [4–10]. OTA-C filters also have great limitations. Good linearity of filters needed a highly linearized OTA. The increase in the linear range will inevitably reduce the usable range of transconductance of the OTA at a given power supply voltage, and increase the OTA noise. At present, great importance is attached to the implementation of integrated filters using sub-micron CMOS technology. CMOS technology provides favorable features for high-density integration, such as low power consumption, Power supply voltage and low static power consumption of digital circuits.

2 Basics of Filters

The function of an ideal low-pass filter is that, it will pass the signals below the cut off and eliminate the signals above the cut off frequency. When any filter is designed for a particular application various trade-offs should be considered between the parameters. So many types of filters provide the trade off between attenuation and phase response which will depend on the application. Butterworth filters provides the good trade off between attenuation and phase response. Some times butterworthe filter is known as maximally flat filter [11].

The realization of a second-order low-pass Butterworth filter is made with the following transfer function

$$H = \frac{K}{\left(\frac{f}{f_c}\right)^2 + 1.414\frac{jf}{f_c} + 1} \tag{1}$$

Butterworth filter has zero ripples in the pass band and stop band. Frequency domain response and time domain response plays a important role while designing a filter for a particular application which further decides the complexity and cost of the filter. In all pole filters category two filters are generally used Butterworth and Bessel [13–15]. Butterworth filter gives good amplitude with fair trasient behaviour. Chebyshev filters give smaller transition region in comparison of butterworth. For higher order filters butterworth filter is preferred. In designing higher order filter multiple sections of first/second order filters are used. The characteristics of these sections should be aligned for good response of a higher order filter.

2.1 Basics of Operational Transconductance Amplifier

Due to the feature of tunability of transconductance with bias current operational transconductance amplifier become very useful in the realization of active filters. OTA provides linear electronic adjustability. OTA circuits consume less power and can be operated at lower voltage. At present high frequency, high linearity, and low power are the important parameters of CMOS OTAs [16]. Filters designed using OTA do not need resistors that are why they are easier to fabricate. Filter performance directly depends on the characteristics of the OTA (Figs. 1 and 2).

OTA:

$$I = g_m(V_+ - V_-) \tag{2}$$

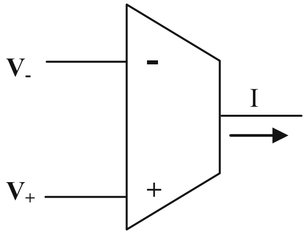

Fig. 1. Basic OTA

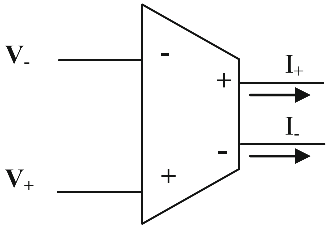

Fig. 2. Balanced OTA

Balanced OTA:

$$I_{+} = g_{m}(V_{+} - V_{-}) \tag{3}$$

$$I_{-} = g_{m}(V_{+} - V_{-}) \tag{4}$$

$$g_{m} = \frac{I_{BIAS}}{2V_{T}} \tag{5}$$

$$I_{BIAS} = \left[\frac{\beta}{\beta + 2}\right] I_{R} \tag{6}$$

3 Results and Discussion

3.1 Conventional OTA

With three high performance current mirrors and using a differential pair (M_1, M_2) the conventional OTA is achieved. This OTA is working on low operating voltage. By using a super cascode transistor high slew rate, a large bandwidth and a high open loop gain have been achieved [17]. Both the transistors M_1 and M_2 are working in the saturated region.

So, the differential input voltage is as follows

$$V_{id} = V_{in+} - V_{in-} = V_{GS1} - V_{GS2} = \sqrt{\frac{I_1}{\beta n}} - \sqrt{\frac{I_2}{\beta n}} \tag{7}$$

Expressions of current I_{out} is as follows

$$I_{out} \cong \sqrt{2\beta_n} I_{ss} \times V_{id} - \frac{1}{4}\sqrt{2\beta_n} I_{ss}(2\beta_n I_{ss}) \times V_{id}^3 \tag{8}$$

Where $\beta_n = \mu_n C_{ox}\left(\frac{W}{L}\right)_{1,2}$ and Iss is the bias current and Gm is given by

$$g_m = \sqrt{2\beta_n} I_{ss} \tag{9}$$

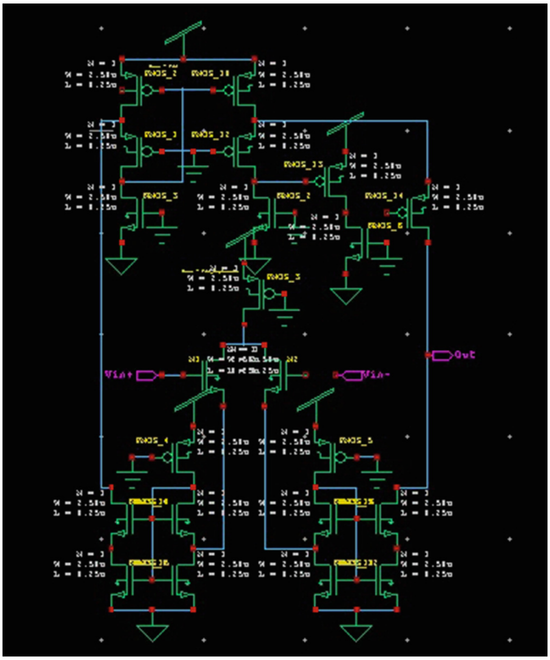

Fig. 3. Simulated conventional OTA on tanner EDA

Proposed OTA

By using stage attenuation technique linearity can be better than the conventional OTA (Fig. 3). MOS transistor pair (M1a, M2a) forms attenuator and (M3, M4) transistors of the PMOS type will act as load [18, 19]. Both M1a and M2a are operated in the saturated region. So the differential input voltage is defined by

$$V_{ida} = V_{ina+} - V_{ina-} = V_{GSa1} - V_{GSa2} = \sqrt{\frac{I_{1a}}{\beta n}} - \sqrt{\frac{I_{2a}}{\beta n}} \tag{10}$$

Output current is as follows

$$I_{out} \cong I_{ssa}/2 - \frac{1}{2}\sqrt{2\beta_n} I_{ssa} \times V_{ida} + \frac{1}{8}\sqrt{2\beta_n} I_{ssa}(\beta_n I_{ssa}) \times V_{ida}^3 \tag{11}$$

The differential gate voltage of the load transistors is given below:

$$\Delta V_g = \frac{V_{idA}}{\sqrt{m}} \tag{12}$$

Where m = attenuation factor

$$m = \frac{\beta_p}{\beta_n} \tag{13}$$

$$\beta_p = \mu_p C_{ox}\left(\frac{W}{L}\right)_{3,4}$$

Transconductance is given by

$$g_{ma} = \frac{\sqrt{2\beta_n I_{ss}}}{\sqrt{m}} \tag{14}$$

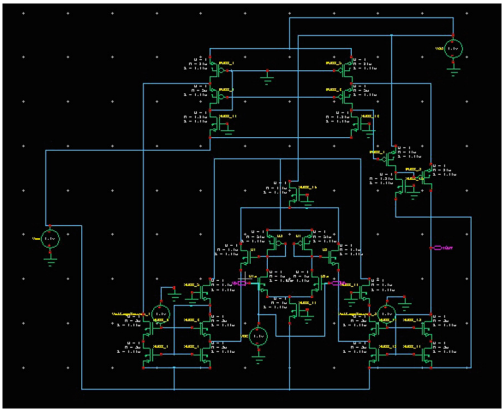

Fig. 4. Simulated conventional OTA on tanner EDA

The simulation results of the proposed CMOS OTA and Conventional OTA has been done by using Tanner EDA tool using TSMC 180 nm technology (Fig. 4 and Table 1). This circuit is working with ±1.0 V supply voltage with a dc voltage $V_{B1} = 0.1$ V and the value of capacitive load is 10 pF. The DC transfer characteristic of the proposed OTA is shown in Fig. 5, the OTA (proposed) provides good linearity in the range [−0.6 V, 0.6 V].

The trascondcutance Gm of the OTA proposed is plotted and it can be seen that it is more stable in the interval of [−0.6 V, 0.6 V] and the maximum value of gm is seen to be equal to 360 μS (Fig. 6) (Table 2).

Table 1. DC transfer characteristics

S. no.	Differential input voltage	Output current	
		Conventional OTA	Proposed OTA
1	−1	−25	−210
2	−0.8	−25	−200
3	−0.6	−25	−150
4	−0.4	−25	−100
5	−0.2	−13	−50
6	0	0	0
7	0.2	65	60
8	0.4	110	120
9	0.6	125	180
10	0.8	125	200
11	1	125	200

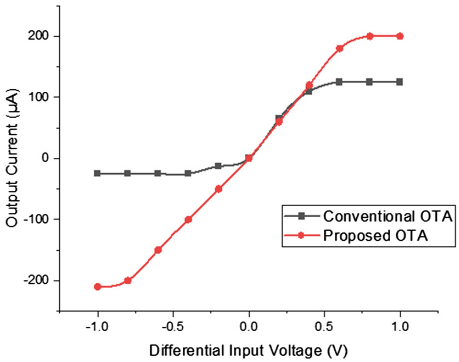

Fig. 5. DC transfer characteristics

The frequency response of the conventional and proposed OTA is shown in Fig. 7. The open loop gain of proposed OTA 76 dB. For OTA conventional, a less gain of 44 dB is acheived. In Table 3, the performance parameters of both OTA (conventional and proposed) along with some of the works are compared (Table 4).

Table 2. Simulated transconductance

S. no.	Differential input voltage	Transconductance	
		Conventional OTA	Proposed OTA
1	−1.0	0	0
2	−0.8	0	25
3	−0.6	0	125
4	−0.4	18	360
5	−0.2	270	322
6	0.0	300	320
7	0.2	270	300
8	0.4	150	350
9	0.6	25	340
10	0.8	24	175
11	1.0	13	10

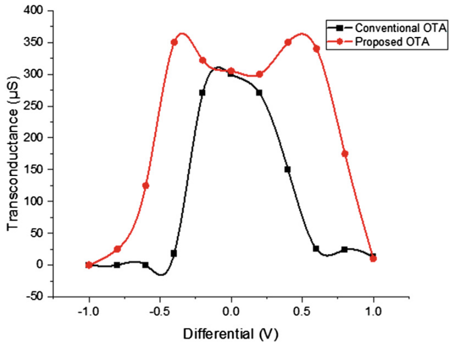

Fig. 6. Transconductance

Table 3. Performance comparison with previously reported work

Performance parameters	Conventional OTA	Proposed OTA	OTA (18)	OTA (20)
Technology CMOS (μm)	180 nm	180 nm	180 nm	180 nm
Supply voltage (V)	±0.8	±1.0	1.8	0.9
Power consumption (mW)	0.39	0.42	0.45	0.0588
Transconductance (μS)	320	360	110	38.8
DC gain (dB)	44	76	–	34.8
Linear range (V)	–	±0.6	±0.5	±0.6
CMRR (dc) (dB)	16.04	88.53	–	139.8

Table 4. Open loop frequency response

S. no.	Frequency	Open loop frequency response (dB)	
		Conventional OTA	Proposed OTA
1	10	47	76
2	100	47	76
3	1000	47	76
4	10,000	47	70
5	100000	33	54
6	1000000	12	36
7	1E7	−4	14

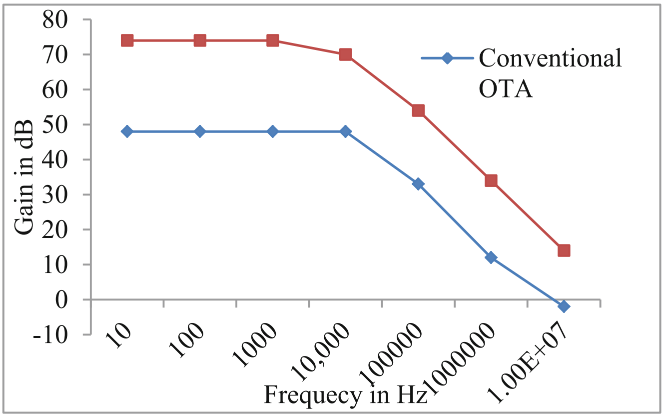

Fig. 7. Open loop frequency response of OTA

4 Application

4.1 Theoretical Analysis

Range of transconductance can be increased for the filter applications. For analog base band circuit low pass filter plays important role.

$$I_o = g_m(V_{in} - V_-) \tag{15}$$

$$V_- = V_{out} \tag{16}$$

On putting value of V_- from Eq. (16) into Eq. (15)

$$I_o = g_m(V_{in} - V_{out}) \tag{17}$$

On applying KVL

$$I_o = sCV_{out} \tag{18}$$

Equating (17), (18) and then solving

$$sCV_{out} = g_m(V_{in} - V_{out}) \tag{19}$$

$$\frac{V_{out}}{V_{in}} = \frac{g_m}{(sC + g_m)} \tag{20}$$

$$\frac{V_{out}}{V_{in}} = \frac{\frac{g_m}{C}}{\left(s + \frac{g_m}{C}\right)} \tag{21}$$

Comparing with standard transfer function, It is Low Pass Filter.

Second order butterworth low pass filter is shown in Fig. 8. Transfer fuction of this filter is given in Eq. (29).This circuit is designed using two proposed OTA.

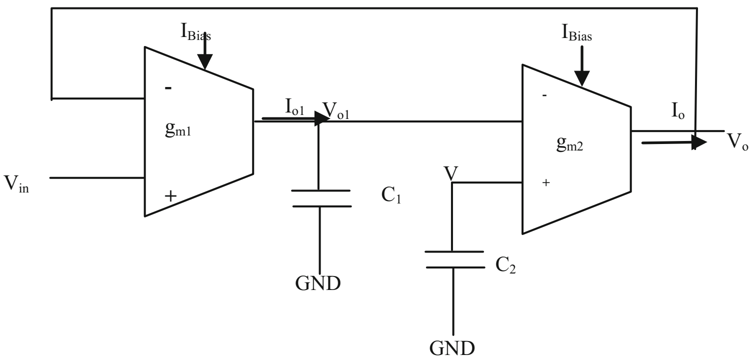

Fig. 8. Second order LPF

$$I_{o1} = g_{m1}(V_{in} - V_o) \tag{22}$$

$$I_{o1} = V_{01}sC_1 \tag{23}$$

$$I_o = g_{m2}(V_{o1} - V_o) \tag{24}$$

$$I_o = V_o sC_2 \tag{25}$$

$$I_o = g_{m2}\left\{\left(I_{o1}/sC_1\right) - V_o\right\} \tag{26}$$

$$V_o sC_2 = g_{m2}\left\{g_{m1}\left(V_{in} - V_o/sC_1\right) - V_o\right\} \tag{27}$$

$$V_o sC_2 + V_o g_{m2} = {}^{g_{m1} g_{m2}}\!/_{sC_1}(V_{in} - V_o) \tag{28}$$

$$\frac{V_o}{V_{in}} = \frac{(g_{m1} g_{m2}/sC_1)}{(sC_2 + g_{m2} + g_{m1} g_{m2}/sC_1)} \tag{29}$$

Simulation Results

The proposed filter operates at a low supply voltage of ±1.0 V. Power consumption of this filter is 0.8 mW (Table 5 and Fig. 9).

Table 5. Frequency response of LPF

S. no.	Frequency (GHz)	Voltage gain (dB)
1	1	0
2	5	0
3	10	0
4	50	0
5	60	0
6	80	−3
7	100	−8
8	200	−13
9	300	−16
10	500	−24
11	1000	−24
12	2000	−24

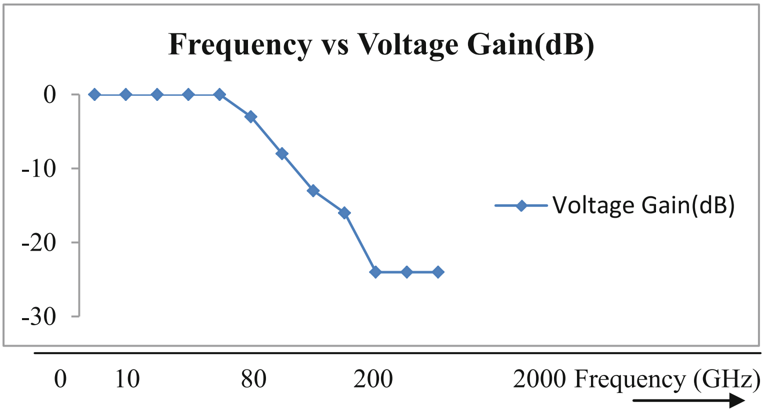

Fig. 9. Frequency response of low pass filter

5 Conclusion

In this first a low voltage and low power OTA was implemented using CMOS technology using TSMC 0.18 nm parameters. Which improves the linearity of operational transconductance amplifier. In this OTA signal attenuation technique is used. This topology acheives a good differential input range ±0.6 V with a gain of 76 dB. Based on this circuit, a second order voltage mode low pass filter has been implemented and a power consumption 0.7 mW has been obtained.

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