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OTA기반의 차단대역 조정이 가능한 3-입력/1-출력 구조의 다기능 Gm-C 필터

Stopband Tunable Multifunctional Gm-C Filter based on OTA with Three-Input/Single-Output

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요 약 본 논문에서는 연산 트랜스컨덕턴스 증폭기를 기반으로 하여 차단주파수 대역의 조정이 가능한 3-입력와 1-출력단을 갖는 Gm-C필터가 제안되었다. 제안된 필터는 대역통과, 저역통과 및 고역통과의 다기능 필터 특성을 갖는다. 구현된 필터의 중심주파수(f_c)와 특성요소(Q)값은 다른 필터특성의 변형없이 독립적으로 조정이 가능할 수 있음을 확인하였다. 또한 전체 시스템에 영향을 줄 수 있는 다양한 파라미터들과 기생요소들에 대한 감도특성과 비이상성분석이 수행되었다. 제안된 필터를 CMOS 소자로 구현하기 위하여 1.8V-0.18um 공정파라미터를 사용하였고 HSPICE를 활용하여 특성을 분석한 결과와 기 정리된 이론값들과 비교하여 나타내었다.

Abstract A new electronically stopband tunable filter is proposed with three-input single-output using Operational Transconductance Amplifier (OTA) in this paper. The proposed filter provides band pass, low pass and high pass multifunctional responses. Centre frequency (f_c) and quality factor (Q) of the realized filters could independently tuned without disturbing each other. Various network sensitivity and non-ideal characteristic analysis are done to check the sensitivity and parasitic effect of different circuit parameters. The CMOS realization of filter is done with 1.8V-0.18um process parameters and HSPICE simulation results are presented to assert the presented theory.

Key Words : OTA, Multifunctional filter, Transconductance, Gm-C, Bandpass

Ⅰ. Introduction

The evolution of the wireless and low voltage devices has led Operational Transconductance Amplifiers (OTA) to appear in the field of analog integrated circuit design[1]-[4]. Unlike Op-Amps which have input stage, gain stage and output stage OTAs have only input stage and gain stage. With no output stage, the OTA is more compact and consumes less power and have overall output resistance of a large value. The gain stage in OTA produces a current output rather than a voltage which is transconductance (g_m). The single stage gain of OTA further simplifies the internal design, resulting in a simple, fast, compact

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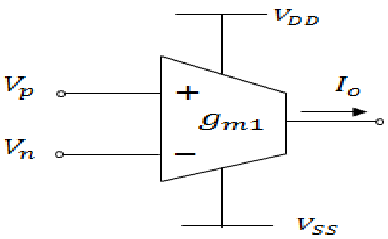
amplifier which proves to be efficient in high-frequency and low voltage applications allowing very advanced filters to be implemented on a single silicon chip[5]-[6].

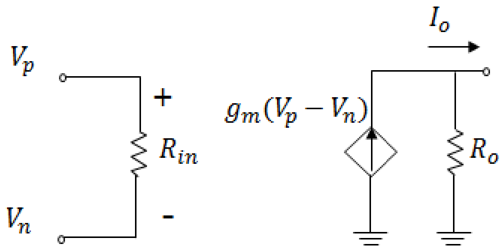
Filters can be classified as single input multiple output (SIMO) or multiple input single output (MISO) type depending upon the number of input and output ports[7]-[10]. Unlike SIMO, the MISO configuration can realize multifunction outputs by altering the way in which the input signals are connected. Also they provide a variety of circuit characteristics with different input voltage and usually does not require any parameter matching conditions. Therefore to realize a larger variety of filter functions MISO configuration seems to be more desirable[11]-[12]. Proposed filter is a multifunctional voltage mode biquadratic filter with three input single output. The proposed filter exhibits low circuit parameters sensitivity and orthogonal tuning capabilities of ω_0 and Q. The proposed filter uses minimum number of active (g_m) and other passive (C) elements [Table 1]. The circuit is simulated in HSPICE using Metal Oxide Semiconductor Implementation Service (MOSIS) 1.8V-0.18 μm SPICE datasheet process parameters.

II. Operational Transconductance Amplifier (OTA)

OTA circuits are extensively used in active filters design. An ideal OTA is a voltage controlled current source (VCCS). It uses it inverting and non-inverting voltage inputs to give current output with the externally controlled transconductance (g_m) gain as shown in Figure 1.



(a)



(b)

Fig. 1. (a) Block diagram of OTA (b) Small Signal Equivalent Circuit of OTA
그림 1. (a) OTA 블록다이어그램 (b) OTA 소신호 등가 회로

Fig. 1(a) represent block diagram of OTA and Fig. 1(b) represents small signal equivalent circuit of OTA.

$$I_0 = g_m(V_p - V_n) \quad (1)$$

Here, I_0 is the output current and g_m is the transconductance gain V_p and V_n and are inverting and non-inverting voltage inputs respectively.

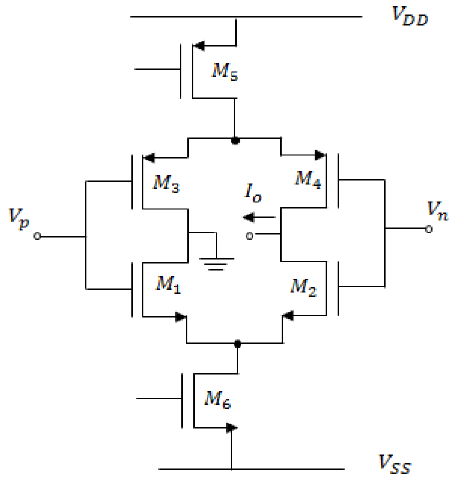


Fig. 2. CMOS implementation of OTA
그림 2. CMOS로 구현된 OTA

Assuming four MOS transistors operating in saturation regions, the g_m value can be expressed as equation (2).

$$g_m = \sqrt{u C_{ox} \frac{W}{L} I_b} \quad (2)$$

where I_b is the bias current, u 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.

Ⅲ. Design of a Multifunctional Filter

A second order multifunctional filter with 5 MHz is realized using three OTAs and two capacitors as shown in Figure 3. OTA-based filters are referred to as Gm-C filters because they use OTAs and capacitors.

Here, Fig. 3 is the designed second order Gm-C filter which can realize low pass (LP), high pass (HP) filter and band pass (BP). If V_1 and V_4 are taken as input and output respectively while assigning $V_2=0$ and $V_3=0$, the LP filter transfer function can be realized as in the equation (3). Similarly, if V_3 and V_4 are taken as input and output respectively while assigning $V_1=0$ and $V_2=0$ the HP filter transfer function can be realized as in the equation (4). Lastly, if V_2 and V_4 are taken as input and output respectively while assigning $V_1=0$ and $V_3=0$ the BP filter transfer function can be realized as in the equation (5).

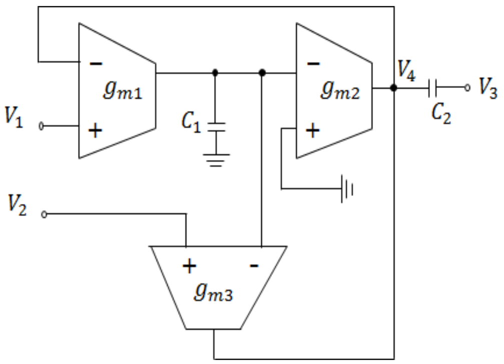


Fig. 3. The designed second order multifunctional Gm-C filter
그림 3. 설계된 2차 다기능 Gm-C Filter

$$TF_{LP}=\frac{V_4}{V_1}=\frac{\frac{g_{m1}g_{m2}}{C_1C_2}}{S^2+S(\frac{g_{m3}}{C_2})+\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (3)$$

$$TF_{HP}=\frac{V_4}{V_3}=\frac{S^2\frac{g_{m1}g_{m2}}{C_1C_2}}{S^2+S(\frac{g_{m3}}{C_2})+\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (4)$$

$$TF_{BP}=\frac{V_4}{V_2}=\frac{S\frac{g_{m3}}{C_2}}{S^2+S(\frac{g_{m3}}{C_2})+\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (5)$$

The angular frequency (ω_0) and Q factor of the multifunctional filter can be derived as in equation (6) and (7) respectively.

$$\omega_0=\sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (6)$$

$$Q=\omega_0\frac{C_2}{g_{m3}} \quad (7)$$

If all the other transconductances are kept constant and only g_{m3} is adjusted separately then a controllable value for Q factor can be derived.

Also, if every transconductance gain are assigned equal value i.e $g_{m1}=g_{m2}=g_{m3}=g_m$, then we have center frequency as shown in equation (8).

$$f_c=\frac{g_m}{2\Pi\sqrt{C_1C_2}} \quad (8)$$

Hence, the realized band pass filter circuit can independently control and Q factor. The sensitivity analysis of the proposed multifunctional filter can be derived as in equation (9).

$$S_{g_m}^{\omega_0}=1,\ S_{g_m}^{Q}=0 \quad (9)$$

The effect of parasitic elements are also considered to have a non-ideal circuit analysis of the multifunctional filter as shown in Figure 4.

Here R_{p1}, R_{p2}, R_{p3} and R_p are parasitic resistances whereas C_{p1}, C_{p2} , C_{p3} and C_p are parasitic capacitances in the filter . Generally value of C_1 and C_2 are in excess of the expected parasitic capacitances, these parasitic capacitances can be absorbed at working frequencies. However to minimize the parasitic resistances following condition must be fulfilled as shown in equation (10).

$$\frac{1}{SC_1} \ll R_{p1}, \ \frac{1}{SC_2} \ll R_{p3} \tag{10}$$

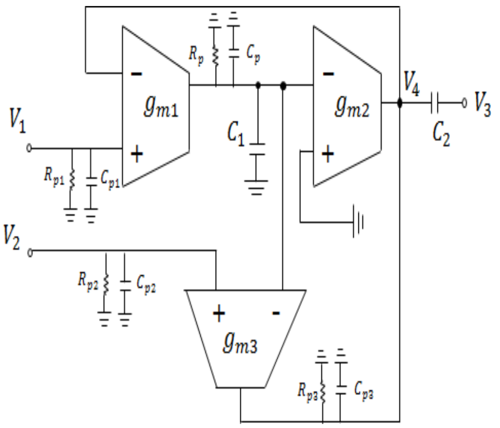


Fig. 4. Parasitic impedance of Gm-C filter
그림 4. Gm-C 필터의 기생 임피던스

The following table compares the number of passive and active elements used in realizing a second order filter with other papers published so far.

Table 1. Comparison of Proposed Filter with other references
표 1. 다른 필터 구조와의 비교

References	Number of Passive and active Elements used		
	g_m	R	C
[6]	6	3	0
[7]	6	0	2
[8]	4	2	3
[9]	4	0	2
Proposed	3	0	2

As seen in the Table 1. reference [6] and [7] has used six transconductances with three resistors and two capacitors respectively. Reference [8] has only used four transconductances but it has included two resistors and three cpapacitors. Reference [9] has used four transconductances with only two capacitors eliminating resistors. The proposed method only uses three transconductances and two capacitors for constructing a biquad filter.

Ⅳ. Simulation Results

The internal structure of the OTA (Fig.2) was simulated using MOSIS 0.18㎛ CMOS process model parameters with DC supply voltage of 1.8 V. All the parameter values were assigned to pull 400μA tail current. Aspect ratio (W/L) of all current biasing PMOS and NMOS transistors were taken as 15.6 and 3.44 respectively. And value of 38.22 and 52.27 was taken for all remaining NMOS and all PMOS transistors respectively. Active component values were selected as g_m = 31.428μS. In the case of the simulated multifunctional filter, both C_1 and C_2 were assigned with the value of 1 pF.

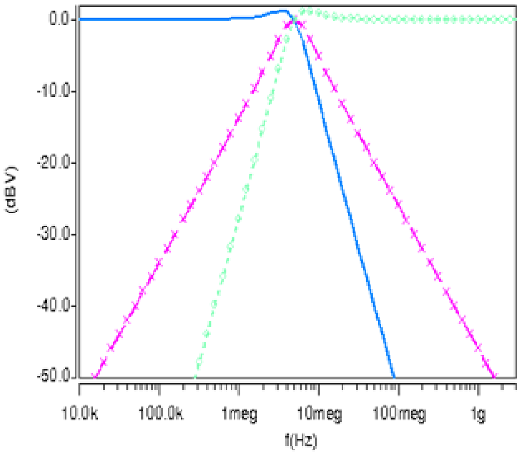


Fig. 5. Frequency response of the designed multifunctional filter
그림 5. 설계된 다기능 필터의 주파수 응답

Here, Fig. 5 represents simulated frequency response of LP, BP and HP filter with 5 MHz center frequency.

Fig. 6 and 7 represents tuning of from 1.5 MHz to

10 MHz and Q factor from 3.1 to 0.62 when value is changed from 10 μS to 50 μS. Thus the simulation result confirms the presented theory.

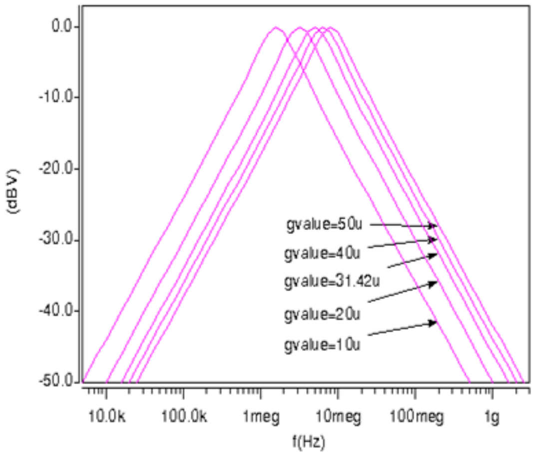


Fig. 6. Tuning f_c of the designed BP filter
그림 6. 설계된 BP 필터의 f_c 조정특성

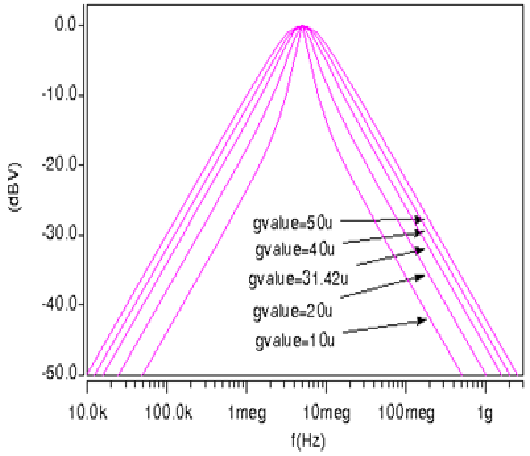


Fig. 7. Tuning Q factor of the designed BP filter
그림 7. 설계된 BP 필터의 Q값 조정특성

V. Conclusion

This paper presents design of a voltage mode biquadratic Gm-c filter with three input one output. It only employs three OTAs and two capacitors for realizing a multifunctional filter frequency responses. This circuit offers electronically tunable capability of f_c and Q factor without disturbing each other. Parasitic element analysis were also done as non-ideal analysis and HSPICE simulation results were presented using MOSIS 0.18 μm process parameters as a functional verification. The proposed multifunctional Gm-C filter will be applied for designing small size and low power analog circuits.

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