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Novel operational transconductance amplifier based on floating gate MOSFET tunable grounded resistor

[Sumit Verma, Rishikesh Pandey]

***Abstract*—The design of tunable operational transconductance amplifier with wide linear range has become increasingly challenging with the scaling in the power supply voltage. Use of control voltage for the purpose of tunning often results in narrow linear range. In recent years the use of voltage as a control parameter has even become more difficult with the reduced supply voltage environment. In this paper, bias current approach is used to achieve the tunability of proposed FGTGR based OTA. The proposed circuit is developed using balanced CMOS OTA and FGTGR. A low-pass filter has also been proposed as an application of FGTGR based OTA. The proposed circuits have been simulated using 0.18 µm CMOS technology. The simulation results have been presented to show the effectiveness of the proposed circuits.**

***Keywords*—OTA, FGTGR, transconductance, Tunability.**

I. Introduction

Operational Transconductance Amplifier (OTA) is a device that translates voltage inputs to current output. It is basically a voltage- controlled current source. More specifically the term “operational” comes from the fact that it takes the difference of two voltages as input for the current conversion [1]. When the transconductance of the OTA can be varied then it is known as tunable OTA. Tunable OTA is a versatile building block for analog signal processing. Tunable OTA are widely used to develop floating and grounded resistors, balanced output integrators, adders, subtractors, multipliers, g_m-C active filters, automatic gain control circuits [2-4, 5] etc. Tunability is frequently accomplished by the use of MOS transistors functioning as source degeneration devices in the triode region [6-7]. There are numerous techniques to design linear tunable OTA based on MOS transistors functioning in saturation region. But most of them operate in voltage-control mode and the controllable voltage range is rather limited. Another method of tuning the transconductance (g_m) is by changing the bias current of the differential pair. However transconductance is proportional to the square root of bias current which limits the allowable input swing. In the past various approaches have been suggested to make transconductance linearly dependent on bias current. EOTA [8] gives a new method to make g_m linearly dependent on I_B. However the structure is quite complicated because of the use of three balanced CMOS OTAs. In this paper, FGTGR based OTA, which uses two balanced CMOS OTAs [8] and a floating-gate MOSFET based tunable grounded resistor [9] is proposed. A low-pass filter has also been suggested as an application of the proposed FGTGR based OTA.

II. Circuit Descriptions

A. *A balanced single-output CMOS OTA*

The balanced CMOS OTA suggested in [8] is shown in Fig.1. The transistors M_1-M_8 are biased in the saturation region and the transistors M_1 and M_2 are perfectly matched. Using KCL at the output node, the output current (i_{out}) is given as

$$i_{out} = I_2 - I_1 \tag{1}$$

where I_1 and I_2 are drain currents of transistors M_1 and M_2, respectively and are given as

$$I_1 = \frac{\mu C_{OX} W_1}{L_1} (V_{GS1} - V_T)^2 \tag{2}$$

$$I_2 = \frac{\mu C_{OX} W_2}{L_2} (V_{GS2} - V_T)^2 \tag{3}$$

where V_T is the threshold voltage, µ is carrier mobility, C_{ox} is the channel capacitance per unit area, W_1& W_2 are channel width and L_1&L_2 are channel length of transistor M_1 and M_2 respectively.

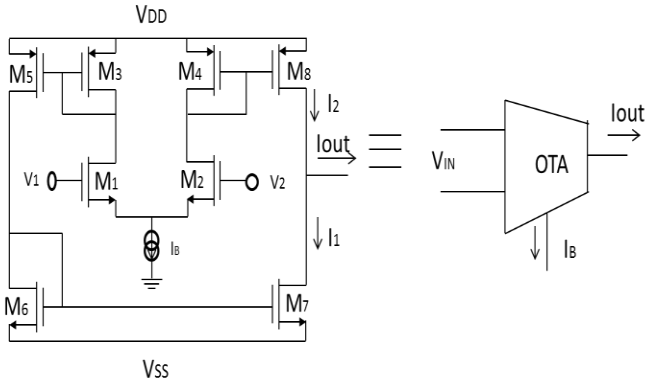

Fig.1. Schematic diagram of a balanced CMOS OTA [8]

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Using equations (1), (2) and (3) the output current (i_{out}) is given as

$$i_{out} = \sqrt{2I_BK}\, V_{in}\sqrt{1-\frac{kV_{in}^2}{2I_B}} \quad \text{for} \quad -\sqrt{\frac{I_B}{K}} \ll V_{in} \ll \sqrt{\frac{I_B}{K}} \qquad (4)$$

The transconductance (g_m) can be obtained by differentiating equation (4) as

$$g_m = \sqrt{2I_BK} \quad \text{for} \quad -\sqrt{\frac{I_B}{K}} \ll V_{in} \ll \sqrt{\frac{I_B}{K}} \qquad (5)$$

Using equation (4) and (5), the output current reduces to

$$i_{out} = g_mV_{in} = \sqrt{2I_BK}\, V_{in} \qquad (6)$$

From equations (5) and (6) it is clear that transconductance (g_m) and output current (i_{out}) both depend on bias current I_B but relationship is non-linear. In [8], it has also been suggested that by using three balanced CMOS OTAs, the linear relationship between the transconductance (g_m) and biased current (I_B) can be achieved.

B. *Proposed FGTGR based OTA*

The proposed FGTGR based OTA is shown in Fig. 2. The circuit has been developed using two balanced CMOS OTAs and one FGTGR. The OTA_1 converts a differential input voltage into a current i_{o1}, which flows into the FGTGR. The second OTA (OTA_2) converts the voltage drop (V_R) across FGTGR into the output current.

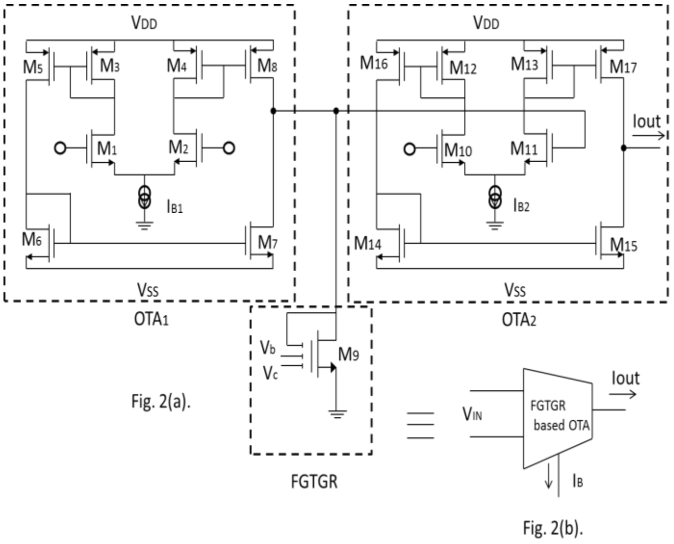

Fig. 2(a).

Fig. 2(b).

Fig. 2(a). Schematic diagram of the proposed FGTGR based OTA. 2(b). Symbol of the proposed FGTGR based OTA.

The voltage drop (V_R) across the FGTGR is given as

$$V_R = i_{o1}R \qquad (7)$$

where i_{o1} is the output current of OTA_1 and R is the resistance of FGTGR which is given by

$$R = \frac{V_{in}}{I_{in}} = \frac{1}{K_n(k_1V_C+k_2V_b-V_T)} \qquad (8)$$

where $k_1 = C_1/C_T$ and $k_2 = C_2/C_T$ are the capacitive coupling ratios, C_1 and C2 are capacitances between floating-gate and control voltages, C_T is the total capacitance ($C_T=C_1+C_2$), V_C is the control voltage, V_b is the bias voltage and V_{in} is the input voltage.

Using equation (6) and (7) the voltage drop (V_R) across FGTGR can be written as

$$V_R = i_{o1}R = g_{m1}V_{in}R \qquad (9)$$

where $g_{m1} = \sqrt{2I_{B1}K}$ is the transconductance of OTA_1.

The OTA_2 convert the voltage drop V_R into output current (i_{out}) given as

$$i_{out} = g_{m2}V_R \qquad (10)$$

where $g_{m2} = \sqrt{2I_{B2}K}$ is the transconductance of OTA_2.

Using equations (9) and (10) the output current (i_{out}) is given as

$$i_{out} = g_{m2}g_{m1}V_{in}R \qquad (11)$$

or

$$i_{out} = g_{mT}V_{in} \qquad (12)$$

where $g_{mT} = g_{m1}g_{m2}R$ is the total transconductance of circuit

A low-pass filter (LPF) using FGTGR based OTA is shown in Fig. 3

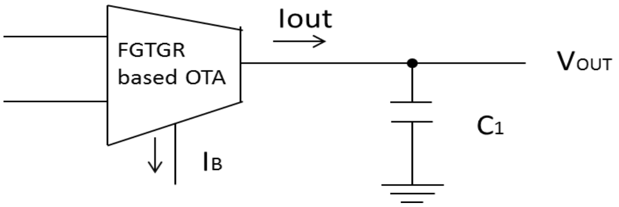

Fig. 3. Low-Pass Filter using proposed FGTGR based OTA

III. Simulation Results

The proposed circuits have been simulated using 0.18 μm CMOS technology. The circuit is operated at the supply voltages of ±0.5V. The transistors dimensions of proposed FGTGR based OTA are listed in Table I.

Table I: Transistor Sizing

MOSFETS	W(μm)	L(μm)
M_1-M_2,M_{10}-M_{11}	25	0.5
M_3-M_8, M_{12}-M_{17}	22	0.5
M_9	20.84	0.5

The DC characteristics of the proposed FGTGR based OTA of Fig. 2 are shown in Fig. 4. The plot is drawn between output current (I_{OUT}) and the input voltage (V_{in}) for the different DC bias currents (I_B), which show that the proposed FGTGR based OTA converts input voltage into output current.

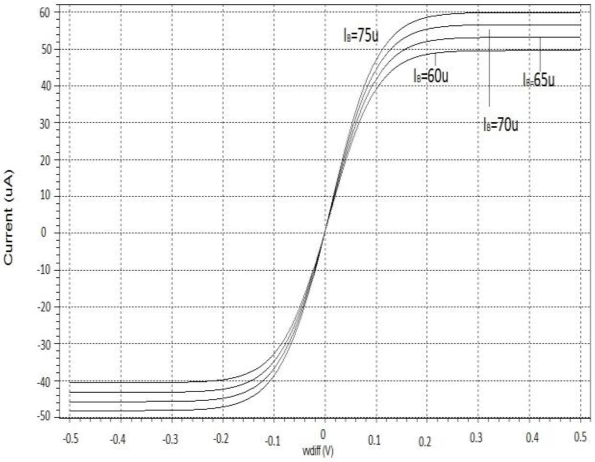

Fig. 4. DC Characteristics of the proposed FGTGR based OTA

The frequency response of the proposed FGTGR based OTA is shown in Fig. 5. From Fig. 5, it is clear that -3dB frequency of the circuit is 22 MHz.

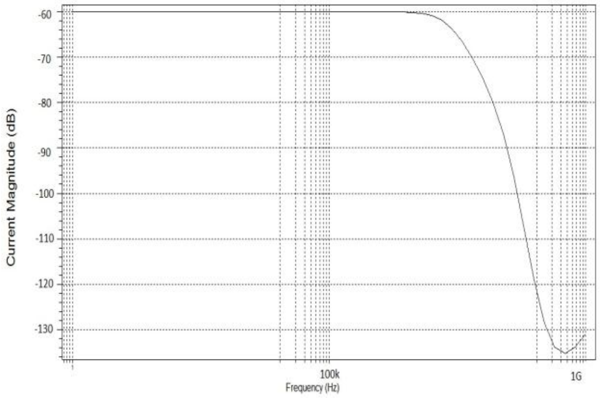

Fig. 5. Frequency response of the proposed FGTGR based OTA

The cut-off frequencies of low pass filter using proposed FGTGR based OTA for different values of biased current I_B is listed in Table II.

Table II: Cut-Off frequencies of LPF for different values of bias current $I_{B.}$

Bias Current	Cut-Off Frequencies
90 μA	18 KHz
110 μA	20 KHz
130 μA	24.5 KHz
150 μA	28.7 KHz

Table III compares the circuit parameters of proposed FGTGR based OTA with different OTAs available in literature [5, 8, 10, 11]. From the table, it can be seen that the proposed FGTGR based OTA has lower supply voltage requirement and lower power dissipation.

Table III Comparison of the proposed FGTGR based OTA with the previous OTAs

	This Work	[5]	[8]	[10]	[11]
CMOS Tech.	0.18 μm	0.35μm	0.5μm	0.5μm	0.5μm
V_{DD}(V)	1	2.5	5	3.3	3.3
Tunability	Current	Voltage	Current	Voltage	Current
HD3	-39dB	NA	NA	NA	-83dB
Power	6.19x10 -9	NA	NA	NA	1.25x10 -3
-3dB Bandwidth(MHz)	22	146	47	NA	NA

* Not Available

IV. Conclusion

In this paper, a low-voltage FGTGR based OTA has been proposed. The proposed circuit consist of two balanced CMOS OTAs and a FGTGR. The transconductance (g_m) and output current of the proposed circuit is varied either by bias current or resistance of FGTGR. One of the applications such as low-pass filter based on the proposed circuit has also been suggested, whose cut-off frequency can be varied either by changing the bias current or by changing the resistance of the FGTGR.

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