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Design of Electronic Tunable CMOS OTA : A Comparative Study

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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 tunability often results in narrow linear range. With the reduction in supply voltage in recent years the use of voltage as the control parameter has even become more difficult. Bias current can be used for controlling gain but it requires high supply voltage. This paper is a study of various techniques that can be used to achieve electronic tunability in CMOS OTA.**

Keywords **– CMOS, EOTA, Filters, OTA, Trans-conductance.**

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].The OTA symbol is shown in Fig. 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 continuous time 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, 16], etc. Common-mode range (CMR) and differential-mode range (DMR) are two important aspects of OTA filters and are strongly dependent on tuning [5]. Transconductance tuning is required not only to compensate for fabrication tolerances but also to achieve programmability of relevant parameters [6].

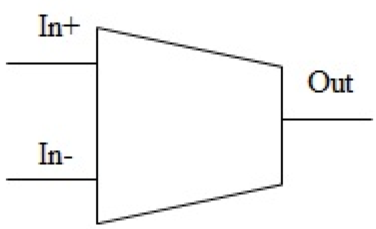

Fig.1. OTA symbol [1]

Tunability is frequently accomplished by the use of MOS transistors functioning as source degeneration devices in the triode region [7-8], since their equivalent resistance can be freely adjusted. To improve their linearity active cascades are regularly used to limit the drain to source voltage difference of the input transistor. The several techniques to design linear tunable OTA based on MOS transistors operating in saturation region have been reportedin [9, 11, 18, 19, 21, 22].However most of them operate in voltage-control mode and the controllable voltage range is rather limited. Another method of tuning transconductance (g_m)is by changing the bias current (I_{bias}) of the differential pair. Transconductance is proportional to the square root of bias current which limits the allowable input swing. Various approaches have been proposed to make transconductance gain linearly dependent on bias current. With recent scaling in CMOS technologies use of voltage as control parameter for tuning is becoming increasingly difficult and thus for low voltage OTA applications, tuning is often achieved using bias current as it shows better linear range at low voltages. In this manuscript, the various techniques to design tunable OTA are discussed.

II. Tunable Operational Transconductance Amplifier

Tuning in OTA is achieved by either varying transconductance as function of control voltage or biasing current.

2.1) Voltage-Controlled OTA

Several researches have suggested voltage-controlled operational transconductance amplifier [10-16]. By changing the control voltage, the transconductance of an OTA can be changed. In these circuits the device is operated in either square law region or triode region. The main advantage of voltage mode OTA circuits is that the operationof these circuits is quite simple.

Alinear tunable transconductor proposed in [10], uses linear composite n- channel MOSFETs and CMOS composite FET as basic cell. A differential linear relation is attainedby cross-coupling the elementary cells. The linear range of circuit is modified by replacing the transistors in elementary cell with CMOS composite transistor. The circuit is biased by a constant current source. The use of constant current source prevents the transistors from leaving strong inversion region and hence improves the linearity. Wang *et al.* [11] have proposed bias offset technique to design a tunable gain OTA. Two cross coupled differential transistor pairs operating in saturation region are used to obtain perfect linear transfer characteristics. The differential pair is biased with two different voltages. Current mirror is used to obtain single ended output. Channel length modulation, mobility reduction and mismatch between differential pair give rise to non-linearity in the circuit. A low-voltage triode operational transconductance amplifier has been proposed

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in [12], which use three transistors between the supply rails. The input transistor is biased in triode region and is tuned by varying the control voltage V_C. The self-cascode configuration has been used to improve the linearity, output resistance and bandwidth of the circuit. The non-linear effects in the Pseudo differential operational transconductance amplifier have been presented in [13]. The circuit uses pseudo differential structure with common mode feedback (CMFB). The pseudo differential structure provides wider input range and low voltage applications because the voltage drop across the tail current source is avoided. Common mode feedback circuit fixed the common mode voltage at different high impedance nodes. Mahmoud *et al.*[14]proposed balanced operational transconductance amplifier (BOTA) developed using balanced differential output configuration. The BOTA is programmed using a control voltage (V_C) and have two input voltages and two balanced output currents as shown in Fig. 2. Because of the use of balanced output configuration the circuit gives less distortion.

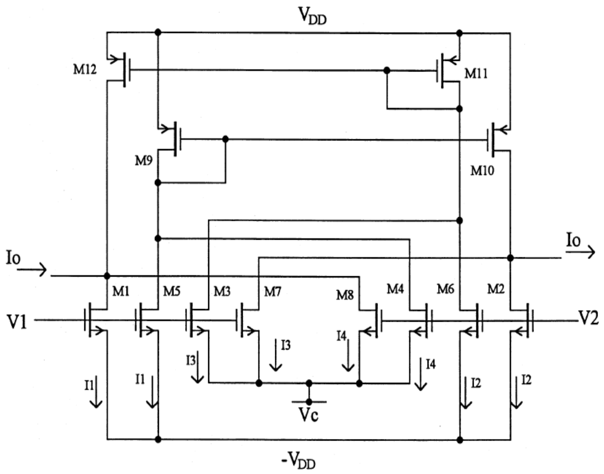

Fig.2. BOTA [14]

Soliman *et al.* [15]have presented digitally controlled balanced output transconductor based on BOTA suggested in [14] and MOS switches. The transconductance of the circuit is controlled by either analog voltage V_C or n-bit digital controlword. The design method is based on choosing an optimum value of V_C to obtain a wide linear range and controlling the transconductance value through the n-bit digital word. The common mode feedback circuit is used to prevent the drift in the output common mode voltage. Vijaya*et al.* [16] have presented a high frequency, low voltage highly linear OTA. The circuit involves two differential amplifiers with their outputs cross coupled. The desired transconductance is achieved using main differential amplifier and other transconductor act as compensatory differential amplifier to compensate third harmonic distortion. Tunability is achieved by using bias offset at the gate of both the differential amplifiers using level shifters. Compensation is obtained through adjusting bias currents of cross coupled differential amplifiers and by maintaining these amplifiers in strong inversion region.

2.2) Current-Controlled OTA

The main disadvantage of voltage-controlled OTAs is that their limited controllable voltage range. Hence narrow linear tunable transconductance ranges are available in literature. But for some applications,operational transconductors whose transconductance gain can be linearly controllable by a DC bias current are preferable. Several researches have suggested current-controlled operational transconductance amplifier [17-22]

Koizel *et al.* [17] have proposed OTA whose input stage is the cross-coupled quad cell formed by two unsymmetrical differential pairs and a conventional, symmetrical differentialpair followed by a current mirror. The use of current mirror at the output improves the linearity.

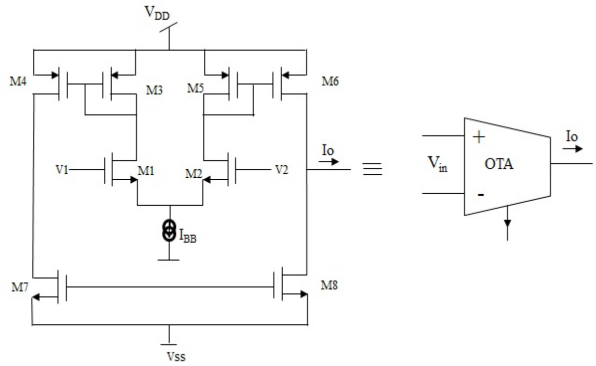

Fig.3. Schematic diagram of a balanced CMOS OTA [18]

Abalanced single-output CMOS OTA suggested in [18] uses bias current approach. The circuit is developed by MOS coupled pair M1-M2 and current mirrors M4-M3 and M5-M6 shown in Fig. 3.All the transistors in the circuit are biased in saturation region. The transconductance of balanced CMOS OTA varies non-linearly with bias current. The linear variation is obtained by the use of three balanced OTAsas shown in Fig 4. The OTA_1 converts a differential input voltage into a current i_L, which flows into an active resistor R_L, developed by the OTA_2. The third OTA (OTA_3) converts the voltage drop across OTA_2 into the output current..

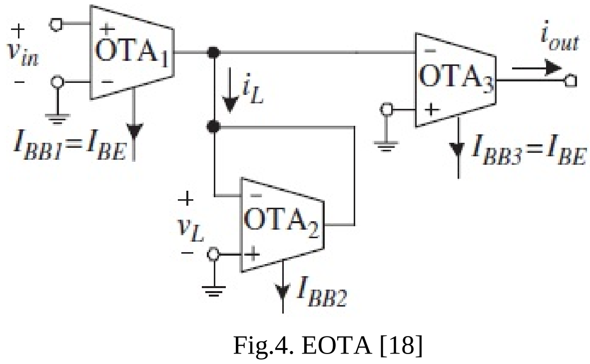

Fig.4. EOTA [18]

In [19], a modified form of EOTA, shown in Fig. 5 has been presented, which is developed by two OTA and one active resistor. The basic circuit of modified EOTA remains same as the balanced single output CMOS OTA [18] with same principle. The active resistor is formed by two NMOS transistors and the value of resistance is equal to $\frac{1}{4}K(V_{DD} - V_T)$, where V_{DD} is the supply voltage, V_T is the threshold voltage and K is the transconductance parameter of NMOS transistor.

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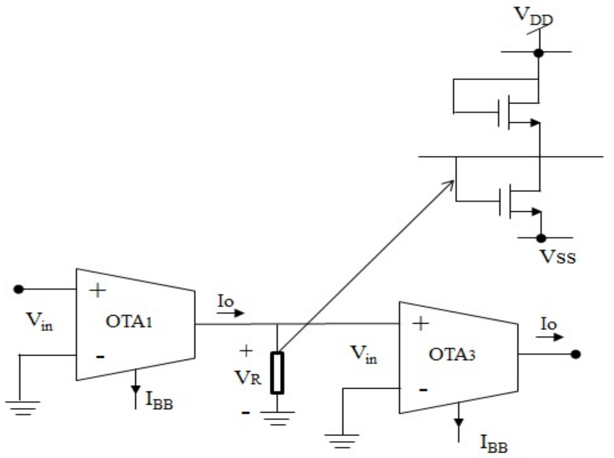

Fig.5. EOTA with active Resistor [19]

OTA suggested in [20] is based on MOS resistor linearization technique that uses quasi floating gate (QFG). The input signal is transferred to the voltage to current (V-I) conversion element by means of a high-speed feedback loop. Quasi-floating-gate MOS transistors biased in the triode region are used to accomplish linear V-I conversion. Also low sensitivity to transistor mismatch and reduced harmonic distortion in the circuit has been achieved due to the absence of current mirrors in the signal path.

Wanlop*et al.* [21]suggested a balanced output transconductance amplifier shown in Fig.6that accepts two input voltages and provides balanced output currents. The fixed gain differential transconductor is followed by variable current gain cell. The current gain cell is modified from a current-mode translinear circuit. Variable current gain cell basically consists of current mirror circuit. The current at port I_1 and I_2 are multiplied n time by the current mirror arrangement to produce differential output currents i_{out}^{+} and i_{out}^{-} at the ports A1 and A2, respectively. Fully balanced differential transconductor provides balanced output which is used to drive current gain cell.

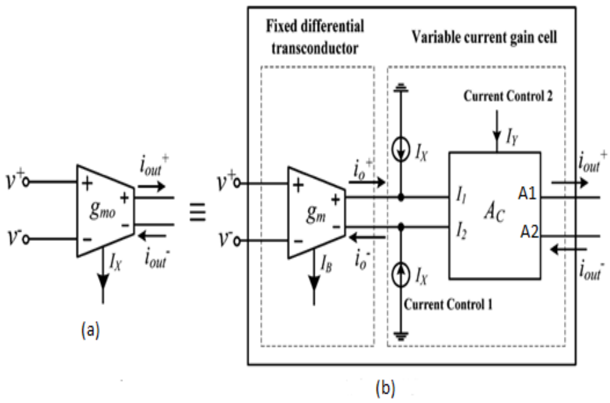

Fig.6. Balanced output transconductance amplifier (BOTA)(a) Symbol (b) Building block of the balanced output CMOS OTA [21]

OTA presented in [22]employed the pseudo-differential configuration circuit for the V-I conversion. The main difference between the pseudo – differential and fully differential configuration is that the negative input should be used as a reference only. Negative input is not intended to carry signal of interest. The overall block diagram of the circuit is shown in Fig.7. It consists of the fully balanced pseudo-differential transconductor cascaded with the programmable gain current amplifier. Programmable gain cell basically consist of network of current mirrors.

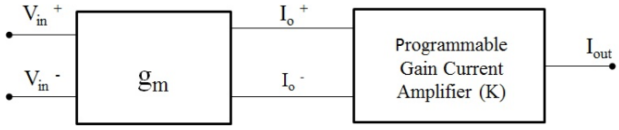

Fig.7. Building block of CMOS pseudo transconductor [22]

Li *et al.* [23] proposed an operational transconductance amplifier whose gain is digitally as well as linearly controlled. The tunable OTA is realized using a class AB current mirror, a current division network and two fully balanced differential transconductors. The first differential transconductor is developed using PMOS differential pair and the other by NMOS differential pair. Biasing current is used to change the g_m of the OTA which is provided by the output of class AB current mirror.

III. Comparison

The voltage-controlled OTAs[11-12, 14-16] have been compared in table I. From the table, it is observed that the maximum transconductance range, minimum power supply voltage requirement and maximum bandwidth available in [14], [15,16] and [16] respectively.

Table I: Comparison of voltage-controlled OTAs

Circuit Parameters	[11]	[12]	[14]	[15]	[16]
CMOS Technology	NA	3µm	0.5 µm	2µm	0.35 µm
V_{DD}(V)	5	4	3.3	2.5	2.5
g_m(µA/V)	NA	6	640-1350	25	539
Bandwidth (MHz)	NA	NA	NA	NA	146

Various current-controlled operational transconductance amplifiers [17- 22] have been compared and their parameters are listed in table II. From the table, it can be seen that the pseudo differential operational transconductance amplifier presented in [22] uses minimum power supply voltage and gives maximum transconductance, and OTA suggested in [20] gives minimum harmonic distortion of -83 dB whereas OTA proposed in [21] has maximum bandwidth of 780 MHz.

Table II: Comparison of Current-Controlled OTAs

Circuit Parameters	[17]	[18]	[19]	[20]	[21]	[22]
CMOS Technology	.5 µm	1 µm	1 µm	0.5µm	.5 µm	.18
V_{DD}(V)	5	5	5	3.3	1.5	.9
g_m (µA/V)	34-105	539	102.4	50-200	854	3.36-452.4
Power (mW)	5.7	NA	NA	1.25	NA	NA

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HD3	-47dB	NA	NA	-83dB	NA	NA
Bandwidth (MHz)	NA	120	47	NA	780	687.5

NA(Not available)

IV. CONCLUSION

In this paper various suggested techniques to develop tunable OTA have been addressed and their performances are also compared. Tunable OTA is versatile building block in various applications.g_m-C filters made using tunable OTA gives excellent high frequency response and are thus preferred over Op-Amp filters. Tuning in OTA can be achieved by either varying bias current or control voltage. Scaling of supply voltage over the years has made the use of voltage as control parameter very difficult. Tunable OTAs developed using bias current technique have high linear ranges and can operate at low voltages and hence they are preferred.

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