REALIZATION OF A HIGH OUTPUT EMPEDANCE CMOS DO-OTA WITH EXTENDED LINEARITY RANGE

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ABSTRACT

This paper presents a new dual operational transconductance amplifier (DO-OTA) structure with enhanced linearity compared to conventional DO-OTA circuits. A high output impedance structure is combined with a highly linear input stage, which is easy to implement for on chip applications. With its high output impedance and highly linear characteristics, this structure can be used for several purposes in analogue IC design.

I. INTRODUCTION

The current-mode analogue circuits employing active elements such as operational transconductance amplifiers (OTAs), current conveyors (CCIIs), dual output operational transconductance amplifiers (DO-OTAs), dual output current conveyors (DO-CCIIs), four terminal floating nullors (FTFNs) play an important role in the IC design, since these active elements exhibit greater linearity, wider bandwidth and wider dynamic range over the voltage mode counterparts. The operational transconductance amplifier (OTA) is the oldest and frequently used circuit among the current-mode circuits. [1-9].

An important drawback of these active devices is the finite output resistance, which is parallel with the load capacitor causing a lossy integration, thus generating filtering errors. Therefore very high output impedance output stages are required both to enable filtering at low frequencies and to reduce filtering errors. Some works were performed for this purpose and appeared in the literature [1,2,5,9]. Another drawback of the OTAs and DO-OTAs is the limited input voltage range, which influences seriously the device linearity. Several works were performed in the last twenty years to overcome this shortcomings and new topologies to replace the conventional differential input stages are proposed. The aim of this paper is to propose a high performance CMOS DO-OTA structure combining the high performance input and output stage properties.

II. OTA EXPRESSIONS

The circuit symbol of the DO-OTA (dual-output operational transconductance amplifier) is given in Fig. 1.

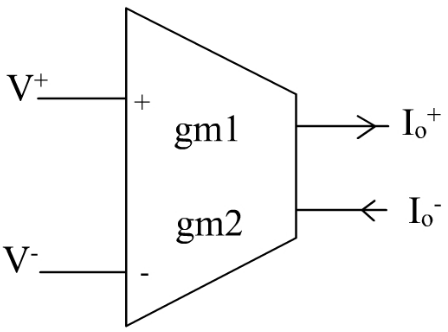

Figure 1 DO-OTA symbol

Ideally, DO-OTA is assumed as an ideal voltage controlled current source and can be described by following equations:

$$I_o^+ = g_{m1}(V^+ - V^-) \quad I_o^- = g_{m2}(V^+ - V^-) \qquad (1)$$

III. CIRCUIT TOPOLOGY

From equation (1) one can observe that the relationship between input voltage and output current is linear for ideal case. But in real world this relationship is not linear. In today's world, the linearity is an important subject for telecommunication applications. Thus, the circuits realized must be very linear to have the best performance. On the other hand, another limit for the circuits is the output impedance. To achieve enhanced performance the circuits realized must have high output resistances [1].

The classical DO-OTA circuit is illustrated in Figure 2. The properties of this circuit will be used later to compare the characteristics of the proposed topology. The proposed topology is the combination of Nedungadi [3] input cell and output stage [1].

Output stage: The output stage of the proposed DO-OTA circuit is based on a previous work by Zeki and Kuntman [1]. The output stage is realized by the use of high-output-impedance current mirrors [1,2]. Furthermore it was demonstrated that this type output stage exhibits improved output characteristics compared to the conventional circuits constructed with cascode-current mirrors. The output stage achieves a much larger output resistance R_{out} and therefore a much larger DC gain with respect to its classical cascode counterpart while keeping mirroring precision and GBW high.

Intput stage: The linearized input circuit proposed by Nedungadi [3] is used to obtain an extended linearity range. The input stage is illustrated in Figure 3. The input linearity and the input-voltage range of the circuit are extended by adding a constant voltage source between the gate of the MOS transistor at one input and the source of the MOS transistor at the opposite signed input.

The behaviour of Nedungadi circuit [3] can be described by Eqns. 2, 3 and 4 as follows:

$$x = \frac{\nu}{V_b}\ ,\ y = \frac{i}{I}, V_b = \sqrt{\frac{I}{k}}, \nu = V_{INP} - V_{INN} \tag{2}$$

$$\alpha = \frac{4n}{n+1},\ \beta = \frac{n}{(n+1)^2},\ \gamma = \frac{n(n-1)}{(n+1)^2} \tag{3}$$

$$y = \alpha x\sqrt{1-\beta x^2}, \qquad |x| \le \sqrt{\frac{n+1}{n}} \tag{4}$$

The proposed topology is the combination of the Nedungadi [3] input cell and Zeki-Kuntman output stage [1]. Figure 4 illustrates the complete circuit of the proposed DO-OTA structure. The Nedungadi input stage consists of M1, M2, M1A and M2A which have the same channel length, but M1A and M2A are made n times wider than M1 and M2.

IV. SIMULATION RESULTS

SPICE simulations were performed to demonstrate the extended circuit performance of the proposed circuit shown in Fig.4. The supply voltages are taken as V_{DD}=2.5V, V_{SS}=-2.5V. AMS 0.8µ model parameters were used for simulations.

To demonstrate the improvement provided by the proposed DO-OTA topology, the performance of a classical DO-OTA circuit shown in Fig.3 is also characterized by SPICE simulation program.

The DC output current vs. input voltage for both DO-OTA realizations are given in Fig. 5 This figure contains the characteristics of the two circuits. It is obvious that the output current follows the input voltage linearly along an input range of 2416 mV for proposed circuit, and along a range of 534mV for classical circuit; outside of this region the relation between output current and input voltage becomes nonlinear.

The frequency dependencies of the DO-OTA transconductances obtained by SPICE simulations for the conventional input circuit and for the proposed topology are shown in Fig. 6. Both circuits are biased to have a transconductance (gm) of 150 µA/V.

From Figs. 5 and 6 it can be easily observed that an extended linearity range is obtained for the proposed circuit compared to conventional counterpart while the bandwidth of the transconductance is almost the same for both circuits.

The linearity of the proposed DO-OTA is also demonstrated by comparing the large signal and harmonic distortion properties of both structures. The variation of the total harmonic distortion (THD) at the outputs is depicted in Fig. 7. As it can be easily observed from Fig. 7, the total harmonic distortion THD at the output of the proposed DO-OTA remains in acceptable limits at high input levels; whereas the DO-OTA structure with conventional input stages exhibits high THD values even at low input signals.

The performance of DO-OTA circuits is tested on an application example of band pass filter (BPF) given in Figure 8. The circuit is a current mode band pass filter, which is derived from the voltage mode equivalent proposed in [7].

Equations describing the BPF of Figure 8 are defined by

$$H(s) = \frac{a_1 s}{s^2 + b_1 s + b_0} \tag{5}$$

$$\frac{g_{m1}}{C_1} = \frac{b_0}{b_1}, \quad \frac{g_{m2}}{C_2} = b_1, \quad \frac{g_{m3}}{C_2} = a_1 \tag{6}$$

For simulations the basic quantities are chosen as g_m=150µA/V, C_1=30pF and C_2= 15 pF.

The filter characteristics are illustrated in Figure 9. From the figure, it can be seen that the BPF consisting of proposed circuits has an extended performance compared to the filter constructed with classical DO-OTA structure. As a result of high output impedance provided by the proposed structure, low frequency behaviour of the filter circuit is better than the classical one [8].

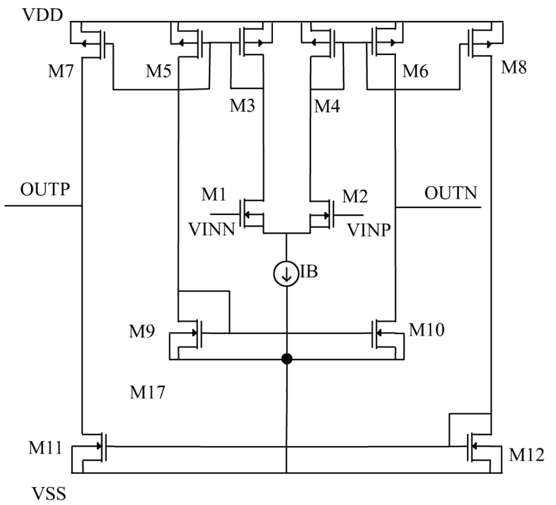

Figure 2 Classical DO-OTA circuit

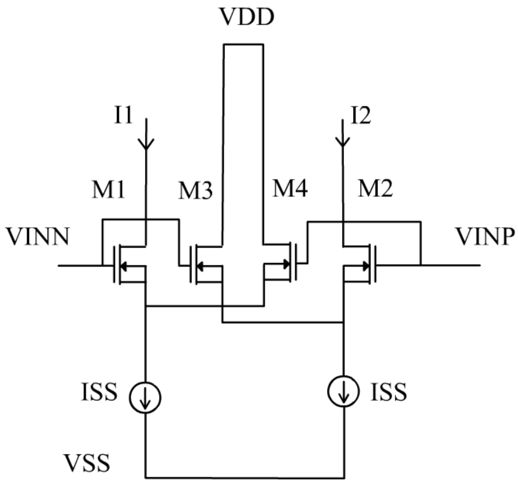

Figure 3 Nedungadi input cell [3]

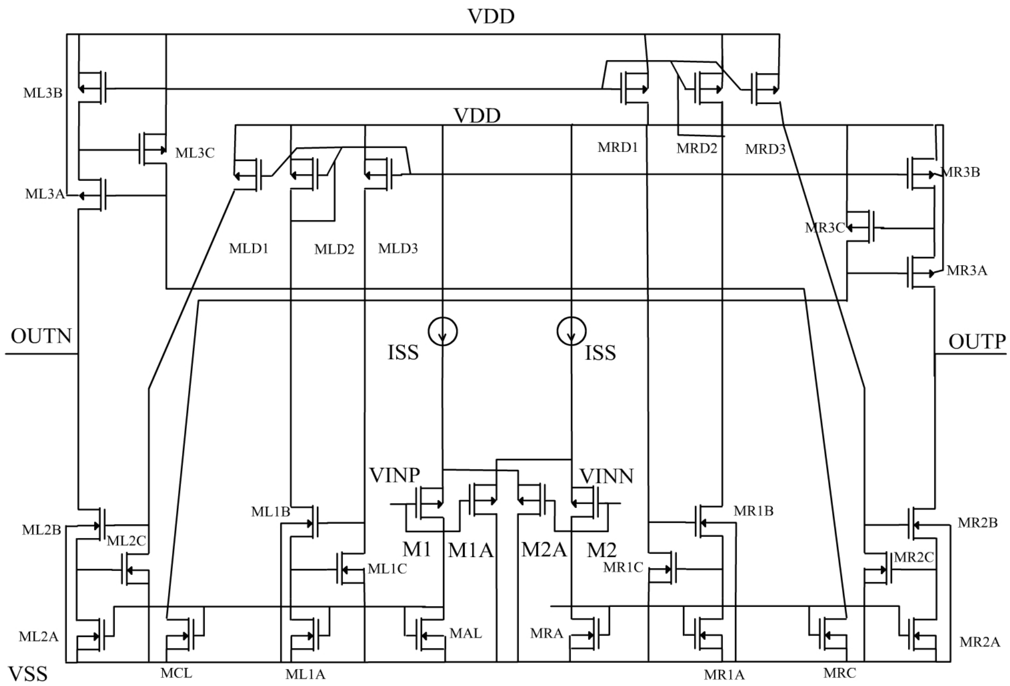

Figure 4 Proposed DO-OTA circuit

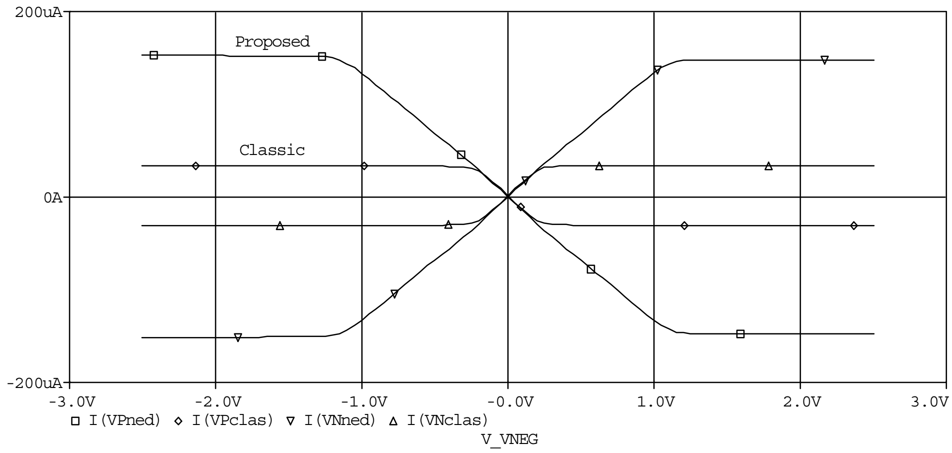

Figure 5 Io-Vin characteristics of DO-OTA circuits

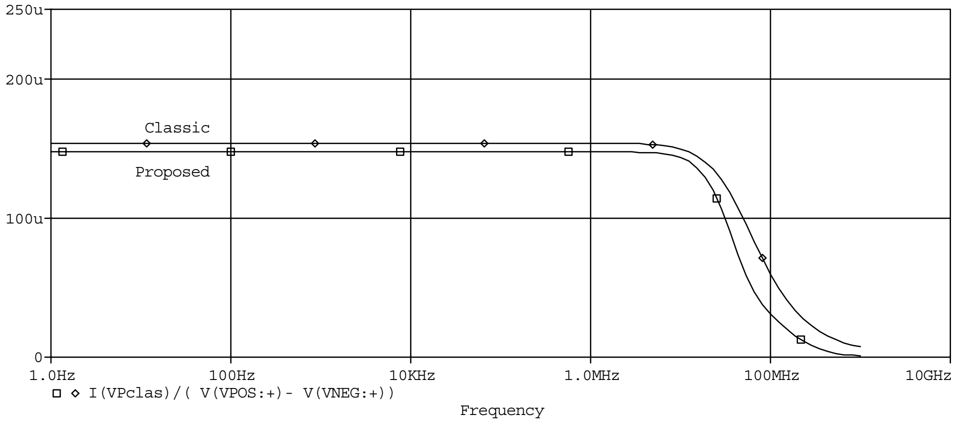

Figure 6 AC characteristics of DO-OTA circuits

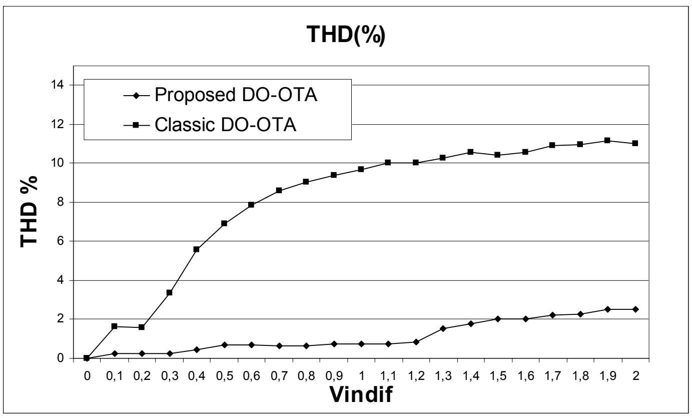

Figure 7 Dependence of total harmonic distortion THD at the circuit output on input signal level

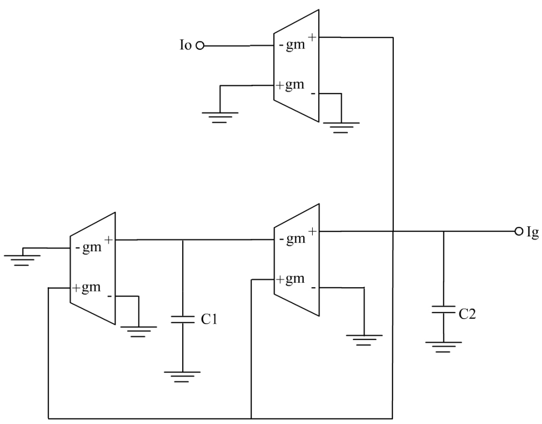

Figure 8 Current mode BPF circuit

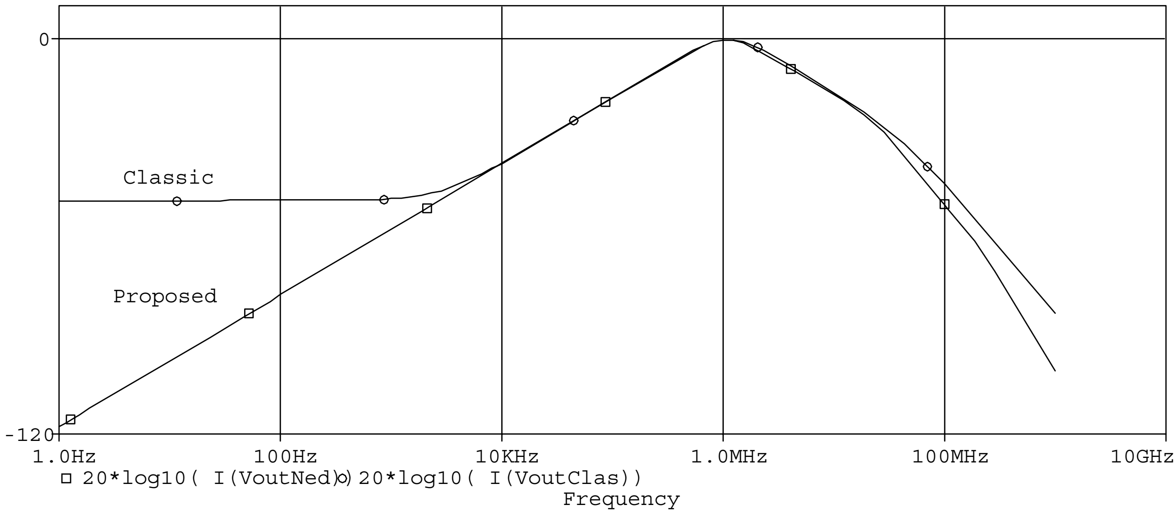

Figure 9 Simulated frequency responses of BPF circuits constructed with classical and proposed DO-OTA structures.

V. CONCLUSION

In this study it is aimed to propose a high performance dual OTA (DO-OTA) structure, which provides an extended linearity range with extremely high output impedance together. The high performance of the proposed DO-OTA circuit introduce new possibilities to the IC designer for realization of high performance DO-OTA-based active filters, oscillators, immittance simulators etc. so that their usage area is extended for further applications.

REFERENCES

[1] A. Zeki and H. Kuntman, ‘High-output-impedance CMOS dual-output OTA suitable for wide-range continuous-time filtering applications’, *Electronics Letters*, 16, pp 1295-1296, 1999.

[2] B. S. Ergün and H. Kuntman, ‘Yüksek Lineerlikte DO-OTA Gerçekleştirilmesi’ *Proceedings of ELECO 2000*: National Conference on Electrical, Electronics and Computer Eng., pp 77-81, 8-12 November 2000, Bursa Turkey.

[3] A. Nedungadi and T. R. Viswanathan, ‘Design of Linear CMOS Transconductance Elements’ *IEEE Trans. Circuits Syst.*, vol CAS31, pp 891-894

[4] A. Zeki, ‘Novel High Performance OTA Structures Suitable for Continuos Time OTA-C Filters’, PhD Thesis, *İstanbul Technical University, Institute of Science and Technology*, October 1997.

[5] R. J. Angulo and E.S. Sinencio, ‘Active Compensation of Operational Transconductance Amplifier Using Partial Positive Feedback’ *IEEE JSSC*, 25, pp 1024-1028, 1990.

[6] R. J. Angulo, E.S. Sinencio and M. Howe, ’Large f_0 Q Second Order Filters Using Multiple Output OTAs’ *IEEE CASII*, 41, pp 587-592, 1994,

[7] C. Acar, F. Anday and H. Kuntman, On the realization of OTA-C filters, *International Journal of Circuit Theory and Applications*, 21, pp.331-341, 1993.

[8] B. S. Ergün, ‘Yüksek Lineerlikte CMOS DO-OTA Gerçekleştirilmesi’, *MSc Thesis*, *İstanbul Technical University, Institute of Science and Technology*, July 2001.

[9] B. S. Ergün, H. Kuntman and S. Özcan, ‘Realization of a high performance CMOS DO-OTA with extended linearity range’, *SCS 2001*: International Symposium on Signals, Circuits and Systems, 10-11 July 2001, Iasi, Romania.