A Novel Approach to the Design of a Linearized Widely Tunable Very Low Power and Low Noise Differential Transconductor

Hamid Reza Sadr M.N.
Islamic Azad University, South Tehran Branch
+98-21-6556926, +98-21-6516959, +98-912-2503048
hsmn1@yahoo.com

Abstract. In this paper, a novel economically linearized widely tunable very low power and low noise differential transconductor is proposed and compared with the conventional differential pair. The application of the resulted transconductor as a negative resistor is presented. The linearity, power, noise, speed, and tunability performances are simulated, discussed, and compared with the conventional differential pair's.

Keywords: Differential transconductors, negative resistors, analog circuits and filters, low noise, low power, widely tunable circuits, GHz range frequencies, continuous-time filters, Q-enhanced active filters, Gm-C filters, RF, VCO.

1 Introduction

Generally speaking, as well as tunability, due to their simple structure and hence the superior speed and noise performances, transconductors have occupied a significant role in the design of analog circuits especially continuous-time filters. These cells also offer the excellent features such as high input and output impedances, ability to work in GHz range frequencies, ability to replace OP-Amps in math operations, ability to model the positive and negative resistors, and small chip area.

Most of the time, the linearity of these cells in their conventional shape, which due to the least possible parasitics and active parts enjoy superior speed and noise performances does not satisfy the applications at hand. On the other hand, due to technology non-idealities, as soon as the simple topology of the conventional differential pair is modified to improve the linearity of these cells, the speed and noise performances degrade. Many different linearization techniques have been discussed in design of differential transconductors [1][2][3][5][7][8][9][10]. The target essentially is to present linearization techniques, which, while being low power, do not degrade the noise performance and keep the speed of the linearized transconductor as close as possible to its equivalent conventional differential pair’s. The speed of interest nowadays is in the range of GHz, while the linearized topologies capable of working in this range and at the same time satisfy the RF requirements are rare.

The new linearized transconductor proposed in this paper, while being simple and economic, has the advantage of being very low power and low noise, widely tunable, and as fast as the simple conventional differential pair to work in GHz range frequencies. One important application of these cells is in Silicon based Q-enhancement tech-
niques; in which transconductors are used as tunable negative resistors to eliminate the losses of on-chip reactive elements (especially spiral inductors) [3][4]. Other important applications of these cells are in VCOs and Gm-C filters, where they are used as voltage to current converters, positive and negative resistors, and the gyrator-C, simulating the inductor’s behavior [4].

Since the differential transconductors have the advantage over the single ended ones that they can omit the even order harmonics [5][7][8], here the discussion is made on these configurations. As well, since the analysis of a differential transconductor and its resulted negative resistor are similar, here, in order to show the application, it is chosen to analyze and simulate the proposed transconductor in its negative resistor configuration.

In section 2, the new differential transconductor named GGD3 (God Given Design 3) is analyzed. Its transconductance is calculated and compared with the conventional differential pair’s. GGD3, while securing wider tuning range, collects the advantages of its two ancestors i.e. GGD [1] and GGD2 [1,2] transconductors.

In sections 3, 4, and 5 the linearity, power, and noise performances of GGD3 are evaluated respectively, and compared with conventional diff. pair’s. Finally, in section 6, the Hspice simulation results of the two approaches are compared.

2 GGD3 Transconductor

Figure 1 shows the GGD3 transconductor connected to act as a negative resistor. This is a modification to the GGD3’s ancestor, i.e. GGD transconductor shown in figure 2. As can be seen, the only difference between the two topologies is that, in GGD, M_{3,4} are diode connected and hence their output impedances can not be practically very high. Also, there, despite the superior advantages, we have the disadvantage of decreased value to the degeneration resistor caused by the GGD’s topology. To overcome these disadvantages and improve the performance of GGD’s topology while maintaining its simplicity and hence advantages, the easiest solution is to use a cross connection as in GGD3 in figure 1. If matching is assumed, due to the symmetry of both topologies, the DC voltages at the sources of M_{1,2} are essentially the same, and hence GGD and GGD3 are expected to have the same power performances. Also, the same as GGD, in GGD3 no DC current passes through R_{deg} and it is always isolated from the DC current path. M_{3,4} work in saturation and hence are ideally true current sources with high output impedances which act as the paths for the DC currents.

As M_{3,4} configure a negative resistor in parallel with R_{deg}, considering R’ as the negative real part of this resistor, and \( R_{eq} \equiv R_{deg} \parallel R' \) seen at the sources of M_{1,2}, we are dealing with three major work regions for GGD3; \( R' >> R_{deg} \): in this case \( R_{eq} \equiv R_{deg} \), \( R' \geq R_{deg} \): in this case \( R_{eq} = a \) positive value, and \( R' \leq R_{deg} \): in this case \( R_{eq} = a \) negative value. As it is clear, an analytical solution to the measurement of \( R_{eq} \) and hence the output impedance of GGD3 is not easy. On the other hand, for GGD3 in its negative resistor shape, the region of our interest is where we can have a negative resistance at its output. As well, if we can measure the current passing through \( R_{deg} \) directly, then, using the KVL we can ignore the effect of the negative resistance of \( M_{3,4} \) on \( R_{eq} \) and the analysis of GGD3 becomes much easier. Using this idea, since \( M_{1,2} \) are in saturation, the transconductance (Gm) of GGD3 may be calculated as: