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Design of Second Order Low Pass Filter with Differential Floating Inductor

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Abstract: This paper presents a second order low pass filter designed with active elements, based on the use of Complementary Metal Oxide Semiconductor (CMOS) technology. The simulation has been carried out on Tanner EDA tool 13.0 on 0.5 μm technology. In this paper, proposed differential floating inductor, floating node voltage-controlled linear variable resistor is used in the circuit of second order low pass filter (LPF). The 3-dB frequency obtained are related with bias current which is due to suited value of floating inductance of the filter, by varying the bias current inductance can be varied. The spiral inductor occupies a large chip size and is difficult to obtain a high value of cut off frequency. Second order low pass filter (LPF) designed with proposed active inductor provides the high cut off frequency then the conventional floating inductor.

Keywords: *Active inductor, Floating inductor, LPF, CMOS, cut off frequency.*

1. INTRODUCTION

Inductors, either passive or simulated by active devices are key components in Radio Frequency Integrated Circuits (RFIC) analog building blocks such as filters, oscillators, phase shifters, and low-noise amplifiers (LNA). As integrated circuit technologies are progressing, the usage of passive inductors is degrading due to their large chip area, low-quality factor, and less tenability [1]. Mainly the inductor is the major chip area consuming building block; the higher the inductance required, the higher the chip area. While tunability can be implemented using passive inductor and low-resistance switches, continuous tuning is not easily achieved. Due to these disadvantages, the concept of active inductors is becoming more attractive. Higher noise, nonlinearity and power consumption are the major disadvantages of active inductors due to the fact that these circuits are realized using active devices. Though the on-chip spiral inductors are good passive devices, it is difficult to realize it for larger inductance values, high quality factor and smaller chip area [2].

An active filter is a type of analog electronic filter that uses active components such as an amplifier. Amplifiers included in a filter design can be used to improve the performance and predictability of a filter, while avoiding the need for inductors (which are typically expensive compared to other components). An amplifier prevents the load impedance of the following stage from affecting the characteristics of the filter. An active filter can have complex poles and zeros without using a bulky or expensive inductor [3]. The shape of the response, the Q (quality factor), and the tuned frequency can often be set with inexpensive variable resistors. In some active filter circuits, one parameter can be adjusted without affecting the others. Such filter circuits are widely used in such applications as noise reduction, video signal enhancement and many other areas. Analog filters can be found in almost every electronic circuit [4]. Audio systems use them for pre amplification, equalization, and tone control. An analog filter, by contrast, operates directly on the analog inputs and is built entirely with analog components, such as resistors, capacitors, and inductors. The performance of analog filters is directly related to the quality of the components used and the circuit design. Floating node voltage-controlled linear variable resistor is widely used for analog integrated signal processing building blocks, telecommunication applications, signal generators, and automatic gain control amplifiers [5][6]. In particular, MOSFET resistors are useful since they are compatible with analog and digital MOS IC technology.

In section II, the circuitry of conventional inductor, proposed inductor and second order RLC low pass filter is discussed. Section III presents the experimental results and we draw the conclusions in Section IV.

2. CIRCUIT DESCRIPTION

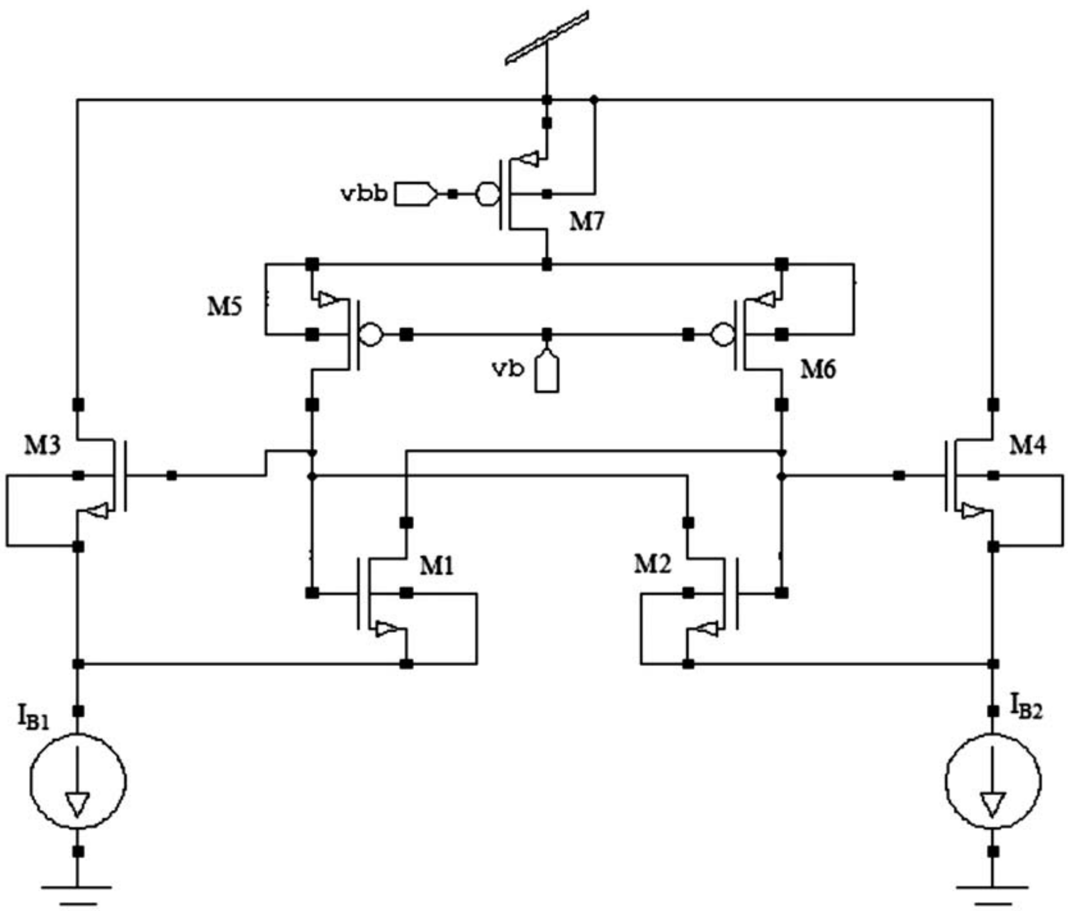


Figure 1: Proposed active inductor

Inductors are necessary for the synthesis of most useful passive filter characteristics, and these can be prohibitively expensive if high accuracy (1% or 2%, for example), small physical size, or large value is required. Standard values of inductors are not very closely spaced, and it is difficult to find an off-the-shelf unit within 10% of any arbitrary value, so adjustable inductors are often used [6]. Tuning these to the required values is time consuming and expensive when producing large quantities of filters. The schematic of the proposed active inductor is shown in fig. 1.

At the quiescent bias point, it is obvious that transistors M_1 to M_4 are saturated. Transistors M_5, M_6 and M_7 can operate either in the saturation region or in the triode region, depending on the controlled voltages V_b and V_{bb} at the gates [8] [9]. Therefore M_5, M_6 and M_7 are modelled as g_{ds5}, g_{ds6} and g_{ds7} representing the drain conductance at the associated bias points.

As shown in figure 1 the circuit is with 7 transistors which include 4 NMOS from M_1 to M_4 and 3 PMOS from M_5 to M_7. From a dc point-of-view, M_1 and M_6 form a cross-coupled pair, while M_3 and M_4 are in the common-drain configuration [10]. By deriving the port voltage V_{in} for a given input current $I_{in,}$ the input impedance Z_{in} at the differential port can be expressed as:

$$Z_{in} = \frac{V_{in}}{i_{in}} = \frac{[j\omega(C_{gs1} + C_{gs3}) - g_{m1} + g'_{ds5}]}{g'_{ds5}[g_{m1} + g_{m3} + j\omega(C_{gs1} + C_{gs3})]} \tag{1}$$

By solving it with approximation the value of inductance L_{eq} can be expressed as:

$$L_{eq} = \frac{(C_{gs1} + C_{gs3})}{d'_{ds5}(2g_{m1} + g_{m3} - d'_{ds5})} \tag{2}$$

Fig. 2. (*a*) shows the simplified small-signal equivalent circuit of the active inductor and fig. 2.(*b*) shows the equivalent impedance circuit of active inductor. Hence, a small-signal analysis is performed to characterize the behaviour of the differential active inductor M_1 to M_7.

where g'_{ds5} is expressed as:

$$g'_{ds5} = \frac{(C_{ds7} + g_{ds6}\,M_1)g_{ds5}}{g_{ds7} + g_{ds6}\,M_1 + g_{ds5}} \tag{3}$$

where g_{ds6}M1 and g_{ds6}M2 are given as:

$$g_{ds6}M_1 = \frac{g_{ds6}}{1 - K} \tag{4}$$

and

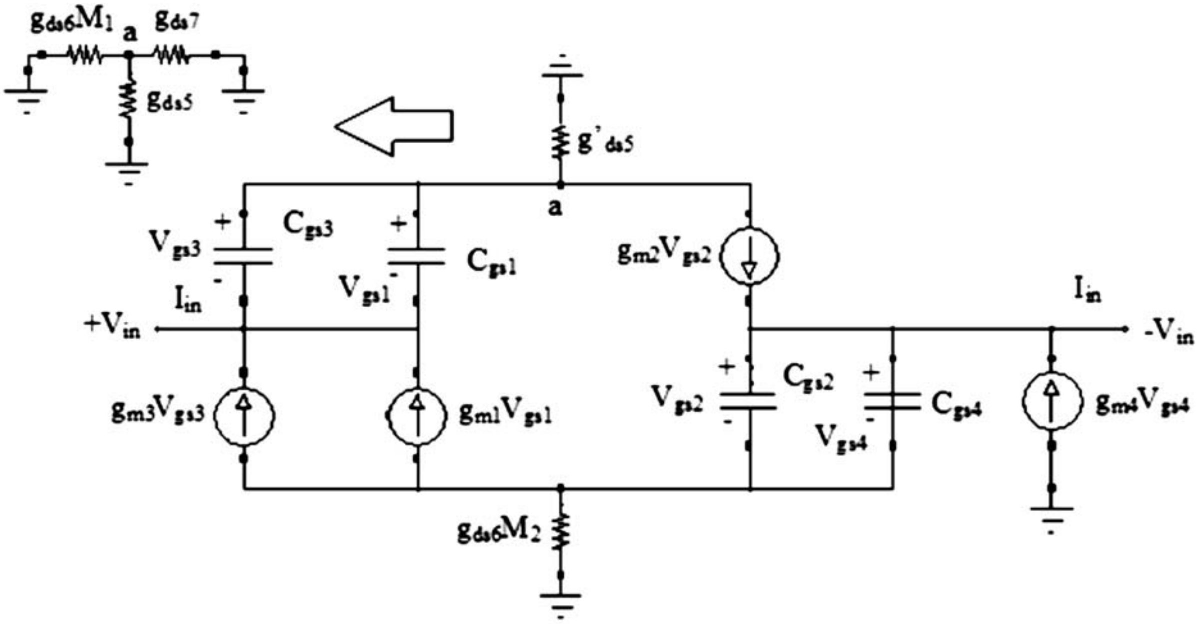
$$g_{ds6}M_2 = g_{ds6}\frac{K}{1 - K} \tag{5}$$

The Miller constant K is expressed as:

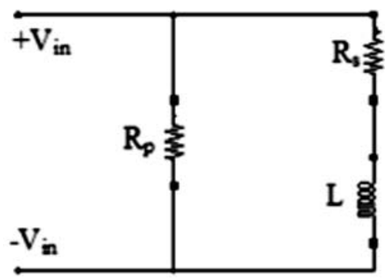
$$K = \frac{V_2}{V_1} \tag{6}$$

From (2), it is observed that the equivalent inductance depends on the circuit parameters including C_{gs1}, C_{gs3}, g_{m1}, g_{m3} and g'_{ds5}. An effective way for the inductance tuning is to manipulate the drain conductance by the gate voltage [11]. Therefore, V_b and V_{bb} can be used as the control mechanism for the tunable active inductor.

Fig.3. (*a*) shows a floating node voltage controlled linear variable resistor circuit, which is used as active element in the circuit of second order low pass filter [12] [13].



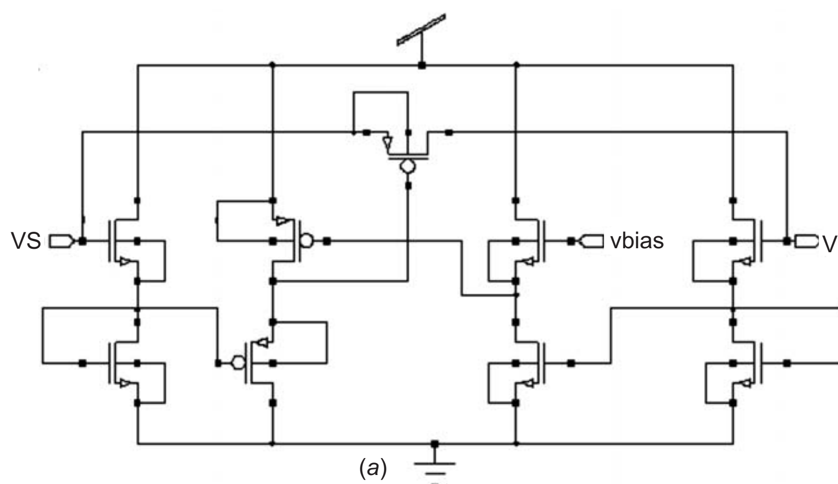
(*a*)



(*b*)

Figure 2: (*a*) Small signal model of proposed active inductor, (*b*) Equivalent circuit of proposed active inductor

Active elements resistor shown in fig. 3.(*a*) and proposed inductor shown in fig. 1. are used in the RLC low pass filter scheme shown in fig. 3. (*b*). Fig.4. Shows the schematic of second order low pass filter that was designed with conventional active inductor and floating node variable resistor.



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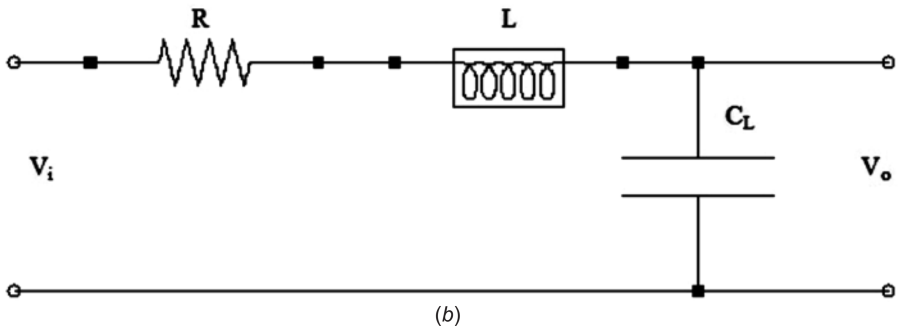


Figure 3: (*a*) Floating node voltage-controlled linear variable resistor; (*b*) RLC low pass filter scheme

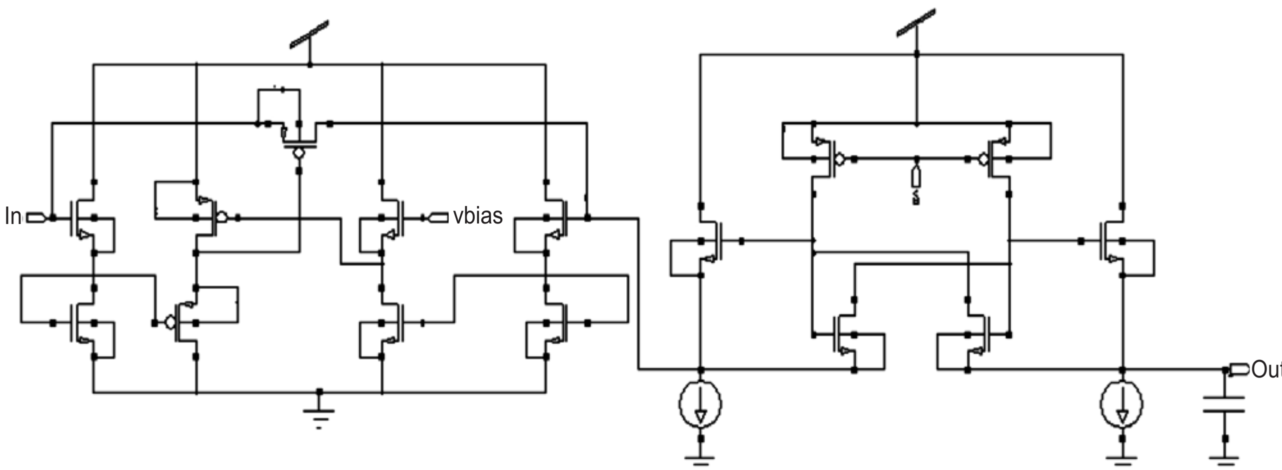


Figure 4: Second order RLC low pass filter with conventional inductor

Proposed active inductor and floating node variable resistor are used in the schematic of the second order low pass filter shown in fig. 5.

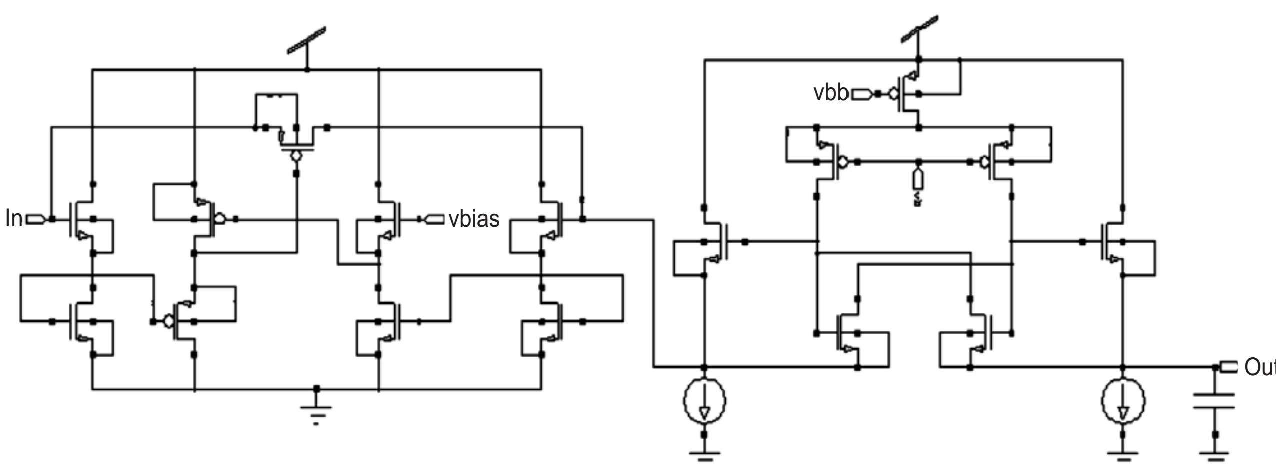


Figure 5: Second order RLC low pass filter with proposed inductor

3. SIMULATIONS AND COMPARISON

The proposed inductor and floating node voltage controlled linear variable resistor circuit is used in the structure of the second order RLC low pass filter as shown in fig. 3. (*b*). The proposed and conventional circuits were simulated using TSPICE; the circuit was realized by CMOS implementation in using 0.5 µm CMOS technology process parameters. The power supplies are selected as $V_{dd} = 2.5$, $V_{bb} = V_b = 2.05V$. Fig. 6. shows the frequency response of proposed second order RLC low pass filter.

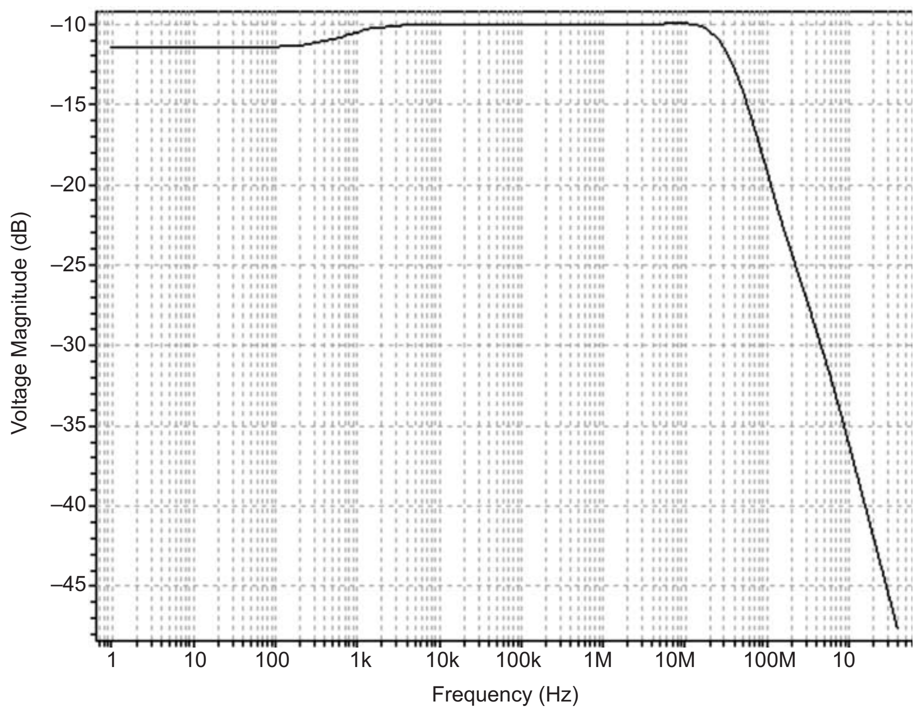
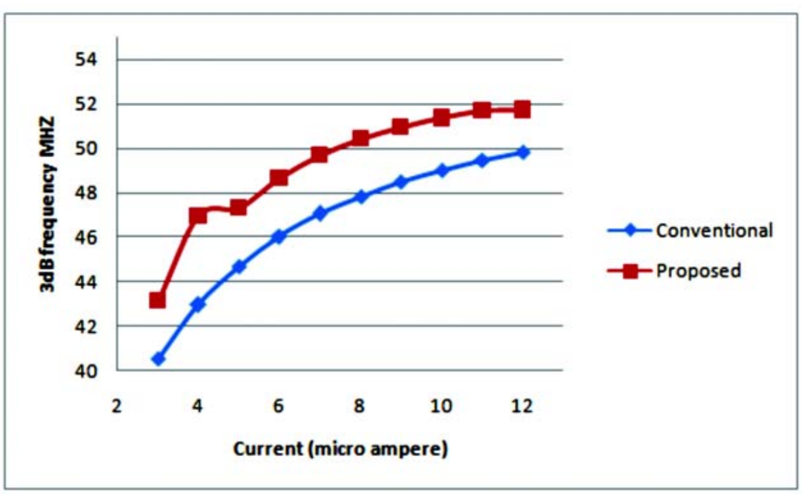
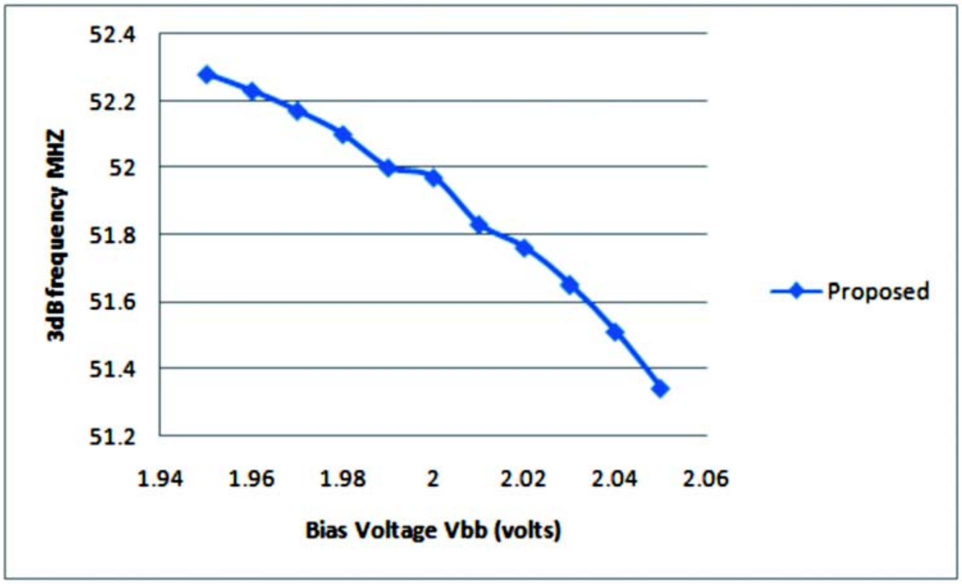


Figure 6: Frequency response of second RLC low filter with proposed active inductor

Different cut off frequencies has been observed with the variations of current fig. 7. (a) shows the variations in 3db frequency with the change in current. These figures reveal that as the value of simulated inductance increases, the cut-off frequency of the low pass filter becomes sharper which results in the better performance.



(*a*)



(*b*)

Figure 7: (*a*) Variation in 3dB frequency with current of second RLC low pass filter with proposed active inductor; (*b*) Variation in 3dB frequency with bias voltage Vbb of second RLC low pass filter with proposed active inductor

Fig. 7. (*b*) Shows the graph variation in 3dB frequency with bias voltage V_{bb} of second RLC low pass filter with proposed active inductor. It can be seen that the proposed floating inductor can be employed instead of conventional if we are using CMOS technology.

4. CONCLUSIONS

In this paper, the simulation has been carried out on Tanner EDA tool 13.0 on 0.5μm technology. The proposed inductor and floating node voltage controlled linear variable resistor circuit is used in the structure of the second order RLC low pass filter is presented which increases the cut off frequency. Proposed active inductor circuit is designed by using CMOS technology with two current sources and bias voltage V_{bb}. The 3-dB frequency obtained are related with bias current which is due to suited value of floating inductance of the filter, by varying the bias current inductance can be varied. The proposed active inductor is used for implementation of a low pass filter with high cut off frequency.

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