Design and analysis of differential floating inductor for filter

Suman Nehra  
Department of Electronics and Communication Engineering  
College of Engineering and Technology  
Mody University of Science and Technology, Lakshmangarh  
Lakshmangarh, INDIA  
nehra.sumanvlsi@gmail.com

P. K. Ghosh  
Department of Electronics and Communication Engineering  
College of Engineering and Technology  
Mody University of Science and Technology, Lakshmangarh  
Lakshmangarh, INDIA  
pkghosh.ece@gmail.com

Er. Priyanka Soni  
Junior Engineer  
Jd. V. V. N. L  
Bikaner, INDIA  
priyankamec@gmail.com

Abstract— This paper presents a technique for circuit implementation of active inductor, based on the use of Complementary Metal Oxide Semiconductor (CMOS) technology as an active element and current source. The spiral inductor occupies a large chip size and is difficult to obtain a high value of cut off frequency. The proposed active inductor is used for implementing a low pass filter with high cut off frequency. The resulting inductance can be electronically tuned by varying the circuit current accordingly. The simulation has been carried out on Tanner EDA tool 13.0 on 0.5 μm technology.

Keywords—Floating inductor, active inductor, CMOS, cut off frequency, low pass filter.

I. INTRODUCTION

An inductor is an important circuit element and can be used in many blocks such as filters, oscillators, phase shifters and impedance matching circuits. Indeed, there is a critical need for inductive characteristics in high-speed applications [1].

Active inductors are found to be applicable in many microelectronic applications such as telecommunication instruments, measuring instruments, analog and mixed signal filters and medical instruments etc [2]. They are preferable over their spiral wound passive inductor which is too bulky, expensive and incapable to operate at the moderate frequency range (KHz and MHz ranges) without offering any signal loss [3]. An on-chip passive inductor also presents major disadvantages such as large silicon area, limited inductance value and quality factor [4].

Implementation of inductors with active elements, offers several attractive advantages over their spiral counterparts that include large and tunable inductance and low silicon consumption [5]. Using the active inductor the low pass filter can be designed with higher cut off frequency [6]. Simulation results verified that proposed design has good performances compared to conventional designs.

This paper is organized as follows. In Section II, we briefly present the description of the theory of filters. In section III, the circuitry of proposed inductor is discussed. Section IV presents the experimental results and we draw the conclusions in Section V.

II. FILTER

Filter is a type of device or electronic circuitry that allows only specific signals or frequencies to pass through it but rejects or distinguishes the unwanted signals or frequencies [7]. A filter is an electrical network that alters the amplitude and/or phase characteristics of a signal with respect to frequency as depicted in figure 1.

![Filter Diagram](image)

Figure 1: Using a filter to reduce the effect of an undesired signal at frequency $f_2$, while retaining desired signal at frequency $f_1$.

Ideally, a filter will not add new frequencies to the input signal, nor will it change the component frequencies of that signal, but it will change the relative amplitudes of the various frequency components and/or their phase relationships. Filters are often used in electronic systems to emphasize signals in certain frequency ranges and reject signals in other frequency ranges. Such a filter has a gain which is dependent on signal frequency. As an example, consider a situation where a useful signal at frequency $f_1$ has been contaminated with an unwanted signal at $f_2$. If the contaminated signal is passed through a circuit as shown in figure 1 that has very low gain at...
Compared to that at $f_1$, the undesired signal can be removed, and the useful signal will remain. Note that in the case of this simple example, we are not concerned with the gain of the filter at any frequency other than $f_1$ and $f_2$. As long as $f_2$ is sufficiently attenuated relative to $f_1$, the performance of this filter will be satisfactory. In general, however, a filter's gain may be specified at several different frequencies, or over a band of frequencies.

## III. CIRCUIT DESCRIPTION

In the schematic of the proposed active inductor is shown in Figure 2.

The active inductor proposed by Lu et al. is chosen as a conventional circuitry [8]. It is a differentially configured gyrator-C active inductor in a simplest geometry [9] [10].

As shown in Figure 2 the circuit is with 7 transistors which include 4 NMOS from M1 to M4 and 3 PMOS from M5 to M7. From a dc point-of-view, M1 and M6 form a cross-coupled pair, while M3 and M4 are in the common-drain configuration. Figure 3 (a) shows the simplified small-signal equivalent circuit of the active inductor and figure 3(b) shows the equivalent impedance circuit of active inductor. Hence, a small-signal analysis is performed to characterize the behavior of the differential active inductor M1 to M7.

The above circuit works as an inductor at the input voltage $V_{in}$. At the quiescent bias point, it is obvious that transistors M1 to M4 are saturated. Transistors M5, M6 and M7 can operate either in the saturation region or in the triode region, depending on the controlled voltages $V_s$ and $V_{bb}$ at the gates. Therefore M5, M6 and M7 are modeled as $g_{ds5}$, $g_{ds6}$ and $g_{ds7}$ representing the drain conductance at the associated bias points.

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:

$$Z_{in} = \frac{v_{in}}{i_{in}} = \frac{[j\omega (C_{gss1} + C_{gss3}) - g_{m1} + g_{ds}]}{g_{ds5} [g_{m1} + g_{m3} + j\omega (C_{gss1} + C_{gss3})]} \quad (1)$$

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

$$L_{eq} = \frac{g_{ds5} (C_{gss1} + C_{gss3})}{2g_{m1} + g_{m3} - g_{ds5}} \quad (2)$$
where $g'_{ds5}$ is expressed as:

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

where $g_{ds6}M_1$ and $g_{ds6}M_2$ are given as:

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

And

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

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.

IV. EXPERIMENTAL RESULT

To demonstrate the electronically variable properties of inductor, the capacitance $C_L$ of fig.4 is chosen to be 0.05pf, resistance 200Ω and bias currents $I_{B1}$ and $I_{B2}$ (wide fig.2) are set to 10 μA. The proposed inductor is used in the structure of the RLC low pass filter as shown in figure 4.

![Figure 4: RLC low pass filter scheme](image)

The proposed circuit was 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 $V_{DD} = 2.5$, $V_{IL} = V_{bb} = 2.0V$.

![Figure 5: Frequency response of RLC filter with proposed active inductor](image)

Figure 5 shows the plot of frequency response of RLC low pass filter by using proposed active inductor.

Different cut off frequencies has been observed with the variations of current figure 6 shows the variations in 3db frequency with the change in current.

![Figure 6: Variation in 3dB frequency with current](image)

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. It can be seen that the proposed floating inductor can be employed instead of conventional if we are using CMOS technology.
V. CONCLUSION

In this paper, a new active inductor is presented which increases the cut off frequency. Proposed circuit is designed by using CMOS technology with two current sources.

The proposed active inductor is used for implementation of a low pass filter with high cut off frequency. The resulting inductance can be electronically tuned by varying current. The simulation has been carried out on Tanner EDA tool 13.0 on 0.5μm technology.

ACKNOWLEDGMENT

The authors Suman Nehra and P. K. Ghosh thankfully acknowledge the authority of College of Engineering and Technology, Mody University of Science and Technology, Lakshmangarh for providing the opportunity to use the resources of the Institute.

REFERENCES


