A NOVEL ACTIVE INDUCTOR WITH VOLTAGE CONTROLLED QUALITY FACTOR AND SELF-RESONANT FREQUENCY

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Abstract. In this paper, a novel CMOS differential active inductor with self-resonant frequency and quality factor tuning is presented. Based on a current reuse technique, the proposed active inductor has two additional MOS transistors. Both transistors are used for enhancing and actively modifying the quality factor of the active inductor. The self-resonant frequency of the active inductor can be also modified through a variable current mirror.

Key words: active inductor; quality factor; self-resonant frequency; voltage control.

1. Introduction

An important advantage of active inductors compared to passive ones is tunability. In other words, the quality factor or the self-resonant frequency of an active inductor can be modified and their values controlled by electrical signals. An active inductor can be implemented using two main concepts (Yuan, 2008; Bakken & Choma, 2003): gyrator-C or transistor only simulated inductors. Gyrator-C active inductors are usually designed for low-frequency

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applications because of the limitations imposed by the use of the operational transconductance amplifiers in the gyrator-C structure and the simulated inductance is obtained through an external capacitor. Transistor only simulated inductor concept is a variation which uses the parasitic capacitances of the transistors to simulate inductors, the necessity of using an external capacitor being eliminated. Transistor only simulated inductors (TOSI) can be designed in CMOS technology to overcome the frequency limitations of the gyrator-C concept, being able to function at GHz frequencies. Several TOSI structures designed in CMOS technology have been reported in (Andriesei, 2010, Andriesei & Goraș, 2008).

In this paper a novel TOSI structure inspired from the above mentioned references is presented.

2. Structure of the Differential Active Inductor

The structure of the differential active inductor including biasing circuitry (Johns & Martin, 1996) is presented in Fig.1. Transistors $M_9$, $M_{10}$, $M_{11}$ and $M_{12}$ are components of a variable current mirror. The biasing source for $M_2$ and $M_3$ is realized with a stable $g_{m}$ circuitry. It ensures more stable transistor transconductances, and thus a more stable biasing voltage for $M_2$, $M_3$, $M_5$ and $M_6$. The value of total current used by this structure is less than 3 μA which is smaller than the value of the current used by other biasing circuitry. The active inductors are composed of transistors $M_1$, $M_2$, $M_3$, $M_7$ and $M_4$, $M_5$, $M_6$ and $M_8$. Transistors $M_1$, $M_3$, $M_4$ and $M_6$ are biased in the active region. Transistors $M_2$ and $M_5$ are biased in the triode region.

3. Quality Factor of the Differential Active Inductor

Any active inductor practically behaves as a resonator (Andriesei, 2010; Andriesei & Goraș, 2008). In the case of a TOSI, there are many parasitic capacitances of the MOS transistors and finally, the architecture exhibits a parallel-like resonance.

By comparison with a passive resonator which has a fixed quality factor and self-resonant frequency determined by the values of the components, the active inductor presented in this paper is designed to allow a controlled variation of these parameters.

The PMOS transistors $M_7$ and $M_8$ have been introduced to inject currents that modify the transconductances of $M_1$ and $M_4$. These currents obviously depend on the $V_{gs}$ voltage of these transistors. As a result, the variation of these currents leads to modifications of the quality factor and self-resonant frequency which present an interdependency, meaning that a variation of one parameter is followed by the variation of the other parameter.
The value of the quality factor varies with the voltage applied at the gate of transistors \( M7 \) and \( M8 \), \( \text{Vinj} \). Thus the quality factor of the active inductor can be modified as shown in Fig 2. The quality factor of the active inductor is modified with the help of \( \text{Vinj} \) which varies from 0 to 1.5 V. The non-linear variation of quality factor can be divided into four regions. For values of \( \text{Vinj} \) between 0 and 600 mV it presents a linear zone with a slow increase of the value from 1 to 4.5. The second region is represented by values of \( \text{Vinj} \) between 600 mV and 930 mV where the quality factor presents a rapid increase of the value from 4.5 to the maximum value of 36. The third region is determined by values of \( \text{Vinj} \) between 930 mV and 1.11 V where the quality factor exhibits a rapid decrease from the maximum value to approximately 3. The fourth region is determined by values of \( \text{Vinj} \) between 1.11 V and 1.5 V where the quality factor has a very small variation and settles to a constant value of approximately 1.2.

![Diagram of the differential active inductor with biasing circuitry.](image-url)
The self-resonant frequency of the active inductor is not constant when \( V_{inj} \) varies and has the maximum value of 1.331 GHz when \( V_{inj} \) has a value of 600 mV and the quality factor has a value of 4.5, as shown in Fig. 3. When the quality factor has the maximum value of 36 the self resonant frequency has a value of approximately 1.06 GHz.

Fig. 2 – Variation of the quality factor with respect to \( V_{inj} \).

Fig. 3 – Variation of the self-resonant frequency; \( V_{inj} \) varies from 0 to 1.5 V.
From both analyses a conclusion can be drawn: the self-resonant frequency is not constant when \( V_{inj} \) is modified between 0 V and 1.5 V. The quality factor can be varied between a minimum value of 1 and a maximum value of approximately 36. The maximum value is attained when \( V_{inj} \) has a value equal to 930 mV; the self-resonant frequency is equal to 1.06 GHz.

4. Self-Resonant Frequency of the Differential Active Inductor

The self-resonant frequency of the differential active inductor can be modified by means of a variable current mirror controlled by the voltage \( v_{tosi} \) applied at the gates of the transistors \( M_{10} \) and \( M_{12} \). The value of the frequency can be varied from 272 MHz to 2.5 GHz as shown in Fig. 4.

![Fig.4 Variation of self-resonant frequency; \( v_{tosi} \) varies from 0 V to 1 V](image)

The quality factor of the active inductor is not constant when \( v_{tosi} \) varies, and has a different type of variation. The frequency response was realized with a resolution of 40 steps and it shows a maximum value for magnitude equal to approximately 250 mV at a frequency equal to 1.122 GHz. The variation of \( v_{tosi} \) in 0,…,1 V interval determines a nonlinear behavior of the quality factor and can be analyzed as follows. For values of \( v_{tosi} \) between 0 and 300 mV the quality factor has a slow increase of the value from 0 to approximately 2. Next region is represented by values of \( v_{tosi} \) situated in 300 mV - 420 mV interval where the quality factor has a rapid increase and reaches the maximum value of approximately 35. In the third region, determined by values of \( v_{tosi} \) between 420 mV and 620 mV, the quality factor has a rapid decrease from 35 to 0, as shown in Fig. 5.
The periodic steady state analysis with a current source which has an amplitude equal to 1 μA, and a frequency equal to 1.122 GHz shows that the differential output voltage has a negligible distortion and the fundamental component has a value of 135 mV, as shown in Fig. 6.

Fig. 5 – Variation of quality factor; $v_{tosi}$ varies from 0 V to 1 V.

Fig. 6 – PSS analysis of the differential active inductor: $a$ – time; $b$ – spectrum.
5. Conclusions

In this paper a novel differential active inductor with self-resonant frequency and quality factor tuning is presented. It was demonstrated that the quality factor can be modified between 1 and approximately 36. The self-resonant frequency of the active inductor can be modified with certain constraints regarding the quality factor and the voltage swing with negligible distortion is very good.

REFERENCES


O NOUĂ INDUCTANŢĂ ACTIVĂ CU FACTOR DE CALITATE ȘI FREQVENTĂ DE REZONANŢĂ PROPRIE CONTROLEATE ÎN TENSIUNE

(Rezumat)

Se prezintă o nouă structură de inductanţă activă cu factor de calitate şi frecvenţă de rezonanţă proprie modificabile prin intermediul unor tensiuni. Pentru îmbunătăţirea factorului de calitate şi respectiv pentru modificarea acestuia au fost introduse două tranzistoare suplimentare. Frecvenţa proprie de rezonanţă poate fi modificată cu unele constrângeri în ceea ce priveşte factorul de calitate şi este controlată de tensiunea aplicată pe grila unui tranzistor ce intră în componenţa oglindii variabile de curent. Tensiunea diferenţială de ieşire nu este distorsionată şi are o amplitudine relativ mare.