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Impact of Temperature Variation on Resonant Frequency of Active Grounded Inductor-based Bandpass Filter

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Abstract

Objective: This paper proposes an electronically tunable active grounded inductor circuit using VDVTA as a new active element. The circuit can replace spiral passive inductors for all Analog Signal Processing and data communications operations. **Method/Analysis:** The impact of temperature variation on its resonant frequency is investigated using Virtuoso Analog Design Environment of Cadence @ 45-nm CMOS technology node. **Findings:** This paper carries out a study on CMOS realization of Voltage Differencing Voltage Transconductance Amplifier (VDVTA) and its application as an active grounded inductor. A Bandpass filter circuit is realized using the VDVTA based grounded inductor. Furthermore, the impact of temperature variation on the response of the bandpass filter is analyzed and presented. **Novelty/Improvement:** The proposed circuit uses only active elements and a grounded capacitor. Due to this, the circuit finds applications in all canonical operations and integrated circuit implementations.

Keywords: Active Inductor, Bandpass Filter, Volatge Differencing Voltage Transconductance Amplifier (VDVTA)

1. Introduction

There is a wide range of applications of CMOS spiral inductors in high speed Analog Signal Processing and data communications. The limitations of these spiral inductors include a low-quality factor, a small and non-tunable inductance, a low self-resonant frequency and the need for a large silicon area[1]. The passive spiral inductors also cannot scale with the process technology. However, the active inductors have a large tunable quality factor, large tunable inductance and high self-resonant frequency. The cost of production of active inductors are also too less and they are fully compatible with digital CMOS technologies. Hence, realization of active inductor has become a popular research topic in research community to aid design engineer.

Several circuit topologies of various active elements such as operational amplifiers[2–4], current feedback operational amplifier (CFOA)[5,6], voltage differencing buffered amplifiers (VDBA)[7], current conveyor (CCI)[8], current differencing transconductance amplifier (CDTA)[9] were proposed in the literature for realizing active inductor circuits. But these circuits suffer from one or more problems use of external passive resistors, need of some floating passive components, cannot be tuned electronically, etc. In this paper, a new active element namely voltage differencing voltage transconductance amplifier (VDVTA) is used as a building block for realizing active grounded inductor[10–12]. VDVTA consists of a current source controlled by the different of two input voltages and a multiple output amplifier which provides electronic tunability by varying its transconductance gain.

VLSI circuits often operate at elevated temperature due to heat generation. Moreover, the temperature of VLSI chip does not remain same throughout entire chip. Hot-spots are found to exist due to variation in activity. The circuit block which is more active gets heated and its temperature is raised generating hot-spot. Due to

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generation of hot-spot and variation of temperature, the circuit behavior varies. In an integrated circuit, billions of chips exist. If the performance of chip varies, then the entire integrated circuit performs poorly. This paper investigates the impact of temperature variation on circuit response when VDVTA is used as grounded inductor for realizing bandpass filter.

2. CMOS Realization of Voltage Differencing Voltage Transconductance Amplifier

A symbolic representation of VDVTA is shown in Figure 1. VDVTA contains p, n, v as high impedance input terminals and z, x^+, x^- as high impedance output terminals. VDVTA is characterized by the following matrix:

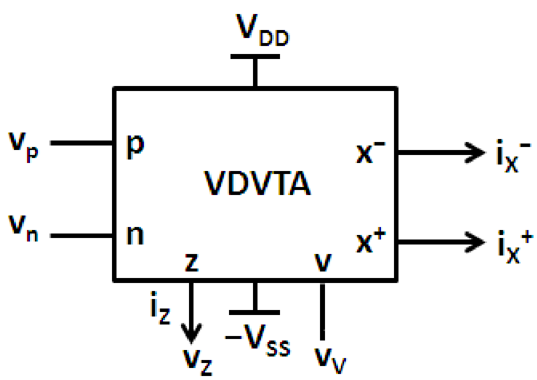

Figure 1. Voltage differencing voltage transconductance amplifier (VDVTA) block diagram.

$$\begin{bmatrix} i_z \\ i_{x^+} \\ i_{x^-} \end{bmatrix} = \begin{bmatrix} g_{m_1} & -g_{m_1} & 0 \\ 0 & 0 & g_{m_2} \\ 0 & 0 & -g_{m_2} \end{bmatrix} \begin{bmatrix} v_p \\ v_n \\ v_z - v_v \end{bmatrix} \quad (1)$$

The port equations obtained from the aforementioned matrix are

$$i_z = g_{m_1}\left(v_p - v_n\right), \quad (2)$$

$$i_{x^+} = g_{m_2}\left(v_z - v_v\right) \quad (3)$$

$$i_{x^-} = -g_{m_2}\left(v_z - v_v\right). \quad (4)$$

where, gm_1 and gm_2 are the two Arbel-Goldminz transconductances (AGTs) given in[13].

Figure 2 represents a CMOS realization of VDVTA with the terminal 'v' grounded[13]. AGT-I and AGT-II denote positive and negative transconductances respectively.

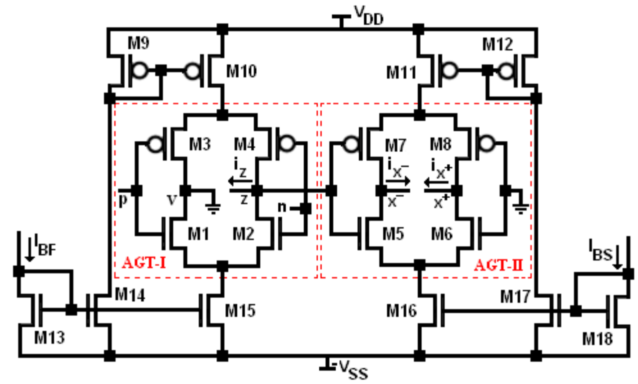

Figure 2. CMOS realization of a voltage differencing voltage transconductance amplifier (VDVTA).

3. Application of VDVTA as Grounded Inductor

VDVTA based grounded inductor circuit is shown in Figure 3. It consists of one VDVTA and a capacitor (C_1). Based on equations obtained from (2-4) and approximating we get the Input Impedance (Z_{in}) of the circuit as:

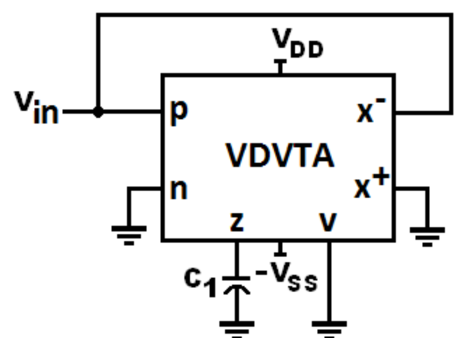

Figure 3. Voltage differencing voltage transconductance amplifier (VDVTA) based grounded inductor.

$$Z_{in} = \frac{sC_1}{g_{m_1} g_{m_2}}. \quad (5)$$

The equivalent input impedance of the grounded inductor is

$$Z_{in} = sL_{eq}. \tag{6}$$

Comparing (5) with (6), the equivalent inductance is found to be

$$L_{eq} = \frac{C_1}{g_{m_1} g_{m_2}}. \tag{7}$$

The inductor obtained from Figure 3 is electronically tunable with both gm_1 and gm_2.

4. Application of VDVTA as Bandpass Filter

The working of the proposed inductor was verified by employing it in a bandpass filter. The bandpass filter circuit realized with VDVTA is shown in Figure 4.

Let the equivalent inductance of the VDVTA configuration is given by 'L'. The expression of resonant frequency of the bandpass filter circuit is given by

$$\omega = \frac{1}{\sqrt{LC}} \tag{8}$$

$$\omega = \sqrt{\frac{g_{m_1} g_{m_2}}{C_1 C_2}} \tag{9}$$

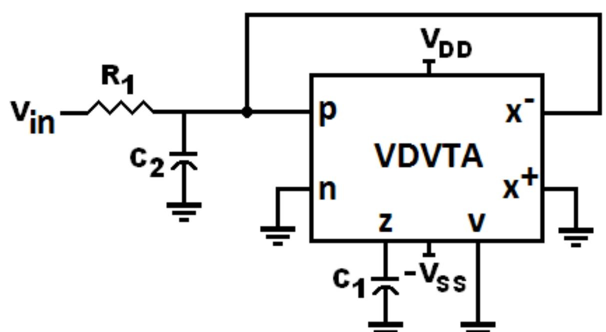

Figure 4. Bandpass filter circuit realized with voltage differencing voltage transconductance amplifier (VDVTA).

4. Results and Discussion

This section presents the AC analysis of bandpass filter which is designed using grounded inductor. The grounded inductor in turn is realized employing voltage differencing voltage transconductance amplifier (VDVTA). The analysis is carried out at different temperatures.

5.1 Variation of Input Impedance of Voltage Differencing Voltage Transconductance Amplifier based Active Grounded Inductor with Frequency

All the simulations in this work were performed using 45-nm industrial CMOS process technology with dual supply of ±0.9 V. Virtuoso Analog Design Environment of Cadence was used as a simulation tool. Figure 5 shows the input impedance versus frequency plot of the proposed active inductor circuit using VDVTA configuration. The simulated active inductance value was found to be 8.5μH. As expected the input impedance of the inductor varies linearly with frequency.

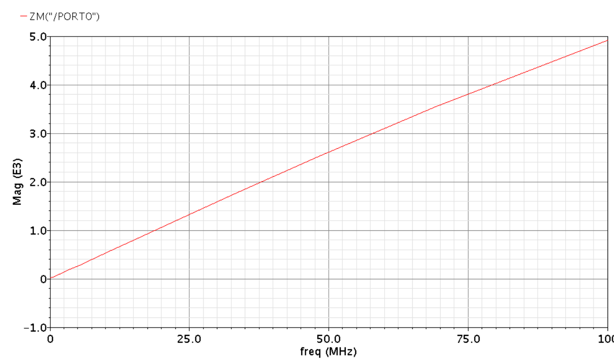

Figure 5. Simulation results showing input impedance variation with frequency.

5.2 Impact of Temperature Variation on Resonant Frequency of Bandpass Filter

The carrier mobility μ_n, and the threshold voltage V_T decrease with temperature. Temperature dependence of V_T is expressed as

$$V_T(T) = V_T(T_0) + \alpha_{V_T}(T - T_0) \tag{10}$$

Where T_0 is the reference temperature and α_{V_T} is a negative constant.

Temperature dependence of mobility is given by

$$\mu_n(T) = \mu_n(T_0)\left(\frac{T}{T_0}\right)^{\alpha_\mu}. \tag{11}$$

It is observed that the effect of decrease in mobility with temperature dominates and thus the transconductance of a MOSFET decreases with increase in temperature[14].

To verify the temperature dependence of resonant frequency of the bandpass filter circuit, extensive simulations on Virtuoso Analog Design Environment of

Cadence using 45-nm Technology Model are performed. The response of the bandpass filter is analyzed at three different temperatures to observe the departure of resonant frequency from the theoretical values. They are 27°C (room temperature), 40°C, 80°C and 120°C shown in Figure 6. The simulation results are tabulated in Table 1. It is observed that the resonant frequency shifts towards lower frequencies as the temperature increases. This is attributed to the fact that the transconductance of a MOSFET decreases with increase in temperature due to the dominant effect of mobility.

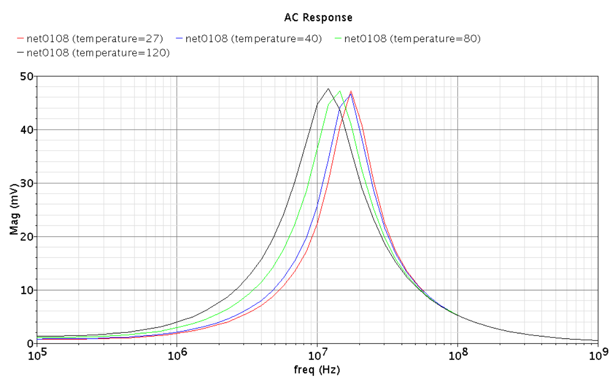

Figure 6. Variation of resonant frequency of Bandpass Filter with temperature. The graph shows decrease of resonant frequency with increase in temperature. It shows fr = 17.37 MHz @ 27°C, fr = 16.5 MHz @ 40°C, fr = 13.99 MHz @ 80°C and fr = 12.023 MHz @ 120°C.

Table 1. Resonant frequency values at various temperatures

Temperature(in °C)	27	40	80	120
Resonant Frequency(in MHz)	17.37	16.5	13.99	12.023

6. Conclusion

An electronically-controllable active grounded inductor circuit was designed based on the voltage differencing voltage transconductance amplifier (VDVTA) configuration using Virtuoso Analog Design Environment of Cadence. Temperature variability analysis was performed to observe the temperature dependence of resonant frequency of the bandpass filter designed using VDVTA based active grounded inductor. The resonant frequency of the active grounded inductor can be electronically tuned. At higher frequencies, the active inductor is subjected to various parasitic effects. The active inductor circuit finds its application in high-speed analog signal processing and data communication systems.

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