CMOS Digitally Programmable Lossless Floating Inductor

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Abstract— **A CMOS digitally programmable lossless floating inductor is proposed. The proposed inductor is based on current conveyors and resistor array to provide digital tuning of the inductance value. The presented block realizes a programmable floating inductor tuned from 0.42763 mH to 5.67 mH. As an application for the proposed circuit a resonant circuit and low pass filter have been realized using the digital programmable circuit. The simulation results have been demonstrated and discussed using a SPICE simulation for 0.25 µm TSMC CMOS technology and supply voltages ±1.5 V.**

Keywords- CCII, Digitally programmable, Floating inductor, Resonator.

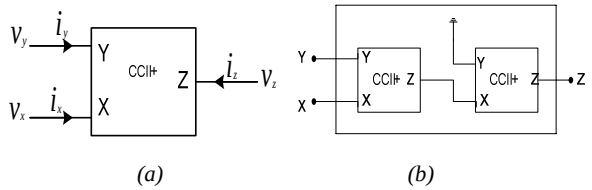
I. INTRODUCTION

It is a well known fact that inductors are not desirable in the integrated circuits fabrication; lots of active realizations are introduced for floating and grounded inductor using various high performance active building blocks, such as, current conveyor, current feedback op-amp and operational transconductance amplifier [1-11]. The inductance simulators can be used in many applications such as active filter design, oscillator design, analog phase shifters and cancellation of parasitic elements.

The most famous active inductor realization was proposed in [1] and utilizes two op-amps and five passive elements. However using current conveyor as an active element instead of op-amps has many advantages such as greater linearity, wider band width and better dynamic range compared to op-amps. Active realization of floating inductance using second generation current conveyor is introduced in [2-5].

In this paper, digitally programmable lossless floating inductor realization based on second generation current conveyor [6-8] (CCII) and resistor array will be proposed. PSPICE simulation results are included to confirm the presented theory. Also, the performance of the proposed Inductor realization is applied on a series RLC resonance circuit and a 5th order Chebyshev low pass filter which can be used in various applications.

The paper is organized as follows section I introduction, Section II presents the CMOS second generation current conveyor, Section III Illustrates the digitally programmable lossless floating inductor simulator, Section IV discuss the non-idealities effects, Section V introduce some applications of the digitally programmable block and finally section VI drawn the conclusion.



(a) *(b)*

Figure 1. Symbol diagram (a) CCII+, (b) CCII-

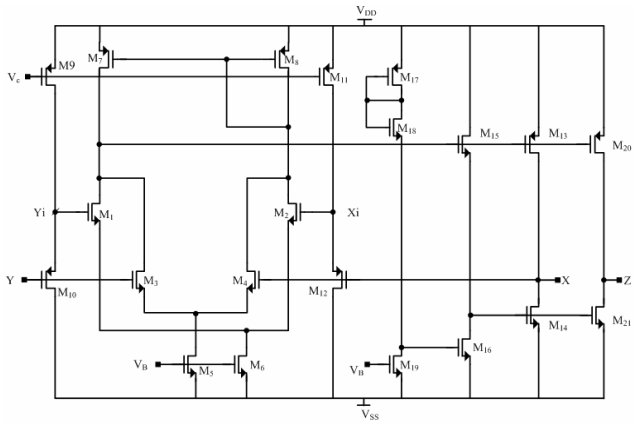


Figure 2. A CMOS implementation of the CCII+ [12].

II. SECOND GENERATION CURRENT CONVEYOR (CCII±)[6-8]

The second generation current conveyor (CCII±) is a three port network with terminal characteristics described by the following matrix:

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & k & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \qquad (1)$$

Where v_x , v_y , v_z and i_x , i_y , i_z are voltages and currents of x-,y- and z-terminals respectively. The current gain equals 1 for CCII+ and -1 for CCII-. The Y terminal has high input impedance while the X terminal has low input impedance. The basic building block of CCII is shown in Fig.1 while Fig.2 shows the CMOS implementation of the CCII+ block given in [12].

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III. DIGITALLY PROGRAMMABLE FLOATING INDUCTOR

The circuit as shown in Fig.3 [9] uses four CCII±, grounded capacitor and two resistors to realize a floating inductor. The admittance matrix can be written as in eqn. (2):

$$[Y] = \frac{1}{CR_1R_2}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \quad (2)$$

The equivalent inductance can be represented as in eqn. (3):

$$L_{equ} = CR_1R_2 \quad (3)$$

The active inductor realization shown in Fig.3 [9] has been modified to be digitally tuned by replacing resistor R_1 by array of resistors and controlled NMOS switches as shown in Fig.4. Each branch contains different resistor value and NMOS transistor acts as a switch. The resistor value is divided into two identical values around the switch to decrease the loading effect of CCII.

Depending on the applied voltage on switch gate the switch is on or off and as well the resistor is connected or not and that is determined logically through values of b_i which is integer may take value of 0 or 1 where i=0,1,2,3, 4.

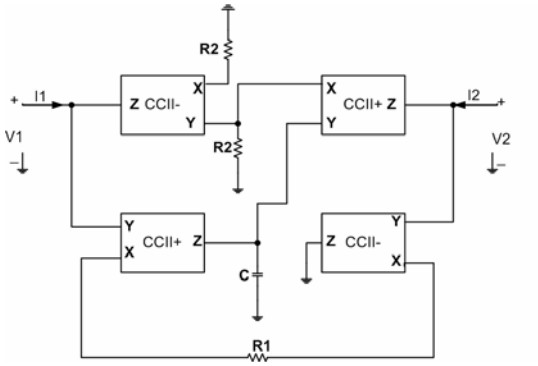

Figure 3. Floating inductor realization [9].

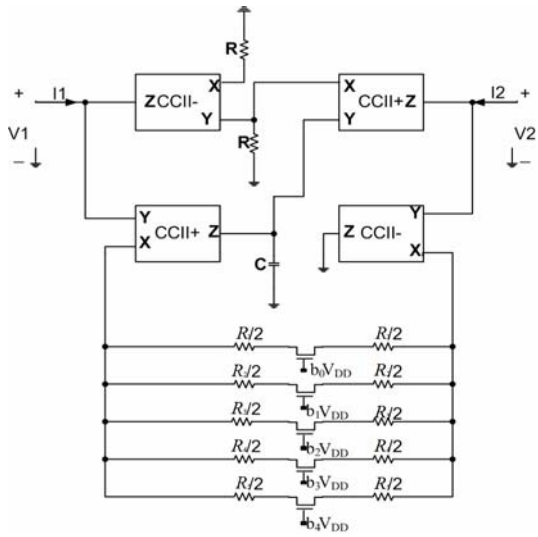

Figure 4. Digitally programmable Inductor realization

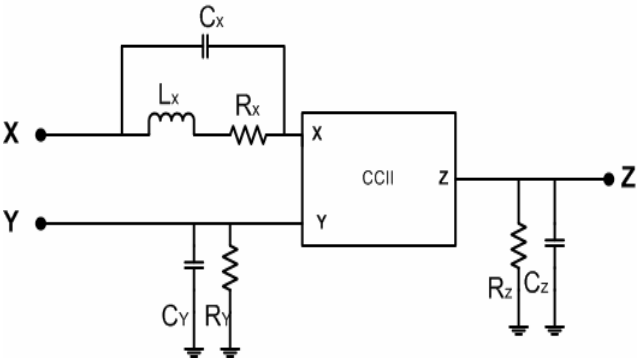

Figure 5. Non idealities of CCII [10]

IV. NON IDEALITIES EFFECTS

Taking into consideration non ideality effect of current conveyors due to the presence of the parasitic elements, these parasitic elements are commonly modeled by three impedances Z_x, Z_y and Z_z as shown in Fig. 5 [10]. Among these parasitic elements R_x is the most dominant one that affects the CCII performance, in the used CCII $R_x \leq 7\Omega$ [8] its effect won't be so obvious in the applied resistor array.

V. APPLICATIONS AND SIMULATION RESULTS

In this section the proposed digitally programmable inductor realization is used to implement a programmable resonator circuit and a programmable low pass filter.

A. Programmable resonator

The RLC series resonance circuit shown in Fig.6 with center frequency 159 KHz has been simulated using floating inductor realization shown in Fig. 4. The floating inductor circuit is realized with the following values R= 1KΩ, R_1= 100K Ω, R_2=50K Ω, R_3=25K Ω, R_4=12.5K Ω, R_5=6.25KΩ and C=100pF. Fig.7 shows the actual inductor response relative to ideal. Varying resonator frequencies by using tunable inductor realization shown in Fig.4. Table1 contain the different values of simulated inductance and its corresponding resistor array values.Fig.8 shows simulation results for different frequencies. It can be used as a tunable band pass filter.

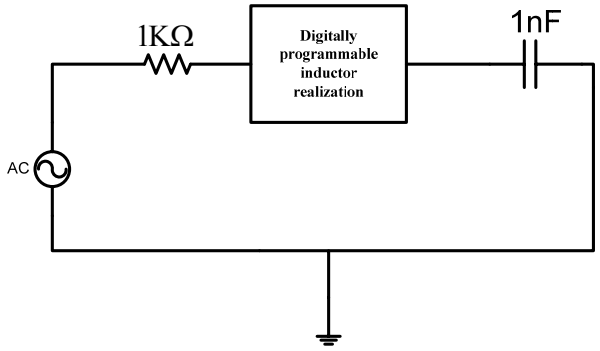

Figure 6. Passive circuit for a resonator.

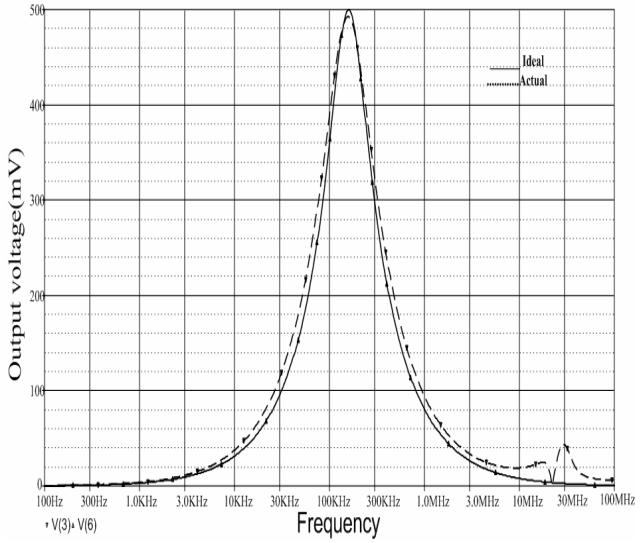

Figure 7. Ideal and actual frequency response of output voltage for the resonator circuit.

TABLE I. THE TUNABLE INDUCTOR VALUES USED IN RESONATOR CIRCUIT.

Inductance value (mH)	Frequency (KHz)	b's values				
		b_0	b_1	b_2	b_3	b_4
3.333	87	1	1	0	0	0
1.67	123	0	1	1	0	0
0.714	188	0	1	1	1	0
0.4276	243	0	0	0	1	1

The active inductor realization is simulated using SPICE based on 0.25 μ m TSMC CMOS technology parameters. The aspect ratios of transistors are given in Table 3. The current conveyor (CCII-) realizations are simulated by using the schematic implementation shown in Fig.2 and aspect ratios given in Table II together with the MOS switch aspect ratio .

TABLE II. ASPECT RATIOS OF CIRCUIT IN FIG. 2

Transistor	W (μm) / L (μm)
M1- M4	320/5.25
M5 , M6	5.25/0.25
M19 , M18	120/3.25
M15 , M16	4/3.25
M14 , M21	120/3.25
M7 , M8	115/1
M9 - M12	140/1.25
M13 , M17, M20	290/3.25
M Switch	50/0.25

B. Programmable low pass filter

A 5th order Chebyshev low pass filter with cutoff frequency 1 MHz and the pass-band ripple is 1dB is shown in Fig.9 [11]. It can be used in many applications such as Medium waveband radio broadcasts, Non-directional navigational radio beacons (NDBs) for maritime and aircraft navigation. It has been simulated using the floating inductor realization shown in Fig.4. Fig.10 shows the actual inductor response relative to ideal response. Taking the values of the resistors as in section A and the capacitance C= 170pF. Varying inductor value relative to Table III the filter cutoff frequency will be changed as well. Fig. 11 shows the response of filter due to the cutoff frequency changes.

TABLE III. INDUCTOR VALUES USED IN LADDER LOW PASS FILTER

Inductance value (mH)	b's values				
	b_0	b_1	b_2	b_3	b_4
5.67	1	1	0	0	0
2.83	0	1	1	0	0
1.89	1	1	1	1	0
1.13	0	0	0	1	1

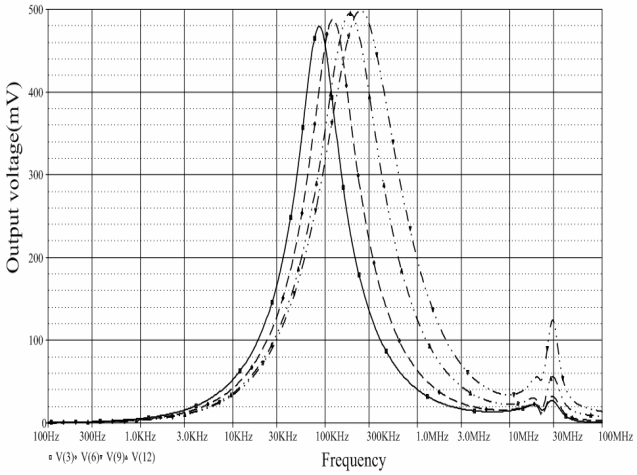

Figure 8. Frequency response of output voltage for different center frequency of the resonator circuit 87, 123, 188 and 243 KHz.

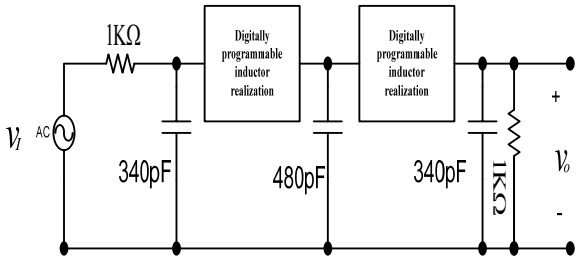

Figure 9. Fifth order Chebyshev low pass Ladder filter [11].

VI. CONCLUSION

In this paper, a CMOS digitally programmable floating inductor based on CCIIs, NMOS switches and a resistor array has been proposed. As an application of the proposed inductor, a resonator circuit and a low pass filter have been designed and realized. Non ideality effects have been studied on the performance of the inductor. SPICE simulation has been done to verify the usefulness of the proposed tunable floating inductor realization in the building active filter implementations. The proposed inductor simulator is expected to be useful in designing of analog signal processing applications.

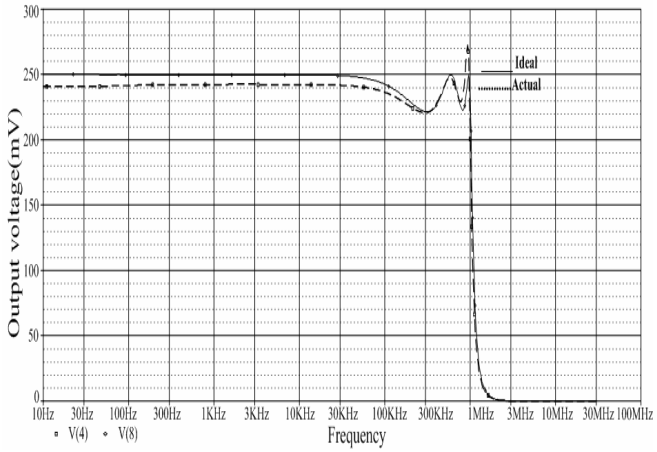

Figure 10. Ideal and actual frequency response of output voltage for the filter circuit.

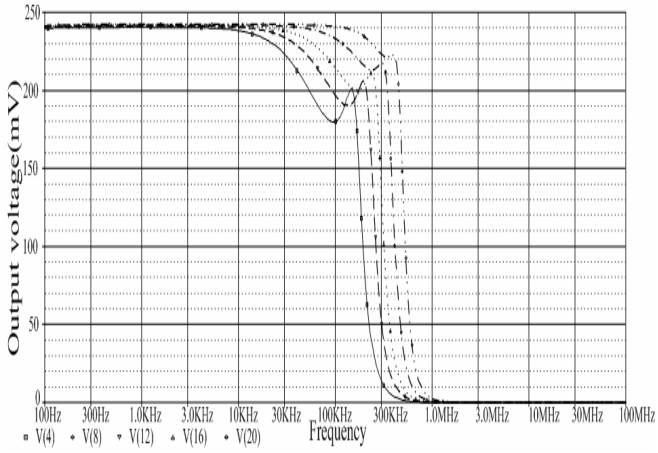

Figure 11. Frequency response of output voltage for different cut off frequency of the filter circuit 150, 196, 240, 300, 397 KHz.

REFERENCES

[1] A. Antoniou, "Realization of gyrators using operational amplifiers, and their use in RC-active network synthesis," Proc of IET journal, vol.116, no. 11, pp.1838-1850, 1969.

[2] K. Pal "Floating inductance and FDNR using positive polarity current conveyors," Active and Passive Electronic Comp Journal, vol.33, no. 21, pp. 81–83, 2004.

[3] W. Kiranon and P. Pawarangkoon, "Floating inductance simulation based on current conveyors," Electronics letters, vol. 27, pp. 1748-1749, 1997.

[4] F. Runovc, "Novel floating inductance using current conveyors," Electronics letters, vol.17, no. 18, 1981.

[5] H.Sedaf and C.Acar, "Simulation of resistively LC ladder filters using a new basic cell involving current conveyors", Microelectronics journal ,vol 30,pp.63-86,1999

[6] A. Sedra and K. C. Smith, "A second generation current conveyor and its applications," IEEE Trans. Circuit Theory, vol. CT-17, pp. 132–134, 1970.

[7] W.Surakampontom,V. Riewruja, K. Kumwachara and K. Dejhan, "Accurate CMOS-based current conveyors ," IEEE Tranactions on instrumentation and measurmentss,vol.40, no. 4, pp.699-702, 1991.

[8] A. H .Madian, S.A. Mahmoud and A. M. Soliman, "Low voltage CMOS fully differential current feedback amplifier with controllable 3-dB bandwidth," IEEE International conference on signal processing and communications, pp. 93-96, 2007.

[9] K. Pal "New inductance and capacitor floatation schemes using current conveyors,"Electronics letters, vol.17, no21, 1981.

[10] A.Chatterjee ,M.Fakhfakh and P.Siarry, "Design of second-generation current conveyors employing bacterial foraging optimization, " Microelectronics journal,2010

[11] M. Sagbas ,U.E. Ayten , H. Sedef and M. Koksal, " Floating immittance function simulator and its applications," Circuits Syst Signal Process, vol. 28, pp.55-63, 2008.

[12] Ahmed H. Madian, Soliman A. Mahmoud and Ahmed M. Soliman, "New 1.5V CMOS second generation current conveyor based on wide range transcondutor," *Analog Integr. Circ. Sig. Process.,* vol. 49, pp.267-297, 2006