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. Based on Differential negative impedance networks without tail current, it provides the compensation to reduce resistive loss the active inductor in certain frequency range but self-resonant frequency and quality factor tuning is to introduce. Founded on a Differential negative impedance networks technique,the proposed active inductor has additional Differential negative impedance networks. This last utilized for enhancing and actively to change the quality factor of the active inductor. The self-resonant frequency of the active inductor can be also to change below a variable current mirror. The active inductor was implemented in tsmc13rf-0.35um 3.3V CMOS technology and analyzed using SpectreRF with BSIM3V3 device models.

Index Terms—active inductor; quality factor; self-resonant frequency; voltage control.

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I. INTRODUCTION

An majeur advantage of active inductors compared to passive ones is tunability. In other words, the quality factor or/and the self-resonant frequency of an active inductor can to change and their values controlled by electrical signals. An active inductor can be implemented using two capital concepts [1], [2]: gyrator-C or transistor only simulated inductors. Gyrator-C active inductors are usually designed for low-frequency applications because of the limitations impressive by the use of the operational transconductance amplifiers in the gyrator-C structure and the simulated inductance is obtained below an external capacitor. Gyrator-C active inductors are negative feedback systems.

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 to be deformed.

Transistor only simulated inductors (TOSI) can be designed in CMOS technology to beat the frequency limitations of the gyrator-C notion, being capable to function in Ghz frequencies. Various TOSI structures modeled in CMOS technology ressources carry in [3], [4], [5].

In this work a new TOSI structure breathed from the above mentioned references is presented and for enhancement quality factor (Q) we proposed an approche which based on technique the added a negative resistor network(resistor compensation and capacitor compensation).

II. STRUCTURE OF THE DIFFERENTIAL ACTIVE INDUCTOR

First, The structure of the Wu current-reuse differential active inductor indusive biasing circuitry [6] is to introduce in Fig.1. Transistors M9, M10, M11 and M12 are components of a variable current mirror.

The biasing source for M2 and M3 is realized with a stable gmi circuitry. It ensures more stable transistor transconductances, and thus a more stable biasing voltage for M2, M3, M5 and M6.

The active inductors are composed of transistors M1, M2, M3, M7 and M4, M5, M6 and M8. Transistors M1, M3, M4 and M6 are biased in the active region. Transistors M2 and M5 are biased in the triode region.

III. QUALITY FACTOR OF THE DIFFERENTIAL ACTIVE INDUCTOR

Any active inductor practically se works as a resonator [3],[4],[5]. In the case of a TOSI, there are a lot parasitic capacitances of the MOS transistors and finally, the architecture display a parallel-like resonance. Active inductors are RLC tanks when real impedance (Zin)is zero and Cp (part of the imaginary impedance) are accounted for. 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 quality factor of a passive LC tank at a given frequency is independent of the current of the tank. Unlike passive LC tanks, the inductance of the active inductors varies with the current / voltage of the inductors.

The PMOS transistors M7 and M8 have been introduced to inject currents which to change the transconductances of M1 and M4. These currents evidently depend on the Vgs voltage of these transistors. As a result, the variation of these currents conducts to modifications of the quality factor (Q) and self-resonant frequency (f0) that present an interdependency, acceptation that a variation of one parameter is succeeding by the variation of the other parameter. Figure .2 shows the simulation of quality factor versus voltage (vinj is the gate of the transistors M 7 and M8 which are matched), where the quality factor instantaneous defined as a ratio part imaginary impedance to part real impedance at frequency f in large signal.

The value of the quality factor varies with the voltage to apply at the gate of transistors M7 and M8, vinj. Therefore the quality factor of the active inductor can be changed as shown in Fig 2. The quality factor of the active inductor is modified with the aide of Vinj that varies from 0 to 1.75 V.

For precedent analyses a conclusion can be concern: The quality factor can be diversify among a minimum value of 2.313 and a maximum value of about 5.23 .

IV. SELF-RESONANT FREQUENCY OF THE DIFFERENTIAL ACTIVE INDUCTOR.

Him self-resonant frequency of the differential active inductor can be changed by motive of a variable current mirror in upper current sinks (M10-M12) must be equal a current across the active inductors controlled by the voltage vtosi to apply at the gate of the transistor M9. For change the current of the transconductors of the active inductor negative, means that changes the transconductances of these transconductors its must be to change the gates voltage of the transistors M1 and M4 where self-resonant frequency and quality factor are increased as shown in Figure.1. Inductors are extensively used in the design of radio-frequency circuits.

An active inductor is realized with a circuit configuration consisting of only a few transistors [7]. Therefore, an active inductor requires a fraction of the area of an on-chip passive inductor. The inductance of an active inductor depends on small-signal transconductances, conductances, and capacitances of transistors. Therefore, an active inductor provides a high Q due to low losses(real(Zin)), and exhibits a high self-resonant frequency due to its small size.Theoretically, passive inductors do not consume DC power while active inductors require DC biasing that consumes a small amount of power. However, the power consumption of an active inductor is significantly low compared to the overall power consumption of an RF circuit, where it is intended to be used.

V. PARAMETERS OF ON-CHIP PASSIVE INDUCTORS

After Inductors are characterized by quality factor Q and self-resonant frequency f0. The parameter Q determines losses in an inductor, and the f0 determines its impedance characteristics (inductive or capacitive) over frequency [8]. The impedance of an inductor becomes capacitive when the operating frequency exceeds f0.

Indeed, The maximum Q value is increased and the frequency of maximum Q and the self-resonance frequency are decreased. The self-resonance frequency is the frequency where the inductors inductance and parasitic capacitances become equal i.e. the reactance is zero.

At frequencies higher than the resonance frequency the inductor acts as a (low quality factor) capacitor.

Inductor is now becoming a highly attractive choice for CMOS wireless communication systems. It is interesting and unique advantages over spiral inductors include the following factors:

☐ occupying smaller die area,

☐ High quality factor,

☐ Tunable inductance,

☐ and the possibility of achieving higher inductance with high resonance frequency. For better gain Vgs has to be fixed to the different voltage for various center frequencies and quality factor.

The center frequency f0 and quality factor are tuned through the controllable voltages vinj and vtosi, and Figures 3, 4 , 6 and 7, shown the tuning of the active inductor for various center frequencies and quality factor. The designed active inductor have wide tuning range of 3.019 GHz to 3.308GHz(see Figure. 3), and 2.612GHz-5.67GHz (see figure.6). We conclure that the voltage vinj and vtosi are responsible for tuning maximum of the quality factor range 2.471-3.325 (see Figure. 4) , and 1.145-4.014 (see Figure. 7) whereas the tuning of the center frequency by voltage vinj is weak, compared to the voltage vtosi (see Figure.6).

Quality factor is tuned through the controllable bias voltage (vinj and vtosi) of Figure.4 and 7. Figure. 3 and Figure.6. shown the variation of Zinput for different values of controllable bias voltage . When vinj and vtosi are varied, the Zinput brings corresponding changes in real of the active inductor and imaginary of the active inductor . As shown in Figure 4 and 7 varying the Q value does not unchange the value of inductance and pursuant to Figure.5 (maximal inductance varies from 528.7 nH-750nH)varying the value of inductance does not unchanges the Q value of active inductor.

Therefore, the quality factor can be tuned through active inductors are RLC tanks when the real(Zin) and imag(Zin) are accounted for. Unlike passive LC tanks, the inductance of the active inductors varies with the current / voltage of the inductors.

The quality factor Q operated in a large-signal mode and in a small-signal mode, such as LC tank oscillators.

The periodic steady state analysis with a voltage source which has an amplitude equal to 580mV, and a frequency equal to 4.701 Ghz shows that the differential output voltage has a negligible distortion and the fundamental component has a value of 1.223V, as shown in Fig. 8.

The sensitivity of the quality factor of the active inductor with respect to real(Zin) is investigated in Fig.3and 6. To boost the quality factor of active inductors, real(Zin) must be minimized by used differential negative impedance networks as shown in Fig.9.

Note that the resistance of the negative resistor should be made tunable such that a total cancellation can be achieved. The simulated the magnitude and quality factor of the inductor with resistance negative in function the frequencies with value different of the voltage vinj are shown in Figure 10 and 11 respectively.

The circuit has a very wide operating bandwidth where the inductive characteristic extends from

Zero frequency (depend the loss of the active inductor) up to the self-resonance frequency at f0 with a frequency f=f0 the quality factor a vicinity 0 because zin take a maximum magnitude as shows in Figure.10 for the value frequency f0 around 3GHz, whereas the quality factor take a maximum value 4.698-10 (Figure.11) where loss is minimized.

versus frequency f with vinj is varied from 0V to 1.4V and vtosi=1V.

The results of simulation of the range the f0 performance of the active inductor is shown in Figure.3(range f0=3.019GHz-3.308GHz) . It can be seen that the curve of the proposed active inductor, which is added negative resistance for compensating the loss, is inclined to the when the frequency is increase as shown in Figure12 between 2.7GHz and 3.14GHz. This result indicates that the loss is decreased, and the Q-value is greatly increased (see figure 13).This results obtained for circuit illustrated in Figure.9 (Qmax=10) compared with circuit indicated in Figure .1 (Qmax=5.23), these results with variation of the voltage vinj.

It should be noted that because serie resistance Rs and parallel resistance Rp are the real(Zin) are frequency-dependent, Rcomp(real(Zin negative)) should be designed in such a way that a total resistance cancellation is achieved across the frequency range of the active inductor. It should also be noted that although the negative resistor compensation Rcomp technique is widely used to improve the quality factor of spiral inductors, a total compensation in this case is difficult to achieve. This is because an active negative resistor is used to cancel out the largely skin-effect induced parasitic series resistance of spirals.

Figs. 16,15 and 17, show the Q-value,Q versus frequency f and the f0 comparisons between the active inductor with negative resistance and the one without it. Figure .17, 16 and 15 indicate that in the range of f0 1.488GHz to 5.841GHz, the maximum Q-value is around 36.12 with variation the vtosi and Q changes versus the frequency with the variation the vtosi respectively The Q-value and the f0 of the active inductor with negative resistance are higher than that of the one without it.

Fig. 14 shows the minimum equivalent loss of a proposed active inductor with negative resistor is 0.2E3Ω and it is much smaller than that of the one without the negative resistor. As a conclusion we noted that quality factor and frequency f0 of the circuit with negative resistor is higher than circuit without it, (Qmaxwith=36.12, range f0with=1.488GHz to 5.841GHz , and Qmaxwithout=4.014, range f0without=2.612GHz-5.67GHz).These results with variation the vtsoi.

When replica-biasing (M7, M8) is used to minimize the effect of supply voltage fluctuation on the inductance of active inductors, as to be seen shortly, the power consumed by the replica-biasing network must be accounted for. Also, when negative resistors are employed for boosting the quality factor of active inductors, their power consumption must also be included. Often the power consumption of an active inductor is set by that of its replica-biasing and negative resistor networks.

VI. DESIGN CIRCUITS AND THEIR SIMULATION

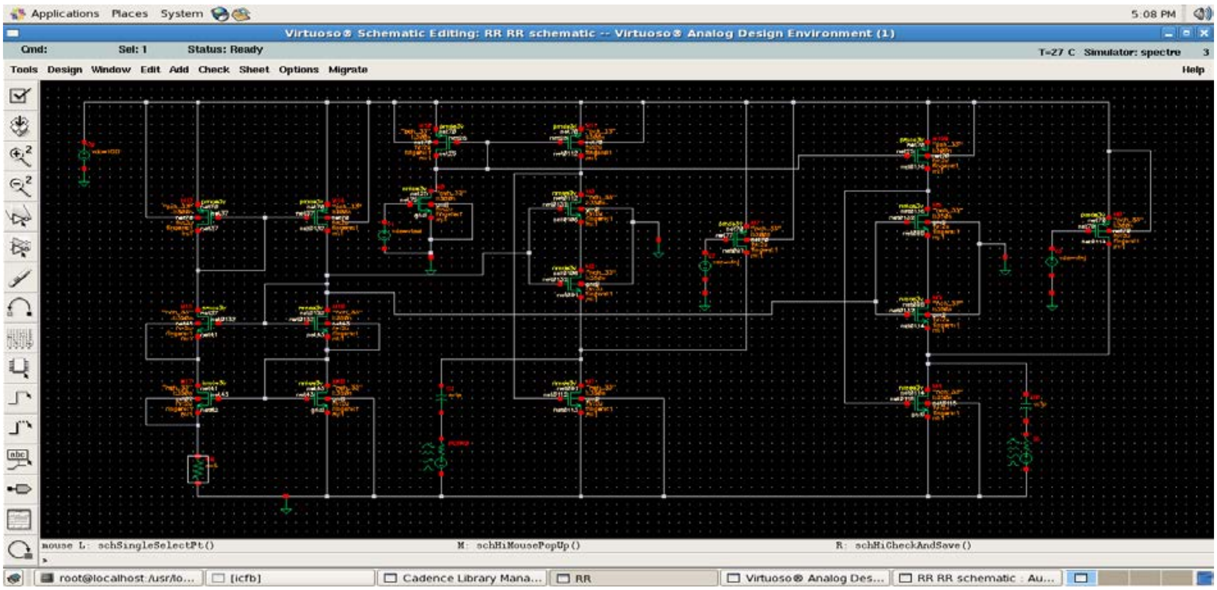

Fig.1. Structure of the Wu current-reuse differential active inductor (Differential Active Inductor).

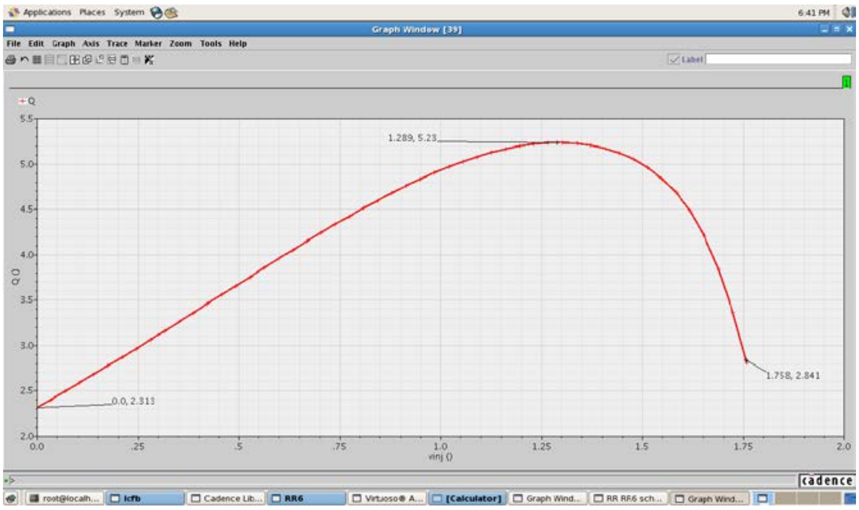

Fig.2. Quality factor varies with the voltage vinj with vtosi=700mv.

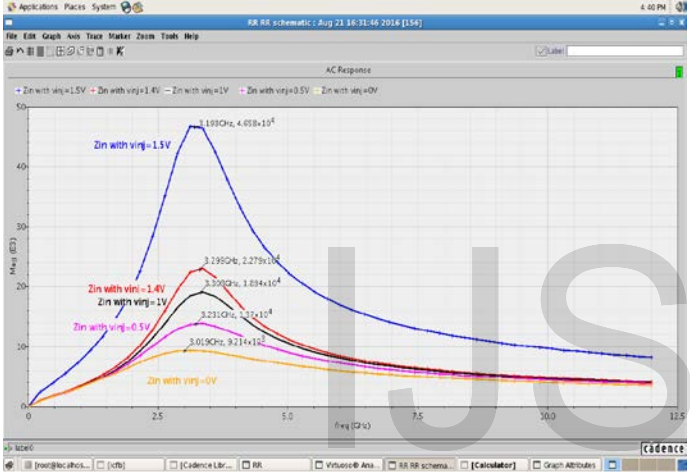

Fig. 3. impedence(Zin) of active inductors versus frequency f and vinj is varied from 0V to 1.5V with vtosi=700mV.

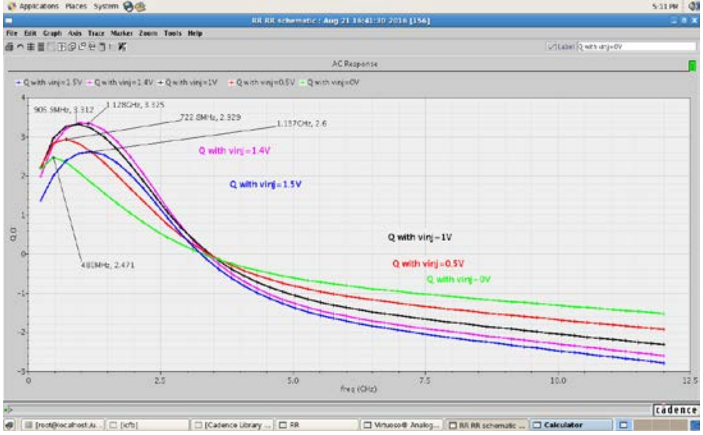

Fig. 4. quality factor(Q) of active inductors versus frequency f. vinj is varied from 0V to 1.5V with vtosi=700mV.

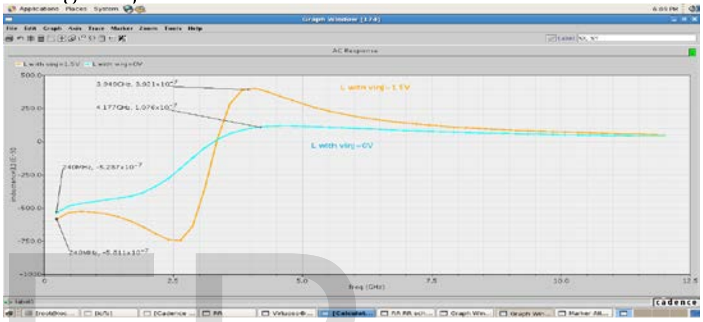

Fig.5. The effect of vinj on the inductance(L) of the active inductors versus frequency f with vinj is varied from 0V to 1.5V and vtosi=700mV.

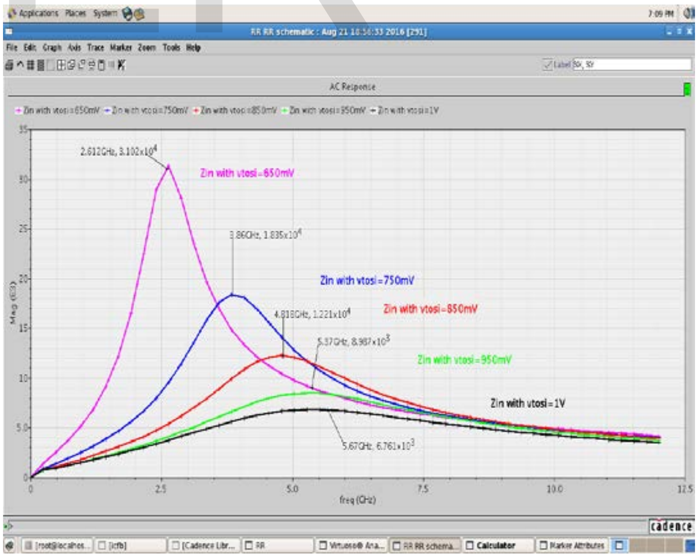

Fig. 6. The effect of vtosi on the impedance(Zin) of the active inductors versus frequency f and vtosi is varied from 650mV to 1V with vinj=1.5v.

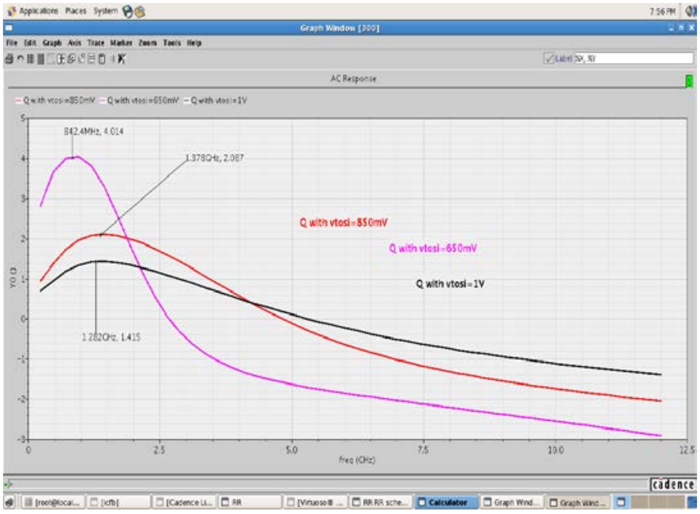

Fig.7. The effect of vtosi on the quality factor(Q) of the active inductors versus frequency f and vtosi is varied from 650mV to 1V vinj=1.5v.

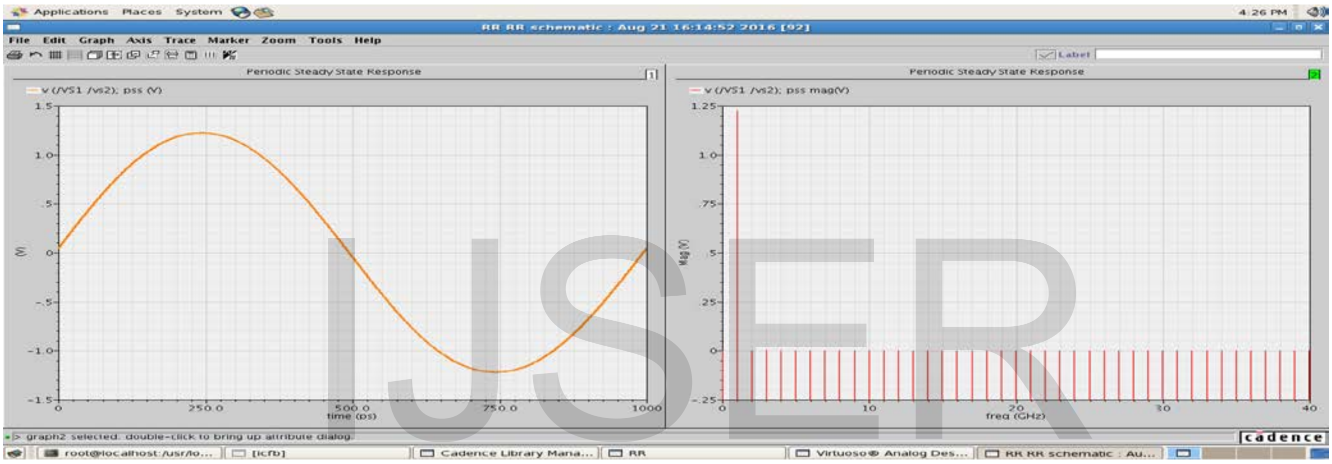

Fig. 8. Periodic steady state analysis of the function voltage differential in sweep time and spectrum.

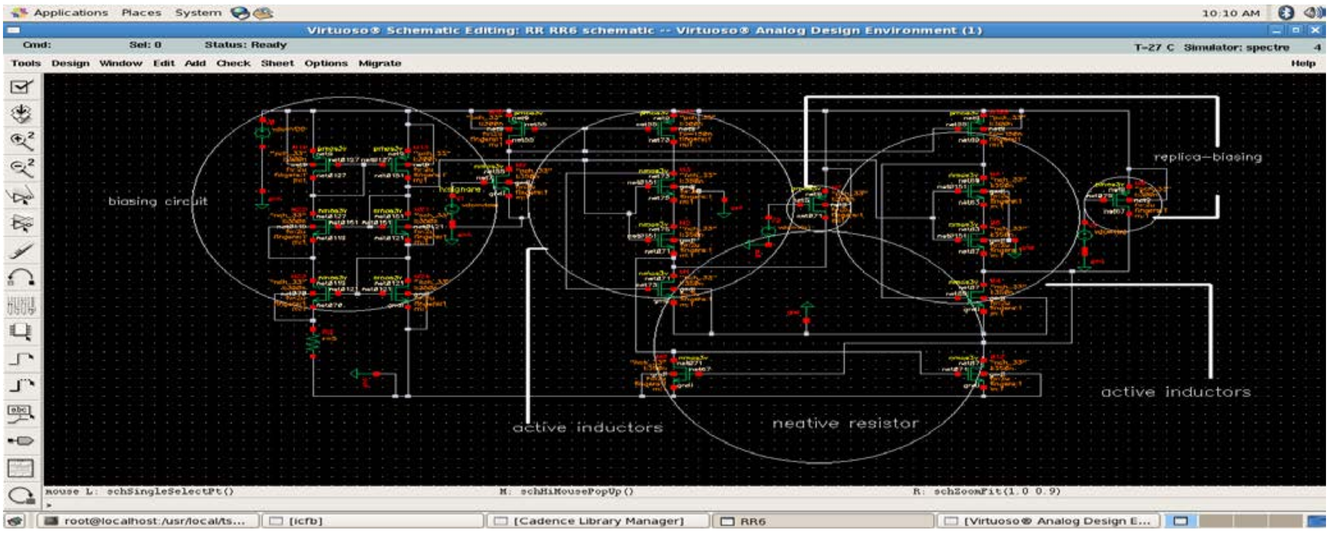

Fig.9. differential active inductor with differential negative impedance networks.

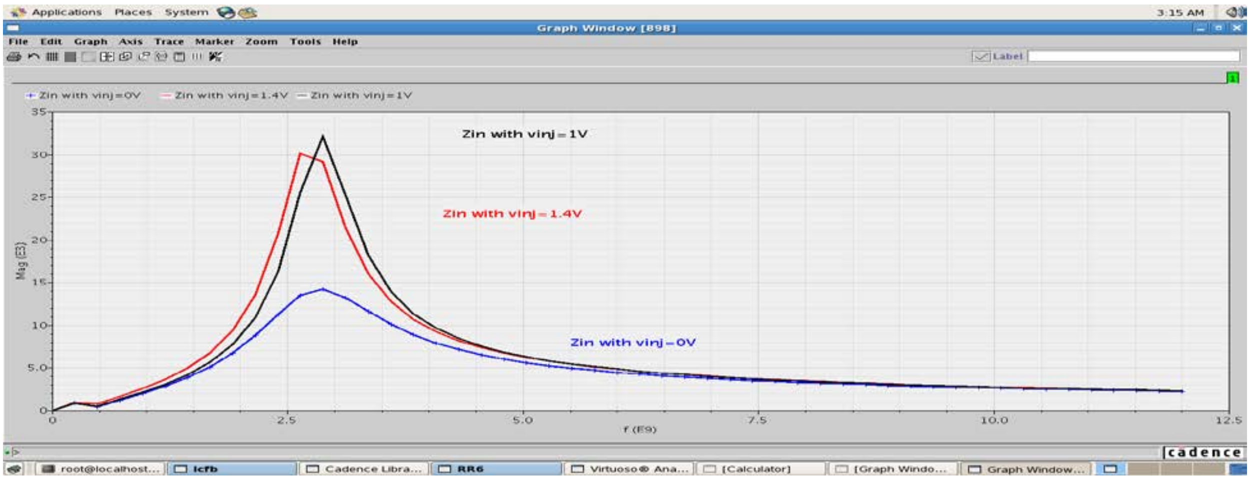

Fig. 10. The effect of vinj on the impedance(Zin) of the differential active inductors with negative resistance versus frequency f with vinj is varied from 0V to 1.4V and vtosi=1V.

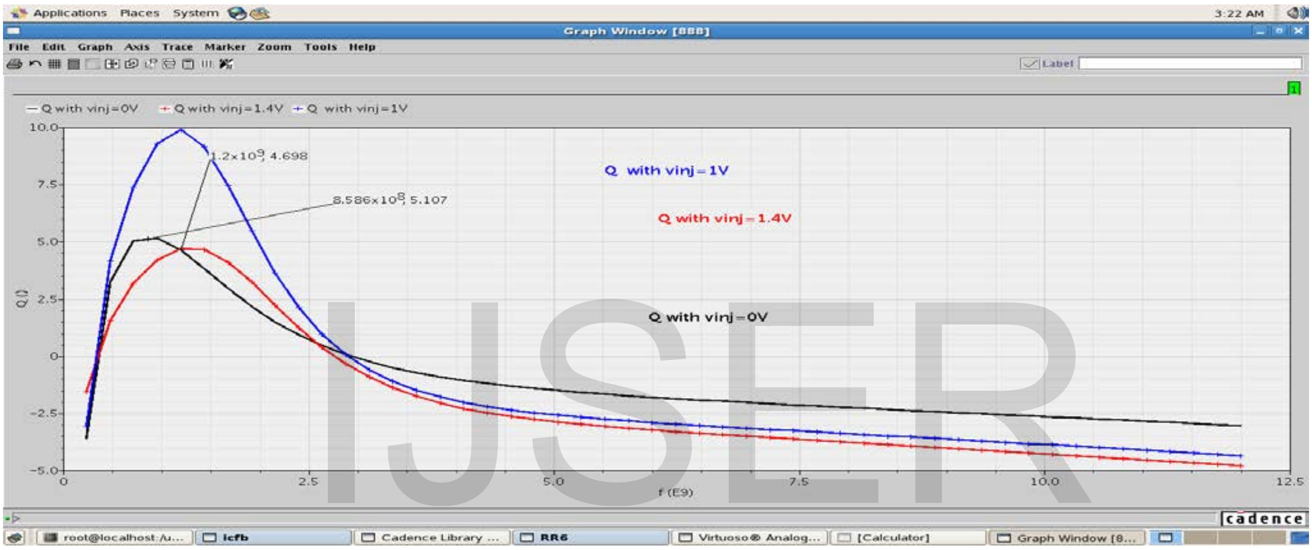

Fig. 11. The effect of vinj on the quality factor (Q) of the differential active inductors with negative resistance versus frequency f with vinj is varied from 0V to 1.4V and vtosi=1V.

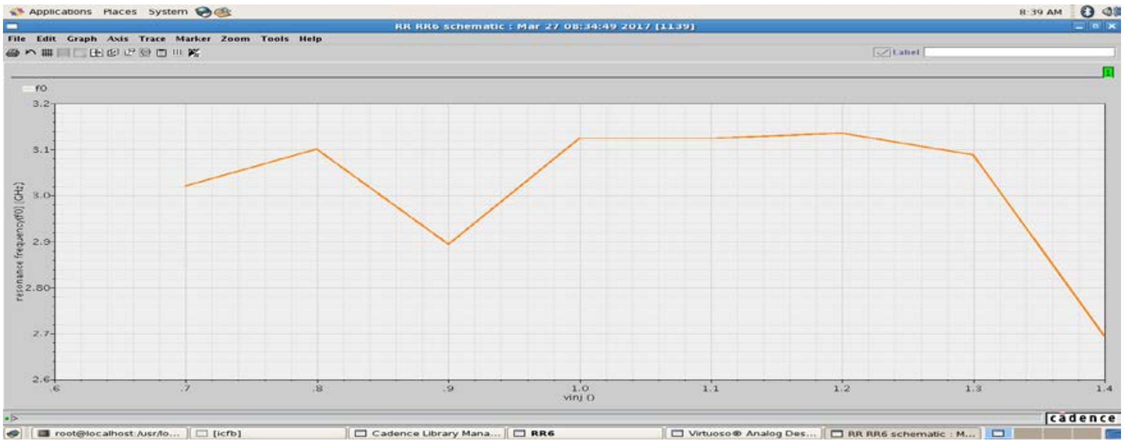

Fig.12.self-resonant frequency(f0) of the differential active inductor with negative resistance versus voltage vinj and vtosi=1V.

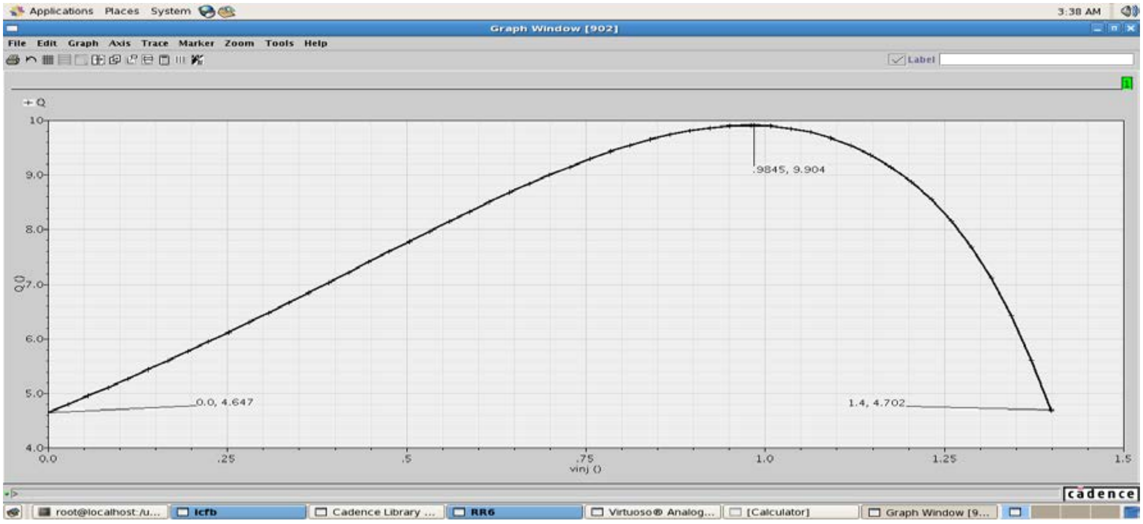

Fig.13.Quality factor(Q) of the differential active inductor with resistor negative varies per voltage vinj with vtosi =1v.

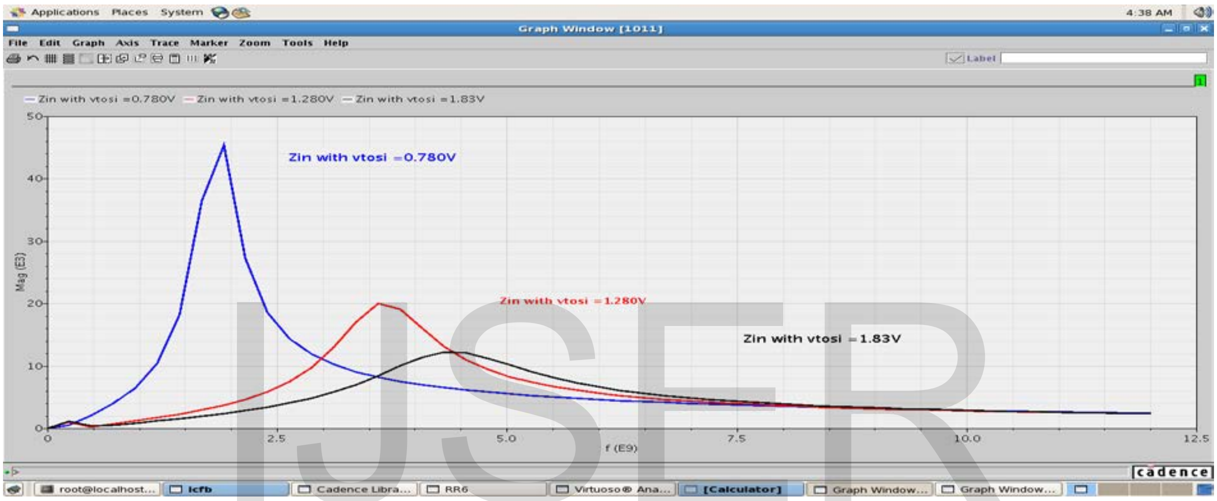

Fig.14.Tuning of the impedance (Zin) of the differential active inductor with resistor negative versus frequency f with differrents voltage vtosi and vinj=1v.

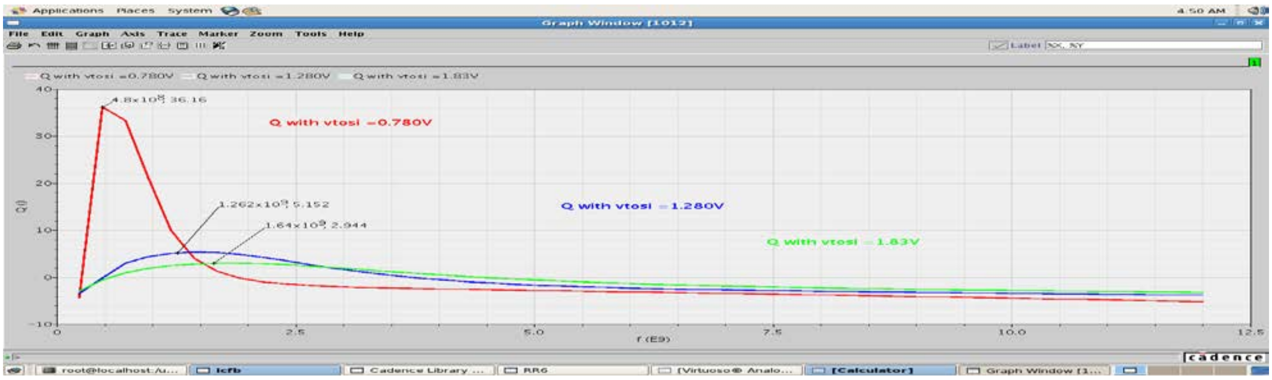

FIG.15.TUNING OF THE QUALITY FACTOR(Q) OF THE DIFFERENTIAL ACTIVE INDUCTOR WITH RESISTOR NEGATIVE VERSUS FREQUENCY WITH VALUE DIFFERENT OF VTOSI AND VINJ=1V.

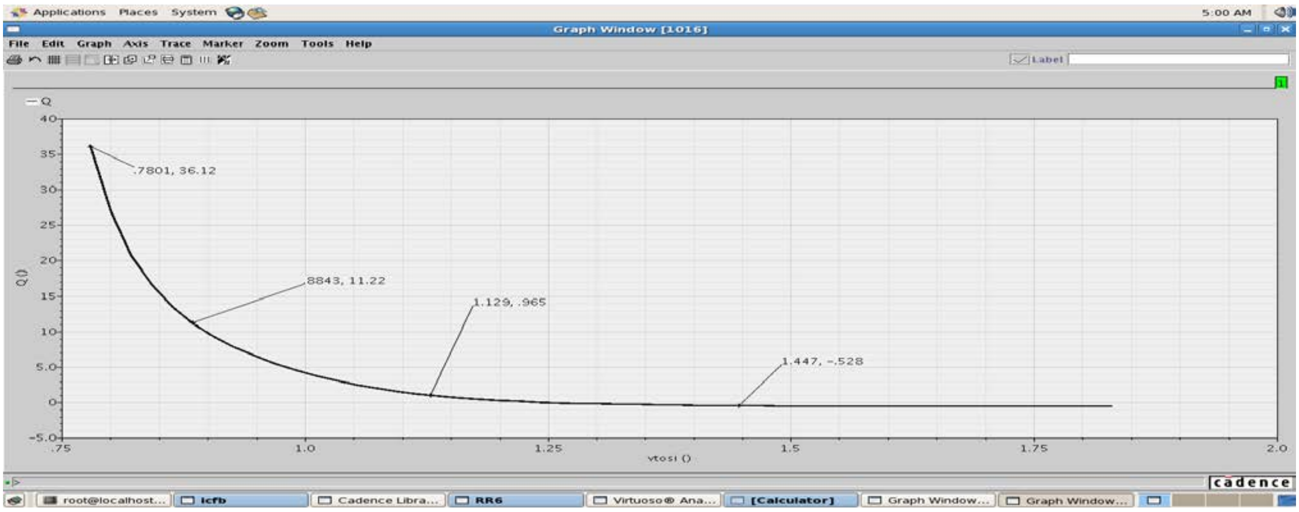

Fig.16.Quality factor(Q) of the differential active inductor with resistor negative versus voltage vtosi and vinj=1v.

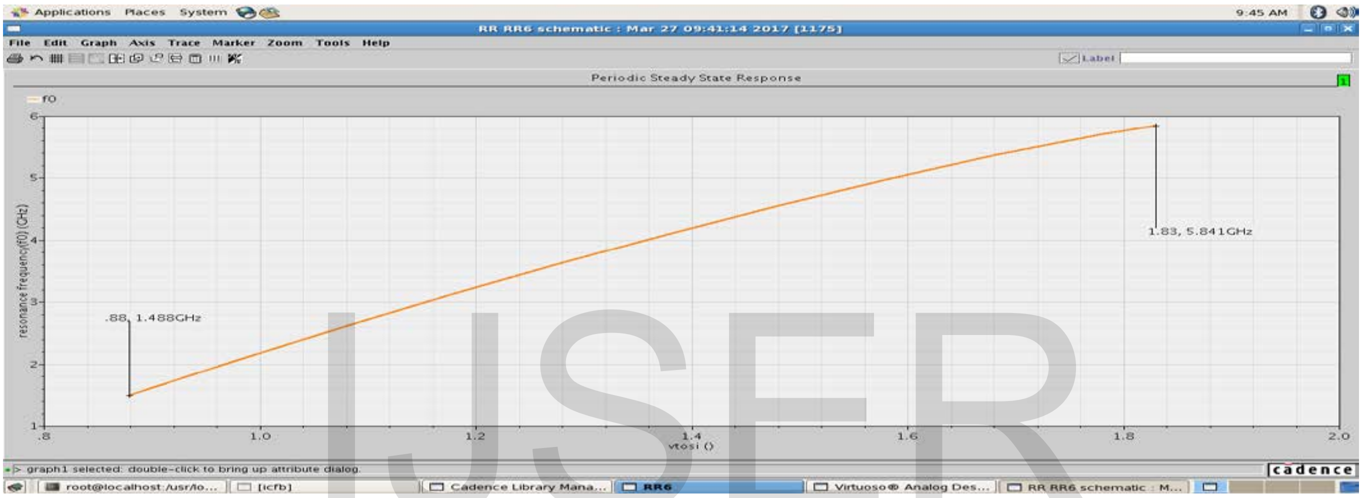

Fig.17.Self-resonant frequency (f0) of the differential active inductor with resistor negative versus voltage vtosi and vinj=1v.

VII. CONCLUSIONS

In this paper a novel differential active inductor high quality factor in CMOS. its application to filter as future work. Because of its small size and programmability, it's has the potential to be applied to new multi-standard or softaware-defined radio system.

REFERENCES

[1] Yuan F., CMOS Active Inductors and Transformers, Principle Implementation, and Applications.Springer, 2008.

[2] Bakken T., Choma J., Gyrator-Based Synthesis of Active On-Chip Inductances. Analog Integrated Circ. a. Signal Proc., 34, 171–181, Kluwer Academic Publ. (2003).

[3] Andriesei C., Study of Active Filters Topologies for Telecommunications Applications.Ph.D.Diss., Cergy-Pontoise Univ., Technical University "Gheorghe Asachi" of Iaşi, 2010.

[4] Andriesei C., Goraş L., On Frequency and Quality FactorIndependent Tuning Possibilities for RF Band-
Pass Filters with Simulated Inductors. Romanian J. of Information Sci. a. Technol., 11, 4, 367-382 (2008).

[5] Andriesei C., Goraş L., On the Tuning Performance of an Active RF Bandpass Filter.Acta Technica Napocensis, 49, 3 (2008).

[6] Johns D.A., Martin K., Analog Integrated Circuit Design. John Wiley & Sons, 1996.

[7]. A. Thanachayanont, —A 1.5-V CMOS Fully Differential Inductorless RF Bandpass Amplifier‖, Proc. IEEE ISCAS, pp. 49-52, Vol. 1, 2001.

[8]. W. B. Kuh, F. W. Stephenson, and A. Elshabini-Riad, —A 200 MHz CMOS Q-enhanced LC Bandpass Filter, ‖ IEEE Journal of Solid-State Circuits, vol. 31, no. 8, pp. 1112-1122, Aug.199.