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Low-Phase Noise CMOS Voltage Controller Oscillator (LC Oscillators) Using High-Q Active Inductors with the Transistors in Strong Inversion

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***Abstract*— This paper presents a CMOS LC oscillators based on this high-Q active inductor, a negative resistance LC-tuned oscillator with low-constant-power consumption and wide tuning-range can be achieved with low phase noise, wide tuning range, and quality factor in 0.13µm CMOS technology. The active inductor with one feedback resistor results in a gain-boosting factor to improve the Q-value and the inductance (L) of the active inductor. The designed Voltage Controller Oscillator (VCO) demonstrates an oscillation frequency range from 3.268GHz and 4.76GHz, Q-value of 1.975E4, a phase noise of -100dBc at 4-MHz offset, phase noise deviation is less than -247.946dbc/Hz and output power of 12.6531mW with a dc power consumtion of 0.4418mW.**

***Index Terms*— CMOS, Active Inductor,Q-value, Voltage control oscillator (VCO), phase noise, frequency tuning range, and Power Consumption.**

I. INTRODUCTION

The recent exponential growth in higher integration and wireless communication has attracted tremendous effort to develop more channels in mobile communication applications [1]. Today, CMOS technology is widely used for the implementation of RF integrated circuits. Voltage controlled oscillator (VCO) is one of the main blocks in RF systems. To accomplish a high-performance oscillator, low power consumption, wide tuning-range, and exacting phase noise should be simultaneously considered in the RF circuit applications [2, 3]. However, a low Q-value passive spiral inductor in fabricating CMOS process will severely limit the wide tuning-range and the phase noise. The lower Q-value spiral inductor will limit the wide tuning-range [4] and result in lower phase noise [5]. Newly, wide tuning-range ring oscillators in digital circuit and low phase noise LC oscillators using passive spiral inductors have been demonstrated [6].

On the other hand, CMOS active inductors have been applied in microwave/RF amplifier and oscillator designs to achieve high power gain, wide tuning-range and save chip area [7-9].

The LC-tuned oscillator circuits can achieve lower phase noise, but the low Q-value passive inductor limits the frequency tuning-range [10]. In addition, the oscillators using active inductors have wide tuning-range and small chip area, but the large phase noise is also encountered due to the Q-value of the active inductors is not high enough [11-12] . Also, the power consumption of these oscillators will be sensitively influenced by the frequency tuning as well, resulting in extra circuit noise in different operating frequency. Therefore, it is desired to design an oscillator using high-Q active inductor to improve wide tuning-range, reasonable phase noise, and small chip area. Besides, constant power consumption and low deviation of phase noise in target wide frequency band can be achieved. VCOs are considered to be one of the important parameters in analogue and digital systems. Nowadays, the demand for high-performance, VCOs is increased; in turn, this demand has imposed more strict requirements on the phase noise of the VCO [13].

The phase noise of the VCO is used to describe phase fluctuations due to the random frequency fluctuations of a signal. Phase noise can be caused by a number of conditions, but is mainly affected by VCO frequency stability. It is one of the most important parameters for the quality and performance of information transfer, in turn affecting the reliability purposes in data communication.

In this paper, we propose a CMOS wide tuning-range LC oscillator using high-Q active inductors. The active inductor, simpler than the circuit of [11], results in improving both Q-value and inductance (L) of the active inductor. Based on this inductor, a negative resistance LC-tuned oscillator with wide tuning-range, reasonable phase noise, constant power consumption, and low deviation of the phase noise has been designed.

II. IMPROVING HIGH-Q ACTIVE INDUCTOR DESIGN

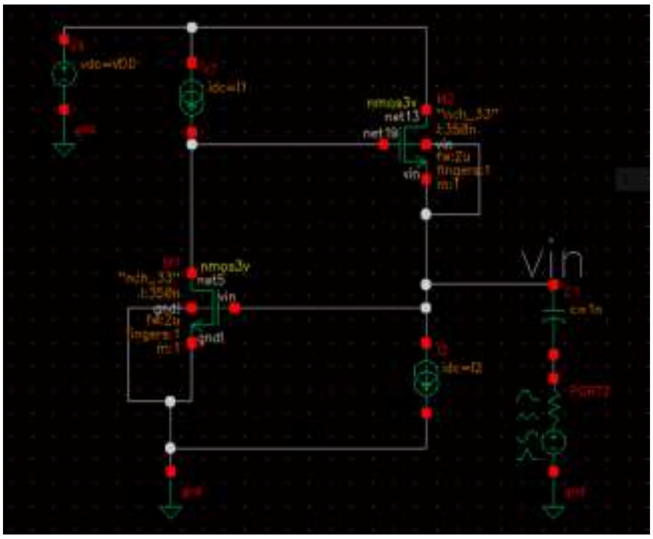

Fig.1.Simple grounded active inductor circuit.

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Based on the gyrator theory [12], the simple grounded active inductor circuit shown in Fig.1.Each MOS transistor is modeled by the equivalent device components including gm, gds, Cgs, and Cgd. where gmi, gdsi, and Cgsi are the transconductance, output conductance, and gate-source capacitance of correspondence transistors, respectively.

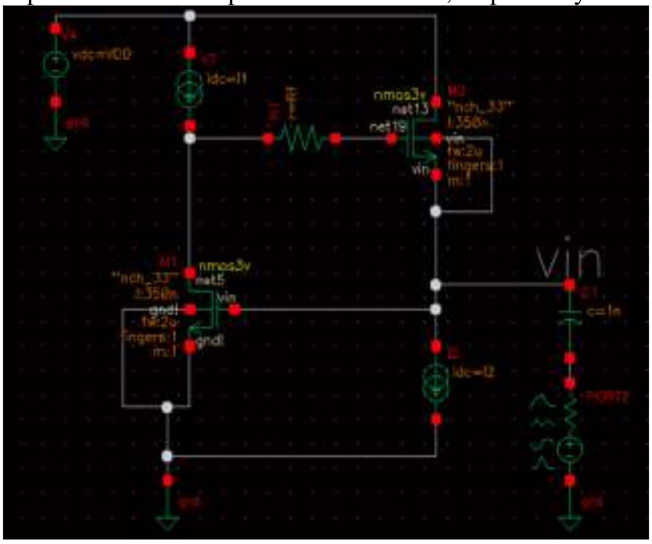

Fig.2.Improved high-Q active inductor circuit.

Therefore, in order to improve the performance such as the Q-value and the inductance (L), we propose high-Q active inductors with a feedback resistor. The improved high-Q active inductor circuit is illustrated in Fig. 2. This circuit is composed of common source transistor M1, common drain transistor M2, feedback resistor Rf and two biasing current sources I1 and I2.

Feedback resistor Rf and transistor M1 construct a gain network. This network produces a gain factor to reduce the parallel conductance (G) in such a way that the internal loss of the inductor will be decreased, and then the Q value is increased.Therefore, the inductance (L) is also increased due to the feedback resistor.

Fig. 3 and 4show Simulation inductance(L) ,Image(Zin) ,real(Zin) , Zin and Quality factor(Q) with resistive negative, where Fig 5 and 6 show Simulation inductance(L) ,Image (Zin),real(Zin) , Zin and Quality factor(Q) without resistive negative .

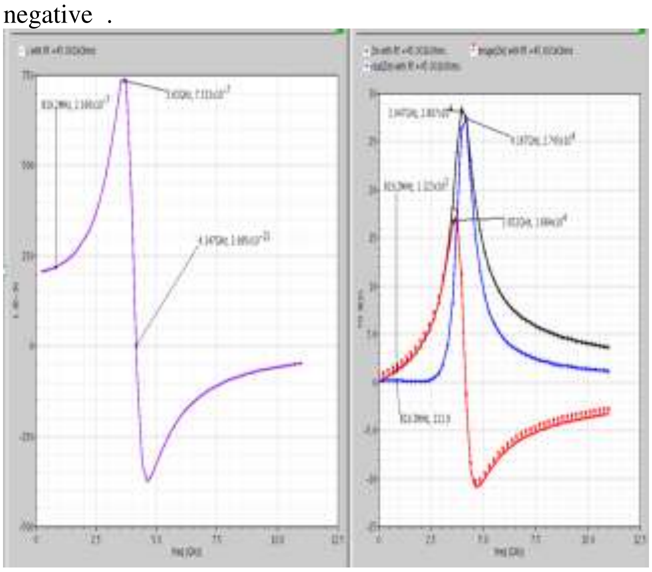

Fig.3.Simulation inductance (L) ,image(Zin),real(Zin) and Zin with resistance negative feedback Rf=45.001KOhms.

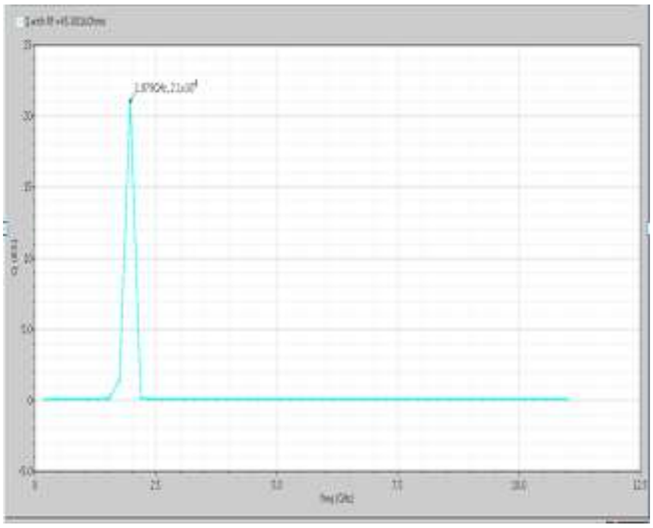

Fig.4.Simulation Quality factor(Q) with resistance negative feedback Rf=45.001KOhms.

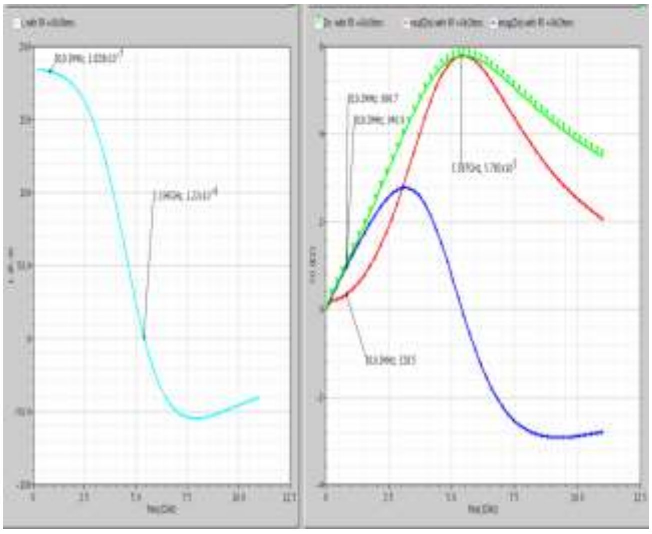

Fig.5.Simulation inductance(L) ,image(Zin),real(Zin) and Zin without resistance negative feedback Rf.

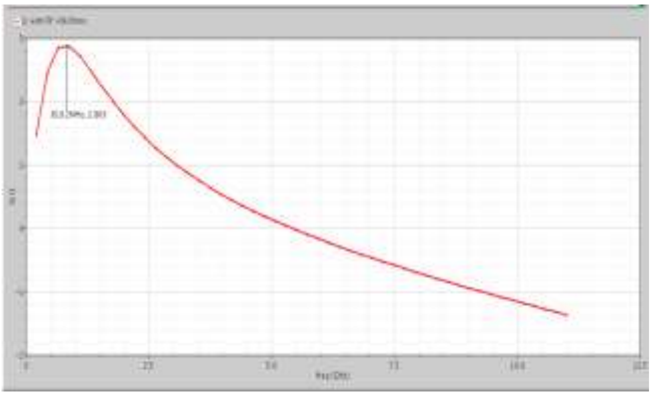

Fig.6.Simulation Quality factor(Q) without resistance negative feedback Rf.

Figs 3, 4, 5 and 6 indicate that in the range of 4.147GHz to 5.396GHz, the maximum Q-value is around 2.1E4 and the inductance changes from 182.8nH to 733.3nH. The Q-value and the inductance of the active inductor with feedback resistor are higher than that of the one without it.

Fig. 3 shows the minimum equivalent loss of a proposed active inductor with feedback resistor is1.119E2Ω and it is much smaller than that of the one without the feedback resistor between the frequency ranges of 0MHz and 819.2MHz. Consequently, the active inductor has shown a significant improvement.

The power consumption is only about 0.1056mW under 3.3 V supply voltage, and there is lesser power consumption in this active inductor as shown in Fig.7 with and without resistance negative Rf.

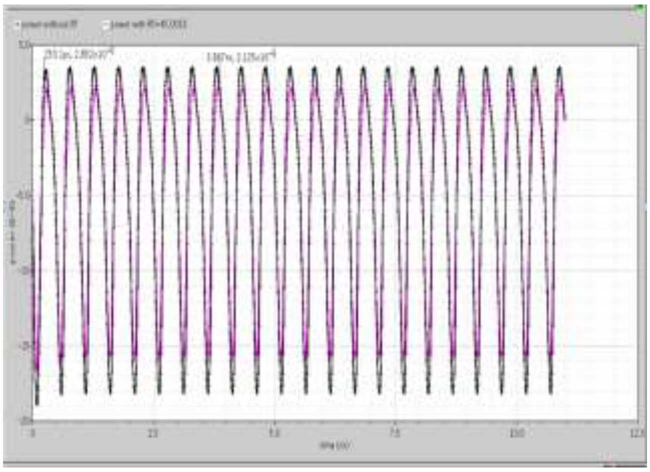

Fig.7. power consumption of active inductor with and without resistance negative feedback Rf.

Furthermore, in this active inductor, the external bias voltages are used to tune the characteristics of the active inductor due to the variation in the circuit implementation. Therefore, it can be achieved the performances that independent of the process variation. The comparisons between improved and original is shown in table1.

	Active Inductor without Rf	Active Inductor with Rf
Quality Factor(Q) =Qmax	2.863	2.1E4
Image(Zin=Z11)=imagmin	9.409E2Ω	1.123E3 Ω
Real(Zin=Z11)=realmin	3.285E2 Ω	1.119E2Ω
Inductance(L)=Lmax	1.828E2nH	7.333E2 nH
Power consumption	0.1056mW	0.1056mW

Therefore, the Q-value is favored with the feedback resistance Rf by factor dominates (Q with Rf divided by Q without Rf greather than one) and the trend variation of the Q-value is shown in Fig. 8.

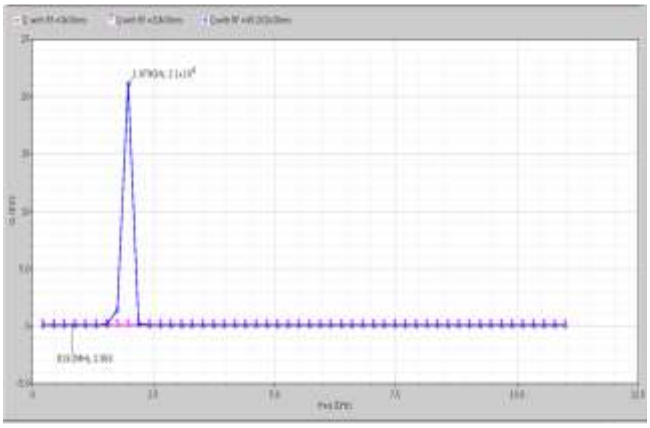

Fig. 8.Improved quality factor by a resistance negative feedback Rf.

The Q-value is increased with the increasing feedback resistance Rf. In Fig. 9, the inductance of the inductor is also increased by the increasing feedback resistance Rf in the range of 4.147GHz to 5.396GHz.Therefore, it can be achieved the performances that independent of the process variation (external bias voltage). For example here we used resistance negative feedback Rf such as shown in Fig.10 which demonstrated tuning the imaginary part and real part of the impedance (Zin=Z11).where tuning quality factor versus resistance negative feedback is shown in Fig.11.

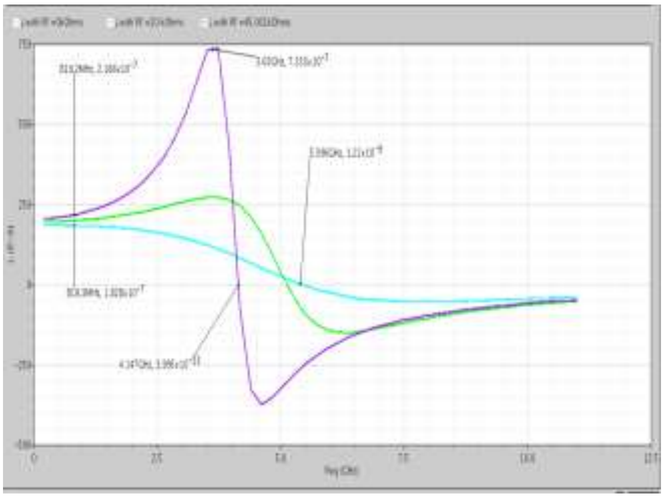

Fig.9.Improved inductance by a resistance negative feedback Rf.

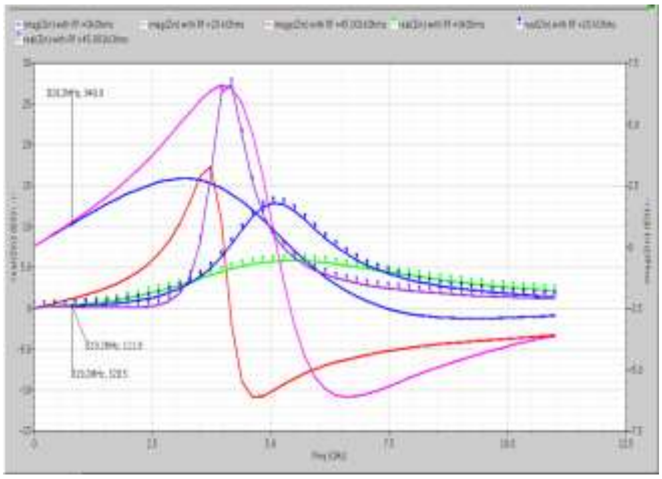

Fig.10.Tuning the imag(Zin) and real(Zin) by a resistance negative feedback Rf.

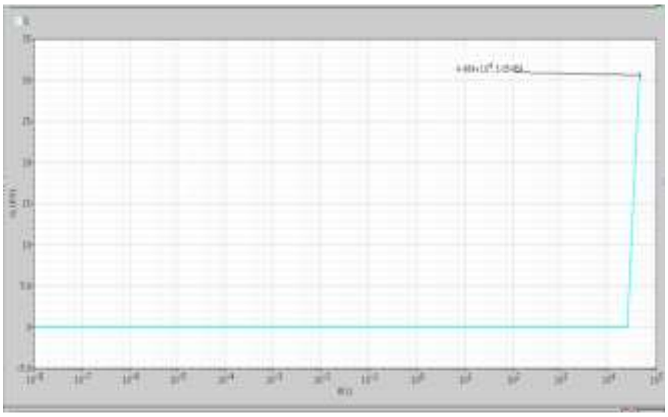

Fig.11.Variation of the quality factor with respect to resistance negative feedback Rf.

The quality factor of the active inductor is modified with the help of Rf which varies from 0 kohms to 45.001kohms.The nonlinear variation of quality factor can be divided into two region. For values of Rf between 0 to 12KOhms its presents a weak quality factor zone with a slow increase of the value from the 2 to 30. The second region is represented by of values Rf=12KOhms to 45.001KOhms where the quality factor presents a rapid increase of the value from 30 the maximum value of 3.054E4. As a result, the performances of the proposed active inductor containing the Q value and the inductance may be tremendously improved with a simple loss compensation network.

Because the dc current does not pass through the feedback resistance Rf, the voltage drop of the feedback resistance is zero, and then the voltage will not be changed when the resistance Rf is varied.

Consequently, power consumption of the improved active inductor can be retained constant.Therefore, the unchanged power consumption characteristic can be applied to design a constant power consumption oscillator circuit with wide tuning-range.

III. Oscillator Circuit Design

The chief design considerations of the oscillator are to obtain a low constant-power consumption, wide tuning-range and low phase noise. The circuit diagram of the proposed oscillator shown in Fig. 12.

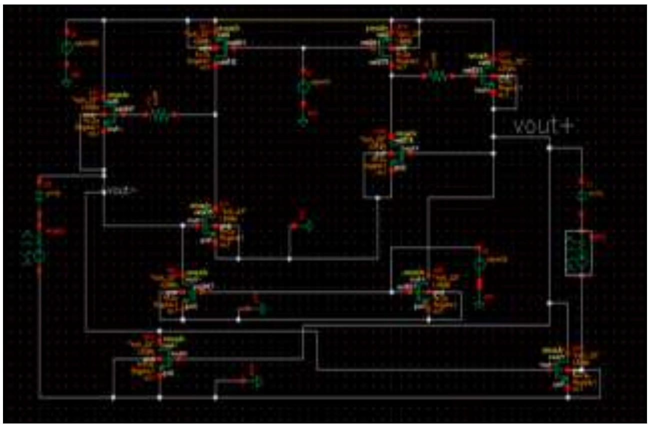

Fig. 12.Circuit diagram of the proposed oscillator.

Has a cross-coupled connection of NMOS transistors MNR and MNL to form a positive feedback loop for providing negative resistance, called negative impedance converter (NIC) to compensate the loss of the active inductor in the LC tank. The cross connected differential pair provides the negative resistance to neutralize the tank losses with less current consumption.

Two improved high-Q active inductors depicted in Fig. 2 replace the conventional inductors of the LC tank. Through these active inductors a superior oscillator, being composed of M1R, M1L, M2R, M2L, MSR, MSL, MPR, MPL, RfR and RfL, can be completely designed. These active inductors are behaved as the equivalent inductance in this oscillator with variation the quality factor, imaginary part and real part of equivalent impedance of oscillator(Zin=2*Z11) are shown in Figs.13.14 and 15 respectively. Because the oscillator circuit is symmetric and the Q value of the active inductor is high enough, all transistors only have the same minimum dimension, where the length(L) and the width(w) of each MOSFET are 0.35um and 2um, respectively but cross-coupled connection of NMOS transistors MNR and MNL have the dimension (LNR=LNL=0.35um , WNR=WNL=3um).

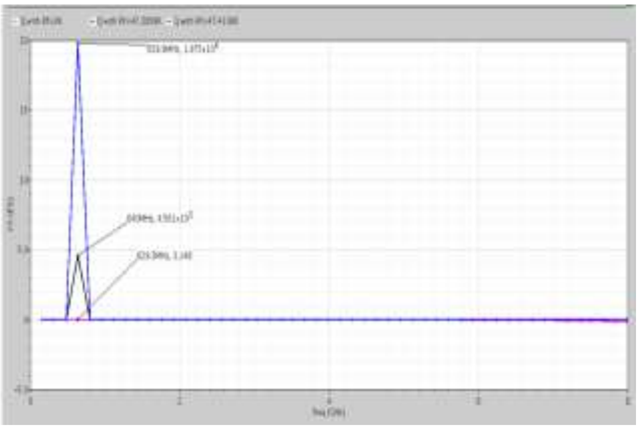

Fig.13.Quality factor tuning of equivalent inductance in this oscillator versus frequency with Rf varies from 0 to 47.4199KOhms.

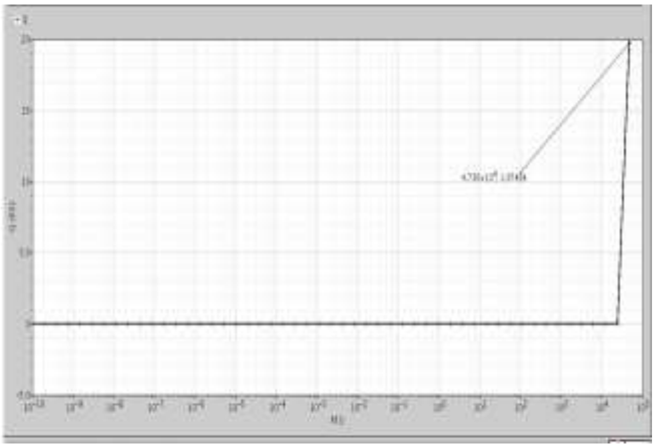

Fig.14.Quality factor of equivalent inductance in this scillator versus Rf with Rf varies from 0 to 47.4199 KOhms

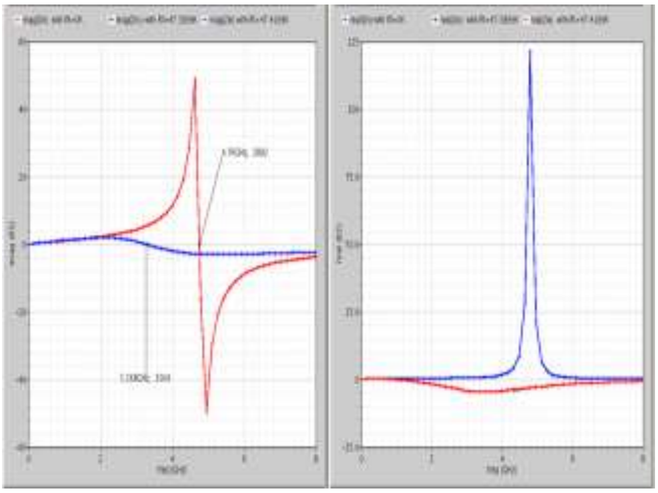

Fig.15.Half of Imaginary part and real part of impedance equivalent inductance (Zin) tuning in this oscillator versus frequency with Rf varies from 0 to 47.4199KOhms.

No varactors are employed in this oscillator; the oscillator frequency modulation function will be compelling. To provide an adjustable frequency range, the feedback resistance Rf of the active inductor is added to tune the desired oscillator frequency. Though the capacitance is kept unchanged, the equivalent inductance values are deviated by the resistance Rf. Thus, the output frequency of the oscillator will only be adjusted by Rf.

Fig.16. shows that the power consumption of settles to a constant value of approximately 0.4418mW in this range 0ns to 25ns and Fig.17. Shows that the output power of settles to a constant value of approximately 12.6531mW for 2.29037GHz .

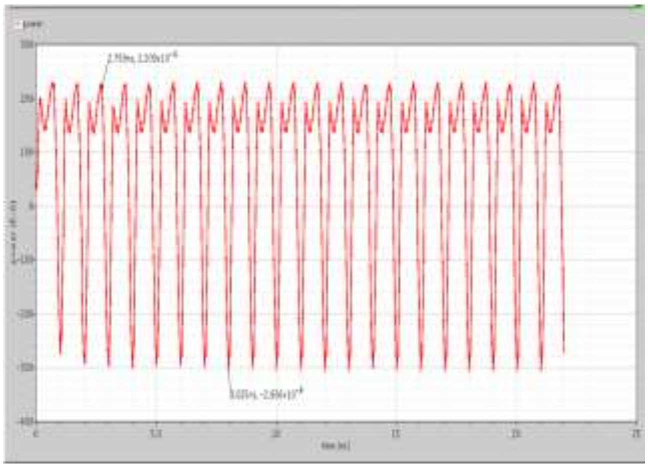

Fig.16. Power consumption of oscillator.

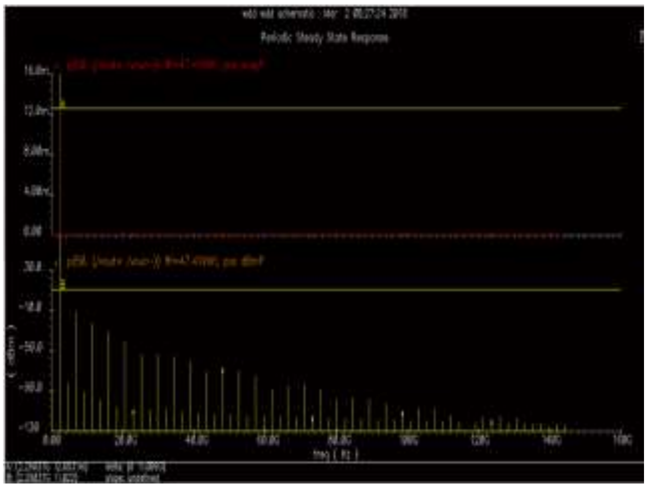

Fig.17. output power of oscillator.

The relationship between the output amplitude and the output frequency is appeared in Fig. 18.

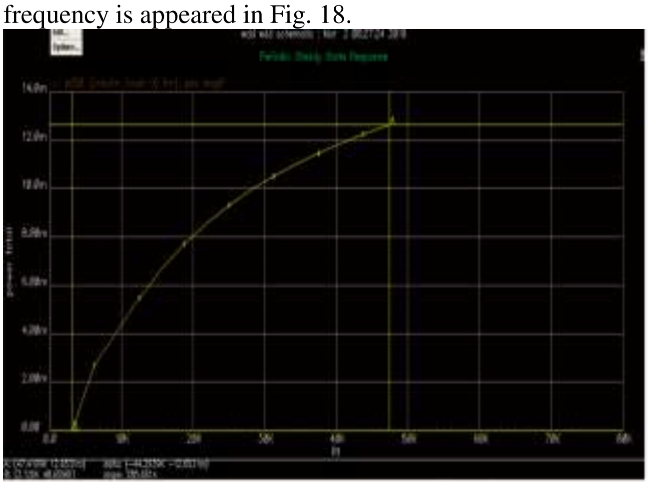

Fig.18.Output amplitude versus tuning frequency.

It indicates that the variation of the output amplitude is about 12.6531 mW during the wide tuning-range.Fig. 19. shows the tuning of voltage controllator oscillator for various center frequencies for different values of controllable Rf.Besides, the phase noise in the wide tuning-range is exposed in Fig. 20.

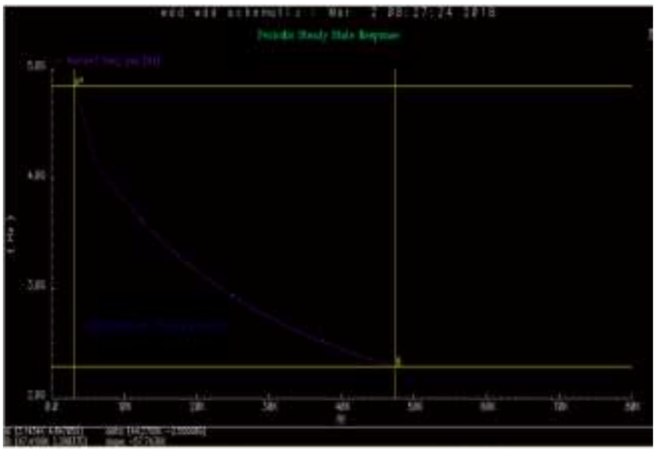

Fig.19.various center frequencies.

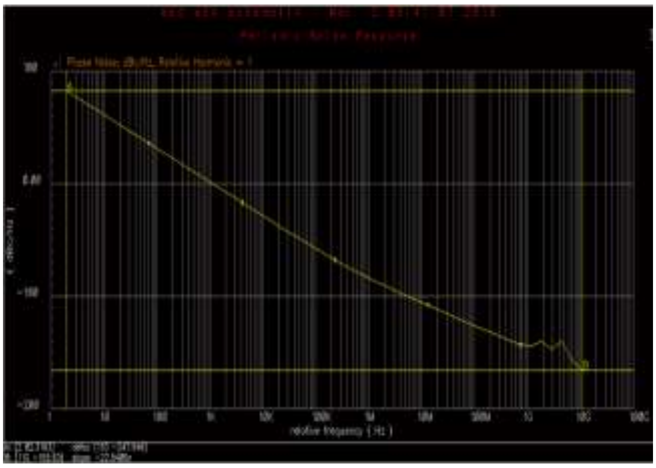

Fig.20. phase noise in the wide tuning-range.

It explores that the variation of the phase noise during 2.82Hz to 11GHz. is around -247.946dBc/Hz. Moreover, the oscillator has the reasonable phase noise below -165.53dBc even though the active inductors have the higher noise than the passive counterparts. Finally, this proposed circuit exhibits wider tuning-range, constant power consumption, and reasonable phase-noise.

IV. Conclusion

The tunable VCO based on CMOS active inductor are simulated in 130nm CMOS process. The simulation results of active inductor show that the circuit has wide inductive bandwidth and high resonance frequencies. The simulation result of VCO features lower power and better tuning range. The designed VCO is more suitable to design low power RF front end circuits.

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