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# Design of a New LC VCO using Active Inductor

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***Abstract*—** In this paper, a novel differential LC voltage-controlled oscillator (VCO) is presented. The VCO is based on the gm-boosted structure to relax the oscillation start-up current requirement and reduce the DC power consumption in comparison to conventional Colpitts structures. In the proposed VCO, a tunable active inductor is utilized as a part of LC tank instead of passive inductor with constant inductance. The proposed VCO is designed and simulated in ADS in a 0.18µm CMOS process. Simulation results indicate that the proposed VCO has a wide tuning range in comparison to other reported designs while consumes less DC power.

***Keywords*—** VCO, Ring, Phase noise, Frequency range

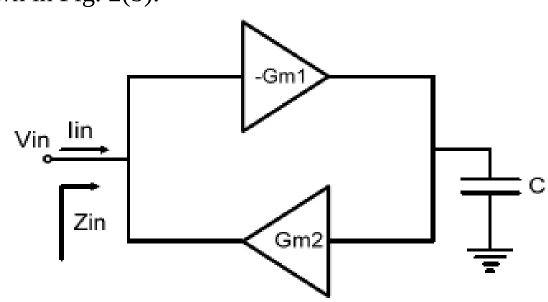
## 1. Introduction

Frequency of the voltage-controlled oscillators (VCOs) based on LC tank is tuned by changing the capacitance of the tank; because in a fully integrated architecture, changing the inductance value is not possible. Tunable capacitors are based on pn-junction varactors or accumulation-mode MOS varactors in which the value of capacitance is changed by tuning the DC bias of the varactor. However, the VCOs based on this kind of tuning system suffer from limited tuning range between 10%-30% [1], [2]. Using a tunable active inductor instead of passive one is a suitable choice to enhance the tuning range of the VCO. Today, tunable active inductors have attracted great attention in designing filters, phase shifters, VCOs, and injection-locked frequency dividers (ILFDs) [3]-[5]. At low gigahertz, passive inductors occupy large chip area and increase the cost. So, using the active inductor helps to achieve lower cost and wide tuning range chip. Although, the active inductor-based VCO has a wide tuning range, it has higher phase noise in comparison to its passive inductor-based one. But, due to the fact that this kind of VCO is the core of the wide locking range ILFD, designing an active inductor-based VCO should be taken into consideration [6], [7].

This paper presents the design procedure of a new differential Colpitts VCO based on active inductor. Simulation results indicate that the proposed VCO has a wide tuning range and high output power in comparison to other reported designs while consumes less DC power. The proposed architecture is capable to be used as the core of the wide locking range ILFDs.

## 2. Proposed topology

The block diagram of the active inductor based on the gyrator-C theorem is shown in Fig. 1(a). Two transconductors connected in back-to-back, form a gyrator. The transconductor in the forward path has a negative transconductance and the one in the feedback path has a positive transconductance. By replacing the common-source and common-drain architectures for the transconductors, the circuit level realization of the active inductor can be achieved as shown in Fig. 1(b) [8]. Mn and Mp act as current sources for biasing the circuit. But, this active inductor suffers from fixed low inductance, low quality factor, and limited tuning range. To enhance the performance of the circuit, an active tunable resistor (Rf) can be used at the gate of M2. This resistor consists of the parallel connection of a NMOS transistor MR and a passive resistor which its resistance is usually large (Fig. 2(a)) [9]. The resistance of the active tunable resistor can be controlled by changing the gate-source voltage of the parallel transistor. The tuning capability of the active resistor versus control voltage in 0.18µm CMOS process is shown in Fig. 2(b).




(a)

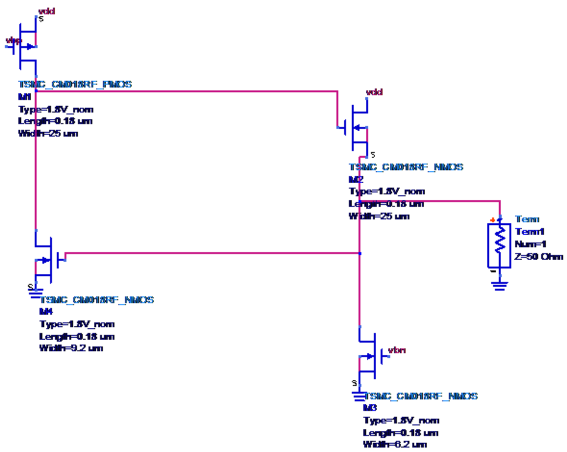



Fig. 1. (a) Block diagram, (b) circuit level realization

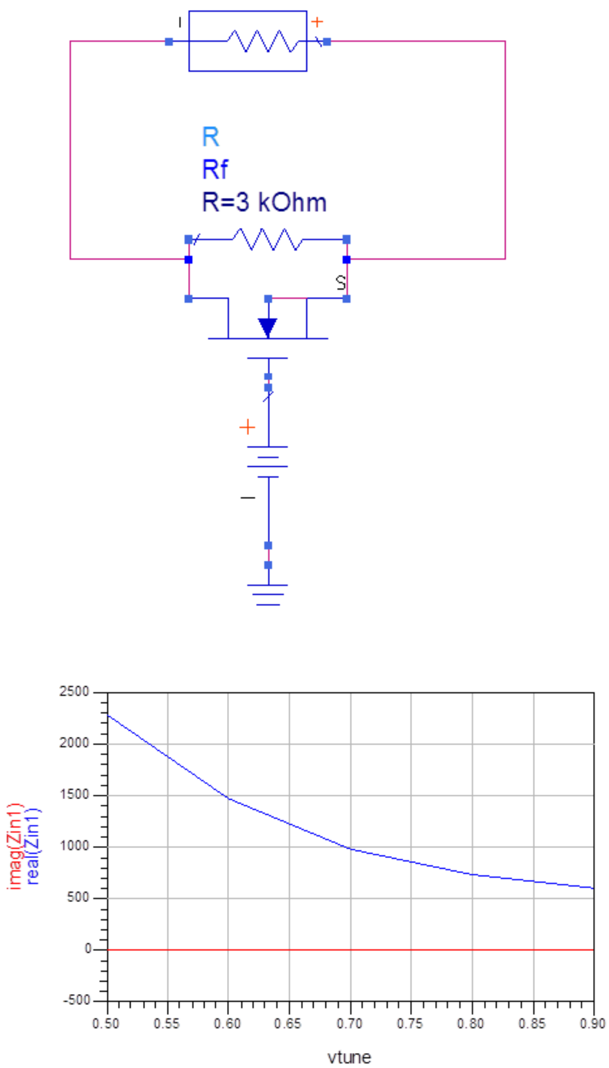



Fig. 2. (a) Active resistor structure, (b) tuning capability of the active resistor versus control voltage

As it is obvious from Fig. 2, the resistance will be decreased when $V_{tune}$ is increased. The equations of active inductor are as follows

$$R_{eq} = \frac{g_{dsp}}{\left(g_{m1}g_{m2} + g_{m2}g_{dsp} + g_{dsn}g_{dsp}\right)} \quad (1)$$

$$L_{eq} = \frac{C_{gs2}\left(1 + R_f g_{dsp}\right)}{\left(g_{m1}g_{m2} + g_{m2}g_{dsp} + g_{dsn}g_{dsp}\right)} \quad (2)$$

$$C_{eq} = \frac{C_{gs2}\left[g_{m1} + g_{dsp} + g_{dsn}\left(1 + R_f g_{dsp}\right) + C_{gs1}g_{dsp}\right]}{\left(g_{m1}g_{m2} + g_{m2}g_{dsp} + g_{dsn}g_{dsp}\right)R_{eq}} \quad (3)$$

The proposed VCO based on the tunable active inductor is shown in Fig. 3. In this circuit, transistors M1-M6 in conjunction with active resistors form a differential tunable active inductor to realize a fully differential VCO. The oscillation frequency of the VCO depends on the equivalent inductance of the active inductor, capacitors C1-C5, and parasitic capacitance of transistors M7-M10.

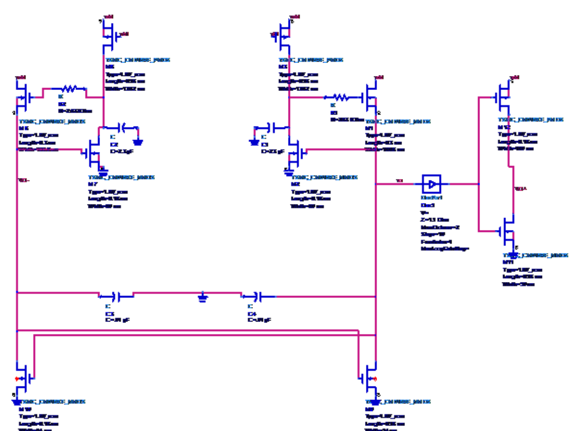


Fig. 3. The proposed VCO

The results of proposed VCO are shown in Fig 4 to Fig. 6. Fig. 4 shows the transient response of proposed VCO. One can see that the swing of output signal is 2 V and its shape is sinusoidal. The phase noise of proposed VCO is shown in Fig 5. The phase noise of proposed VCO is -131.8 dBc/Hz. The frequency range of this VCO is 0.3- 1GHz. Table 1 compares the resulte of prposed VCO with previous works.

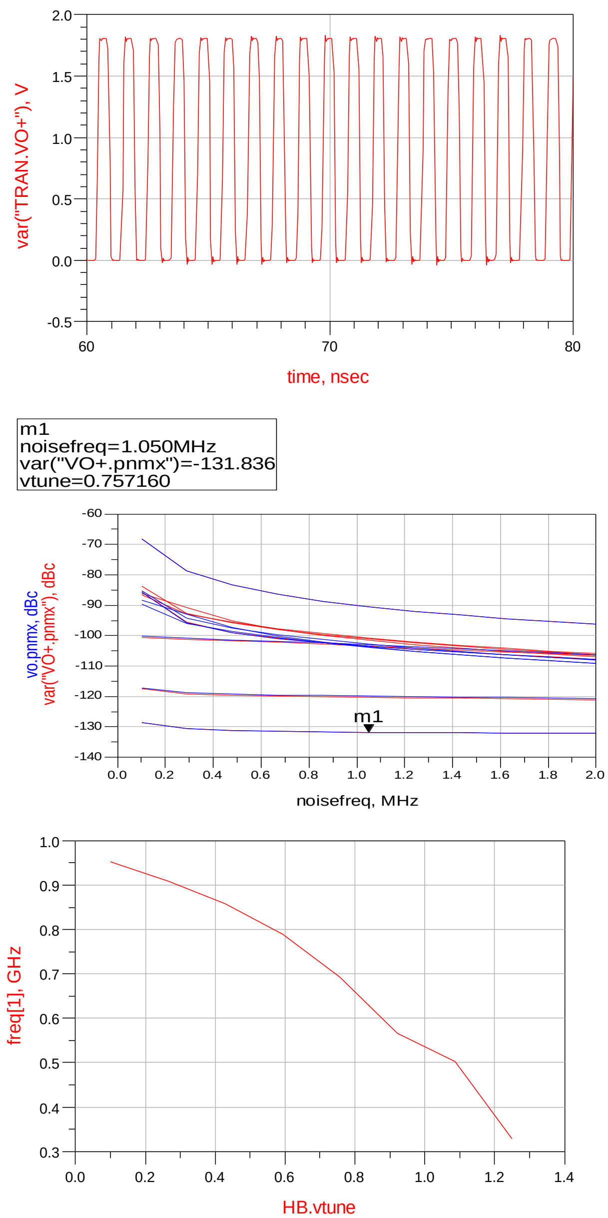



Figure 4

Table I. Performance comparison of the proposed VCO and recently works

| | [19] | [12] | [13] | [14] | This Work |
|---|---|---|---|---|---|
| Thechnology | 0.18 um CMOS | 0.18 um CMOS | 0.18 um CMOS | 0.18 um CMOS | 0.18 um CMOS |
| Supply Voltage | 1.8 V | 1.8 V | 1.8 V | 1.8 V | 1.8 V |
| Power consumption | 70 mW | 28 mW | 13.8 | 26 | 65 mW |
| Phase noise | -95 dBc/Hz | -101 | -78 | -88 | -131.8 dBc/Hz |
| Frequency range | 0.752-0.757 GHz | 0.5- 3 GHz | 0.5-2 | 0.4-1.6 | 0.3-1GHz |
| Control voltage | 0.5-0.9 V | - | - | - | 0-1.2 V |

## 3. Conclusion

A new wide tuning range Colpitts VCO in 0.18µm CMOS process is introduced in this paper. In order to achieve a wide tuning range and small die area, in this structure, a tunable active inductor is used as a part of LC tank. Simulation results indicate that the proposed VCO has a wide tuning range of 149% and is a good choice for design wide locking rang ILFDs.

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