

A 23.7 to 29.9 GHz Tunable Fully Differential Voltage Controlled Oscillator Designed in 180nm CMOS process

Karthik Kakaraparty and Ifana Mahbub
Department of Electrical and Computer Engineering
University of Texas at Dallas, Dallas, TX, USA
Karthikeya.Kakaraparty@UTDallas.edu

Abstract— This paper presents the design of a 23.7 to 29.9 GHz wide tuning range VCO (Voltage Controlled Oscillator) designed using a 180 nm CMOS process. In order to achieve a good phase noise performance and get a wide frequency tuning range, cross-coupling and gate biasing techniques are utilized in the proposed cross-coupled LC VCO architecture. The simulated phase noise of -130 dBc/Hz is achieved at a 1 MHz offset. With the supply voltage of 1.8 V, the total power consumption of the VCO is 32.04 mW. The proposed VCO has good performance in terms of low-phase noise and has a wide frequency tuning range, which makes it highly suitable for millimeter wave-based applications.

Keywords— VCO, fully differential oscillator, 180nm CMOS process, tunable oscillator, cross-coupled VCO, low phase noise.

I. INTRODUCTION

Recent advances in CMOS technology have made millimeter-wave (mm-Wave) circuitry more attractive for many interesting applications, including automotive radar, military applications, V2V (vehicle-to-vehicle) communications, and mm-Wave-based high-frequency power transfer applications. The circuit implementations based on CMOS (Complementary Metal-Oxide Semiconductor) technology appear to be particularly well suited for high-frequency applications over 20 GHz due to their high level of integration and the capability to achieve high data rates. Voltage-controlled oscillators (VCOs) are indispensable components involved in various mm-Wave based wireless communication systems. Low-phase noise with a widely tunable VCO is essential for this extensive mm-Wave based applications in which quality of communication is an essential criterion. The specific parameters such as low phase noise and wide oscillating frequency range are considered to be one of the most important factors which determine the performance of the designed VCO. In prior works, there were various methods that were used to enhance the phase noise performance [1-3]. For instance, Lin et al. proposed a transformer feedback topology that gave a better phase noise performance. However, due to the large parasitic capacitance of the transformer, the frequency tuning range is narrower [1]. There are a few prior works that implemented various methods to enhance the wide frequency tunability. Zhang et al. proposed an NMOS switched inductor-based architecture which results in a wide frequency tuning range, but large parasitic capacitance affects the overall performance in terms of phase noise and output power [3]. Most circuits have a limited supply voltage, which results in degrading the output amplitude and in turn results in a degraded phase noise performance. Several design methods and circuit

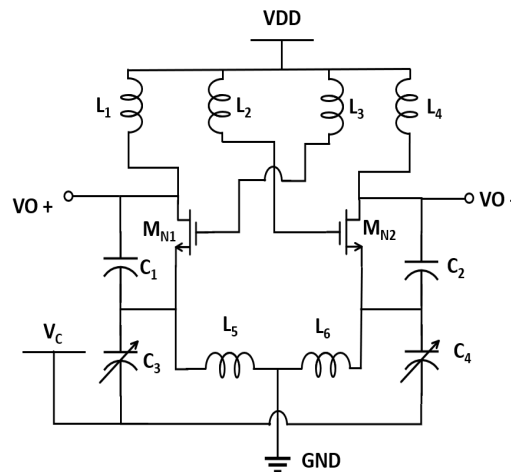


Fig. 1. Schematic of the proposed VCO.

technologies have been reported to solve these aforementioned problems [4-7]. Among these approaches, drain-source

Table I. List of components and their respective values.

Inductors	Value	Capacitors	Value
L_1, L_2, L_3 and L_4	154 pH	C_1, C_2	400 fF
L_5 and L_6	162 pH	C_3, C_4	340 fF

Table II. MOSFET parameters and region of operation.

MOSFET	Type	W/L	Operation region
M_{N1}	NMOS	$2.25\mu/0.18\mu$	Saturation
M_{N2}	NMOS	$2.25\mu/0.18\mu$	Saturation

transformer feedback is widely used to increase the amplitude of the output signal and to reduce phase noise. In this paper, a low phase noise and wide frequency tunable fully differential VCO are presented. The cross-coupling and gate biasing techniques were utilized in order to enhance VCO's performance with respect to phase noise and wide frequency range tunability. The circuit design and VCO performance results are discussed in Section II, and Section III respectively and the conclusion along with future works are presented in Section IV.

Table III. Comparison among prior works.

* The work presented in this paper is a simulation-based work

References	Technology	Supply Voltage (V)	Frequency Range (GHz)	Phase Noise (dBc/Hz)	Output power (dBm)	Power consumption (mW)
[4]	180 nm	1.8	22.20 to 24.20	-114	-10	13.92
[5]	65 nm	1	21.95 to 24.25	-100	-10	8.0
[6]	0.25 μ m	3	21.94 to 25.64	-120	-5.7	113.64
[7]	65 nm	1.3	22.00 to 24.50	-120	-8.0	31.5
*This work	180 nm	1.8	23.70 to 29.90	-130	-5.0	32.04

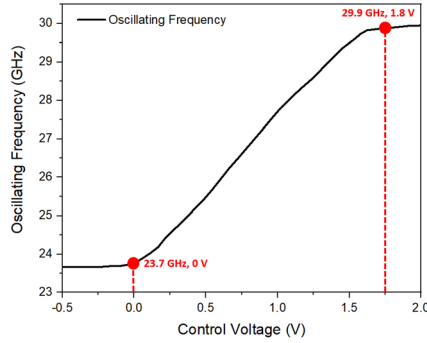


Fig. 2 Frequency tuning range of the proposed VCO.

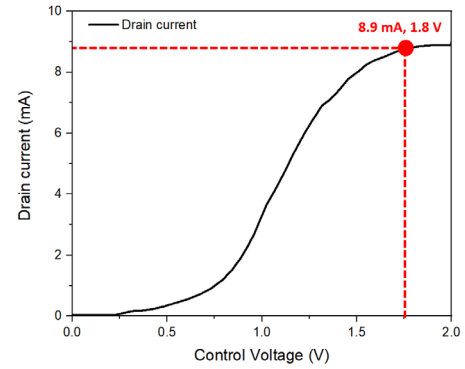
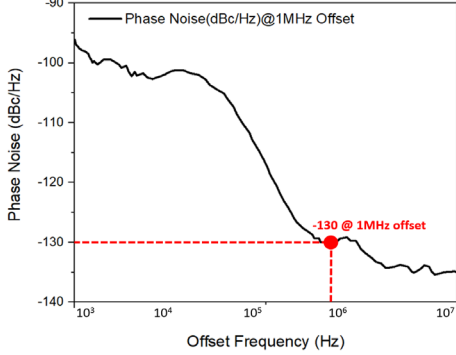
Fig. 5 I - V characteristics of the MOSFET.

Fig. 3 Phase noise vs offset frequency.

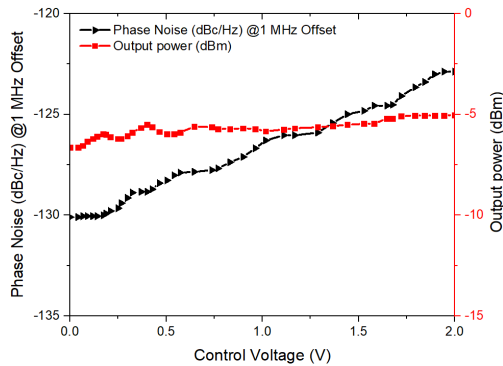


Fig. 4 Phase noise and output power variations with respective control voltage sweep.

II. CIRCUIT DESIGN

The schematic of the proposed fully differential cross-coupled VCO is shown in Fig. 1. The proposed VCO is designed using a standard 180 nm CMOS technology. To enhance the output swing which helps to attain the low phase noise value, four identical inductors (L_1 , L_2 , L_3 , and L_4) are used, among which L_1 and L_4 inductors are connected to the drain terminals and L_2 and L_3 are connected to the gate terminals of the transistors M_{N1} and M_{N2} , respectively which helps in forming the inductive couple pairs (L_1 , L_2) and (L_3 , L_4). As a result, high output swing and low phase noise can be attained.

The capacitor and inductor values used in the design are tabulated in Table I, and the transistor parameters are mentioned in Table II. For achieving a low-phase noise, M_{N1} and M_{N2} must operate in the saturation region. For M_{N1} and M_{N2} to operate in the saturation region and thus obtain a large output swing of the VCO, it makes sense to use an LC configuration to bias the NMOS, as shown in Figure 1. The design contribution of this work is to reduce the required supply voltage and eliminate the additional noise which arises due to the usage of current sources, the current sources are replaced with on-chip source inductors (L_5 and L_6). As the source and the drain inductors used are having an in-phase relationship the voltage swing at the drain end is boosted beyond the supply voltage.

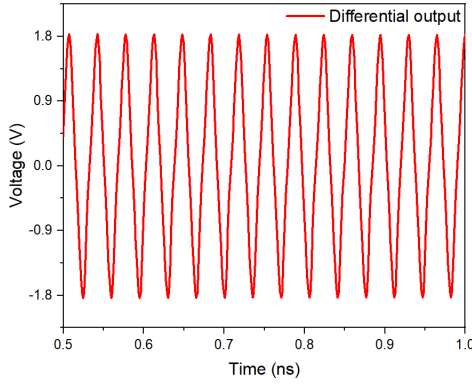


Fig. 5 Differential output of the proposed VCO.

In order to enhance the wide frequency tuning capability, the varactor capacitors were used at the source terminals on both sides as shown in Fig. 1. It is evident that on-chip source inductors are helpful in reducing the required supply voltage and thus facilitates low-phase noise. The proposed VCO is designed utilizing the cross-coupling and forward bias techniques so that it can operate well even with reduced supply and control voltages while maintaining good circuit performance with respect to low phase noise and amplitude of differential output swing.

The relationship between bias voltage and the maximum oscillation frequency can be expressed as:

$$V_c \leq VDD - \left(1 + \frac{1}{K}\right) V_{of} + V_{th} \quad (1)$$

Where, V_c is the control voltage, VDD is the supply voltage, K is the attenuation factor, V_{th} is the threshold voltage, V_{of} is the maximum oscillation frequency. The bias voltage plays a crucial role in achieving the highest amplitude for the differential output of the VCO.

III. RESULTS AND DISCUSSION

The oscillating frequency of the designed VCO has its ranges from 23.7 GHz to 29.9 GHz (Fractional bandwidth of 23.13 %) with an incremental sweep of control voltage value from 0 V to 1.8 V. The frequency tuning range as shown in Fig. 2 portrays the wide frequency tunability of the proposed VCO. The phase noise value of -130 dBc/Hz for the 1 MHz offset as shown in Fig. 3 determines the VCO has good low-phase noise. The phase noise and the output power (in dBm) responses respective to variation in the control voltage are shown in Fig. 4. The low phase noise value of -130 dBc/Hz and output power – 5 dBm indicates that the proposed VCO performs well in the high frequency of 23 to 30 GHz.

With the supply voltage of 1.8 V, the proposed VCO has a total power consumption value of 32.4 mW, and the differential

output voltage swing is 3.6 Vpp (peak to peak voltage) as shown in Fig. 5, which indicates the theoretically expected output amplitude and is the reason for attaining a good low phase noise value. The lower the phase noise value the better the VCO performs. The wide frequency tuning range of the proposed VCO which is from 23.7 GHz to 29.9 GHz is indeed necessary for extensive mm-Wave based advanced applications. This indicates the proposed VCO is suitable for high-frequency applications that require a wide frequency range. The comparison among prior works is tabulated as shown in Table III. When compared with similar prior works the proposed VCO design has a better low phase noise value of -130 dBc/Hz at 1 MHz offset frequency and a wide frequency tuning ranging from 23.7 GHz to 29.9 GHz. This designed VCO is intended for utilization in front-end circuit for providing signal input to the beamforming phased antenna array proposed in Kakaraparty *et al.* [8].

IV. CONCLUSION

A 23.7 GHz to 29.9 GHz wide frequency tunable fully differential VCO, which has a considerably low phase noise value (-130 dBc/Hz) at 1MHz offset, designed using 180 nm CMOS technology is presented in this paper. The desired output differential voltage swing facilitated the enhancement of phase noise parameters to a significant level. The wide frequency tunability of the proposed VCO indicates its suitability for high-frequency-based mm-Wave applications. As a future work, we plan to fabricate the proposed design to have a thorough analysis between measured and simulated performance parameters.

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