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Dual Band Switchable Voltage Controlled Oscillator in 65-nm CMOS Technology

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***Abstract*-- A switchable differential voltage-controlled oscillator (VCO) has been fabricated in 65nm CMOS. It is a dual frequency VCO whose oscillation frequencies can be changed from 40GHz (VCO1) to 80GHz (VCO2). The tuning range for VCO1 is 1GHz and for VCO2 is 4GHz. The inductor switching is attained with the help of transistor as a switch and inductors are fabricated in a stacked manner for saving die area. The output power of VCO1 is 1 dBm and for VCO2 is 0dBm with a total power consumption of 42mW. The phase noises were -94.62 dBc/Hz and -81.43 dBc/Hz at 1MHz offset for VCO1 and VCO2 respectively. The chip area is 500 x 560 um^2 including probing pads.**

***Keywords*- Switchable, voltage-controlled oscillator (VCO), CMOS, phase noise**

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I. Introduction

THE signal sources play a vital role in either analog or digital SIGNAL systems. In recent studies, the PLLs for W and D band have been realized in 65nm and 0.13um [1,2]. For V and W band, no such type of VCOs is observed. In designing of VCO normally two approaches are used one is fundamental oscillator and other one is harmonic oscillator either 2nd harmonic or higher order. After designing the oscillator there are many factors that affect the performance of an oscillator like phase noise, low output power and spurs [3,4]. The circuit components other than transistors are also contributing for performance degradation. Due to low quality factor of varactors the oscillation frequency decreases from estimated theoretical value. The quality factor of inductor and line losses are also degrading the performance of an oscillator not only in terms of frequency but also in terms of output power. The process variations and temperature are also the parameters who add alterations in the circuit performance [5]. More than 100 GHz oscillation frequency has been achieved already in several VCOs with variety of circuit topologies.

In this paper, we proposed a cross coupled differential VCO with no capacitor for frequency tuning. The transistors are being used as a varactor for tuning output frequency in this VCO. This is dual band VCO for W and D band.

This work is arranged as follows. The circuit description of proposed VCO is illustrated in Section II. Section III summarizes the experimental results of the proposed work.

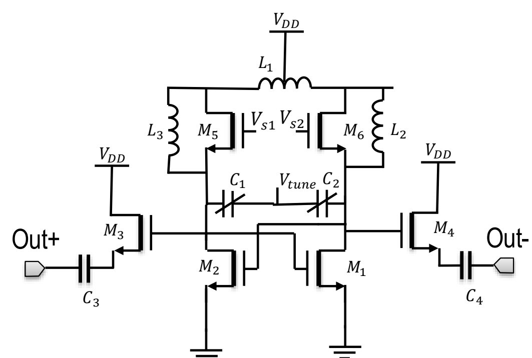

Fig. 1. Schematic of proposed dual band switchable VCO

Finally, Section IV includes the conclusion of this work.

II. Circuit Description

Fig. 1 shows the schematic of proposed VCO. The cross coupled technique is used for base oscillator.

A. Methodology

The cross coupled oscillator working principle is stated that the real part of oscillator core circuit's impedance or negative transconductance (g_m) of the transistor must be higher enough for both frequencies (for dual oscillator) to compensate the real part of impedance or loss of the resonator to meet the 1st oscillation condition. The imaginary part of the impedance of core circuit should be equal and negative to the imaginary part of the resonator for 2nd condition meet up.

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The required minimum transconductance is given as:

$$g_m = \frac{1}{R_p}$$

Where R_p is the loss of the resonator and g_m is the transconductance of the core circuit [6].

The oscillation frequency of the oscillator can be estimated from the below mentioned expression:

$$\omega_{osc} \approx \frac{1}{\sqrt{L_1 + L_2 + L_3(C_1 + C_2)}}$$

The M_1 and M_2 with gate width of 36 um are used for core circuit. The ω_{osc} will vary due to change in inductor values which depends on the switch selection either for 40GHz or for 80GHz.

B. Circuit Design

The transistors with shorted drain and source are used as varactors whose labels are C_1 and C_2 with 20 um gate width. The M_3 and M_4 are worked as source follower for output termination. The gate width for source follower transistors is 20 um. The output capacitors C_3 and C_4 with source follower are having value of 800fF with metal insulated metal (MIM) design configuration. These capacitors are designed with OA top metal layer which is less lossy as compare to other metal layers. The capacitance value of different widths of transistor with respect to tuning voltage is depicted in Fig. 2. Fig. 3 shows quality factor of varactors with respect to tuning voltage. This is the reason for selection of 20 um gate width for wider tuning range.

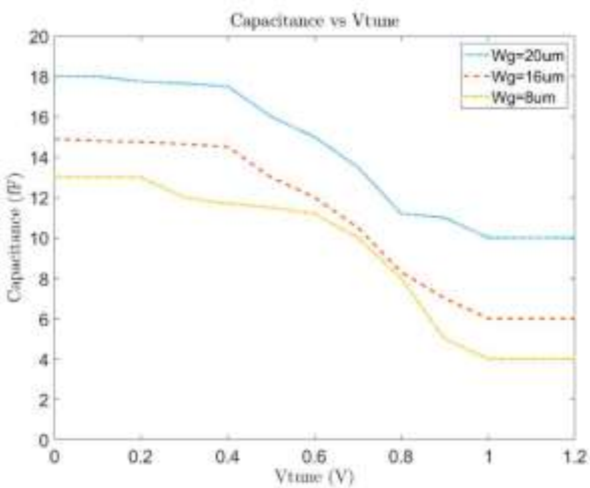

Fig. 2. Variation of different gate width capacitances w.r.t tuning voltage

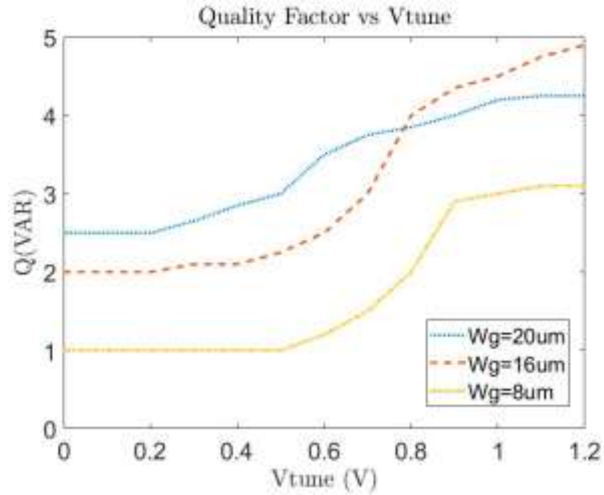

Fig. 3. Varactors quality factor w.r.t tuning voltage variation

The core circuit is leading the switching circuit which is used for inductor switching. The 1st switch V_{sw1} is used for small oscillator with large inductor whose output frequency is 40 GHz and 2nd switch V_{sw2} is utilizes the small inductor for high frequency oscillation with 80 GHz output. The M_5 and M_6 are used with gate width 20 um for switching purpose.

The L_1, center tapped inductor is designed separately with inductance of 40 pH and it is utilized in both VCO modes. The L_2 and L_3 are designed in stacked fashion for saving die area with values of 20 pH and 70 pH respectively.

The micro-photograph of the dual band VCO with probing pads is portrayed in Fig. 4 with a die area of 500 x 560 um^2.

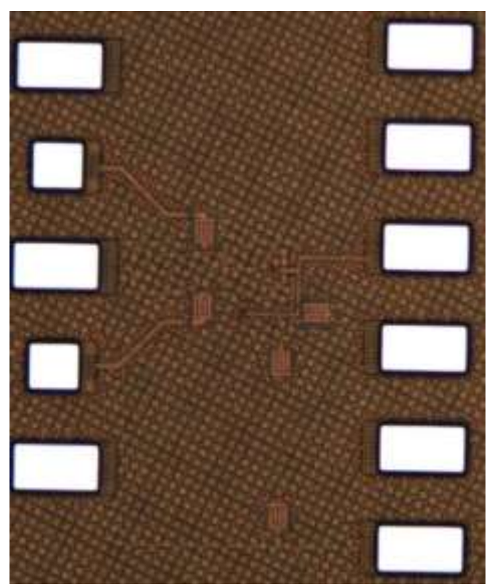

Fig. 4. chip microphotograph of proposed dual band VCO

III. Experimental Results

The proposed VCO is simulated with EM momentum setup in ADS design tool. The schematic is designed in Spectre (Cadence) with 65nm CMOS process design kit. The two different oscillation frequencies are observed with switched VCO characteristics. 80GHz with output power of 0dBm is

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achieved with switch 1 and inductor L_2, sensitivity of VCO w.r.t time is shown in Fig. 4 with a tuning range of 4GHz .

Table 1: Performance Comparison with Prior Dual Band VCOs

Ref #	[10]	[11]	[12]	This work
Freq (GHz)	45/60	24/60	38/19	40/80
Tech.	0.25um BiCMOS	0.13um CMOS	0.25um BiCMOS	65nm CMOS
PN@1M (dBc/Hz)	-99/-93 (@10M)	-120/-114 (@10M)	-106.8/-112	-94/-81
Pdc (mW)	32.5/17.5	24/11	105.6/69.3	42
FOM_{PN}	158/156	177/176	178/180	170/163

$$FOM_{PN} = -L(\Delta f) + 20\log\frac{f_{osc}}{\Delta f} - 10\log\frac{P_{dc}}{1mW}$$

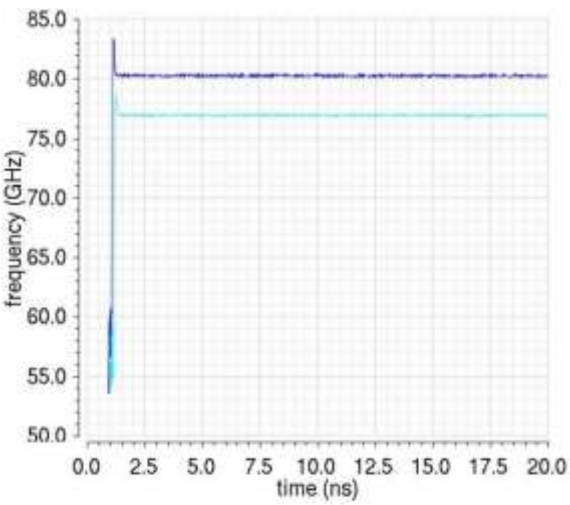

Fig. 4. Output Frequency sensitivity w.r.t time for 80GHz VCO

Similarly, 40GHz can be obtained with switch 2 and inductor L_1 as described in Fig. 5. The tuning range for 40GHz is 1GHz and it can also be observed in Fig. 5.

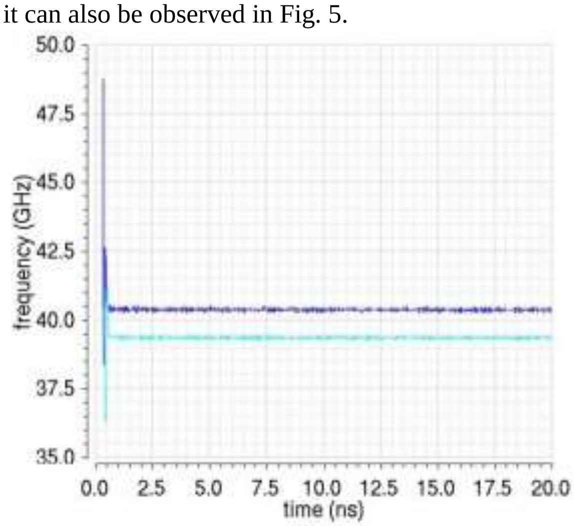

Fig. 5. Output Frequency sensitivity w.r.t time for 40GHz VCO

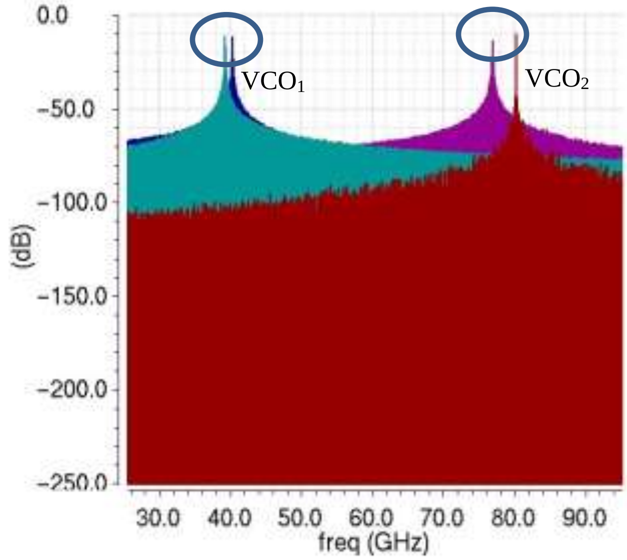

Fig. 6. Frequency spectrum for both VCO_1 and VCO_2

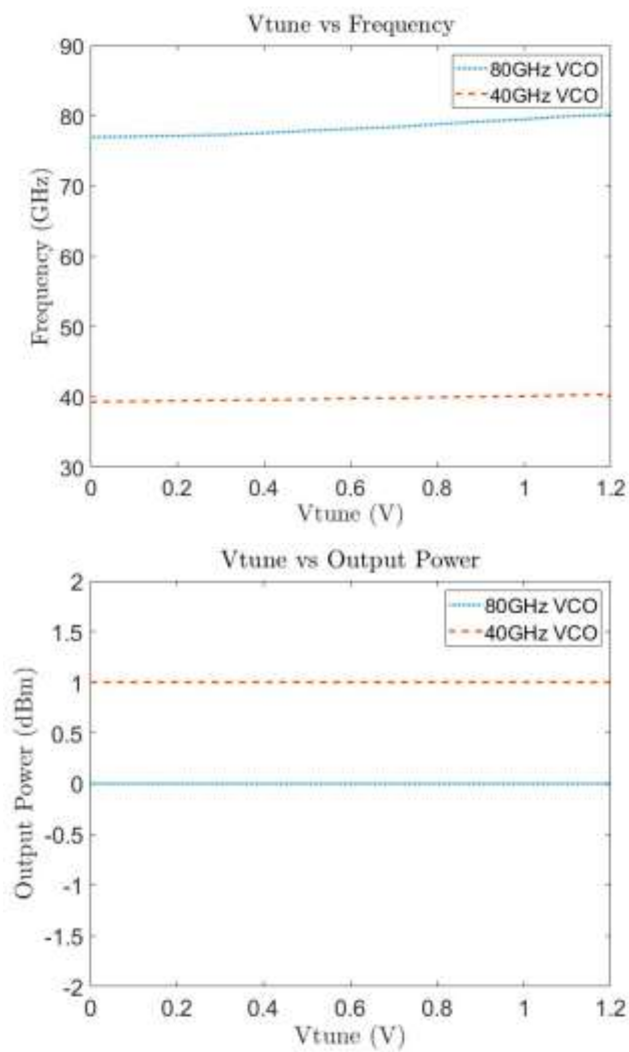

Fig. 7. Tuning range for both VCO_1 and VCO_2 w.r.t tuning voltages

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Fig. 8. Output power for both VCO_1 and VCO_2 w.r.t tuning voltages

The frequency spectrum for both VCO modes can be seen in Fig. 6 and it is also verifying the results of Fig. 4 and Fig. 5.
The tuning range of output frequency and output power of output signal are also plotted w.r.t tuning voltage in Fig. 7 and Fig. 8 respectively.
The phase noise is the most important parameter of an oscillator and it is necessary to illustrate phase noise for both modes of VCO and it is shown in Fig. 9 with reasonable phase noise of -94.62 dBc/Hz and -81.43 dBc/Hz at 1MHz offset for VCO_1 and VCO_2 respectively.
Table 1 compares the performance with state-of-the-art dual band VCOs. For comparison, the figure of merit considering phase noise (FOM_{PN}) is used. The proposed VCO achieves superior FOM_{PN}.

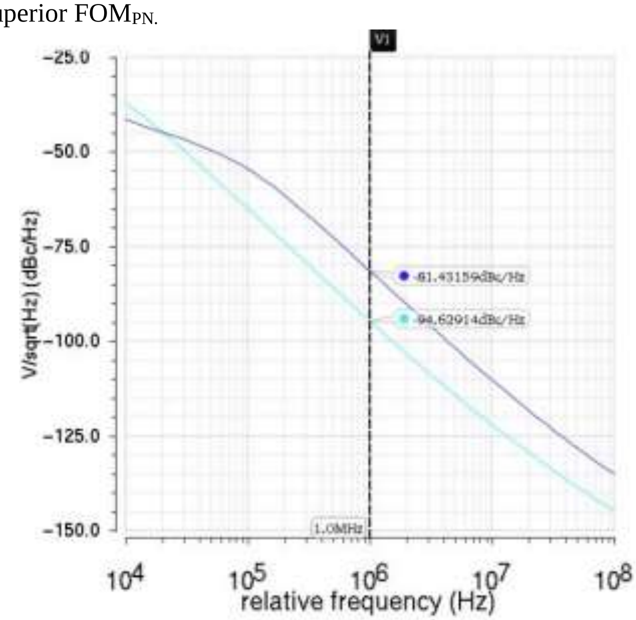

Fig. 9. Phase noise for both VCO_1 and VCO_2 at offset of 1 MHz

IV. Conclusion

The implemented dual band VCO has been presented with 40 GHz and 80GHz output frequencies. Inductor switching using transistor and transistor-based varactors are implemented in this work. The low power consumption with 0 to 1 dBm output power is observed for both modes of VCO.

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