Transformer Tuned VCO for MMW Application

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ABSTRACT
Differential cross coupled voltage controlled oscillator with transformer tuning is presented here for millimeter wave (mmw) application. Here Tuning is done by on chip octagonal transformer which is used as inductive element in LC tank. Proposed scheme provides wide Frequency Tuning Range (FTR) up to 7 GHz of bandwidth and gives low phase noise as compared to inductor based oscillator design. In this method transformer tuned VCO is implemented in UMC 65 nm CMOS Technology which gives FTR from 55 GHz to 62.4 GHz with phase noise variation -116.5 to -114.5dBc/Hz at 10 MHz offset.

Keywords
Phase noise, quality factor, Tuning range VCO, mmw

1. INTRODUCTION
In modern wireless communication there is a big requirement to increase the speed of system and Voltage controlled oscillator (VCO) [7] is the most critical and important building block of wireless communication system, in which difficult task is to get mmw frequency with wide tuning range and low Phase Noise (PN). There are so many techniques have been adopted to increase the operating frequency and tuning range of voltage controlled oscillator with low phase noise performance. To gain better phase noise performance LC type of voltage controlled oscillator is being used, but it has narrow tuning range and also mmw frequency generation is a major issue. To get millimeter-wave (mmw) band conventionally, a MOS Varactor in accumulation mode is used in LC type VCOs for frequency tuning [6]. In general to increase the Frequency Tuning Range (FTR) of oscillator multiband operation is normally adopted with reduced VCO gain. To achieve that multiband operation capacitive tuning is being employed which is done by switched capacitor bank, but there are some limitations of capacitive tuning that are produces parasitic capacitance which becomes too large in capacitor bank and also gives low quality factor of capacitor. Now a days new inductive tuning is a substitute of capacitive tuning and it is being used by loaded transformer [1] [9]. Inductive tuning has another advantage that it isolates DC noise from tuning element and have high quality factor.

Rest of the paper is organized as below. Section 2 describes the principle of inductive tuning upon which proposed topology is presented, proposed inductive tuning scheme and EM simulated results are given in section 3, section 4 describes VCO design, simulation results are being presented in section 5, section 6 contains conclusion acknowledgement is provided in section 7 and section 8 gives references.

2. TRANSFORMER TUNING METHOD
Principle Behind the inductive tuning [8][9] is explained in Fig 1 Transformer is assumed to be ideal with L1 and L2 as the self inductances of primary and secondary respectively, k is the coupling coefficient of transformer, Leff is total inductance of the transformer and Cf is the tuning capacitance which includes Varactor and other parasitic capacitance.

Equivalent circuits Leq and Req can be calculated as

\[ L_{eq} = L_1 + \frac{R^2[1-\alpha^2CL(1-k^2)]^2 + \alpha^2L_2^2(1-k^2)^2}{R^2[1-\alpha^2CL(1-k^2)] + \alpha^2L_2^2(1-k^2)} \] (1)

\[ R_{eq} = \frac{R^2L_2[1-\alpha^2CL(1-k^2)]^2 + \alpha^2L_2^2(1-k^2)}{Rk^2L_1} \] (2)

Now the Oscillation Frequency is

\[ \omega_0 = \frac{1}{\sqrt{C_L\omega_{eq}}} \] (3)

3. PROPOSED TRANSFORMER RESONATOR
In the proposed type of inductively tuned VCO design Octagonal transformer is used which is implemented in top metal (m9). Single turn transformer is designed for the sake of simplicity with width of 4 um and spacing between primary and secondary being 2.5 um. To provide multiple band operation proposed transformer uses MOS switches at primary and secondary of center tapping of the transformer. As shown in fig.2 equivalent model of transformer with MOS switches at primary and secondary center tapping is given. Simple MOS transistors are used as switches in the circuit. Z1 and Z2 are the modeled impedances of switches at primary and secondary center tapping respectively. Here the design of transformer is EM simulated in VPCM (Virtuoso passive component designer) which is integrated in Cadence 5.1.41.Fig 3, Fig 4 and Fig.5 gives the layout of octagonal transformer and plot of the transformers primary and secondary inductance for different operating frequencies respectively.

4. TRANSFORMER TUNED VCO
The schematic of our transformer tuned VCO design is shown in Fig 6. It consists of two complementary cross coupled differential pairs. Here the performance of this circuit was implemented in a standard 65 nm CMOS process. This schematic has been chosen because it provides better isolation from the voltage supply and better noise performance.

In the proposed circuit the double cross coupled NMOS (M1, M2) and PMOS (M3, M4) differential pair provides the negative resistance to cancel losses coming from LC tank. MOS transistor in the circuit are biased in such a way that
resulted transconductance of each of the cross coupled pair is 
equal that is \(-gm/2\) and hence total transconductance of the 
circuit will be \(-gm\). That total transconductance \(-gm\) is the 
negative resistance of the circuit to compensate the loss 
associated with LC tank. Advantage of use of double cross 
coupled pair is that less current is used by the circuit that 
results in lower power consumption. In the proposed circuit 
design 4 PMOS Varactor is used to tune the different. 
Frequency band obtained from switching ON and OFF the 
NMOS switches connected at the center tapping position of 
the octagonal transformer. By switching ON/OFF switches 
we get three bands of frequency for mmw application. Main 
function of the switches in this circuit is that while switching 
ON/OFF a switch, current will flow in that coil which then 
induced in secondary coil so the effect is that total inductance 
\((Leq)\) and resistance \((Req)\) will get change according to the 
equations presented in section 2 depending on the positions of 
switches.

5. SIMULATION RESULTS

Proposed circuit is simulated in cadence virtuoso 5.1.41 and 
EM simulation of transformer is carried out in VPCM 
(Virtuoso Passive Component Designer). The circuit generate 
stable periodic signal. The results obtained from the 
simulation of the Transformer based LC tank VCO design 
show that the phase noise have been drastically reduced. Fig 7 
shows the variation of phase noise at frequency of 62.33 for 
the offset of 1 KHz to 10 MHz and fig 8 give plot for FTR. 
To compare the performance of previously published 
oscillators, and FOM (Figure of merit) we have used method 
by Ham and Hajimiri [8], It is defined by equation (4)[2]:

\[
FOM = PN - 20\log(\frac{f_0}{\Delta f}) + 10\log(\frac{P_{diss}}{mW})
\]

(4)

Where \(\Delta f\) is the offset frequency, \(f_0\) is the oscillating 
frequency, \(PN\) is the phase noise at the offset frequency and 
\(P_{diss}\) is the power dissipation of the VCO.

Table I summarizes VCO performance and comparison with 
other wideband VCO

6. CONCLUSION

In this work a transformer based LC tank VCO is designed 
and analyzed for mmw application with the advantage of wide 
FTR and low phase noise from variation -116.5 to -114.5 
dBC/Hz at 10 MHz offset for the tuning range of 55 GHz to 
62.4GHz. Figure of merit (FOM) obtained is from -182.8239 
dBC/Hz to -181.4564 dBc/Hz. Here at 1.1 V power supply 
average power is 13 nW.
Figure 6 Transformer tuned VCO

Figure 7 measured phase noise of transformer tuned VCO at 62.3 GHz

Figure 8 Tuning range of proposed VCO with change in control voltage from 0.5v to 1v

Table I Performance summary and Comparison

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Tech.</th>
<th>Centre Freq.(GHz)</th>
<th>TR.(Tuning range)</th>
<th>PN Ref Freq.</th>
<th>PN@10MHz dBc/Hz</th>
<th>Power (mw)</th>
<th>FOM (dBc/Hz)</th>
<th>Vdd(V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3]</td>
<td>90 nm CMOS</td>
<td>61.7</td>
<td>4.9%</td>
<td>61.7</td>
<td>-110</td>
<td>1.2</td>
<td>-185</td>
<td>1.2</td>
</tr>
<tr>
<td>[4]</td>
<td>130 nm</td>
<td>62.1</td>
<td>10%</td>
<td>62.1</td>
<td>-115</td>
<td>3.9</td>
<td>-185</td>
<td>1.0</td>
</tr>
<tr>
<td>This work</td>
<td>65 nm</td>
<td>58.7</td>
<td>12.6%</td>
<td>62.3</td>
<td>-114.66</td>
<td>13</td>
<td>-189.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

7. ACKNOWLEDGMENTS
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8. REFERENCES


