A 0.5V 2.4GHz Low Power Cross-Coupled Voltage Controlled Oscillator for a BLE Receiver

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1. Abstract

This work presents the design of a voltage controlled oscillator (VCO) based on cross-coupled topology, which is part of a Bluetooth 5.0 receiver, for bluetooh low energy (BLE) mode operation. The VCO is implemented in 130nm CMOS technology with regular VT, and a 0.5 V supply. Furthermore, an analysis of the design equations and performance parameter is made in order to justify its implementation.

2. Introduction

With the continuous growth of handheld devices, the design of an entire system on chip (SoC) is becoming very important nowadays. To satisfy this demand, low voltage and low power design are usually required, as these devices operate with limited battery power and often low voltage sources, like energy harvesting devices.

A main block in a Radio-Frequency (RF) system is the VCO, that can controls its oscillation frequency through a reference voltage. This block deals with trade-off between power and phase noise, that can causes huge problems in RF system when this noise occurs into signal frequency band.

In order to use this VCO project in a BLE 5.0 core it is necessary follow the system specifications, e.g., the regulatory frequency range between 2.4-2.4835 GHz and the 1 MHz RF channels spacing [1]. With these informations the VCO design must generates frequencies from 2.4 GHz to 2.4835 GHz at least, and generates the smallest phase noise possible, under -75dBc/Hz at 1 MHz for the Local Oscillator (LO) [2], to prevent the signal from one channel invades the other channel. Also, to meet the low power specification, this project uses a 0.5V supply.

3. Cross-Coupled Topology

The response of an ideal LC tank to an impulse is an infinity oscillation at the resonant frequency (f_{osc}) that occurs when

$$f_{osc} = \frac{1}{2\pi * \sqrt{L*C}} \quad (1)$$

Where L and C are the inductance and capacitance of the tank respectively. Unfortunately the process fabrication of real devices deals with parasitics issues, causing attenuation and vanishing the signal. This parasites are represented in the quality factor (Q) of the device, and its importance for design will be discussed later.

The main characteristic of the cross-coupled topology is create a negative resistance and replenish the energy dissipated in the device parasites. Also, thanks to its differential topology, has a robust operation becoming the most chosen topology [3].

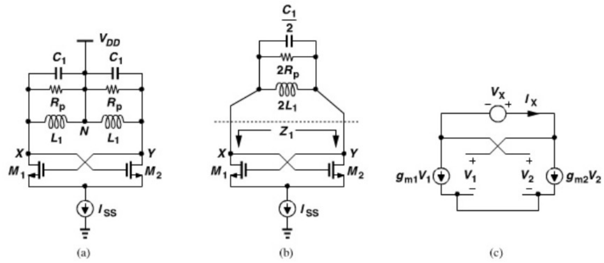

Fig.1.*(a) Redrawing of cross-coupled oscillator, (b) load tanks merged, (c) equivalent circuit of cross-coupled pair*

From Fig.1 is possible to determines the impedance seen by the tank (Z1), where Rp is the parallel parasite resistance associated to the capacitor and inductor, and g_m is the transconductance of the transistors. For $g_{m1} = g_{m2} = g_m$ we have

$$\frac{V_X}{I_X} = \frac{-2}{gm} \quad (2)$$

As previously discussed, to ensure oscillation this negative resistance must cancel the loss of the tank generated by 2*Rp. It occurs when

$$g_m \geqslant \frac{1}{Rp} \quad (3)$$

Unfortunately only the equation (3) do not guarantee the oscillation. For large output voltage swing those transistors can switch completely, leading gm to falls below 1/Rp for part of the period, not being able to sustain the oscillation [3].

Another important point that can be seen from equation (3) is about the Q factor of the tank. As Q increases, Rp also increases, and so, a lower gm value is necessary to achieve oscillation. Thus, it is possible to achieve oscillation with less current, which leads to less power consumption.

Fig.2. shows the schematic used in this project. The frequency oscillation, from equation (4), depends on the

tank capacitor (Cp), the inductor (Lp), the parasitic capacitances of transistors M0 and M1 formed for C_{GS}, C_{DB} and C_{GD}, and the varactor's capacitance (CVAR), which depends on the control voltage applied at the terminal.

$$f_{osc}=\frac{1}{2\pi\sqrt{Lp*\left(Cp+C_{VAR}+C_{GS}+C_{DB}+C_{GD}\right)}} \quad (4)$$

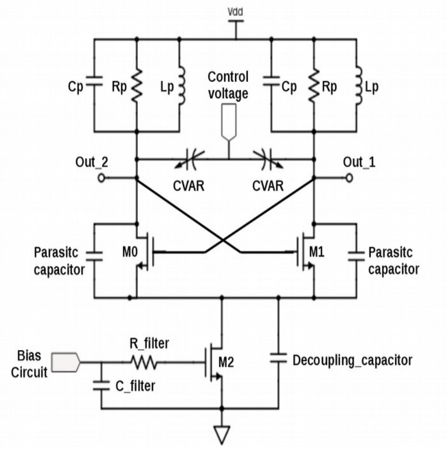

Fig.2.*Cross-Coupled VCO schematic*

The M2 transistor generates the current bias to achieve the desired gm at M1 and M2. The decoupling capacitor shunts the noise generated by the oscillation, maintaining the voltage across M2 constant. Also, to prevent noise generated from oscillation flows to the bias circuit, a RC low pass filter formed for R_{filter} and C_{filter} is used.

Reference [4] shows that is possible predict the VCO phase noise using the Leeson's Phase Noise Model. A quick analysis in equation (5) shows that is possible achieve lower phase noise if use devices with higher Q,

$$L(\Delta w)=10\log\left[\frac{2FKT}{P_{sig}}\left(1+\left(\frac{wo}{2Q\Delta w}\right)^2\right)\left(1+\frac{\Delta w_{1/f^3}}{|\Delta w|}\right)\right] \quad (5)$$

Where $L(\Delta\omega)$ is the phase noise, $\Delta\omega$ is the frequency offset, ω_0 is the central frequency, P_{sig} is the signal power, K is the Boltzmann constant, T is the temperature in kelvin and F is a correction factor to account the increased noise in the $1/(\Delta\omega^2)$ region.

4. VCO Design Results

This section presents the VCO design results based on cross-coupled topology for Bluetooth 5.0 core.

The Bluetooth 5.0 core operates with a frequency range from 2.4 GHz to 2.4835 GHz. To attend this specification the varactor must be able to produce a capacitance variation, varying the control voltage from 0 to 0.5 V, capable to tune the tank in a range of 83.5 MHz from the central frequency (2.4 GHz). Fig.3 shows that this topology reaches an oscillation frequency range from 2.385 GHz to 2.503 GHz.

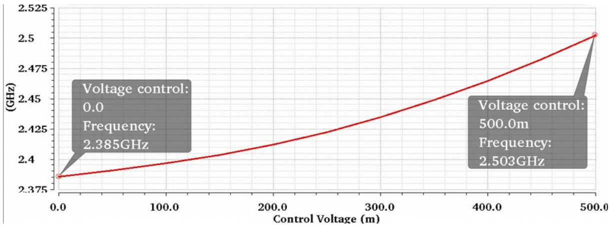

Fig.3. *Frequency oscillation controlled by voltage*

Other specification that has previously discussed is the phase noise. Fig.4 shows a phase noise of -90.64 and -111.8 dBc/Hz at 100KHz and 1Mhz respectively from center frequency.

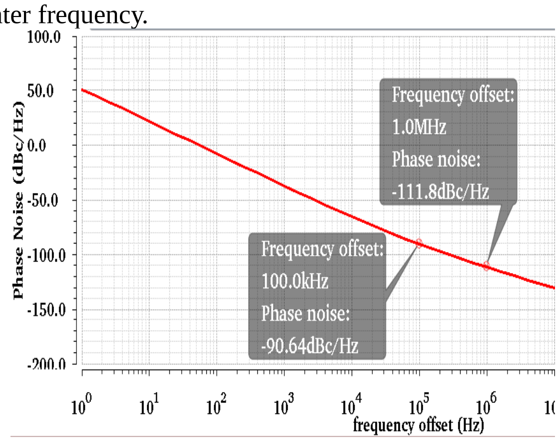

Fig.4.*VCO Phase Noise*

5. Conclusions

The main idea of this work is to analyze the feasibility of using a low voltage cross-coupled VCO with a BLE 5.0 core. Observing the obtained results we can conclude that is possible to use this topology to achieve the specification, using a 0.5V supply and 1 mA DC current.

References

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