InGaP/GaAs HBT 기반의 필터 기술을 이용한 차동 LC 전압조절발전기의 분석 및 최적화

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Analysis and Optimization of Differential LC VCO with Filtering Technique in InGaP/GaAs HBT Technology

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Abstract : In this paper, differential cross coupled LC VCOs with two noise frequency filtering techniques are proposed. Both VCOs are based on symmetric capacitor with asymmetric inductor tank structure. The VCO using low pass filtering technique shows low phase noise of -130.40 dBc/Hz at 1 MHz offset when the center frequency is 1.619 GHz. And the other VCO using band pass filtering technique shows -127.93 dBc/Hz at 1 MHz offset frequency when center frequency is 1.604 GHz. Two noise frequency filtering techniques are approached with different target.

Key Words : Filtering technique, heterojunction bipolar transistor (HBT), phase noise

1. Introduction

Integrated Voltage Controlled Oscillators (VCOs) are important blocks in today's radio frequency communication systems. Efforts to improve the phase noise performance of integrated LC VCOs have resulted in the use of differential topology. The differential pair of bipolar transistors is the common building block in modern RF integrated circuits. One advantage of this architecture is its high loop gain making it popular for differential VCO designs in RFICs. Hybrid VCO circuits are usually produced using the more traditional Colpitts design, avoiding the added complexity of the differential VCO configuration. Because of its primary usage in proprietary RFICs, only limited differential VCO design and modeling information are available. In this paper, fully differential LC VCOs using noise frequency filtering structure for AF-ICS applications, which have low current consumption and low phase noise, are presented [1].

2. Design of Precision Subminiature Adaptor

The VCOs implemented in this work consist of a symmetric capacitance and asymmetric inductance tank, a negative resistance and a pair of emitter follower buffers. The core circuits of VCOs are shown in Fig. 1 and Fig. 2. To reduce the 1/f noise, a cross-coupled differential structure with capacitive coupling feedback is used to realize the VCO. The cross-coupled transistors (Q3 and Q4) form a positive feedback loop in providing a negative resistance which cancels the loss in the LC-resonator. This loop increases the loop gain through the capacitors and thereby acts to suppress the up and down-conversion noise as well

as to block the dc bias of the cross-coupling transistors. The VCO core is isolated from the load impedance (50Ω) by means of two buffers. The source of the current mirror provides constant current to the differential VCO core. Also, low current consumption in the core circuit is maintained by optimizing the emitter fingers of the core transistors. Thus, it is possible to get the required output swing with this transistor arrangement. Furthermore, to obtain low phase noise performance, the high Q tank is optimized; this is the most important aspect of the oscillator design.
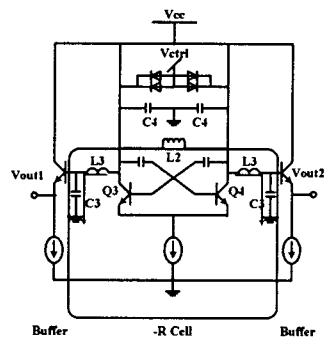

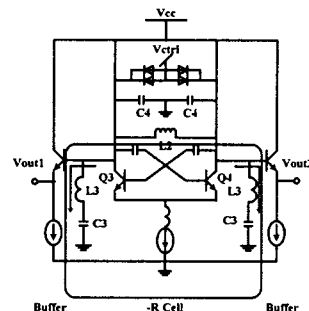Figure 1. VCO using low pass filtering

Figure 2. VCO using band pass filtering

3. Buffer Design

The buffer stage is another important factor that impacts the maximum attainable frequency of oscillation. Generally, buffer stages are implemented as emitter followers due to their high input impedance and wide bandwidth. Fig. 3 shows the simplified schematic for VCO core coupled to a buffer. The Buffer stage is optimized by different parameter.

The input admittance Y_{BI} of the buffer stage can be written as [2].

$$Y_{BI} = \frac{1}{Z_L}\left[1 + \frac{r_\pi}{1 + j\omega C_\pi r_\pi}\left(g_m + \frac{1}{Z_L}\right)\right] \tag{1}$$

When the load impedance is resistive, $Z_L = R_S$, the effective input shunt resistance and capacitance looking into the buffer are given by
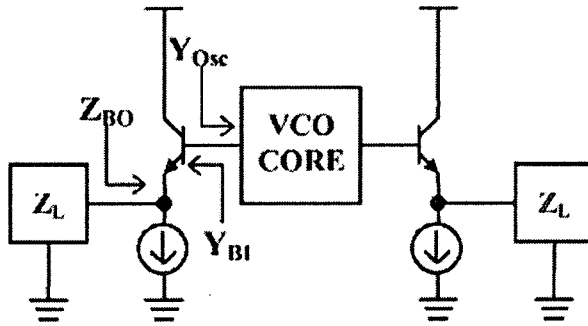

Figure 3. Emitter-follower buffer stage schematic

$$R_{Eq,BI} = R_S \frac{\left[1 + \beta\left(1 + \dfrac{1}{g_m R_S}\right)\right]^2 + \left(\beta\dfrac{\omega}{\omega_T}\right)^2}{1 + \beta\left(1 + \dfrac{1}{g_m R_S}\right) + \left(\beta\dfrac{\omega}{\omega_T}\right)^2}$$

$$\approx R_S\left[1 + \left(\frac{\omega T}{\omega}\right)^2\left(1 + \frac{1}{g_m R_S}\right)^2\right] \tag{2}$$

$$C_{Eq,BI} = C_\pi \frac{r_\pi^2\left(\dfrac{g_m}{R_S} + \dfrac{1}{R_S^2}\right)}{\left[1 + r_\pi\left(g_m + \dfrac{1}{R_S}\right)\right]^2 + (\omega C_\pi R_\pi)^2}$$

$$\approx \frac{1}{\omega_T R_S}\frac{\left(1 + \dfrac{1}{g_m R_S}\right)}{\left(1 + \dfrac{1}{g_m R_S}\right)^2 + \left(\dfrac{\omega}{\omega_T}\right)^2} \tag{3}$$

If we assume that $\beta \gg 1$ and $\omega \approx \omega T$, then we can make the approximations shown in Eq. 2 and Eq. 3. It is essential that $R_{Eq,BI}$ is large enough so as not to reduce the loaded Q of the tank, while $C_{Eq,BI}$ is small enough not to limit the frequency tuning range. In many integrated transceiver designs, the buffer drives an internal capacitive load C_L, in which case the effective shunt resistance and capacitance looking into the buffer input are now as follows:

$$R_{Eq,BI} = -\frac{(1 + g_m r_\pi)^2 + \omega^2 r_\pi^2(C_\pi + C_L)^2}{\omega^2 r_\pi(g_m r_\pi C_\pi - C_L)} \tag{4}$$

$$C_{Eq,BI} = \frac{(1 + g_m r_\pi)C_L + \omega^2 r_\pi^2 C_\pi C_L(C_\pi + C_L)}{(1 + g_m r_\pi)^2 + \omega^2 r_\pi^2(C_\pi + C_L)^2} \tag{5}$$

Eq. 4 predicts a negative input resistance at the buffer input when $g_m r_\pi > C_L/C_\pi$. This condition is easily met as $g_m r_\pi (=\beta)$ can easily be greater than ten. This additional negative resistance provided by the buffer can be utilized by the VCO core when driving a capacitive load. The combined negative resistance is equal to $(R_{Eq}\|2R_{Eq,BI})$. The negative resistance provided by the buffer reduces the gm requirement of the cross-coupled cell and hence can be used to reduce power consumption and noise. Eq. 5 predicts that the effective shunt capacitance is smaller than C_π or C_L, which allows for high-frequency design and wider tuning range. This basic negative resistance seen in the buffer due to capacitive emitter degeneration will be briefly analyzed to build the negative resistance cell for the VCO [3].

References

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