A wideband low phase noise VCO design

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Abstract. A frequency synthesizer with high reliability and low noise was designed and manufactured by 0.13um SiGe BICMOS process. The frequency synthesizer circuit is capable of generating 7.5GHz-15GHz RF output signals (the entire VCO output band). The normalized phase noise of the frequency synthesizer reaches -230 dBC/Hz, and the VCO phase noise of the frequency synthesizer reaches -119dBC/Hz@1MHz at the oscillation frequency of 13GHz.

1. Introduction

Use With the development of mobile communication technology, the performance requirements of wireless communication equipment have become more stringent, and gradually towards the goal of broadband and low power consumption. Due to the shortage of spectrum resources in the current wireless communication system, the limited communication bandwidth seriously restricts the development of wireless communication technology. In the millimeter wave frequency band, the spectrum resources are very rich, and compared with the current wireless communication frequency band, it has higher anti-interference and better security, so the millimeter wave frequency band has become the focus of research in the industry. As an important part of the frequency synthesizer, VCO plays an important role in the performance of the whole wireless communication system. Therefore, it is of great theoretical significance and application value to study the circuit design of silicon-based wide band low phase noise millimeter wave VCO.

This project will use the inductor capacitor as the resonant network, the cross coupling tube as the negative resistance and the circuit structure of the Class C oscillator, which can achieve a wide VCO tuning range and low VCO phase noise performance. Therefore, this design adopts 0.13um SiGe BICMOS process, and through the selection of these circuit structures to achieve VCO frequency (7.5-15GHz) output, and the output frequency is inversely proportional to the tuning voltage the high tuning voltage corresponds to the low VCO output frequency. The VCO's output frequency range and tuned gain KVCO are designed to meet different process and temperature boundaries. The VCO also contains a calibration module, which enables fast frequency locking and fast amplitude calibration of the VCO.

Circuit frame:
Parameter design: first, the range of oscillation frequency oscillator is designed in this paper is wide (almost 8 GHz bandwidth), so when I design the inductance capacitance oscillator again, choose the structure of multiple narrow band, will be divided into the oscillation frequency of the seven frequencies, through seven VCO to cover the entire frequency range, in order to solve the temperature loss of lock wait for a phenomenon, make each of the VCO frequency range covers about 1.2 GHz, has a certain frequency range overlap each other. Seven VCOs are combined through a selector, resulting in a wide tuning range of nearly 8GHz. For a single VCO, its negative resistance circuit mainly adopts NMOS type LC cross-coupled oscillator. At the same time, considering the influence of phase noise of VCO, we replace NMOS tube with triode with better phase noise performance. [1]

The main circuit structure of these seven VCOs is similar, but the difference is the inductance and capacitance of the on-chip inductor that affects the oscillator. The core circuit structure of each oscillator includes LC tuning network, negative resistance structure and output buffer circuit. In the LC tuning network, it is further divided into two modules: coarse-tuned capacitor array and MOS transformer.
In the design of VCO, the design of on-chip inductor and switched capacitor array is quite difficult, and how to keep the inductor and capacitor resonator with a high Q value in the whole range of VCO oscillation frequency has become the focus of design.

\[
Q = \frac{\text{Im}(Z_1)}{\text{Re}(Z_1)} = \frac{1}{\omega SR} \left(1 - \frac{\omega^2}{\omega_{SR}^2}\right)
\]

Switching capacitor array in a VCO circuit
Compared to the traditional class C oscillator cross coupling structure, isolation circuit adds two additional capacitance off the power supply voltage provided to cross coupling of bias voltage, and then through additional bias voltage for MOS tube grid bias, at the same time using NMOS tube current mirror as the tail current source, common mode point in the circuit also added a tail capacitance, its circuit structure as shown in figure 4. 16.

There are three main advantages of class C VCO.
1. Class C VCO can avoid the entry of cross-coupled pair of MOS tubes into the deep triode region by providing appropriate gate bias to the cross-coupled pair of MOS tubes and selecting appropriate tail capacitance value, so as to reduce the phase noise of VCO.

2. Because of the low bias voltage of the MOS tube, the two MOS tubes will work in the cut-off state at a certain time. The conduction Angle of the circuit is similar to that of the C-type amplifier, so this structure is called the C-type VCO. Therefore, the output swing is $V_{PP} = ISS_{rp}$, from which it can be seen that the output swing of Class-C VCOS is larger than the traditional circuit structure, which can achieve the purpose of improving the performance.

3. The power consumption of class-C VCO is lower than that of the traditional structure, because the circuit works in class C state, the circuit conduction Angle is small, so the voltage and current overlap is smaller, and the power consumption is therefore reduced. [3]

A wide tuning range can be achieved with a switched capacitor array, and a wide frequency bandwidth can be designed. The oscillation frequency can be expressed as:

$$f = \frac{1}{2\pi \sqrt{L \left( C_f + C_p + C_{SCA} + C_f \right)}}$$

(6)

$C$ is the capacitance of the switched capacitor array to access the resonant circuit, and its value is determined by the digital control signal. $SCA$When the control signals take different values, $C$ will take different discrete values, resulting in multiple low-gain frequency tuning curves to achieve a wide tuning range. $SCA$When the switch is on, the switch capacitance is equivalent to the series of the on-resistance and the capacitor, and its quality factor is expressed as:

$$\frac{1}{Q} = \frac{R_{ON} C u}{\mu C_w \omega_o} \frac{W/L (V_{GS} - V_{TH})}{C \omega_o}$$

(7)

Multiple arrays are used to switch different frequency bands to achieve rough modulation of output frequency. In the frequency band, the oscillating frequency is fine-tuned by adjusting the variable capacitance. This allows the circuit to achieve optimal performance in all frequency bands. [2]

2. Results

F Frequency coverage of the entire VCO

![Figure 8. VCO oscillation frequency coverage.](image-url)
Figure 9. The VCO tuning curve.

Table 1. VCO frequency coverage table.

| VCO  | The lowest/GHz. | The highest/GHz. | cover | KVCO |
|------|-----------------|------------------|-------|------|
| VCO1 | 7.43            | 8.65             | 100M  | 71   |
| VCO2 | 8.58            | 9.84             | 109M  | 79   |
| VCO3 | 9.74            | 10.87            | 96M   | 93   |
| VCO4 | 10.63           | 12.11            | 89M   | 84   |
| VCO5 | 11.96           | 13.02            | 260M  | 86   |
| VCO6 | 12.80           | 14.02            | 128M  | 112  |
| VCO7 | 13.83           | 15.01            | 100M  | 120  |

Figure 10. VCO phase noise results.

3. Conclusion

The circuit mentioned in this paper can produce RF output signals of 7.5GHz to 15GHz; The phase noise of VCO reaches -119 dBC/Hz. It can be seen from the above figure that the phase noise of the oscillator reaches -119dBc/Hz, which is at a relatively high level at present.

References

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