CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759144

Design of a CMOS Low Power Voltage Controlled Oscillator

Fucui Huo

Institute of Applied Electronics, Chongqing College of Electronic Engineering, Chongqing 401331, China
huofucui@163.com

In the millimeter wave wireless communication system, frequency source is an indispensable device in the communication equipment. It is designed to provide a local oscillator signal for the receiving and transmitting system. Its tuning range, phase noise and frequency stability are very important to the quality of the whole communication link. For this purpose, this paper studies the low power millimeter wave voltage controlled oscillator based on CMOS technology, and designs a Q band voltage controlled oscillator used for Q-LINKPAN standard. Firstly, this paper designs the voltage controlled oscillator (VCO) circuit structure, the voltage controlled oscillator circuit, cross coupled pair, on-chip inductor and variable capacitance tube, and studies the connection layout method to reduce the layout parasitic, summarizes the method of imitation of the VCO after using the electromagnetic simulation software HFSS, accumulates certain design experience for the circuit design, layout design and post simulation of millimeter wave VCO, and gives the simulation results for Q band voltage controlled oscillator used for Q-LINKPAN standard. The simulation results show that the designed voltage controlled oscillator has low power consumption and high performance, showing the correctness of the design.

1. Introduction

The development of mobile intelligent devices, such as mobile phones and a variety of mobile terminals popularizing, prompts people's need of high-speed wireless communication getting greater. In recent years, millions of Wi-Fi hots-pots have been set up all over the country, and with the improvement of people's quality of life, more and more wireless access points will be set up. But the electromagnetic spectrum that the wireless communication system uses is mostly below 6GHz. The spectrum resources are limited, and each band only has tens to hundreds of megabytes' bandwidth, seriously restricting the development of high-speed short distance wireless communication technology. As a result, the electromagnetic spectrum currently used in wireless communication systems has become a scarce resource (Ge et al., 2016), and in the millimeter wave band, many broadband spectrum resources have not been developed or utilized, and the unique advantages of millimeter wave band, such as the short wave length, can integrate the antenna in it, and make a band phased array, which makes millimeter wave band become a popular choice of the future wireless communication technology, attracting a lot of attention of universities and enterprises. In such current situation and demand, the countries around the world have opened ISM (Industrial, Scientific, Medical) free licensed spectrum resources near 60GHz spectrum. However, 60GHz locates in atmospheric attenuation window, while in long-distance transmission, the loss is larger, so it can only be used for short-distance transmission. Therefore, theresearch of high stability, low phase noise, wide bandwidth and low power consumption frequency source is the inevitable trend in the future. Based on this, this paper studies the low power voltage controlled oscillator based on CMOS, which is working in the Q band.

2. Research method

2.1 Basic principle of oscillator

The basic working principle of the oscillator can be divided into two types. One is based on the positive feedback principle to produce oscillations, continuously amplifying the signal in the circuit to form the periodic signal; the second one is the negative resistance theory. Since that there is capacitor that consumes energy in the circuit, thus introduce negative resistance to offset part of the energy consumption so as to maintain the

Please cite this article as: Fucui Huo, 2017, Design of a cmos low power voltage controlled oscillator, Chemical Engineering Transactions, 59, 859-864 DOI:10.3303/CET1759144

oscillation circuit. This section will reveal the basic concepts of the oscillator circuit from two aspects of positive feedback and negative resistance.

1) Two-port feedback model

The oscillator can be considered as a negative feedback amplifier with design failure in a sense. It is so worse that its phase margin is zero or even negative. This paper takes a simple linear negative feedback model as an example.

The expression of the negative feedback system is:

$$\frac{X}{Y}(s)=\frac{H(s)}{1=H(s)} \tag{1}$$

Assuming that at a frequency point w_o, the system transfer function H($s=\mathrm{j}w_o$) is -1, the closed-loop gain in the frequency point will be close to infinity, the circuit continues to amplify the noise component, and ultimately form a stable output signal. Since H (s) is a complex function, H($\mathrm{j}w_o$)=1 can be equivalent to the following (2):

$$|H(j\omega_0)|=1 \tag{2}$$

$$<H(j\omega_0)=180^\circ \tag{3}$$

The two formulas are called "Barkhausen's criteria", while it is necessary condition, but not the sufficient condition for the oscillator. The Barkhausen's criterion is obtained in small signal condition, while the transistor gain under the condition of large signal will decrease, and it is subject to the effects of process and temperature offset. In order to ensure the oscillation, in the practical application, the loop gain will usually choose the several times of the value that is able to make the oscillator start oscillation.

2) Single-port energy compensation model

In the last section, the oscillator is regarded as a negative feedback system with positive feedback at some frequency points. While another view takes the oscillator as the two single port parts, one is the resonant circuit with loss, and the other one is the active circuit used to offset the loss of the circuit. This view is the single-port energy compensation of the oscillator.

As shown in figure 1, it is assumed that the current pulse source $\mathrm{I}\delta(\mathrm{t})$ is used for a loss-less oscillation circuit. The pulse signal is fully absorbed by the capacitor C, generating a voltage signal of I/C size. Then the current in the capacitor C begins to flow through the inductor L, and the output voltage signal is gradually decreased. When the value of the Vout voltage drops to 0, the capacitor C will no longer store energy, and the current size of the inductor L is LdV_{out}/dt, this current gives reverse charge to the capacitor C, driving the Vout change to the negative peak. At last, the energy shows a periodic transformation between the capacitor C and the inductor L, resulting in the cycle signal, whose size is determined by the initial pulse signal.

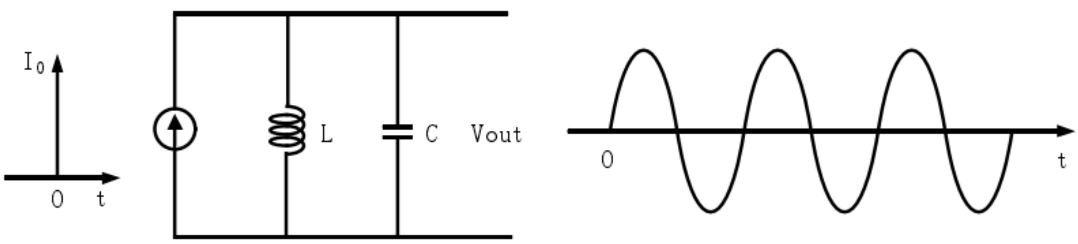


Figure 1: Loss-less resonance circuit

Now, suppose that there is a resonant circuit with loss, the circuit, compared with figure 1, is added with a resistor Rp. In every energy recycling process, it will consume the energy stored in the capacitor C, thus resulting in the exponential decline of the output signal amplitude. Therefore, if introducing an active circuit to compensate for the energy losing in each cycle, then the circuit can be sustained oscillation. From the circuit, it can be seen that, if adding an active circuit that can produce the equivalent resistance in the oscillation circuit, it can counteract the effects of parallel resistance Rp, so the circuit becomes the ideal oscillating circuit. The structure is called "single-port oscillator", also "negative resistance" concept.

From the principle of oscillator, two-port positive feedback theory is the same as single-port negative resistance theory, and the feedback analysis method is equivalent to negative resistance analysis method. Whereas, the negative resistance analysis method, compared to the feedback analysis method, is simpler and

more convenient for the analysis and design for the designer. Therefore, in practical application, the negative resistance analysis method is used to discuss a voltage controlled oscillator circuit, and the negative resistance analysis method can very easily be used to analyze the cross coupled oscillator.
Negative resistance can be introduced by the equivalent circuit of the cross coupled oscillator, and the equivalent circuit of the cross coupled oscillator is shown in figure 2.

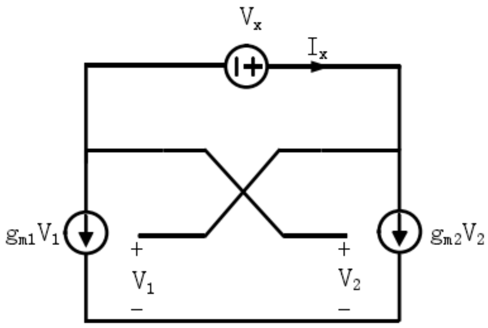


Figure 2: The equivalent circuit of the cross coupled oscillator

First of all,

$$V1=V2=VX \quad (4)$$

$$IX=-gm1V1=gm2V \quad (5)$$

By gm1= gm2= gm, it can obtain:

$$\frac{V_X}{I_X}=-\frac{2}{g_m} \quad (6)$$

From the analysis of the negative resistance, it is known that, in order to make the circuit vibration, the negative resistance in the circuit must be less than or equal to the equivalent impedance 2Rp of the circuit:

$$\frac{2}{g_m}\leq R_p, g_m R_p \geq 1 \quad (7)$$

In practice, in order to ensure the circuit vibration, generally, it will leave with the design margin. In the meanwhile, since that the GM is so small that itwill affect the amplitude of the oscillation, as well as considering the temperature, process and other changes, the value of gmRp is generally larger.

2.2 Voltage controlled oscillator circuit structure design

The oscillator can be regarded as an unstable amplifier in a certain degree, and as long as the oscillation condition is reached, the circuit can work normally. At present, the oscillator circuit has a wide variety of structures, such as ring oscillator, Hartley oscillator, Colpitts oscillator, Clapp oscillator and cross coupled oscillators and so on. In the fabrication process, Colpitts and the cross coupled oscillator are the most commonly seen voltage controlled oscillators. Colpitts oscillator is often used in bipolar transistor technology, and its phase noise performance is excellent, and tuning bandwidth is smaller. While, the cross coupled oscillator oscillating condition is simple, circuit structure is simple, phase noise is moderate, tuning range is large, so it is often used in the CMOS process.

2.3 Cross coupling design

The cross coupling pipe design is critical for VCO. First of all,only the cross coupling tube selects appropriate size can it ensure the voltage controlled oscillation of the oscillator, and choosing the larger cross coupling is conductive to reduce the flicker noise of MOS tube, thereby reducing the proximal ends phase noise. But if MOS is too large, it will introduce additional thermal noise, resulting in deterioration of phase noise performance. In the 90nm CMOS process, the layout of the MOS tube uses the cross-finger structure. This structure can effectively reduce the gate equivalent resistance of the transistor, reduce the thermal noise of the MOS tube, and then reduce the phase noise of the circuit. In the 90nm CMOS process, the grid index N is 1-64, then the gate equivalent resistance R_G= R_g/N, so choose the larger grid index, which is advantageous to reduce the thermal noise. A single finger gate width W is 1-5um, and in the power amplifier design, generally select the maximum to ensure the power density. But in the VCO design, in the same grid index case, select the large gate width can reduce flicker noise, but also introduce thermal noise. After the actual test, the gate width selects the minimum lum. In the design of millimetre wave voltage controlled oscillator, select the size of the NMOS tube as 1*44um, which not only meets the requirements of the vibration, but also can achieve the most advantage of phase noise. At the same time, in order to reduce the parasitic effect, the layout method as shown in figure 4 is adopted. The drain electrode of MOS tube is connected to the gate of another MOS tube, and the source electrode is connected with the signal line. The cross coupling tube, by a Guard Ring, isolates the interference brought about by the substrate and other components.

3. Research results

This paper uses TSMC 90nm CMOS process, and taking into account the process deviation and temperature changes, the working frequency leaves about 1GHz margin. In order to reduce the requirements of power consumption of the voltage controlled oscillator on the system, so low power consumption is designed. The current of the core part of voltage controlled oscillator is 6mA, and the power consumption is 7.2mW. In order to get more power to facilitate the test, so the Buffer current is 10mA, and the oscillator circuit power consumption is 19.2mW. Voltage controlled oscillator circuit simulation results in the 45GHz frequency is shown in figure 3. The phase noise in the 1MHz frequency offset is -91.45dBc/Hz.

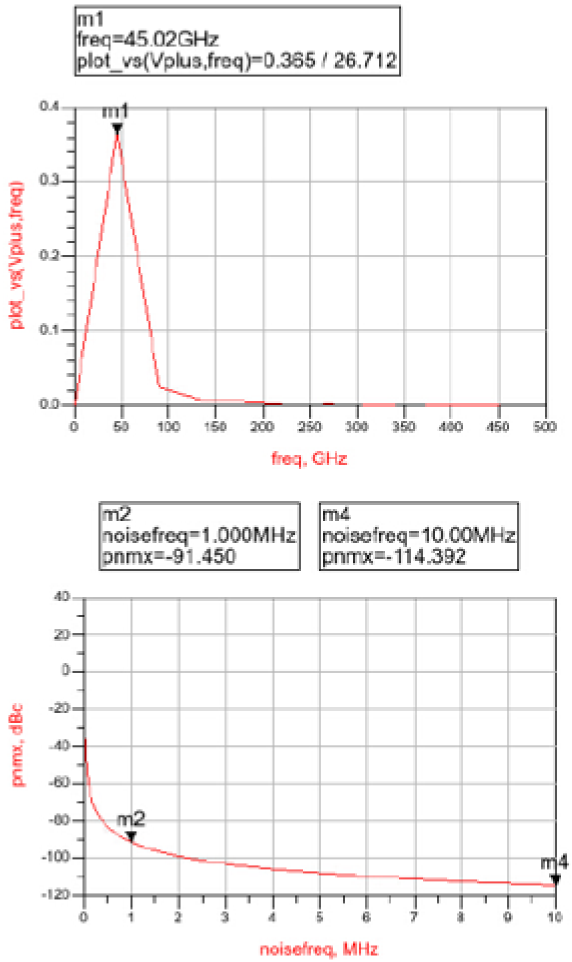
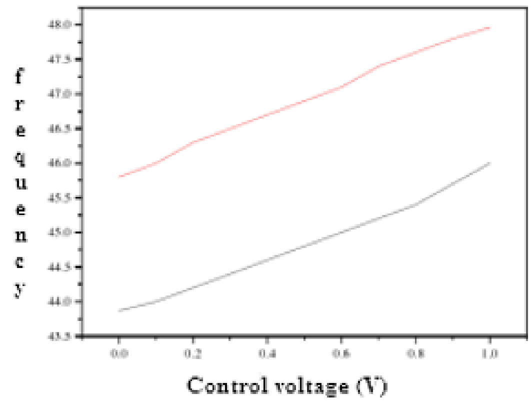


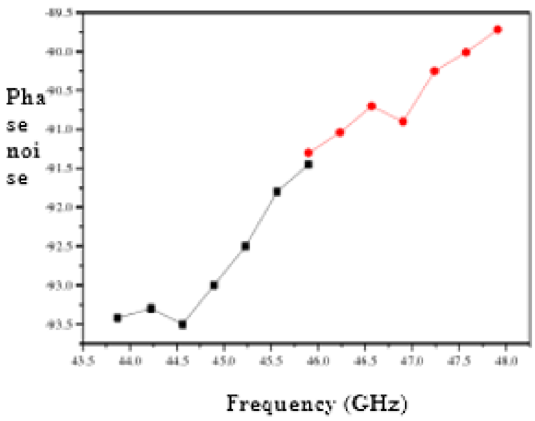
Figure 3: Voltage controlled oscillator circuit simulation results in the 45GHz frequency

Since the oscillator uses 2 tubes, the voltage controlled oscillator has two tuning curves. The tuning range is 43.87GHz - 47.96GHz, as shown in figure 4 (a). At 1MHz frequency offset, the best phase noise is -93.42dBc/Hz, and the worst is -89.72dBc/Hz, as shown in figure 4 (b).

Analysing the simulation results, it can be known that, the phase noise of the designed VCO phase noise in 45GHz to 1MHz is -91.45dBc/Hz, bandwidth is 4GHz, power consumption is 19.2mW, and the area is 600um*600um, and compared to other similar VCOs, it has low power consumption.



(a) The tuning range



(b) The phase noise

Figure 4: Circuit simulation results

4. Conclusion

The requirements of modern communication system for frequency spectrum bandwidth and transmission rate promote academic and industrial designers to higher and wider area spectrum resources. While millimeter wave band, as an undeveloped wide spectrum resources region, has huge potential in research and application. With the domestic scholars' research on remote ultra-high-speed transmission standard-LINKPAN, as well as the development of IEEE 802.11aj standard, the Q band wireless communication chip has become a research focus in the next generation of wireless communication standards, and domestic academic circles have made a series of achievements.

Frequency source is an important part of millimeter wave wireless communication system, and it is very important to the channel quality of wireless communication equipment. At present, the academic and industrial circles mostly use the III-V process to design the Q band frequency source. This frequency source, despite the performance is good, the cost is higher and not conducive to the integration and digital circuit, cannot be used widely. Nevertheless, using the frequency source designed by CMOS process, although the CMOS technology is high in loss, resulting in phase noise performance in-superior to the III-V process, with the development of CMOS RF technology, it has become possible to meet the millimeter wave communication system requirements through the reasonable design of the circuit. This paper uses 90nm CMOS process to design a low power voltage controlled oscillator operating at Q band, and gives the simulation results of the designed voltage controlled oscillator. The simulation results show that the voltage controlled oscillator designed in this paper is low in power consumption and high in performance, showing the correctness of the design, which has accumulated certain experience in designfor the domestic CMOS millimeter wave voltage controlled oscillator development.

Acknowledgments

This work is supported by the Science and technology research project of Chongqing Municipal Education Committee (No. KJ1602908).

Reference

Chang W., Meng C., Chang C., Huang G., 2016, 5–6 GHz CMOS low-noise direct conversion receiver using a differential RF VGA with a differential inductor load, In Radio-Frequency Integration Technology (RFIT), 2016 IEEE International Symposium on, 1-3.

Chen C., Fayed A., 2015, A Low-Power Dual-Frequency SIMO Buck Converter Topology With Fully-Integrated Outputs and Fast Dynamic Operation in 45 nm CMOS, IEEE Journal of Solid-State Circuits, 50(9), 2161-2173, DOI: 10.1109/JSSC.2015.2422782.

Chen Z., Tang A., Kim Y., Virbila G., Reck T., Yei J.F., Du Y., Chattopadhyay G., Chang M.C., 2015, A wide-band 65nm CMOS 28–34 GHz synthesizer module enabling low power heterodyne spectrometers for planetary exploration, In 2015 IEEE MTT-S International Microwave Symposium, 1-3, DOI: 10.1109/MWSYM.2015.7166709.

Choi B.S., Jo S.H., Bae M., Kim S.H., Shin J.K., 2016, A CMOS image sensor with variable frame rate for low-power operation, Electronic Imaging, 12, 1-4.

Gazziro M., Braga C.F., Moreira D.A., Carvalho A.C., Rodrigues J.F., Navarro J.S., 2015, Transmission of wireless neural signals through a 0.18 µm CMOS low-power amplifier, International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), 5094-5097.

Ge H.M., Chen L., Liang J., 2016, The study of feature extraction method based on multi-scale morphological spectrum entropy, Chemical Engineering Transactions, 51, 559-564, DOI: 10.3303/CET1651094

Jeong S., Lee I., Blaauw D., Sylvester D., 2015, A 5.8 nW CMOS Wake-Up Timer for Ultra-Low-Power Wireless Applications, IEEE Journal of Solid-State Circuits, 50(8), 1754-1763, DOI: 10.1109/JSSC.2015.2413133

Kim H., Hwang S., Kwon J., Jin D., Choi B., Lee S., Park J., Shin J., Ryu S., 2016, A Delta-Readout Scheme for Low-Power CMOS Image Sensors With Multi-Column-Parallel SAR ADCs, IEEE Journal of Solid-State Circuits, 51(10), 2262-2273, DOI: 10.1109/RFIC.2015.7337752.

Li M., Chen C., Li C., Chin C., Li S., 2015, A monolithic CMOS-MEMS oscillator based on an ultra-low-power ovenized micromechanical resonator, Journal of Microelectromechanical Systems, 24(2), 360-372.

Sako M., Watanabe Y., Nakajima T., Sato J., Muraoka K., Fujiu M., Kono F., 2016, A Low Power 64 Gb MLC NAND-Flash Memory in 15 nm CMOS Technology, IEEE Journal of Solid-State Circuits, 51(1), 196-203.

Tseng S.T., Kao Y.H., Peng C.C., Liu J.Y., Chu S.C., Hong G.F., Hsieh C.H., 2015, A 65nm CMOS low power impulse radar for respiratory feature extraction, In Radio Frequency Integrated Circuits Symposium (RFIC), IEEE, 251-254, DOI: 10.1109/RFIC.2015.7337752.