CMOS VCO DESIGN

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In this article, the design of quadrature voltage controlled oscillator (Q-VCO), which covers the Bluetooh requirements is described. A methodology which makes easy the design of oscillators with negative resistance is shown. Standard 0.35um CMOS process was used. The circuit is fully monolithic, and this decreases its price. The oscillator has output buffers, which ensure the necessary power of the output signal. The supply voltage is 1,5 volts and is limited by the used technology and the parameters necessary for the normal work of the oscillator. The overall power consumption of the oscillator and the output buffers is 107 mW, and the phase noise is -108dBc/Hz, at 600 kHz from the carrier.

Keywords: QVCO, negative resistance, Bluetooth, CMOS technology

1. INTRODUCTION

The demand for low cost, low power, and small size has been increasing with the extensive researches on transceiver architecture and RF circuit design. In implementing the RF transceivers, the low power consumption is one of the challenging requirements due to the battery lifetime. In the last few years, the popularity of direct conversion architecture has been dramatically increased because of the possibility for the low power, low cost, and single-chip transceiver [1]. The quadrature VCO is one of the key elements that are required to implement direct conversion transceiver. The low power QVCO design has been one of the most challenging hurdles in implementing the low power transceivers since the QVCO tends to dissipate too much current.

2. PROBLEMS



Fig. 2. A negative resistance circuit

In the radio electronics textbooks the circuit with negative resistance is widely studied and discussed [2,6]. In order to analyse it, the circuit is divided into two

blocks (fig.1) –active stage and load (resonator). Due to the losses in the real resonators, each oscillation die away after a time. In order to be achieved continues oscillations, the resistance R_P have to be compensated by the amplification of the active circuit. When it is put into practice, there are no losses in the circuit and the oscillations are non-dumped. This means that each loss of energy in the resonator is restored by the active circuit. A practical circuit with negative resistance is shown in fig.2. According to the well-known equations [2] the necessary transconductance g_m of the transistor is derived from (1).

$$(1) g_m > -\frac{2}{R_P}$$

But the transconductance g_m depends nonlinearly on number of factors: operating frequency, supply voltage, current through the transistors and so on. The dependence of Q of the monolithic inductors on the frequency is highly nonlinear too. On the other hand it is difficult these effects to be taken into account, because the equations describing the elements are too complex, and with too many parameters to be used by hand. Because of these problems, the design of an oscillator turns into number of iterations until the designer manages to "extract" the best from the circuit at given operating frequency, supply voltage, manufacturing process, etc.

In this article a simple method, which does not require complex calculations is proposed. Thanks to it the iterations of the design process can be decreased considerably. By this method, a monolithic Q-VCO with output buffers was designed according to the Bluetooth specifications, with minimal supply voltage and cheap 0,35 CMOS process.

3. SOLUTION

The proposed by us method has the sequence described below. First the designer starts with the basic circuit with negative resistance (fig.2). The circuit is built in the schematic editor of used CAD program (in our case CADANCE). Then the wanted parameters of the transistors – number of gates, width and length of the gate, and the current through the transistors are set. Next measurement of the resistance R_A of the circuit follows. To do that we set voltage between the two outputs and then we measure the current through the voltage source. As the transconductance of the transistors depends on Ugs, and Ugs in this case is the same as U_V , then R_A of the circuit depends on U_V . By this way, we obtain R_A for given value of U_V . If we make a DC analysis, changing U_V , we will get R_A as a function of U_V . And when the circuit is at resonance, the voltage at the outputs $U_V = V_{0+} - V_{0-}$ is (2):

$$(2) U_V = U_{DD} - U_{DSsat} \text{ or }$$

(3)
$$U_{DD} = U_V + U_{DSsat}$$
, where

 U_{DD} is the supply voltage, and U_{DSsat} is the saturation voltage of the transistors at given operating point. By this way we obtain with acceptable accuracy the dependence of R_A on the supply voltage. It is not necessary to know the exact value of the saturation

voltage. It is enough about 0.2-1 volts (it depends on the process) to be added to U_V to get the supply voltage U_{DD} .



On fig.3 the dependence of R_A on U_V is shown graphically, at given current value and channel length and width, but for different number of gates – 10, 15 and 20 gates. By this way, if we have the value of the resistance R_P of the tank (for the operating frequency) calculated beforehand, it is very easy the minimal supply voltage of the circuit to be found. Also we can see that above given value of the supply voltage, g_m saturates and R_A stops changing. Thus the designer is able to choose the optimal operating point of the circuit. Decreasing the power consumption to minimum. In case of need, R_A at different values of the current could be investigated. And the reader

should have in mind that this graphic is actual at frequencies at least ten times less than the transit frequency of the transistor.

4. RESULTS

The circuit chosen for our oscillators is so called bottom-series Q-VCO [3]. Our aim was to create an oscillator which covers the Bluetooth specifications [4]. The number of gates of the transistors was set to 20, because g_m is highest (according to fig.3). Then a choice of inductance follows. For our purpose we used standard in our process coils. Next we estimated Q of the coil for the operating frequency (2.4Ghz) by simple simulation and using (4) we got the resistance R_P of the LCR tank.

$$(4) R_P = \frac{2\pi fL}{Q}$$

Because Q of the varactors in the tank is significantly larger than Q of the inductors, we ignored their influence. Next we built the circuit shown on fig.4. The circuit represents the one arm of the Q-VCO. Here the voltage source from fig.2 is re-



arm of the Q-VCO.

placed with the sources V1 and V6 and they change their voltage in opposite directions.



Thus $U_V = U_{V1} - U_{V2}$. The current through the transistors is determined by the current mirror (transistors MN3 and MN2).



Then by the parametric analysis we get $R_A = f(U_V)$ for different values of the current. The purpose is to find R_A which satisfy $-R_A > R_P$ at values of the current and the voltage as low as possible. In our case that condition was met at $V_{DD} = 1,5V \ \mu I_d =$ 5mA. Finally we simulated the circuit of the whole oscillators (fig.5) with output buffers. The results are shown on fig.6. The phase error is less than 0.8°. Unfortunately the resimulation showed significant phase error – about 45 degrees.

This bad result is due to badly designed layout, which shows that this kind of oscillators is very sensitive to the placement and the routing of the components. The phase noise is -108dBc/Hz at 600kHz offset (fig.9). The power consumption of the oscillator and the buffers is 107mW at 50 ohms load. The tuning range is from 2,1 to 2,6 GHz and the change of $V_{control}$ is from 0 to 1,5 volts.

5. CONLUSION

In the present article, a new algorithm for design of negative resistance oscillator is shown. The approach is distinguished with simplicity and clearness of the results, decreasing the number of the iterations in the design process. By this algorithm, a monolithic quadrature voltage controlled oscillator was designed according to the Bluetooth specifications, using AMS 0.35um CMOS process. The oscillator run as we expected which proved the applicability of the algorithm. Because of the badly designed layout the phase error is too large and the oscillator could not meet the Bluetooth requirements. The improvement of the layout is our next task.

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