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Design and Simulation of Voltage-controlled Oscillator with Minimum Transistors

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Abstract

A voltage-controlled oscillator is an oscillator whose output frequency can be changed by varying an input voltage. A voltage-controlled oscillator is an important part of the frequency synthesizer used in most telecommunication transceivers. In the design of VCO(voltage-controlled oscillator), we try to study its nonlinear effects (transient effects) and its effect on phase noise. The phase noise relationship of between the oscillator harmonics and the transfer functions should be investigated and then the phase noise can be improved by eliminating and controlling them. To eliminate these nonlinear effects, filters can be used to eliminate the harmonics and reduce the amplitude and bandwidth of the transmission function to help linearize the circuit and reduce phase noise. The purpose of this paper is to reduce phase noise and power consumption while increasing to gain. The circuit design of the circuit of the ADS(Advanced Design System) software is designed with 0.18μMm technology.

Keywords: *VCO, ADS, Circuit design, Phase noise, Transfer Function*

1. Introduction

The growing trend of wireless telecommunications has led to increased demand for smaller size wireless products, lower power consumption, and lower cost. This increased demand for high-speed wireless communications and consequently the use of advanced protocols and modulations increase the sensitivity to phase error in the respective modulations. The increased sensitivity means that the voltage-controlled oscillator (VCO) circuit must have less phase noise [2].

A voltage-controlled oscillator is an oscillation whose output frequency can be changed by changing an input voltage. A voltage-controlled oscillator is an important part of the PLL or frequency a synthesizer used in most telecommunication transceivers. In CMOS technology a VCO can be implemented as a circular oscillator, LC oscillator, or by using a transmission line. The use of transmission lines of VCO gives better phase noise but consumes a lot of chip level and therefore is not used [8]. A circular oscillator consists of an individual number of inverting classes connected to series. This oscillator occupies a small chip surface and has a wide tuning range but its phase noise is not desirable and therefore not used in telecommunication applications [3]. The CMOS oscillator has good phase noise and can be implemented on the chip, and this circuit is also suitable for low voltage applications. Due to the unique properties of the CMOS oscillator over other

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oscillators, this paper attempts to design VCO with CMOS and improve phase noise and power consumption [9].

2. Circular Oscillator

A circular oscillator is accomplished by placing a number of individuals or even pairs of open-loop amplifiers or delay cells in a feedback loop. The delay cells of a circular oscillator may be unilateral or differential. The number of unilateral cyclic oscillator delay cells must be individual. The simplest type of delays cell that can be used is a simple digital inverter shown in Figure 1. This structure is a three-stage circular one-way oscillator [1].

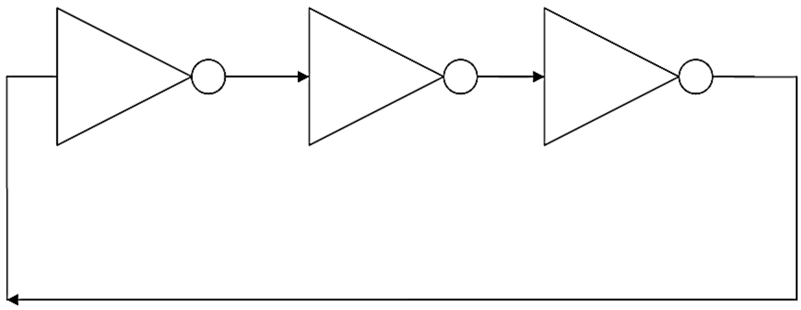

Figure 1. A circular oscillator realized using three digital inverters[1].

This circuit will fluctuate and will propagate into the loop for each half-period. This change will be propagated through all three inverters at time T/2 where the output from the first inverter will be changed to 0 and after an additional time T/2 the output of the first inverter will return to 1 [5]. Suppose every inverter has a delay τ_p and N inverter, so we have:

$$\frac{T}{2} = N\tau_p \Rightarrow f_{osc} = \frac{1}{2\tau_p N} \tag{1}$$

The number of cells in the differential cyclic oscillator can be even or even. Differential circular oscillators can be made with the active or passive load. The performance of the differential cyclic oscillator in both analog and digital modes is better than one-way. Figure 2 shows a block diagram of a three-stage differential circular oscillator [7].

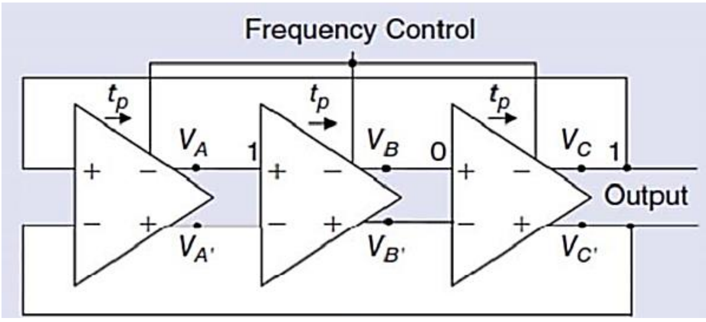

Figure 2. Diagram block of a three-stage circular differential oscillator [7].

2.1. Design of a circular oscillator

In this section, we design a circular oscillator in the 0.18-micron process. Figure 3 shows a schematic of a circular oscillator drawn in the schematic environment of the ADS software. The supply voltage of the circuit is set at 1.2 volts.

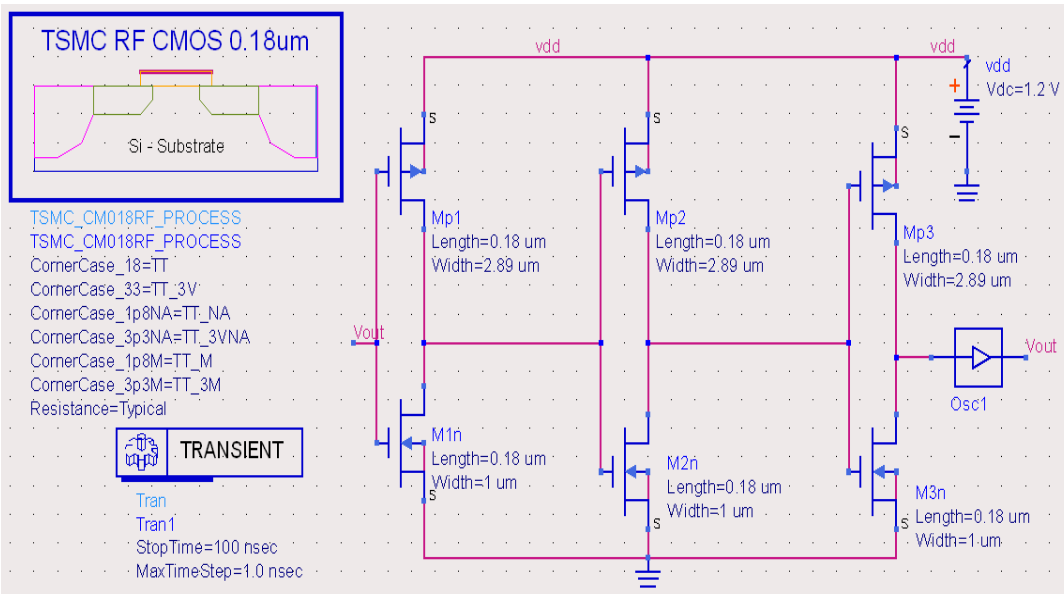

Figure 3. Schematic of a cyclic oscillator in the ADS software environment.

Table 1 shows the dimensions of the transistors used in the oscillator circuit structure.

Tabale 1. Dimensions of transistors used

Transistor	Type	W(µm)	L(µm)
Mn1/ Mn2/ Mn3	NMOS	1	0.18
Mp1/ Mp2/ Mp3	PMOS	2.89	0.18

2.1.1. Tran analysis

In the schematic environment of the ADS software tran simulation palette was selected and simulated. The result of the tran simulation is shown in Figure 4.

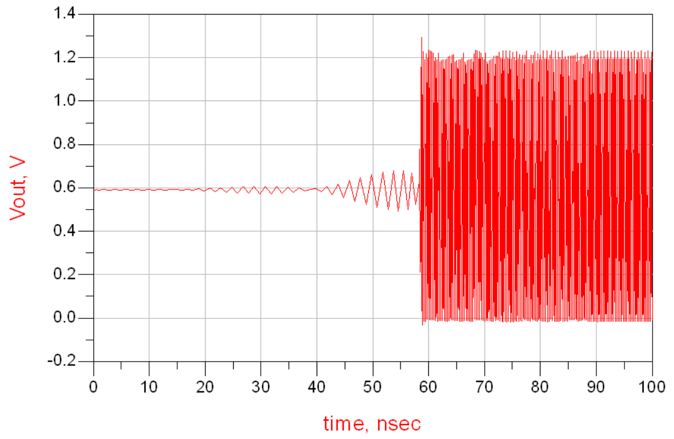

Figure 4. Tran simulation result.

2.1.2. Envelope Analysis

Envelope analysis is performed to determine the oscillation frequency and the influence of parameters such as supply voltage, temperature, or load capacitance on the oscillation frequency. Output times and frequency diagrams for envelope analysis are shown in Figures 5 and 6. According to Figure 5, the period of oscillation of this shape is approximately 0.292 ns. It is also clear about Figure 6 that the first harmonics occur at a frequency of 3.42 GHz, which is the oscillator oscillation frequency.

$$T = 311 - 18.35 \cong 292.65\, ps \quad \Rightarrow f = \frac{1}{T} = \frac{1}{0.2926\, ns} \cong 3.42\, GHz \tag{2}$$

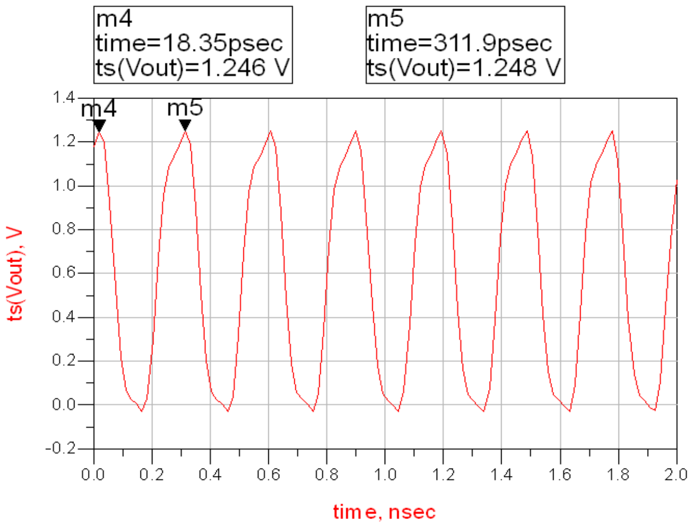

Figure 5. Output timing chart.

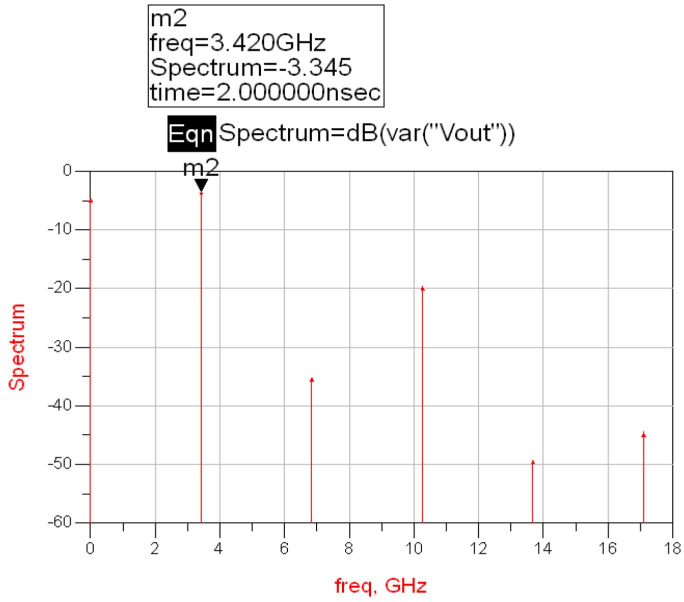

Figure 6. Output Frequency Chart.

2.1.3. Noise Analysis

Figure 7 shows the phase noise that if we extend this graph with the oscillation frequency we can see that the phase noise is -137.95 dB / Hz.

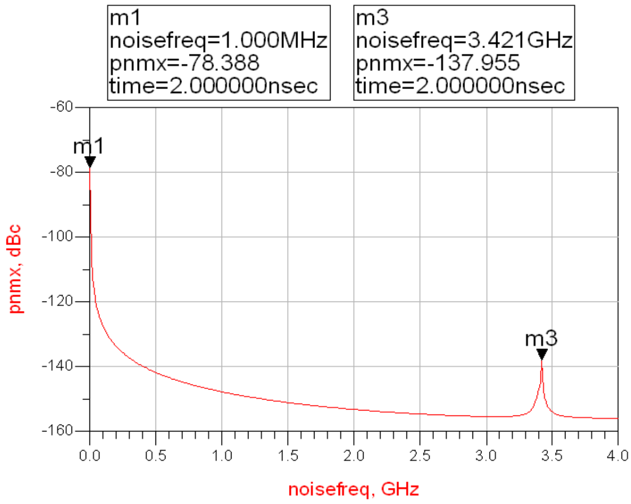

Figure 7. Phase Noise.

3. Design of Voltage-controlled Circular Oscillator

In this section, we propose a voltage-controlled oscillator design at 0.18 microns. Figure 8 shows the schematic of the proposed voltage-controlled oscillator in the schematic environment of the ADS software. The supply voltage of the circuit is set at 1.2 volts.

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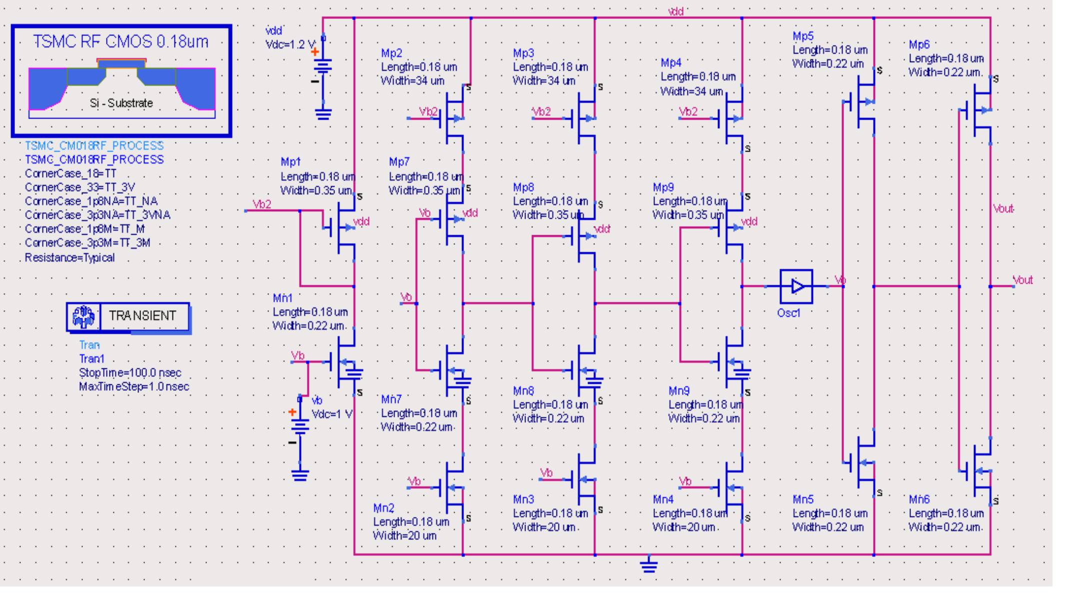

Figure 8. Proposed voltage controlled oscillator schematic in ADS software environment.

Table 2 shows the dimensions of the transistors used in the oscillator circuit structure.

Tabale 2. Dimensions of transistors used.

Transistor	Type	W(μm)	L(μm)
Mn1/ Mn5/ Mn6/ Mn7/ Mn8/ Mn9	NMOS	0.22	0.18
Mn2/ Mn3/ Mn4	NMOS	20	0.18
Mp1/ Mp7/ Mp8/ Mp9	PMOS	0.35	0.18
Mp5/ Mp6	PMOS	0.22	0.18
Mp2/ Mp3/ Mp4	PMOS	34	0.18

3.1. Tran analysis

In the schematic environment of the ADS software tran simulation palette was selected and simulated. The result of the tran simulation is shown in Figure 9.

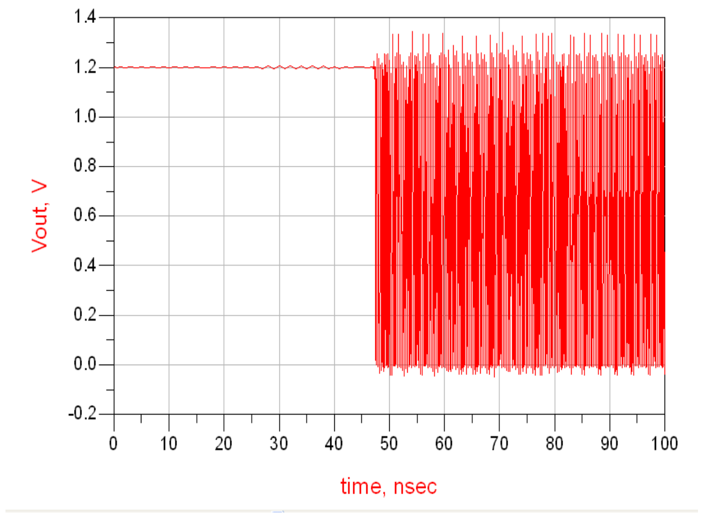

Figure 9. Tran simulation result.

3.2. Envelope analysis

Envelope analysis is performed to determine the oscillation frequency and the influence of parameters such as supply voltage, temperature, or load capacitance on the oscillation frequency. Output times and frequency diagrams for envelope analysis are shown in Figures 10 and 11. According to Figure 10, the oscillation of this shape is approximately 0.394 ns. It is also clear about Figure 11 that the first harmonics occur at a frequency of 3.42 GHz with an amplitude of approximately 2.7 dB, which is the oscillator oscillation frequency.

$$T = 50.432 - 50.14 \cong 292.5\ ps \quad =\gg f = \frac{1}{T} = \frac{1}{0.292\ ns} \cong 3.42\ GHz$$

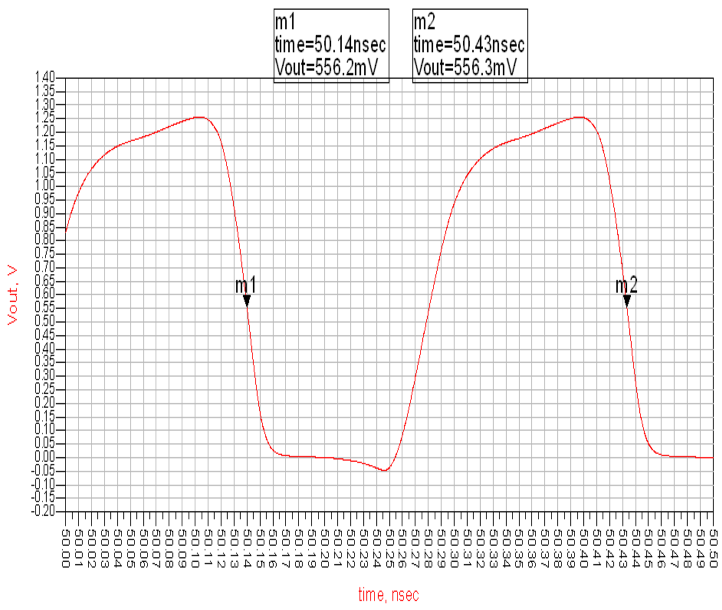

Figure 10. Output timing chart.

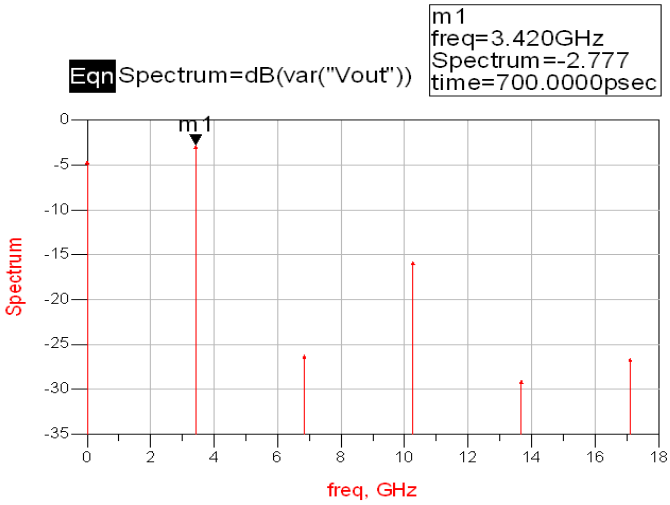

Figure 11. Output Frequency Chart.

3.3. Noise analysis

Figure 12 illustrates the phase noise that if we extend this graph with the oscillation frequency, the phase noise is -131.75 dB / Hz.

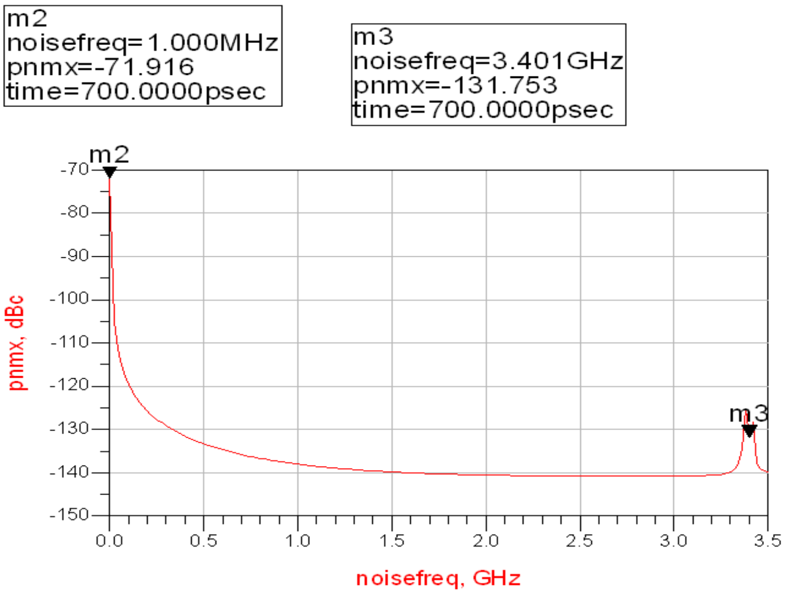

Figure 12. Phase Noise.

Figure 13 shows the variation of the oscillation frequency in terms of control voltage.

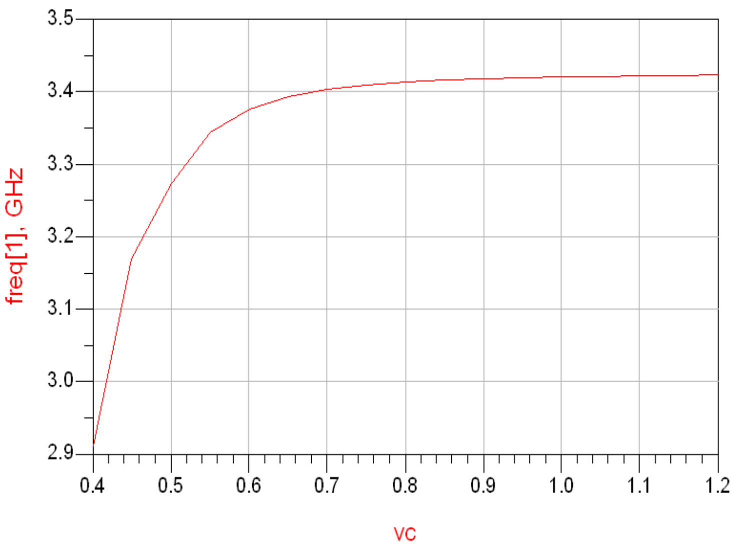

Figure 13. Fluctuating frequency variations according to control voltage.

As shown in Figure 14, the current consumption of the circuit are 38.1A and therefore the power consumption is 45 microwatts.

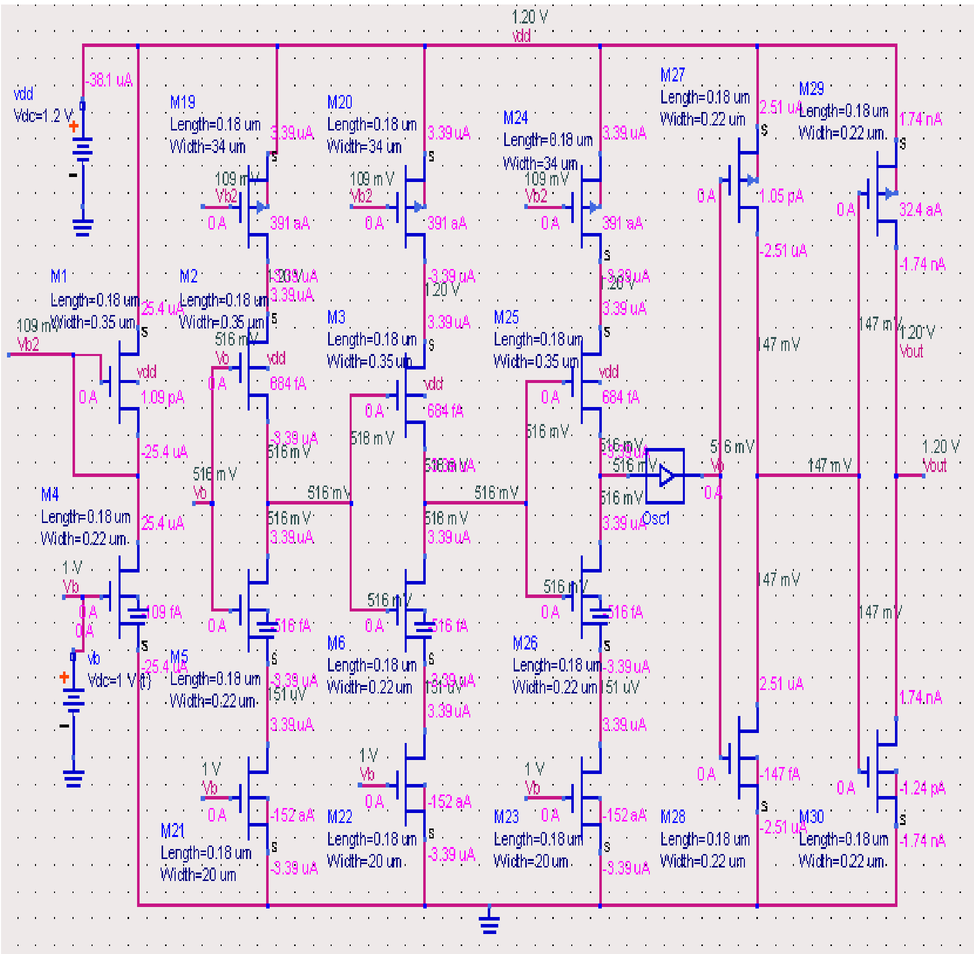

Figure 14. Schematic of current consumption of different parts of the circuit.

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4. Conclusion

There are many specifications for a good oscillator. The most important ones are low fuzzy noise, constant frequency in the frequency spectrum, relatively linear characteristic in the range used, high-frequency spectrum, low power dissipation, and so on. Circuits should be optimized for the application in question and other conditions that are not needed will be improved as far as possible since we will not have a well-designed design just to satisfy one. Today, we work at higher frequencies than in the past, and these high frequencies require higher precision than before, so the circuits must have high precision in the working frequency, which is one of the factors of high precision low noise. Voltage-controlled oscillators (VCOs) are the basic building blocks of modern communication systems. VCO performance in the phase noise and vibration modes determine the main performance characteristics of a transmitter-receiver. The current trend for multi-band transceivers and broadband systems has generated interest in VCOs that simultaneously provide widespread oscillation range and low phase noise performance. As the transistors become smaller and smaller and the need for a wider frequency spectrum for the oscillators, we should consider the above problems along with the linearization of the frequency spectrum. Because as the transistors shrink, the channel length is reduced and there is more fuzzy noise. In this paper, we investigate the above conditions for different parameters with a design of 0.13 µm and 0.18 µm technologies and finally obtain the following practical results.

4.1. Compare the results of the design with previous

works Table 3 compares the simulated results with previous works on different technologies.

Tab. 3. Comparison of values of simulation results with previous work

Parameter	Paper [4]	Paper [6]	Paper [10]	This Work
Technology (µm)	0.18	0.13	0.13	0.18
Oscillator type	LC	LC	LC	RLC
Supply Voltage (V)	1.8	1.2	1.2	1.2
Frequency (GHz)	0.5~3	2~4.1	0.8~3.7	2.9~3.43
Phase Noise (dB/Hz)	-101~-118	-123	-104~-109	-131.174~-136
Offset (MHz)	1	1	1	1
Power (mW)	6~28	9~16	8~13	0.045
Transistor QTY.	18	20	24	18

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Homayoon Oraizi(SM) received B.E.E. degree from American University of Beirut, Lebanon, in 1967, M.Sc. and ph.D. degrees in electrical engineering from Syracuse University, Syracuse, NY, in 1969 and 1973, respectively. From 1973 to 1974, he was at Toosi University of Technology, Tehran, Iran. From 1974 to 1985, he was with the Communication Division, Iran Electronics Industries, Shiraz, Iran. In 1985, he joined the Department of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran, where he is a Full Professor of electromagnetic engineering. He has authored and translated several textbooks in Farsi. He has authored or coauthored over 300 papers in international journals and conference. In 2006, he was elected an exemplary nation wide university professor in Iran. He is an Invited Professor of the Electrical Engineering Group, Academy of Sciences of Iran, and is listed as an elite engineer by the Iranology Foundation.