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Design of a High Precision RC Oscillator

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Abstract: This paper introduces a high-precision RC oscillator circuit that is less affected by temperature and supply voltage. The circuit mainly consists of a bandgap reference voltage source, a low-voltage linear regulator, a low-pass filter, and a digital trim circuit, which reduces the circuit's sensitivity to temperature variations and achieves high stability of the oscillator frequency over a wide temperature range. Because of the current digital trimming technique, the circuit's ability to cope with the effects of frequency instability caused by process deviations is further enhanced.The simulation results show that the output center frequency accuracy is maintained within ±0.5% under the supply voltage range of 2.5V~5.5V, temperature range of -40℃~125℃, and different process corners. The RC oscillator has a high precision output frequency and can be used as a clock signal for a number of highly integrated and high precision applications.
Keywords: High-precision; RC Oscillator;Temperature Sensitivity; Digital Trimming

1. INTRODUCTION

As a clock signal circuit, oscillator is an important part of many electronic systems. With the rapid development of integrated circuits, oscillators will play an extremely important role in digital and digital-analog hybrid integrated circuits. Therefore, a highly stable and high-precision integratable oscillator is needed.

An oscillator is an oscillator that generates a periodic output signal by self-excited oscillation of the circuit alone without an applied input signal. Generally, the more common ones are RC oscillators, ring oscillators and crystal oscillators.RC oscillator has adjustable frequency, can be integrated, small size, low price, etc. However, the output frequency of RC oscillator is related to the power supply voltage and temperature fluctuations[1,2].Crystal oscillators are minimally affected by supply voltage and temperature fluctuations, but their large size and inability to be integrated affects their range of use [3].

This paper introduces a high-precision RC oscillator circuit whose circuit's internal current source circuit uses a high-order temperature-compensated design scheme to obtain a current source circuit with temperature-independent operation over a wide temperature range, and the circuit is virtually unaffected by temperature. In addition, a current digital trim circuit is used to improve the stability of the oscillator frequency for the deviation that the process will bring.

2. RC OSCILLATOR STRUCTURE

In The core components of RC oscillator are: current source circuit, LDO circuit, comparator, RS latch, digital trimmer circuit, integer inverter and other modules. the schematic diagram of RC oscillator, as shown in Figure 1..

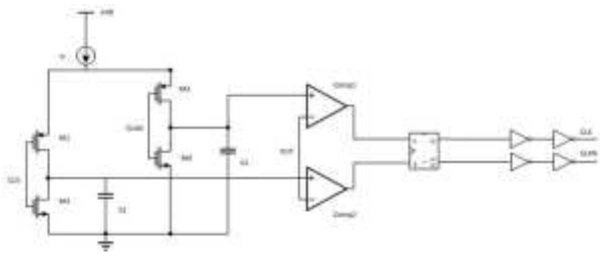

Figure 1. RC Oscillator

The operation principle of RC oscillator is as follows: assume that after the circuit is powered on, the output of RS latch in the initial state is Q=0, and the output of integer inverter is CLK=0 and CLKN=1. At this time, switch tube M1 is on, M2 is off, charging current Ic charges capacitor C1, and the voltage across the capacitor rises continuously, at the same time, switch tube M3 is off, M4 is on, and capacitor C2 is discharged to ground until 0V. When the voltage across capacitor C1 rises to Vref, the output of comparator Comp2 jumps to 1. At this time, the output of RS latch is Q=1, the output of integer inverter CLK=1, CLKN=0. Switching tube M3 is on, M4 is off, capacitor C2 is charged by current source current I_c, and at the same time, the voltage across capacitor C1 is put to 0V. When the voltage at both ends of capacitor C2 is charged to Vref, the output of comparator Comp1 jumps to 1, the output of RC latch changes again to Q=0, the output of integer inverter CLK=0, CLKN=1, the circuit returns to the initial state, the capacitor completes a charge/discharge cycle, the circuit forms an oscillation cycle, and so on and so forth, so that the RC oscillator at a certain frequency continuously.

According to the previous analysis and the charging and discharging characteristics of the capacitor, it is known that the capacitor completes charging time t1 and discharging time t2 as follows

$$t_1 = \frac{C \times \Delta U}{I_c} \quad (1)$$

$$t_2 = \frac{C \times \Delta U}{I_c} \quad (2)$$

C is the capacitance of the capacitor and ΔU is the difference in voltage across the capacitor. When the charge/discharge current Ic is a fixed value, the period T=t1+t2 for a complete capacitor charge/discharge.

Therefore, the output frequency of the RC oscillator is obtained as

$$f = \frac{I_c}{2C \times \Delta U} = \frac{I_c}{2C \times V_{ref}} \qquad (3)$$

In equation (3), Ic is the charging current, i.e., as the charging current of capacitors C1 and C2, V_ref is the bandgap reference voltage value, and C is the capacitor value. When the capacitors C1 and C2 are charged until they are equal to the bandgap reference voltage value Vref, the charging current I_c stops charging the capacitors, and then the capacitors start discharging to ground until the voltage across the capacitors is 0. After the charging current charges the other capacitor, the charging and discharging time of the two capacitors is one oscillation cycle.

3. CIRCUIT STRUCTURE DESIGN

3.1 Bandgap Reference Voltage Sources

The voltage reference circuit is a current-type low-voltage bandgap reference, which is based on the principle that the current with positive temperature coefficient and the current with negative temperature coefficient can be summed up in a certain ratio to make I_D4 with zero temperature coefficient. As shown in Figure 2.

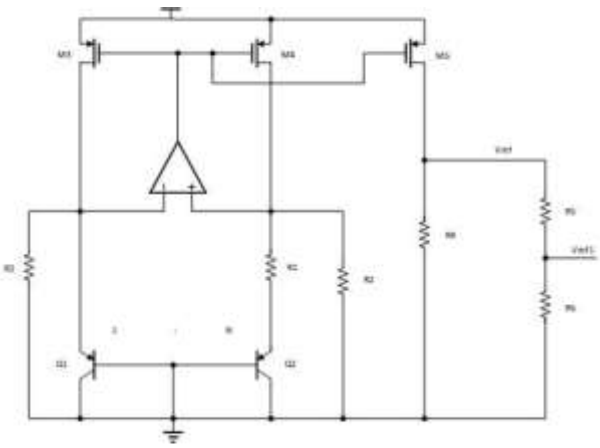

Figure 2. Voltage Reference Circuit

Vref and Vref1 are both reference voltages with zero temperature coefficient of order 1.

3.2 LDO Regulators

LDO regulator is low dropout linear regulator. It is widely used for its simple structure, low dropout voltage, and output voltage is less affected by the change of supply voltage. As shown in Figure 3, it mainly consists of error amplifier, power tube, feedback resistor, etc. Since the error amplifier, power tube Mp, and resistor R1 form a negative feedback structure, the feedback voltage will gradually approach the reference voltage Vref until the voltage values of both are equal. Therefore, the output voltage can be seen as minimally influenced by the supply voltage [4]. By analysis, the output voltage expression can be obtained as

$$V_{OUT} = V_{ref}\left(1 + \frac{R_1}{R_2}\right) \qquad (4)$$

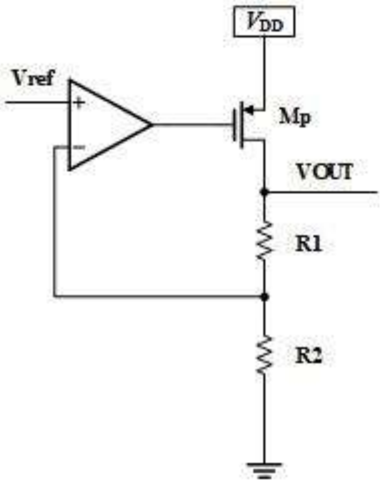

Figure 3. Video Low Dropout Linear Regulators

The From the above analysis, it can be seen that when the LDO output voltage VOUT becomes larger, after the feedback resistor divides the voltage, the negative input of the error op-amp will also become larger, at this time the error op-amp output becomes larger, so that the power tube VGS becomes smaller, the current flowing through the power tube is reduced, which in turn reduces the value of the output voltage VOUT, and vice versa.

Therefore, the LDO circuit can obtain a stable output voltage, which is almost constant by the supply voltage and temperature, and use this voltage value as the supply voltage for the core module of the RC oscillator.

3.3 Low-pass filter

The RC oscillator circuit system in this paper contains both analog and digital circuits. The core circuit of the oscillator is mainly a digital circuit, while its supply voltage is powered by the output voltage VOUT of the analog circuit LDO, and in addition, the voltage reference and current source circuits are also analog circuits. However, when high and low potential transitions occur in the digital circuit, a certain amount of jitter occurs on the power supply, which is directly transferred to the output of the LDO, and thus affects the performance of the analog circuit. The analog circuit can be isolated from the digital circuit, as shown in Figure 4.

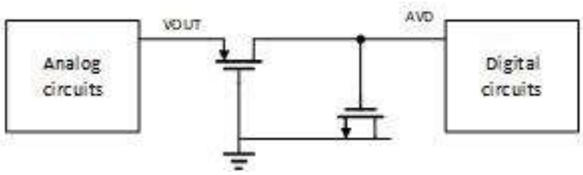

Figure 4. Schematic diagram of the isolation of analog circuits from digital circuitst

The analog circuit is isolated from the digital circuit by using a PMOS tube operating in the linear region and an NMOS capacitor to form an RC low-pass filter. The simulation results show that this approach can effectively improve the power supply jitter phenomenon and optimize the performance of the analog circuit when jitter noise is generated in the power supply of the digital circuit.

3.4 Digital trimming circuit

In fact, the entire circuit design, and then the final simulation verification process, the RC oscillator circuit is functional without considering the digital trim module. However, there is a process drift, which affects the output frequency of the RC oscillator, and this error value is large, which affects the normal use.Therefore,digital trimming of the circuit's charging current, resistor and capacitor arrays is required [5-7].

The digital trim circuit is composed of MOS tubes only and occupies a small area. The 8-bit modulation signal is used to control the on/off of PMOS switch. The initial trim data is 01111111, and each bit controls one switch. When the output signal frequency decreases, more switches are opened, for example, 01111000, the charging current Ic increases, and the output frequency increases. The higher the number of trim bits, the higher the accuracy of the oscillator. As shown in Figure 5.

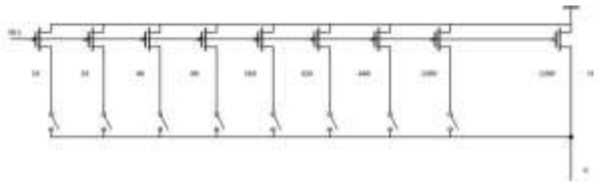

Figure 5 Current digital trimming circuit

4. SIMULATION RESULTS AND ANALYSIS

In this paper, the circuit is simulated and analyzed using CSMC 0.18 um CMOS process using Cadence Spectre circuit simulation tool. The simulation conditions are: tt process corner, supply voltage 2.5V~5.5V, and temperature -40℃~125℃. In addition, the results are simulated for ss and ff process corners after trimming.

The accuracy of the LDO output voltage can be measured by the linear adjustment rate, the smaller the linear adjustment rate, the higher the accuracy of the LDO output voltage. This output voltage provides the supply voltage for the RC oscillator. The simulation results show that the output voltage is around 2V with an error of no more than 0.5% under the supply voltage of 2.5V~5.5V. As shown in Figure 6.

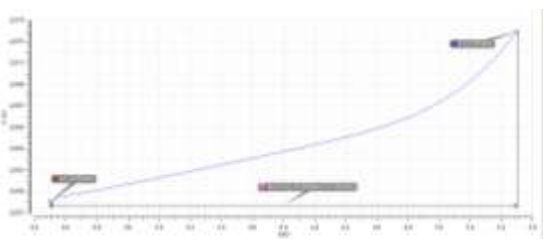

Figure 6 LDO Simulation Diagram

The output of the RC oscillator at tt process corner, at a temperature of 27 degrees Celsius, is shown in Figure 7.

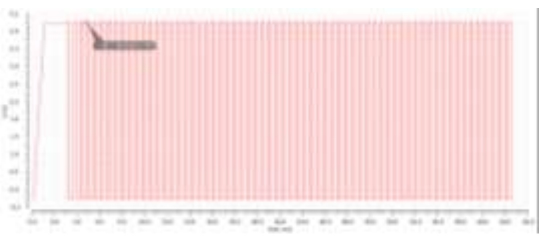

Figure7 RC oscillator output signal

The maximum value, minimum value, error and trimmed results of the output frequency of the RC oscillator at three different process corner at temperatures of -40°C to 125°C and supply voltages of 2.5V to 5.5V. As shown in Table 1.

Table 1. Output frequency of RC oscillator at different process corner

Process corner	Maximum /MHz	Minimum /MHz	Error /%	Trimmed results
tt	2.008	1.9916	±0.42	01111111
ss	2.0058	1.9942	±0.29	11110111
ff	2.0062	1.9939	±0.31	00010101

The simulation results of the high-precision RC oscillator designed in this paper are compared with the design performance indexes of domestic and foreign references. As shown in Table 2.

Table 2. Comparison of the oscillator results in this paper with those in the literature

	Process /um	Frequency /MHz	Error /%	Supply Voltage/V	Temp /℃
This work	0.18	2	±0.42	2.5~5.5	-40~125
[8]	0.18	2.3	±0.51	1.3~2.0	-40~125
[9]	0.18	1.6	±0.15	1.2~1.52	0~90

5. CONCLUSION

In this paper, a high-precision RC oscillator is implemented based on CSMC 0.18 um CMOS process by using a high-order temperature compensated current source and current digital trimming technique. The simulation results show that the output center frequency of the oscillator is maintained within ±0.5% at the supply voltage of 2.5V~5.5V and the temperature of -40℃~125℃; the output center frequency is also maintained within ±0.5% at different process corners (TT,SS,FF) after adding current digital trimming. The circuit can be integrated into a digital-to-analog hybrid system as an on-chip clock, for example, as an internal clock for an ADC, or as a separate clock chip.

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