MOS Temperature Compensated Crystal Oscillator

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Abstract: A temperature compensated Crystal Oscillator is widely used for the stable frequency source of mobile communication equipments. Recently, it has become necessary to reduce power consumption of TCXOs. In this paper, we have proposed a TCXO using weak inversion MOS transistors and have evaluated its fundamental characteristics.

1. Introduction

A temperature compensated crystal oscillator is widely used as a stable frequency source of mobile communication equipments. Recently, it has become necessary to reduce power consumption of temperature compensated crystal oscillators, because of increasing demand for low power dissipation of mobile communication equipments. Temperature compensated crystal oscillators have been built by bipolar transistors for the communication use so far, because bipolar transistors are superior in noise figure to MOS transistors. But recent development of low noise MOS transistors promote the development of temperature compensated crystal oscillator using MOS transistors. On the other hand, in the research of low power circuit design, the circuit design using weakly inversion MOS transistors has attracted attention, recently.

In this paper, we propose a novel temperature compensated crystal oscillator using weakly inversion MOS transistors. Main idea of our design technique lies in the exponential characteristics of weakly inversion MOS transistors. In the proposed temperature compensated crystal oscillator, we use the low drive level MOS colpitts crystal oscillator and the original variable capacitance circuit in which MOS transistor biased at non-saturation region is used as a variable resistor. And we also use the temperature sensor and the compensation function generator circuit obtained from bipolar circuits replacing bipolar transistors by weakly inversion MOS transistors.

We will explain the circuit structure of the proposed TCXO and the component circuits and describe their performances in section 2. In section 3, we will evaluate the frequency temperature characteristics of the proposed TCXO by simulation.

2. Circuit structure

Figure 1 shows a block diagram of TCXO. TCXO is constructed by a crystal oscillator, temperature sensor, compensation function generator, and variable capacitance circuit.

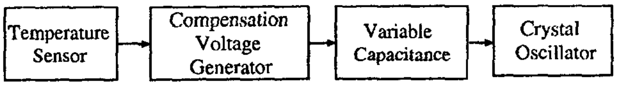

Figure 1. Block Diagram of TCXO

2.1 Crystal oscillator circuit

Figure 2 shows a circuit structure of a colpitts crystal oscillator. A colpitts crystal oscillator is composed by transistor M1, capacitor C_A, C_B and a crystal resonator. Bias currents are fed by the current mirror circuit made by transistor M_4, M_5 and M_6. Bias resistors are replaced by diode connected MOS transistors to reduce IC area size.

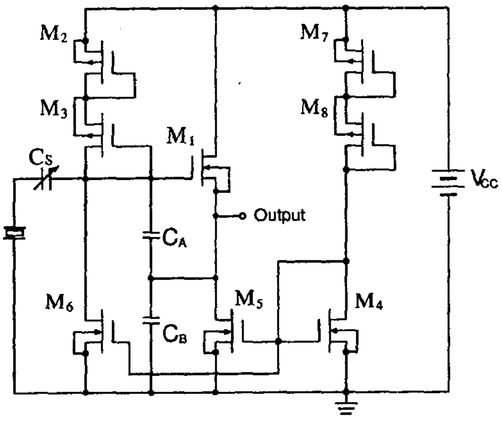

Figure 2. MOS Colpitts Crystal Oscillator

The characteristics of the oscillator circuit seeing into at the crystal terminal is described by the series circuit of negative resistance and equivalent capacitance. The negative resistance is an important parameter to estimate the oscillation strength, steady-state oscillation crystal current, and oscillation start-up time, etc.

A sample circuit is designed by the specification of table 1. Table 2 shows a sample of circuit parameters. The negative resistance dependence on the crystal current has been simulated and shown in figure 3. Small signal negative resistance is about 250 Ω and margin of negative resistance required for oscillation is sufficiently large enough. The steady-state crystal current is about

$35\mu A$. This value is sufficiently small to suppress the effect of the heat up of small sized crystal resonator.

Table 1. Specification.

Characteristics	Value
Power supply voltage V_{CC}	$3V$
Frequency f	$12.8MHz$
Small signal negative resistance r_n	$\leq -100\Omega$
Second harmonic of Vout	$\leq -10dB$
Duty	40~60%

Table 2. Circuit parameters of MOS colpitts crystal oscillator.

Parameter		Value	
MOS transistor		$W[\mu m]$	$L[\mu m]$
M_1	NMOS	10	0.7
M_2	PMOS	7.0	1.9
M_3	PMOS	7.0	1.9
M_4	NMOS	10	0.7
M_5	NMOS	30	1.8
M_6	NMOS	0.5	0.7
M_7	PMOS	5.0	2.5
M_8	PMOS	5.0	2.5
C_A		$2.2pF$	
C_B		$2.0pF$	
Crystal		$12.8MHz$	

Figure 4 shows the simulated output voltage. Table 3 shows the duty and second harmonics of the output voltage. These results show that almost nearly sinusoidal waveform is obtained and the proposed oscillator circuit satisfies the requirement for connected digital circuits. The obtained output voltage is small compared to the usual crystal oscillator realized by MOS inverter. But it does not reduce usefulness of this circuit because sufficient output voltage can be obtained by adding the low gain amplifier.

Table 3. Wave parameters of output voltage

Characteristics	value
Output voltage	$40mV_{pp}$
Second harmonics	$-30.3dB$
Duty	50%

.2 Variable capacitance circuit

Figure 5 shows a schematic diagram of the variable apacitance circuit. The variable capacitance circuit is he parallel circuit of resistor R and the series circuit of capacitance C_p and MOS transistor operating at non-saturation region. The equivalent circuit of the variable capacitance circuit is described by figure 6. The equivalent capacitance C_L and resistance R_L are expressed by the following equations.

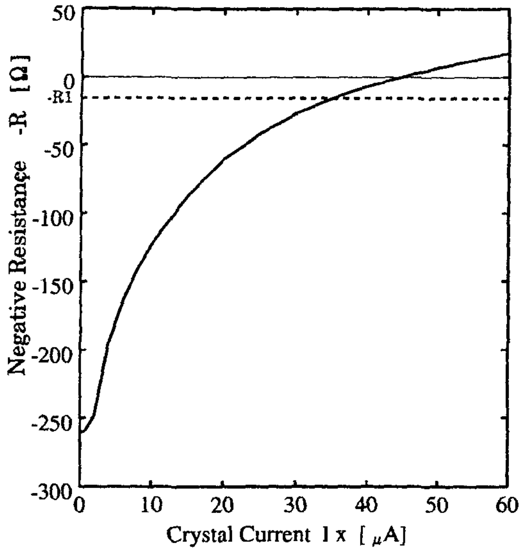

Figure 3. Negative Resistance Characteristics

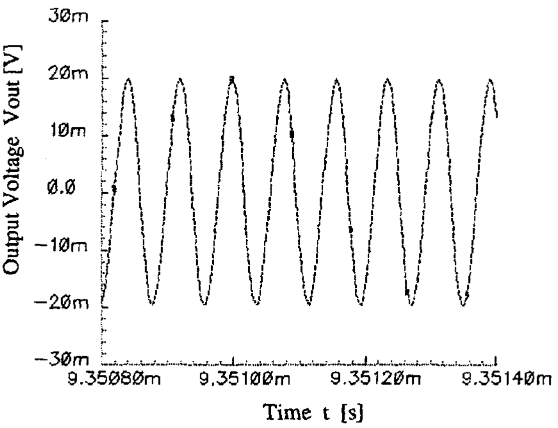

Figure 4. Output Voltage

$$R_L = \frac{R\{RR_P + R_P^2 + 1/(wC_P)^2\}}{(R+R_P)^2 + 1/(wC_P)^2}$$

$$C_L = \frac{(R+R_P)^2 + 1/(wC_P)^2}{R^2/C_P} \quad (1)$$

The capacitance variation has been simulated for the gate voltage variation between 1 through 3 volt. Figure 7 shows the simulated result. About $50pF$ through $130pF$ variation have been obtained for gate length 0.3 through 0.7 μm and are sufficient for the compensation of frequency deviation of crystal resonator.

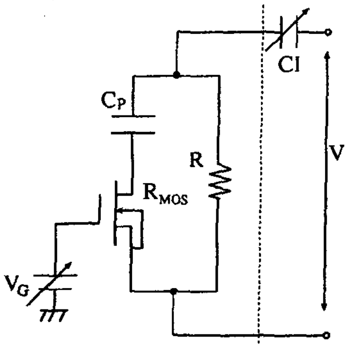

Figure 5. Variable Capacitance Circuit

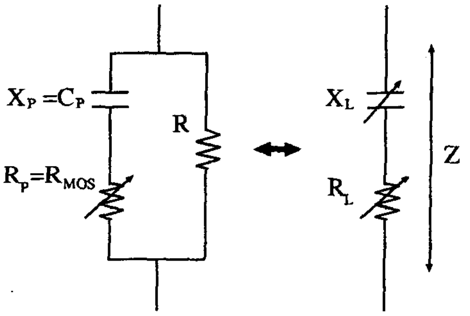

Figure 6. Equivalent Circuit of Variable Capacitance Circuit

2.3 Temperature sensor circuit

Figure 9 shows the temperature sensor circuit. This circuit uses the gate voltage change caused by temperature variation. The output voltage of the sensor Vout is expressed as follows;

$$V_{out} = (2\frac{k}{q}\frac{R_2}{R_1}ln\frac{A_1}{A_2})T \qquad (2)$$

where A is a ratio of area factor of MOS transistors.

Table 4 shows the designed parameters. Figure 9 shows the temperature dependence of the sensor output voltage. Sufficient linearity is obtained. The sensitivity of output voltage is about 1.17[mV]/℃.

Table 4. Circuit parameters of temperature sensor.

Parameter		Value	
MOS transistor		$W[\mu m]$	$L[\mu m]$
M_1	NMOS	10	0.9
M_2	NMOS	2.0	0.7
R_1		$70K\Omega$	
R_2		$350K\Omega$	
R_3		$10K\Omega$	
R_4		$10K\Omega$	

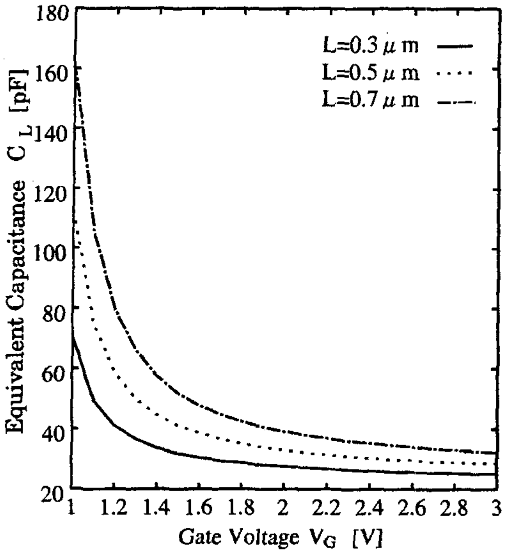

Figure 7. Equivalent capacitance of variable capacitance circuit

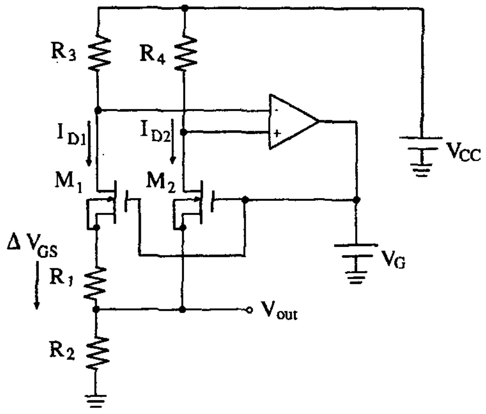

Figure 8. Temperature Sensor Circuit

2.4 Compensation function generator circuit

Figure 10 shows the compensation function generation circuit. The compensation function is the sum of cubic and linear function. The compensation function generation circuit is composed by exponential amplifier and logarithmic amplifier where the bipolar transistors are replaced by weakly inversion MOS transistors. Table 5 shows a sample circuit parameters of the compensation function generation circuit.

3. Evaluation of frequency temperature characteristics by simulation

To evaluate the performance of the proposed temperature compensated crystal oscillator, the frequency temperature characteristics has been simulated. Figure 11 shows the simulated results. In this figure, the doted line show the characteristics of a crystal resonator, the solid line shows the one of compensation function, and the dot-dashed line shows the compensated one of the total system. The frequency deviation of obtained tem-

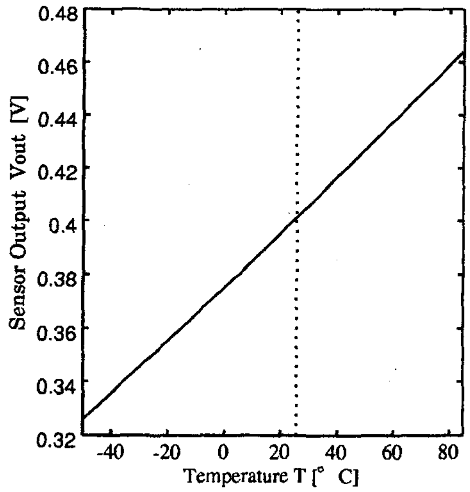

Figure 9. Sensor output characteristics

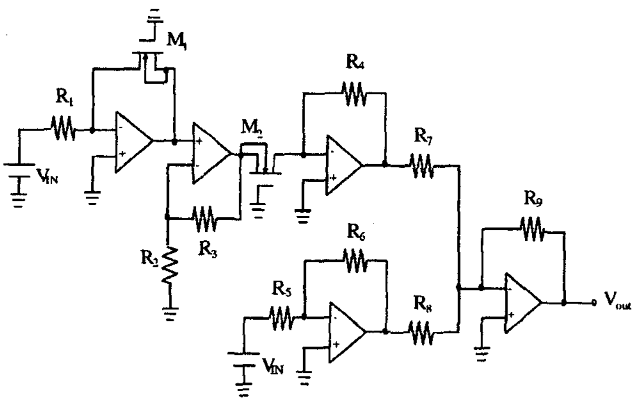

Figure 10. Compensation Function Generator Circuit

perature compensated crystal oscillator is within ±1*ppm* for the temperature range between -35 ℃から 85 ℃ and is sufficient for the practical use.

4. Conclusion

We have proposed a novel temperature compensated crystal oscillator using weakly inversion MOS transistors. Simulation have shown that the frequency temperature characteristics of the proposed TCXO is sufficient for practical use. For future work, we are going to make a sample circuit by MOS process and measure its performance.

References

[1] E. A.Vittoz, M.G.R.Degrauwe and S.Bitz : "High-Performance Crystal Oscillator Circuits Theory and Application"

[2] U. Tietze, Ch. Schnk : "Electric Circuits" Springer-Verlag, pp. 296-302, 1991

Table 5. Circuit parameters of compensation function generator.

Parameter		Value	
MOS transistor		$W[\mu m]$	$L[\mu m]$
M_1	NMOS	1.0	10
M_2	NMOS	1.0	100
R_1		$1K\Omega$	
R_2		$600K\Omega$	
R_3		$800K\Omega$	
R_4		$10K\Omega$	
R_5		$80K\Omega$	
R_6		$80K\Omega$	
R_7		$80K\Omega$	
R_8		$600K\Omega$	
R_9		$600K\Omega$	

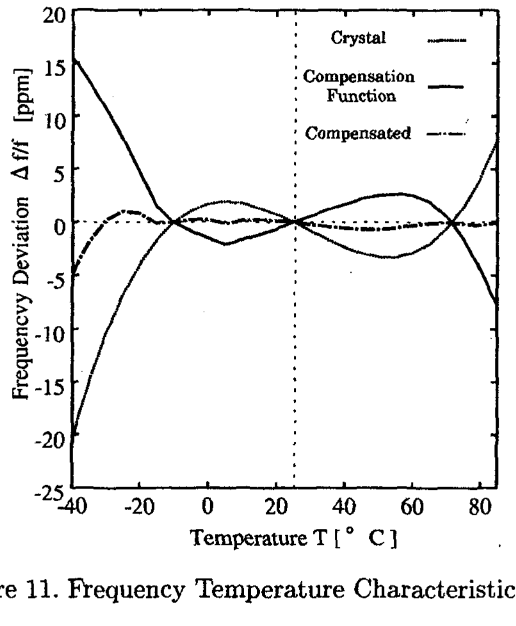

Figure 11. Frequency Temperature Characteristics