

# A CMOS Temperature Control Circuit for Crystal-on-Chip Oscillator

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**Abstract** - This paper reports design and fabrication of CMOS temperature sensor circuit using MOSIS 0.25um CMOS technology. The proposed circuit has a temperature coefficient of 13mV/°C for a wide operating temperature range with a good linearity. This circuit may be applicable to the design of one-chip IC where quartz crystal resonator is directly mounted on CMOS oscillator chips.

**Keywords:** CMOS temperature-voltage converter, crystal oscillator, PLL chip.

## 1 Introduction

Oscillators for providing highly accurate and stable reference clocks are very important for most communication and network systems, mobile phone, wireless modem, and GPS navigation systems, and so on. Recently, with the miniaturizing and addition of data communication function to mobile phones, the demand for smaller-sized and light-weight oscillator module has increased. The conventional oscillator module was generally composed of VCO and an external crystal oscillator. As a result, it has become difficult to make the small oscillator module.

A one-chip crystal oscillator has been proposed by Eda *et al*[1]. However, they could not minimize the chip size because the resonator was bonded next to the circuit, not on top of it. The solution which is suitable for very small oscillator module is fabricating one-chip IC where crystal oscillator is directly mounted on the oscillator[2],[3]. The elimination of an off-chip interface for the PLL chip and separate crystal packaging will reduce the size and the cost of the entire clock generation system. It also can improve precision, reliability, and stability of the system. In this paper, we report initial results of temperature-voltage converter for direct mounting of quartz crystal resonators on CMOS oscillator chips.

## 2 Oscillator and Temperature Sensor

The main blocks of oscillator IC are VCXO, PLL, digital control circuitry and temperature sensor circuit. The chip was fabricated with MOSIS 0.25um CMOS technology.

### 2.1 Voltage Controlled Oscillator(VCXO)

Voltage controlled oscillator(VCXO) is a crystal controlled oscillator where the frequency change is a direct proportion to the control voltage. In most commercial VCXOs, varactor diode is employed for the

modulator. This semiconductor diode is designed to act as a variable capacitor when a control voltage is applied to it.

Figure 1 shows a VCXO circuit diagram. In this circuit, two varactors are used as variable capacitive loads to provide frequency control[4]. The ring oscillator and the crystal included in the dashed box will be integrated on a chip.

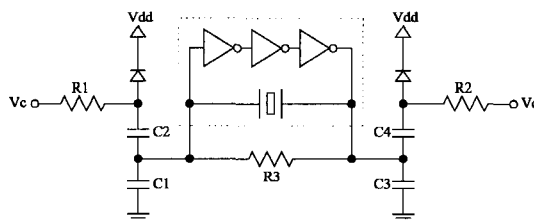


Figure 1. VCXO circuit diagram.

### 2.2 Phase Locked Loop(PLL)

Figure 2 shows the block diagram of a basic PLL system. The PLL reference frequency divider(RFD) and output frequency divider(OFD) are designed using T-flip flops. The 16kHz external reference(ExRef) signal is applied to the RFD and is fed into a phase frequency detector(PFD). The 155.52MHz clock from the VCXO is divided by the OFD and the output.

The output of the phase detector indicates a relationship between the two inputs[5]. This signal is applied to the charge pump(CP) and then to the loop filter. It is the loop filter that determines the dynamic characteristics of the PLL. The filtered signal controls the VCXO.

The two main components in this circuit are loss of lock(LOL) and loss of reference(LOR) blocks. The LOL detects whether two reference signals are locked or not. An output of LOL goes to high and forces an 'Alarm' signal to high if there is more than a  $\pm 90^\circ$  phase difference between the external and internal reference signals. The

LOR detects whether the external reference is coming into the PLL system or not. The output of LOR also goes to high and triggers an Alarm signal to high, if the external reference is locked up at either high or low.

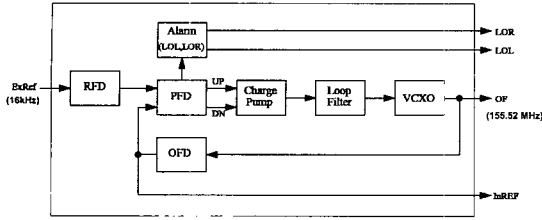


Figure 2. A block diagram of PLLT

### 2.3 Temperature sensor

Temperature sensor is a fundamental block for oscillator module. Furthermore, a temperature-voltage converter is one of the key building blocks for the temperature sensor. The temperature-voltage converter has been implemented by using the bipolar transistors[6], because its implementation is relatively easy for its strong dependence on temperature. Recently, however, a CMOS technology has been a mainstream in terms of low power dissipation, low cost and the mixed-signal LSI's.

Figure 3 shows the proposed CMOS temperature-voltage conversion. The bias voltage  $V_B$  and input voltage  $V_{in}$  are applied to the gate of PMOS transistor(M2) and to the gate of NMOS transistor(M1), respectively. The DC transfer characteristics of the circuit can be adjusted by bias voltage  $V_B$ .

It is important to make sure that the temperature-voltage conversion circuit design is robust against process parameter variations, which may affect the slope of the transfer characteristic. The slope of transfer curve is determined by the relative size of transistor M1 and M2 as well as the voltage  $V_B$ . As PMOS bias voltage  $V_B$  increases, the slope is also tends to increase.

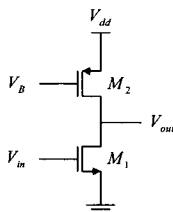


Figure 3. CMOS temperature-voltage conversion circuit.

Figure 4 shows the control loop circuit for temperature compensation. It consists of a temperature-voltage conversion circuit, op-amp and heater. When the temperature of the chip decreases, output voltage of the temperature sensor decreases and Op-Amp output voltage

increases. Consequently, the gate voltage of the heater increases, which then results in self-heating. When the temperature increases, the current in the heater decreases. Therefore, the self-temperature control has been achieved.

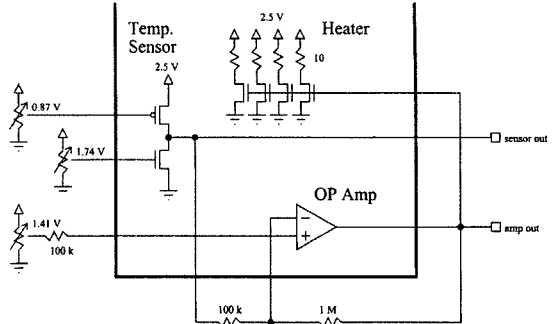


Figure 4. A Loop circuit for temperature control.

## 3 Simulation and Experimental Results

### 3.1 Simulation Results

SPICE simulation was accomplished with 0.25um CMOS n-well process parameter. DC transfer characteristics of temperature-voltage conversion circuit for various values of the bias voltage  $V_B$  between 1.6 and 2.3V(to every 50mV), are shown in Fig. 5. The transfer curve is shifted to the left and the slope is increased with the increase of the bias voltage.

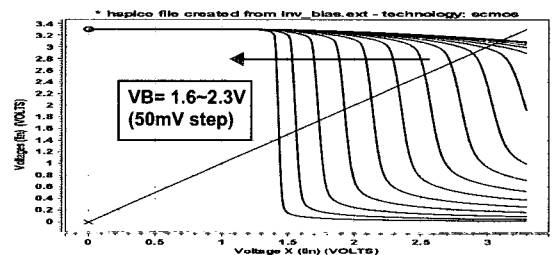


Figure 5. DC transfer characteristics for bias voltage.

Figure 6 shows a relationship between output voltage and temperature variation(20 to 100 °C) for bias voltage  $V_B=2.1V$ . Here input voltage  $V_{in}$  varies from 2.19 to 2.21V at 10mV step. Figure 7 shows characteristics of output voltage versus temperature variation(50 to 100 °C) for input voltage  $V_{in}=2.19V$ , 2.2V, and 2.21V, respectively. Here, the bias voltage was set to 2.1V.

Simulated output voltage shows the high linearity over a wide range of temperature from 20 to 100 °C. The slope factor of the simulated result is about 13mV/°C. The target frequency of oscillator is 155.5MHz at 93 °C. Thus, this

circuit may be applicable to the design of on-chip crystal oscillator.

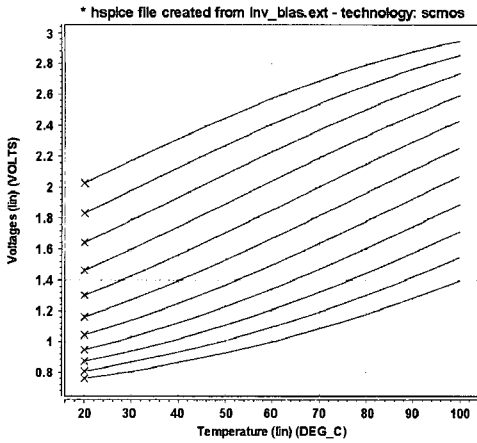


Figure 6. Characteristics of out voltage according to the temperature variation(20 to 100 °C).

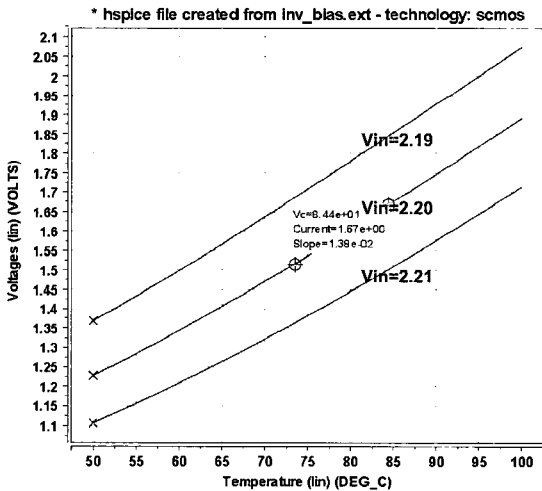


Figure 7. Characteristics of out voltage according to the temperature variation(50 to 100 °C).

### 3.2 Experimental Results

The oscillator chip is fabricated by using standard 0.25um CMOS n-well process. Figure 8 and 9 show that the layout and die photo of the fabricated chip, respectively. Special attention in layout has been paid to the matching of transistors and capacitors.

The power supply is set to 2.5V supply voltage because of leakage current. The leakage current of the chip is about 25mA.

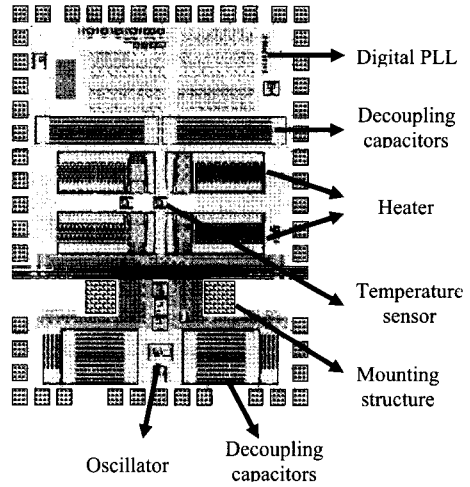


Figure 8. Die Photo of a fabricated chip.

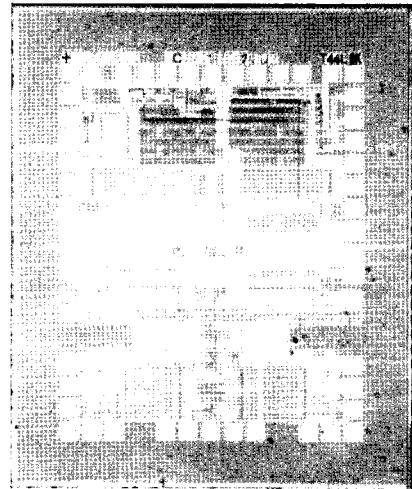


Figure 9. Die Photo of the fabricated chip.

Figure 10 shows a test board with fabricated chip. Jitter is a typical way to evaluate a performance of a PLL system. Table 1 shows jitter measurement on packaged device with external standard 155.52 MHz stand-alone quartz oscillator. For the unbuffered output with the digital circuits off, the jitter is 3.5ps

Table 1: Jitter measurement on packaged device with external standard 155.52 MHz stand-alone quartz oscillator.

	Jitter measurements (ms)
Buffered output with all circuits on and PLL locked	130 ps
Unbuffered output with PLL locked	35 ps
Unbuffered output with the digital circuits off	3.5 ps

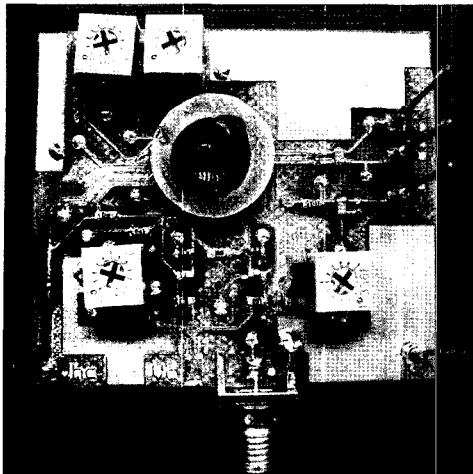


Figure 10. Test board with a fabricated chip.

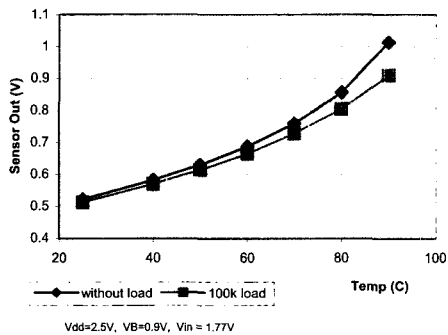


Figure 11. Characteristics of sensor output voltage.

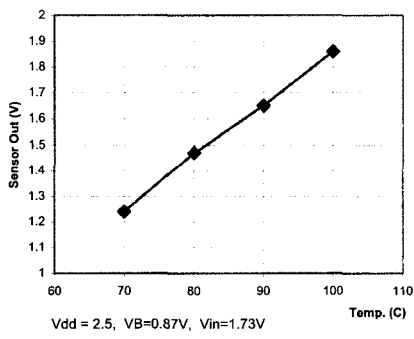


Figure 12. Characteristics of control loop circuit.

Figure 11 shows characteristics of the measured sensor output voltage according to the temperature variation in the proposed CMOS temperature-voltage converter with load and without load, respectively.

Measured output voltage shows a good linearity over the range of temperature from 20 to 100 °C. Characteristics of control loop circuit according to the temperature variation from 70 to 100 °C is shown in Fig. 12. It can be observed that the slope factor of the tested result is about 20mV/°C.

## 4 Conclusions

In this paper, CMOS temperature-voltage converter has been designed and fabricated by using 0.25um 3.3V CMOS technology. The experimental result indicated that the proposed circuit has a temperature coefficient of 13mV/°C for a wide operating temperature range(0 to 150 °C) with a good linearity. The temperature coefficient of output voltage can be controlled by adjusting external bias voltage. This circuit may be applicable to the design of one-chip IC where quartz crystal resonators is directly mounted on CMOS oscillator chips.

## References

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