The Design of Temperature-Compensated Surface Acoustic Wave Oscillator

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Abstract: - The design technique of a temperature-compensated SAW oscillator (TCSO) was thoroughly studied. The circuit of the TCSO contains two main parts, one is oscillation circuit and the other is temperature compensation circuit. In this work, the oscillator circuit adopted a commercial one-port SAW resonator at 433.92MHz in its resonant circuit. The reflection circuit model for oscillator design was applied. The performances of the designed TCSO are output power 10.6dBm, phase noise -138dBc/Hz at 10 KHz offset from carrier frequency, and maximum frequency deviation -40ppm from -10ºC to 85ºC.

Key-Words: - Oscillators, Surface Acoustic Wave Resonator, Temperature-Compensated Circuit.

1. Introduction

Surface acoustic wave (SAW) devices have the advantages of compact, superior performance, highly reproducible and reliable. Recently, owing to the improvement in design and fabrication techniques, SAW devices have been widely applied on the products of communication, computer and consumer electronics, such as RF and IF filters and oscillators [1]. Although SAW oscillator presents better phase noise and frequency stability than LC oscillator, the frequency stability with temperature changing is still a crucial issue for a high performance communication system. In this paper, a temperature-compensated SAW oscillator was designed and verified by experiment. This TCSO employed a one-port SAW resonator operated at 433.92MHz in its oscillation circuit and along with a temperature-compensated circuit.

2. Method for temperature compensation

The circuit of TCSO is divided into two parts, one is the voltage controlled SAW oscillator (VCSO) and the other is the temperature-compensation circuit as shown in figure 1. The VCSO includes an amplifier, a varactor diode and an one-port SAW resonator. As stated in many circuit design textbook [2-3], the oscillation frequency can be expressed as

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Where, L and C are equivalent capacitance and inductance of the resonant tank circuit, respectively. The varactor diode is eventually a PN diode operated in reverse bias. The junction capacitance of a varactor, considered as a parallel capacitor, can be calculated by $C = kA/d$, where C is capacitance, A is the cross section area of the junction, d is the width of depletion region and k is a constant. The capacitance C is direct proportion of the area A and inverse proportion of the width d. When the reverse voltage decreases, the depletion region of PN junction becomes narrower and the capacitance increases. On the contrary, the capacitance decreases as the reverse bias increases. The temperature compensation circuit senses the temperature variation and transfers to a bias voltage signal on varacator diode. By variation the junction capacitance of varacator diode, the frequency compensation can be achieved. Figure 2 depicts the principle of temperature compensation effect. In this figure, the horizontal axis represents the variation of temperature and the vertical axis shows the relation of compensation voltage and frequency of oscillation. Curve A is the oscillation frequency without the temperature compensation, curve B is compensation voltage applied on varactor diode, and curve C depicts the oscillation frequency after compensation.

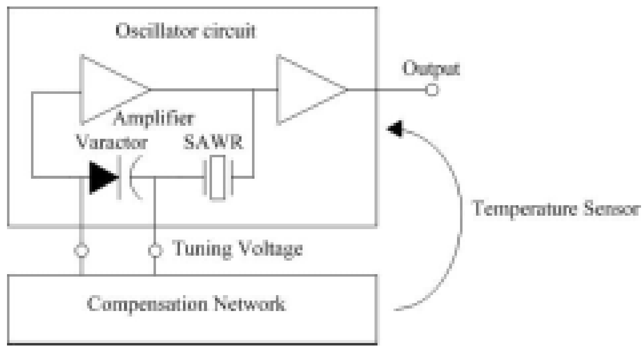

Fig.1 Block diagram of temperature-compensated SAW oscillator.

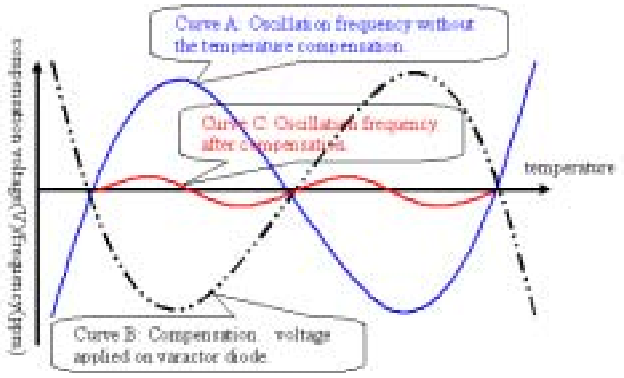

Fig.2 The operation principle of a temperature compensation oscillator.

3. Theorem of Oscillation

The reflection model was used to analysis the oscillator. Figure 3 shows the equivalent circuit model of the oscillator, where Z_{in} is the impedance of active circuit and Z_L is the load impedance of passive circuit. a_n indicates a noise source. a_{in} and b_{in} represent the amplitude of incident and reflection voltage to and from Z_{in}, and a_L and b_L represent the amplitude of incident and reflection voltage to and from Z_L, respectively [3-6].

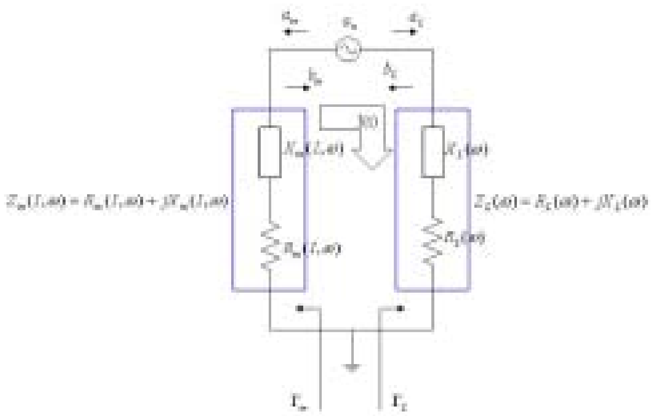

Fig.3 Equivalent circuit of oscillator using reflection model.

The reflection coefficients looking into source and load are defined as $\Gamma_{in} = \frac{b_{in}}{a_{in}}$ and $\Gamma_L = \frac{b_L}{a_L}$. From circuit analysis:

$$a_{in} = \frac{\Gamma_L a_{in}}{1 - \Gamma_L \Gamma_{in}} \qquad (2)$$

The condition for oscillation is:

$$\Gamma_L \Gamma_{in} = 1 \qquad (3)$$

From the relationship of load impedance and reflection coefficient, equation (3) can be derived:

$$\Gamma_L \Gamma_{in} = \frac{Z_{in} Z_L - Z_0 (Z_{in} + Z_L) + Z_0^2}{Z_{in} Z_L + Z_0 (Z_{in} + Z_L) + Z_0^2} = 1 \qquad (4)$$

where, Z_0 is the characteristic impedance of the system. The equation (4) is valid when $Z_{in} + Z_L = 0$, i.e.,

$$\begin{aligned} R_{in} + R_L &= 0 \\ X_{in} + X_L &= 0 \end{aligned} \qquad (5)$$

Since the load is a passive network, the real part of load impedance R_L is positive. To satisfy the oscillation condition, the real part of active circuit R_{in} should be a negative value which means the active circuit should provide enough energy to support a stable oscillation. The equation of imaginary part determines the frequency of oscillation that is oscillation can only occurs at the frequency where X_L=-X_{in}. Therefore, as illustrated by the diagram of reflection model of oscillator shown in figure 4, the criteria of for initial oscillation are expressed in equations (6) and (7) [5].

$$\left| \frac{1}{S_{11}} \right| < |\Gamma| \qquad (6)$$

$$\angle \left(\frac{1}{S_{11}} \right) = \angle \Gamma \qquad (7)$$

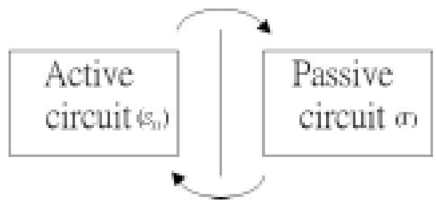

Fig.4 Diagram of reflection oscillated circuit.

4. Design Example

Based the theory mentioned above, the designed oscillation and temperature compensation circuits are given in figures 5 and 6. In figure 5, R_1, R_2, R_c and R_e are for bias resistors; C_3 and C_4 are coupling capacitors for DC block. Shunt-feedback capacitors C_1 and C_2 are employed to grantee the active circuit operate in unstable region (S_{11}>1). An RF chock is placed to separate the RF signal and DC voltage. In figure 6, OP1 and OP2 work as voltage follower which use the nature character of operation amplifier that have a large input impedance to avoid loading effect on output voltage. The output voltage of OP1 V_a is the reference voltage and the output voltage of OP2 V_b is the voltage transferred from the temperature sensor AD590. OP3 is a differential amplifier that takes the voltage difference between V_b and V_a. If R_3=R_2 and R_4=R_5, the gain and the output voltage of OP3 are equal to $K = \frac{R_4}{R_3}$ and $V_C = \frac{R_4}{R_3}(V_b - V_a)$. OP4 works as voltage scalar that adds a reference voltage V_d to the output voltage of OP3. By adjusting K and V_d, the purpose of temperature compensation can be obtained.

The designed parameters of oscillation circuit are listed as follows:

(1) center frequency is 433.92MHz for SAW resonator.
(2) topology of the circuit: Colpitts oscillator.
(3) active device: NEC NE85633
(4) DC bias: V_{ce}=5V, I_c=15mA
(5) PCB substrate: FR4 substrate with dielectric thickness 1.6mm.

The simulation results of the oscillator are shown in figures 7 to 10, respectively. Figure 7 shows the criteria for initial oscillation where $\left|\frac{1}{S_{11}}\right| < |\Gamma|$. Figure 8 shows the imaginary part of impedance is equal to zero at frequency 433.83MHz, and the real part of the impedance is negative. The power spectrum and the phase noise of the oscillator are given in figures 9 and 10 respectively.

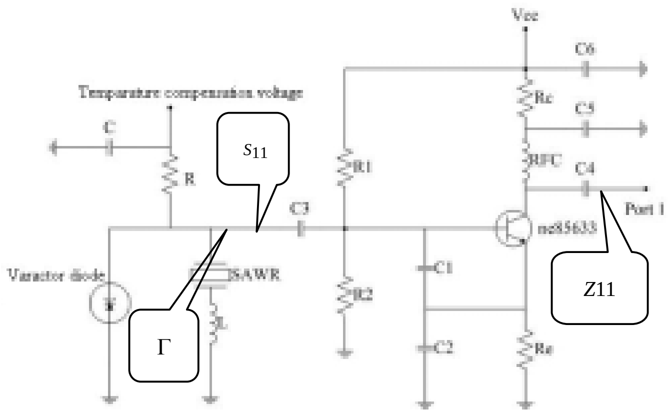

Fig.5 The schematic diagram of oscillation circuit.

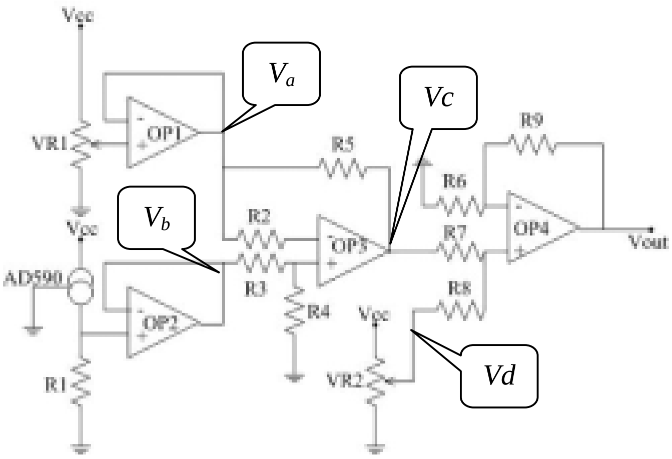

Fig.6 The schematic diagram of temperature compensation circuit.

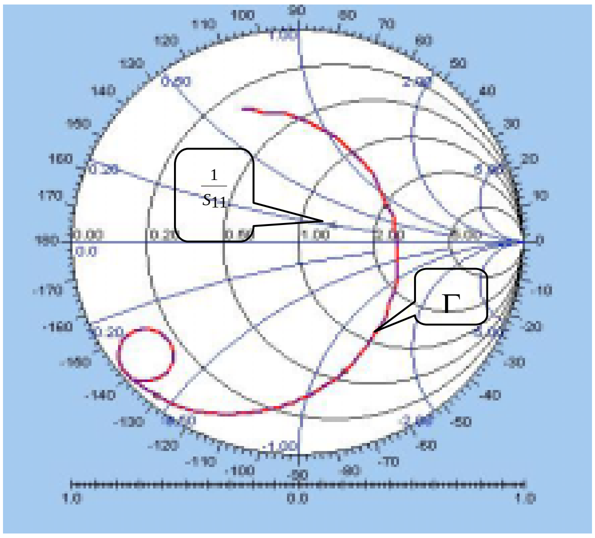

Fig.7 Simulated the criteria of oscillator, $\left|\frac{1}{S_{11}}\right| < |\Gamma|$ and $\angle\left(\frac{1}{S_{11}}\right) = \angle\Gamma$.

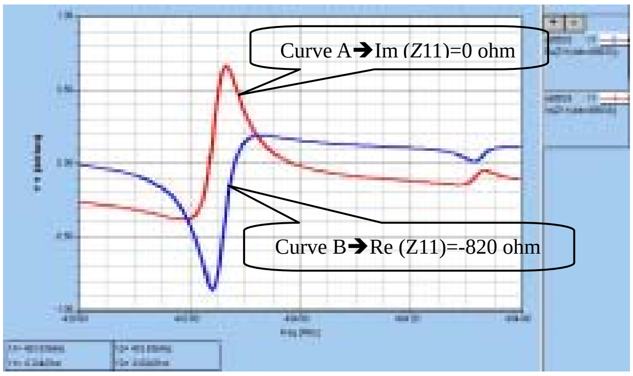

Fig.8 Simulated impedance performance, curve A is imaginary part and curve B is real part of impedance.

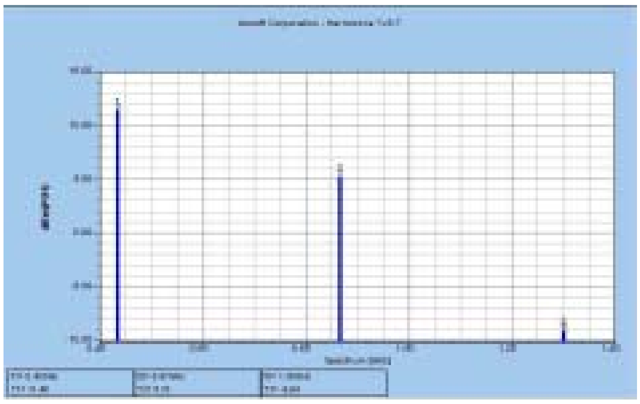

Fig.9 Simulate power spectrum.

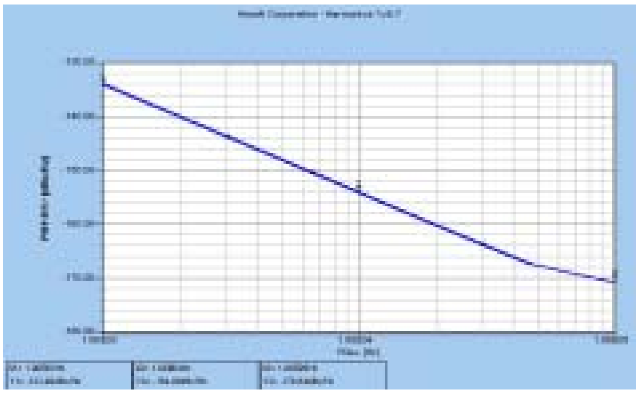

Fig.10 Simulated phase noise.

5. Experiment and Measurement

The realized TCSO hardware is shown in figure 11, and the measurement results are represented in figures 12 and 13. The frequency versus temperature from -40ºC to 80ºC of uncompensated oscillator is displayed in figure 14. The temperature characteristic of uncompensated oscillator is a parabolic curve with turnover temperature near 20 ºC. In order to compensate the frequency from -40ºC~80ºC, two compensated circuits were needs, one for below 0ºC and the other one for above 0ºC. All the measurements are done with a frequency counter in an environmentally controlled chamber (temperature range and tolerance: -40°C to 100°C and ±0.2°C, humidity range and tolerance: 10% to 98%RH and ±2%). The oscillation frequencies are recorded on 10°C per step. The temperature characteristics of compensated oscillator are shown in figures 15 and figure 16. From the measurement results, the maximum frequency deviation above 0°C is improved from 136ppm to 40ppm.

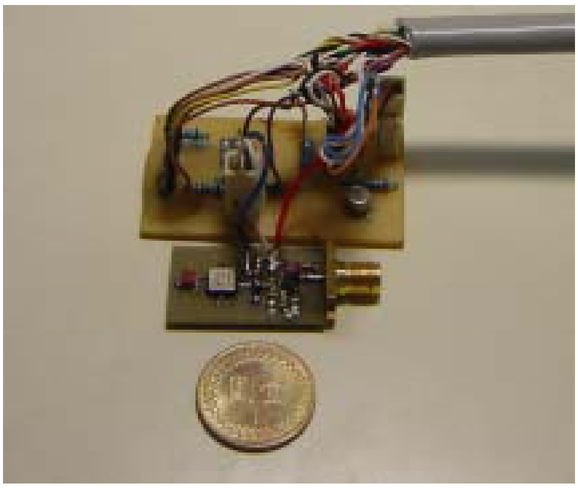

Fig.11 Realized TCSO hardware

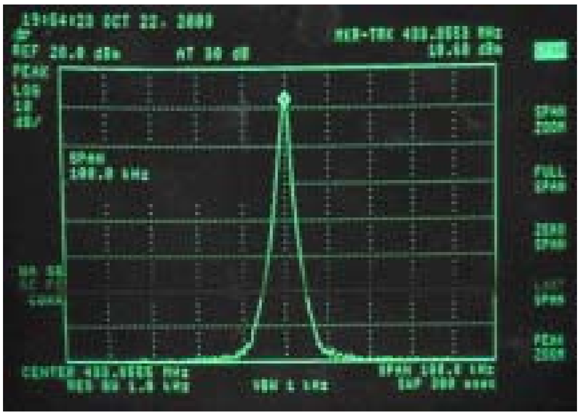

Fig.12 Measured power spectrum.

Fig.13 Measured phase noise.

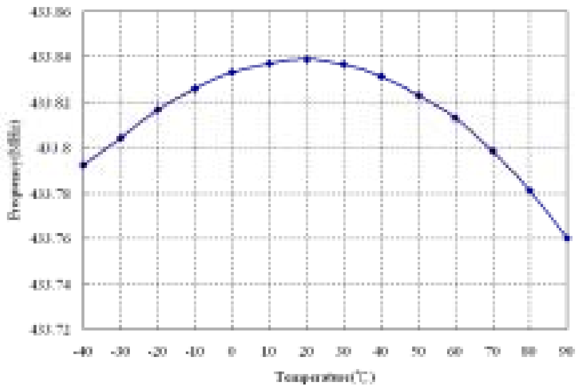

Fig.14 Temperature characteristic of uncompensated VCSO

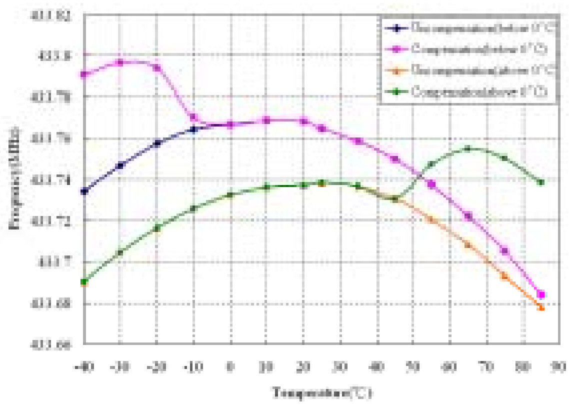

Fig.15 Temperature characteristics of TCSO.

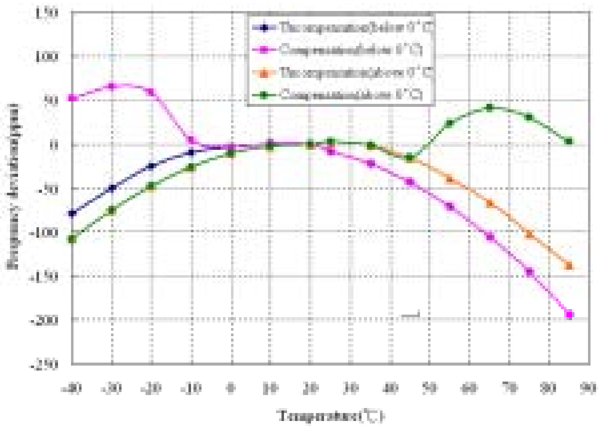

Fig.16 The frequency deviation of TCSO.

6. Conclusions

In this paper, a temperature-compensated SAW oscillator was designed successfully. The reflection oscillator model was employed to design a high output power and low phase noise SAW oscillator. The oscillator frequency is 433.85 MHz, output power is 10.6dBm and -138dBc/Hz phase noise at 10 KHz offset from carrier frequency. The temperature compensation circuit using temperature sensor IC AD590 improved the frequency deviation from 136ppm to 40ppm.

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