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Phase-noise characteristics in Colpitts crystal oscillators using high Q filters

高 Q フィルタを用いた狭帯域コルピッツ水晶発振回路における位相雑音特性

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1. Introduction

For many years, bipolar junction transistor (BJT) Colpitts crystal oscillators have been used as circuits that have low phase noise characteristics for communications. At the 1996 IEEE Frequency Control Symposium, Watanabe and coworkers greatly improved Colpitts oscillators. [1] The circuit was inserted into the quartz resonator in the emitter-base “returning branch” of the standard colpitts oscillators in order to restrict the narrow-band negative resistance zone and improve phase noise. In this paper, we report on low phase noise BJT Colpitts crystal oscillators that use the filter resonator Q value, i.e., SC-cut, of a filter element. The relation of low phase noise to is analyzed quantitatively and systematically. From the analysis result, we evaluated the effectiveness of these oscillators by manufacturing a system and demonstrated the improvement in near-career frequency phase noise.

2. Methods

2-1. Narrow Band Colpitts Oscillators

A narrow band Colpitts crystal oscillator is shown in Figure 1.

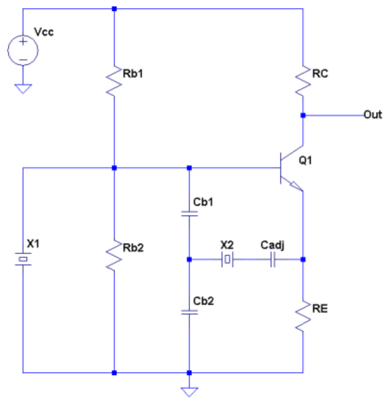

Fig. 1 Narrow band Colpitts oscillators.

Generally, a crystal resonator is connected between the base-GND and C_{b1}, C_{b2}, and the resonator form a loop to oscillate. In the circuit of Figure 1, a crystal resonator filter was inserted into the feedback path between C_{b1} and C_{b2} and the capacitance between the emitter and base.

2-2. High-Frequency-Equivalent-Circuit Model

Figure 2 shows a small signal equivalent circuit of the oscillator shown in Figure 1. The input impedance and input capacitance of the bipolar junction transistor have been taken into account for the equivalent circuit. The equivalent circuit is simplified by using the Δ-Y transform so that we can derive impedance Z_{in} seen from crystal resonator side. Therefore, negative resistance and reactance can be calculated by programming numerical calculation. Table 1 shows the target oscillator specifications used in this analysis, and the parameters used in this analysis are shown in TableS 2 to 4.

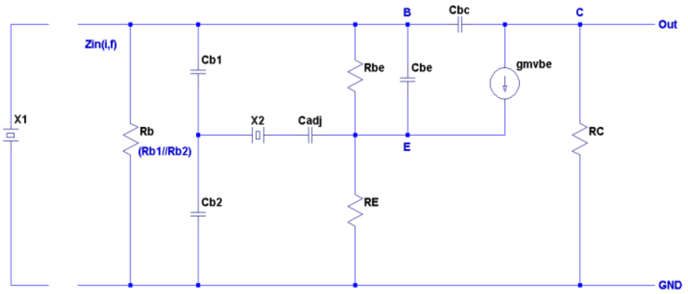

Fig. 2 High frequency equivalent circuit model of Colpitts oscillators with filter.

Table 1 Specifications of oscillator

Nominal Frequency	10MHz
Supply Voltage	DC+12V
Phase Noise	-118dBc/Hz@1Hz -148dBc/Hz@10Hz

Table 2 Circuit parameters in Fig. 1

R_{b1}	R_{b2}	RC	RE	C_{b1}	C_{b2}
120kΩ	220kΩ	100Ω	4.3kΩ	100pF	51pF

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Table 3 Equivalent parameters of SC-cut quartz resonator for oscillator

$R_1(\Omega)$	L_1(H)	C_1(fF)	C_0(pF)	f_s(Hz)	Q
74.9	1.549	0.163	1.956	9999926	130×10^4

Table 4 Equivalent parameters of SC-cut quartz resonator for filter

$R_1(\Omega)$	L_1(H)	C_1(fF)	C_0(pF)	f_s(Hz)	Q
77.2	1.554	0.163	1.962	9999928	126×10^4

2-3. Negative Resistance and Open-Loop Reactance Analysis

The frequency characteristics of negative resistance and merged reactance can be calculated by the derived Z_{in} in Section 2-2. A reactance analysis is used to estimate the loaded Q, and the component of the reactance can be estimated by a frequency slope and represented by equation (1).

$$Q_L = \frac{f_s}{2\cdot\Delta f}\cdot\frac{\Delta X}{R} \qquad (1)$$

2-4. Analysis of Phase Noise by Leeson's Model

Leeson's model is a closed loop model composed of amplifier and feedback elements for phase noise analysis and is given by the following equation.

$$S_\phi(f)=\alpha\cdot(v_0/2Q_L)^2/f^3+\beta\cdot(v_0/2Q_L)^2/f^2+\alpha/f+\beta \quad (2)$$

α is a 1/f noise level constant of open-loop, Q_L is the loaded Q of an oscillator, and β is a noise floor level.

3. Result

Figure 3 shows the results of analysis and measurement of negative resistance. It can be seen that bandwidth was limited to the extent necessary by inserting a filter.

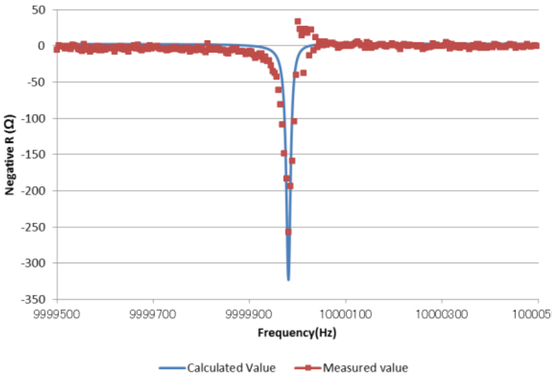

Fig. 3 Negative resistance result.

Figure 4 shows the results and the reactance analysis. 3.5 times the load Q could be improved by using filters with a high Q value.

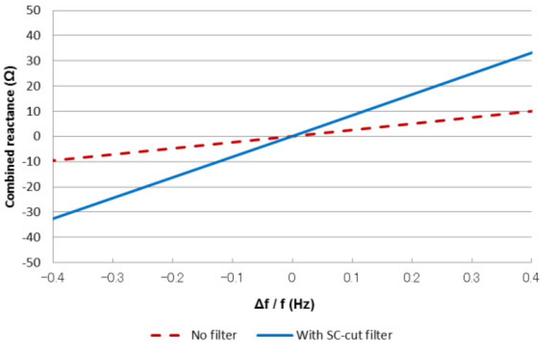

Fig. 4 Frequency characteristic of reactance near the oscillating frequency.

The results produced by the oscillator we examined for the analysis were then evaluated by actual measurement. Figure 4 shows the results of the analysis on phase noise value and the measured value. In good agreement with the analysis result, which had a phase noise of -117dBc/Hz at an offset frequency of 1Hz, we were able to obtain a low phase noise of -148 dBc/Hz at an offset frequency is 10Hz.

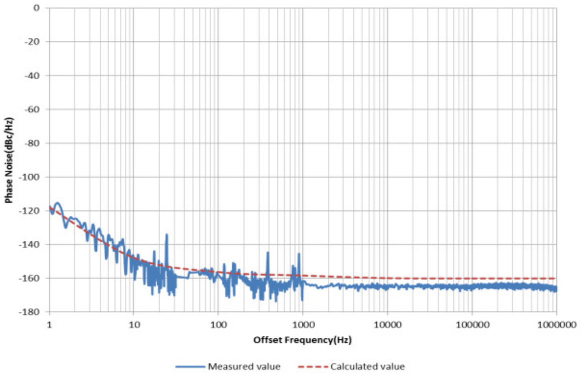

Fig. 5 Phase noise analysis and measurement result.

4. Conclusion

By using narrow band Colpitts crystal oscillators with high Q value filters, we obtained a low phase noise of -148dBc/Hz at an offset frequency of 10Hz. As future work, we will investigate how to correct the band of the filter and further stabilize the temperature of the crystal oscillators.

5. Reference

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2. T. Uchida, Y. Watanabe, H. Sekimoto and Y. Oomura; Proc.1996IEEE Int. Frequency Control Symp.,pp. 749-751,(1996)