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Effects of Corrector Filter on Phase Noise Characteristics of Butler Crystal Oscillators

バトラー水晶発振回路位相雑音におけるコレクタフィルタの影響

Yuxuan Zhong [‡], Jing Wang[†], Yasuaki Watanabe[†] and Katsuaki Sakamoto[1]
(Tokyo Metropolitan Univ., Former NDK[1])
鐘　雨軒[‡]，王　景[†]，渡部泰明[†]，坂元克明[1] (東京都立大院[†]，元日本電波工業[1])

1. Introduction

Quartz crystal oscillators are widely used as stable frequency sources in communications systems[1,2]. Recent advancements in mobile communications technology require that quartz crystal oscillators exhibit high stability and spectral purity. An important performance index of quartz crystal oscillators is phase noise characteristics. It is necessary to reduce such noise as digital mobile telephone networks continue to expand.

To reduce phase noise, we previously developed the Colpitts quartz crystal oscillator circuit, which exhibited a low phase noise floor, at the Institute of Electrical and Electronic Engineers (IEEE) of the Frequency Control Symposium (FCS)[3]. We then developed a low phase noise oscillation circuit using the stress compensated cut of quartz crystal resonators by improving upon our Colpitts crystal oscillator circuit. In our studies, we conducted experiments involving the above quartz crystal resonators at a resonance frequency of 10 MHz at which low phase noise can be easily attained. We also reported on the phase noise reduction in the carrier vicinity. In another study, we used simulation to evaluate the resonance frequencies of two quartz crystal resonators connected to a Butler crystal oscillator.

The limit of the resonance frequencies in the Colpitts quartz crystal oscillator circuit is about 90 MHz; therefore, a Butler crystal oscillator circuit is generally used when the resonance frequency exceeds about 100 MHz.

In this study, we assumed that two crystal oscillators were prepared for the Butler crystal oscillator circuit—one for the main resonance circuit and the other for the collector filter—to determine whether the area irrelevant to the frequency, i.e., the flat noise, could be reduced. Originally, this circuit was applied to the Colpitts crystal oscillator circuit; our purpose is to investigate whether phase noise can be reduced by applying it to the Butler oscillator circuit[4].

e-mail : y.watanabe@ieee.org

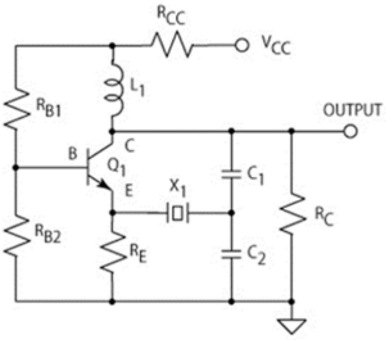

Fig. 1. Butler quartz oscillator

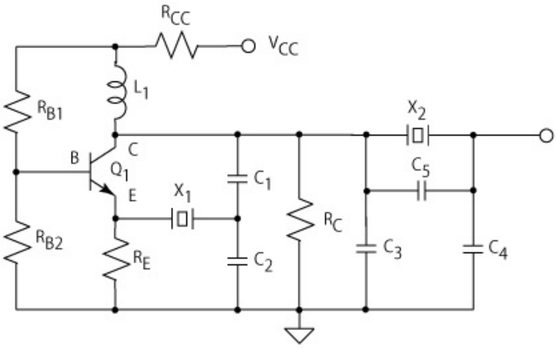

Fig. 2. Butler quartz oscillator with crystal unit X_2

In this research, we set the resonance frequency set to 125 MHz for a Butler crystal oscillator with an additional filter and examined the reduction in phase noise. The experimental results showed that the phase noise was reduced by - 6 dBc/Hz at a floor phase noise frequency.

2. Principle

Figure 1 shows a basic Butler crystal oscillator, in which a quartz crystal resonator is connected to an emitter terminal. This circuit is used in many oven controlled crystal oscillators (OCXOs) for optimal phase noise characteristics. The phase noise has been made into low noise for the purpose of this research.

Figure 2 shows the second quartz crystal resonator for a collector terminal. The quartz crystal was introduced to reduce phase noise via Fourier frequencies in the power of zero of f. The X_2 resonator had been used similary with Butler crystal oscillators in a previous attempt in Fig. 1 and tested in the application of the Butler crystal oscillator. However, such a resonator structure has not been been implemented with the Butler crystal oscillator.

3. Experimental Methods

The quartz crystal resonator was set up for two materials with the fifth higher harmonics of 125 MHz. Table 1 shows the equivalent parameters of the quartz crystal resonator. These quartz crystal resonators were inserted in the oscillators shown in Figs. 1 and 2. The phase noise was measured and the power of zero of f was compared on the Fourier frequency.

We used a signal-source analyzer (E50521B by Keysight) for the oscillation circuit output and measured the phase noise.

Table 1 Equivalent circuit of quartz crystals

	fs(MHz)	Q	R(Ω)
X_1	125.000	80000	52
X_2	124.998	80000	52

4. Measurement Results

For the measurement circuit using the quartz crystal resonator X_1, an approximate line (10–100 KHz) was used together with floor phase noise measurement to estimate the noise. Figure 3 shows the results of the phase noise measurement and the approximate line. The floor phase noise was measured to be about -132 dB.

The performance of the Butler crystal oscillator cannot be understood from floor phase noise characteristics alone. However, it is relative to the floor phase noise measurement, so it can be assumed that phase noise will be reduced by implementing quartz crystal resonator X_2. In contrast to X_1, the noise in this Butler crystal oscillator is measured with a terminal connecting X_2.

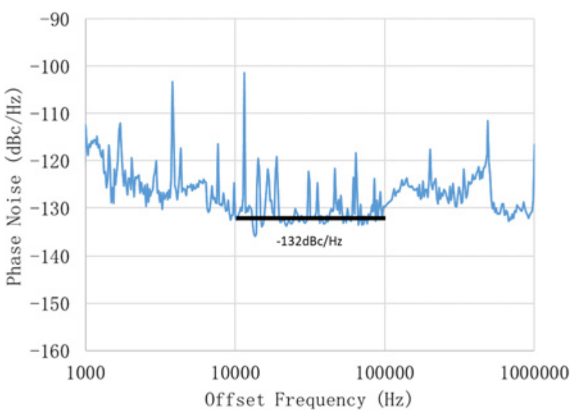

Fig.3. Phase noise results of Fig. 1 and straight line

Fig. 4 shows the floor phase noise characteristics of the Butler crystal oscillator when X2 was inserted into the circuit shown in Fig. 2. The phase noise decreased by about -6 dB (-138 dB) from 10 KHz to 100 KHz.

It is given that Figures 3 and 4 contain noise in similar areas; the straight lines are drawn on the basis of the measurements excluding these noises.

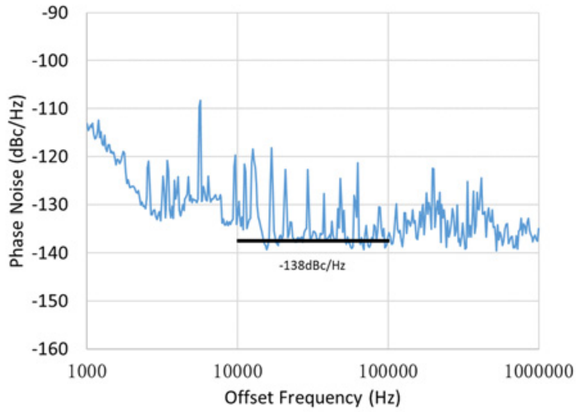

Fig.4. Phase noise results of Fig. 2 and straight line

5. Conclusions

Crystal oscillators require low phase noise for optimal performance. We evaluated floor phase noise by inserting a quartz crystal resonator into the collector terminal of a Butler crystal oscillator. When quartz crystal resonators of 125 MHz were used, the reduction rate of the phase noise was -6 dB.

Since the frequency characteristics of transistors are 300 MHz or higher, it is necessary to expand on this experiment by using a higher quartz crystal resonator.

Acknowledgments

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