

Effect of Base Filters on Phase-Noise Characteristics of Butler Crystal Oscillators

バトラー水晶発振回路の位相雑音におけるベースフィルタの影響

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1. Introduction

Crystal oscillators are widely used to construct a frequency source with low phase noise at low cost.¹⁾ An important performance index of the crystal oscillator is the phase-noise characteristics.²⁾ Much research has been conducted on reducing the phase noise of crystal oscillators.

With the spread of digital mobile telephone networks, it is a necessary to reduce phase noise. Butler crystal oscillators, which have one crystal, are widely used at frequencies exceeding 50–200 MHz.³⁾ It was verified through simulation that a Butler crystal oscillation circuit was completely oscillated.³⁾

We propose a Butler oscillator that has two crystals. From the simulation results, -22.5 dBc/Hz and an extremely low value were obtained compared with a one-crystal oscillator with near-carrier phase-noise characteristics.

2. Measurement Methods

The Butler crystal oscillator used for this study is shown in Fig. 1. A crystal was added to the base of a normal Butler oscillation circuit.³⁾ This circuit performed well in the simulation, but was unfinished with the works. This is because two quartz crystal resonators must be a certain distance apart by this circuit and cannot remove phase noise.

Therefore, we examined two quartz crystal resonators that agree with the simulation results. An equivalent circuit model of the simulation is shown in Fig. 2.

Two AT-cut quartz crystal resonators of 85 MHz (3rd) were investigated ($Q \approx 100000$). The quartz crystals of about 10 KHz were used for peak frequencies of two resonators X_1 and X_2 .

3. Phase Noise Measuring System

Figure 3 shows a block diagram of the entire phase-noise measurement system using the proposed oscillator. A signal-source analyzer (E50521B by Keysight) is connected for the oscillation-circuit output, and the phase noise is measured.

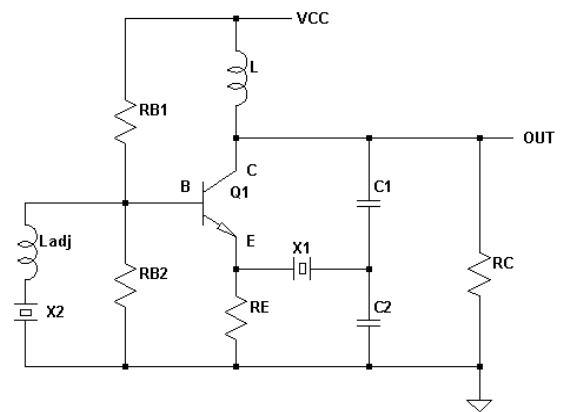


Fig. 1. Narrow band Butler quartz oscillator

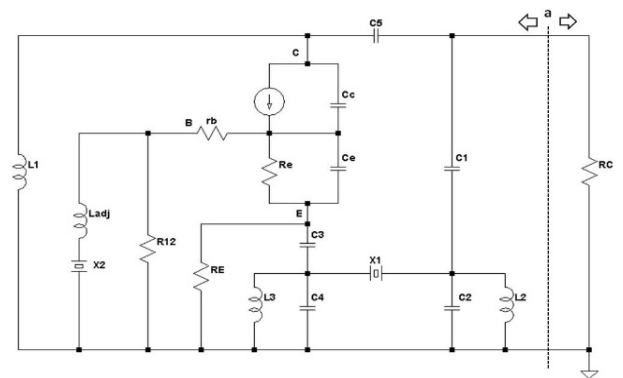


Fig. 2. High-frequency equivalent models of transistor Butler oscillator with a crystal filter

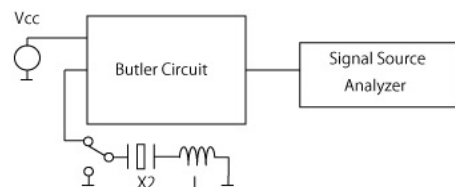


Fig. 3. Phase noise measurement set up

Fig. 3 changed it with a switch to compare both who applied X_2 to quartz crystal resonator circuit and circuit not to apply to.

4. Simulation

The supply voltage was first set to 4.0V. Figure 4 shows the measurement data and linear simulation results. The phase noise was analyzed based on the Leeson model.⁴⁾ The simulation was calculated using Eq. 1.

$$S_{\phi}(f) = \left[1 + \left(\frac{\nu_0}{2Q_{OSC}f} \right)^2 \right] \left(\frac{\alpha_L}{f} + \beta_L \right) \quad (1)$$

where ν_0 is the official frequency, α_L is the 1/f constant noise level in the open loop, and β_L is the noise floor level.

The simulation was carried out to estimate the frequency slant in the phase with the oscillatory frequency as a quantification of the Q of the oscillation circuit, which can be expressed as a frequency slant in the oscillatory frequency of the reactance as follows,

$$Q_{OSC} \propto \left. \frac{\partial \text{Im}(Z_{OSC})}{\partial \omega} \right|_{\omega=\omega_0} \quad (2)$$

Figure 4 shows the results of calculated phase noise using Eq. 1. By without AT-cut filter data complements it in a linear line approximation. Using Eq. 2 and other computing, it is a linear line of a little lower part and was -22.5 dBc/Hz.

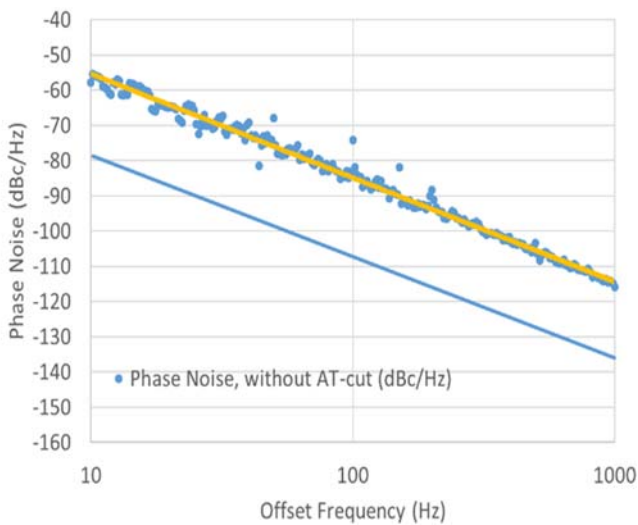


Fig. 4. Measured / simulation phase noise characteristics.

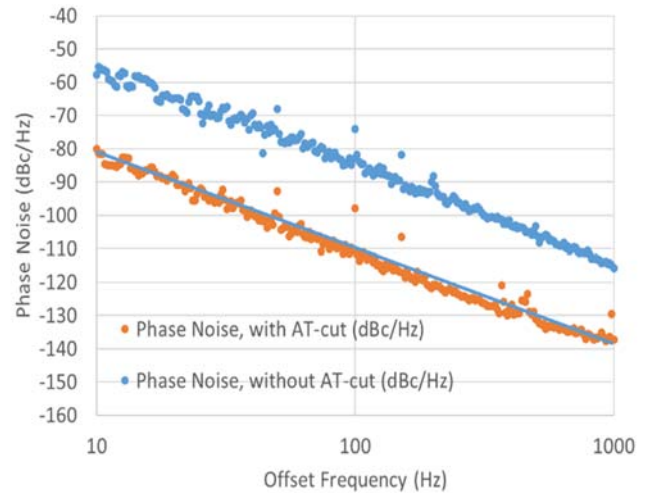


Fig. 5. Measured phase noise characteristics

5. Experimental Results

Figure 5 shows the offset frequency for the phase noise of the measurement data. Phase noise approximately equal to that in the simulation was obtained. As for the near-carrier phase noise, noise characteristics less than -22.5 dBc/Hz were obtained compared with using the one-crystal oscillator. These analysis results agree with the measurement results and confirms that phase-noise analysis by load Q estimation is effective.

6. Conclusions

Narrow-band Butler crystal oscillator was measured for phase noise with two resonators. As a result, a carrier was phase noise of neighboring, and an improvement of -22.5 dBc was obtained. Where phase noise goes down to by this result is simulated and experimenting is for future work. A collector should be also applied to three new resonators with a filter function, and phase noise should be measured.

Reference

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