A Study on Configuration of Extremely Low Phase Noise Oscillator Circuit

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Abstract: The low phase noise frequency source to be used for measurements and so on realizes by oscillator having highly output signal power against output noise power. SAW devices can be used by high power than BAW devices. So we examine on configuration of SAW oscillator circuits with the power gain. In this paper we shall discuss a configuration of oscillator circuit to obtain an extremely low phase noise and an oscillator operating at a non-reactive frequency of SAW resonator.

1. Introduction

In a point of view as on a rapid progress in recent years in mobile communications and on a metrology of frequency, a demand to achieve a low phase noise in standard frequency source is emphasized [1],[2].

It is well known that a phase noise in oscillator performs by a ratio of signal power and noise power. Therefore, a way which the power of oscillating signal is increased efficiently is available to be achieved an extremely low phase noise.

Since SAW devices can be used by high power than BAW devices, as a crystal resonator, SAW oscillators are available at a point to be achieved a low phase noise [3]. Although there are a many type in configuration of oscillator circuit, we have not understood which type of configuration is better for the extremely low phase noise.

This paper is discussed a configuration of oscillator circuit to obtain the extremely low phase noise and an oscillator operating at a non-reactive frequency, called as Fr oscillator, in a point of view as to be achieved an extremely low phase noise.

2. Phase noise in oscillator

Figure 1 shows an oscillator circuit model represented by D. B. Leeson [4]. The circuit consist of a feedback circuit and an amplifier circuit with phase noise $S_{\Delta\theta}(f)$. The phase noise $S_{\Delta\phi}(f)$ at output of oscillator is represented as following equation.

$$S_{\Delta\phi}(f) = \left\{1 + \left(\frac{f_0}{2Q_L}\frac{1}{f}\right)^2\right\} \cdot S_{\Delta\theta}(f) \qquad (1)$$

where, $S_{\Delta\theta}(f)$: Phase noise in amplifier, Q_L: Loaded Q, f_0: Oscillating frequency.

Equation (1) denotes that power spectral density function of $S_{\Delta\phi}(f)$ appeared at output of oscillator causes by phase noise $S_{\Delta\theta}(f)$ in amplifier, and a part of phase noise $S_{\Delta\theta}(f)$ within band width of closed loop of oscillator

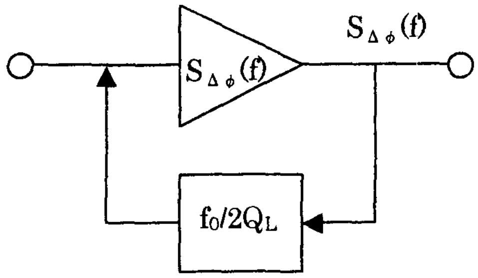

Fig.1 Oscillator circuit model.

circuit, $f_0/2Q_L$, is magnified by oscillation mechanism. Therefore, to consider in a point of extremely low phase noise, it is important to make a design as Q_L is larger and $S_{\Delta\theta}(f)$ is smaller.

Then, the oscillating signal power and the noise power in neighborhood of oscillating frequency are denoted by P_S and P_N, respectively, $S_{\Delta\theta}(f)$ is represented as following equation[4].

$$S_{\Delta\theta}(f) = \frac{P_N}{P_S} = \frac{2FkT}{P_S} \qquad (2)$$

where, Ps: Oscillating signal power, P_N: Noise power neighborhood of oscillating frequency, F: Noise figure of amplifier, k: Boltzmann's constant, T: Absolute temperature.

From equation (2), we have understood that an available approach to make smaller $S_{\Delta\theta}(f)$ is a way which the power of oscillating signal is increased efficiently, since the F to be able to control at the numerator exist a restrict of state of arts.

Since the SAW devices can be used at highly drive level, it must to be able designed P_S very large. Then, we could be expected $S_{\Delta\theta}(f)$ in equation (1) is smaller.

3. Relation of noise figure in amplifier and CN ratio

An Oscillator circuit consists of an amplifier circuit and a feedback circuit. The oscillation condition is that a closed loop gain along the oscillation loop exceeds $1\angle 0°$, as well known.

The oscillation condition is an idea to be able oscillate by using the amplifier circuit having a large power gain against a loss of the feedback circuit. But, to consider from a point of view as to be achieved an extremely low

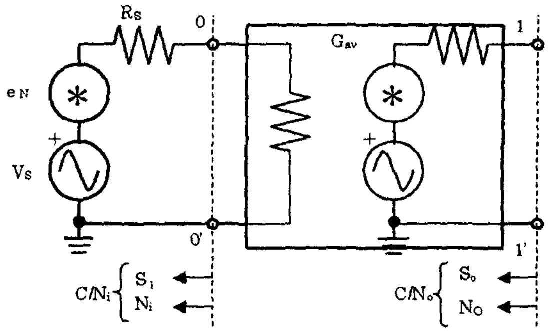

Fig.2 The relationship between noise figure and L(f).

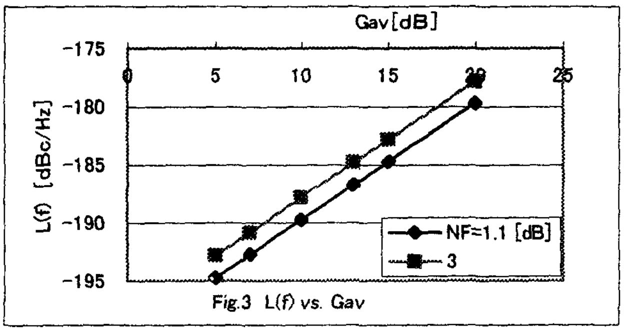

Fig.3 L(f) vs. Gav

phase noise, we have not understood what the relationship between the loss of feedback circuit and the gain of amplifier circuit is.

So, in this paper, as a first step for an estimation of phase noise in an oscillator, we have considered about the ratio of carrier to noise at output of amplifier circuit, the CN ratio, according to an idea of the noise figure NF of amplifier.

Figure 2 shows a configuration to examine the relationship between NF and L(f) of an amplifier circuit. In figure 2, V_S denotes an input signal source, R_S is an internal resistance, e_N denotes a thermal agitation noise source of R_S. A square part in figure 2 shows an amplifier circuit having available power gain G_{av}.

Now, the available signal power and the available noise power at input terminal represent S_i and N_i, respectively. Also, the available signal power and the available noise power at output terminal represent S_o and N_o, respectively. Then, NF is represented as following equation.

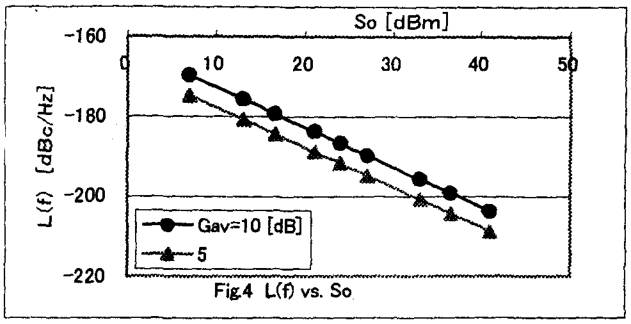

Fig.4 L(f) vs. So

$$NF = \frac{S_i/N_i}{G_{av}S_i/N_0} = \frac{N_0}{G_{av}N_i} = \frac{G_{av}N_i + N_0'}{G_{av}N_i} \quad (3)$$

where, $S_i = V_S^2/(4R_S)$, $N_i = kT \cdot BW$, k: Boltzmann's constant, T: Absolute temperature, BW: Band-width, N_o': Internal noise in amplifier circuit.

Let's consider the SSB phase noise, L(f), from the signal power and the noise power at the output of amplifier circuit. Here, L(f) is defined as a measure of the phase noise, means the inverse of the CN ratio per one Hz.

Then, the L (f) on the floor level is derived by following equation:

$$L(f) = \frac{N_0/BW}{S_0} = \frac{G_{av} \cdot NF \cdot N_i/BW}{S_0} = \frac{G_{av} \cdot NF \cdot kT}{S_0} \quad (4)$$

Equation (4) denotes that a necessary condition to obtain an extremely low phase noise is that signal power S_0 is large and the product of available power gain G_{av} and noise figure NF in amplifier under impedance matching is small.

Now, to consider when the internal resistance of amplifier circuit is 50 ohms, KT is 0.414×10^{-20}W/Hz(T; room temperature, 300K).

Figure 3 shows the result of L(f) vs. G_{av}, as a parameter of NF in a case of S_0=27dBm. From Figure 3, we have understood which smaller G_{av} is better for L(f).

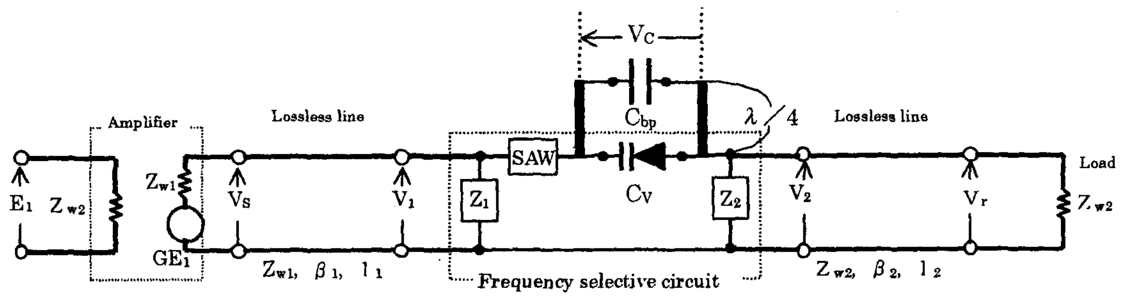

Fig.5 Configuration of Fr oscillator circuit having a function of frequency control.(Open circuit)

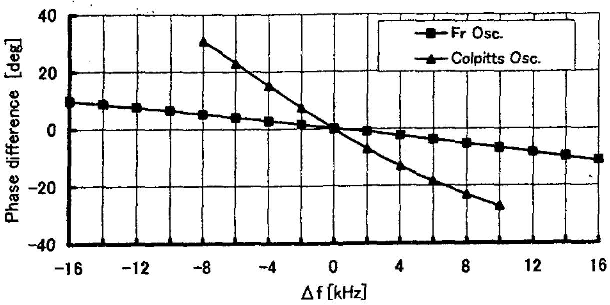

Fig. 6 Phase changes in neigborthood of oscillating frequency.

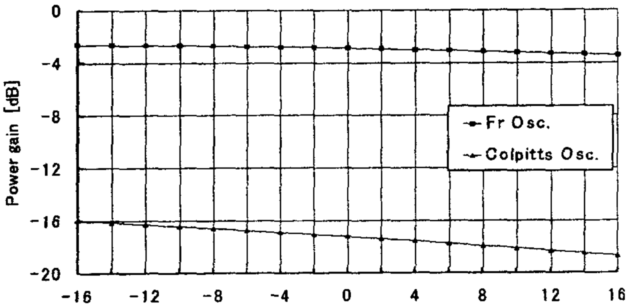

Fig.7 Power gain in neigborthood of oscillating frequency.

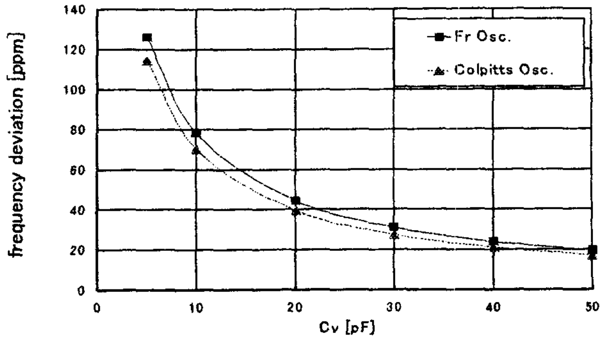

Fig.8 Changes of oscillating frequency with Cv.

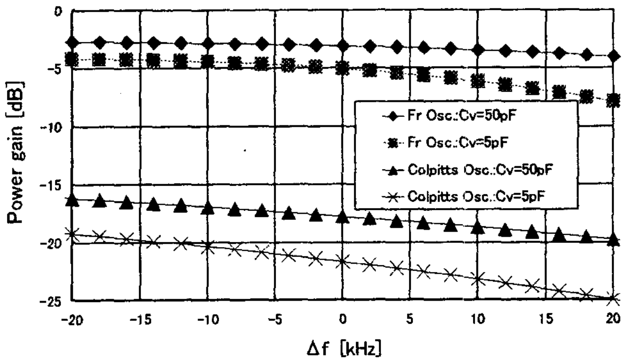

Fig.9 Power gain of VCO.

Figure 4 shows the result of L(f) vs. S_0, as a parameter of G_{av} in a case of NF=1.1dB. Figure 4 denotes that larger S_0 gives better L(f).

4. Configuration and characteristics of Fr oscillator

Figure 5 shows a configuration of open circuit of Fr oscillator having a function of frequency control, so called Fr-VCO(voltage controlled oscillator). Fr-VCO consists of amplifier circuit, transmission lines and frequency selective circuit. Frequency control is implemented by varying the capacity C_V of varactor diode in series the SAW resonator. The varactor diode is connected with a length λ /4 of transmission line having the characteristic impedance Z_0, to apply a control voltage V_C. Also, the end of the transmission line is terminated with bypass capacity C_{bp}. Influence of C_{bp} is negligible small against C_V.

An amplifier for Fr-VCO is using non-inverting amplifier, impedances Z_1 and Z_2 are using resistance R. Then, the frequency selective circuit acts as attenuator since series resonant circuit which consists of SAW resonator and variable capacity Cv is pure resistance at its non-reactive frequency. We have thought to use micro-strip line having characteristic impedances Z_{w1} and Z_{w2} as the transmission lines. Parts for the oscillator circuit will be set on the micro-strip lines.

Also, if the amplifier in Fig. 5 is used inverting type amplifier and impedances Z_1 and Z_2 are used capacitance C, the oscillator circuit is Colpitts type oscillator as well known.

Figures 6, 7 show example of calculated results. The condition for simulation are follows: resonant frequency of SAW resonator is 360.82 MHz, transmission lines are lossless, characteristic impedance $Z_{w1}=Z_{w2}=50\,\Omega$, electric length is negligible. In a case of Fr oscillator, frequency selective circuit acts as 3dB attenuator to satisfy impedance matching at non-reactive frequency. Also, in a case of Colpitts oscillator, values of C is decided $\omega C Z_{w1} \fallingdotseq 10$ to satisfy $Z_{w1}=Z_{w2} \gg 1/\omega$.

Figure 6 shows the phase shifts between E_1 and V_r in neighborhood of the oscillating frequency. $\Delta f=0$ in the horizontal axis means the oscillating frequency. From figure 6, the phase shifts of Colpitts oscillator is larger than that of Fr oscillator.

The characteristic of the phase shift against frequency is involved the term in braces of right side in equation (1). The large slope means that Q_L is large[6]. To consider from these characteristics , therefore, Colpitts oscillator may become smaller than Fr oscillator, against fluctuation of the oscillating frequency caused by fluctuation of the phase in the amplifier circuit.

Figure 7 shows power gain in neighborhood of the oscillating frequency, from the output of amplifier to the terminated load. This figure denotes that fr oscillator has large power gain than Colpitts oscillator and a little change of power gain against frequency, too. Also, we have understood that the gain of amplifier in Colpitts oscillator needs above ten times than that in Fr oscillator, to obtain same voltage gain $|V_r/E_1|$ when colpitts oscillator has a value of C as $\omega C Z_{w1} \fallingdotseq 10$.

Therefore, Fr oscillator circuit gets an advantage on the power gain, makes to oscillate by an amplifier having a small gain.

Figures 8, 9 show the results of simulation when Cv is changed. The condition for simulation are same to previous ones.

Figure 8 shows frequency deviation for the change of Cv, from 5 pF to 50 pF. In this figure, zero position in vertical axis means oscillating frequency in a case of Cv= ∞. Although frequency deviation of Colpitts oscillator is approximate 95 ppm, that of Fr oscillator is approximate 105 ppm. Therefore, Fr oscillator has good performance of frequency control than colpitts oscillator.

Although there is a problem that a frequency deviation caused by an ambient temperature in SAW oscillator is large, Fr oscillator has advantageous configuration for the temperature compensation since a range of frequency control is wide.

Figure 9 shows an example of calculated results, power gain from amplifier's output to load neighborhood the oscillating frequency, for each Fr oscillator and Colpitts oscillator, respectively. In this figure, $\Delta f=0$ in horizontal axis means oscillating frequency. Power gain of Colpitts oscillator varies from −17dB to −22dB, for the change of Cv. For the same change of Cv, power gain of Fr oscillator varies from −3dB to −5dB. Therefore, Fr oscillator has a good power gain than Colpitts oscillator. And, the change of power gain according to the change of Cv is a little.

Hence, we have understood that power gain of Fr oscillator has better than that of Colpitts oscillator even if with a function of frequency control. Also, Fr oscillator can be oscillated with a small power gain of amplifier, rather than Colpitts oscillator.

5. Conclusion

In this paper, we have discussed a configuration of oscillator circuit to obtain extremely low phase noise and an oscillator operating at non-reactive frequency of SAW resonator, so called Fr oscillator. Power gain of Fr oscillatoris better than that of Colpitts oscillator. This means a demand against power gain of amplifier becomes little when oscillator circuit is designed. In a design on high frequency oscillator, this performance is very important since a design of amplifier having high power gain become difficult.

We have also examined on Fr oscillator having a function of frequency control, Fr-VCO, for practical use. We have clarified Fr-VCO has a wide range of frequency control than that of Colpitts oscillator, and can be oscillated under good power gain even if in this case.

We will study on experiment and loaded Q.

Acknowledgement

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