A Low Phase Noise 19 GHz-band VCO using Two Different Frequency Resonators

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***Abstract* — A low phase noise 19GHz-band VCO is presented in this paper. The VCO has a novel tuning circuit which consists of two resonators, and they have a different resonant frequency. With these two resonators, the Q factor of the tuning circuit of the VCO is improved, and a low phase noise can be achieved. The measurement results of the developed VCO achieve the phase noise from -120 dBc/Hz to -122 dBc/Hz at 1 MHz from the carrier over a 290 MHz tuning bandwidth in 19 GHz-band. This VCO is one of the VCOs with lowest phase noise at K-band.**

I. Introduction

In recent years, a millimeter-wave utilization has been studied and developed for short distance radar systems and high speed data communication systems [1][2]. In these systems, a voltage controlled oscillator (VCO) is a key device. In a VCO, many electrical characteristics are required, for example, a low phase noise, a wide tuning bandwidth, small size, and low cost. A phase noise is most important characteristic for the VCO in these systems. In short distance radar systems, the ability to detect different targets at the same time is dependent on a phase noise of the VCO. In high speed data communication systems, the bit error rate (BER) characteristic is dependent on a phase noise of the VCO.

In general, a resonator with a high Q factor is used in order to achieve a low phase noise in a VCO [3]. A dielectric resonator (DR) has a high Q factor, and it is generally used to achieve a low phase noise in a VCO [4]. However, the VCO employing a DR has a narrow tuning bandwidth, high cost, and large size. On the other hand, a VCO with a microstrip resonator (MSR) has a wide tuning bandwidth, and is low cost. Moreover, a MSR is a plane and small circuit, and appropriate for a process of manufacturing semiconductors. However, a phase noise of the VCO using a MSR is inferior to that of the VCO using a DR since a Q factor of a MSR is less than that of a DR.

This paper describes that a Q factor of a tuning circuit can be improved by making a phase slope of a reflection coefficient in the tuning circuit steep at a resonant frequency, and presents a low phase noise 19 GHz-band VCO with a novel tuning circuit employing a MSR. The proposed tuning circuit has two resonators, and their resonant frequency is desinged to different frequency. Since the phase of the reflection coefficient changes rapidly in the tuning circuit, the Q factor of the VCO is improved, and a low phase noise characteristic is achieved. This paper also presents a developed 19 GHz-band harmonic VCO using the proposed tuning circuit.

II. Proposed Configuration Of Vco

A. Conventional Configuration Of Tuning Circuit

In general, a VCO with a high Q factor has a low phase noise characteristic [3]. A Q factor of a VCO is dependent on a Q factor of the tuning circuit of the VCO. So, in order to achieve lower phase noise characteristic of a VCO, we propose a VCO using a tuning circuit with a high Q factor.

Figure 1 shows a configuration of a conventional tuning circuit [5]. It has two resonators of a main-resonator and a sub-resonator. The main resonator is a half-wavelength microstrip open circuited stub. The sub-resonator consists of a varactor diode and a series inductor, which is connected to a main-resonator via a 90-degree inverter. A VCO using this tuning circuit has a low phase noise characteristic, because it has two resonators.

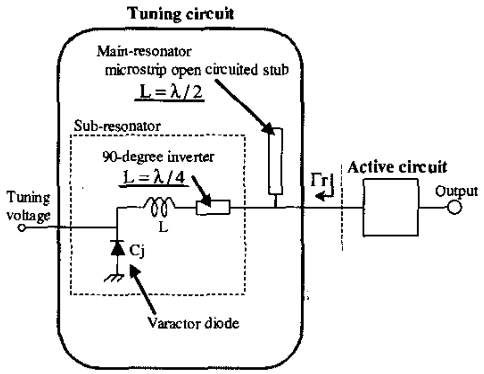

Fig. 1. Configuration of a conventional tuning circuit.

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Figure 2 shows a simple equivalent circuit of a conventional tuning circuit. In Fig. 2, R is a resistance, L is a inductance, C is a capacitance, and Γ is a reflection coefficient in the equivalent circuit of the tuning circuit. A Q factor of the equivalent circuit is given by

$$Q = \omega_0 RC = \frac{R}{\omega_0 L} \quad (1)$$

where ω_0 is a resonant frequency of the circuit.

The admittance of the equivalent circuit at frequency ω is given by

$$Y = \frac{1}{Z} = \frac{1}{R} + j \cdot \left(\omega C - \frac{1}{\omega L} \right) \quad (2)$$

Γ is given by

$$\Gamma = \frac{Z - Zo}{Z + Zo} \quad (3)$$

where Zo is a load impedance.

From equation (1), (2), and (3), a Q factor of the simple equivalent circuit is given by

$$Q \propto -\frac{\omega_0}{4} \cdot \frac{d\theta}{d\omega} \quad (4)$$

where θ is a phase of the reflection coefficient Γ in the equivalent circuit.

Equation (4) means that the Q factor of a tuning circuit is improved by making the phase slope of Γ at a resonant frequency steep. So, we propose a tuning circuit with a steep phase slope of the reflection coefficient, in order to achieve a very high Q tuning circuit and a very low phase noise characteristic of a VCO.

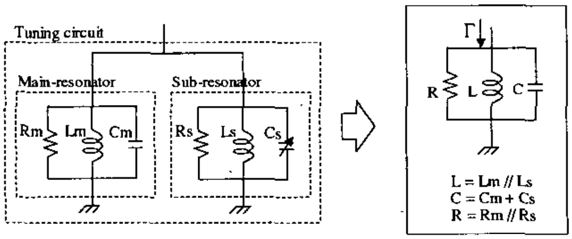


Fig. 2. Simple equivalent circuit of a conventional tuning circuit.

B. Proposed Configuration Of Tuning Circuit

Figure 3 shows a configuration of a proposed tuning circuit. It has a main-resonator and a sub-resonator. A microstrip resonator is used as a main-resonator. A sub-resonator consists of a varactor diode and a series inductor , and it is connected to a main-resonator via a microstrip line. The length of a microstrip line in the main-resonator is not a half-wavelength, and the length of the microstrip line between the main-resonator and the sub-resonator is not a quarter-wavelength.

Figure 4 shows a principle of achieving a high Q tuning circuit: (a) shows the phase of reflection coefficient of a conventional tuning circuit. (b) shows the phase of reflection coefficient of a proposed tuning circuit. The phase of reflection coefficient of the main-resonator and the sub-resonator are also shown in Fig. 4. The phase of reflection coefficient in a tuning circuit is dependent on the phase of reflection coefficient of a main-resonator and a sub-resonator. In Fig.4, fo is a resonant frequency of a tuning circuit. fmo and fso are parallel resonant frequencies of a main-resonator and a sub-resonator respectively. fms and fss are the first series resonant frequencies of a main-resonator and a sub-resonator respectively. fso and fss depends on a capacitance of the varactor diode, and it is controlled by the tuning voltage.

In the conventional tuning circuit, as shown in Fig. 4 (a), fmo and fso are set to a desired oscillation frequency, so that fo becomes a desired oscillation frequency. In the proposed tuning circuit, as shown in Fig. 4 (b), keeping fo a desired oscillation frequency, fms is set lower than a required oscillation frequency, and fss is set higher than a desired oscillation frequency. Since a series resonant frequency of a tuning circuit is equal to fms and fss, the phase slope of the reflection coefficient in the tuning circuit at fo is decided by fms and fss. As fms and fss are set closer, the phase slope of the reflection coefficient of

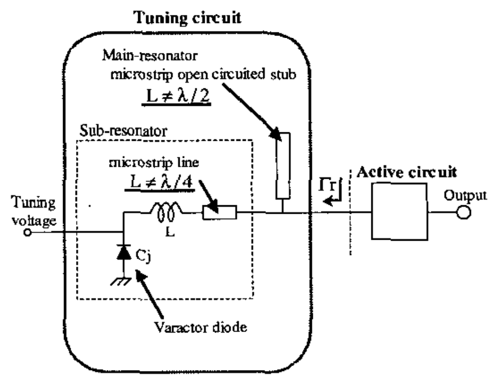
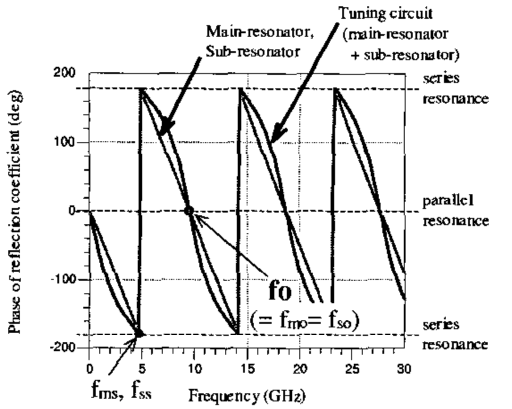
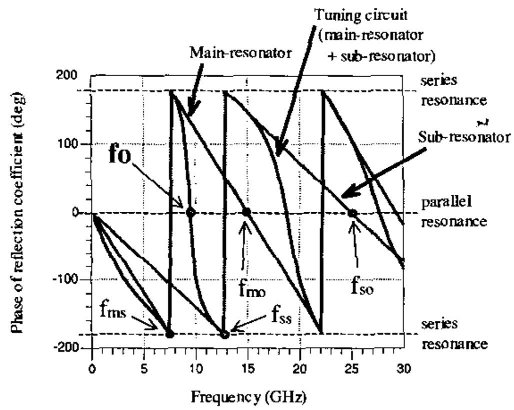


Fig. 3. Configuration of a proposed tuning circuit.

the tuning circuit becomes steeper at fo, and a high Q factor is achieved in the proposed tuning circuit. Therefore, The VCO using the proposed tuning circuit achieves a low phase noise characteristic.



(a)



(b)

Fig. 4.Principle of achieving a high Q tuning circuit: (a) shows the phase of reflection coefficient of a conventional tuning circuit. (b) shows the phase of reflection coefficient of a proposed tuning circuit: The phase of reflection coefficient of a main-resonator and a sub-resonator are also shown.

C. Proposed Configuration Of VCO

Figure 5 shows a configuration of the developed VCO. The resonant frequency of the tuning circuit is 9.5 GHz-band and output signal is 19 GHz-band to suppress the fluctuation caused by the change of load impedance. A HFET is employed as an active device. A substrate is a dielectric substrate, and its thickness is 0.6 mm.

In the tuning circuit for 9.5 GHz-band, the length of the

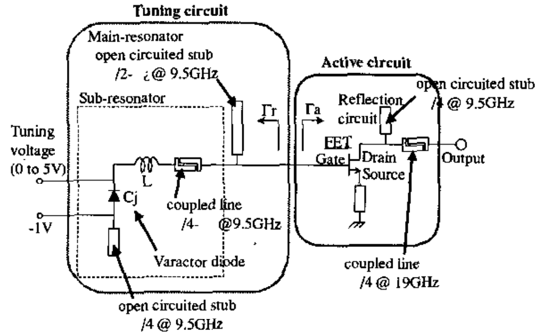


Fig. 5. Configuration of the developed 19 GHz-band harmonic VCO.

open circuited stub in a main-resonator is shorter than a half-wavelength at 9.5 GHz-band. The microstrip coupled line is used to adjust the phase of the sub-resonator and prevent DC passing. The length of the coupled line is shorter than a quarter-wavelength at 9.5 GHz-band. A voltage of −1V is applied to an anode of the varactor diode to improve a frequency linearity for a tuning voltage.

The active circuit has a quarter-wavelength microstrip open circuited stub at 9.5 GHz-band in order to reflect a 9.5 GHz-band signal, and a quarter-wavelength microstrip coupled line at 19 GHz-band in order to pass the 19 GHz-band output signal.

III. MEASUREMENT RESULTS

A 19 GHz-band harmonic VCO using a proposed tuning circuit has been developed.

Figure 6 shows a photograph of the developed VCO. The size is 17 mm X 19 mm. Figure 7 shows a output spectrum of the VCO. Figure 8 shows a phase noise characteristic at 1MHz from the carrier of the VCO. The phase noise from −120 dBc/Hz to −122 dBc/Hz is achieved. Figure 9 shows a output frequency of the VCO. The tuning bandwidth of 290 MHz from 19.08 GHz to 19.37 GHz is obtained for a tuning voltage from 0V to 5V. Figure 10 shows an output power of the VCO. The output power is from 0 dBm to +2 dBm.

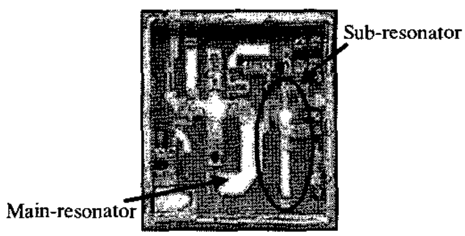


Fig. 6. Photograph of the developed VCO. The size is 17mm X 19mm.

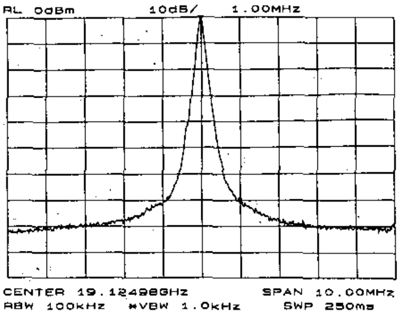


Fig. 7. Output spectrum of the developed VCO.

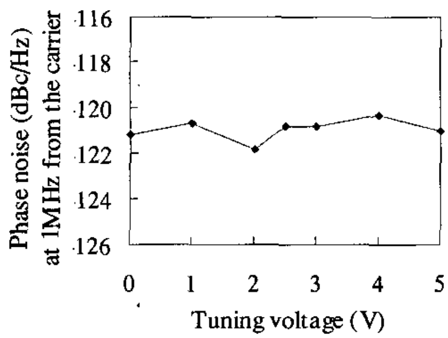


Fig. 8. Phase noise characteristic of the developed VCO.

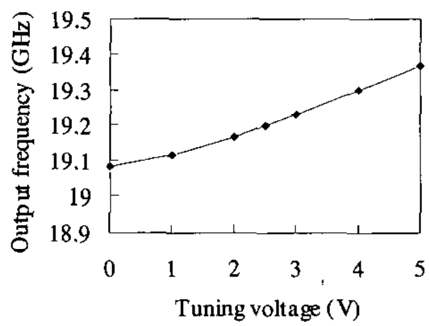


Fig. 9. Output frequency of the developed VCO.

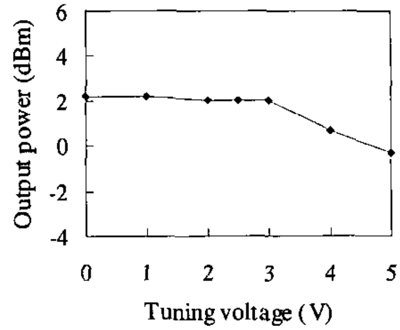


Fig. 10. Output power of the developed VCO.

IV. Conclusion

A novel tuning circuit with a high Q factor has been proposed in order to achieve a low phase noise of a VCO. The developed 19 GHz-band VCO achieves the phase noise from -120 dBc/Hz to –122 dBc/Hz at 1MHz from the carrier over a 290 MHz tuning bandwidth.

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