A 40 GHz-band Fully Monolithic VCO with a One-Wave Length Microstrip Resonator for Accurate Oscillation Frequency

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***Abstract* — A 40 GHz-band fully monolithic VCO with a one-wave length microstrip resonator (MSR) associated with a dumping resistor is presented. Employing a one-wave length MSR, high setting accuracy of oscillation frequency can be obtained, and it is a very effective method to improve yield of millimeter wave MMIC oscillator. Also the one-wave length MSR with a dumping resistor is proposed for suppression of parasitic oscillation. In analytical approach, variation of oscillation frequency is less than 150 MHz over $C_{gs}/C_{ds}/C_{dg}$ variation of ±10 % in worst case. The measured VCO tuning range is 493 MHz and it is well wider than the variation of oscillation frequency caused by process variations.**

I. Introduction

In recent years, a millimeter-wave utilization has been studied for short distance radar systems and high speed data communication systems [1]. A voltage controlled oscillator (VCO) is one of the key devices in these systems. In past, most of high frequency sources in millimeter-wave region have been developed using lower frequency VCOs and frequency multipliers. In this topology, both a wide tuning bandwidth and low phase noise characteristics can be implemented. However multistage filters are necessary for suppressing spurious components generated by multipliers. Hence, thw frequency sources that employ this topology become larger size and higher cost. On the other hand, fundamental oscillators have advantages of small size and low cost. However, it is difficult to set the oscillation frequency accurately especially in millimeter-wave region. For consumer utilization, yield improvement is key issue for low cost. Thus, high accuracy of setting oscillation frequency is necessary. VCOs that employ dielectric resonators have high accuracy of oscillation frequency, but tuning bandwidth of these oscillators is about 0.1 % of the oscillation frequency [2],[3]. So, frequency adjustment should be done by a mechanical tuning of the dielectric resonator. This requires complicated fabrication procedure for mass production. Furthermore, the dielectric resonators occupy a large space in the VCO.

Authors have already presented a 60 GHz-band VCO with a half-wave length microstrip resonator (MSR) [4]. This VCO achieves tuning range of 570 MHz, output power of 0.5 dBm and phase noise of −78 dBc@1 MHz offset. In this paper, a 40 GHz-band fully monolithic VCO employing one-wave length MSR is presented. To improve accuracy of oscillation frequency, one-wave length MSR employed for this VCO. Also, frequency variations of the VCO are analyzed for clarification of the effectiveness on the proposed VCO. Furthermore, experimental implementations are indicated for confirmation of the VCO characteristics.

II. Configuration And Its Behavior

Fig. 1 shows a circuit topology of the developed 40 GHz-band MMIC VCO employing a one-wave length MSR with a dumping resistor. In a tuning circuit section, Schottky junctiojns on GaAs substrate are used as tuning varactors. The sub-resonator is consisted of these varactors and a series inductor. A series resonant frequency of the sub-resonator is set to a center frequency of a desired tuning band. The one-wave length MSR is

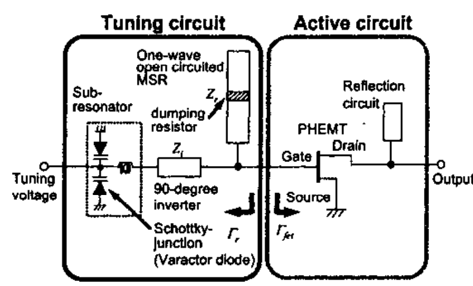

Fig. 1. Circuit topology of the developed 40 GHz-band MMIC VCO employing a one-wave length MSR with a dumping resistor

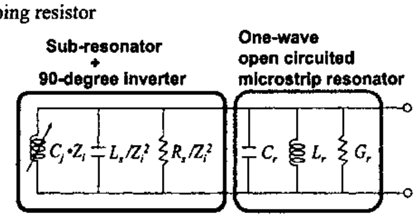

Fig. 2. Equivalent circuit of the tuning circuit section employing sub-resonator coupled by a 90-degree inverter

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employed for a main resonator. The main resonator is coupled to the sub-resonator through the 90-degree inverter. By insertion of the 90-degree inverter, impedance of the sub-resonator is inverted to parallel resonance at the point where the 90-degree inverter is connected to the main resonator. Fig. 2 shows an equivalent circuit of the tuning circuit section employing the sub-resonator coupled by the 90-degree inverter. The equivalent inductance (L_t), capacitance (C_t) and conductance (G_t) of the whole tuning circuit section shown in Fig. 2 are derived:

$$
\begin{aligned}
L_t &= L_r \,//\, (G_j \cdot Z_i) \\
C_t &= C_r + L_s / Z_i \\
G_t &= G_r + R_s / Z_i
\end{aligned}
\qquad (1)
$$

where L_r, C_r, G_r are the parameters of an equivalent parallel resonant circuit of the main resonator, Z_i is an impedance of the 90-degree inverter and L_s is an inductance of the series inductor of the sub-resonator.

As shown in Fig. 2, conductance components of R_s/Z_i and G_r are constant under variation of tuning voltage of varactor diodes. This makes the oscillation stable, thus this configuration is effective especially for millimeter-wave VCO with low active element gain. An active circuit section is consisted of a p-HEMT and reflection circuit. The p-HEMT is biased in a reverse channel mode which a drain electrode is terminated to a ground electrically. With this configuration, negative resistance is obtained for oscillation.

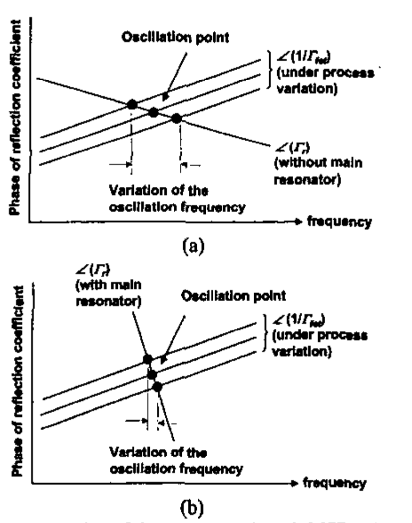


Fig. 3. Behavior of the one-wave length MSR. Phase of reflection coefficients are indicates: (a) shows without MSR, (b) shows with MSR.

In this VCO, a one-wave length MSR is employed for accurate frequency setting. Fig. 3 shows behavior of the tuning circuit with a one-wave length MSR. Phase of reflection coefficients of tuning circuit (Γ_r) and active circuit ($1/\Gamma_{fet}$) are indicated in Fig. 3. The cross points between Γ_r and $1/\Gamma_{fet}$ mean the oscillation frequency. Also variation of $1/\Gamma_{fet}$ is indicated, concerning about the process variation. As shown in Fig. 3 high Q tuning circuit with a one-wave length MSR makes lower variation of oscillation frequency. This means higher yield of the VCO under the process variation.

This VCO configuration with the one-wave length MSR has penalty of parasitic oscillation. Fig. 4 shows impedance locus of the one-wave length MSR. In addition to main resonant frequency (f_r), there are parasitic resonance at $f_r/2$ and $3f_r/2$. These parasitic resonance make

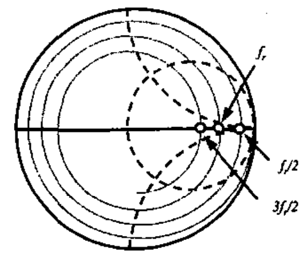


Fig. 4. Impedance locus of the one-wave length MSR.

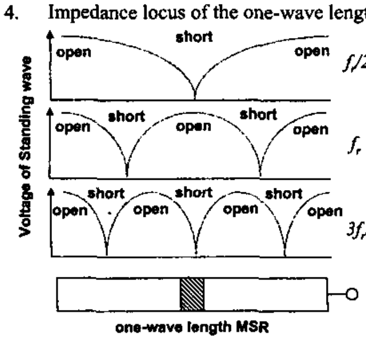


Fig. 5. Effect of the dumping resistor allocated at the mid-point of one-wave length MSR.

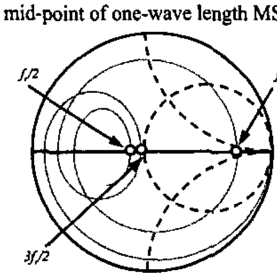
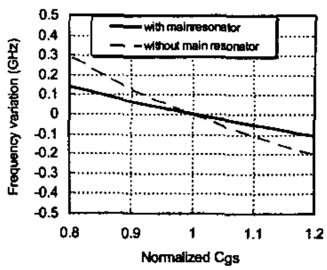


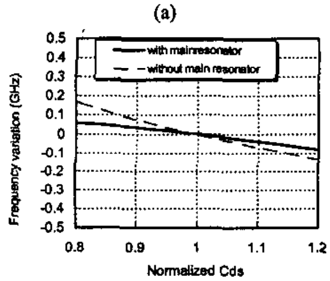
Fig. 6. Impedance locus of the proposed one-wave length MSR with dumping resistor.

high possibility of undesired parasitic oscillation. For suppression of parasitic resonance, a dumping resistor allocated at the mid-point of the one-wave length MSR, as shown in Fig. 1. Fig. 5 shows effect of the dumping resistor. At the frequency of f_r, the mid-point of the one-wave length MSR behaves as the open point. So, there is low loss of the resistor. At the frequency of the $f_r/2$ and $3f_r/2$, the mid-point of the one-wave length MSR behaves as the short point. Because of a high RF current at the dumping resonator, there is high loss of the resonator.

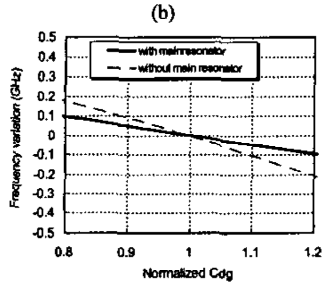
Fig. 6 shows the impedance locus of the proposed one-wave length MSR with the dumping resistor. We can see only main resonance at the frequency f_r. As mentioned above, parasitic resonance of the one-wave length MSR can be suppressed.



(a)



(b)

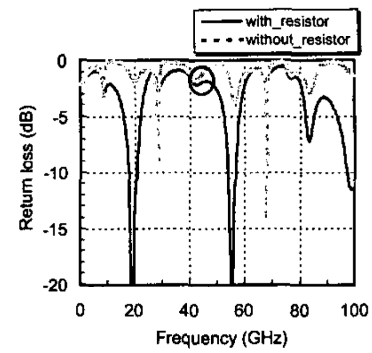


(c)

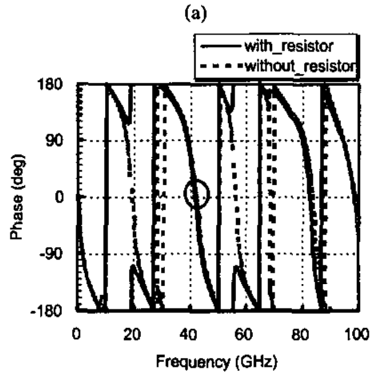
Fig. 7. Simulated variation of the oscillation frequency: —— shows with a main resonator, – – shows without a main resonator.

III. Design Of The Tuning Circuit Of The 40 GHz-band MMIC VCO

For the 40 GHz-band MMIC VCO, AlGaAs/InGaAs p-HEMT [5] is employed. And the return gain of Γ_{fet} is more than 4.1 dB at 40 GHz-band. Thus, return loss of tuning circuit Γ_r is should be enough lower than 4.1 dB to achieve a stable oscillation. In the developed 40 GHz-band MMIC VCO, Z_r and Z_i are chosen to 25 Ω and 50 Ω respectively, and under this condition, the loss of the tuning circuit is less than 1.9 dB. This value is small enough compared with the return gain of 4.1 dB. Fig.7 shows simulated variation of oscillation frequency. Fig.7 (a) is the variation of the oscillation frequency versus C_{gs}, Fig.7 (b) shows variation vs. C_{ds} and Fig.7 (c) shows variation vs. C_{dg}, respectively. With an assumption of ±10 % variation of $C_{gs}/C_{ds}/C_{dg}$, the variation of oscillation frequency is 290 MHz without main resonator in worst



(a)



(b)

Fig. 8. Calculated results of the return loss and return phase of the tuning circuit of the VCO. The solid line shows characteristics with the resistor and the dashed line shows without resistor: (a) shows Amplitude, (b) shows phase and ° (Circle) marks show desired frequency f_r.

case. On the other hand, variation of the oscillation frequency with one-wave length MSR is less than 150 MHz.

As a dumping resistor, 16 Ω thin-film resistor is inserted to the mid-point of one-wave MSR. Fig. 8 shows calculated results of the return loss and return phase of the tuning circuit of the developed VCO. As mentioned previously, the impedance of $f_r/2$ and $3f_r/2$ is parallel resonance without resistor. Otherwise, with resistor, the return phase of these undesired modes have no cross point with zero-degree line. Hence, the phase condition of the starting oscillation can not be satisfied at $f_r/2$ and $3f_r/2$.

IV. Experimental Results

TABLE I shows the experimental results of the developed 40 GHz-band VCO. Fig. 9 shows a photograph of the VCO. The chip size is 1.5 mm × 2.9 mm. The thickness of the GaAs substrate is 100 μm. Fig. 10 shows an oscillation frequency and an output power of the VCO. The oscillation frequency is from 41.56 to 42.05 GHz. The tuning bandwidth is 493 MHz. This tuning range of 493 MHz is enough high value than the predicted variation of oscillation frequency of 150 MHz, with the assumption of ±10 % $C_{gs}/C_{ds}/C_{dg}$ variation. The range of output power is between −7.6 and −4.3 dBm. The drain current is less than 22.5 mA. The phase noise at 1 MHz offset is less than −84 dBc/Hz. Also no parasitic oscillation can be observed. With these results, effectiveness of the proposed configuration can be confirmed.

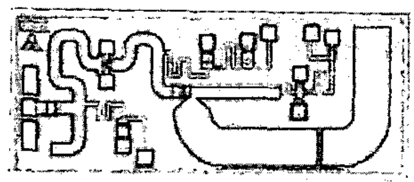


Fig. 9. Photograph of the VCO. The chip size is 1.5 mm × 2.9 mm. The thickness of the GaAs substrate is 0.1 mm.

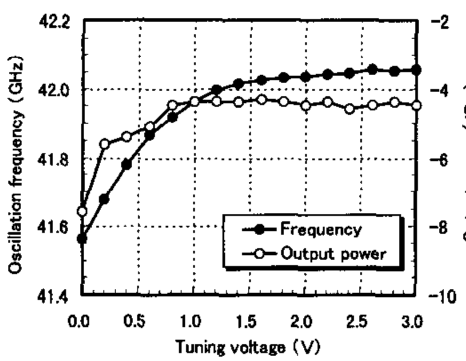


Fig. 10. Oscillation frequency and the output power of the VCO. The oscillation frequency is from 41.56 to 42.05 GHz. The tuning bandwidth is 493 MHz. The output power is from −7.6 to −4.3 dBm.

TABLE I
Experimental Results Of The Developed VCO

Items	Experimental results
Oscillation frequency	41.56 GHz to 42.05 GHz
Range of tuning voltage	0 V to 3 V
Output power	−7.6 dBm min.
Drain current	22.5 mA max.
SSB phase noise @1 MHz offset	−84 dBc/Hz max.

V. Conclusion

The motivation of this paper is the improvements of the yield for the millimeter-wave VCO. For this objective, the configuration of the MMIC VCO with the one-wave length MSR is proposed for reducing frequency variation by the process variation. Also, the dumping resistor at the mid-point of the one-wave length MSR is employed to suppress parasitic resonance of the resonator. In experimental investigations, effectiveness of the proposed VCO can be verified.

References

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