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A 900 MHz VCO Having 7-dB Phase Noise Improvement at 100 kHz Offset

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Abstract

In this paper, the phase noise of 900 MHz VCO is improved using modified stripline square ring resonator. In order to demonstrate the phase noise improvement of the proposed VCO, the same circuit was manufactured using shorted-circuit resonator. In condition of the same bias current, the phase noise of the proposed VCO with modified square ring resonator is suppressed by 7 dB as －103 dBc/Hz at 100 kHz offset compared to the conventional VCO with short-circuit resonator. From the proposed VCO, we achieved output power of －4.8 dBm, harmonics suppression of 16 dB, and tuning bandwidth of 100 MHz. The proposed VCO consumed 5 mA at 3 V, and its size is 1.2 cm × 1.0 cm.

Key words : MSRR, SCR, Resonator, VCO, Phase Noise, Oscillator, Oscillation, Frequency, 900 MHz, Q-Factor, Stripline, PCB.

Ⅰ. Introduction

In mobile wireless phones using CDMA and GSM, the phase noise of local oscillator must be improved to enhance the communication quality. The phase noise of VCO is mostly dependent on the quality of resonator, and so many researchers have reported several techniques to improve the quality of resonator[1]~[3]. The phase noise of those VCOs was improved, but their sizes are large at 900. So, more compact resonators using ceramic materials have been developed, but their cost is high. So, a small size of VCO with short-circuited resonator(SCR) was manufactured using multilayer PCB, and that resonator was highly integrated[4].

However, it is required to increase the Q-factor of the resonator and enhance the phase noise of VCO through modifying the geometry of resonator. In a few of papers, ring resonators have been used in fabricating band pass filter, band stop filter, and oscillator[7]~[9].

In this paper, the phase noise of 900 MHz VCO was improved using the modified square ring resonator (MSRR) in the proposed VCO circuit. From the MSRR, we achieved 7 dB phase noise improvement and the size reduction of the conventional square ring resonator in the proposed VCO. Its size is compact, and highly integrated with active and passive components. The MSRR was implemented in the commercial FR4 4-layer PCB substrate. The frequency tuning range of the proposed VCO is measured from 908 MHz to 1008 MHz. The proposed VCO represents harmonics suppression of 16 dB, and output power of －4.8 dBm. Its dimension is 1.2 cm × 1.0 cm × 0.2 cm.

Ⅱ. Square Ring Resonator Characteristics

Saavedra invented microstrip square ring resonators with quarter wave couplers. The Q-factor of the square ring resonator is high because of its low insertion loss. Also, The dual-mode resonance is suppressed by surrounding the square ring resonator with coupled lines[6].

From simulation, we unexpectedly found out that the square ring resonator could represent either series resonance or parallel resonance according to the coupling gap size of the asymmetric coupled line. That is, the resonance splitting phenomenon is vanished by increasing the coupling gap S of coupled line.

Fig. 1 shows the resonance characteristics of the asymmetric square ring resonator according to the coupling gap. If the coupling gap S is more than 0.17 mm, the conventional square ring resonator displays single mode resonance called series resonance, and if less than 0.17 mm, it shows dual mode resonance

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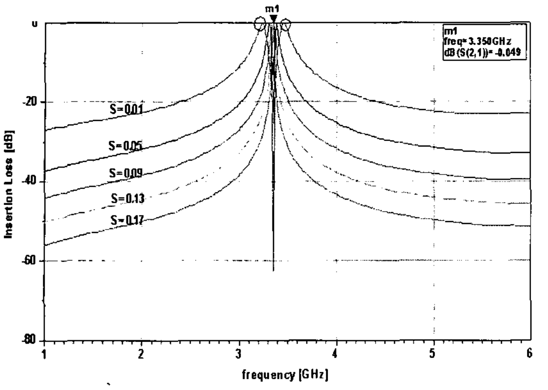

Fig. 1. Resonance of asymmetric square ring resonator according to coupling gap size(Dimensions: W= 0.3 mm, L=10.1 mm).

called parallel resonance. Fig. 1 indicates that as the larger is the coupling gap S, the smaller is the dual-mode resonance, and the more dominant becomes the single-mode resonance.

In the Fig. 1, two crests marked by circles represent the dual-mode resonance whose resonance frequencies are 3.24 GHz and 3.46 GHz, respectively. The geometry of the square ring resonator is in detail described in reference[6]. The asymmetric square ring resonator was designed and simulated using the commercial 4-layer FR4 PCB substrate that represents relative dielectric constant of 4.5, height of 0.8 mm, and conductor thickness of 0.018 mm. The dimensions of asymmetric ring resonator are shown below the title of Fig. 1.

III. 900 MHz VCO Circuit Design using MSRR

The conventional square ring resonator should be large to properly operate at 900-MHz carrier frequency because the length of the coupled line in the square ring resonator is $\lambda_g/4$[6]. In order to obtain the practical size of the square ring resonator at 900 MHz, therefore, both discontinuity step and tuning capacitor C_t are used in the modified square ring resonator as shown in Fig. 4.

Here, the modified square ring resonator was designed and optimized using Ansoft Ensemble simulation tool. Fig. 2 shows the S-parameter simulation result of the modified square resonator using Ensemble simulator. The resonant harmonics of the modified square ring resonator is generated about 100 MHz, 1.7 GHz and 6 GHz.

The resonance frequency of the modified ring resonator can be controlled by varying tuning capacitor C_t. The tuning capacitor C_t provides external trimming to flexibly control the fixed resonance frequency of the stripline modified square ring resonator. In Fig. 3, the input impedance of the MSRR resonator is simulated indicating parallel resonance. As the value of C_t increases, the resonant peak point of modified square ring resonator moves to lower frequency as shown in Fig. 3. Also, as the value of C_t is larger over 4 pF, the value of Q-factor of the resonator becomes smaller as shown in Table 1. The maximum Q-factor is 39 at 1.167 GHz with 2 pF tuning capacitance. The Q-factor of the modified square ring resonator is calculated using equation (1).

Table 1. Variation of Q versus the values of C_t.

C_t [pF]	f_o [GHz]	Δf_o [MHz]	Q
1	1.356	19	35
2	1.167	15	39
3	1.026	15	34
4	0.938	13	36
5	0.864	14.5	30
6	0.803	14	29
7	0.756	13.5	28
8	0.717	13.4	27
9	0.682	16.3	21
10	0.650	17.3	19

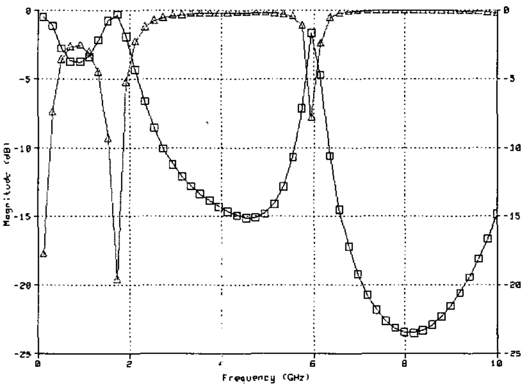

Fig. 2. S-parameter simulation of the modified square ring resonator(square: S_{21}, triangle: S_{11}).

$$Q = \frac{1}{BW} = \frac{\omega_o}{2\Delta\omega} \tag{1}$$

where BW is 3-dB bandwidth, $\Delta\omega$ is difference between lower and upper 3-dB point frequency, and ω_o is resonance frequency.

The optimized dimensions and value of both MSRR resonator and C_t follow as: S=0.3 mm, Wt=2 mm, Ws =0.3 mm, L=4 mm, C_t=1.3 pF. The width and length of the SCR resonator are 1 mm and 26 mm, respectively. As shown in Fig. 4, the simulated resonance frequencies of the optimized MSRR and SCR resonators are 1.3 GHz and 1.38 GHz, repectively. The $\Delta\omega$ frequencies of each resonator are 18 MHz and 31 MHz, repectively. The calculated Q-factors of both MSRR and SCR resonators are 36 and 22 using equation (1). Therefore, the Q-factor of the MSRR resonator is improved by 63 % compared with the SCR resonator.

Fig. 5 represents 900 MHz VCO circuit diagrams with stripline short-circuited resonator. Both the conventional VCO with short-circuited resonator and the proposed VCO with modified square ring resonator are fabricated using 4-layer PCB[4].

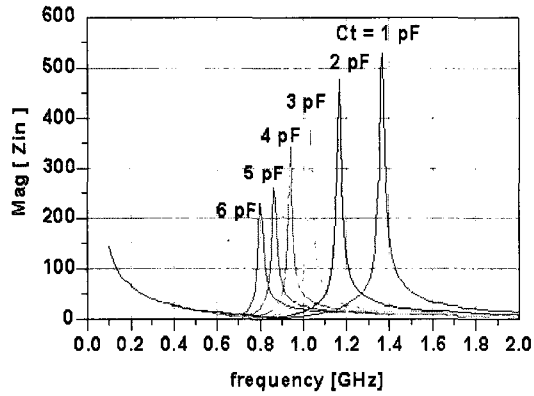

Fig. 3. Resonance frequency variations of the modified square ring resonator according to the value of C_t.

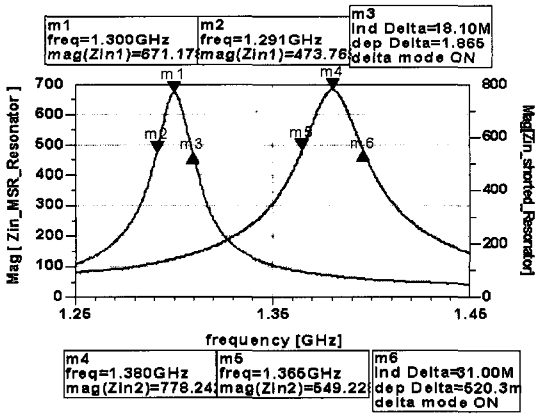

Fig. 4. Resonance characteristics of the optimized MSRR and SCR resonator.

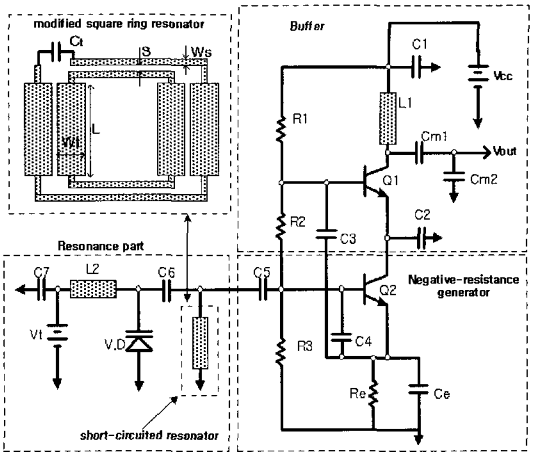

Fig. 5. 900 MHz VCO circuit diagram.

Ⅳ. Measurement and Review

In condition of the same bias current and signal power, the phase noise of the proposed VCO using modified square ring resonator is compared to that of the conventional VCO using short-circuited resonator in Fig. 6. The phase noise of the two VCOs can be calculated using the Lesson' phase noise model of equation (2)[10].

$$L(f_m) = 10 * \log\left\{\left[1+\left(\frac{f_{osc}}{2Qf_m}\right)^2\right]\cdot\left(1+\frac{f_c}{f_m}\right)\cdot\frac{FkT}{2P_s}\right\} \tag{2}$$

where f_{osc} is oscillation frequency, f_c is flicker noise corner frequency, f_m is offset frequency, F is noise figure of the transistor amplifier, P_{out} is signal power, k is boltman's constant, T is temperature. The phase noises of the two VCOs are calculated from Eq. (2) using parameters in Table 2 and 3. The results are summarized in Table 2. Although the calculated and measured phase noises are different, the effect of the increased Q-factor of the MSRR resonator is reflected by 5 dB in the phase noise improvement. The phase noise of the proposed VCO and conventional VCO is measured as －103 dBc/Hz and －96 dBc/Hz at 100 kHz offset frequency from 996 MHz carrier, respectively. The phase noise of the proposed VCO is impro-

Table 2. Calculated phase noises of the two VCOs.

Param. Type	f_c	F	Q	Phase noise
VCO with MSRR	10 kHz	6 dB	36	－153 [dBc/Hz]
VCO with SCR			22	－148 [dBc/Hz]

Table 3. Performance results of the conventional VCO with SCR and the proposed VCO with MSRR.

Measurement conditions & results	Short-circuited resonator	Modified square ring resonator
V_{cc} (supply voltage)	3 V	
I_c (current consumption)	5 mA	
P_{out} (output power)	−4.8 dBm	
f_{osc} (carrier frequency)	996 MHz	996 MHz
Phase noise @ 10 kHz offset	−76 dBc/Hz	−78 dBc/Hz
Phase noise @ 50 kHz offset	−89 dBc/Hz	−95 dBc/Hz
Phase noise @ 100 kHz offset	−96 dBc/Hz	−103 dBc/Hz
Phase noise @ 600 kHz offset	−114 dBc/Hz	−119 dBc/Hz

ved as much as 7 dB compared to the conventional VCO. It is supposed that the difference between the calculated and the measured phase noise is due to both parasitic effects in fabricating VCO and other nonlinear effects that are not expressed by Eq. (2)[11].

As shown in Fig. 7, the proposed VCO suppress harmonics by 16 dB with output power of −4.8 dBm. Agilent 85652 spectrum analyser is used in measuring the two VCOs. In Table 3, the performance results of two VCOs are summarized. Fig. 8 displays the test board of the proposed VCO. The two VCOs have been fabricated using discrete SiGe HBT transistors.

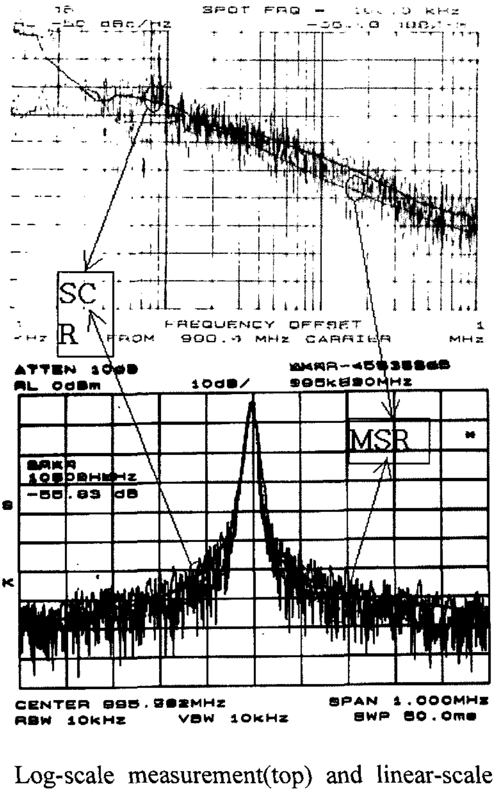

Fig. 6. Log-scale measurement(top) and linear-scale measurement(bottom) about the phase noises of the two VCOs.

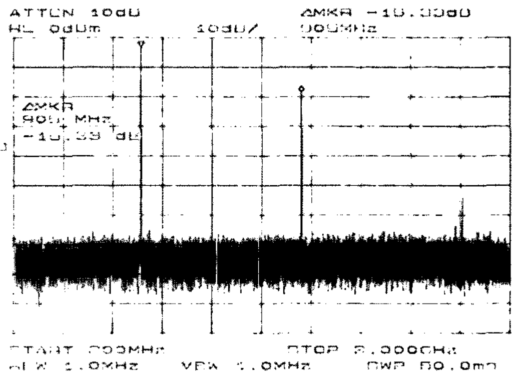

Fig. 7. Measured carrier frequency spectrum.

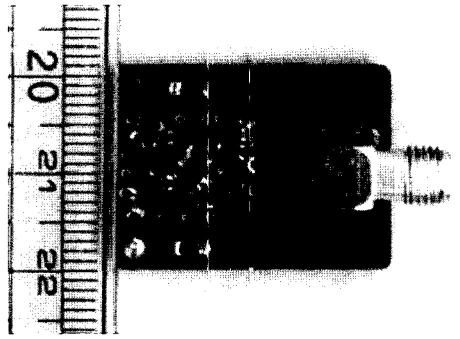

Fig. 8. Test board of the proposed VCO.

V. Conclusion

In this paper, it was demonstrated that the dual-mode resonance of the conventional square ring resonator either showed up or disappeared according to the coupling gap size. Since the dimensions of the conventional square ring resonator are impractically large at 900

MHz carrier frequency, both discontinuity steps and tuning capacitor C_t are utilized to diminish the size of the conventional square ring resonator. The tuning capacitor C_t provides flexible method to control and trim resonance frequency, externally. In conclusion, the modified square ring resonator is compact, highly integrated, and contributes to enhance the phase noise of the 900 MHz VCO with showing 7 dB improvement at 100 kHz offset frequency from 996 MHz carrier.

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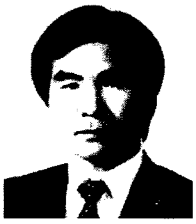

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