A Low Phase Noise Microwave Oscillator Using Split Ring Resonators

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***Abstract*— The split ring resonators (SRRs) are utilized to implement a microwave oscillator in this paper. Since the SRRs provide a sharp band reject characteristic, a high Q-factor is realizable for microwave oscillators. Several identical SRRs are simultaneously employed to obtain as large a high reflection coefficient as possible which generates the oscillation condition incorporated with a microwave transistor. The output power is obtained as 10.6 dBm at 5.2 GHz with 2.0 V DC supply and 18 mA current consumption. Due to the sharp performance of the resonators, the phase noise is observed excellently around -115 dBc/Hz at 1 MHz offset. DC-RF conversion efficiency is measured 30.7 % and the figure of merit is 178.72 dB. Since further miniaturization of the resonators is possible adjusting the proposed configuration, this kind of oscillator can easily be adapted to the MMIC fabrication.**

***Index Terms*— SRRs, microwave oscillator, phase noise.**

I. Introduction

The SRRs have been widely used in designing various circuitry requiring the band reject performance [1]-[4]. Because of the sharp band reject characteristic, the SRRs are appropriate for the narrow band-stop filters and other circuits necessitating a high-Q band stop performance. Using this characteristic, microwave oscillators can be realized for obtaining good phase noise performance. There have been increasing demands for low phase-noise and small physical dimension in the oscillator design since the modern communication systems including the oscillator require lower noise, smaller size, and larger channel capacity. The most important factors to determine the oscillator performance are the phase noise, power consumption, real estate and DC-RF conversion efficiency because these factors play key roles in driving other circuitry such as the mixer and the PLL synthesizer. A large amount of effort has been invested to reduce the phase noise. Since the Q factor of the resonator determines the phase noise dominantly, most of work has been performed by people focusing on the increase of Q factor of the resonator. For doing this, high Q resonators have been widely utilized or loaded Q factor has been sought for resonators [5]-[7].

In this paper, a number of physically identical SRRs are located in series beside the both sides of the center microstrip line. The SRRs provide a very sharply narrow band characteristic of the reflection coefficient. These SRRs are incorporated with a microwave FET to generate oscillation as described in Section II. The simulation and measurement results will be discussed in Section III. Finally, this paper will be concluded in Section IV.

II. Design of the Resonator and Oscillator

The equivalent circuit of the SRR coupled to microstrip line is depicted in Fig.1. The inductance L_s and the capacitance C_s determine the resonant frequency of the SRR, and resistance R_s represents the loss components [8]. All these value are determined from the structure of the resonator, such as total line length, width, and gap of resonator. Since the single microstrip line cannot provide a high Q-factor performance, SRRs are employed incorporated with the microstrip line to provide a very sharp band rejection.

SRR is designed and fabricated using hybrid technique. In this work, the physical dimension of SRR is decided based on the desired resonant frequency. Distance between each SRR is optimized for giving a better band rejection. Fig.2 shows the simulation results for various distances between SRRs, providing the best result when $d = 9mm$ (= $\lambda_g/4$).

The number of SRRs has been varied for better band reject performance. Considering the physical size and

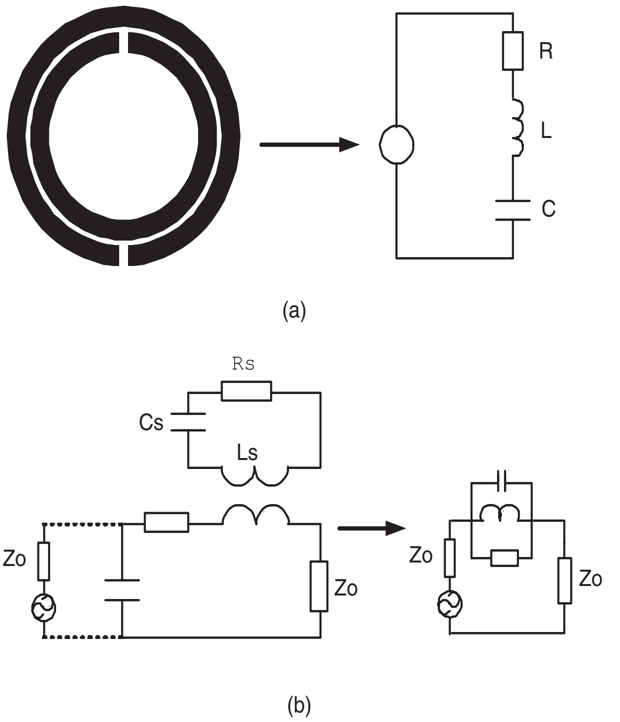

Fig. 1. Equivalent circuit of the SRR coupled to microstrip line.
(a) SRR equivalent circuit (b) SRR and microstrip line equivalent circuit.

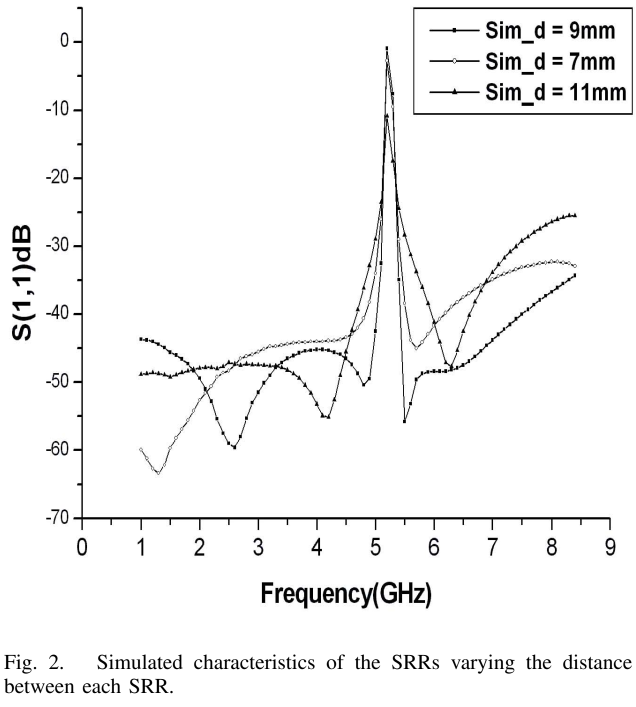

Fig. 2. Simulated characteristics of the SRRs varying the distance between each SRR.

performance, 2,4 and 6 SRRs have been simulated, respectively. The simulation result of the reflection coefficient for the resonator is obtained as shown in Fig.3 which expresses a very sharp narrow bandwidth at six SRRs used, in other words, more SRRs give a high Q-factor. Six identical SRRs are finally employed and adjusted facing a microstrip line as shown in Fig.4 to comprise a microwave oscillator. Those SRRs are located in series beside the both sides of the microstrip line to give a high-Q band-stop characteristic. For an oscillation to occur, the following condition about the reflection coefficient should be satisfied over the oscillator circuitry.

$$\Gamma_r \times \Gamma_{in} = 1 \qquad (1)$$

When the reflection coefficient looking into the resonator side remains the maximum, oscillation occurs successfully and it is maintained stably. Therefore, the band-stop characteristic needs to be kept as sharply as possible to give a high Q-factor.

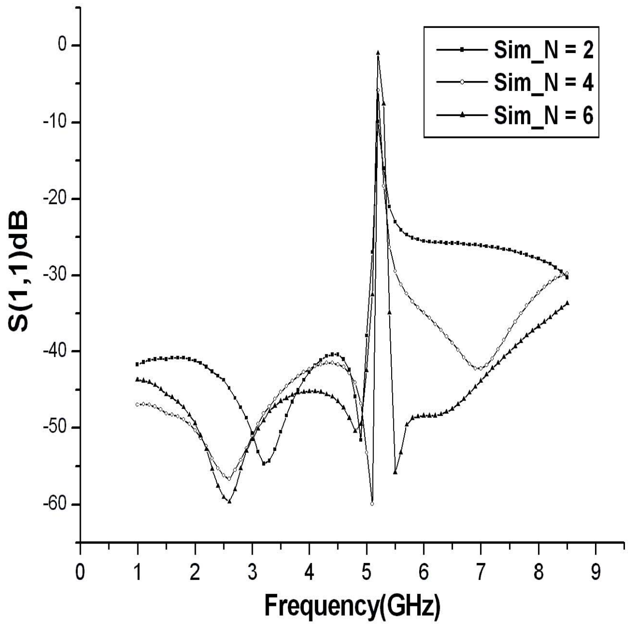

Fig. 3. Simulated reflection coefficient of the resonator part.
(N= the number of SRRs).

Each SRR is designed based on the resonant frequency which determines the radius of the outer and inner rings. The length of the microstrip line is adjusted suitably for accommodating 6 SRRs and can be reduced for further miniaturization. The resonator part consisting of a microstrip line and 6 identical SRRs was designed using Agilent Momentum. As known in the Eq. (2), the phase noise is dominantly dependent upon the carrier power and

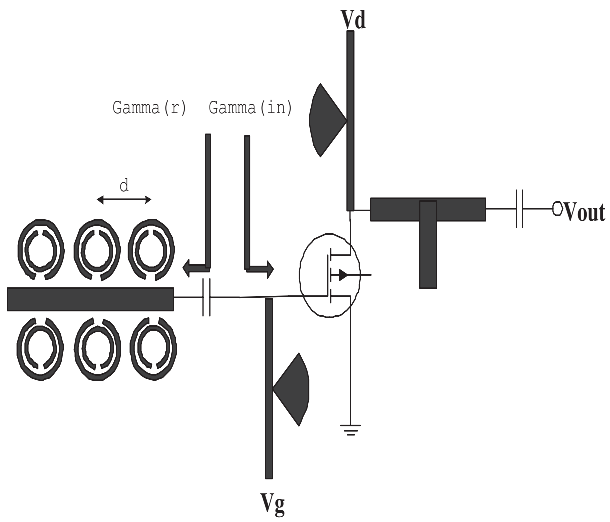

Fig. 4. Block diagram of the microwave oscillator using SRRs.

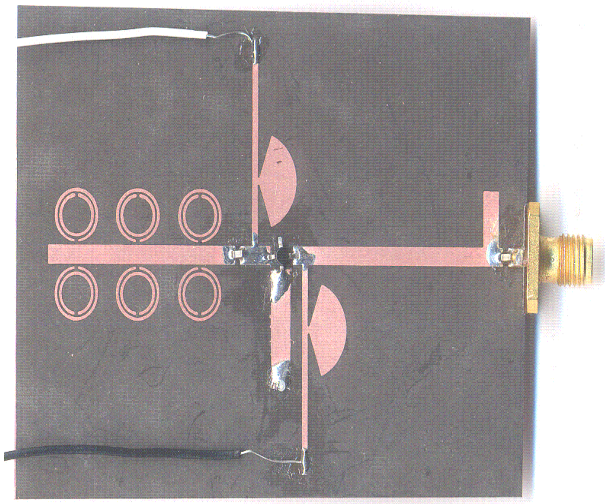

Fig. 5. Photograph of the fabricated 5.2 GHz oscillator.

the Q-factor of the resonator. In this work, we tried to increase the Q-factor of the resonator using SRRs.

$$L(\Delta\omega) = 10log[\frac{2FkfT}{P_{sig}}\{1 + (\frac{\omega_0}{2Q\Delta\omega})^2\}(1 + \frac{\Delta\omega_{1/f^3}}{|\Delta\omega|})] \quad (2)$$

where P_{sig} is the carrier signal power, F is the empirical value, k is the Boltzmann constant, T is the temperature, Q is the quality factor of the resonator, ω_0 is the resonant frequency and $\Delta\omega$ is the small offset from the resonant frequency as expressed in [9]-[10].

III. MEASUREMENT RESULT

Based on the design philosophy proposed in this work, a microwave oscillator employing the SRRs is simulated using Agilent ADS and Momentum, and fabricated on an RT Duroid substrate. Agilent's ATF13786 GaAs MESFET was utilized for this oscillator. Fig.5 shows the photograph of the fabricated oscillator at 5.2 GHz.

The measured result with a spectrum analyzer is shown in Fig.6. The carrier signal power was observed as 10.44 dBm including a cable loss (in this work, 3 dB) at 5.2 GHz exactly. This means that the proposed circuit behaves excellently as a microwave oscillator as expected. This oscillator achieves phase noise of about -115 dBc/Hz at 1 MHz offset as seen in Fig.6. This phase noise performance is caused by the high-Q band-stop characteristic of the resonator employed here. Since 2.0 V DC supply and 18 mA current consumption was observed, the DC-RF conversion efficiency is calculated as 30.7 % which is quite a bit high compared to the general microwave oscillators.

Using the definition of a figure of merit (FOM) in Eq. (3), this oscillator achieves 178.72 dB FOM.

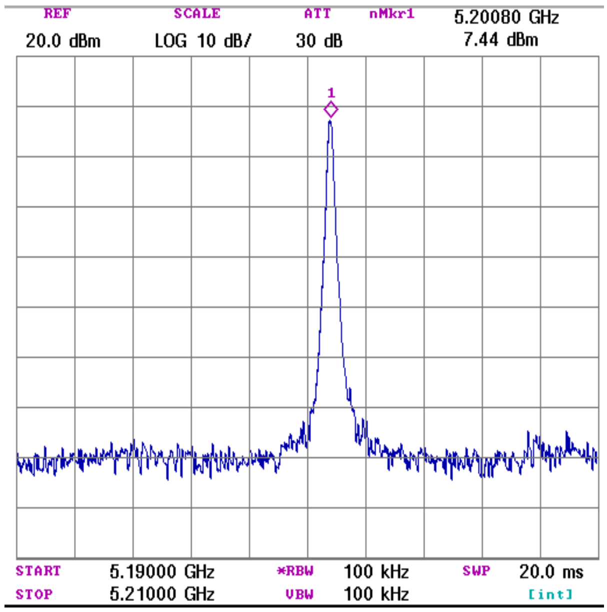

Fig. 6. Measured result of the fabricated 5.2 GHz oscillator.

$$FOM = 10log((\frac{\omega_0}{\Delta\omega})^2\frac{1}{L(\Delta\omega)P_{sig}}) \quad (3)$$

IV. CONCLUSION

A 5.2 GHz oscillator using SRRs was presented. Narrowing the bandwidth of the resonator part gives rise to the significant improvement of the phase noise. The number of the SRR was optimized to obtain a higher Q-factor for the resonator part. The distance between each SRR has also been optimized. This oscillator shows a fairly high DC-RF conversion efficiency due to the low loss of the resonator. Adjusting the number and physical layout of the SRRs can reduce the real estate of the whole oscillator circuit, and further can be applied to VCO circuit with MMIC technology.

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