A Compact-Size Microstrip Spiral Resonator and Its Application to Microwave Oscillator

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***Abstract*—This letter presents a compact size microstrip spiral resonator and its application to a low phase noise oscillator. This resonator has stopband characteristics to be used in the series feedback oscillator topology. The whole circuit area of the proposed resonator is within 1/10 wavelength, which results in the reduction of the circuit area and cost. A 10-GHz oscillator incorporated with this resonator was designed, fabricated and measured. It shows low phase noise performance of −95.4-dBc/Hz at 100 kHz offset.**

***Index Terms*—Microstrip spiral resonator, oscillator, phase noise.**

I. INTRODUCTION

THE MODERN communications systems require low phase noise, low cost local oscillators, and these are the main objectives of the microwave and millimeterwave oscillators. The most popular method to reduce the phase noise is to employ high Q resonator or to improve loaded quality factor [1]–[4]. Dielectric resonators have been widely used for this purpose [1], but these are not adequate for the monolithic microwave integrated circuits (MMIC) because they have a three-dimensional (3-D) structure. To overcome this problem, fully planar type resonators have been developed to be applied in an MMIC and to improve the quality factor and resulting phase noise of an oscillator [2], [3]. However, the total size of these circuits can be large because the electrical lengths of these resonators are nearly half wavelength, so this results in the increase of the cost of the MMIC.

In recent years, there have been increasing interests in the microwave devices using superconducting materials. The main advantages of these approaches are the miniaturization of the elements and low loss property. In particular, reduced size superconducting bandpass filters have been reported [5], [6]. In their works, they employed the microstrip line spiral resonators to reduce the size of filters at UHF and *L* band, respectively.

In this paper, an *X*-band oscillator with reduced size and low phase noise property using microstrip spiral resonator is presented. This resonator can also be used at millimeterwave oscillators. This circuit was fabricated with hybrid technique, but can be fully compatible with the MMIC due to its entirely planar structure.

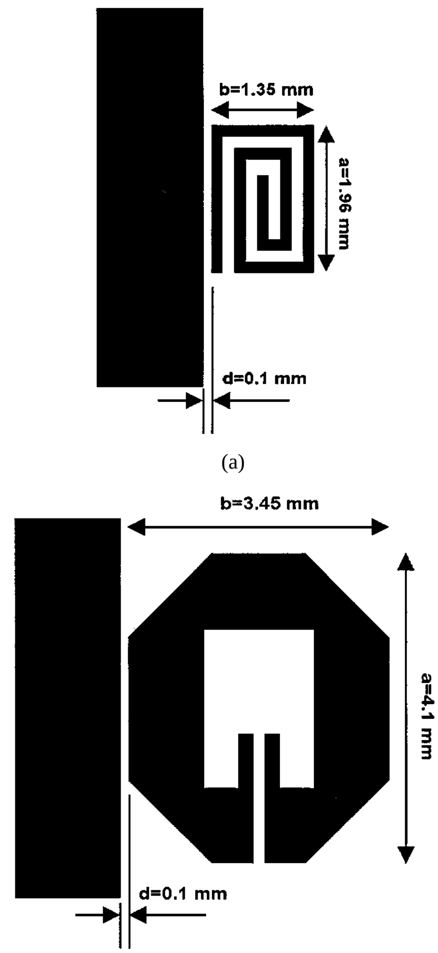

Fig. 1. (a) Layout of the proposed stopband microstrip line spiral resonator and (b) layout of the conventional miniaturized hairpin resonator.

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II. COMPACT SIZE MICROSTRIP SPIRAL RESONATOR

Fig. 1(a) shows the layout of the proposed spiral resonator coupled to a 50-Ω microstrip line. It was fabricated using a Teflon substrate of 0.504-mm thickness and a dielectric constant of 2.52.

The equivalent circuit of the spiral resonator coupled to microstrip line is depicted in Fig. 2 [7]. The inductance Lr and the

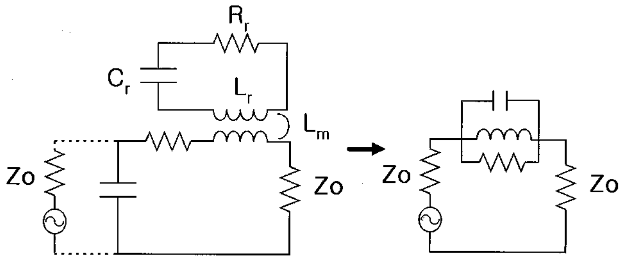

Fig. 2. Equivalent circuit of the spiral resonator coupled to microstrip line.

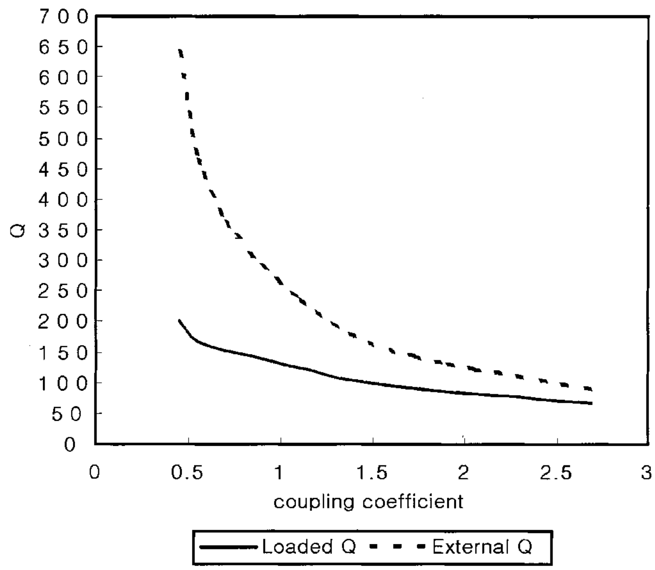

Fig. 3. Calculated loaded and external quality factors depending on the coupling coefficient.

capacitance Cr determine the resonant frequency of the spiral resonator. The resistance Rr represents the loss components. All these values are determined from the structure of the resonator, such as total line length, line width, and gap of the resonator. The Lm indicates the magnetic coupling between the microstrip line and resonator. The simplified equivalent circuit is also shown in Fig. 2. The magnitude of the coupling coefficient is determined from the length of the coupled line, a and the distance between 50 ohm microstrip line and spiral resonator, d. In this work, the line width and gap of the spiral resonator was set to 0.15 mm and the distance d was set to 0.1 mm, respectively. Under these conditions, the total line length is the only remaining parameter to calculate the resonant frequency. The relationship between the calculated coupling coefficient and the quality factors is indicated in Fig. 3.

The whole size of this resonator is within 2 mm, 1/10 wavelength (20 mm for one wavelength at 10 GHz). It should be noted that the area of the spiral resonator is much smaller that that of the miniaturized hairpin resonator—only 19% of the area of the hairpin resonator—without significant cost of quality factor as shown in Figs. 1 and 4. The calculated loaded quality factors of the spiral resonator and hairpin resonator are 86 and 82, respectively.

The measured results are close to the simulated ones, as shown in Fig. 4. There are some disagreements between simulated and measured ones, such as resonant frequency, return and insertion loss, and quality factor. It is believed that this is because there exists conductor loss, which was not considered in the simulation. In addition, this is because the whole size of this resonator is so small that there are some errors in the fabrication process; also, there are some losses in the connectors for measurement. However, these problems would be overcome if this resonator is designed and fabricated in an MMIC technology. Also, further optimization for this structure would lead to the improvement of the quality factor.

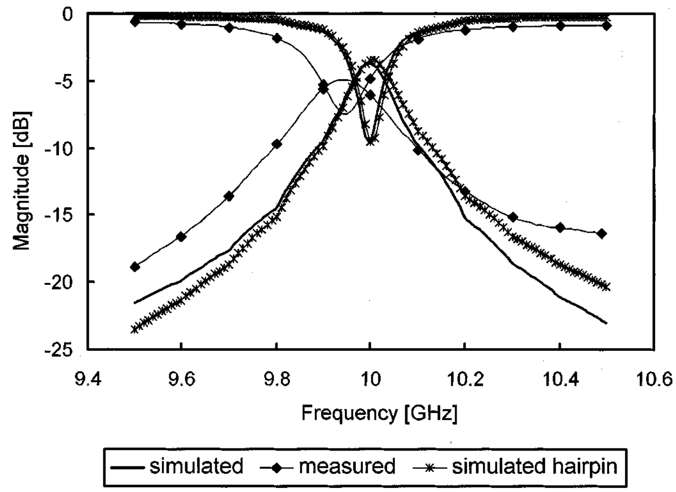

Fig. 4. Simulated and measured characteristics of the proposed microstrip line spiral resonator with the simulated characteristics of the hairpin resonator.

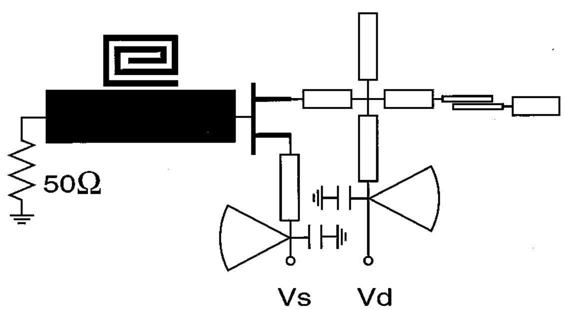

Fig. 5. Schematic of the *X*-band oscillator. The spiral resonator was connected to the gate terminal of the active device.

III. Oscillator Design

An oscillator incorporated with the proposed microstrip spiral resonator was designed and fabricated using a NE32484 HEMT device with hybrid technique. This oscillator adopted series feedback topology and the resonator was placed at the gate circuit with 50-Ω termination as shown in Fig. 5.

The two signal method [8] was employed to obtain the embedding impedances considering the resistance component at the gate circuit resulting from the return loss of the resonator. Using the nonlinear design technique, the oscillation frequency can be exactly predicted, in this work 10 GHz, which is the resonant frequency of the proposed resonator.

IV. Measurements and Results

The measured output spectrum of the fabricated oscillator is illustrated in Fig. 6. The oscillation frequency is 9.998 GHz,

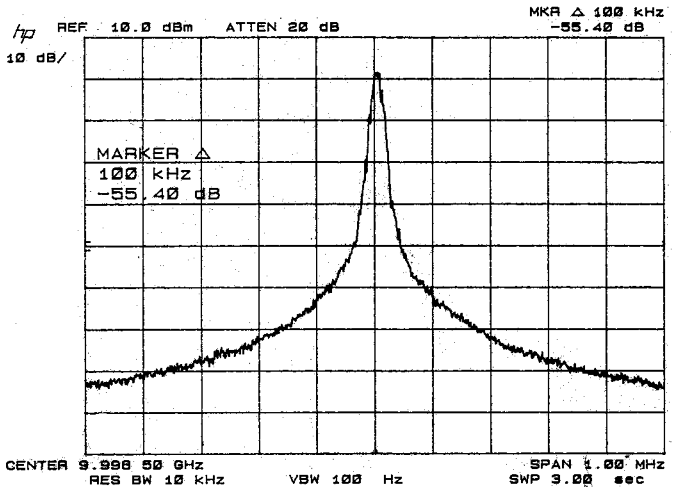

Fig. 6. Output spectrum of the fabricated oscillator incorporated with the spiral resonator ($Vgs = -0.4$ V, $Vds = 1.5$ V).

which is near the resonant frequency and design frequency. Also, it exhibits a low-phase noise performance: −95.4 dBc/Hz at 100 kHz offset and output power of 10.16 dBm at $Vgs = -0.3$ V and $Vds = 2$ V with a dc to RF conversion efficiency of 18.5% including cable loss.

The quality (Q) factor of an oscillator is calculated as the pulling figure method—the maximum oscillation frequency change for a load mismatch of all phases [9]. It has been calculated from the harmonic balance simulation that the Q factor of this oscillator is about 190. In experiment, pulling figure was measured for the load VSWR of 1.22. Under this condition, the maximum frequency change is 13.68 MHz, which gives the Q factor of 146. The ratio of the Q factor of the simulated and measured one is 1.3, which implies the 2.2–dB degradation in phase noise. This is mainly due to the disagreement between the simulated and measured characteristics of the spiral resonator. However, it is expected that this error would be decreased if this approach is applied to the MMIC technology.

V. Conclusion

A low phase noise oscillator utilizing a new compact size stopband microstrip spiral resonator has been developed. This approach can be fully integrated in an MMIC due to its planar structure, and reduce the total circuit area and resulting cost. The designed and fabricated 10-GHz oscillator shows low phase noise performance of −95.4 dBc/Hz at 100 KkHz offset. Due to its simple design procedure and planar structure, it is expected that this technique can be effectively used for low cost, low phase noise MMIC oscillators.

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