JOURNAL OF THE KOREA ELECTROMAGNETIC ENGINEERING SOCIETY, VOL. 6, NO. 3, SEP. 2006 JKEES 2006-6-3-03

An Oscillator Incorporating a Planar Helical Resonator for Phase Noise Reduction and Harmonic Suppression

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Abstract

This paper describes a compact printed helical resonator and its application to a microwave oscillator circuit implemented in coplanar waveguide(CPW) technology. The high Q-factor and spurious-free characteristic of the resonator contribute to the phase noise reduction and the harmonic suppression of the resulting oscillator circuit, respectively. The designed resonator resonating at the frequency of 5.5 GHz showed a loaded Q of 180 in a chip area of only 40 % of the corresponding miniaturized hairpin resonator without any spurious resonances. The fully planar oscillator incorporated with this resonator showed additional phase noise reduction of 10.5 dB at 1 MHz offset and a second harmonic suppression enhancement of 6 dB when compared to those of a conventional CPW oscillator without the planar helical resonator(PHR) structure.

Key words : Helical Resonator, Oscillator, Phase Noise, Harmonic Suppression.

Ⅰ. Introduction

The Q-factor of a resonator is one of the most important parameters in the design of oscillator circuits, because it determines the phase noise performance of an oscillator[1],[2]. Although a high-Q dielectric resonator has been widely used to reduce the phase noise of an oscillator circuit, researchers have recently endeavoured to replace this type of dielectric resonator with a novel high-Q planar component because of the inherently bulky size and little compatibility with monolithic microwave integrated circuits(MMIC's) of a dielectric resonator[1],[2]. Miniaturization of the chip also has been another important design criteria in planar resonator design due to the high cost of the gallium arsenide substrate used in MMIC fabrication. Y. T. Lee *et al.* achieved a size reduction of a planar resonator introducing a small-sized spiral resonator instead of a conventional half wavelength resonator[3]. In their study, however, very little increment in Q was observed when compared to that of the conventional resonator due to the similar operation principles between them. Although, J. Lee *et al.* reported a high-Q planar resonator incorporating an active filter into the conventional miniaturized hairpin resonator, the increased circuit size and complexity of the circuit were remained disadvantages to be overcome[4]. In addition to that, because these results are based on microstrip technology, the direct application of these results to the CPW-based oscillator circuit is inherently limited.

In this paper, we present a novel planar high-Q resonator and its application to a microwave oscillator circuit with reduced phase noise and superior harmonic suppression characteristics in CPW technology. For the resonator component of the oscillator circuit, we modified a planar printed helical resonator, which was originally suggested by C. Broomfield and J. Everard in 2003 for the application of a planar filter implemented in microstrip technology[5]. From the introduction of this resonator, we could achieve the high-Q and spurious-free resonance characteristic of a resonator and resulting low phase noise and superior harmonic suppression characteristics of an oscillator circuit in a very small chip area. Although the fabrication processes were done in hybrid method, the circuit can be directly applied to the MMIC because of perfect planar characteristic of the components.

Ⅱ. Design of a Planar Helical Resonator

Fig. 1 shows our PHR in CPW technology, which consists of two helixes coupled to a transmission line with a characteristic impedance of 50 Ω. Each helix has a three-quarter turn metal strip on each side of the substrate connected through a metal via hole. To make a metal strip pattern on the both sizes of a substrate, we used a CPW line without a metal plane on the bottom as a transmission line instead of a microstrip line.

The structure was fabricated on an RT/Duroid 6010 substrate with a dielectric constant of 10.2 and a thick-

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Manuscript received May 2, 2006 ; revised July 25, 2006. (ID No. 20060502-014J)

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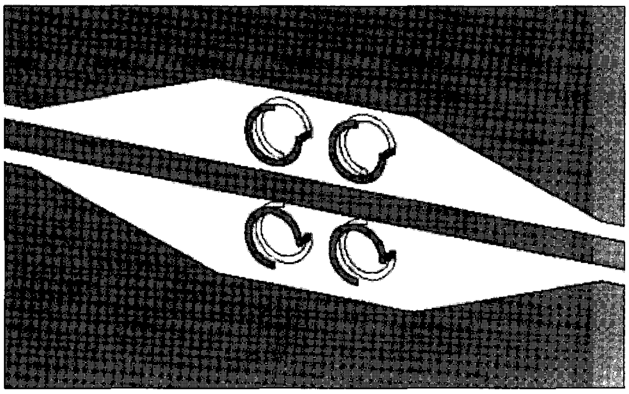
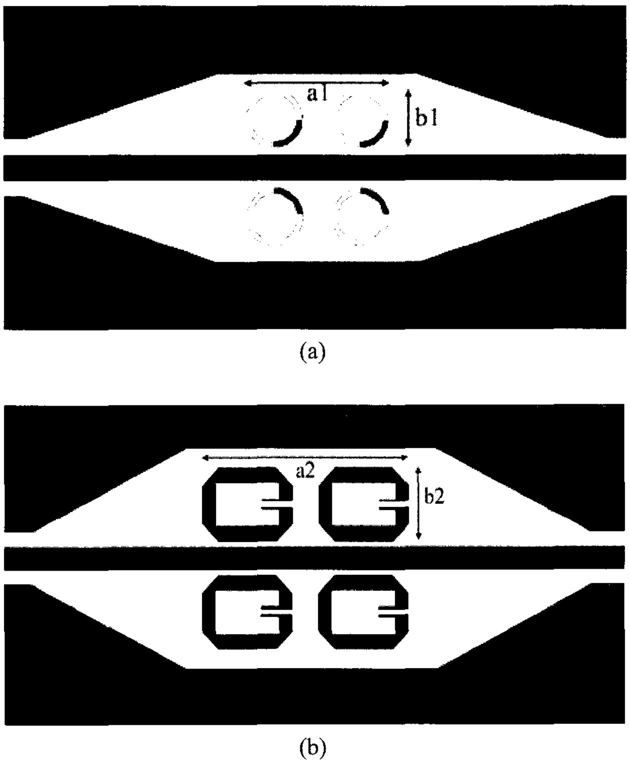


Fig. 1. Planar helical resonator coupled to CPW line.



(a)

(b)

Fig. 2. (a) Layout of the proposed planar helical resonator (a1=5 mm, b1=2 mm), (b) Layout of the conventional miniaturized hairpin resonator (a2=8.87 mm, b2=2.84 mm).

ness of 25 mil. The resonator stage is composed of four identical unit resonators. Although we have initially tried the resonator stage with two unit resonators having the advantage of single resonance characteristic, we observed not so much enhancement in Q due to the connector loss. So, we changed the structure as coupled one with 4 resonators. Then, we obtained the characteristics shown in Fig. 3. Although we observed the two null points in simulation stage, these unwanted null points are disappeared in real measurement stage due to the losses and coupling. Additionally, we obtained more deep insertion loss performances due to the energy storage enhancement effects which came from addition of another resonator stage.

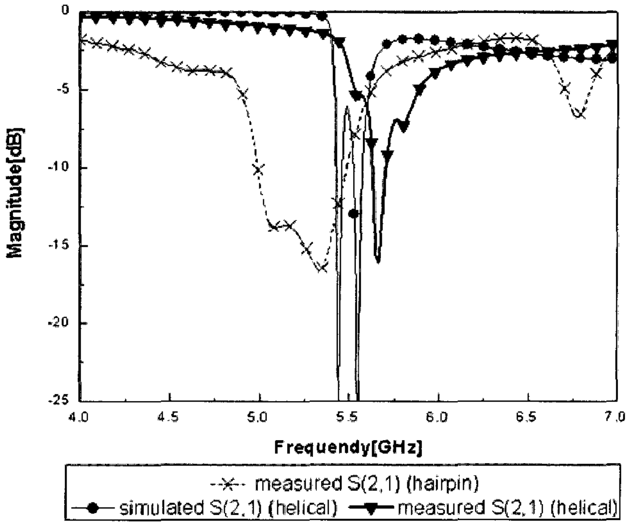


Fig. 3. Simulated and measured S-parameter characteristics of the resonator.

We calculated the width of the center line and the gap between the center line and each ground plane of the 50 Ω CPW transmission line to be 0.9 mm and 0.55 mm, respectively. To accommodate the helix cells and to improve the impedance matching, we inserted tapered lines, as well as slots that were wider than the external diameter of the unit cell. Then, after considering the minimum allowable resolution of the etching process and miniaturization of the unit cell, we set the width of each helix to 0.2 mm, and designed the radius of the helix to be 0.9 mm in order to provide a resonant frequency at 5.5 GHz. The size of the unit resonator was only 2 mm×2 mm, which corresponds to 0.094 λg ×0.094 λg, where λg is the guided wavelength at a resonance frequency of 5.5 GHz. As can be seen in Fig. 2, this circuit area is measured to be only 40 % of that of the conventional miniaturized hairpin resonator resonating at the same frequency of 5.5 GHz. This size reduction is due to the equal distribution of the standing wave inside the resonator between the upper and lower metal rings.

Fig. 3 shows the simulated and measured S-parameter characteristics of the resonator. For comparison, measured S-parameter characteristic of the corresponding miniaturized hairpin resonator is also given in the figure. The loaded Q of the helical resonator was calculated as 180, whereas that of the conventional hairpin resonator was only 32.9. The origin of this high Q-factor was reported to be originated from the increased energy storage per unit volume of the resonator due to the 3D helical nature of the structure. Additionally, the loss reduction in the via hole of the resonator by ensuring the exact location of the null point of the standing wave current at this point also contributes to the increase in Q[3]. For more optimization of Q-factor, we can also optimize the coupling between the PHR and CPW line.

Another advantage of the PHR is its harmonic-free characteristic. The spurious resonances, which are observed in most conventional quarter- or half- wavelength resonators, are not observed in the helical resonator. This phenomenon is due to the fact that the inductance and the capacitance of the helical resonator are generated from the helical ring and the gap between the rings on each side of the substrate, respectively. This LC resonance characteristic of the helical resonator generates no spurious resonances whereas most planar resonators are vulnerable to the harmonic generation. The parasitic attenuation of S(2, 1) characteristic over 10 GHz is believed to be originated from the impedance mismatch of the tapered line. However, this problem does not affect the resonance generation at 5.5 GHz and can be easily solved by more careful matching circuit design. These spurious-free resonance characteristics of the PHR contribute to the superior harmonic suppression and high efficiency of the resulting oscillator circuit.

Ⅲ. Oscillator Design

Fig. 4 shows the layout of the 5.5 GHz oscillator incorporated with the high-Q helical resonator. We followed the conventional small signal oscillator design procedure[6]. The negative resistance, which would compensate for the positive resistance generated from the resonator stage, was generated from the transistor with a shunt stub added to its source terminal. After attaching the resonator stage to the negative resistance stage, we checked the famous Barkhausen oscillation condition at the target frequency of 5.5 GHz by tuning the output matching stubs of the circuit. The final circuit was fabricated by etching a metal layer on substrate using a standard photo/mask etching technique and soldering a transistor of Agilent ATF-36077 packaged pHEMT. Lumped elements are completely removed for the planarity and easier fabrication of the circuit. The reference planar oscillator without the PHR was also designed following the identical design procedure.

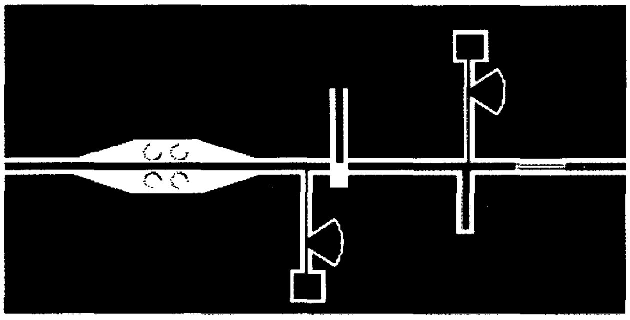
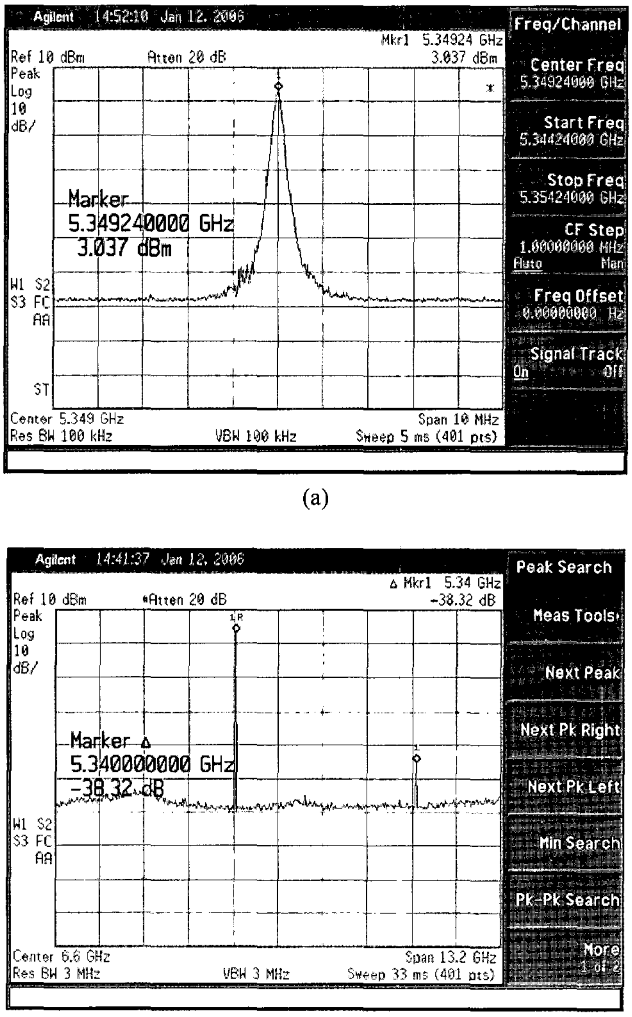


Fig. 4. Layout of the oscillator circuit.

Ⅳ. Experimental Results

A typical output spectrum of the fabricated oscillator measured using an Agilent 8565E spectrum analyzer is shown in Fig. 5. The oscillator showed a stable oscillation at a frequency of 5.3 GHz, which is similar to the expected result from the simulation. The output power of the fundamental oscillating signal was measured as 3.037 dBm with the second harmonic suppression of



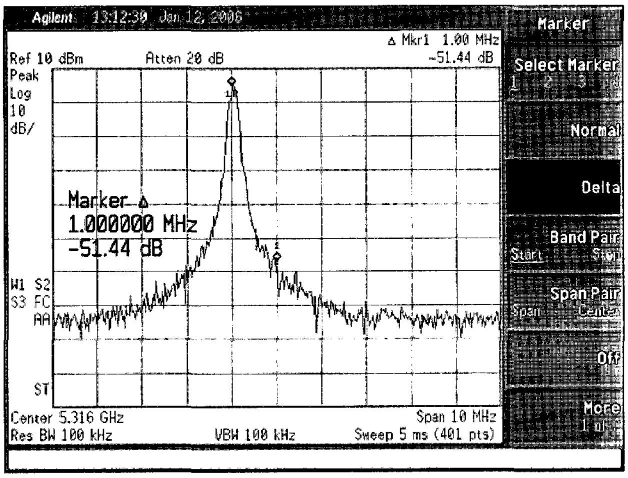
(a)

(b)

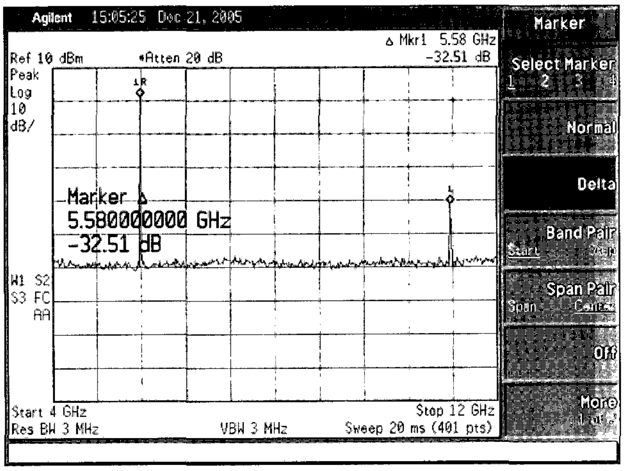
Fig. 5. (a) Typical output spectrum and (b) Harmonic characteristic of the fabricated oscillator (V_{ds}=1.5 V and V_{gs}=−0.2 V).

38.32 dBc at the bias condition of $V_{gs}=-0.2$ V and V_{ds} =1.5 V. The phase noise was measured as −91 dBc/Hz −112 dBc/Hz at the offsets of 100 kHz and 1 MHz, respectively.

In Fig. 6, for comparison, we show the measured fundamental output spectrum and harmonic performance of the reference CPW oscillator without any PHR structure. Other parts of oscillator except the resonator component were designed perfectly identical in both reference and this PHR-based oscillator. The same bias condition, layout and transistor were also used in both oscillators. The output power of the reference oscillator oscillating at 5.31 GHz was measured as 3.1 dBm with 32.51 dB rejection of the second harmonic. The phase noise was measured as −81 dBc/Hz −101.5 dBc/Hz at the offsets of 100 kHz and 1 MHz, respectively. These results constitute a 6 dB reduction in second harmonic suppression and phase noise improvement of 10.5 dB at 1 MHz offset of the newly developed oscillator when compared to those of a conventional CPW oscillator without the PHR structure. More reduction of phase noise could also be possible by changing our transistors with higher power and lower noise characteristics.



(a) Fundamental output power spectrum



(b) Harmonic characteristic

Fig. 6. Measured output spectrums of the reference oscillator without the PHR structure.

V. Conclusion

We designed and fabricated a novel compact planar microwave oscillator based on a PHR. The introduction of the printed helical resonator was verified to be effective in reducing the phase noise and enhancing the harmonic performance of an oscillator circuit without any use of a bulky 3-D resonator or additional compensation circuit. The fully planar and compactness of the circuit shows the perfect compatibility to the low cost monolithic application of the chip.

This research was supported by EMERC(ElectroMagnetic Environment Research Center) at CNU (Chungnam National University) and ADD(Agency for Defense Development) through RDRC(Radiowave Detection Research Center) at KAIST(Korea Advanced Institute of Science and Technology).

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