Novel Oscillator Incorporating a Compact Microstrip Ring Type Resonant Cell with High Efficiency and Superior Harmonic Characteristics

Cheol-Gyu Hwang · Noh-Hoon Myung

Abstract

This paper presents a novel microwave oscillator incorporating a simple microstrip ring type resonant cell as its terminating resonance component. Reduced chip size, higher dc-ac power efficiency, superior harmonic characteristics can be achieved from the introduction of a compact microstrip ring resonator cell. The oscillator provides a second harmonic suppression of 26.51 dB and the output power of 2.046 dBm at 2.11 GHz.

Key words : Oscillator, Microstrip Ring Resonator, Bandstop Filter, Harmonic Suppression.

I. Introduction

Recently, there has been much interest in the microwave application of PBG structure, and several novel microwave components utilizing the advantages of PBG structure were proposed. Improvement in radiation pattern of antenna[1], power added efficiency characteristics of amplifiers[2], and suppression of higher order harmonics of resonators[3] were achieved from the active research of PBG structure in theoretically and experimentally.

In spite of these active researches, compact microwave integrated circuits with a PBG structure were difficult to be implemented because of the inherently required five or six periods of unit cell in the implementation of such a structure. Although a compact microstrip resonator cell(CMRC) that is composed of only one unit cell was derived in order to overcome this size problem[4],[5], lack of the design rule and complexity in the resonator component became new technological barriers to be overcome.

Recently, Kee *et al.* introduced a novel microstrip ring shaped PBG structure that shows very similar characteristics to the conventional CMRC structure[6]. The easy tuning characteristic and compactness of the ring shape of the cell motivated the microwave resonant component application of this structure. In this paper, a novel, simple and easily tunable oscillator incorporating this novel PBG structure as a resonant component in an oscillator circuit with high efficiency and superior harmonic characteristics is presented.

Additionally, though the authors of the paper[6] explained the deep insertion loss in S_{21} is due to the generation of PBG at that frequency, it is more reasonable to analyze the phenomenon is originated from the even mode harmonic suppression characteristic of the structure. Thorough analysis about this phenomenon is also given in this paper.

II. Design of a Resonant Cell

2-1 Analysis of the Structure

The strong impedance mismatch at the discontinuity and the direct connection of feed lines give multiple reflections with a suitable phase correlation that is necessary in PBG formation[7],[8]. Thus the microstrip ring with a narrow gap can exhibit a PBG. This condition is met when the ring satisfies the condition of

$$2\pi r - g = n\lambda_{pbg}, \text{ for } n=1, 2, 3, \cdots \quad (1)$$

where r is the radius of the PBG ring, g the length of the gap, n is the mode number, and λ_{pbg} is the guided wavelength in the ring at the PBG generation. The radius r and the gap g are designed as 4.8 mm and 0.25 mm, respectively. With these dimensions of the ring,

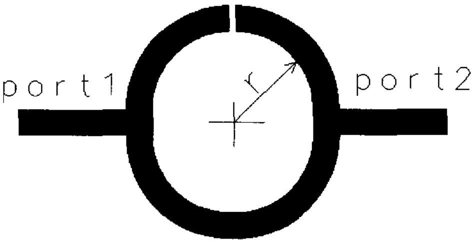

Fig. 1. PBG resonant cell.

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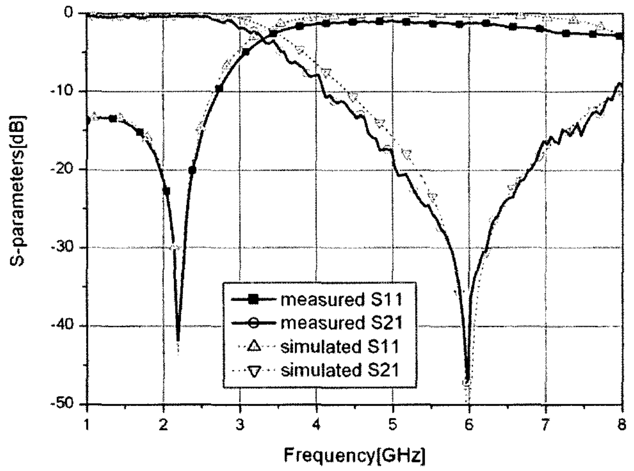


Fig. 2. S-parameter characteristics of the resonant cell.

PBG generation at 6.0 GHz can be obtained.

The PBG structure was fabricated on a Taconic TLC30 substrate(relative permittivity=3, height=20 mil., metal thickness=0.7 mil., and loss tangent=0.001). The S-parameter characteristics are tested by an HP 8722ES network analyzer. And the measured results can be seen in Fig. 2.

As can be seen in Fig. 2, there are strong insertion losses in frequency range from 4 GHz to 8 GHz, which comes from the generation of PBG. Also, deep S_{11} attenuation at 2.2 GHz is observed which comes from the transmission line characteristic of the structure. However, no S_{11} attenuation is observed at 4.4 GHz due to the PBG formation at that frequency. Adopting this PBG structure to a 2.2 GHz resonator component in an oscillator circuit, reduced second harmonic characteristics corresponding to 4.4 GHz can be achieved.

Additionally, the PBG generation frequency and the resonator application frequency can be easily controlled

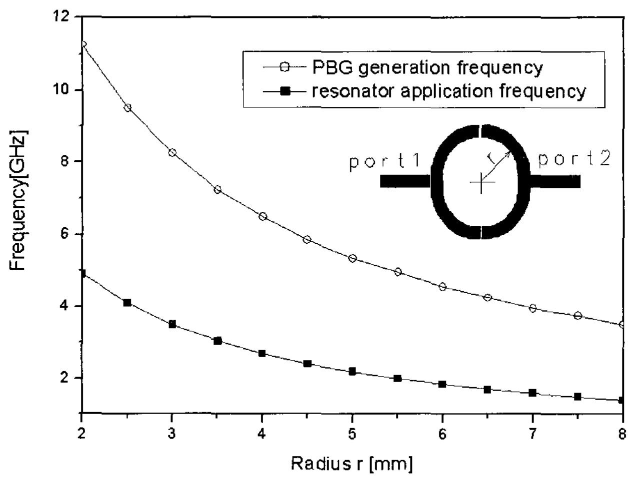


Fig. 3. Tuning characteristics of the resonant cell.

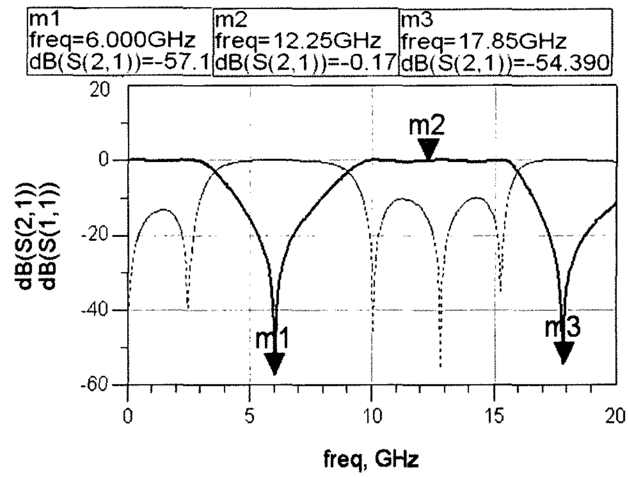


Fig. 4. Detailed S-parameter simulation result of the resonant cell(S_{21}=solid, S_{11}=dot).

by changing only the radius of the structure during the design stage as can be seen in Fig. 3. This is another advantage of this PBG resonator over previous CMRC resonators.

2-2 Standing Wave Approach to the Analysis of a Deep Insertion Loss in S_{21}

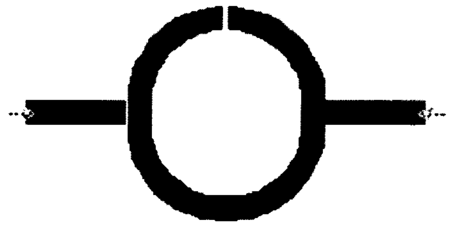
The deep insertion loss at 6 GHz of the structure can also be explained using the conventional wave propagation theory. Fig. 4 is the S-parameter simulation result of the resonant cell shown in Fig. 1 up to 20 GHz. As can be seen from the figure, there is another deep insertion loss at 18.3 GHz which is the triple frequency of the fundamental PBG generation frequency of 6 GHz. This phenomenon can hardly be explained using the conventional PBG theory. Instead, it can be explained observing the characteristic of propagating waves through the structure.

The electric field at the gap of the ring should be at a maximum due to the reflection at the gap boundary of the ring. In addition to that, the electric field at the input/output port should be zero due to the strong reflection at the gap boundary. These two boundary conditions forces the generation of a standing wave inside the ring when n is an odd number in equation (1).

Therefore, wave does not propagate through the ring and the deep attenuation is generated at this condition. On the other hand, when n is an even number, no standing wave can be observed inside the ring. Therefore, no attenuation is observed in S_{21} at this condition as can be seen in Fig. 4.

Although we could use the m1 point in Fig. 4 as a second harmonic suppressed resonator application of an oscillator circuit, we utilized the deep attenuation in S_{11}

(a) Equivalent structure



(b) Proposed structure

Fig. 5. Comparison to the equivalent structure to the proposed resonant cell.

at 2.2 GHz as a resonating point. As can be seen in Fig. 4, there are no second and third harmonics in S_{11} corresponding to 4.4 and 6.6 GHz due to the deep attenuation in S_{21} in those frequencies. Additional size reduction could be achieved because the dimension of the ring is comparable to that of a 6 GHz ring resonator structure.

The comparison to the equivalent circuit of the proposed structure can be seen in Fig. 5.

Compared to the conventional structure, the proposed structure shows a chip size reduction of 40 %.

In addition to that, the novel structure shows an easy frequency tuning characteristic when the center gap is replaced by a variable capacitor. Fig. 6 shows the resonance frequency tuning characteristic when the center gap capacitance is varied from 36 fF to 196 fF with an increment of 40 fF. This characteristic can be easily

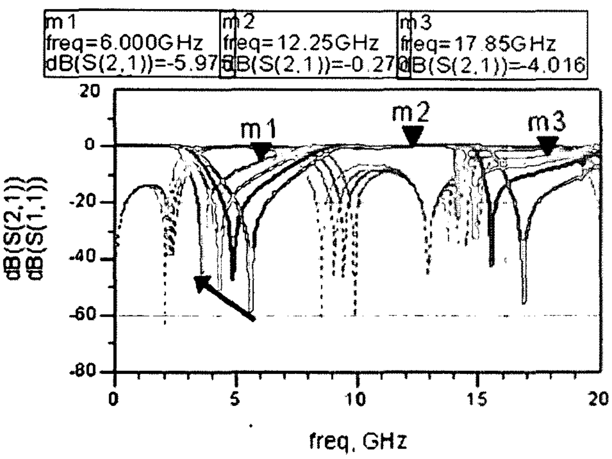
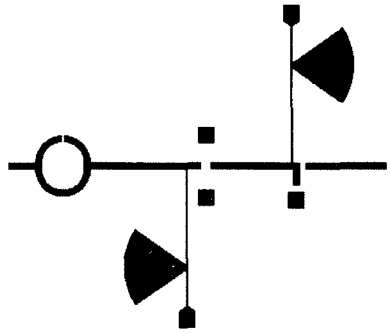
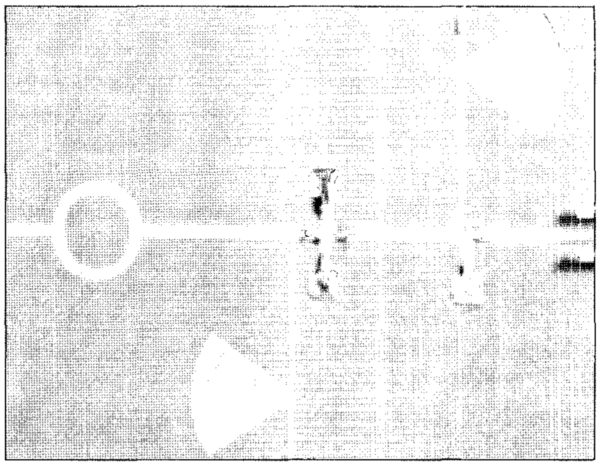


Fig. 6. Frequency tuning characteristic with the capacitance variation of the center gap capacitor(Direction of an arrow: capacitance change from 36 fF to 196 fF with an increment of 40 fF).



(a) Layout



(b) Photograph

Fig. 7. The fabricated oscillator circuit.

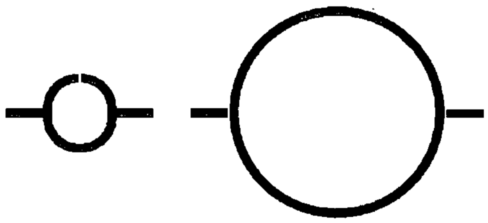
applied to the frequency tuning resonator of a conventional MMIC VCO.

Ⅲ. Design of a Harmonic Suppressed Oscillator

Fig. 7 shows the layout and photograph of the 2.2 GHz oscillator circuit. The transistor used was Agilent ATF-36077 pHEMT. A capacitor of 1 pF and an inductor of 1 nH were soldered to the source terminal of the transistor to achieve the negative resistance and dc feed/ac block characteristic from source terminal to ground, respectively.

Due to the lack of a large signal model of the p-HEMT, the output power of the oscillator circuit was difficult to estimate during the design process. Instead, output matching stubs were tuned to meet the small signal oscillation condition derived in [9]. Designed PBG cell was used as a fundamental frequency selection and harmonic suppression component of an oscillator circuit.

As can be seen in Fig. 8, the cell takes the area of only 10 % of the conventional ring resonator at the frequency of 2.2 GHz. This drastic size reduction is due to the discrepancy between the PBG generation fre-



(a) PBG ring resonator: radius is 4.2 mm (b) Conventional ring resonator: radius is 13.3 mm

Fig. 8. Size comparison between the conventional ring resonator and the PBG resonator in 2.2 GHz oscillator application.

quency of 6.0 GHz and real resonator application frequency of 2.2 GHz of the PBG resonator. In case of conventional ring resonator, the radius of the ring is determined by following equation (2).

$$2\pi r = n\lambda_{reso}, \text{ for } n=1,\ 2,\ 3, \cdots \tag{2}$$

where r is the mean radius of the ring, λ_{reso} is the guided wavelength at the 2.2 GHz resonator application in the ring, and n is the mode number. Comparing equation (1) and (2), we can easily know that the radius of the PBG ring for 2.2 GHz application is same to that of the conventional ring resonator for 6.0 GHz application. This small size characteristic of the PBG ring can act as an advantage in future monolithic integration of the circuit.

Ⅳ. Experimental Results

Measurements of oscillation frequency, output power, and harmonic characteristics were performed using an Agilent 8565E spectrum analyzer. Bias was chosen as V_{ds}=1.5 V and V_{gs}= − 0.2 V as recommended by the data sheet of the transistor. Fig. 9 shows a typical output

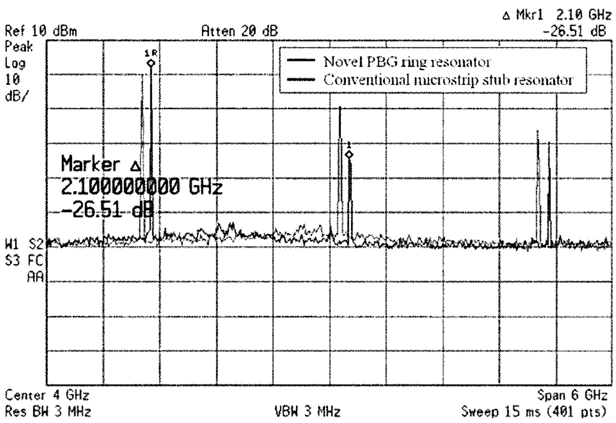


Fig. 9. Spectra of the PBG oscillator and the conventional microstrip open stub resonator oscillator (mark 1 indicates the harmonic suppression of the PBG ring oscillator).

spectrum of the fabricated oscillator. The oscillation frequency and the output power were 2.1 GHz and 2.046 dBm, respectively. And, the second harmonic suppression was measured as 26.51 dB. Also shown in Fig. 9 is the spectrum of the reference conventional oscillator with the PBG ring resonator replaced by a conventional microstrip open stub. The output power of the reference oscillator at the same frequency was 0.07 dBm with only 8.85 dB rejection of the second harmonic 16.35 dB rejection of the third harmonic. This result shows the PBG ring resonator is effective in reducing the harmonics and improving the output power and efficiency of an oscillator with drastic size reduction.

Ⅴ. Conclusion

In this paper, we presented a novel oscillator incorporating a simple PBG structure as a resonant component of an oscillator with high efficiency and superior harmonic characteristics. Simpler tunable resonator structure and smaller size when compared to the conventional CMRC or ring oscillators were achieved by introducing a novel ring PBG structure. A VCO can be easily achieved by locating a varactor between the gap of the resonant cell. The small size and planar structure characteristic of the circuit can be easily applied to the MMIC application of the circuit, and a Ka-band MMIC oscillator application is under development by author's group.

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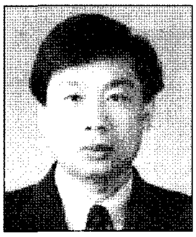

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