An Oscillator with Reduced Phase Noise and Improved Harmonic Characteristics Based on a Corrugated CPW EBG Structure

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Short Abstract—This paper presents a novel microwave oscillator circuit incorporating a corrugated coplanar waveguide (CCPW) electromagnetic bandgap (EBG) structure as its resonator component. The fully planar oscillator showed a reduced phase noise characteristic of -90.2 dBc/Hz at 100 kHz offset and a superior second harmonic suppression of -42.67 dBc.

Keywords—corrugated CPW; EBG; harmonic suppression; oscillator; phase noise

I. INTRODUCTION

In the last several years, the EBG structure, which has its origin in optics, has been successfully applied to various microwave components such as power amplifiers [1], filters [2], and antennas [3]. There has also been strong interest in application of this structure in microwave oscillator applications. In this regard, several novel oscillator circuits utilizing the advantages of the EBG structure have been proposed, where planar integration of the chip is the primary concern. H.W. Liu et al. reported an efficiency improved VCO using a defected ground structure (DGS) as a harmonic tuner of the oscillator circuit at the expense of additional chip area [4]. Y.T. Lee et al. showed the phase noise enhancement of an oscillator using a DGS structure as a resonator component of a conventional oscillator circuit [5]. They used a DGS as a harmonic suppressor or a novel phase noise reduction component of a conventional oscillator circuit.

However, DGS based oscillators inherently have the disadvantages of requiring an additional air gap between the perforated backside metal plane and a metallic shielding enclosure package [6],[7]. These problems in turn lead to reliability problems and difficulty in miniaturization of the chip. Also, the inherently required five or six periods of the unit cell in the implementation of such a structure may lead to a size problem. Additionally, the extra processing of the backside metal plane increases the complexity in a fully monolithic application of the chip. In this paper, a novel compact EBG based oscillator based on CCPW technology is presented for the first time. The CCPW structure, originally suggested as a low pass filter, is modified to the microwave resonator component of the oscillator circuit maintaining its advantages of uniplanar structure and compactness. The higher quality factor of the structure relative to that of the conventional CPW resonator plays a role of phase noise reduction of the oscillator circuit. In addition, the unique harmonic characteristic of the CCPW plays a role of harmonic suppression of the oscillator circuit, which leads to enhancement in dc–ac power efficiency of the circuit.

II. DESIGN OF A CCPW RESONANT CELL

Recently, a one-quarter wavelength deep high impedance CCPW structure [8] was proposed as a planar version of Sievenpiper’s high-impedance surface originally proposed in [9]. As can be seen in Fig. 1, the CCPW structure consists of a center strip separated by a narrow gap from two ground planes.

Fig. 1. Corrugated CPW EBG structure.
and a numerous high impedance slots running down into the ground planes of the structure. The width of the slot is much shorter than the wavelength and the depth of the slot is one-quarter wavelength. This one-quarter wavelength of each slot transforms the zero impedance of the ground plane to infinite, and forbids the propagation of transverse magnetic surface waves along the CPW line. Consequently, a deep stopband corresponding to the bandgap of any other EBG structure is generated. Its inherent uniplanar characteristic and compactness in size solve the aforementioned problems of conventional DGS based oscillators and affords greater possibility of monolithic application of EBG structures.

Fig. 2 shows the simulated and measured S-parameter of the CCPW structure fabricated on a RT/Duroid 6010 substrate having a dielectric constant of 10.2 and thickness of 25mil. The widths of the line and the gap of the 50 ohm CPW transmission line were calculated as 0.9 mm and 0.55 mm, respectively. The depth of the slot was set to 5 mm, which corresponds to one quarter wavelength at the offset frequency of 6 GHz.

The cutoff frequency of 6 GHz near the resonator application frequency of 5.5 GHz causes the input impedance of the CCPW structure to vary rapidly from 50 ohm as the frequency deviates from the resonant frequency. This characteristic contributes to a higher input phase slope at the gate circuit. From this, a higher quality factor than that of a circuit without the CCPW structure is achieved [5],[10]. Therefore, an oscillator with reduced phase noise could be achieved utilizing the deep attenuation in S(1,1) at 5.5 GHz as the resonance frequency of the circuit. The resonance frequency and subsequent oscillation frequency can be easily tuned by changing the depth of the CCPW structure.

Another advantage of the CCPW resonator is its harmonic tuning characteristic. The harmonics of the circuit can be suppressed by controlling the reflection phase of terminating resonance, as suggested in [11]. The length between the CCPW structure and the transistor was tuned to 9.09 mm in order to negatively feedback the second harmonic component signal of the oscillator circuit. In addition to this methodology, we utilized the inherent absence of any nth-harmonic in the S11 characteristic of the 5.5GHz CCPW resonator so as to reduce the harmonics of the final oscillator circuit. From this suppression of harmonics, an increase in the fundamental output power and dc–ac power efficiency could be achieved.

The total size of the CCPW EBG resonator structure was only 12 mm × 9.5 mm, which corresponds to 0.57 λg × 0.45 λg, where λg is the wavelength of resonance frequency.

III. DESIGN OF OSCILLATORS

Fig. 3 shows the layout and fabricated result of a 5.5 GHz oscillator circuit. Negative resistance to compensate for the loss in the resonator was generated using a short stub in the source terminal of the transistor, which can be easily fabricated in CPW technology. Output matching stubs were tuned to meet the small signal oscillation condition, and the designed CCPW cell was implemented as a fundamental frequency selection component of an oscillator circuit. For co-
Fig. 4. Measured output spectrums.(a) Fundamental output power spectrum. (b) Harmonic characteristic.

Comparison, a conventional CPW oscillator without the CCPW resonator structure was also designed and fabricated. The other components, i.e. except the CCPW structure, were set to be identical including the transistor, an Agilent ATF- 36077 pHEMT. The fabrication processes of the oscillators were extremely simple without any via-hole process, pattern on the backside metal layer, or any lumped element soldering process.

IV. MEASUREMENT RESULTS

Fig. 4 shows the photograph of the measured fundamental output spectrum and harmonic performance of the fabricated CCPW oscillator. The oscillator exhibits a measured oscillation frequency of 5.41 GHz with a measured peak output of 3.50 dBm at a bias condition of $V_{ds} = 1.5$ V and $V_{gs} = −0.2$ V. Phase noise is measured as $−90.2$ dBC/Hz and $−115.3$ dBC/Hz at offsets of 100 kHz and 1 MHz, respectively.

The second and third harmonic suppressions were measured as $−42.67$ dBC, and $−27.00$ dBC, respectively. Even more harmonic suppression is expected if we add another CCPW harmonic tuner at the output stage of the circuit.

These results constitute a greater than 10 dB improvement in phase noise performance and more than 20 dB improvement in second harmonic suppression when compared to those of a conventional CPW oscillator without the CCPW structure.

V. CONCLUSION

In this paper, a novel oscillator that incorporates a uniplanar CCPW EBG structure as a resonator component of the conventional CPW oscillator circuit was presented. The introduction of the CCPW EBG structure was verified to be effective in reducing the phase noise and enhancing the harmonic performance and dc–ac power efficiency of the oscillator circuit in a very small chip size increment. The small size and uniplanar structure characteristic of the circuit can be easily applied to MMIC applications of the circuit while avoiding the drawbacks of the conventional DGS based EBG oscillators.

ACKNOWLEDGMENT

This research was supported by KOSEF through MICROS and ADD through RDRC at KAIST.

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