S-band Oscillator using ForeS Resonator

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1. Introduction

The modern communication systems require low cost, low phase noise local oscillators. The dielectric resonator oscillators have been widely used, but these are not compatible to monolithic microwave integrated circuit (MMIC), because the dielectric resonators have height dimension. On the other hands, the left-handed (LH) resonators have many advantages over traditional ones. First, they have planar profile, second, they are cheap to implement, and third, they have high quality factors. Among them, the high quality factor property made the microwave oscillators utilizing left-handed resonator as its resonator one of the promising research areas, because of their high Q led to excellent phase noise characteristic of microwave oscillators [1-4].

The phase noise characteristic of an oscillator is strongly dependent on the quality factor of its resonator [5]. But the quality factor of a microstrip resonator is inherently limited by the substrate loss and conductor loss of microstrip structure. Despite this limitation, the left-handed resonators like ForeS show relatively high quality factor even when it is implemented in microstrip structure, which can be utilized for low phase noise oscillator application.

In this paper, a novel low phase noise oscillator using ForeS resonator is presented for the first time. The ForeS resonator which is left-handed, has planar profile and high quality factor that lowers the cost and phase noise of the oscillator, respectively.

![Resonators](image)

Figure 1: Resonators based on spiral resonators and dimension (a) grounded-spiral (b) grounded double spiral (c) ForeS

2. Resonator configuration

With the emerging of left-handed material, the spiral resonator (SR) received much attention because of its compact size [6, 7]. A grounded-spiral resonator is a spiral resonator whose one end is short circuited by connecting it to the ground. Therefore, two grounded-spirals can compose a grounded double spiral, and four grounded-spirals can compose a ForeS resonator (Fig. 1).

The ForeS was first developed by B. Jocanovic for filter application [8-10], and the loaded quality factor was over 30, and it was relatively high among microstrip resonators. As shown in Fig. 2, the resonator is end-coupled to the host microstrip line through small gap to pad. The gap between resonator and microstrip line pad is minimized to 100μm, in order to foster the coupling. In Fig. 2, the four small circles at the ends of each spiral represent via holes connected to ground. The dimensions of the ForeS resonator are shown in Table 1. The resonator was realized on 0.5mm
Taconic RF-35 substrate with $\varepsilon_r = 3.5$, $\tan\delta = 0.0018$, and its overall size was equal to $\lambda_g/7 \times \lambda_g/8$, where $\lambda_g$ denotes the guided wavelength of the fabricated microstrip structure at 2GHz.

An optimization process was followed to critically couple the resonator to the microstrip transmission line. By varying the pad width and height of ForeS resonator in Fig. 2, the quality factor was calculated. Then the width and height which resulted in the highest quality factor were chosen. The optimal pad width and height are given in Table I. A numerical evaluation was performed by computer simulation tool Ansoft Designer™. The simulation and measurement results are shown in Fig. 3.

The simulation and measurement results in Fig. 3 show similar pattern, but they do not exactly coincide. The reason is the very thin dielectric coating, maybe few mils, covered the entire pattern during the fabrication process (shown in Fig. 4(b) as a green surface). This coating with some amount of adhesive material and ink increased the effective permittivity of the microstrip structure and physically narrowed the gap between resonator and the pad. This effect lowered the resonance frequency, and enhanced the coupling, so led to lower S11 and higher S21. The simulated and measured Q is 140 and 14, respectively. The reason of deteriorated Q is explained above.

<table>
<thead>
<tr>
<th>Table I. Dimensions of ForeS resonator</th>
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<td>Dimension (mm)</td>
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<td>Dimension (mm)</td>
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Figure 2: ForeS resonator optimized for maximum Q

Figure 3: Measurement and simulation results

3. Oscillator configuration
The oscillator was fabricated on the same substrate with the resonator. The size of final circuit was 94mm x 67mm. NEC NE851M03 NPN silicon RF transistor was used to start the oscillation. This transistor was chosen, because it had low corner frequency, which led to low flicker noise. The necessary bias voltage was supplied by MC7085 DC voltage regulator through a variable resistor. The emitter current was set as small as 5mA, because the phase noise is smaller if emitter current is small [11]. The negative resistance to compensate for the loss in the resonator was provided by the short stub at the emitter terminal. Output matching stub were tuned to satisfy the small signal oscillation condition, and matched to the band that the oscillation occurred, 2GHz. Although the matching stub has high Q which means narrow matching bandwidth, it is of no problem to retrieve maximum oscillation power because the oscillation frequency is fixed at 2GHz. Fig. 4(a) and 4(b) show the layout and photograph of the proposed ForeS oscillator, respectively.

![Figure 4: ForeS oscillator (a) layout (left) (b) photograph (right)](image)

4. Measurement results

Fig. 5(a) and 5(b) show the fundamental output spectrum of the fabricated oscillator with 50kHz and 1MHz span, respectively. The oscillator exhibits a measured oscillation frequency of 1.96GHz with a measured peak output of 0dBm at the bias status of $I_E=5$mA and $V_{CE}=1.5$V. Phase noise is measured and tabulated in Table II. The low corner frequency of NE851M03 transistor and high quality factor of ForeS resonator resulted in low phase noise performance at small offset frequencies.

![Figure 5: ForeS oscillator’s output spectrum with (a) 50kHz span (left) (b) 1MHz span (right)](image)
<table>
<thead>
<tr>
<th>Offset</th>
<th>5kHz</th>
<th>10kHz</th>
<th>100kHz</th>
<th>1MHz</th>
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<tr>
<td>Phase noise (dBc/Hz)</td>
<td>-75</td>
<td>-80</td>
<td>-100</td>
<td>-115</td>
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</table>

5. Conclusion

In this paper, a novel oscillator which incorporated the ForeS resonator was presented. The planar structure and small size of the proposed resonator provide high compatibility with the MMIC technology. High quality factor provides low phase noise characteristic of -75dBc/Hz at 5kHz offset with maximum output power of 5.9dBm.

Acknowledgments

This research was supported by BK21 (Brain Korea 21), and ADD (Agency for Defence Development) through the RDRC (Radiowave Detection Research Center) at KAIST (Korea Advanced Institute of Science and Technology).

References


