Novel Oscillator Incorporating a Compact Microstrip Resonant Cell

Quan Xue, Kam Man Shum, and Chi Hou Chan

***Abstract*—A novel transistor oscillator incorporating a compact microstrip resonant cell (CMRC) as its terminating resonance is proposed. Adjusting the dimensions of the cell, it is possible that the fundamental frequency can be positively fed back and the second harmonic negatively fed back at the input port of the oscillator. So that the fundamental output is enhanced with the second harmonic being suppressed. The output power of the proposed CMRC oscillator is 14.7 dBm at 2.5 GHz with 27.1 dB rejection of the second harmonic, outperforming the conventional microstrip termination with a 40% size reduction.**

***Index Terms*—CMRC, microstrip, oscillator, photonic bandgap, resonator.**

I. Introduction

MICROSTRIP photonic bandgap (PBG) structures are finding their applications in microwave antennas, filters, resonators, power amplifiers and mixers [1]–[5]. In this letter, a transistor oscillator is designed using a novel microstrip structure, namely, the compact microstrip resonant cell (CMRC). Although there is only one unit cell in this structure, it possesses the characteristics of the general PBG structure, i.e., slow-wave and bandgap. This CMRC structure is employed as the terminating resonance in the construction of a transistor oscillator to improve its performance. By designing the oscillator so that its second harmonic is within the range of the stop-band of the CMRC, the phase of reflection coefficient of the CMRC can be tuned independently for the fundamental frequency and the second harmonic. The fundamental frequency is positively fed back by the CMRC at the input port of the oscillator for the oscillation setup at the fundamental frequency. And if the second harmonic is negatively fed back in the same time, the output of the fundamental frequency can be enhanced with simultaneous suppressing of the output of the second harmonic. Because of the slow-wave effect of the CMRC at the fundamental frequency, the dimension of the oscillator can be reduced.

II. CMRC and Its Application in Oscillator

Fig. 1 shows the CMRC structure first proposed in [6]. It is a section of microstrip line with a pattern etched on the line itself. The narrow connecting lines in the CMRC pattern lead to the increase of series inductance. In contrast, the coupling edges of the triangular patches and the microstrip line increase the shunt capacitance. The enhanced series inductance and shunt capacitance produce the slow-wave and bandgap effects. A CMRC circuit was fabricated and tested. The circuit substrate is Duroid 5870 with a relative permittivity 2.94 and height 1.524 mm. The cell parameters in Fig. 1 are $w_0 = 0.2$ mm, $w_1 = 0.6$ mm, $w_2 = 3.4$ mm, $w_3 = 3.8$ mm, $l_1 = 10.0$ mm, $l_2 = 12.0$ mm, and $l_3 = 10.0$ mm. The width of the cell is identical to that of a 50-Ω microstrip line on the same substrate. A CMRC structure with above parameters was fabricated and measured on HP8515A/8510C vector network analyzer. Fig. 2 shows the measured S-parameter of the CMRC structure. It can be seen from Fig. 2 that there is an insertion loss of 0.33 dB at 2.5 GHz, but a 19-dB isolation exists at 5.0 GHz. For this characteristic, when CMRC is used as terminating resonance, the reflecting coefficient for 2.5 GHz and 5.0 GHz can be tuned independently. On the above described substrate, the effective dielectric constant of a normal 50 Ω microstrip

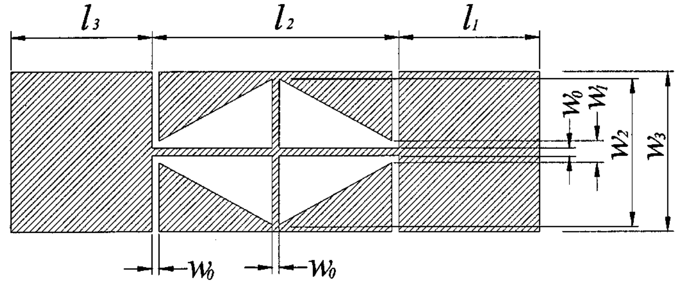

Fig. 1. CMRC structure.

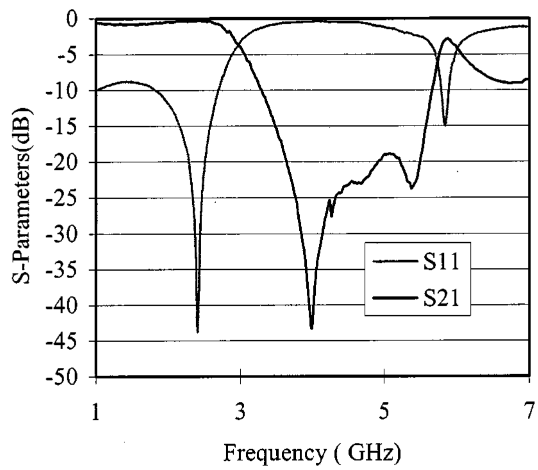

Fig. 2. Measured S-parameter of the CMRC structure.

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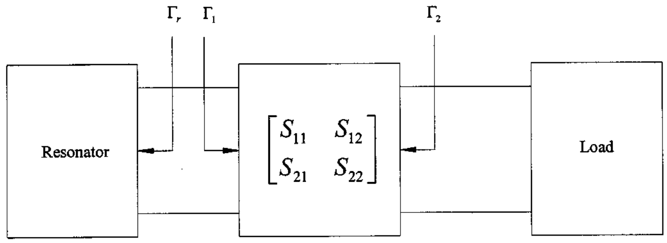

Fig. 3. Block diagram of the transistor oscillator.

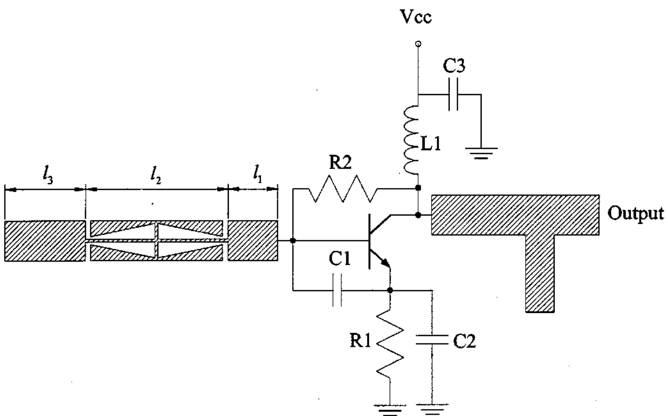

Fig. 4. Oscillator using CMRC as terminating resonance.

transmission line is 2.4, while for the CMRC structure, the effective dielectric constant is 4.3. This means that CMRC is a slow-wave structure at the fundamental frequency.

Fig. 3 is a block diagram for the transistor oscillator. The 2-port network includes the transistor and its bias and feed-back circuits. The resonator and the load of the oscillator are the two terminals at port 1 and port 2, respectively. The output amplitude of the network including resonator to the load at frequency f is

$$|\Gamma_2(f)| = |S_{22}(f)| + \frac{|S_{12}(f)S_{21}(f)\Gamma_r(f)|}{|1 - S_{11}(f)\Gamma_r(f)|} \qquad (1)$$

where Γ_r is the reflection coefficient of the resonator. Its amplitude is smaller than but near to 1 because the resonator is usually a low loss component. It can be seen from (1) that the maximum output amplitude of the network appears when

$$\angle\Gamma_r(f_0) = -\angle S_{11}(f_0) \qquad (2)$$

where f_0 is the frequency at which the oscillation will setup. On the other hand, the minimum amplitude appears when

$$\angle\Gamma_r(f_1) + \angle S_{11}(f_1) = \pm 180^\circ \qquad (3)$$

where f_1 is the frequency at which the output of the oscillator will be suppressed inside the two-port network. Referring to Fig. 4, we calculate the reflection phase of the transistor at the input port, or the base of the transistor, at 2.5 GHz (denoted as θ_0) and at 5.0 GHz (denoted as θ_1). We then tune l_1, so that the reflection phase of terminating resonance θ_1' at 5.0 GHz satisfies $\theta_1' + \theta_1 = \pm 180^\circ$ for a negative feedback. This is followed by tuning l_3, so that the reflection phase of

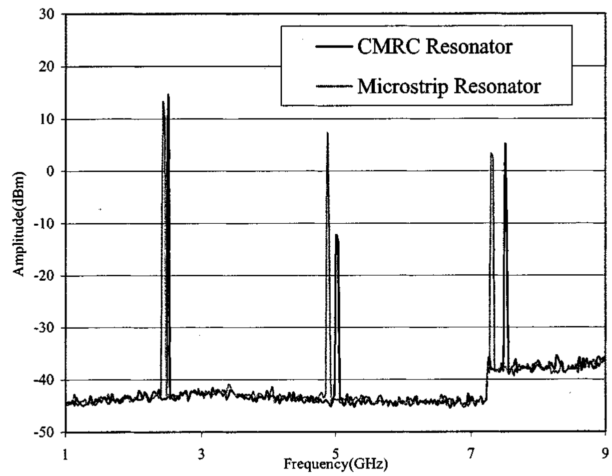

Fig. 5. Spectra of the CMRC oscillator and the conventional oscillator.

terminating resonance θ_0' at 2.5 GHz which satisfies $\theta_0' = -\theta_0$ for the positive feedback. By this procedure, the oscillator can oscillate at 2.5 GHz while its second harmonic is suppressed by the negative feedback at the base of the transistor. Because the second harmonic is not filtered out by a filter at the output port as conventional oscillators do, but suppressed inside the oscillator, the fundamental power output and dc–ac power efficiency can be increased. The same design procedure can also be adopted for microwave FET, Gunn diode, and other negative oscillators.

III. Experimental Results

A 2.5-GHz oscillator in Fig. 1 is fabricated on Duroid 5870 substrate with thickness of 1.524 mm. The dimensions of CMRC in Fig. 4 are $l_1 = 2.9$ mm, $l_2 = 12$ mm, and $l_3 = 1.0$ mm. The transistor used is IBM43RF0100 of IBM Microelectronics. The dc voltage of collector to the base is 3.9 V with collector current 36 mA. Fig. 5 shows the spectrum of the oscillator with the CMRC. Also shown in Fig. 5 is the spectrum of the reference oscillator with the CMRC in Fig. 4 replaced by a section of microstrip open stub. It can be seen that the output power of CMRC oscillator is 14.7 dBm with 27.1 dB rejection of the second harmonic. In contrast, the output power of the reference oscillator at the same frequency is 12.9 dBm with only 6.6 dB rejection of the second harmonic. The total length of the CMRC terminating resonance is 15.9 mm, a 40% reduction from the resonance of the reference oscillation using a normal microstrip, which is 26.5 mm long. The phase noise of the CMRC oscillator is -64.7 dBc at an offset of 100 kHz, while, that of the reference oscillator is -76.2 dBc. This phase noise deterioration of the CMRC oscillator is because the relatively large loss, or low Q-factor, of CMRC resonator. This can be compensated by incorporating with phase-locked-loop (PLL) or dielectric resonator (DR).

IV. Conclusion

We have presented an oscillator incorporating a novel CMRC structure as the terminating resonance circuitry. The 2.5-GHz CMRC oscillator demonstrates that it has a higher output power, higher dc–ac power efficiency, better second harmonic rejection and smaller in size when compared to the conventional microstrip terminating oscillator. It is possible to incorporate a varactor or DR into this CMRC oscillator to form a VCO and DRO. It can also be adapted to other negative resistance oscillators.

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