Design of Oscillator Using Zeroth-order Resonator Based on Composite Right/left-handed Transmission Line

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Abstract— The application of novel zeroth-order resonator in RF circuit is investigated in this paper. The zeroth-order resonator is composed by composite right/left handed transmission lines, full-wave simulations with 1-cell and 4-cell resonators are carried out, respectively. Microwave oscillators used zeroth-order resonators, which performed as tuning network, are proposed. The zeroth-order resonators in oscillators determine the frequency. The simulation frequencies of oscillators are 10.5 GHz of 1-cell resonator and 10.1 GHz of 4-cell resonator, respectively.

1. INTRODUCTION

The composite right/left-handed (CRLH) transmission line (TL) is the practical implementation of left-handed metamaterials based on transmission line theory [1]. The CRLH TL structure is composed of unit cells with a series capacitance C_L and a shunt inductance L_L as well as a series inductance L_R and a shunt capacitance C_R. A typical microwave CRLH TL constituted by interdigital capacitors and stub inductors shorted to the ground plane by a via, which was first introduced by Caloz and subsequently used in various applications [2]. In this structure interdigital capacitors and stub inductors provide C_L and L_L, performing left-handed (LH) nature as dominant mode, whereas the parasitic reactances (parasitic capacitance is due to development of voltage gradients, and parasitic inductance is due to current flow along the metallization) provide C_R and L_R performing right-handed (RH) nature at higher frequencies.

Transmission-line resonators, usually open or short circuited, have been developed and practically used in microwave and millimeter-wave circuits. Generally, the resonant frequencies of transmission-line resonators are determined by the length of the lines. Because of the unique feature of CRLH metamaterials that a β of zero can be achieved, zeroth-order resonators have been proposed and developed. Zeroth-order resonator has the advantage that resonant frequency is not related to the physical length of the TL, therefore it can be realized, theoretically, arbitrarily small [3, 4]. Zeroth-order resonators can be exited in open- and short-ended case, as well as variable reactance loads at both ends [5]. By changing load impedance at the terminals the resonant condition of the zeroth-order resonator can be controlled. Researches on zeroth-order resonator are popular in recent years; however the applications in RF circuit, such as oscillator, are not very much.

In this paper, zeroth-order resonators with one terminal open-ended and the other terminal capacitive are developed. Full-wave simulations of resonators, $N = 1$ and $N = 4$, (N is the number of the unit cells in resonator.) are carried out. In addition, oscillators using these resonators as tuning network are proposed.

2. THEORY

AS shown in Fig. 1(a), the unit of a typical equivalent-circuit model for transmission-line resonator based on CRLH TLs is composed of a series branch and a shunt branch. Figs. 1(b) and (c) show the T-type and Π-type unit cell, respectively.

In the open-ended case, shunt resonance in shunt branch is dominant. The shunt admittance is given by

$$Y_{sh} = j\omega C_R + \frac{1}{j\omega L_L} = j\omega C_R \left\{1 - \left(\frac{\omega_{sh}}{\omega}\right)^2\right\} \tag{1}$$

where $\omega_{sh} = 1/\sqrt{L_L C_R}$, which is the shunt frequency. In contrast, in the short-ended case, series resonance in series branch is dominant, The series impedance is given by

$$Z_{sh} = j\omega L_R + \frac{1}{j\omega C_L} = j\omega L_R \left\{1 - \left(\frac{\omega_{se}}{\omega}\right)^2\right\} \tag{2}$$

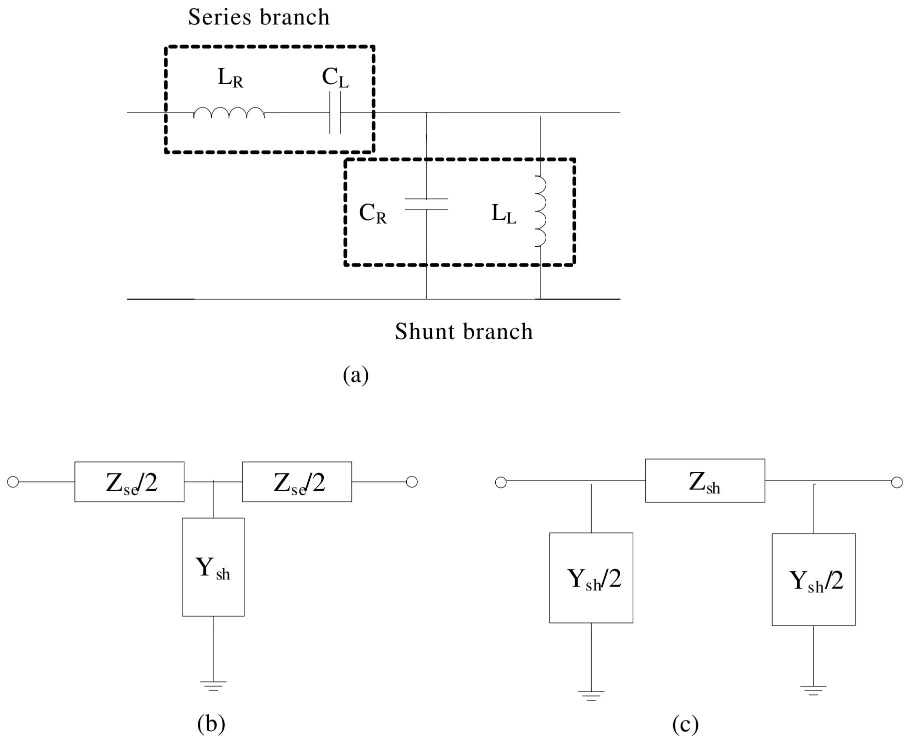

Figure 1: (a) Unit fell of equivalent circuit model. (b) T-type unit cell. (c) Π-type unit cell.

where $\omega_{se} = 1/\sqrt{L_R C_L}$, which is the series resonant frequency. In the particular case of balanced resonances, when $\omega_0^{balanced} = \omega_{se} = \omega_{sh}$, the zeroth-order resonance occurs for both the open-ended and short-ended resonators.

Resonators used in two ports oscillators perform as tuning network, which determine the frequencies of oscillators, shown in Fig. 2. In order to act in oscillator, resonator should obtain good frequency selectivity in oscillator frequency, phase condition also should be satisfied. The phase relation holds:

$$\Delta\varphi = 2m\pi \tag{3}$$

with $m = 0, \pm 1, \ldots, \pm\infty$. CRLH TLs and terminals of zeroth-order oscillator both contribute to $\Delta\varphi$.

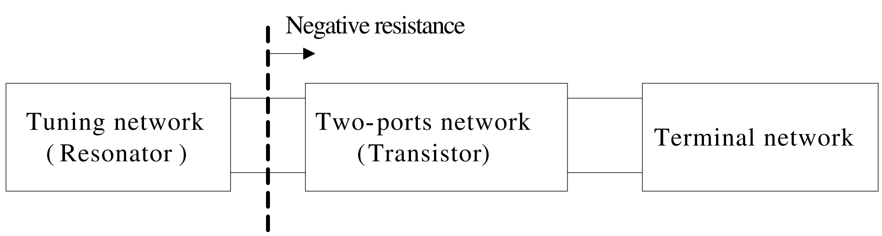

Figure 2: Two ports oscillator circuit.

3. DESIGN AND SIMULATION

The geometries of the designed resonators are shown in Figs. 3(a) and (b), which are 1-cell resonator and 4-cell resonator, respectively. The resonators are constituted by interdigital capacitors, stub inductors and a transmission line, and the transmission line is used to satisfy the phase relation. Parameter extraction was based on the resonators of Fig. 3 with $l_{tl} = 5$ mm, $w_{tl} = 1.1$ mm, $l_c = 0.8$ mm, $l_s = 3$ mm, $w_s = 0.5$ mm. The number of electrode pairs is 3, and the width of the electrode and the gap between the electrodes are 0.2 mm and 0.15 mm, respectively. The thickness and dielectric constant of the dielectric substrate are 0.51 mm and 3.66.

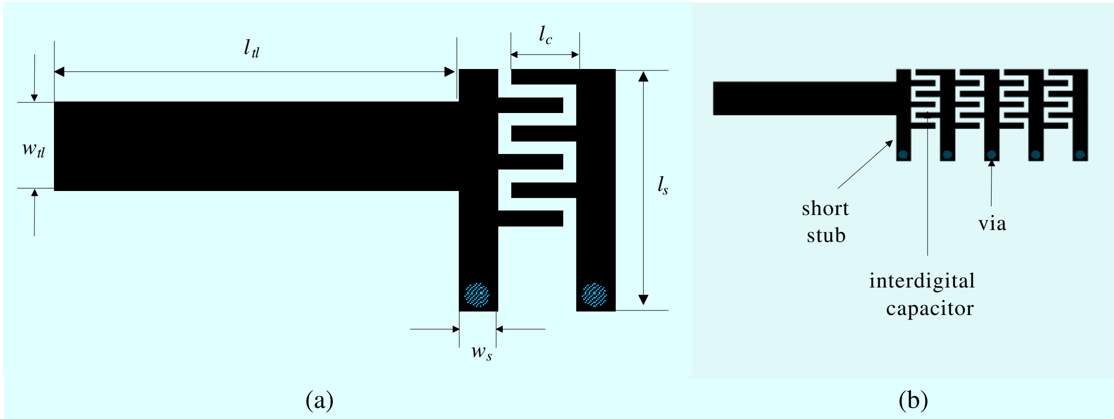

Figure 3: Geometry of zeroth-order resonator. (a) 1-cell resonator. (b) 4-cell resonator.

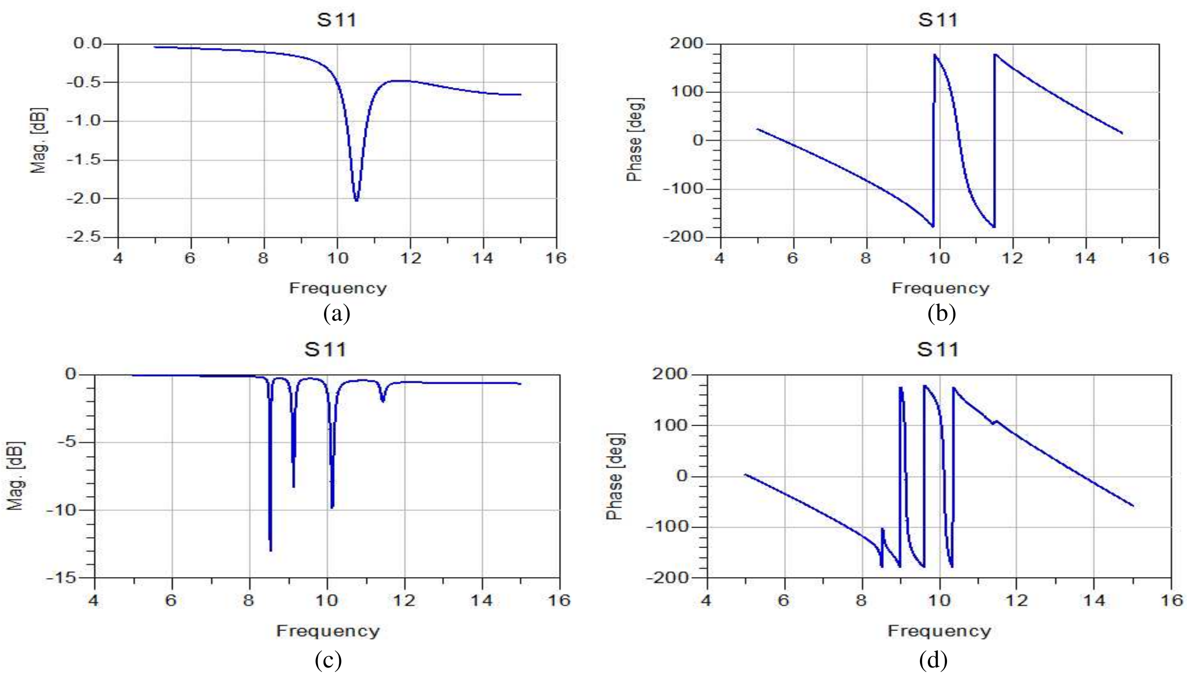

Figure 4: Simulation results of resonator. (a) S_{11} magnitude of 1-cell resonator. (b) S_{11} phase of 1-cell resonator. (c) S_{11} magnitude of 4-cell resonator. (d) S_{11} phase of 4-cell resonator.

In Fig. 4, the full-wave (MOM) simulated S_{11} for proposed resonators are shown. The selective frequency of 1-cell resonator is 10.5 GHz. In resonant frequency, the magnitude of S_{11} is about -2 dB and phase is 0.4 resonances of 4-cell are obtained. Only the second and the third resonances satisfy the phase relation. The simulation results also show that the frequency selectivity of 4-cell resonator is better than that of 1-cell resonator. It is noted that the physical length of zeroth-order resonator is smaller than traditional transmission line resonator.

Oscillator circuit, which is in a common gate configuration, using zeroth-order resonator is shown in Fig. 5. The inductor in series with gate is utilized to increase the instability of transistor. Zeroth-order resonator in series with drain determines the frequency of oscillator. An appropriate terminal network is design to match to a 50 Ω load Z_L.

Transient simulation results of oscillator are shown in Fig. 6. In the Fig. 6(a), oscillator frequency using 1-cell resonator is 10.7 GHz, which is a little higher than the resonant frequency of 1-cell resonator. This is also occurred in 4-cell resonator case. In order to observe oscillogram clearly the plots present only 0.5 ns from 50 to 50.5 ns, shown in Figs. 6(b) and (d). Figs. 6(c) and (f) give the phase noises of oscillator using 1-cell resonator and oscillator using 4-cell resonator, respectively.

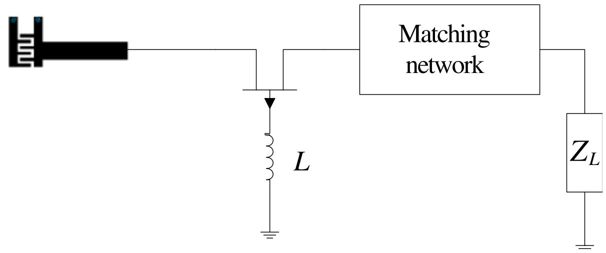

Figure 5: Oscillator circuit using zeroth-order resonator.

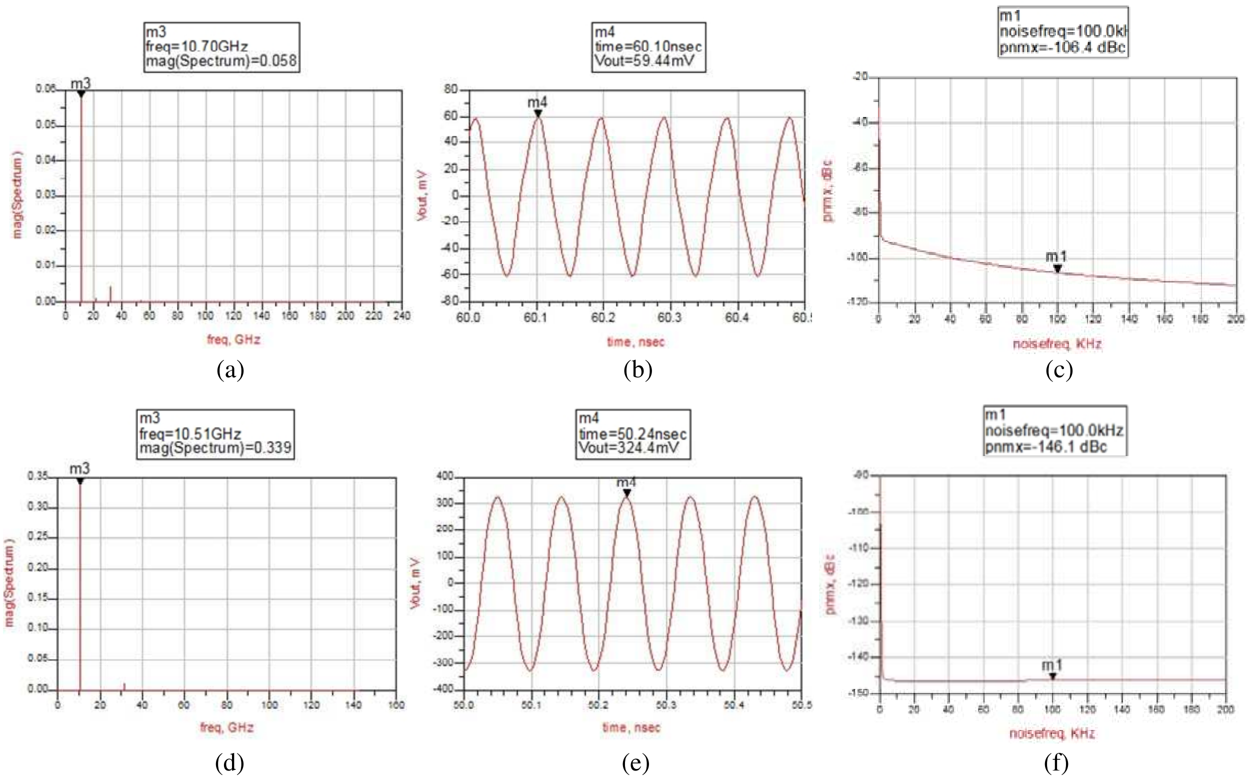

Figure 6: Simulation result of oscillator. (a) Frequency of oscillator using 1-cell resonator. (b) Oscillogram of oscillator using 1-cell resonator. (c) Phase noise of oscillator using 1-cell resonator. (d) Frequency of oscillator using 4-cell resonator. (e) Oscillogram of oscillator using 4-cell resonator. (f) Phase noise of oscillator using 4-cell resonator.

Comparing the results of the two oscillators, we can see the performance of oscillator using 4-cell resonator is better. This indicates that increasing the number of CRLH unit could improve the performances of resonator and oscillator. Above simulations demonstrate that zeroth-order resonator can be applied in RF oscillator.

4. CONCLUSION

Zeroth-order resonators constituted by interdigital capacitors, stub inductors and a transmission line are presented. Full-wave simulations of resonators, with 1-cell case and 4-cell case, are carried out. In addition, oscillators using zeroth-order resonators are designed, which certify the zeroth-order resonators can be applied in RF circuits. Because of the better frequency selectivity of 4-cell resonator, oscillator using 4-cell resonator has better performance at the magnitude of output signal and phase noise. The research we have carried out indicates that increasing the number of CRLH unit could improve the performances of resonator and oscillator.

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