A Spiral-Shaped Defected Ground Structure for Coplanar Waveguide

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***Abstract*—This letter presents a spiral-shaped defected ground structure for coplanar waveguides (DGSCPW), which can be used as a kind of periodic structure for planar transmission line. The proposed spiral-DGSCPW adopts spiral-shaped defects on both ground planes of CPW. Due to the spiral-shaped defects, the equivalent shunt inductance and slow-wave effects increase more rapidly than the standard CPW or CPW lines combined with the conventional PBG. The modeling and analysis to extract the equivalent circuit, increased slow-wave factor, and simulated and measured performances are presented.**

***Index Terms*—CPW, DGS, DGSCPW, spiral.**

I. Introduction

PERIODIC structures such as photonic bandgap (PBG) and defected ground structure (DGS) for planar transmission lines have drawn great interest due to their great potential applicability. The transmission lines combined with the periodic structures have a finite pass and rejection band like low pass filters (LPF), while the standard transmission lines show only the simple transmission characteristics over broadband.

The PBG in [1] and the DGS in [2] and [3] are typical periodic structures proposed previously for microstrip line. However, these are neither uniplanar nor truly one-dimensional (1-D) structures since their defected ground planes are on the backside of substrate.

On the other hand, periodic structures for CPW can be realized on the same plane, because CPW have a real uniplanar, 1-D structure. Yang *et al.* proposed a conductor-backed CPW (CBCPW) using a large number of PBG lattices [4], and Yun *et al.* presented a CPW with simple square-defected PBG cells [5]. More recently, Mao *et al.* proposed a PBG structure having narrow signal line and finite-width ground strip for CBCPW [6].

One of the most important advantages of PBG is the slow-wave effect, which is caused by the equivalent L-C components. The transmission lines with PBG have much higher impedance and increased slow-wave factor than standard lines.

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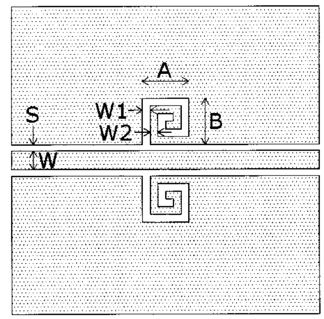


Fig. 1. Structure of the proposed uniplanar, 1-D spiral-DGSCPW. ($W = 1.2$ mm, $S = 0.42$ mm. The other dimensions are shown in Table I as "Case 1". The substrate is RT/Duroid 6010 with 25 mils of thickness and 10.2 of dielectric constant.).

Hence, the circuit size can be reduced using these properties [7]–[9].

A new periodic spiral-shaped defected ground structure for CPW (spiral-DGSCPW) is suggested in this study. The proposed spiral-DGSCPW has true one-dimensional structure. It has more degrees of freedom in terms of dimensions than the previous PBG for CPW (PBGCPW) in [5]. It is possible to obtain more flexible frequency responses by adjusting the dimensions and distances between spiral-DGS cells.

The required area for spiral-DGSCPW is much smaller than PBGCPW or the CPW line having a simple straight defected ground [10], [11] for the same frequency response due to the increased equivalent inductance and slow-wave effects. Additionally, the slope of cutoff characteristics is very steep even with only one or a few elements cascaded.

II. Structure of the Spiral-DGSCPW and Modeling

The spiral-DGSCPW is composed of a standard CPW line and spiral-shaped defected ground structure on both ground planes. It is known that the equivalent L-C components of defects give rise to form a band rejection characteristic, in other words, a cut-off frequency and rejection for a certain frequency band [2], [3]. Fig. 1 shows the unit cell of the proposed spiral-DGSCPW, which has five variable dimensions such as $A, B, W1, W2$, and distance between spirals in series. Additionally, the number of turns of defected-slot and number of spiral-DGS elements are factors for determining the characteristics. The shape of spiral is not limited only to rectangle, but circular or octagonal shape can be used. However, in this letter, only rectangular spiral is used for convenience.

Fig. 2 shows the predicted performances for Fig. 1. Table I summarizes the performances for various unit spiral-DGSCPW

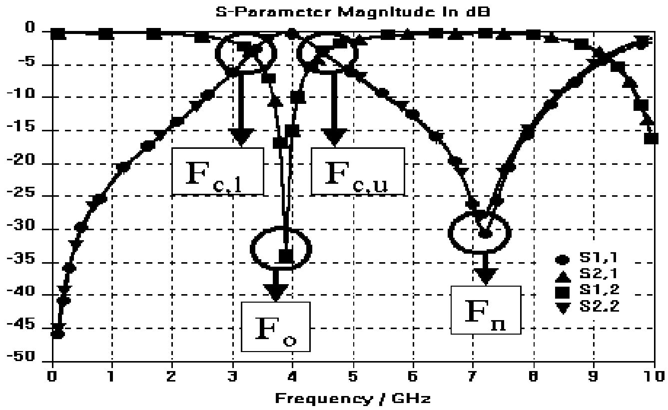


Fig. 2. Predicted characteristics of the unit element shown in Fig. 1 using EM simulation.

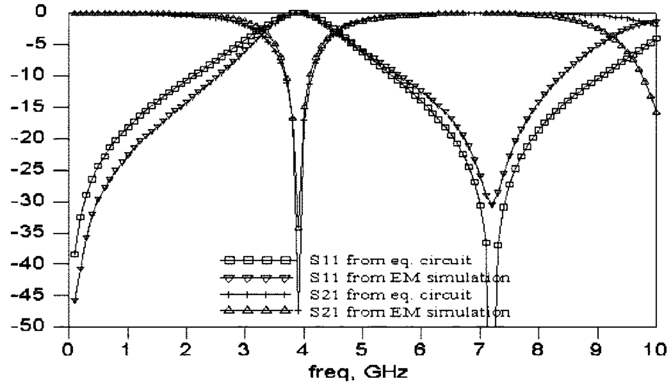


Fig. 4. Comparison of the predicted characteristics of the equivalent circuit to the EM simulation results (Case 1).

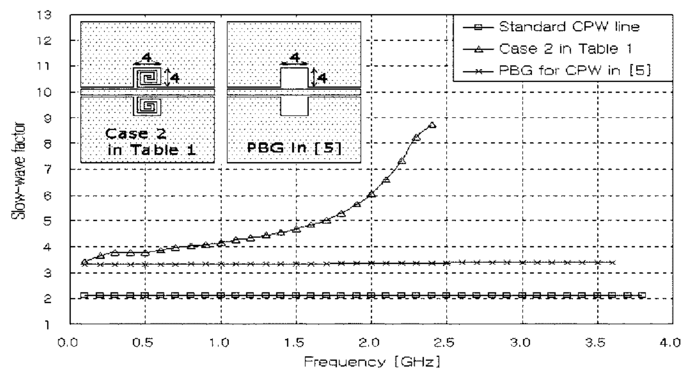
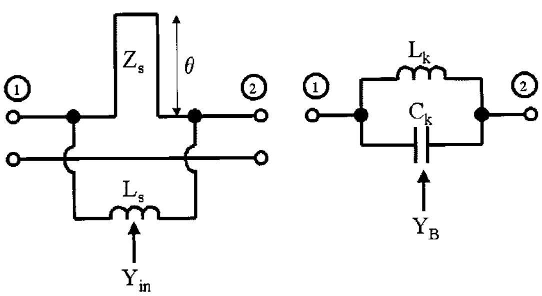


Fig. 5. Comparison of slow-wave factors.

TABLE I

DIMENSIONS FOR SIX CASES OF VARIOUS SPIRAL-DGSCPW. (N: NUMBER OF TURNS OF SLOTS, $F_{c,l}/F_{c,u}$: THE LOWER/UPPER 3 dB CUTOFF FREQUENCY, F_o: THE FIRST RESONANT FREQUENCY, and F_n: THE FIRST NOTCH FREQUENCY. UNITS ARE mm, GHz, nH, AND Ω)

Case	A=B	W1	W2	N	$F_{c,l}$	F_o	$F_{c,u}$	F_n	L_s	Z_s
1	3	0.5	0.5	1.5	3.343	3.903	4.521	7.202	10.24	33.27
2	4	0.5	0.5	2	2.126	2.399	2.759	4.2	10.59	36.31
3	5	0.5	0.5	2.5	1.473	1.7	1.877	2.8	7.75	28.97
4	6	0.5	0.5	3	1.11	1.3	1.397	2.1	6.66	21.36
5	4	0.3	0.7	2	2.002	2.2	2.473	4.1	15.47	24.69
6	4	0.7	0.3	2	2.234	2.6	2.991	4.3	7.85	43.76



(a) (b)

Fig. 3. (a) Proposed equivalent circuit; (b) Prototype of the one-pole Butterworth band rejection filter.

with different dimensions. All simulations were performed using MicroWave Studio V3.0. The larger the size of defect, the lower the cutoff frequency as can be expected easily.

It is needed to extract the equivalent circuit through the modeling in order to apply the proposed spiral-DGSCPW to other microwave circuits easily. Fig. 3(a) shows the equivalent circuit of the proposed spiral-DGSCPW. Due to the spiral-shaped defect on the ground planes, the equivalent circuit is composed of a short stub and inductor, where Z_s is the characteristics impedance of the stub and L_s is the inductance value. Fig. 2 looks like the characteristics of a one-pole band rejection filter (BRF). In practice, the CPW line having a simple straight defect was referred as a BRF in [11]. Therefore, Fig. 3(b), the prototype of a one-pole BRF, can be used for the modeling. The input admittance of Fig. 3(a) and (b) are expressed as follows:

$$Y_{\text{in}} = -j\left(Y_s \cot\theta + \frac{1}{\omega L_s}\right) \tag{1}$$

$$Y_B = j\omega_o C_k\left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right) \tag{2}$$

where ω_o = the first resonant frequency, $C_k = \omega_1'/(\omega_o g_k W), \omega_1'$ = the cutoff frequency in low-pass prototype, g_k = the prototype element value for a filter with Butterworth attenuation, and $W = (\omega_2 - \omega_1)/\omega_o$.

The equivalent circuit elements can be extracted using the following three conditions; 1) $Y_{\text{in}} = 0$ at F_o; 2) $Z_{\text{in}} = 0$ and $\theta = \pi$ at the first notch frequency (F_n); and 3) $Y_{\text{in}} = Y_B$ at the 3-dB cutoff frequencies ($F_{c,l}$ and $F_{c,u}$). The modeling results for six cases are summarized in Table I. Fig. 4 shows the good agreement between Fig. 2 and the results of circuit simulation on Agilent ADS.

III. SLOW-WAVE EFFECTS

Fig. 5 shows the comparison of the slow-wave factors of the proposed spiral-DGSCPW and the PBGCPW in [5] for the same defected area on the ground planes. It is observed that the proposed spiral-DGSCPW has greater slow-wave factor. It is expected that the circuit sizes can be quite reduced by applying the spiral-shape DGS.

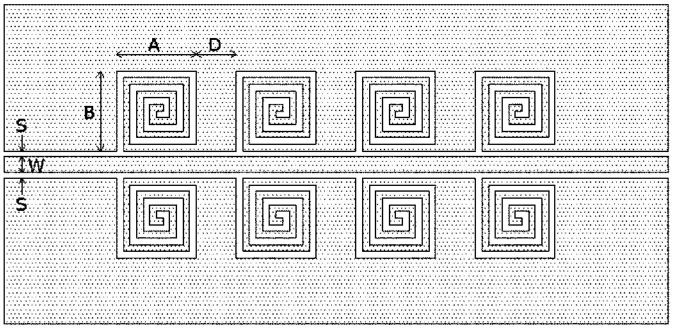
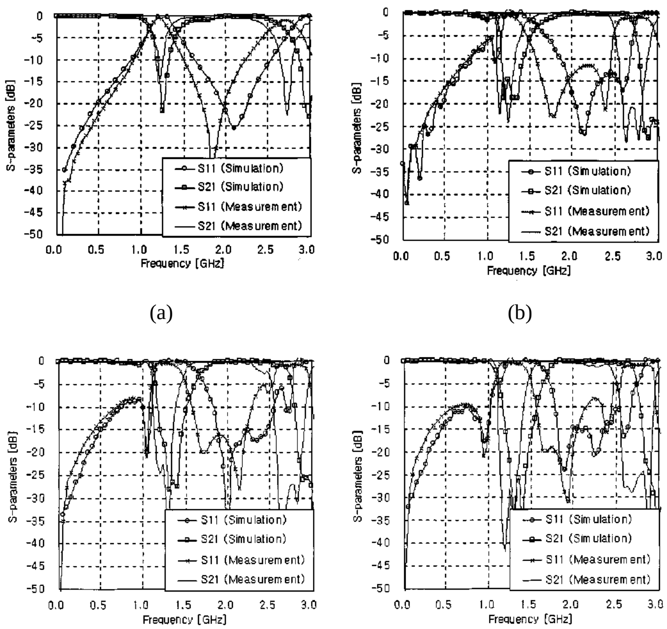


Fig. 6. Layout of a spiral-DGSCPW with 4 defect elements cascaded using the dimensions of "Case 4." ($D = 3$ mm).



(a) (b) (c) (d)

Fig. 7. Predicted and measured S-parameters of the spiral-DGSCPW using the dimensions of "Case 4" ($D = 3$ mm): (a) one defect element, (b) two defect elements, (c) three defect elements, and (d) four defect elements.

IV. Measured Performances of the Cascaded Spiral-DGSCPW

The unit element of the spiral-DGSCPW can also be cascaded periodically. Fig. 6 depicts the spiral-DGSCPW line formed by four unit elements. Although more flexible characteristics can be obtained by changing all the dimensions, we fixed the dimensions of "Case 4" and $D = 3$ mm. Only the number of the unit defected element is variable from one to four.

The predicted and measured performances are shown in Fig. 7. It is apparent that the rejection slopes of the cutoff characteristics are very steep, even when there are only one or two unit spiral-DGSCPW elements, while other PBGs must be cascaded at least five to seven elements to obtain such level of steep rejection [4]–[6]. The results shown in Fig. 7 suggest that there are great potential of the proposed spiral-DGSCPW for the applications in RF and microwave circuits.

V. Conclusion

One-dimensional spiral-DGSCPW has been proposed. A modeling technique was discussed using the prototype circuit of a one-pole band rejection filters. Additionally, the periodic cascading of the unit elements and the comparison of performances through the simulation and measurement were mentioned.

The proposed spiral-DGSCPW has greatly increased slow-wave factor than other PBG structures for CPW. It is expected that the potential applications will be extended widely to many RF and microwave circuits with MIC, MMIC, and RFIC technologies.

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