Multi-band Rejection DGS with Improved Slow-wave Effect

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***Abstract*— New techniques to suppress multiple frequency bands with a single defected ground structure(DGS) unit are developed. The proposed stacked spiral DGS, in which the spiral-shaped defects with different size are aligned in the transverse direction to the guiding direction of the coplanar waveguide(CPW), provides multiple resonance frequencies. Also, a composite spiral-rectangular DGS is proposed to provide two resonance frequencies with the same characteristic of the cascaded spiral- and dumbbell-shaped DGS units. The slow-wave effects for the proposed DGSs are greater than that of conventional spiral- or dumbbell-shaped DGS. The proposed DGSs are successfully designed and fabricated and the measured results are in a very good agreement with the simulated results.**

I. INTRODUCTION

With the proliferation of multi-band operation in wireless communication systems such as mobile communication and wireless LAN, multi-band receivers and transmitters for multi-standards are becoming important technologies. For composing compact and low-cost multi-band systems, multi-band active devices and passive devices are needed. These multi-band systems, however, have multiple harmonics caused by the nonlinear properties of the multi-band active devices. These undesired harmonics have to be removed to avoid a serious degradation of the system performance.

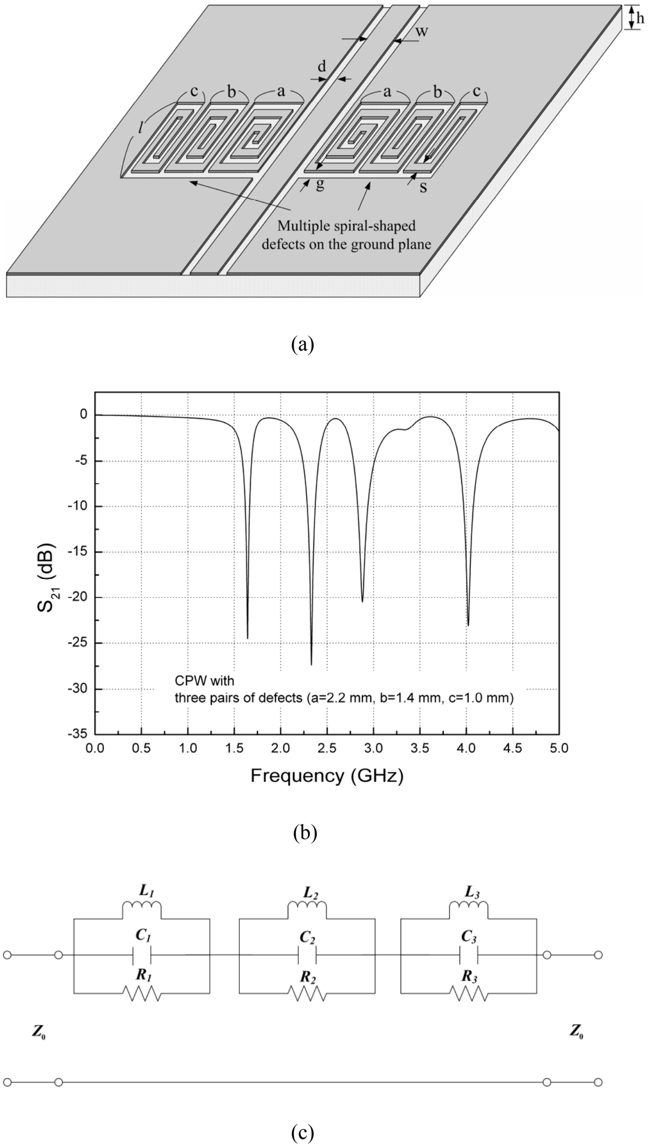
Recently, several researches on electronic band gap (EBG) and defected ground structure (DGS) have been reported with various configurations, and they have led to a wide range of applications in the microwave and millimeter wave circuits [1]-[5]. EBG and DGS can be integrated within the device active region, avoiding the need to cascade additional stages. This is an important aspect to avoid the increase of final layout area. Although effective, frequency selectivity in EBG structures is based on their periodicity and several stages are required to obtain significant rejection levels. The required dimension of EBG structures is too big and it is difficult to model the equivalent circuit. To the contrary, for the DGS which can be modeled by a simple equivalent circuit, although they are generally implemented in periodic configurations, the reason for periodicity is not physics but convenience [2].

The defect of the conventional DGS is with the dumbbell-shape or the spiral-shape and those have a single rejection band due to the equivalent inductive and capacitive components. To suppress multi frequency bands with conventional structures, DGSs with different defect sizes have to be cascaded. However, the cascaded DGS configuration requires a larger area along the direction of propagation or introduces significant radiation and conductor losses. The asymmetric spiral DGS (ADGS) has been reported by the authors, and the single asymmetric DGS effectively suppresses two frequency bands and the required area is small [5]. However, the asymmetric spiral DGS provides only two different resonance frequencies by its configuration limit.

This paper presents newly developed stacked spiral DGS and composite spiral-rectangular DGS to provide multi-band rejection properties. The stacked spiral DGS(SS-DGS) consists of multiple spiral-shaped defects on the ground plane in both sides of the coplanar wave guide and provide multiple resonance frequencies due to the different sizes of the spiral defects. The slow wave effect of the SS-DGS is greater than the conventional spiral or dumbbell DGS. In the composite spiral-rectangular DGS(CSR-DGS), the spiral- and the rectangular-shaped defects are stacked in the same unit. The characteristic of CSR-DGS contains the properties of both the spiral DGS (steep rejection, increased slow wave effect) and the dumbbell DGS (wide band rejection), with improved slow wave effect. Electromagnetic simulator was used to calculate the characteristics and the Rogers RO3010 substrate with a relative dielectric constant of 10.2 and thickness of 1.27 mm was used for all simulations and fabrications. The CPW and microstrip line considered in this paper corresponds to 50Ω characteristic impedance.

II. STACKED SPIRAL DGS

Fig.1 (a) shows the schematic of the stacked spiral DGS(SS-DGS) pattern etched on the ground plane in both sides of a coplanar wave guide. The proposed SS-DGS, in which the defects on the ground plane consist of three spirals aligned in the transverse direction to the coplanar wave guide, is symmetric and provides three resonance frequencies because each defect has different size. Because the sizes of defect-pair decrease to the outer direction, the resonance frequency due to the closest defect to the signal line is lower than the others, as can be expected easily. The simulated transfer characteristic of the proposed SS-DGS is presented in Fig. 1(b). For SS-DGS within three different sizes of defect-pairs, there are three different resonance frequencies, f=1.64, 2.33 and 2.88 GHz and the first spurious resonance frequency



(a)

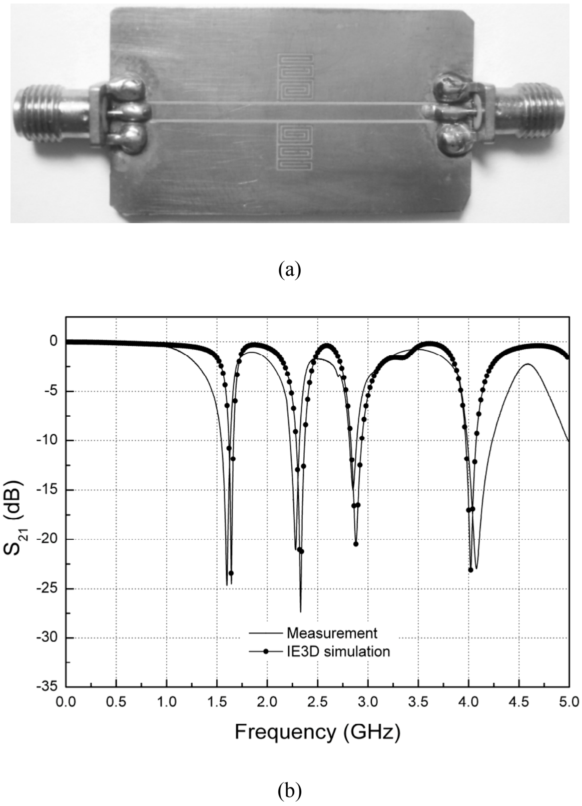
(b)

(c)

Fig. 1. (a) SS-DGS with three pairs of defects on the ground plane of the CPW. (b) Simulation result of the proposed SS-DGS (a=2.2 mm, b=1.4 mm, c=1.0 mm. l=3 mm, g=s=0.2 mm, d=0.4 mm, w=1.6 mm). (c) Equivalent circuit model.

due to the first defect-pair is at 4 GHz, as shown in Fig. 1(b). This result indicates that the SS-DGS can provide multiple resonance frequencies without additional area in the direction of wave propagation on a transmission line. Thus, the proposed design method can be used for suppression of multiple unwanted signals in the various microwave and millimeter circuits with small area.

The presence of three resonance frequencies can be presented by the equivalent circuit model shown in Fig. 1(c). It consists of three cascaded parallel RLC resonator circuits that block the signal as an open at the resonance frequencies. From the EM simulated data, the parameter extraction is straightforward as well [5].



(a)

(b)

Fig. 2. (a) Fabricated structure (a=2.2 mm, b=1.4 mm, c=1.0 mm. l=3 mm, g=s=0.2 mm, d=0.4 mm, w=1.6 mm). (b) Comparison of transfer characteristics versus frequency of simulation and measurement on the fabricated SS-DGS with three pairs of defects on the ground plane of the CPW.

In this case, the extracted parameters were found to have the following values: R_1 is 1.82 kΩ, L_1 is 1.04 nH, C_1 is 9.0 pF, R_2 is 2.4 kΩ, L_2 is 0.82 nH, C_2 is 5.63 pF, R_3 is 0.975 kΩ, L_3 is 0.515 nH, and C_3 is 5.933 pF.

Fig. 2(a) shows the photograph of the fabricated SS-DGS with three pairs of defects on the ground plane of the CPW, where the dimensions of the each defect-pair are different (a=2.2 mm, b=1.4 mm, c=1.0 mm). In Fig. 2(b), the transfer characteristics measured from the fabricated structure are compared with those simulated using EM simulator. The full agreement with the EM simulated and measured result is achieved.

The simulated transfer characteristics for various numbers of defect-pairs are shown in Fig. 3. As expected, the CPW structure within a pair of defects (a=2.2 mm, b=c=0 mm) has one resonance frequency of 1.69 GHz, and for the case within two pairs of defects (a=2.2 mm, b=1.4 mm, c=0 mm), it can be seen in Fig. 3 that there are two resonance frequencies of 1.65 GHz and 2.40 GHz.

By inserting the second defect-pair (b=1.4 mm), the resonance frequency due to the first defect-pair (a=2.2 mm) changes from 1.69 GHz to 1.64 GHz. The frequency shift is only a little, so this indicates the resonance frequencies can be

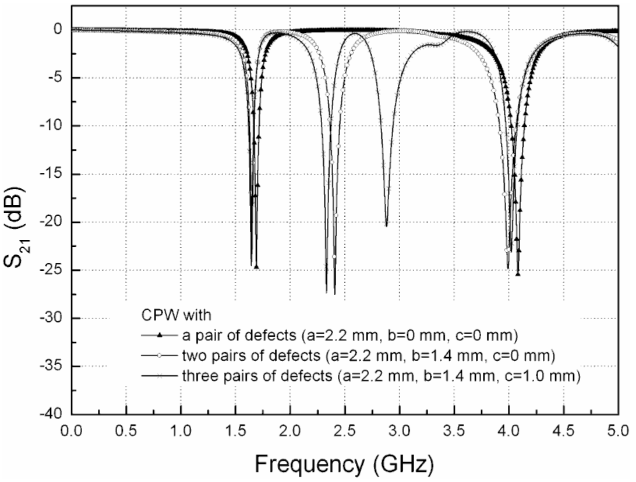


Fig. 3. Simulated transfer characteristics of the SS-DGS for various pair of defects (*l*=3 mm, g=s=0.2 mm, d=0.4 mm, w=1.6 mm).

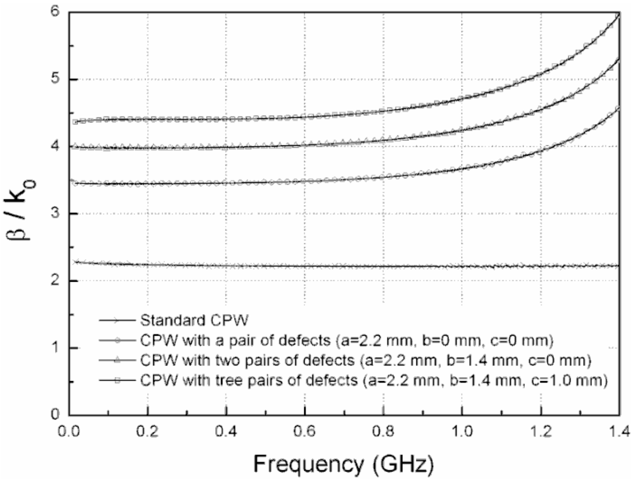
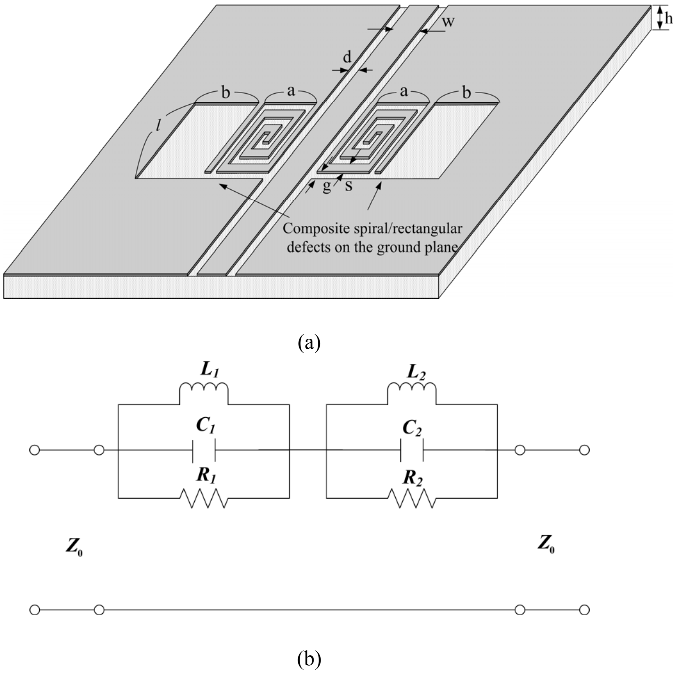


Fig. 4. Normalized phase constants of standard CPW and CPW with proposed stacked spiral defects on the ground plane for various number of defect-pairs (*l*=3 mm, g=s=0.2 mm, d=0.4 mm, w=1.6 mm).

controlled independently by adjusting the size of each defect-pair. In the same manner, one can observe that the CPW within three defect-pairs (a=2.2 mm, b=1.4 mm, c=1.0 mm) aligned has three different resonance frequencies, i.e., *f*=1.64, 2.33, 2.88 GHz, as shown in Fig. 3.

Fig. 4 shows the simulated normalized phase constants β/k_0 (or slow-wave factor), where k_0 is the free space wave number, of the proposed SS-DGS for various numbers of defect-pairs and, for comparison, the simulated one of the standard CPW is also included. As the number of defect-pairs increases, the slow-wave factor increases. It is believed that the larger β/k_0 of the proposed SS-DGS can be easier obtained by inserting additional defect-pairs in the transverse direction to the CPW. From the results in Figs. 3 and 4, if the additional defect-pairs are smaller than the first defect-pair (the closest defect-pair to the signal line) then the slow-wave factor increases without reduction first resonance frequency. This confirms that the SS-DGS can be utilized for miniaturization and undesired harmonics suppression for various microwave and millimeter wave circuits without degrading transfer characteristic around the operating frequency band.

III. COMPOSITE SPIRAL-RECTANGULAR DGS



(a)

(b)

Fig. 5. (a) Coplanar wave guide with composite spiral-rectangular defects on the ground plane. (b) Equivalent-circuit of the proposed CSR-DGS.

It is well known that the dumbbell-shaped DGS has wide band-gap property and the attenuation pole of the spiral-shaped DGS shifts much lower than that of the dumbbell-shaped DGS in the same occupied defect area. In this section, a composite spiral-rectangular DGS (CSR-DGS), which has two frequency characteristics of the dumbbell- and spiral-shaped DGS, is presented. In the CSR-DGS, the spiral- and the rectangular-shaped defects are stacked in same unit as shown in Fig. 5. The equivalent circuit of the CSR-DGS can simply be presented by two cascaded parallel resonance circuits, as shown in Fig. 5(b).

Fig. 6 shows the simulation results of the CSR-DGS and conventional spiral-shaped DGS. As shown in the figure, for the conventional spiral-shaped DGS (a=2.2 mm, *l*=6 mm), there is one resonance frequency, i.e., *f*=1.13 GHz. It can also be seen that the Q-factor is 7.3 where 3dB band width is 0.154 GHz. By incorporating the rectangular-shaped defect-pair (b=1.4 mm, *l*=6 mm), an additional band-gap property presents around 2.346 GHz with Q-factor of 2.6 while the first stop-band due to the spiral-shaped defect-pair is not changed as shown in Fig. 6. In this case, the extracted circuit parameters are R_1=1.95 kΩ, L_1= 1.99 nH, C_1= 9.97 pF, R_2=1.74 kΩ, L_2=2.93 nH, and C_2=1.57 pF for Fig. 5(b). The calculated normalized phase constants β/k_0 of the proposed CSR-DGS, conventional spiral-shaped DGS and standard

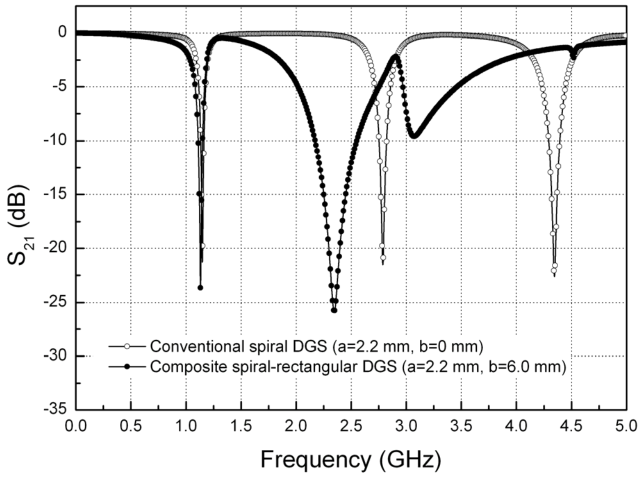


Fig. 6. Comparison simulation results between the transfer characteristics of the CSR-DGS and conventional spiral-shaped DGS (*l*=6 mm, g=s=0.2 mm, d=0.4 mm, w=1.6 mm).

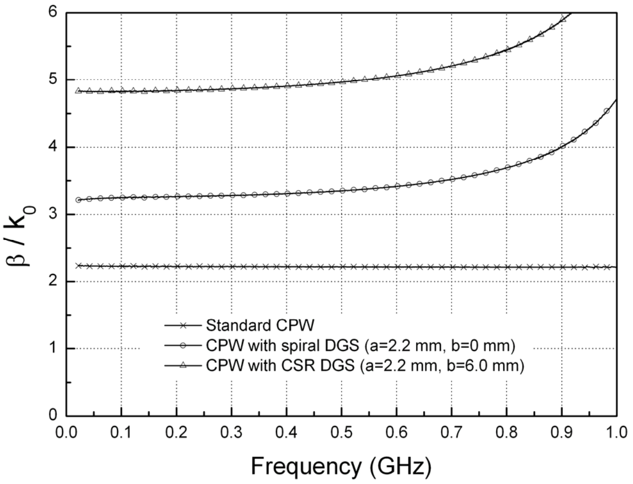


Fig. 7. Normalized phase constants of CPW with proposed CSR-DGS, conventional spiral-shaped DGS and standard line (*l*=6 mm, g=s=0.2 mm, d=0.4 mm, w=1.6 mm).

CPW are shown in Fig. 7. Note that the β/k_0 of the CSR-DGS is about 1.5 times larger than that of the conventional spiral-shaped DGS over the frequency range below 1 GHz. This result indicates that the CSR-DGS has improved slow wave effect and dual band-gap properties of spiral- and dumbbell-shaped DGS without additional area in the direction of wave propagation on the transmission line.

IV. CONCLUSIONS

Two types of DGS well suited for suppression of multiple frequency bands and miniaturization of microwave circuits have been proposed. The SS-DGS, in which the defects on the ground plane consist of multiple spirals aligned in the transverse direction to the CPW, has multi-band rejection property at resonance frequencies and provides an efficient attenuation within the band-gap regions. Also, the CSR-DGS provides two transfer characteristics of dumbbell-shaped DGS and spiral-shaped DGS, simultaneously. The slow wave factors of the both structures are larger than those of convention DGSs.

REFERENCES

[1] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "Novel 2-D photonic bandgap structure for microstrip Lines," *IEEE Microwave and Guided Wave Lett.*, vol. 8, no. 2, February 1998, pp. 69-71.

[2] C. S. Kim, J. S. Park, D. Ahn, and J. B. Lim, "A novel 1-D periodic defected ground structure for planar circuits," *IEEE Microwave Guide Wave Lett.,* vol. 10, no. 4, pp. 131-133, Apr. 2000.

[3] J. S. Lim, S. W. Lee, C. S. Kim, J. S. Park, D. Ahn, and S. Nam, "A 4:1 unequal Wilkinson power divider," *IEEE Microwave Wireless Comp. Lett.*, vol. 11, no. 3, pp. 124-126, Mar. 2001.

[4] D. Ahn, J. S. Park, C. S. Kim, J. N. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Trans. Microwave Theory Tech.*, vol. 49, no.1, pp. 86-93, January 2001.

[5] D. J. Woo and T. K. Lee, "Suppression of harmonics in Wilkinson power divider using dual-band rejection by asymmetric DGS, "*IEEE Trans. Microwave Theory Tech*., vol. 53, no. 6, part Ⅱ, pp. 2139-2144, June 2005.