A Compact Reconfigurable Bandstop Resonator Using Defected Ground Structure on Coplanar Waveguide

Jun Wang, Huansheng Ning, *Member, IEEE*, and Lingfeng Mao

***Abstract*—A compact modified dumbbell-shaped defected ground structure (CM-DGS) resonator on coplanar waveguide (CPW) is proposed in this letter. By adding a smaller square resonator to the conventional modified dumbbell-shaped DGS (M-DGS), the path difference for the electromagnetic wave propagation will be increased with a maximum 55.6% of the M-DGS size reduction. The scheme for the reconfigurable bandstop resonator is presented after considering the influence of the inserted short circuits on the resonant frequency. Finally, the reconfigurable bandstop resonator with mounted varactor diodes and dc biasing circuits has been fabricated and measured. Both simulated and measured transmission coefficients indicate a 24.4% tuning range centered at 1.92 GHz. The resonant frequency can be reduced further by increasing the dimensions of the smaller square, and varactor diodes with higher tunability may widen the tuning range.**

***Index Terms*—Coplanar waveguide (CPW), defected ground structure (DGS), tunable bandstop resonator.**

I. Introduction

RECONFIGURABLE or tunable bandstop resonators, with compact size, tunability, and high performance, play an important role in the development of wireless communication systems. Recently, a wide attention has been concentrated on an argument that the location of the stopband can be controlled by a reconfigurable defected ground structure (DGS) resonator and loaded varactor diodes or p-i-n diodes [1]–[5]. The argument enables a new solution to the implementation of miniaturized tunable bandstop resonators. This is due to the unique properties of DGS like slow-wave effect and prominent stopband [6], [7].

A modified dumbbell-shaped DGS (M-DGS) resonator based on coplanar waveguide (CPW) is proposed in [3], and varactor diodes are mounted between the added patch and ground to realize the tunability. Compared to [1] and [2], the main advantage of this configuration is that it only requires a single metal level, facilitating the shunt connection to ground. An additional square resonator in serials connection to the M-DGS in [4] can completely control the resonant frequencies by using a number of p-i-n diodes. These resonant frequencies are explained from the electromagnetic (EM) wave propagation principle. A novel reconfigurable DGS resonator presented in [5] can be regarded as a development of the structure in [4] to achieve the layout compactness. However, it should be noted that the dc biasing and tuning range of the above two resonators need to be further investigated.

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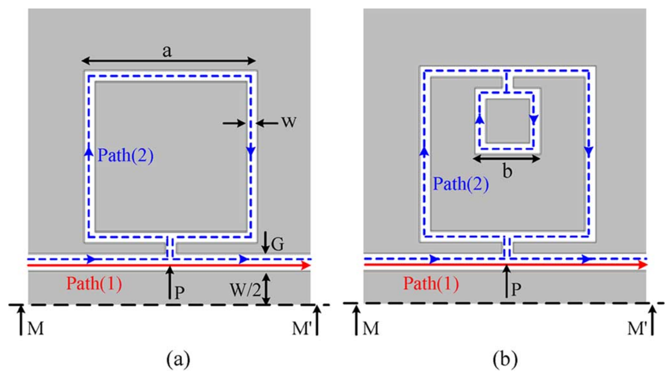

Fig. 1. Schematic diagram of (a) M-DGS resonator and (b) proposed compact M-DGS resonator (half symmetrical view).

First, a compact M-DGS (CM-DGS) resonator with an internal smaller square resonator is proposed in this letter. The difference between the structure presented in [5] and our proposed structure is that the smaller square resonator is connected to the slot of the bigger square resonator instead of the slot of CPW. Thus, the path for EM wave propagation is increased. This means that the proposed structure in our work can be compacted. Second, after analyzing the influence of the inserted short circuits on the resonant frequency, the scheme for the reconfigurable bandstop resonator is presented. Varactor diodes are mounted on the CM-DGS resonator, and the biasing circuits are implemented to achieve tunability. Eventually, the reconfigurable bandstop resonator is fabricated and measured.

II. Design of the CM-DGS Resonator

For the M-DGS resonator shown in Fig. 1(a), a square strip with width w and side length a is etched in the ground planes of CPW. It is connected to the slot of CPW by means of a transverse gap. Compared to the M-DGS, the proposed CM-DGS resonator shown in Fig. 1(b) includes an additional smaller

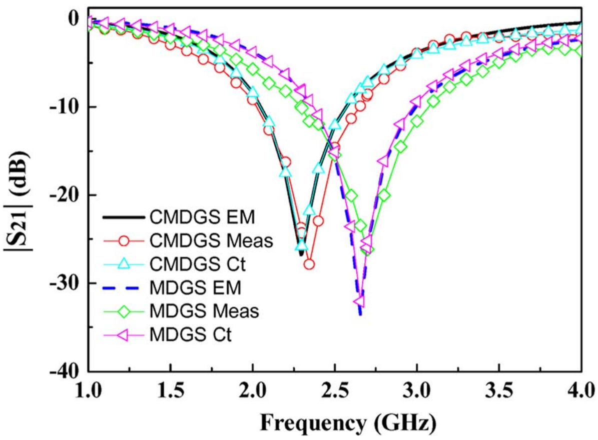

Fig. 2. Electromagnetic (EM) and circuit (Ct) simulated and measured transmission coefficients for the M-DGS and CM-DGS resonator.

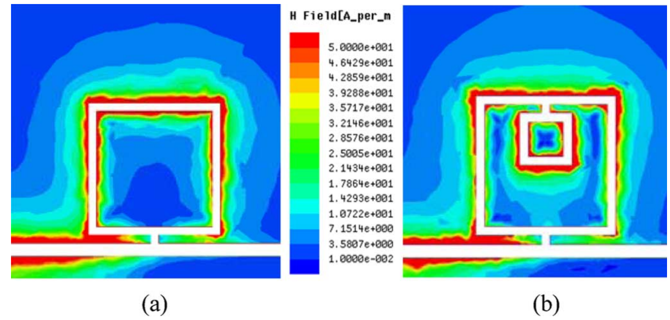

Fig. 3. Magnetic field distribution of (a) the M-DGS resonator at 2.7 GHz and (b) the CM-DGS resonator at 2.3 GHz.

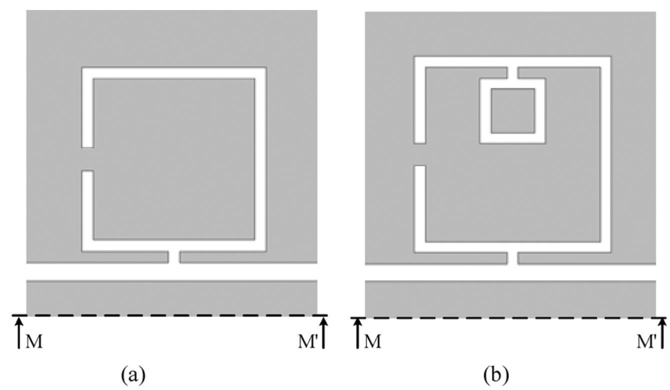

Fig. 4. Layout of the short circuits configuration for (a) M-DGS resonator and (b) CM-DGS resonator (half symmetrical view).

square resonator with side length b, which is located inside and connected to the bigger square resonator by another transverse gap. Different from the compact structure presented in [5], this configuration increases the path of EM wave propagation to achieve a lower resonant frequency.

Both resonators shown in Fig. 1 are simulated by Ansoft's High Frequency Structure Simulator (HFSS). The substrate with dielectric constant of 12.0 and height of 0.8 mm is used in the simulations. The CPW parameters $G/W/G$ are 0.8/3/0.8 mm to obtain a characteristic impendence of 50 Ω. Other parameters are as follows: w is 0.5 mm, the length of the two transverse gaps is chosen to be equal to w, a is 8 mm, and b is 3 mm. The M-DGS resonator and the proposed CM-DGS resonator with above dimensions are fabricated and measured. Fig. 2 shows that the measured transmission coefficients agree well with those obtained from the circuit and EM simulations. The CM-DGS resonator has a resonant frequency at 2.3 GHz, lower than 2.7 GHz for the M-DGS resonator.

Compared to the M-DGS resonator, lower resonant frequency for the proposed resonator can be explained from the perspective of EM wave propagation to provide design rule. The path difference of the CM-DGS resonator between path(1) and path(2) (denoted by the continuous line and dotted line, respectively) as shown in Fig. 1 is increased more than that for M-DGS resonator. Thus, the resonant frequency should be reduced to produce a 180° phase difference at point "P." As shown in Fig. 3, we could find that there is much magnetic field distribution along the smaller resonator of the CM-DGS, which means the path difference between path(1) and path(2) is increased compared to the M-DGS, demonstrating the validity of above analysis. When side length a and b for the CM-DGS resonator is set to be 8 and 6 mm, respectively, the resonant frequency will be reduced to 1.81 GHz. For the M-DGS resonator, the side length a needs to be chosen as 12 mm to achieve the same resonant frequency. Therefore, the occupying single-side rectangular area of the CM-DGS resonator is 64 mm^2, only 44.4% of the M-DGS resonator.

An approximate design rule for the resonant frequency of the CM-DGS resonator is $4a + 4b - 2w = \lambda_{g0}/2$, where λ_{g0} is the slotline wavelength and can be acquired through the slotline closed-form expressions in [8]. Although this equation gives a useful and initial guidance for the resonator design, more efforts should be devoted to the consideration of the slotline discontinuities. Therefore, a further accurate design should be conducted with the help of full-wave EM simulation.

III. Compact Reconfigurable Bandstop Resonator

For the purpose of tunability, the influence of added short circuits on the resonant frequency of the CM-DGS resonator should be studied first to determine the location of the inserted variable devices. Actually, this can be approximately predicted from the view of a $\lambda_{g0}/4$ resonator described in [4]. Fig. 4(b) shows the short circuits configuration for the CM-DGS resonator, while Fig. 4(a) is its counterpart for M-DGS resonator. The short circuits are inserted in the middle of the square resonator, and the length is chosen to be 1 mm.

It can be clearly seen in Fig. 5 that the CM-DGS resonator with short circuits has the lowest resonant frequency at 1.58 GHz. This means that the compactness of the CM-DGS resonator is further demonstrated because the resonant frequency of M-DGS resonator with short circuits is 1.81 GHz. Meanwhile, the change of the resonant frequency can be also clearly observed between CM-DGS resonator with short circuits and CM-DGS resonator without that. Henceforth, varactor diodes can be inserted to this position to realize tunability.

The schematic layout of the reconfigurable bandstop resonator is shown in Fig. 6(a). To keep the advantage of CPW, the dc biases are provided through a wire that connects the

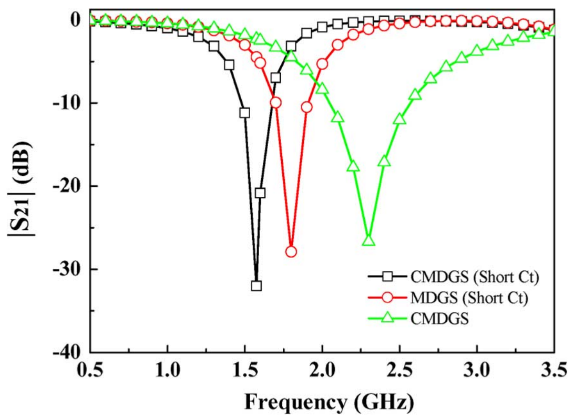

Fig. 5. Simulated transmission coefficients for the CM-DGS resonator with short circuits, M-DGS resonator with short circuits, and CM-DGS resonator.

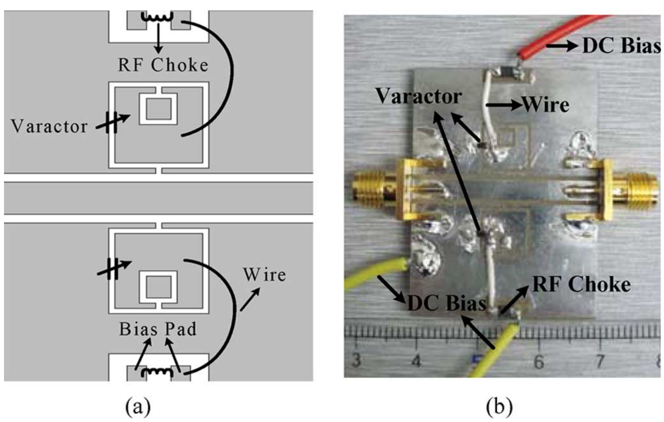

Fig. 6. (a) Schematic layout of the tunable bandstop resonator. (b) Fabricated tunable bandstop resonator.

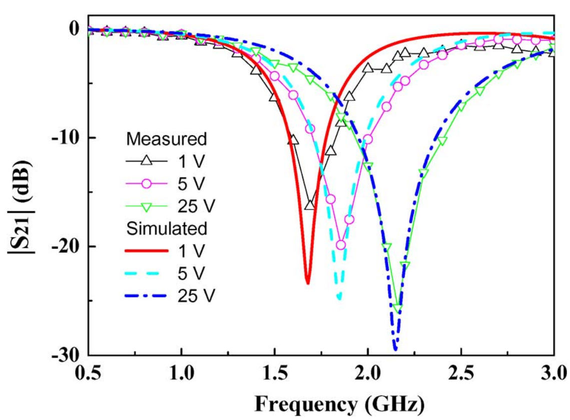

Fig. 7. Simulated and measured transmission coefficients for the tunable bandstop resonator.

inside patch to the bias pad. RF chokes are needed between the dc biases and varactor diodes to block the RF signal from leaking into the dc paths. Fig. 6(b) shows the fabricated tunable bandstop resonator. The Infineon BB857 varactor diodes are used and mounted across the gap in the final resonator, which provides a tuning range of capacitance from 6.7 to 0.5 pF with applied biasing voltage varying from 1 to 28 V [9].

Fig. 7 shows the simulated and measured transmission coefficients of the tunable resonator for different applied dc bias. The measurements agree well with the simulations. It should be noted that when the varactor diode BB857 is operated at lower voltage region, its series resistance will increase significantly, leading to larger insertion loss. Thus, the slight discrepancy between the simulated and measured transmission coefficient when the applied voltage is 1 V may be understood. By using the varactor diodes with smaller resistance at higher capacitance region, better performance of the tunable bandstop resonator can be obtained.

When the varactor diodes are applied with 1, 5, and 25 V dc bias, the resonant frequency occurs at 1.69, 1.85, and 2.16 GHz, respectively. A tuning range of 24.4% centered at 1.92 GHz is obtained. Lower center frequency can be achieved through the increased side length of smaller square resonator for the CM-DGS resonator, and wider tuning range may be obtained via higher variation range of capacitance for the varactor diodes.

IV. Conclusion

In this letter, a compact design of the M-DGS resonator is proposed, and its approximate design rule is given. By adding a smaller square resonator in the M-DGS, the size can be reduced to 44.4% of the M-DGS for the same resonant frequency. The scheme of tunable bandstop resonator is presented, and the resonator is fabricated and measured. Both the simulations and measurements show a 24.4% tuning range centered at 1.92 GHz with commercially available varactor diodes. The proposed compact reconfigurable bandstop resonator will be easily integrated with tunable amplifiers or antennas for enhanced performance in the wireless communication systems.

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