2D Periodic Defected Ground Structure for Coplanar Waveguide

Ehab K. I. Hamad¹, Amr M. E. Safwat², and Abbas S. Omar¹

¹ Chair of Microwave and Comm. Eng., Otto-von-Guericke-University Magdeburg, Magdeburg 39016, Germany
² Electronics and Comm. Eng. Dept., Faculty of Eng., Ain Shams University, Cairo 11517, Egypt

ehamad@iesk.et.uni-magdeburg.de, asafwat@ieee.org, and a.omar@ieee.org

Abstract — A two-dimensional (2D) periodic defected ground structure for coplanar waveguide (PDGSCPW) is proposed. It is based on the repetition of a unit-cell in a simplified and systematic way. The equivalent circuit model of the defected ground is a simple parallel resonance circuit, which is connected to the main line. The 3D EM simulation and the equivalent circuit model suggest that the capacitance is almost constant while the inductance varies linearly relative to the number of cells, which implies the simplicity of the design process. The center frequency varies from 7 GHz down to 4 GHz with more than 20 dB rejection in the stopband when the number of cells increase from 2 to 9-cells. Measurements are in excellent agreement with theoretical predictions.

Index Terms — Defected ground structure (DGS), Coplanar waveguide, 2D Periodic defected ground structure.

I. INTRODUCTION

Defected ground structures (DGS) have shown increasing potential for implementation in different applications: MIC, MMIC, and RFIC [1-5]. They provide sharp, distinct electromagnetic band-gap and high slow wave factor, which lead to smaller size circuits. They have been used numerously in the recent years, however most of the applications are in microstrip structures [6-8]. In these structures, well-defined shapes are etched at the back metal. This requires a precise double-sided processing and adequate packaging to keep an air-gap between the ground and the package. Coplanar waveguides (CPW) on the other hand have both signal and ground on the same surface. Though they occupy larger area than microstrip lines, they can be considered as a good compromise for DGS. Moreover, CPWs are used for circuit design since they can be easily integrated into existing RF ICs without the need for incorporating via-holes. They are less sensitive to the substrate thickness and substrate dielectric constant than the microstrip structures [9].

To our knowledge, few applications for DGS on CPW have been reported, among them are: The dumbbell shaped DGS is presented in [1], a vertically periodic DGS is proposed in [3] for microstrip and CPW line in which the periodicity takes place in the vertical direction only, a one-dimensional DGS structure where the periodicity is in the horizontal direction is presented in [4], and a spiral shaped DGS is proposed in [10].

In this contribution, a 2D periodic dumbbell structure is proposed, the dumbbell structure is added as a unit-cell in a systematic way in both horizontal and vertical directions to construct the 2D periodic DGS. This technique best utilizes the area to get very low stop band frequencies. Design methodology, electromagnetic simulation and equivalent circuit model are presented in the next section. These are followed by the experimental verification in section III.

II. STRUCTURE DESIGN METHODOLOGY

The periodic DSGSCPW structure is based on the standard dumbbell structure, shown in Fig. 1.a. The cells are added such that the symmetry along the axes (A-A) of the dumbbell is kept unchanged. Thus, for the two-cells structure, the cell is added above cell one. For three-cells, two-cells are placed to the left and to the right of the original cell. The same process is applied for larger number of cells. The schematic diagram of 7-cells is shown in Fig. 1.b. The schematic diagrams of 2, 3, 4, 5-cells are shown in
The unit dumbbell structure was designed for coplanar waveguide line with 50-\(\Omega\) characteristic impedance for good RF impedance matching. \(G/W/G\) is 0.2/2.8/0.2 mm, where \(W\) is the width of the center conductor and \(G\) is the slot width as shown in Fig. 1. The dielectric constant of the substrate is 3.38, its height is 0.813 mm, and the metal thickness is 35 \(\mu m\). The first step in the design is to optimize the parameters of the unit-cell to get a stop band response centered at a certain frequency, e.g., 12 GHz, with the constraint that the unit-cell has dimensions of \(a\times a\) and it has been etched in both ground planes symmetrically a distance \(a/2\) far from the slot of the CPW line. This was achieved using the 3D EM simulator, Microwave Studio v. 5. The optimized dimensions for the unit-cell are: \(a\times a = 2\times 2\) mm, and gap width \(t=0.2\) mm.

Two, three, and up to nine-cells are arranged as explained in the previous section. Their performances are investigated using Microwave Studio. The S-parameters of the 8 structures are shown in Fig. 3. \(S_{12}\) depicts a minimum at a frequency determined by the structure geometry. Its value decreases as the number of cells increase. For \(n=2\) (\(n\) is the number of cells) this frequency is 7 GHz, while for \(n=9\), the frequency is 4 GHz. In all structures, the magnitude of \(S_{12}\) at the resonance frequency is more than 20 dB.

**B. Circuit Modeling**

The performance of the periodic defected ground structures is modeled using circuit lumped elements. Fig. 4 illustrates the equivalent circuit model. It consists of a shunt capacitance, inductance, and resistance to model the defected region [11] and two sections of transmission lines connected in series at both sides. The length of the transmission line is equal to the distance from the center of the basic unit-cell to the reference plane, \(L/2=14\) mm, the characteristic impedance is 50.6-\(\Omega\) and the effective dielectric constant is 1.885 as determined by the EM simulator. This equivalent circuit model is the same for any number of repeated cells. Fig. 5 shows the variation of the equivalent capacitance, the equivalent inductance and the equivalent resistance as a function of the number of cells. The equivalent capacitance is approximately constant independent of the number of cells, the equivalent inductance increases linearly as the number of cells
increases and there are minor changes in the resistance. These results can be interpreted to the structure geometry as follows: As the number of cells increases, the path of the current increases, which increases the value of the inductance linearly since all cells have constant perimeter. The capacitance is mainly determined by the capacitance of the gap of the first cell, which is kept constant in all iterations. The resistance corresponds to the radiation, conductor, and dielectric losses in the defect.

III. EXPERIMENTAL VERIFICATIONS

Two, three and four-cells periodic DGS for CPW line are fabricated on Ro4003c substrate with all design parameters similar to that described in the simulation. The picture of the fabricated structures is shown in Fig. 6. The structures are measured using 8722D vector network analyzer from 1-10 GHz. Fig. 7. shows the measured S-parameters for the three structures. Results of the EM simulator and circuit simulator are also shown on the same graph. Excellent agreement has been achieved.

Fig. 4. Equivalent circuit model of the PDGSCPW structure, L, C, and R correspond to the defected region.

![Equivalent circuit model of the PDGSCPW structure](image)

Fig. 5. Equivalent capacitance, inductance, and resistance versus the number of cells for the PDGSCPW

![Capacitance, Inductance, and Resistance](image)

Fig. 6. Picture of the fabricated PDGSCPW 2, 3 and 4 cells

![Fabricated PDGSCPW 2, 3 and 4 cells](image)

Fig. 7. Measurement, EM simulation, and circuit simulation for the PDGSCPW (a) 2-Cells, (b) 3-Cells, and (c) 4-Cells

![S-Parameters for PDGSCPW](image)
IV. CASCADED PDGSCPW

The PDGS is cascaded to get a wide stop band with very sharp edges filter. The number of cells in the cascaded PDGS sections controls the center frequency of the stop band. The number of the cascaded sections and the separation between them control the sharpness and the width of the band. Two, and four sections separated by 3 mm using four-cells PDGSCPW are fabricated and measured with 2.5, 3.8 GHz bandwidth and more than 27, 33 dB rejection respectively. Pictures for the fabricated structures are shown in Fig. 8.a. The measured and simulated RF performances are shown in Fig. 8-b and c. Good agreement has been achieved.

V. CONCLUSION

A 2D periodic defected ground structure for coplanar waveguide has been proposed. The proposed structure is based on the standard dumbbell structure, which is repeated periodically to control the central frequency. The proposed structure has the advantage of having an almost constant capacitance while the inductance varies linearly as the number of cell increases, which simplifies the design process. Two and four sections of PDGS are cascaded to form wide-bandstop filters with high rejection. Excellent agreement has been achieved between the EM simulation, the circuit simulation and the experimental results.

REFERENCES