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Cross Dumbbell Periodic Defected Ground Structure Characteristics

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Abstract

The defected ground structure (DGS) is one such technique which were intentionally modified to enhance the performance of the ground plane metal of a microstrip circuit. Importantly, in microwave application, the DGS plays an important role in analyzing the effect of surface and leaky waves. Tthe time of Practical verification, the surface and leaky waves are affected by the propagation errors so the performance of microstrip circuit is also affected. So, proper mathematical model is needed for justifying the propagation uncertainty of DGS and to improve the performance. In this paper, the curve fitting mathematical model is used for analyzing the propagation uncertainty. In the used model, the bi-segmentation process is applied to the experimental characteristics. The proposed curve fitting model is implemented and the Cross Dumbbell Periodic defected ground structure propagation uncertainties are analyzed.

Keywords

DGS, Propagation Characteristics, Experimental Model, Mathematical Model, Curve Fitting, Uncertainty

1. Introduction

Currently, the defected ground structure (DGS) is gaining much attention in the fields of microwave and millimeter wave applications [1]. It is extensively used in microwave circuit design such as power divider, power amplifier and specifically in filter design [2] High performance, compact size and low expense often meets the stringent requirements of modern microwave communication systems [3]. Ultra-wideband (UWB) technology has turned into one of the most competent solutions for future short-range high-speed indoor data communication applications [6]. Nowadays, there is an increasing interest in developing UWB radio for short-range high-speed wireless communication networks [8]. DGS is realized by engraving off a simple shape defect from the ground plane. The shielded current distribution in the ground plane is disturbed based on the shape and dimensions of the defect, resulting in a controlled excitation and propagation of the electromagnetic waves via the substrate layer [4]. The effect of DGSs is to place parallel inductance and capacitance in the lumped model, which includes a pole to the transfer function and results in a resonant frequency [5]. DGS has the characteristics of stop-band, slow-wave effect, and high impedance that have been created to reduce the harmonics as well as to realize the compact physical dimensions of RF circuits [7]. The DGS reduce the mutual coupling between the microwave antenna array elements. The effect of mutual coupling increases the propagation uncertainty of microwave antenna. So, the accuracy of the propagation of microwave is affected and more chance for occurring confliction in the DGS size. To overcome this problem, a curve fitting mathematical model for analyzing the experimental model uncertainty is proposed in this paper. The function of the proposed curve fitting mathematical model is to determine the size of the DGS. The detailed problem formulation and the proposed curve fitting model are described in Section 3. Before that, the recent related researches are analyzed in Section 2. In Section 4, the results and discussion of the proposed model is described. In Section 5, conclusion of the paper is given.

2. Related Research work

Several research works already exist in the literatures that are based on the characteristics of DGS are reviewed in this section. X. Q. Chen *et al*. [9] have proposed a dual band transmitter that functions either as power amplifier of DGS. It works as a power amplifier at 2.4 GHz which satisfies the 802.11b/g wireless LAN standard or functions as an active frequency double at 6.8 GHz which relies on the input frequency. The equivalent circuit and the stop band characteristic of the proposed microstrip DGS have been evaluated and simulated. Also, it has been found that for the proposed transmitter, the second harmonic suppression was below −52.6 dBc in the amplifier mode, and the fundamental suppression was below −41 dBc in the frequency doubler mode with the stop band characteristic of

DGS. The proposed transmitter has utilized a GaAs InGaP Heterojunction broadband MMIC. It has achieved 13.7dBm of P1dB and its gain was 16.5 dB in amplifier mode, and its maximum output power was 7.8dBm at 6.8 GHz in frequency double mode.A DGS, which has better slow-wave effect than the cross or dumbbell one has been proposed in [10]. Its equivalent parameters have been extracted using the model of transmission line. Then, the proposed DGS with good omni-directional properties has been employed in the design of a proximity coupled antenna for increasing its efficiency. Moreover, the protrudent stub length has been diminished from 26.9mm to 18.94 mm by adding two artificial cells on the feed line. Finally, the size of proximity coupled antenna has been diminished substantially by means of the DGS and artificial cells.

3. Problem Statement and Proposed Methodology

In the related work section, the different kinds of DGS structures and their propagation characteristics are analyzed. The propagation characteristic of DGS is varied based on their structure changes and it affects the performance of designed microwave antenna. So, the propagation uncertainty is occurred. Hence, an analytical model is needed for analyzing the propagation characteristics uncertainty of DGS structure. In existing works, the rectangular and dumbbell models are analyzed the uncertainty of wave dispersion and transmission characteristics of DGS structures. The reason for occurring propagation uncertainty is the gap between adjacent slots of DGS. The model determines the performance of DGS structures and realizes the slow wave effect. When the DGS structure is used without proper model, the performance, slow wave effect, and Q-factor are affected. Moreover, the surface wave polarization of DGS structure is also affected by the microwave integrated circuit. In this paper, an integrated multi-segmentation curve fitting mathematical model is proposed for analyzing the propagation characteristics and the propagation uncertainty of the Cross dumbbell Periodic DGS structure. The proposed mathematical model is based on the Cross dumbbell Periodic DGS and their microwave propagation characteristics.

4. Curve Fitting Mathematical Model

The curve fitting is the process of developing mathematical model and analyzing the best possible fit of a curve. The Mathematical model is developed from the characteristics of experimental data. In this paper, a multi segmentation based curve fitting method is developed. The objective of the proposed method is to segment the propagation characteristics and to develop an integrated model of the corresponding segment characteristics. From the integrated model, the uncertainty of the segmentation characteristics is analyzed. The experimental data is obtained from the propagation characteristics of Periodic Defected Ground Structure (PDGS). Then, the curve fitting based generated model is chosen as the reference model and using the reference model, the propagation uncertainty of the experimental data is determined. Cross Dumbbell Periodic DGS structure are chosen to develop the curve fitting mathematical model and analyze the propagation uncertainty.. Then, the considered DGS structures dispersion and the surface power transmission of microwave are analyzed. In the considered characteristics, the curve fitting process is applied. The curve fitting process is performed by polynomial curve data points. The steps used for developing the curve fitting mathematical model are described as follows.

Step 1: Initialize the DGS structure and the appropriate experimental microwave characteristics.

Step 2: Develop the general equation.

$$G_N^{(n)} = H_N^{(1)} + H_N^{(2)} + H_N^{(3)} + H_N^{(4)} + \dots\dots\dots\dots + H_N^{(n)}$$

Step 3: Apply bi-segmentation process in the microwave characteristics. The output of the bi-segmentation process is denoted as S_g. The value of S_g is the corresponding $G_N^{(n)}$ and $H_N^{(n)}$ points

$$G_N^{(n)} = \begin{bmatrix} G_1^{(1)} \\ G_2^{(2)} \\ \vdots \\ \vdots \\ G_N^{(n)} \end{bmatrix} \quad H_N^{(1)} = \begin{bmatrix} H_1^{(1)'} \\ H_2^{(1)'} \\ \vdots \\ \vdots \\ H_N^{(1)'} \end{bmatrix} \quad H_N^{(2)} = \begin{bmatrix} H_1^{(2)'} \\ H_2^{(2)'} \\ \vdots \\ \vdots \\ H_N^{(2)'} \end{bmatrix} \quad \& \quad H_N^{(n)} = \begin{bmatrix} H_1^{(n)'} \\ H_2^{(n)'} \\ \vdots \\ \vdots \\ H_N^{(n)'} \end{bmatrix}$$

where, $G_N^{(n)}$ is the Y-axis values of the characteristics and $H_N^{(n)}$ is the related to X-axis values.

Step 4: Apply multi-segmentation process and develop the integration model.

Step 5: Determine the uncertainty of the experimental characteristics. Then, the polynomial equation used for developing the curve fitting model is described as follows.

$$y = a_0 x_i^0 + a_1 x_i^1 + a_2 x_i^2 + \dots\dots\dots\dots + a_{n-1} x_i^{n-1} + a_n x_i^n \quad (4)$$

where, $a_0, a_1, \dots . a_n$ are the curve coefficients and $i = 0,1,2,...,n$. From the above polynomial equation, the Cross Dumbbell PDGS microwave dispersion characteristics and the surface wave characteristics mathematical curve fitting models are developed. The equations of developed model are illustrated below.

$$(\beta/k_0) = a_0\, f_i^0 + a_1\, f_i^1 + a_2 f_i^2 + ... + a_{n-1}\, f_i^{n-1} + a_n\, f_i^n \quad (5)$$

$$(S21) = a_0\, f_i^0 + a_1 f_i^1 + a_2 f_i^2 + ... + a_{n-1}\, f_i^{n-1} + a_n\, f_i^n \quad (6)$$

$S21$ is the microwave transmission coefficient, f is the frequency in kHz. In eq.5, the brillouin, bounded wave, and leaky wave zones are analyzed separately. Then, the graph segmentation process is applied to the characteristics. The number of segmentation (S_N) depends on the number of increasing and decreasing points. Here, $S_N = 1,2....N$, and then, the equation (5) is written as follows.

$$(\beta/k_0)_1 = a_0(f_i^0)_1 + a_1(f_i^1)_1 + a_2(f_i^2)_1 + ... + a_{n-1}(f_i^{n-1})_1 + a_n(f_i^n)_1 \quad (6)$$

$$(\beta/k_0)_2 = a_0(f_i^0)_2 + a_1(f_i^1)_2 + a_2(f_i^2)_2 + ... + a_{n-1}(f_i^{n-1})_2 + a_n(f_i^n)_2 \quad (7)$$

$$(\beta/k_0)_n = a_0(f_i^0)_n + a_1(f_i^1)_n + a_2(f_i^2)_n + ... + a_{n-1}(f_i^{n-1})_n + a_n(f_i^n)_n \quad (8)$$

The matrix model expression of the above equation can be represented as,

$$\begin{bmatrix} (\beta/k_0)_1 \\ (\beta/k_0)_2 \\ : \\ : \\ (\beta/k_o)_n \end{bmatrix} = \begin{bmatrix} 1 & f_1 & f_1^2 & ..... & f_1^n \\ 1 & f_2 & f_2^2 & ..... & f_2^n \\ : & : & : & & : \\ : & : & : & & : \\ 1 & f_n & f_n^2 & ..... & f_n^r \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ : \\ : \\ : \\ a_n \end{bmatrix} \quad (9)$$

Then, solving the eqn (6), (7) and (8), the curve coefficient values are determined. From the determined curve coefficient values, a new equation model and the corresponding characteristics are generated. Likewise, the mathematical model and the corresponding output performance of the DGS are analyzed. The matrix model of surface wave transmission of microwave is described as follows

$$\begin{bmatrix} (S21)_1 \\ (S21)_2 \\ : \\ : \\ (S21)_n \end{bmatrix} = \begin{bmatrix} 1 & f_1 & f_1^2 & ..... & f_1^n \\ 1 & f_2 & f_2^2 & ..... & f_2^n \\ : & : & : & & : \\ : & : & : & & : \\ 1 & f_n & f_n^2 & ..... & f_n^r \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ : \\ : \\ : \\ a_n \end{bmatrix} \quad (10)$$

Using the above generated equation, the curve fitting mathematical model of both the dispersion and the surface wave transmission of the microwave characteristics are developed. Then, the uncertainty propagation of the experimental charactertics are justified and compared with the used curve fitting mathematical model.

5. Result and Discussion

The proposed curve fitting mathematical model is implemented in MATLAB working platform. Then, the dispersion and surface transmission microwave characteristics are chosen for analyzing the proposed model. The analyzed results are compared with experimental model of DGS structure. The analyzed DGS structure are Cross Dumbbell PDGS. From the experimental results of the Cross Dumbbell Periodic DGS structure, the curve fitting mathematical model is developed. The propagation characteristics of the curve fitting model are analyzed with the experimental characteristics. Then, from the analyzed characteristics, the propagation uncertainty is determined. After that, the error deviation improvement of the proposed model is evaluated. The dispersion and surface transmission of microwave of Cross Dumbbell PDGS are described as follows.

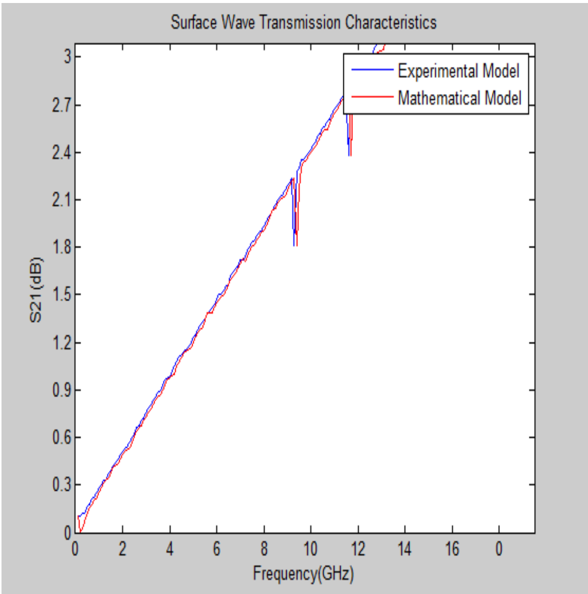

Figure 1: Surface wave Transmission Characteristic of Dumbbell PDGS

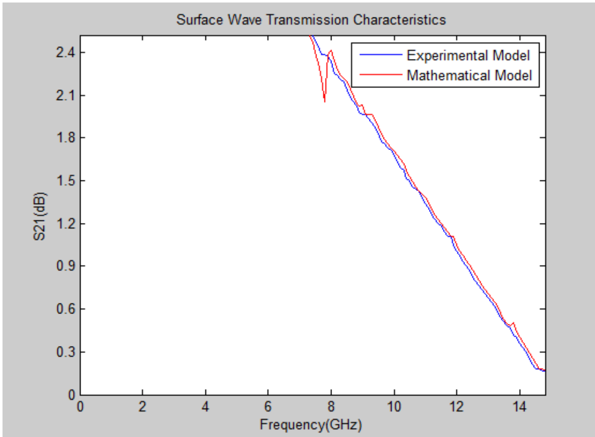

Figure 2: Surface wave Transmission Characteristic of Dumbbell PDGS

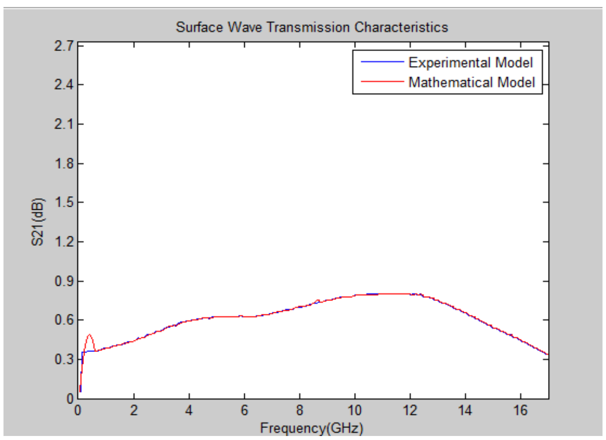

Figure 3: Surface wave Transmission Characteristic of Dumbbell PDGS

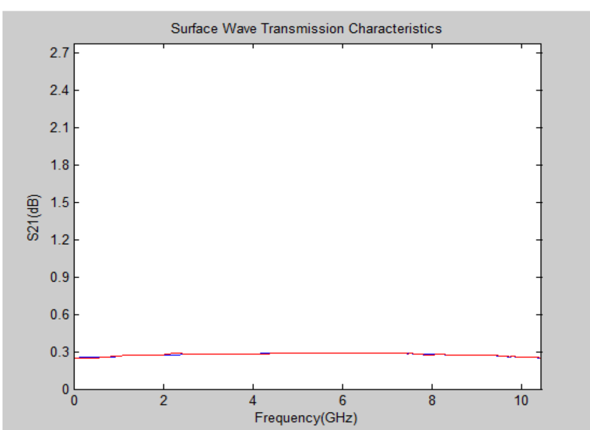

Figure 4: Surface wave Transmission Characteristic of Dumbbell PDGS

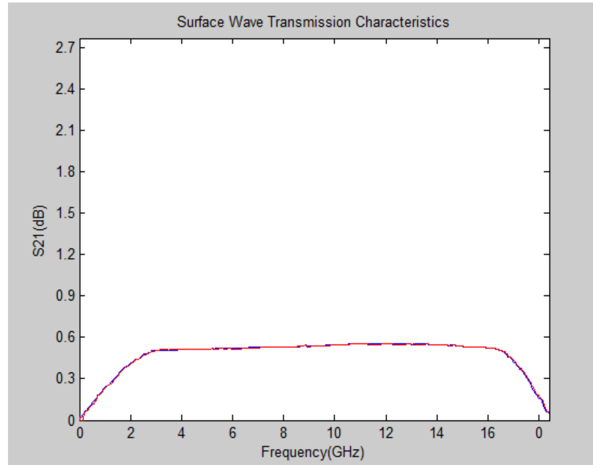

Figure 5: Surface wave Transmission Characteristic of Dumbbell PDGS

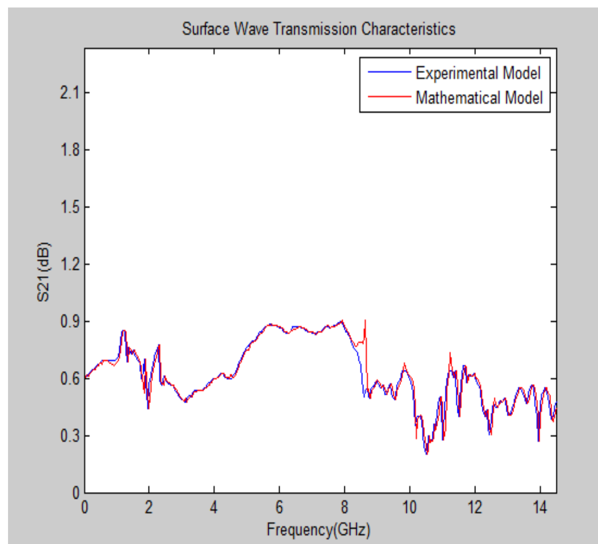

Figure 6: Dispersion Characteristic of Cross Dumbbell PDGS

Then, the propagation errors of the proposed curve fitting model are compared with the experimental model. The propagation errors deviation is determined in terms of percentage. The experimental results of error deviation from curve fitting model are described in table I. The performance deviation of percentage of propagation deviation is illustrated in Fig.7. The formula is used for determining the percentage of error deviation is described as following them.

Table 1: Segmentation Points of Different PDGS and the Error Deviation

PDGS	Propagation Characteristics	Segmentation points of Experimental Model	Segmentation points of Curve Fitting Model	% of Error Deviation
Cross Dumbbell	Dispersion	200355.7578	201281.0041	0.461802
	Transmission	37668	37877.0625	0.555014

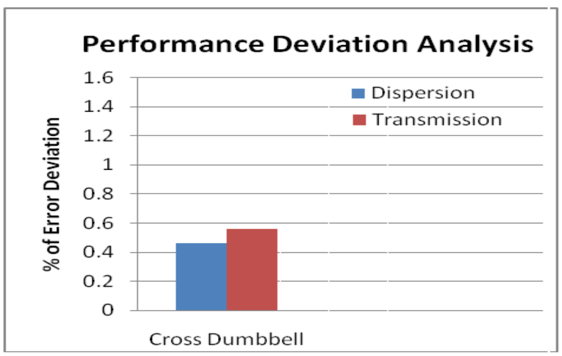

Figure 7: Performance Error Deviation Analysis

In Fig.7, the dispersion and surface transmission characteristics errors of Cross Dumbbell periodic structures is analyzed for both mathematical model and experimental model. Then, the percentage of error deviation of the proposed model is determined from the experimental model. The error deviation of Cross Dumbbell periodic structure is plotted in bar chart. From the performance of error deviation, it is clear that the proposed curve fitting mathematical model error is reduced remarkably. So, the proposed mathematical model based periodic structure characteristics analysis is better than the experimental model. Because, the proposed model characteristics analysis helps to design an accurate periodic structure and also reduces the propagation uncertainty.

6.Conclusion

In this paper, a curve fitting mathematical model was used for justifying the propagation uncertainty of microwave antenna. For justifying the propagation errors, the proposed model results were compared with the experimental model. Here, the Cross Dumbbell PDGS structures were used for analyzing the propagation characteristics. The DGS structure dispersion and surface wave transmission characteristics were considered for evaluating the performance of the proposed model. The bounded, leaky and brillouin wave zone boundary were chosen for analyzing the dispersion wave attenuation. From the error deviation, it was clear that the error of the proposed curve fitting model was deviated than the experimental model. Thus, the proposed curve fitting model was more efficient in determining the accurate size of DGS. In future, more DGS structure will be considered for analyzing the performance of proposed curve fitting model.

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