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PHASE PROPERTIES OF ELECTROMAGNETIC BANDGAP STRUCTURES (EBGS)

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Abstract- *The phase properties of EBG structure has become a great field of interest for the scientists. The EBGS assisted mictrostrip transmission line is used to improve the phase. These EBGS are perturbated at the ground plane of microstrip transmission line. A simple, standard fifty ohm microstrip transmission line has been studied. Various pattern of EBGS including circular, square dumbbell shape of both uniform non-uniform structure and their relative phase have been investigated in this paper. Among them the non-uniform chebyshev pattern shows best performance. This EBG assisted transmission line is further being used in the phased array antenna which enhances the beam squinting capabilities. A four by one feed network has been designed which can be used as the base of phased array antenna.*

Keywords: EBGS, Mictrostrip transmission line, Relative phase of non uniform structures, Chebyshev pattern.

1. INTRODUCTION

In recent years the planar Electromagnetic Bandgap Structure (EBGS) assisted microstrip transmission lines are of much interest in microwave technology. Planar EBGS are a type of periodic dielectric which has similarities with semiconductor[1]. Periodic perturbation such as rectangular, circular and annular ring pattern are introduced in the ground plane of microstrip line which form Planar EBGS. Through this photonic substrate electromagnetic wave propagates just like electrons travel in semiconductor. EBGS shows some specific characteristics for which they are of great interest in microwave engineering. By varying the EBGS structure, the characteristics are differed such as the passband is used as slow wave medium, stopbands for suppressing the surface wave, leakage and spurious transmission and also the phase property can be improved. Due to these unique properties of EBGS they find potential application in filter, antenna, waveguide, phased array antenna and many other microwave devices and components.

EBG engineering structures are charming product in microwave engineering[6]. The EBGS provides many advantageous features at a time such as beam steering capabilities[7] in the design of EBG assisted phased array antenna[8]. This beam steering is needed to change the direction of the radiation pattern. These EBGS assisted microstrip lines are widely used in the phased array antenna to improve this transmission phase.

2. OBJECTIVES

The goal is to investigate Planar EBGS assisted microstrip transmission line which is used to improve the phase. This improved phase structure is used to design phased array antenna. We will investigate the uniform and nonuniform pattern of EBG structure. In nonuniform pattern two distributions – Binomial and Chebyshev polynomial are of great interest to improve the relative phase shift. The EBGS have different forms and their lattice structures are different. The investigation will be confined mainly to circular and square pattern EBG structure. Uniform EBG structure has constraints of filling factor (FF). By varying the FF, number of EBG elements, the relative phase shift can be improved. Non-uniform EBGS are free from these problem. So these non-uniform structure opens a new field to improve the transmission phase. The thesis has following objectives:

- Design of Planar EBGS periodic perturbation such as circular, square in the ground plane of microstrip line.
- Implementing uniform and non-uniform distribution of EBG unit cell in EBGS array.
- Chebyshev distributed EBGS are investigated to achieve better performance.
- By varying the structure of EBG, FF, number of EBG elements the relative phase shift is investigated.

3. METHODOLOGY

3.1 Calculation Method

The designing theme of EBG structure in case of microstrip antenna indicates that the operating frequency of the microstrip antenna should fall within the stop band of the applied EBG structure. To do this a designing equation is needed which will be helpful to find out the useful EBG structure for a microstrip antenna.

EBG structure can be designed using the following equation,

$$\beta a = \pi \qquad (1)$$

Where a is the distance between two unit cell and β = the wave number in the dielectric slab.

$$\beta = \frac{2\pi}{\lambda_g} \qquad (2)$$

Here, $$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \qquad (3)$$

Again, $a = \lambda g/2$ (4)

A one dimensional EBG microstrip line with etched periodic circular holes in the ground plane is designed by using Taconic substrate, in which
Relative dielectric constant ε_r =2.45
Thickness=0.787mm

Using PCAAD 2.1 software the value of
Conductor strip width, w=0.22630cm=2.263mm
Effective dielectric constant ε_{eff} =2.068
Now,

$$\lambda_0 = \frac{300(mm)}{f_o(GHz)} \quad ; f_0 = 10 \text{ GHz} \qquad (5)$$

$$= \frac{300}{10}$$

= 30mm

Again,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

$$= \frac{30}{\sqrt{2.07}}$$

=20.85mm
Now,

$$a = \frac{\lambda_g}{2}$$

$$= \frac{20.85}{2}$$

= 10.426mm

Filling Factor, $FF = \dfrac{r}{a}$ (6)

The stard value of FF for circular holes is 0.25

$\therefore$ r =FF × a Here, a=10.426 mm
=0.25 × 10.426
=2.61mm

Filling factor of 0.25 is found to be efficient for circular EBG structure and for square unit Cell it is found to be 0.5. In case of non-uniform distribution the FF is 0.4 for binomial and chebyshev distribution.

3.2 Designing Equation

The nonuniform EBGSs have two types of distribution: Binomial and Chebyshev. These two distributions give better performances than the uniform type by suppressing passband ripples and producing distinct wide stopbands. The chebyshev distribution gives much better performance than the binomial distributed EBGS. Here the transmission coefficients vary with minute ripple [4] over the stopband. This equal ripple characteristic is obtained by making distribution according to chebyshev polynomial.The basic properties of the polynomial [4] are expressed as follows:

$$T_m(z) = 2zT_{m-1}(z) - T_{m-2}(z) \qquad (7)$$

Where Tm (z) is expressed as

$$T_m(z) = \cos[m\cos^{-1}(z)] \text{ for } z<=1 \qquad (8)$$

The co-efficient of the polynomial are determined for any particular SLL (Side lobe level voltage ratio) for a voltage ratio between the peak and the SLL for instance for 25db the amplitude are determined as follows:

0.36 0.49 0.71 0.78 1 1 0.78 0.71 0.49 0.36

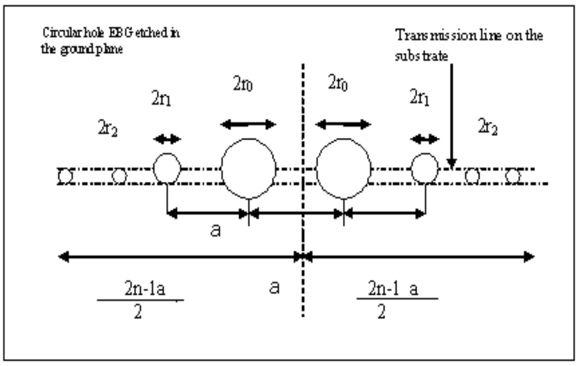

Fig 1 : Geometry of a microstrip transmission line where chebyshev distributed EBGSs are etched in the ground plane

For EBG design we shall vary the radii, areas of the circles and annular rings proportionally to the relative amplitude.

For chebyshev distribution two distinct relationships between amplitude of the coefficient of the polynomials and the physical dimensions[1] of the EBG circles .They are:

1) Polynomial coefficient amplitude are proportional to the radius of the circle(r) called type A
2) Polynomial coefficient amplitude is proportional to the areas of the EBG circles (Πr2) called type B.

3.3 Design Structures

3.3.1 Ideal Transmission Line

In this structure of ideal transmission line there is no perturbation in the ground plane.

Designing parameter:

Characteristics impedance, Zo=50 ohm;
Center frequency of the stopband, f_o=10GHz;
Height=0.787; width=2.263; ε_r =2.45;

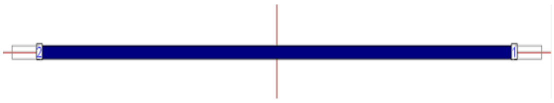

Fig 2: Ideal Transmission Line

3.3.2 Uniform Circular EBGS

In this structure of uniform circular EBGS, there are periodic circular perturbations in the ground plane.

Designing parameter:

Characteristics impedance, Zo=50 ohm;
Center frequency of the stopband, f_o=10GHz;
Height=0.787; width=2.263; εr =2.45;
Inter element spacing, a = 10.426; FF= 0.25;
radius of the circle, r= FF×a= 0.25 × 10.426= 2.6065
=2.61mm

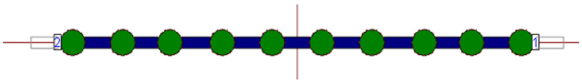

Fig 3: Uniform Circular EBGS (10 elements)

3.3.3 Uniform Square EBGS

Design Parameter:

Characteristics impedance, Zo=50 ohm;
Center frequency of the stopband, f_o=10GHz;
Height=0.787; width=2.263; εr =2.45.
Inter element spacing, a = 10.426mm; FF= 0.25×2=0.5;
The arm length, b=FF×a=0.5×10.426=5.213mm

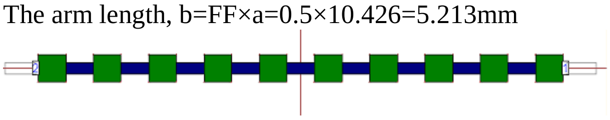

Fig 4: Uniform Square EBGS (10 elements)

3.3.4Chebyshev distributed non-uniform EBGS

3.3.4.1 Chebyshev Distributed Non-uniform Circular EBGS (Type-A)

This design structure has Chebyshev distributed non-uniform circularly perturbated ground plane. It is named type-A structure in which polynomial coefficient's are proportional to the radius of the EBG circle(r).

Designing parameter:

Characteristics impedance, Zo=50 ohm;
Center frequency of the stopband, f_o=10GHz;
Height=0.787; width=2.263; εr =2.45;
Inter element spacing, a = 10.426; FF= 0.4;
radius of the circle, r= FF×a= 0.4×10.426=4.17mm.

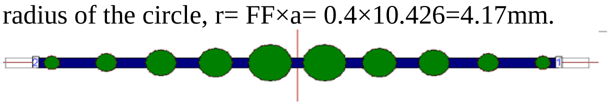

Fig 5: Chebyshev Distributed Uniform EBGS type-A (10 elements)

3.3.4.2 Chebyshev Distributed Non-uniform Circular EBGS (Type-B)

This design structure has Chebyshev distributed non-uniform circularly perturbated ground plane. It is named type-B structure in which polynomial coefficient's are proportional to the areas of the EBG circle (πr^2).

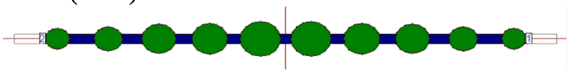

Fig 6: Chebyshev Distributed Uniform EBGS type-B (10 elements)

3.3.5 Square Chebyshev Non-uniform EBGS

Design Parameter:

Characteristics impedance, Zo=50 ohm;
Center frequency of the stopband, f_o=10GHz;
Height=0.787; width=2.263; εr =2.45.
Inter element spacing, a = 10.426mm; FF= 0.4×2=0.8;
Arm length= 0.8×10.426= 8.3408mm;

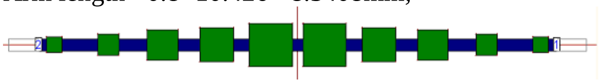

Fig 7: Square Chebyshev Distributed EBGS (10 elements)

4. COMPARATIVE STUDY OF DESIGN STRUCTURES

4.1. Simulation

The EBGS assisted microstrip transmission line is designed and simulated with the help of Zeland IE3D software. The software provides very much impressive agreement with experimental investigation.

In our present work,we use Taconic substrate having dielectric constant ε_r = 2.45, thickness = 0.787 mm. The center frequency is selected at 10 GHz and the period a = 10.426 mm. Based on the designing parameter uniform, non-uniform including chebyshev EBG patterns have been designed and analyzed. The transmission phase is investigated in the passband of the EBG assisted transmission lines such that the insertion loss of the lines is minimum. This insertion loss co-efficient is measured from the S-parameter graph. The three frequency points are chosen such a way that these are at the edge of the stop band. If we observed the S-parameters graph we see that the stop bands starts from the 7.0 GHz and the phase properties are investigated at 5.5,6.0 and 6.5 frequency points.

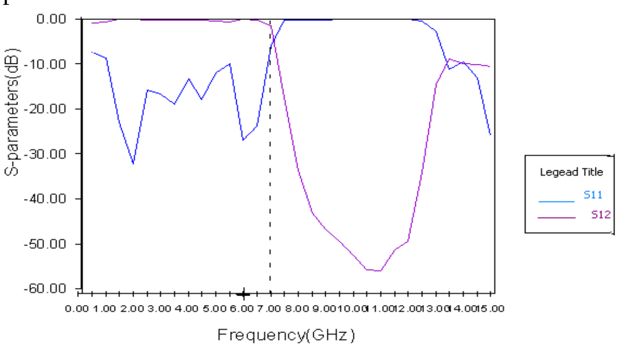

Fig 8: S-parameter performances of a microstrip transmission line having the stop bands starts at the 7.0GHz.

4.1.1 1-D Ideal Transmission Line

Figure 9 shows angular parameter vs. frequency for ideal 1-D transmission line. The phase properties are investigated at the edge of the stopband. For this purpose three points have been chosen namely 5.5, 6.0 and 6.5 GHz from the S-parameters performances because of the variation of the stopband range through these points. The reference phases are 130.1, 43.21 and -43.77.

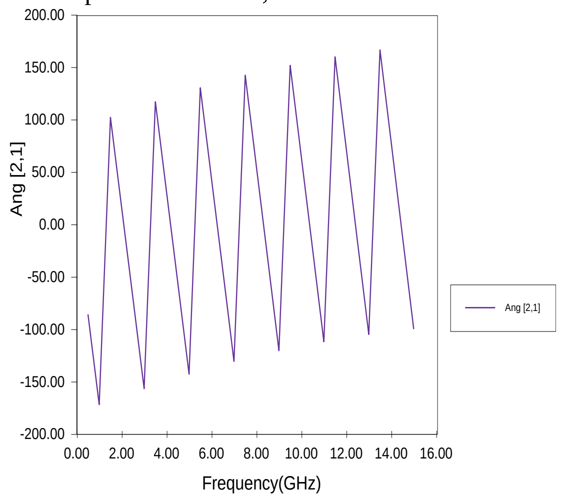

Fig 9: Phase properties of an ideal transmission line over Taconic substrate having dielectric constant of 2.45 and thickness of 0.787 mm

4.1.2 Uniform 1-D Microstrip EBGS

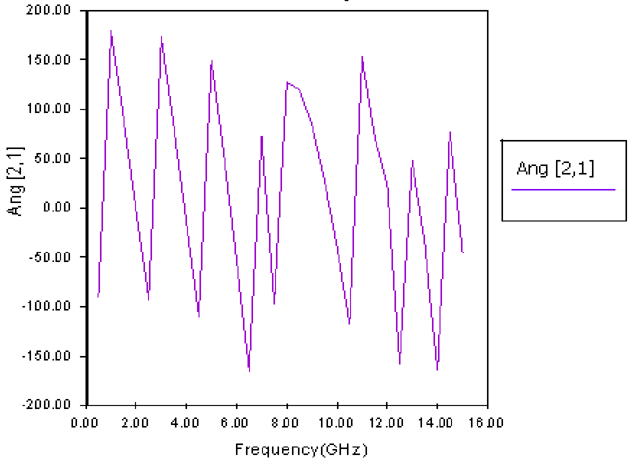

Fig 10: Phase properties of uniform circular EBGS assisted transmission line over the Taconic substrate having dielectric constant 2.45.thickness of 0.787 mm, radius 2.61 and FF 0.25

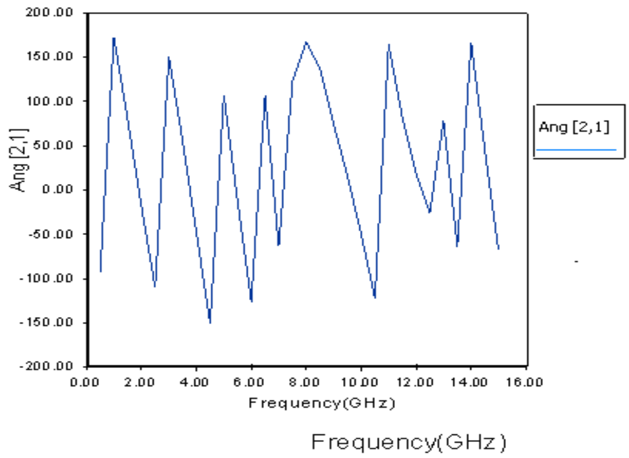

Fig 11: Phase properties of uniform square EBGS assisted transmission line over the Taconic substrate having dielectric constant 2.45.thickness of 0.787 mm, arm length 5.2125 mm and FF 0.5

4.1.3 Chebyshev Distributed Non-uniform EBGS

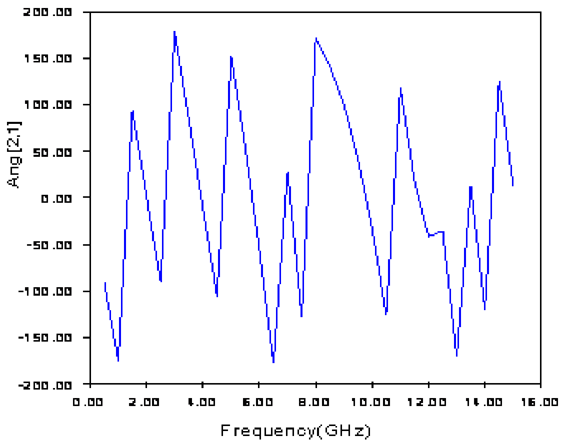

Fig 12: Phase properties of chebyshev distributed(type-A) non-uniform circular EBGS assisted transmission line over the Taconic substrate having dielectric constant 2.45.thickness of 0.787 mm and FF 0.4.

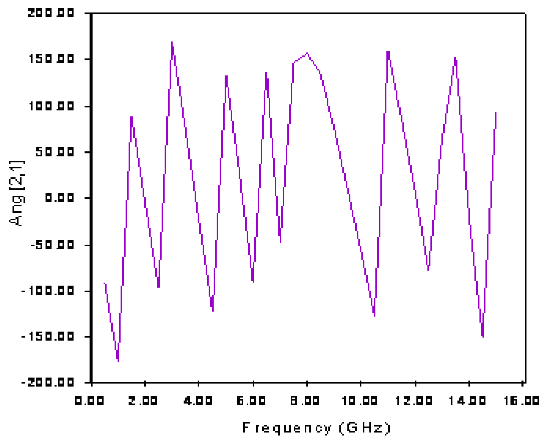

Fig 13: Phase properties of chebyshev distributed(type-B) non-uniform circular EBGS assisted transmission line over the Taconic substrate having

dielectric constant 2.45.thickness of 0.787 mm and FF 0.4.

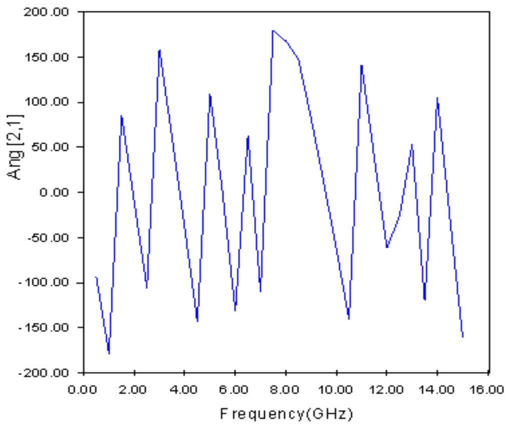

Fig 14: Phase properties of chebyshev distributed non-uniform square EBGS assisted transmission line over the Taconic substrate having dielectric constant 2.45.thickness of 0.787 mm and FF 0.8

4.2 Results

Relative Phase Shifts for Different Design

Table 1**:** Comparison list of relative phase shifts of different circular EBGS

Name	Frequency (GHz)		
	5.5	6.0	6.5
	Relative phase shift (^{0})		
Uniform Circular	77.84	95.88	121.33
Non-uniform Circular Chebyshev (Type-A)	79.04	98.39	132.83
Circular Chebyshev (Type-B)	103.43	134.03	179.47

Table 2: Comparison list of relative phase shifts of different square EBGS

Name	Frequency (GHz)		
	5.5	6.0	6.5
	Relative phase shift(^{0})		
Uniform Square	131.28	150.27	169.31
Non-uniform Square Chebyshev	142.49	174.41	185.48

5. CONCLUSION

The main motivation of this work is to investigate the relative phase shift with the help of different EBG structure. Different EBG structure has been proposed here. We have investigated uniform, circular and square pattern EBGS etched on the ground plane of microstrip transmission line having 10 elements. The phase properties have been observed by taking the ideal line as reference. The relative phase shift has been calculated by taking the positive slope's magnitude directly. Negative slope magnitude is taken as difference from the top value of that slope to the real value. To find better performance non-uniform chebyshev structure has been observed. The Zeland IE3D software simulation result shows that the chebyshev shows much improved performance than the uniform. The filling factors are varied in each case. We have observed that the filling factor plays a vital role in improving the phase shift. These EBG assisted structures are used as base of the phased array antenna. Conventional phase shifters are very expensive. The EBG assisted line offering much improved phase shift which is less expensive and very light in weight. They are used in microstrip antennas which are used in many modern devices such as airplane, radar, satellite communication networks and so on.

7. REFERENCES

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