Tunable Electromagnetic Gradient Surface For Beam Steering by Using Varactor Diodes

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***Abstract* - In this paper, tunable beam steering has been realized by arranging Electromagnetic Band- gap (EBG) that has constant phase difference, Δφ. The proposed structure is the active periodic Electromagnetic Gradient Surface (EGS) that consist of the 4 by 4 matrix form of unit cells to easily control the several varactor diodes. The phase gradient ±120° of the proposed EGS is selected. Moreover this structure uses only one diode per four unit cells. The conventional loading of a single varactor for each of the unit cells of the EBG is overcome by connectdkgkding the unit cells to a feeding network directly without via. Thus, the EGS can steer reflected beam to -9° at Δφ = 120° and to +9° at Δφ = -120° by actively changing the biasing voltage of varactor diode.**

I. Introduction

Nowadays, the electromagnetic band gap (EBG) structures have attracted increasing interests because of their desirable electromagnetic properties that cannot be observed in natural materials. Conventional EBG, also called as High impedance surface (HIS), is typically constructed as an array of small («λ) metal patches on the top layer and a metal ground plane on the bottom layer. The EBG have been applied to improve performances of many devices such as low profile antennas[1], absorbers[2], TEM waveguides[3], and microwave filters[4].

Another interesting approach is phased reflector which is physically flat surface but electromagnetically gradient surface. A mushroom-type EBG structure with a linearly graded reflection phase shows electromagnetic gradient properties across its surface. Its ability to create an EGS of a physically flat structure allows it to reflect incident plane wave to other direction [5]. By decreasing or increasing the length of each lattice, the phase curve of the reflection coefficient moves right or left respectively, on frequency domain. In [5], difference size of metallic patches with via can make the reflection phase for steering beam pattern of incident wave. However this structure has phase discontinuity error and steered beam pattern is fixed.

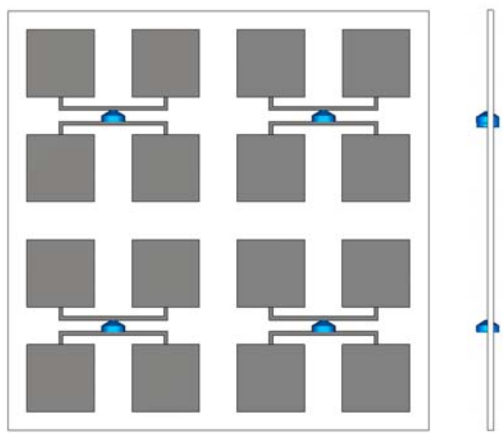
On the other hand, the resonance frequency and reflection phase of EBG unit cell is controlled actively by using phase shifters, which increase the complexity and cost of the system. The lumped device such as varactor diodes between each of the elements instead of by changing structure physically also can change the resonance frequency and reflection phase of a tunable high impedance surface[6]. It has also been demonstrated in [7] that tunable EBGs are feasible for beam steering applications. The disadvantages of these structures are that the active element is sensitive to environment, thus more errors by using many active devices become serious problems. Moreover, in order to make the linear phase gradient, system for controlling the various voltages for biasing varactor diodes is too complex.

The aim of this paper is to illustrate the advantage of using reduced varactor diodes in a simple EBG structure to tune the reflection phase and to use this property in tunable tilting the reflected beam pattern. Moreover, if we consider the unit price of microwave varactors, reduced lumped devices can decrease the cost and complexity for manufacture.

II. Theory And Design

A. Tunable reflection phase of the 4x4 group cell

The resonance frequency and the reflection phase of the EBG are tuned by changing the capacitance, C, the inductance, L, or both. From this principle, we can shift the reflection phase without varying the patch size. Generally, the L is difficult to tune because it is a product of magnetic permeability μ and thickness of the substrate t. The C is easier to control by changing the geometry and arrangement of the metal plates, or by adding tunable lumped capacitors.



(a) (b)

Figure 1. Configuration of the tunable EBG Structure
(a) Top view. (b) Side view

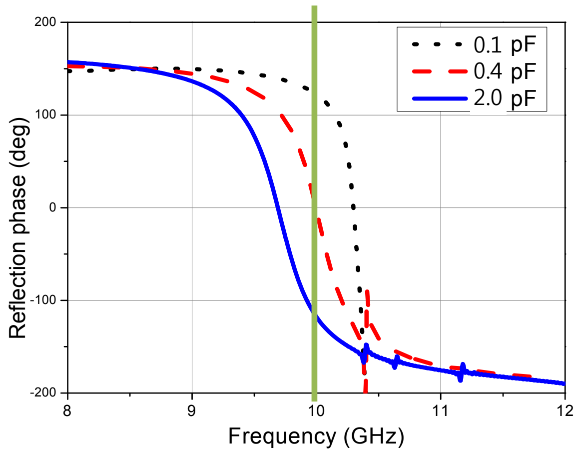


Figure 2. Reflection phase of the EBG for various capacitances

The active EBG structure is shown in Fig.1. It consists of a ground, matrix of grouped unit cells, a dielectric substrate of Tarconic TLY-5 with a thickness of 0.79 mm and a dielectric constant of 2.2 and tanδ=0.0009, a varactor diode, and thin line with width of 0.5mm. The distance between neighboring cells is 14 mm, satisfied the condition of < λ/2 at 10 GHz. Therefore, the EBG's physical dimension is 56 mm x 56 mm.

Each unit cell between neighboring patches of the conventional tunable EBG should be connected by varactor diodes[6]. For the purpose of reducing the lumped elements, four unit cells are grouped by one using only one diode. If 4x4 array structures in [6] use 12 diodes, the proposed EBG structure uses only four diodes in the same array. Therefore when the active EBG is implemented, the design complexity of its feeding network can be reduced, and also can be controlled the four cells by one bias at one time. Then, 4 unit cells operate one group cell that varies all together. The width of the thin line is not so serious for phase curve

The reflection phase of the structure for various capacitances is shown in Fig. 2. CST microwave studio, which is a commercial 3D full field simulation tool, was used to model the EBG using appropriate boundary conditions surrounding the EBG to ensure an effective infinite EBG. The active elements are represented by the RLC models. For a fixed frequency, by changing diode capacitance, a different reflection phase is achieved. The larger capacitance, phase curve shifts to left. When the value of capacitance is 0.1 pF, 0.4 pF and 2 pF, the phase curve is +120°, 0° and -120° at 10 GHz, respectively.

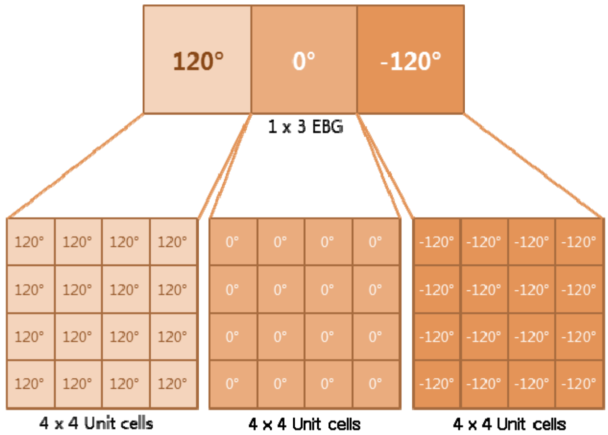
B. Periodic Electromagnetic Gradient Surface (EGS)

If an array is considered, in which all its elements are placed at a fixed distance but different phase, it is possible to electrically steer the beam by a variation of the elements' phase. The normal EGS requires a full phase reflection range of -180° ~ +180°. The passive EGS can change reflected direction of incident plane wave[5]. However, when the EGS is arranged to cover large surface area, it cannot have the linearly reflection phase gradient, because the limited reflection phase range with one via in unit cell and it cannot be change the reflected beam direction.

The proposed active periodic EGS consists of the 4 by 4 matrix form of unit cells to easily control the several varactor diodes. When the active EBGs arrange by introducing a phase difference along the E-field direction, a beam steering is obtained. By adjusting the phase gradient, Δφ, and the distance, Δs, between neighboring EBGs, the proposed periodic EGS can determine the reflected angle of the incident plane wave[8]. Assuming normal incident of electromagnetic wave to the EGS, the reflected angle θ_r is given by

$$\theta_r = \sin^{-1}\left(-\frac{\Delta\varphi}{\Delta s}\cdot\frac{\lambda}{2\pi}\right) \tag{1}$$

To satisfy the reflection phase continuity, the periodic arrangement along the x-axis, the phase gradients ±180°, ±120° and ±90° can be selected. In this case, full range of reflection phase is not necessary.



(a)

(b)

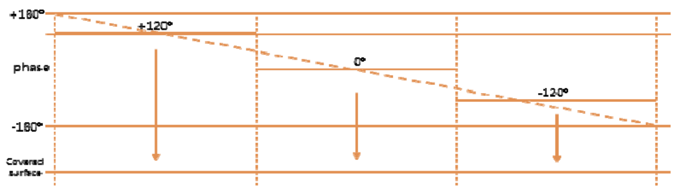


Figure 3. Concept of the periodic EGS
(a) Configuration of periodic EGS (ex: Δφ=-120°) (b) Reflection phase of periodic EGS

The larger the phase difference is and the smaller size of the EGS is, the larger the tilted reflection angle is achieved. In particular, by applying a linear variation with respect to the position, a voltage gradient is applied along the E-plane, obtaining the desired beam deflection.

For example, the phase gradient of Fig. 3 is 120°, thus, the proposed active EGS can cover the large surface area using the only three biasing, +120°, 0°, and -120°, with the matrix form to make linearly reflection phase gradient. And this EGS can be expanded periodically.

In case of the active EBG, the diode junction capacitance can be independently changed for each EBG. In particular, by applying a linear variation with respect to the row position, a voltage gradient is applied along the E-plane, obtaining the desired beam deflection

C. Reconfigurable Reflected beam pattern

By using the easy tuning characteristic of varactor diode it simply change the reflection phase gradient direction of the EGS with difference bias voltage, and then the reflection phase gradient turns reversely at the fixed frequency. As a result, reconfigurable beam steering gets accomplished.

The proposed active EGS is illustrated in Fig. 4. The active EGS structure can have phase gradient ± 120 by controlling the bias voltage. The distance between the neighboring EBG is 56 mm and overall dimension is 168 mm x 56 mm. Thus, in the equation (1), expected reflection angle is -9° at Δφ = 120° and to +9° at Δφ = -120°.

III. SIMULATION RESULT

Fig. 5 shows the normalized beam reflection patterns obtained in correspondence of 10 GHz. Since the radar cross section (RCS) of the EGS is used to characterize the reflective behavior of the phased reflector, we use RCS pattern in this study. As shown in the 2D pattern graph, the simulated reflection angle is -9° at Δφ = 120° and to +9° at Δφ = -120° and 0° when the structure is PEC. Since the phase gradient changes opposite, the tilting angle also is symmetry.

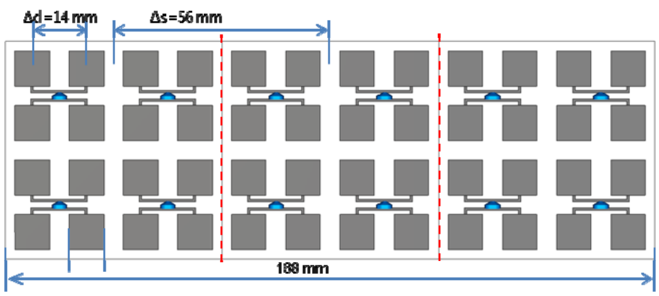
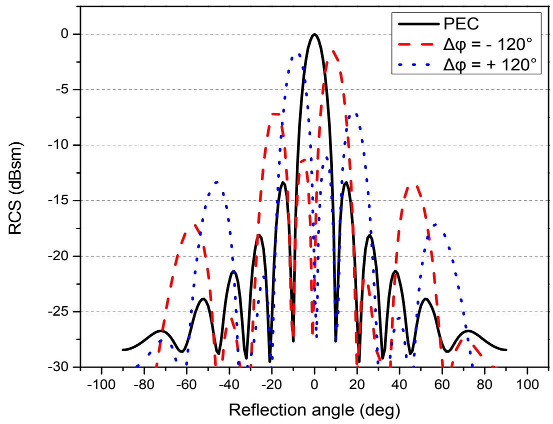


Figure 4. The proposed active EGS structure with Δφ = ± 120°



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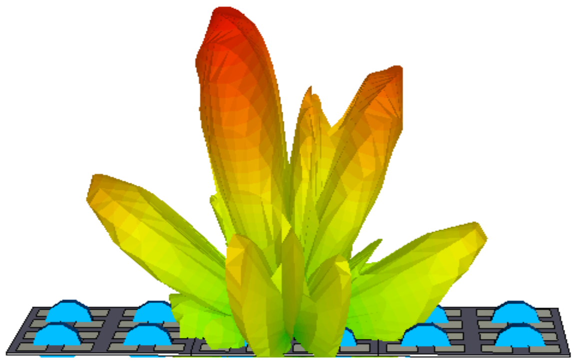

(b)

Figure 5. The steered reflection beam patterns
(a) The 2D pattern Δφ = ± 120° and PEC (b) The 3D pattern Δφ = + 120°

IV. CONCLUSION

The active periodic EGS for reconfigurable tiling the reflected beam is proposed and studied. The active EGS is composed of three EBGs with 4 by 4 matrix form and constant phase gradient. This matrix form makes easy to control the bias voltage for varactor diodes. In this paper, only three values of capacitance are needed. Moreover, since the each four unit cells are connected by one varactor diode, we can reduce the number of the active devices. Because the active element is sensitive, reducing the diode can decrease the errors and the cost of system. The size of the proposed EGS reflector is 168 mm x 56 mm and the number of the varactor diodes is 12. The reflection angles -9° at Δφ = 120° and to +9° at Δφ = -120° are obtained in correspondence of 10 GHz.

Although the structure in this study can use the two changeable angles, it is expanded to 2D structure then more various angles can be accomplished with further studies on the EGS.

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