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Optimization of elliptically designed patch mushrooms and investigation of low profile dipole antenna – HIGP interaction

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In this study, we investigate high impedance ground plane structures consist of elliptic metallic mushrooms. In this structure gaps and metallic patch dimensions have an effect on electromagnetic band gap is observed. It is shown that elliptic mushrooms can show much better performance compared to its conventional counterpart such as perfectly electric conductor. Good return loss in the EBG frequency range for HIGP- low profile dipole antenna is obtained. Miniaturized and improved antenna system is satisfied by this new elliptic mushrooms.

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1. Introduction

Antennas have deep effect in the development of wireless communication that includes cell phones for GPS systems, laptops adapted with third generation mobile system [1]. All these antenna systems require compact size, broad bandwidth and low profile properties. Development in computational electromagnetic techniques such as method of moments (MoM), finite element method (FEM) and finite difference time domain (FDTD) method have contributed to optimization of antenna systems [2,3], so observation of novel antenna results with these techniques coherent with experiments expanded rapidly to the new antenna developments.

Ground plane applications in antenna design are widespread to redirect electromagnetic radiation in one required direction and avoid other sides [4]. Most common ground plane is perfect electric conductors which are positioned at a quarter wavelength distance from the antenna to provide phase matching with both side radiations. Since the electromagnetic waves include both parallel and perpendicular components to the ground plane, parallel components force up to the surface waves to flow from one side of the surface to the other side on PEC ground plane. The exciting solutions to these problems have been found by the discovery of electromagnetic band gap structures (EBG) which have periodic properties [5].

EBGs are defined as man made periodic or non periodic structures that reflect or transmit electromagnetic waves in an adjustable frequency band and polarization. EBG structures include periodically arranged dielectric materials known as photonic crystals [6] and metallic conductors named as frequency selective surfaces [7] (FSS) and high impedance ground planes (HIGP). If the EM field behaves as surface wave, EBG structures exhibit surface wave band gap properties independent to the polarization or angle of waves and avoid the propagation of waves. EBG structures reflect the incident plane wave with different phases, even with zero degree as perfect magnetic conductor that doesn't exist in nature.

Beside the surface wave application, widespread implementation of EBG structures is ground plane usage with low profile wire antennas to enhance radiation efficiency [8]. Although the antenna-PEC ground plane system shows enhanced efficiency since the reflected wave that has same direction with the radiation one but the antenna system dimensions are getting larger due to the quarter wavelength distance [9]. Thus, this antenna system has relatively larger dimensions from single antenna without EBG. To eliminate this problem, antenna may be positioned close to the PEC, but radiation efficiency reduces due to the phase mismatch. The low profile configuration may be provided by EBG surfaces by positioning close to the antenna [10].

In this study, HIGP surface that is composed of elliptical patch mushrooms will be numerically analyzed by FEM. Altering the dimensions of the mushroom and elliptical patch inclusions, broadband EBG will be attempted to obtain. In this situation, a better radiation will be provided for antenna array system consists of different frequency radiator that is positioned near HIGP since the minimized surface waves. It is hoped that better radiation pattern and EBG values will be observed by the low profile antenna used with this new type of HIGP than the free space antenna. Beside this it will be proved that HIGP- antenna distance is not necessary to be $\lambda/4$, so antenna –HIGP system dimension will be reduced.

2. The dimension effect of elliptic mushrooms on surface wave suppression (EBG)

HIGP-antenna system efficiency is tested in three phased procedure. The first phase is observation of the surface wave suppression on the ground plane with two coaxial antenna probes mounted between mushrooms. The minimization of the transmission in a broadband frequency range from one coax antenna mounted at one side of HIGP to the other antenna is succeed of mushroom structure. Antenna reflection reduction (S11) in the same frequency range with EBG is the second phase of system design. If S11 values are below -20dB in the surface wave suppression frequencies, antenna-HIGP impedance matching is satisfied and maybe used together as a system. Although both these tests are sufficient for antenna-HIGP system design, directivity and radiation pattern must be obtained to decide exactly to the radiative efficiency of the system.

Many types of mushrooms such as rectangular, circular, square are applied as a HIGP surface instead of PEC. All these mushrooms have different advantages and disadvantages. One another geometry may be used as mushroom is elliptic. In this study we used elliptic geometries to suppress surface waves. The HIGP system consists of periodic metallic elliptic shape mushrooms, metal ground plane and Rogers RT duroid dielectric (thickness=3,175mm) between them. The resonance of each mushroom is achieved by drilling the elliptic metal inclusions and connecting each one with metallic ground by thin wire. Since the elliptic structure is non-symmetric the gap between horizontal and cross side elliptics are different (g_1, g_2) and w_x is the dimension of the elliptic along x direction. W_y is depend on the w_x by a factor of 0,6.

The surface wave properties of the mushrooms for different dimensions are obtained by using two coaxial feds which are positioned at two different sides of HIGP. The HIGP system is defined in a 40mmx70mmx30mm dimension cubic free space and all the edges are assigned as radiation surface. The numerical analysis is solved in 1 - 20 GHz frequency range. To decide the effect of dimensions, optimization is done by varying g_1, g_2 and w_x.

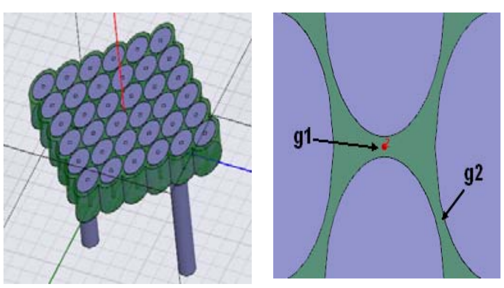
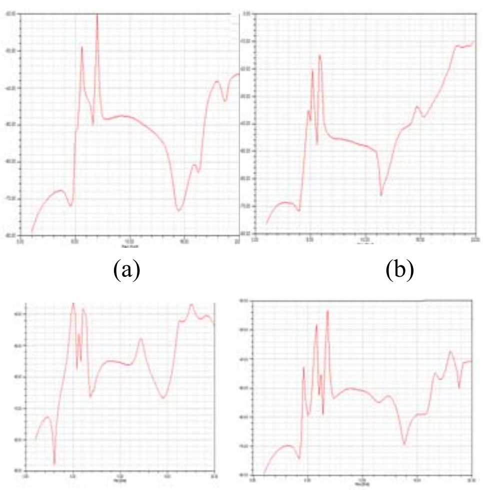


Fig. 1. HIGP with elliptic patch mushrooms.

One of the effective parameter is the elliptic metallic patch dimensions. Although the electromagnetic band gap frequency is 7-18 GHz for wx=4mm, it is decreasing to 6-17.5 GHz for wx=5 mm. This change results from the inductive behaviour of the elliptic mushroom. Since the gaps may be represented by capacitive elements in a lumped circuit, each mushroom can be represented as L-C resonant circuit and the increment of the inductive effect reduce the resonance frequency;

$$f_0 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{LC}} \tag{1}$$

The other parameter that affects the electromagnetic band gap is the dimension of gaps between elliptic patches. Since increasing of the gap between patches reduce the capacitive effect of the resonant circuit, resonance frequency and EBG increase. To observe this effect, both the gaps around the elliptic patch are changed and the variation on the EBG frequency range is followed. When the EBG is between 6,5 – 16,2 GHz for wx=4 mm, g_1=0,2 mm and g_2=0,1 mm, it shifts to 7 – 18 GHz band for wx=4 mm, g_1=0,3 mm and g_2=0,2 mm and clearer EBG is observed with capacitive reduction as shown in Fig. 2.



(a) (b)

(c) (d)

Fig. 2. Transmission values (S21) of coax probes with elliptic patch HIGP surface a. w_x=4 mm, g_1=0.4, g_2=0.3 mm b.w_x = 5 mm,g_1 = 0.4, g_2 = 0.3 mm c.w_x = 4 mm, g_1=0.2,g_2 =0.1 mm d. w_x=4 mm, g_1=0.3, g_2=0.2 mm.

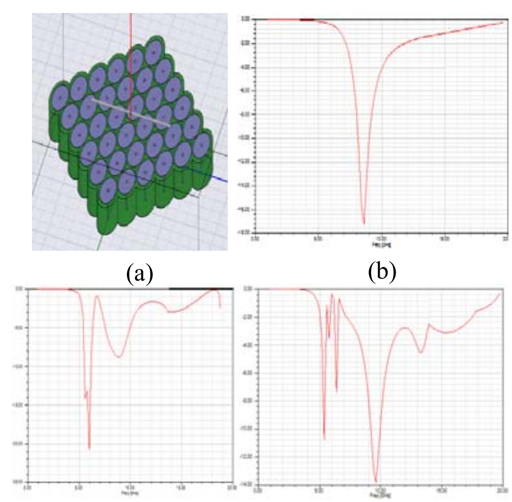
3. Antenna reflection reduction and radiation pattern enhancement

A broadband EBG range is observed for all these values of HIGP upto 11GHz. Since this band gap includes S-X-Ku bands, it is possible to use with many different length and types of antennas that radiate in this range. EBG frequency range is an important verification to decide efficiency of HIGP but the interaction of an antenna with HIGP must be investigated to have an exact idea.

A low profile dipole antenna that radiates at 8,5GHz in free space is used to compare HIGP antenna interaction. This dipole antenna is applied with HIGP that have dimensions; w_x=5mm, g_1=0,4mm, g_2=0,3mm and the distance between them is 1mm. This distance between dipole –HIGP is much lower than the dipole-PEC value (λ/4=8,8mm), so this provide miniaturization of the antenna system. Although S11 value for the free space dipole is -17dB at 8,5GHz, two different radiation frequency (6GHz and 8,8 GHz) is observed for HIGP-horizontal antenna system. The S11 value at 6GHz is approximately -21dB that is better than the free space radiation. One of the other exciting results is the radiation frequency that is 70% of the free space radiation, so the dipole length can be reduced below usual λ/2 dimension and the miniaturization of the system is possible.

The most important result is good return loss for two different frequencies. As a result this system can be used for more than one frequency point. Morever the return loss frequencies are in the EBG range of HIGP. Due to the non-symmetric behaviour of the elliptic mushrooms, rotation of the dipole around z axis on the exactly same HIGP changes the return loss frequencies. Two different return losses below -10dB is observed in the EBG frequency range.

Low return loss and broadband EBG frequency range must be satisfied but it is not enough to decide the overall system efficiency. The radiation pattern is one another necessity to finish the system design. The electric field directivity of free space dipole at 8GHz that is in the maximum return loss frequency range is symmetrically radiate at both side of dipole and electric radiation value is 20 for the same frequency of vertically positioned dipole (Fig. 3.d).

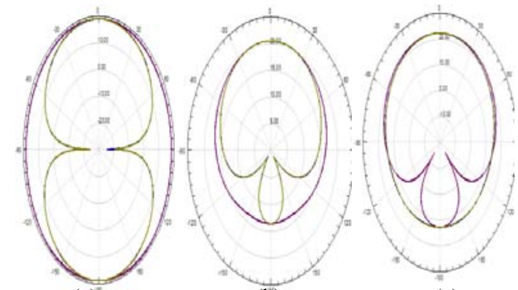


(a) (b)

(c) (d)

Fig. 3. a Dipole-HIGP antenna system b. Free space dipole return loss c. Horizontally positioned dipole-HIGP return loss d. Vertically positioned dipole- HIGP return loss.

Horizontal and vertical dipole antenna radiation pattern is investigated for the elliptic mushrooms of which dimensions are w_x=5mm, g_1=0,4 mm g_2=0,3 mm and the distance between dipole and HIGP is fixed at 1mm. Although the minimum return loss frequency is not 8,5 GHz for vertical polarization of dipole, its radiation and electric directivity is as good as free space, but the radiation pattern is non-symmetric and side lobes are reduced. The radiation pattern of horizontally positioned dipole on HIGP is approximately same properties with vertical one (Fig. 4).



(a) (b) (c)

Fig. 4. Radiation Pattern of a. free space dipole b. Horizontal dipole-HIGP c. Vertical dipole-HIGP.

4. Conclusions

In this paper, first we investigated EBG properties of HIGP composed of elliptic mushrooms and we showed that by changing the dimensions of unit elliptic mushroom, EBG characteristics can be improved. Based on these results, the optimized values are chosen for gap between mushrooms and mushroom dimensions to have broadband and clear EBG. Then free space low profile dipole antenna return loss is compared with specified HIGP which have broadband EBG. Band gap range of this new HIGP has been widened in comparison with free space antenna. Also elliptic mushroom has better directivity with dipole antenna due to impedance matching with each other.

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