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Electromagnetic Band Gap Materials Simplify the Structure of Dual Polarized Satellite Communications Antennas

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Abstract: The dual polarized reflector antenna used for satellite communications consists of two reflectors; one reflector is solid, the other consists of metal grid. The structure is complicated and the bandwidth is narrow. This antenna structure can be simplified by removing the metal grid and using the solid reflector together with a thin electromagnetic band gap material pasted to the surface of the reflector. The reflector works as a ground plane for the electromagnetic band gap material. The material is of the mushroom-like type. The material reflects the two orthogonal linearly polarized plane waves incident upon it without any change of polarization after reflection. A simple procedure for the design of the electromagnetic band gap material is developed. The antenna is wideband and the bandwidth is defined in advance. The dependence of the material dimensions upon the bandwidth is studied.

Keywords: electromagnetic band gap materials; dual-polarized antennas; satellite communications.

I. Introduction

Dual polarized antennas used for satellite communications consists of two reflectors, one of them is solid the other is a grating of conducting bars. This complicates the antenna structure and makes its operation narrow band. Electromagnetic band gap (EBG) materials allow very powerful control of polarization, [1]. The aim of this paper is to design an EBG material to reflect two linearly polarized orthogonal incident waves and to keep the polarization without any change after reflection. The EBG material is a few millimeters thick and sticks to the surface of the solid reflector. Thus the grating of the conducting bars is completely removed. The advantages of the EBG solution are: simpler structure and wider bandwidth. Section (II) reviews the operation of the conventional dual polarized antenna used for satellite communications. Section (III) explains the operation of the EBG material. The developed design technique is presented in section IV. The results are shown in section V and section VI contains conclusions.

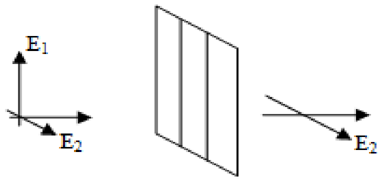


Fig. 1. A wire grid polarizer.

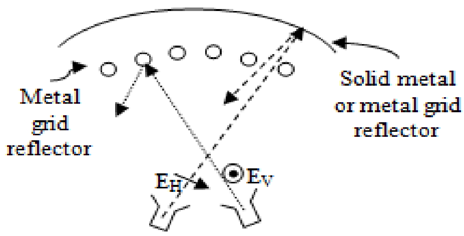


Fig. 2. A wire grid polarizer used in a dual polarized antenna.

II. Dual Polarized Antenna

To obtain an antenna radiation pattern having high polarization isolation, one approach is to use a reflector consisting of a grid, that is an array of conductors parallel to the required linear polarization. When the grid is illuminated by a radio wave, only the component of the electric field parallel to the grid is reflected (Fig. 1). Current can flow only along the conductors and the field component orthogonal to the grid cannot exist. Two separate antennas whose grids are perpendicular can be used to generate two beams with linear orthogonal polarization, [2,3]. The antenna consists of two reflectors with offset feed mounted one behind the other with a slight bias so that their foci are located at two different points (Fig. 2).

To illuminate each reflector, it is thus easy to locate the radiating elements operating with a given polarization at the corresponding focus. The front reflector is formed from a material which is transparent to radio waves on which an array of conductors is arranged parallel to the electric field of the waves generated by the associated illuminating source. These waves are thus reflected by the first reflector. The waves radiated by the other source have orthogonal polarisation. Hence they pass through the front reflector and are reflected by the rear one before again passing through the front reflector. The rear reflector can be either a grid (whose orientation is orthogonal to the first) or a conventional reflector. Even if a component with polarization orthogonal to the nominal polarization is generated due to offset mounting, this orthogonal component, which is parallel to the grid of the front reflector, is blocked at the rear of the grid. The front reflector, and the structure between the two reflectors, must be transparent to radio waves but capable of withstanding mechanical and thermal stresses. For instance, Kevlar layers can be bonded on each side of a honey comb core of the same material. The array of conductors can be embedded in the composite material and produced either by chemical etching of a conducting deposit or mechanically cutting a copper deposit formed on the Kevlar layer before bonding to the honeycomb.

III. EBG Solution

It is required to design an EBG material to cover the surface of the solid reflector. The designed material reflects two orthogonal linearly polarized incident waves with no change in polarization after reflection. The EBG structure (fig.3) is a rectangular patch mushroom like. The two orthogonal linearly polarized waves incident normally on the EBG structure are represented by:

$$E^i = a_1 e^{jkz} a_x + a_2 e^{jkz} a_y \qquad (1)$$

The reflected wave takes the form:

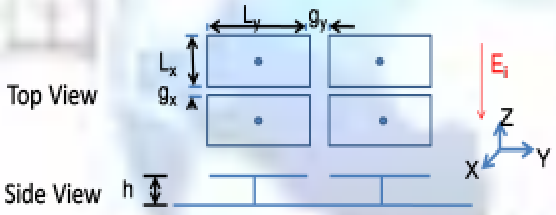
$$E^r = a_1 e^{-jkz} e^{j\theta x} a_x + a_2 e^{-jkz} e^{j\theta y} a_y \qquad (2)$$

θ_x and θ_y are the reflection phase of the x- and y-components of the electric field [4].

Now it is required that the polarization of the reflected wave be parallel to that of the incident wave. Thus:

$$[\, a_1 a_x + a_2 a_y \,] \,.\, [\, a_1 a_x + a_2 e^{(j\theta y - j\theta x)} a_y \,]/(\, a_1^2 + a_2^2 \,) = 1 \qquad (3)$$

Solving Eqn.(3) gives: $\theta_y - \theta_x = 0$. This result means that the reflection phase for the x-component of the electric field must be equal to that for the y-component.



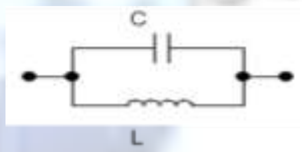


Fig. 3. Mushroom-like EBG material **Fig. 4. Resonant circuit representation.**

The parameters of the EBG structure are : the patch width (l_x), the patch length (l_y), gap widths (g_x, g_y), substrate thickness (h), dielectric constant (ε_r). When the periodicity (l_x+g_x, l_y+g_y) is small compared to the wavelength, the operation mechanism of the EBG structure can be explained using an effective medium model with lumped LC elements, [5]. The capacitor results from the gap between neighboring coplanar patches. This can be obtained using conformal mapping, [6,7]. The capacitance is given by:

$$C = \frac{l\varepsilon_o(1+\varepsilon_r)}{\pi} Cosh^{-1}\left(\frac{l+g}{g}\right) \qquad (4)$$

The reflection phase (θ_x or θ_y) is determined by the capacitance (C_x or C_y). The capacitance in its turn is determined by the patch length (l_x or l_y) and the patch spacing (g_x or g_y). Since θ_x and θ_y are equal $l_x = l_y$ and $g_x = g_y$. This means that the patches must be square with equal spacing in the x and y directions.

The inductance L results from the current along adjacent patches and depends only on the thickness of the substrate and permeability:

$$L = \mu h \qquad (5)$$

The surface is represented by a parallel resonance circuit (Fig.4) with impedance given by:

$$Z_s = \frac{j\omega L}{1-\omega^2 LC} \ldots\ldots\ldots\ldots..(6) \qquad (6)$$

The reflection coefficient at the surface of the EBG material is given by:

$$R = \frac{Z_s - \eta}{Z_s + \eta} \ldots\ldots\ldots.(7) \qquad (7)$$

where η is the intrinsic impedance of free space.

The bandwidth (bw) is given by, [5] :

$$bw = \frac{\sqrt{L}}{\eta\sqrt{C}} \ldots\ldots\ldots\ldots\ldots\ldots..(8) \qquad (8)$$

IV. EBG Design

The design procedure is summarized below, [8,9].

1. Define the operating frequency (f_{op}) , and required percentage bandwidth (bw) .

2. Find f_L and f_U, the boundaries of the frequency band width as follows: $f_L = f_{op}$ (1-bw/2), $f_U = f_{op}$ (1+bw/2).

3. At the operating frequency (f_{op}) resonance of the equivalent circuit takes place. Thus:

$$f_{op} = \frac{1}{2\pi\sqrt{LC}} \ldots\ldots(8) \qquad (9)$$

4. From Eqns.(6) and (7) above, we have:

$$R = \frac{\omega^2L^2 - \eta^2(1-\omega^2LC)^2 + j2\omega L\eta(1-\omega^2LC)}{\omega^2L^2 + \eta^2(1-\omega^2LC)^2} \ldots(9) \qquad (10)$$

From which the reflection phase is;

$$\theta = tan^{-1}\frac{2\omega L\eta\,(1-\omega^2LC)}{\omega^2L^2 - \eta^2(1-\omega^2LC)^2} \ldots\ldots\ldots(10) \qquad (11)$$

In this equation : $\theta = \pi/2$, at $\omega = \omega_L$ (the lower boundary of the bandwidth). The only unknown in (11) is the inductance L which can be determined.

5. From Eqn.(5) find h, the substrate thickness.

6. From Eqn.(9) above find C.

7. From Eqn.(4) , choose ε_r (substrate material), replace g by 0.1l find l. Taking the gap g a fraction of the patch length (l) is an arbitrary reasonable choice.

Thus all the dimensions of the structure are obtained.

V. Results

The variation of reflection phase with frequency is shown in Fig.(5). The reflection phase is zero at the operating frequency which is the resonance frequency of the equivalent circuit, taken to be 3 GHz. The curve is steeper for narrower bandwidths. The dependence of substrate thickness on bandwidth is shown in Fig.(6).

Table 1: Dimensions of the structure as a function of the bandwidth

Band width %	Patch length mm	Patch gap mm	Substrate thickness mm
15	32.4	3.2	2.5
30	15.5	1.5	5.2
45	9.8	1	8.2

When the thickness (h) increases, the inductance L increases (Eq. 5) and the bandwidth increases (Eq. 8). Patch size dependence upon bandwidth is shown in Fig. (7). As the patch size increases, the capacitance C increases (Eq. 4) and the bandwidth decreases (Eq. 8). The dimensions of the structure corresponding to the three values of the bandwidth considered are given in table (1).

The three EBG structures corresponding to the three values of bandwidth were analyzed using HFSS. The reflection phase was computed and compared to that obtained by the design procedure developed here. The results are shown in Figs. (8), (9), and (10). The dashed curves are those obtained by HFSS. The agreement between the results becomes better as the bandwidth increases. This is because, increasing bandwidth results in decreased capacitance which means decreased patch size. The smaller the patch size compared to wavelength, the better will be the approximation provided by the developed technique. For the example given in this paper, the operating frequency is 3 GHz which corresponds to a wavelength of 100 mm. The patch size for 15% bandwidth is 32.4 mm (0.32 λ). The patch size for 45% bandwidth is 9.8 mm (0.1 λ).

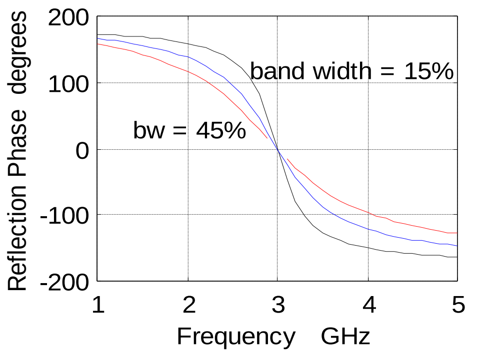


Fig. 5. Reflection phase vs. frequency.

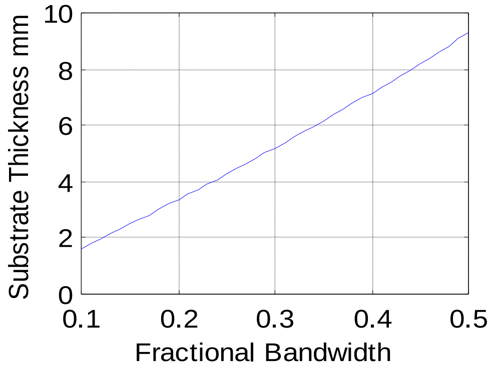


Fig. 6. Substrate thickness vs. fractional bandwidth.

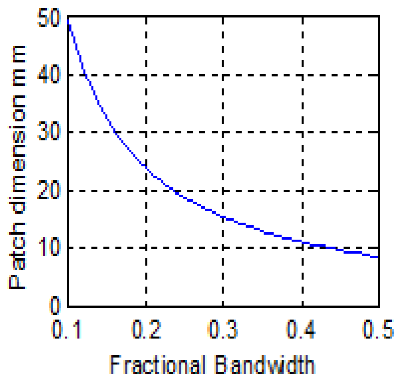


Fig. 7. Patch side vs. fractional bandwidth.

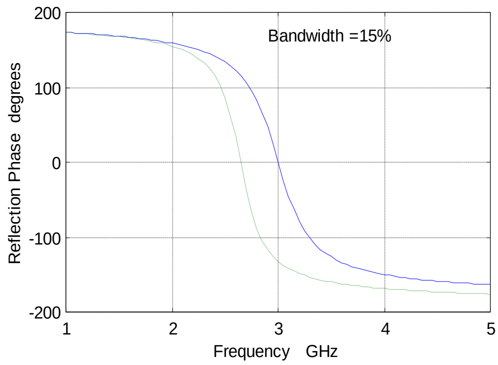


Fig. 8. Comparison between reflection phase obtained by HFSS (dashed curve) and that obtained by the developed technique. Bandwidth = 15%.

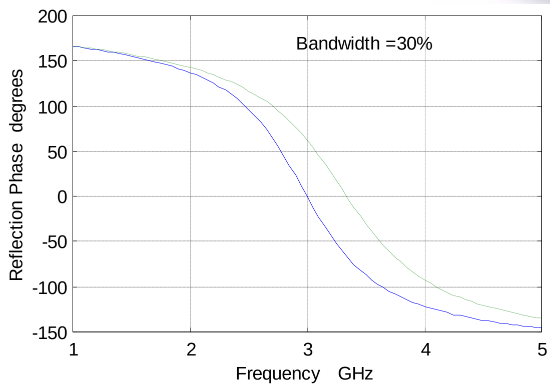


Fig. 9. Comparison between reflection phase obtained by HFSS (dashed curve) and that obtained by the developed technique. Bandwidth = 30%.

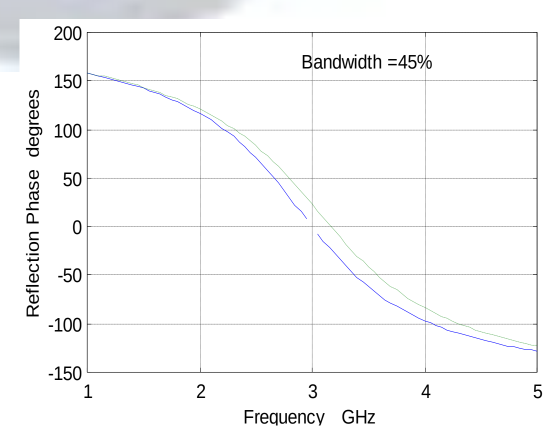


Fig. 10. Comparison between the reflection phase obtained by HFSS (dashed curve) and that obtained by the developed technique. Bandwidth = 45%.

VI. Conclusions

The designed material consists of square patches on a dielectric substrate with vias through the center of the patches. The gap between the patches is equal in both x- and y- directions. The equivalent inductance L increases with the band width. Hence, substrate thickness increases. For a 45% fractional bandwidth the substrate thickness is 8.2 mms. The equivalent capacitance C is connected with the equivalent inductance L through the operating frequency : $w_{op} = 1/(LC)^{0.5}$. The inductance increases with the bandwidth. Therefore, the capacitance decreases as the bandwidth increases. Since the side of the square patch is directly proportional to the equivalent capacitance, the patch side decreases as the bandwidth increases. For a 45% bandwidth the patch side is about 9.8 mms. The accuracy of the technique was checked by comparing the reflection phase with that obtained by HFSS. As the dimensions decreases (compared to wavelength) the accuracy becomes better.

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