Suppression Mutual Coupling between the Resonators in Microstrip Antennas by using PBG Substrates

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Abstract – **In the paper investigations related to suppress the mutual couplings using 1D and 2D dielectric structures are presented. Investigations and analysis are made in the sequence: offering dependencies applicable method – moments in the case of one-and two-dimensional periodic dielectric structures; simulation study of periodic and non-periodic dielectric structures to reduce mutual influences between the planar microstrip antenna grids.**

Keywords – **Microstrip antenna, PBG, substrate, antenna array.**

I. INTRODUCTION

Reduction of mutual coupling between the resonators in microstrip antenna arrays can be achieved by change of permittivity in the area between resonators or by periodic dielectric structures. In essence, these techniques are further developing the theory of dielectric antennas, but the regimes in which they do not radiate or play the role of dielectric band-stop filters.

Periodic dielectric materials (PBG - photonic-band gap), or also known as photon crystals are periodic inhomogeneous materials that stops the propagation of electromagnetic waves in a given bandwidth. The stop-band of the frequency range depends on the lattice constant of *b* (the ratio of the size of individual elements to the distance between elements), which are built this structure [1, 2]. Exact frequency band of a PBG structure depends on many physical parameters such as parameters of the environment and type of the lattice geometry of the individual element. In the antenna arrays, applications the structures are mainly constructed in one and two-dimensional grids. In the most commonly used substrate, are made holes or slots with a fixed period of the lattice. In more complex lattice configurations can have any configuration and shape.

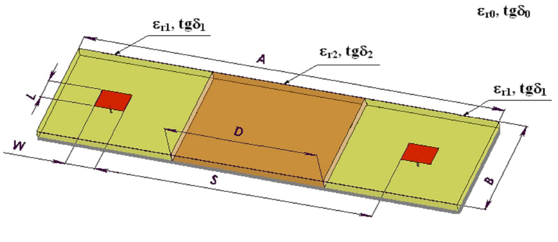

Fig. 1. Test setup for the study of the mutual influences between the two microstrip resonators by changing of permittivity in the area between them and the change in the width of this area.

Besides these parameters influence has and thickness of the substrate. As a rule we can say that in order to obtain the effect of suppression of surface wave it is necessary to use relatively thick (compared to wavelength) substrate with a large relative permittivity. Of course, in a real dielectric substrate thickness affects the transmission losses and the relative coefficient of refraction of electromagnetic waves.

II. ONE DIMENSIONAL PERIODIC DIELECTRIC STRUCTURES

A. Mutual coupling between two resonators in the change of permittivity in the area between them

In this point has been made simulation investigation of the mutual coupling between two microstrip resonators as the parameters of the dielectric substrate does not modify the whole structure, but only in a specific area between them.

In other words interest represents, what impact has the introduction of the permittivity no uniformity with certain size and a relative permittivity in the area between resonators. The calculations were made with parameters: substrate thickness h = 1,5 mm; relative permittivity for the area of the resonators ε_{r1}=10,2; modification of the relative permittivity of the area between resonators ε_{r2}=1… 20; dielectric losses $tan\delta_{\varepsilon}$ = 0.003; thickness of the metallization t = 17.5 μ m; surface resistance of copper R_s = 1,82 μς/cm; baseline distance between the resonators $S[mm]$ = 0.5λ_0; modification of the width D $[mm]$ permittivity of non-uniformity $0 \le D \le S$, i.e. change in the ratio $D/S \in [0,1]$.

B. Numerical results

Electromagnetic simulation is made using RF electromagnetic simulator. Parameters as defined in the study are conducted by maintaining the best matching of the resonators. On Fig.2 is a Smith chart of the configuration of Fig.1. It clearly can be seen that the change of permittivity dielectric between the two does not submit additional parasitic resonance.

Fig. 3 shows the dependence of coefficients S_{12} (S_{21}) in the modification of the ratio D / S (Fig.1.) for three different values of permittivity of the intermediate dielectric. Clearly the highest value of the mutual coupling between the resonators is in the case when is used highest dielectric permittivity value, but at lowest value is at ε_{r2}=1. When

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ε_{r2}=11 the amendment is minor, because the value of permittivity is very close to that of $r_1 = 10.2$ (patches area).

From the figure can be observed that for $D/S \cong 0{,}73$ in the value of ε_{r2}= 20 is seen maximum and down on the value of the S_{12} starts to decline slightly. Graph relating to ε_{r2} = 1 in value of the ratio $D/S \cong 0{,}64$ starts to decrease more quickly. This character of change of mutual influence as a function of the size of the second dielectric for different values of ε_{r2} has important practical significance. Because of this feature may be designed frequency-selective structures to suppress the propagation of surface wave. Given the above can be made the following conclusions:

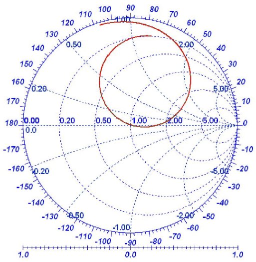

Fig. 2. Smith chart of S11 and S22 parameters of the two patches.

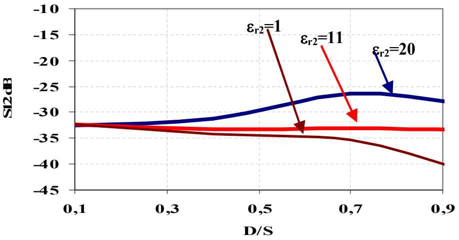

Fig. 3. Results from the study of mutual influence between two microstrip resonator with a change of permittivity in the field between them and the change in the breadth of this area

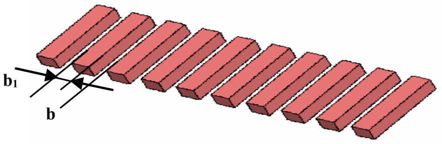

Fig. 4. One-dimensional dielectric periodic structure with a period b and width of the dielectric layer b_1.

Changing the relative permittivity in the area between resonators does not lead to significant suppressing of surface waves and the mutual influence between the resonators.

Weak resonance character, which is seen when comparing the graphs of Fig. 3 due to mish-matching of the resonators as result of changes in the permittivity adjacent to them;

Least mutual influence was observed in the case using air. This is because in this case have not propagation of surface waves and the mutual influence is mainly due to the impact of the metal ground plane. Reduce this influence can be further achieved if instead of a complete ground plane metallization using resonance structure.

A. Analytical Model for The Presentation Of The Field In One-Dimensional Periodic Dielectric Structures

In this section is made mathematical analysis and simulation of one-dimensional dielectric structures in order to reduce the mutual influences between the planar antenna grids.

For spreading modes in a periodic permittivity structure, field in the neighboring cells is associated with a complex constant [4]. This may be shown in the following ways:

$$E(x,y,z+b) = E(x,y,z)e^{-j\beta_0 b}, \tag{1}$$

where $E\ (x,\ y,\ z)$ is a periodic function of z with a phase constant in a direction z β_0.

Distributed modes in the z direction can be represented as:

$$E(x,y,z) = E_p(x,y,z)e^{-j\beta_0 z}, \tag{2}$$

where $E_p(x,y,z)$ is a periodic function of z with period b, then

$$E(x,y,z+b) = E_p(x,y,z+b)e^{-j\beta_0(z+b)}, \tag{3}$$

Because $E_p(x,y,z)$ is a periodic function with period *a:*

$$E_p = (x,y,z+b) = E_p(x,y,z) \tag{4}$$

By substitute (3) in (4) can be obtained the following formula:

$$E(x,y,z+b) = E_p(x,y,z)e^{-j\beta_0(z+b)}. \tag{5}$$

But taking into account (2) is obtained exactly theorem of Floquet:

$$E(x,y,z+b) = E(x,y,z)e^{-j\beta_0 b} \tag{6}$$

$$E(x,y,z) = \sum_n E_n(x,z)e^{-j\frac{2\pi n}{b}z}e^{-j\beta_o z} = \sum_n E_n(x,y)e^{-j\beta_n z} \tag{7}$$

where

$$E_n(x,y) = \frac{1}{b}\int_0^b E_n(x,y,z)e^{j\frac{2\pi n}{b}z}dz \tag{8}$$

are coefficients which represent the dependencies on x and y

$$\beta_n = \beta_0 + \frac{2\pi n}{b}$$

is the phase constant of these n-harmonics.

Thus, the field in the periodic structure may be decayed to the infinite number of harmonics by the theorem of Floquet, each with frequency f and propagation constant β_n.

Be considered a flat electromagnetic wave, which propagates across the periodic structure with a permittivity and a dielectric layer of width b.

The decision of the wave equation for one-dimensional dielectric structures of the type shown in Fig. 4 can be obtained by decomposition in a periodic series of Fourier.

Electrical field is a periodic function decay of flat waves in x with period b, (which determines the constant of distribution k_{x0}) and obtained in following form:

$$E(x,y)=\hat{z}E_z(x,y)=\hat{z}E_p(x)e^{-jk_{x0}x}e^{-jk_y y} \tag{9}$$

where $E_p(x)$ is a periodic electric field which is distributed only in the XY-plane, i.e. $k_z = 0$. Assuming that the parallel layers in endless directions y and z, wave equation can be simplified and presented as:

$$-\frac{d^2}{dx^2}E_z(x,y)+k_0^2\varepsilon_r(x)E_z(x,y)=k_0^2\varepsilon_r(x)E_z(x,y) \tag{10}$$

Periodic electric field to decay by a Fourier series along the axis x with unknown coefficient a_n, which serves to present dependence on the axis Y.

$$E_p(x)=\sum_n b^n e^{-j\frac{2\pi n}{b}x} \tag{11}$$

Permittivity is also periodic and is suitable for the decomposition in Fourier series with coefficient b_m

$$\varepsilon_r(x)=\sum_m b_m e^{-j\frac{2\pi m}{b}x} \tag{12}$$

Make a substitution of the Fourier decomposition of the field and in the dielectric (9) and obtained:

$$\sum_n\left[\left(\frac{2\pi n}{b}+k_{x0}\right)^2+k_y^2\right]a_n e^{-j\frac{2\pi n}{b}x}=$$

$$k_0^2\sum_n\sum_m a_n b_m e^{-j\frac{2\pi m}{b}x}e^{-j\frac{2\pi n}{b}x} \tag{13}$$

In accordance with the determination of the unknown coefficients a_n and b_m Eq. (12) are multiplied by orthogonal function and is integrated for a single cell with a specific index using Kroneker's delta function.

$$\sum_n\left[\left(\frac{2\pi n}{b}+k_{x0}\right)^2+k_y^2\right]a_n\delta\left(\frac{2\pi p}{b}-\frac{2\pi n}{b}\right)=$$

$$k_0^2\sum_n\sum_m a_n b_m\delta\left(\frac{2\pi p}{b}-\frac{2\pi m}{b}-\frac{2\pi n}{b}\right) \tag{14}$$

Likewise can be determined and propagating *TM*-modes. By using the derived relationships is relatively easy to determine the frequency and extent of distribution of *TE* modes in periodic-permittivity substrate. This is a convenient approach to applying the method of moments.

B. *Evaluation of mutual influence between two microstrip resonators using one-dimensional periodic structure in permittivity between them*

Dielectric periodic structures as explained can be constructed in such a way as to achieve effective filtration structure for suppression of certain modes. Given the complexity of this issue in such configurations must be taken into account the fact that the most influential has TM_0 mode of surface waves. Matching the appropriate values of thickness and relative permittivity of the dielectric substrate may reduce the propagation of the TE_1 mode. Thus, the periodic structure can be realized only suppression of TM_0 mode of surface waves. After defining the geometry of the periodic structure, the dispersion relationships for transverse field components can be calculated by the method described above. The main parameter to be calculated is the ratio b_1 / b to obtain the desired effect of reducing the respective mode.

Practical computing of band-stop ranges can be made using the microstrip line located on one particular made periodic permittivity substrate with a b_1 / b (Fig. 5). Graphs obtained from the calculations can be presented as Brillouin zones (BZ). They represent the dependence of normalized frequency, depending on the distribution constant for the area. In the case of *1D* structure constant of the distribution depends only on the ratio b_1 / b.

Basic configuration, which may find application in the antenna arrays is shown in Fig. 5. Again as in previous models, the parameters of permittivity substrate in the resonators are fixed and they not changed during the study but the relative permittivity of the area between resonators is changing [3]. This is a modular approach to build antenna arrays, i.e. have not used a single permittivity substrate. Thus it is possible to optimize the antenna further when in the area between radiating elements are placed specific filtering material for the wished bandwidth properties. Although seemingly more complex structure such antenna array is not a problem in technological terms, and in some cases can be used to reduce cost, weight and dimensions.

Parameters of permittivity substrate and microstrip line are:

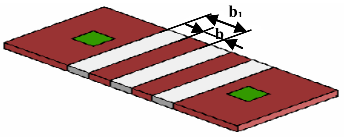

Fig. 5. Setup for determining the level of reduction of the mutual influences through *1D* periodic structure with permittivity *b* time and width of dielectric layer *b1*

input impedance *Zin* =50Ω; filling factor of the intermediate dielectric *b1/b* = 0,5; permittivity of the substrate ε_r= 10,2; width of the dielectric substrate h=1,27mm;

Graphic results of calculations of the mutual influence between two adjacent microstrip resonators *1D* dielectric structure with between them are presented in Fig. 6. Can be seen that the main focus the analysis on the impact, which has the value of relative permittivity on the coefficient of correlation of two adjacent microstrip resonator in *E*-plane to one another. It should be noted that in the entire sequence of tests for different values of ε_r resonance frequency of microstrip resonators is constant and is therefore presented a picture for the S_{11}.

Completely logically equivalent when increasing the relative permittivity in the area between the two resonators increases the mutual influence between the frequency of resonance. The latter is indeed true and observed values in the relative permittivity of ε_r = 1 to ε_r = 31. For large value of relative permittivity ε_r = 50 (eg using special ceramics) the value of the S_{12} is considerably smaller than even the case when using air. This fact can be explained by the fact that in a certain ratio between the permittivity of air and the second dielectric and, in certain size resonance occurs.

Resonance character can be observed with other graphics, but for other frequencies. Graph of these areas are marked with circles. Watching them more closely you can see that in the linear change of relative permittivity is observed slightly exponentially change the frequency of such resonance. However with increasing frequency, ε_r is reduced. This dependence is illustrated in Fig.7.

It is observed that a large change in relative permittivity does not lead to a drastic change of resonance frequency. However, the study shows that in the optimal selection of sizes and permittivity can achieve significant reduction of the mutual influences between the elements.

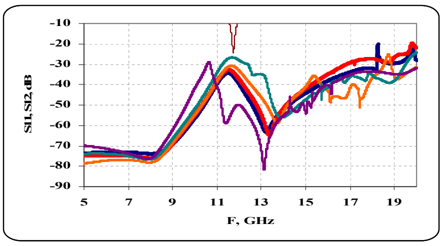

Fig. 6. Numerical results of the investigation of mutual influence between two microstrip resonators with permittivity placing *1D* structure

III. OUTPUT DATA AND METHOD OF ANALYSIS TO DETERMINE AREAS OF SURFACE WAVE PROPAGATION IN THE CASE OF 2D STRUCTURES

The simplest way to obtain the permittivity of two-dimensional structure is in plain permittivity substrate with certain values of relative permittivity and thickness to drill holes with defined diameter and period (Fig. 8).

Parameters of permittivity substrate and microstrip line are: input impedance of microstrip line Z_{in} = 50Ω; b_1 / b = 0,5; permittivity ε_r = 10,2; substrate thickness h = 1,27 mm.

Calculation of microstrip line is made using the electromagnetic simulator *SV Ansoft Designer*, whose width is W = 1.3314mm. To calculate the Brillouin zones is necessary to determine the configuration of the structure (rectangular or triangular lattice of holes).

Fig. 9 presents the results of the simulation study of the structure of Fig.8. For comparison, the graph shows the coefficient of correlation in the case when no holes. Can be seen that is possible to receive frequency band, in which the structure has high impedance (11 GHz).

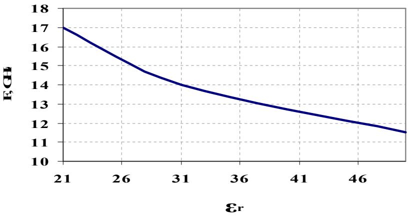

Fig. 7. Graphical representation of the variation of resonance frequency change of the value of the relative permittivity of the periodic structure

Survey shows that in an appropriate selection of the relative permittivity and thickness of the permittivity substrate can reduce the degree of mutual influence between the planar antenna grids. From the graph in Fig. 9 shows that the suppression of mutual influences is very narrow bandwidth.

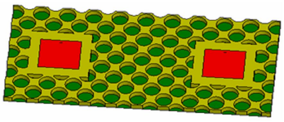

Fig. 8. Setup for investigation of mutual coupling in *2D* periodic structure (PBG) patch antenna.

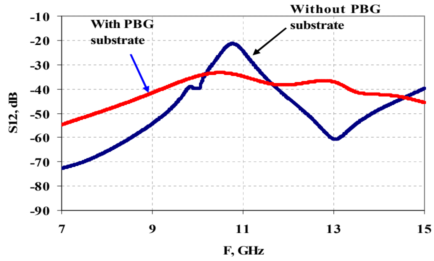

Fig.9. Comparison of the degree of mutual influence in the cases with and without the use of PBG structures

IV. CONCLUSIONS

Based on the theoretical and simulation studies on the possibility of suppression of mutual influence between the planar antenna arrays can be used fully periodic dielectric structures (one or two-dimensional). As a disadvantage may be stated that to obtain a strong effect is necessary to use materials with high permittivity (ε_r> 10) and substrates with high thickness. In addition, it is necessary to note that in this way is difficult to reduce the size of structures, because to obtain a desired field distribution of electromagnetic field (to achieve high impedance) is necessary to ensure a minimum volume. Another feature is that when using periodic dielectric structures can reduce the weight of the antenna, but at the expense of her physical strength.

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