Investigation of Periodic EBG Structures with Increased Bandwidth

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Abstract –This paper represents investigation of methods for mitigation of mutual coupling between the elements of planar antenna arrays by using EBG substrates. Closed-form expressions for fast calculating of the band-gap frequencies based on simplified equivalent circuits are presented. The results can be used for reducing of mutual coupling between the elements in planar antenna arrays and other RF devices.

***Keywords* – Patch antennas, surface wave, EBG, high surface impedance.**

I. INTRODUCTION

In the last few years a new class of periodic structures, which have frequency band-gap, are designed. This class of structures is known as EBG (electromagnetic band-gap structure) structures. They have a large number of applications as: compact waveguide, suppressing of surface wave, commutation noise in the digital circuits and so on. [1], [2]. The most used periodic structures are two dimensional (2D). 2D metal-periodic structures are mainly investigated in the paper. It is accepted that there are conditions for quasi-stationary.

If the dimension ***a*** of each element is smaller than wavelength, electromagnetic property can be described with equivalent circuits – capacitances and inductances (fig. 1.). In the frequency band with high impedance, tangential magnetic field is low even if there is high electric field in the surface. For this reason sometimes such structures can be described as "magnetic conductor" [4]. The most elementary periodic structure of this type is the periodic structure with grounded microstrip patches. In the paper it is taken notice of such structures with increased frequency band.

II. EBG SUBSTRATE DESIGN

The basic characteristic of periodic structures prototype is the usage of additional equivalent resonance circuits in each element [5]. If each microstrip line is examined like an equivalent inductance and the distance between them is examined like a capacity, it is not hard to be seen that parallel resonance circuits are formed. On the other hand, using the above-mentioned conception, equivalent transmission line between all elements is formed (1).

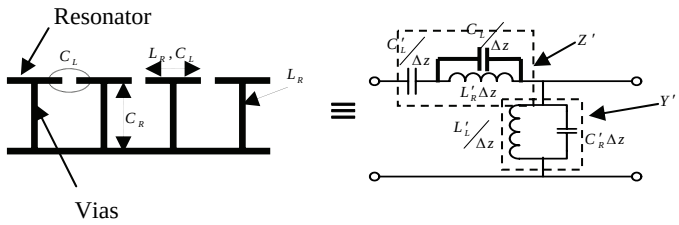

Fig. 1. Equivalent circuits of the meta-materials with increased bandwidth by using transmission line theory

The formula for the self capacitance can be presented:

$$C_1 = \xi \frac{a\varepsilon_0(1+\varepsilon_r)}{\pi} \cosh^{-1}\left(\frac{a+g}{g}\right) \tag{1}$$

The filling ratio ξ f is defined as the area of the metal surface of a spiral-shaped element with sizes $d \times d$ divided by the area of a square patch d^2.

Equivalent inductance is formed on the surface of the dielectric substrate in the area of each of these elements [3]:

$$L_{str}(nH) = L(nH) \pm M(nH) \tag{2}$$

where L is the self-inductance of the microstrip line, M is the mutual inductance. They can be expressed with the following equations:

$$L(nH) = 2.10^{-4} l \left[\ln\left(\frac{l}{W+t}\right) + 1.193 + \frac{W+t}{3l} \right] K_g \tag{3}$$

$$R_s(\Omega) = \frac{KR_{sh} l}{2(W+t)} \tag{4}$$

$$C_{R\_str}(pF) = 16{,}67.10^{-4} l \frac{\sqrt{\varepsilon_r}}{Z_0} \tag{5}$$

where all dimensions are in microns and

$$K_g = 0.57 - 0.146 \ln\frac{W}{h}, \qquad \frac{W}{h} > 0.05 \tag{6}$$

$$K = 1.4 + 0.217 \ln\left(\frac{W}{5t}\right) \qquad 5 < \frac{W}{t} < 100 \tag{7}$$

The term K_g accounts for the presence of a ground plane and decreases as the ground plane is brought nearer. Another term

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K is a correction factor that takes into account the crowding of the current at the corners of the conductor. The terms W, t , h, l and R_{sh} are the line width, line thickness, substrate thickness, length of the section, and sheet resistance per square of the conductor, respectively. The mutual inductance is:

$$M_{ij} = 2.10^{-4} l_e \left[\ln\left\{ \frac{l_e}{d} + \sqrt{1 + \frac{l_e^2}{d^2}} \right\} - \sqrt{1 + \frac{d^2}{l_e^2}} + \frac{d}{l_e} \right] \qquad (7)$$

where, l_e is the effective length of both adjacent sections, d is the distance between the sections.

III. Experimental Investigations of Metalo-Dielectric Structures with Grounded Vias.

The analytical expressions for the design of the structures with grounded vias are used. For that purpose the basic configuration from fig. 1. is used. Instead of microstrip resonators microstrip lines with definite width are used (fig. 2). The main objective is bandwidth increase by a group of adjacent resonances. The computation of this structure is performed approximately by the expressions (1) - (8).

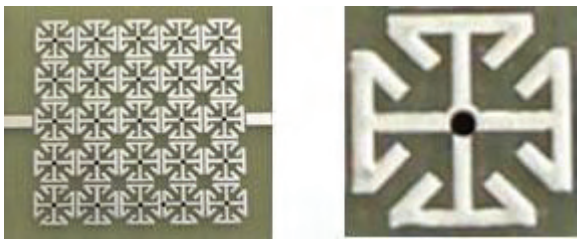
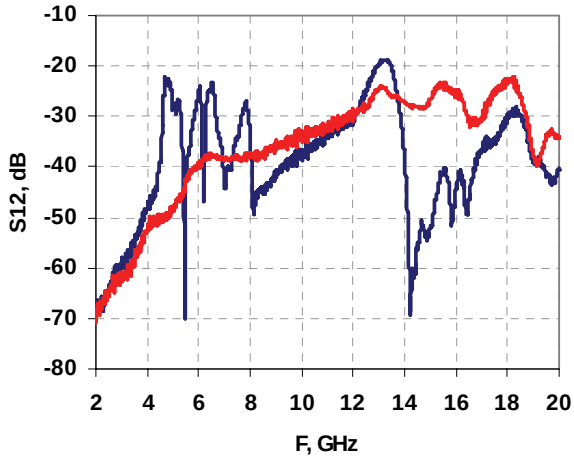


Fig. 2. EBG structure with inductive elements and grounded vias

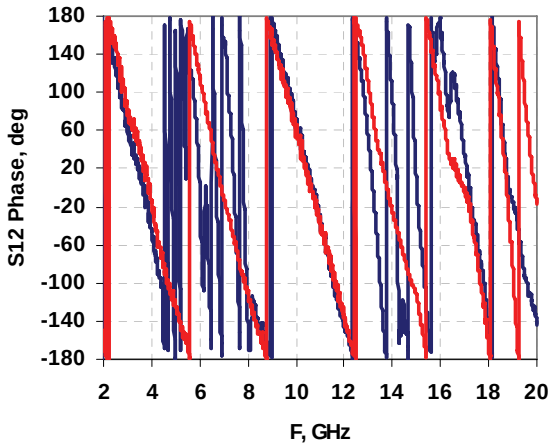
The parameters of this structure are as follows: material of the dielectric substrate *FR4* with relative dielectric permittivity $\varepsilon_r \approx 4{,}4$; height of the dielectric substrate $h = 1{,}5$ *mm*; width of microstrip line $W=0{,}3$ *mm*; gap between the elements of the structure $g = 0{,}3$*mm*; period of the structure $p = 6$*mm*; radius of the holes $r = 0{,}4$ *mm*.

Determination of the band-gap is realized by microstrip lines with characteristic impedance $Z_c=50\ \Omega$. Self-calibration of the vector network analyzer is performed in the range of *2 GHz to 20 GHz* where the frequency points are $N=1601$ ($\Delta f \approx 11$ *MHz)* in number.

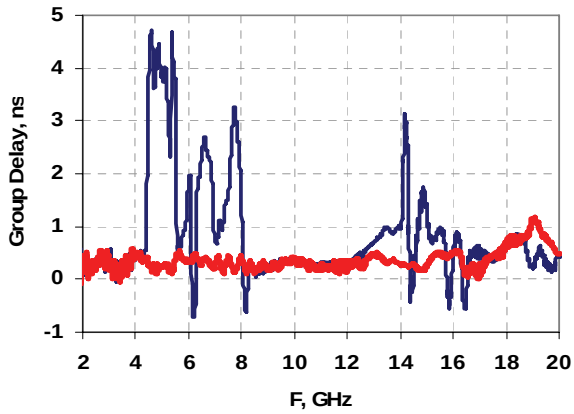
The measurement results are presented on fig. 3.



a)



b)



c)

Fig. 3. The measurement results of the structure are shown on fig. 6.16. a) Magnitude of S_{12} vs. frequency, dB b) Phase of S_{12} vs. frequency c) Group delay τ, *ns* vs. frequency

The plots for S_{12} [dB] show relatively wide band with low mutual coupling that is formed by several narrow band

resonances. A great mitigation of the mutual coupling at 14,2 GHz that is 40 dB and also 16,8 GHz that is 20 dB can be seen. The frequency band with 10 dB mitigation is 3 GHz and above 3 dB is greater than 4 GHz. In practice, the mitigation of the mutual coupling can be also achieved in the frequency band 8-9 GHz.

Fig. 3.b shows multiple phase variation for the regions where increasing or decreasing of the mutual coupling exists. The sign of these variations is shown on the group delay plot. It must be mentioned that in the frequency band between 5 and 8 GHz the sign of the group delay coincides with the sign of magnitude of S_{12} [dB]. This property is inherent to the electrical filters. In this frequency band the structure is alike the band pass filter. For the frequency region about 5 GHz the mutual coupling is 25 dB greater than in the case without this structure.

In the band from 9 to 12 GHz the variations of the magnitude and the phase of S_{12} are setting up in steady state. This results in the phase of S_{12} that is equal to the phase for grounded dielectric substrate without any metal structures. At frequency f = 14,1 GHz the group delay grows very fast but the mutual coupling is reduced due to the increasing of the surface impedance. At frequency f = 14.2 GHz the group delay is decreased and changes its sign. After reaching the minimum value of the group delay it can be seen maximum of the attenuation again (fig. 4).

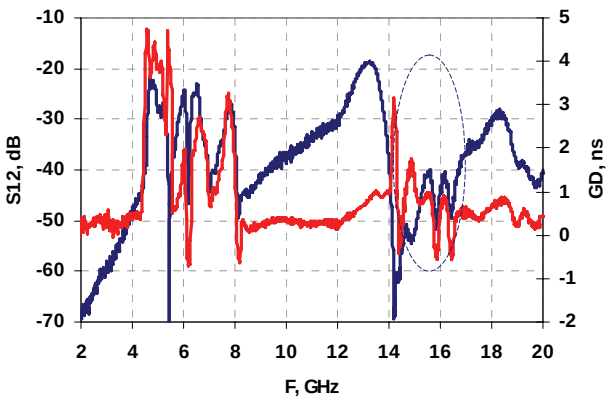


Fig. 4. The magnitude of S_{12}, dB and the group delay τ, ns vs. frequency

The magnitude of S_{12} and the group delay are shown on the same plot in order to represent the variations of these terms in the frequency band with high surface impedance. In fact, in this frequency band the structure changes the signs of the effective permettivity and permeability. At the points where the impedance reaches its maximum the constant of propagation is zero and the phase alters its sign.

Another topology of the periodical structure with high surface impedance that contains vias is shown on fig. 5. Despite of the previous topology, in this structure all inductive elements have common starting point and a capacitive coupling is formed in the opposite ends.

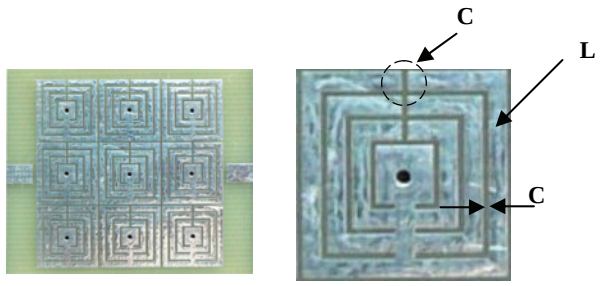
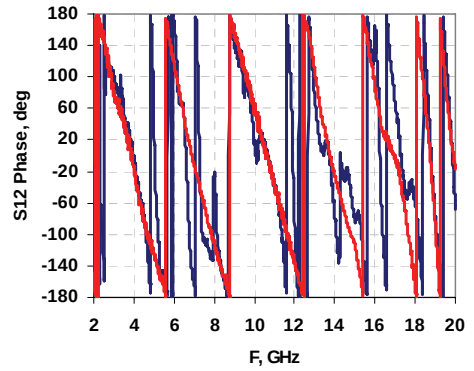
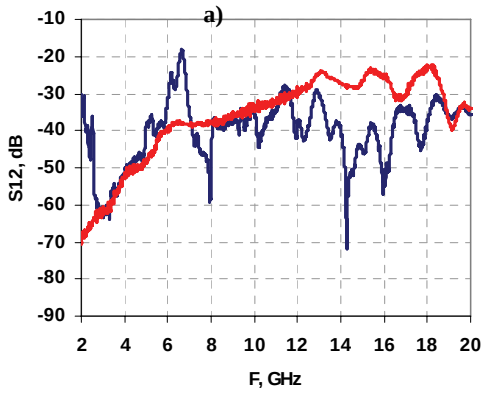
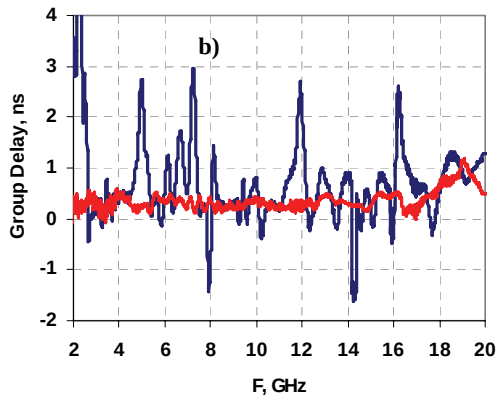


Fig. 5. Combined metal-dielectric periodical structure with modified inductive elements and vias







c)

Fig. 6.The measurement results for the structure a) Magnitude of S12 vs. frequency, dB b) Phase of S vs. frequency c) Group delay τ, ns vs. frequency

These plots show that the variation of the transmission coefficient is very much alike the structure on fig. 6. The main advantage of new structure is the presence of resonators that results in high surface impedance. Consequently, it decreases of the surface wave propagation in sufficiently wide band by appropriate selection of the inductors and capacitors can be achieved. The vias usage is the main disadvantage of the above- mentioned structures.

IV. CONCLUSION

In this paper are made investigations of two kinds of periodic metal-dielectric structures, which are used to increase the surface impedance of the dielectric substrate between the elements. Contemporary methods for design of periodic frequency selective structures with high surface impedance for reducing of mutual coupling between the elements in the planar antenna arrays are used.

The results can be used for development and design of antenna arrays with a low mutual coupling between the elements, for reducing of switching noise in the active antennas and other RF devices.

REFERENCE

[1] C. Balanis "*Antenna Theory (Analysis and Design)*", John Willey and Sons, Inc. N.Y. 1998

[2] Helszajn, J., "*Microwave planar passive circuits, and filters*", JohnWiley&Sons, 1994

[3] I. Bahl, "*Lumped Elements for RF and Microwave Circuits*", Artech House, London, 2003

[4] D. Sievenpiper, Lijun Zhang; R.F.J. Broas, N.G.Alexopolous, E.Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band*" IEEE Transactions on Microwave Theory and Techniques, , vol.47, No.11, pp.2059-2076, November 2003*

[5] D. F. Sievenpiper, "High-Impedance Electromagnetic Surfaces", PHD dissertation, 1999.