Three Layer Planar Antenna with Metamaterial
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Abstract — This paper presents a structure of three layers of the planar antenna including metamaterial substrate of negative refraction index. The theory uses the concise full wave Transverse Transmission Line (TTL) method. The use of this method is important for the simplification of algebraic equations involved in the development. The resonance frequency was determined. The results for this application are presented at the first time.

Key Worlds — Metamaterial, TTL Method, Planar antenna, Multilayers.

I. INTRODUÇÃO

Currently the planar antenna has been used widely because of its many advantages. They can be used in several systems, such as: radars, wireless, biological applications, mobile telephony and satellites communication.

This paper presents an application of three layer antenna with metamaterial at the first time. The analysis is made using the concise full wave TTL method.

There is a great challenge to integrate multilayer dielectric antennas. These antennas have many advantages such as flexibility in the frequency band operation and have a physical size reduced.

The three regions of the structure are shown in the Fig.1. The moment method is applied and adequate basis functions are used to expand the current densities in the metallic patch.

The metamaterial substrate shown in region 1 of Fig.1 is modeled by utilizing by anisotropic tensor properties, which are expressed as [1] – [2]:

\[
\varepsilon = \varepsilon_0 \begin{pmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{pmatrix}
\]

\[
\mu = \mu_0 \begin{pmatrix} \mu_{xx} & 0 & 0 \\ 0 & \mu_{yy} & 0 \\ 0 & 0 & \mu_{zz} \end{pmatrix}
\]

II. THEORY

The Transverse Transmission Line method is used in the determination of the electromagnetic field components in the Fourier transform domain (FTD), for the three regions of the structure. The moment method is applied and adequate basis functions are used to expand the current densities in the metallic patch. The component of propagation in the y direction is used, treating the general equations of electric and magnetic field as functions of \( E_y \) and \( H_y \) [3]-[5].

The identification of the permittivity and permeability tensors, with an inhomogeneous structure allows the properties of the metamaterial to be expressed conveniently, in analytic form. The term electromagnetic metamaterial has been applied to artificial structures, that possess properties beyond those available in naturally materials. The term metamaterial can be replaced by artificial material, or photonic crystal at optical frequencies, at region 1 of the Fig. 1. The type of structure presented here is shown in the Fig. 2.

Starting from the Maxwell equations, and after several algebraic manipulations, the equations that represent the electromagnetic fields in the x and z directions are obtained for the dielectric 2 and 3 regions as:
The solutions of Helmholtz’s equations for the three regions of the antenna were obtained.

Substituting these solutions in the equations of the fields, in function of the unknown constants $A_{xi}$, $A_{xh}$, $A_{ze}$ and $A_{zh}$ is obtained, for example, for the region 2[3]:

$$
\tilde{E}_{z2} = \frac{-j}{\gamma^2 + K_z^2} \left[ a\gamma_2 A_{z2} \sinh[\gamma_2(y-h)] + jw\beta k A_{z2} \sinh[\gamma_2(y-h)] \right]
$$

(13)

$$
\tilde{H}_{z2} = \frac{-j}{\gamma^2 + K_z^2} \left[ \beta k A_{z2} \sinh[\gamma_2(y-h)] - jw\mu A_{z2} \sinh[\gamma_2(y-h)] \right]
$$

(14)

To the determination of the unknown constants described above the boundary conditions are applied in the structure shown in Fig. 1, in $y = h_1$ and $y = h = h_1 + h_2$.

The general equations of the electromagnetic fields as function of $\tilde{E}_{xh}$ and $\tilde{E}_{zh}$, which are the tangential components of the electric fields, are obtained to calculate the propagation constant.

$$
\tilde{E}_{x1} = \tilde{E}_{x2}, \quad \tilde{H}_{x1} = \tilde{H}_{x2}
$$

(17)

$$
\tilde{E}_{z1} = \tilde{E}_{z2}, \quad \tilde{H}_{z1} = \tilde{H}_{z2}
$$

(18)

After calculations are obtained the following constant values:

$$
A_{ze} = \frac{j(\gamma_2^2 + K_z^2) \tilde{E}_{z2} - jw\mu \beta k A_{ze} (\mu_{z2} + \mu_z) \sinh[\gamma_2(y)]}{\sinh(\gamma_1 y) \alpha_2 \gamma_1}
$$

(19)

$$
A_{zh} = \frac{-j}{\gamma_2^2 + K_z^2} \left[ \alpha_2 \gamma_2 A_{z2} \cosh[\gamma_2(y-h)] + jw\mu \beta k A_{zh} \cosh[\gamma_2(y-h)] \right]
$$

(20)

$$
B_{z2} = \frac{\left( \alpha_2 \tilde{E}_{x2} + \beta_2 \tilde{E}_{z2} \right)}{A} \left( \tilde{E}_{x2} \cosh(\gamma_2 h) \cos(\gamma_2 h_2) - \frac{\gamma_2}{\gamma_1} \sinh(\gamma_2 h) \sin(\gamma_2 h_2) \right)
$$

(21)

$$
B_{z2} = \frac{\left( \beta_2 \tilde{E}_{x2} - \alpha_2 \tilde{E}_{z2} \right)}{A \mu B} \left( \sinh(\gamma_2 h) \cos(\gamma_2 h_2) - \frac{\gamma_2}{\gamma_1} \cosh(\gamma_2 h) \sin(\gamma_2 h_2) \right)
$$

(22)

The following equations relate the current densities on the patch ($\tilde{J}_{xy}$ and $\tilde{J}_{zy}$) and the magnetic fields in the interface $y = h_1 + h_2$:
After the obtaining of the electromagnetic fields components, the magnetic boundary conditions are applied, being \([Y]\) the dyadic Green matrix.

\[
\begin{bmatrix}
  Y_{xx} & Y_{zx} \\
  Y_{xz} & Y_{zz}
\end{bmatrix}
\begin{bmatrix}
  \vec{E}_{x} \\
  \vec{E}_{z}
\end{bmatrix}
= 
\begin{bmatrix}
  \vec{j}_{x} \\
  \vec{j}_{z}
\end{bmatrix}
\]  

(25)

The matrix inversion is used and the current densities in the interface are expanded using base functions [4]:

\[
\begin{bmatrix}
  Z_{xx} & Z_{zx} \\
  Z_{xz} & Z_{zz}
\end{bmatrix}
\begin{bmatrix}
  \vec{j}_{zh} \\
  \vec{j}_{zh}
\end{bmatrix}
= 
\begin{bmatrix}
  \vec{E}_{xh} \\
  \vec{E}_{zh}
\end{bmatrix}
\]  

(26)

\[
\vec{j}_{zh} = \sum_{i=1}^{n} a_{ij} \cdot \tilde{f}_{ij}(\alpha_{ij}, \beta_{ij})
\]  

(27)

\[
\vec{j}_{zh} = \sum_{j=1}^{m} a_{ij} \cdot \tilde{f}_{ij}(\alpha_{ij}, \beta_{ij})
\]  

(28)

Applying the Galerkin technique, the electric fields out of the metallic strip are eliminated. The current densities are expanded in terms of appropriate basis functions, and become a homogeneous complex matrix as shown in (29):

\[
\begin{bmatrix}
  K_{xx} & K_{xz} \\
  K_{xz} & K_{zz}
\end{bmatrix}
\begin{bmatrix}
  a_{x} \\
  a_{z}
\end{bmatrix}
= 
\begin{bmatrix}
  0 \\
  0
\end{bmatrix}
\]  

(29)

Each element of the \([K]\) characteristic matrix is:

\[
K_{xx} = \sum_{i=-p}^{n} \tilde{f}_{i}(x,z)z_{xx} \tilde{f}_{i}^{*}(x,z)
\]  

(30)

\[
K_{xz} = \sum_{i=-p}^{n} \tilde{f}_{i}(x,z)z_{xz} \tilde{f}_{i}^{*}(x,z)
\]  

(31)

\[
K_{zx} = \sum_{i=-p}^{n} \tilde{f}_{i}(x,z)z_{zx} \tilde{f}_{i}^{*}(x,z)
\]  

(32)

\[
K_{zz} = \sum_{i=-p}^{n} \tilde{f}_{i}(x,z)z_{zz} \tilde{f}_{i}^{*}(x,z)
\]  

(33)

III. RESULTS

The numerical results were obtained using a computational program developed in Fortran Power Station language.

As proof of the results of this program, a replacement of the metamaterial by an isotropic material was made. The Fig.3 shows the resonant frequency as functions of the resonator’s length antenna, compared with [7]-[9], and similar results were obtained. The cavity model results and the TTL, for one layer and for three layers, as one layer case, are much closed, confirming the good results of this application. Observing the Fig.3, one notices that the dielectrics three-layer resonator works correctly when it simulates a resonator of one layer.

The Fig. 4 shows the results of the resonance frequency depending on the length \(L\) of the patch resonator, simulated for two cases.

Case one: 1 layer dielectric substrate comprised of metamaterial EBG 2D considering focusing on the wave polarization \(s\), 2 dielectric layer composed of RT Duroid 5880 and dielectric layer 3 is the air.

Case two: 1 layer dielectric substrate comprised of metamaterial EBG 2D considering focusing on the wave polarization \(p\), 2 dielectric layers composed of RT Duroid 5880 and dielectric layer 3 is the air.

The analysis of Fig. 4, we can conclude that when the metamaterial [10]-[11] EBG is the first layer beneath the patch irradiator, the frequency of resonance does not suffer significant changes with the change in the wave incidence in the substrate (polarization \(s\) or \(p\)). This effect is due to difference in heights of layers, when \(\varepsilon_{r} = 2.2\) predominate on the EBG metamaterial.

Fig. 4 – Frequency of resonance as a function on the length of patch metamaterial for EBG 2D for the polarization \(s\) and \(p\)

Comparing the first two layers of the structure mentioned in Fig. 1, with another one antenna structure of one layer, we see that the results are similar as shown in Fig.5.
V. CONCLUSIONS

The results obtained can be used to the design of novel meta-materials with potential applications in wireless systems.

The full wave Transverse Transmission Line - TTL method, was used to obtain the numeric results of the planar antennas with three metamaterial layers.

In this work, the insertion of the metamaterial influence was realized through of the use in tensor permeability and permittivity, and good results were obtained.

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REFERENCES


