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ANTENNA PARAMETERS ENHANCEMENT BY USING ARTIFICIAL MAGNETIC STRUCTURE

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The paper deals with microwave patch antenna designing using metamaterial structure to enhance the gain and radiation pattern of patch antenna. In the paper are introduced numerical simulations of scattering parameters, which are used for calculation of relative permittivity and permeability for assessment of negative refraction index region of designed metamaterial structure. The parameters of designed patch antenna with metamaterial structure were experimentally verified.

Keywords: metamaterial, microwave frequencies, patch antenna design

1 INTRODUCTION

Metamaterials which are defined as effectively homogeneous electromagnetic structure exhibiting unusual electromagnetic properties especially the backward wave and negative refraction not readily available in nature, represent a new paradigm in electronics and photonics.

Conventional patch antennas have some limitations, such as lower gain, lower efficiency and narrow bandwidth [1]. Most of the previous published works connected with optimisation of antenna parameters were aimed at solution with an array of several antennas. Directive radiation pattern from antenna is strongly desirable for antennas to achieve high radiation power gain. This antenna property is important for many technical and medical applications, which need to control the accurate electromagnetic beam focusing and maximum power gain achievement.

In the past few years, new methods for improving the antenna gain by metamaterial are proposed [2-4] and theoretically discussed [5]. In those works, various metallic structures are used as metamaterials to achieve certain unusual characteristics which are suitable for high gain design. However, most of those former works are suitable for high frequency applications, such as X-band or millimetre wave.

In the paper we describe the approach with implementation of metamaterial structure (MMS) with negative permeability over the patch antenna in order to increase the gain and achieve the optimal radiation pattern of designed patch antenna in microwave X-band.

The paper is organised as follows. The paper presents the radiation principle of proposed antenna. Next simulated results and measurement results for conventional and tuned patch antenna are presented and there are in end of the paper given some conclusions.

2 THEORY

The currently available artificial structures are realized by using planar structures with specific topology in *x-y* plane. These planar structures provide enhanced permeability only in the direction normal to the plane of the MMS and enhanced permittivity in the directions tangent to the plane [6]. In our paper we study the influence of negative permeability medium on the performances of a single rectangular patch antenna. Metamaterial structure used for patch antenna tuning consists of arrays of unit cells of split resonators (SR), which was designed by Pendry et al. [6]. Split resonators behave as LC resonant circuits which can be excited by a time-varying electromagnetic field with a non-negligible component applied parallel to the split resonator axis.

Artificial magnetic materials are in general anisotropic and dispersive; therefore a various numerical method should determine the permeability tensor at different frequencies. Usually, metamaterial anisotropic magnetic medium can be characterised by the permeability tensor

$$\overline{\overline{\mu}} = \begin{bmatrix} \mu_{xx} & 0 & 0 \\ 0 & \mu_{yy} & 0 \\ 0 & 0 & \mu_{zz} \end{bmatrix} \tag{1}$$

where $\overline{\overline{\mu}}$ follows a Lorentz model and $\mu_{xx} = 1$, $\mu_{yy} = 1$, $\mu_{zz} = 1 - \frac{F\omega^2}{\omega^2 - \omega_\mathrm{m}^2 + \mathrm{j}\gamma\omega}$, where ω is the angular frequency, γ is the loss coefficient, ω_m is the magnetic plasma angular frequency and F is the fractional volume of SR unit cell [6]. Value of parameter F depends on geometrical parameters of designed resonant unit cell which create the metamaterial structure.

When the antenna radiation frequency is chosen in the SR resonant region where the permeability gains negative value $\mu_{zz} < 0$ the *x*-axis component of the electromagnetic wave vector

$$k_x = \sqrt{\varepsilon_{yy}\mu_{zz}} \tag{2}$$

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is imaginary. In (2) ε_{yy} approximates the permittivity of substrate, so that the y-component of the electric field

$$E_y = E_0 e^{j(k_x z - \omega t)} \quad (3)$$

is the evanescent field. In this case, the electromagnetic wave can not propagate, that means, sideward radiation – the E_y component of the electromagnetic wave along the metamaterial plane will be forbidden, only the normal component E_z of electromagnetic wave can transmit Fig. 1 [7].

Metamaterial cover of patch antenna plays a role of controlling the electromagnetic wave propagation direction. In the far-field view, the sideward radiation will be reduced and forward radiation can be enhanced in the radiation patterns. As a result, a more directional and higher gain antenna will be obtained.

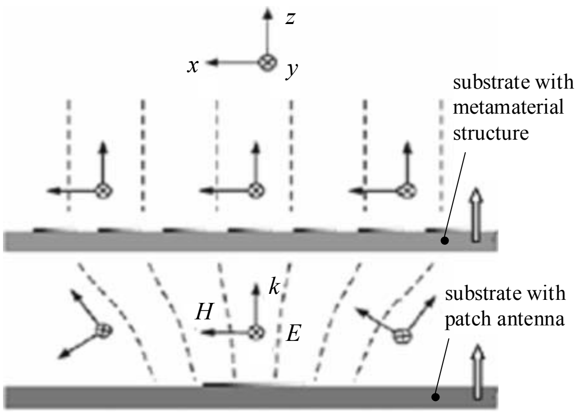

Fig. 1. Radiation principle of patch antenna tuned with metamaterial structure

As shown in Fig. 2 a conventional rectangular patch antenna was designed with radiation patch on one side of a dielectric substrate ROGERS RT/DUROID 5870 with relative permittivity ε = 2.33 and thickness h = 0.508 mm. Dielectric substrate has a ground plane on the other side.

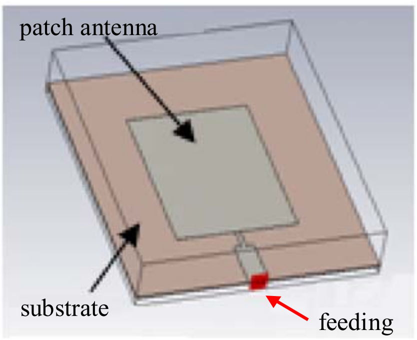

Fig. 2. Design of patch antenna for frequency f = 2.5 GHz

The dimensions of the rectangular patch antenna (width W = 30 mm and length L = 39 mm) were designed for antenna working frequency f = 2.5 GHz by using equations in [7]. As a feed the patch antenna was designed the transmission 50 Ω microstrip line connected with quarter-wavelength transformer, which insures impedance matching to avoid reflections. The microstrip patch antenna was designed by using commercial software CST Microwave Studio.

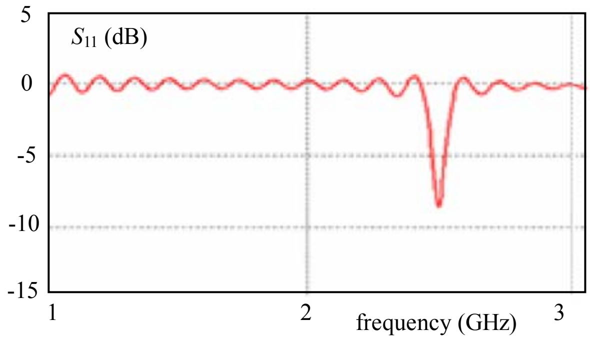

Fig. 3. Frequency dependence of scattering parameter S_{11} amplitude for conventional patch antenna

The simulated return loss curve represented by scattering parameter S_{11} amplitude of the conventional patch antenna is shown in Fig. 3. It can be observed in Fig. 3 that conventional antenna has return loss of 8 dB for desired operation frequency f = 2.5 GHz.

The simulation radiation pattern at the operation frequency for the conventional antenna is shown in Fig. 4.

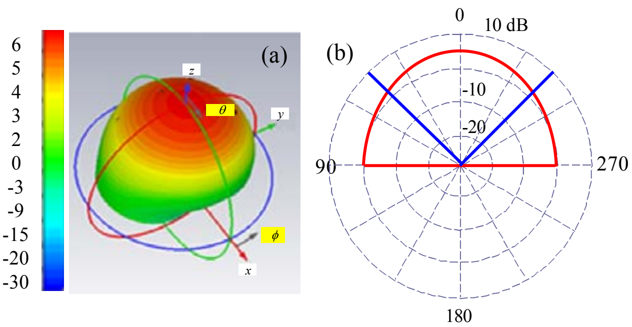

Fig. 4. Simulated radiation pattern of conventional patch antenna: (a) - 3D image, (b) - polar coordinates

The designed conventional antenna has at operation frequency f = 2.5 GHz for main lobe the gain of 6.3 dB and the radiation angle at the drop 3dB has a width 91°

To investigate the focusing and gain upping effect of SR structure the designed conventional patch antenna was tuned with metamaterial structure. The region of metamaterial structure negative permeability was proposed to embody the working frequency of designed conventional patch antenna (f = 2.5 GHz).

The SR structure is strongly resonant around the magnetic plasma frequency ω_m, which is induced by the currents and split, which imitates magnetic poles. This resonant behaviour is due to the capacitive element such as splits, and in turn results in very high positive and negative values of permeability close to the magnetic plasma frequency. The SR would yield a negative value of permeability in the case when $\omega < \omega_{\mathrm{m}}$.

The resonant behaviour of SR can be numerically simulated and experimentally observed by measuring the transmission through SR. Subsequently a dip in the transmission spectrum of the SR structure can be attributed to the resonant nature of SR [8].

Metamaterial plate with cell units, Fig. 5 was designated for conventional patch antenna tuning. The cell units are placed on dielectric substrate with relative permittivity $\varepsilon = 2.33$ in the form of a 2–D and provide negative reflection of phase.

Figure 5 shows the metamaterial structure incorporated with the microstrip patch antenna. The structure is placed in the front of patch microstrip antenna. The number of unit resonant cells along the x and y axis is $N_x = 5$ and $N_y = 5$. The incident electromagnetic wave propagates along the z direction, while the vector of electric intensity $\bar{E}$ is oriented along the y direction, and magnetic intensity $\bar{H}$ is oriented along the x direction.

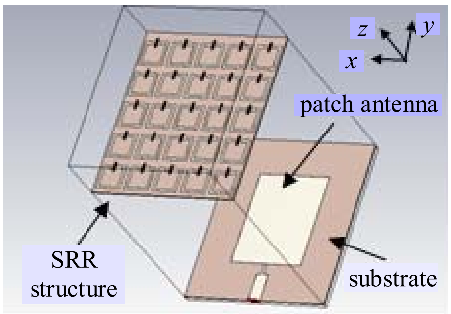

Fig. 5. Design of patch antenna, frequency $f = 2.5$ GHz

The distance between the patch and metamaterial structure d influences the performances of the patch antenna. Therefore this parameter was numerically optimised. The simulation results in Fig. 6 have shown, that parameter d mostly influences the gain of designed antenna. The optimal distance of metamaterial structure from the conventional patch antenna is 78

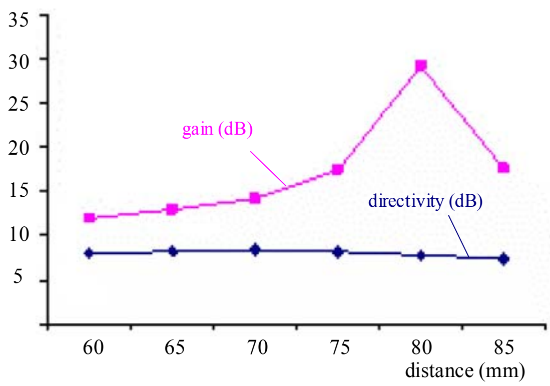

Fig. 6. The gain and directivity of tuned antenna dependence from distance of MMS from patch antenna mm, which meets the resonant conditions.

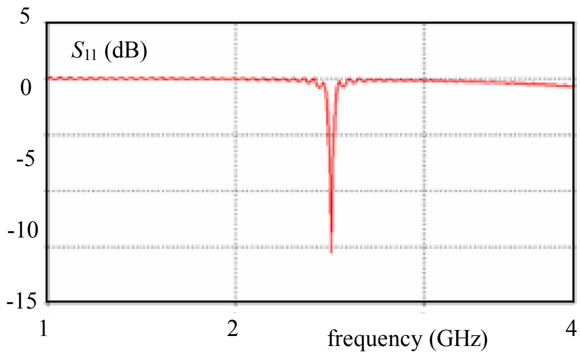

Fig. 7. Frequency dependence of scattering parameter S_{11} amplitude for conventional patch antenna with metamaterial structure

The simulated return loss of antenna with metamaterial structure is as shown in Fig. 7.

The return loss (represented by scattering parameter S_{11}) when patch antenna is incorporated with metamaterial structure was shifted to higher region to 15 dB in comparison with antenna without metamaterial structure. Return loss is in a good agreement between microstrip antenna with and without metamaterial structure, where in both conditions; the antenna still operates at 2.5 GHz. The bandwidth of the antenna was decreased after its incorporation with metamaterial structure.

Figure 8 shows the simulation results for radiation pattern of the microstrip patch antenna tuned with metamaterial (E – plane, operating frequency $f = 2.5$ GHz).

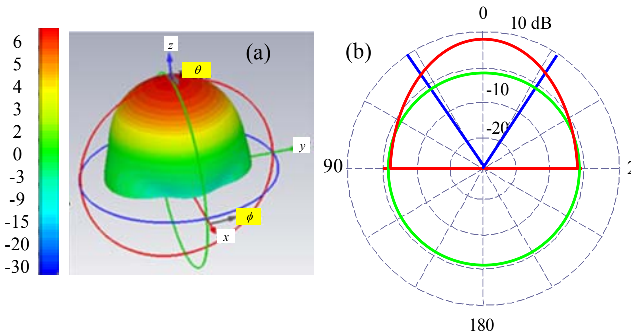

Fig . 8. Simulated radiation pattern of patch antenna covered with SR structure, a) 3D image, b) polar coordinates

The directivity of tuned antenna was increased from 6.3 dBi to 7.9 dBi. From Fig. 8 it can be seen, that at the half-power bandwidth (3 dB) is the radiation pattern angle in the E-plane 67.9°. In comparison with radiation pattern angle for conventional patch antenna the radiation pattern was decreased about 23.1°. That means, the antenna with incorporated metamaterial structure becomes more convergent in comparison with conventional patch antenna.

The gain of tuned antenna was after metamaterial structure incorporation increased from 6 dB to the 9 dB in the centre of antenna operating bandwidth Fig. 4 and Fig. 8.

3 EXPERIMENTS

The antenna measurements were carried out at the standard laboratory equipment Fig. 9. The far-field radiation pattern measurements were performed by using a standard horn antenna as a receiver. The antenna was placed horizontal on a pedestal, which was rotated to record data for angle α from interval <-90°, 90°>. From measurement obtained data after careful system calibration a horizontal gain pattern of patch antenna was calculated [9].

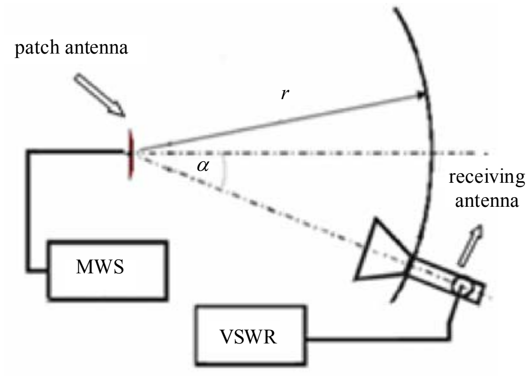

Fig. 9. The experimental set up for radiation pattern of patch antenna measurement. MWS – microwave source, VSWR – voltage standing wave ratio meter

The measured E – plane far field radiation patterns of the conventional patch antenna and antenna tuned with metamaterial structure is given in Fig. 10.

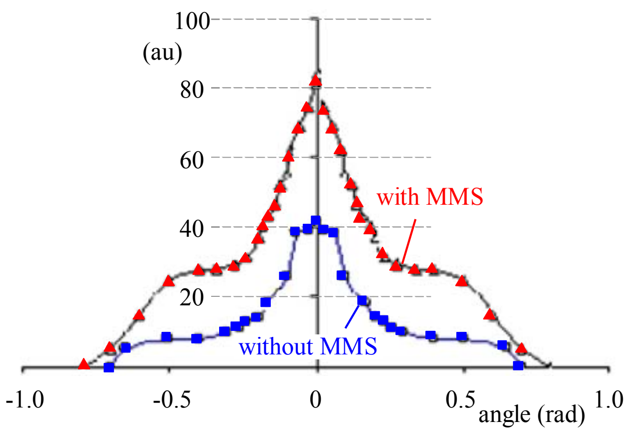

Fig. 10. Radiation pattern of patch antenna with an without metamaterial structure

The radiation pattern is unidirectional and broadside to the resonance cone as was expected from numerical simulation results. The maximum power gain was measured in the middle of measured radiation pattern of patch antenna.

CONCLUSIONS

In our paper, a study has been made to discuss and analyze the properties of metamaterial structure and the performance of a single patch microstrip antenna with and without metamaterial structure.

The conventional microstrip patch antenna was designed for desired operation frequency. The appropriate metamaterial structure was suggested by using commercial software for operating patch antenna frequency in the negative region of metamaterial structure permeability.

The numerical simulations were used at the designing of both patch antenna and metamaterial structure and also for the calculation of patch antenna parameters such gain and directivity was done with numerical simulation using commercial software.

The experimental results have validated the simulation results and show that appropriate design of metamaterial structure improves the constitutive properties of patch antenna – its gain and directivity.

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