Design of 4 Elements Rectangular Patch Antennas with High Gain

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***Abstract*-- In recent years, there has been a growing interest for the use of metamaterial as superstrate in the antenna design in order to enhance its performances. The designed antenna using a superstrate had the capability of producing high performance in terms of gain and bandwith ,due to negative refractive property of metamaterial .It has been proved that high gain can be achieved if the superstrate layer is appropriately designed and placed above antenna. In this paper we propose an analysis and simulation of an array patch antenna loaded with a 9x9 array of U and T shaped resonators superstrate with high magneto-dielectric characteristics. The antenna consists of 2x2 patches printed on the Roger RO3003C substrate of 0.75mm thickness and with a relative permittivity of 3. By simply adjusting the distance The distance between the patches and superstrate ,the resonance condition for high gain can be Obtained. Multiple lines in a feed network arrangement is used for the excitation of the proposed structure. The purpose Ansoft HFSS Software has been used for numerical simulation. The results obtained From the simulation of an array design working at the resonance frequency of 10 GHz show an improvement of the gain and a better bandwidth of the antenna.**

Index Terms-- Patch antenna, metamaterial, bandwith, microwave, High-gain, superstrate.

1. Introduction

An antenna is defined as a part of a transmitting or receiving system which is designed to radiate or to receive electromagnetic waves. Microstrip antennas (MSAs) offer many attractive features such as low cost, low weight, and low profile, easy fabrication, and planar structure.However these antennas have some drawbacks like narrow-bandwidth, low gain and lower radiation efficiency [1].A new design technique adopted to overcome Patch Antenna's drawbacks, is the use of metamaterial onto antenna's superstrate.Metamaterials are specially designed artificial composite structured and engineered to exhibit unusual electromagnetic characteristics generally not found in nature. In the frequency domain, the electromagnetic properties of materials can be characterized by their complex permittivity (ε) and permeability (μ), These two parameters are admissible into Maxwell's equations, and together, determine the response of the material to the electromagnetic radiation. The permittivity (ε) is used to describe the response of a material to applied electric fields and the magnetic permeability is obtained from the effects of induced magnetic polarization. Generally, ε and μ are both positive in ordinary materials,called as double positive (DPS) materials . In contrast to conventional material, metamaterials are characterized by electromagnetic proprieties of negative permittivity and/or negative permeability.In such materials the index of refraction is negative and therefore, phase and group velocity of an electromagnetic (EM) wave can propagate in opposite directions with respect to the direction of energy flow[2-3]. This concept was first theoretically analyzed by Veselago in 1968, who had also investigated various optical properties of the negative refractive index structures [4]. The objective of this paper is to investigate the high performance in terms of gain and directivity of array patch antenna based on metamaterial superstrate. It has been reported that the introduction of double negative materials (DNG) as a superstrate layer above an antenna may affect the antenna's basic performance characteristics, such as gain, radiation and efficiency. The metamaterials, which consists of 9x9 array U and T shaped, is used to simulate a high dielectric slab and placed above **a** 2x2 patches. The distance of the air-gap, which is sandwiched between the array and the metamaterial is adjusted to obtain the best gain performance at the operating frequency of 10 GHz.First of all, the resonance structure of the metamaterial is studied and analyzed. It has been verified that this structure satisfies the Double-Negative properties by using Nicolson-Ross-Weir Method (NRW)[5-6].Simulation results of proposed antenna parameters like resonance frequency, return loss, and radiation efficiency are discussed .Simulated Numerical results indicate that the gain of the antenna with metamaterial superstrate is efficiently increased and the antenna directivity is enhanced. The prototypes LHM array patch antenna was numerically simulated/designed by High Frequency Simulation Software (HFSS). This is a full-wave electromagnetic field simulator capables of modeling 3D complex volumetric structures. It employs an automatic adaptive meshing and Finite Element Method (FEM) . It can be used to calculate and plot the resonant frequency, S-parameters, current distributions and fields.

2. ARRAY ANTENNA DESIGN AND CONFIGURATION

The single patch element is first designed. The size width W and length L of the radiating copper patch are calculated from the basic mathematical equation (1, 2):

$$W = \frac{c}{2f_0}\sqrt{\frac{\varepsilon_r+1}{2}} \qquad (1)$$

The actual length of the patch is given by

$$L = L_{eff} - 2\Delta l \qquad (2)$$

Where

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_\varepsilon}} \qquad (3)$$

The effective dielectric constant of the substrate can be determinated by

$$\varepsilon_\varepsilon = \frac{1}{2}(\varepsilon_r+1) + \frac{1}{2}(\varepsilon_r-1)\sqrt{\left(1+\frac{10h}{W}\right)} \qquad (4)$$

And the extension to the length, Δl due to fringing field can be expressed

$$\Delta l = 0.412h\,\frac{(\varepsilon_\varepsilon+0.3)\left[\frac{W}{h}+0.264\right]}{(\varepsilon_\varepsilon-0.258)\left[\frac{W}{h}+0.8\right]} \qquad (5)$$

The resonance frequency for the TM_{10}mode is given by:

$$f_0 = \frac{c}{2L_{eff}\sqrt{\varepsilon_r}} \qquad (6)$$

The structure superstrate suggested in this work is a 9x9 array cells of the U and T Perfect Electric Conductor (PEC), etched on the sides of the Rogers RT/duroid 5880 (tm) substrate of 0.81mm thickness, with a permittivity $\varepsilon = 2.2$ and loss tangent $\delta = 0.0009$, as shown in Figure.1

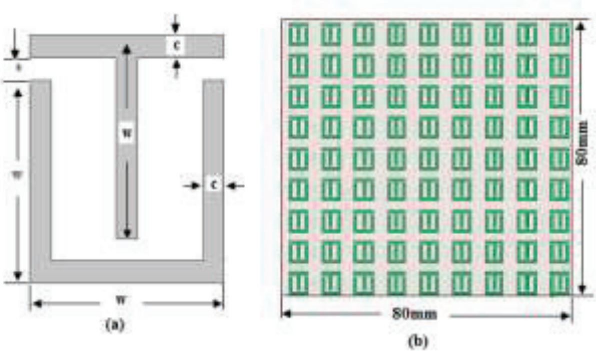

Fig 1.Configuration of U and T shaped metamaterialsuperstrate (a) The unit cell dimensions and parameters w= 5mm,c= 0.66mm (b) 9x9 aarray of the U and T shaped metamaterial.

The designed array structure is depicted in Figure 2.the antenna array is composed of three layer structure which consists of substrate,air-gap,and superstrate . The superstrate is placed above the radiating patches at a distance d.the array antenna has been designed with a desired centre frequency of 10 GHz ,on substrate Rogers RT/duroid4003 ($\varepsilon_r = 2.2\delta = 0.0009$) with a thickness of 0.75mm (h) and an area of 80x80mm2.it consists of 2x2 rectangular patches of dimension 10.6mm× 8.75 mm ,placed on the top of the substrate. The element spacing of this array antenna was 17.02mm at 10 Ghz.A coaxial feed is connected to the center of the array from the bottom side of the substrate. Power divider and quarter-wave transformer impedance matching sections are used to couple the power to each element for radiation.

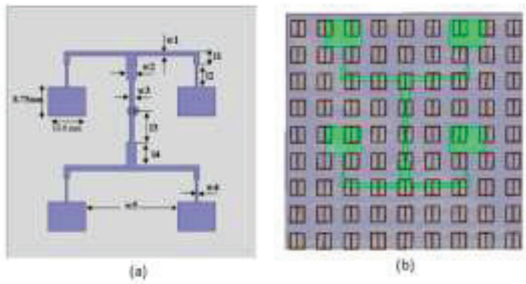

Fig 2. (a) 2 x 2 patch antenna array,dimensions and parameters:w1=1.511mm,w2=2.94mm,w3=mm,w4=0.516mm,,w5=17.02mm,l1=2.511mm,l2=7.5mm,l3=10mm,l4=7.5mm (b) 2 x 2 patch antenna array with superstrate

3. SIMULATION & RESULT

Simulated results of return loss plot (S11) characteristics of the 2x2 array patch antenna with and without the superstrates are plotted in the same figure for comparison and shown in the Fig. 3. According to this figure ,the conventional and proposed antenna array are resonating at 10 GHz ,and 9.3Ghz with a return loss -22dB and 29.75 dB respectively . A slight shift is observed in the resonant frequency of the structure array patch antenna with superstrate which is attributed to the change in the near field properties of the array antenna. The return loss plot, also shows that the antenna array is matched, before and after the application of the superstrates since the resonant of return losses were more than -20 dB.

The bandwidth of proposed array antenna is remarkably increased by 675 MHz (75 %) compared with conventional array patch antenna. It is clearly shown that the bandwidths of array antenna without and with superstrate are 0.225 GHz and 0.9 GHz, respectively.

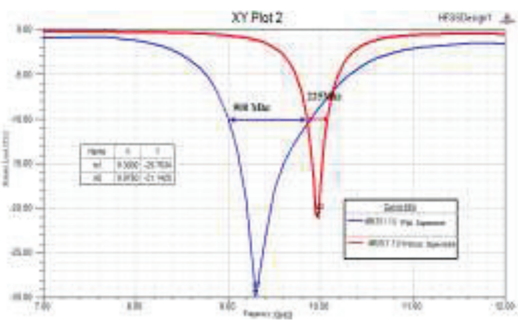

Fig 3. Return loss without and with superstrate

The 3D and 2D gain plot (without and with superstrate) are given in Fig.4 and Fig.5 respectively. It is seen that the gain of the structure array patch antenna with a superstrate is higher than that of the array antenna without a superstrate. The gain was about 12.07 dB (with a superstrate) and 8.38 dB (without a superstrate) at the center frequency of 10Ghz. Thus, a gain enhancement of about 4 dB was obtained over the gain of the patch without a superstrate. Fig. 6 indicates the radiation pattern of the array antenna with and without the superstrate at 10 GHz.

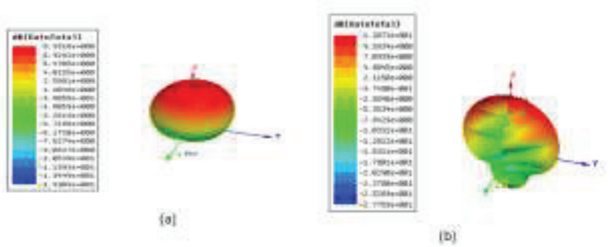

Fig 4. 3D Gain of proposed antenna array *(a)* without superstrate metamaterial structure,(b) with superstrate metamaterial structure

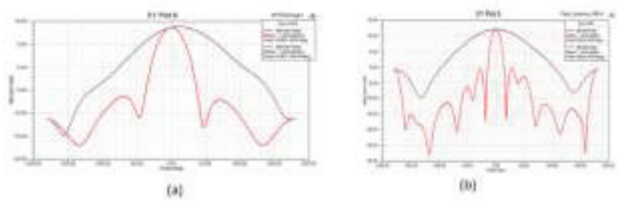

Fig 5.2D Gain (a) without superstrate metamaterial structure,(b) with superstrate metamaterial structure

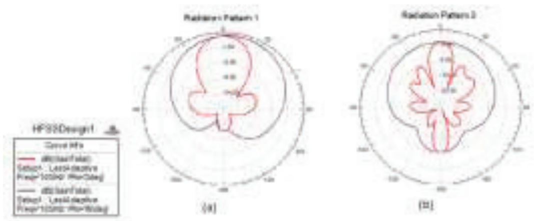

Fig 6. Radiation Pattern of proposed antenna array (a)without superstrate metamaterial structure,(b) with superstrate

4. CONCLUSION

In this paper, a Gain enhancement of 2x2 antenna array has been achieved by using the DNG metamaterial as superstrate above the antenna. This proposed structure has been simulated and analysed on the commercial software HFSSTM. the height which separates the patch from the DNG superstrate is optimized for maximum antenna gain. To demonstrate the usefulness of the proposed design method, the performance parameters of array antenna like resonance frequency, return loss, gain and radiation efficiency are discussed . the antenna operates at at the X band range (10 GHz). the gain of a patch array with a superstrate was compared with that of a patch array without a superstrate. Results obtained are encouraging and showed that the gain was significantly improved between 3 dB to 4dB.

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