Effect on Bandwidth of Using Double Substrates Based Metamaterial Planar Antenna

Smrity Dwivedi

Abstract**—**The present paper has revealed the effect of double substrates over a bandwidth performance for planar antennas. The used material has its own importance to get minimum return loss and improved directivity. The author has taken double substrates to enhance the efficiency in terms of gain of antenna. Metamaterial based antenna has its own specific structure which increased the performance of antenna. Improved return loss is -20 dB, and the voltage standing wave ratio (VSWR) is 1.2, which is better than single substrate having return loss of -15 dB and VSWR of 1.4. Complete results are obtained using commercial software CST microwave studio.

Keywords**—**Metamaterials, return loss, standing wave ratio, directivity, CST microwave studio.

I. Introduction

METAMATERIALS are designed to have specific properties that have not been found in nature yet. It is being accepted worldwide for its special properties and uses. It can reduce the losses and improve the efficiency of structure. Metamaterial is accepted for wide range of frequencies including terahertz range. This material is a composite material, but its properties cannot be defined by elements which are being used to form it. Its properties are basically defined by its structure. Mostly, metamaterial are periodic structures which have certain periodic length and repeated after that periodic length. Metamaterials are defined according to permittivity and permeability of materials. Double negative (DNG), negative permittivity (ENG), negative permeability (MNG), and negative refractive index types are used as resonant type metamterials, whereas the anisotropic and hyperbolic ones are the nonresonant type metamaterials, which are widely used for many applications such as to generate surface plasmonic waves. Today, metamaterials based structures are more commonly used in waveguides, antennas designs, filters designs, and in other applications where requirement of good performance at low loss and low cost is necessary.

Simple microstrip antenna radiates, not only from patch side, but also from the substrate layer that supports patch and ground plane. Basically a surface wave generates, which is responsible for radiation losses or surface radiation losses (surface plasmonic waves); that is the main disadvantage associated with the antenna and it produces low bandwidth, low efficiency, poor directivity as well as higher losses.

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These losses can only be reduced by keeping the values of permittivity and permeability as low as possible, and for solving such problems, use of metamaterials is helpful. At the same time, non-resonant type metamaterials underneath photonic band gap (PBG) or electromagnetic band gap structures (EBG) come and play an important role to achieve higher bandwidth with greatest potential applicability from 4G network to 5G network systems.

PBG and metamaterials are the best solutions to enhance the bandwidth and spectrum range for communication network.

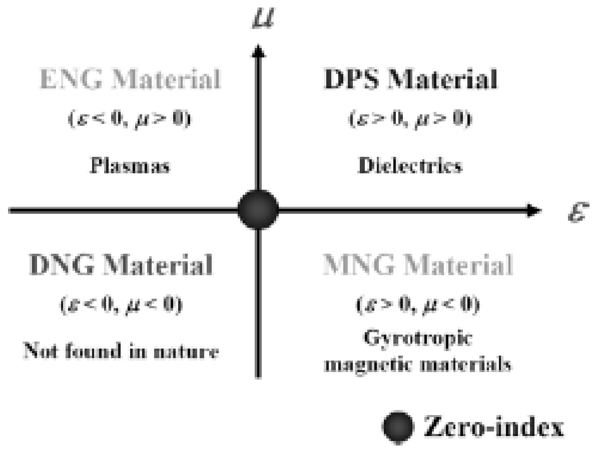

Fig. 1 Classification of metamaterials on the basis of their permittivity and permeability [1]

Fig. 1 shows the classification of metamaterials where each coordinate represents the metamaterials properties on the basis of their permittivity and permeability, having negative or positive values, which separates all types from each other. Left handed metamaterial (LHM) is used in third coordinate system, having negative permittivity and negative permeability with negative refractive index, as well as negative thickness of structure, which is being used here for antenna design purposes. These properties are bound to give special properties in connection with Maxwell's equations.

II. Analysis and Validation

There are so many models which describe how metamaterials work and what is the effect of negative permeability and permittivity on performance of antennas. Most important and widely accepted model, given by Lorentz, known as Lorentz oscillator model, is being taken to solve the complex boundary value problems [2]. After generation of electric fields and magnetic fields, they become polarized and displaced the continuum of electrons. Equation (1), which is valid for electromagnetic waves, is used in this paper, to show the motion of electron inside the material. In (1), first term in left hand side denotes inertia, second term is taken as loss and third term represents the restoring force, whereas in right hand side applied electric fields are shown. Now, due to these terms, electron gets polarized and starts to work according to electrical forces and it is combined with the wave, which is out of phase and generates oscillation.

$$m\frac{\partial^2 r}{\partial t^2}+m\Gamma\frac{\partial r}{\partial t}+m\omega_0^2 r=-qE\ . \tag{1}$$

The split E-shape metamaterial antennas produce magnetic field response and negative permeability, which represents the plasmonic type frequency in form [3]-[5].

$$\mu(\omega)=\mu_0\left(1-\frac{\omega_{pm}^2}{\omega(\omega-j\Gamma_m)}\right), \tag{2}$$

where, ω_{pm} = Magnetic plasma frequency, Γ_m = Damping coefficient, μ_0 = Permeability in free space.

Negative permeability also arises, when $\omega < \omega_{pm}$, whereas capacitor based structure is responsible for negative permittivity due to strong dielectric effect which is exhibited by this design [6].

The major formulas which are used for calculating antenna parameters are written as [7]:

$$W=\frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}\ , \tag{3}$$

$$L=\frac{v_0}{2f_r\sqrt{\varepsilon_{reff}}}-2\Delta L\ , \tag{4}$$

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}, \tag{5}$$

$$\Delta L=0.412h\frac{(\varepsilon_r+0.3)}{(\varepsilon_r-0.258)}\frac{\left(W/h+0.264\right)}{\left(W/h+0.8\right)}\ . \tag{6}$$

These are the well known equations to find out each parameter such as length, width, effective dielectric constant, and effective length after fringing field effect of the planar antenna.

III. Results and Discussions

The structure proposed here, is mend for Wi-Max band (2-6 GHz) with complex geometry and reliable ports. The designed structure is made up of two different substrates (Duroid FR-epoxy, Rogers) as well as metamaterial patch having negative permeability and negative permittivity as shown in Fig. 2. Fig. 3 shows the planar antenna, having only one substrate with the same metamaterial patch and same dimensions as well as same frequency. Results obtained here are significantly validated and simulated using commercial software CST microwave studio.

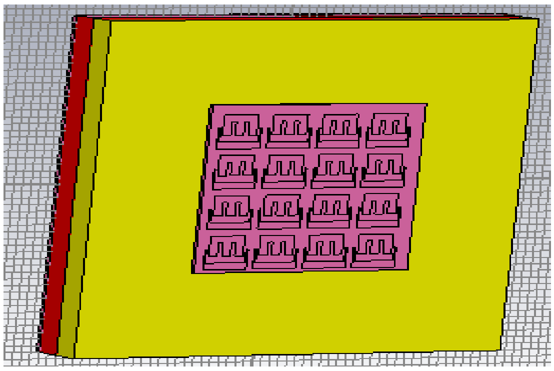

Fig. 2 Planar metamaterial antenna with double substrates

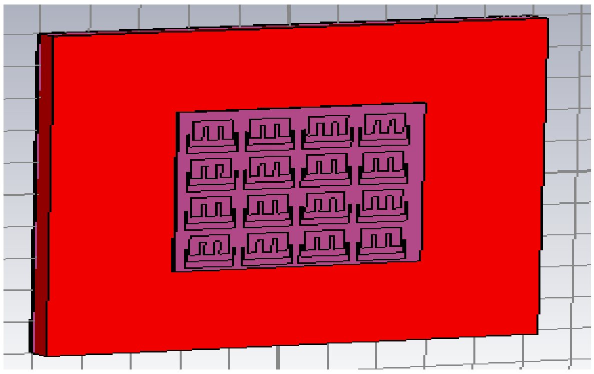

Fig. 3 Planar metamaterial antenna with single substrate

Parameters (Table I) have been obtained with the help of Section II, where the equations have already been given.

TABLE I
DIMENSIONS OF PROPOSED METAMATERIAL BASED E-SHAPE PLANAR ANTENNA

Substrate material 1	Duroid ε_r =2.2
Substrate material 2	Rogers ε_r =1.96
Thickness of substrate 1	3 mm.
Thickness of substrate 2	3 mm
Length of ground plane	25 mm
Width of ground plane	25 mm
Length and width of patch ($L_p \times W_p$)	12.5 mm× 12.5 mm
Thickness of patch	0.4 mm

Figs. 4 and 5 show the scattering matrix parameter in terms of return loss (S11) for given designed double substrate and single substrate metamaterial structures, respectively. Results obtained are -20.68 dB and -15.49 dB at 2.68 GHz frequency for double and single substrate, respectively.

Figs. 6 and 7 show VSWR to define the total reflection of wave for given designed double substrate and single substrate metamaterial structures respectively. Results obtained are 1.2 and 1.4 at 2.68 GHz frequency for double and single substrate, respectively.

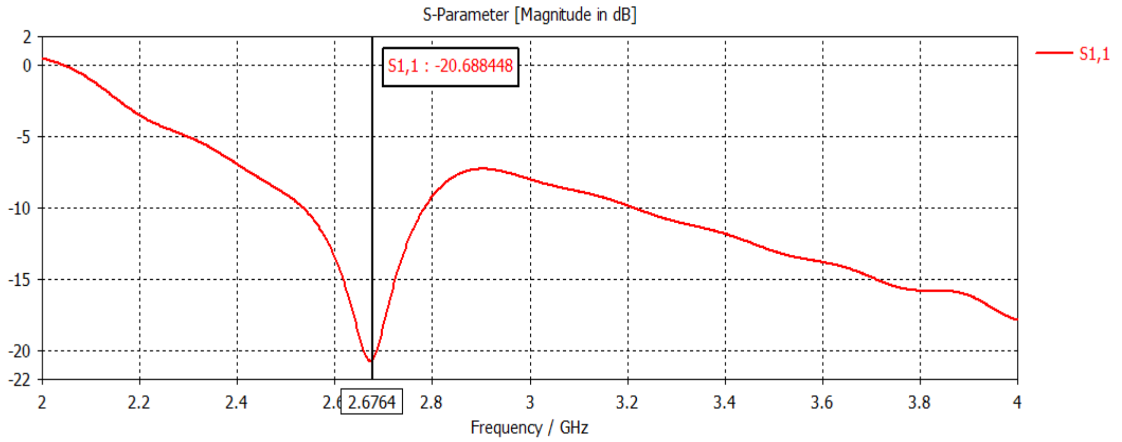

Fig. 4 Return loss for double substrate metamaterial planar antenna

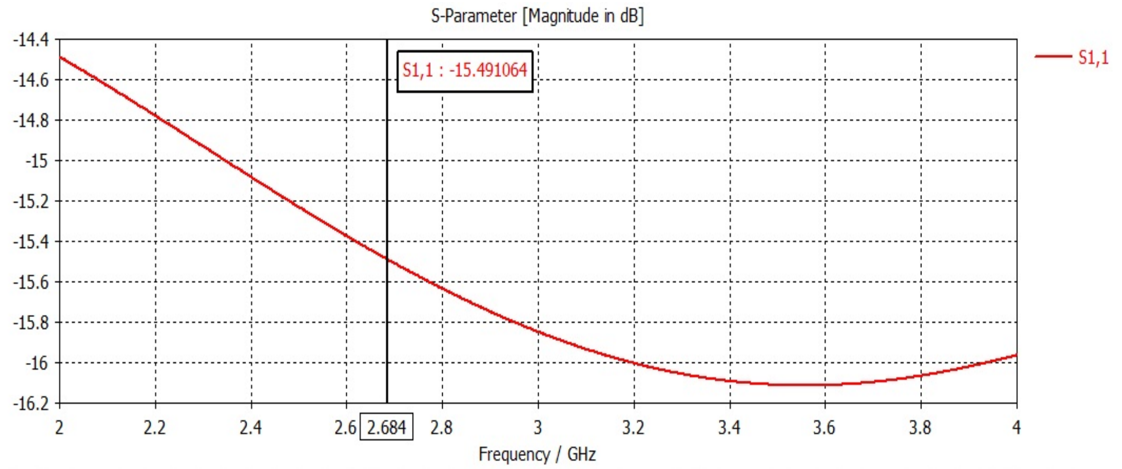

Fig. 5 Return loss for single substrate metamaterial planar antenna

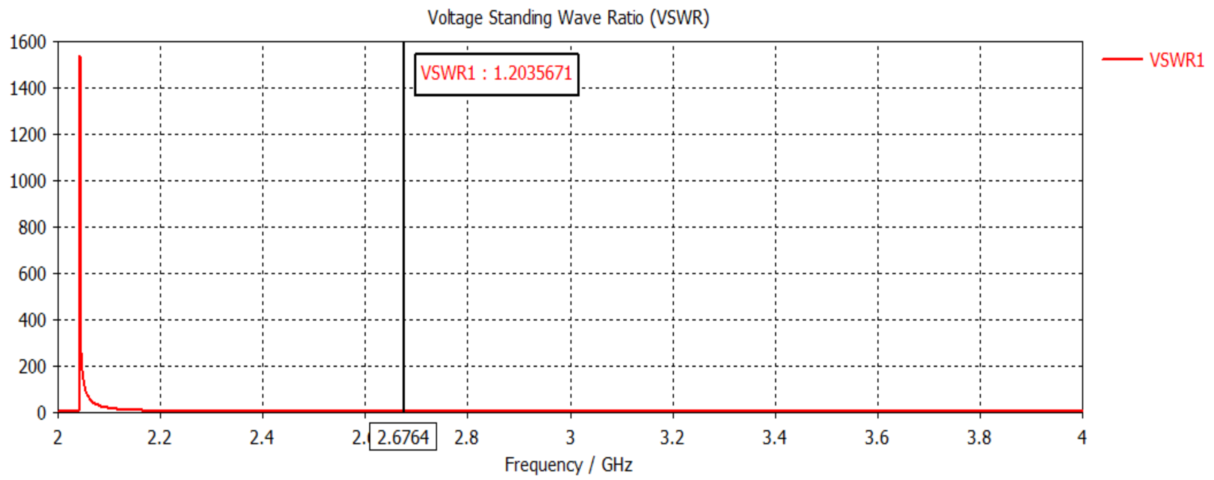

Fig. 6 VSWR for double substrate metamaterial planar antenna

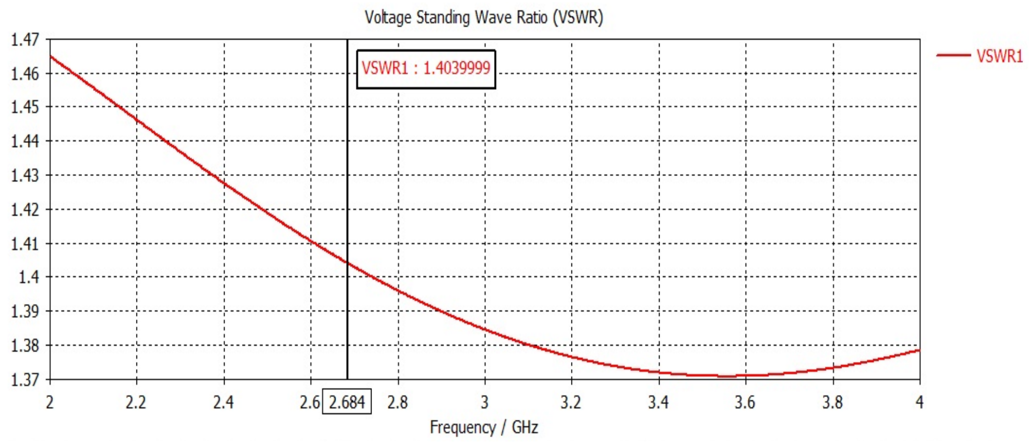

Fig. 7 VSWR for single substrate metamaterial planar antenna

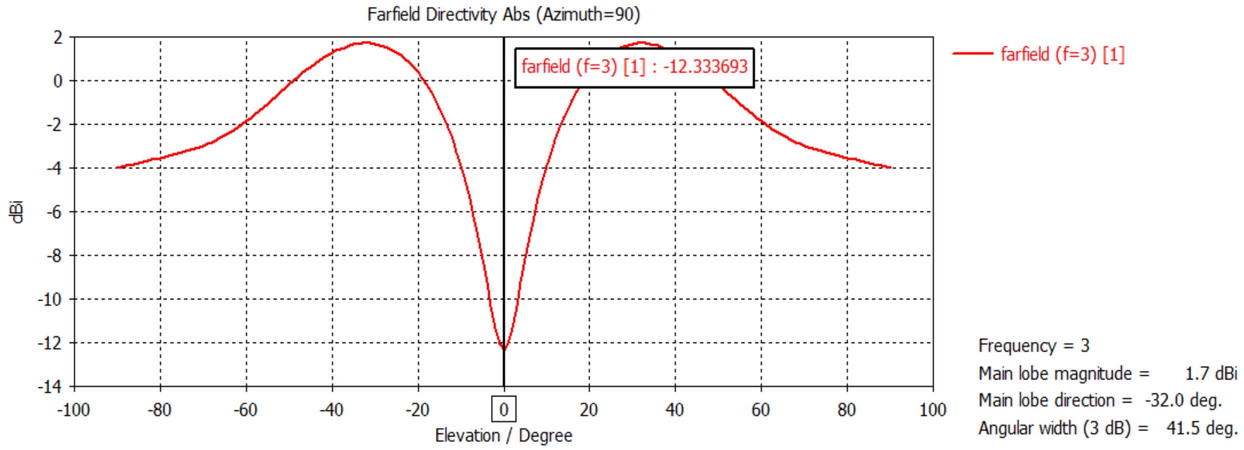

Fig. 8 Farfield pattern for double substrate metamaterial planar antenna

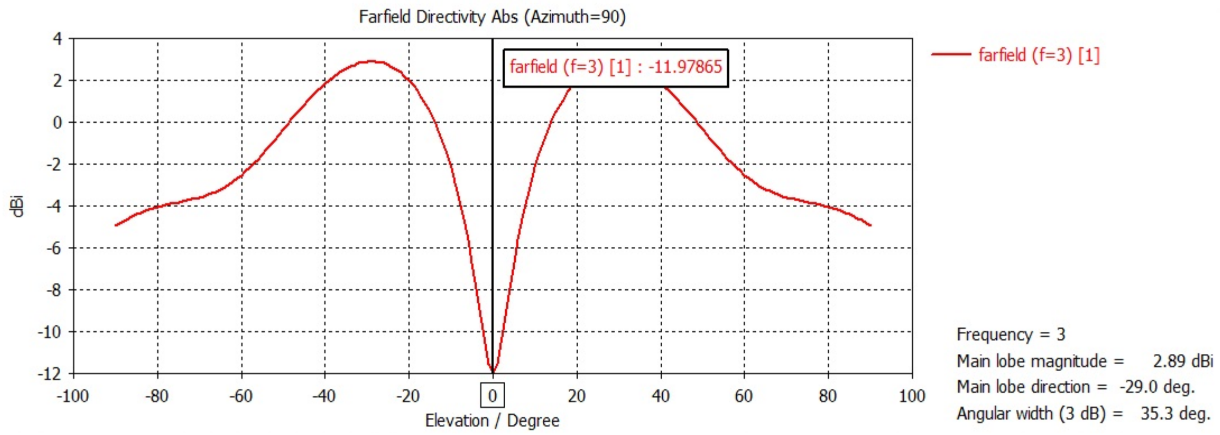

Fig. 9 Farfield pattern for single substrate metamaterial planar antenna

Figs. 8 and 9 show farfield pattern for given designed double substrate and single substrate metamaterial structures at 2.68 GHz.

Comparison of bandwidth between double substrate and single substrate planar antennas which are 0.5 GHz and 0.2 GHz, is very interesting.

IV. Conclusion

In the present paper, planar metamaterial based antenna has been analyzed for double substrate and single substrate to check the usability as well as performance improvement. Return loss for double substrate planar antenna is better than single substrate antenna, and VSWR for double substrate antenna is closer to the ideal value as compared to single substrate antenna. The most important parameter, bandwidth, is 0.5 GHz and 0.2 GHz for double and single substrates respectively for WiMax band.

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