International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:5, 2014

High Directivity and Gain Enhancement for Small Planar Dipole Antenna at 11 GHz Using Symmetrical Pyramidal Block Based On Epsilon Negative Medium

V. Kesornpatumanun, P. Boonek, W. Silabut, N. Homsup and W. Kuhirun

***Abstract*—**This paper increases directivity and gain of Small Planar Dipole Antenna (SPDA) by using Symmetrical Pyramidal Block (SPB) which operates in X band at 11 GHz. The SPB consists four sides; each of which is metamaterial with Epsilon Negative Medium (ENG) and Epsilon Near-Zero (ENZ). The results simulated using the High Frequency Structure Simulator (HFSS) show that the SPB is capable of enhancing directivity and gain for the SPDA with maximum gain of 2.46 dB. The reflection coefficient is -13.7037 dB with narrow beam width.

***Keywords*—**Small Planar Dipole Antenna, Symmetrical Pyramidal Block, metamaterials, Epsilon Near-Zero, Epsilon Negative Medium.

I. Introduction

METAMATERIALS are artificial structures the electromagnetic properties of which don't exist in nature [1]. These properties are classified by two parameters - electric permittivity (ε) and magnetic permeability (μ) of which are divided into 4 classifications [2]. Firstly, the double positive (DPS) has ε and μ greater than zero ($\varepsilon > 0$, $\mu > 0$). Secondly, the epsilon negative (ENG) has ε less than zero and μ greater than zero ($\varepsilon < 0$, $\mu > 0$). Thirdly, the mu negative (MNG) has ε greater than zero and μ less than zero ($\varepsilon > 0$, $\mu < 0$). Finally, the double negative (DNG) has ε and μ less than zero ($\varepsilon < 0$, $\mu < 0$).

Recently, metamaterials have been received considerable attention from researchers to develop applications in antenna engineering; ones of which are performance improvement and miniaturization. The emergence of artificial materials such as high impedance surfaces, reactive impedance surfaces, magneto-dielectrics provides new ways to achieve these applications [3]-[7].

This paper presents increasing in the directivity gain of a small planar dipole antenna (SPDA) operating in X band at 11 GHz. Instead of being mounted on a ground plane, the SPDA is mounted on the symmetrical pyramidal block (SPB) as shown in Fig. 1.

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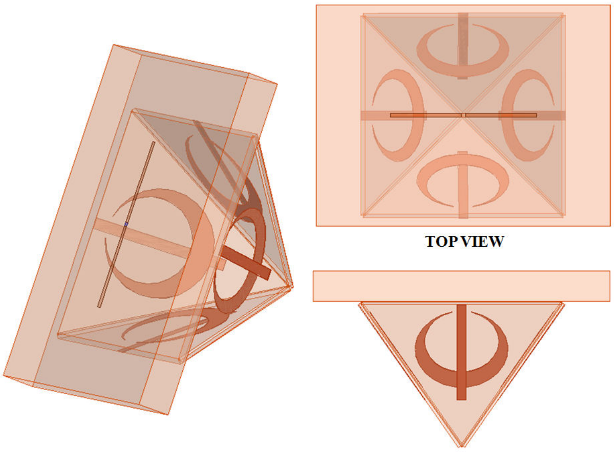

Fig. 1 Small Planar Dipole Antenna (SPDA) mounted on a Symmetrical Pyramidal Block (SPB)

II. Metamaterial Theory

Although metamaterials are capable of improving antenna performance and miniaturizing antennas, metamaterials are not found in nature and, hence, must be artificially fabricated.

Consider a small planar dipole antenna mounted on a symmetrical pyramidal block. By a rough approximation, the wave emitted from the antenna is a uniform plane wave. It averagely incidents perpendicularly on an equilateral triangle dielectric substrate. While incidenting on a dielectric substrate, the uniform plane wave partially scatters back into free space. The scattering parameter extraction method is used to calculate the permittivity, the permeability, the refractive index, the refractive index, the wave number, the reflection coefficient and the transmission coefficient. The permittivity and permeability can be computed from (1) and (2) [8]:

$$\varepsilon = n/z \tag{1}$$

$$\mu = n \times z \,. \tag{2}$$

where z is the wave impedance, n is the refractive index which can be calculated using (3) and (4) [9]:

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)\right] \tag{3}$$

$$z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (4)$$

where S_{11} is reflection coefficient, S_{21} is transmission coefficient, k is wave number and d is thickness of slab. As refractive index $n = \sqrt{\mu\varepsilon}$ can be realized by making its permittivity approach 0 at the frequency of interest, hence, n= 0. It is well known that the boundary of materials with refractive index of zero exhibits full reflectivity [4]. The intrinsic impedance or wave impedance and the wave number were computed from the equations of $\eta = \sqrt{\mu / \varepsilon}$ and $k = \omega\sqrt{\mu}\sqrt{\varepsilon}$. In free space values of these parameter are $\eta_o = \sqrt{\mu_o / \varepsilon_o}$ and $k_o = \omega_o\sqrt{\mu_o}\sqrt{\varepsilon_o}$. The reflection and transmission coefficient can be calculated as followed.

$$S_{11} = \frac{\eta - \eta_O}{\eta + \eta_O} \frac{1 - e^{-j2kd}}{1 - \left(\frac{\eta - \eta_o}{\eta + \eta_o}\right)^2 e^{-j2kd}} \quad (5)$$

$$S_{21} = \frac{4\eta\eta_O}{(\eta + \eta_O)^2} \frac{e^{-j2kd}}{1 - \left(\frac{\eta - \eta_o}{\eta + \eta_o}\right)^2 e^{-j2kd}} \quad (6)$$

Considering (5) and (6), the permittivity approach 0, the intrinsic impedance will approach infinity $\eta = \sqrt{\mu / \varepsilon} \rightarrow \infty$ [10]. Hence, S_{11} will approach +1 and S_{21} approach 0. On the other hand, if permittivity approaches infinity, the intrinsic impedance will approach 0 so S_{11} and S_{21} will approach -1 and 0, respectively.

III. Antenna Design

A. Small Planar Dipole Antenna

The SPDA operating at frequency 11 GHz is a dipole with length of 7.63 mm, width of 0.19mm mounted on a dielectric substrate and the feed gap is 0.19mm in length as shown in Fig. 2. The dielectric substrate used for fabrication is FR4-epoxy with the dimension of 11.5mm x 15.3mm x 1.575 mm. Its relative permittivity (ε_r) is equal to 4.4 whereas dielectric loss tangent (tan δ_ε) is equal to 0.02.

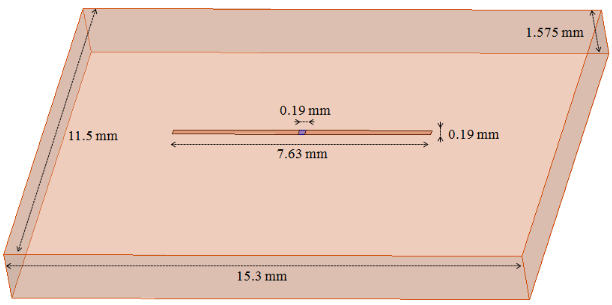

Fig. 2 Small Planar Dipole Antenna (SPDA)

B. Symmetrical Pyramidal Block

The SPB consists of four congruent equilateral triangle faces. SPB is fabricated using dielectric substrate (FR4-epoxy). Crescent-shaped copper with thickness of 0.017 mm is patched on one side of each individual dielectric substrate and rectangular copper with thickness of 0.017 mm on the other side [11]. The dimensions of the crescent shape copper and the rectangular copper on ETDS are shown in Fig. 3. Dielectric substrates used are FR4-epoxy with thickness of 0.25mm. The reflection coefficient S_{11} and transmission coefficient S_{21} of ETDS are shown in Fig. 4. The permittivity and permeability of ETDS are calculated from S-parameter by retrieval method shown in Figs. 5 and 6.

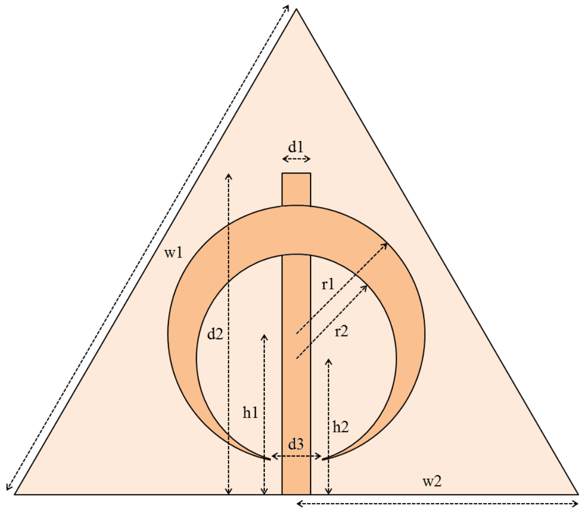

Fig. 3 Copper patched on ETDS with w1 = 10.4 mm, w2 = 5.2 mm, r1 = 2.4 mm, r2 = 1.914mm, h1 = 3 mm, h2 = 2.514 mm, d1 = 0.48 mm, d2 = 6 mm and d3 = 0.942 mm

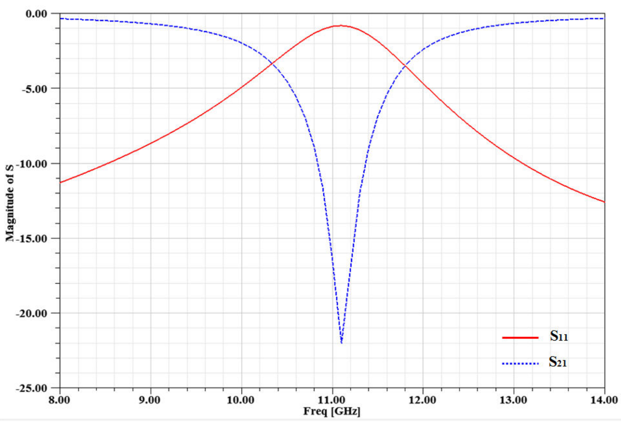

Fig. 4 Magnitude of S Parameters of ETDS

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ISSN: 2517-9438
Vol:8, No:5, 2014

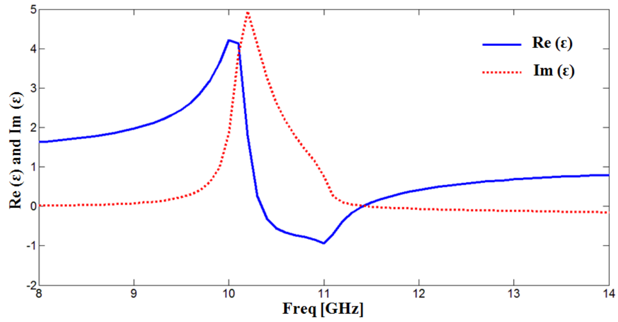

Fig. 5 Constitutive Permittivity of ETDS

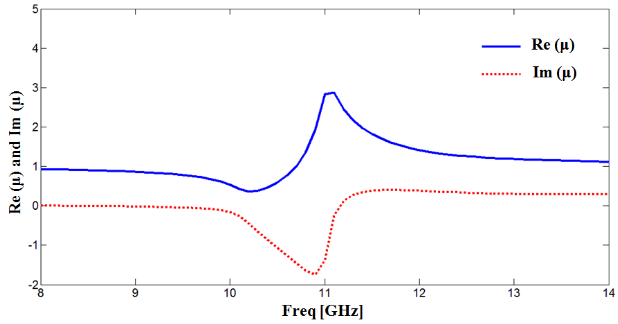

Fig. 6 Constitutive Permeability of ETDS

Constitutive Permittivity and constitutive permeability determined at 11 GHz are shown in Table I.

TABLE I
CONSTITUTIVE PERMITTIVITY AND PERMEABILITY OF EQUILATERAL TRIANGLE DIELECTRIC SUBSTRATES AT 11GHZ

Structures	Permittivity	Permeability
Equilateral Triangle Dielectric Substrates (ETDS)	-0.94+0.75i	2.84-1.38i

IV. CONCLUSION

By using the in-phase total reflection (S_{11} = + 1), SPB, one of ENG material, is able to increase gain of SPDA. By being mounted on SPB, the performance of the antenna under test can be improved in the following. Firstly, the reflection coefficient can be improved from -11.7593 dB to -13.7037 dB at frequency of 11 GHz. Secondly, SPDA is available between 10 to 12.7 GHz. the reflection coefficient of SPDA and SPDA with SPB are shown in Fig. 7. Finally, the gain of antenna is increased from 1.4 dB to 2.46 dB as shown in Fig. 8.

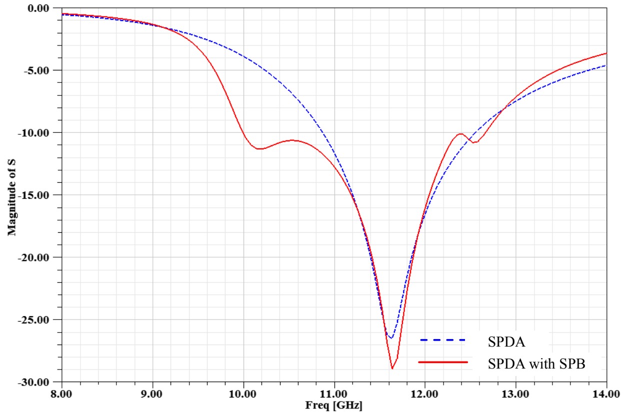

Fig. 7 The Reflection Coefficient of SPDA and SPDA with SPB

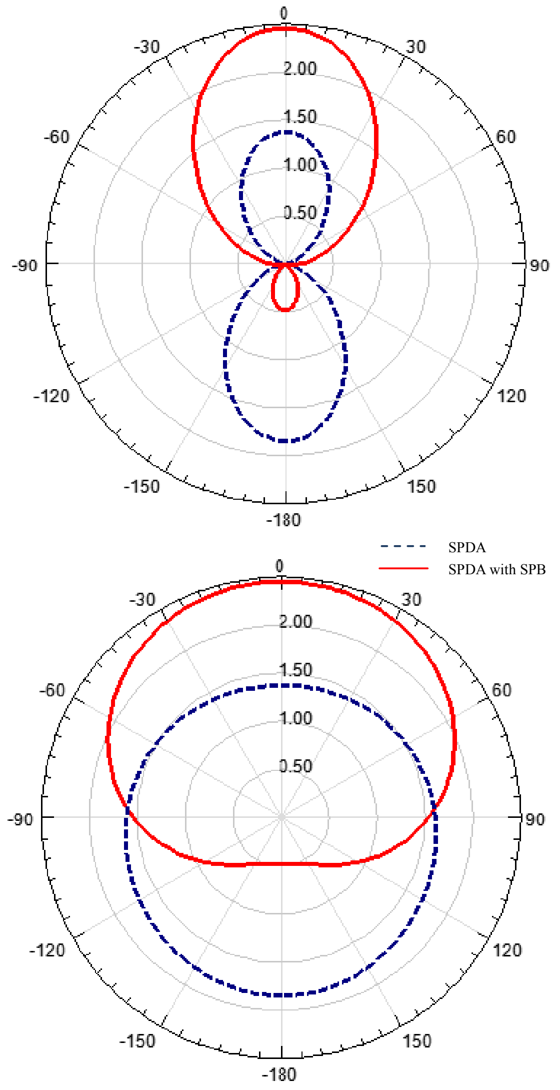

Fig. 8 The Radiation Pattern of the SPDA and the SPDA with SPB

ACKNOWLEDGMENT

The authors gratefully thank to Mass Rapid Transit Authority of Thailand (MRTA) and Expressway Authority of Thailand (EXAT) for simulation equipment. Also, the authors thank to Kasetsart University Research and Development Institute (KURDI) and The Petroleum and Petrochemical College, Chulalongkorn University for financial support.

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