DESIGN OF ZEROTH-ORDER RESONANCE ANTENNA ARRAY WITH A PAIR OF DPS AND ENG MATERIALS

Dang Thi Tu My[1], Huynh Nguyen Bao Phuong[1], Tran Thi Huong[2]

[1]Quy Nhon University; dangthitumy@qnu.edu.vn, huynhnguyenbaophuong@qnu.edu.vn
[2]The University of Danang; tranhuong@dut.udn.vn

Abstract - This paper proposes one-dimensional antenna arrays of the four-element and the eight-element using composite materials. Firstly, the single element is designed to resonate at Zeroth-order using a pair of Double positive (DPS) and Epsilon negative (ENG) materials meta-structured transmission line (MTL). Secondly, three of 1:2 T-Junction power dividers and seven of 1:2 T-Junction power dividers based on micro-strip technology are designed for feeding the four-element and the eight-element array antennas, respectively. Finally, the proposed arrays are optimized using FEM-based simulation to operate at the frequency of 8,5 GHz. The simulated results show that both antenna arrays have Zeroth-order resonance (ZOR) property, in which the four-element array has a bandwidth spreading from 8.39 to 8.61 GHz and a maximum gain of 8.82 dB while the other one of the eight-element array is 8.39 – 8.60 GHz and 12.2 dB, respectively. The proposed array antennas can be used for wireless applications or mobile communications.

Key words - Epsilon Negative; Double positive; Metamaterial; Antenna array; Zeroth-Order Resonance.

1. Introduction

At present, the demand for compact radiators with high-gain grows rapidly in many fields of application. Several techniques have been proposed in order to squeeze the resonant dimensions of patch radiators while maintaining their other radiation features. The abnormal electric field properties of metamaterials have attracted a lot of attention in recent years for some electromagnetic applications. It is very important to minimize path antenna so that the ENG MTL can have the unique property of an infinite wavelength wave at a specific non-zero frequency where permittivity and permeability are zero [1]. Zeroth-order resonator (ZOR) occurs in the meta-structured transmission line (MTL) with the epsilon negative (ENG) [1], [2]. The different applications use infinite wavelengths such as power divider, Zeroth-order resonator (ZOR) and ZOR antenna. However, the radiation of the antennas is the same as monopole radiations, in particular, modern wireless telecommunication systems and space communications require a compact antenna with patch-like radiation.

The new model has been proposed to reduce the resonance size of the antenna mushroom shape consisting of the rectangular patch with a series gap and grounded via hole and has negative permittivity property in the specific frequency band [3], [4]. Due to the compactness, the proposed array antenna has overcome the disadvantage in large dimension of the antennas which are presented in [5], [6].

The rest of this paper is organized as follows. In Section 2, the elementary theory is proposed. The detailed design of the proposed antenna structure is presented in Section 3. The conclusions are offered in Section 4.

2. Elementary theory

The structure used to design the ZOR antenna using the ENG material is a mushroom model structure on a micro-strip circuit depicted in Figure1. The mushroom structure is usually employed to realize the meta-structured transmission line. This mushroom structure is composed of a combination of the rectangular patch with a series gap and a grounded via hole. The ENG MTL is realized with only grounded via hole and has negative permittivity property in the specific frequency band. The equivalent circuit parameters can be extracted from full-wave simulation data of the unit cell. To achieve the impedance matching of ZOR antennas, a gap feed is employed. DPS MTL is realized by the common transmission line.

In this model, the left-handed elements are capacitance C_L and inductance L_L. Capacitance C_L is formed by the gap between two adjacent patches while the inductance L_L is constructed by the metal via, which is connected to metal patch and metal ground plane and the right-handed elements are L_R and C_R. From that, the inductance L_R is formed by the metal patch and the capacitance C_R is constructed by the split etched on the surface of the metal ground plane [7-10].

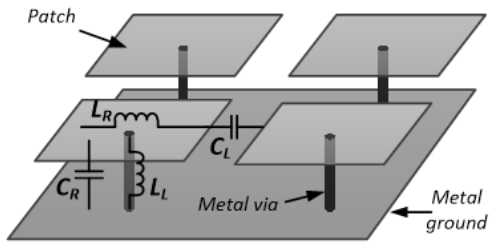


Figure 1. *Mushroom-like model*

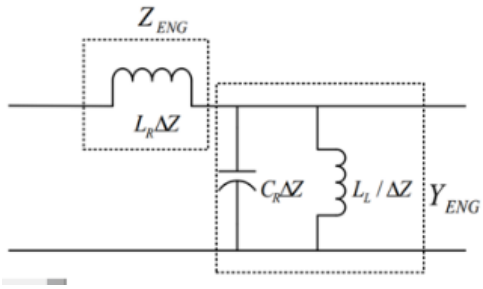


Figure 2. *Equivalent circuit*

By changing the physical characteristics of fungal unit cells (e.g., metal cell dimensions, cylindrical radius, di-electric constant), we can adjust the inductance and capacitance values.

A metal patch can be square or rectangular. The size of the metal patch, the dielectric constant, cycle of the unit cell

and the radius of the axon are the factors that influence the dispersion curve and the resonant frequency of the antenna. An increase in the metal cell area or dielectric constant would lead to an increase in the C_R capacitance while a decrease in the radius of the metal shaft would result in an increase the L_L inductance. The center resonant frequency of the proposed antenna is defined as follows:

$$f_0 = f_{sh} = \frac{1}{2\pi\sqrt{L_L C_R}} \quad (1)$$

where L_L and C_R are total left-handed capacitance and inductance, respectively. Where

$$L_L = 2h\left(ln\left(\frac{2h}{d}\left(1+\sqrt{1+\left(\frac{d}{2h}\right)^2}\right)\right) - \sqrt{1+\left(\frac{d}{2h}\right)^2} + \frac{\mu}{4} + \frac{d}{2h}\right) \quad (2)$$

With: h dielectric thickness (mm);

d is the cylinder diameter (mm)

$$C_R = 2C_P \quad (3)$$

With $C_P = \varepsilon_r \varepsilon_0 \frac{S}{h}$

$\varepsilon_0 = 8.846.10^{-12}$ ($\frac{F}{m}$);

S is the area of the cell (mm^2);

h is the substrate thickness.

3. Antenna design

In order to reduce the size and improve the power of the antenna, the DPS material is added. The antenna design pattern consists of two components with different electromagnetics.

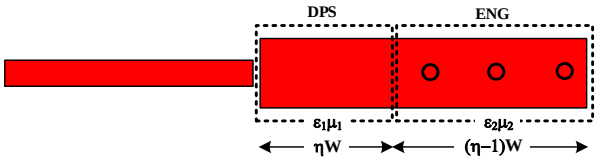


Figure 3. *Proposed antenna form*

The resonant frequencies of the equivalent cavity for the modes may be easily obtained by applying all the boundary conditions, and they correspond to the solution of the following dispersion equation [1]:

$$\frac{k_1}{\omega\mu_1} tan[k_1 \eta W] = -\frac{\omega\varepsilon_2}{k_2} tan[k_2(1-\eta)W] \quad (4)$$

Where $k_i = \omega\sqrt{\varepsilon_i \mu_i}$ with i = 0,1,2.

With the aim of determining the DPS segment size, we shorten the antenna length from 32mm to 4mm. This will lead to significantly changing the resonant frequency. With S = 6.10^{-6} m^2, C_R = 0.168 pF and f = 22.3 GHz. Simulation results are illustrated in Figure 4

Then, the DPS structure is added to the above antenna. With the presence of DPS, the antenna frequency reduces dependence on the length of the DPS segment, which is shown in Figure 5.

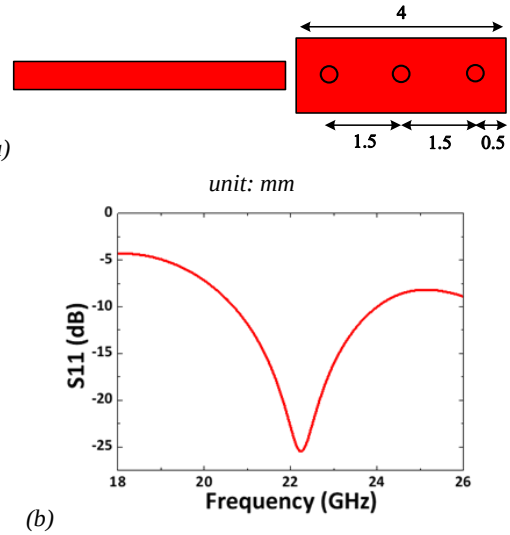


Figure 4. *(a) Antenna form after shortening; (b) S11 of the antenna after shortening*

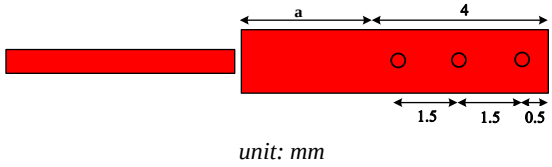


Figure 5. *Antenna form after adding the DPS segment*

The Optimetrics tool in HFSS is utilized to change the parameter from 2mm to 4mm in order to find the DPS that matches the desired frequency. Selection of the design frequency of 8.5 GHz, corresponding to a = 3.17 mm is shown in Figure 6.

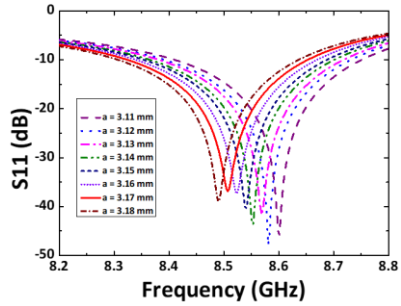


Figure 6. *Simulated S11 of a single antenna for different value of a*

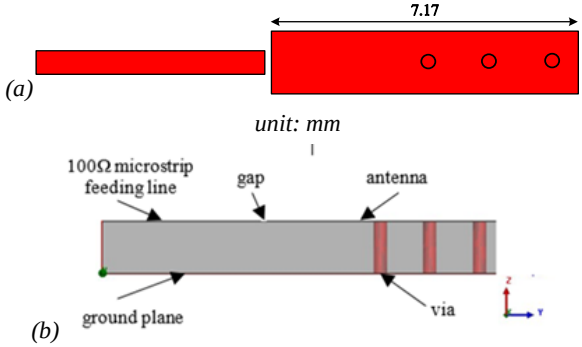
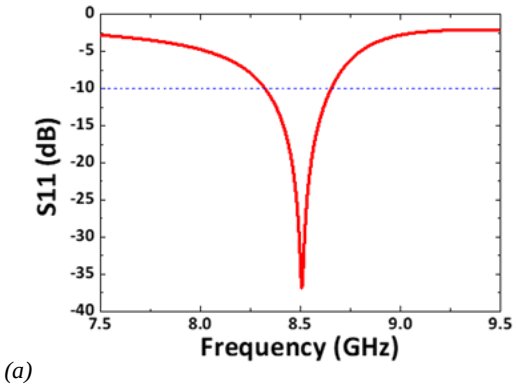
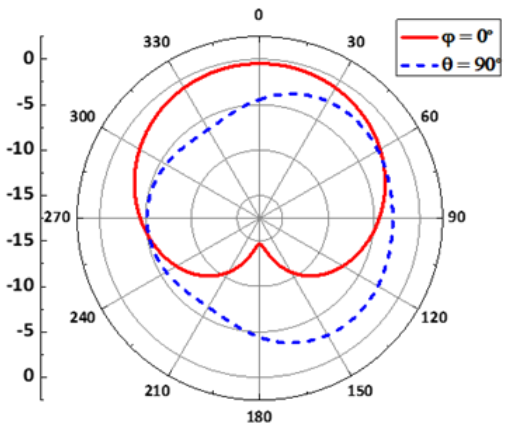


Figure 7. *Proposed single antenna; (a) Antenna size after being added the DPS segment with a = 3.17; (b) Side view of the single antenna*



(a)

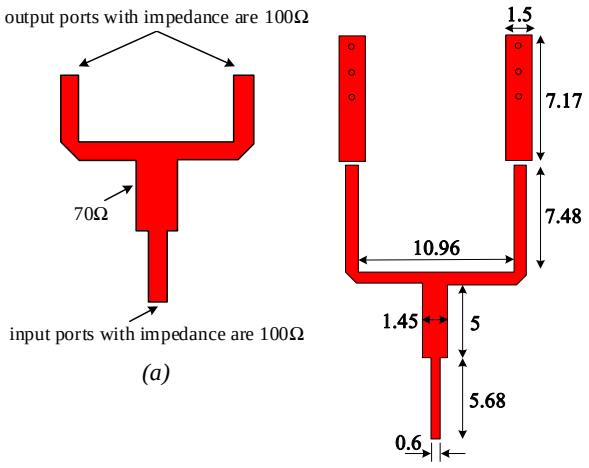


(b)

Figure 8. *(a) Simulated of S11 of a single antenna; (b) Radiation pattern of a single antenna*

A single antenna simulation uses HFSS software, draws the antenna according to the dimensions. The radius of the cylinder via r = 0.2mm, the position of the cylinders distributed equally on the surface, the gap between the path and the antenna (g) is 0.2mm and S11 coefficient as shown in Figure 8a. It can be seen that the single antenna operates at a center frequency of 8.5 GHz with the -10 dB bandwidth of 320 MHz.

The simulated radiation pattern of the single antenna is presented in Figure 8b. From this figure, the maximum gain of the antenna is 1.33 dB.

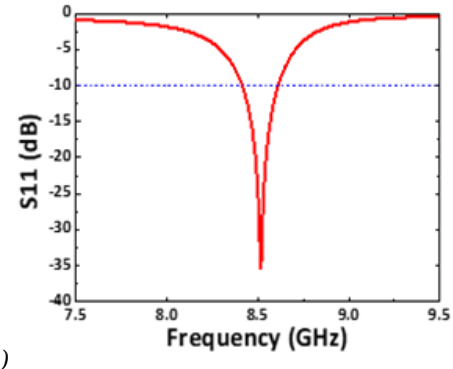


(a) (b)

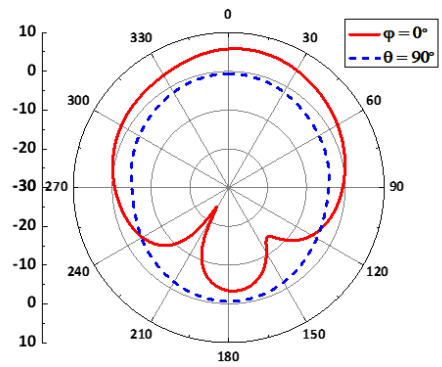
Figure 9. *(a) T-Junction power dividers 1:2; (b) Antenna array of two elements*

By integrating the single antenna shown in Figure 7(a) and the power dividers in Figure 9(a), the one-dimensional antenna array of two-element using composite materials is designed as shown in Figure 9(b).

The simulated S11 of the antenna array of two-element is shown in Figure 10(a). It can be seen that two element array resonates at the center frequency of 8.5 GHz with the -10 dB bandwidth of 200 MHz.



(a)



(b)

Figure 10. *(a) Simulated of S11 and (b) radiation pattern of the two-element antenna array*

Figure 10(b) presents the simulated radiation pattern of the two-element array. From this figure, it can be observed that the array achieves the highest gain of 5.95 dB and higher than that of a single antenna.

Next, by using three of 1:2 power dividers and proposed single antenna elements, the one-dimensional antenna array of the four-element is formed as shown in Figure 11.

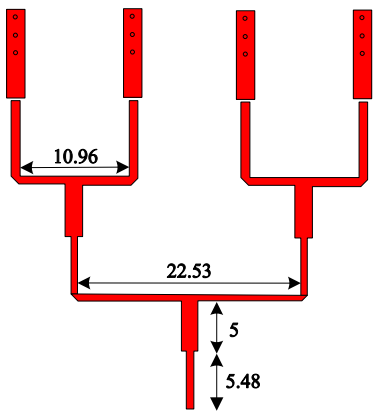
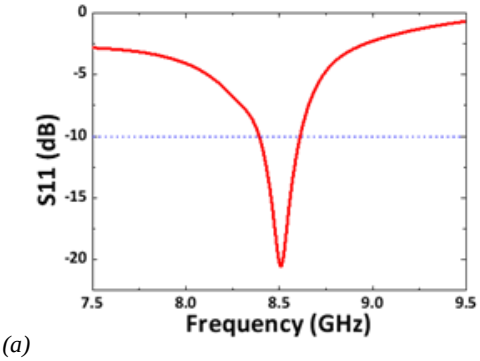


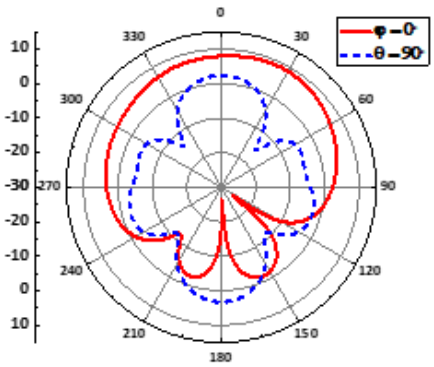
Figure 11. *The configuration of the four-element array*

Figure 12(a) presents the simulated S11 of the four-element array. The array has -10 dB bandwidth of 220 MHz at the center frequency of 8.5 GHz. The simulated radiation pattern in Figure 12(b) shows that the array has a directionally radiated with the highest gain of 8.82 dB.

Finally, we use seven of 1:2 power dividers and the proposed antenna elements to construct the one-dimensional antenna array of the eight-element which is depicted in Figure 13.

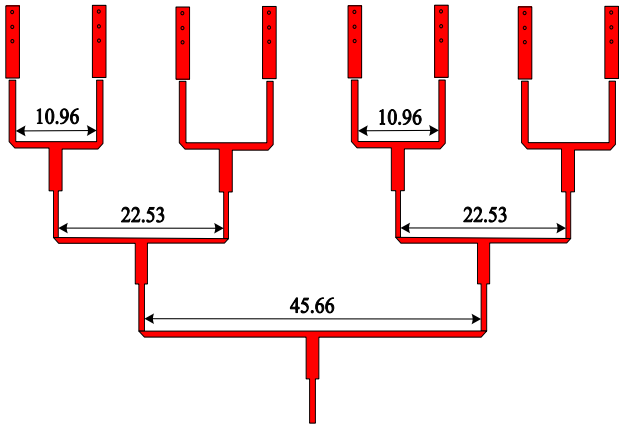


(a)



(b)

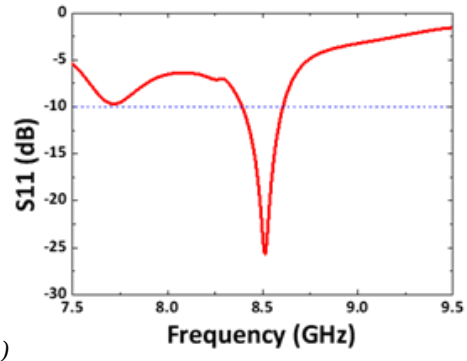
Figure 12. *(a) Simulated of S11 and (b) radiation pattern of the four-element antenna array*



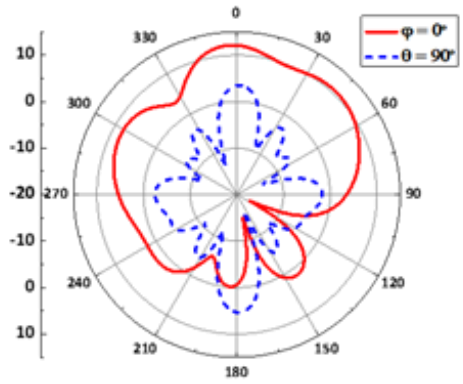
unit: mm

Figure 13. *The configuration of the eight-element array*

Simulated S11 of the eight-element array is shown in Figure 14(a). It is observed that the array resonates at the center frequency of 8.5 GHz with a -10dB bandwidth of 210 MHz. Figure 14(b) presents the simulated radiation pattern of the eight-element array. From this figure, the array radiates directionally and achieves a maximum gain of 12.2 dB.



(a)



(b)

Figure 14. *Simulated of S11 and radiation pattern of the eight-element antenna array*

Table 1. *Comparison of the parameters of the designed antennas*

	Single antenna	**Two-elements antenna array**	**Four-elements antenna array**	**Eight-elements antenna array**
Resonant frequency	8.5 GHz	8.5 GHz	8.5 GHz	8.5 GHz
Reflection coefficient	-36 dB	-35 dB	-21 dB	-26 dB
Highest gain	1.33 dB	5.95 dB	8.82 dB	12.2 dB
-10 dB Bandwidth	320 MHz	200 MHz	220 MHz	210 MHz

The comparison of parameters between single and array antennas has been done in Table 1. It is clear that the increase in antenna elements leads to the increase in antenna's gain.

4. Conclusions

The combination of two material structures in this paper has contributed to a significant reduction in size of antennas. Applying array antennas into the design has helped markedly improve orientation as well as increase in gain level. In the paper, a simple antenna pattern is designed and simulated, resulting in the S11. The radiation pattern is quite good and meets the requirements set out. Since the calculation and simulation are approximate, there will be more or fewer errors and no conditions for the antenna construction to be measured on the meter. However, the actual measurement results will not differ much from the simulation results. In a future study, it is planned to use

the proposed array antenna for wireless applications such as wireless imaging transmission systems or mobile communications [11-15].

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