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A MINIATURIZED FOLDED MICROSTRIP ANTENNA ARRAY FOR MIMO APPLICATIONS BASED BIOMEDICAL SYSTEM

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ABSTRACT: - In this paper, the focus on designing a microstrip antenna for wearable biomedical applications is investigated. The antenna array is folded on a cylindrical substrate for MIMO applications. The proposed array is based on two identical antenna elements. The separation distance between antennas elements is reduced using metamaterial (MTM) structures. The proposed MTM structure provides an excellent rejection band at 2.45 GHz. It is found that the antenna provides excellent matching at 2.45 GHz with gain of 4.8 dBi. The maximum coupling between antenna elements is -20 dB based on flat profile. However, the antenna array maintains the same performance after folding on a cylinder of 20 mm with coupling degradation, only, of -15 dB. The evaluation of the antenna array performance based on flat and folded profiles is carried out using Finite Integral Technique (FIT) based on CST Microwave Studio (CSTMWS) formulations.
Key words*:* Microstrip Antenna, Metamaterial, MIMO, FIT, and CSTMWS.

1. INTRODUCTION

Over the past decade, MTM supported engineers with manipulating the material has intrinsic parameters to control and utilize the propagation of electromagnetic waves [1]. Thus, MTM structures attracted the attentions of researchers due to their unusual electromagnetic properties that can be artificially-engineered [2]. Generally, they can be explained in the context of periodical structures of unit cells that are much smaller than the guided wavelength [3]. These structures provide simultaneously negative permittivity and/ or permeability, are referred to as left-handed, which are rarely available by nature [4]. Therefore, the developments of new concepts, devices, and possible utilization in many novel applications have been enabled [3]. The combinations of the right-handed, traditional material, structures and left-handed structures lead to right/left-handed structures [5]. Frankly speaking, all the practical left-handed structures lies under the composites of right/left-handed materials since their left handed properties is available in a small bandwidth [6]. It is very important to mention that only the right- and left- handed structures allow the electromagnetic waves to propagate [7]. The left-handed structure is described by anti-parallel phase and group velocities and backward-wave propagation that are different from the right-handed structure [8]. The intersection of the various types of materials is indicated as zero-index media due to its infinite wavelength propagation [9].

In this paper, the investigation of a miniaturized microstrip antenna array design for wearable biomedical applications is demonstrated. The patch geometry of the microstrip antenna is based on meander triangular structure. The pair of the same antenna structure is placed on folded substrate for MIMO application. The patch structure is fed with a 50 Ω microstrip line. The MTM structure is introduced to minimize the separation distance between the antenna elements.

2. ANTENNA GEOMETRY

The proposed antenna array is constructed from a patch and ground plane of copper mounted on a Roger 3006 substrate with an effective relative permittivity, ε_{reff}= 5.785, and a loss tangent, tanδ = 0.00134. In an effort to miniaturize the antenna size, the patch is shaped as a truncated triangular line to provide a 68.43 mm effective length for the current path within a limited area and to ensure robustness against twisting and bending. These values are calculated according to the given equation in (1). The position of the feed is determined by the distance between the inset section in the patch conductor and the edge of the substrate.

$$L_{eff} = \frac{\lambda_g}{2} = \frac{\lambda}{2\sqrt{\varepsilon_{eff}}} \quad (1)$$

where L_{eff} is the effective length, λ_g is the guided wavelength, λ is the wavelength at the frequency of interest, and ε_{eff} is the effective relative permittivity.

A. Single Antenna Structure

The proposed antenna array is based on two identical antenna elements as depicted in Fig. 1. In this section, the antenna structure based on flat profile of the proposed array is used as a reference design to optimize its performance to achieve the optimal performance as at 2.45 GHz.

B. Folded Profile

The antenna array is folded on a cylindrical substrate of 40 mm in diameter for MIMO applications. The antenna elements are separated with MTM structures as shown depicted in Fig. 2.

C. MTM Structure

The periodical structure of single unit cell of the proposed MTM is illustrated in Fig. 3. The proposed MTM structure provides an excellent rejection band at 2.45 GHz. By adjusting the unit cell number and separation distances around 2.45 GHz, the maximum mutual coupling reduction between adjacent antennas is achieved. The maximum dimensions of the presented MTM unit cell are $0.3\lambda \times 0.3\lambda$ where λ is wavelength at 2.45 GHz. The periodical repetition of the MTM unit cell are aligned to be parallel to the x and y axes.

3. RESULTS AND DISCUSSION

The performance of the antenna array structure based on folded profile is evaluated using CSTMWS. The antenna parameters S-parameters, bandwidth, and the radiation patterns at the fundamental resonant frequency are discussed.

The following procedure is adopted to optimize the performance of the single element structure. As far as the simulations are concerned, the length of the patch and feed position are adjusted through several iterative simulation steps in order to restore resonance around 2.45 GHz with good impedance matching for the folded geometry.

This approach is justified by running two tests to ensure convergence at the accurate solution. The first test is done by discretizing the geometry and field quantities in space. The adaptive mesh is applied from an initial mesh at Nx = 37, Ny = 36, and Nz = 20, a mesh line ratio limit to 50, along the x, y, and z directions, respectively. A convolutional Perfectly Matched Layer (PML) of four layers with a reflection coefficient of 0.0001 at normal incidence is invoked. The structure surrounded with minimum distance of one-eighth of the wavelength at 2.45 MHz. A tetrahedral mesh is applied and refined mesh with a factor of 20 is conducted to the metal edges. The second test is performed to terminate the simulation when S_{11} does not change above 2% between at least two consecutive passes over the frequency band of interest. This test has been terminated when the energy inside the structure has dropped by at least 40 dB below its maximum value.

A. Antenna Performance based on Single Element

The mesh cell distribution is displayed in Fig. 4, the fine mesh densities for the single element case are essential to arrive at an accurate field and current induced on the narrow portions is presented. In Fig. 5, the maximum value of S_{11} is shown versus the number of adaptive mesh iterations.

The numerical results show a resonant frequency close to 2.45 GHz with a -12 dB return loss bandwidth of approximately 0.09 GHz as seen in Fig. 6.

The radiation efficiency is defined as the ratio of the power radiated from the antenna to the input accepted power by the antenna. The evaluated radiation patterns are presented in Fig. 7. The induced electric field on the patch structure is presented in Fig. 8.

B. Antenna Array Performance based on Flat Profile

The obtained results from the numerical simulation for the antenna array performance based on flat profile are discussed in this section. It is found that the maximum coupling at 2.45 GHz is below -25 dB, this is shown in Fig. 9, of gain about 4.5 dB; this is achieved from introducing the MTM structure to the antenna design.

C. Antenna Array based on Folded Profile

CST MWS simulations are carried out for the antenna array with a 1mm resolution in order to characterize the performance in terms of the resonant frequency, bandwidth, gain, and efficiency. The S-parameters of the proposed antenna array are presented in Fig. 10. The radiation patterns are presented in Fig. 11.

4- CONCLUSION

The design of a folded microstrip antenna array for wearable biomedical applications is discussed in this paper. The proposed antenna array is investigated based on two identical patch elements separated with MTM structures mounted on a cylindrical Roger 3006 substrate of 35 mm in diameter. The maximum separation distance between antenna elements is a reduced using MTM structure of an excellent rejection band around 2.45 GHz. The antenna provides a less than -10 dB matching at 2.45 GHz with gain of 4.8 dBi and maximum coupling between patch elements of -20 dB in their flat profile. However, it is found that the antenna array maintains the same performance after folding it on the cylindrical substrate. Finally, the antenna array performance based on flat and folded profiles is carried out and compared using CSTMWS formulations.

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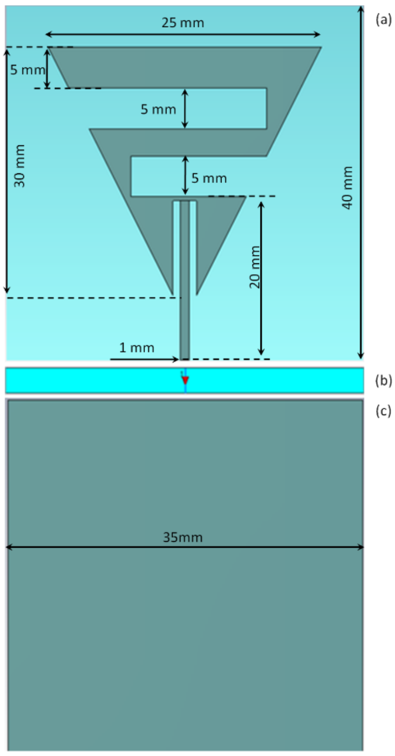

Fig 1: Single antenna structure: (a) front view, (b) side view, (c) back view.

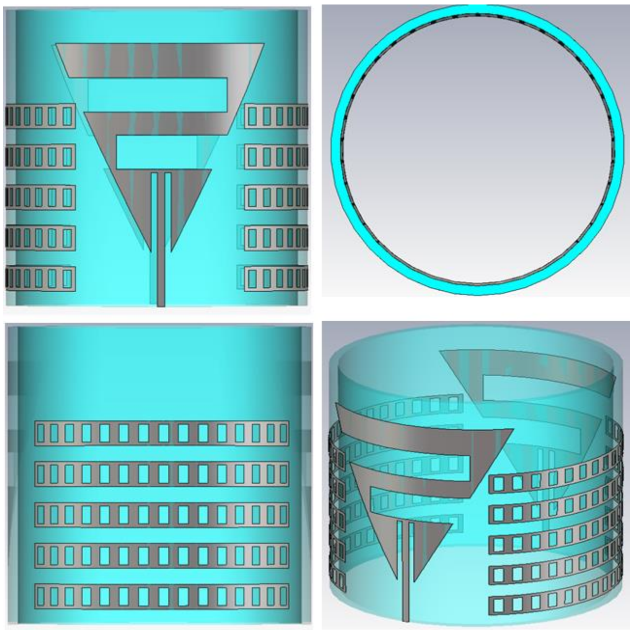

Fig 2: The antenna elements separated with MTM structures.

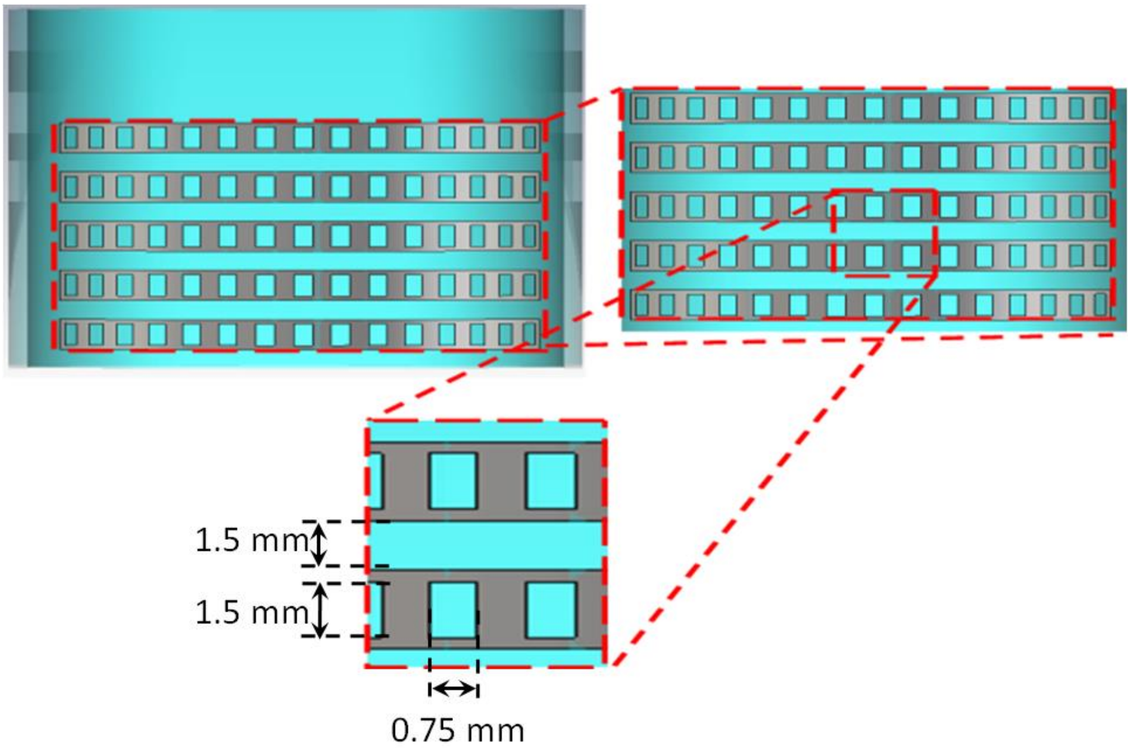

Fig 3: The periodical structure of single unit cell of the proposed MTM.

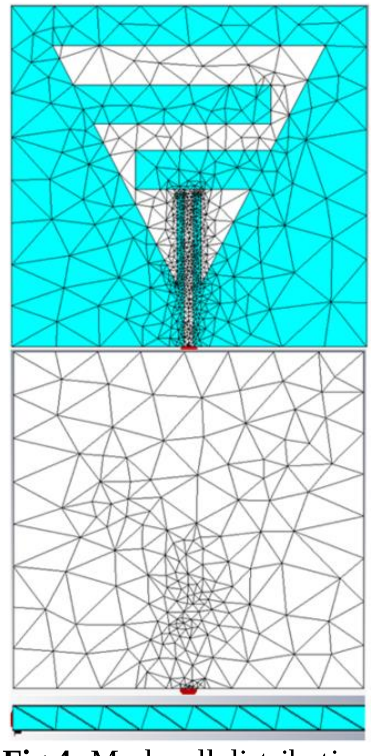

Fig 4: Mesh cell distribution.

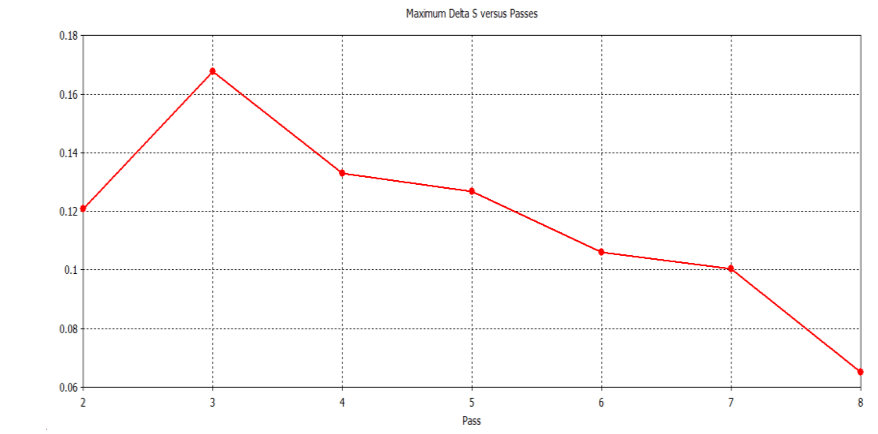

Fig 5: The maximum value of S_{11}

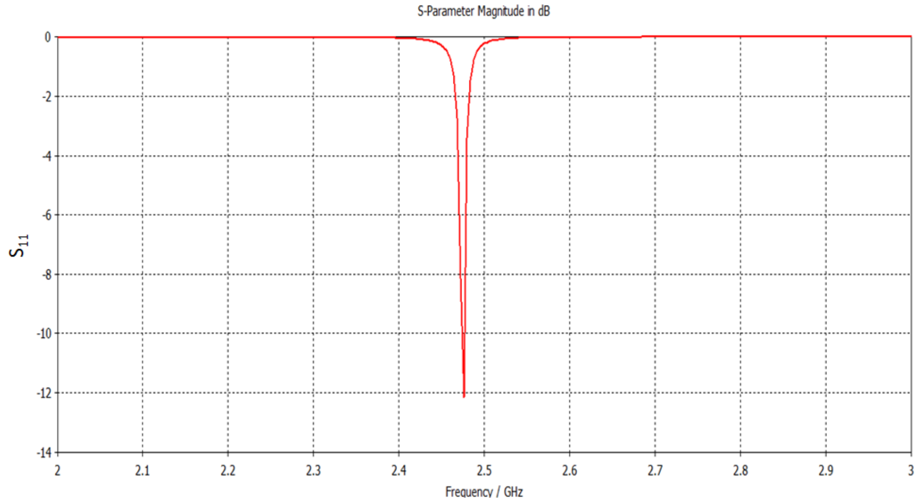

Fig. 6: The numerical results

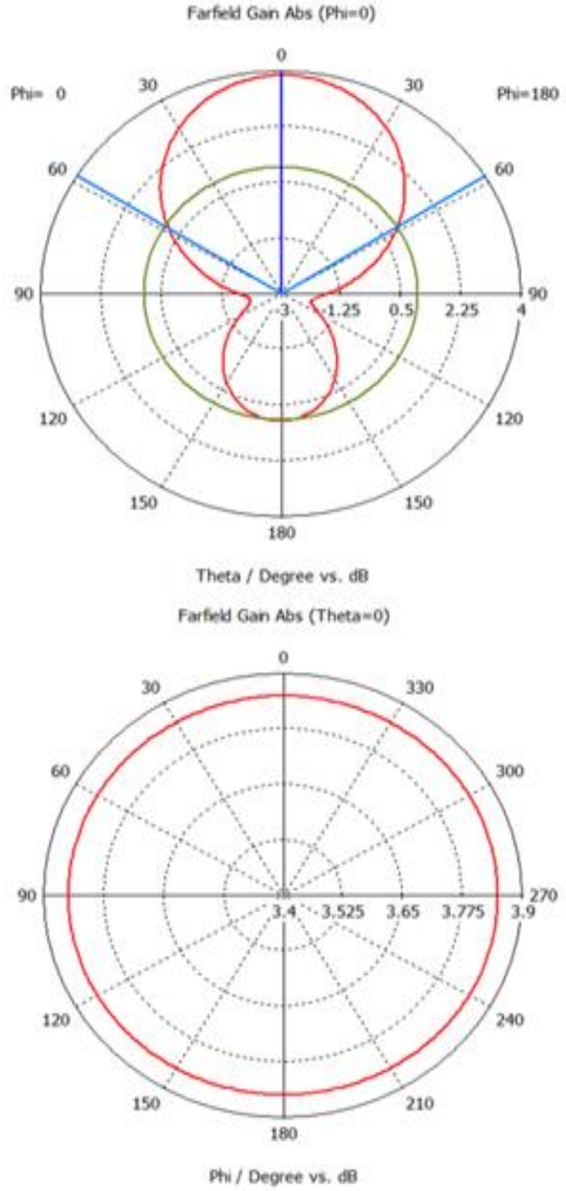

Fig 7: The radiation patterns

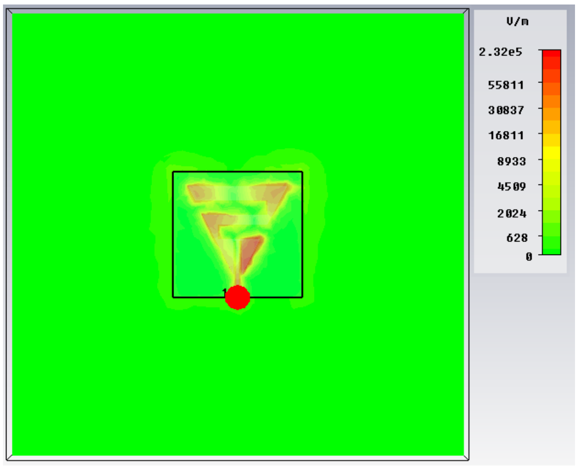

Fig 8: The electric field on the patch.

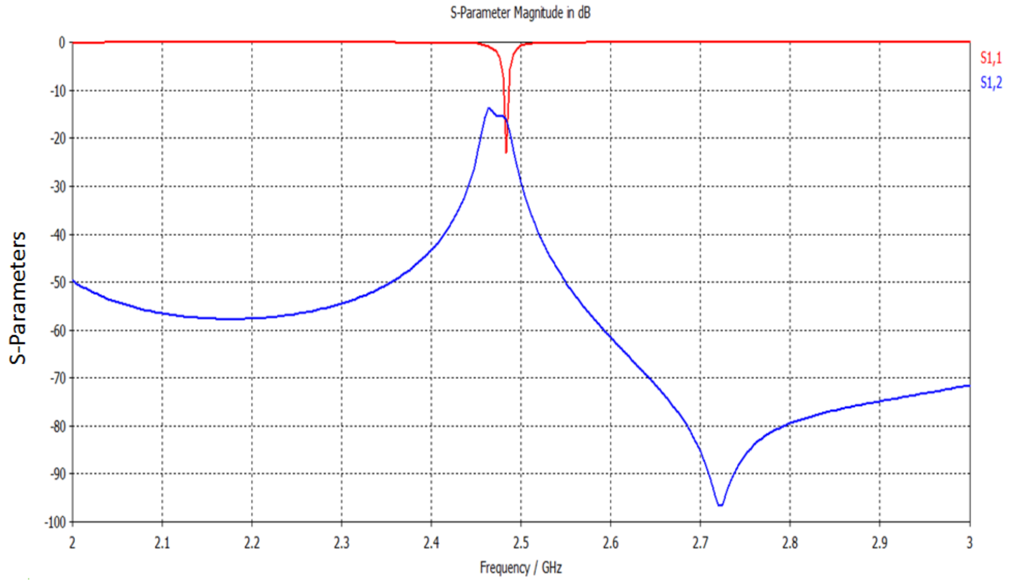

Fig. 9: The unit cell of the MTM.

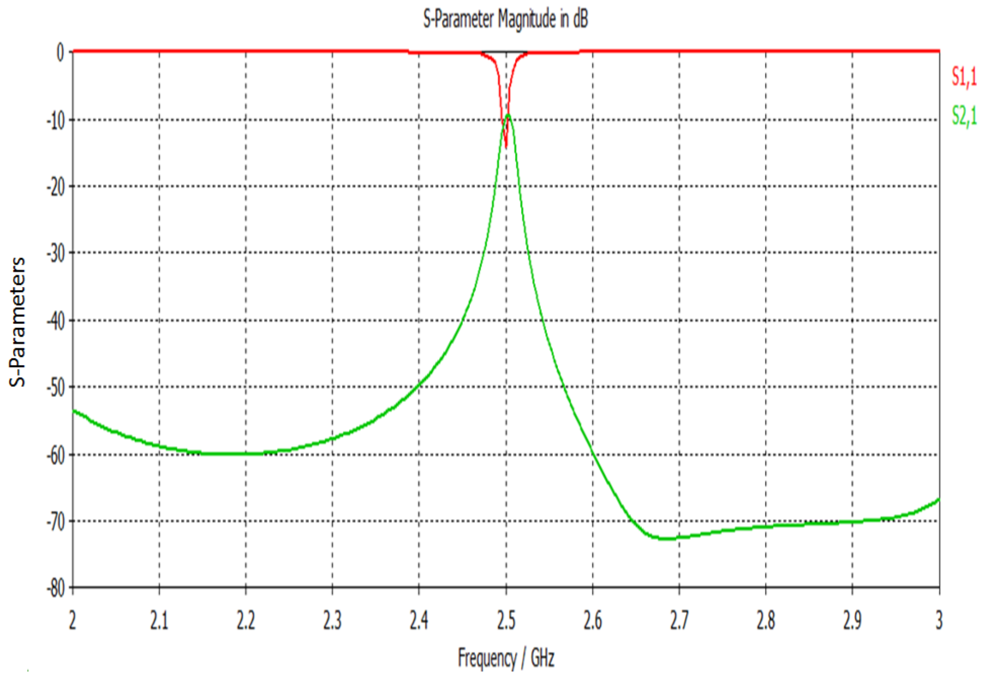

Fig 10: The mutual coupling

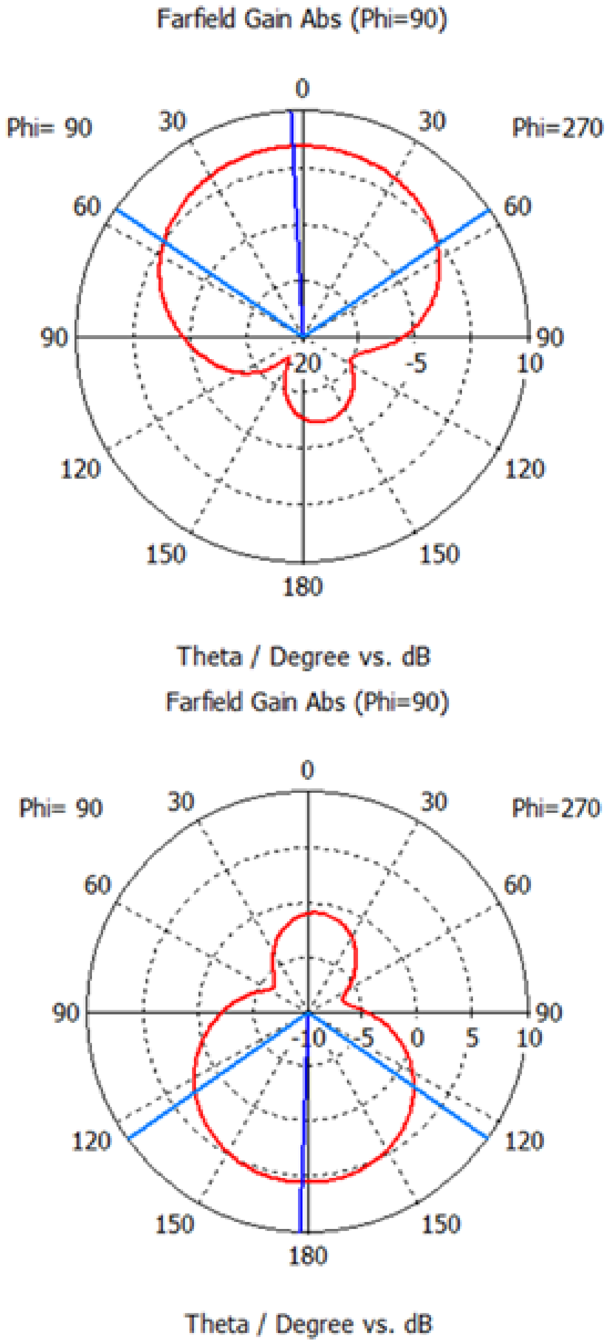

Fig 11: Radiation patters

تصميم مصفوفة الهوائيات الشريطية الدقيقة المستخدمة في التطبيقات الخاصة بالطب الحيوي

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الخلاصة:

هذا البحث تم التركيز على تصميم الهوائي الشريطي الدقيق يستخدم في التطبيقات الخاصة بالطب الحيوي. ان مصفوفة الهوائي تم طيها على ركيزة اسطوانية مخصصة لتطبيقات Multi–Input–Multi–Output (MIMO) .ان المصفوفة المقترحة تعتمد في تصميمها على عنصرين متماثلين للهوائي ,المسافة الفاصلة بين هذان العنصران تم تقليلها باستخدام تراكيب Metamaterial (MTM) ان تركيبة MTM المقترحة تقدم رفض ممتاز للحزمة في تردد 2.45 GHz وقد تم الوصول الى ان الهوائي له تطابقا ممتازا في حزمة 2.45 GHz وفي ربح مقداره 4.8 dBi .وفي هذا التصميم نسبة الازدواج بين عنصري الهوائي هي 20– dB بالاعتماد على المقطع المسطح. على اي حال، فان مصفوفة الهوائي حافظت على نفس الاداء بعد طيها على اسطوانة بقطر 20 mm وبتقليل نسبة الازدواج الى 15– dB.ان تقييم اداء مصفوفة الهوائي المعتمد على المقطع المسطح والمقطع المطوي تم انجازها باستخدام تقنية التكامل المنتهي FIT بالاعتماد على الحقيبة البرمجية CST MICROWAVE STUDIO .

الكلمات الدالة: الهوائي الشريطي الدقيق, المادة ألخارقة, عدة مدخلات–عدة مخرجان, تقنية التكامل المنتهي, الحقيبة البرمجية.