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Four port Honeycomb-slotted Line strip with Round cap MIMO Nanoantenna for Optical Frequency Applications

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***Abstract*—A four-port MIMO Nanoantenna is proposed in this article. The proposed antenna consists of microstrip lines with honeycomb-shaped slots with a round cap with each radiating element. The structural dimension of the MIMO antenna is 20 nm $\times$ 20 nm $\times$ 1 nm based upon a graphene substrate. The proposed nanoantenna resonates at 3.12 THz, 9.7 THz, and 16.35 THz. Each radiating element is isolated by at least 25dB reaching up to 89.89 dB. The proposed antenna possesses a maximum gain of around 4.5 dB and radiation efficiency of around 92%. The ECC (<0.4), DG (9.6-10 dB), TARC(<-10dB), CCL (<4bps/Hz), and MEG (<-3dB) are also studied with satisfied diversion performance.**

***Index Terms*—MIMO, Nanoantenna, Optical Frequency, THz.**

I. Introduction

Microwave researchers are focusing on modern communication technologies and modulation techniques to solve bandwidth challenges [1]. This helps improve how efficiently the spectrum is used and boosts data rates and frequency reuse. Even with MIMO technology, Shannon's theory sets a limit on channel capacity. To address this, optical frequency bands are considered as suitable bands, up to 10 THz [2]. Recently, A communication range from 110 THz to 292 THz was suggested for a bow-tie antenna [3]. An aluminum dipole antenna is placed upon a glass substrate to optimize its parameters. Despite its potential, THz signals aren't used as much as electrical or optoelectronic signals. One major issue in advancing THz wireless systems is the shortage of fabrication processes, especially for nanodevices. Firstly, Nanosecond lasers have been available since the 1980s along with photoconductive antennas to generate THz waves [4]. This has led to their use in several applications [5]. THz communication offers benefits like improved directionality, data safety, and less attenuation [6]. However, its use for short-distance communication is limited by higher atmospheric absorption. Despite being in high demand for the past 20 years, implementing THz communication hardware remains challenging. Lately, various metallic nanoantennas and array patterns, such as reflector antennas, light-conducting dipole antennas, lens antennas, horn antennas, planar antennas, along with 'bow-tie' antennas, are being developed for THz services [7–11]. Fabricators face challenges because of the measurement issues in the THz range as the measuring instrumentation in this range is yet to develop. Conventional antenna materials will result in reduced skin depth, so researchers are exploring carbon-based materials such as graphene and carbon nanotubes (CNT) [12]. In recent studies, material selection for Nanoantenna and its performance is analyzed for THz communication [12]. A silicon substrate is used to design a nanoantenna covering it with a silicon lens [13], and applying multiple layers with certain dielectric constant over the lens surface to enhance antenna functionality. A similar method has been adopted in [14] to match the dielectric constant of the substrate with the air to improve the gain effectively, also different substrate materials have been studied for optimization.

This article proposes a Four-port Honeycomb-slotted Line strip with a Round cap MIMO Nanoantenna for Optical Frequency Applications. The proposed antenna resonates at multiple optical frequencies i.e. 3.12 THz, 9.7 THz, and 16.35 THz. It offers a good performance in terms of gain and efficiency. The proposed antenna is also capable of a good MIMO antenna and it is designed using HFSS software.

II. Proposed Antenna Design & Dimensions

The proposed design of the Nano MIMO antenna has gone through several steps upon a Carbon Nano Tube (CNT) substrate as given in Figure 1. In the first step, a microstrip line antenna is designed to resonate at 3.56 THz. Then, several small regular hexagonal honeycomb slots with 0.3 nm arm length are cut away resulting in to resonate at the 3.2 THz and 9 THz. Then, a round cap of 1nm radius is introduced on the microstrip line to resonate the antenna at 3.13 THz, 9.7 THz, and 16.35 THz frequencies. These bands are useful in some specific applications like Imaging and Spectroscopy, Biomedical Appliances, High-Resolution imaging, Gas sensing, Quantum Computing, and Advanced Material research etc. All these results are shown in Figure 2. Then, the proposed MIMO antenna is formed as shown in Figure 3.

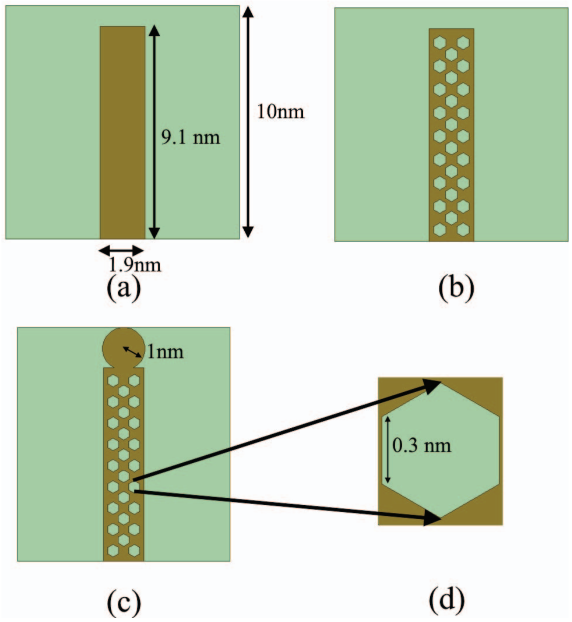

Fig. 1. Step by step Single Element Antenna Design

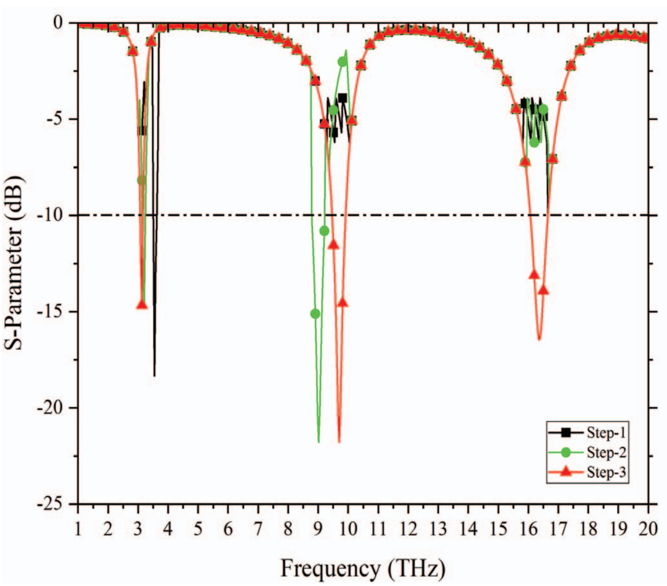

Fig. 2. S-Parameter (stepwise single element)

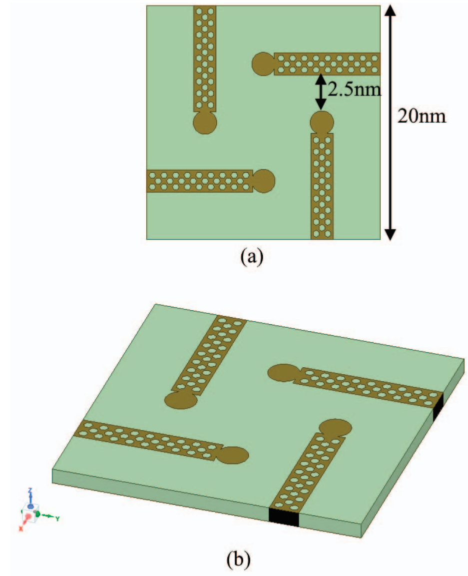

Fig. 3. Proposed Antenna (a) Top view, (b) stereoscopic view

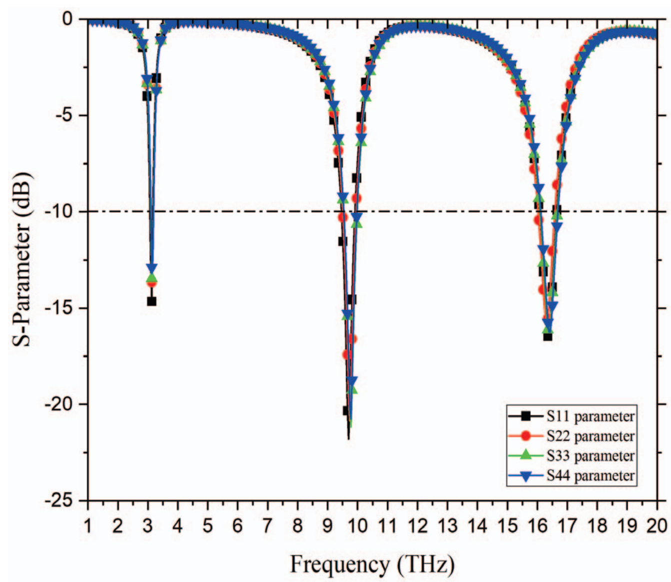

Fig. 4. S-Parameter of the proposed MIMO antenna

III. Simulated Results

A. S-parameter

In the proposed 4-port MIMO antenna (Figure 3), the first parameter needed to be found is impedance bandwidth. In this section, the impedance bandwidth is to be found with the help of S-parameters along with the mutual coupling between each radiating element. Figure 4 illustrates the impedance bandwidth of the radiating elements whereas Figure 5 brings out the mutual coupling between them. From these figures, it is seen that each element of the proposed MIMO antenna is highly isolated at least by 25dB up to 89.89 dB.

B. Radiation Pattern

Both E-Plane and H-Plane radiation patterns are studied along the resonant frequencies of the proposed antenna. The maximum gain of is found at 16.35 THz frequency among them around 3.45 dB whereas the other frequencies also produce positive gains in both the planes. All the patterns are nearly showing an omnidirectional characteristics.
These patterns are shown in Figure 6.

C. Surface Current Distribution

This section shows the current distribution at the patch surface at resonance frequencies.

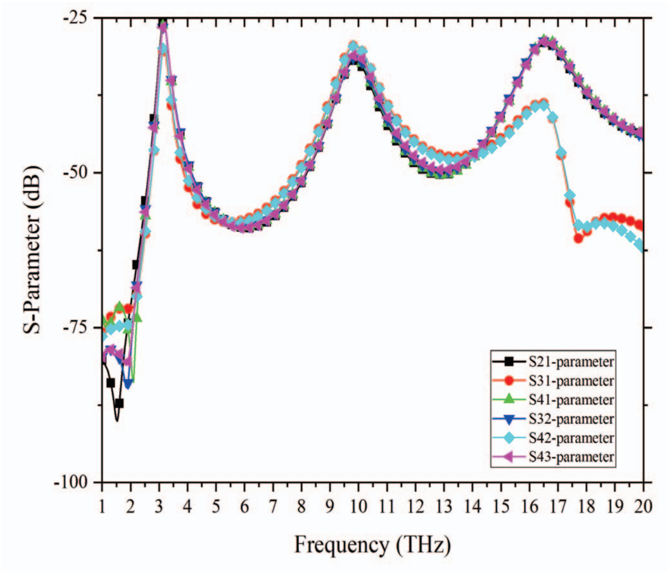

Fig. 5. Mutual Coupling between radiating elements

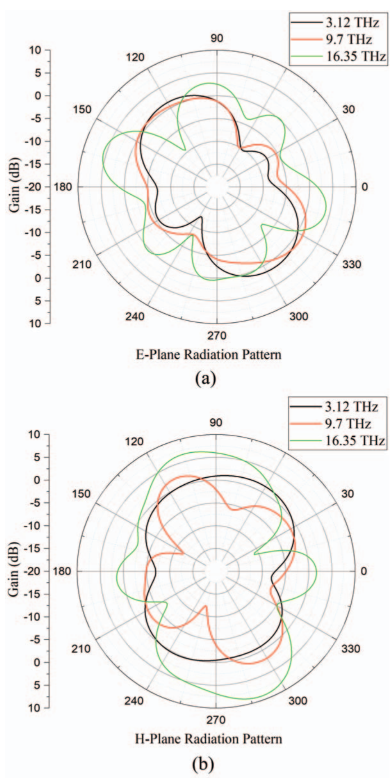

Fig. 6. Radiation Pattern at Resonant Frequencies

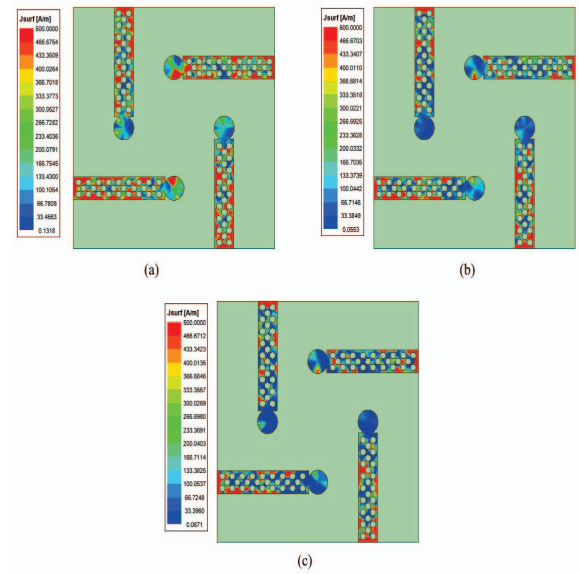

Fig. 7. Surface Current Distribution at (a) 3.12 THz, (b) 9.7 THz, (c) 16.35 THz

D. Overall Performance

In this section, two major technical parameters are studied. These are Gain and Radiation Efficiency. The Gain of the proposed MIMO antenna shows a good value. The maximum gain is around 4.5 dB and the maximum radiation efficiency is around 0.92 i.e. 92%. These parameters are shown in Figure 8. The Gain at 8 THz exhibits lower value due to impedance missmatch.

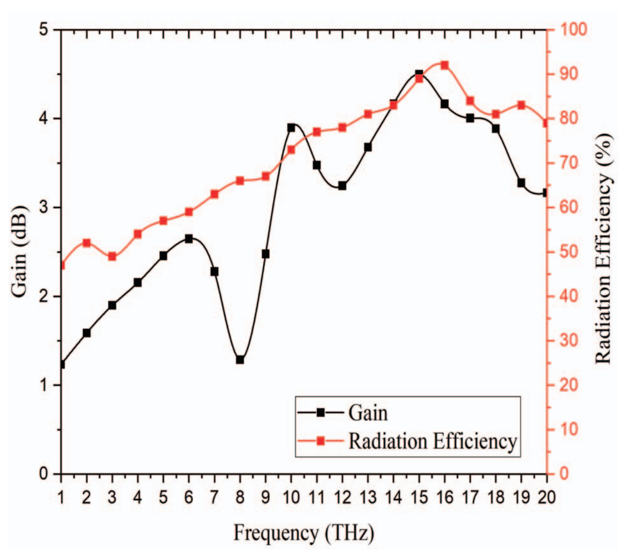

Fig. 8. Gain and Efficiency

IV. Technical Aspects as MIMO antenna

The proposed Nano MIMO antenna is also simulated and verified to get well certified as a MIMO antenna. The main parameters are discussed under this section as MIMO antenna.

These are Envelop Correlation Coefficient (ECC), Diversity Gain (DG), Total Active Reflection Coefficient (TARC), Channel Capacity Loss (CCL) and Mean Effective Gain (MEG).

A. ECC, DG & TARC

ECC, DG, and TARC are the three critical parameters to be studied for MIMO antenna [15]. ECC is used to determine the mutual relation between the radiating antenna to the non-working radiating elements. It can be calculated from equation (1). The standard value of ECC is zero whereas in practical scenario, it is acceptable upto the value of 0.5.

$$\rho = \frac{[\sum_{m=1}^{P} S_{im}^{*} S_{mj}]^2}{(1-\sum_{m=1}^{P}|S_{mi}|^2)(1-\sum_{m=1}^{P}|S_{mj}|^2)} \tag{1}$$

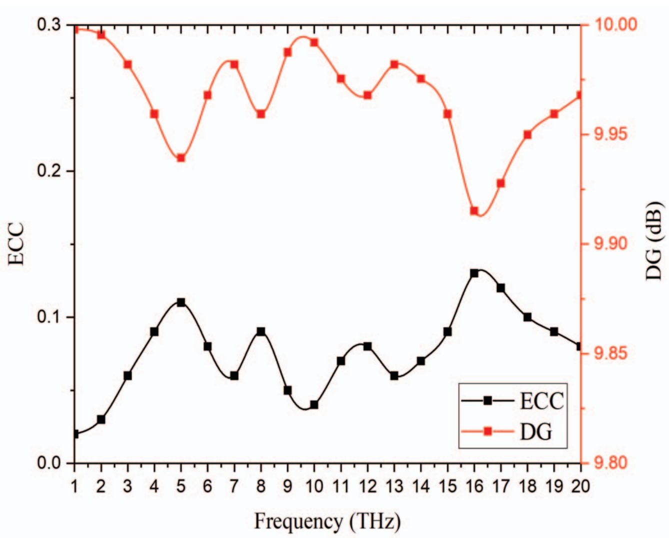

Fig. 9. ECC and DG

DG is the diversion based Signal to Interfere ratio. Ideally, 10 dB is the standard value for MIMO antenna, whereas the acceptable range is in between 9.5 dB and 10 dB. Equation (2) is useful to determine the DG. Figure 9 provides both the simulated ECC and DG curve for the porposed antenna.

$$Gain_{DG} = \sqrt{1-\rho^2} \tag{2}$$

TARC is more precise compared to s-parameter as it takes the count of mutual coupling also. The acceptable value is below -10 dB in occupied band [16]. The equation (3) determines the TARC and it is depicted in Figure 10.

$$TARC = \frac{\sum_{m=1}^{P}|b_i|^2}{\sum_{m=1}^{P}|a_i|^2} = \sqrt{\frac{|S_{ii}+S_{ij}^{e^{j\theta}}|^2+|S_{ji}+S_{jj}^{e^{j\theta}}|^2}{m}} \tag{3}$$

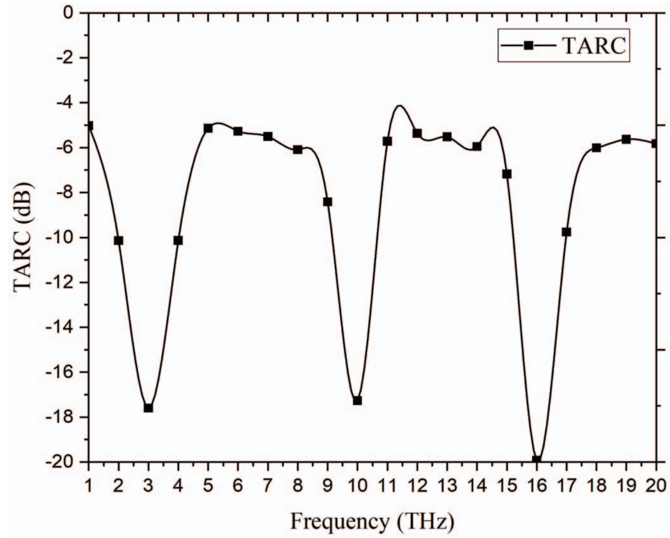

Fig. 10. TARC

B. CCL and MEG

CCL is a measure that points out the enhanced channel capacity. It should lie below 0.4 bps/Hz [16]. CCL can be found out from equation (4), (5), (6), and (7) [16].

$$CCL = -log_2|\delta| \tag{4}$$

where,

$$\delta = \begin{bmatrix} \rho_1^1 & \rho_1^2 & \rho_1^3 & \rho_1^4 \\ \rho_2^1 & \rho_2^2 & \rho_2^3 & \rho_2^4 \\ \rho_3^1 & \rho_3^2 & \rho_3^3 & \rho_3^4 \\ \rho_4^1 & \rho_4^2 & \rho_4^3 & \rho_4^4 \end{bmatrix} \tag{5}$$

$$\rho_x^x = 1 - (\sum_{m=1}^{P}|S_{xm}^{*} S_{mx}|) \tag{6}$$

$$\rho_x^y = -(\sum_{m=1}^{P}|S_{xm}^{*} S_{mx}|) \tag{7}$$

MEG is the effective gain to be practically reliable around -3dB [16], which can be determined using equation (8).

$$MEG = \frac{1}{2}[1-\sum_{j=1}^{P}|S_{ij}|^2] \tag{8}$$

Both CCL and MEG are shown in Figure 11.

V. Comparison

A comparison is made below to distinguish this work with other related works in Table 1.

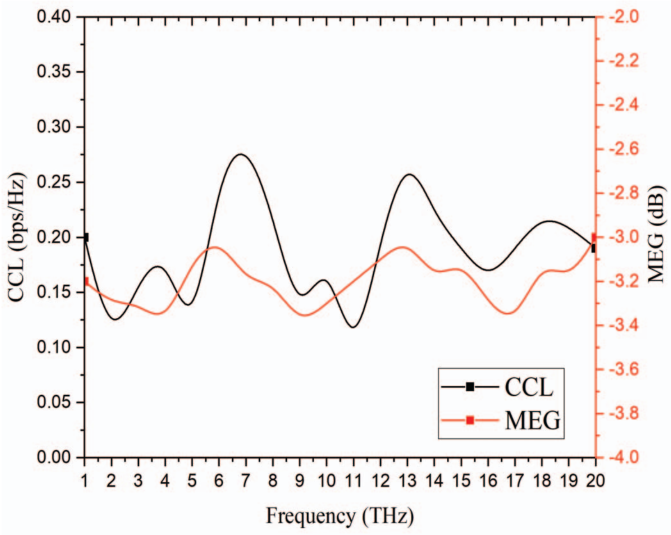

Fig. 11. CCL and MEG

TABLE I
COMPARATIVE STUDY

Ref. No.	***Dimension*** (nm^3)	***No. of*** Bands	***Resonant Frequencies*** (THz)	***Gain*** (dB)	***Efficiency*** (%)
[9]	46×24×0.432	2	0.2-0.6 (BW)	25.5	NG
[10]	10×6.7×1.5	1	0.3	13.4	99.5
[13]	NG	2	0.3, 1	32.81	93.7
[14]	6×6×0.3	3	0.4, 1, 2.2	36.89	97
TW	**20×20×0.8**	**3**	**3.12, 9.7, 16.35**	4.5	92

*[*NG=Not Given]*; *[*TW=This Work]*

VI. CONCLUSION

The proposed Nano MIMO antenna is designed for futuristic speedy communication in optical frequency and has achieved every aspect or good characteristic to play a major role as a MIMO antenna. All the simulated results are illustrated in this article. It works in three bands of 3.12 THz, 9.7 THz, and 16.35 THz. Each radiating element is isolated by at least 25dB reaching up to 89.89 dB. The proposed antenna has a maximum gain of 4.5 dB at around 15 THz and a radiation efficiency of around 92% at 16 THz. The ECC (<0.4), DG (9.6-10 dB), TARC(<-10dB), CCL (<4bps/Hz), and MEG (<-3dB) are also studied with satisfied diversion performance. All these parameters provide a satisfactory value for futuristic wireless communication proving it to be an excellent candidate for a Nano MIMO antenna and it will be greater if the nano-antenna fabrication technology comes into practice, which will be available in the near future.

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