Nanomaterial-Based Microstrip Patch Antenna Array for X Band Operation

Parisimita A. Kashyap, Smriti Rekha Das, and Sunandan Baruah

Abstract Antenna designers around the globe have extensively researched upon the patch antenna and its array structures for achieving better performance for various operations. One of the novel techniques is to use nanomaterial composites over the substrate of a microstrip patch antenna to enhance its performance. Nanostructures can provide unique characteristics and have the potential to improve the performance of the patch antenna. This paper focuses on the study and design of a nanomaterial-based 1 × 2 rectangular microstrip patch antenna array for X band operation. The proposed antenna array is designed over an FR4 substrate where the individual radiating patches are realized using gold deposited Zinc Oxide (ZnO) nanorods. The comparison of performance parameters of the proposed antenna array with the conventional copper (Cu)-based patch antenna array is made. The results obtained show that there is an improvement in the return loss and bandwidth of the proposed array structure.

Keywords Microstrip patch antenna · Nanorods · Return loss · Bandwidth

1 Introduction

Microstrip antennas are the ideal choice for wireless devices because of its characteristics like low weight, low cost, and ease of fabrication [1]. However, microstrip antennas also have disadvantages like less bandwidth and low gain [2]. Intensive

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research has been done in recent years to develop different performance enhancement techniques of the microstrip patch antenna. These techniques include utilization of thick substrates with low dielectric constant, slotted patch, metamaterial-based antenna, antenna array, and nano-material-based antenna, etc. [3]. Microstrip antennas are very versatile and are also used, to synthesize a required pattern that cannot be attained with a single element. In addition, microstrip patch antennas are used to scan the beam of an antenna system which increases the directivity and performs various other functions which would be difficult with only one element [4]. Hence, array structures are used. But, as the patch antenna suffers from a number of drawbacks, it is of utmost importance to improve these parameters while using it in an array.

Designing of patch antennas using nanomaterials is a new trend because using nanomaterials the size of the antenna as well the return loss can be reduced [5]. The use of conductive carbon nanotubes (CNT) in radiating elements has led to the development of low-cost and lightweight patch antennas. However, the biggest challenges involved in working with nanomaterial like CNTs is the ability to make reliable electrical contacts with other conductive parts of the antenna such as feed line, matching transformer, stub, etc. This unreliability contact makes it difficult to determine the RF properties of the designed antenna [5].

In this paper, the performance of nanomaterial-based patch antenna array is investigated and compared with Cu-based patch antenna array for operation in the X band. A 1×2 antenna array with Cu-based patch using corporate feeding is first simulated in High Frequency Structure Simulator (HFSS) software in the X band and then the same structure is fabricated and the results are obtained. The proposed nanomaterial-based antenna array consisted of ZnO nanorods formed over FR4 substrate by hydrothermal process and gold depositions over the nanorods. These metallic nanorods serve as the radiating element or patch of the antenna. The results of the proposed antenna array and the Cu-based antenna array are compared to investigate the feasibility and effectiveness of nanomaterial-based antenna arrays for operation in the X band.

The rest of the paper is organized as follows: Sect. 2 discusses about the structure of the proposed antenna array, Sect. 3 includes the fabrication technique and methodology. Simulation and fabrication results are discussed in Sect. 4. A small acknowledgement to the organizations is provided without whose helping hands this work would not have been possible. Section 5 concludes the work.

2 Proposed Antenna Design

The geometry of the proposed 1×2 antenna array is shown in Fig. 1. In this work, a two-element antenna array is designed with copper as well as gold as metal nanoparticles deposited over semiconductor ZnO nanorods which are grown on patch with two different concentration, i.e., 5 mM and 10 mM. Initially, simulation of two-element antenna array is done. Table 1 shows all the physical dimensions of the two-element

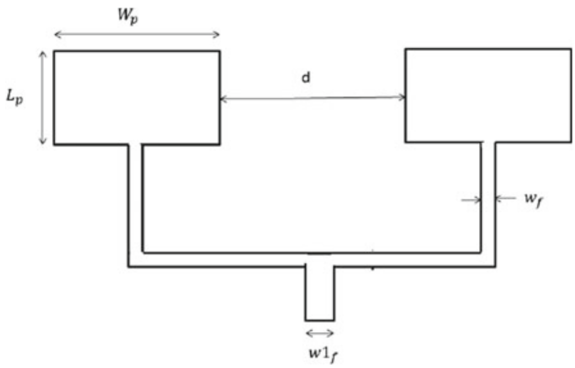


Fig. 1 Geometry of the 1 × 2 antenna array

Table 1 Physical Dimension of the 1 × 2 Antenna Array

Parameters	Values
Operating frequency,f_r	10 GHz
Length of the individual patch,L_p	6.4 mm
Width of the individual patch,W_p	9 mm
Length of the ground plane,L_g	26 mm
Width of the ground plane, W_g	40 mm
Height of the FR4 substrate, h	1.5 mm
Inter-element distance, d	15 mm
Width of the 50 Ω impedance line, w_{1f}	2.86 mm
Width of the 100 Ω impedance line, w_f	0.664 mm

array. The most critical aspect in designing antenna array is the spacing between the individual elements of the array, which can be between 0.2λ and λ. The proposed array is designed using corporate feeding technique.

3 Fabrication of the Nanomaterial-Based Antenna

The various steps during the fabrication of the nanomaterial-based antenna are discussed in the subsections below:

3.1 Synthesis of ZnO Nanomaterial

20 ml of 4 mM zinc acetate dihydrate ($Zn(CH_3COO)_2.2H_2O$) was stirred rigorously at 50 °C for 45 min and then it is diluted with 20 ml fresh ethanol. At room temperature, 20 ml of 4 mM NaOH is added drop-wise under mild stirring which is continued for

about 15 min. The mixture is then put in a water bath at 50° to 60 °C for 2-3 h [6]. The solution is then cooled to room temperature. The chemical reaction taking place is:

$$Zn[(CH_3COO)]_2 \cdot 2H_2O + 2NaOH \rightarrow ZnO + 2NaCH_3COO + H_2O \,[7] \quad (1)$$

3.2 Direct Seeding in FR4 Epoxy Substrate

At first, the copper layer on the substrate is etched out using Iron Chloride. After etching the substrate is rinsed with deionized water. After that masking is done on whole part of the substrate except the size of the patch. Then 2 ml of ZnO nanoparticle is added with 2 ml of deionized water and then it was dropped on the substrates which is marked as patch for 5 times at 100 °C.

3.3 Synthesis of ZnO Nanorods

Nanorods are grown in a sealed chemical bath containing equimolar solution of zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$) and hexamethylenetetramine ($C_6H_{12}N_4$) [6].

Solvent: Deionized water.

Stock solution of 100 ml of 5 mM ($Zn(NO_3)2.6H_2O$) and 100 ml of 5 mM hexamethylenetetramine ($C_6H_{12}N_4$) and 100 ml of 10 mM ($Zn(NO_3)2.6H_2O$) and 100 ml of 10 mM hexamethylenetetramine ($C_6H_{12}N4$) are prepared by taking two conical flasks or beaker. 100 ml of distilled water is taken in both of them and 0.297 g of ($Zn(NO_3)_2.6H_2O$) and 0.140186 g of ($C_6H_{12}N_4$) is put in the conical flask, respectively. The seeded substrates are arranged in such a way that the seeded side is kept upside down inside the petri dish with a slight elevation. Pour 30 ml each of solution of ($Zn(NO_3)2.6H_2O$) and ($C_6H_{12}N_4$) in a petri dish. The substrate should be completely inside the solution. The hot air oven is set at 90° C and the petri dish is kept inside it. The solutions are changed after 5 h. The growth is continued up to 15 to 20 h. The substrate is heated at 100 °C temperature for annealing to remove organic deposits. After hydrothermal growth of ZnO nanorods on FR-4 substrate, a metallic Au layer is deposited on the ZnO nanorods grown on the substrate.

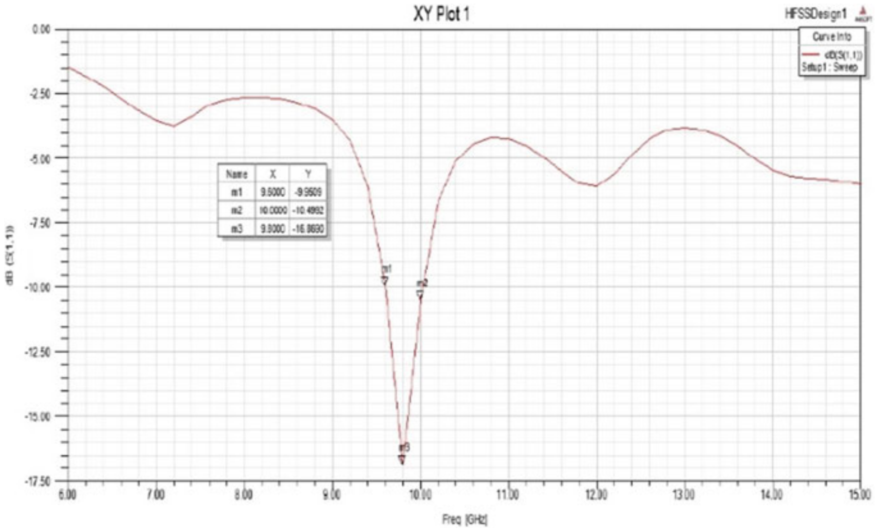


Fig. 2 Return loss of 1 × 2 antenna array

4 Results and Discussions

4.1 Simulation of Cu-Based Antenna Array

As mentioned, a 1 × 2 Cu-based antenna array is first simulated in HFSS software. The simulated return loss is shown in Fig. 2.

It can be seen that the return loss is about −16.86 dB at 9.8 GHz which is quite good for a microstrip patch array antenna. The bandwidth obtained is 0.4 GHz. Figure 3 shows the radiation pattern of the array. It can be seen that the pattern is directive with some about of losses in the form of sidelobes.

Figures 4 and 5 shows the gain and directivity of the simulated antenna array respectively. The gain is found to be 7.952 dB and the directivity is 9.337 dB, which is quite obvious as the gain and directivity are enhanced in an array structure compared to single antennas.

4.2 Measured Results of Cu-Based Antenna Array

The fabricated Cu-based 1 × 2 antenna array with corporate feed is shown in Fig. 6. Return loss of the fabricated Cu-based 1 × 2 antenna array is shown in Fig. 7. The return loss is found to be −15.79 dB at 11.18 GHz which is found to be quite similar with the simulation result. The shift in frequency is due to change in electrical length of the patch during the fabrication process. The bandwidth is found to be 0.47 GHz.

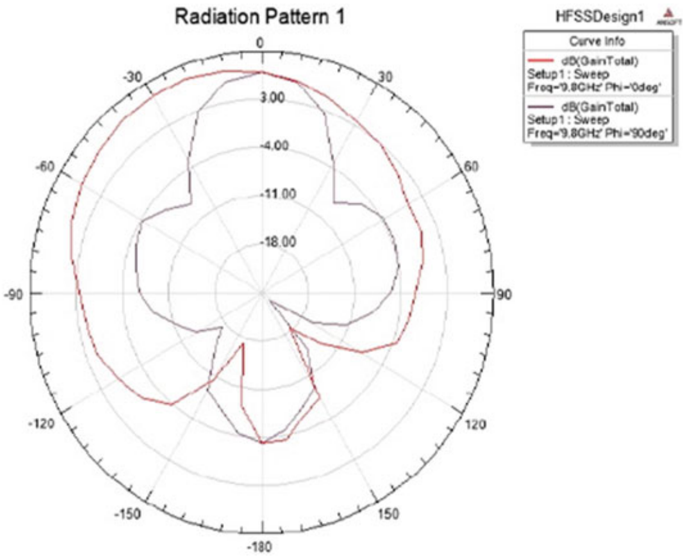


Fig. 3 Radiation pattern of the 1 × 2 antenna array

Fig. 4 Gain of 1 × 2 antenna array

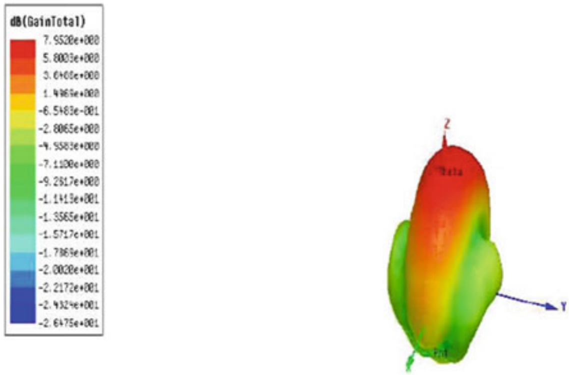
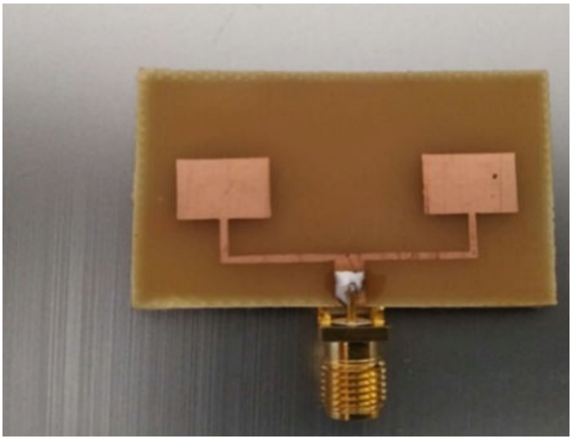


Fig. 5 Directivity of 1 × 2 antenna array

Fig. 6 Fabricated Cu-based 1 × 2 antenna array



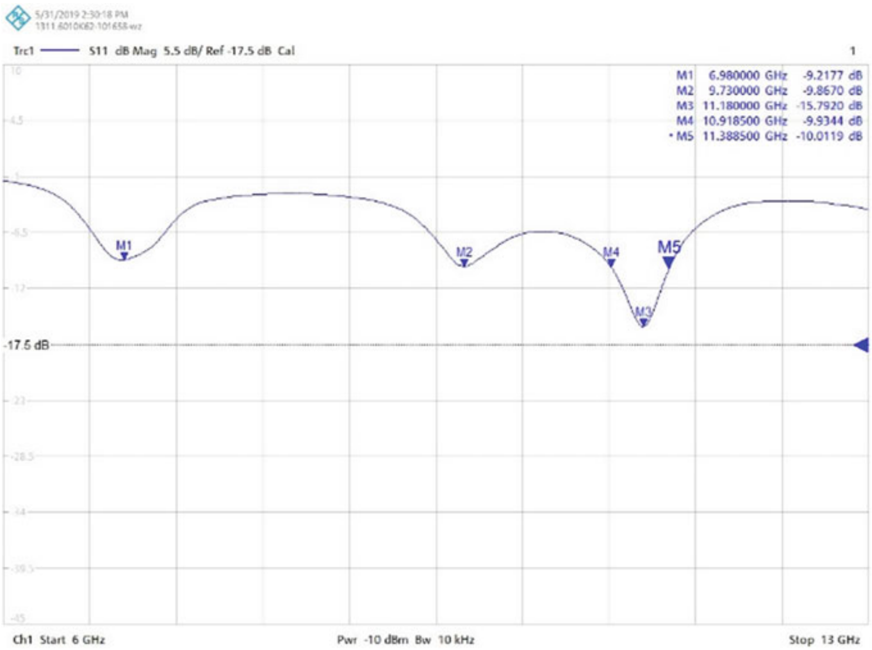


Fig. 7 Return Loss of Cu-based 1 × 2 antenna array

Figure 8 shows the radiation pattern of the array which is also similar to the one found in simulation.

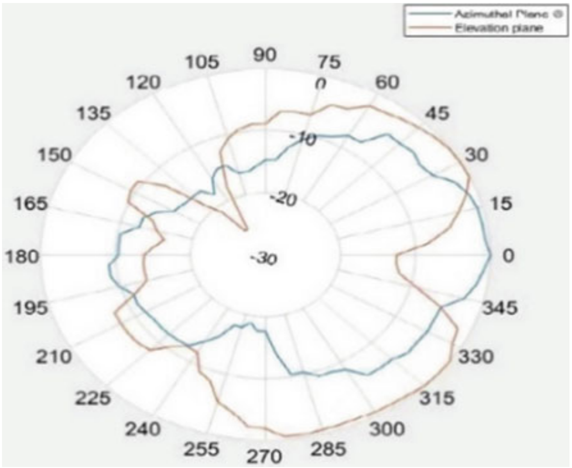


Fig. 8 Radiation pattern of Cu-based 1 × 2 antenna array

4.3 *Measured Results of Proposed Nanomaterial-Based Antenna Array*

The fabricated 1 × 2 antenna array with 5 mM and 10 mM concentration Au deposited over ZnO nanorods grown on patch is shown in Figs. 9 and 10, respectively.

The return loss of the fabricated arrays with 5 mM and 10 mM concentrations respectively, are shown in Figs. 11 and 12. It can be seen that the array with 5 mM concentration has a return loss of −17.02 dB at 12.12 GHz and a bandwidth of 1.16 GHz. The array with 10 mM concentration has a return loss of −21.10 dB at 9.05 GHz and a bandwidth of 0.805 GHz. In both cases, it is observed that the return loss and especially the bandwidth of the nanomaterial-based arrays are improved compared to the conventional Cu-based patch antenna array. The radiation pattern of both 5 mM and 10 mM concentrations arrays are also shown in Figs. 13 and

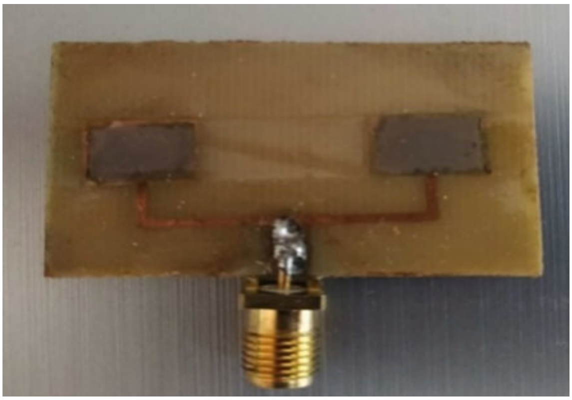
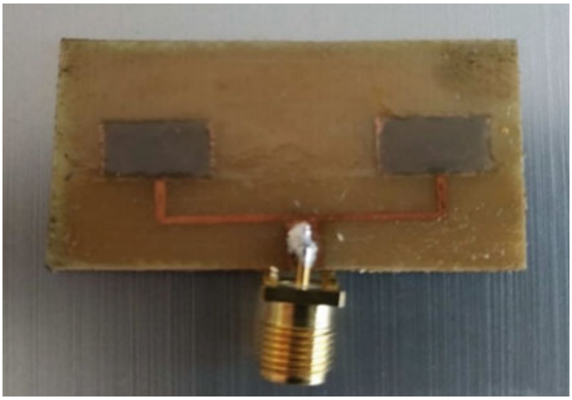


Fig. 9 Fabricated 1 × 2 antenna array with 5 mM Au deposited ZnO nanorods on patch

Fig. 10 Fabricated 1 × 2 antenna array with 10 mM Au deposited ZnO nanorods on patch



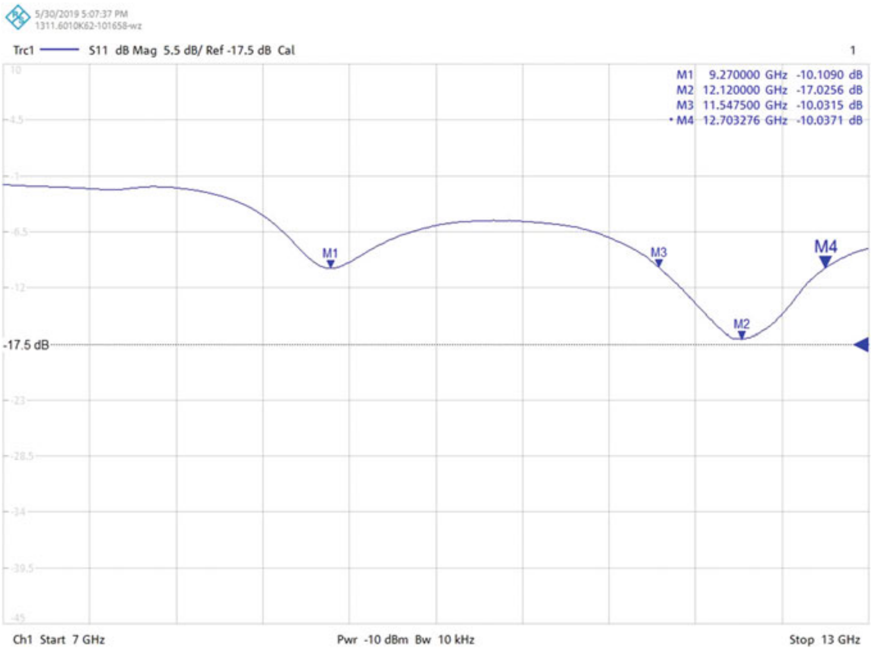


Fig. 11 Return Loss 1 × 2 antenna array with 5 mM Au-deposited ZnO nanorods on patch

14, respectively and in this too, an improvement in directivity is seen compared to conventional Cu-based array.

Table 2 provides a comparison of the measured parameters like return loss, bandwidth, and beamwidth of all the fabricated antennas. From the table, it is observed that the resonant frequency of fabricated patch antennas is different with different material. This is due to the electric length of that material. Again, it can be observed

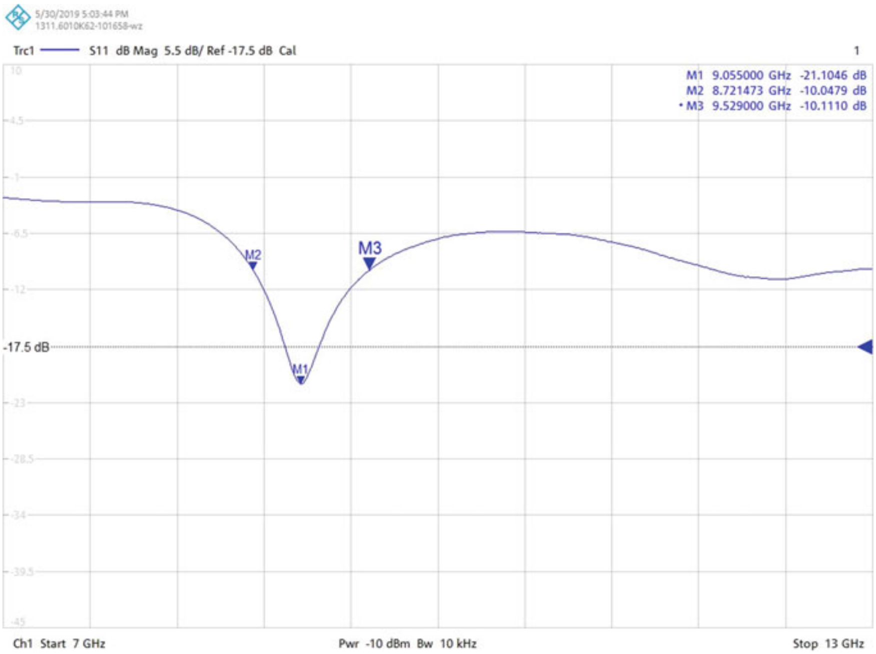
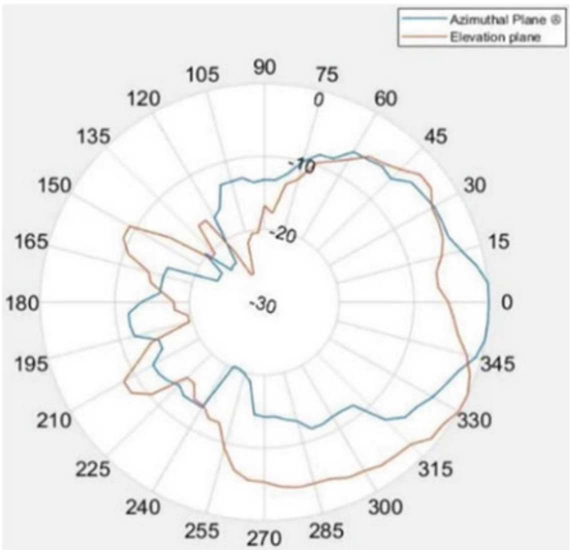


Fig. 12 Return Loss 1 × 2 antenna array with 10 mM Au-deposited ZnO nanorods on patch

Fig. 13 Radiation Pattern of 1 × 2 antenna array with 5 mM Au deposited ZnO nanorods on patch



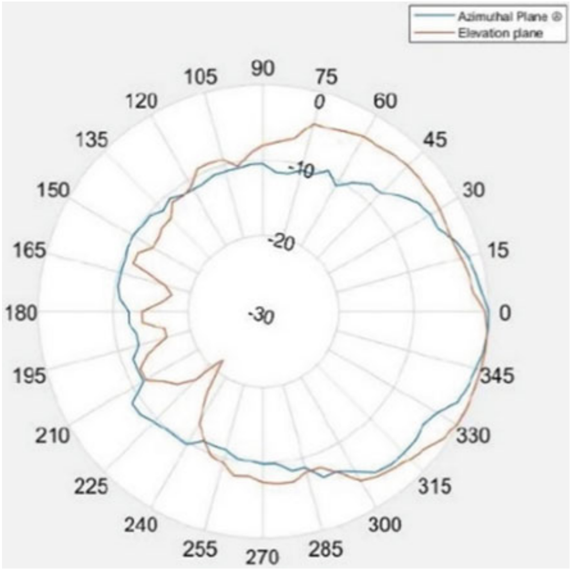


Fig. 14 Radiation Pattern 1 × 2 antenna array with 10 mM Au deposited nanorods on patch

Table 2 Comparison of measured performance parameters for different patch material

Patch with different materials	Operating frequency (GHz)	Return Loss (dB)	Bandwidth (GHz)	Beamwidth (degree)
Copper	11.181	−15.79	0.47	45
5 mM ZnO nanorods with gold	12.12	−17.02	1.16	40
10 mM ZnO nanorods with gold	9.05	−21.10	0.805	50

that the antenna arrays with nanomaterials have narrow beamwidth. With narrow beamwidth, the antenna arrays provide high directivity.

5 Conclusion

The use of nanomaterials on patch antennas can provide a low return loss and wider bandwidth. So, in this paper a 1 × 2 patch antenna array with individual radiating elements using gold as metal nanoparticles deposited over semiconductor ZnO nanorods have been fabricated to study the effects of nanomaterials on patch antenna array. The measured results of metal-semiconductor patch antenna arrays show an improvement of −1.23 dB for 5 mM and −5.31 dB in the return loss and an improvement of 0.69 GHz for 5 mM and 0.335 GHz for 10 mM in operating bandwidth compared to conventional Cu-based patch antenna array. The bandwidth of nanomaterial-based array is high due to the presence of the resistive part. Due to the resistive element Q value of the system decreases. As Q value decreases bandwidth of the patch array increases. The beamwidth of fabricated patch antenna arrays is also calculated. As compared to Cu-based patch array, the array with 5 mM concentration nanomaterial have narrow beamwidth which proves that the directivity is enhanced. Hence, the array with 5 mM concentration provides a better result compared to the 10 mM concentration array.

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