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Simulation and Performance Analysis of Carbon Nano-Materials based Patch Antennas

Sandeep Dhariwal[1*], Vijay Kumar Lamba[2] and Ajay Kumar[3]

[1]Lovely Professional University, Phagwara - 144411, Punjab, India; sandeep.19381@lpu.co.in
[2]Global College of Engineering and Technology, KahnPur Khui - 140117, Punjab, India.
[3]Guru Jambheshwar University of Science and Technology, Hisar - 125001, Haryana, India.

Abstract

In this paper, rectangular and circular shape antennas are designed for analyzing the performance characteristics of an antenna. Semiconducting Carbon Nanotube (CNT), Metallic Carbon Nanotube (MCNT), Copper and Graphene are considered as the patch materials. There are different parameters but conductivity has been taken to differentiate between these patch materials. Each patch material has its own conductivity through which a comparative analysis has been implemented in this paper. Different types of parameters like Return loss, Gain, Voltage Standing Wave Ratio (VSWR) and Radiation pattern are obtained and discussed to analyze the results. Resonant frequency for the metallic CNT rectangular patch antenna has been noticed at 2.85 GHz. Resonant frequencies of 2.87 GHz and 2.88 GHz has been obtained for Copper and Graphene patch antenna in rectangular shape. Comparison of simulated results has been obtained in the same manner for circular shape antenna. A resonant frequency of 18.74 GHz has been noticed for patch antennas in circular shape. On comparing the simulated results, Graphene patch antennas has been observed to deliver best performance.

Keywords: Conductivity, Graphene, Metallic CNT, Patch Antenna, Semiconducting CNT, VSWR

1. Introduction

Copper and Silicon were known the best materials to be used as interconnects and semi-conducting devices. But as the technology is scaling to nano-scale dimensions, new problems are arising[1]. Graphene and Carbon Nanotubes (CNTs) are two important allotropes of carbon to be used as remedy of these problems[1]. Due to high current carrying capacity and thermal stability, these materials can be used as patches[2]. In a design of a patch antenna, one side of a dielectric substrate acts as a radiating patch and other side of substrate acts as ground plane. Top view of a rectangular patch antenna with coaxial feed has been shown in Figure 1. Patch and ground plane together creates fringing fields and this field is responsible for creating the radiation from the antenna. Radiation of the patch can be enhanced by enhancing the fringing field. Therefore width of the patch W is increased to increase the fringing field. Other methods of increasing the fringing fields for the patch antennas are by increasing the thickness of the substrate (h) or by means of decreasing the value of relative dielectric constant of the substrate[3–4]. As compared to conventional microwave antennas, a patch antenna has been found to act as perfect radiator[5]. Today many applications are based on patch antennas due to several advantages. With the advantages of light in weight and small volume, a low profile planar configuration attracts most of its features as a patch antenna[6]. Several advantages have been achieved and some more advantages are yet to be achieved as conformable and printable antennas on the fabrics. There is also a possibility of using these antennas in dual and triple frequency operations. In the defence communications, thin and conformable antennas are needed to be installed on the missiles. Small arrays

* Author for correspondence

of these patch antennas are mounted on radar altimeters to be used as perfect radiators[7]. Applications of patch antennas are effectively utilized in aircraft-related area for satellite imaging systems and communications. In this paper for simulation, coaxial feed line has been chosen for feeding patch antennas[8].

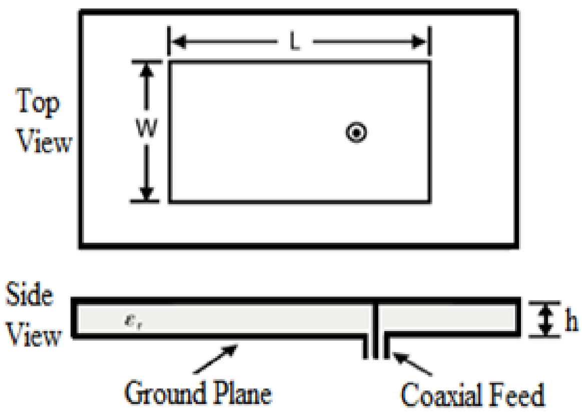

Figure 1. Top view of rectangular patch antenna.

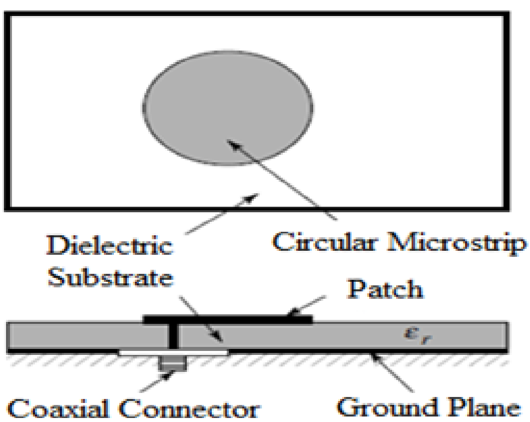

Figure 2. Circular patch antenna (coaxial feed).

Circular patch structure with hybrid coupler feeding techniques can be designed to operate at even 8.1 GHz frequency and can also be implemented for military applications[9]. For the circular patch (Figure 2), it can be observed that outer portion of conductor is connected to the ground plane and inner portion of the conductor is connected to the radiating patch through the dielectric from the coaxial feed[10]. Basic antenna parameters can be stated as return loss (reflection coefficient), gain, input impedance, Voltage Standing Wave Ratio (VSWR) and radiation pattern[11]. Return loss can also be termed as reflection coefficient having negative sign. Return loss calculates the power reflected back and defined as ratio of incident power to the reflected power in dB. Voltage standing wave ratio is a parameter to show the matching of an antenna to the transmission line.

The radiation pattern can be defined as a graphical representation of the maximum power radiated in a particular direction. Conformable patch antenna is a new emerging field in the innovation of flexible electronics and wireless communication. Flexible[12] and organic electronics[13] are the new research areas for developing flexible and printable supporting systems having a number of potential applications. These supporting systems can be effectively used in medical field, defence applications and communication network connections. Electronics and communication devices are going towards nano-scale dimensions. For the operation of these devices, low power devices are preferred and these flexible patch antennas can be operated with low power transceivers.

2. Methodology of Analysis

Methodology for modeling the patch antennas is based on transmission line model and Method of Moments (MoMs). The transmission line modeling technique distributed the magnetic current uniformly over the edges of patch[11]. In combination with transmission line modeling, method of moments is responsible for utilizing the solution of full wave in the frequency domain. The solution is based on Maxwell's integral equations and in this method only the structure is used in discretised form. For the modeling of magnetic and dielectric medium, some recommended extensions are included in method of moment's formulation in FEKO tool.

The patch radiator acts as a resonator having transverse field varying along the length of the radiator. Open circuited ends are responsible for creating of fringing field that causes radiation in the patch antennas. This methodology is applied on both the shapes (i.e. rectangular and circular) of antennas. The resonator length divides the two slots to represent a patch antenna. However this model is not so effective to analyze the variation in the propagation of orthogonal mode. Materials considered as patch for the simulation are semiconducting CNT, metallic CNT, Copper and Graphene. Conductivity is the basis of differentiating the properties obtained through simulation carried out through the FEKO software tool.

2.1 Carbon based Patch Antenna

Carbon Nanotube and Graphene exhibits remarkable electronic and material properties. Carbon Nanotube can be semiconducting or metallic depending on the helicity and chiral indices. Depending on the properties in the relevant categories, both types of CNTs are very prominent in the field of nano-electronics. Graphene is a single graphite sheet in which atoms are bonded in hexagonal form and one of the youngest allotropes of the carbon[1]. Today, most of the electronic devices can be fabricated in combination with Graphene. Electronic device community is looking forward with Graphene to remove nano-scale related problems e.g. electro-migration and large current carrying capability. Graphene transistors are next the remarkable achievement in the field of electronic nano-devices. In the coming scenario, patch antenna of Graphene based material can be manufactured to meet the requirements of terahertz band in radiating electromagnetic waves[2].

Recently, many research papers are being published to observe the characteristics of patch antennas based on CNT-polymers in different electronic and wireless applications[14,15]. With the help of Graphene, rapid development in the field of wireless communication system is transforming patch antennas to flexible and portable wireless communication devices. Different frequency band can be achieved by using patch antennas in the field of wireless communication applications. On the basis of simulation, this paper is contributing in the field of patch antennas in which CNTs and Graphene are used as patch materials. In this paper, conductivity parameter has been used to compare performances of patch antennas based on Copper, Carbon Nanotube and Graphene as shown in Table 1.

2.2 Modeling Equations

Equations used in calculating the geometry of patch Width (W) and Length (L) of antennas are as follows16:

$$W = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right)\left(\frac{\varepsilon_r - 1}{2}\right)\left(\frac{1}{\sqrt{1 + 12\frac{h}{W}}}\right) \quad (2)$$

$$\Delta L = 0.412 h \frac{\left(\varepsilon_{eff} + 0.3\right)}{\left(\varepsilon_{eff} - 0.258\right)} \frac{\left(\frac{W}{h} + 0.264\right)}{\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

$$L = \frac{1}{2 c f_r \sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (4)$$

3. Results for Rectangular Patch Antenna

A rectangular patch antenna has been designed using transmission line model (Figure 3). In this design, the dielectric substrate used is assumed to be of infinite dimensions. The design is simulated for different patch materials i.e. Metallic Carbon Nanotube, Copper and Graphene. All the simulation work has been completed through FEKO simulator. Table 2 gives us values of different geometries considered in designing the rectangular patch antenna.

Table 1. Properties of different materials

	Copper	SCNT	MCNT	Graphene
Conductivity(S/m)	5.96 X 10^7[17]	10^2 [18]	10^5 [19]	10^8 [20]
Melting Point (K)	1356		3800(graphite)	
Tensile Strength (GPa)	0.22	22.2+ 2.2	11-63	130
Thermal Conductivity (x 10^{-3}W/m-K)	0.385	1.75- 5.8	3	3-5
Temp. Coeff. of resistance(x10^{-3}/K)	4	< 1.1	-1.37	-1.47
Mean Free Path @ room temperature	40	10^3	2.5 X 10^4	10^3
Maximun Current Density(A/c.m^2)	10^7	10^9	10^9	10^8

Table 2. Geometry of the Rectangular Patch Antenna

Length	46.6 mm
Width	33.0 mm
Thickness	0.51 mm
Feed Distance from centre	8.8 mm
Height of Substrate	2.86 mm
permittivity of substrate	2.2

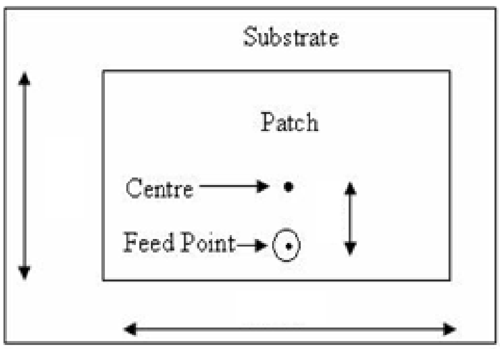

Figure 3. Rectangular patch antenna.

Other geometrical parameters are Feed Radius = 0.65 mm, Input Port = Middle of Feed Line, Input Voltage = 1 volt, Minimum Frequency for Simulation = 2.6 GHz, Maximum Frequency for Simulation = 3.0 GHz. Performance of the antenna has been analyzed through Voltage Standing Wave Ratio, Return loss (or reflection coefficient), Radiation Pattern and Antenna Gain. For the acceptable range, it has been noticed that the value of return loss should be less than -10 dB. In the simulation work, frequency results are observed to note down the resonant mode. Resonant mode has been observed for the MCNT at a frequency of 2.85 GHz. On the other hand, Copper and Graphene based patch antenna shows the resonant mode at a frequency of 2.88 GHz. From the simulated results, impedance bandwidth has been observed at10 dB scale equal to 110.430 MHz for the metallic CNT. Similarly copper patch antenna shows an impedance bandwidth of 106.029 MHz and 105.890 MHz impedance bandwidth has been observed for the graphene patch antenna.

All these impedance bandwidth has been analyzed considering the central frequency equal to 2.85 GHz. Simulation results for the return loss has been plotted in Figure 4 and gain results are observed in the Figure 5. All the patch antennas are plotted simulataneously in simulation results and maximum gain has been noticed for graphene equal to 7.22 dBi. For Copper, gain is slightly less than Graphene and equal to 7.19 dBi. Lowest gain has been observed for the metallic CNT equal to 6.87 dBi. For optimum operation of an antenna, the value of gain parameter should be less than 2. However it is not easy to establish such satisfactory performance parameters. By observing the simulated results of voltage standing wave ratio (Figure 6) . It has been concluded that the patch antennas (Copper, Graphene and MCNT) have same value equal to 1. VSWR for semiconducting CNT patch antenna is poor. Radiation pattern is defined for maximum radiated power in a given direction in a graphical manner. At the particular operating frequencies, a simulated radiation pattern is obtained for all the patch antennas as shown in Figure 7. Radiation pattern is almost similar for all three patch antennas. Table 3 gives a collective comparative simulated results for the patch antennas. By observing different parameters, best patch antenna can be predicted from Copper, Graphene and metallic CNT patch antennas.

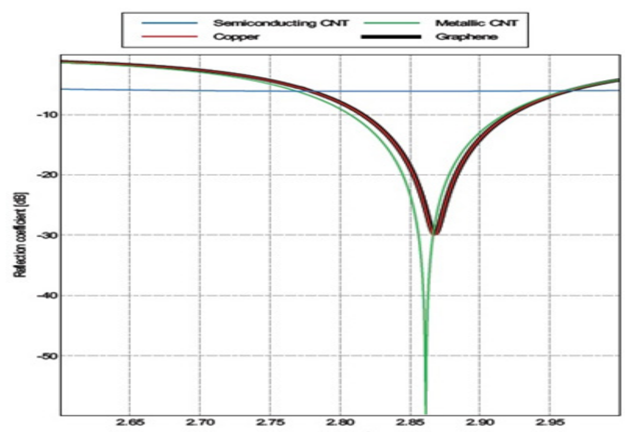

Figure 4. Return loss of the rectangular patch antenna.

Table 3. Results for rectangular patch antenna

S.No.	Parameter	SCNT	MCNT	Copper	Graphene
1	Resonant Frequency (GHz)	-	2.85	2.87	2.88
2	Gain (dBi)	-5.52	6.87	7.19	7.22
3	Reflection Coefficient (dB)	-6.125	-58	-30	-30
4	Bandwidth (MHz)	-	110.430	106.029	105.890
5	VSWR	2.94	1	1	1

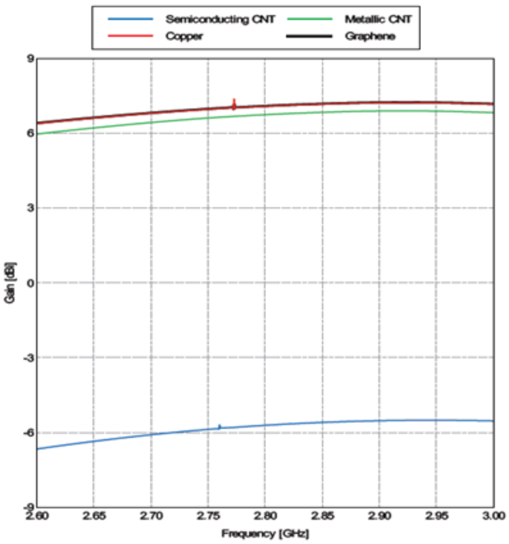

Figure 5. Gain of the rectangular patch antenna.

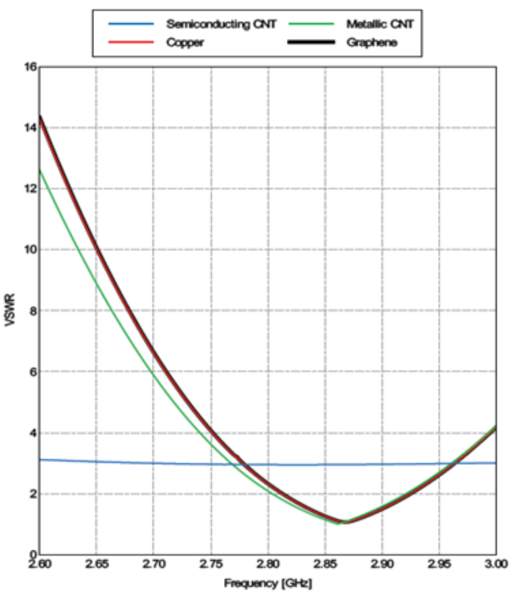

Figure 6. VSWR of the rectangular patch antenna.

4. Results for Circular Patch Antenna

In this section, simulated results for the circular patch antenna are discussed. A patch in the form of a circle is set on a substrate of infinite dimension. Figure 8 shows a coaxial feed diagram for circular patch antenna and top view of circular patch antenna.

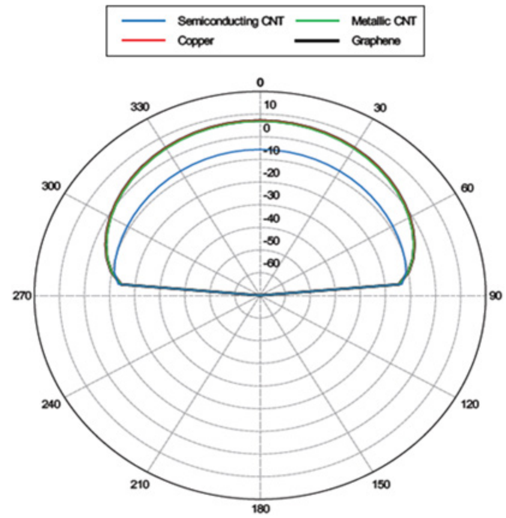

Figure 7. Radiation Pattern of rectangular patch antenna at 2.85 GHz frequency.

Table 4. Geometry of the circular patch antenna

Diameter	6.2 mm
Thickness	0.52 mm
Feed Distance from centre	2.6 mm
Height of Substrate	1.89 mm
permittivity of substrate	2.2

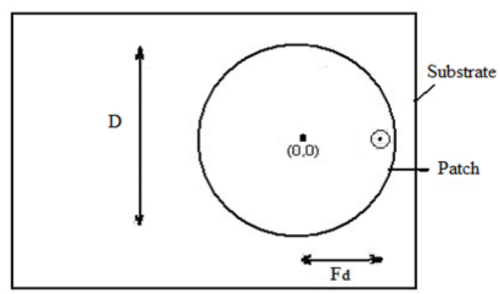

Figure 8. Circular patch antenna.

Dimensions of the patch antenna are shown in the Table 4. Other geometric configuration parameters are Feed Radius = 0.25 mm, Input Port = Middle of Feed Line, Input Voltage = 1 volt, Minimum Frequency for Simulation = 17.5 GHz, Maximum Frequency for Simulation = 21.0 GHz. Return loss is said to be less than -10 dB for the desirable and acceptable operation of an antenna. Graphene patch antenna has been observed to provide good result for return loss (Figure 9). Resonant mode at a frequency of 18.74 GHz has been observed for metallic CNT. Copper and Graphene patch antenna also shows same resonant mode frequency. Semiconducting CNT patch antenna delivers a resonant frequency mode of 18.24 GHz. Maximum gain is observed for the Graphene patch antenna equal to 6.96 dBi at a frequency of 18.74 GHz. Semiconducting CNT patch antenna attains the minimum value of gain equal to 4.12 dBi (Figure 10), whereas gain for metallic and Copper patch antennas are 6.72 and 6.82 respectively. The simulated antenna is delivering maximum bandwidth for Graphene patch antenna at 1.872 GHz. Bandwidth for metallic patch antenna is equal to 1.851 GHz and bandwidth for copper patch antenna is 1.861 GHz. Minimum bandwidth is obtained for semiconducting patch antenna equal to 0.821 GHz.

Table 5. Results for circular patch antenna

S. No.	Parameter	SCNT	MCNT	Copper	Graphene
1	Resonant Frequency (GHz)	18.24	18.74	18.74	18.74
2	Gain (dBi)	4.12	6.72	6.82	6.96
3	Reflection Coefficient (dB)	-10.28	-13.78	-13.90	-14
4	Bandwidth (GHz)	0.821	1.851	1.861	1.872
5	VSWR	1.89	1.5	1.5	1.49

All the comparative values are shown in Table 5 corresponding to each parameter and patch antennas simulated. Voltage Standing Wave Ratio (VSWR) is also an important parameter and simulated results are plotted in Figure 11.

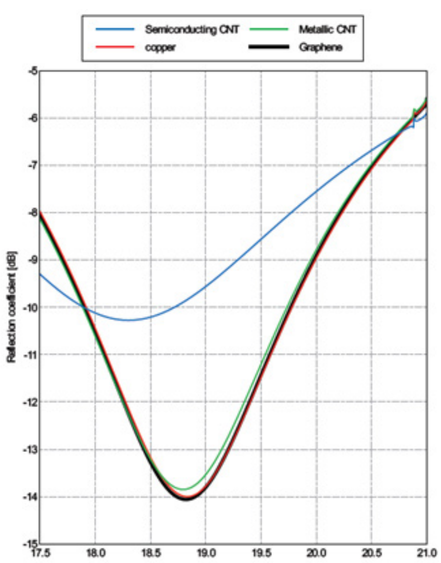

Figure 9. Return loss of circular patch antenna.

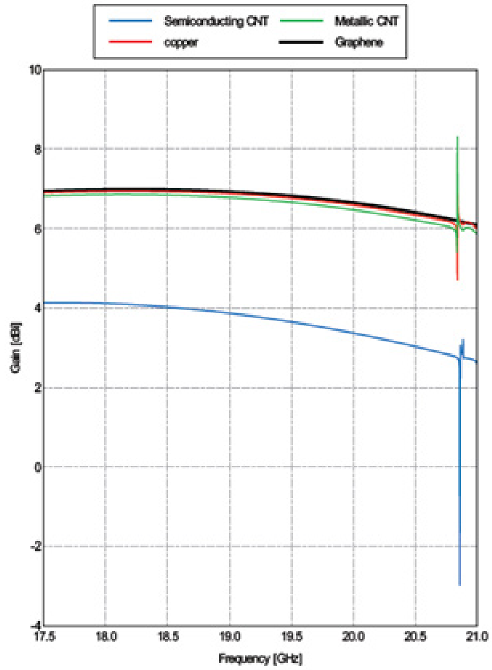

Figure 10. Gain of circular patch antenna.

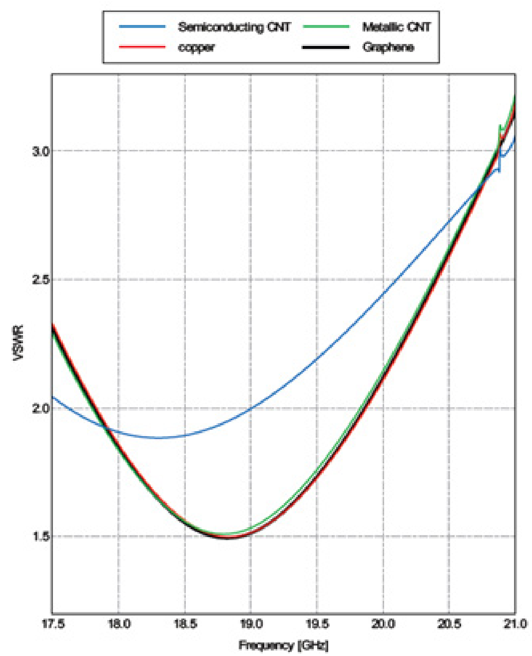

Figure 11. VSWR of circular patch antenna.

From this simulation result, minimum VSWR has been observed for Graphene patch antenna. Although VSWR for the metallic and Copper patch antennas are just slightly greater than Graphene. Smaller the value of VSWR, better is the matching of antenna with the transmission line feed. Radiated power in a particular direction can be noticed by a radiation pattern. Radiation patterns for all patch antennas have been simulated in graphical representation in Figure 12. A stabilized radiation pattern is observed for patch antennas, however radiation pattern is less satisfactory for semiconducting patch antenna.

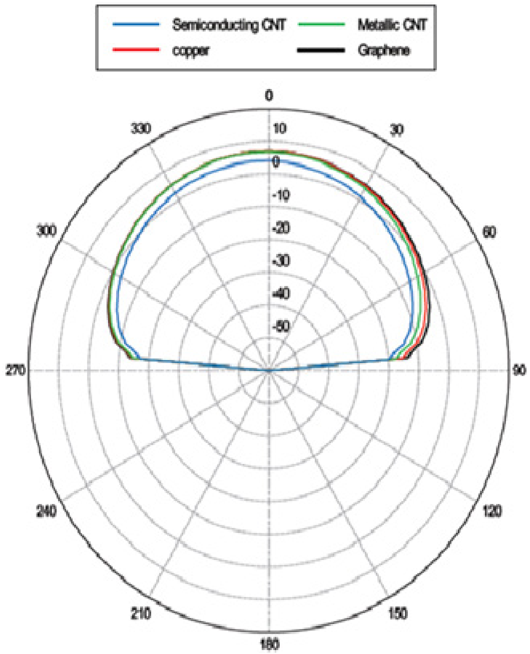

Figure 12. Radiation pattern of circular patch antenna.

5. Conclusion

This paper presents the characteristic analysis of different antenna parameters. Further, these parameters have been analyzed by simulating two different shape patch antennas. Rectangular patch antenna performance has been analyzed at a resonant frequency of 2.88 GHz and circular patch antenna at a resonant frequency of 18.74 GHz. Performance for semiconducting patch antenna is poor and metallic patch antenna is average. However performance of semiconducting and metallic patch antenna for both shapes is inferior to Copper and Graphene patch antennas. Performance of Copper patch antenna is slightly less than Graphene patch antenna in some cases. So, overall the best performance of considered parameters has been observed for Graphene patch antenna in both the shapes simulated in this paper. One of the future scopes in the patch antenna is in terms of conformable patch antenna. Conformable patch antenna can be printed in arrays on fabrics and considerable progress is already going in this application. So, carbon nano-materials can be the next change in the coming scenario to replace the metal conductors and silicon semiconducting devices.

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7. References

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