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Enhanced Bandwidth Characteristics of Multiwall Carbon Nanotube Microstrip Patch Antenna at X-Band Frequencies

Chaya Devi K S[1], Basavaraj Angadi[2], Mahesh H M[1*]

[1]Department of Electronic Science, Bangalore University, Jnana Bharathi, Bangalore – 560056,India
[2]Department of Physics, Bangalore University, Jnana Bharathi, Bangalore 560056, India

Abstract: ***In this paper we report the preliminary investigation on the novel Multi walled Carbon Nano Tube (MWCNT) based composites for Microstrip patch antenna design. The MWCNT based nano composite layer with two configurations viz., PAni – pTsA with MWCNT (Polyaniline–para-Toluene Sulfonic acid with MWCNT) and PAni –NSA with MWCNT (polyaniline – Naphthalene Sulfonic acid with MWCNT) above the conventional copper patch antenna was designed and studied using High Frequency Structure Simulator software (HFSS) in the X – band of frequencies. The simulation results revealed that the Nano composite based antenna exhibits an excellent antenna characteristic with stable Gain and radiation pattern around 9.5 GHz to 10.5 GHz frequency range by using inset feed configuration. MWCNT based nano composite antenna is simulated and the performance is compared with a conventional patch antenna. The results shows that, insertion of MWCNT nano composite layer over the microstrip patch antenna increases its operation bandwidth up to 3.12% without considerable degradation in other parameters. The proposed MWCNT nano composite antenna is finds application for stealth aircrafts.***

Keywords: Nano composites, Microstrip Antenna, MWCNT, Enhanced Bandwidth, X-band

1. Introduction

In the current communications systems, the copper is being commonly used material in the design and fabrication of microstrip patch antenna, due to their diversified microwave communication application such as SAR antenna, and military Radars. Recently researchers used nano composite materials as a replacement for the copper antenna to overcome the limitations of the metals such as fabrication procedure, weight, and corrosion resistance [1-5]. Therefore, novel material like carbon nanotube with conducting polymer is used to replace the copper patch antennas to overcome the limitations [6-7].

Carbon nanotubes (CNT) are the hexagonal shaped cylindrical structure made up of graphene. Based on the geometry the carbon nano tubes (CNT) can be classified into single walled nanotubes (SWCNT) and multiwalled nanotubes (MWCNT). SWCNT is a single graphene sheet and MWCNT made up of multiple concentric tubes. The CNT exhibits excellent electrical, thermal, mechanical properties [8]. and other special properties such as, CNT is gaining significant interest in the electromagnetic field of GHz domain[9] , EMI shielding[10], large current-carrying capability[11], low mass density[12], high electron mobility[13], high thermal conductivity[14]. Hence, the characteristic features of CNT based composite materials have been exploited in the design of CNT based microstrip antennas.

2. The Conceptual Design

The basic conceptual design of the present study involves deposition of thin film of novel Nano composites above a copper patch using RT Duroid substrate as shown in figure (1). The nature of nano composite thin film above the radiating patch consists of resistive sheet using inset fed rectangular pattern made of lossy materials can be applied to the design of patch antenna structure, which is separated by a dielectric substrate and metallic ground plane. This resistive sheet can improve the bandwidth due to the dielectric characteristics of the MWCNT nano composite material [15]. However, the MWCNT nano composite is good candidate for the resistive sheets and advantageous due to electrical conductivity control, effective surface coating, and compatibility [16].

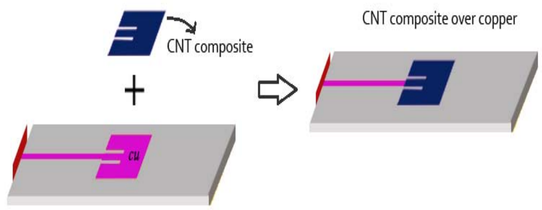

Figure 1: Typical structure of Nano composite thin film over the copper patch antenna

3. Designing

3.1 Design Specifications and Procedure

The microstrip patch antenna consists of the radiating patch of a length of L and width W, and inset y_o used for impedance matching between the patch and 50Ω feed line. Table 1 shows the design considerations of Microstrip patch antenna.

Table 1: Design considerations of the Microstrip patch antenna

Frequency	9.5 GHz – 10.5 GHz
Substrate	RT Duroid 5880
Dielectric Constant	2.2
Height	0.787 mm

The width and length of the patch antenna are calculated by using transmission line design equations.

The width of the patch is given by

$$w = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Actual length of the patch is determined as

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2(\Delta l) \qquad (2)$$

The input resistance for the inset- feed is given by

$$R(y=y_0) = R(=y_0)\ \mathrm{Cos}2\left[\frac{\pi y0}{L}\right] \qquad (3)$$

Using the above equations the width and length of rectangular microstrip patch on RT duroid substrate was estimated and designed.

3.2 Design of Standard Microstrip Patch Antenna

Initially, a conventional rectangular microstrip patch antenna was designed and simulated by 3D electromagnetic HFSS analysis software. Three essential parameters for the design of patch antenna *viz.,* the frequency of operation (f_r), the dielectric constant of the substrate (ε_r), and the height of the substrate (h) were considered. The resonant frequency of 10 GHz in 9.5GHz-10.5GHz frequency range on RT Duroid substrate with dielectric constant (ε_r=2.2) was considered. The height of the substrate was 0.707 mm. The antenna was defined with the values
W= 11.8mm, L = 10mm, Y_0 = 2.9mm and W_0 = 3mm. Figure (2) shows the design model of the standard patch antenna.

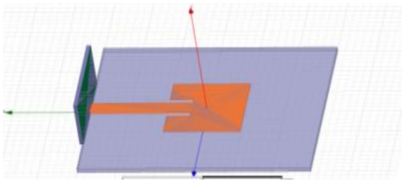

Figure 2: Single Element modelled in HFSS (Standard antenna*)*

3.3 Designing of MWCNT Nano composites patch antenna

In this study, we applied the thin film of MWCNT Nano composites to the microstrip patch antenna in order to enhance the bandwidth without compromising the antenna's performance. The permittivity, loss tangent, conductivity of the PAni-PTsA with MWCNT, PAni-NSA with MWCNT used in the patch antenna design was measured in prior research and is listed in table 2 (15). The combination of design variables, such as rectangular size, gap were decided by a parametric optimization study that used HFSS software tool. The detailed configuration and design of patch antenna are shown in figure 3 and 4.

Table 2: Design parameters of the Patch antenna and material property for Radar absorbing material

Patch antenna		PAni-PTsA with MWCNT	PAni-NSA with MWCNT
L = 10mm	W= 11.8mm	$\dot{\varepsilon}$ = 7.3 and $\ddot{\varepsilon}$ = 9.31	$\dot{\varepsilon}$ = 20.2 and $\ddot{\varepsilon}$ = 34.4

Y_0= 2.9mm	W_0= 3mm	σ = 1.3 s/m	σ = 1.7 s/m

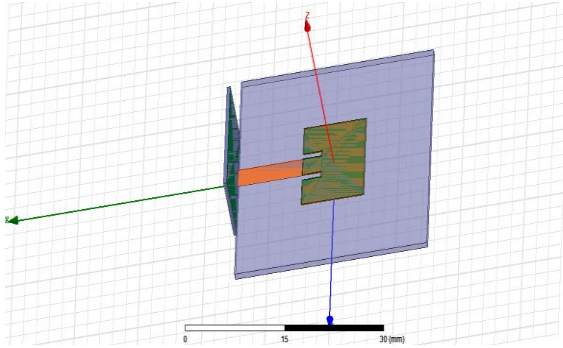

Figure 3: PAni-PTsA+MWCNT patch antenna

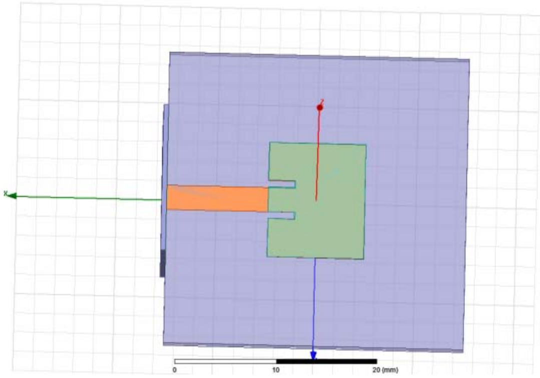

Figure 4: PAni-NSA + MWNT patch antenna

4. Results and Discussion

4.1 Simulation results of conventional microstrip patch antenna and PMMA-CNT antenna

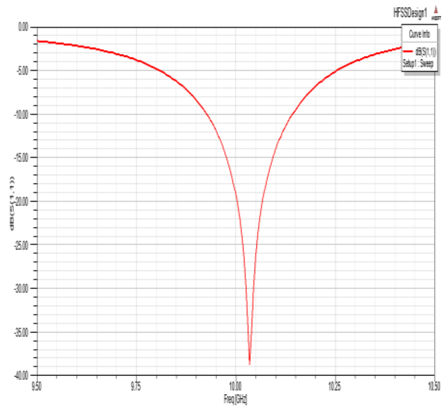

Figure 5: simulation of S11 [dB] conventional antenna

Figure 5 shows the variation of *Return* loss verses frequency plot of a conventional patch antenna. Since the designed frequency of conventional rectangular microstrip path antenna (RMSA) is 10GHz, the impedance bandwidth over return loss less than -10dB is measured from 9.5 GHz to 10.5 GHz bands of frequency in conventional patch antenna. From the figure 5, it is seen that the antenna resonates at 10.01 GHz of frequency, which is close to the designed frequency of 10 GHz with a minimum return loss of -39 dB. From this graph upper frequency (f_H) 10.08 GHz and Lower frequency (f_L) is 9.89 GHz of the band respectively when its return loss reaches -10dB, f_r is the centre frequency between f_H and f_L. From the figure 5 the impedance bandwidth of conventional RMSA is found to be 2.20%.

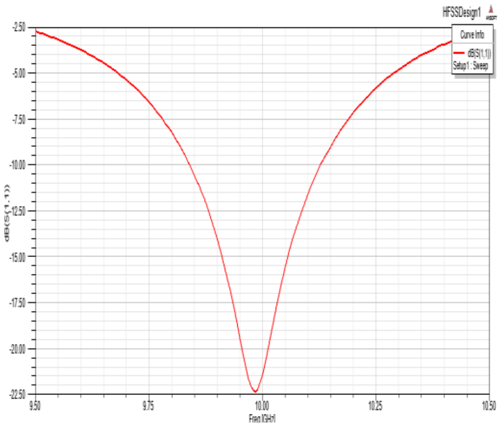

Figure 6: Simulated S11 of PAni-PTsA with MWCNT patch antenna

Figure 6 shows the variation of return loss verses frequency of PAni-PTsA with MWCNT nanocomposite antenna. Impedance bandwidth over return loss less than -10dB is measured from 9.5 GHz to 10.5 GHz band of frequency in PAni-PTsA with MWCNT nanocomposite antenna. From the figure 6, the antenna resonates at -22dB at 10GHz, over 9.5 GHz to 10.5 GHz frequencies range. This is due to independent resonance of patch with the insertion of PAni-PTsA with MWCNT nanocomposite film [15]. The overall impedance bandwidth is found to be 2.86%.

The insertion of PAni-PTsA with MWCNT nanocomposite is replaced by PAni-NSA with MWCNT on the copper patch as shown in figure 4.

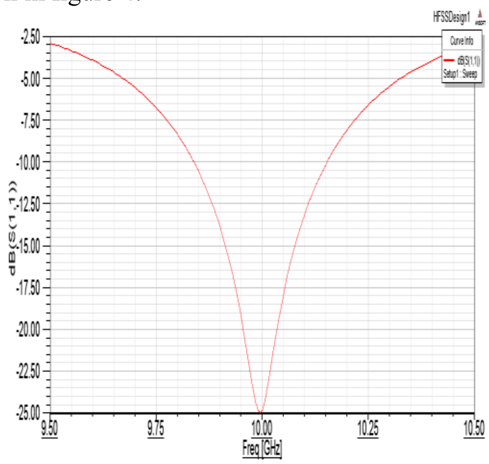

Figure 7: Simulated S11 of PAni-NSA with MWCNT patch antenna

From figure 7, shows the variation of return loss versus frequency of PAni-NSA with MWCNT nanocomposite antenna over the band of 9.5GHz to 10.5GHz frequency range. The PAni-NSA with MWCNT antenna resonates at -24.5dB at 10GHz, which is equal to the designed frequency of 10GHz. The overall impedance bandwidth was found to be 3.12%. It is cleared that, the insertion of nanocomposite film over the patch acts as additional resonance. If these additional resonances are near to the patch resonance, adding to them together causes enhancement bandwidth compared to the conventional patch antenna.

4.2 Simulation study of Radiation pattern

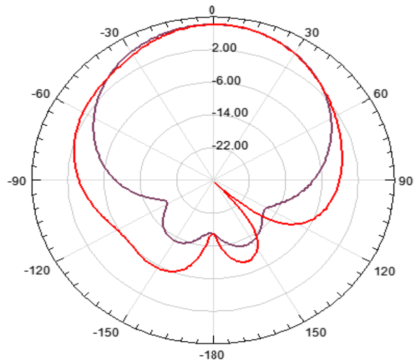

Figure 8: Radiation pattern of conventional patch antenna, Gain (dB)

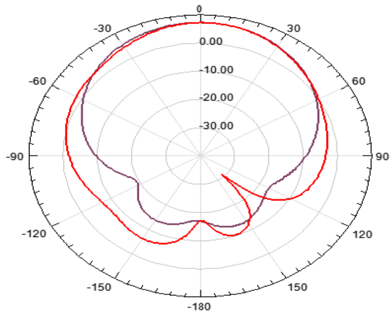

Figure 9: Simulated radiation pattern of PAni-PTsA with MWCNT

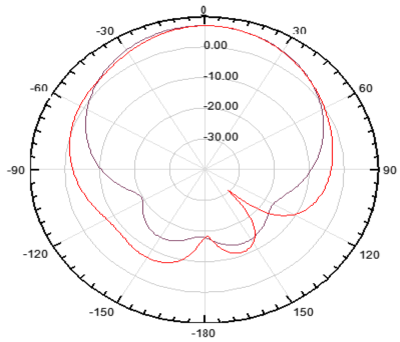

Figure 10: Simulated radiation pattern of PAni-NSA with Patch antenna MWNT patch antenna

Since, the radiation patterns of conventional microstrip patch antenna, PAni_PTsA with MWCNT and PAni_NSA with MWCNT are studied through simulation shown in figure (8) to (10). The co-polar radiation patterns of the conventional microstrip patch antenna, PAni_PTsA with MWCNT and PAni_NSA with MWCNT are simulated at the frequency of 10GHz respectively as shown in figure (8) to (10). From the figures it can be observed that the co-polar patterns are broadsided and linearly polarized. The -3dB half power beamwidth (HPBW) of conventional rectangular microstrip patch antenna, PAni_PTsA with MWCNT and PAni_NSA with MWCNT are 71˚, 70˚ and 68˚ respectively. Hence it is clear that the PAni_NSA with MWCNT improves sharpness of beam when compared to the conventional RMSA by reducing the HPBW from 71˚ to 68˚. This is because of PAni_NSA with MWCNT suppresses the maximum back radiations among conventional rectangular microstrip patch antenna, which in turn sharpens the beam and hence improves the radiation patterns.

5. Comparisons of performances of conventional and CNT based antenna

Table 3: Comparison of simulated antenna performance

Antennas	*Frequency*	*Gain*	*Bandwidth*	*Efficiency*
Standard copper patch antenna	10GHz	8.3dB	2.1%	95%
Low RCS antennas a) *PAni-PTsA1+MWCNT patch antenna*	10GHz	7.9dB	2.8%	99%
b) *PAni-NSA + MWNT patch antenna*	10GHz	7.5dB	3.1%	94.5%

The radiation efficiency is also the ratio of the radiated power to the total input power of the antenna at the resonant frequency. The efficiency of the designed antennas was 99% and 94.5% respectively, which was an ideal case without losses at the terminals and within the structure of the antenna.

The conventional patch antenna, *PAni-PTsA* with MWCNT and PAni-NSA with MWNT antenna radiation pattern measurements were performed from 9.5 GHz to 10.5 GHz frequency range for bandwidth comparison. Figure 11 is the comparison of bandwidth (BW) of the antennas covered with *PAni-PTsA* with MWCNT and PAni-NSA with MWCNT composites is greater than standard antennas bandwidth in the X-band range, without considerable degradation in gain that is 7.9dB and 7.5dB respectively. The antenna covered *PAni-PTsA* with MWCNT shows 2.84% bandwidth enhancement and PAni-NSA with MWCNT shows 3.12% bandwidth enhancement, compared to the standard antenna bandwidth.

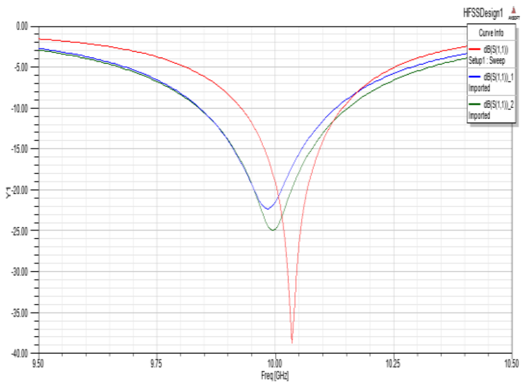

Figure 11: Bandwidth (BW) enhancement of MWCNT composite antennas compared to standard antenna. For (PAni-PTsA) MWCNT composite, 28.4% larger BW (Blue line); for MWCNT(PAni-NSA) composite, the BW is 31.2% larger (Green line) than the standard Microstrip antenna (red line).

6. Conclusions

MWCNT –nano composite Patch antenna was designed and simulated. All three patch antennas had nearly same resonating frequency of 10GHz. The MWCNT nano composites antennas such as PAni-PTsA with MWCNT composite enhance the bandwidth of 2.84% and PAni-NSA with MWCNT nano composite antenna enhance 3.12% bandwidth compared to the conventional patch antenna. The radiation pattern and antenna gain were slightly the same that is 7.3dB. The above result shows that a suitable design of MWCNT Nano composites patterns has almost no effect on the performance of the antenna. The configuration of microstrip patch antenna has numerous advantages like easy of fabrication, low profile, light weight, flexibility in design techniques. In conclusion, MWCNT nano composite antenna can be applied in stealth applications such as aircrafts or warships.

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