

ENHANCED MICROWAVE ABSORPTION OF QUARTIC LAYERED EPOXY-MWCNT COMPOSITE FOR RADAR APPLICATIONS

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Received 25 April 2017; accepted 15 June 2017

ABSTRACT

In this paper we presented the electromagnetic analysis of multilayered Radar Absorbing Structure (RAS) composed of Multi-Wall Carbon Nano Tubes (MWCNTs) with different weight percentages. The complex permittivity and permeability of MWCNT/epoxy composites with different wt% are analysed and the microwave absorbing characteristics are evaluated. The permittivity and permeability of MWCNT composites increased with increase in MWCNT concentration. Absorption properties like reflection loss of multilayered RAS are estimated analytically using electromagnetic wave theory for different layers and with different layer order based on impedance matching condition. The quartic layer MWCNT/epoxy composite achieves a better microwave absorption when compared to other multilayer RAS. The microwave absorption was attributed to dielectric loss of the material. The simulated quartic layer RAS is fabricated and validation of reflection loss is done experimentally using free space measurement technique. From free space measurement the minimum reflection loss in entire X-band is observed to be approximately -12 dB (95% of absorption), -15 dB (97% of absorption), with 3 GHz band width, -20 dB (99% of absorption) with 2 GHz bandwidth and maximum peak of -44 dB at 11.5 GHz. Hence the composite material has great potential of application as highly efficient microwave absorber.

Keywords: Nano materials, Electromagnetic Theory, Waveguide Measurement, Microwave absorption, Simulation.

1. INTRODUCTION

Electromagnetic interference is harmful to various electronic devices, such as control panels of airplanes, computer local area networks, mobile phones, and personal computers and has adverse effects on humans causing diseases, such as breast cancer and leukemia. To overcome the problems, much effort has been dedicated for seeking suitable electromagnetic wave (EMW) absorption materials [1 and 2]. Many researchers have made great efforts to produce electromagnetic wave absorbing materials with improved performance especially in X-band (8.2-12.4 GHz) as frequency sub-bands are used in civil, military and government institutions for weather monitoring, air traffic control, maritime vessel traffic control, defense tracking and vehicle speed detection for law enforcement.

Microwave-absorbing materials are currently in high demand for many expanded electromagnetic inter-

ference (EMI) shielding and Radar Cross Section (RCS) reduction applications with both commercial and defense purposes. By reducing the detectability of aircrafts or warships, of which the RCS is a measure, they could evade radar detection, which affects not only the mission success rate but also survival of them in the hostile territory [2 and 3]. In fact reduction of RCS can be categorized into two methods. One is the shape optimization of the body so that incident electromagnetic wave can be scattered yielding minimum reflective wave. The other is the use of electromagnetic wave absorption materials and/or structures. In general, the shaping conflicts with the design to improve the aerodynamic performance. Therefore, the developments of Radar Absorbing Material (RAMs) and Radar absorbing Structure (RAS) using fibre-reinforced polymeric composite materials have become essential for RCS reduction [4 and 7].

In general the radar absorbing materials can be categorized into magnetic and dielectric absorbers according to their lossy fillers [5]. The magnetic absorbers have been fabricated by coating materials by mixing rubbers or polymeric resins with magnetic fillers such as Fe-Co-Ni flakes [8], Mn and Ni doped zinc oxides [9], surface-modified planar-anisotropy Fe-Ni particle [10], Fe-Ni alloy nanoparticles [11-13]. The magnetic fillers are used to control both complex permeability and complex permittivity. In microwave absorption properties complex permittivity and permeability of the absorbers play significant roles. These magnetic fillers are compounds of relatively heavy metals or ceramics and mostly used at high mixing ratios, so that most of the magnetic absorbers have high aerial weight. On the other hand dielectric absorbers utilize conductive fillers like CB (Carbon Black) [5], MWCNT (Multi Walled Carbon Nano Tubes) [4-6,10-11,19-21], CNF (Carbon Nano Fibre) [5], SWCNT (Single walled Carbon Nano Tubes) [16] etc. The conductive fillers are used to control the complex permittivity only. The conductive fillers are relatively of low density and their mixing ratios are very low in comparison with those of the magnetic fillers. Although RAMs have the strong advantage of being easily applied to the surfaces of existing structures; however, RAMs increase structure weights and have poor mechanical and environment-resistant properties. Thus, RAMs cannot be used as load-bearing structures and they require constant maintenance and repair [7].

A RAS [7, 15, 17, 18, 25 and 26] is composed of multilayer structures with different wt% lossy fillers dispersed into the matrix of the composites. Nature and wt% of lossy fillers influences the EM properties of these. High stiffness and strength of RASs avoid the disadvantages of RAMs and they also able to have the same EM energy dissipating ability of RAMs. High conductivity for shielding by reflection, high aspect ratio for a conductive network, extraordinary electrical and magnetic properties make lossy filler highly effective. In this study, multi-walled carbon nanotube satisfying those requirements was selected as lossy filler. Moreover, the MWCNT is expected to act as a mechanical reinforcement.

In this work, for the requirement of light-weight microwave absorbers, MWCNT/epoxy composites are prepared by simple chemical method. The complex permittivity and permeability of MWCNT/epoxy composites with different wt% are analysed and the microwave absorbing characteristics are evaluated.

2. MATERIALS AND METHODS

2.1. Materials

Commercially available MWCNTs (Multi-Wall Carbon Nanotubes) with an average diameter of 9.5 nm, length 1.5 μm and with purity of 90% are produced by ARCI-Hyderabad, India. Epoxy resin (Epofine LY 556), carbon fibres (T 300), glass fibre (12,000 strands per tow) and high temperature hardener Di Ethyl Tetra Di Amine (DETDA) used in the preparation of composite are purchased from high chem. laboratories, India.

2.2. Preparation of nanocomposite specimens:

Selective oxidation of MWCNTs was done at 450°C in furnace for 2 Hrs. Then acid dilution with H_2SO_4 and HNO_3 in 3:1 ratio at 120°C for 4 Hrs followed by cleaning of MWCNTs with water till pH of water becomes neutral. Finally MWCNTs are dried at 70°C for 24 Hrs in the oven. SEM image of purified MWCNTs and as received NiFe alloy nano powder is as shown in Fig.1. Then 0.5% wt of treated MWCNTs were dispersed in the epoxy resin by using high-speed mechanical stirrer at 1000 rpm (Remi motors, model-124 A) for 60 min followed by sonication at 50 MHz frequency with a bath type sonicator (TRANS-O-SONIC, M/s Shanti Industrial Estate, Mumbai, India) for 90 min. MWCNTs-epoxy mixture was added with the hardener (24 parts of hardener to 100 parts of epoxy resin by weight) and this mixture was further sonicated for 15 min. Glass fabric was cut into specific dimensions and impregnated with MWCNTs/epoxy dispersed resin hardener mixture. Impregnated fabric layers were stacked and compressed to attain the thickness of 2 mm. The prepared composite is cured in oven at 100°C for 1 hour followed by 160°C for one more hour and post curing at 180°C for 3 hours. The same

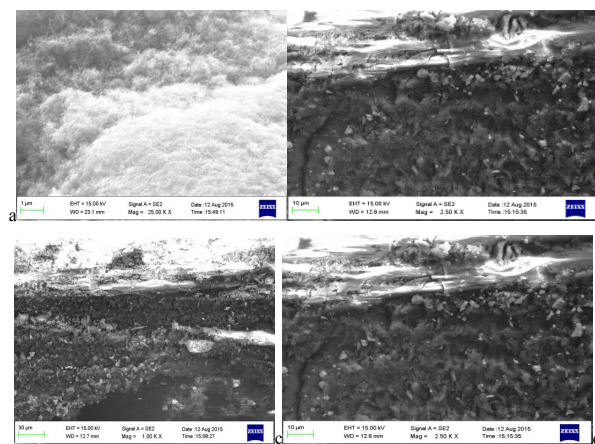


Fig.1: SEM images of a) Treated MWCNTs b) 0.5 wt% of MWCNT c) 1.5 wt% of MWCNT d) 2.5 wt% of MWCNT composites.



Fig.2: Waveguide measurement setup and sample in X band wave guide

procedure was repeated for other wt% of MWCNT/epoxy composites.

2.3. Measurement of EM properties

The composite material is precisely cut into samples of dimensions 22.86 mm × 10.16 mm (WR 90) for wave guide measurement in order to determine the EM properties of the samples in X band frequency range i.e. 8.2- 12.4 GHz. S –Parameters have been measured using two port vector network analyser (Rhodes & Schwarz model ZVB 20) through wave

guide technique. The vector network analyser, coaxial cables, calibration kit with necessary accessories and wave guide WR 90 (X Band) are shown in Fig.2. TRL (Thru, Reflect, Line) calibration technique is adopted for dielectric measurement in the X- band. Permittivity and permeability of all the samples are extracted using canonical algorithms like NRW, NIST etc.

3. RESULTS AND DISCUSSION

3.1 Morphology of composites manufactured

Degree of dispersion of the conductive fillers within the epoxy matrix plays a significant role. In order to analyse the state of dispersion of the various fillers i.e. MWCNTs within the matrix and to evaluate agglomeration, different samples were investigated by scanning electron microscopy. In particular, 0.5%, 1.5 and 2.5 wt % of MWCNTs samples are showed in Fig.1 b), c) and d) respectively. It was observed that in all the samples the conductive fillers are well dispersed in the epoxy matrix. EDAX studies of these nanocomposites clearly revealed the incorporation of MWCNTs nanoparticles in the epoxy matrix.

3.2 Complex permittivity and permeability

Real and imaginary part of complex permittivity of samples with different wt. % of MWCNT and pure epoxy using wave guide measurement technique are shown in Fig.3 and Fig.4. The complex permittiv-

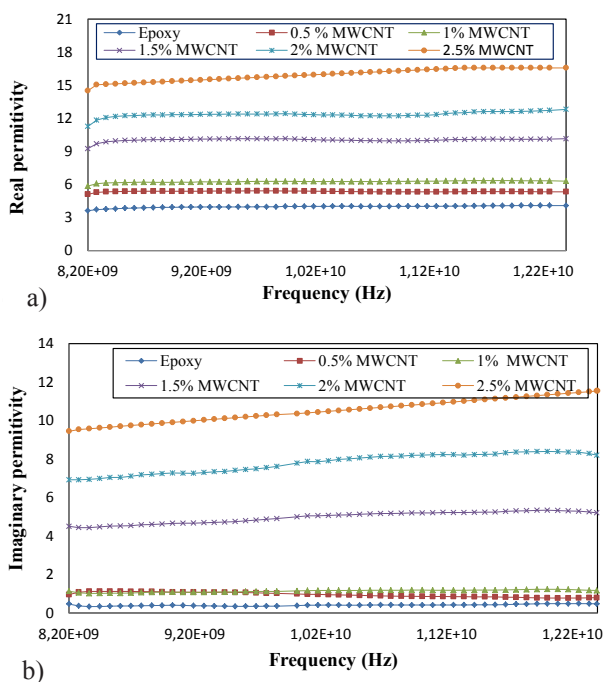


Fig. 3: a) Real component b) imaginary component of complex permittivity of epoxy/MWCNT with different wt% in X – band

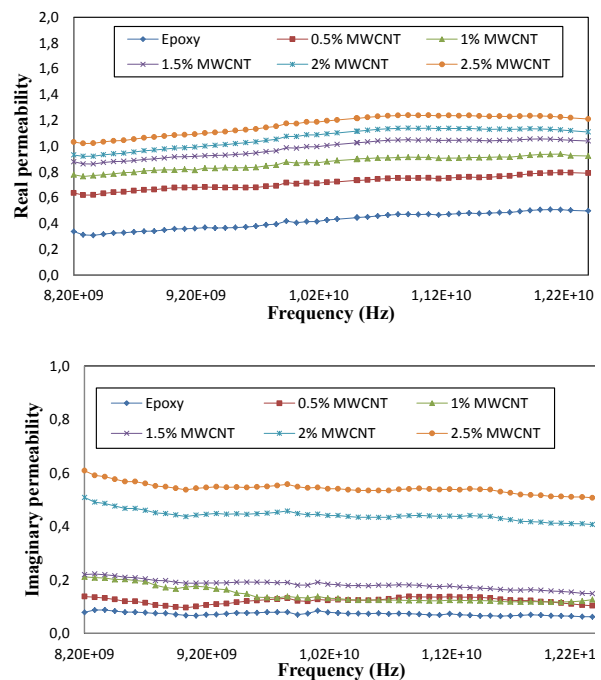


Fig.4: a) Real component b) imaginary component of complex permeability of MWCNT/epoxy composite with different wt% in X – band

ity measured in the frequency range of 8.2 to 12.4 GHz increases with filler concentration and almost constant with frequency [5 and 6]. It can be found that the value of real permittivity increases from 5 to 15 due to increase in MWCNT wt% from 0.5 to 2.5 where as the imaginary permittivity increased from 1 to 10. The measured values of the real and imaginary parts of the magnetic permeability were 1.0 and 0.1 for all materials, as expected. As the processed materials are dielectric absorbers, the values of magnetic losses are so low that they can be disregarded ($\mu' = 1$, $\mu'' \approx 0$).

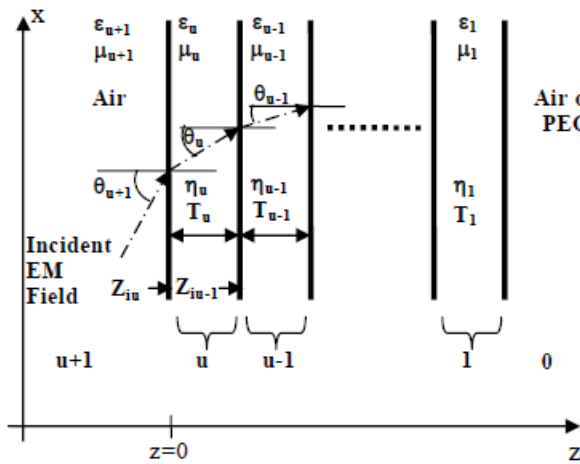


Fig. 5: Multi layered microwave Radar absorbing structure

3.3. Simulation of multilayered Radar Absorbing Structure:

Simulation of multilayered RAS is carried out by using electromagnetic wave theory in order to measure absorption in terms of reflection loss of the structure. Reflection loss of multi layered RAS depends upon electromagnetic properties like complex permittivity and permeability, thickness and frequency. Reflection loss of multi-layer RAS as depicted in the Fig.5 is determined using following equations which are well cited in literature [7, 12, 15 and 18].

$$RL = -20 \log_{10} \left(\left| \frac{Z_i - Z_0}{Z_i + Z_0} \right| \right) \quad (1)$$

Where $Z_0 \cong 377 \Omega$ is the free space impedance and Z is the input impedance at the first air-absorber interface. The input wave impedance of the multilayer, backed by PEC, can be expressed iterating the following equation for each layer i .

$$Z_i = i \left(\frac{Z_{i-1} \cos(k_i t_i) + j Z_0 \sin(k_i t_i)}{Z_0 \cos(k_i t_i) + j Z_{i-1} \sin(k_i t_i)} \right) \quad (2)$$

Here, t_i is the layer i thickness in mm, whereas the wave number k_i is:

$$k_i^2 = (2\pi f)^2 \mu_0 \epsilon_0 \mu_{ri} \epsilon_{ri} = (2\pi f)^2 \mu_0 \epsilon_0 \mu_{ri} (\epsilon_{ri} - j \epsilon_{ri}') \quad (3)$$

Where f is frequency of the incident electromagnetic wave in Hz, ϵ_0 free space permittivity, μ_0 free space permeability, μ_{ri} is i^{th} layer permeability, ϵ_{ri} is real part of complex permittivity and ϵ_{ri}' is imaginary part of complex permittivity of i^{th} layer. MATLAB code was developed based on fundamentals of EM wave theory using impedance matching condition in order to measure microwave absorption. Simulations are done for different cases by varying number of layers and order of layers from two layered RAS to six layered structure.

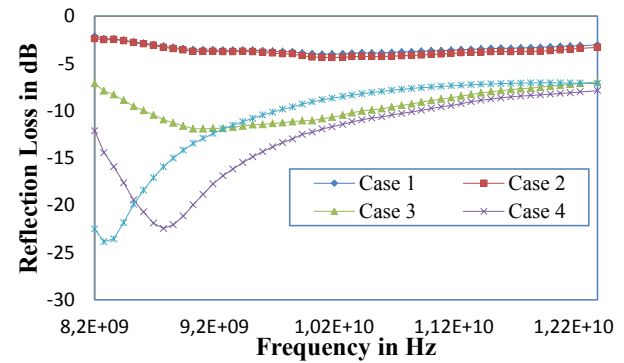


Fig.6: Reflection loss of two layered RAS consisting of MWCNTs with different wt%

Initially simulation of multi-layer RAS composed of MWCNTs with different weight % i.e. 0.5, 1, 1.5, 2 and 2.5 has been carried to determine microwave absorption in terms of the reflection loss. Table.1 shows the different RAS cases composed of MWCNTs with different weight % that are considered to measure microwave absorption in terms of reflection loss. The multi layered RAS considered here consists of two, three, four, five and six layered RAS based on impedance matching condition with different wt% of MWCNTs. Results of all the cases are discussed in the subsequent section.

3.3.1 Two layered RAS based on MWCNTs:

The reflection loss of the all cases of two layered RAS obtained from the simulation is as shown in the Fig.6. It can be observed from the result that reflection loss of case 1 and 2 is almost coincident and has value of less than -3 dB in the entire band where as for the remaining cases i.e. case 2 to case 5 reflection loss of below -8 dB is observed in the entire X band. In these cases the maximum peak is shifted towards left as the weight % of MWCNTs is increased in the middle layer. A maximum peak of -24 dB is observed at 8.3 GHz for case 5. Reflection

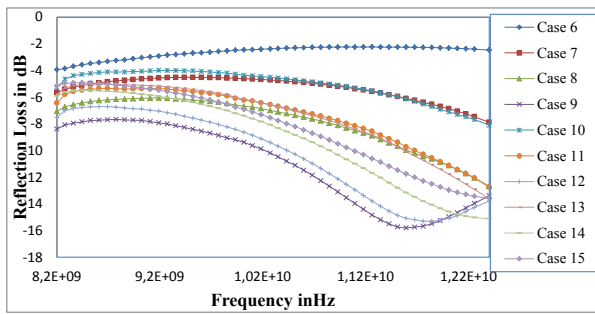


Fig.7: Reflection loss of three layered RAS consisting of MWCNTs with different wt%

loss of -10 dB is become wider i.e. from 8.2 – 10.7 GHz for case 4 and 8.5 GHz – 10.5 GHz for case 3 when compared to other cases. The maximum peak of reflection of -12 dB at 9.1 GHz for case 3 and -22 dB at 8.7 GHz for case 4 is observed.

3.3.2 Three layered RAS based on MWCNTs:

Fig.7 illustrates the deviation of reflection loss of the four layered RAS i.e. for cases 6 – 15 obtained from the simulation. The reflection loss is below -2 dB for case 6, -4 dB for cases 7 and 10, -5 dB for cases 11, 13, 14 and 15, -6 dB for case 8, -7 dB for case 9 and 12 is observed in the entire X band. A maximum peak of -16 dB is observed for case 9 at 11.7 GHz of frequency. The variation of reflection loss is following the same trend in all the cases except cases 9, 12 and 14. The reason might be the presence of high wt% of MWCNTs i.e. 2.5% of MWCNTs in the middle layers. Reflection loss of -10 dB band widths have become wider in the frequency range 10.4 GHz - 12.4 GHz and -12 dB bandwidths in the frequency range 10.7 GHz – 12.4 GHz for case 9.

3.3.3 Four or quartic layer RAS based on MWCNTs:

The four layered RAS reflection loss discrepancy is identical for all cases i.e. cases 16-25 as depicted in Fig.8. Reflection loss of less than -4 dB for case 16, -5 dB for cases 17 and 18 and less than -8 dB for cases 19-25 is examined. -10 dB reflection has

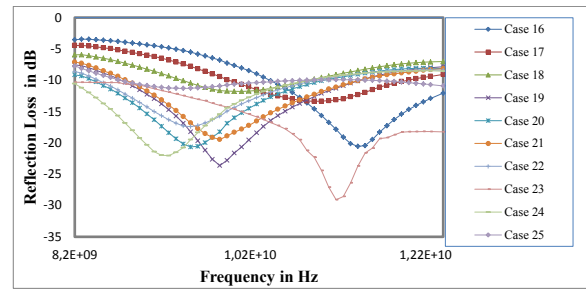


Fig.8: Reflection loss of four layered RAS consisting of MWCNTs with different wt%

become wider for the cases 19-25. A maximum peak of -29 dB is observed for case 23 at 9.4 GHz and -12 dB reflection loss has become much wider i.e. 8.2-11.2 GHz. The variation of reflection loss has followed similar lines for case 23 and 24 except the peak. Reflection loss of -10 dB has become much wider for case 25 i.e. from 8.7 GHz- 12.4 GHz. Case 23 i.e. epoxy as first layer, 1% MWCNT as second layer, 1.5 % MWCNT as third layer, 2.5 % MWCNT as fourth layer and PEC as last layer has better microwave absorption in the entire X band when compared others.

3.3.4 Five or quintic layer RAS based on MWCNTs:

Fig.9 shows the absorption characteristics of the epoxy-MWCNT five layered composite. Similar variation in absorption characteristics is noticed in the cases 26-28 with less than -6 dB in the entire X band and maximum peak of -16 dB and -11.88 dB at 8.2 GHz for case 26, case 27 and 28 respectively. Similar behaviour of microwave absorption is identified for cases 29 and 30 as the last three layers in both the cases are same. -10 dB reflection loss is observed for case 29 in the entire band with a maximum peak of -15.79 dB at 8.2 GHz where as for case 30 the reflection loss in the entire band is below -9 dB. From the above results it is evident that case

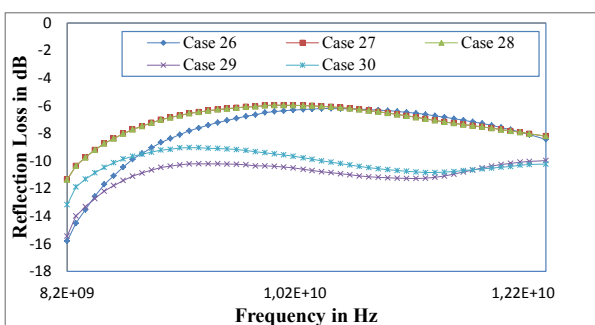


Fig.9: Reflection loss of five layered RAS consisting of MWCNTs with different wt%

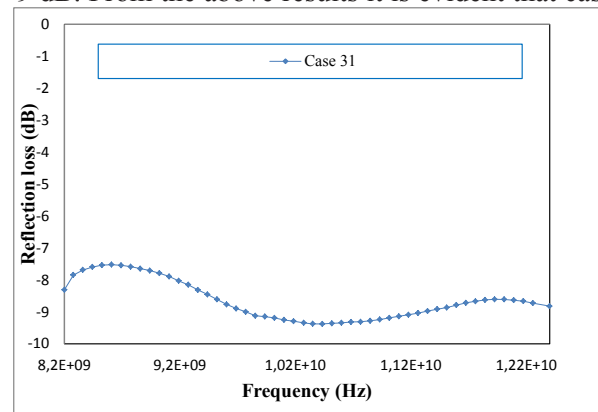


Fig.10: Reflection loss of six layered RAS consisting of MWCNTs with different wt%

29 has better absorption characteristics.

3.3.5 Six layered RAS based on MWCNTs:

The absorption characteristics of six layered RAS i.e. dependency of reflection loss with frequency for case 31 is as depicted in the Fig.10. The reflection loss is below -7 dB in the entire X band with a maximum peak of -9.5 dB at 10.4 GHz. From above results it is evident that reflection loss does not increase with the increase in number of layers although it depends upon the number of layers. The other parameters like thickness, permittivity, permeability and order of layers plays significant role microwave absorption of a multilayered RAS.

Out of all the cases four layered RAS with layer order of epoxy, 1 % of MWNT, 1.5 % of MWNT, 2.5 % of MWNT backed by PEC which was shown in Fig.11 has better reflection loss compared to others. The reflection loss of the above structure obtained from simulation is as shown in Fig.8. From the results it is observed that almost -12 dB reflection loss is observed in the entire X band and a maximum peak of -29 dB is observed at 11.2 GHz. The reflection loss obtained are better than multi-layer RAS composed of MWCNTs in the literature [7, 15, 17, 18 and 26] where the reflection loss was -10 dB in

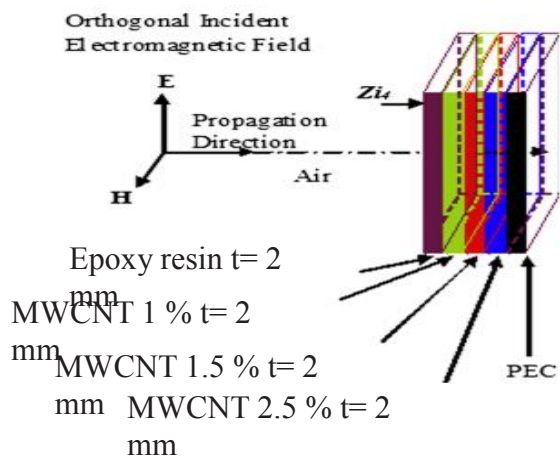


Fig. 11: Four layered Radar Absorbing Structure



Fig. 12: Free space measurement technique samples of $150\text{ mm} \times 150\text{ mm}$ in different views

the entire X band with 3.3 mm and 4 mm thickness of RAS, [7 and 15], -11 dB in the entire band with 7 mm thickness [17 and 26], -9 dB with a thickness of 6.1 mm [18].

3.4. Experimental validation through free space technique

The finalized quartic layer RAS has been fabricated in similar procedure as explained earlier. The last layer of RAS i.e. PEC (Perfect Electric Conductor) is made of carbon fibre reinforced plastic. The prepared RAS has been precisely cut into $150\text{ mm} \times 150\text{ mm}$ for free space measurement and is as shown in Fig.12. The free space measurement system in this study is composed of a pair of spot-focusing horn lens antennas (transmit and receive antennas), a specimen holder, vector network analyser, and a personal computer for data acquisition as shown in Fig.13. The reflection loss of the finalized RAS measured using free space technique is as shown in Fig.14. From free space measurement the minimum reflection loss in entire X – band is observed to be approximately -12 dB (95% of absorption), -15 dB (97% of absorption), from $9.4 - 12.4$ GHz, -20 dB (99% of absorption), from $10.3 - 12.4$ GHz and maximum peak of -44 dB at 11.5 GHz.

The reflection loss of quartic layer RAS measured using free space technique is compared with analyti-



Fig.13: Free space measurement setup

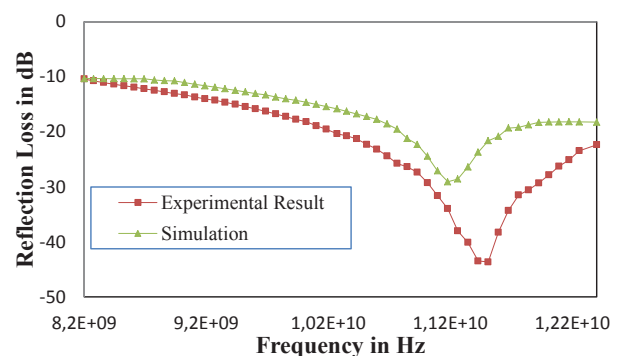


Fig.14: Comparison of analytical and experimental data of multilayered RAS

Table.1: Different case studies of multilayered RAS composed of MWCNTs

S.No	Description	Different Cases	Order of layers
1	Two layered RAS	Case 1-5	First layer: Epoxy, Second layer: MWCNT with varying wt% from 0.5 to 2.5 for cases 1-5 with an increment of 0.5, Third layer: PEC
2	Three layered RAS	Case 6-15	First layer: Epoxy, Second layer: MWCNT with varying wt% from 0.5 to 2, Third layer: MWCNT with varying wt% from 1 to 2.5 for cases 6-14 with an increment of 0.5 Fourth layer: PEC
3	Four or quartic layered RAS	Case 16-25	First layer: Epoxy, Second layer: MWCNT with varying wt% from 0.5 to 1.5, Third layer: MWCNT with varying wt% from 1 to 2 Fourth layer: MWCNT with varying wt% from 2 to 2.5 for cases 15-23 with an increment of 0.5 Fifth layer: PEC
4	Five or quintic layered RAS	Case 26-30	First layer: Epoxy, Second layer: MWCNT with varying wt% from 0.5 to 1, Third layer: MWCNT with varying wt% from 1 to 1.5 Fourth layer: MWCNT with varying wt% from 1.5 to 2 Fifth layer: MWCNT with varying wt% from 2 to 2.5 for cases 24-29 with an increment of 0.5 Sixth layer: PEC
5	Six layered RAS	Case 31	First layer: Epoxy, Second layer: 0.5wt% MWCNT Third layer: 1wt% MWCNT Fourth layer : 1.5wt%, Fifth layer: 2wt%, MWCNT, Six layer: 2.5wt% MWCNT and Seventh layer: PEC

cal result and is as shown in Fig.14. The measured curve is in accordance with theoretical calculations. The measured reflection loss using free space measurement does not fit exactly on the theoretical curve. The difference in the measured values is attributed to the reflections caused by the mismatch from various components of waveguide, the surface irregularity of absorbing sample, the gap between the sample and waveguide dimensions and unstabilized frequency source of microwave bench [28].

4. CONCLUSIONS

In this paper complex permittivity and permeability of MWCNT/epoxy composites has been measured in the frequency range 8.2 GHz- 12.4 GHz. With the increase in MWCNT weight percentage the real permittivity and permeability of the nano composite is increased. MATLAB code was developed based on EM wave theory and impedance matching condition to simulate multilayered RAS by changing the layer order and number of layers. Quartic layer RAS was finalized based simulation results for better microwave absorption. The reflection loss obtained from simulation is almost below -12 dB (95% absorption of incident wave) at 8.2 GHz- 11.2 GHz and a maximum value of -29 dB at 11.5 GHz which is better than results in the literature. In addition experimental validation of estimated reflection loss in X – Band was done using free space technique. The estimated reflection loss using free space technique

is in accordance with simulated results. Hence simulation code developed was proper and the composite material has great potential of application in the highly efficient microwave absorber.

ACKNOWLEDGEMENTS

This research was performed as a part of research project funded by Naval Research Board (NRB), Ministry of Defense Government of India. The authors would like to thank Prof. CH. Subramanayam of IIT Hyderabad, India for providing facilities for fabrication and characterisation.

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