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Development of E-waste based Composite Microwave Absorbing Material

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ABSTRACT

Microwave absorbing materials (MAMs) are widely researched due to their use in many practical applications including both civil and defense sectors. Irrespective of the humongous efforts of various researchers, the development of a wide bandwidth, thin coating thickness, and low-cost microwave absorber is still a challenging task. The existing materials have not been able to meet all the specifications together at once and require a trade-off in the performance parameters. In this paper, we have empirically corroborated a cost-effective technique using E-waste material for synthesising composite MAM. It is herein shown that the addition of different wt% of copper, graphite, and titanium dioxide in the E-waste successfully resulted in enhanced absorption due to altered electrical properties of the E-waste suitable for microwave absorption. The multilayering technique with the help of a genetic algorithm has also been used to broaden the bandwidth. As a result, a three-layer MAM with the total coating thickness of 3.2 mm has been synthesised showing the wideband absorption bandwidth of 8.47 GHz in the frequency range from 6.92 to 15.39 GHz. The results suggested that microwave absorption of E-waste can be drastically improved by appropriately tailoring electrical parameters such as permittivity and permeability.

Keywords: Dielectric characterisation; E-waste; Microwave absorbing materials; Reflection loss; Wideband

1. INTRODUCTION

Over the past few decades, there has been a tremendous increase in the use of personal handheld communication devices, wireless data communication, local area networks, satellite, and radar systems, altogether utilising the broad range of microwave frequencies from 2 to 18 GHz resulting in serious electromagnetic (EM) pollution[1,2]. This EM pollution adversely disturbs the operation of electronic equipment, and is also harmful to human health. This development of technology has resulted in widespread research on microwave absorbing materials (MAMs)[3]. The MAMs also hold considerable importance in stealth applications. For their effective use, the MAMs should be lightweight, easy to handle, resist corrosion and be simpler to synthesise than traditional absorbers[4]. A single dielectric or magnetic material is incompetent in converging with desirous requirements due to difficulty in achieving impedance matching. Thus, some composite materials have also been developed which results in good impedance matching[5].

Recent studies show that many dielectrics, magnetics, and composite materials have been developed for microwave absorption, but some researchers have also used waste composite materials. Bora[5], *et al*. studied industrial waste fly ash cenosphere (FAC) for microwave absorption. He coated NiO and CoO_X over FAC by chemical precipitation and thermal reduction method for studying the microwave absorption property. Yah[6], *et al*. used coconut fiber coir and charcoal powder materials and measured the dielectric properties of the materials over the X-band frequency (8.2 to 12.4 GHz). Zhao[7], *et al*. used biomass cotton to fabricate carbon-cotton/Co@nanoporous carbon (NPC) products and obtained the optimal reflection loss −51.2 dB at 13.92 GHz with the bandwidth of 4.4 GHz and thickness 1.65 mm. Guan[8], *et al*. fabricated $Ni(OH)_2$ nanosheets and $Ni(OH)_2$/AC (activation carbon) composites using jackfruit peel and investigated the microwave absorption performances in 2 to 18 GHz. They obtained maximum reflection loss of -23.6 dB at 15.48 GHz with a total 6 mm thickness. Few researchers have also paid attention to electronic waste[9].

With increasing innovations, the production of electrical and electronic equipment has increased incredibly, resulting in large electronic-waste (or E-Waste). Every year, a large quantity of electronic waste is thrown at the open space, from which computers and mobile are unevenly abundant due to their short life span. It is becoming difficult to manage this hazardous E-waste[10]. As dielectric, magnetic and conducting elements are present in electronic waste which may be useful in absorption. Thus, the use of E-waste for microwave absorption has opened up new avenues for research. By adding the proper amount of copper, graphite and titanium dioxide bandwidth and absorption can be enhanced.

In this work, waste computer printed circuit boards (PCBs) are used for the absorption of microwaves due to its ease of availability, low density, easy handling, and cost-effectiveness. Their permittivity and permeability values are measured from 2 to 18 GHz frequency range using transmission line technique.

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Further, the multi-layering technique is used to enhance the bandwidth of the single-layer absorbers. But to design, a multilayer absorber that has many unknown parameters is really a difficult task. Therefore, a three-layer MAM has been optimised using Genetic algorithm (GA)[11]. To validate and verify the optimisation technique, full-wave simulation using Ansys high frequency structure simulator (HFSS) has been carried out and the results of both the techniques are compared.

2. THEORETICAL BACKGROUND

As the EM wave propagates from free space to a material, the wave will be reflected, transmitted, and absorbed at the air-material interface. EM wave absorption depends on two basic methods; the first is by varying EM parameters to enhance the absorption of the EM wave and the second is by changing the nanostructures of the absorbers such as pores, defects, interfaces, etc. so that the transmitted pathways of the EM wave increased in the absorbers. In the following subsections, the basic principles are explained for EM wave absorption.

2.1 Microwave Absorption Mechanisms

The absorption of the EM wave inside the material is calculated by the complex permittivity, complex permeability, and tangential loss of the material. Using transmission line theory, the reflection loss of the microwave absorber can be computed with the measured complex permittivity and permeability values at a particular frequency and thickness of the single-layer absorber. The equations used in calculating reflection loss (RL) are as follows[9]:

$$Z_{in} = Z_o\left(\frac{\mu_r}{\varepsilon_r}\right)^{\frac{1}{2}} \tanh\left[j\left(\frac{2\pi fd}{c}\right)(\mu_r\varepsilon_r)^{\frac{1}{2}}\right] \quad (1)$$

$$RL(dB) = -20\log\left|\frac{(Z_{in}-Z_o)}{(Z_{in}+Z_o)}\right| \quad (2)$$

where, Z_{in} is the characteristic input impedance of the absorber, Z_0 is the characteristic impedance of free space (where, $Z_0 = 120\pi = 377\Omega$), ε_r is the measured complex permittivity, μ_r is the measured complex permeability, f is the frequency of the EM wave, d is the absorber thickness and c is the speed of light.

To achieve good EM wave absorption, there must be an effectual complementarity between dielectric and magnetic losses as well as impedance characteristics of the absorber. The dielectric loss is mainly due to conductivity loss and polarisation loss (space charge polarisation). According to free-electron theory,

$$\varepsilon'' \approx 1/2\pi\rho f\varepsilon_0 \quad (3)$$

where, ρ is the resistivity. The imaginary parts of complex permittivity can be increased by increasing the electrical conductivity or decreasing the resistivity ($\rho=1/\sigma$) of the material and hence, the conductivity loss plays an important role in dielectric loss[12]. The loss mechanisms which affect the magnetic losses for complex permeability measurements are hysteresis loss, magnetic resonance, and eddy current loss. In addition to dielectric as well as magnetic losses, EM wave absorption can also be explained using the quarter wavelength concept. According to this concept, the matching thickness (t) is given by the following equation[13]:

$$t = \frac{nc}{4f\sqrt{|\varepsilon_r||\mu_r|}} \quad (4)$$

where, n=1,3..., c is the speed of light, and f is the frequency of the EM wave. The incident EM wave on the first interface of the absorber cannot be normally reflected and the waves reflected by the last interface cannot cross the first interface because there occurs a 180° phase difference between both of them which leads to an interference phenomenon.

2.2 Absorption Mechanisms in Multilayer Absorbers

Multi-layering approach is used to broaden the bandwidth as well as reduce the total thickness of the absorber. Multilayer structures are the structures which consist of two or more than two absorbing layers. In this technique, the number of boundaries and interfaces of layers are increased. As EM wave is incident on multilayer absorber, multiple internal reflections occur at these boundaries as well as phase cancellation takes place at the interfaces which results in overall absorption of the EM wave inside the absorber as shown in Fig. 1.

As EM wave incident normally at the first interface of the absorber, some part of it gets reflected and some transmitted through the first interface, but the transmitted part cannot be reflected back due to phase cancellation between them (the quarter wavelength concept). Thus, absorption is enhanced. RL at the air-multilayer absorber interface can be calculated using following equation[14]:

$$RL(dB) = -20\log\left|\frac{(Z_N - Z_o)}{(Z_N + Z_o)}\right| \quad (5)$$

where,

$$Z_N = \eta_N \frac{Z_{N-1}\cos(k_N t_N) + j\eta_N \sin(k_N t_N)}{\eta_N \cos(k_N t_N) + jZ_{N-1}\sin(k_N t_N)} \quad (6)$$

here, t_N is the N[th] layer thickness, f is the EM wave frequency, η_N is the N[th] layer characteristic impedance and k_N is the N[th] layer wavenumber given as,

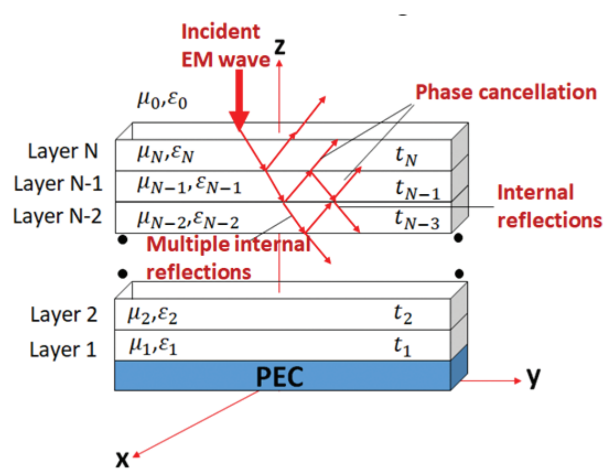


Figure 1. Multi-layering technique for enhanced microwave absorption.

$$k_N^2 = (2\pi f)^2 \mu_0 \mu_{rN} \varepsilon_0 \varepsilon_{rN} \tag{7}$$

and, $$\eta_N = \sqrt{\frac{\mu_0}{\varepsilon_0}\frac{\mu_{rN}}{\varepsilon_{rN}}} \tag{8}$$

3. PROPOSED METHODOLOGY, RESULTS AND DISCUSSION

This section explains the material synthesis process, characterisation results, and full wave simulation validation using Ansys HFSS required for studying the EM absorption properties of E-waste based composite MAM.

3.1 Synthesis Process of E-waste based Composites

For the synthesis of materials, waste computer printed circuit boards (PCB), 500 gm in weight, have been collected and broken into small pieces using an electric cutter. Further, the crushed powder (approximately 150 gm in weight) was collected with the help of an Impact Hammer Mill. Sieving of the crushed powder has been done by the vibratory sieve shaker and the fine powder was collected. It contains particles whose size varies between two different ranges i.e. 20 to 32 microns (say as 20EW) and 32 to 45 microns (say as 32 EW). The EM properties were noted down. Afterwards, different weight % of copper, graphite powder, and titanium dioxide were mixed with 20 EW and 32 EW samples. Composition details are given in Table 1. As the copper metal powder is metallic and has high electrical conductivity so the proper addition of it results in conductive loss inside the material[15]. The Graphite powder works as a dielectric-type absorbent and has been generally used as radar-absorbing material for stealth aircraft. The graphite powder has high thermal conductivity as well as electrical conductivity which maybe helpful in absorption[16]. Titanium dioxide is purely dielectric and thus, it increases the dielectric loss and significantly improves the EM absorption properties[17].

Finally, the cylindrical pellets were made with the addition of epoxy and binder in prepared samples. Thereafter, the pellets were kept in the oven at 55°C for 2 h. These pellets were further used to characterise the dielectric properties of materials.

Table 1. Details of composition (wt. %) of as-synthesised Host and its composite samples

Material Name	E-waste (EW)	Copper (Cu)	Graphite (G)	Titanium Dioxide (TiO_2)
20EW	100	-	-	-
20EW50Cu50	50	50	-	-
20EW50Cu50_90G10	45	45	10	-
20EW50Cu50_80G20	40	40	20	-
20EW50Cu50_80G20_50T50	20	20	10	50
32EW	100	-	-	-
32EW50Cu50	50	50	-	-
32EW50Cu50_90G10	45	45	10	-
32EW50Cu50_80G20	40	40	20	-
32EW50Cu50_80G20_50T50	20	20	10	50

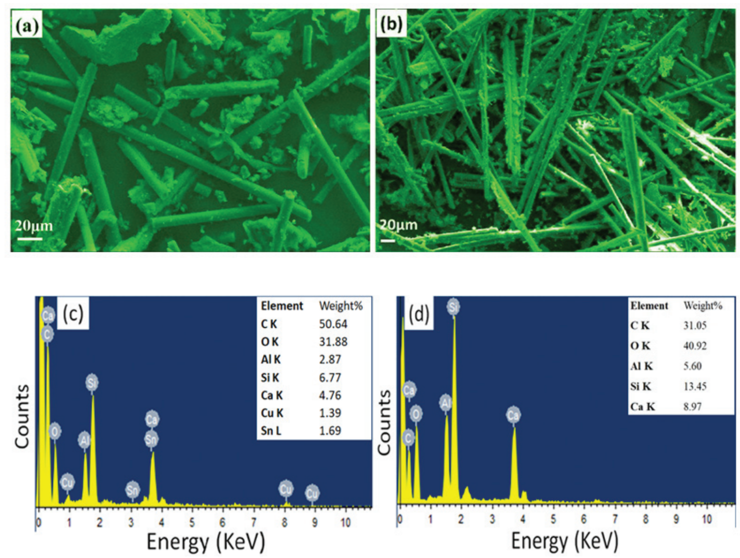


Figure 2. FESEM image of (a) 20 EW, (b) 32 EW, and EDX spectrum of (c) 20 EW, (d) 32 EW.

3.2 Morphological and Compositional Analysis

The morphological study of the host materials has been done by field emission scanning electron microscope (FESEM). Figures 2(a) and 2(b) represent the FESEM image of 20 EW and 32EW respectively. FESEM images reveal some rod-like structures as well as irregular shape particles. The rods were found to be 7.96 µm and 8.52 µm in diameter as shown in Figs. 2(a) and 2(b) respectively. Multiple scattering and internal reflections of the incident EM wave inside the rods can create a large number of propagation paths for incident EM waves to travel and trap inside the rod. The rods are agglomerated more in 32 EW in comparison with 20 EW as shown in Fig. 2(b) which results in more internal reflections and scattering inside 32 EW[18]. The energy dispersive X-ray (EDX) results in Fig. 2(c) reveal that 20EW consists of Tin, Copper, Calcium, Silicon, Aluminum, Oxygen, and Carbon elements. Figure 2(d) shows that Calcium, Silicon, Aluminum, Oxygen and Carbon elements are present in 32 EW. It is observed that 6.77 wt% and 13.45 wt% of silicon, is present in 20EW & 32EW samples respectively, while other elements like aluminum is 2.87 wt.% & 5.60 wt.% and calcium is 4.76 wt% & 8.97 wt% in 20EW and 32 EW respectively. It can be observed that wt% of some elements are approximately twice in 32EW than 20EW.

3.3 Characterisation of Electrical Properties

It is well-known that dielectric and magnetic losses are mainly responsible for microwave absorption. The permittivity is the ability to polarise a material in the presence of electric field. It arises from the different types of polarisation like electronic, ionic, and orientation polarisation. Permittivity is largely dependent on the morphology and composition[19,20]. In this study, the real part (ε_r' and μ_r') and the imaginary part (ε_r'' and μ_r'') of complex permittivity and permeability of the prepared samples were extracted at room temperature with the help of reflection/

transmission method. The prepared pellets, as explained in the previous section, were used for the characterisation. The absolute relative permittivity and permeability of the prepared samples from 2 to 18 GHz frequency range are shown in Figs. 3(a-b). Using the Eqns (1-2), the reflection loss at a thickness of 1.5 mm is computed for all the samples and the results along with absorption percentage are shown in Figs. 3(c-d). It is evident from the results that composite materials have enhanced absorption properties and have a direct correlation with altered permittivity and permeability.

3.4 Material Selection using Genetic Algorithm

To design multilayer absorber, a genetic algorithm optimisation technique has been applied on the as-synthesised samples (Ref. Table 1) for optimisation of the number of layers, layer preferences, selection of material, and their thicknesses. The performance of the multilayer absorber is mainly evaluated from three aspects i.e., thickness of the absorber (3.5 mm), minimum reflectance, and the effective absorption bandwidth (RL≤ −10dB). Mishra[21], *et al.* explained the procedure for the optimisation of various multilayer parameters using genetic algorithm as shown by a flowchart in Fig. 4. The RL value of the multilayer absorber can be evaluated with the help of experimentally measured permittivity and permeability values of as-synthesised samples using Eqns (5-6).

For material selection, the variables consist of the type of material and its thickness are selected as per the number of layers required for multilayered MAM. The materials are varied among as-synthesised samples (Ref. Table 1) and their thicknesses have been varied from 0.1 to 3.0 mm. The dielectric and magnetic losses are calculated as shown in Fig. 5 for selected materials to analyse the absorption behaviour of the multilayered MAM. The dielectric loss tangent is the ratio of imaginary part and real part of complex relative permittivity ($\tan\delta_\varepsilon = \varepsilon_r''/\varepsilon_r'$) which arises due to the loss of polarisation of dipoles toward the electric field and magnetic loss tangent is the ratio of imaginary part and real part of complex relative permeability ($\tan\delta_\mu = \mu_r''/\mu_r'$) which is mainly due to hysteresis loss and eddy current. The plot of dielectric and magnetic loss tangent is shown in Fig. 5.

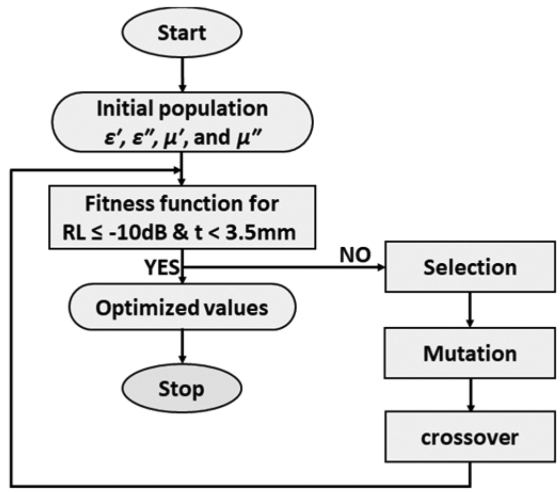


Figure 4. Flowchart of genetic algorithm for an optimal multilayer absorber.

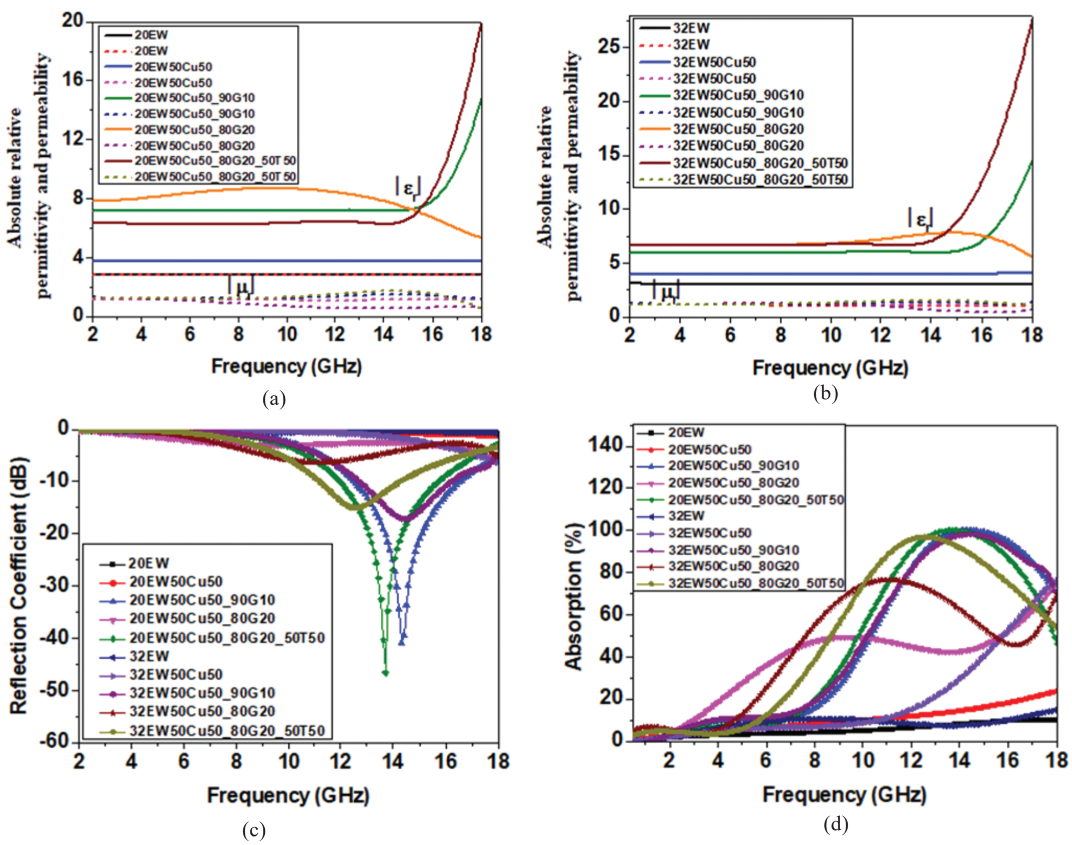


Figure 3. Absolute relative complex permittivity and permeability of (a) 20EW and its composites (b) 32EW and its composites, (c) reflection coefficient, and (d) absorption of all synthesised samples at thickness t = 1.5 mm.

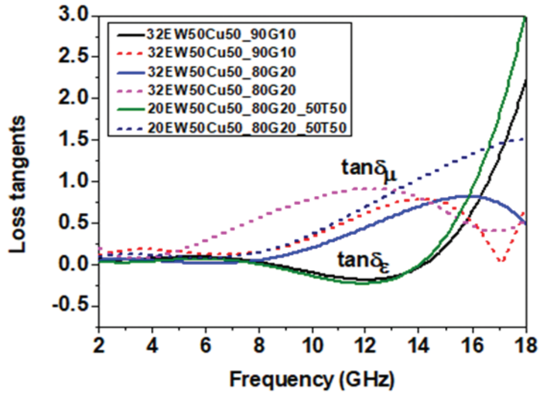


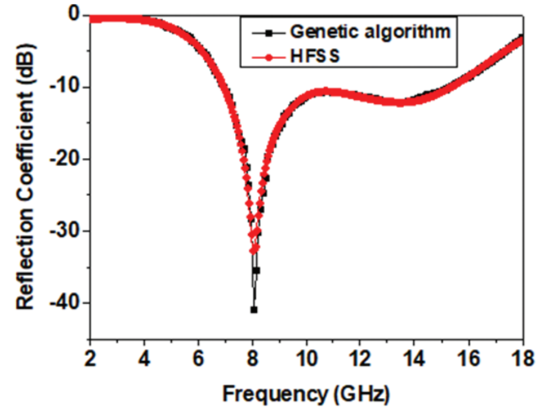
Figure 5. The Dielectric and magnetic loss tangent of selected samples.

The optimised results obtained by GA in terms of suitable choice of materials, their thicknesses, and layer preferences for three-layer microwave absorber are shown in Table 2. The layer sequence of the three-layer absorbing structure optimised by GA, considered 32EW50Cu50_90G10 for layer L1 (bottom layer), 32EW50Cu50_80G20 for layer L2 (middle layer), and 20EW50Cu50_80G20_50T50 for layer L3 (top layer).

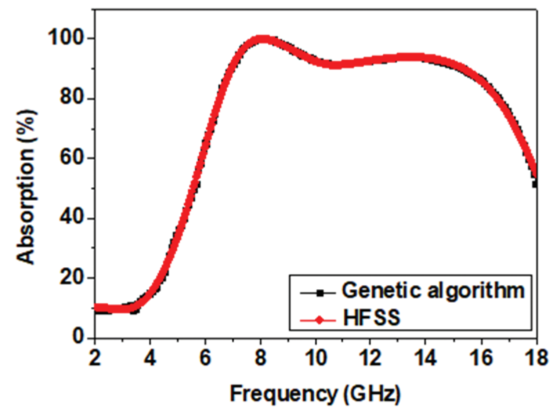
Table 2. Details of Multilayer MAM

Layers	Thickness (mm)	Materials
L1	t1=0.8	32EW50Cu50_90G10
L2	t2=1.8	32EW50Cu50_80G20
L3	t3=0.6	20EW50Cu50_80G20_50T50

Figure 6(a) shows the optimised reflection properties and Fig. 6(b) shows the absorption percentage of three-layer absorber obtained from GA- based approach and also as calculated using Eqns (5-6) in 2 to 18 GHz range. The three-layer absorber provides the value of RL is -32.8 dB at 8 GHz with the total coating thickness of 3.2 mm. Comparison of our work with some recently reported absorbers is illustrated in Table 3. Our results reveal that the E-waste exhibit outstanding EM wave absorbing performance in 6.92 to 15.39 GHz frequency range, which is of course more than that of the previously designed absorbers. Thus, it is beneficial to choose multi-layering technique to broaden the bandwidth of EM wave absorber.



(a)



(b)

Figure 6. (a) Reflection coefficient, and (b) Absorption of three-layer absorber using genetic algorithm and HFSS model.

3.5 Validation and Comparison

The design model of multilayer microwave absorber is shown in Fig. 7 and is validated using full wave simulation in HFSS. The model contains 3 layers of different composites: an upper layer (L3), a middle layer (L2), and a bottom layer (L1) with different thicknesses. The perfect electric conductor (PEC) is placed at the lower surface of the bottom layer so that there will be no transmission. To make the unit cell as an infinite periodic structure Master-Slave periodic boundary conditions are used and excitation is provided using Floquet port. The comparison between HFSS full wave simulation and the optimised result is shown in Fig. 6. The simulation results validate that the combination of L1, L2, and L3 give wideband absorption in the band from 6.92 to 15.39 GHz.

Table 3. List of EM wave absorption parameters of some recently designed Absorbers

Material	Coating thickness (mm)	RL_{min} (dB)	Absorption bandwidth (GHz) (RL< -10dB)	Refs.
A Single layer absorber using E-waste	2.5	-27.98	3.9	[9]
A Single layer absorber using NiO/Biomass Porous Carbon	8	-33.8	6.7	[22]
Single layer absorber using $Ti_3C_2T_x$/CNZF Composites	4.2	-58.4	2.2	[23]
Four-layer absorber using thermoplastic polyurethane/carbon based composite	4.8	-33.9	6.43	[24]
Three-layer absorber using composites of E-waste	3.2	-32.8	8.47	This study

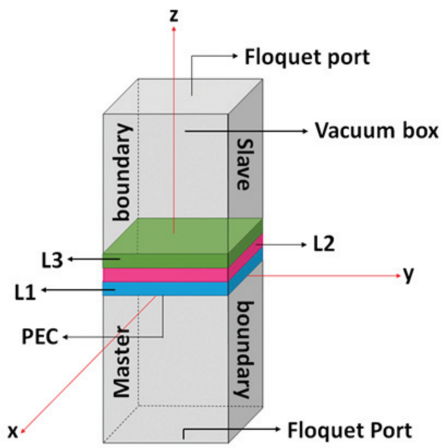


Figure 7. HFSS simulation model.

4. CONCLUSIONS

The synthesis and characterisation of E-waste based composite MAM has been explained in detail. The results showed that the value of RL is -32.8 dB at 8 GHz frequency and wide bandwidth from 6.92 to 15.39 GHz with the layer thickness of 3.2 mm. The study also showed that the proper amount of copper, graphite, and titanium dioxide in E-waste works as a composite candidate material for wideband microwave absorption. The proposed cost-effective material is useful in many practical EM applications.

REFERENCES

1. Gill, N.; Singh, J.; Puthucheri, S. & Singh, D. Thin and Broadband Two-Layer Microwave Absorber in 4–12 GHz with Developed Flaky Cobalt Material. *Electron. Mater. Lett.,* 2018, **14**(3), 288–297. doi: 10.1007/s13391-018-0025-2
2. Wei, Y.; Liu, H.; Liu, S.; Zhang, M.; Shi, Y.; Zhang, J.; Zhang, L. & Gong, C. Waste cotton-derived magnetic porous carbon for high-efficiency microwave absorption. *Composites Communication,* 2018, 9, 70–75. doi: 10.1016/j.coco.2018.06.007
3. Zhang, F. W.; Zhu, W.; Cheng, B.; Qiu, H. & Qi, S. Core-shell nanostructured CS/MoS2: A promising material for microwave absorption. *Appl. Surf. Sci*, 2019, 463, 182–189. doi: 10.1016/j.apsusc.2018.08.121
4. Lan, D.; Qin, M.; Yang, R.; Chen, S.; Wu, H.; Fan, Y.; Fu, Q. & Zhang, F. Facile synthesis of hierarchical chrysanthemum-like copper cobaltate-copper oxide composites for enhanced microwave absorption performance. *J. Colloid Interface Sci.*, 2019, **533**, 481–49. doi: 10.1016/j.jcis.2018.08.108
5. Bora, P. J.; Porwal, M.; Vinoy, K. J.; Kishore; Ramamurthy, P. C. & Madras, G. Industrial waste fly ash cenosphere composites based broad band microwave absorber. *Compos. B. Eng.*, 2018, **134**, 151–163. doi: 10.1016/j.compositesb.2017.09.062
6. Yah, N. F. N.; Rahim, H. A.; Lee, Y. S.; Wee, F. H. & Zainal, H. H. Electromagnetic Wave Absorption Properties of Novel Green Composites Coconut Fiber Coir and Charcoal Powder over X-band Frequency for Electromagnetic Wave Absorbing Applications. *Advanced Electromagnetics*, 2018, **7**(1), 13–18. doi: 10.7716/aem.v7i1.598
7. Zhao, H.; Cheng, Y.; Ma, J.; Zhang, Y.; Ji, G. & Du, Y. A sustainable route from biomass cotton to construct lightweight and high-performance microwave absorber. *Chem. Eng. J.*, 2018, **339**, 432–441. doi: 10.1016/j.cej.2018.01.151
8. Guan, H.; Wang, H.; Zhang, Y.; Dong, C.; Chen, G.; Wang, Y. & Xie, J. Microwave absorption performance of Ni(OH)2 decorating biomass carbon composites from Jackfruit peel. *Appl. Surf. Sci.*, 2018, 447, 261–268. doi: 10.1016/j.apsusc.2018.03.225
9. Panwar, R.; Agarwala, V. & Singh, D. A cost effective solution for development of broadband radar absorbing material using electronic waste. *Ceramics International*, 2015, **41**(2), 2923–2930. doi: 10.1016/j.ceramint.2014.10.118
10. Marques, A. C.; Cabrera, J. M. & Malfatti, C. F. Printed circuit boards: A review on the perspective of sustainability. *J. Environ. Manage.* 2013, 131, 298–306. doi: 10.1016/j.jenvman.2013.10.003
11. Padhy, S.; De, A.; Debata, R. R. & Meena, R. S. Design, Characterization, and Optimization of a Multilayer U-type Hexaferrite-Based Broadband Microwave Absorber. *IEEE Trans. Electromagn. Compat.*, 2018, **60**(6), 1734–1742. doi: 10.1109/TEMC.2018.2805364
12. Panwar, R.; Puthucheri, S; Singh, D. & Agarwala, V. Design of Ferrite–Graphene-Based thin broadband radar wave absorber for stealth application. *IEEE Trans. Magn.*, 2015, **51**(11), 2802804. doi: 10.1109/TMAG.2015.2454431
13. Zhang, X.; Qiao, J.; Liu, C.; Wang, F.; Jiang, Y.; Cui, P.; Wang, q.; Wang, Z.; Wu, L. & Liu, J. A MOF-derived ZrO_2/C nanocomposite for efficient electromagnetic wave absorption. *Inorg. Chem. Front.*, 2020, **7**(2), 385-393. doi: 10.1039/c9qi01259a
14. Khani, O.; Shoushtari, M. Z.; Ackland, K. & Stamenov, P. The structural, magnetic and microwave properties of spherical and flake shaped carbonyl iron particles as thin multilayer microwave absorbers. *J. Magn. Magn. Mater.,* 2017, **428**, 28–35. doi: 10.1016/j.jmmm.2016.12.010
15. Rani, S.; Marwaha, A.; Marwaha, S.; Bindra, S.; Chavali M. & Reddy, P. N. Characterization and measurement of nanostructured copper-based electromagnetic wave absorber. *Electromagnetics*, 2020, **40**(5), 313-321. doi: 10.1080/02726343.2020.178037
16. Ansari, A. & Akhtar, M.J. Co/graphite based light weight microwave absorber for electromagnetic shielding and stealth applications. *Mater. Res. Express*, 2017, **4**, 016304. doi: 10.1088/2053-1591/aa570c
17. Das, S.; Nayak, G.C.; Sahu, S.K.; Routray, P.C.; Roy, A.K. & Baskey, H. Microwave absorption properties of double-layer composites using CoZn/NiZn/MnZn-ferrite and titanium dioxide. *J. Magn. Magn. Mater.*, 2015, **377**, 111–116.

doi: 10.1016/j.jmmm.2014.10.059

18. Kumar, N. & Somay, S. Multiwall carbon nanotube enhance the invisibility effect from radar *Results Phys.*, 2020, **18**, 103171.
doi: 10.1016/j.rinp.2020.103171
19. Jia, Z.; Lan, D.; Lin, K.; Qin, M.; Kou, K.; Wu, G. & Wu, H. Progress in low-frequency microwave absorbing materials. *J. Mater. Sci. Mater. Electron.* 2018, **29**, 17122–17136.
doi: 10.1007/s10854-018-9909-z
20. Hou, T.; Wang, B.; Jia, Z.; Wu, H.; Lan, D; Huang, Z.; Feng, A.; Ma, M. & Wu, G. A review of metal oxide-related microwave absorbing materials from the dimension and morphology perspective," *J. Mater. Sci. Mater. Electron.,* 2019, **30**, 10961–10984.
doi: 10.1007/s10854-019-01537-0.
21. Mishra, V.; Puthucheri, S. & Singh, D. Development of Analytical Approach to Fabricate Composites for Microwave Absorption *IEEE Trans. Magn.*, 2017, **53**(8), 1–10.
doi: 10.1109/TMAG.2017.2698401.
22. Wang, H.; Zhang, Y.; Wang, Q.; Jia, C.; Cai,P.; Chen, G.; Dong, C. & Guan, H. Biomass carbon derived from pine nut shells decorated with NiO nanoflakes for enhanced microwave absorption properties. *RSC Adv.*, 2019, **9**, 9126-9135.
doi: 10.1039/c9ra00466a
23. Liu, P.; Yao, Z.; Ng, V.M.H.; Zhou J. & Kong, L. B. Novel Multilayer-like structure of $Ti_3C_2T_x$/CNZF Composites for Low-Frequency Electromagnetic Absorption. *Materials Letters,* 2019, **248**, 214-217.
doi: 10.1016/j.matlet.2019.04.042
24. Kasgoz, A.; Korkmaz, M. & Durmus, A. Compositional and structural design of thermoplastic polyurethane/carbon based single and multi-layer composite sheets for high-performance X-band microwave absorbing applications. *Polymer Journal,* 2019, **180**, 121672.
doi:10.1016/j.polymer.2019.121672

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CONTRIBUTORS

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In the current study, she conceived the idea of current study and methodology, performed the experimental work, collected the data, simulated the results and analysed the data.

Dr Naina Narang, completed her PhD in 2017 from CSIR National Physical Laboratory, New Delhi and thereafter worked as Assistant Professor at Department of Computer and Communication Engineering, Manipal University Jaipur, India for one year and nine months. Presently, she is carrying out her post-doctoral research work in Department of ECE at IIT Roorkee. Her research area includes automated instrument control, simulation techniques and computational electromagnetics.
In the current study, she contributions include: numerical explanation along with the original draft preparation.

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