Design Optimization of Triple Layer Microwave Absorber Based on Expanded Graphite - Phenolic Resin Composites for X-band Applications

Jyoti Prasad Gogoi
Dept. of Physics, Kaziranga University
Nidhi Saxena Bhattacharyya
Dept. of Physics, Tezpur University
Anup Kr. Bordoloi
Det. of CS&E, USTM

Abstract

In this present work, transmission line model is used to design triple layer microwave absorbers with developed Expanded Graphite (EG) – Novolac Phenolic Resin (NPR) composites having 5 wt. %, 7 wt. %, 8 wt. % and 10 wt. %. The EG-NPR composites of 5 wt. %, 7 wt. %, 8 wt. % and 10 wt. % are designated as **A, B, C** and **D,** respectively for design convenience. Optimization of composite layer arrangement and individual layer thickness is carried out to achieve minimum value of reflection loss (dB) and a broad microwave absorption bandwidth. The thickness of the absorber ***d*** is varied in the range 3 to 5.4 mm following Rozanov theoretical limit for a broadband response for multilayer absorber structure. Triple layer design combinations with total thickness viz. BCA_3.4, CDB_3.1 and BDC_3.1 show -25dB absorption bandwidth of 2.21 GHz, 2.24 GHz and 2.75 GHz respectively and the -30dB absorption bandwidth for the same layer combinations as 1.53 GHz, 1.46 GHz and 2.34 GHz respectively. The maximum absorption peak or minimum value of RL_m are obtained for BCA_3.4 is -66dB at 12.23 GHz, for CDB_3.1 is -57 dB at 9.7 GHz and for BDC_3.1 is -66 dB at 11.1GHz.

***Keywords*:** Microwave absorber, Expanded graphite, Transmission line model, Reflection loss.

Introduction

Proliferation of wireless communication systems with increasing stride towards gigahertz frequencies range enhance Electromagnetic Interference (EMI) affecting electronic control systems in airplanes, Television, mobile, data transmission, malfunction of biomedical equipments, target error in military warfare etc.,[1]. X-band frequency range finds applications in terrestrial communication and networking (10.15 to 10.7 GHz), military communication satellites (7.9 to 8.4 GHz for uplink & 7.25 to 7.75 GHz for downlink), weather radars (9.3-9.5 GHz), medical sciences, motion detectors (10.525 GHz) etc. [2-6]. To ensure electromagnetic compatibility for electronic equipment from EMI of these frequencies, proper shielding mechanism is required. Microwave absorbers with broadband absorption capacity are of high demand to cover a broad frequency range of unwanted signals. To develop a microwave absorber, selection of material with proper microwave characteristics and optimized design configuration is most crucial part.

The authors in their previous work reported that expanded graphite (EG)-Novolac Phenolic Resin (NPR) of 5 wt. %, 7 wt. %, 8 wt. % and 10 wt. %, showed a wide bandwidth of -10 dB absorption in the X-band frequency range [7]. Also, the absorption frequency ranges can be shifted by nearly changing the wt % of EG.

In this endeavor, three layer microwave absorbers are design with the developed EG-NPR composite (5 wt. %, 7 wt. %, 8 wt. % and 10 wt. %,) layer arrangements and their thickness variation keeping the over three layer thickness fixed. Employing transmission line model, the reflection loss of the designed absorbers is calculated as a function of frequency and estimated the absorption bandwidth range for -25dB and -30dB.

Design And Thickness Optimization Of Triple Layered Absorber

A three layer EG-NPR composite dielectric absorber is designed in which the composition and layer thickness is optimized to get the best performance. The schematic diagram of a conductor backed triple layer absorber consists of EG-NPR composite layers having intrinsic parameters $\varepsilon_{r1}, \mu_{r1}, \eta_1, \gamma_1, d_1$ for the layer 1 in vicinity to the metal plate, layer 2 with intrinsic parameters $\varepsilon_{r2}, \mu_{r2}, \eta_2, \gamma_{2,}, d_2$ as sandwiched layer and $\varepsilon_{r3}, \mu_{r3}, \eta_3, \gamma_{3,}, d_3$ parameters for the front-facing layer-3 with the free space as shown in figure 1.

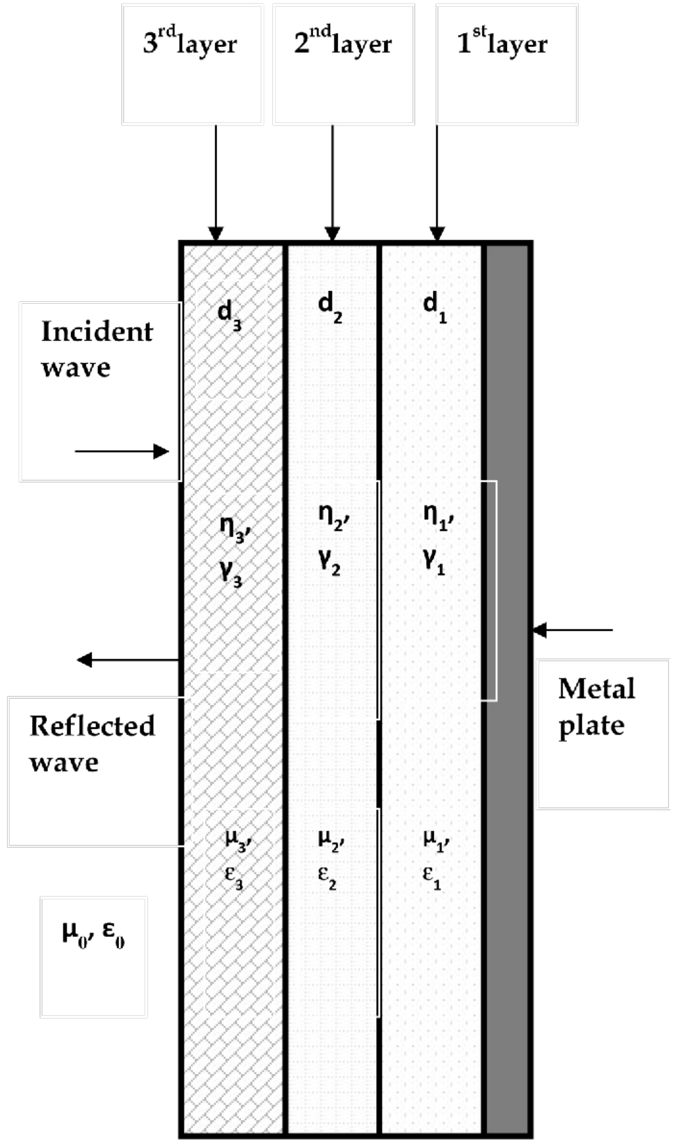

Figure 1: A schematic diagram of EG-NPR graded triple layer absorber

The nonmagnetic characteristics of the composites, renders the complex permeability $\mu_{r1} = \mu_{r2} = \mu_{r3} = 1 - j0$.

The input impedance, Z_{in}, and computed reflection loss, RL_c, are determined from the conductor backed triple layer absorber discussed [8] and for the dielectric absorber reduces to

$$Z_3 = \eta_3 \frac{\eta_2 \frac{\eta_1 \tanh\gamma_1 d_1 + \eta_2 \tanh\gamma_2 d_2}{\eta_2 + \eta_1 \tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2)} + \eta_3 \tanh\gamma_3 d_3}{\eta_3 + \eta_2 \frac{\eta_1 \tanh\gamma_1 d_1 + \eta_2 \tanh\gamma_2 d_2}{\eta_2 + \eta_1 \tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2)} \tanh\gamma_3 d_3} \quad (1)$$

$$RL_c = 20\log\left| \frac{\eta_3 \frac{\eta_2 \frac{\eta_1 \tanh\gamma_1 d_1 + \eta_2 \tanh\gamma_2 d_2}{\eta_2 + \eta_1 \tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2)} + \eta_3 \tanh\gamma_3 d_3}{\eta_3 + \eta_2 \frac{\eta_1 \tanh\gamma_1 d_1 + \eta_2 \tanh\gamma_2 d_2}{\eta_2 + \eta_1 \tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2)} \tanh\gamma_3 d_3} - \eta_0}{\eta_3 \frac{\eta_2 \frac{\eta_1 \tanh\gamma_1 d_1 + \eta_2 \tanh\gamma_2 d_2}{\eta_2 + \eta_1 \tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2)} + \eta_3 \tanh\gamma_3 d_3}{\eta_3 + \eta_2 \frac{\eta_1 \tanh\gamma_1 d_1 + \eta_2 \tanh\gamma_2 d_2}{\eta_2 + \eta_1 \tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2)} \tanh\gamma_3 d_3} + \eta_0} \right| \quad (2)$$

where $\eta_1 = \eta_0 \sqrt{1 / \varepsilon_{r1}}$ (3)

$$\eta_2 = \eta_0 \sqrt{1 / \varepsilon_{r2}} \quad (4)$$

$$\eta_3 = \eta_0 \sqrt{1 / \varepsilon_{r3}} \quad (5)$$

$$\gamma_1 = j(2\pi f / c)\sqrt{\varepsilon_{r3}} \quad (6)$$

$$\gamma_2 = j(2\pi f / c)\sqrt{\varepsilon_{r3}} \quad (7)$$

$$\gamma_3 = j(2\pi f / c)\sqrt{\varepsilon_{r3}} \quad (8)$$

From the above equations, it is seen that RL_c value of the absorber depends on frequency dependent complex permittivity, $\varepsilon_{r1}, \varepsilon_{r2}, \varepsilon_{r3}$ and the thickness of the individual layers, d_1, d_2, d_3. The minimum RL_c value is achieved by optimization of effective intrinsic properties of the three layers and the thickness. For the three layer design, the four material compositions of 5 wt. %, 7 wt. %, 8 wt. % and 10 wt. % EG-NPR composites are considered and designated **A**, **B**, **C** and **D**, respectively. The three layers combination of fixed thickness, d, is considered at a time, for example if, 5 wt. % is assigned to layer 1, 7 wt. % is assigned to layer 2 and 8 wt. % assigned to layer 3, the combination is termed as **ABC** and the corresponding layer thickness as d_1, d_2 and d_3 so that $d = d_1 + d_2 + d_3$. A MATLAB program is developed based on the equations 1 to 8 to optimize the layer thickness for the triple layer absorber and finds the minimum RL_c for the following combinations tabulated in table 1.Following Rozanov theoretical limit [9] for a broadband response for multilayer absorber structure the total thickness of the absorber is varied from 3mm to 5.4mm at a step size of 0.5mm in order to find the required bandwidth of absorption. The program is executed for one particular total thickness range say 3mm to 3.4mm and then finds the combination of individual thickness d_1, d_2 and d_3 to calculate the minimum RL_m and maximum absorption bandwidth over the range.

Table 1: EG-NPR composites triple layer design combinations

Air-absorber Interface layer	**Sample code I-II-III layer**	**Sample wt. % combination (I-II-III layer)**
A-interface	**BDA**	**7-10-5 wt. %**
	BCA	**7-8-5 wt. %**
	CDA	**8-10-5 wt. %**
	CBA	**8-7-5 wt. %**
	DCA	**10-8-5 wt. %**
	DBA	**10-7-5 wt. %**
B-interface	**ADB**	**5-10-7 wt. %**
	ACB	**5-8-7 wt. %**
	CAB	**8-5-7 wt. %**
	CDB	**8-10-7 wt. %**
	DAB	**10-5-7 wt. %**
	DCB	**10-8-7 wt. %**
	ABC	**5-7-8 wt. %**

C-interface	**ADC**	**5-10-8 wt. %**
	BAC	**7-5-8 wt. %**
	BDC	**7-10-8 wt. %**
	DAC	**10-5-8 wt. %**
	DBC	**10-7-8 wt. %**
D-interface	**ACD**	**5-8-10 wt. %**
	ABD	**5-7-10 wt. %**
	BCD	**7-8-10 wt. %**
	BAD	**7-5-10 wt. %**
	CBD	**8-7-10 wt. %**
	CAD	**8-5-10 wt. %**

The minimum thickness of the individual layer is fixed at 0.5mm for ease of practical fabrication of the absorber.

Results And Discussion

Calculated reflection loss of the design absorbers are tabulated in table 2**.** From this table the best design combinations**BCA_3.4**, **CDB_3.1** and **BDC_3.1** show -25dB absorption bandwidth of 2.21 GHz, 2.24 GHz and 2.75 GHz respectively and the -30dB absorption bandwidth for the same layer combinations as 1.53 GHz, 1.46 GHz and 2.34 GHz respectively. The maximum absorption peak or minimum value of RLm are obtained for **BCA_3.4** is -66dB at 12.23 GHz, for **CDB_3.1** is -57 dB at 9.7 GHz and for **BDC_3.1** is -66 dB at 11.1GHz. The graphical representation of these combinations is given in fig 2. Thus, the design optimization of EG-NPR layer arrangement and thickness of individual layer gives broadband microwave absorption.

Table 2: Different combinations of triple layer design with RL_c<-40dB, -25dB and -30dB bandwidth > 1 GHz

Air-absorber Interface layer	**Layer combination with total thickness**	**Thickness of individual layer (mm)**			**Bandwidth in (GHz)**		**Maximum absorption with corresponding frequency**	
		d_1	d_2	d_3	-25 dB	-30 dB	$RL_{c\,min}$(dB)	f_0 (GHz)
A-interface	BCA_3.4	0.54	1.96	0.9	2.21	1.53	-66	12.3
	CBA_3.4	2.19	0.51	0.7	1.92	1.4	-61	12.2
B-interface	ADB_3.1	0.52	2.05	0.53	2.25	1.45	-57	9.7
	ADB_3.5	0.5	0.6	2.4	1.01	0.72	-43	11.9
	CAB_3.4	2.2	0.7	0.5	1.8	1.5	-57	12.3
	CDB_3.1	0.56	2.04	0.5	2.24	1.46	-57	9.7
	CDB_3.5	0.5	0.54	2.46	1.06	0.72	-46	11.92
C-interface	ABC_3.2	0.52	0.52	2.16	2.7	2.28	-70	11.1
	ADC_3.1	0.52	0.61	1.97	2.66	2.28	-63	11.2
	BAC_3.2	0.53	0.51	2.16	2.68	2.22	-66	11.1
	BDC_3.1	0.5	0.64	1.96	2.75	2.34	-67	11.11
	DAC_3.2	0.51	0.52	2.17	2.72	2.26	-65	11..09
	DBC_3.2	0.54	0.51	2.15	2.83	2	-71	11.09
B-interface	ABD_3.0	0.89	0.54	1.57	2.02	1.33	-56.9	9.67
	ACD_3.0	1	0.53	1.47	2.1	1.37	-55.7	9.66
	BAD_3.0	0.53	0.8	1.67	1.99	1.32	-56.99	9.64
	BCD_3.0	1.06	0.5	1.44	2.12	1.38	-55.26	9.66
	CAD_3.0	0.59	0.75	1.66	1.98	1.32	-56	9.67
	CBD_3.0	0.53	0.9	1.57	2.14	1.37	-56.7	9.67

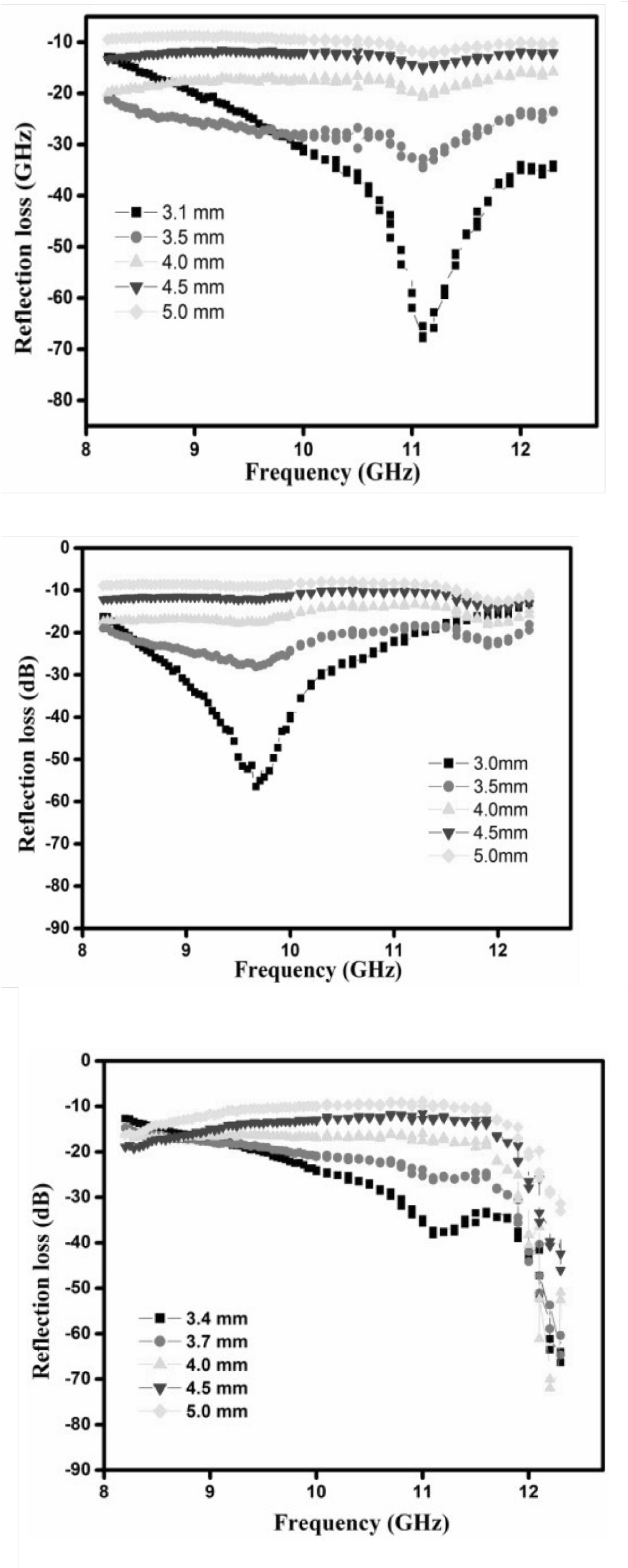

Figure 2: Calculated reflection loss value of designated BCA, CDB, and BDC triple layer absorbers

Conclusion

This paper presents a triple layer microwave absorber design composed of EG-NPR composites for application in the X-band frequency. Optimization of composite layer arrangement and individual layer thickness is carried out to achieve a broadband absorption. The triple layer design structures show -25dB and -30dB absorption bandwidth greater than 2GHz and 1GHz. As tabulated in Table 2, particular combination of absorber can be used for specific frequency application in X-band considering the minimum reflection loss peak at the desired frequency

References

1. Tong, X. C., (2009). Advance Materials and Design for Electromagnetic Interference Shielding, Taylor and Francis, London.

2. Huang, Y., Li, N., Ma, Y., Du, F., Li, F., He, X., Lin, X., Gao, H., & Chen, Y., (2007). The influence of single-walled carbon nanotube structure on the electromagnetic interference shielding efficiency of its epoxy composites, Carbon vol. 48, pp. 1614-1621.

3. Hanna, S. M., (1999) Applications of x-band technology in medical accelerators, in Proceedings of the 1999 Particle Accelerator Conference, New York.

4. Damini, A., McDonald, M., & Haslam, G. E., (2003). X-band wideband experimental airborne radar for SAR, GMTI and maritime surveillance, IEEE., Proc.-Radar Sonar Navig. vol. 150, pp. 305-312.

5. Jung, E. Y., Lee, J. W., Lee, T. K., & Lee, W. K., (2012). SIW-based array antennas with sequential

feeding for X-band satellite communication, IEEE Transactions on Antennas and Propagation, vol. 60, pp. 3632-3639.

6. Chu, C. K., Huang, H. K., Liu, H. Z., Lin, C. H., Chang, C.H., Wu, C.L., Chang, C. S., & Wang, Y. H., (2008). An X-band high-power and high-PAE PHEMT MMIC power amplifier for pulse and CW operation, IEEE Microw. Wirel. Compon. Lett. vol. 18, pp. 707–709.

7. Gogoi, J. P., Bhattacharyya, N. S., & Bhattacharyya, S., (2014). Compos. Part B. Eng. vol. 58, pp. 518.

8. Qin, F., & Brosseau, C., (2012). J. Appl. Phys. 111, 061301.

9. Rozanov, N..K.., IEEE. Trans. Antenn. Propag. vol.. 48, 2000, pp.1230.