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An Analytical Approach to Design Camouflage Net for Microwave Absorption

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ABSTRACT

Microwave absorption has been the key for reduction of radar cross section in the field of stealth technology. In this field, hiding troop details from reconnaissance systems is taken care by enhancing the absorption properties of the material. The demand of masking detectable equipment can be met with the help of a flexible net type structure called camouflage net. Optimising and measuring the absorption of the net, comprising of cloth and coating of the radar absorbing materials over the cloth is a very challenging task. This task is usually being accomplished by using trial and error method, which is a very cumbersome process and leads to tremendous waste of potential, material and manpower. Therefore, an attempt to develop an analytical methodology using the permittivity and permeability of the fabric material, to minimise this limitation, has been presented in this paper by critically analysing simulated results for various composites. The proposed approach seems to have a good potential for developing the camouflage net, especially in the microwave regime.

Keywords: Radar absorbing materials; Camouflage; Mixing model

1. INTRODUCTION

Stealth technology deals with the deception of target from being detected and camouflage is a measure for degree of nullifying the accuracy and prediction of sensors, by hiding the details from it, which are being used to locate and identify the target. The frequency spectrums such as thermal, ultraviolet and microwave have been exploited for the use of detection technique. Though all these spectrums have their own merits and demerits but microwave has proved itself deadly for the detection of combat equipment. Radar cross section (RCS) area of the target is used as the parameter which is taken as the reference for the measurement of detectability with the help of microwave sensors. To avoid this detection of the target and making it invincible, geometry shaping and coating of radar absorbing materials (RAM) on the metallic surface of the target have been constantly studied to minimise its RCS, i.e., radar signature. Variation in structural design is primarily focused with the aim to improve its aerodynamic shape for manoeuvres and stability instead of scattering. Hence, geometry shaping faces the constraint in RCS reduction. Requirement of broadband absorption, instead of scattering of the incident radar waves, lead to the development of RAM[1]. Different types of RAM which have been scrutinised till date are graded interface for impedance matching, resonant materials, circuit analog RAM, magnetic RAM and adaptive RAM[2,3]. The effectiveness of RAM is analysed in terms of impedance matching at the interface of the two media, for smooth and complete transfer of the EM power between the materials [4].

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In current scenario, prime focus has been on the method of coating/printing RAM on the reflecting surface of the equipment, which is a very cumbersome process. Hence, the need of a flexible fabric type material was felt and the same has been fulfilled by the textile industry. This flexible fabric type net (camouflage) is being used as the cover for the metal targets to minimise their RCS and making them safer from the eye of the radar. It has been observed from literature that for the designing and fabrication of the camouflage net, various knowledge based material and fabrics are used and then a struggle with trial and error method for the optimisation of absorption in the camouflage type fabric is faced by the scholars[5]. This constraint of trial and error method for achieving required absorption, leads to tremendous waste of potential, material and manpower, which is very critical in textile industry and is making the process incommodious. Therefore, a dire need to develop an analytical methodology to minimise this current limitation has been observed.

To minimise this constraint of empirical analysis, in this paper, we are trying the analytical approach for camouflage development. Instead of using empirical model to calculate the absorption of final camouflage net, we have tried using mixing model technique for the calculation of effective permittivity and permeability values of the composite. In the aforementioned mixing model, cloth fabric has been taken as the base material and a combination of ferrite, cobalt and aluminium fillers (covering different frequency bands), has been used as doped materials to meet specific absorption characteristics. This in turn has been used for the calculation and analysis of absorption property of the camouflage net. A flow chart of the study is as depicted in the Fig. 1.

A look up table consisting of various materials to be

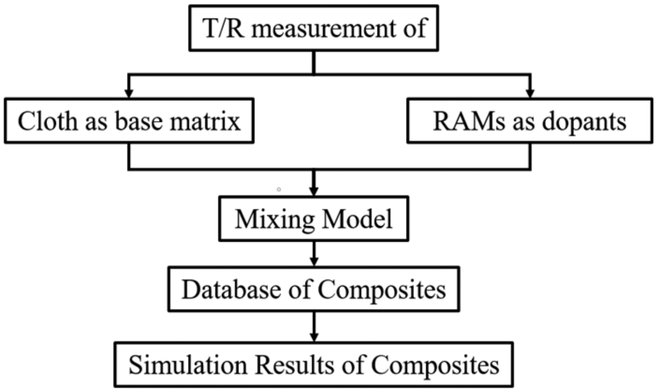

Figure 1. Flow chart of the study.

used for the dopants inside the fabric has been included and their corresponding absorption, transmission has also been presented. The main aim of look up table is that the required composition can be used for obtaining the end product specification.

2. METHODOLOGY

Two important factors playing the key role in the design of the camouflage net are cloth (working as base fabric) and radar absorbing material (to be applied over the cloth for doping). Absorption depends on tangent loss of the materials; hence tangent loss calculation of the camouflage net can lead to the determination of the amount of loss occurring. The task of obtaining electromagnetic properties of the camouflage with the help of empirical method can be a tedious process as it can be measured only after the complete fabrication of the net. Hence, the current study deals with the concept of mixing model for the former task. Effective permittivity and permeability has been calculated with the help of formula given as [6]

$$\varepsilon_{eff} = \varepsilon_b + \frac{\frac{1}{3}\sum_{i=1}^{n} D_{vf}\left(\varepsilon_d - \varepsilon_b\right)\sum_{k=1}^{3}\frac{\varepsilon_b}{\varepsilon_b + N_{ik}\left(\varepsilon_d - \varepsilon_b\right)}}{1 - \frac{1}{3}\sum_{i=1}^{n} D_{vf}\left(\varepsilon_d - \varepsilon_b\right)\sum_{k=1}^{3}\frac{N_{ik}}{\varepsilon_b + N_{ik}\left(\varepsilon_d - \varepsilon_b\right)}} \quad (1)$$

$$\mu_{eff} = \mu_b + \frac{\frac{1}{3}\sum_{i=1}^{n} D_{vf}\left(\mu_d - \mu_b\right)\sum_{k=1}^{3}\frac{\mu_b}{\mu_b + N_{ik}\left(\mu_d - \mu_b\right)}}{1 - \frac{1}{3}\sum_{i=1}^{n} D_{vf}\left(\mu_d - \mu_b\right)\sum_{k=1}^{3}\frac{N_{ik}}{\mu_b + N_{ik}\left(\mu_d - \mu_b\right)}} \quad (2)$$

where, ε_d and ε_b are the permittivity of the dopant and base materials respectively, μ_d and μ_b are the permeability of the dopant and base materials respectively, D_{vf} is the doping volume fraction (ratio of volume of dopants to total effective volume of the composite). n is total no of dopants in the base (here, n=1 has been taken in the current study as there is only one doping material during the formation of composite). N_{ik} is the depolarisation factor of i^{th} dopant material corresponding to k^{th} spatial dimension[7].

EM properties measurement of the cloth as base material has been carried out with the help of free space transmission/reflection method and measurement of RAMs as guest materials, with the help of using coaxial T/R method. In both the cases, Nicolson Ross method has been used for the calculation of their EM properties from measured scattering parameters[8]. All the measurements are carried with Vector network analyser (N5222A, 10MHz-26.5GHz). EM properties of few selected materials have been presented as in Fig. 2. The doped materials with various doping volume fractions have been used to create the initial database of 13×9 mixed materials.

Required characteristic of the camouflage material can be fulfilled by doping of adequate combination of absorbing materials as fillers, impregnated on the cloth fabric matrix which is behaving as base material. Mixing model has been used to avail the required changes in the electric properties of the materials. The mixing model formulated for homogeneous doping in the base which has been verified with different mixing model theories over the period of time [6,7]. Along with absorption, the need of flexibility and portability of the RAMs in accordance with the terrain lead to the use of fabrics comprising of materials which proves to be a thin product for military and civil purposes. There has been comprehensive research with the focus of the fabrics to be taken as the solution for the flexibility and mobility of the RAM[9].

In the current paper, the concept of mixing highly absorbing materials, showing absorption at individual frequency bands, has been used with the help of mixing model concept. To test the applied methodology, some materials from our material database, with good absorption at different frequency regime, have been taken and are as tabulated in Table 1. The coding has been taken as per their respective absorption frequency and these selected materials have been taken as dopants. The doping fraction of the dopant to composite has been varied from 0.1 to 0.9, making it a combination of total 117 composite materials to be used as absorption fabric for the lookup table. The composite which will be fabricated at the end of the study will be acting as a single layer material, its reflection and transmission has been calculated using[4]

$$\Gamma_{in} = \frac{E^r}{E^i} = \frac{(1-Z_{12})(1+Z_{23}) + (1+Z_{12})(1-Z_{23})e^{-2\gamma_2 d}}{(1+Z_{12})(1+Z_{23}) + (1-Z_{12})(1-Z_{23})e^{-2\gamma_2 d}} \quad (3)$$

$$T = \frac{E^t}{E^i} = \frac{4}{(1-Z_{12})(1-Z_{23})e^{-\gamma_2 d} + (1+Z_{12})(1+Z_{23})e^{\gamma_2 d}} \quad (4)$$

where, $Z_{ij} = \frac{\mu_i \gamma_j}{\mu_j \gamma_i}$ $i, j = 1,2,3$ and $\gamma_k = \pm\sqrt{j\omega\mu_k(\sigma_k + j\omega\varepsilon_k)}$

and absorption of the layer can be calculated from[10]

$$A = 1 - \left|S_{11}\right|^2 - \left|S_{21}\right|^2 \quad (5)$$

The transmission loss of the composite layer has been taken as the analysing parameter and simulated results have been presented in the following section.

3. IMPLEMENTATION AND SIMULATED RESULTS

Individual materials to be used as base as well as dopants have been measured as RAM for the thickness of 0.5 mm, 1 mm, 1.5 mm and 2 mm. Data of base material absorbance, corresponding to 2 mm thickness, and respective resonant frequency has been presented in Table 1. This will be used for guiding the user, so that appropriate material can be selected as base with its maximum absorption at required resonant frequency.

Cloth as base material has been impregnated with RAMs

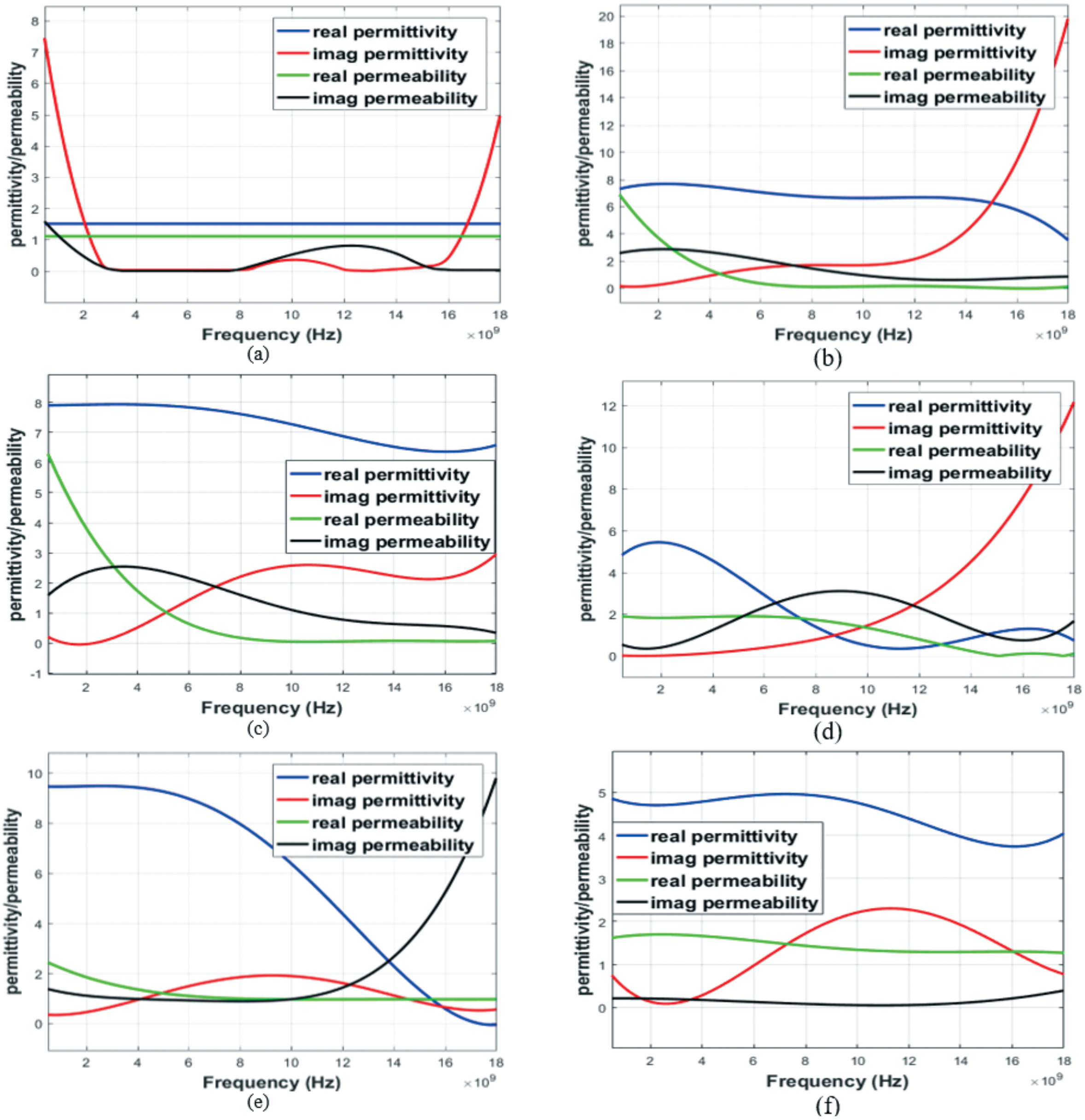

Figure 2. Permittivity and permeability of (a) cloth (M1) as base material, (b) M2, (c) M3, (d) M4, (e) M5 and (f) M6 as few selected dopant materials.

Table 1. Lookup table of base materials that can be used as dopants corresponding to required resonant frequency

Dopants code	Resonant frequency (GHz)	Maximum absorption (percentage)
M2	7.15 and 15.9	56.6 and 62.5
M3	8.2	60.2
M4	12.58	92
M5	14.23	85.7
M6	18	51.8

of doping fraction varying from 0.1 to 0.9 with a step size of 0.1. A database of 13×9 composite and 14 base materials has been prepared with the help of mixing model. The look up table leads to selection of specific base material or a combination of materials as per the required end product specifications. Effective dielectric values of each layer has been calculated with the help of (1) and (2).

The results of five dopants have been presented in current study at the thickness of 2 mm corresponding to different doping. On the observation of the results, it can be clearly inferred that as level of doping increasing, RL of the composite is also increasing correspondingly. This is obvious as the increase in doping level contributes to more no. of doping particles per unit volume, which in turn will enhance the dielectric losses[11,12]. Although the use of base is compromising the transmission yet it is a necessary devil as the aim over here is providing a camouflage net. Figure 3 depicts the minimised transmission corresponding to various frequency regimes as per their dependency on material being used as dopants. This dependency is due to oscillation of atoms of the dopants[2] and hence directly related to resonant frequency of the dopant particle.

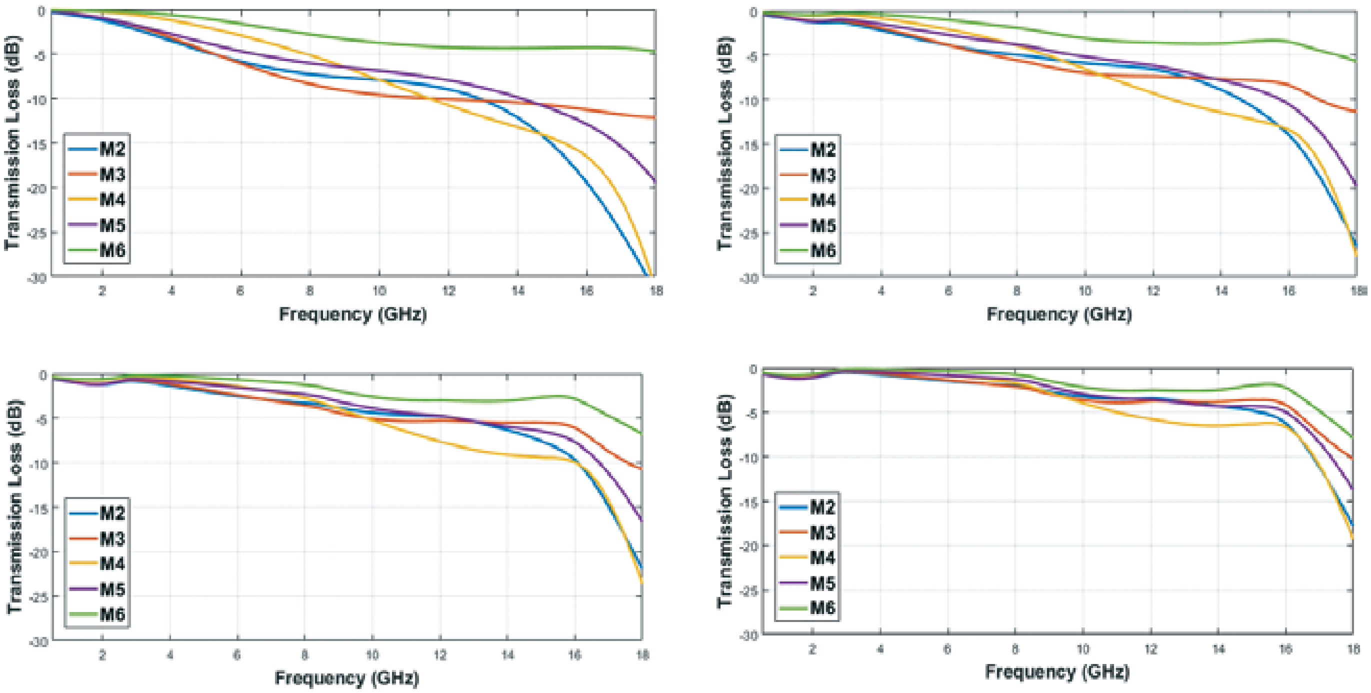

Figure 3. Transmission loss corresponding to various doping volume fractions (a) $V_f = 1$, (b) $V_f = 0.8$, (c) $V_f = 0.6$ and (d) $V_f = 0.4$, at a constant thickness of 2 mm.

4. CONCLUSIONS

In order to meet the end user requirement to decide the fraction of the dopants on the base material a lookup table has been derived through this work. This process, of analysing camouflage data with the help of mixing model, can be used to select the materials and corresponding doping volume fraction of the dopants on the base material as per absorbance and resonant frequency requirement. Transmission loss, presented in the paper, has been considered as the primary feature of optimisation in case of camouflage net. The idea of analytically calculating the transmission loss by mixing the dopants over the base material can be used to minimise the existing tedious trial and error approach which in turn will be helpful in reducing the wastage of material, manpower and time.

REFERENCES

1. Rao, J.V.R. Introduction to Camouflage and Deception. New Delhi: Defence Research & Development Organisation, 1999.
2. Pozar, D.M. Microwave engineering. John Wiley & Sons.; 2009.
3. Saville, P. Review of radar absorbing materials. Defence Research and Development Atlantic Dartmouth (CANADA), 2005.
4. Balanis, C.A. Advanced engineering electromagnetics. John Wiley & Sons.; 1999.
5. Redlich, G.; Obersztyn, E.; Olejnik, M.; Fortuniak, K.; Bartczak, A.; Szugajew, L. & Jarzemski, J. New textiles designed for anti-radar camouflage. *Fibres Text. East. Eur.*, 2014, **1**(103), 34–42.
6. 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.
7. Sihvola, A.H. & Kong, J.A. Effective permittivity of dielectric mixtures. *IEEE Trans. Geosci. Remote Sens.*, 1988, **26**(4), 420–429.
doi: 10.1109/36.3045.
8. Nicolson, A.M.; Ross, G.F. Measurement of the intrinsic properties of materials by time-domain techniques. *IEEE Trans. Instrum. Meas.*, 1970, **19**(4), 377–382.
doi: 10.1109/TIM.1970.4313932.
9. Kim, J.-B. Broadband radar absorbing structures of carbon nanocomposites. *Adv. Compos. Mater.,* 2012, **21**(4), 333–344.
doi: 10.1080/09243046.2012.736350.
10. Singh, B.P.; Saket, D.K.; Singh, A.P.; Pati, S. & Gupta, T.K. Microwave shielding properties of Co/Ni attached to single walled carbon nanotubes. *J. Mater. Chem. A,* 2015, **3**(25), 13203–13209.
doi: 10.1039/C5TA02381E.
11. Wang, X.; Gong, R.; Li, P.; Liu, L. & Cheng, W. Effects of aspect ratio and particle size on the microwave properties of Fe–Cr–Si–Al alloy flakes. *Mater. Sci. Eng. A,* 2007, **466**(1), 178–182.
doi: 10.1016/j.msea.2007.02.051.
12. 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.

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In the current study, he has conceived the idea of current study and collected the database, simulated the results and analysed the data.

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In the current study, he has framed the flow of study and supervised all the activities of the current research work.