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ESTIMATION OF REFLECTIVITY AND SHIELDING EFFECTIVENESS OF THREE LAYERED LAMINATE ELECTROMAGNETIC SHIELD AT X-BAND

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Abstract—Electromagnetic shields are designed to optimize the performance for shielding effectiveness and reflectivity. Multilayered laminates of different materials are developed to achieve excellent results in terms of not only in shielding effectiveness but also for reflectivity. In this paper, a three layered laminate is considered for estimation of the required parameters in the X-band frequency range. A sandwich of conductive polymer between a conductor and microwave absorber yields very good performance. Several investigations were carried out for the estimation of shielding effectiveness and reflectivity of the three layered laminate structure at different thickness of each layer and for a combination of different materials.

1. INTRODUCTION

Electromagnetic shields are to be designed and developed to minimize the electromagnetic interference and to improve compatibility of the microwave circuits. Various types of electromagnetic shields

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like single [2, 13] and multi layered conductors [2–4], conductive polymers [13–17] sandwiched between conductive layers, etc. are reported in the open literature whose design concentrates on optimizing performance on shielding effectiveness. Electromagnetic reflectivity is also one of the most important parameter for designing perfect electromagnetic shield. Several investigations were carried out and reported [5–12] for the estimation of reflectivity for different microwave absorbers and thicknesses. In this work, a multilayer laminate consisting of a conductor, conductive polymer and microwave absorber is developed as an electromagnetic shield which caters the needs for high shielding effectiveness and reflectivity. A highly efficient microwave absorber is considered for achieving good results for reflectivity. Several microwave absorbers with different thicknesses as reported in the literature [5–8] were considered as a first layer of the three layered laminate. This layer ensures high reflectivity of the shield.

A layer of conductive polymer [13] is introduced as a sandwich between microwave absorber and conductor layers. A conductive polymer has a very high conductivity to weight ratio and thus, it can yield same shielding effectiveness performance as that of a conductor with less weight. High conductive polymeric sheets with thickness small compared to skin depth can be used as electromagnetic shield. Several conductive polymers with different conductivity to weight ratio give different performances at different frequency ranges.

Mathematical formulations were developed for the estimation of reflectivity and shielding effectiveness of the proposed three layer laminate. Several investigations were carried out for the estimation of shielding effectiveness and reflectivity of the three layered laminate at microwave X-band frequency range. The design can be optimized considering formulations of thickness of the layers in the laminate and also the materials for the layers in the laminate. The selection of the material and its thickness in the three layered laminate for a given application is also based on mechanical ability of the structure.

2. REFLECTIVITY

Reflectivity of the microwave absorber backed by conductive polymer-conductor can be estimated using the transmission line analysis for normal incidence.

Considering the single interface of thickness t, E_i, H_i be the incident electric and magnetic fields, E_r, H_r be the reflected electric and magnetic fields due to impedance mismatch between the two media and E_t, H_t be the transmitted electric and magnetic fields strengths respectively [2]. Since the tangential field components across the interface are continuous

$$E_i + E_r = E_t; \quad H_i + H_r = H_t \tag{1}$$

And

$$E_i = \eta H_i, \quad E_r = -\eta H_r, \quad E_t = -Z(t) H_t \tag{2}$$

where η is the intrinsic impedance of the planar sheet and $Z(t)$ is the impedance looking to the right of the plane $x = t$.

The reflection coefficients across the single interface can be given as

$$\begin{aligned} q_E &= \frac{E_r}{E_i} = \frac{Z(t) - \eta}{Z(t) + \eta} \\ q_H &= \frac{H_r}{H_i} = \frac{\eta - Z(t)}{\eta + Z(t)} \\ q_E &= -q_H \end{aligned} \tag{3}$$

The intrinsic impedance of any medium [1] is given as

$$\eta = \sqrt{\frac{j\omega\mu}{(\sigma + j\omega\varepsilon)}} \tag{4}$$

where permeability $\mu = \mu_o \mu_r$, permittivity, $\epsilon = \epsilon_0 \epsilon_r$, conductivity, $\sigma = \sigma_0 \sigma_r$ of the medium respectively and $\omega = 2\pi f$.

Where μ_o, ϵ_0 are the free space permeability and permittivity, μ_r, ϵ_r are the relative permeability and permittivity of the medium, σ_0 is conductivity of copper, σ_r is the relative conductivity of the medium with respect to copper and f is the frequency of operation.

The propagation constant through the medium [1, 2] is given as

$$\gamma = \sqrt{j\omega\mu(\sigma + j\omega\epsilon)} \tag{5}$$

From the above equation, the intrinsic impedance of any medium in terms of propagation constant can be derived to be

$$\eta = \sqrt{\frac{-(2\pi f \mu)^2}{\gamma^2}} \tag{6}$$

Reflection coefficient [1] at an interface of microwave absorber-conductive polymer is given as

$$\Gamma_1 = \frac{\eta_p - \eta_A}{\eta_p + \eta_A} \tag{7}$$

Where η_p is the intrinsic impedance of conductive polymer and η_A is the intrinsic impedance of the microwave absorber.

Intrinsic impedance [13] of the conductive polymer is

$$\eta_p = (1 + j)\sqrt{\frac{\pi f \mu_p}{\sigma_p}} \tag{8}$$

Where μ_p, permeability $= \mu_o \mu_{rp}$, μ_o is free space permeability and σ_p is the conductivity of the conductive polymer [13] given as

$$\sigma_p = 2\pi f_0 \varepsilon_0 \varepsilon'' \tag{9}$$

f_0 is the resonant frequency of the cavity [13, 14], ε_0 is the permittivity of free space and ε'' is the imaginary part of relative permittivity of the conductive polymer [13, 14].

From the above Equation (6), the intrinsic impedance of the microwave absorbing material can be written as

$$\eta_A = \sqrt{\frac{-(2\pi f \mu A)^2}{\gamma_A^2}} \tag{10}$$

where μ_A, permeability of microwave absorber $= \mu_o \mu_{rA}$, $\mu_{rA} = \mu'_{rA} - j\mu''_{rA}$, is relative permeability of microwave absorber and γ_A, propagation constant in the microwave absorber [9] can be given as

$$\gamma_A = j\left(\frac{2\pi f}{c}\right)\sqrt{\mu_{rA}\epsilon_{rA}} = j\left(\frac{2\pi f}{c}\right)\sqrt{\left(\mu'_{rA} - j\mu''_{rA}\right)\left(\epsilon'_{rA} - j\epsilon''_{rA}\right)} \tag{11}$$

where relative permittivity of the absorber $\epsilon_{rA} = \epsilon'_{rA} - j\epsilon''_{rA}$ and c is the speed of light in free space.

The reflection coefficient at the interface of free space-microwave absorber is assumed to be very small and is neglected in this analysis.

The reflectivity at the interface of microwave absorber-conductive polymer in the laminate, as shown in the Fig. 1, is defined as the

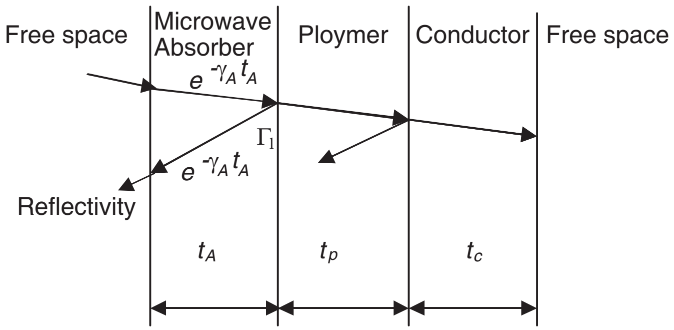

Figure 1. Reflectivity of microwave absorber-conductive polymer-conductor laminate.

path loss of the electromagnetic energy while it propagates from free space to microwave absorber-conductive polymer interface and back after reflection by the conductive polymer in the interface.

Thus, the reflectivity of the laminate can thus be derived as

$$r = e^{-\alpha_A t_A}\Gamma_1 e^{-\alpha_A t_A} = e^{-2\alpha_A t_A}\Gamma_1 \tag{12}$$

where t_A is the thickness of the microwave absorber and α_A is the attenuation constant of the microwave absorber [9] which is given as

$$\alpha_A = \frac{\sqrt{2}\pi f}{c} \sqrt{\left(\mu''_{rA}\epsilon''_{rA} - \mu'_{rA}\epsilon'_{rA}\right) + \sqrt{\left(\mu''_{rA}\epsilon''_{rA} - \mu'_{rA}\epsilon'_{rA}\right)^2 + \left(\epsilon'_{rA}\mu''_{rA} + \epsilon''_{rA}\mu'_{rA}\right)^2}} \tag{13}$$

Reflectivity expressed in dB as

$$R = 20\log_{10}(r)\ \text{dB} \tag{14}$$

3. SHIELDING EFFECTIVENESS

Shielding effectiveness of the three layer laminate of microwave absorber, conductive polymer and conductor is defined as the attenuation loss of the electromagnetic energy while it propagates through the three layers of the laminate. In other words, the shielding effectiveness is nothing but transmission coefficient of the laminate.

The transmission coefficients across the single interface [2] can be given as

$$\begin{aligned} P_E &= \frac{E_t}{E_i} = \frac{2Z(t)}{Z(t)+\eta} = 1 + q_E \\ P_H &= \frac{H_t}{H_i} = \frac{2\eta}{\eta + Z(t)} = 1 + q_H \end{aligned} \tag{15}$$

When two mismatched interfaces are considered with planar sheet of thickness t, the transmission coefficient [2, 3] across the two boundaries is

$$p = p_E = p_H = p_E(0)\cdot p_E(t) = p_H(0)\cdot p_H(t) = \frac{4Z(t)\eta}{(Z(t)+\eta)^2} \tag{16}$$

Thus, the transmission coefficient [2] across the planar sheet can be estimated to be

$$\begin{aligned} T_H &= \frac{H(t)}{H_i} = \frac{H(t)}{H(0)}\frac{H(0)}{H_i} \\ T_E &= \frac{E(t)}{E_i} = \frac{Z(t)}{Z_w}\frac{H(t)}{H_i} = \frac{Z(t)}{Z_w}T_H \end{aligned} \tag{17}$$

where $E(0)$, $H(0)$ and $E(t)$, $H(t)$ are the actual values at interfaces $x = 0$ and t respectively and Z_w is the impedance of the incident wave.

The transmission coefficient [2] of electric and magnetic fields across the planar sheet are given by $T_E = T_H = T$ and it is expressed as

$$T = p\left(1 - qe^{-2\gamma t}\right)^{-1} e^{-\gamma t} \tag{18}$$

where

$$p = \frac{4Z_w\eta}{(Z_w + \eta)(Z(t) + \eta)}$$
$$q = \frac{(Z_w - \eta)(Z(t) - \eta)}{(Z_w + \eta)(Z(t) + \eta)}$$

The transmission coefficient across the interface at three boundaries (absorber-conductive polymer, conductive polymer-conductor and conductor-free space) [2, 3] is given as

$$p = \frac{16\eta_0\eta_A\eta_p\eta_c}{(\eta_0 + \eta_A)(\eta_A + \eta_p)(\eta_p + \eta_c)(\eta_c + \eta_0)} \tag{19}$$

where η_0 is the free space intrinsic impedance $= 120\pi$ ohms and the intrinsic impedance [2] of metallic conductor can be estimated as

$$\eta_c = (1 + j)\sqrt{\frac{\pi f \mu_c}{\sigma}} \tag{20}$$

where μ_c, permeability of the conductor $= \mu_o\mu_{rc}$, conductivity of the metal $\sigma = \sigma_o\sigma_r$, μ_{rc} is relative permeability of the conductor, σ_r is the relative conductivity of the conductor with respect to copper.

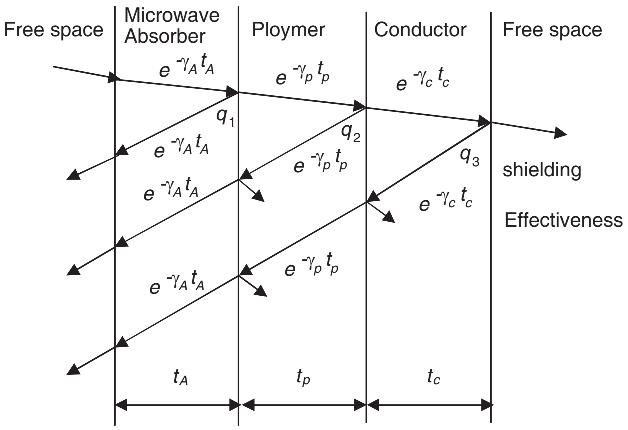

Figure 2. Shielding effectiveness of microwave absorber-conductive polymer-conductor laminate.

Reflection coefficient [2] at absorbing material-conductive polymer interface is q_1, that at conductive polymer-conductor interface is q_2 and that at conductor-free space interface is q_3

$$q_1 = \frac{(\eta_A - \eta_o)(\eta_A - z(p))}{(\eta_A + \eta_o)(\eta_A + z(p))} \quad (21)$$

$$q_2 = \frac{(\eta_p - \eta_A)(\eta_p - z(c))}{(\eta_p + \eta_A)(\eta_p + z(c))} \quad (22)$$

$$q_3 = \frac{(\eta_c - \eta_p)(\eta_c - \eta_o)}{(\eta_c + \eta_p)(\eta_c + \eta_o)} \quad (23)$$

where $z(p)$, $z(c)$ [2] are the impedance to the right of the absorber-conductive polymer interface and impedance to the right of the conductive polymer-conductor interface respectively.

$$z(p) = \eta_p \left[\frac{z(c)\cosh(\gamma_p t_p) + \eta_p \sinh(\gamma_p t_p)}{\eta_p \cosh(\gamma_p t_p) + z(c)\sinh(\gamma_p t_p)} \right] \quad (24)$$

$$z(c) = \eta_c \left[\frac{\eta_o \cosh(\gamma_c t_c) + \eta_c \sinh(\gamma_c t_c)}{\eta_c \cosh(\gamma_c t_c) + \eta_o \sinh(\gamma_c t_c)} \right] \quad (25)$$

where t_p, t_c are the thicknesses of the conductive polymer and conductor respectively, γ_p and γ_c are the propagation constants of the conductive polymer [13] and metallic conductor [2] respectively

$$\gamma_c = (1 + j)\sqrt{(\pi f \mu_c \sigma_c)} \quad (26)$$

$$\gamma_p = (1 + j)\sqrt{(\pi f \mu_p \sigma_p)} \quad (27)$$

Considering successive re-reflections at the interface of the three layers, the total transmission coefficient [2, 3] across the laminate can thus derived to be

$$T = p\left[\left(1 - q_1 e^{-2\gamma_A t_A}\right)\left(1 - q_2 e^{-2\gamma_p t_p}\right)\left(1 - q_3 e^{-\gamma_c t_c}\right)\right]^{-1} e^{-\gamma_A t_A - \gamma_p t_p - \gamma_c t_c} \quad (28)$$

The shielding effectiveness [2, 3, 13] of the three layer laminate can thus be expressed in decibels as

$$S = -20\log_{10}(T)\ \text{dB} \quad (29)$$

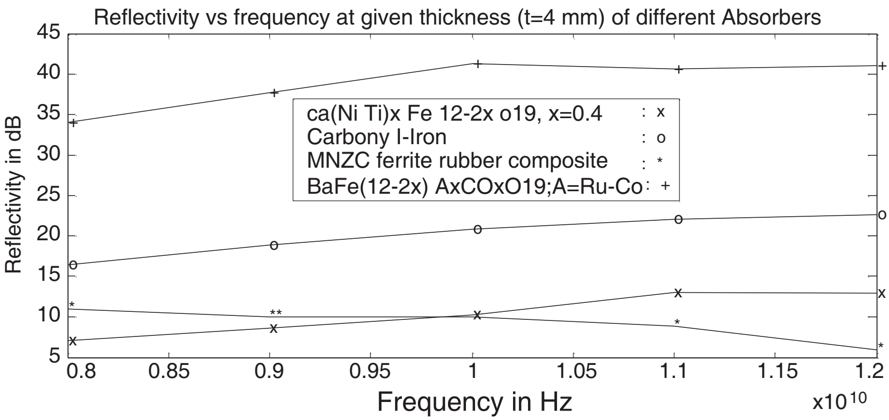

Figure 3. The variation of the reflectivity as a function of frequency for different microwave absorbers at absorber thickness of 4 mm.

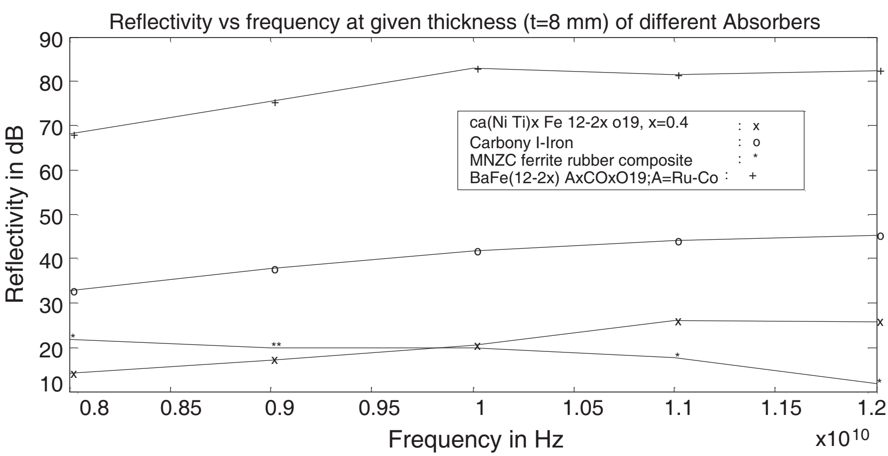

Figure 4. The variation of the reflectivity as a function of frequency for different microwave absorbers at absorber thickness of 8 mm.

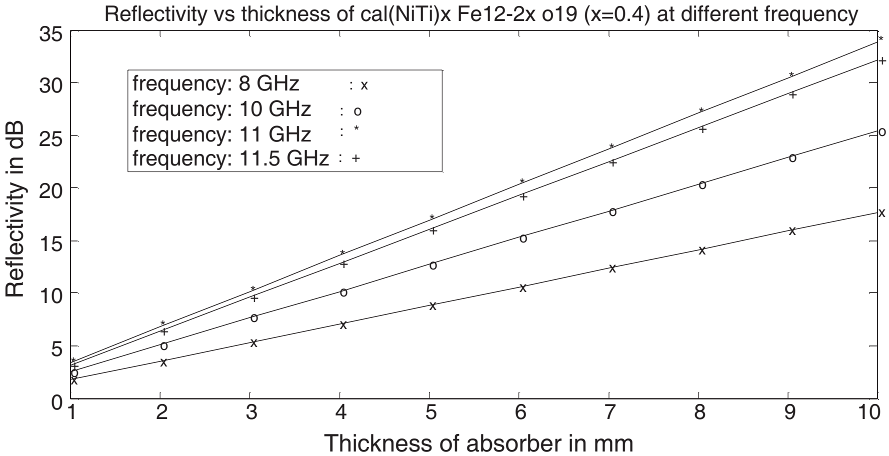

Figure 5. Variation of the reflectivity as a function of thickness for the $(Ca(NiTi)_xFe_{12-2x}O19)$ for $x = 0.4$ at different frequencies.

Table 1. Shielding effectiveness of laminate of Carbonyl iron-conductive polymer-copper for different conductive polymers of layer thicknesses Carbonyl iron absorber — 5 mm, conductive polymer — 40 mil, copper — 5 mil.

FREQUENCY GHz	**Shielding Effectiveness** (dB)		
	Polymer 1	**Polymer 2**	**Polymer 3**
6	1363.5	1358.6	1690.5
7	1463.7	1459.4	1752.1
8	1555.3	1551.8	1773.2
9	1629.2	1631.3	1631.2
10	1731.8	1727.9	1975.6
11	1818.9	1813.2	2180.9
12	1901.3	1893.7	2364.1
13	1981	1971.9	2537.1
14	2058.2	2047.7	2703.5
15	2133.1	2121.1	2864.7
16	2205.5	2192.2	3021.7
17	2273.9	2259.3	3173.2
18	2343	2327	3324.5

Table 2. Shielding effectiveness of laminate of Ca-NiTi hexa ferrite composites (Ca $(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$ — Conductive polymer-copper for different conductive polymers of layer thicknesses Carbonyl iron absorber — 5 mm, conductive polymer — 40 mil, copper — 5 mil.

FREQUENCY GHz	**Shielding Effectiveness** (dB)		
	Polymer 1	**Polymer 2**	**Polymer 3**
8	1550.5	1547.0	1768.3
8.5	1592.7	1589.5	1751.2
9	1623.8	1626.0	1625.9
9.5	1680.2	1677.1	1847.9
10	1726.2	1722.5	1969.9
10.5	1770.4	1765.8	2076.5
11	1814.2	1808.6	2176.0
11.5	1856.3	1849.7	2269.8
12	1896.7	1889.2	2359.4

Polymer 1: poly-p-phenylene-benzobis-thiazole (PBT) have been doped with iodine by Ion implantation of 10^{17} ions/cm^2.
Polymer 2: Polyacetylene have been doped with iodine electrochemically; 4.5% I2 by weight.
Polymer 3: Polyacetylene have been doped with iodine electrochemically; 80% I2 by weight.

Table 3. Materials parameters for Ca-NiTi hexa ferrite composite $(Ca(NiTi)_xFe_{12-2x}O_{19})$ for $x = 0.4$.

S. No	**Frequency (GHz)**	μ'	μ''	ϵ'	ϵ''
1	8	1.05	0.36	4.1	1
2	8.5	1.051	0.365	3.82	1.06
3	9	1.051	0.385	3.71	1.1
4	9.5	1.052	0.392	3.6	1.15
5	10	1.054	0.42	3.4	1.155
6	10.5	1.053	0.45	3.3	1.155
7	11	1.058	0.56	3.10	1.145
8	11.5	1.06	0.6	2.73	1.06
9	12	1.06	0.54	2.35	1

Table 4. Material parameters for Carbonyl-Iron particle composites with volume fraction $v_f = 40\%$.

S. No	Frequency (GHz)	μ'	μ''	ϵ'	ϵ''
1	3	3.2	1.21	4.1	1.01
2	4	2.6	1.30	4.1	1.02
3	5	2.3	1.31	3.7	1.01
4	6	2	1.3	4.1	1.01
5	7	1.9	1.27	4.6	1.02
6	8	1.6	1.2	6.5	1.02
7	9	1.5	1.15	7.3	1.01
8	10	1.4	1.12	7.3	1
9	11	1.4	1.1	6.8	0.98
10	12	1.32	1	6.6	1
11	13	1.30	0.98	6.7	1.01
12	14	1.29	0.95	8.4	1.02
13	15	1.23	0.93	10	1.01
14	16	1.20	0.92	11.1	1
15	17	1.16	0.87	10.1	1
16	18	1.11	0.85	12.1	1

Table 5. Material parameters for M-Type Barium ferrites.

S. No	Frequency (GHz)	μ'	μ''	ϵ'	ϵ''
1	1	2.5	0.2	15	0
2	2	2.5	0.3	15	0
3	3	2.6	0.4	15	0
4	4	2.5	0.8	15	0
5	5	2.3	0.9	15	0
6	6	2.2	1	15	0
7	7	2.2	1.1	15	0
8	8	2	1.5	15	0
9	9	1.7	1.8	15	0
10	10	1.1	1.7	15	0
11	11	0.75	1.6	15	0
12	12	0.55	1.4	15	0
13	13	0.53	1.2	15	0
14	14	0.5	1	15	0
15	15	0.51	0.8	15	0
16	16	0.5	0.6	15	0
17	17	0.5	0.58	15	0
18	18	0.5	0.55	15	0

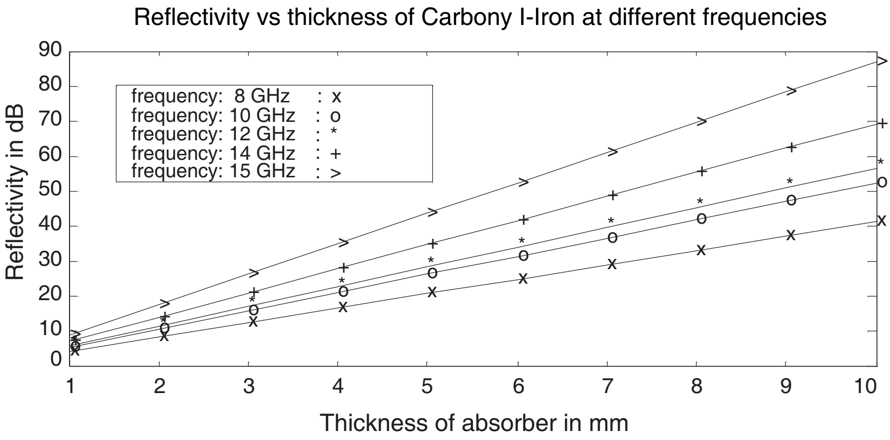

Figure 6. The variation of the reflectivity as a function of thickness for the Carbonyl-Iron particle composites at different frequencies.

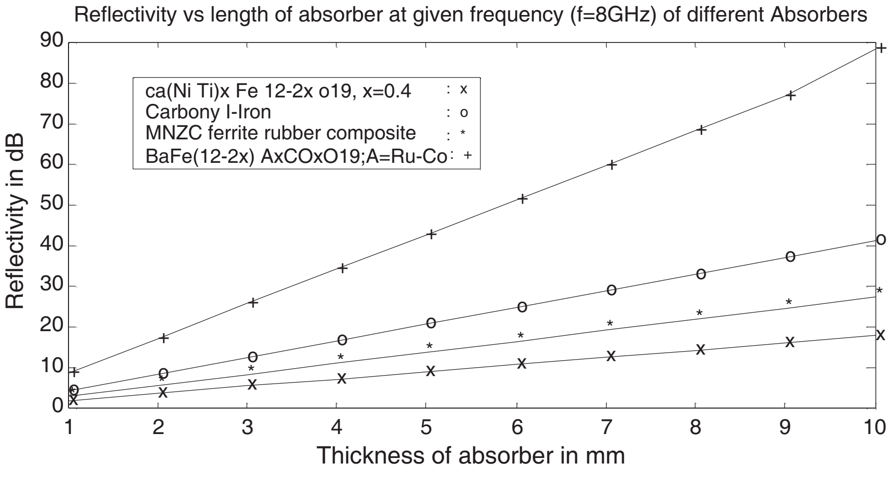

Figure 7. The variation of the reflectivity as a function of thickness for different microwave absorbers at 8 GHz frequency.

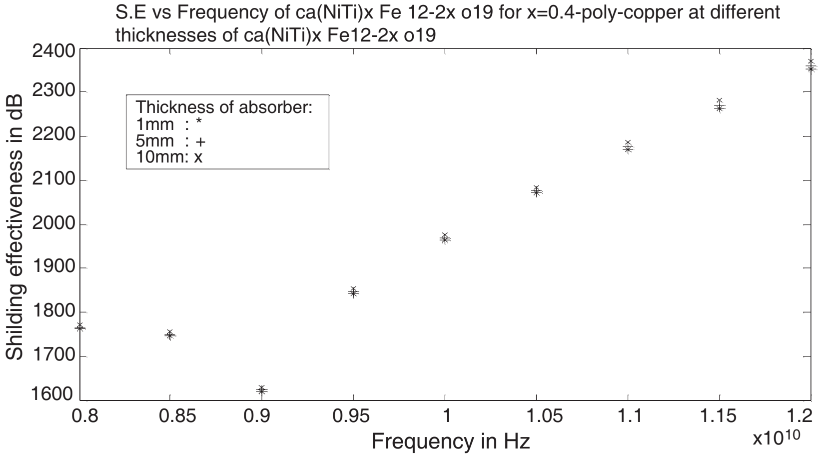

Figure 8. The variation of the Shielding effectiveness as a function of frequency of ($Ca(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$-Polyacetylene doped electro chemically with 80% by weight by iodine-copper laminate for different thicknesses of microwave absorber with 40 mil, 5 mil thicknesses of polymer and copper respectively.

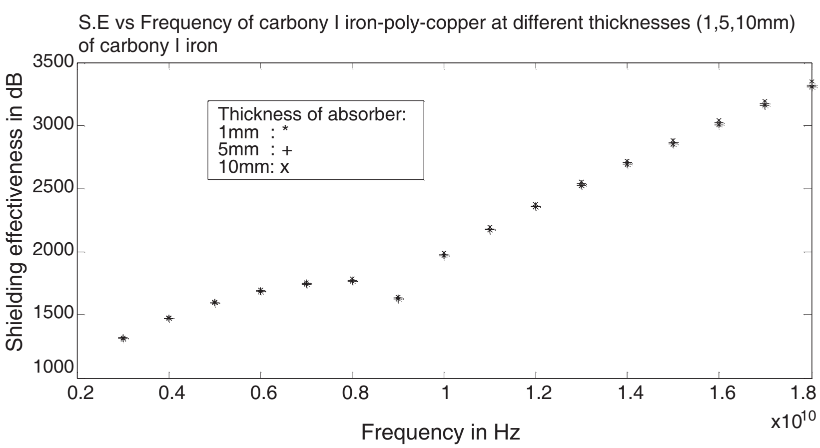

Figure 9. The variation of the shielding effectiveness as a function of frequency of Carbonyl-Iron-Polyacetylene doped electro chemically with 80% by weight by iodine-copper laminate for different thicknesses of microwave absorber with 40 mil, 5 mil thicknesses of polymer and copper respectively.

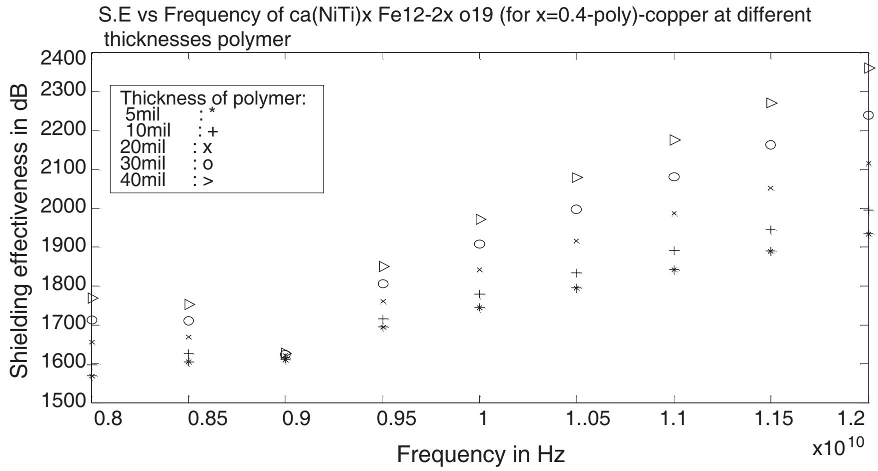

Figure 10. The variation of the Shielding effectiveness as a function of frequency of $(Ca(NiTi)_x Fe_{12-2x} O_{19})$ for $x = 0.4$-polymercopper laminate for different thicknesses of conductive polymer (Polyacetylene doped electro chemically with 80% by weight by iodine) with 5 mm, 5 mil thicknesses of microwave absorber and copper respectively.

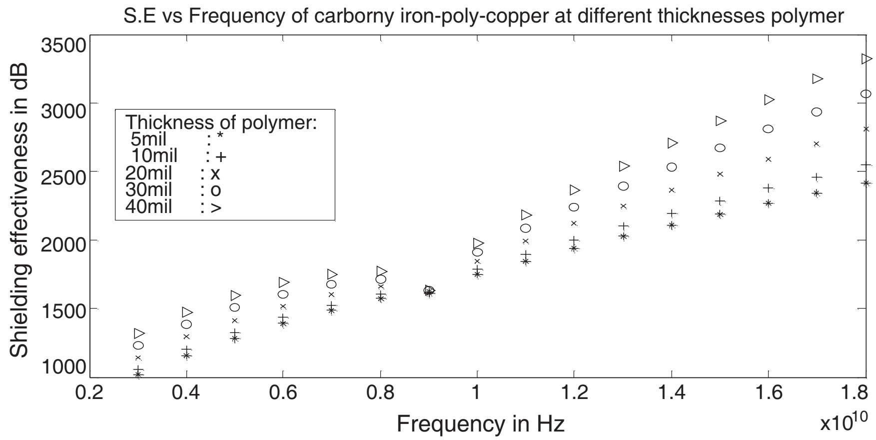

Figure 11. The variation of the shielding effectiveness as a function of frequency of Carbonyl-Iron-polymer-copper laminate for different thicknesses of conductive polymer (Polyacetylene doped electro chemically with 80% by weight by iodine) with 5 mm, 5 mil thicknesses of microwave absorber and copper respectively.

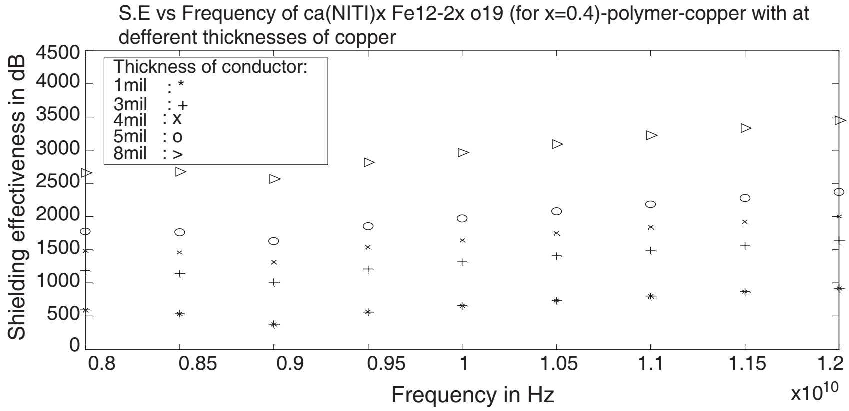

Figure 12. The variation of the Shielding effectiveness as a function of frequency of $(Ca(NiTi)_x Fe_{12-2x} O_{19})$ for $x = 0.4$-(Polyacetylene doped electro chemically with 80% by weight by iodine)-copper laminate for different thicknesses of copper with 5 mm and 40 mil thicknesses of absorber and polymer respectively.

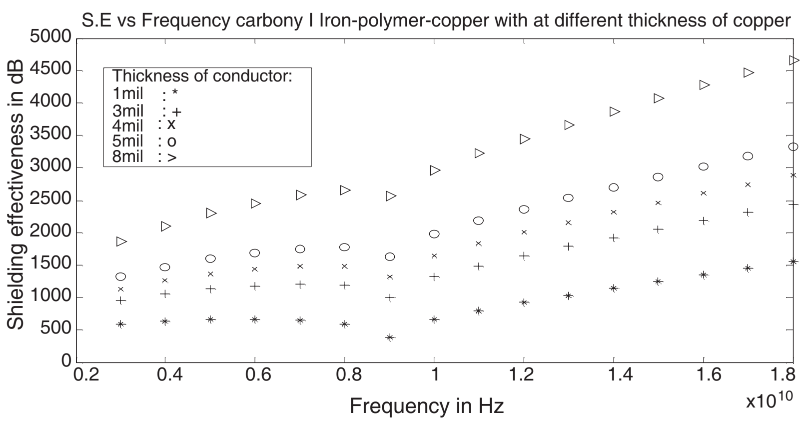

Figure 13. The variation of the Shielding effectiveness as a function of frequency of Carbonyl-Iron-(Polyacetylene doped electro chemically with 80% by weight by iodine)-copper laminate for different thicknesses of copper with 5 mm and 40 mil thicknesses of absorber and polymer respectively.

Table 6. Material parameters for MnZn ferrite-Rubber composites with volume fraction $v_f = 0.4$.

S. No	Frequency (GHz)	μ'	μ''	ϵ'	ϵ''
1	1	2.75	0.7	11	1.2
2	2	2.2	1	10.2	1.2
3	3	1.6	1.1	10.1	1.1
4	4	1.2	1	10	1.12
5	5	1.1	0.8	9.8	1.1
6	6	0.9	0.7	9.7	1.01
7	7	0.8	0.6	9.6	1
8	8	0.8	0.5	9.5	0.7
9	9	0.79	0.4	9.4	0.6
10	10	0.792	0.37	9.2	0.4
11	11	0.799	0.3	9.3	0.3
12	12	0.81	0.28	9.4	0

Table 7. Material parameters for various conductive polymers.

Mnemonic	Material	Doping	$\epsilon_r = \epsilon' - j\epsilon''$	μ_r
A	Poly-p-phenylene-benzobis-thiazole (PBT)	Ion implantation to a fluence of 10^{16} ions/cm^2	3−j838	1
B	Poly-p-phenylene-benzobis-thiazole (PBT)	Ion implantation of a fluence of 10^{17} ions/cm^2	3−j1158	1
C	Polyacetylene cis-(CHI0.045)x	Electrochemical; 4.5% I2 by weight.	5−j607	1
D	Polyacetylene Trans-(CHI0.045)x	Electrochemical; 4.5% I2 by weight	5−j909	1
E	Polyacetylene cis-(CHI0.8)x	Electrochemical; 80% I2 by weight	5−j4.E5	1

4. RESULTS & CONCLUSIONS

Analysis was carried out for the estimation of reflectivity of laminate of microwave absorber-conductive polymer-conductor for various types of absorbing materials and conductive polymers at various thicknesses of materials. The reflectivity of the three layered laminate is estimated by using Equation (14) for four different absorbing materials (i) Ca-NiTi hexa ferrite composites ($Ca(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$ [6], (ii) Carbonyl-Iron particle composites with volume fraction v_f=40% [5], (iii) M-Type Barium ferrites ($BaFe_{12-2x}A_xCo_xO_{19}$ for the tetravalent A ions, Ru^{4+} is chosen) [7] and (iv) MnZn ferrite-Rubber composites with volume fraction $v_f = 0.4$ [8].

The material parameters permittivity, permeability and conductivity of the considered microwave absorbing materials and conducting polymers were listed in the Tables 3–7 [5–8, 13]. The conductivity of copper is 5.82×10^7 mhos/m, permittivity is 8.854×10^{-12} F/m and permeability is $4\pi \times 10^{-7}$ H/m [2].

The variation of reflectivity with respect to frequency for different microwave absorbers at a thickness of 4 & 8 mm are plotted in the Figs. 3 & 4 respectively. Figs. 5 & 6 are the plots for estimation of reflectivity with thickness of absorber in the laminate at different frequencies for Ca-NiTi hexa ferrite composites ($Ca(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$ and carbonyl iron respectively. Fig. 7 shows the variation of the reflectivity at 8 GHz for four considered absorbing materials of different thicknesses backed by conductive polymer-copper.

The analysis of shielding effectiveness is carried out for various combinations of microwave absorbing materials, polymers and different thicknesses of various layers in X-band frequency range. Figs. 8 & 9 are the plots of variations of shielding effectiveness with frequency at a constant thickness for Ca-NiTi hexa ferrite composites ($Ca(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$ [6], Carbonyl-Iron particle composites with volume fraction $v_f = 40\%$ [5] absorbing materials. Figs. 10 & 11 show the variation of shielding effectiveness at different thicknesses (5, 10, 20, 30, 40 mils) of polymers for the two absorbing materials Ca-NiTi hexa ferrite composites ($Ca(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$ [6] and Carbonyl-Iron particle composites with volume fraction $v_f = 40\%$ [5] respectively. Figs. 12 & 13 shows the effect of variation of thickness of conductor on shielding effectiveness with the above two microwave absorbing materials and the different polymers respectively.

A comparison of shielding effectiveness for different polymers (poly-p-phenylene-benzobis-thiazole (PBT) have been doped with iodine Ion implantation of 10^{17} ions/cm^2, Polyacetylene have been doped with iodine electrochemically; 4.5% I2 by weight, Polyacetylene have been doped with iodine electrochemically; 80% I2 by weight) in the three layer laminate (of layer thicknesses copper — 5 mil, conductive polymer — 40 mil, ($Ca(NiTi)_xFe_{12-2x}O_{19}$) for $x = 0.4$ absorber-5 mm) in X-band frequency range shown in the Table 1. Table 2 presents a comparison of shielding effectiveness for different polymers in the three layer laminate in 6–18 GHz frequency band.

From the above analysis an electromagnetic shield can easily be designed to achieve required combination of reflectivity and shielding effectiveness. The thickness of each layer in the laminate and the materials of laminate layers can be selected as per the requirements of the application.

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