An attenuation Layer for Electromagnetic Shielding in X- Band Frequency

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ABSTRACT

Uncontrolled exposure to X-band frequency leads to health damage. One of the principles of radiation protection is shielding. But, conventional shielding materials have disadvantages. Therefore, studies of novel materials, as an alternative to conventional shielding materials, are required to obtain new electromagnetic shielding material. Therefore, this study investigated the electromagnetic shielding of two component epoxy thermosetting resin for the X - band frequency with workplace approach. Two components of epoxy resin mixed according to manufacturing instruction with the weight ratio that was 100:10 .Epoxy plates fabricated in three different thicknesses (2, 4 and 6mm) and shielding effectiveness measured by Vector Network Analyzer. Then, shielding effectiveness measured by the scattering parameters.The results showed that 6mm thickness of epoxy had the highest and 2mm had the lowest average of shielding effectiveness in X-band frequency that is 4.48 and 1.9 dB, respectively. Also, shielding effectiveness increased by increasing the thickness. But this increasing is useful up to 4mm. Percentage shielding effectiveness of attenuation for 6, 4 and 2mm thicknesses is 64.35%, 63.31% and 35.40%. Also, attenuation values for 4mm and 6mm thicknesses at 8.53 GHz and 8.52 GHz frequency are 77.15% and 82.95%, respectively, and can be used as favourite shields for the above frequency. 4mm-Epoxy is a suitable candidate for shielding application in X-band frequency range but, in the lower section, 6mm thickness is recommended. Finely, the shielding matrix can be used for selecting the proper thickness for electromagnetic shielding in X- Band frequency.

Key words*:* Epoxy, Microwave, Electromagnetic Shielding, radiation protection, X-band frequency, half-value layer

INTRODUCTION

Microwave is defined as the electromagnetic radiation with frequency range from 300MHz to 300 GHz that divided into some Frequency bands. X-band (8-12.5 GHz) is part of the radar frequency band in the microwave spectrum and descript as super high frequency. X-band frequency have various applications such as satellite, communications, radar, navigation, air traffic Control, marine and weather station and etc.[1]. Therefore, many workers are exposed to these waves. A study was conducted by American Navy about 40,581 soldiers. It determined that half of the soldiers were exposed to radar frequency[2]. This is an example of researches that showed many of the workers have exposure to X-band frequency. Uncontrolled exposure of microwave lead to thermal and non-thermal effects[1] . Cataracts, skin burns, and damage to the testes are some of thermal effects[1, 3]. Furthermore, the non-thermal effects of X-band frequency are very wide that including; Reproductive effects, cancers, blood effects, genetic, adverse immune effects and mental effects. Also, there are many unknown aspects of the biological effects that did not determined very well, such as oxidative stress and mental effects[4].Therefore, it is necessary to protect workers from it. The principles of radiation protection for non-ionizing radiation is the same as those for ionizing radiation—namely, time, distance, and shielding. On the other hands, microwave safety measures include minimizing exposure time, maximizing distance from the source, and interposing shielding when necessary [1].In occupational health, use of engineering measures to prevent adverse health effects is a priority. Thus, the use of shielding is a superior method for prevention of occupational exposure to microwave. Previously, in order to microwave shielding in the workplace ,wire mesh and metal solid has been used frequently for their high Conductivity [1]. However, these conventional shielding materials have serviceability disadvantages, such as their heavy weight, corrosion susceptibility and limited physical/mechanical flexibility. Therefore, studies of novel materials, as an alternative to conventional shielding materials, are required to obtain efficient Electromagnetic shield/absorber [5, 6]. Electromagnetic shielding refers to the reflection and/or absorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through the shield [7].As regards to Electromagnetic shielding definition; EM shielding is the process of limiting the flow of Electromagnetic fields between two locations by a barrier. The shielding barrier needs to have high conductivity or magnetic permeability[8]. Epoxy resin is one of the thermosetting polymer with suitable properties that including; excellent mechanical properties, chemical and heat stability, antibacterial properties, low contractibility, strong adherence [9], good dielectric Constance , excellent electrical characteristics, Low shrinkage, mechanical resistance, Chemical resistance and Favorable strength-to-weight[10].As for the above reasons, especially dielectric constant that is one of the required elements for Electromagnetic shielding, this study investigated the efficiency of epoxy as a half value layer (HVL) for Electromagnetic shielding in X-band frequency.

MATERIAL AND METHODS

Sample fabrication

This study used a two component epoxy thermosetting resin. EI-403 as the epoxy (base on epoxy bisphenol A) and HA-14 as the curing agent (Polyamido Amine Immadozolin Hardener) provided (Mokarrar Engineering Material co, Iran). Viscosity and density (at 25^{0C}) were 720 centipoises and 1.04 gr/cm^3, respectively. Samples fabricated according to manufacturing instruction with the weight ratio that was 100:10 (epoxy: curing agent). The samples were made in three different thicknesses (2, 4 and 6 mm) and in triplicate with the 3cm*3cm dimension.

Fabrication procedure is summarized as follows:

1. Addition of epoxy resin into the glass beaker.
2. Addition of curing agent.
3. Mechanical mixing for 1 min at 700 RPM.
4. Ultrasonic bath for 8 min.
5. Removing the bubbles by Vacuum Drying Oven (DZF-6024, China) for 8 min.
6. Pouring the mixing into the silicone mould
7. Keeping the moulds on the balanced desk at the room temperature (21^{oC}-23^{oC}) for 7 days.

Finally, after seventh day all samples (9 samples) unhinged, out of the silicone moulds.

Electromagnetic properties characterization

Shielding effectiveness (SE) in the X-band frequency range (8-12.5 GHz) was measured by the set-up that including: an Agilent 8510C Vector Network Analyzer, Agilent 8517B S- Parameter test set, two coaxial to waveguide adapters . Coaxial calibration carried out by 3.5 mm calibration kit.

S-parameters

Microwave SE is the logarithm of the ratio of the transmitted power when there is no shield (P_I) to the power when there is a shield (P_T) in a unit of dB[11, 12]. Since it is difficult to measure the electromagnetic properties directly, the SE can be expressed in terms of S-parameters (scattering parameters). In a waveguide, a radiated wave undergoes shielding (reflection, absorption, and transmission) when the incident wave at a point (port i) passes toward another point (port j), and these waves scattering values are expressed as S_{ji}. For example, S_{21} is the energy acquisition at port 2, having originated in port 1. Therefore, the scattering parameters S_{11} and S_{21} designate the amount of reflected energy and transmitted energy, respectively. In the present study, the S-parameters were obtained from an SE test under room temperature and humidity conditions [13] and the SE value was calculated using a following equation[14, 15].

$$T = |S_{21}|^2 = |S_{12}|^2 \quad \text{Eq. (1)}$$

$$SE = -20\ \log_{10}|T| \quad \text{Eq. (2)}$$

In that equation $|S_{21}|$ and $|S_{12}|$ are the amount of transmitting energy and T is transmitted power density. In this study, SE is directly given experimentally by the Vector Network Analyzer by the S-parameters. The input power used for all tests was 10 dBm, corresponding to 10 mw. The results were obtained in decibels and also transformed into percentages[8]:

$$\text{SE}(+\text{dB}) = 10 log\frac{Pi}{Pt} \rightarrow SE_{\%} = \left(1 - \left(\frac{1}{10^{\frac{SE}{10}}}\right)\right) \times 100 \quad Eq.(3)$$

RESULTS

The aim of this study is investigation the efficiency of the net epoxy resin for electromagnetic shielding in X-band frequency to protect workers in the workplace. The results of table 1 showed that 6 mm epoxy thick plate had the highest average of shielding effectiveness and 2 mm epoxy thick plate had the lowest average of shielding effectiveness in X-band frequency range that are 4.48 dB (64.35%) and 1.90 dB(35.40%), respectively. Our study also found that the maximum SE value (7.68 dB or 82.95%) is about 6 mm that occurred at 8.52 GHz frequency and the minimum SE value (0.86 dB or 17.48%) is about 2 mm that occurred at 9.9 GHz frequency. Moreover, survey on standard deviations showed that the shielding effectiveness for 6 mm epoxy thick plate is very variable .

Table1: The SE values for each thicknesses of epoxy in X-band frequency

Thickness (mm)	SE average ±SD		SE $_{Max}$ (frequency*)		SE $_{Min}$ (frequency*)	
	(%)	(dB)	(%)	(dB)	(%)	(dB)
2	35.40±9.01	1.9±0.41	50.16 (12.43 GHz)	3.02 (12.43 GHz)	17.88 (9.90 GHz)	0.85 (9.90 GHz)
4	63.31±18.15	4.36±0.87	77.15 (8.53 GHz)	6.41 (8.53 GHz)	49.08 (9.86 GHz)	2.93 (9.86 GHz)
6	64.35±52.90	4.48±3.27	82.95 (8.52 GHz)	7.68 (8.52 GHz)	44.30 (12.12 GHz)	2.54 (12.12 GHz)

Fig. 1 showed a comparison of SE values for three different thicknesses in X-band frequency. These results showed that the SE values increased by increasing the thickness .But, it is up to 10.056 GHz and from 10.056 to 12.5 GHz frequency, this result did not obtain. In this frequency range, the 4mm had more SE values than 6 mm thickness. according to this figure, there is a similar attenuation pattern in three different thicknesses. In other words, these thicknesses had similar behaviour in reducing the intensity of the X - band microwave. Based on this pattern, X-band frequency divided into three sections: lower section (8-9.5 GHz), middle section (9.6-11 GHz) and upper section (11.1-12.5 GHz).

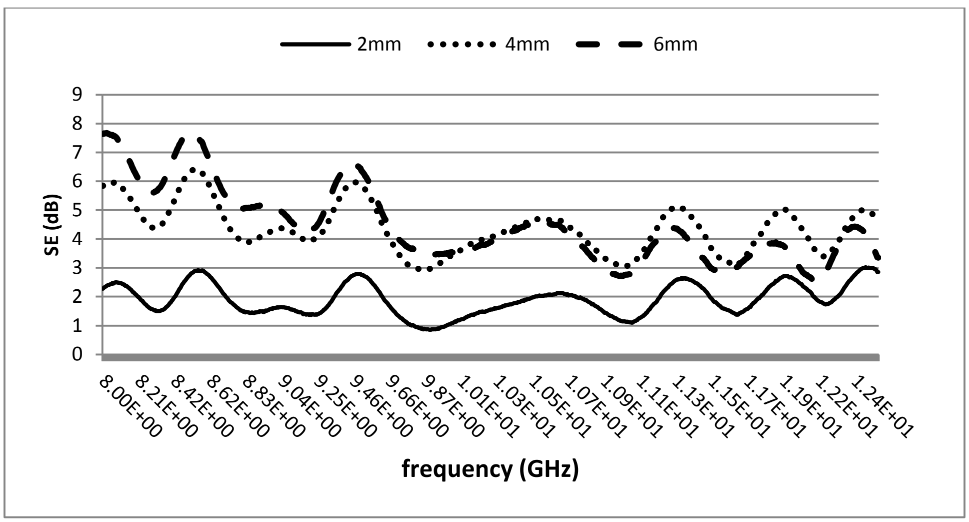

Fig.1: SE values in each thickness of epoxy

Table 2 resents the SE values in a triple section of X-band frequency for each thickness. The SE values for 2, 4 and 6 mm are 2.02 dB (37.16%), 4.97 dB (68.15%) and 5.92 dB (74.41%), respectively in the lower section. Survey on these triple sections demonstrated that 6mm thickness obtained the highest attenuation value among other thicknesses in the lower section of X-band frequency. Therefore, the SE values increased by increasing the thickness in this section. Moreover, in the middle section, the SE value increased up to 4mm then it is fixed. But, in upper section, the SE value increased up to 4mm then decreased, slightly. This table could be designed an easy decision path in X-band and each of triple sections for selecting the proper thickness that is called *shielding matrix.*

It can be seen that, only the SE$_{\%\ average}$ for 2 mm-epoxy is less than 50% both in X-band frequency range and all sections of that. The Shielding matrix showed that the SE$_{\%\ average}$ in the middle section is less than other sections in 2 and 4 mm thicknesses. Also, these results showed that by increasing the thickness, the SE$_{\%\ average}$ is increased only in the lower section. The SE$_{\%\ average}$ for 2, 4 and 6mm in lower section of X-band are 37.16%, 68.15% and 74.41%, respectively. It is noticeable that with increasing the frequency, the SE$_{\%\ average}$ be decreased about 6mm-epoxy. So that, the SE$_{\%\ average}$ from lower to upper section of X-band frequency are 74.14%, 58.38 and 55.87%, respectively. Also, it is considerable that the SE$_{\%}$ values for 4mm and 6mm thicknesses at 8.53 GHz and 8.52 GHz frequency are 77.15% and

82.95%, respectively that occurred in the lower section of X-band frequency.

Table2: The shielding matrix for selection of proper thickness

Frequency range (GHz)	Sections	Thickness(mm)					
		2		4		6	
		$SE_{average}$					
		(%)	(dB)	(%)	(dB)	(%)	(dB)
8-12.5	X-band	35.4	1.9	63.31	4.36	64.35	4.48
8-9.5	Lower Section	37.16	2.02	68.15	4.97	74.41	5.92
9.6-11	Middle Section	29.51	1.52	58.55	3.82	58.38	3.8
11.1-12.5	Upper Section	39.26	2.16	62.12	4.22	55.87	3.56

DISCUSSION

This study investigated the efficiency of epoxy resin as an electromagnetic shielding in X-band frequency range. Our study found that epoxy resin with 4 and 6mm plate thicknesses could be useful for X-band shielding. This study showed that increase in epoxy plate thickness lead to increasing the SE values. But, it is considerable that the SE value of epoxy plate with 6mm thickness is not noticeable. Therefore, an increase in thickness is useful up to 4 mm (table 1). Lakshmi et .al (2009) was considered on polyaniline–polyurethane (PANI–PU) composite for EMI shielding applications. The EMI shielding properties of PANI–PU composite is evaluated both at S-band and X-band frequencies. Their results showed that the shielding efficiency of the composite increased with the thickness of the sample .The shielding efficiency for a thickness of 0.62 mm was 18.2 dB, at 1.26 mm the SE was 20 dB and at 1.9 mm the SE was 26.7 dB[12].In another study, Kim et. al(2010) investigated Intrinsic electromagnetic radiation shielding/absorbing characteristics of polyaniline-coated transparent thin films in a frequency range 1-1600 MHz. The SE values of the PANI-coated transparent thin films increased (14.28%, 30.68%, 46.50%, and 52.67%) with the increase of the thickness of PANI coated in transparent thin films (229 nm, 366 nm, 640 nm, and 823 nm)[6].Figure 1 showed a comparison of SE values for three different thicknesses in X-band frequency .This figure indicated that the SE values in 2mm epoxy plate thickness are less than other thickness in X-band frequency range. The SE values in 6mm epoxy plate thickness unexpectedly are not more than other thickness in X-band frequency range. Table 2 showed that this thickness has greater values than other thicknesses only in the lower section of x-band frequency. Moreover, this figure illustrated that there is a similar attenuation pattern in three different thicknesses. In other words, these thicknesses had similar behaviour in reducing the intensity of the X -band frequency. Based on this pattern, x-band frequency divided into three sections: lower section (8-9.5 GHz), middle section (9.6-11 GHz) and upper section (11.1-12.5 GHz).Previous studies did not demonstrate attenuation pattern. While, knowledge of SE values in each of triple sections can be useful to select the proper thickness of epoxy for electromagnetic shielding. Survey on these triple sections demonstrated that by increasing the thickness, the SE values be increased only, at the lower section of X-band frequency. Moreover, in the middle section, the SE value increased up to 4mm then it approximately is fixed. But, in upper section, the SE value increased up to 4mm thickness, then decreased, slightly (table 2). Lakshmi et .al (2009) studied on Microwave absorption, reflection and EMI shielding of PU-PANI composite they found that shielding effectiveness at 2.23 GHz (in S-band) and 8.82 GHz .(in X-band) were higher than other frequencies .In accord to classification of X-band frequency in our study, they demonstrated that PANI–PU composite is ideal in the lower section of X-band [12]. Also, the finding showed that the $SE_{\%\ average}$ for 4 and 6mm-epoxy both in X-band frequency range and all sections of that, are more than a half-value layer (HVF).In this study the half value layer (HVL) is defined as the thickness of a shield that reduces the radiation level to half the initial level. The HVL is also called a *half value thickness* [1].based on this study, this matrix can be used to select the appropriate thickness for attenuation of intensity of X-band frequency in the workplace. Also, the results showed that the epoxy with 4mm thickness can provide both appropriate shielding and economical benefit. Therefore, this thickness is recommended for shielding application in X-band frequency range. But, in the lower section (8-9.5 GHz), 6mm thickness is recommended (table 2). Eva Ha˚kansson et .al (2007) studied on radiation absorption in thin polypyrrole films. Their results showed that the intrinsically conducting polymer, polypyrrole, doped with anthraquinone-2-sulfonic acid (AQSA) or para-toluene-2-sulfonic acid (pTSA) was applied on textile substrates and the resulting materials were investigated in the frequency range 1–18 GHz. The 0.54 mm thick conducting textile/polypyrrole composites absorbed up to 49.5% at 2.065 GHz of the incident 30–35 W microwave radiation. Also, a maximum shielding effectiveness of 89.9% at 18 GHz was displayed by the sample with an AQSA concentration of 0.027 mol/l. It be seen that maximum SE occurred at high frequency[16].In another study, Eva Ha˚kansson et.al (2006) investigated the Electromagnetic shielding properties of polypyrrole/polyester composites in the 1–18 GHz frequency range. It was found that the total shielding efficiency of these conductive fabrics is significant at short polymerization times and increases to values exceeding 80% with longer polymerization times. Maximum shielding effectiveness, greater than 80% has been achieved in the best performing, conducting textile at high frequency[17].It is noticeable that in our study, maximum $SE_{\%}$ occurred at 8.52 GHz about 6mm thickness and was 82.65%.Also, the maximum shielding effectiveness about 4mm thickness is 77.15% that occurred at 9.287 GHz frequency (table 2). These findings introduce that 6 and 4mm thicknesses can be useful as favourite shields in that specific frequency.

CONCLUSION

This study investigated the efficiency of epoxy resin as a half value layer of shielding the X-band frequency in the microwave spectrum. As regards, epoxy processing is easy and commodious. So, according to $SE_{\%}$ of epoxy, it is a suitable candidate for shielding application and can be applied as well attenuation layer for electromagnetic shielding in the workplace. Also, 4mm thickness can provide both appropriate shielding and economical benefit. Therefore, this thickness is recommended for shielding application in X-band frequency range. But, in the lower section, 6mm thickness is recommended. Finely, the shielding matrix can be used for selecting the proper thickness for electromagnetic Shielding in X- Band Frequency.

COMPETING INTEREST

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Study concept and design: zaroushani and khavanin: Acquisition of data, zaroushani Analysis and interpretation of data, zaroushani, khavanin revising the manuscript, khavanin ,mortazavi: Critical revision of the manuscript for important intellectual content, zaroushani, khavanin Statistical analysis: zaroushani Administrative, technical, and material support: khavanin ,mortazavi; Study supervision: khavanin

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