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DEVELOPMENT OF EXTREMELY LOW FREQUENCY PASSIVE SHIELDING APPLICATION USING MAGNETIC AQUEOUS SUBSTRATE

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Abstract

Public concerns on Extremely Low Frequency (ELF) Electromagnetic Field (EMF) exposure have been elongated since the last few decades. Electrical substations and high tension rooms in commercial buildings were among the contributing factors emanating ELF magnetic fields. This paper discussed various shielding methods conventionally used in mitigating the ELF exposure. Nevertheless, the standard methods were found to be impractical and incapable of meeting currents shielding demands. In response to that, remarkable researches were conducted in effort to invent novel methods which is more convenient and efficient such as magnetic aqueous shielding or paint, textiles and papers shielding. A magnetic aqueous substrate, Manganese Zinc Ferrite was used as shielding material. The magnetic field and flux distribution inside the aqueous magnetic material are evaluated to optimize shielding against ELF-EMF exposure, as to mitigate its exposure.

Keywords: ELF shielding, Magnetic aqueous substrate, Shielding effectiveness, Magnetic material..

1. Introduction

Controversial issues on ELF magnetic field exposure started in 1979 when scientist found the association of ELF exposure with adverse health effects. Series of epidemiological studies were conducted to obtain evidences relating the ELF exposure to cancers and etc. [1]. The issues has arisen the public concerns on the adverse health effects caused. Prior to that, a standard was designated by the World Health Organization (WHO) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) in limiting the exposure levels.

Nomenclatures

B_0	Magnetic fields before shielding
B_s	Magnetic fields after shielding
mG	Milli-Gauss
Greek Symbols	
μ	Permeability
Abbreviations	
CST	Computer Simulation Technology
ELF	Extremely Low Frequency
EMF	Electromagnetic Field
EMDEX	Electric and Magnetic Fields Digital Exposure System
HT	High Tension Room
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronic Engineer
ROW	Right of Way
SE	Shielding Effectiveness
WHO	World Health Organization

According to the guidelines, the recommended values are 1000 mG for public exposures and 5000 mG for occupational exposures [2].

ELF -EMF is defined as the magnetic field emanates from 50-60 Hz electric power lines, substations and electrical appliances. The frequency of fundamental is around 3-3000 Hz. Measurements of ELF exposure levels was carried out in areas where direct exposure was expected, such as electrical transmission lines [3, 4], high voltage substations [5-7] and HT rooms in high rise buildings [8-10] in response to the public concerns. In locations where direct effects are sensible, mitigation methods such as passive shielding were proposed.

Conventionally, the ELF passive shielding method usually introduces conductive and magnetic sheets as a barrier to generate the shielding effects. There are two fundamental types of magnetic shielding which is based on the material properties which is shields of flux-entrapment and lossy. A shield of flux-entrapment is designed with high permeability, μ such as specially annealed ferromagnetic Mu-metal alloy contain of 80% nickel and 20% iron which shield an area from magnetic sources. The magnetic flux line incidents upon the shields of flux entrapment prefer to penetrate the high permeability material rather than shielded area. Meanwhile, lossy shields depend on eddy-current losses that occur in highly conductive and low permeability materials [9].

A study has been reported assessing the shielding effectiveness comparing conductive material such as copper and aluminium and high permeability ferromagnetic material such as mu-metal. It was found that the best shielding efficiency value was for the low-loss silicon steel which reaches 3.81 dB, followed by mu-metal which reaches 2.17 dB while the conductive shielding having the lowest value of 1.3dB [5]. Table 1 shows three phase system of shielding percentage and efficiency exposed [16].

Table 1. Shielding percentage and efficiency exposed under three phase system.

Materials	Reduction Field [%]	Shielding Efficiency [SE]
No Shield	0	1
GO (M5)	96.06	25.38
NGO (50H470)	93.06	14.41
GI (G3303)	6.88	1.07
EG (G3313)	53.60	2.16
Aluminium Alloy	42.08	1.73

Nevertheless, this method is closely impractical to be used in niche and confined area where magnetic sensitivity is crucial. Standard shielding materials are incapable of meeting shielding demands because they are rigid and inflexible. Many of these materials like Mu-metal cannot tolerate rough handling and must be carefully machined to prevent micro-crack formation due to thermal or mechanical process. Newer commercial shield material for electric and magnetic fields that are flexible such as metal particle dispersed fabrics or papers and paints have recently been developed. However, the dispersed metal particles are oxidized in highly corrosive streams. Thus, there is rapidly growing need for new materials for better shields which is low-cost, easy to manufacture, flexible, non-toxic and environmental friendly.

Magnetic materials can be divided into two types: soft magnetic materials and hard magnetic material. Magnetically soft material can be defined as a material that can absorb magnetic energy without retaining it which makes good shielding materials. The hard magnetic material is a material that can keep strong magnetic field even after the magnetic energy source has been eliminated which make it a good material for permanent magnet. Therefore, for passive shielding applications, soft magnetic materials will be further reviewed.

There are two groups of soft magnetic materials, which is ferromagnetic and ferrimagnetic material. Ferromagnetic material are based on nickel and iron, are more suitable for lower frequencies (<2kHz). Meanwhile, ferrimagnetic materials or so called ferrites are based on metals ceramic oxides which are applicable to frequencies from a few kilohertz to 80 MHz. The advantages of ferrites are high electrical resistivity, high permeability and functional for wide frequency range.

Application of ferromagnetic material in shielding was introduced in the last few decades for passive shielding applications. Aqueous based alternatives are now being developed due to their wide various advantages such as high flexibility, cheap and easy installation.

There are several patents reporting on the invention of coatings composites for shielding. An invention reported by Reddy [11] established a general method of making a paint incorporating ferrite or ferromagnetic material. The method can be accomplished by making a base paint then adding any magnetic material required based on project requirements. This binder system can be used for any powder to make paint. Besides that, the report also concluded that nickel is the best attenuator for low frequency region. Hence, based on this invention, the idea of developing aqueous magnetic shielding in passive shielding applications adopting ferrites or ferromagnetic materials becomes closer to reality. The preparation method of the magnetic fluids was studied to produce a stabilized aqueous magnetic fluid for various applications [12]. In the study, iron oxide nanoparticles produced from a water-based magnetic fluid. Hence the same preparation method can be applied to the aqueous magnetic substrate for the ELF shielding application.

Another idea of applying a barrier coating containing at least one magnetoresistive material (eg: Perovskite manganite) on a surface acting as the shielding of ELF fields introduced in 2004 [13]. This invention provides polycrystalline powders dispersed in sol-gel and paint formulations for coating on flexible fabrics, clothes and papers using the aqueous acetate solution technique developed. The shielding effectiveness of the material was found to be ~15dB at frequency 60Hz.In the proposed method of shielding; Manganese Zinc Ferrite and Nickel Zinc Ferrites will be investigated in terms of their shielding effectiveness and workability as a passive shielding for ELF magnetic fields. The usage of the proposed material has been discussed in several studies done previously in numerous applications [14]. Table 2 shows the properties of the proposed materials.

EMDEX instruments were used to conduct the surveys which focus on standard measurement procedures and protocol recommended by IEEE. Some electromagnetic level variation with the distance from the transmission line ROW are shows from results obtained. As conclusion the EMF level were very much lower than suggested exposure limit by ICNIRP, but the ELF EMF determination effect in the long term, the study and evaluation are still important [3].

Table 2. Typical comparative data of soft magnetic materials [15].

		Silicon Steel	Iron		Alloy	Ferrites	
			Powder	Carbonyl		Mn-Zn	Ni-Zn
Frequency range, △f	Hz	20-1k	400-10k	50k-1M	40-70k	400-250k	200k-10M
Temperature range, △T	°C	-55 to 300	-55 to 125	-55 to 105	-55 to 200	-30 to 105	-55 to 250
Initial permeability, μ_i		500	90	35	160	2700	100
Flux density, B_s at 25°C	T	1.75	0.86	0.86	0.63	0.47	0.24
Remanence, B_r	T	1.2	0.2	0.001	0.02	0.2	0.12
Intrinsic mmf strength, H_i	A/m	440	2560	9120	1448	40	350
Resistivity, ρ	Ωcm	0.1	-	-	-	100	10^5 - 10^6
Curie Temperature, T_c	°C	300	200	150	500	200	450

2. Methodology

Computer Simulation Technology (CST) EM Studio software was used to simulate and determine the magnetic field flux distribution inside the aqueous magnetic material. It also has been used to investigate the magnetic behaviour of various type ferromagnetic materials and as optimization tools for better shielding design validation.

By using the finite element analysis, predictions on the real situations and worst condition can be simulated in order to determine shielding efficiency and design accuracy. Two types of ferrofluids material are chosen and both will undergo the same process. Hence, a shielding design was proposed by applying ferromagnetic materials which are Nickel-Zinc (Ni-Zn) Ferrite and Manganese-Zinc (Mn-Zn) Ferrite as the substrate. Table 3 shows that the ferrofluids magnetic properties [17][18] :

Table 3. Properties of ferrofluids magnetic material.

Properties at 25^{o}C	Mn-Zn ferrite	Ni-Zn ferrite
Dielectric constant, ε	4.650	1.817
Coercitivity (A/m)	12	16
Electrical Resistivity (Ω-m)	6.0	10^5
Permeability, μ	2000±25%	1500±25%
Density, (kg/m$^{3)}$	4.8×10^3	4.4×10^3
Curie Temperature (Tc)	220	100

For this model, the shielding barrier is designed to surround the source of radiation to ensure the electromagnetic field trapped in the ferrofluid while emitted from radiation source. The inner radius (R1) for the barrier design is 4.90 mm while 4.97 mm is set for the outer radius (R2). The shield height and initial thickness is set to 1.0 mm and 0.07 mm each as shown in Fig. 1. Figure 1 shows the proposed design for passive shielding using aqueous magnetic substrate. Figure 2 shows the regions of the curves were placed before, inside and after the shielding barrier. Electromagnetic field changes along each region were measured from the straight line curve perpendicular to the source. The curve distance is fixed at 0.9 mm before and after shielding barrier and the ferrofluid.

Besides the selection of the material, other aspects are necessary in shielding calculations such as shielding material geometry, shielding morphology, source characteristics and physical construction such as thickness and sizes. The measure of shielding performance is determined by shielding effectiveness (SE) equation which is derived from the ratio undisturbed magnetic flux density at the measurement point without shielding to magnetic flux density at the measurement point with the shield applied, B_o as shown in Eq. (1), where B_o is the magnetic field before shielding barrier and B_s is the magnetic field after shielding barrier. The standard unit of SE measurement is the decibel or dB.

$$SE\,(dB) = 20 \log_{10} (B_0/B_s) \quad (1)$$

Results from calculation of shielding effectiveness for every region are compared for every ferrofluid material. The behaviour of magnetic field and flux distribution for both ferrofluids will be observed and evaluated. The graph of the experiment will be categorized into their respective ferrofluid material. The ferrofluid that can mitigate the most field at the other side of the material will be chosen as ferrofluids for shielding purpose in this research.

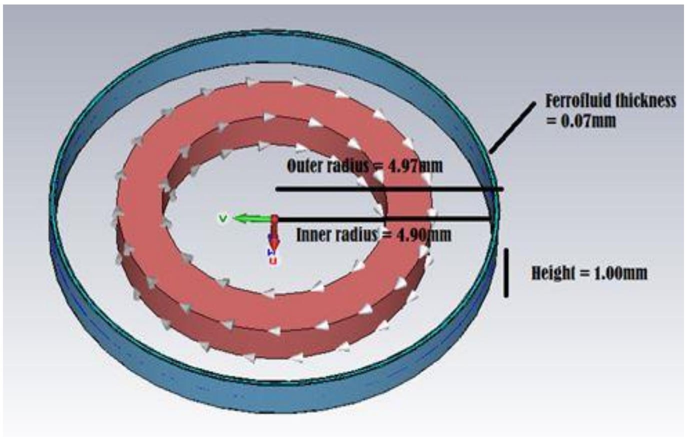


Fig. 1. The design for aqueous magnetic material.

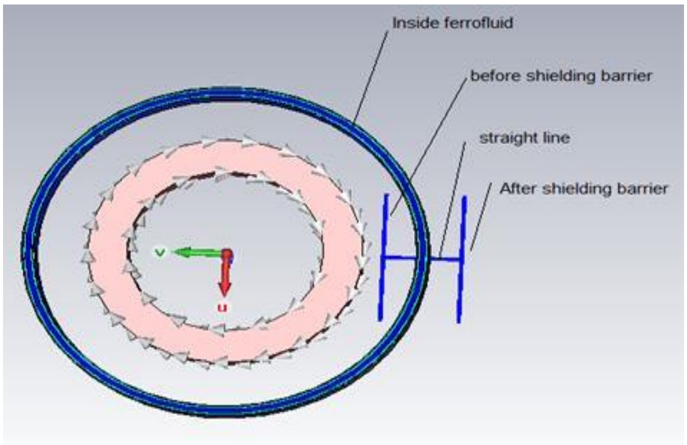


Fig. 2. Regions of the curve.

3. Results and Discussion

Simulation studies on magnetic flux distribution and performance of shielding in terms of shielding effectiveness (SE) of the aqueous magnetic substrate in passive shielding application have been carried out. A proposed design and initial simulation results have been obtained as shown in the Fig. 1. There are three variations of shielding design in this experiment which are shielding thickness, air gap between layers and different types of ferrofluid. The simulation was carried out by manipulating the thickness and air gap is located between the layers of the design and another type of ferrofluid was used with the same parameter in Fig. 1.

The manipulated parameters are:

i) Thickness of ferrofluid = 0.07mm, 0.10mm, 0.13mm, 0.16mm.
ii) Thickness of ferrofluid = 0.07mm with air gap = 0.06mm, 0.09mm, 0.12mm and 0.15mm between the layers.

iii) Thickness of ferrofluid = 0.07mm with Manganese zinc ferrite as ferrofluid.

Result shows that the increases of ferrofluid thickness will increase shielding effectiveness. The optimum shielding thickness selected is 0.16 mm, 0.09 mm as the length of air gap between layers and the ferrofluid material being chosen is Manganese Zinc Ferrite that gives more EMF radiation mitigation.

The optimum simulation model is shown in Fig. 3. From the result, it is observed that the magnetic field reading before entering the shielding barrier is 0.050 T while the reading falls to 3.30 µT after it passes through the shielding barrier. Shielding effectiveness for optimum result,

$$SE\ (dB) = 20 \log_{10} (0.050\ T/3.30\ \mu T)\ dB = 83.68\ dB \tag{2}$$

The shielding barrier performance increased rapidly due to the ferrofluid thickness absorbed more magnetic field and more flux density were divide by the air gap that causing low magnetic field in the outer region.

Graph in Fig. 5 shows shielding effectiveness in against ferrofluid thickness. The shielding effectiveness increase when thickness of ferrofluid increases. Result in the Fig. 6 shows the graph of shielding effectiveness against length of the air gap. The shielding effectiveness increase when length of the air gap increases.

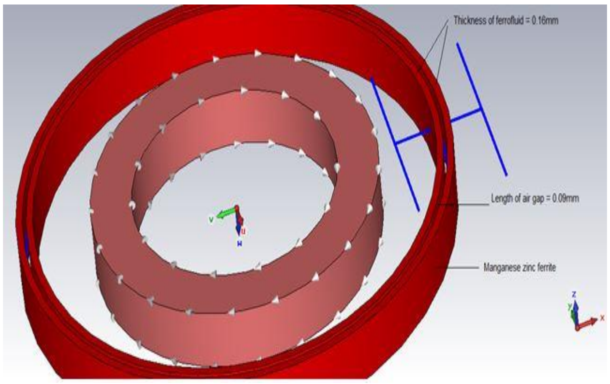
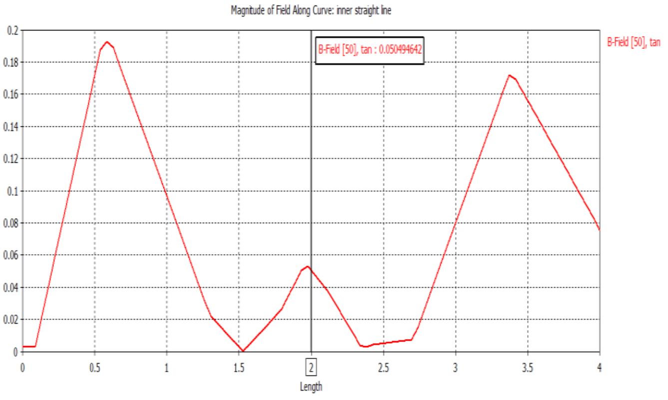
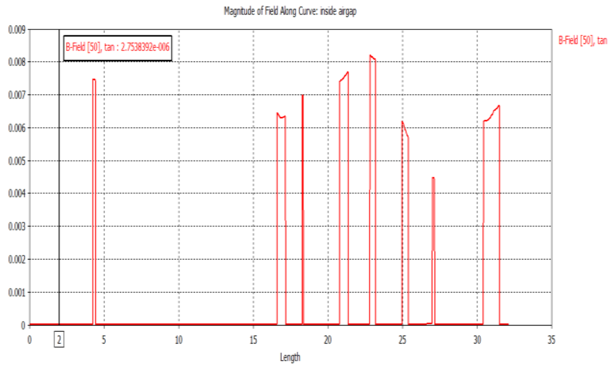


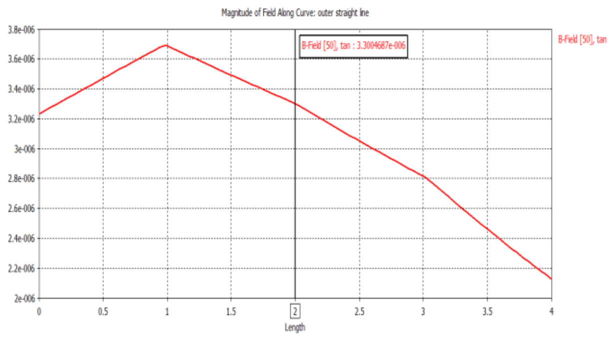
Fig. 3. Design of model to get the optimum result.



(a)



(b)



(c)

Fig. 4. The magnetic field behavior (a) before entering ferrofluid, (b) inside the air gap, (c) after entering ferrofluid.

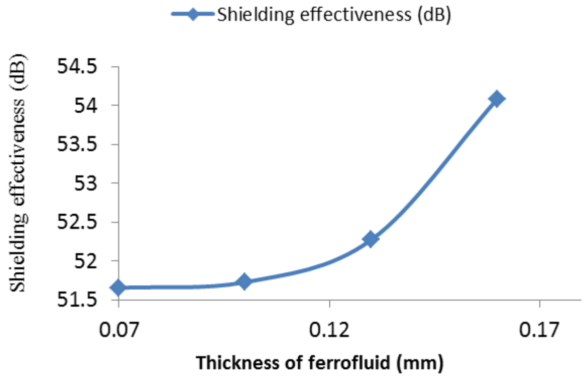


Fig. 5. Shielding effectiveness of materials with different thickness of ferrofluid.

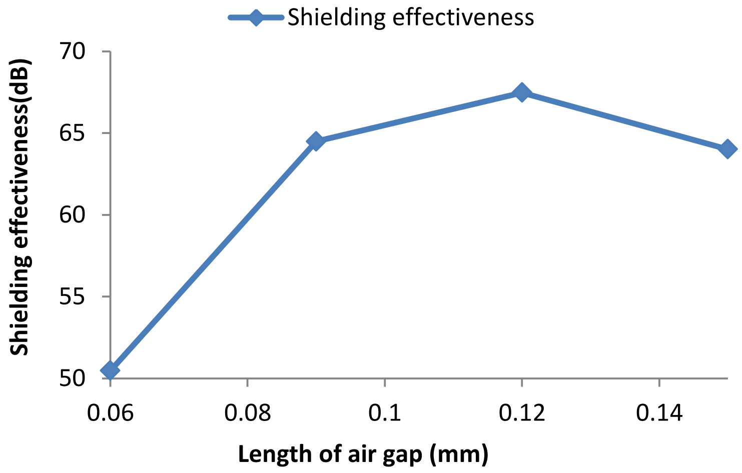


Fig. 6. Shielding effectiveness with different length of air gap.

4. Conclusions

Studies on various techniques and methods of mitigation from ELF magnetic fields have been reviewed. Method utilizing aqueous magnetic substrate Manganese Zinc Ferrite ,$Mn_{0.4}Zn_{0.6}Fe_2O_4$ in passive shielding application has been proposed. The simulation results shows that the shielding barrier thickness and the length of air gap between the shielding barriers plays an important role in mitigating the EMF radiation exposure. The shielding effectiveness were produced are 83.68 dB which the highest shielding performance among the entire model in this research. Results obtained shows that shielding effectiveness up to 83.68 dB can be achieved.

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