SHIELDING EFFECTIVENESS OF MESH WIRE FOR 50Hz MAGNETIC FIELD

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Abstract

A wire mesh shield composed of thin conductive wires will influence the behaviour of electromagnetic fields within it. Many researchers have investigated electromagnetic field behaviour in solid metal, but little of this work has probed into the effects of a wire mesh. The primary goal of this work is to design wire mesh shielding under overhead power lines to investigate the electromagnetic energy transmitted to the ground and possibly can exposed people under certain risk.

The electromagnetic shielding of wire-mesh screens is discussed in the frequency range where the individual meshes are electrically small $(L < 0.1\lambda)$. The screen, whose meshes are assumed to be square, its applicability to the measurement of mesh properties is described. The low-frequency magnetic shielding afforded by mesh enclosures is considered. Because of the reactive character of the mesh surface, the near field source shielding effectiveness decreases with increasing frequency. The enclosure magnetic-field shielding effectiveness increases with increasing frequency, but saturates at a maximum value that depends on the geometry of the mesh size, and the mesh wire radius. The enclosure electrostatic-field shielding effectiveness depends only on the enclosure and mesh geometries.

Experimentally, shielding effectiveness measurements have been performed. The wire mesh Shields designed in different sizes to find the relation between mesh size and shielding effectiveness.

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Abstrak

Jaringan wayar yang diperbuat daripada wayar konduktif yang halus akan mempengaruhi kesan medan electromagnet di persekitarannya. Terdapat ramai penyelidik telah membuat kajian berhubung kesan medan electromagnet di dalam besi padu, tetapi sedikit kajian dibuat terhadap jaringan wayar. Matlamat utama di dalam kajian ini adalah untuk mereka kekebalan jaringan wayar di bawah talian pencawang utama elektrik dan seterusnya menyiasat tenaga yang dihasilkan kepada bumi dan juga kesan pada manusia.

Kekebalan skrin jaringan wayar dibincangkan di dalam julat frekuensi di mana setiap satu jaringan mempunyai keluasan yang kecil $(L < 0.1\lambda)$. Skrin yang dihasilkan di dalam bentuk segi empat sama di dalam pengujian ini. Kekebalan magnetik berfrekuensi rendah juga di ambil kira. Sumber medan yang berdekatan akan mengurangkan sifat kekebalan apabila frekuensi meingkat. disebabkan sifatnya yang reaktif pada permukaan jaringan ini. Walaubagaimanapun, kekebalan medan magnet akan meningkat apabila frekuensi ditingkatkan tetapi akan tepu apabila mencapai saiz geometri maksimum jaringan wayar teserbut. Untuk kekebalan elektrostatik ianya bergantung hanya kepada geometri penutup dan jaringan wayar.

Melalui experiment, kekebalan effektif sudah diukur dan jaringan wayar dibuat untuk mencari kaitan di antara saiz jaringan dan kekebalan effektif.

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LIST OF ABBREVIATIONS AND ACRONYMS

Z_w	-	Wave Impedance
Z_0	-	Characteristic Impedance
Z_s	-	Shield Impedance
μ_r	-	Relative Permeability
σ_r	-	Relative Conductivity
SE	-	Shielding Effectiveness
A	-	Absorption Loss
R	-	Reflection Loss
B	-	Multiple Reflections
δ	-	Skin Depth
L_s	-	Sheet Inductance Parameter
R_S	-	DC Resistance of the Mesh Wires
a_s	-	Length of Wire Mesh
r_w	-	Radius of Wire Mesh
τ_S	-	Time Constant Characteristic of the Mesh
τ_e	-	Time Constant Characteristic of the Enclosure
EMC	-	Electromagnetic Compatibility

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CHAPTER I

INTRODUCTION

Today with the increasing use of electrical power, high magnetic fields of power frequency are often encountered in our environment. Unwanted magnetic fields are a problem when using sensitive measurement equipment. Moreover, there is deep concern about the possible health hazards for persons being exposed to electric and magnetic fields at low frequencies.

Magnetic field shielding refers to the shielding of near field magnetic fields. Near field magnetic fields are frequently described as having a low impedance and, therefore, do not easily reflect off low impedance metals. It is important to realize, however, that near field magnetic fields are not plane waves, and their field distribution is typically complex and source dependent. Shielding of magnetic fields is usually difficult and expensive

1.1 Project Background

Electromagnetic waves consist of two components, a magnetic field (H) and an electric field (E). Electric fields from power lines are relatively stable because line voltage doesn't change very much. Magnetic fields change greatly as current changes due to changing loads. A large current flows in a low-impedance source such as transmission line or a wire loop or a transformer. Such sources are called magnetic field sources. For low-impedance fields, less energy is reflected, and more is absorbed, because the metal is closely matched to the impedance of the field, that is why it is difficult to shield against magnetic field. The absorption loss is important when the interference source is contained within a shielded enclosure because only the absorption loss provides attenuation. In low-frequency, low-impedance circuits, stray magnetic field can cause serious trouble. They are produced by motors, transformers, and transmission line.

Electromagnetic shielding is an important factor in providing protection for sensitive equipment in both military and civilian applications, such as sensors. Undesirable radiation can cause electromagnetic interference (EMI), which can take the form of damage or other unacceptable responses in operation. Shielding against EMI is used to reduce radiated emissions from a system or reduce radiated susceptibility of a system and the term often used for such a specification is shielding effectiveness (SE). Fundamentally, SE is the ratio of the incident wave to the transmission wave for either the electric field or magnetic field, whether in the near-field or far-field.

In the area of electromagnetic compatibility (EMC), as a kind of common structural material, the wire-mesh reinforcement are used widely and the shielding effectiveness (SE) of the wire-mesh reinforcement becomes more and more important with the more attention paid on the problem. Generally, the metallic wire structure is lighter and less cost than metal board.

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1.2 Problem Statements

With the increasing use of electrical power, high magnetic fields of power frequency are often encountered in our environment. Unwanted magnetic fields are a problem when using sensitive measurement equipment. Moreover, there is deep concern about the possible health hazards for persons being exposed to electric and magnetic fields at low frequencies.

To obtain an efficient low-frequency magnetic shield, a substantial amount of shielding material is often required. In general, the choice of shield type and amount of material depends on the required attenuation and on the dominating design criteria: material cost, weight, size, access for maintenance, etc. The shape of the shield is in many cases restricted by practical limitations, and only partial shielding may be possible to use. This problem is often encountered when already-installed electrical power equipment is to be shielded.

The main goal is then to obtain maximum attenuation with the shield configuration that is possible to use. The shielding result depends on both the material used and the shield and source geometry.

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1.3 Project Objectives

1. To develop the formulation of magnetic field shielding (SE) effectiveness of wire mesh at 50 Hz.
2. To enhance understanding on the dependence of the SE on various parameters of the wire mesh.
3. To verify the SE of magnetic field of 50Hz with experimental measurements.

1.4 Project Scopes

The purpose of this project is create a methods and approaches to protect people in public area to exposed to electromagnetic that produced from overhead transmission line, in this project the wire mesh shield was design to reduce 50Hz magnetic field, which produce from transformer. All the experiments have been done in UTHM university substation.

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CHAPTER II

LITERATURE REVIEW

2.1 Introduction

In the near field, the reflection loss to a low frequency magnetic field is small. Because of multiple reflections, this effect is even pronounced in a thin shield. The primary loss for magnetic field is absorption loss. Because both the absorption and reflection loss are small at low frequencies, the total shielding effectiveness is low. It is therefore difficult to shield low frequency magnetic fields. Additional protection against low frequency magnetic field can be achieved only by providing a low reluctance magnetic shunt path to divert the field around the circuit being protected.

2.2 Technology Developments

Solid enclosures have been studied extensively since the 1970s. Most of the work focused on the penetration of EM fields through apertures in the walls of the enclosure. Mendez [2] is an early piece of work that investigated insertion loss of a rectangular enclosure with apertures containing an internal radiating source.

More recently, extensive work has been done by Robinson et al [8, 3] and Sewell et al [6]. Building on some of his own previous work and mathematics from [2], Robinson developed a numerical solution to model a cavity with an aperture and its resulting shielding effect anywhere within the enclosure. Using transmission line

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theory, Robinson and his colleagues' considers only the TE10 mode, but is valid above and below the first cut off frequency. Robinson's numerical model also allows for internal losses, the consideration of multiple apertures, and is a function of the cavity and aperture dimensions.

Today, there exists a variety of methods to determine the electromagnetic fields while considering multiple modes within an enclosure containing apertures. The Method of Moments (MOM), the finite difference time domain (FDTD), and transmission line matrix (TLM) are all techniques that have proven reliable [3, 6]. While each method is capable, there are often differences in the solutions depending on the resolution chosen for the computer simulations and due to the methods themselves. These methods were designed for predicting field strength inside simple metallic structures with a limited number of apertures, and more importantly from an external source.

Casey [4] provides an investigation into the shielding behaviour of wire-mesh screens. In his work, Casey concluded that the plane-wave shielding effectiveness of a mesh screen tended to decrease with an increasing frequency. This is opposite of a solid metal sheet, whose shielding effectiveness increases as frequency does. When a mesh was used to form an enclosure, the shielding effectiveness increased with frequency, saturated at a maximum value, and then began to decrease. Casey also developed equations to estimate the sheet impedance of a wire mesh screen, which will be used on this Chapter. While Casey's work provides insight into wire mesh, he only considered a plane wave in the far field. Magnetic field within wire mesh will primarily be dominated by the near field.

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2.3 The Review of electromagnetic shielding Theory

This section shows important theory about electromagnetic shielding.

2.3.1 Field Theory

Time varying electric and magnetic fields will exist when the conductor conducts ac current.

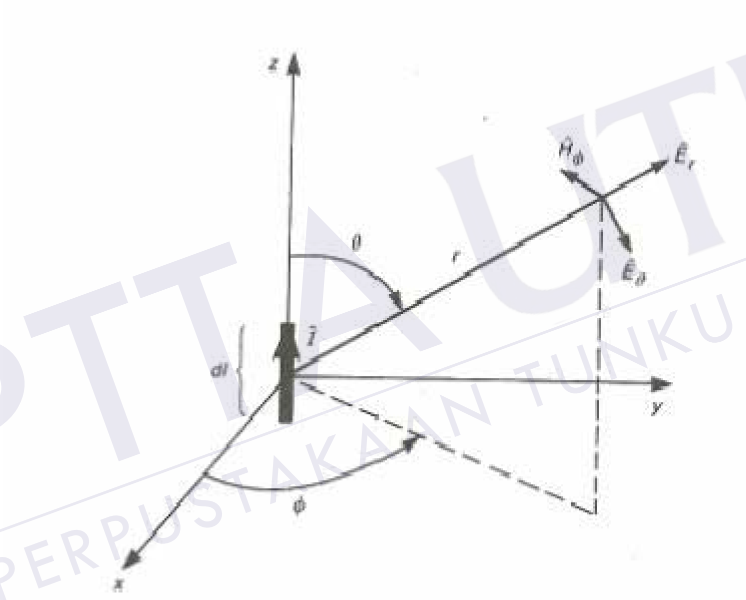

Fig 2.1: The electric (Hertzian) dipole [20]

The well-known mathematical forms of the time varying electric and magnetic field as shown in equation (2.1) are Maxwell's equations.

$$E_\theta = \frac{Z_o ID\pi \sin\theta}{\lambda^2}\left[-\left(\frac{\lambda}{2\pi r}\right)^3 \cos\varphi - \left(\frac{\lambda}{2\pi r}\right)^2 \sin\varphi + \left(\frac{\lambda}{2\pi r}\right)\cos\varphi\right]$$

$$E_r = \frac{2Z_o ID\pi \cos\theta}{\lambda^2}\left[\left(\frac{\lambda}{2\pi r}\right)^3 \cos\varphi + \left(\frac{\lambda}{2\pi r}\right)^2 \sin\varphi\right]$$

$$H_\phi = \frac{ID\pi \sin\theta}{\lambda^2}\left[\left(\frac{\lambda}{2\pi r}\right)^2 \sin\varphi + \left(\frac{\lambda}{2\pi r}\right)\cos\varphi\right] \qquad (2.1)$$

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In equation (2.1), this conductor is the short-wire Conductor. (Conductor length (D) is shorter than wavelength (λ))

$$D << \lambda$$

2.3.2 Near Field and Far Field

The boundary of near field and far field are defined by distanced from short wire to measuring point (r). If $r << \frac{\lambda}{2\pi}$, electromagnetic (EM) field will be "Near Field" and if $r >> \frac{\lambda}{2\pi}$, the EM field will be "Far Field".

The loop current power transformer. Is one of sources of low frequency magnetic field.

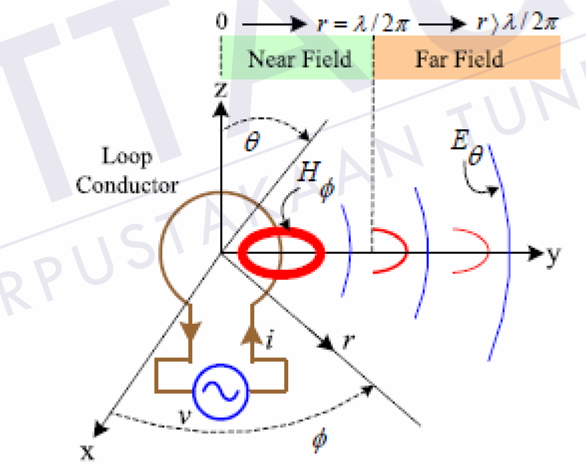

Fig. 2.2 Electric and magnetic field from loop current [21]

The electric field in the near field due to the loop current has small effect. Therefore, this study will be focusing on magnetic shielding.

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2.3.3 Characteristic and wave impedances

For a rod or straight wire antenna, the source impedance is high. The wave impedance near the antenna predominantly an electric field is also high. As distance is increased, the electric field loses some of its intensity as it generates a complementary magnetic field. In near field, the electric field attenuated at a rate of $(1/r)^3$, whereas the magnetic filed attenuates at a rate of $(1/r)^2$. Thus, the wave impedance from a straight wire antenna decreases with distance and asymptotically approaches the impedance of free space in the far field.

For a predominantly magnetic field such as produced by loop antenna the wave impedance near the antenna is low. As the distance from the source increases, the magnetic field attenuated at a rate of $(1/r)^3$ and the electric field attenuated a rate of $(1/r)^2$. The wave impedance therefore increases with distance and approaches that of free space at distance of $\lambda/2\pi$. In the far field, both the electric and magnetic field attenuated at a rate of $1/r$, as shown in Fig 2.3.

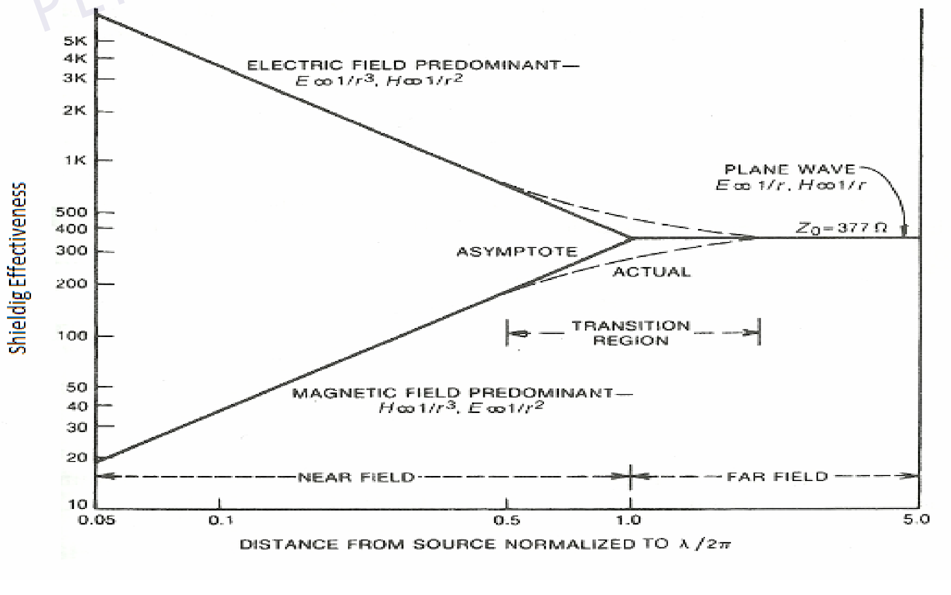

Fig 2.3: Wave impedance depends on the distance from the source [9]

For any electromagnetic wave, the wave impedance is defined as

$$Z_w = \frac{E}{H} \tag{2.2}$$

Where: E the electric field, and H the magnetic field.

The characteristic impedance of a medium is defined by the following expression:

$$Z_0 = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} \tag{2.3}$$

Where: μ is the permeability, σ is the conductivity, and $\omega = 2\pi f$.
Where f is frequency,

In the case of plane wave in the far field, Z_0 is also equal to the wave impedance Z_w. For insulators $(\sigma << j\omega\varepsilon)$ the characteristic impedance is independent of frequency and becomes

$$Z_0 = \sqrt{\frac{\mu}{\varepsilon}} \tag{2.4}$$

For free space, Z_0 equal 377 Ω. In the case of conductors $(\sigma >> j\omega\varepsilon)$, the characteristic impedance is called the shield impedance Z_s and it becomes

$$Z_s = \sqrt{\frac{j\omega\mu}{\sigma}} = \sqrt{\frac{\omega\mu}{2\sigma}}(1+j) \tag{2.5}$$

$$|Z_S| = \sqrt{\frac{\omega\mu}{2\sigma}} \tag{2.6}$$

2.4 Shielding Effectiveness (SE)

The SE can be defined as the ratio of electric or magnetic field in the shielded region and electro or magnetic field in the absence of shield

$$SE = -20\log\left(\frac{E_b}{E_a}\right) \quad dB \tag{2.7}$$

and

$$SE = -20\log\left(\frac{H_b}{H_a}\right) \quad dB \tag{2.8}$$

Where E_b electric field in the shielded region, E_a electro field in the absence of shield, H_b magnetic field in the shielded region, and H_a magnetic field in the absence of shield.

The mechanism of electromagnetic (EM) shielding can be described by three losses. First, The EM wave (incident wave) is propagating in the air to encounter the metal. Some is reflected as shown in Fig 2.4. So, it is attenuated by reflection, called “Reflection Loss”. Second, after the first reflection, the attenuated wave will propagate from air to metal at the left border. Then, it propagates through the metal to the right border. Some is absorbed in the metal, called “Absorption Loss”, this loss is depended on the thickness and permeability of the metal.

Third, the EM wave inside the metal (after reflection and absorption) will encounter the metal at the right border. Some is reflected at this point or internal reflected, the EM wave is attenuated by internal reflection is called “Re-Reflection Loss”. The incident wave is much reduced by these losses.

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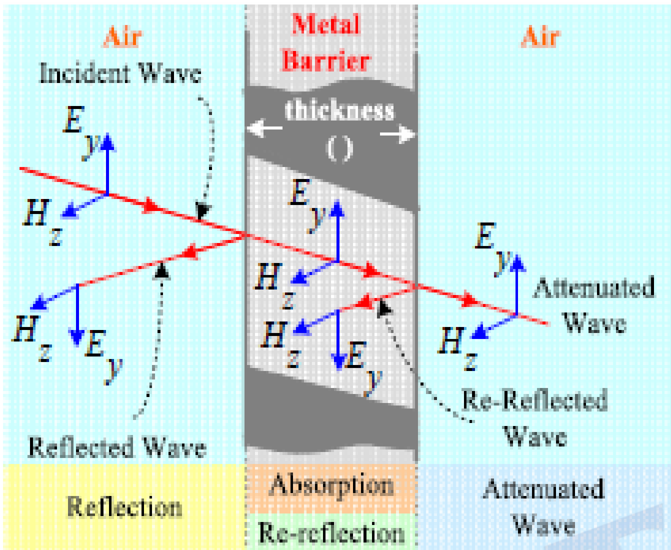

Fig. 2.4 Wave propagation through shielding material [21]

In addition, the electrons in a conductor move in response to the applied time-varying magnetic field. These moving electrons constitute current in the shield. Since all real conductors have a finite conductivity, energy is lost in the conductor will this charge flow. This loss reduces the strength of the field.

The total shielding effectiveness of a solid material with no apertures is equal to the sum of the absorption loss (A) plus the reflection loss (R) plus a correction factor (B) to account for multiple reflections in thin shields. Total shielding effectiveness therefore can be written as

$$S = A + R + B \quad (dB) \tag{2.9}$$

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2.4.1 Absorption loss

When an electromagnetic wave passes through a medium, its amplitude decreases exponentially. This decay occurs because currents induced in the shield produce ohmic losses and heating of the material. Therefore, we can write

$$E_1 = E_0 e^{-t/\delta} \tag{2.10}$$

and

$$H_1 = H_0 e^{-t/\delta} \tag{2.11}$$

Where $E_1(H_1)$, is the wave intensity at a distance t within the shield. The distance required for the wave to be attenuated to $1/e$ of its original value is defined as the skin depth, which is equal to

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{2.12}$$

The absorption loss through a shield can now be written as

$$A = 20\log\frac{H_0}{H_1} = 20\log e^{t/\delta} \tag{2.13}$$

$$A = 20\left(\frac{t}{\delta}\right)\log(e) \quad dB \tag{2.14}$$

$$A = 8.69\left(\frac{t}{\delta}\right) \quad dB \tag{2.15}$$

Substituting Equation (2.12) into Equation (2.15) gives the following general expression for absorption loss:

$$A = 3.34t\sqrt{f\mu_r\sigma_r} \quad dB \tag{2.16}$$

In this equation, t is equal the thickness of the shield in inches.

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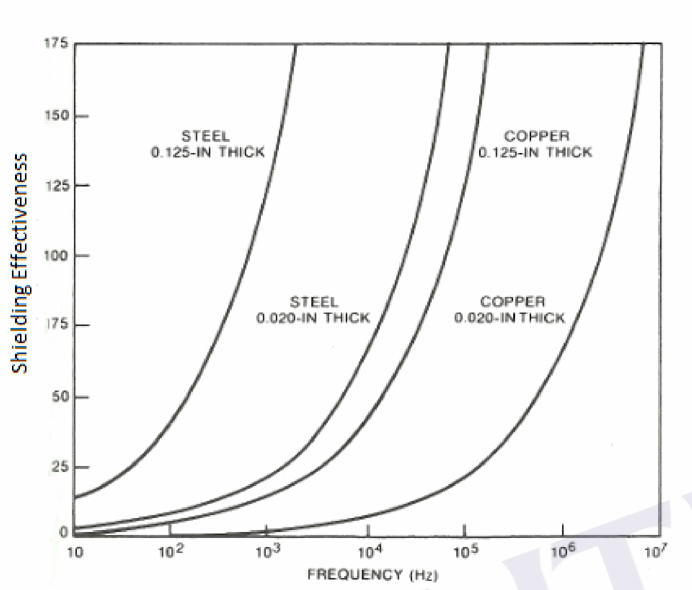

Fig 2.5: Absorption loss increases with frequency and with shield thickness [9]

Absorption loss versus frequency is plotted in Fig2.5, for two thicknesses of copper and steel. As can be observed, a thin (0.02 in) sheet of copper provides significant absorption loss(66 dB) at 1MHz, but virtually no loss at frequency below 1000Hz.Figure 2.5 clearly shows the advantage of steel over copper in providing absorption loss. Even when steel is used, however, a thick sheet must be used to provide appreciable absorption loss below 1000 Hz.

2.4.2 Reflection loss

The reflection loss at the interface between two media is related to the difference in characteristic impedance between the media as shown in Fig 2.6. The intensity of the transmitted wave from a medium with impedance Z_1 to a medium with impedance Z_2 is

$$E_1 = \frac{2Z_2}{Z_1 + Z_2} E_0 \qquad (2.17)$$

and

$$H_1 = \frac{2Z_1}{Z_1 + Z_2} H_0 \qquad (2.18)$$

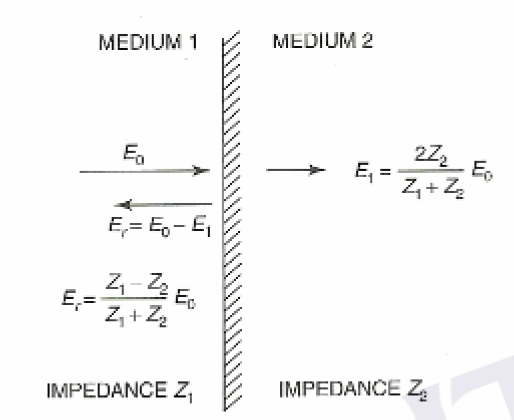

Fig 2.6: An incident wave is partially reflected from, and partially transmitted through, an interface two media [9]

$E_0(H_0)$ is intensity of the incident wave, and $E_1(H_1)$ is the intensity of the transmitted wave.

When a wave passes through a shield, it encounters two boundaries, as shown in Fig 2.7. The secondary boundary is between a medium with impedance Z_2 and a medium with impedance Z_1. The transmitted wave $E_1(H_1)$ through this boundary is given by

$$E_t = \frac{2Z_1}{Z_1 + Z_2} E_1 \qquad (2.19)$$

and

$$H_t = \frac{2Z_2}{Z_1 + Z_2} H_1 \qquad (2.20)$$

The total transmitted wave intensity is found by substituting Equations 2.17 and 2.18 into Equations 2.19 and 2.20, respectively. Therefore, for thick shields the total transmitted wave is

$$E_t = \frac{4Z_1Z_2}{(Z_1+Z_2)^2}E_0 \tag{2.21}$$

$$H_t = \frac{4Z_1Z_2}{(Z_1+Z_2)^2}H_0 \tag{2.22}$$

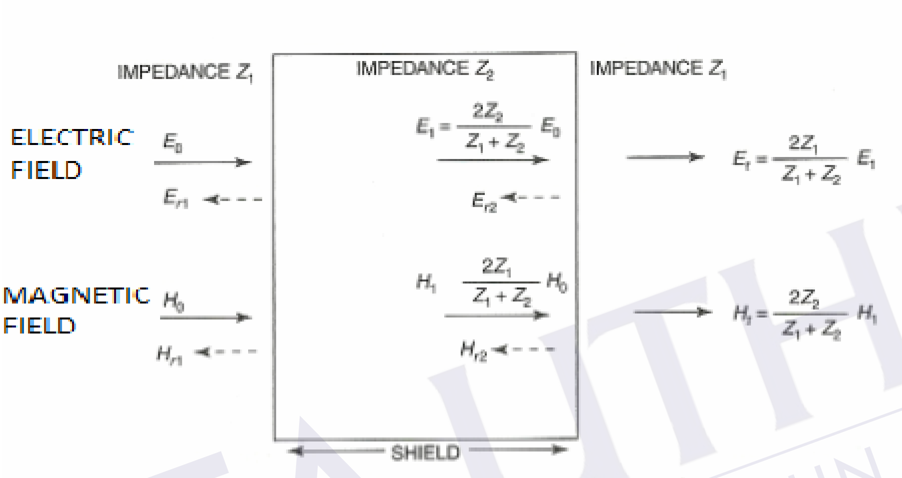

Fig 2.7: Partial reflection and transmission occur at both boundaries of a shield [9]

If the shields is metallic and the surround area an insulator, then $Z_1 >> Z_2$. Under these conditions, the largest reflection occurs when the wave enters the shield for the case of electric field, and when the wave leaves for the case of magnetic field.

$$E_t = \frac{4Z_2}{Z_1}E_0 \tag{2.23}$$

and

$$H_t = \frac{4Z_2}{Z_1}H_0 \tag{2.24}$$

$$R = 20\log\frac{H_0}{H_1} = 20\log\frac{Z_1}{4Z_2} = 20\log\frac{|Z_w|}{4|Z_s|} \quad dB \tag{2.25}$$

Where

Z_w = Impedance of wave prior to entering the shield,

Z_s = Impedance of shield

2.4.2.1 Reflection loss in the near field

In the near field, the ratio of the electric field to the magnetic field is no longer determined by the characteristic impedance of the medium. Instead, the ratio the electric field to the magnetic field depends more on the characteristics of the source. If the source has high voltage and low current, the wave impedance greater than 377Ω, and the field will be high impedance or electric field. If the source has low voltage and high current, then the wave impedance less than 377Ω, and the field will be low impedance or magnetic field.

Figure 2.8 shows that the reflection loss of an electric field decreases with frequency until the separation distance $\lambda/2\pi$. Beyond that, the reflection loss is the same as for a plane wave. The reflection loss of magnetic field increases with frequency, again until the separation becomes $\lambda/2\pi$. Then, the loss begins to decrease at the same rate as that of plane wave.

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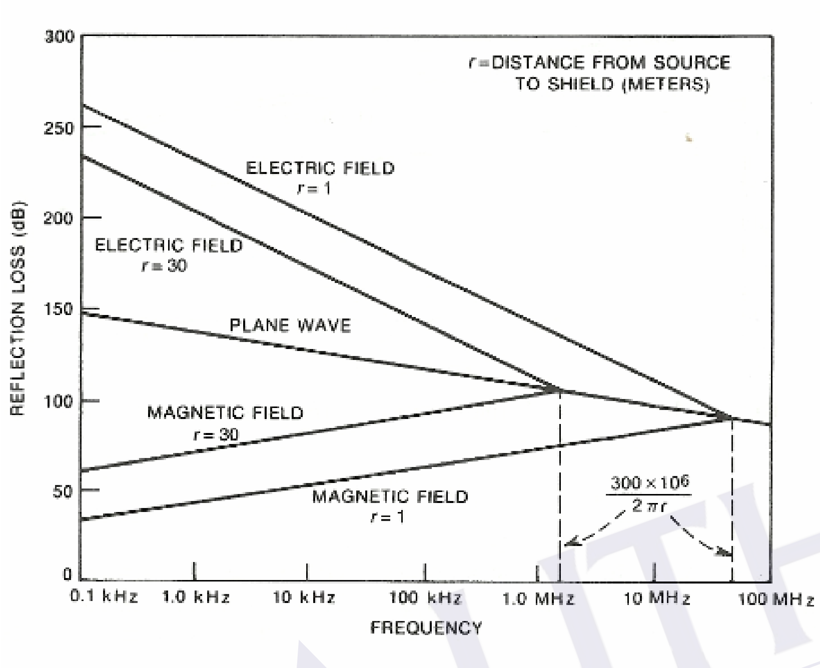

Fig 2.8: Reflection loss in a copper shield varies with frequency, distance from the source, and type of wave [9]

2.4.3 Multiple reflections in thin shields

If the shield is thin, the reflected wave from the second boundary is re-reflected off the first boundary, and then it returns to the second boundary to be reflected again, as shown in Fig 2.9. This can be neglected in the case of a thick shield, because the absorption loss is high. By the time the wave reaches the second boundary for the second time, it is of negligible amplitude, because by then it has passed through the thickness of the shield three times.

For electric fields, most of the incident wave is reflected at the first boundary, and only a small percentage enters the shield. Therefore, multiple reflections within the shield can be neglected for electric fields.

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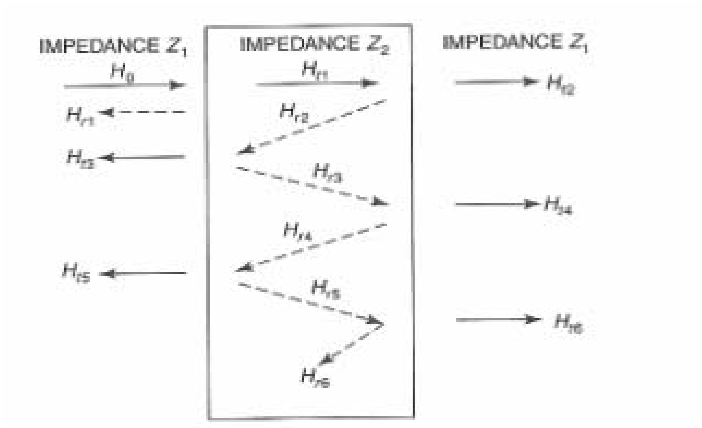

Fig 2.9: Multiple reflections occur in a thin shield; part of the wave is transmitted through the second boundary at each reflection [9]

For magnetic fields most of the incident wave passes into the shield at the first boundary. The magnitude of the transmitted wave is actually double that of the incident wave. With a magnetic field of such large magnitude within the shield, the effect of multiple reflections inside the shield must be considered.

The correction factor for the multiple reflection of magnetic field in a shield of thickness t and skin depth δ is

$$B = 20\log(1 - e^{-2t/\delta}) \quad dB \qquad (2.26)$$

2.4.4 Composite Absorption and Reflection Loss in Magnetic Field

In the near field, the reflection loss to a low frequency magnetic field is small. Because of multiple reflections, this effect is even pronounced in a thin shield. The primary loss for magnetic fields is absorption loss. Because both the absorption and reflection loss are small at low frequencies, the total shielding effectiveness is low. It is therefore difficult to shield low frequency magnetic fields. Additional protection against low frequency magnetic field can be achieved only by providing a low

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reluctance magnetic shunt path to divert the field around the circuit being protected. This approach is shown in Fig 2.10.

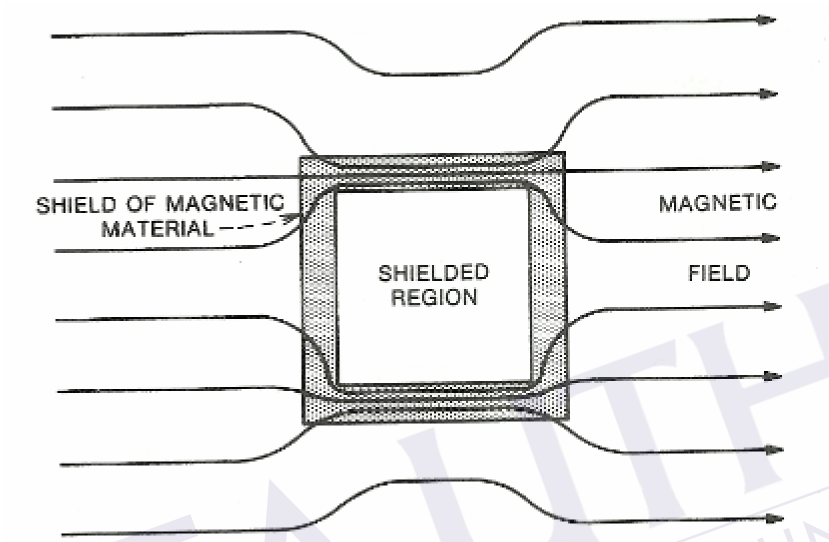

Fig 2.10: Magnetic material used as a shield by providing a low-reluctance for the magnetic field, diverting it around the shielded region [9]

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2.5 Wire Mesh Properties

The number of human beings has to work or reside in places where EMI is considerable. So they suffer physically or psychologically. Hence EMI-shield has become a necessity.

For example Copper may be used to reflect electric field and mu-metal may be taken to absorb magnetic field. But the piece of mu-metal must be thick. This makes the apron weightier. So there should be optimization between the weight of shield and the magnetic field to cancel by the electromagnetic shield.

A wire mesh is often used to provide shielding in place of a solid metal sheet. A mesh is cheaper, lighter, and also allows for air flow – which is particularly important for shield under transmission line in the public area like car park or bus stop etc. The downside is its electromagnetic properties are more complex.

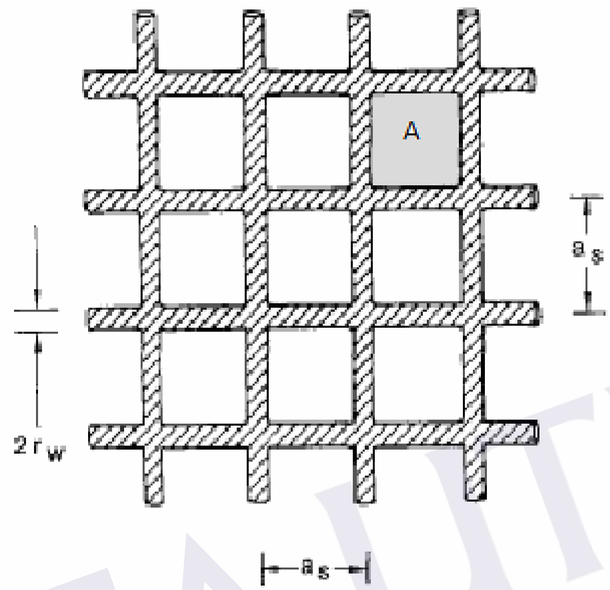

Fig.2.11 Geometry of the wire mesh

2.5.1 Design of wire mesh shields

The shielding effectiveness (S.E.) of materials for electric field:

1. Decreases with increase in frequency.
2. Increases with increase in the density of material.

The shielding effectiveness (S.E.) of material for magnetic field:

3 Increases with increase in frequency.

4 Increases with increase in density of material.

5 Increases with increase in permeability of the material of the shield.

During design the following precautions have been taken:

1. All the apertures are of same dimensions.
2. Each intersection has a good electrical contact.

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2.5.2 The size of apertures

In order to be effective, a size of aperture must be as tight as possible. Figures 2.12 and 2.13 illustrate how a magnetic and an electric field, respectively, will pass through a hole.

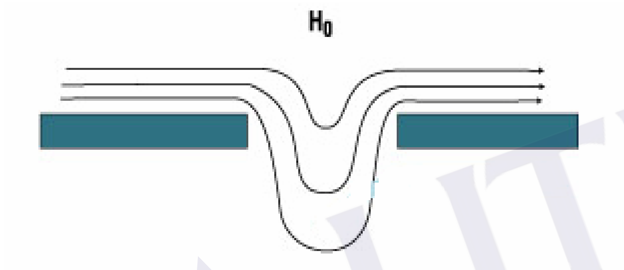

Fig 2.12 An H-field which is predominantly
Tangential close to a metallic screen

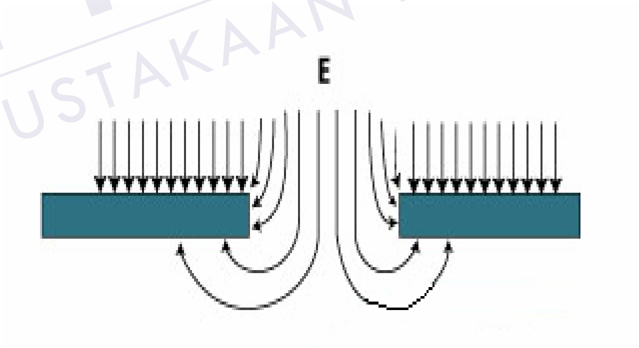

Fig 2.13 An E-field which will hit a metallic
Screen at right angles

Multiple small apertures will provide better protection than a single large one. In such cases, the field will not be able to penetrate very long if the diameter is small compared to the wavelength.

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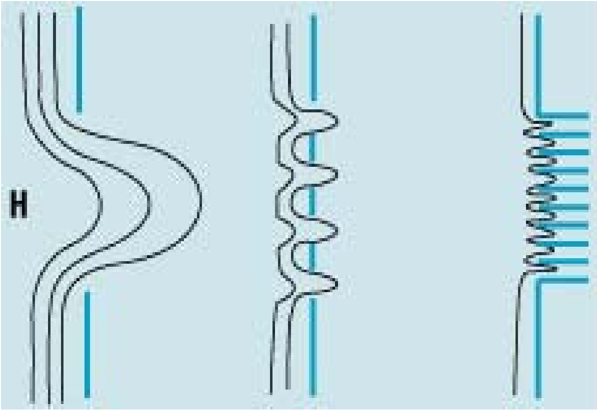

Fig 2.14 Multiple small openings are preferable
To a single large one

2.6 Shielding material

The choice of the most effective shielding material depends on frequency. At low frequency, high permeability magnetic materials are most effective. Mild steel one of several high permeability magnetic shielding materials

2.6.1 Mild Steel

Mild steel is a type of steel alloy that contains a high amount of carbon as a major constituent. An alloy is a mixture of metals and non-metals, designed to have specific properties. Steel is any alloy of iron, consisting of 0.2% to 2.1% of carbon, as a hardening agent. Besides carbon, there are many metal elements that are a part of steel alloys. The elements other than iron and carbon, used in steel are chromium, manganese, tungsten and vanadium.

2.5.1.1 Mild Steel Properties

- A high amount of carbon makes mild steel different from other types of steel. Carbon makes mild steel stronger and stiffer than other type of steel. However, the hardness comes at the price of a decrease in the ductility of this alloy. Carbon atoms get affixed in the interstitial sites of the iron lattice and make it stronger.

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• It has ferromagnetic properties, which make it ideal for manufacture of electrical devices and motors.

• Mild steel is the cheapest and most versatile form of steel and serves every application which requires a bulk amount of steel.

2.7 Shielding effectiveness of wire mesh shield

At low frequency the shielding effectiveness of wire mesh for magnetic field can be derived from the transfer function

$$T_m(j\omega) = \frac{magnetic \cdot field \cdot in \cdot the \cdot shield \cdot region}{magnetic \cdot field \cdot in \cdot the \cdot absence \cdot of \cdot shield} \tag{2.27}$$

Considering a plane wave, Equation 2.27 can be written as [4]

$$T_m(j\omega) = \left(1 + \frac{j\omega\mu_0}{nZ_s}\right)^{-1} \tag{2.28}$$

Where:

n = 1 for the parallel-mesh geometry

n = 2 for the cylindrical geometry;

n = 3 for the spherical geometry.

In the case, we can consider the parallel-mesh geometry.

It is clear that the quantity *a/n* is simply the volume-to-surface ratio $\left(a = \frac{V_e}{S_e}\right)$,

therefore, (2.28) becomes:

$$T_m(j\omega) = \left(1 + \frac{j\omega\mu_0 V_e}{Z_s S_e}\right)^{-1} \tag{2.29}$$

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