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# Electrical and Magnetic Properties of Materials for Electromagnetic Interference

**[1] Samir A Hamouda, [2] Naji S Amneenah**
[1, 2] Department of Physics, University of Benghazi, Libya

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Corresponding Author: **Samir A Hamouda**

**Abstract**
General aspects about electromagnetic interference (EMI) have shown that various electronic and electrical devices, in the field of communications are very sensitive to many sources (emissions) of external electromagnetic waves with various bands of frequency components. All electrical equipment using radio communication contains intentional emitters and sensitive receivers. Since electrical and magnetic materials have different properties, the objective of this paper is to explore the shielding effectiveness of some materials and to suggest new compounds that satisfies the effective shielding requirements.

**Keywords:** Absorption Loss, Reflection Loss, Electromagnetic Compatibility, Shielding Materials, Electromagnetic Emissions

## Introduction

General aspects about electromagnetic interference (EMI) and case histories have been introduced elsewhere [1]. The study showed that various electronic and electrical devices, in the field of communications are very sensitive to many sources (emissions) of external electromagnetic waves with various bands of frequency components. All electrical equipment generates some level of electromagnetic emission as a side effect of its operation. It also has the potential to be affected by incident electromagnetic energy. Equipment using radio communication contains intentional emitters and sensitive receivers [2].

Sources of electromagnetic emissions can be electric motors, relays, fluorescent lights, lightning, magnetic storms, high-voltage power transmission lines, radio transmitters and radar transmitters. In addition, it was stated by [3] that another important and increasingly significant source of electromagnetic emissions is associated with digital computers in particular and digital electronic devices in general. These sources can cause interference (the reception of an unintended) signal or noise to be superimposed on the desired signal in various electrical and electronic devices. It was pointed out by [3] that a strong transmission from an FM radio station or TV station may be picked up by a digital computer, causing the computer to interpret it as data or a control signal resulting in incorrect function of the computer. On the other hand, a digital computer may create emissions that couple into a TV, causing interference.

It can be stated that, the basic principle of EMC is that electromagnetic emission of electrical equipment, whether intentional or unintentional, must not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended and must not exceed the immunity of associated equipment. Which implies that controls must be in place on both emission and immunity [2, 4]. Unfortunately, as the electromagnetic environment becomes more complex, this goal becomes more difficult to achieve [5].

Therefore, it is of great importance to look deeply and into these problems which are resulted from development and intensive technological application in electronic and electrical systems, raise awareness of them, and try to reduce their severity in the environment. In order to reduce the EMI impacts on electrical and electronic devices and in the environment, specific criteria must be setup. Such criteria imply that an electronic system that is electromagnetically compatible with its environment should be able to function compatibly with other electronic systems and not produce or be susceptible to interference or causes interference with itself [3]. Fig 1 shows the main processes by which an electromagnetic interference may occur.

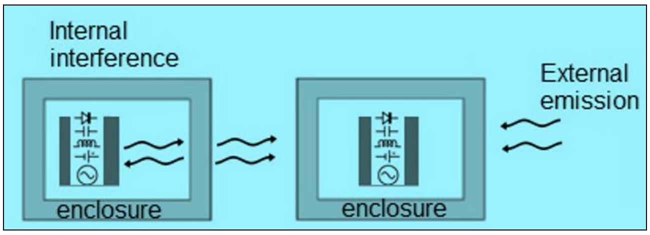



**Fig 1:** Shows sub-electronic units subjected to EMI

However, to achieve the required standards, knowing the electrical and magnetic properties of materials is central. For example, electronic systems enclosed in metallic enclosures may induce currents on these enclosures by internal signals or external signals. These induced currents can then radiate to the external environment or to the interior of the enclosure [3]. On the other hand, the use of nonmetallic enclosures for electronic circuits, such as plastic, are, completely exposed to electromagnetic emissions, and can directly radiate or be susceptible to these emissions [3].

It can be stated that to have good shielding materials against EMI, the above criteria must be satisfied. A reasonable approach to this problem is to look at the nature of the electromagnetic wave. The electromagnetic wave is made up of two parts: Electric and magnetic. It consists of electric components and magnetic components with various amplitudes perpendicular to each other. Fig 2 shows the electrical and magnetic components of the electromagnetic wave. Table 1 gives some values of their frequencies and wavelengths.

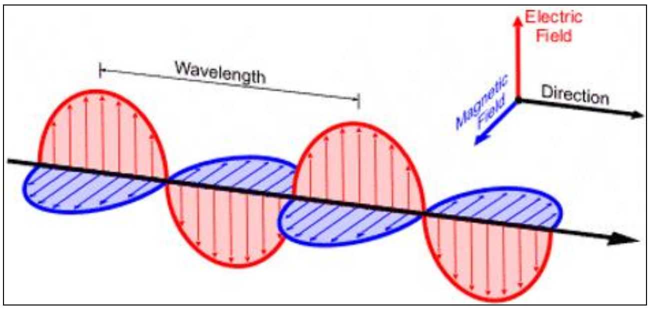



**Fig 2:** Electromagnetic wave

**Table 1:** Frequencies and corresponding wavelengths of the electromagnetic wave [3]

| Frequency ($f$) | Wavelength ($\lambda$) |
|---|---|
| 60 Hz | 3107 miles (5000 km) |
| 3 kHz | 100 km |
| 30 kHz | 10 km |
| 300 kHz | 1 km |
| 3 MHz | 100 m |
| 30 MHz | 10 m |
| **300 MHz** | **1 m** |
| 3 GHz | 10 cm |
| 30 GHz | 1 cm |
| 300 GHz | 1 mm |

Due to the nature of electromagnetic wave, studying the electrical and magnetic properties of materials and their interactions with the electromagnetic wave is essential. The interaction of the electromagnetic wave with matter alters the dielectric and magnetic properties of existing materials namely, their permittivity and the magnetic permeability. Permittivity is related to electrical conductivity (σ) and magnetic permeability is related to the magnetic susceptibility (χ).

### Electrical Conductivity (σ)

Electrical conductivity, σ, is a measure of a material's ability to carry an electrical current. It ranges in value from $10^{-18}$ to $10^{7}$ S $m^{-1}$ (Siemen per meter), depending on the material. Such a measure is connected mainly with the electrons in the outermost shell of atoms in the material. These electrons are responsible for the electrical, magnetic, and chemical behaviour of substances [6]. The electrical conductivity (σ), is the reciprocal of resistivity (ρ), as:

$$\sigma = \frac{1}{\rho} \qquad (1)$$

The resistivity (ρ) $(\Omega.m)$ of material is independent of specimen geometry and is related to the resistance (R) through the relation:

$$\rho = \frac{RA}{L} \qquad (2)$$

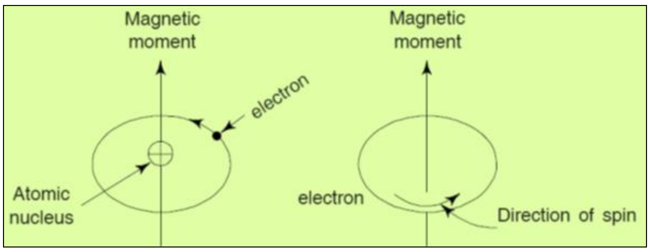
Where R is the resistance of the material, A is the area of cross-section perpendicular to the direction of the current and *l* is the distance between the two points of the specimen at which the voltage is measured [6].

### Magnetic Properties of Materials

It is a fundamental fact that magnetic fields are produced as a result of motion or spin of electric charges. On the other hand, the magnetic effect appears in those atoms with unpaired electrons. These unpaired electrons cause magnetic fields due to their net magnetic moment. A magnetic moment arises whenever a charged particle has an angular momentum. Each electron in an atom has magnetic moments that originate from the following two sources [6].

(i) Orbital magnetic moment of electrons

(ii) Spin magnetic moment of electrons.




(i) (ii)

**Fig 3:** (i) Magnetic moment due to an electron orbital motion. (ii) Magnetic moment due to an electron spin [6]

Magnetic materials mean anything that can be influenced or attracted by a magnet. Magnetic materials are classified mainly according to their magnetic properties, into three principle classes: Diamagnetic, paramagnetic and ferromagnetic materials.

- A paramagnetic material has a small but positive magnetic susceptibility **(χ > 0)**. Paramagnetic material has a small number of unpaired electrons and can be slightly attracted to an external magnetic field but it does not retain its magnetic properties when the source of the magnetic field is removed.

- A diamagnetic material has a weak and negative magnetic susceptibility (**χ < 0**). Diamagnetic materials are slightly repelled by an external magnetic field. Atoms of diamagnetic materials are characterized by paired electrons; thus, the net magnetic moment of the material is zero.
- A Ferromagnetic material has a large, positive susceptibility **(χ >> 0)** to an external magnetic field. It exhibits a strong attraction to magnetic fields and is able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have large number of unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains [6].

Perhaps the most important parameter in magnetism is the term magnetic susceptibility. Magnetic susceptibility refers to the degree to which a material becomes magnetized in response to an applied magnetic field. It is a dimensionless quantity that measures the ratio of the magnetization (**B**) of a material to the applied magnetic field (**H**).

$$B = \mu . H \quad (3)$$

Where μ is the permeability of the medium through which the magnetic lines of force pass. The permeability, μ is related to the relative permeability $\mu_r$ as.

$$\mu_r = \frac{\mu}{\mu_0} \quad (4)$$

The magnitude of the magnetization, **(M)** is proportional to the applied field **(H)** as follows:

$$M = \chi . H \quad (5)$$

The magnetic susceptibility **(χ)** and the relative permeability **($\mu_r$)** are related as follows:

$$\chi = \mu_r - 1 = \frac{M}{H} \quad (6)$$

It can be stated that for good Rf and microwave absorbers, the materials should have high absorption loss and high reflection loss [7]. The absorption loss and the reflection loss relations are given as [7]:

$$\text{Absorption loss} = \sigma . \mu_r \quad (7)$$

$$\text{Reflection loss} = \frac{\sigma}{\mu_r} \quad (8)$$

Where $\mu_r$ is the relative magnetic permeability and σ is the electrical conductivity.

Tabulated data for the electrical conductivity and relative magnetic permeability are given in Table 2 [8, 9].

The materials used in RF shields make or break their ability to function. Radio frequency interference demands incredible shielding effectiveness. That’s because it is the materials themselves that reflect, redirect, or absorb incoming RF signals [10].

It can be seen from Table 2 that copper is highly conductive ($5.8 \times 10^7$ Ω.m) with the exception of silver and is good RF (high reflection loss) shielding materials. Drawback to copper is the fact that it is a diamagnetic metal. Copper has low magnetic permeability ($\mu_r$), therefore, it is a poor magnetic shielding material for low frequency and DC [11]. This is because of its atomic structure. In nature, magnetism in metals is a result of an unpaired distribution of electrons within the atomic structure of the magnetic material. In general, Copper is considered as one of the most effective materials used in RF shields. While copper can be relatively expensive, it provides highly effective conduction, absorption and attenuation of incoming RF signals [10].

On the other hand, aluminum has 50-60% of conductivity of copper. It is a paramagnetic metal and has low magnetic permeability ($\mu_r$), therefore, it is a poor magnetic shielding material for low frequency. It provides less conductivity, yet still effective, radio frequency shielding material [10].

**Table 2:** Electrical conductivity ($\sigma_r$) and magnetic permeability ($\mu_r$) relative to copper for some metals [8, 9]

| Z | Electrical conductivity *σ (S/m) | $\sigma_r$ | Relative magnetic permeability (*$\mu_r$) | $\sigma_r \mu_r$ | $\sigma_r/\mu_r$ |
|---|---|---|---|---|---|
| Ag | $6.2\times10^7$ | 1.05 | 0.99999981 | 1.05 | 1.05 |
| Cu | $5.9\times10^7$ | 1.00 | 0.999994 | 1.00 | 1.00 |
| Al | $3.8\times10^7$ | 0.64 | 1.00000065 | 0.64 | 0.64 |
| Au | $4.5\times10^7$ | 0.76 | 0.9999716 | 0.57 | 0.76 |
| Ca | $2.9\times10^7$ | 0.49 | 1.00002139 | 0.49 | 0.49 |
| Rh | $2.3\times10^7$ | 0.39 | 1.0001693 | 0.39 | 0.39 |
| Na | $2.1\times10^7$ | 0.36 | 1.0000036 | 0.36 | 0.36 |
| W | $2.0\times10^7$ | 0.34 | 1.000068 | 0.34 | 0.34 |
| Ni | $1.4\times10^7$ | 0.24 | 100 | 24 | $2.4\times10^{-3}$ |
| K | $1.4\times10^7$ | 0.24 | 1.0000057 | 0.24 | 0.24 |
| Li | $1.1\times10^7$ | 0.17 | 1.0000137 | 0.17 | 0.17 |
| Pd | $1.0\times10^7$ | 0.17 | 1.0007899 | 0.17 | 0.17 |
| Rb | $8.3\times10^6$ | 0.14 | 1.0000039 | 0.14 | 0.14 |
| Sr | $7.7\times10^6$ | 0.13 | 1.00000347 | 0.13 | 0.13 |
| Cr | $7.9\times10^6$ | 0.13 | 1.0003177 | 0.13 | 0.13 |
| Nb | $6.7\times10^6$ | 0.11 | 1.000237 | 0.11 | 0.11 |
| V | $5.0\times10^6$ | 0.08 | 1.0003837 | 0.08 | 0.08 |
| Ba | $2.9\times10^6$ | 0.05 | 1.00003966 | 0.05 | 0.05 |
| Fe | $1.0\times10^7$ | 0.17 | 5500 | 935 | $3.1\times10^{-5}$ |

Iron and other ferromagnetic materials have much higher magnetic permeability compared to copper or aluminum, and can more effectively absorb and redirect the magnetic field of the EM wave, thereby providing better shielding for low frequency magnetic fields. However, the selection of RF shielding materials should be based on the type of shielding needs. Magnetic permeability is a material's ability to induce an internal magnetic field by an external magnetic field. This property makes iron a preferred choice for applications where magnetic shielding is important, such as in electrical and electronic equipment and devices.

Once the proper shielding materials for (EMI) are selected, it is important to calculate the required thicknesses. One calculation deals with the absorption loss. The absorption property of shielding material is characterized by the term skin depth (δ). The skin depth δ is defined as the minimum thickness or the distance over which the magnitude of the electric and magnetic field is attenuated to 1/e ≅0.3681 (37%) of its initial strength. The skin depth (δ) is given as [7, 11]:

$$\delta = \frac{1}{\sqrt{\pi\sigma\mu f}} \qquad (9)$$

Where: f is frequency, μ is magnetic permeability ($\mu_0\mu_r$), $\mu_r$ is relative magnetic permeability $\mu 0 = 4\pi \times 10^{-7}$ H/m, and σ is the electrical conductivity ($\Omega^{-1}$. $m^{-1}$).

It can be seen from equation that it depends on conductivity, magnetic permeability and frequency of the incident wave. As these parameters increase, the thickness of the shielding material decreases.

Table 3 gives the skin depth (δ) values for some selected materials at different frequencies using equation9.

**Table 3:** Calculated skin depth (δ) for some elements. Parameters are shown

| Material Z | δ(cm) at 1kHz | δ(μm) at 1MHz | δ(μm) at 1GHz |
|---|---|---|---|
| Cu | 0.2062 | 0.652 | 2.06 |
| Al | 0.2594 | 0.820 | 2.59 |
| Au | 0.2383 | 0.753 | 2.38 |
| Ag | 0.2005 | 0.634 | 2.00 |
| Ni | 0.0170 | 5.371 | 0.172 |

It can be seen that the skin depth (δ) deceases with increasing frequency and with increasing magnetic permeability and electrical conductivity. At 1MHz the skin depth (δ) for copper, silver and to some extent gold are approximately the same. This is due to their diamagnetic nature. On the other hand, aluminum has higher skin depth (δ) at 1GHz comparing to copper and silver due to its paramagnetic nature. The lower skin depth (δ) value for nickel at 1GHz comparing to copper and silver is due to its ferromagnetic nature.

## Conclusion

Data have shown that there are some materials that have good property of reflecting electromagnetic waves, and there are other materials that have good property of absorbing electromagnetic waves. Since these materials have different properties, this requires research and finding materials that have both properties. Therefore, it is not easy to design a radio frequency (RF) shield that satisfied both requirements. In addition, (RF) shielding materials should be easy to form and fabricate, have light weights, do not oxidize rapidly when exposed to (STP) conditions, have high level of shielding effectiveness and cost effective. It can be summarized that researches should be directed toward finding new compounds that satisfies the effective shielding requirements or minimize them. This is a future task.

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