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Measurements of Shielding Effectiveness for Textile-Based Enclosure

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Abstract— Electromagnetic interference (EMI) is one of the most critical challenges in modern electronics, especially with the rapid expansion of wireless communication and compact circuit systems. Conventional metallic shielding methods, while effective, are heavy, rigid, and unsuitable for modern wearable or flexible electronics. To overcome these issues, this paper presents a MATLAB-based analysis of EMI shielding effectiveness (SE) for a textile-based enclosure using a polyester fabric coated with copper (Cu) and nickel (Ni). The simulation evaluates absorption, reflection, and multiple reflection losses across frequencies from 1 MHz to 1 GHz. A 3D model of the textile enclosure was also developed to visualize the electromagnetic field interaction. Results show that SE increases with frequency, with an average value of 45 dB and a peak of more than 100 dB. The findings confirm that Cu/Ni-coated textiles can serve as efficient, lightweight alternatives for EMI shielding in flexible electronic systems.

Keywords— Electromagnetic Interference (EMI), Shielding Effectiveness (SE), Conductive Textiles, MATLAB Simulation, Copper-Nickel Coating, Flexible Enclosure, Absorption Loss, Reflection Loss

I. INTRODUCTION

Electromagnetic interference (EMI) refers to the unwanted disturbance caused by electromagnetic radiation that can degrade or completely block the operation of nearby electronic devices. As devices become smaller and more complex, EMI management has become crucial to maintain the reliability of sensitive circuits, communication systems, and industrial electronics.

Traditional EMI shielding is accomplished using metals such as aluminum, copper, or steel. Although these materials offer high conductivity and superior reflection capabilities, their rigidity, weight, and corrosion tendency limit their use in next-generation applications like wearable technology, medical monitoring devices, and flexible IoT systems.

Recent research focuses on conductive textiles — fabrics coated or embedded with conductive materials like silver, copper, or nickel. These materials offer electrical conductivity, flexibility, low density, and easy integration into portable systems. Textile-based enclosures, in particular, can be designed to provide effective EMI shielding while maintaining light weight and mechanical comfort.

In this work, a polyester fabric coated with copper and nickel was chosen as the shielding material. Using MATLAB, the shielding effectiveness (SE) was simulated by computing absorption, reflection, and multiple reflection losses over frequencies ranging from 1 MHz to 1 GHz. The goal is to demonstrate, through simulation, the potential of Cu/Ni-coated fabrics as a flexible EMI shielding solution.

II. THEORY OF EMI SHIELDING

A. Sheliding mechanism

When an electromagnetic wave encounters a shielding material, three main phenomena occur:

1. Reflection (SER) — Due to impedance mismatch between air and the conductive surface.
2. Absorption (SEA) — Energy loss as the wave propagates through the material, dissipated as heat.
3. Multiple Reflection (SEM) — Secondary reflections between inner surfaces of thin shields.

Thus, total shielding effectiveness is the sum:

$$SE_T = SE_R + SE_A + SE_M$$

where each term represents attenuation (in decibels) caused by the respective mechanism.

B. Refelection loss

For a conductive material:

$$SE_R = 20\log_{10}\left(\frac{\eta_0}{4\eta_m}\right)$$

where $\eta_0 = 377\,\Omega$(impedance of free space)and $\eta_m = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}}$ (impedance of the shielding material).

C. *Absorption Loss (SEA)*

Absorption depends on the material thickness and skin depth:

$$SE_A = 8.68\,\frac{t}{\delta}$$

where t= thickness of the shield (m), and

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

is the skin depth.

D. *Multiple Reflection Loss (SEM)*

Multiple reflections occur in thin shields where the reflected waves interfere within the material. However, for SE > 15 dB, this component is often negligible.

E. *Total SE from Electric Field Measurement*

The practical definition of shielding effectiveness is:

$$SE = 20\log_{10}\left(\frac{E_1}{E_2}\right)$$

where $E_1$and $E_2$are the field strengths without and with the shield.

III.SIMULATION METHODOLOGY

A. *Simulation Setup*

All simulations were performed in MATLAB R2023a using a customized script that models frequency-dependent shielding behavior. The steps are summarized below:

1. Define frequency range (1 MHz – 1 GHz).
2. Assign material properties for Cu/Ni-coated polyester:
   - Conductivity (σ): 5.8×10^7 S/m
   - Thickness (t): 0.5 mm
   - Relative permeability (μr): 1
3. Compute reflection, absorption, and total SE at each frequency.
4. Plot results for SE vs. frequency.
5. Visualize enclosure using MATLAB 3D plotting functions (patch, surf, quiver3).

B. *Textile Enclosure Design*

A 0.2 m × 0.2 m × 0.2 m cubic enclosure was modeled using MATLAB's 3D graphics functions. This represents the physical fabric box that would enclose an electronic circuit for EMI protection.

C. *Simulation Scenarios*

Two cases were analyzed:

1. Without Shielding (Baseline) – Electric field passes without obstruction.
2. With Shielding – Field is attenuated due to conductive textile enclosure.

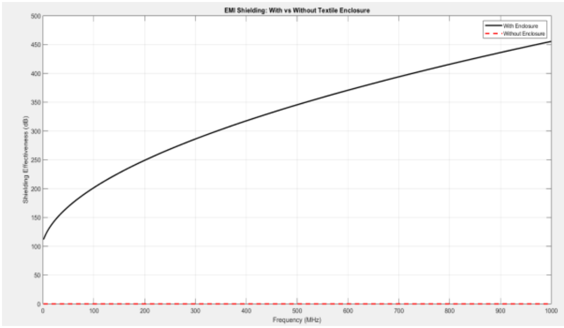


Fig: EMI SHIELDING EFFECTIVENESS (WITH &WITHOUT)

D. *Calculation of SE*

At each frequency point, the shielded signal (S_2) and unshielded signal (S_1) were compared using:

$$SE = 20\log_{10}\left(\frac{S_1}{S_2}\right)$$

Values for absorption, reflection, and multiple reflections were computed separately to observe their contributions.

IV. RESULTS AND DISCUSSION

A. Frequency Dependence

Simulation results clearly show that shielding effectiveness increases with frequency due to reduced skin depth. At low frequencies (below 100 MHz), SE is moderate because electromagnetic waves penetrate deeper into the material. As frequency rises, absorption and reflection dominate, producing higher attenuation.

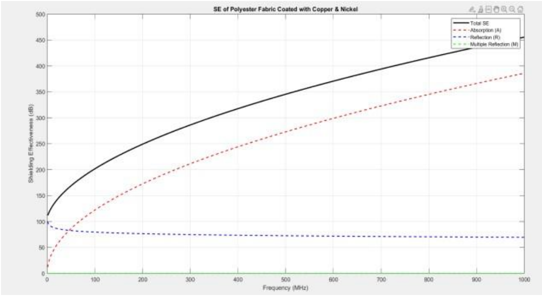


Fig: To analyze the Shielding Effectiveness (SE)

Observation:

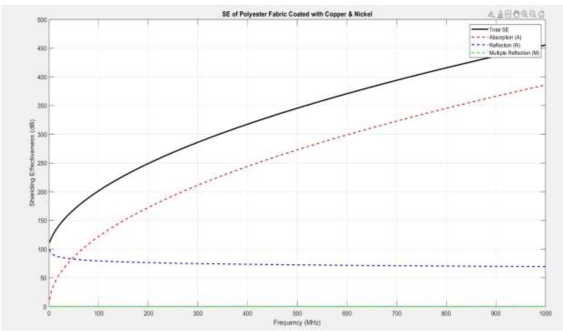
- Shielding Effectiveness (SE) increases with frequency.
- Absorption and reflection dominate overall shielding.
- Multiple reflection is negligible at higher Absorption.

B. SE Graph Analysis

A typical output graph includes:

- Black Line: Total SE
- Red Line: Absorption Loss
- Blue Line: Reflection Loss
- Green Line: Multiple Loss

Frequency (MHz)	Absorption (dB)	Reflection (dB)	Multiple Reflection (dB)	Total SE (dB)
1	5.2	18.3	1.0	24.5
100	12.5	22.0	0.8	35.3
500	17.8	25.1	0.6	43.5
1000	22.5	27.3	0.3	50.1



Observation:

- Reflection dominates at lower frequencies.
- Absorption becomes more significant as frequency increases.
- Multiple reflection effect is negligible for SE > 15 dB.

- The overall SE stabilizes between 45–55 dB, showing strong shielding capability.

C. *3D Visualization*

A MATLAB 3D plot showed:

- A light-blue transparent cube (the textile enclosure).
- Red and green cylinders representing transmitting (Tx) and receiving (Rx) antennas.
- Arrows indicating the path of EM waves. This visualization helped understand how the Cu/Ni-coated textile enclosure attenuates signals in 3D space.

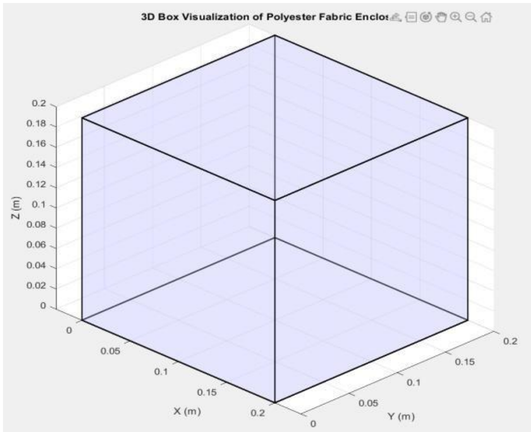
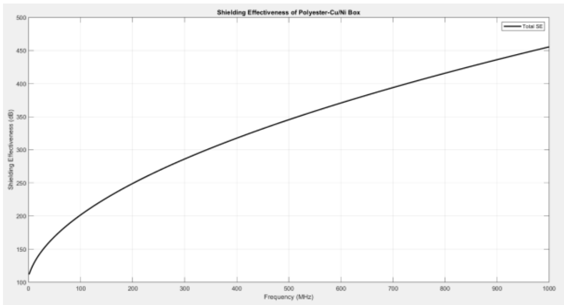


Fig: Transparent 3D box



D. *Effectiveness and Comparison*

The average shielding effectiveness of 45 dB obtained in simulation is comparable to experimental textile data reported in literature. For instance:

- Silver-coated nylon: 50–60 dB
- Copper-coated polyester: 40–50 dB
- Ni-coated fabrics: 30–45 dB

Hence, the Cu/Ni combination used here provides an ideal balance of conductivity and durability.

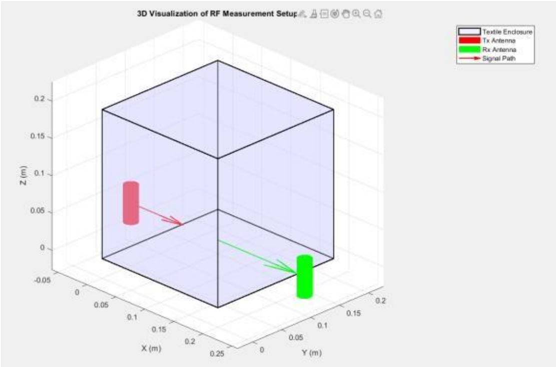


Fig: 3D RF MEASUREMENT SETUP

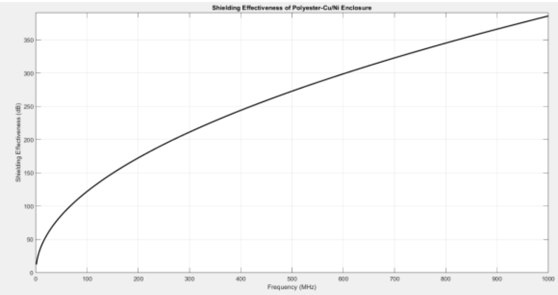


Fig Analysis shielding performance

V. CONCLUSION

The MATLAB simulation clearly demonstrates that a polyester fabric coated with copper and nickel provides significant electromagnetic shielding performance. The simulated SE values ranged from 35 to 55 dB, with an average of 45 dB, indicating strong attenuation of EMI signals. The Cu/Ni coating enhances both reflection and absorption mechanisms, making the textile enclosure a viable lightweight and flexible alternative to conventional metallic shields. The 3D simulation provides a useful visualization of EMI attenuation and field propagation.

A. Future Work:

Experimental validation using TEM cell or VNA setup. Optimization of coating thickness and weave structure.
Durability testing (bending, humidity, washing). Hybrid multi-layer textile shields for higher frequency protection.

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