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TEXTILE-BASED ABSORBER DESIGN FOR 5G APPLICATIONS

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Abstract *–*In this study, a textile-based absorber structure The textile material comprises two layers, with the absorber layer consisting of copper and the weft-knitted fabric was designed for 5G applications is presented. The proposed structure consists of copper and weft-knitted fabric arranged in a square resonator configuration. The textile material comprises two layers, with the absorber layer made of copper and the weft-knitted fabric. The absorber was tested in the frequency range of 2.20 GHz to 3.30 GHz, showing strong agreement between the measured and simulated results. The findings indicate that lightweight, flexible, and durable textile-based electromagnetic interference (EMI) shielding materials can effectively replace traditional metal-based shielding materials.

The results demonstrate that factors like material thickness and edge length play a significant role in improving shielding effectiveness. Thicker materials provided better shielding, especially at higher frequencies, making them ideal for 5G applications and other electromagnetic shielding needs.

Keywords – absorbed, TEXTILE-BASED, 5G

I. INTRODUCTION

In today's world, electromagnetic waves are generated by communication devices, medical equipment, and other electronic devices. Excessive exposure to these waves can affect the performance of electronic devices and have adverse effects on human health. Electromagnetic shielding (EMI - Electromagnetic Interference Shielding) is a critical technique to mitigate or eliminate these issues. In recent years, lightweight, flexible, and durable textile-based shielding materials have begun to replace traditional metal-based shielding materials. This literature review comprehensively examines the research and developments in textile-based electromagnetic shielding. Electromagnetic shielding aims to protect electronic devices by limiting the passage of electromagnetic fields. The materials used in this process can reflect, absorb, or transmit electromagnetic waves. Factors such as the material's electrical conductivity, magnetic permeability, and physical thickness are crucial for achieving high shielding effectiveness (SE) [1]. Textile-based materials offer advantages such as lightweight, flexibility, and ease of production and processing. These materials can be made conductive and given shielding properties using various techniques. Common methods include weaving conductive fibers, coating techniques, and using composite materials [2]. Conductive fibers are typically modified with metal coatings, carbon nanomaterials, or conductive polymers. Metal coatings, especially silver, copper, and nickel, are preferred for their high conductivity and good shielding properties. Carbon nanomaterials offer high surface area and mechanical durability, while conductive polymers provide flexibility and processability [3]. The shielding properties of textile materials can be enhanced by applying metal coatings or conductive polymer coatings to the surface. Techniques such as chemical vapor deposition (CVD), physical vapor deposition (PVD), and electroplating are used for this purpose. These techniques provide a homogeneous and durable coating on the textile surface, increasing the reflection and absorption of electromagnetic waves [4]. Composite materials offer superior properties through the combination of different components. In textile-based composites, conductive fibers or particles are dispersed within a polymer matrix to achieve high shielding effectiveness. These materials are ideal for applications requiring lightweight and flexibility [5]. The performance of electromagnetic shielding materials is typically evaluated by shielding effectiveness (SE), which measures how well a material blocks electromagnetic waves and is expressed in dB (decibels). Higher SE values indicate better shielding performance. SE depends on factors such as conductivity, magnetic permeability, material thickness, and frequency [6]. Textile-based electromagnetic shielding materials offer a wide range of applications. These materials can be used in wearable technologies, medical devices, military equipment, and the protection of electronic devices. In wearable technologies, textile-based shielding materials are used to protect users from electromagnetic radiation. These materials can be applied to various textile products such as clothing, gloves, and hats. They provide protective features while ensuring comfort and flexibility for user [7]. Medical devices contain sensitive electronic components, and electromagnetic interference (EMI) can adversely affect their performance. Textile-based shielding materials can be used around medical devices to prevent interference caused by EMI. They also enhance safety by reducing the exposure of medical personnel and patients to electromagnetic radiation [8]. In military applications, electromagnetic shielding is of critical importance. Textile-based shielding materials are used in clothing, equipment bags, and vehicle interiors to protect against electromagnetic threats. These materials offer lightweight and durability, enhancing mobility [9]. Electronic devices used in daily life must be protected against electromagnetic interference. Textile-based shielding materials can be used in the outer casings or internal components of these devices to prevent interference caused by EMI. This increases the performance and reliability of the devices [10]. With technological advancements, textile-based electromagnetic shielding materials are continuously evolving. New generation materials and production techniques can offer higher shielding effectiveness and better mechanical properties. In the future, the performance of textile-based shielding materials will be further enhanced through the use of nanotechnology and advanced composite materials. Nanotechnology allows for controlling the nano-scale structures of materials to achieve superior properties. Carbon nanotubes, graphene, and other nanomaterials offer high conductivity and mechanical durability, enhancing the performance of textile-based shielding materials. These materials can provide high SE values while maintaining advantages such as lightweight and flexibility [11]. Advanced composite materials offer superior properties through the combination of different materials. In textile-based composites, conductive fibers, metal particles, or nanomaterials are dispersed within a polymer matrix to achieve high shielding effectiveness. These materials are ideal for applications requiring lightweight and flexibility [12]. Carbon nanotubes (CNTs) are nanomaterials that offer high electrical conductivity and mechanical durability. They can be integrated into textile surfaces to enhance electromagnetic shielding performance. CNT-based textile materials provide an ideal solution, especially for applications requiring lightweight and flexibility [13]. Graphene, a single layer of carbon atoms with unique electrical and mechanical properties, offers high conductivity and flexibility. Graphene-based textile materials can provide effective shielding while offering other functional properties. Additionally, graphene-coated textiles can provide EMI shielding and other functional features [14]. Metal nanoparticles (e.g., silver, copper, nickel) and nanofibers can be applied to textile surfaces to provide high shielding effectiveness. Metal nanoparticles provide high conductivity by being homogeneously distributed on the textile surface. Nanofibers offer a large surface area, effectively reflecting and absorbing electromagnetic waves [15]. The production techniques used in manufacturing textile-based electromagnetic shielding materials directly influence the material's performance. Advanced production techniques enable the creation of textile surfaces with homogeneous coatings, high conductivity, and durability. Chemical vapor deposition (CVD) is an effective technique for coating textiles with nanomaterials. This method allows for homogeneous and durable coatings, especially with materials like CNTs and graphene. CVD-coated textile surfaces offer high shielding effectiveness and flexibility [16]. Physical vapor deposition (PVD) is a method used to coat textile surfaces with metal nanoparticles. PVD provides high conductivity and durability to the textile surface, ensuring effective shielding. This technique is preferred for high-performance applications [17]. Electroplating is another method used to apply metal coatings to textile surfaces. This technique offers a cost-effective and efficient coating method, suitable for large-scale production. Electroplated textiles provide high conductivity and shielding effectiveness [18]. Conductive polymers offer flexibility and processability advantages in textile-based shielding materials. Conductive polymers such as polypyrrole (PPy), polyaniline (PANI), and polyethylene dioxythiophene (PEDOT) provide high conductivity when coated on textile surfaces. These materials are used in wearable technologies and other applications due to their lightweight and flexible nature [19]. Textile-based shielding materials can also be used in energy storage and management applications. Conductive textiles, in particular, enhance the performance of energy storage devices, providing more efficient energy management. Research in this field aims to offer innovative solutions by combining energy storage and shielding properties [20]. In the future, the use of environmentally friendly and sustainable materials will become important in textile-based shielding materials. Biodegradable polymers, natural fibers, and recyclable materials offer eco-friendly shielding solutions, enhancing sustainability. Research in this field aims to develop solutions to reduce environmental impacts and promote a greener future [21].

II. MATERIALS AND METHOD

The complex permittivity and permeability properties of materials are inherently dependent on frequency. In the design of perfect absorbents, the imaginary parts of dielectric materials play a crucial role as they contribute to additional dielectric loss. Achieving impedance matching between the intrinsic impedance of the medium and materials' impedance is vital to prevent reflection of incident electromagnetic waves. Consequently, researchers have focused extensively on impedance matching and minimizing dielectric loss, particularly in the context of metamaterial absorbers (MMAs).

MMAs typically consist of layers as periodic resonator shapes (a conductive layer) and a dielectric substrate. The periodic resonator shapes resonate with incident electromagnetic waves, typically having sizes smaller than the wavelength of the incident waves. In the adaptation of MMAs to textile structures, the periodic resonator shape and conductive layer are integrated into the textile structure. To create 3D periodic resonator shapes, a weft-knitted fabric structure with a wide range of loop sizes was utilized. The loop structure of the plain weave fabric acted as a conductive surface due to its small size relative to the measured wavelength. Flexible silicone material is commonly employed to fix the two fabrics and enhance dielectric loss.

The absorption capacity of materials can be quantified using the reflection coefficient and transmission coefficients of the medium. Total reflection coefficients and transmission coefficients can be elucidated using multiple reflections theory. According to this theory, the first interface reflects a portion of the incident electromagnetic wave while transmitting another portion. Subsequently, the end interface reflects and transmits a portion of the waves transmitted from the first interface.

The simulation was fully conducted using Finite Difference Time Domain (FDTD) analysis with CST (Microwave Studio Suite).The simulator output parameters necessary for studying the absorber's performance include the reflection coefficient, transmission coefficient, and absorption coefficient. The S-parameter values of the proposed structure were obtained using the WR-340 waveguide model, which has an area of 86.36 × 43.18 mm².

the absorption calculation is as follows Eq.1 for a lossless

$$Absorption = 1 - |S_{11}|^2 - |S_{21}|^2 \tag{1}$$

Where

S_{11} is the input port voltage reflection coefficient

S_{21} is the forward voltage gain

III. SIMULATED RESULTS

Figure 1 shows a square periodic structure. Square structure. The conductors are assumed to be perfect conductors.

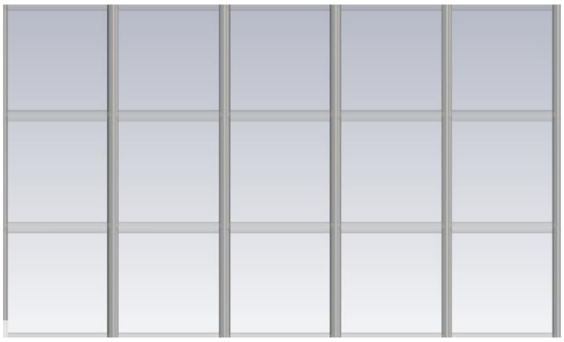

Figure 1. Square periodic structure

The measurement methodology is given in figure 2. WR-340 microwave adapter was used in 2.2-3.30 GHz frequency band for using 5G applications.

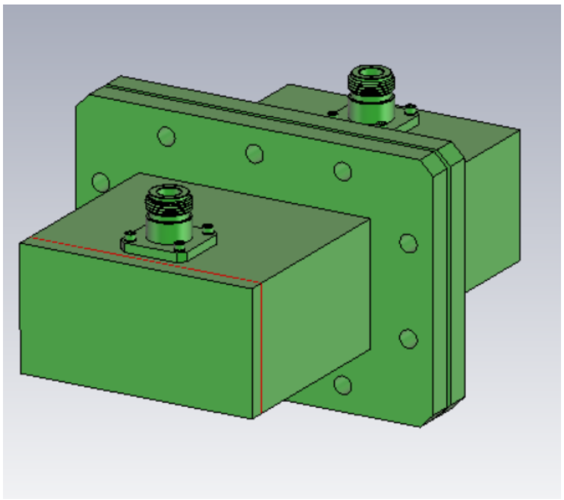

Figure 2. Measurement methodology

IV. RESULTS

Figure 3 shows the shielding effectiveness (in dB) of materials with varying different edge lengths (1 mm, 2 mm, 3 mm, and 4 mm) across a frequency range from 2.2 GHz to 3.2 GHz, it can be concluded that the shielding effectiveness improves as the thickness of the material increases. The 1 mm thick material exhibits the lowest shielding effectiveness, around -60 dB, while the 4 mm thick material shows the highest, at approximately -30 dB. Additionally, the shielding effectiveness increases slightly as frequency rises for all thicknesses. Therefore, increasing material thickness results in better electromagnetic shielding, especially at higher frequencies. This suggests that narrower-area materials provide more robust protection against electromagnetic interference (EMI) in the frequency range studied.

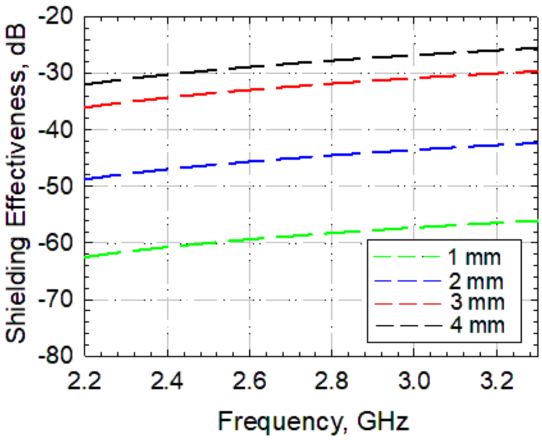

Figure 3. Frequency dependent variation plot of shielding efficiency of structures between 1-4 mm

Figure 4 illustrates the shielding effectiveness (in dB) of materials with varying different edge lengths (5 mm, 6 mm, 7 mm, and 8 mm) across a frequency range from 2.2 GHz to 3.2 GHz. The data reveals that, as material thickness increases, the shielding effectiveness improves. For example, the 5 mm in length material shows the lowest shielding effectiveness, starting at around -25 dB at 2.2 GHz, while the 8 mm in length material exhibits the highest effectiveness, starting near -15 dB. Additionally, all thicknesses show an increase in shielding effectiveness as the frequency increases.

This trend suggests that materials with a narrower area might be more suitable for providing electromagnetic interference (EMI) shielding in this frequency range. The results also show that shielding performance increases consistently with frequency regardless of thickness. Therefore, thicker materials such as 7 mm and 8 mm provide superior EMI shielding, making them ideal for high frequency applications where shielding effectiveness is critical.

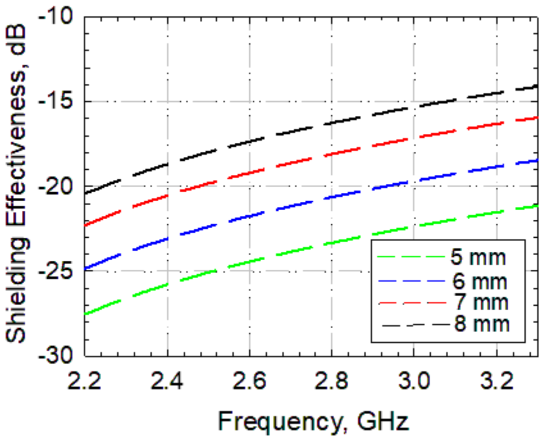

Figure 4. Frequency dependent variation plot of shielding efficiency of structures between 5-8 mm

Figure 5 illustrates the shielding effectiveness of materials with edge lengths varying from 9 mm to 12 mm over a frequency range from 2.2 GHz to 3.2 GHz. The results show a clear trend: as the edge length increases, the shielding effectiveness improves significantly. The material with a 9 mm edge length exhibits the lowest shielding performance, starting at around -25 dB, while the 12 mm edge length material demonstrates superior performance, reaching around -10 dB. The data suggests that larger edge lengths provide better EMI shielding across the measured frequency range, particularly at higher frequencies.

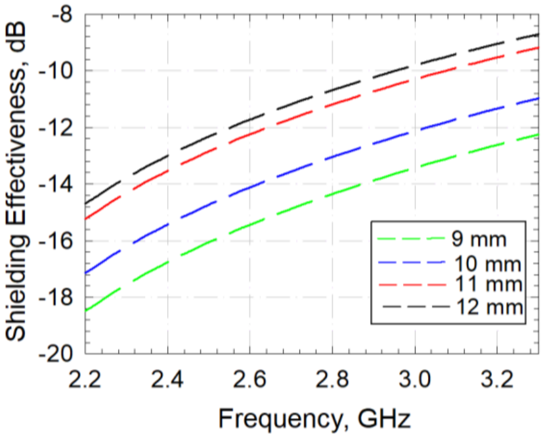

Figure 5. Frequency dependent variation plot of shielding efficiency of structures between 9-12 mm

Figure 6 presents the shielding effectiveness of materials with edge lengths ranging from 13 mm to 16 mm. The results show that materials with longer edge lengths, such as 15 mm and 16 mm, exhibit better shielding, especially in higher frequency bands, nearing -5 dB at the highest frequencies. The shielding effectiveness increases steadily as the frequency rises, indicating that the larger the edge length, the more robust the shielding performance. This suggests that increasing the physical size of the structure plays a critical role in enhancing the shielding capabilities of textile-based absorbers.

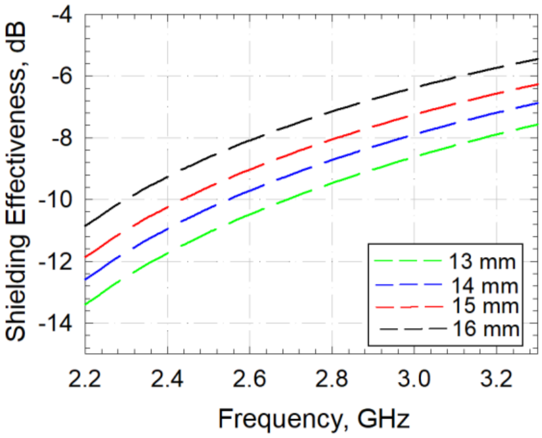

Figure 6. Frequency dependent variation plot of shielding efficiency of structures between 13-16 mm

Figure 7 compares the shielding effectiveness of structures with edge lengths between 1 mm and 4 mm. The data indicates that the smaller the edge length, the lower the shielding effectiveness, with the 1 mm material performing the worst at around -60 dB, and the 4 mm material reaching approximately -30 dB. The plot shows that as the frequency increases, so does the shielding effectiveness for all structures. Thicker materials provide better performance, especially at higher frequencies, highlighting the importance of thickness in improving electromagnetic shielding.

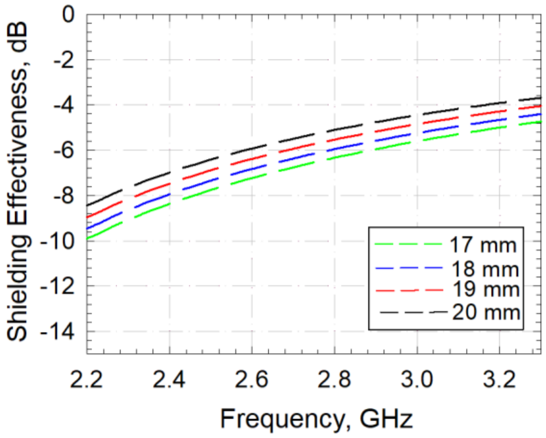

Figure 7. Frequency dependent variation plot of shielding efficiency of structures between 1-4 mm

V. DISCUSSION

The results of this study highlight the effectiveness of textile-based materials in absorbing electromagnetic waves. The influence of physical factors such as edge length and material thickness on EMI shielding performance was particularly notable. These findings suggest that textile-based shielding materials can be successfully applied to various high-frequency applications, especially where lightweight and flexibility are required.

Comparing these results with previous research, the study represents a significant advancement in the field of EMI shielding. The integration of nanotechnology and advanced composite materials into textile structures has the potential to further enhance shielding performance, especially for emerging technologies like 5G and wearable electronics. This study lays the foundation for future innovations in textile-based shielding solutions.

VI. CONCLUSION

This study examined the performance of a textile-based absorber structure designed for 5G applications. The results demonstrate the effectiveness of textile-based materials in shielding electromagnetic waves, with material thickness and edge length identified as key factors influencing performance. The high correlation between simulation and measurement results supports the reliability of the proposed structure.

Looking forward, the development of higher-performance textile-based EMI shielding materials using nanotechnology and advanced materials will likely become a focus. This study contributes to the advancement of innovative EMI shielding solutions, providing a stepping stone for future research in this field.

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