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Simulation of Conductive Fabric Shielding Effectiveness at 0.6 - 2.6 GHz via Transmission Line Analysis

Omar Abdul Aziz

Lecturer, Faculty of Electrical Engineering, Universiti Teknologi Malaysia

Abstract

Protection of devices and systems in the presence of Electromagnetic Interference (EMI) could be realised with the introduction of EM shielding that limit signal wave propagation within an area of interest only. This project attempts to characterise shielding effectiveness (SE) of shielding materials at 0.6 - 2.6 GHz that are currently made available for numerous current and next-generation wireless technology applications. Future technology applications would be driven by intense device-to-device communication taking place very close to one another. Ensuring SE through signal wave absorption instead of signal reflection alone is critical to reduce possible disruption of adjacent wireless system. In order to achieve sufficient SE at investigated frequencies, EM shield need to be designed from different materials that could exhibit high electrical conductivity and high magnetic permeability. Conductive materials in fabric form have potential to achieve strong SE while allowing more freedom in the design process and easy deployment. This study involved theoretical calculation and simulation using CST Studio Suite Student Edition of reflection and absorption losses as well as SE for materials that were selected based on ease of availability off-the-shelf in fabric-form thickness.

Keywords: Shielding Effectiveness (SE); Transmission Line Analysis; Single Layer; Double Layer; Electromagnetic Interference (EMI).

1. Introduction

Ubiquitous connectivity of electronic devices poses a need for reliable communication scheme. Security at physical layer that exploits characteristics of wireless channels including path loss and interference, has been touted to enable stable and safe communication while avoiding interference. Such approach may require placement of boundary to radiated electromagnetic (EM) wave, allowing proprietary systems to continue operate effectively even in the presence of EM threat [1]. Shielding is the use of a structural method to lessen interfering EM fields within a defined region, which safeguard the devices or applications from unwanted external electromagnetic interference. Additionally, it stops the leakage of EM disturbance from the devices as well. EM shield could therefore be deemed as barrier to control the transmission of the EM wave [2].

Researchers have begun looking at implementation strategies including through placement of signal wave shield on building walls, partitions, doors or windows. Numerous analyses had shown that reflection as a mean of shielding performs well especially in the case of high conductivity materials. Nevertheless, the reflected signal may induce multipath effect, delay spread and signal wave degradation of adjacent communication systems. To reduce the impact of signal wave reflection, shielding materials must also exhibit higher absorption loss. Improvements are in need to increase EM wave attenuation especially for frequency range that are used and potentially used for future technologies including in Malaysia.

To ensure minimum impact of EM interference (EMI) for the abovementioned future applications, increasing the shielding effectiveness for these frequency range through signal wave absorption is critical. Two elements are considered pertaining to EMI's impacts, namely immunity and emissions. The degree of obstruction from an outer source of electromagnetic energy on the activity of the electronic equipment or application is referred to as immunity. A proportion of electromagnetic energy from the source of radio frequency are emissions. The equipment or application will be resistant under a specific EMI degree and turn into vulnerable over that degree [3].

This project attempts to characterise shielding effectiveness (SE) of shielding materials for operating frequency range that are currently being made available for numerous current and next-generation wireless technology applications. Future technology applications would be driven by intense device-to-device communication taking place very close to one another. Increasing the SE through signal wave absorption in addition to signal reflection is critical to reduce possible disruption of adjacent wireless system. In order to achieve sufficient SE, EM shield design need to consider possible hybrid of different materials that could exhibit high electrical conductivity and high magnetic permeability. The use of shielding materials in fabric form, allows more freedom in the design process and easy deployment. This project would involve theoretical computation and simulation of SE for several materials with fabric-like thickness from 0.6 GHz to 2.6 GHz spectrum using CST Studio Suite Student Edition. The objective is to analyse whether such shield structure could achieve high SE with attention given to wave absorption.

2. Related Works

2.1 EM Interference (EMI)

RSSI is known as Receive Signal Strength Indicator. It's a measurement of the strength of the received radio signal and commonly used as a wireless network's performance indicator. RSSI performance is usually classified into four categories: excellent, good, fair, and weak [5]. RSSI can be measured using a variety of computer software. The WLAN performance also impacted by the Signal-to-Noise Ratio (SNR). RSSI and SNR have a mathematical relationship, which is SNR is equal to RSSI minus the RF background noise. The noise is the signal interference by other device likes phones, radar, microwaves or others. Good SNR and great signal strength could result better WLAN performance.

2.2 EMI Shielding

EMI shielding is the implementation of a shield structure, commonly shaped from conducting material to enclose electrical / electronic devices or systems either partially or entirely. As a result, it restricts the level of EMI emission of EMI that can affected the devices or systems from outside surroundings and conversely influences how much generated EMI energy that would be able to pass through into outside surroundings. Shielding materials with varying electrical conductivity, magnetic permeability, and geometries have been employed. Practical equipment commonly permit connection to wires or pipes used for signalling and other services. Additionally, there could also exist openings or apertures used for entry and ventilation. If any of these elements breaches the shield's integrity, it would have a significant impact on the shield's actual quality [4]. Shielding is an important solution to reduce EMI radiation, shielding also provides an isolated ground reference that decreases the coupling of internal crosstalk and circuit paths and general common mode coupling too. Shields may be applied at several spatial levels, including integrated circuit, printed circuit board, and building. The shielding design elements are largely the same that is to minimize as well as to absorb unwanted EM wave [8].

Among approaches to materialise control of EM wave radiation is through the modification of building structure materials such as concrete blocks. Through addition of steel fibres, carbon powder and taconite, conductive concrete was introduced to act as EM shield [9]. Using band-stop filter designs on the surface of composite substrate, frequency selective attribute that attenuate unwanted signals while permitting signal wave of desired channels to pass through are achievable. These composite surfaces can be then placed on walls, partitions, doors and windows [10]. The use of woven metal fabrics as EM shield could be beneficial since they are easily available, could be manufactured at lower cost and their physical flexibility allow a more low-profile facade when placed on building interior surfaces [11].

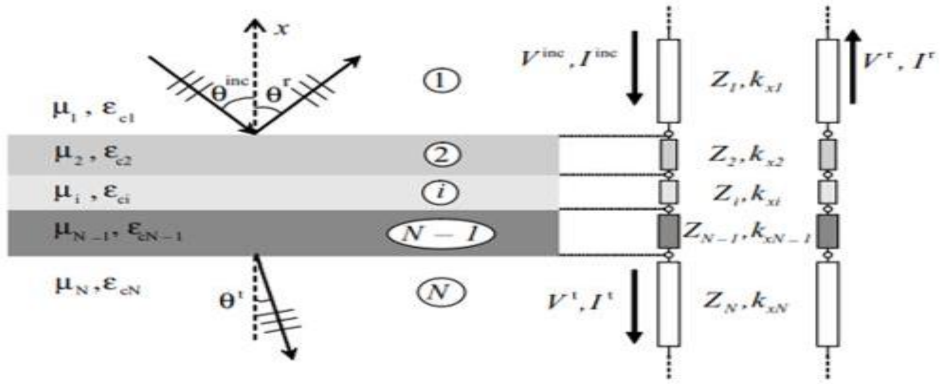
2.3 Related Issues on EMI Shielding

Performance of a shielding material is commonly expressed by the term SE in terms of decibel loss, which is the measure of its opacity to an incident EM wave at a given frequency band [12]. The predominant mechanism of shielding is through the reflection of signal wave impinging a surface plane. Nevertheless, reflection of signal wave may degrade adjacent wireless communication systems due to multipath effect that may cause delay spread. These disruptive effects could be mitigated with the introduction of EM shield that operates through mean of absorption [13]. Absorption loss depends on shielding material's electrical conductivity and magnetic permeability. There is a need to characterize absorption loss to analyse absorption loss characteristics for numerous operating frequencies specifically for contemporary WLANs and cellular networks that mostly operate in the range between 0.6 GHz to 2.6 GHz spectrum [14].

2.4 Transmission Line Approach to Shielding

Transmission line model of shielding material structure could be set up in equivalent circuit model to simulate SE due to absorption loss in a quick and precise manners [15]. Resulting SE introduced from variation of design could be then observed and analysed empirically as a function of operating frequencies, shielding materials properties, and thickness [16]. Simulation analysis could provide mathematical correction to computational modelling that has been carried out and improve accuracy for reference on prediction on reflection as well as absorption losses for the shielding material structure. Figure 1 shows the analogy between a plane-wave transmission problem and propagation along the equivalent transmission line circuit of a multiple shield [17].

Figure 1: Uniform plane wave impinging on a planar multilayer shield and equivalent transmission line model [17].



3. Methodology

3.1 Data Collection

The primary guide required to this project regarding SE using transmission line analysis is based on article by Schulz, Plantz and Brush [18]. The authors highlight the computation of shielding effectiveness by outlining the derivation of the equation to calculate the reflection loss and absorption loss of specific shielding material. The most basic shielding configuration is shown in Figure 2, where a uniform plane wave impinges with an angle, θinc on a single planar shield, assuming infinite extension in transverse y-z directions and a finite thickness d in the x-direction.

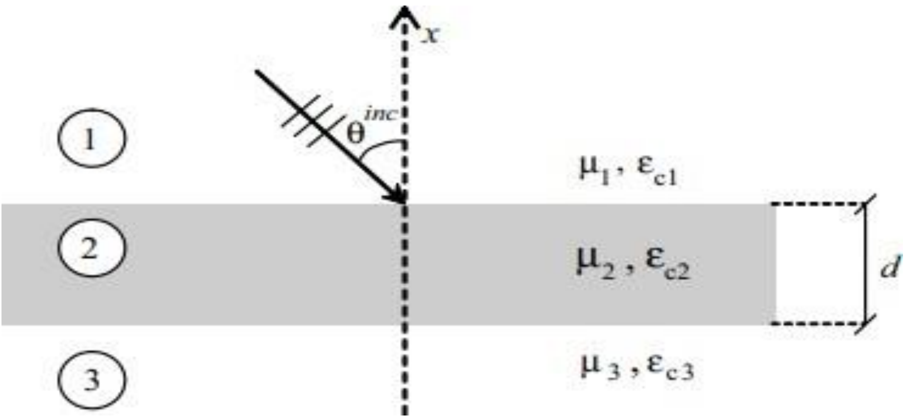


Figure 2: Uniform plane wave impinging on a shield of finite thickness d and of infinite transverse dimensions [17].

The computation of SE is by summing up the reflection loss and absorption, the equations are retrieved from [17]. The first term in the equation, reflection loss R, depends only on the free-space impedance, Z_0 as defined in equation (1) and (2), with the shield medium impedance, η and it accounts for the first field reflection at the two shield interfaces caused by a mismatch between the two impedances at both interfaces.

$$R = 20log\left|\left[\frac{(Z_0+\eta)^2}{4Z_0\eta}\right]\right| \text{ where} \tag{1}$$

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{2}$$

The second term, A, absorption loss, is only a function of the shield characteristics as defined in equation (3) and (4), that accounts for the attenuation that a plane wave experiences while travelling through an electrical depth equal to wavenumber, k_{xS}/k_0 in the shield material.

$$A = 20log\left|e^{jkxS^d}\right| = 8.686\alpha_{xS}d \text{ where} \tag{3}$$

$$\alpha = \sqrt{\pi f\mu\sigma}, d = 0.25\ mm \tag{4}$$

3.2 Material Selection

Ferrite, nickel and stainless steel were chosen to be the Material Under Test (MUT) due to their electrical properties. The shielding materials need to possess not only high conductivity but also high permeability. These materials were also chosen because of their fabric-like structure availability, and affordability in the market. The conductivity and permeability values of the materials mentioned above are obtained from [19]. All of the materials above are good conductor material which has intrinsic impedance angle at 45° and based on Maxwell's equation, we can calculate the intrinsic impedance as in equation (5).

Intrinsic impedance, $\eta = \sqrt{(j\omega\mu/(\sigma + j\omega\varepsilon))}$ (5)

Table 1 shows the list of materials mentioned earlier with their respective conductivity, permeability and permittivity values.

Table 1: List of Materials

Materials	**Conductivity (S/m)**	**Permeability**	**Permittivity**
Nickel	1.43×10^{7}	1.26×10^{-6}	8.85×10^{-12}
Stainless Steel	1.32×10^{6}	1.19×10^{-4}	8.85×10^{-12}
Ferrite	1.70×10^{7}	2.01×10^{-5}	8.85×10^{-12}

Therefore, the calculations of reflectivity and absorption losses, intrinsic impedance as well as SE of these materials, will be computed with the transmission line analysis approach. The frequency range that will be used is between 0.6 GHz to 2.6 GHz.

3.3 CST Studio Suite Simulation

of EMI problems and also can be used to simulate the expected results in terms of S-parameters, farfield radiation and radiational pattern. In this project, the CST Studio Suite will play the role of designing and simulating the set-up for determining the SE in terms of S-parameters. The two-port network with MUTs is situated between port 1 and port 2 which act as the transmitter and receiver respectively. S-parameters determine the response of an N-port network to a signal; for a two-port network, there are four S-parameters, namely S_{11}, S_{12}, S_{21} and S_{22}, where the first subscript represents the input port and the second subscript denotes the output port. S_{11} represents the input reflection coefficient, S_{12} represents the reverse transmission from port 2 to port 1, S_{21} represents the forward transmission from port 1 to port 2, and S_{22} represents the output reflection coefficient.

4. Results and Analysis

Based on the transmission line analysis calculations, the overall reflectivity loss of these three materials; ferrite, nickel and stainless steel are decreasing when the frequency is increasing. However, the overall absorption loss increased as the frequency increased. Figure 3 and 4 below show the graphs of reflectivity loss and absorption loss for the three materials.

Figure 3: Graph of reflectivity loss in dB against frequency

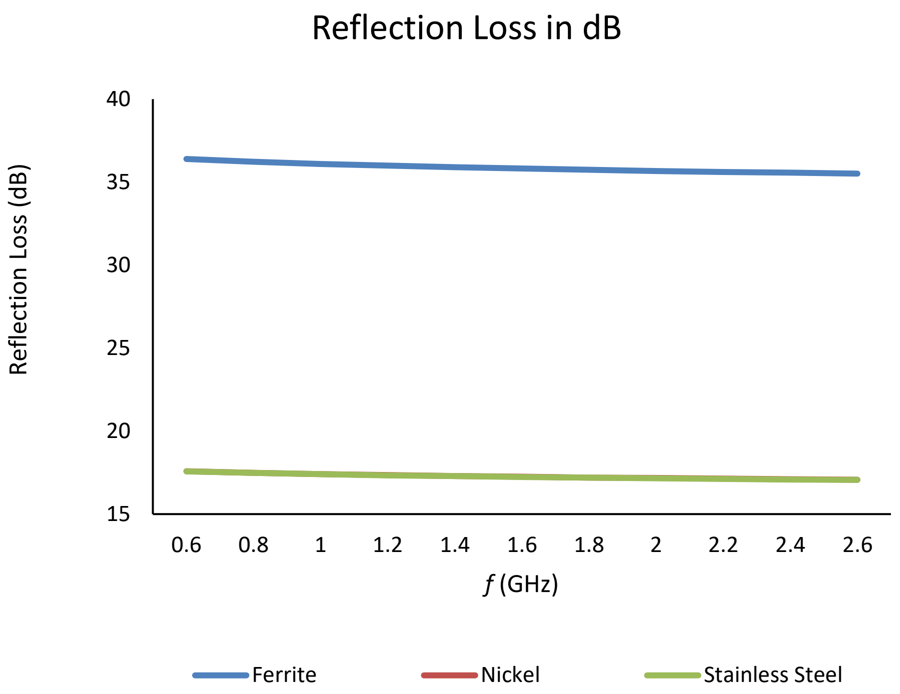
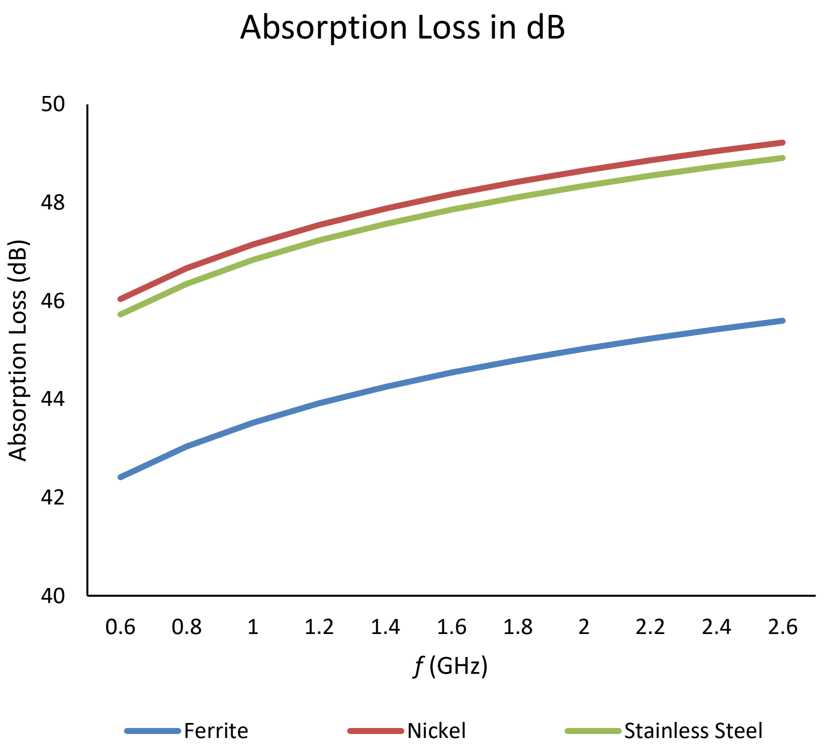
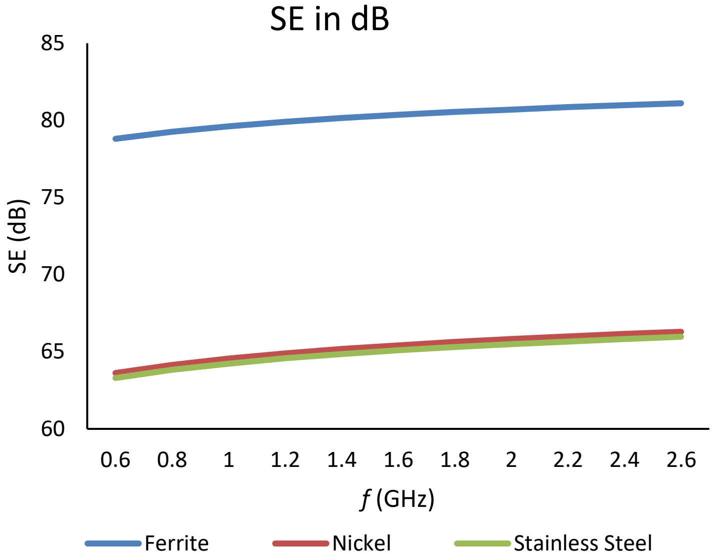


Figure 4: Graph of absorption loss in dB against frequency



In order to compute the value of SE simply adding up the reflectivity and the absorption loss together as shown in Figure 5. From what we can observe is that the SE for these materials is increasing proportionally to the frequency.

Figure 5: Graph of shielding effectiveness in dB against frequency



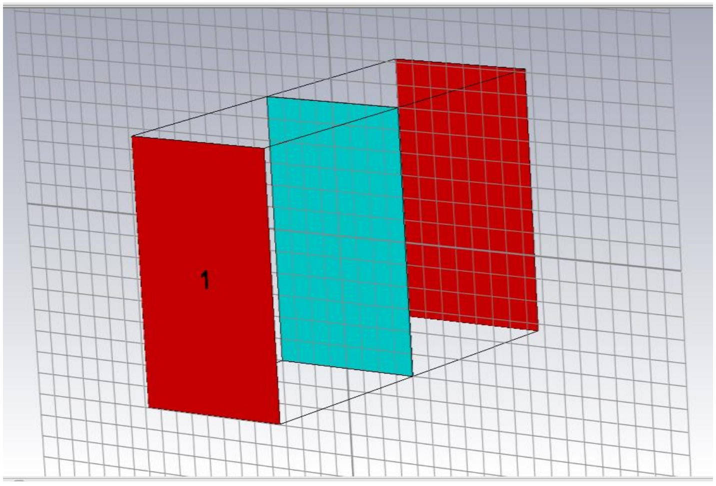
SE is simulated based om CST software tool. In this simulation analysis, we are using two-port network with port 1 acting as a transmitter whereas port 2 acts as a receiver. The material MUT are situated in between these two ports with the distance kept at 30 cm from each other. The MUTs are designed to have the dimension of 200 x 300 for width and length respectively and the thickness is 0.25 cm as shown in Figure 6. The incident signal propagates from port 1 to MUT and the reflected signal from the MUT and port 2 is received in port 1 as known as scattering parameter, S_{11}. The reflectivity loss in decibel, R_{dB} of the MUT was calculated using Equation 6 [20]:

$$R_{dB} = 20\log\left(\frac{10^{\frac{S_{11}}{10}}}{10^{\frac{S_{21}}{10}}}\right), \qquad S_{21} = 0\ dB \qquad (6)$$

$$R_{linear} = 10^{\frac{R_{dB}}{20}} \qquad (7)$$

$$Maximum\ Absorption = 1 - R_{linear} \qquad (8)$$

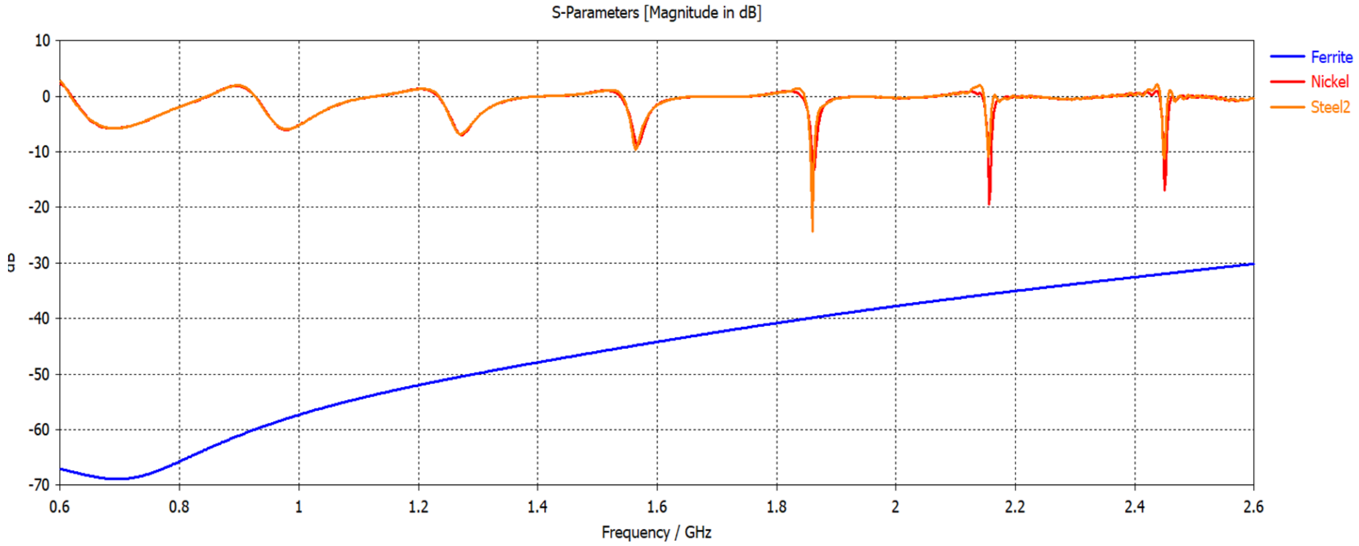
Figure 6: The experimental set-up for the simulation process



The reflected power detected at port 2 known as S_{21} in this case, is 0 dB because the entire signal is nearly reflected due to the properties of MUTs. From both theoretical and simulated results, we can increase the shielding effectiveness when using shields made up of materials that are not only having high conductivity, but also high permeability property as well. Based on the calculations made, it was found that the relationship between the reflectivity loss and absorption loss is inversely proportional to each other. The increase in the reflectivity loss the decrease in the absorption loss and vice versa.

Accordingly, Figure 3 and Figure 4 proved this statement where we witness that although the ferrite has a higher reflectivity loss than the other two materials, its absorption loss is the lowest compared to the rest of the materials. Nevertheless, ferrite exhibits strong absorption loss and reduced reflection loss yielding better shielding effectiveness compared to two other materials. Based on the simulation results, we can make a few discussions on the S-parameters signals for ferrite, nickel and stainless steel. In Figure 7, it shows that despite the nickel and stainless steel exhibit almost the same pattern of S_{11} parameter, nickel has a better reflection coefficient below 10 dB than stainless steel at later frequencies; 2.15 and 2.45 GHz.

Figure 7: CST simulation results for the materials



Overall, ferrite topped all other two materials as it shows a higher reflection coefficient than the rest. Comparison between the calculated theoretical (Calc.) results and the simulation (Sim.) results in terms of reflectivity loss have been made and shown in the table 2 below.

Table 2: Comparison between calculated and simulation results for reflectivity loss in dB

	Ferrite		Nickel		Stainless Steel	
f (GHz)	Calc.	Sim.	Calc.	Sim.	Calc.	Sim.
1.86	35.74	39.84	17.23	12.38	17.16	18.64
2.15	35.68	35.62	17.17	17.23	17.10	10.19
2.45	35.56	31.94	17.06	16.85	16.98	11.23

5. Conclusion

The transmission line analysis method is one of the simplest approach in computing the shielding effectiveness of materials and its accuracy are proven many times in numerous researches. Nickel, stainless steel and ferrite are investigated in this study. The reason why these three materials were chosen to be studied is because of their fabric-like thickness availability that can be easily obtained in the market and is affordable. From findings, the reflectivity loss is inversely proportional to the absorption loss where the increase of reflectivity loss led to the decrease in absorption loss of the materials. It is concluded that ferrite is the best material with respect to SE due to its strong reflectivity within the frequency range from 0.6 to 2.6 GHz compared to nickel and stainless steel. Nevertheless, nickel has the best performance when it comes to absorption loss. It also has slightly better SE than stainless steel. With this observation, future study could look into potential development of hybrid fabric shield based on nickel.

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