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Modeling & Simulation Analysis of Conductive Fabrics for Evaluation of Electromagnetic Shielding Effectiveness using FEKO Simulation Tool

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ABSTRACT

Conductive fabrics have been receiving tremendous growth in the applications across wide spectrum of military, scientific community, aircraft, industry, commercial, and consumer sectors. Being used in almost all sectors, there is a need for these special fabrics to be tested for its Electromagnetic Shielding. The crowded electronics operating in the vicinity poses a potential threat to malfunctioning of the electronics encapsulated by the fabrics. Therefore, there is arequirement for special focus onelectromagnetic radiations throughshielding effectiveness measurements. Shielding of EM waves can be done through the reflection, absorption, multiple reflection by the shield/ barrier. The metals and their alloys can be used as the shields, but they possess the drawbacks in in-flexibility and rigidness, sometime may not be suitable for the applications.The research advancements in the design & machination of conductive fabrics replaced the existing shielding materials.The conductive fabrics with its unique characteristics such as electrical properties, flexibility, processibility and lightweight promises a good barrier material for protecting complex systems against EM radiations and environmental effects.In this paper, we present the design,EM wave simulation, and validation through S-parameters measurements of an EM shielding effectiveness (SE) tester based on the ASTM D4935 standard.

KEYWORDS

ASTM D4935, EMI shielding mechanism, coaxial specimen holder, shielding effectiveness, S-parameters, electrical properties.

1. INTRODUCTION

Research on technologies across the globe accelerated the design &use of electrical and electronic systems in all engineering and technology sectors. The ongoing research trends minimized the size of the electronics allowing large number of electrical components to fit into small space. The crowded electronics creates the problem of electromagnetic interference within & between the systems through conducted or radiation modes.Therefore, there is an increased interest in providing sufficient Electromagneticshielding to the Electronics being operated in the vicinity of the culprit systems. The significance of EM shielding has been extended to commercial, industrial and defense sectors. The selection of material as a barrier to provide the required shielding effectiveness depends on the working environments. The hostile defense environment further demanded a requirement for use of wearable textiles called conductive fabrics across its various sectors. The use of nanotechnology based textiles is now more commonly observed in the medical fields too. Because of increased use of these fabrics, they need to be evaluated for its Shielding Effectiveness for incident electromagnetic waves. Conductive fabrics [2], [3], [5]are promising materials for shielding electromagnetic (EMI) radiation and reducing or eliminating EMI, because of their electrical properties of relatively high conductivity (σ) compared to fabric and dielectric constant (ε). This paper presents the design concepts, modeling & simulation of specimen holder/ zigand the simulation approach for assessing the SE of conductive

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fabrics. The zig is validated for 50Ω impedance across the structure and the S-parameters are evaluated. Four different samples are considered with varied electrical properties and the Shielding Effectiveness of the same are computed and presented.

2. THEORY AND COMPUTATION OF SHIELDING EFFECTIVENESS

The capability of a material for shielding is defined as the ratio of the incident energy to the energy transmitted through the shield. In the simplest study an EM wave initially traveling in the free space hits an obstacle. Due to the difference in impedance between the before and after the obstacle, part of the wave initial incident power (P_I) is reflected (P_R), absorbed (P_A), and transmitted (P_T) at various ratios.

$$P_I = P_R + P_A + P_T \quad (1)$$

The coaxial transmission line holder consists of two equally halved section and material (MUT) is inserted in the middle of the holder. The holder has an impedance of 50 Ωthroughout its length and matches the impedance of the connector assembly such as signal analyzer, cables, connectors, and attenuators. The holder is designed as per ASTM D4935-10 [8] and operates in the frequency range from 30MHz to 1.5GHz. The half-section of the holder as per the standard is shown below in the figure (1).

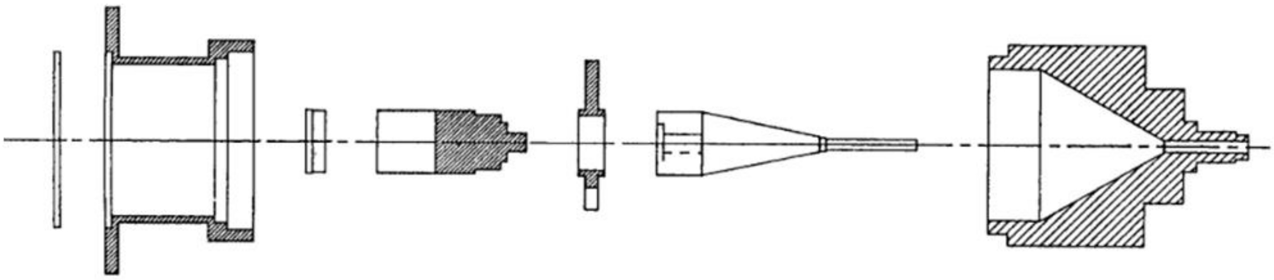

Fig. 1. Half-section of the sample holder as per ASTMD 4935

The impedance was obtained by selecting the diameters of 'D'and'd'to calculate the characteristic impedance, Z_0, of a coaxial line.

$$Z_0 = \frac{\eta_0}{2\pi\sqrt{\varepsilon_r}} \ln\left(\frac{D}{d}\right) \quad (2)$$

Where,η_0 is the free space wave impedance, approximately equal to 377 *Ω*,

ε_r is the relative permittivity of dielectric material,

D is the inner diameter of outer conductor,

d is the diameter of inner conductor.

The upper frequency limit for pure transverse electric mode (TEM) operation is the cutoff frequency $f_c$of the first higher order mode, which can be evaluated is given by (3), as described in [10]:

$$f_c = \left(\frac{n}{\pi}\right)\left(\frac{2c}{D+d}\right) \quad (3)$$

Where n is a positive integer and is equal to one for the principal mode, and c is the speed of light, equal to $3x10^8$ m/sec.

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2.1 S-PARAMETERS

The S-parameters are used to obtain concurring the reflected and transmitted power over a given frequency range. In a two port network there are four S-parameters S_{11}, S_{12}, S_{21}, S_{22}.The $S_{[ij]}$parameter is the fraction of signal reflected back to the same port where the signal was initially introduced when i =j (S11 and S22). The power reflected back to $port_1$($port_2$) is termed as reflection coefficient (R) is given by (2).

$$|S_{11}|^2 = R = \left|\frac{P_R}{P_I}\right|; \left(|S_{22}|^2 = R = \left|\frac{P_R}{P_I}\right|\right) (4)$$

The $S[ij]$ parameter is the fraction of signal transmitted from $port_{[i]}$ to $port_{[j]}$ through the MUT when i≠j (S12 and S21). The total power transmitted from $port_1$ ($port_2$) to $port_2$ ($port_1$) is termed as transmission coefficient (T) is given by (3).

$$|S_{12}|^2 = T = \left|\frac{P_T}{P_I}\right| ; \qquad \left(|S_{21}|^2 = T = \left|\frac{P_T}{P_I}\right|\right) \quad (5)$$

In the case of obstacles for electromagnetic compliance internal multiple reflections and other scattering mechanisms cause part of the signal to be absorbed within the obstacles. Using (1) the ratio of absorbed power $P_A$to the incident power $P_I$is expressed as follows:

$$\frac{P_A}{P_I} = 1 - \left(|S_{11}|^2 + |S_{21}|^2\right) (6)$$

The analysis of the SE of a material using the S-parameters takes in account the shielding due to reflection, S_R and the effective shielding due to absorption, S_A, given in (5) and (6), correspondingly.

$$S_R = 10.\log_{10}\left(1 - |S_{11}|^2\right) \quad [dB] \quad (7)$$

$$S_A = 10.\log_{10}\left(\frac{|S_{21}|^2}{1 - |S_{11}|^2}\right) \quad [dB] \qquad (8)$$

The total shielding of a material (MUT), S_T, is given by the sum of both S_R and $S_A$presents as:

$$S_T = (S_R + S_A)[dB] \qquad (9)$$

The equation (9) is used to measure the total shielding in both cases, with reference ($S_{T\text{-}REF}$) and load specimen ($S_{T\text{-}LOAD}$).The SE value is given by subtracting the total shielding measured with the load specimen, $S_{T\text{-}LOAD}$, from the shielding measured with the reference specimen,$S_{T\text{-}REF}$is given by (8)

$$SE = \left(S_{T-REF} - S_{T-LOAD}\right) \quad [dB] \qquad (10)$$

3. RESULTS AND DISCUSSION

In this paper, coaxial sample holder structure is designed using the 3-D Electromagnetic (EM) simulation software Altair HyperWorks FEKO. A two-port Flanged coaxial sample holder (FCSH) [1], [4], [6]design is shown schematically in Fig. 2(a), with the reference and the load specimen of Fig. 2(b) and (c) inserted between the flanges of the FCSH.

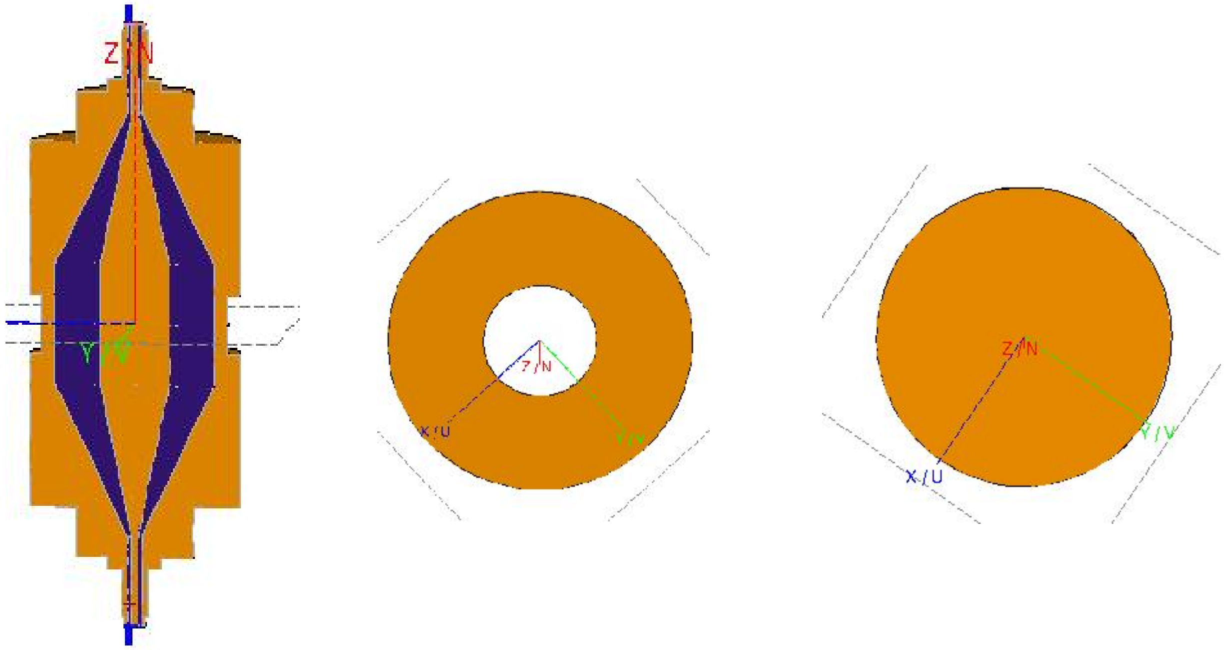
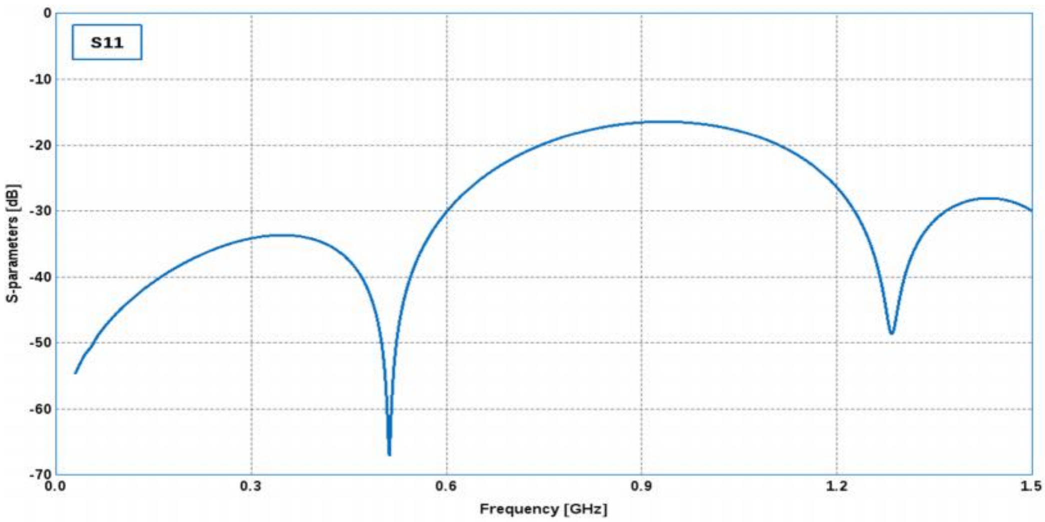
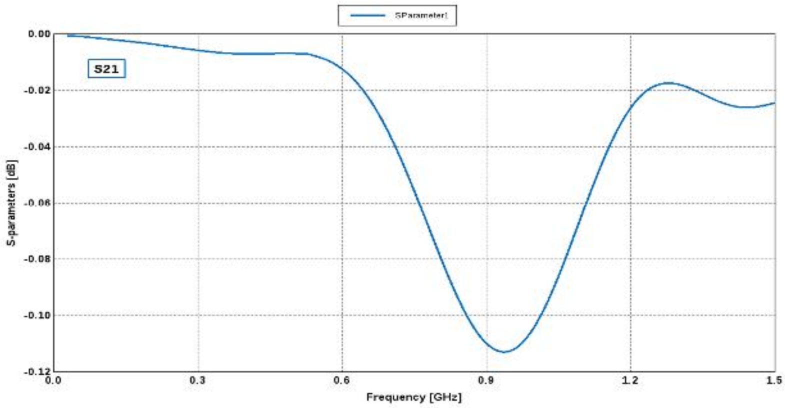


Fig. 2. CAD models of the (a) FCSH, with (b) reference, and (c) Load specimen

The sample is modeled using the Material library from the simulation tool. The materials considered in the modeling are - air(ε=1), Polytetrafluoroethylene (PTFE) for the dielectric medium (ε=2.08), PEC or annealed copper (σ=58e06 S/m) for the conductors.The modeled zig is evaluated for its S-parameters and the current flows. And also, the impedance is computed from the near-fields & currents to check for 50Ω across the zig structure. The S-parameters are evaluated using the simulation tool and the S11 was found to be below -10 dB across the considered frequency which meets the design requirements. Similarly, the S21 is also computed and it is observed to be very close the 0 dB .The S11 & S21 are shown in the following Figure 3(a) and plotthe S_{21} (Transmission coefficient) in Figure 3(b).



(a)



(b)

Fig. 3. S-parameters (a) S11 and (b) S21 of the sample holder

The structural currents flow across the structure is shown in below figure (4).

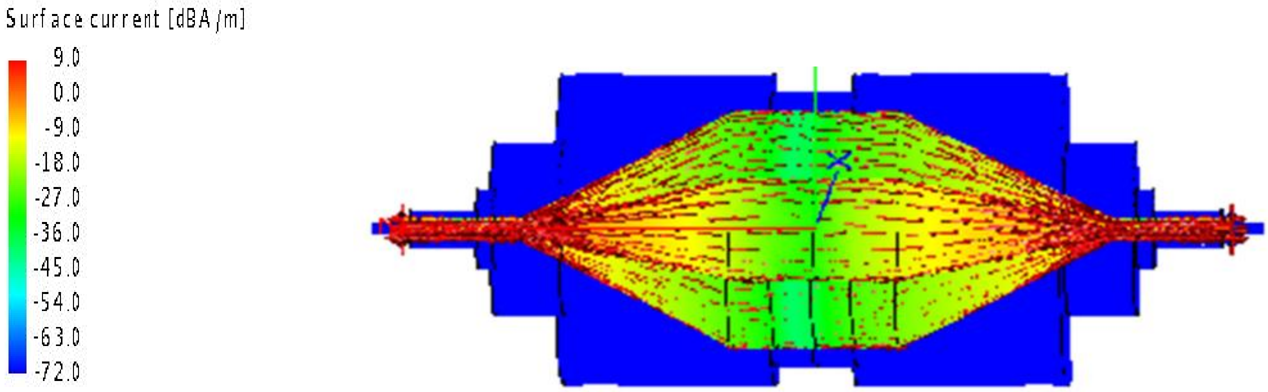


Fig. 4.Currents flowing through Zig structure

The validated zig is used for evaluating the Shielding effectiveness of the conductive fabrics. The material's electrical properties are obtained from the manufacturer's data sheet. The design properties are listed in the below table which are considered for CAD modeling & simulation for assessing their Shielding Effectiveness.

Sample No.	Thickness of the sample	Dielectric Loss Tangent (Tan δ)
Sample1	80 µm	0.99
Sample2	500 µm	6.80
Sample3	500 µm	2.50
Sample4	500 µm	1.40

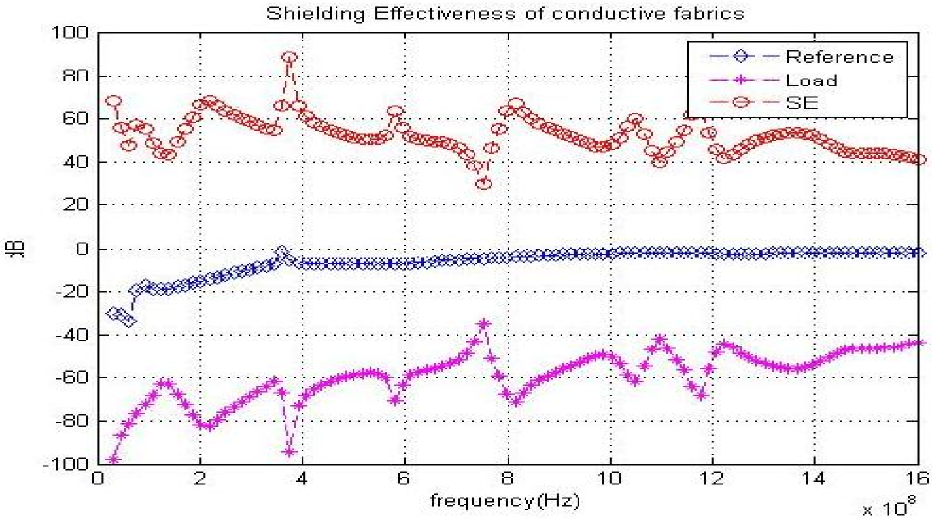
Table 1.The electrical properties of different samples

The zig/ coaxial sample holderis used to compute the Electromagnetic Shielding Effectiveness in the frequency range from 30MHz up to 1.5GHz. The S-parameters are computed for both the reference and load cases. Using the equation (10), the SE of the conductive fabrics are computed.

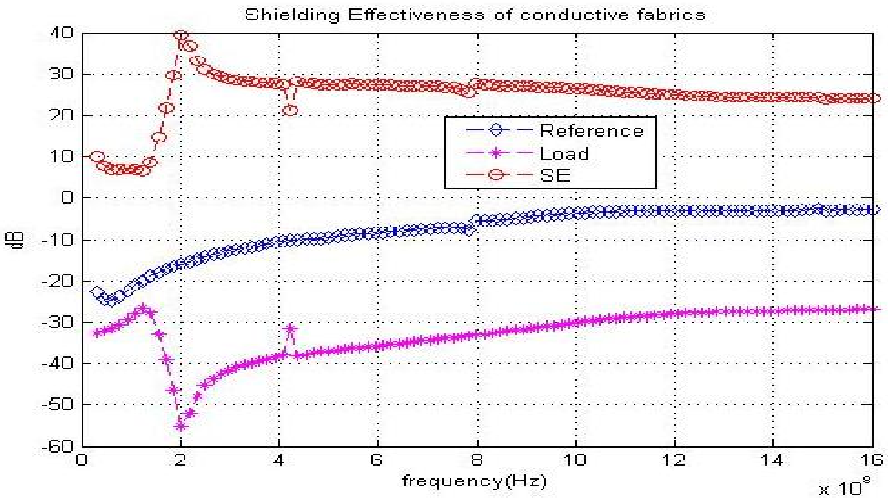
The obtained results are plotted in below figure (5).

The sample1[9] is TsO doped polypyrrole offer high shielding effectiveness compared to polyaniline composites of sample2,3 and 4 by structural variations through chemical processing to yield more SE is summarizes in figure (6).

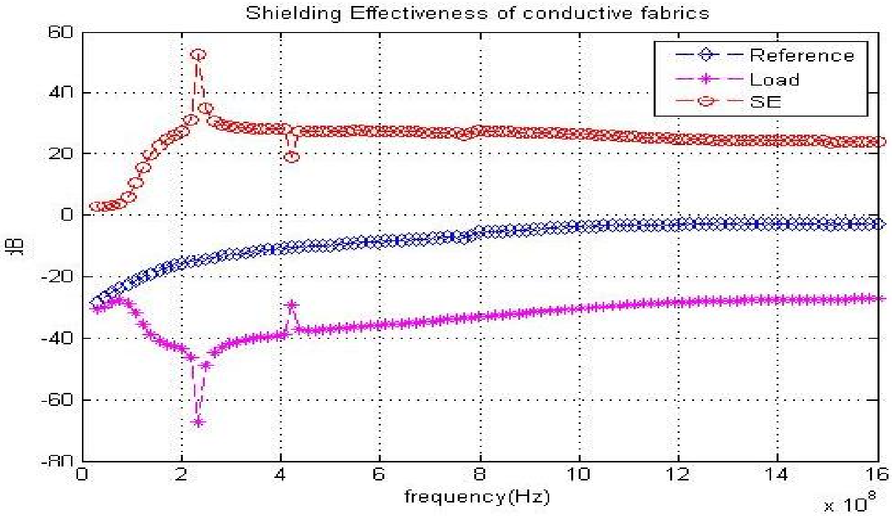
Sample1



Sample2



Sample3



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Sample4

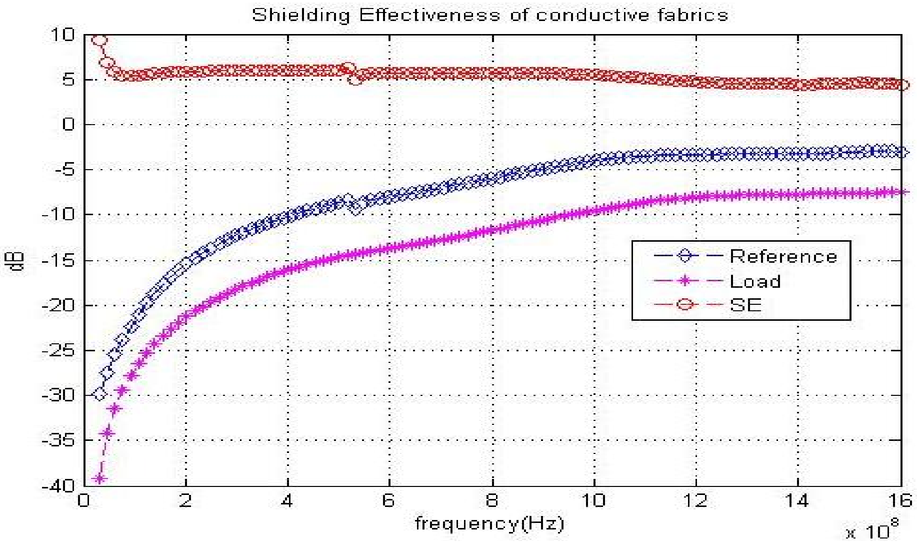

Fig. 5. Measurement of SE with load and reference of different conductive fabrics

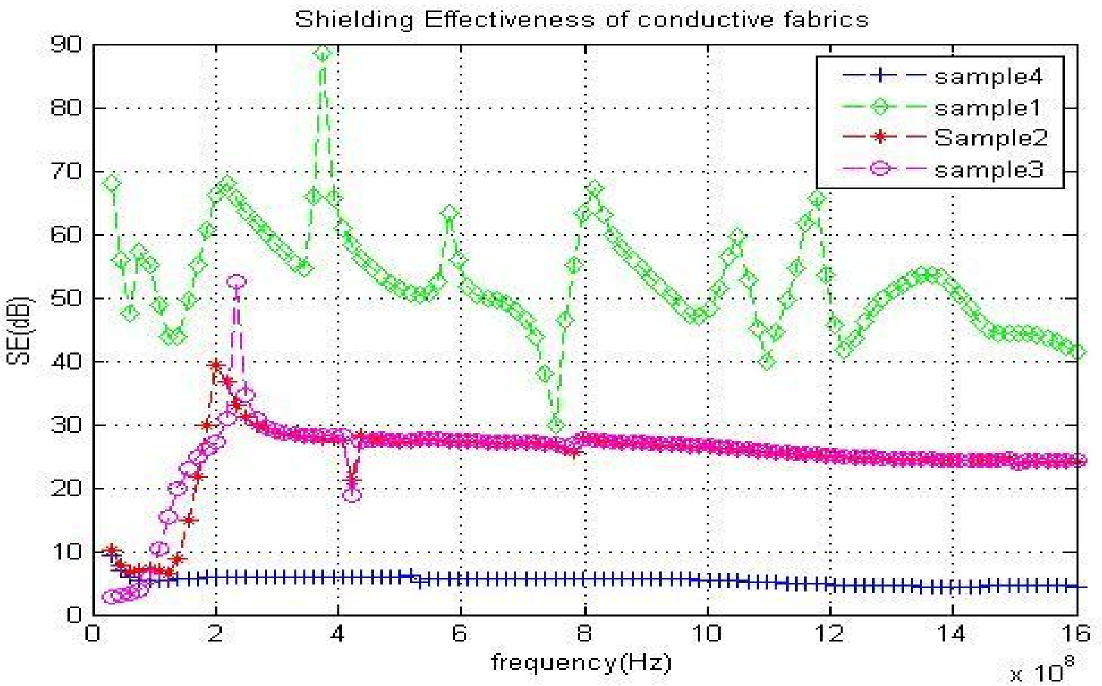

Fig.6.SE Measurement of different conductive fabrics

4. CONCLUSION

Metal based shielding materials suffer from high mass density, corrosion due to environmental effects.It has low flexibility and high rigidity. Therefore conductive fabrics like polyaniline and PPY are the most alternative and attractive composites for EMI shielding due to their lightweight, noncorrosive nature and commercial viability.The potential applications of conductive fabrics are often extended to wide sectors. The increase in demand for these made a need for evaluation of EM shielding. To address the importance of the measurements, simulation analysis is carried out for design of the zig for computing the SE of conductive fabrics. The samples are considered from the literature survey and the specifications are obtained from the manufacture. The comparison in SE offered between different samples is analyzed and presented in this paper. It is observed that the TsO doped polypyrrole (PPY) offereda shielding effectiveness of up to 90 dB.

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