

Electromagnetic shielding tester for conductive textile materials

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Electromagnetic shielding tester has been modified to measure the electromagnetic shielding effectiveness (EMSE) of conductive textile materials using the frequency range 500 MHz - 12 GHz. Various conductive copper filler fabrics have been produced and tested for their electromagnetic shielding effectiveness using both newly modified electromagnetic shielding tester and network analyzer tester (MIL-STD 285), and the values obtained by both the testers are compared and correlated. It is observed that the values measured by the newly modified electromagnetic tester show good EMSE than the network analyzer standard values in the high frequency range 8-12 GHz. The modified system can be used to measure the EMSE of conductive textile materials in the high frequency range 500MHz-12 GHz.

Keywords: Conductive materials, Copper filler fabrics, Electromagnetic wave, Electromagnetic shielding, Network analyzer

Shielding effectiveness is a key parameter which often determines the scope for application of a given material. The shielding effectiveness for metal shields can be determined by knowing the materials' electrical and magnetic parameters, whereas for the materials containing inter-twined metallic or graphite threads, such as plastic materials having metallised surfaces or composite materials, the shielding effectiveness can be determined by actual measuring¹⁻⁵. There are several methods available which allow the shielding effectiveness to be measured⁶⁻¹⁵. However, for flat shielding structures, there are currently no standards defining the evaluation of small samples.

The shielding effectiveness measurement results obtained using currently known methods depend not only on the properties/parameters of the shielding material but also on the size of the test sample, the geometry of the test set-up, and the parameters of the source of electromagnetic radiation¹⁶⁻¹⁸. At the current state of research and development, it is not always possible to take all of these additional factors into account. It should also be noted that there is currently no effective method for comparing the shielding effectiveness results measured using the standards MIL-STD 285 and IEEE-STD-299 with ASTM D4935. There is also lack of generally accepted standardised method for measuring shielding effectiveness of conductive textile materials^{19,20}. The ASTM D4935 (ref. 2) method, however, has numerous disadvantages with regard to measuring EMI shielding performance for small device applications. First, the valid frequency range of the test typically does not exceed 1 GHz, whereas the range of interest for small devices is often, if not usually, higher. In addition, the geometry of the specimen is dissimilar to that found in small devices. Furthermore, the test evaluates substrates with no regard for how they terminate. Finally, experience indicates that the test does not adequately discriminate shielding materials in term of their actual relative performance in small device applications.

Shielding effectiveness can also be measured using a shielding chamber similar to that described in MIL STD 285 (refs 21-28). The shielding chamber method is generally considered a better test in comparison to the ASTM. Unlike the ASTM method, this test can be used to measure at significantly higher frequencies, evaluate an entire shielding system including its termination, and test virtually any shaped sample part as long as one produces an appropriate fixture. On the other hand, the chamber technique has several disadvantages with respect to small device applications. The test is intended for and exhibits the most reliable data for large sized panels and high length gaskets. Data for small samples is difficult to measure accurately. This is deepened by the fact that the method is both highly labor intensive and capital intensive¹⁹⁻²⁸.

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Based on the literature review, it is clear that at the current state of research development there is no measurement method which would singularly define the shielding effectiveness parameters of screening fabrics/textiles. Therefore, in this study, the existing testing equipment has been modified to make it suitable for measuring the electromagnetic shielding effectiveness (EMSE) of textile materials using the frequency range 500MHz - 12GHz. Various fabric samples have been tested for their electromagnetic shielding effectiveness using modified electromagnetic shielding tester and standard network analyzer tester, and the values are compared and correlated.

Modification of Electromagnetic Shielding Tester

The basic shielding mechanisms are reflection, absorption and internal re-reflection of shielding materials. The fabric is placed in between the source and the receiving antenna. The principle involved in the shielding tester includes capturing of the waves that get through the fabric when it is subjected to frequency range. The shielding effectiveness of materials is the ratio of the magnetic strength at the receiver antenna without testing materials to that with the testing materials. In case of MIL-STD 285 system, the output of electromagnetic shielding effectiveness is taken by network analyzer / spectrum analyzer. However, in case of newly modified system, the RF (radio frequency) power meter is used to take the output. In fact, the use of RF power meter increases as the frequency of signals increases. RF power measurement is a key parameter to determine the operation of a circuit at RF or microwave frequencies. Hence, in this study, the output of electromagnetic shielding effectiveness is taken by power sensor and power meter and then computed in computer to estimate the electromagnetic shielding effectiveness in decibel using C programme. The measurement was carried out in open space, thereby eliminating the potential reflections that would introduce errors. The distance between the transmitter and the receiver was calculated by $2D^2/\lambda_0$ and used in the system to avoid the ground reflection, whereas in MIL-STD 285 standard systems, the measurement was carried out in anechoic chambers made of absorbing materials. In case of standard system, there is no separate fabric

clamp, which enables to measure the electromagnetic shielding. However, in modified system a separate frame has been designed for fixing the test sample in different sizes (0.3×0.3 , 0.5×0.5 and 1.0×1.0 m) to measure the electromagnetic shielding effectiveness. It is made up of stainless steel and the distance between transmitting and receiving antenna, and samples frame can be adjusted according to the frequency. The free space measurement system used in the modified tester consists of RF signal source, an isolator, attenuator, a cavity wave meter, transmitting antenna, receiving antenna, power sensor, along with a power meter to measure the output power. The basic test set-up of electromagnetic shielding tester is shown in the Fig. 1. The experiments were carried out from low frequency range 500MHz to high frequency range 12 GHz in open space.

Working Principle

The methodology of designing and fabricating electromagnetic shielding tester is that the electromagnetic wave generated by the RF signal source (500 MHz - 12 GHz) is actuated by the antenna and then passed on to the textile material which is mounted between the transmitting antenna and the receiving antenna on the specimen holder (Fig. 1). The majority of the electromagnetic waves are absorbed and reflected by textile material while the remaining waves are received by the receiving antenna. The power received by the receiver is sensed by the power sensor and actuated to the power meter. The power meter is used to indicate the amount of

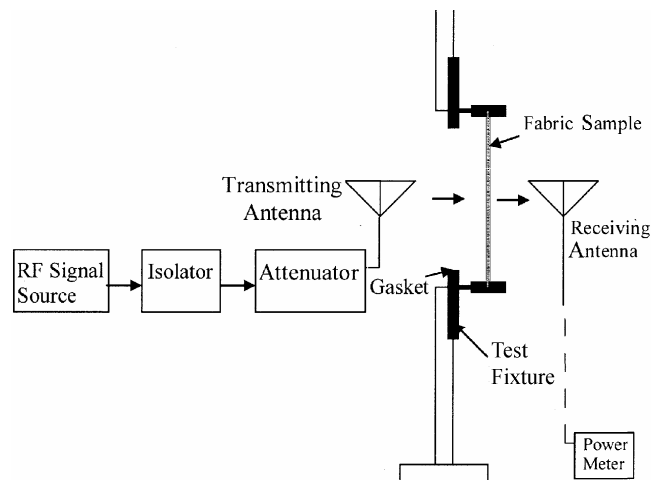


Fig. 1—Shielding effectiveness in closed reference test setup

electromagnetic waves absorbed by the conductive textile material. The shielding effectiveness (SE) is the ratio of the magnetic field strength at the receiving antenna without the testing material (H_0) to that with the testing material (H_1), as shown below:

$$SE, \text{ dB} = 20 \log_{10} (H_0) / (H_1) \quad \dots (1)$$

If a transmission line (propagating energy) is left open at one end, there will be radiation from this end. In case of a rectangular waveguide this antenna presents a mismatch of about 2 m and hence radiates in many directions. The match will improve if the open waveguide is horn shape. The radiation pattern of an antenna is a plot of field strength of the power intensity as a function of the aspect angle at a constant distance from the radiating antenna. An antenna pattern is of course three dimensional but for practical reasons it is normally presented as a two dimensional pattern in one or several planes. An antenna pattern consists of several lobes, such as main lobe, side lobes and back lobe. The major power is concentrated in the main lobe and it is required to keep the power in the side lobes and back lobe as low as possible. The power intensity at the maximum in the main lobe compared to the power intensity achieved from an imaginary omni-directional antenna (radiating equally in all directions) with the same power fed to the antenna. This is the angle between the two points on a main lobe where the power intensity is half of the maximum power intensity. The antenna pattern measurement is always done in far field region. Far field pattern is achieved at a minimum distance which is $2D^2/\lambda_0$, where D is the diameter of the antenna and λ_0 is free space wavelength. The parameter D is also very important to avoid reflection, Antenna measurement is done

outdoor or in anechoic chamber made of absorbing materials. The electromagnetic waves perform two phenomena, namely radiation and induction. The radiation field begins only beyond the distance of $2D^2/\lambda_0$. The distance between sample and transmitting antenna influences the shielding effectiveness of conductive textile materials. As the diameter of the antenna and frequency increases, the distance between sample and transmitting antenna also increases.

Table 1 shows various fabric parameters of copper core conductive textile materials used to measure electromagnetic shielding effectiveness. To analyze EMSE, the samples DCS1, DCS2, DCS3, DCS4, DCS5, DCS6, DCS7 and DCS8 were considered for modified tester and samples CS1, CS2, CS3, CS4, CS5, CS6, CS7 and CS8 for standard network analyzer. Figure 2 shows that there is no significant difference of electromagnetic shielding effectiveness with modified measurement system and network analyzer at 95% confidence level in the frequency ranges 500MHz - 8GHz.

It is observed that the measured values of newly modified system are approximately equal to the standard values of network analyzer. The readings were taken in open space, thereby eliminating the potential reflections that would introduce errors. The distance between the transmitter and the receiver is calculated by $2D^2/\lambda_0$ and used in the system to avoid the ground reflection, whereas the standard process was carried out in chambers which exhibited accurate results. At low frequency range (in terms of MHz), the measured EMSE are approximately equal to the standard values; however, the small variations are due to the influence of the environmental conditions like human influence, atmospheric conditions, complicity and dynamics of scenarios.

Table 1—Copper core conductive fabric parameters

Sample ^a	Thickness, mm	EPI	PPI	Weave	Count, tex	Copper diameter, mm	Cover factor
DCS1	1.05	22	20	Plain	179	0.09	18.4
DCS2	0.9	22	24	2/2 Twill	179	0.09	19.6
DCS3	0.8	22	24	Plain	98	0.09	15.06
DCS4	0.45	22	24	2/2 Twill	98	0.09	15.06
DCS5	0.72	22	25	Plain	118	0.1	17.1
DCS6	1.38	22	24	2/2 Twill	118	0.1	16.79
DCS7	0.9	20	25	Plain	84	0.1	14.5
DCS8	0.55	22	28	2/2 Twill	84	0.1	15.8

^aRespective samples analyzed by standard network analysis are referred as CS1-CS8.

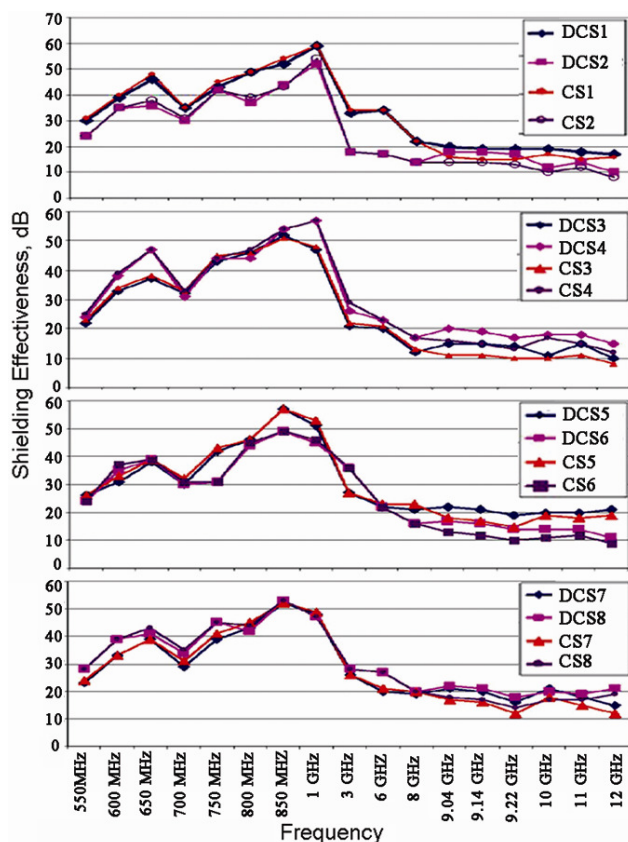


Fig. 2—Comparisons of SE values of various samples

T-tests results of modified tester do not show any significant difference at 95% confidence level in the frequency range 500 MHz - 8GHz, all the measured values are closer to that of standard values of network analyzer. However, the modified values of samples show a significant difference at 95% confidence level in the frequency range 8 - 12GHz. It is also observed that the measured values show good EMSE than the standard values of network analyzer in the high frequency range 8-12 GHz, due to narrow beam width of the parabolic dish antenna before the radiation field begins. The standard values given from the anechoic could not be subjected to low frequency sources. Thus, in the case of low frequency sources like that of a mobile, the anechoic chambers need to be modified accordingly and hence it requires capital investment. It is observed that the modified EMS measurement system can be used to measure the EMSE of conductive textile materials with respect to high frequency range 500MHz-12 GHz.

The total shielding effectiveness of a copper material is equal to the sum of the absorption loss plus the reflection loss. The reflection loss decreases

with increasing frequency due to the increase in shield impedance with frequency. The absorption loss, however, increases with frequency due to the decreasing skin depth. With an increase in wire diameter, a general decrease in shielding effectiveness is observed (Fig. 2). Since copper is a rigid material compared to polymeric textile material, it offers resistance to bend while weaving the fabrics. With the increase in diameter, the bending of copper thread becomes more difficult, resulting in openness in the fabric structure, thereby providing less shielding effectiveness compared to the other samples. If the cover factor of the fabrics is more, the electromagnetic wave (both long and short wave) does not penetrate from one side of the fabric to other side of fabric so that more absorption and reflection of electromagnetic wave would take place by copper core yarn. Hence, the maximum electromagnetic shielding effectiveness can be obtained by using higher cover factor fabrics. It can also be observed from Fig. 2 that electromagnetic shielding effectiveness increases with the increases in thickness and aerial density, since the absorption loss is proportional to the thickness and inversely proportional to the skin depth of the medium.

It is inferred that the newly modified electromagnetic shielding tester can be used for characterization of the electromagnetic shielding effectiveness of conductive textile materials in the low to high frequency range (500 MHz - 12 GHz). The modified tester shows good EMSE results than the standard measurement system (MIL – STD-285) in the high frequency range 8-12 GHz. The technique is simple and reproducible. It is neither labor-intensive nor capital-intensive and can be used to generate statistical data. This tester can be used for less than 1mm thickness of thin conductive textile materials. The possible extension would be the inclusion of anechoic chamber which would further improve the accuracy of the results in case of low frequency.

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