Limitations of Shielding Effectiveness Measurements of Planar Materials using a DTEM cell

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***Abstract*—This paper addresses issues encountered in a method for measuring the shielding effectiveness of planar materials using a dual transverse electromagnetic cell. The aim of this work is to evaluate the performance of the setup and to point out its strengths and weaknesses. The effect of placement of several materials varying in size and texture is examined. Additionally, techniques for improving the setup and therefore the measurement accuracy and sensitivity are presented. The size of the aperture is investigated by applying two different methods in order to observe its effect on the shielding effectiveness results. Restrictions and limitations of the measurement method are discussed and supported by experimental results.**

Keywords— dual TEM cell, shielding effectiveness

I. Introduction

The importance of electromagnetic shielding is rapidly increasing and the study, understanding, analysis and comparison of the various measuring methods are becoming more necessary. Many measurement techniques have been used and discussed in order for the shielding mechanism to be largely understood. Existing measuring techniques include the enclosures and boxes approaches, which are based on IEEE 299 Standard [1] and IEEE 299.1 Standard [2], respectively, along with approaches including reverberation chambers (RCs) [3], nested RCs [4], the dual Vibrating Intrinsic Reverberation Chamber (VIRC) [5], waveguides [6] as well as the dual transverse electromagnetic cell (DTEM) [7].

The work presented in this paper has been carried out of the IEEE project P2715 – Guide for the Characterization of the Shielding Effectiveness (SE) of Planar Materials. The aim of this project is to evaluate and compare different SE measuring techniques by using different equipment with the same samples under test. During the project, it was observed that even though the same materials were used for all the various SE measuring techniques, the results presented strong differences between each other. The spread of the results can be easily justified by the fundamental differences between the measuring procedures. However, during the SE measurements conducted using the DTEM cell in particular, the results presented noticeable deviations. A SE measuring technique requires high repeatability of the results and also low susceptibility to small changes in the setup so that comparisons can easily and efficiently be made between the materials under test (MUTs) as well as between the different SE techniques. The SE performance of different materials as well as various effects concerning the DTEM cell SE measuring technique are discussed and examined in this paper.

During the SE measuring procedure using a DTEM cell, factors such as the nature of MUTs as well as the dimensions of the aperture between the two TEM cells need to be under consideration [9]. Such factors are investigated in this paper. Materials of different sizes and various textures are put under test. The placement of samples on the aperture of the DTEM cell as well as appropriate processing of them are examined through experiments. From the experiments, potential sensitivities of the setup are indicated. Additionally, the effect of the aperture and its significance on the determination of SE are briefly discussed. In conclusion, the strengths and weaknesses of the DTEM cell SE measuring procedure are pointed out.

II. Measurement Setup

The DTEM cell in this paper is used for SE measurements of planar materials. A DTEM cell consists of two TEM cells connected with a common wall (Fig. 1). A single TEM cell consists of a section of rectangular coaxial transmission line tapered down at each end to match 50 Ω coaxial line [7]. The DTEM cell used in this paper operates in the frequency range of 100 MHz to 1 GHz. The MUT is placed on top of an aperture in the common wall between the two cells. The aperture sized 100 x 20 mm can be seen in Fig. 2. From the same figure the permanent installed gaskets placed around the aperture in dimensions 152 x 52 mm can also be seen. The permanent gaskets are used in order to minimize any leakage and maximize the coupling between the aperture and the MUT. After the MUT is set covering completely the aperture and making preferably contact with the around permanent installed gaskets, a thick plate (not displayed in Fig. 2) is placed over it and presses it with the help of 26 screws.

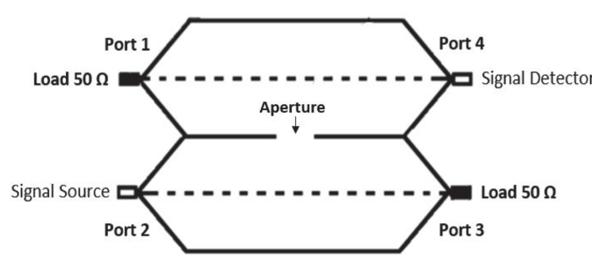

Fig. 1. Schematic of the DTEM cell setup

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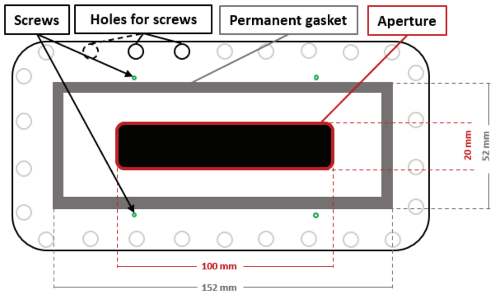

Fig. 2. Schematic displaying the dimensions of the aperture and the permanent gaskets on the common wall of the DTEM cell before the thick plate is placed

As seen from Fig. 1, the power is transferred from Port 2 at the lower cell and is received at Port 4 in the upper cell. The measurements were performed using a vector network analyzer (VNA). The calculation of $\mathrm{SE}_{\mathrm{dB}}$ in dB was conducted using the S-parameters as shown in [9]:

$$\mathrm{SE}_{\mathrm{dB}} = S_{21_{\mathrm{dB(without\,MUT)}}} - S_{21_{\mathrm{dB(with\,MUT)}}} \qquad (1)$$

$$S_{21_{\mathrm{dB}}} = 20\log_{10} S_{21}$$

where $S_{21_{\mathrm{dB(without\,MUT)}}}$ is the magnitude of the transmission coefficient measured with a VNA without the MUT present and $S_{21_{\mathrm{dB(with\,MUT)}}}$ is the magnitude of the transmission coefficient measured with the MUT present.

In the experiments conducted in this paper, the textures and sizes of the MUTs vary. For each case, a different processing of the sample was implemented in order for the materials to be placed appropriately on the aperture. The processing of the materials took place depending on their nature (soft, hard) and their size (bigger or smaller than the permanent gaskets (Fig. 2)). The aim of the MUT processing is to ensure their secure placement on the DTEM cell common aperture to maximize the accuracy and repeatability of the SE results.

A. Types of materials

For the experiments conducted in this paper, two types of materials were used. The first type of materials was characterized as easily processed (e.g., fabrics, cloths, coated fiber materials, different textiles, etc.) while the second type included materials of harder nature (e.g., conductive plastics, metal flaxed plastics, etc.). For each type, a different processing of the materials took place.

For the easily processed materials, the available samples were in size 120 mm x 70 mm. Therefore, they covered the aperture efficiently but were bigger than the permanent gaskets placed around the aperture. Three different processing techniques were examined in these materials:

1) Cutting the MUT in the dimensions covering the permanent gaskets i.e. 120 mm x 52 mm
2) Folding the two smaller opposite sides of the MUT to cover the permanent gaskets and form the dimensions 120 mm x 52 mm
3) Making holes in the MUT for the four screws around the aperture (shown in Fig. 6)

In this paper, a Silver -Ag- plated Nylon fabric material [10] called Bremen-RS was put under test in order for the three processing techniques to be investigated. For all the experiments, additional gaskets as shown in Fig. 3 were put in order for any potential leakage to be minimized.

For the MUTs of harder nature, the available sizes were smaller than the around permanent gasket i.e., 120 mm x 40 mm and 120 mm x 27 mm. The MUTs used for these experiments were all conductive plastics. To maximize the coupling through the MUT and minimize the leakage, another type of gasket was additionally used, as seen in Fig. 4.

B. Aperture size

The aim of the experiments described in this subsection is to investigate the aperture size influence on the SE results. In this paper, two methods changing the aperture were implemented. For both implemented methods, carbon fiber in size 120 x 70 mm with additional gaskets (as seen in Fig. 3) was put under test. Since the dimensions of the MUT were bigger than the original aperture (original aperture: 20 x 100 mm) and can be characterized as an easily processed material, as mentioned in the previous subsection, holes were made onto the MUT for better contact (Fig. 6).

For the first method, copper tape was placed in the original aperture sized 20 x 100 mm to create two types of smaller apertures, one of dimensions 20 x 46 mm and another with dimensions 20 x 26 mm (Fig. 5). Then, the MUT with additional gaskets was placed on top of the apertures as seen in Fig. 6. For the second method, two fixed aluminum plates, which are shown in Fig. 7 and Fig. 8 were used. The sizes of the two apertures were 50 x 10 mm and 100 x 10 mm respectively.

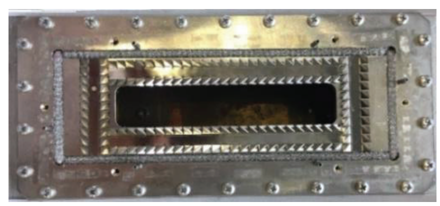

Fig. 3. Additional gaskets used for minimazing the leakage between the MUT and the wall

Fig. 4. Extra gasket placed around the harder nature materials for better contact between the MUT and the aperture

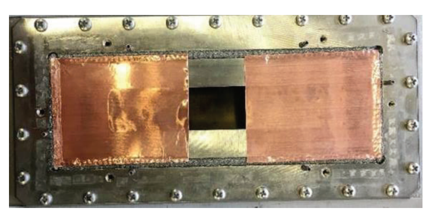

Fig. 5. Aperture decreased with copper tape

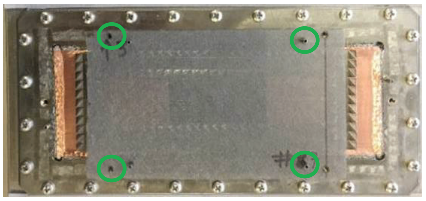

Fig. 6. Aperture decreased with copper tape and MUT processed with made holes

Fig. 7. Fixed aluminum plate with aperture 50 x 10 mm

Fig. 8. Fixed aluminum plate with aperture 100 x 10 mm

III. Measurement Results

The SE performance of the various materials of different types and dimensions are displayed and discussed in the first subsection followed by the results regarding the aperture investigation in the second subsection.

A. Types of materials

For the easily processed materials, described in Section II, the results are shown in Fig. 9. The SE results with Bremen-RS as MUT in the three optional processing techniques (cut, folded, with holes), are portrayed along with a sample of size 152 x 52 mm (covering the permanent gasket and the aperture). It is shown, that both *folded* and *with holes* cases have similar effect on the results and present higher SE levels compared to the other cases examined. Oppositely, the cases with the *cut* material and the sample having the exact dimensions of the plate result in lower SE values. Additionally, in the same figure, it can be observed that with the inclusion of additional gaskets, the results present higher SE. The additional gaskets help to maximize the coupling between the MUT and the aperture, while minimizing the leakage between the TEM cells. As the deviations are not too high (around 2 dB) in the three applied cases, the choice of material processing depends on the user and the available sample. Sufficient contact of the MUT and the common wall seems to be necessary for the material to be adequately investigated. The SE results of the materials of harder nature are shown in Fig. 10. The effect of the extra gaskets as described above and depicted in Fig. 4 can also be clearly seen in Fig. 10.

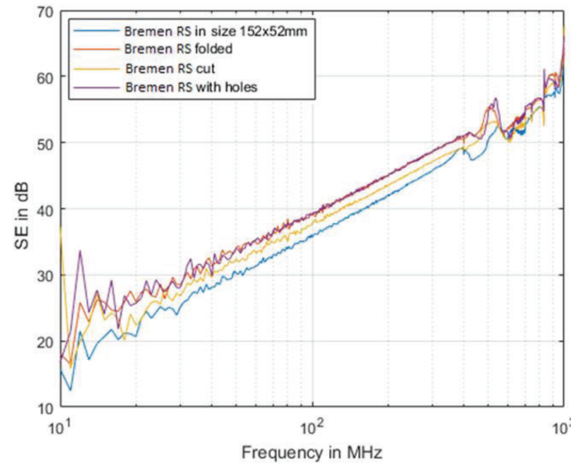

Fig. 9. Bremen-RS tested with different processing techniques

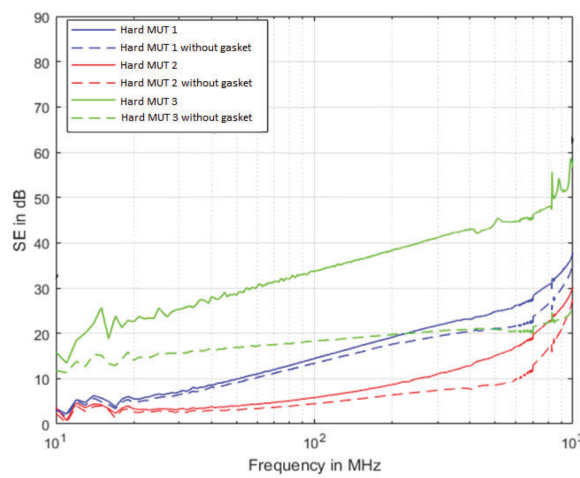

Fig. 10. Effect of the gasket around the MUTs of harder nature

As it can be observed, the application of extra gaskets around the MUTs increases the SE values also in this type of materials. Even though it seemed that sufficient contact is made even without them. It is noticed that as the frequency increases, the difference between each material with and without gaskets increases as well. Especially for hard MUT 3 the difference reaches around 30 dB at 1 GHz. For lower frequencies, the deviations are smaller for all the materials. This behavior is also a result of the nature of the materials, which doesn't allow adequate contact between the MUT and the aperture.

The application of gaskets in both types of materials seemed to be of great importance in the levels of SE values. Thus, it should be noted that sufficient mounting of the MUT on the aperture and therefore elimination of the error regarding leakage should be always taken under consideration. Incorrect placement of the materials or avoidance of the appropriate preparations before each measurement could lead to high deviations.

B. Aperture size

The results of the two aperture-altering methods discussed in Section II are presented in this subsection. First, the S_{21} values of the apertures made with the use of copper tape along with the original aperture of the DTEM cell are shown in Fig. 11. It can be observed that the size of the aperture does affect the results indeed. As expected, the smaller the aperture, the lower the level of the S_{21} parameter values. The depicted curves present a difference over 10 dB between each other. The SE results with the MUT placed on the different apertures can be seen in Fig. 12. It can be observed that even though the same MUT is used for all these experiments, the results differ. Therefore, as it seems, the definition of SE does not refer directly to the characteristics of the material but to the fixed framework and settings of each measurement individually, including the MUT size, shape, and how its mounted in the cell. Similar determination of SE, focused on the mounting and size of the sample, present also the RCs. RCs have the advantage of varying in size and therefore, they can be used in practical cases with corresponding correction factors [3]. The DTEM cell, though, as seen from the results, needs different corrections concerning the aperture size, in order to be compared with other SE methods. A more theoretical SE approach concerning the materials in particular, is measured in anechoic chambers (ACs) [1] but the mechanism of the DTEM cell differs from the AC.

Additionally, it can be observed, that as the frequency increases, the S_{21} parameters in Fig. 11 increase as well in all three cases due to the aperture becoming electrically and physically larger. The same behavior is also seen in the SE results of the MUT placed on the different apertures in Fig. 12.

The application of fixed metal plates and the investigation of smaller sized apertures concludes again to different results for each case, as can be seen in Fig. 13. The S_{21} parameters of the two cases presented in Section II along with the original aperture (20 x 100 mm) are depicted. Again, the smaller sized aperture results in smaller S_{21} parameter values. The SE results of carbon fiber as MUT can be seen in Fig. 14. The use of different sized apertures result to different levels of SE. Therefore, the same material is measured to have a different SE in the two cases. The observations in this investigation using the fixed metal plates are similar as in the case of using copper tape explained previously. The aperture, again, plays an important role in the definition of SE and influences the results significantly.

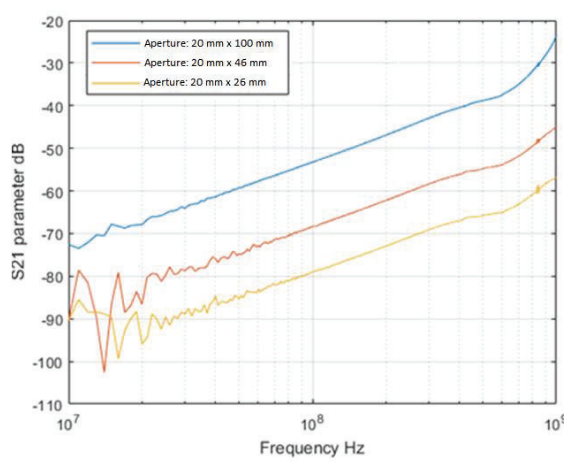

Fig. 11. S_{21} parameter values of various aperture sizes formed with copper tape

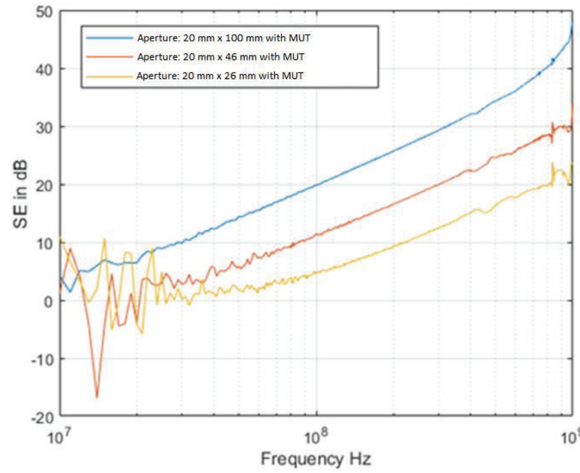

Fig. 12. SE of various aperture sizes formed with copper tape and with carbon fiber under test

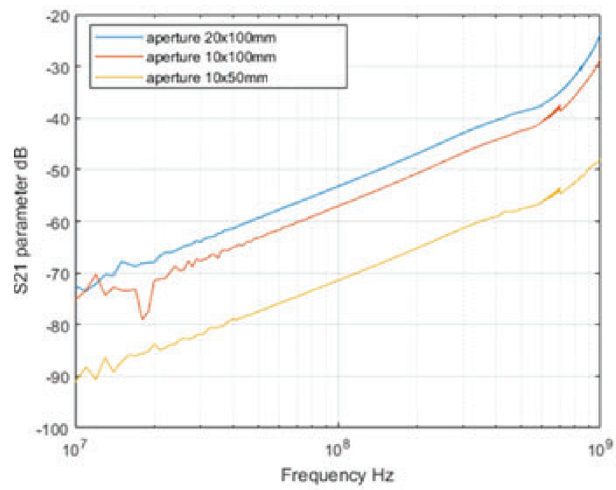

Fig. 13. S_{21} parameter values of various aperture sizes using fixed metal plates

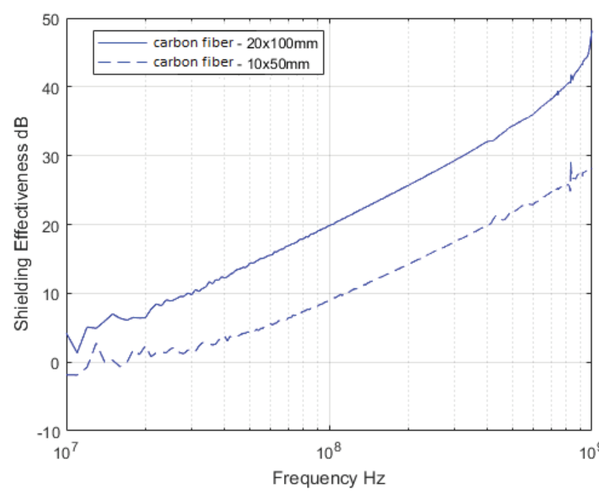

Fig. 14. SE of various aperture sizes using fixed metal plates with carbon fiber under test

IV. CONCLUSION

From the different investigations presented in this paper it can be concluded that many parameters should be taken under consideration while conducting SE measurements using the DTEM cell. First, the appropriate placement of the material in the DTEM's common aperture is a factor that needs to be addressed. Depending the size and the nature of the MUTs, the materials need to be accordingly processed in order to be placed appropriately on the aperture before any measurement. This processing is fully dependent on the user and any human error during the measurement could lead to false and inaccurate results. Sufficient connection between the MUT and the aperture should always be under consideration as it effects highly the SE levels. Gaskets can be of great help to achieve high contact between the MUT and the aperture in the common DTEM cell wall. This maximizes the transmission of the energy through the MUT and not leaking around it, which would underestimate the SE. Additionally, the aperture set for the measurements seems to significantly influence the determination of the SE results of each material. It should be noted that the SE results do not refer directly to the material characteristics, but they depict the behavior incorporating the aperture effects and the overall way the MUT is mounted in it. The use of different apertures concludes to different results each time making the aperture one of the more influential parameters of the setup.

As can be observed from all the presented experiments in this paper, the DTEM cell is quite an inconsistent SE measuring technique. The setup can be very sensitive when it comes to the human error and it depends significantly on the effects of the common aperture. It does not produce with ease repeatable results and therefore it is difficult to compare its SE results with other measurement techniques. The DTEM cell might be a quick and effective technique when it comes to comparing the SE between materials of similar shapes but it is not appropriate for providing the absolute characteristics of each material individually. It has been shown that the method of calculating the SE is not sufficient and needs fundamental improvements by introducing further correction factors.

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