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Electromagnetic Shielding Efficiency Measurement of Composite Materials

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This paper deals with the theoretical and practical aspects of the shielding efficiency measurements of construction composite materials. This contribution describes an alternative test method of these measurements by using the measurement circular flange. The measured results and parameters of coaxial test flange are also discussed. The measurement circular flange is described by measured scattering parameters in the frequency range from 9 kHz up to 1 GHz. The accuracy of the used shielding efficiency measurement method was checked by brass calibration ring. The suitability of the coaxial test setup was also checked by measurements on the EMC test chamber. This data was compared with the measured data on the real EMC chamber. The whole measurement of shielding efficiency was controlled by the program which runs on a personal computer. This program was created in the VEE Pro environment produced by © Agilent Technology.

Keywords: Shielding Efficiency, Composite Materials, Scattering Parameters, Measuring Flange

1. Introduction

The measurement of shielding efficiency of shielded, absorbing and EMC chambers or boxes is usually done by the setup which contains the transmitting and receiving antennas, test signal generator and test signal receiver. As test signal receivers are usually used the EMC receivers or spectral analysers. The measurement itself runs as follows. The receiver with the receiving antenna and also with essential cable is situated inside the chamber or tested box. The transmitter (signal generator) and transmitting antenna are placed at the outer side of the tested object. The location of the antennas is changed around the chamber or box and peak signal on desired frequency is recorded by the spectral analyser. The worst case, when the shielding efficiency is the lowest, is reliably identified by the positioning of antennas around the tested chamber [1] and [2]. These chambers are usually made from metal plates.

The problem arises immediately when it is necessary to measure the shielding effectiveness of the material from which the chamber or box will be constructed. Especially in the development stage it is not possible to construct the whole chambers or boxes in the huge sizes for accurate measurements. This approach is expensive and also time consuming. There are constructional problems which extend the development of the composite materials.

A similar problem appears when it is necessary to know the shielding efficiency of construction materials like bricks, plasterboard, concrete etc. These materials could be also called composite materials, especially during their development stage. The main construction problem of the chambers or boxes from these types of materials for the measurement setups mentioned above is the construction of the doors. The door of these chambers or boxes has usually the main influence on the whole shielding efficiency. In other words, the doors always represent the weakest part of these shielded chambers. Construction of the doors from the concrete-based material is really complicated, in a lot of cases nearly impossible.

2. Subject & Methods

The alternative test method for the testing of shielding efficiency of shielding materials is discussed in [3]. The presented coaxial test apparatus is mainly suitable for thin materials like plastic or metallic boards, fabric material and so on. This setup is not proper for the construction materials (concrete, bricks etc.). It is very complicated to produce the thin concrete plain with maximal height around 1 mm for the presented test setup. The modified test setup according to Fig.1 was produced after analyses of commonly available measurement solutions and setups. Fig.1 shows the technical drawing of the measurement coaxial flange. This flange was mainly designed for frequency range from 9 kHz up to 1 GHz. The shape and dimensions of the flange were calculated for the 50 Ω input and output impedances [4].

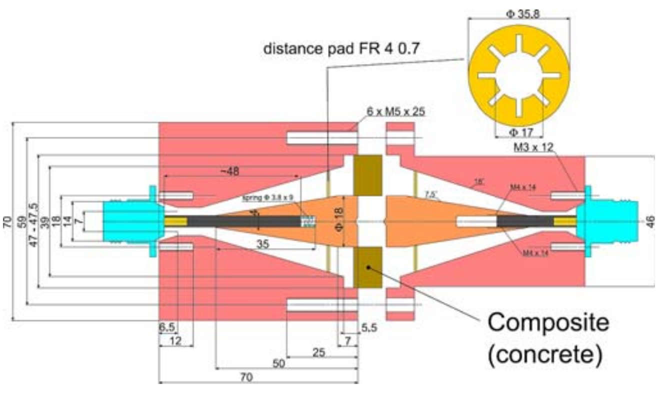

Fig.1 Basic dimension drawing of the circular flange (dimensions are given in mm)

The impedance of the flange was calculated on the 50 Ω, due to the impedance matching of the whole measuring system. The design of the flange was done according to the basic mathematical relation [4]

$$Z_{\mathrm{m}} = \frac{60}{\sqrt{\varepsilon_{\mathrm{r}}}} \ln \frac{a_2}{a_1} , \quad (1)$$

where Z_M is the characteristic impedance of the measurement system (50 Ω); ε_r is the relative permittivity (in this case is equal to 1, air); a_1, a_2 are the radii of the coaxial line (flange).

The transition from the N-type connector to the opposite end of the flange has the linear shape for both parts of the flange, central and external one. This shape was chosen for better construction. The liner shape should be optimised for better impedance matching especially at frequencies over 1 GHz. The central flange conductor was constructed from brass. The rest of the flange was made from aluminium alloy. The flange has been tightened by the torque wrench after inserting the test composite by the same torque every time. This setup increases the accuracy of each measurement and also increases the repeatability during several measurements.

The measured scattering parameters of the flange itself are given in Fig.2. The measurements of scattering parameters were done according to [5]. The s_{11} and s_{22} are in the whole range of interest under -15 dB which refers about the good matching of both test ports with the measuring system. The insertion losses in both directions (s_{21} and s_{12}) are in the whole frequency measuring range below 1 dB. This data refers about the accurate design of the whole coaxial flange. The flange itself will have insignificant influence on the total dynamic range of the whole measurement setup. The dynamic range will be mainly affected by the used measuring devices (by generator and spectral analyser). The measured scattering parameters refer about the accurate design of the coaxial flange.

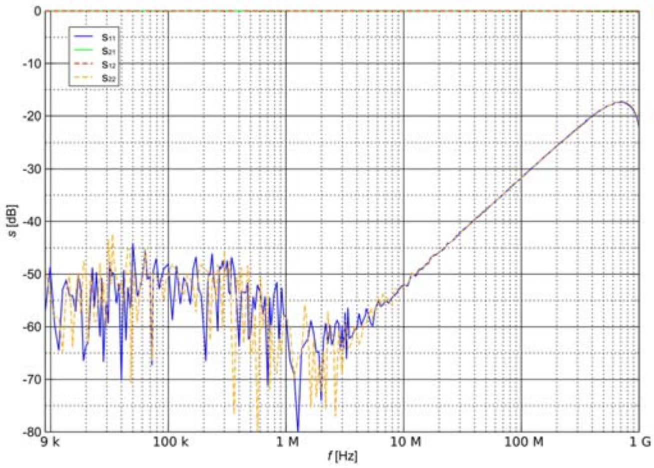

Fig.2 Measured scattering parameters of realised coaxial flange

3. Verification of measurement setup

Verification of the coaxial flange was done by measurement of the metal plate that forms the EMC chamber. The EMC chamber at the Department of Radio Electronics is made from exactly the same material. So at the first stage the shielding efficiency of the whole chamber was measured by the "classical test setup" with two antennas. Second measurement data was produced by the coaxial flange. Obtained results are given in Fig.3. The measured data of the brass calibration ring was also added for comparison.

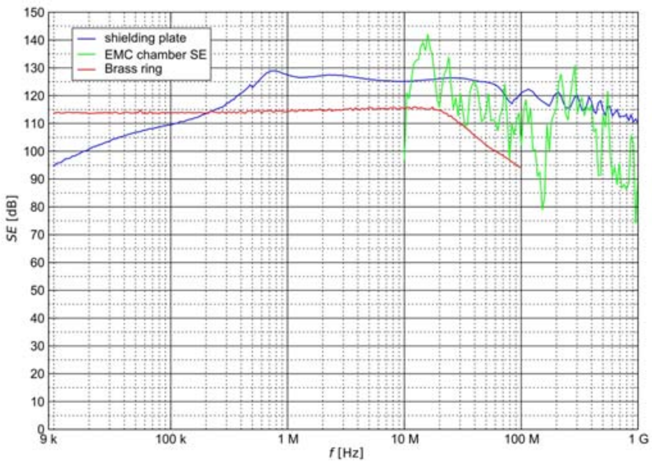

Fig.3 Performance comparison of the shielding measurement methods

Data presented in Fig.3 for the metal EMC chamber plate shows great agreement for both types of measurements. The results obtained in "classical" test setup are not so stable. The fluctuations are caused by the construction aspects of the EMC chamber. The chamber is not made from one full plate only, but it is bolted from several metal plates. Bolted connection reduces the whole shielding efficiency of the whole EMC chamber. This is the reason for the deviation of the total shielding efficiency. But the average progress corresponds very well with the data measured in the coaxial flange. In this flange the full plate without any defects or bolting was measured. Fig.3 shows great agreement between these two measurements. It could be established that the coaxial flange is appropriately designed and it is suitable for the intended shielding efficiency measurements.

4. Shielding efficiency measurements of composite materials

After the design and verification of the coaxial flange by the shielding measurements on the "known" material, the composite materials were measured. Firstly the test samples of concrete materials were produced. There were problems with the precise prefabrication of the test concrete rings. These rings have to be produced with high accuracy of their dimensions and the rings have to be firmly set into the flange. The real produced flange with the tested composite ring is depicted in Fig. 4. It is necessary to provide ideal connection between the centre conductor and the outer braid of the coaxial flange. In an ideal case, the composite material has to shorten the coaxial conductors. It means that the composite material has to have the lowest impedance possible for great shielding similar to the shielding plates. In another case the composite material has to have very high attenuation in longitudinal direction for attenuation of the RF energy inside the composite material.

Fig.4 Physical realisation of the coaxial flange

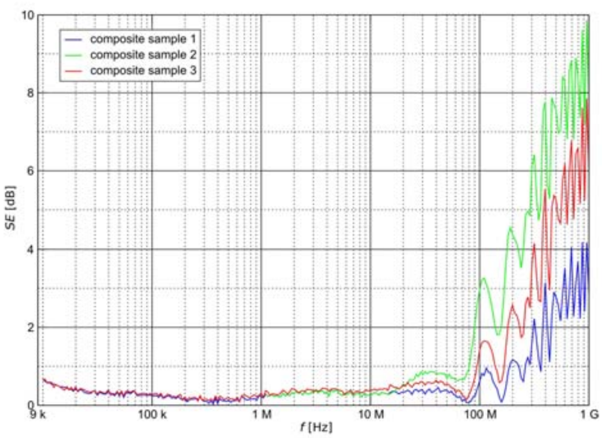

Fig.5 Shielding efficiency of the composite materials

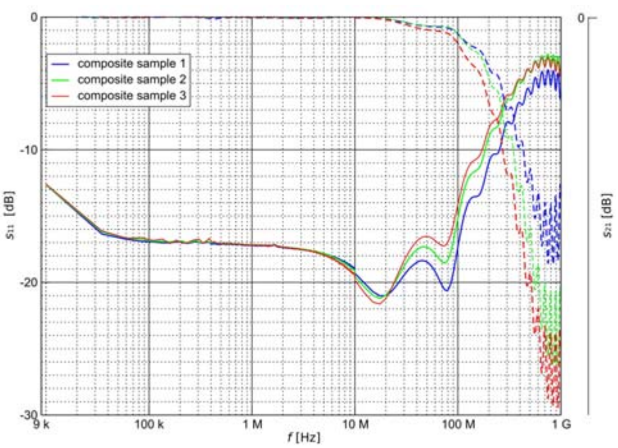

Fig.6 Scattering parameters of tested composite materials (s_{11} - full lines, s_{21} - dashed lines)

The shielding effectiveness measurements of the composite material were done on the test samples with about 8 mm thickness. The test sample is also shown in Fig.4. The measurements were focused mainly on the concrete with graphite during the development stage of these concrete-based materials as potential shielding materials. Some results are depicted in Fig.5. In this stage of the development, the shielding efficiency is not so high. The improvement of shielding efficiency is the main target of further development.

5. DETERMINATION OF THE ELECTROMAGNETIC SHIELDING FACTORS FROM THE SCATTERING PARAMETERS

The total electromagnetic shielding is usually composed of and also influenced by several factors. These factors are mainly reflection loss, absorption loss and multiple path reflection losses. The knowledge of the quantity of each factor could be useful for the next development stage.

The realised coaxial flange is also suitable for that type of measurement. It is necessary to measure the scattering parameters s_{11} and s_{21}. Measured data for some composite samples are given in Fig.6. This data had to be divided into two parts and reflection and absorption losses could be determined. The multiple path reflection loss is not put into effect in this case. These losses are mainly significant in low frequency range.

The reflection SE_{RL} and absorption SE_{AL} losses could be calculated from measured scattering parameters s_{11} and s_{21} by the following formulas:

$$SE_{\mathrm{RL}} = 10 \cdot \log\left(1 - 10^{\frac{s_{11}}{10}}\right), \tag{2}$$

$$SE_{\mathrm{AL}} = 10 \cdot \log\left(\frac{10^{\frac{s_{21}}{10}}}{1 - 10^{\frac{s_{11}}{10}}}\right). \tag{3}$$

Where s_{11} and s_{21} are measured scattering parameters by the coaxial test flange and SE_{RL} is determined reflection loss by the composite material. The SE_{AL} means the absorption loss in the composite material. The SE_{RL} coefficient represents reflections on both sides of the composite test sample. This fact is caused by the used measurement technique. The applied technique uses basic vector network analyser with peak detectors, so both reflections on the edges are added up into the one measured s_{11} parameter. The calculated reflection and absorption losses for some samples are depicted in Fig.7.

The data is shown for several composite materials with the thickness of 8 mm. By increasing the thickness two times, it becomes obvious that the shielding efficiency will not increase two times. In this case, the absorption loss will increase twofold only and reflection loss remains the same. The determined data flows make the increase in the conductivity of the tested samples necessary for better shielding. The increase in thickness of the material will not lead to the desired results.

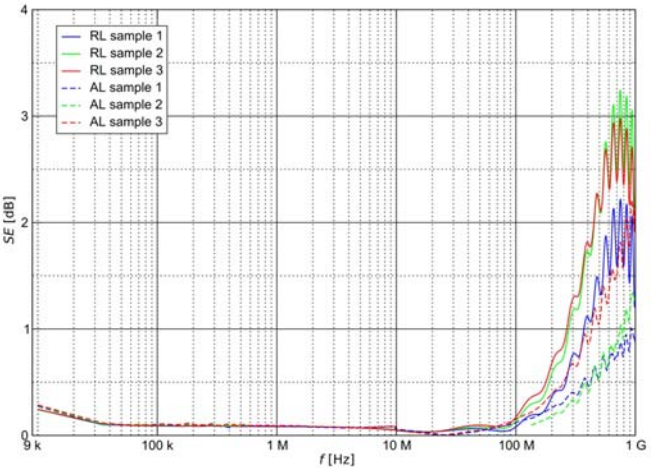

Fig.7 Calculated shielding efficiency components (reflection and absorption losses)

6. CONCLUSIONS

The modified test setup for the shielding efficiency measurements of the constructional materials like concrete or fabric was presented in the paper. The electric part of the shielding efficiency component should be measured by the shown setup and the measurement itself was done by the realised coaxial test flange. The properties of the flange were checked by several measurements. According to the measured data, it is possible to say that the coaxial test flange was optimally designed. Measured scattering parameters refer about the great matching of the coaxial test flange with the whole measuring system. The insertion loss caused by the flange is also negligible. There are not any dynamic range degradations. The presented test setup could provide the measurement with 140 dB dynamic range. Test flange was designed for the frequency range from 9 kHz up to 1 GHz. Indispensable optimization in the design will be required in the extension over 1 GHz. Linear shape transition should be replaced by any other shape.

The accuracy of the used test method with the flange was proven by the measurement of the same material two times. This material was used for the EMC chamber construction. The measurements were taken on the EMC chamber by the antennas and also by the coaxial flange. Measured results are in good agreement, which refers about the suitability of measurements with the test flange.

The scattering parameters of the composite materials were also measured. The reflection and absorption losses were determined according to this data (Fig. 7). From these results, it will be possible to establish the performance of the composite material if their thickness increases. It is obvious that the increasing thickness will not lead to the desired performance of the e.g. 30 dB shielding efficiency. It is necessary to reduce the conductivity of the composite material, but this is not the aim of this article. The goal of this article was to introduce the measuring setup and discuss the parameters of the design flange and test setup. The high performance of the whole measurement setup was increased by the created control program in VEE Pro environment by which the measurements were controlled. The performance of the whole setup is on high level and the measurements produce accurate results.

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