EXPANDING THE FREQUENCY RANGE OF THE TEM-t CELL FOR THE MEASUREMENT OF SHIELDING MATERIALS UP TO 12 GHz

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Abstract: The characterization of the shielding effectiveness (SE) of planar materials can be determined over a large range of frequencies in a non-destructive way by measuring the transmission loss in a TEM-t cell. The cell has been described and analysed in literature since a long time, but the frequency range was restricted to 1 GHz. This papers show the possibility to use the existing TEM-t cell up to the frequency of 8 GHz.

Keywords: measurement , shielding, TEM-t cell

1. INTRODUCTION

The characterization of the shielding effectiveness (SE) of planar materials can be determined over a large range of frequencies in a non-destructive way by measuring the transmission loss in a TEM-t cell. The cell has been described and analysed in literature since a long time, but due to its dimensions, the frequency range was restricted to 1 GHz [1]–[3] . The TEM-t cell consists of two identical halfs and the construction is shown in the next figures 1 – 2.

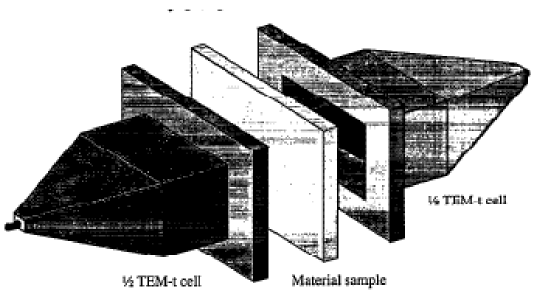


Figure 1. TEM-t cell

Each half contains:
- a tapered section from coax to rectangular section with septum (inner conductor)
- a rectangular cross section with a rectangular outer conductor and a centered plate as inner conductor
- the inner conductor does stop just before (< 1mm) the plane of the flanges
- the surface of the flanges of the outer conductor is quite large to provide large capacitive coupling
- the samples under test must cover completely the flanges, and make no contact with the inner conductor

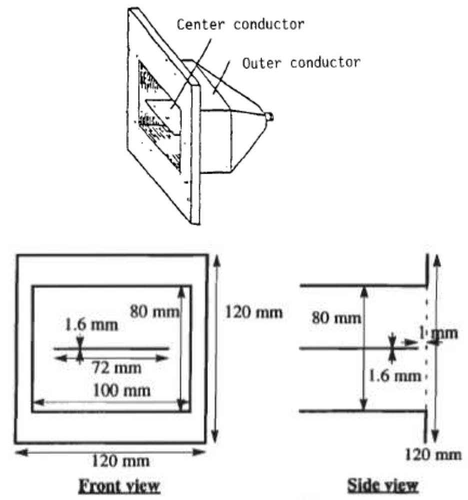


Figure 2. Dimensions of the TEM-t cell

As the cell can be considered as a kind of expanded coaxial line, it might be supposed that the internal field distribution is near to the one of a TEM propagation mode, as was also reported in [1] by calculating the potential distribution at the frequencies of 100 MHz and 1 GHz.

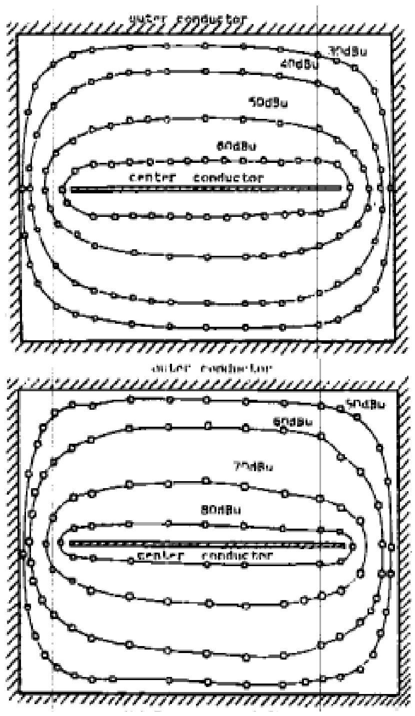


Figure 3. Potential distribution in the TEM-t cell at 100 MHz (upper) and 1 GHz (lower)

3. LOW FREQUENCY CIRCUIT

Regarding the lower frequency range, where TEM conditions are applicable, an equivalent circuit diagram can be drawn for both the empty cell (reference measurement) and loaded cell.

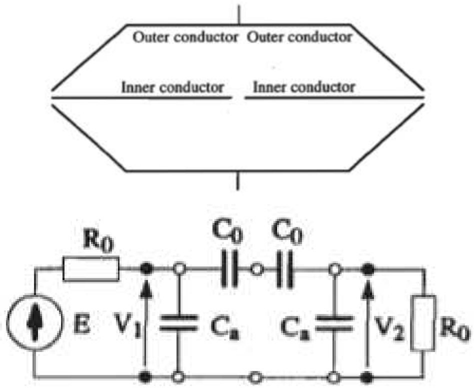


Figure 4. Equivalent circuit diagram for the empty cell

Using a simple static 3D solver, the capacitances C_0 and C_a can be derived: C_0 = 3.6 pF and C_a = 0.06 pF The same can be done for the loaded cell:

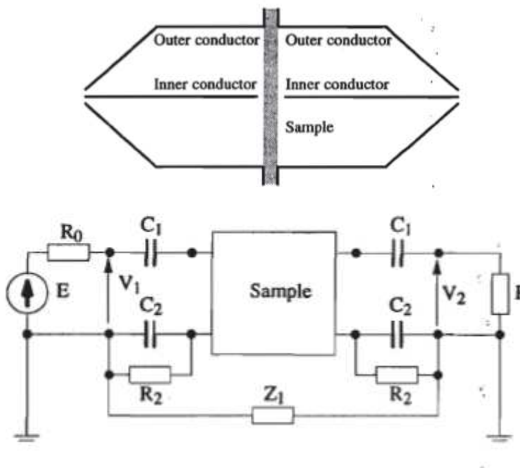


Figure 5. Equivalent circuit diagram for the loaded cell

A good correlation between theory and practical measurements was observed. The next figures shows some calculated results, and special attention is given to the empty cell transmission coefficient, with a slope of 20 dB/decade.

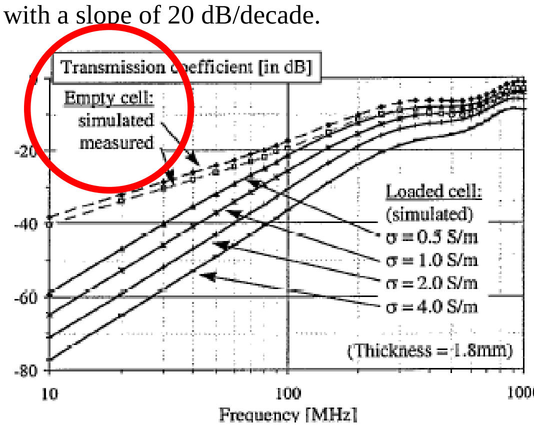


Figure 6. Calculated transmission coefficient for TEM-t cell

In more, a good agreement has been found between the measured SE values by using the TEM-t cell and the standardized ASTM D4935 cell [8]. The next figures shows the correlation between the measured SE values using both cells and the square resistance R□ of the samples of a material, made of plastic filled with a given Volume % of stainless steel fibres [10] , at the frequency of 400 MHz.

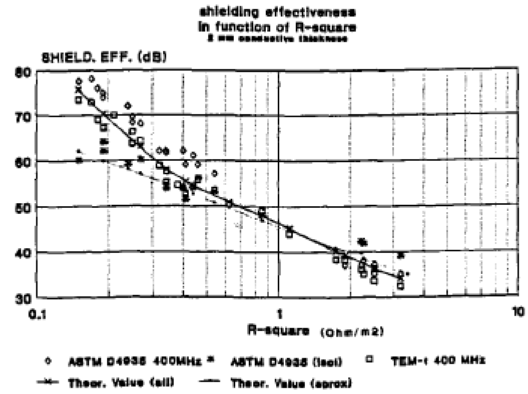


Figure 7. Corrrelation between TEM-t and ASTM D4935 cells

As a reference for this study of expanding the frequency range of the TEM-t cell, the SE results of two samples of a plastic filled with stainless steel fibres [10] are given in the next figure 8.

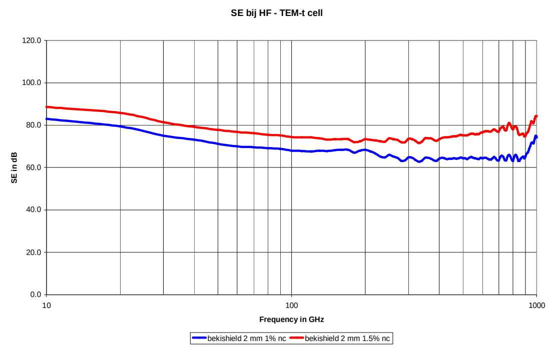


Figure 8. Measured SE values of two samples

4. HIGHER FREQUENCY RANGE

As the frequencies (and the harmonics of clock frequencies) are increasing, the question raises to characterize small samples of shielding materials up to higher frequencies. New methodologies are under development, but the expansion of the frequency range of the existing cells up to higher frequencies could offer a quick and easy evaluation of the materials under test.

As the identification of the polarization of the impinging waves is a very crucial parameter for the final interpretation of SE results, the question is raised how the field distribution in the TEM-t cell is behaving at higher frequencies.

As the cross section of the TEM-t cell is rectangular, the frequency of the first higher order mode of propagation can be estimated by considering the cell as a rectangular waveguide.

This transition frequency is estimated as 1.5 GHz. However, it is well known that higher order modes may occur, but that they have to be excited in order to occur. Normally, higher order modes are excited in waveguides by asymmetrical excitation. As the construction of the TEM-t cell is symmetrical, the question is up to which frequency the cell could be used under well known TEM conditions.

In order to have an insight in the field distributions within the TEM-t cell, numerical simulations have been performed.

5. NUMERICAL SIMULATIONS

Numerical simulations have been performed by using the Agilent 3D EMPro solver. The next set of figures show a summary of some of these simulation results.

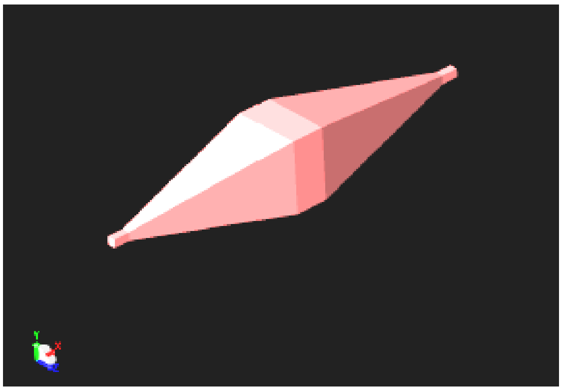


Figure 9. TEM-t cell as used for the simulations

The X-axis is in longitudinal direction. Y and Z axes are located in the cross section area. In this model, the septum or inner conductor has a vertical orientation and is parallel with the Y-axis.

A full set of simulated results is obtained, but only a restricted number of typical results of the E field distribution will be shown in this paper.
First of all, as a good reference, the E field is given at the lower frequency range of 100 MHz.
The next figures are taken respectively for 1 GHz, 4 GHz, 8 GHz, 9 GHz, 11 GHz and finally 12 GHz.

Due to the length of the cell, and the fact that the tapering is acting as a (smooth) physical discontinuity, some variations of the longitudinal Ex component are clearly observed. But just starting above 8 GHz, the effect of the excitation by some higher order mode is observed, generating very varying field distributions in function of frequency.

To be observed is the nearly uniform Ez field distribution at 11 GHz. It suggests that in the frequency range from 8 GHz up to 12 GHz, nearly uniform Ez field distributions may occur, making SE measurements up to 12 GHz reasonable, if interpreted in a correct and intelligent way.

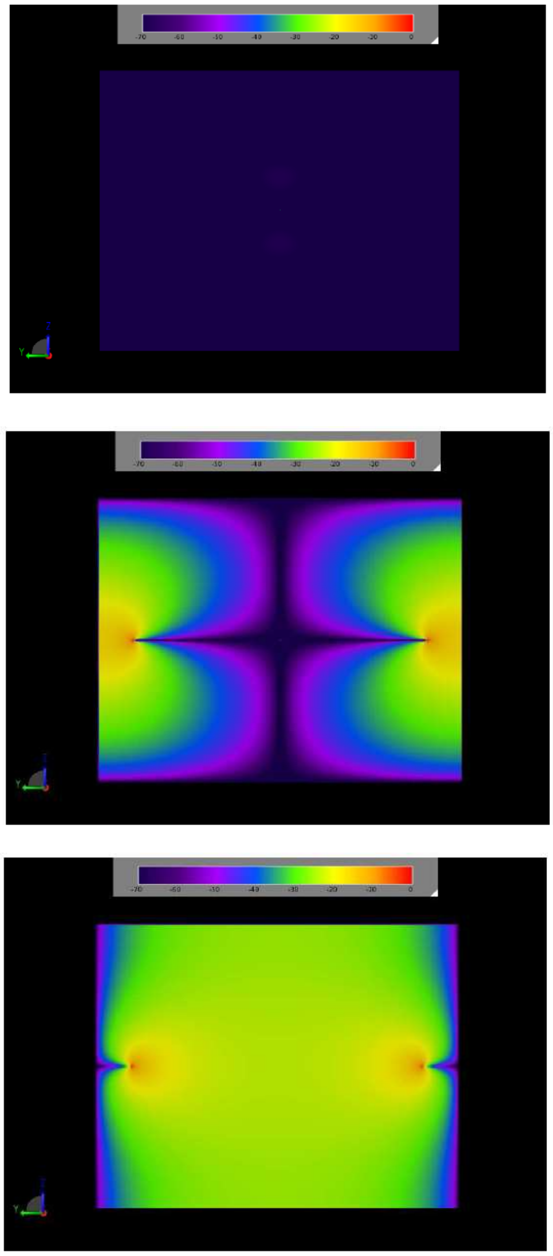
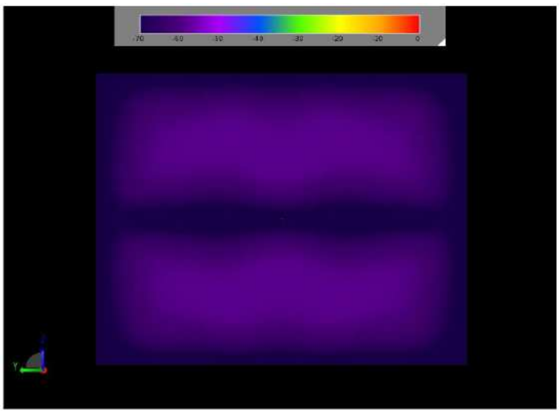


Figure 10. E field distribution at 100 MHz, Ex (upper), Ey (middle) and Ez (lower)

Looking at both Ey and Ez, it is clearly seen that in the centre part of the cell, a uniform E field is obtained, perpendicular to the septum.



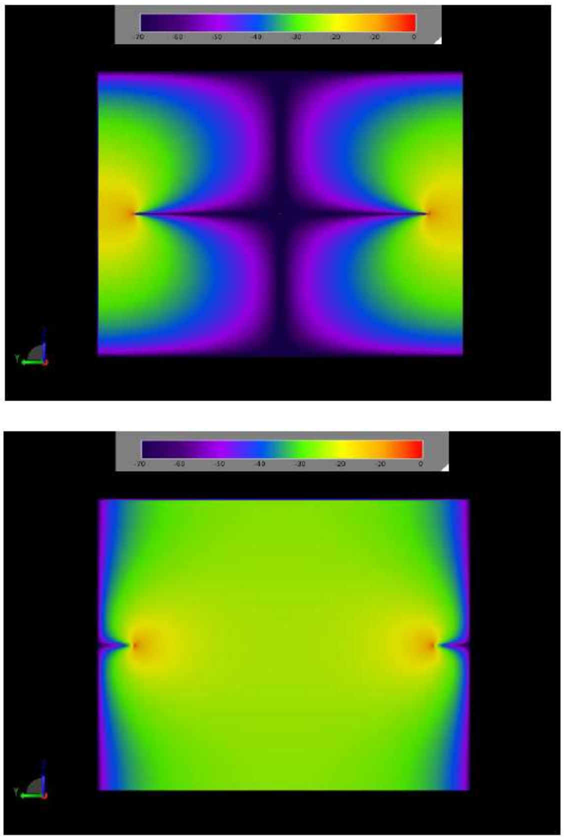
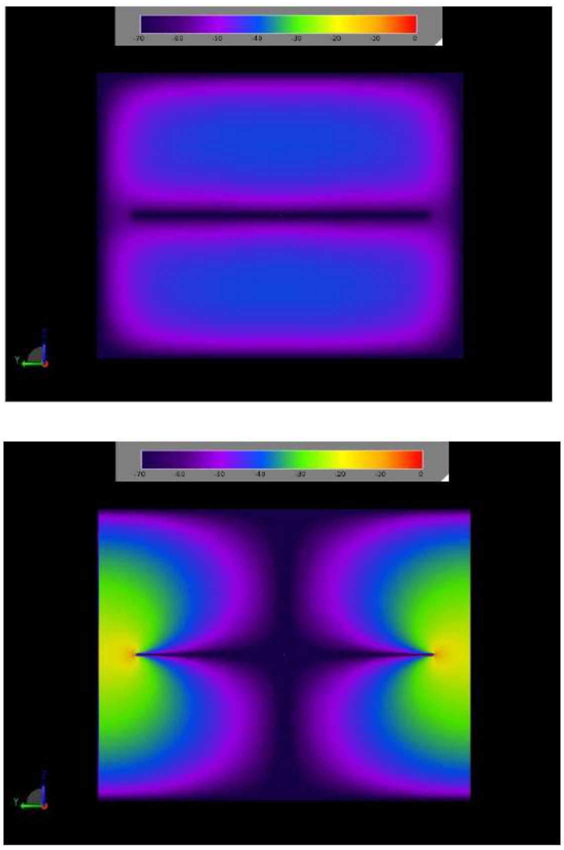


Figure 11. E field distribution at 1 GHz, Ex (upper), Ey (middle) and Ez (lower)



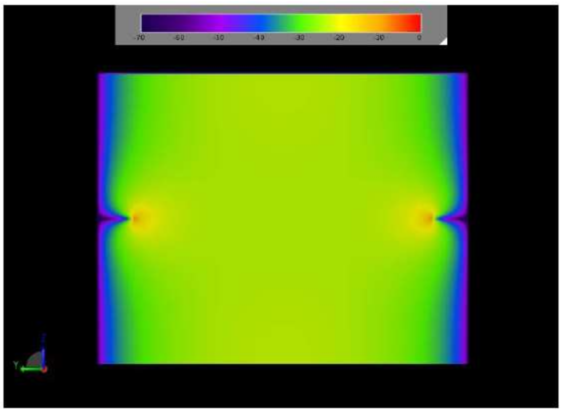


Figure 12. E field distribution at 4 GHz, Ex (upper), Ey (middle) and Ez (lower)

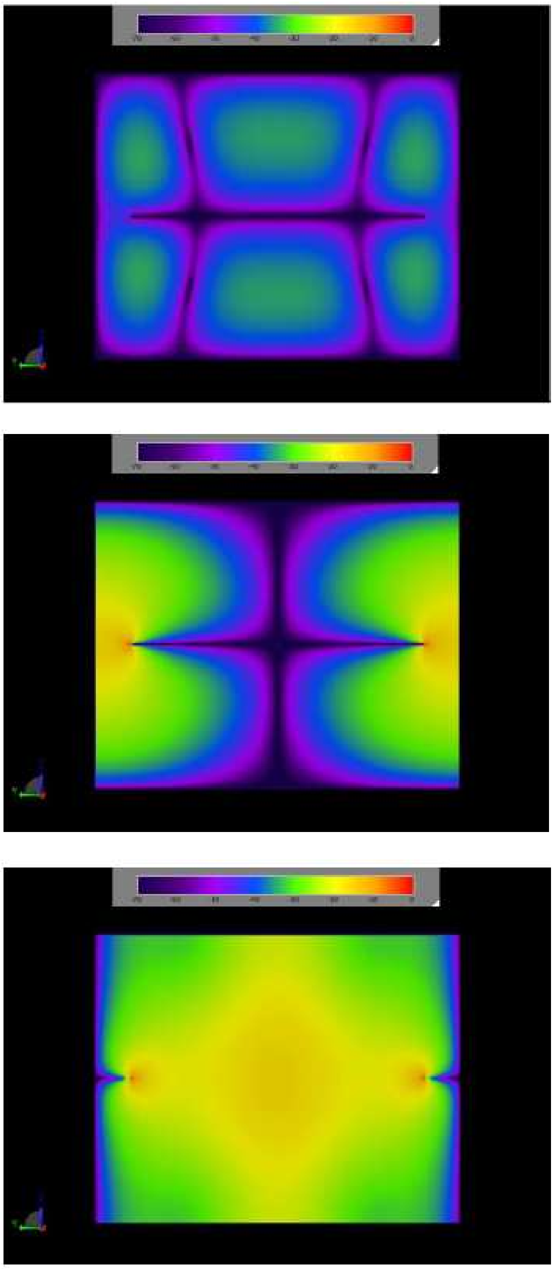
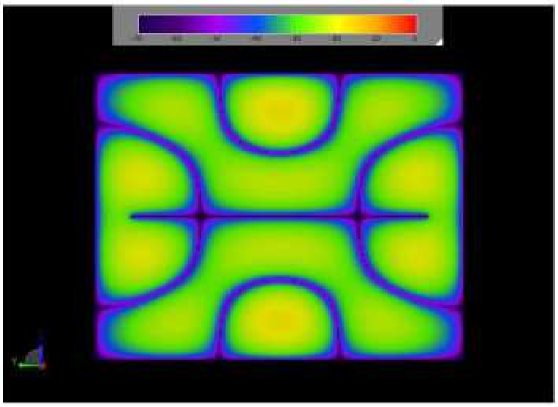
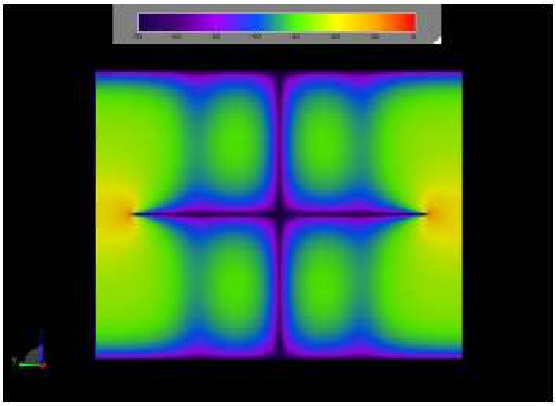


Figure 13. E field distribution at 8 GHz, Ex (upper), Ey (middle) and Ez (lower)





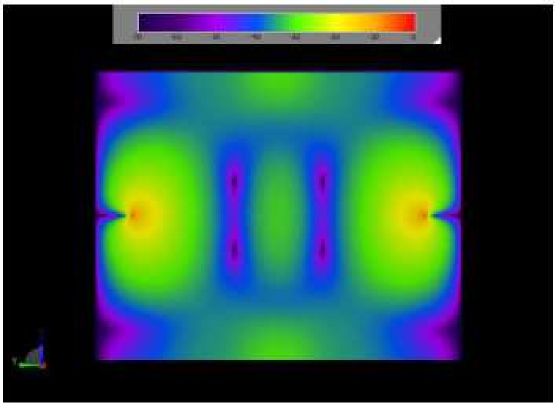
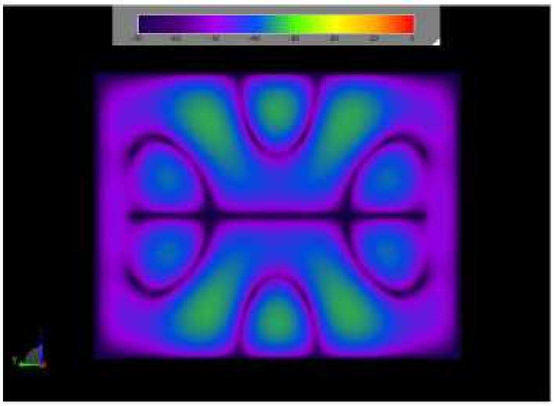
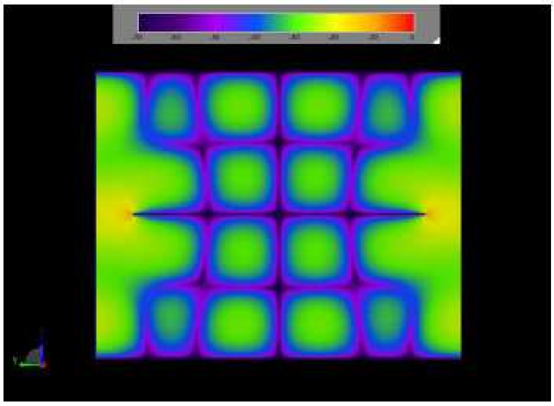


Figure 14. E field distribution at 9 GHz, Ex (upper), Ey (middle) and Ez (lower)





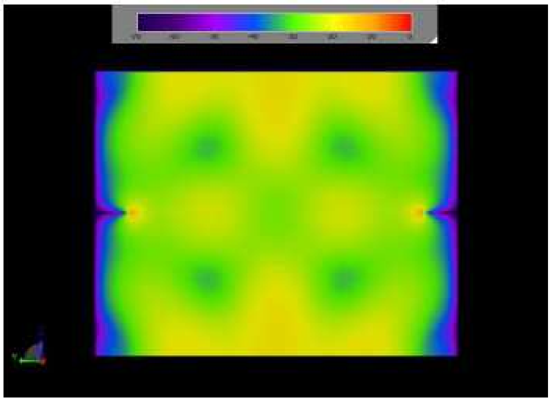
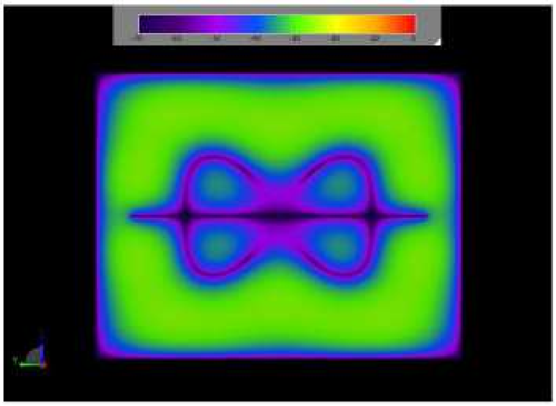
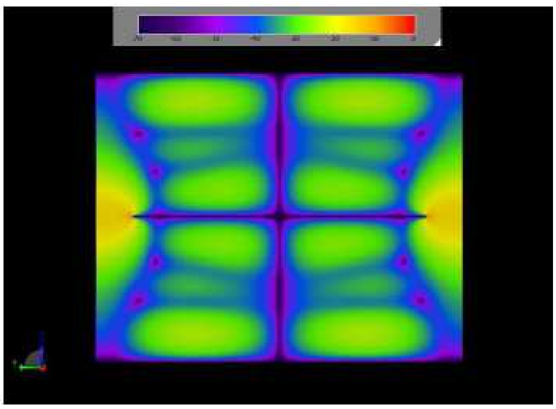


Figure 15. E field distribution at 11 GHz, Ex (upper), Ey (middle) and Ez (lower)





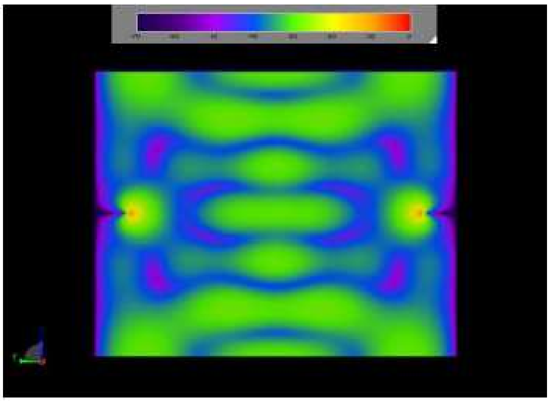


Figure 16. E field distribution at 12 GHz, Ex (upper), Ey (middle) and Ez (lower)

6. SE MEASUREMENTS UP TO 12 GHz

A first set of measurements has been performed in order to characterize the measuring set up in the frequency range from 1 GHz up to 12 GHz. For this purpose, a Vector Network Analyzer (VNA) is used. The graphs in figure 17 are giving the noise floor of the system, and the attenuation of the empty cell, taking into account the attenuation forthcoming from the cabling. It is clear that the TEM-t cell itself has an attenuation of only -3 dB at 12 GHz. Even without a power amplifier, a dynamic range (DR) of about 100 dB is maintained.

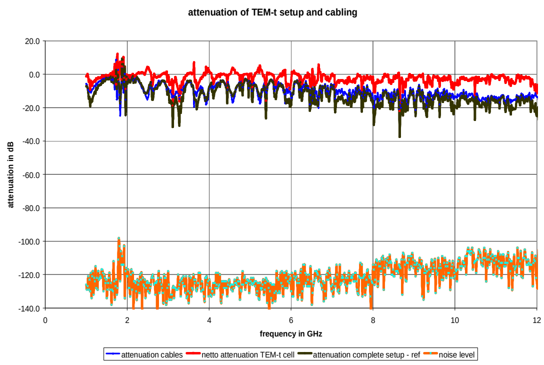


Figure 17. Characterization of empty TEM-t cell

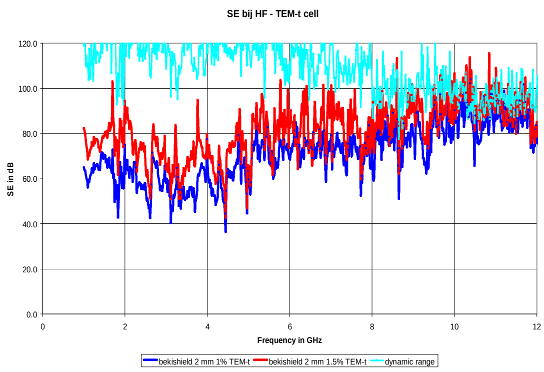


Figure 18. Examples of SE measurements

An example of measured SE is given in figure 18. First of all, the tendency of increasing SE is observed, which could be allocated to the absorption phenomenon of thicker planar materials. As it was already observed concerning the E-field distribution at the higher frequencies, similar large variations are identified for the SE measured values. However, the tendency is clear and a good averaging algorithm should be applied (or developed) in order to make the discrimination between the measurements as such, and the material characteristics, by excluding the influence of the measuring set up itself.

CONCLUSIONS

The expanded use of the TEM-t cell for the characterisation of shielding planar materials has been discussed and analyzed. Although the fundamental characteristic of the cell concerning a restricted frequency range for the TEM propagation mode, SE measurements are possible far over the 'normal' upper frequency limit.
An upper frequency of 12 GHz has been found, with a dynamic range of about 10 dB. An appropriate signal processing algorithm is needed to be developed for an easy interpretation of the resulting measuring results of SE.

References

[1] E. Haryia et al., "Instruments for the measurement of Electromagnetic Shielding Effectiveness", EMC Tokyo, 1984

[2] R. Desmedt, J. Catrysse et al., "Circuit Theory of the TEM-t cell with application to the measurement of the shielding effectiveness of thin, conductive sheets", Proceedings of EMC Roma 94, 1994

[3] J.Catrysse, R. De Smedt, "Some aspects of Shielding Effectiveness Related to Measurements and Simulations", Proceedings IEEE Int. Symposium on EMC, Seattle, 1999

[4] IEEE Std 1302™ – 2008, "IEEE Guide for the Electromagnetic Characterization of Conductive Gaskets in the Frequency Range of DC to 18 GHz", IEEE, nov. 2008

[5] J. Catrysse et al., "Comparative testing of filled conductive plastics: theoretical analysis and practival measurements", Proceedings 9th Int. Symposium on EMC, Zurich, 1991

[6] J. Catrysse et al., "The influence of the test fixture on shielding effectiveness measurements", IEEE Trans. on EMC, Vol. 34, No 3, Aug. 1992, pp. 348-351

[7] J. Catrysse et al., "Correlation between shielding effectiveness measurements and alternative methods for the characterization of shielding materials", IEEE Trans. on EMC, Vol. 35, No 4, Nov. 1993, pp. 440-444

[8] ASTM D4935, "Standard test method for measuring the Electromagnetic Shielding Effectiveness of planar materials", American Society for Testing and Materials

[9] Agilent Technologies, Agilent EMPro, available from: http://www.home.agilent.com/

[10] Bekishield®, Bekaert Fibres Technologies, Zwevegem, Belgium