Higher Order Mode Suppression in Triaxial Cells

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Abstract

At higher frequencies the Triaxial cell becomes in principle a cavity resonator which shows different resonance frequencies depending on the dimensions of the cell as well as on the size of the DUT. Above these resonance frequencies propagation of TEM waves is disturbed and measurements of screening attenuation with triaxial test method according to IEC 62153-4-15 are limited.

Higher order modes respectively resonance frequencies can be suppressed by using conductive absorber material such as ferrites, nanocrystalline absorbers, magnetic absorbers or foam absorbers, placed in the Triaxial cell. With these absorbers, the frequency range of the screening attenuation measured in Triaxial cell can be extended up to several GHz.

Keywords: Triaxial cell; transfer impedance; screening attenuation; triaxial test procedure; ferrite absorber; nanocrystalline absorber, magnetic absorber.

1. Introduction

The triaxial test method according to [2] and [3] was originally designed for measuring the transfer impedance and the screening attenuation of communication cables and connectors.

Meanwhile, also transfer impedance and screening attenuation e.g. on high-voltage cables (HV-cables) and assemblies for electric vehicles, on larger connectors and components e.g. for communication networks can be measured with the triaxial test approach by using the Triaxial cell, (Fig. 1), [4].

Figure 1 – Different designs of Triaxial Cells

At higher frequencies the Triaxial cell becomes in principle a cavity resonator which exhibits resonances depending on its dimensions. Above these resonance frequencies, propagation of TEM waves is disturbed and measurements of screening attenuation with triaxial test method are limited.

Higher order modes can be suppressed by using conductive material like ferrite tiles, magnetic absorbers, nanocrystalline absorbers or foam absorbers. This has been demonstrated in [5] in context with the TEM cell. With these absorbers placed in the Triaxial cell, the frequency range of the screening attenuation measured in the Triaxial cell can be largely expanded.

The following work describes the expansion of the frequency bandwidth of the Triaxial cells using absorber materials. Different measurements of the screening attenuation with the improved Triaxial cell are presented (Section 3 to 4). At first we would like to point out the two main parameters dealt with to express the shielding effectiveness of the equipment under test (EUT), (Section 2).

2. Definition and Meaning of the Transfer Impedance and the Screening Attenuation

In order to obtain electromagnetic compatibility (EMC) adjacent electric and electronic systems require sufficient isolation. This is very often achieved by using electromagnetic screens. Since dominant coupling paths are acting between and along transmission lines the shielding quality of cables, connectors and also housings of the electric components is of special interest. To describe this shielding quality two parameters are used which are commonly known as the transfer impedance and the screening attenuation.

The coupling mechanism caused by the transfer impedance Z_T becomes visible when we look at its definition. Z_T is defined as the relation between the voltage U_2 and the current I_1 [1], [2].

$$Z_T = \frac{U_2}{I_1} \qquad (1)$$

This equation describes the coupling mechanism between two loops coupled by a common return path. As soon as a current I_1 is floating on its way back to the source in the return path of the primary loop a voltage U_2 is acting as a noise source disturbing the signal in loop of secondary side. The transfer impedance is a very important screening measure at low frequencies where the regarded system is electrically short compared to the wavelength. The totally acting transfer impedance in the return path of the system can be calculated by summing up the single transfer impedance elements of the screening chain built by total cable length, the connector screens and the screened housings.

At higher frequencies the wavelengths gets relatively short compared to the elongation of system and we have the situation where a not homogenous current distribution is acting along the screen.

In this situation the screening attenuation a_S should be used as the measure to describe the effectiveness of a cable screen or a screened component.

It is defined as the logarithmic ratio of the feeding power P_1 in the inner system to the maximum radiated power $P_{r,max}$ in the outer system [3].

$$a_S = 10 \cdot \lg \left| \frac{P_1}{P_{r,max}} \right| \text{ (dB)} \tag{2a}$$

Since voltage measurements and not power measurements are done in reality, the acting impedances of the source (generator) and drain (receiver) become important. That is why [3] offers an additional definition to accomplish real life conditions and comparability to alternative measurement methods:

$$a_S = 20 \cdot \lg \left| \frac{U_1}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_1} \right] \tag{2b}$$

where Z_S = 150 Ω is the normalized impedance of the environment (outer system) of a typical cable installation and Z_1 is the characteristic impedance of the EUT.

3. Design and Principle of the Triaxial Cell

The Triaxial cell is a transmission line, which is designed to operate as a shielded 50 Ω multi-line with sides closed to prevent radiation of RF energy into or out of the cell's test environment.

It consists of a section of rectangular triaxial line of preferably 1 m length and a side length of 150 mm to 300 mm. Electromagnetic fields propagate inside the cell when RF energy is coupled to the line from the transmitter respectively the EUT connected at the input port. The receiver at the other port collects the transmitted energy (Fig. 2). The cell is extremely broad band in having linear phase and amplitude response from DC to cell's cut-off frequency [4].

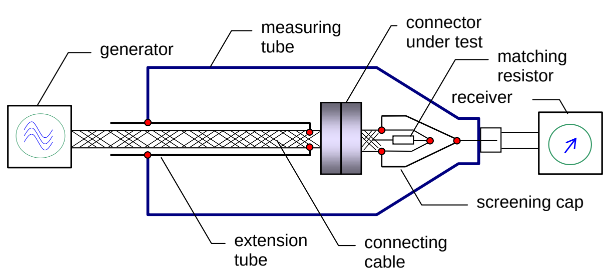

Figure 2: Principle of the triaxial test set-up to measure the transfer impedance and screening attenuation with tube in tube

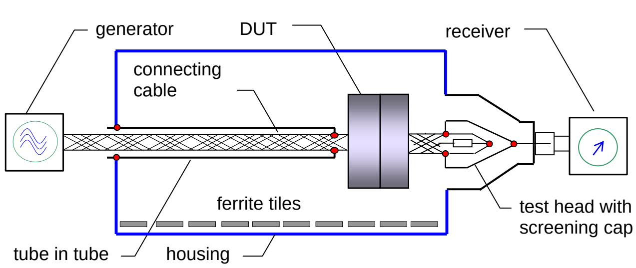

Figure 3: Principle of the Triaxial cell with tube in tube and ferrite tiles as absorber

4. Measurements

4.1 The Test Set-up

The test set-up consists of a vector network analyser (VNA), ZNB8 from R&S and a Triaxial cell as described here above. The two ends of the waveguide are connected to ports of the VNA. The device under test (DUT) which is centred in the middle of the waveguide, forms in combination with the transmission line a triaxial system (Fig. 3). The DUT plays the role of the septum, whereby its screen is actually the device under test.

By using the Triaxial cell both the transfer impedance at the lower frequency range as well as the screening attenuation at higher frequencies can be measured [6], [7].

Measurements were performed with four different set-ups without and with absorber materials on the cell floor: The Triaxial tube CoMeT 40, the Triaxial cell CoMeT 140/140/100, the Triaxial cell CoMeT 1000/150/150 and the Triaxial cell CoMeT 1000/300/300. As absorbing materials, ferrite tiles, foam absorbers and magnetic flat absorbers (Fig. 4) were used. In principle, a large number of floor absorber materials may be used to suppress higher order modes.

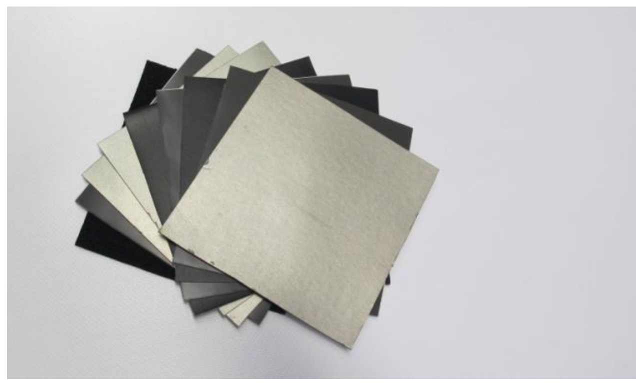

Figure 4: Different magnetic flat absorbers

Figure 4 shows a photo of different flat magnetic absorbers with different substrates and thicknesses. Absorbers used for the measurements in figures 7 and 8 are the upper ones.

For the intended application absorbers should suppress higher order modes but should not influence TEM mode. Better says, their influence on the principal mode should be reduced at minimum.

In analogy to the philosophy followed when carrying measurement in (G)TEM cells, the electromagnetic field in a Triaxial cell can be considered as TEM as long as higher order modes are at least 6 dB below the needed principal mode [10].

4.2 Measurements with Cell 140/140/100

The cell was loaded with a rectangular box with an aperture as depicted in Fig. 5. The EUT was arranged double symmetrically with respect to its geometry and position in the cell to reduce the number of modes which can be excited in the waveguide (Table 1) [8], [9] and was terminated with a 50 Ω matching impedance to minimize reflexions in the inner system [6], [7].

A double screened Rosenberger RTK 062 cable with a good contact to the short circuit at the near end was used as feeding cable. The connection to the test head was ensured using a 1 m long standard bedea cable.

Figure 5: Rectangular box with aperture in a Triaxial cell 140/140/100 lined with floor absorber

The size of the box under test (EUT) in the cell 140/140/100 was 58x28x26 mm with an aperture of 4.2 mm.

The measurement system was calibrated by the full two-port calibration procedure at the connector interface of the connecting cables to correct the system errors. The signal was fed from port 1 of the VNA into the cell and measurement of the transmission coefficient S21 was carried out. The measurement frequencies were from 9 kHz up to 6 GHz. This frequency range was chosen to cover most of the higher-order modes which might be excited within the cell and influence the measurement results.

Table 1: Cut-off frequencies of first higher order modes of cell 140/140/100

fc [GHz]			
n↓ \ m→	1	2	3
0	**1.1029***	2.2059	**3.3088***
1	1.5598	2.4663	3.4878
2	**2.4663****	3.1196	**3.9767****

Values marked in bold are modes which may be excited by a double symmetrical arranged EUT.

The cut-off frequency f_c is calculated by:

$$fc = \frac{c_0}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \quad (3)$$

where $a=.140$ m is the width of the cell and $b=.140$ m its length; m and n indicate the mode configuration, while c_0 stands for the free space velocity.

***Excited TE_{mn} modes.**

****Excited TM_{mn} modes.**

Fig. 6 shows the measurement of the rectangular box with aperture in a triaxial cell 140/140/100 without absorber. The curves show peak values at certain discrete frequencies as a result of the multimoding operation associated with the cell size. These peaks correspond to resonances of higher order modes propagating within the cell as soon as they are above their respective cutoff frequency (Table 2).

The aforementioned presence of higher order modes represent the main drawbacks of the triaxial cell, since they limit the bandwidth of the cell and alter the measurement results. Indeed, the first resonance corresponding to first resonance of the TE10 or TE01 mode appears at around 1400 MHz, thus limiting the used bandwidth of the cell.

To suppress these modes and thereby extend the overall frequency range of operation of the line, the cell floor was covered with magnetic absorbers (Fig. 5) and measurements were carried out again.

Table 2 show resonances of excited modes and frequencies of peaks of cell 140/140/100. The resonance frequencies *fr* are calculated by:

$$fr = \frac{c_0}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2} \quad (4)$$

where a, b, c are the dimensions of the cell, m, n, p are number of modes (even, 2 of 3 > 0) and c_0 is the velocity of light in free space.

Table 2: Resonances of excited modes and frequencies of peaks of Cell 140/140/100.

Wave Type	Resonance Number	Frequency f_r [GHz]	Peak at f_p [GHz]
TE10	1st	1.842	1.430
	2nd	3.183	
	3rd	4.622	
	4th	6.090	
	5th	7.570	
TE20	1st	3.684	3.685
	2nd	4.393	4.421
TE30	1st	3.544	
	2nd	4.393	4.421
	3rd	5.526	5.567
TM11	1th	2.137	2.130
	2th	3.358	3.391
TM12	1st	2.824	2.934
	2nd	3.836	3.833
	3rd	5.094	5.040
	4th	6.885	
TM32	1st	4.141	
	2nd	4.887	4.847
	3rd	5.926	5.878
	4th	7.131	
	5th	8.430	

Screening attenuation results obtained from measurements in the modified cell are depicted in figures 7 and 8. As can be seen, resonances are strongly suppressed and the operation bandwidth of the cell is largely expanded up to several GHz.

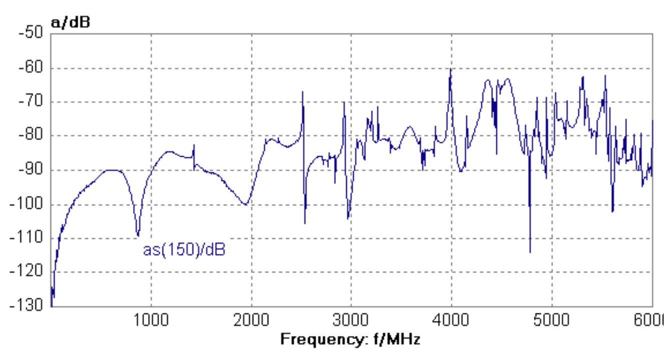

Figure 6: Screening attenuation of the rectangular box with an aperture in the triaxial cell 140 without absorber.

A comparison result corroborating the statement is graphed in Fig. 9, shown above.

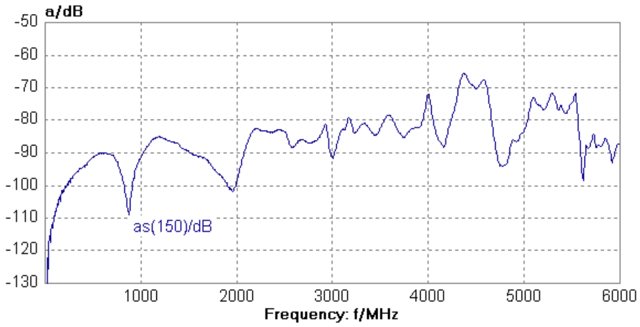

Figure 7: Screening attenuation of the rectangular box with aperture in a Triaxial cell 140 with magnetic absorbers of 0.5 mm thickness.

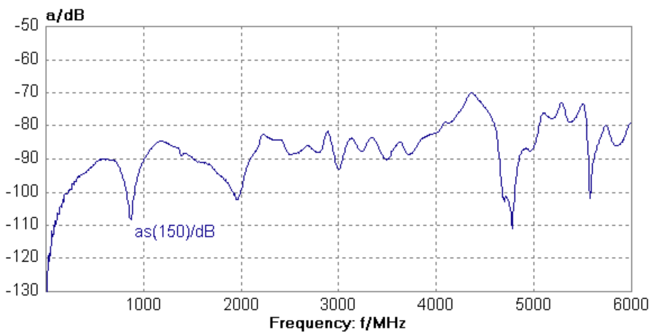

Figure 8: Screening attenuation of rectangular box with aperture in a Triaxial cell 140 with magnetic absorber with silicone carrier of 1.5 mm thickness.

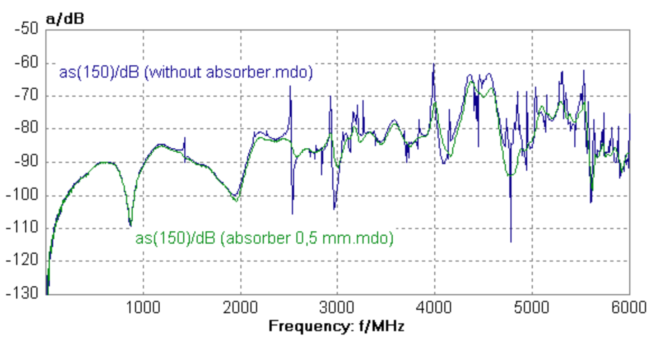

Figure 9: Comparison of the screening attenuation of the rectangular box with aperture in a Triaxial cell without and with magnetic absorber of 0.5 mm thickness.

4.3 Measurements with Cell 1000/150/150

Besides the measurement of the return loss as shortly presented at the end of the preceding section, the 150/150/1000 cell was also used to investigate the screening attenuation of coaxial cables. The aim was to compare obtained results with that of the reference measurements in a cylindrical triaxial tube.

Screening attenuation curves of cables with single or double braid show typical behavior when measured with the triaxial tube due to the reflections at the short circuit of the tube at the generator side as can be seen in figure 10 where the screening attenuation of a RG 214 cable is depicted. The curve shows maximum peak values of -81.5 dB as expected [3].

For comparison purposes, the screening attenuation of the same cable measured in a 1000/150/150 Triaxial cell is graphed in figures 11 and 12 with and without absorbers respectively.

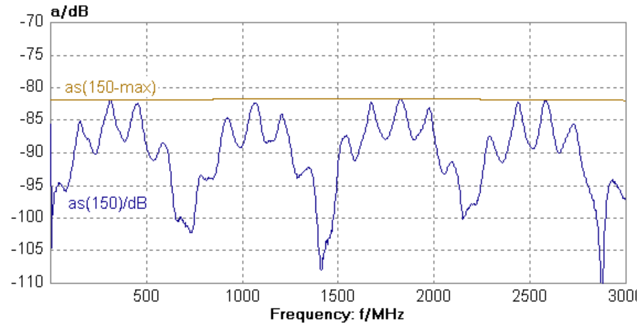

Figure 10: Screening attenuation of RG 214 in Tube CoMeT 40

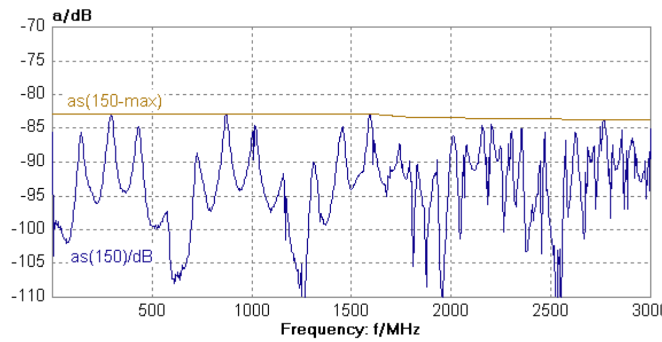

Figure 11: Screening attenuation of RG 214 in the Triaxial cell 1000/150/150 without absorber.

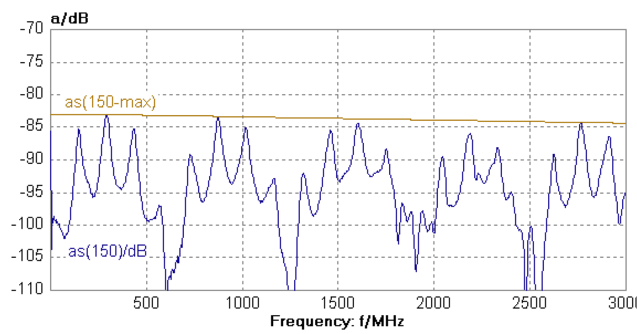

Figure 12: Screening attenuation of RG 214 in the Triaxial cell 1000/150/150 with magnetic absorber of 0.5 mm thickness.

Clearly, high frequency resonances can be observed in the results gained in the cell without absorbers, as soon as higher order modes propagate within the cell; while the curve obtained from measurement in the cell lined with microwave floor absorbers shows the same behavior as the reference curve (Fig.10). The deviation of the max. values at about 1600 MHz and at about 2200 MHz is due to the influence of the absorbers.

4.4 Measurements with Cell 1000/300/300

The cell 1000/300/300 was loaded with a box of 11.5 x 8.5 x 6 mm with an aperture of 14 mm in the cover of the box. The box was connected with bedea RG 214 cables with screening attenuation of about 82 dB, (Fig. 13). Measurements of screening attenuation were performed with and without absorbers, (Figures 14 to 16). The envelope curve of the measurements shows the principle behavior of a hole in a screened device; a decrease of screening attenuation to higher frequencies up to a max. value continued with an increase of the screening attenuation.

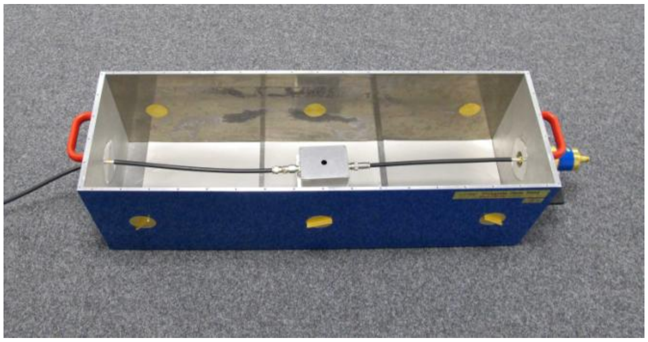

Figure 13: EUT 11.5x8.5x6 mm with Triaxial cell 1000/300/300 with magnetic absorber 0.5 mm (3x30x30)

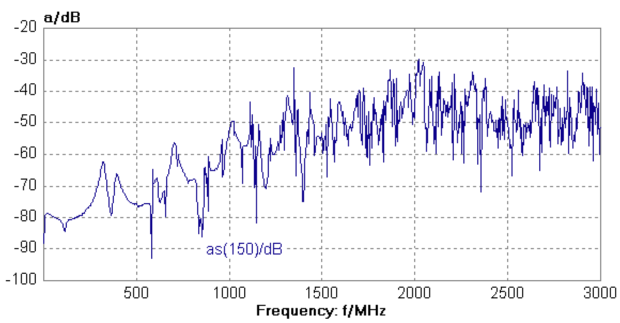

Figure 14: box 11.5 x 8.5 x 6 mm with Triaxial cell 1000/300/300 without absorber

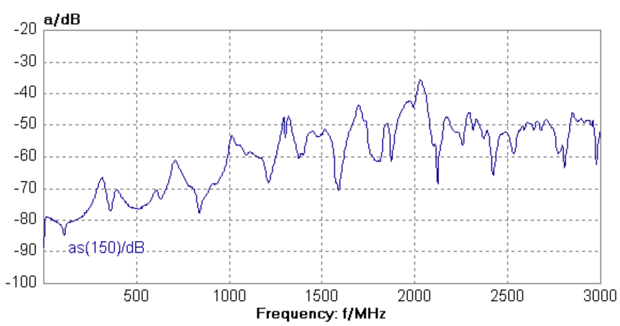

Figure 15: Box 11.5 x 8.5 x 6 mm with Triaxial cell 1000/300/300 with 16 ferrite tiles

Fig. 14 show the screening attenuation of a box 11.5 x 8.5 x 6 mm with Triaxial cell 1000/300/300 without absorber. Resonances of higher order modes can be observed from about 600 MHz.

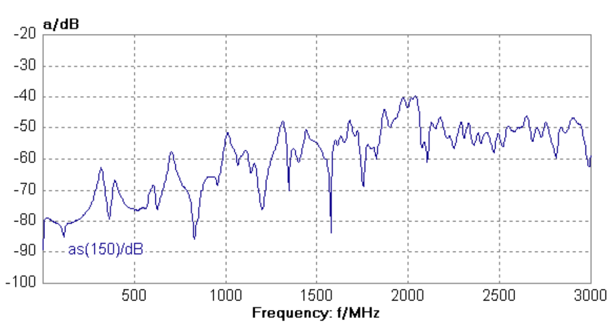

Figure 16: Box 11.5 x 8.5 x 6 mm with Triaxial cell 1000/300/300 with magnetic absorber 0.5 mm (5x30x30)

After covering the bottom of the cell with absorbing material, resonances are suppressed.

The comparison of the measurement of the same box 11.5x8.5x6 mm with absorbing clamp MDS 22 according to IEC 62153-4-5 in the range of 500 MHz to 2500 MHz shows good correlation.

Absorbing clamp measurement was performed at near and far end. The worse value of both measurements is the value of the screening attenuation.

It should be noted that only the envelope curves respectively the max. values of clamp measurement and triaxial measurement can be taken for comparison.

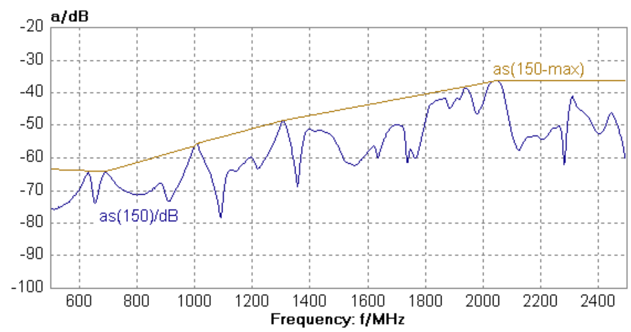

Figure 17: Triaxial cell 1000/300/300 with box 11.5 x 8.5 x 6 mm with magnetic absorber 0,5mm (4x15x30).

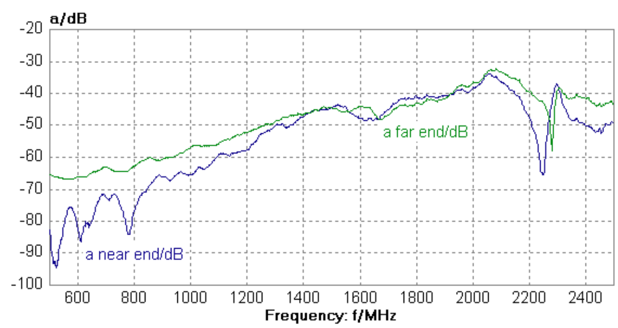

Figure 18: Box 11.5 x 8.5 x 6 mm measured with absorbing clamp MDS 22

4.5 Influence of the Absorber Material on the TEM Mode

Besides the fact that resonances of higher order modes are strongly suppressed, Figs. 9 and 12 give valuable insight on the effect of the used absorbers on the TEM mode. In fact the absorbers do not have an adverse influence on the TEM mode as long as it is the only mode present within the cell.

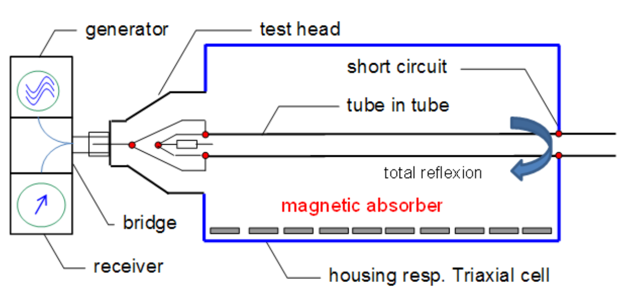

Figure 19: Principle depiction of the return loss measurement with Triaxial cell
(fig. 19 corrected vs. original paper)

It can be observed that, below the cut-off frequency the first higher order mode, i.e. at frequencies where only the TEM mode propagates within the cell, the two curves in Fig. 9 match well together. However at higher frequencies where the cell is in multimode operation, part of the energy of the principal mode is indirectly dampened as a result of high frequency resonance's and multimode's suppression (Fig. 21).

In a multimode operation, energy conversion between modes occurs as a consequence of mode coupling within the cell. When higher order modes are suppressed, the part of TEM energy converted into the higher order modes is also dampen.

This effect is fortunately minimal as can be seen from comparison of the return loss in a 1000/150/150 cell with and without absorber (Figs. 20 and 21).

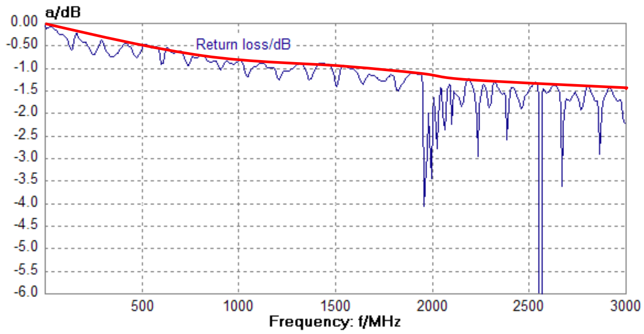

Figure 20: Return loss of the Triaxial cell 1000/150/150 without absorber

After covering the cell bottom with microwave absorbers resonances are suppressed, see figure 19.

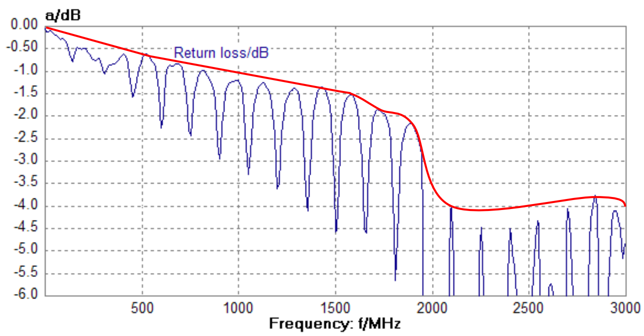

Figure 21: Return loss of the Triaxial cell 1000/150/150 with magnetic absorber 0.5 mm

5. Concluding Remarks

The Triaxial cell commonly used to determine transfer impedance and screening attenuation for cables and connectors shows some drawbacks which are inherently due to its geometry. Among others is the bandwidth limitation due to the existence of higher order modes propagating within the cell as from certain frequencies.

The present work proposes an approach to circumvent the main limitation of the cell and thereby improve its overall performance.

It is shown that by lining the cell floor with microwave absorbers, higher order mode resonances are strongly dampen.

Thus, expanding the overall bandwidth of the cell by several GHz. The influence that the absorbers can have on the TEM mode is indirect and minimal.

First comparison measurements between Triaxial tube and Triaxial "Absorber" cell and between Triaxial "Absorber" cell and absorbing clamps are promising. Further comparison measurements of different EUTs are in progress.

The results of the present work will be discussed at the next meeting of working group IEC TC 46/WG 5, Screening effectiveness in order to amend IEC 62153-4-15 [4].

6. Acknowledgments

Special thanks to Jean Eudes Yotcha for performing numerous measurements and Sabine Köhler for proofreading.

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8. Authors

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