A GTEM GOOD PRACTICE GUIDE – THE USE OF GTEM CELLS FOR EMC MEASUREMENTS APPLYING IEC 61000-4-20

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Abstract: The draft standard IEC 61000-4-20 includes the GTEM cell as a measurement facility for EMC emission and immunity testing. The Good Practice Guide [1] presented here gives guidance how to perform measurements according to this standard, and with acceptable uncertainties. This paper presents an overview of the Guide with some results of the research performed to produce it.

1. Introduction

The GTEM cell is a TEM waveguide with the upper frequency limit extended to the GHz range. It is under consideration as an alternative measurement facility for both radiated emission and immunity measurements. It is included in the recently published standard IEC 61000-4-20 *"Emission and Immunity Testing in Transverse Electromagnetic (TEM) Waveguides"*[2].

The Good Practice Guide covers field uniformity tests for TEM cells and the use of a GTEM cell for emission measurements above 1 GHz.

For immunity tests, the field uniformity and the cross-polar coupling of the cell have to be within certain limits set by IEC 61000-4-20. In Section 2 the upper frequency, for which these limits are kept, is investigated, including a study of sizes of uniform areas.

For emission measurements a representative EUT was built, and tested in GTEM cells and on open area test sites. GTEM to OATS correlations were performed according to IEC 61000-4-20. The EUT is described in Section 3 with some of the measurement results.

Other results can be found in a paper presented at the 2003 Zurich Symposium on EMC [3].

2. Immunity Measurements

According to IEC 61000-4-20, a TEM cell used for immunity measurements has to be tested for field uniformity and cross-polar coupling. Depending on the test volume, the field strength has to be measured at a certain number of calibration points in a vertical plane. The field strength has to be within 6 dB of the nominal value at 75 % of these measured points. Cross-polar components have to be at least 6 dB lower than the resultant field strength calculated from the three field components.

Generally, the calibration is performed with a field sensor while the field strength is generated using a signal generator and amplifier monitored by a power meter. Example results for measurements performed according to this method are presented in the Guide [1].

As shown in [4] and applied in [5] reciprocity is valid, and radiating sources of known levels (Comparison Noise Emitter – broadband noise source) can be used instead of field sensors. These sources can be battery powered and hence do not need any connection to equipment outside the cell. The radiating sources are placed at the calibration points in the cell and the radiation is detected at the GTEM port with a spectrum analyser. Therefore, the measurement setup is the same as for the emission measurements shown in Figure 8.

For the results presented here two different radiating sources were used. A CNE III (Comparison Noise Emitter III) radiating from 30 MHz to 2 GHz, and a CNE VII radiating from 1.5 to 7 GHz . The cross-polarisation inherent to both CNEs had previously been tested in a fully anechoic room, and found to be low. For the CNE III the cross-polar field components were in the noise floor of the measurement, and for the CNE VII the difference between the co-polar and the cross-polar components was more than 20 dB. The CNE III is 17 cm high and the CNE VII 15 cm high.

2.1 Field Uniformity

Figure 1 shows different grid sizes for the uniform area as required by IEC 61000-4-20. Other sizes are possible, as for example a 1.5 m by 1 m 12-point grid. For a smaller 0.5 m by 0.5 m area an extra central point would have to be added to a 4-point grid.

For the work presented here, a 9-point 1 m by 1 m, a 12-point 1m by 1.5 m and a 16-point 1.5 m by 1.5 m grid were used. The 16-point grid is obviously very large for the GTEM 1750 used here; but it was deliberately chosen to test the GTEM uniformity to the limits.

According to IEC 61000-4-20, 12 of 16 points or 9 of 12 points have to be within 6dB of the nominal field strength value. Since no nominal value is given in the test setup used here, the maximum difference between the calibration points was calculated for each frequency.

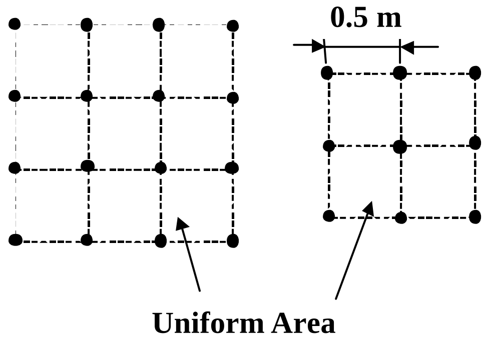

Figure 1: The 16-point and the 9-point grid for field uniformity

In Figure 2 this difference is shown for 12 points of the 16-point 1.5 m by 1.5 m grid. It can be seen that is does not stay within the 6 dB limit. But considering the size of the grid compared to the size of the GTEM, the field uniformity is better than expected.

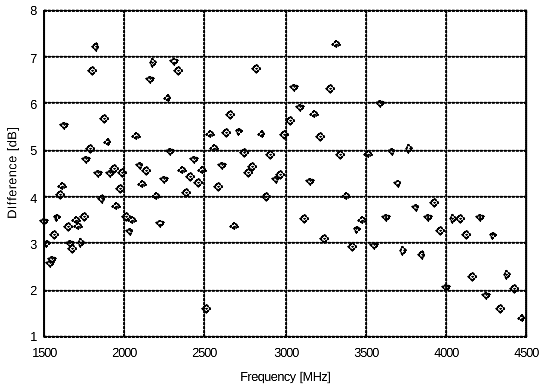

Figure 2: Maximum difference from 12 of 16 points

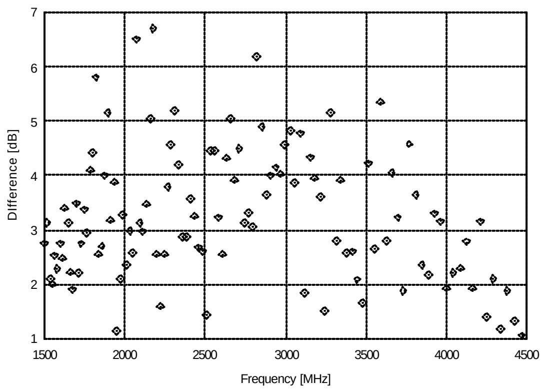

Figure 3: Maximum difference from 9 of 12 points

The 12-point grid is still 1.5 m wide, but only 1 m high. The field strength difference for 9 of the 12 points is shown in Figure 3. It stays within the 6 dB limit for most of the frequencies. No obvious frequency limit for field uniformity could be found in this experiment.

2.2 Cross-Polar Coupling

According to IEC 61000-4-20, secondary field components have to be at least 6 dB lower than the resultant field strength. However at the time of writing this paper it is still in discussion if the secondary field components should be compared to the primary field component or to the resultant field strength. In this paper the secondary field components are compared to the primary field component, since this is a stricter criterion.
In the measurements presented here, the vertical field is the primary component, while the horizontal and longitudinal fields are the secondary cross-polar components.
The CNEs were placed at each point of the different uniformity grids. But only the results for some grid points are presented here.

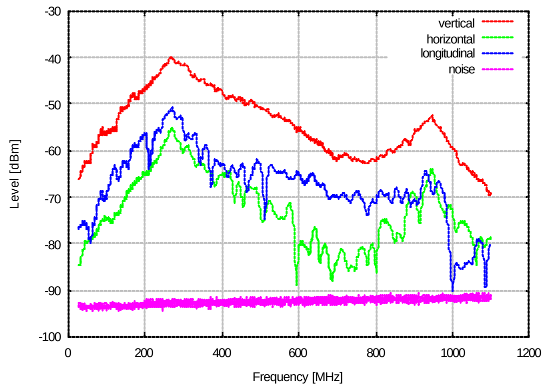

Figure 4: Field components in a top corner of the nine-point grid

Figure 4 shows the field components achieved with the CNE III between 30 MHz and 1.1 GHz. The location in the GTEM is at a corner point of the 9-point grid, at a height of 1.25 m and horizontally 0.5 m from the centre of the GTEM cell. The septum height at this location is 1.6 m.
The difference between the primary and the secondary field components is well above the 6 dB required across the full frequency range, although the measurement location is fairly close to the septum.

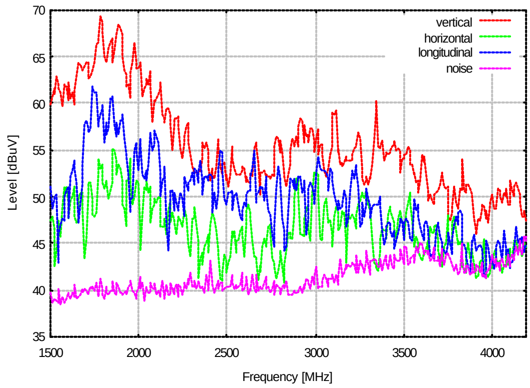

Figure 5: Field components in a central point of the 16-point grid

Figure 5 shows results of the CNE VII between 1.5 GHz and 4.2 GHz. The location is at a central point of the 16-point grid, at a height of 0.53 m and horizontally 0.25 m from the centre of the cell. Up to 2.3 GHz sufficient differences can be seen between the vertical and the cross-polar field components. At higher frequencies the longitudinal component can become even larger than the vertical component.

Moving closer to the septum of the GTEM cell, this becomes even more obvious. In Figure 6 the differences between the primary and each secondary field component are shown for a location close to the septum. Here, the difference between the vertical and the longitudinal component is rarely above the required 6 dB, and from 2.3 GHz it even becomes negative, with the longitudinal component being larger than the vertical.

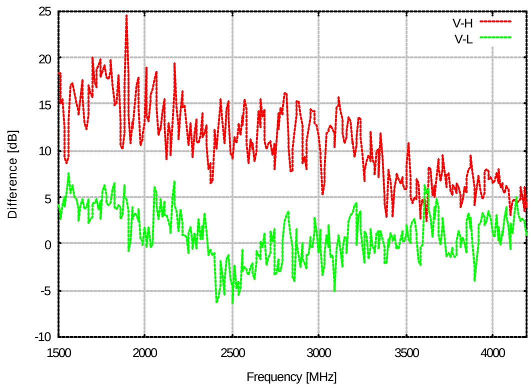

Figure 6: Difference of field components in a top point of the 16-point grid

Looking at these results however, it has to be kept in mind that a high longitudinal component is to be expected near the GTEM septum.

3. Emission Measurements

According to CISPR 22 [6], the standard environment for radiated emission tests between 30 MHz and 1 GHz is the Open Area Test Site (OATS) with 10 m separation between the receiving antenna and the EUT (a 3 m separation is also allowed). In most cases, the results from alternative test methods have to be correlated to the OATS.

The concept of emission measurements in a GTEM cell is simple, since only the cell and a receiver are required. In order to correlate the results to an OATS, a set of at least three measurements and some computational post processing of the results are required.

3.1 Radiating Sources

For these investigations, a Representative EUT for Emissions (REUTE) was built. It consists of a 19″ brass enclosure with a removable lid and side panel. Both lid and side panel can be held away from the body of the box by plastic spacers to provide a radiating gap between the body and the panel. The panels also contain slots, which may be open or covered.

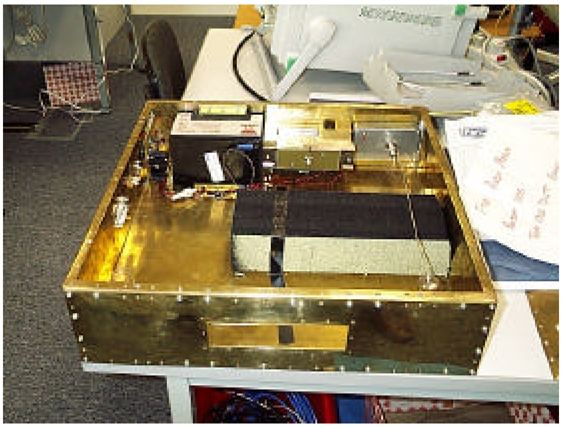

Figure 7: Radiating EUT showing battery (top left), 7 GHz CNE (top centre), 2 GHz CNE (top right)

The REUTE comprises two broadband radiating sources based on two Comparison Noise Emitters (CNEs), which can be selected via an external switch. These two CNEs operate over different frequency ranges. The lower frequency unit (30 MHz to 2 GHz) is connected to a metal rod, which runs around inside the enclosure and is terminated on the inner conductor of a panel mounted bnc connector. This means that most resonant modes within the enclosure are excited and also allows an external cable to be excited directly for maximum radiated emissions. The 1.5 GHz to 7 GHz CNE drives a small (1.5 cm) antenna. The REUTE is battery powered.

This EUT was used in four different configurations, with slots, gaps, slots and gaps, or an attached cable radiating, and tested in a GTEM cell and on an Open Area Test Site (OATS). The measurements were then compared using the correlation algorithm described in IEC 61000-4-20. It was investigated whether this correlation algorithm is still applicable above 1 GHz.

The CNE III and the CNE VII described in Section 2 were also used as radiating sources for these emission tests.

3.2 Measurement Setup and Test Sites

The measurements in the GTEM cell were performed with a simple setup using a spectrum analyser operating up to 4.2 GHz and the EUT placed in three orthogonal orientations. The measurements presented here were performed in two different test laboratories.
At the YES Castleford EMC Test Laboratory the emissions measurements were carried out in an EMCO 5311 GTEM cell with a maximum septum height of 1.1 m, and using an Anritsu spectrum analyser, model MS 2663B.
At the National Physical Laboratory (NPL), the instruments used were a Marconi spectrum analyser, MI2383, connected to the GTEM cell with a screened cable. The GTEM cell used at NPL is an MEB GTEM 1750. At the absorber end, this cell has a septum height of 1.75 m. The measurements with the CNEs and the REUTE were performed at a septum height of 1.6 m at the centre of the EUT.

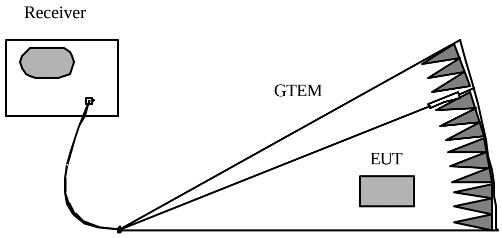

Figure 8: Emission measurement setup

At each laboratory, the same analyser was used with identical settings on the OATS and in the GTEM. On the OATS, a bilog was used as the receiving antenna for the lower frequency range, while a ridged waveguide horn antenna was used for frequencies above 1.5 GHz. The EUT was rotated and the antennas were scanned from 1m to 4m. The OATS measurements were performed for 3m and 10 m separation between the EUT and the receiving antenna.

3.3 GTEM to OATS Correlation Results

EMC tests aim to find the maximum radiation of an EUT. Therefore, on an OATS, the maximum field strength is recorded with the receiving antenna in vertical and horizontal polarisation. Hence, it is reasonable to compare the maximum value predicted from the GTEM cell with the maximum radiation detected on the OATS (highest emission of both horizontal and vertical polarisation).
For this comparison, an algorithm presented by Wilson [7] is used to correlate the GTEM measurements to the OATS. This algorithm, which is applied in IEC 61000-4-20, is based on a dipole model of the EUT and requires the radiating source to be permutated in three orthogonal orientations.

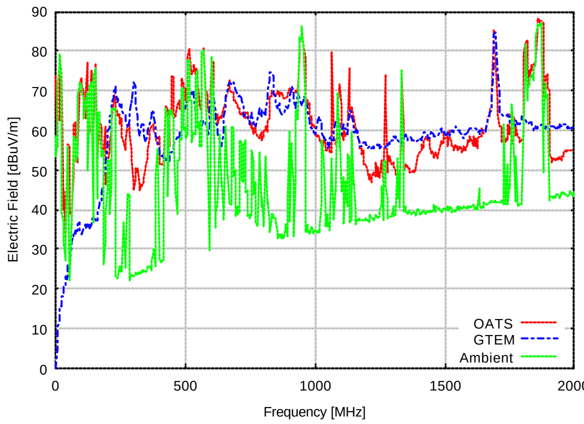

Figure 9: GTEM-OATS Comparison for maximum radiation of REUTE in Slot and Gap Mode, 3 m

Figures 9 and 10 show the comparison between GTEM and OATS results from the NPL test sites with the REUTE operating in its lower frequency range of 30 MHz to 2 GHz.
In Figure 9 results are shown for the REUTE in the slot and gap mode. This means, the slots in the panels are open and there is a gap between the panels and the enclosure. Good agreement can be seen between the GTEM and the OATS results. For 10 m separation between the EUT and the receiving antenna, as shown in Figure 10, the correlation is even better.
Generally, these results demonstrate the advantage of the GTEM cell to show the radiation of the EUT without disturbance from the ambient. In Figure 10, for example, it becomes obvious that the peak at 1700 MHz is a feature of the REUTE, while the peaks around 1800 MHz are purely due to ambient signals.

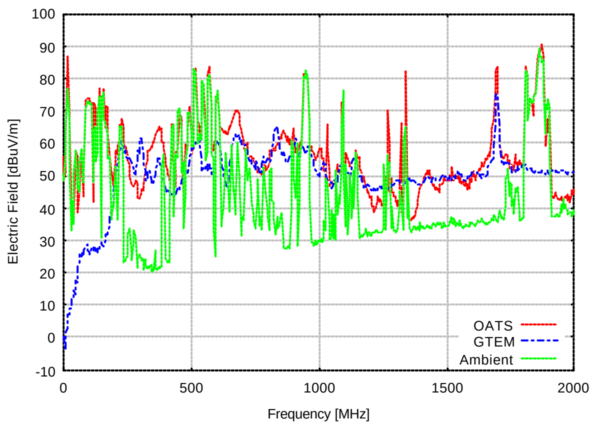

Figure 10: GTEM-OATS Comparison for maximum radiation of REUTE in Slot and Gap Mode, 10 m

Figures 11 and 12 show some results for the REUTE operated in the higher frequency range above 1.5 GHz. In Figure 11, the REUTE is operated in the gap mode, and the distance between the receiving horn antenna and the REUTE on the OATS is 3 m. Here, the GTEM and the OATS results agree well up to 3 GHz. Above 3 GHz differences of 10 dB or more can be seen.

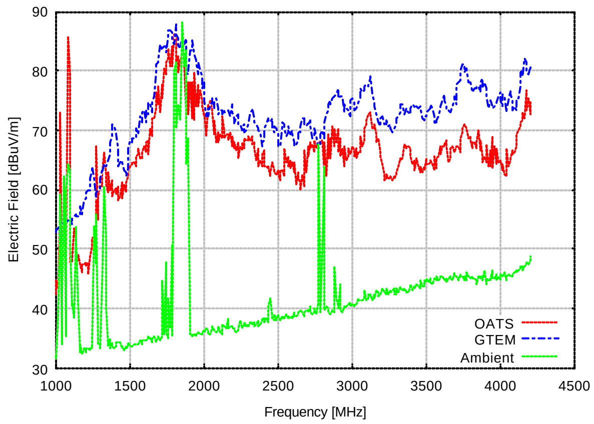

Figure 11: GTEM-OATS Comparison for maximum radiation of REUTE in Gap Mode, 3 m

It has to be noted that the receiving horn antenna is highly directive and therefore does not have the dipole pattern assumed in the correlation algorithm.
Figure 12 shows the correlation results for the REUTE in slot mode and an antenna separation of 10 m. In this case, the agreement between GTEM and OATS results is very good over the full frequency range up to 4.2 GHz. Therefore, no limitation of the GTEM cell below 4.2 GHz could be observed in this work.

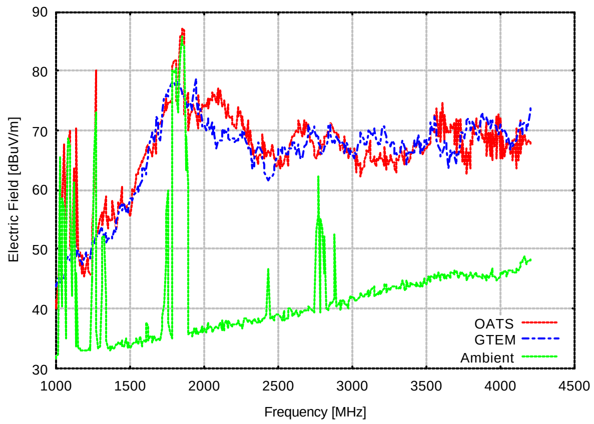

Figure 12: GTEM-OATS Comparison for maximum radiation of REUTE in Slot Mode, 10 m

The EUT was also operated with a cable attached to the external bnc connector. The cable was a single thin wire of 0.8 m length. It could either be fixed on a rigid and non-metallic structure or left hanging loose. The measurements with the cable were performed between 30 MHz and 2GHz, since the cable was directly connected to the output of the CNE III). All slots and gaps in the REUTE are closed, since only the cable radiation is investigated. The results presented here are for an antenna separation of 10 m on the OATS.

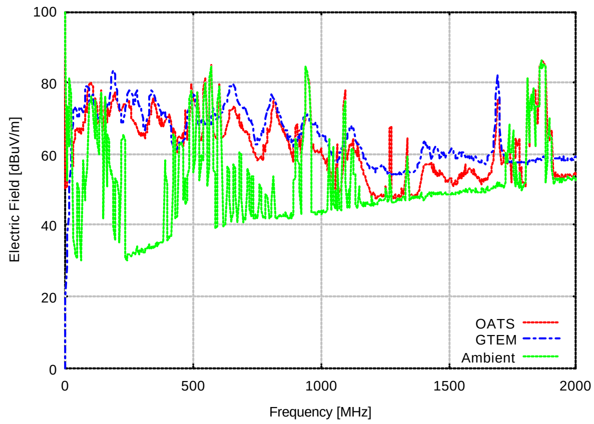

Figure 13: GTEM-OATS Comparison for maximum radiation of REUTE with loose cable, 10 m

In Figure 13 the results of the GTEM to OATS comparison are shown for the loose cable. In this case the cable is simply left hanging from the REUTE. Therefore, in the GTEM measurement, the cable is hanging vertical in all three orientations of the REUTE. The GTEM to OATS correlation algorithm requires the radiating source to be permutated in three orthogonal orientations. Since this requirement is not met with the cable remaining vertical, differences between the GTEM and the OATS results were expected. However, with differences up to 10 dB, the agreement is better than expected.

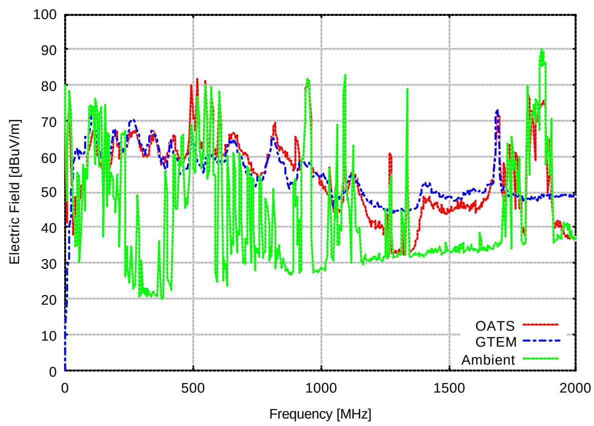

Figure 14: GTEM-OATS Comparison for maximum radiation of REUTE with fixed cable, 10 m

In Figure 14 the comparison is shown for the fixed cable. Here, the wire was attached to a rigid and non-metallic frame and therefore underwent the permutations required by the correlation algorithm. As expected, the agreement is better than for the loose wire.

3.4 Results from Different GTEM Cells

Some of the measurements were repeated in a third laboratory to investigate possible measurement variations between laboratories. The third laboratory participating was EMC-Hire, using an EMCO GTEM, cell with a maximum septum height of 1.1m.

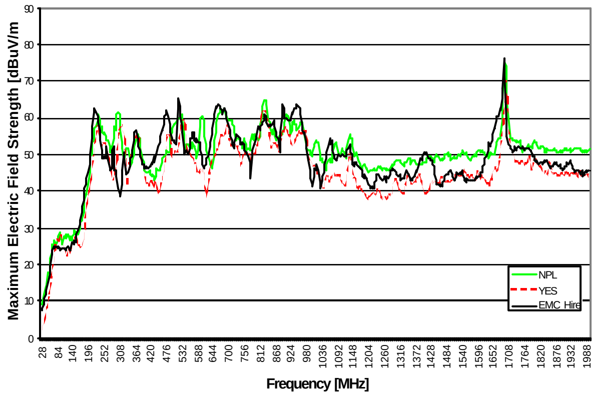

Figure 15: REUTE in slot and gap mode

Figure 15 shows the comparison between NPL, YES and EMC-Hire in the case of the REUTE operated in slot and gap mode. The measurement results between the three laboratories are overall in good agreement. It is believed that the discrepancies in the measurement results are likely due to the size of the GTEM with respect to the size of the EUT. Further work will be required to investigate this discrepancy.

4. Conclusions and Outlook

Generally, it can be concluded from the measurements performed so far, that the GTEM cell can be used up to 2.3 GHz for immunity tests and at least up to 4.2 GHz for emission tests.

From the emission measurements it was found that the GTEM cell generally overtests the EUT. No obvious frequency limit of the GTEM cell or the correlation algorithm could be observed for the emission tests.

Neither could a frequency limit be seen for the field uniformity for immunity tests. The cross-polar coupling however, was seen to exceed the 6 dB limit given by the standard above 2.3 GHz. This frequency range can possibly be extended if the secondary field components are compared to the resultant field strength rather than to the primary field component.

To determine the frequency limits for different GTEM sizes and to verify the results presented here, further measurements should be performed in different test houses and for smaller EUTs. Diverse cable configurations should be investigated in future research.

5. References

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