# A GTEM BEST PRACTICE GUIDE – APPLYING IEC 61000-4-20 TO THE USE OF GTEM CELLS

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***Abstract:*** The draft standard IEC 61000-4-20 includes the GTEM cell as a measurement facility for emission and immunity tests. A Best Practice Guide is being written, giving guidance how to perform measurements according to this standard, and with acceptable uncertainties. This paper presents some results of the research performed to produce this guide.
Frequencies above 1 GHz are increasingly required for radiated emission and immunity tests. This paper describes measurements performed to investigate the upper frequency limit for the use of GTEM cells. First results show that the GTEM used for these measurements can be used up to 2.3 GHz for immunity tests and at least up to 4.2 GHz for emission tests.

## 1. Introduction

The GTEM cell is under consideration as an alternative measurement facility for both radiated emission and immunity measurements. It is included in the draft standard IEC 61000-4-20 *"Emission and Immunity Testing in Transverse Electromagnetic (TEM) Waveguides"* [1]. The GTEM cell is a TEM waveguide with the upper frequency limit extended to the GHz range.
The Best Practice Guide covers emission and immunity measurements as well as the use of a GTEM cell above 1 GHz.
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 and some results are shown in Section 2.
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 3 the upper frequency, for which these limits are kept, is investigated, including a study of sizes of uniform areas.
Until recently most EMC standards assumed a top frequency of 1 GHz. However, measurements at higher frequencies are increasingly required. IEC 61000-4-20 does not specify a certain frequency range but declares it to depend on the testing requirements. The latest issue of IEC 61000-4-3 [2], the standard on measurement techniques for radiated immunity tests, includes a frequency range from 1.4 to 2 GHz to accommodate the mobile telephone bands. But with increasing computer processor clock speeds even higher frequencies are anticipated.
This opens the question, to which upper frequencies are GTEM cells suitable for radiated emission and immunity measurements? Therefore, frequencies above 1 GHz were considered in the measurements presented below.

## 2. Emission Measurements

### 2.1 Radiating Source and Measurement Setup

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.

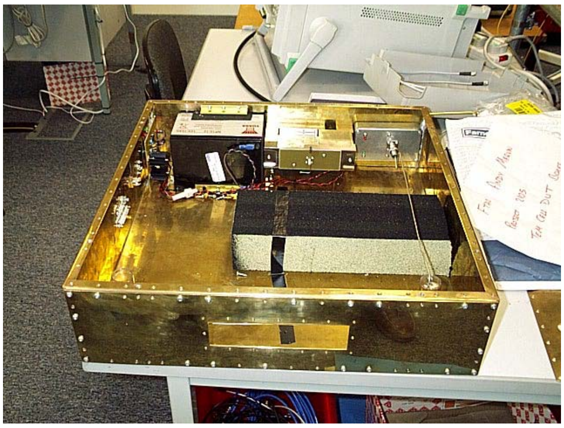

**Figure 1: Radiating EUT showing battery (top left), 7 GHz CNE (top centre), 2 GHz CNE (top right)**

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 ex-

ternal 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.
The block of carbon loaded absorber which can be observed in Figure 1 is included to reduce the Q of resonances within the enclosure and also reduces an oscillation which occurred in one of the CNEs when it was driving into the undamped enclosure.
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.

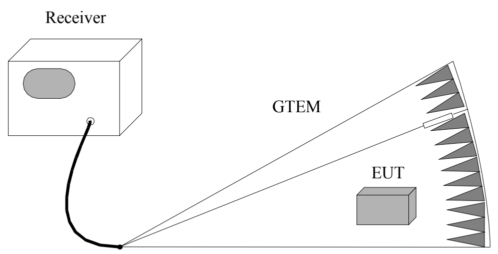


**Figure 2: Emission measurement setup**

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 a GTEM 1750 at a septum height of 1.6 m. Model 1750 denotes that the maximum separation height between the septum and the floor is 1750 mm.
The same analyser was used on the OATS. For the lower frequency range a bilog was used as the receiving antenna, while a ridged waveguide horn antenna was used for frequencies above 1.5 GHz. The EUT was rotated and the antennas were scanned from 1 m to 4 m.

## 2.2 GTEM to OATS Correlation Results

The OATS measurements were performed for 3 m and 10 m separation between the EUT and the receiving antenna. Figures 3-7 show the comparison between GTEM and OATS results with the REUTE operating in its lower frequency range of 30 MHz to 2 GHz.
Figures 3 and 4 show results for the REUTE operated in slot mode. In this case there is no gap between the panels and the enclosure, but both the side panel and the lid have a 4 cm by 16 cm slot, as can be seen in Figure 1.
For Figure 3 the receiving antenna was in horizontal polarisation with 3 m separation between the antenna and the EUT. Differences between GTEM and OATS results of around 10 dB can be seen through the whole frequency range, but the GTEM results are always higher. This was expected, as the GTEM cell is known to overpredict the OATS results.

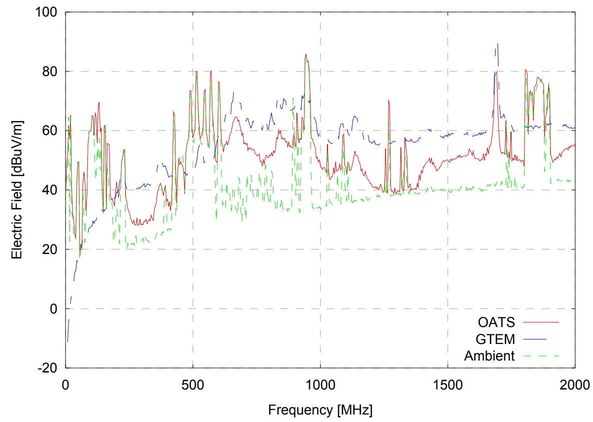


**Figure 3: GTEM-OATS Comparison for REUTE in Slot Mode, horizontal polarisation, 3 m**

This is due to the theory of the GTEM to OATS calibration algorithm. It calculates the maximum radiated power of the EUT from three GTEM measurements. This power is assumed to be radiated by a dipole over a ground plane, and the maximum field strength at the receiving antenna is calculated for the dipole being either vertically or horizontally polarised.

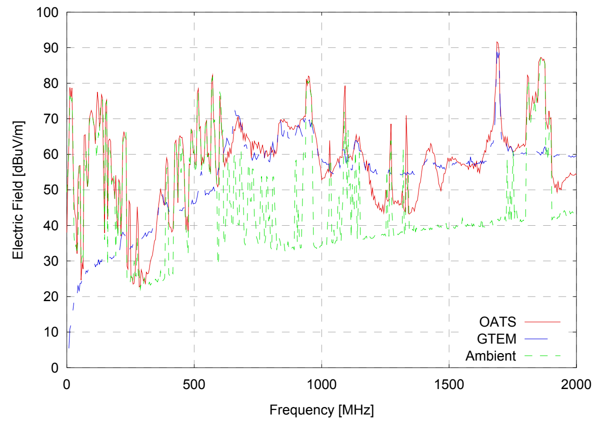


**Figure 4: GTEM-OATS Comparison for REUTE in Slot Mode, vertical polarisation, 3m**

With the receiving antenna in vertical polarisation (Figure 4) the comparison is much better with very good agreement through the whole frequency range. This is due to predominantly vertical radiation of the REUTE leading to a higher field strength detected on the OATS. On the other hand, the GTEM results for horizontal and vertical polarisation are similar since the EUT is permutated through three orthogonal orientations and a maximum radiation is calculated. Hence, the higher OATS show better agreement with the GTEM correlation.
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. This is done in the following figures.
For the results shown in Figure 5, the REUTE was operated in gap mode. This means that both the lid and the side panel were separated from the enclosure using per-

spex spacers, creating a radiating gap of a few millimetres.

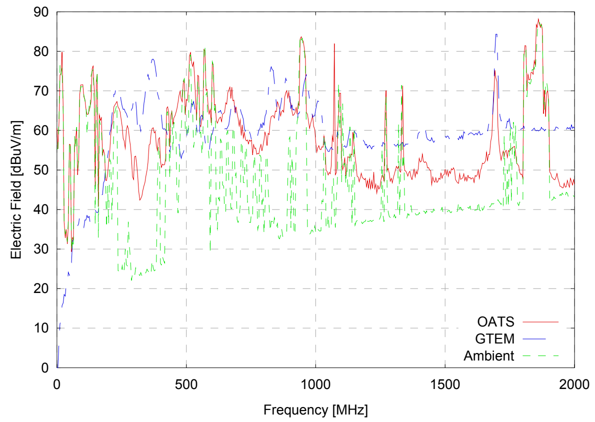


**Figure 5: GTEM-OATS Comparison for maximum radiation of REUTE in Gap Mode, 3 m**

Good agreement between the GTEM and the OATS results can be seen between 500 MHz and 1 GHz. At other frequencies discrepancies of around 10 dB can be observed. An obvious advantage of the GTEM result is that it is not obscured by the numerous ambient signals.

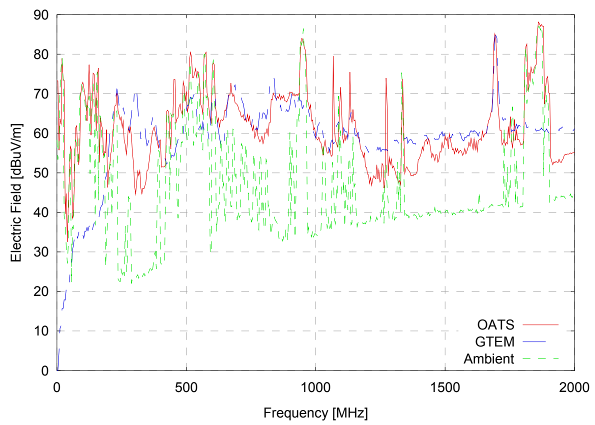


**Figure 6: GTEM-OATS Comparison for maximum radiation of REUTE in Slot and Gap Mode, 3 m**

In Figure 6 results are shown for the REUTE in 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 again between the GTEM and the OATS results. For 10 m separation between the EUT and the receiving antenna, as shown in Figure 7, 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 7, 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.

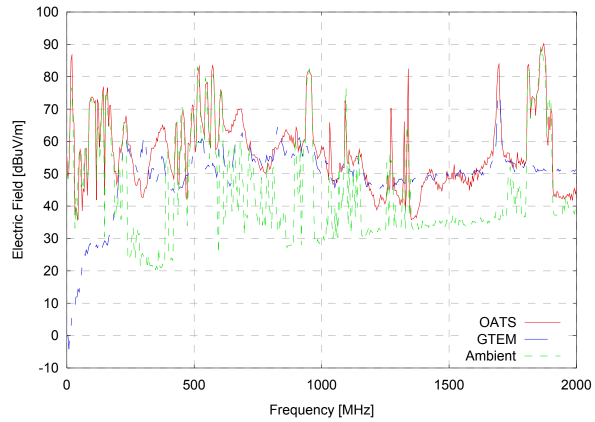


**Figure 7: GTEM-OATS Comparison for maximum radiation of REUTE in Slot and Gap Mode, 10 m**

Figures 8 and 9 show some results for the REUTE operated in the higher frequency range above 1.5 GHz. In Figure 8, the REUTE is operated in 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.

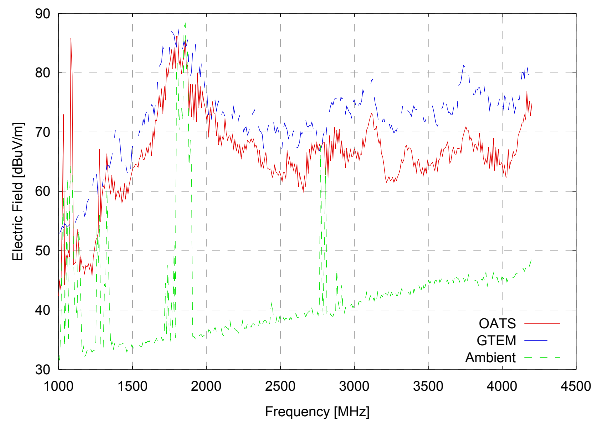


**Figure 8: GTEM-OATS Comparison for maximum radiation of REUTE in Gap Mode, 3 m**

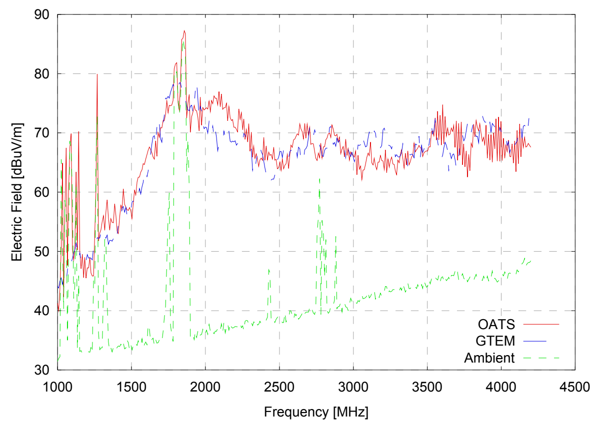


**Figure 9: GTEM-OATS Comparison for maximum radiation of REUTE in Slot Mode, 10 m**

It has to be noted that the receiving horn antenna is directive and therefore does not have the dipole pattern assumed in the correlation algorithm. Taking this into

account, the agreement between GTEM and OATS results is better than expected.
Figure 9 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 research.

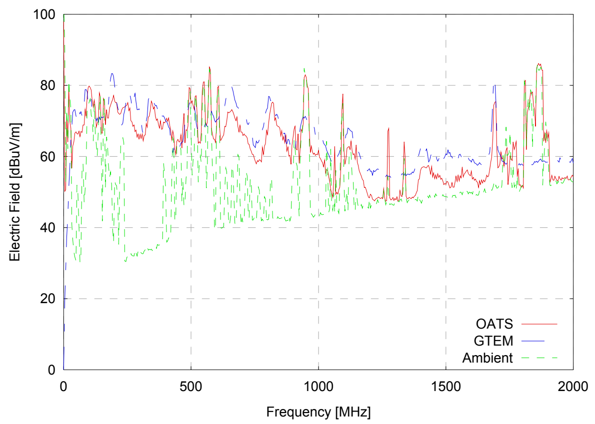


**Figure 10: GTEM-OATS Comparison for maximum radiation of REUTE with loose cable, 10 m**

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 wooden frame or left hanging loose. The measurements with the cable were performed between 30 MHz and 2 GHz, since the lower frequency unit of the REUTE drove the connector. 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.

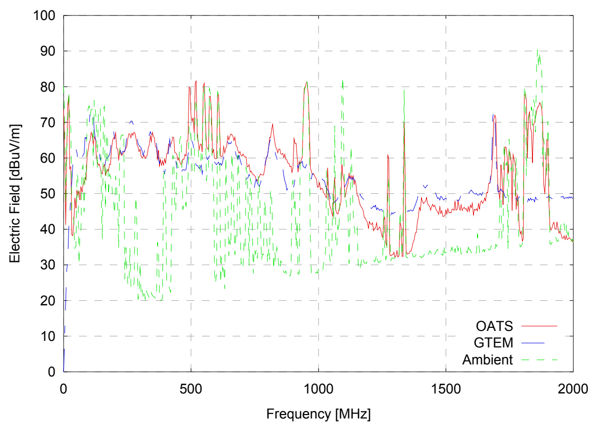


**Figure 11: GTEM-OATS Comparison for maximum radiation of REUTE with fixed cable, 10 m**

In Figure 10 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 is based on a dipole model of the EUT and requires the radiating source to be permutated in three orthogonal orientations. Since this requirement is not met with the cable remaining vertical, a large difference between the GTEM and the OATS results was expected. However, with differences up to 10 dB, the agreement was better than expected.
In Figure 11 the comparison is shown for the fixed cable. Here, the wire was attached to a wooden frame and therefore underwent the permutations required by the correlation algorithm. As expected, the agreement is better than for the loose wire.

## 3. 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.
As shown in [3] and applied in [4] reciprocity is valid, and known radiating sources 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 2.
For the results presented here two different radiating sources were used. A CNE 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 and the CNE VII 15 cm high.

### 3.1 Field Uniformity

Figure 12 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 research presented here, a 9-point 1 m by 1 m, a 12-point 1 m 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 to the limits.
According to IEC 61000-4-20, 12 of 16 points or 9 of 12 points have to be within 6 dB 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.

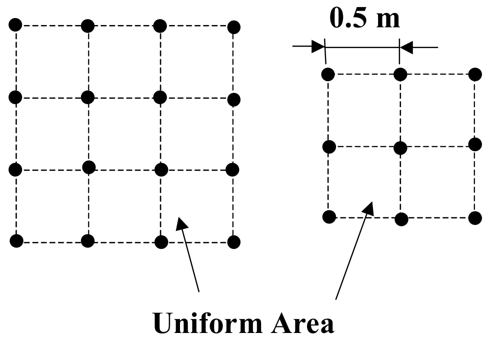


**Figure 12: The 16-point and the 9-point grid for field uniformity**

In Figure 13 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.

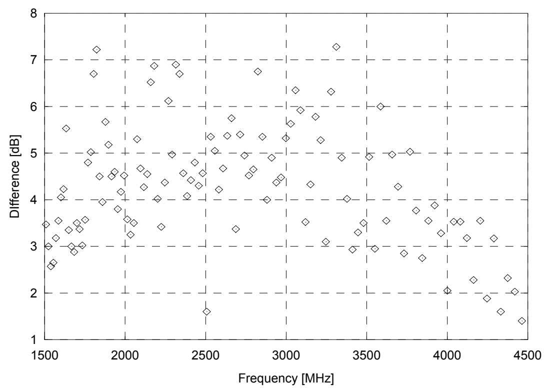


**Figure 13: Maximum difference from 12 of 16 points**

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 14. 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.

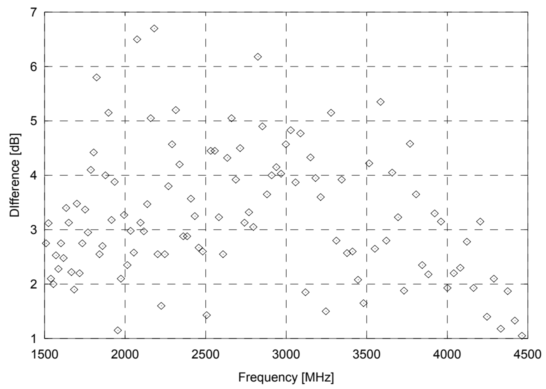


**Figure 14: Maximum difference from 9 of 12 points**

## 3.2 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.

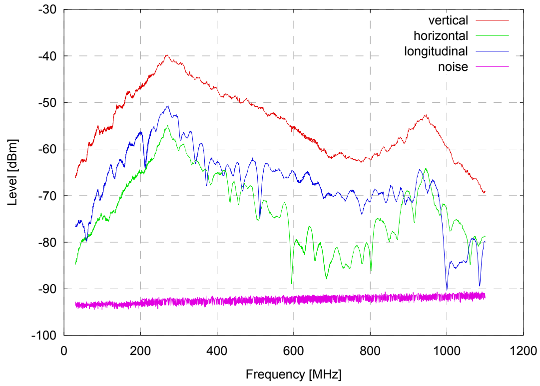


**Figure 15: Field components in a top corner of the nine-point grid**

Figure 15 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.

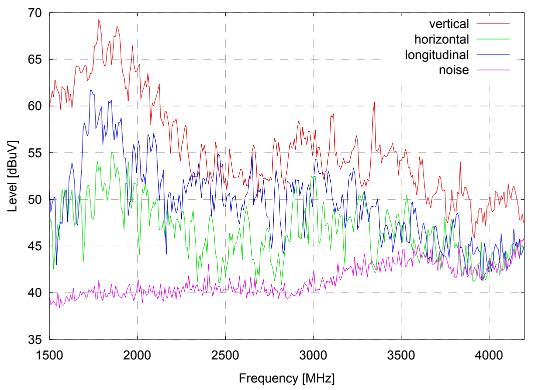


**Figure 16: Field components in a central point of the 16-point grid**

Figure 16 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 17 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.

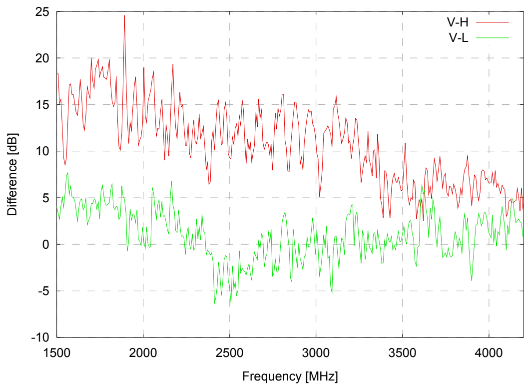


**Figure 17: Difference of field components in a top point of the 16-point grid**

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.
More tests in different GTEM cells are required to verify the frequency limit at 2.3 GHz that is suggested by the initial results presented here.

## 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. The correlation was better for vertical polarisation than for horizontal polarisation of the receiving antenna since the vertical field emitted by the EUT was higher and the GTEM correlation determines the maximum field strength. 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 have to be performed. Comparative tests have been performed in a GTEM 1100, and a purpose built immunity EUT is presently being tested in GTEM cells and a fully anechoic room (FAR).

## 5. References

[1] IEC 61000-4-20 Electromagnetic Compatibility (EMC) – Part 4: Testing and measurement techniques. Section 20: Emission and Immunity Testing in Transverse Electromagnetic (TEM) Waveguides. International Electrotechnical Commission, Geneva, Switzerland, Draft 2CD 61000-4-20, 2001.

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[3] G. Mönich and J. Krause. Draht- und glasfaserlose Feldhomogenitätsmessungen in TEM-Zellen. In EMV'98, 6. Int. Fachmesse und Kongreß für Elektromagnetische Verträglichkeit, Düsseldorf, Germany, February 1998.

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