Measurement Environment Influence Compensation to Reproduce Anechoic Chamber Measurements with Near Field Scanning

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***Abstract*— Field and cable scan methods can be an alternative for antenna measurements in anechoic chambers. Space, cost efficiency and more accurate information about the system under test are the most important benefits. Using scan methods source distribution can be obtained and simulation models can be built. To find the relation between a field scan based radiation model, giving the electromagnetic field at any location, and an anechoic chamber measurement the differences between model and real environment must be considered. When first a current distribution is reconstructed from a near field distribution the electromagnetic far field of the measured equipment can be calculated only assuming simplified conditions. An antenna measurement is done in an anechoic chamber environment. Residual wall reflections, antenna interaction, edge currents of the metallic table or interfering measurement equipment cables influence the antenna voltage. In this paper an approach for finding the field measurement results of an anechoic chamber using near field scans is shown. The method applies a measured correction or transfer function.**

Keywords*— *ALSE substitution; near field scan; multi dipole model; measurement environment influence

I. Introduction

Knowing electro-magnetic field emission levels from automotive systems is very important. Usually an ALSE (Absorber Lined Shielded Enclosure) antenna method defined e.g. in CISPR 25 [1] is used for evaluation. ALSE method suffers from the need of large and expensive anechoic chambers and not sufficient knowledge of the full EMC behaviour of a device under test [2]. Space- and cost-effective methods which give exact information of the radiation properties of an electronic system under test are desirable.

The electromagnetic emissions of typical automotive electronic systems can be distinguished in the emission of cables and the emission of PCBs and the housing. Cable and field scan methods which try to identify an equivalent source distribution can be good alternatives [5]. By cable scanning, the dominant common-mode currents [3] and an equivalent source distribution in the cable can be obtained. Current distribution on PCB can be found by field scanning, including geometry properties and correlation of sources [4][6]. Complex field data from Time Domain or Frequency Domain measurements in amplitude and phase with special synchronisation are needed in most cases. Furthermore knowing the sources, respectively the current distribution, an electromagnetic behavioural model can be created and calculation of the overall EM-fields can be done.

When using cable and field scan methods, comparability to the corresponding standardized and established ALSE antenna measurement results is necessary. As the cable and PCB models, based on near field scanning, assume for far field calculation a simplified environment, ALSE antenna method is done in a chamber which might have complex behaviour. Interactions with the antenna, residual reflections from the absorber lined walls, edge effects of metallic table, and interfering emissions from the measurement equipment cables, as shown in fig. 1, are influencing the measured antenna voltage. Taking into account these influences is essential for substituting antenna measurements in anechoic chamber with field scan based methods.

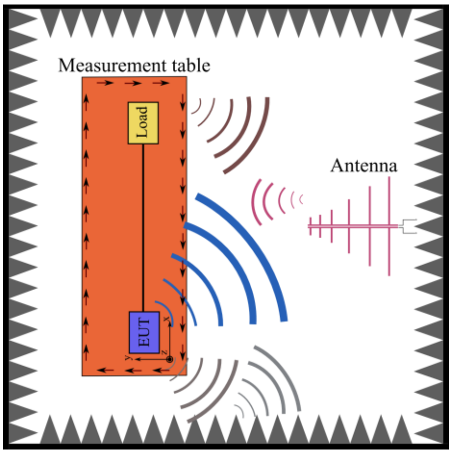

Fig. 1. Influencing factors of CISPR 25 ALSE

Fig. 2 shows MoM simulation results for the vertical field component E_z radiated from a small cable structure (representing a current path on a PCB, shown in fig. 8) in comparison to a real antenna measurement of the small structure in an anechoic chamber. The results are inaccurate in the frequency range from 1 MHz to 1 GHz with errors of more than 10 dB. Varying table model from infinite to finite with additional ground still shows deviations caused by measurement environment. Using simplified field radiation models which assume free space radiation or unlimited table dimensions require a correction process.

In this paper a procedure to simulate ALSE antenna method results with help of field scans is improved. Therefore a measurement data based transfer function is introduced taking into account the environment influences mentioned above.

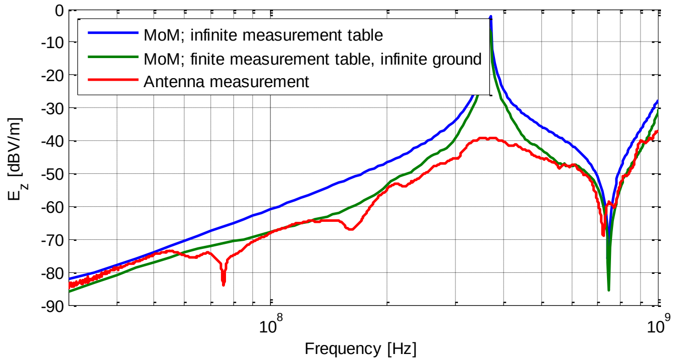

Fig. 2. E_z of MoM result of radiation from a simple structure above an infinite table and finite table in comparison to real antenna measurement (+ antenna factor from data sheet) in anechoic chamber

II. Reproducing ALSE Antenna Measurement Results with Near Field Scanning

The following section presents the theoretical process for computing ALSE antenna measurement with field scan method regarding real measurement environment influences.

A. Theoretical method of transfer function calculation

The radiated electric and magnetic fields depend on the current distribution on the PCB. In ALSE antenna setup the electric field is received by the antenna in anechoic chamber and antenna voltage is measured.

Known currents in x-, y-, and z-direction for short segments allow determining the transfer function between a current segment and the resulting antenna voltage. Therefore the antenna voltage must be measured for the three current directions at each point of a calibration area. The resulting transfer functions change depending on the spatial discretisation of the calibration area and the respective frequency. It is assumed that the short segment sources can, be approximated with Hertzian dipoles. The theoretical method for transfer function calculation with Hertzian dipoles is shown in fig. 3.

To reduce the number of impressed currents spatial interpolation or, in case of a small calibration area, the application of only one transfer function is possible.

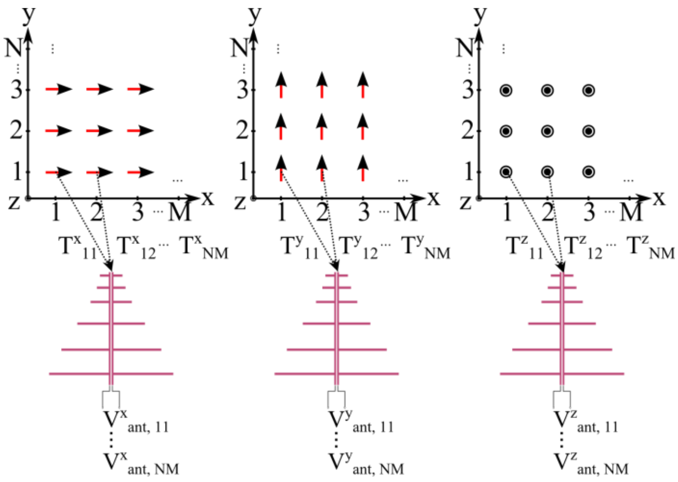

Fig. 3. Transfer function calculation of antenna voltage and impressed currents (Hertzian dipoles)

For this approach special structures are needed to generate the known currents for the different orientations in the Cartesian coordinate system. If these special structures are small enough, it is possible to approximate them with a single dipole. Fig. 4 shows the approximation of a small monopole antenna with a dipole in z-direction and the approximation of a small dipole antenna by a dipole in x-direction.

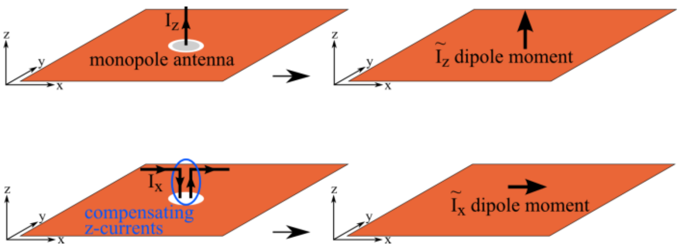

Fig. 4. Approximation of small antennas with Hertzian dipoles; monopole antenna (above) and dipole antenna (below)

As the monopole antenna can be easily fed, the small dipole antenna has to be fed with two vertical wires. In observation point or, respectively, antenna position, in case of a sufficiently small spacing between the vertical wires and in case of symmetric impressed currents the vertical components compensate each other. To produce a symmetric feeding and symmetric electromagnetic field a "balanced-unbalanced" device can be used. Here measurements are done with a 4-channel network analyzer and balancing is performed by a transformation of single-ended to mixed-mode S-parameters.

Considering image theory the dipole moments of these structures are determined by measuring a single observation point in near field. As the far fields of monopole and dipole antenna and their approximating Hertzian dipoles are the same the approximation of the near fields is inaccurate.

To calculate an accurate dipole moment the observation point for field measurement is located close to the antenna in an area of minimal deviation between antenna near field and its approximating dipole near field. Fig. 5 and fig. 6 show the comparison (simulation) between the near fields of monopole antenna and elementary dipole and between dipole antenna and elementary dipole. The measurement area is here marked with a white frame.

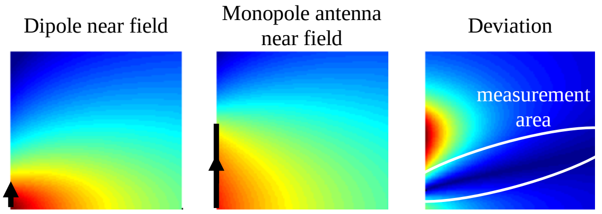

Fig. 5. Comparison of elementary dipole near field and monopole antenna near field

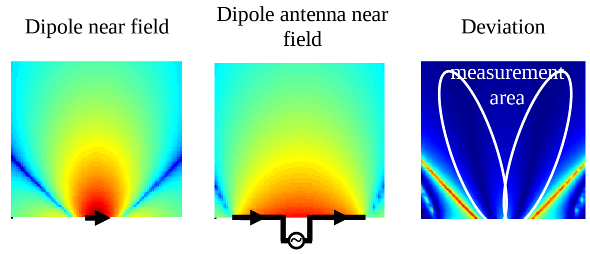

Fig. 6. Comparison of elementary dipole near field and dipole antenna near field

The transfer function can be calculated in relation to the dipole moment:

$$T^x = \frac{V^x{}_{ant}}{\tilde{I}_x} \tag{1}$$

$$T^y = \frac{V^y{}_{ant}}{\tilde{I}_y} \tag{2}$$

$$T^z = \frac{V^z{}_{ant}}{\tilde{I}_z} \tag{3}$$

Here $T^{x,y,z}{}_{nm}$ are the transfer functions, $V^{x,y,z}{}_{ant}$ are the antenna voltages and $I_{x,y,z}$ are the dipole moments. All variables are given in complex form.

Knowing the transfer function for each possible current path in x-, y- and z-direction on a PCB the next step is to do a near field scan of the PCB. A multi dipole model of the PCB can be computed from near field data [3][6][7]. Each dipole moment can be transformed with use of the related transfer function to antenna voltage. The sum of the antenna voltages caused by dipoles results in the total antenna voltage of the entire PCB:

$$V_{ant} = \sum_{n=1}^{N} \sum_{m=1}^{M} T^x{}_{nm} \tilde{I}^x{}_{nm} + T^y{}_{nm} \tilde{I}^y{}_{nm} + T^z{}_{nm} \tilde{I}^z{}_{nm} \tag{4}$$

Fig. 7 shows the process chain of TF (transfer function) method.

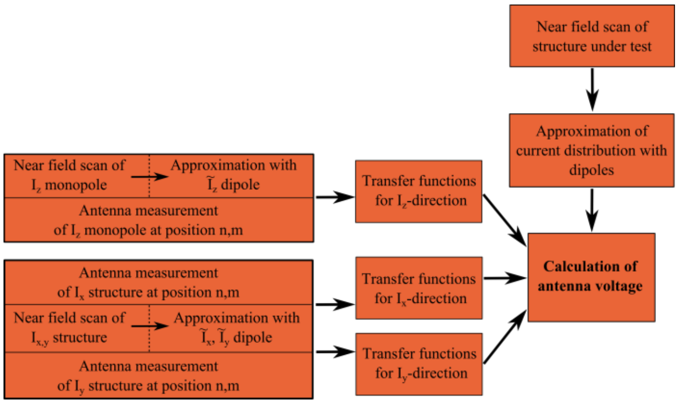

Fig. 7. Process chain of TF method

B. Dominance of vertical currents

ALSE antenna measurements are done in horizontal E_x and vertical E_z polarization. Fig. 8 shows a simulated structure consisting of a single cable with a length of 200 mm, 3.5 mm above ground plane and an open end. It is fed by a voltage source with amplitude of ~1.3 V (according to reference measurements done with a 12 dBm signal generator). The current distribution in the structure can be approximated by a set of Hertzian dipoles, as shown in fig. 8.

Although, taking into account the smaller dimension of the vertical part of the cable in relation to the horizontal part and regarding the given frequency range between 1 MHz and 1 GHz, the vertical current is the dominant radiation factor. Fig. 9 shows a comparison of the E_x and E_z field at observation point [615, 1615, 14] mm (according to reference measurements done with an antenna at observation point) of the given structure. The vertical field component is dominant with roughly 20 dB. Furthermore, fig. 9 shows the E_z field of different dipole approximation models in comparison to MoM simulation data. Obviously the electric field of the structure can be calculated accurately if the vertical currents are considered. It even is possible to achieve an exact E_z field with information about the vertical current I_z only. Considering image theory there is a field accumulation of vertically orientated currents which leads to a dominant behavior, as shown in fig. 8.

In an ideal vertical polarized measurement only the vertical currents have to be regarded whereas in an ideal horizontal polarized measurement the horizontal and the vertical currents are needed (fig. 9). However in real measurements, respectively, measurements with LPDA, the vertical oriented antenna is not sensitive for vertical field component only, but also for the horizontal field component. This fact can produce a visible difference in measured antenna voltage in case of a non-dominant vertical field.

Summarized vertical and horizontal current components have to be regarded in the calculation of both horizontal and vertical antenna polarization voltages.

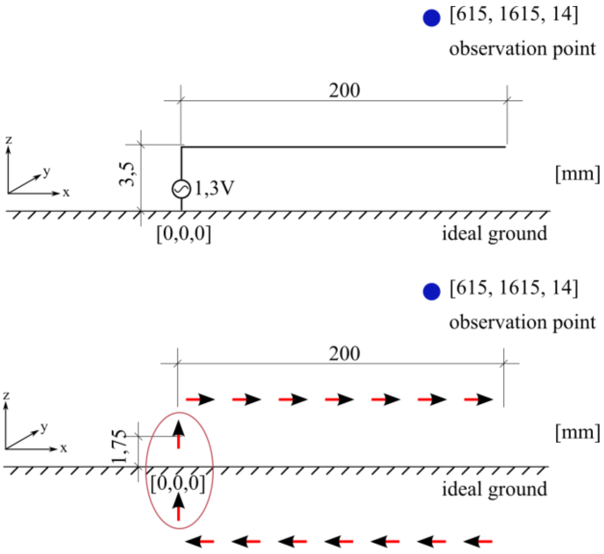

Fig. 8. Approximation of cable structure with Hertzian dipoles

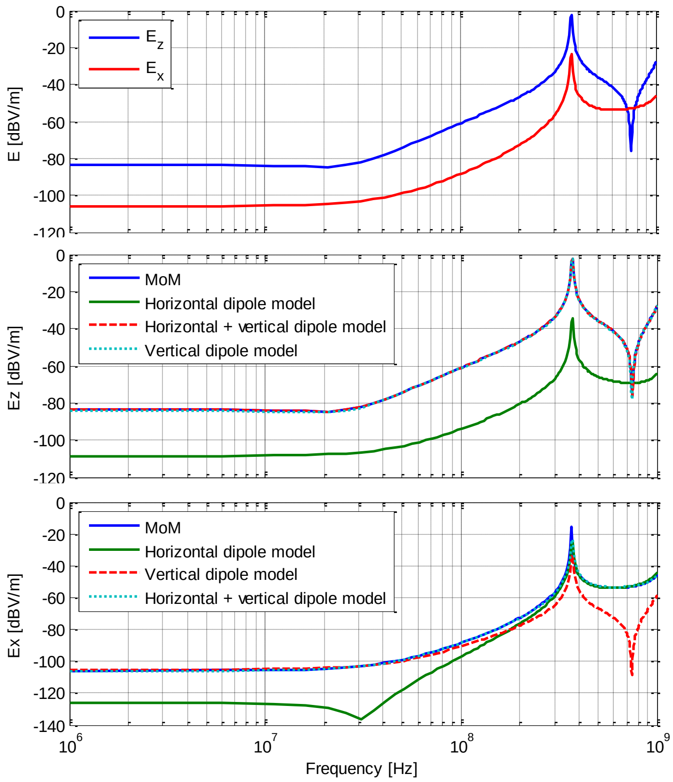

Fig. 9. Comparison of Ex and Ez components at observation point (above); Comparison of E_z fields of different dipole models (center); Comparison of E_x fields of different dipole models (below)

III. Results

In the following section results of the TF method for vertical and horizontal polarization of a LPDA in the frequency range from 30 MHz to 1 GHz are presented. As test structure the DUT shown in fig. 8 is used. It consists of a single cable with height of 3.5 mm over ground, a horizontal length of 200 mm and one open end.

All investigations are performed in frequency domain with a 4-channel network analyzer. In order to get a good comparability and to simplify the analysis of the TF method all results are processed using S-parameter measurements. The computation of the equivalent antenna voltages follows

$$V_{ant} = s_{12} \cdot \frac{1}{2} V_{input} \quad \textbf{(5)}$$

A. Transfer function calculation by near field scan and antenna measurement in anechoic chamber

The application of the proposed TF-method is done by measurements and calculations following the process chain, presented in fig. 7. Due to the small dimension of the DUT only one transfer function for each current direction is needed.

To determine the transfer functions for vertical currents I_z a monopole antenna with a length of 30 mm is used. In the first step the magnetic near field is measured at a single position (fig. 5) near to the monopole antenna. From measured data the dipole moment is calculated. In the next step the antenna measurements for vertical and horizontal orientation of LPDA antenna in the anechoic chamber are done. Fig. 10 shows the measurement setups for both steps.

To determine the transfer functions for horizontal currents $I_{x,y}$ a dipole antenna with a length of 30 mm and a height of 3 mm above ground is used. As already mentioned in chapter II.A here a 3-port measurement with transformation of single-ended to mixed-mode S-parameters is applied. Field measurement for dipole moment calculation is done at a single position (fig. 6) near the antenna. Fig. 11 shows the measurement setups of dipole antenna and the antenna.

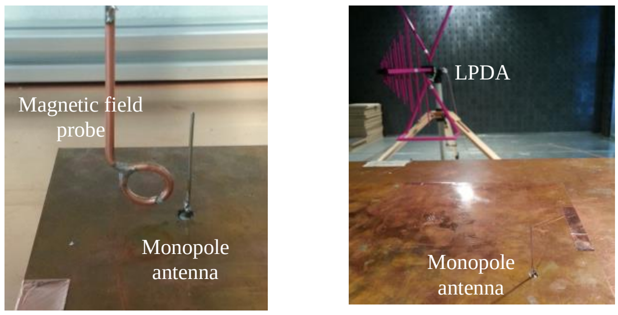

Fig. 10. Near field measurement (left) and vertical polarized antenna measurement (right) of monopole antenna

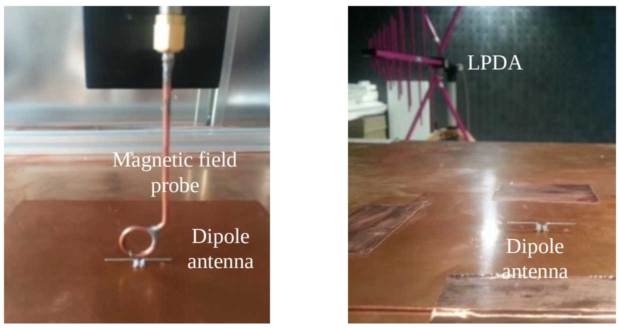

Fig. 11. Near field measurement (left) and vertical polarized antenna measurement (right) of dipole antenna

Fig. 12 shows the results of antenna measurement of the monopole and dipole antenna in vertical and horizontal polarization. The noise up to a frequency of 150 MHz is consequence of the low signal amplitude of the fields produced by the horizontal current component.

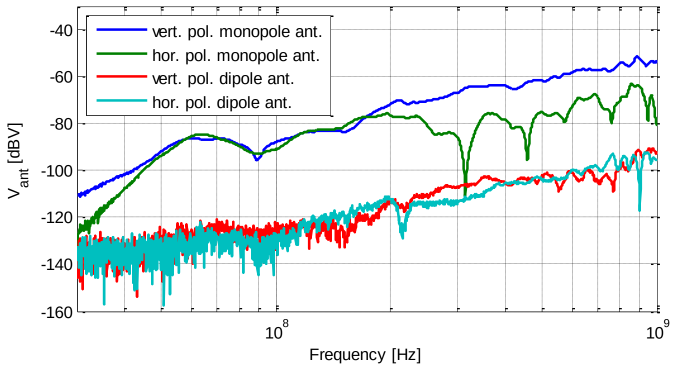

Fig. 12. Antenna measurements of monopole and dipole antenna

Finally the transfer functions for T_x and T_z are calculated from the collected data as described in (1) and (3).

B. *Near field scan of structure and final results*

To apply the measured transfer functions to the current distribution of the structure under test a multi dipole model of the structure must be identified.

The model is created by a near field scan in a 250 mm x 60 mm plane 11 mm above ground. The scan is done in 520 observation points for x- y- and z-direction of the magnetic field, as shown in fig. 13. The sources are correlated by specifying the known current path. From the measured near field data the dipole moments arranged along the current path were computed.

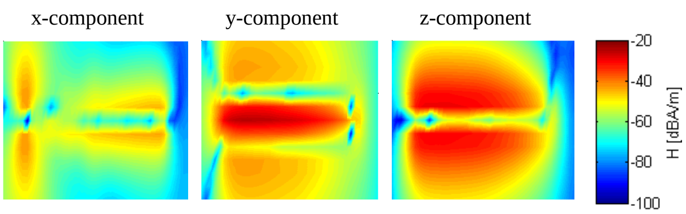

Fig. 13. Near field scans of magnetic field of the structure under test in x-, y- and z-direction at 420 MHz

For comparison with the calculated antenna results based on TF method a direct measurement of the antenna voltage produced by the structure under test is done in the anechoic chamber. The measurement setups for near field scanning of structure and the direct antenna measurement are shown in fig. 14.

For computing the antenna voltage with TF method the previously obtained transfer functions are applied to the dipole emission model of the structure under test. The calculation is done using equation (4).

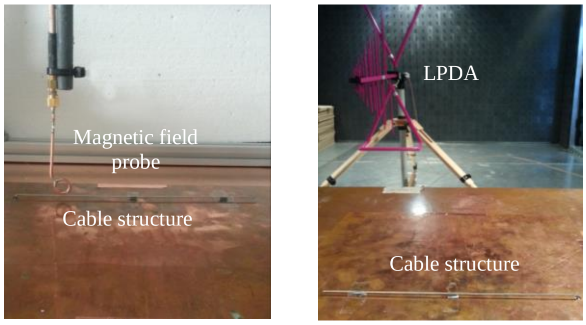

Fig. 14. Near field measurement (left) and antenna measurement (right) of cable structure

Finally the results from direct antenna measurement and TF method related to the antenna voltages for vertical polarization are shown in fig. 15. The results of horizontal polarization are presented in fig. 16. For comparison the results of free space calculation based on near field scanning emission model are included in the figures.

The TF method result of vertical antenna polarization is very accurate in the whole frequency range up to 900 MHz. In the frequency range from 900 MHz to 1000 MHz there is a maximum error of 6 dB. The result of the horizontal polarization agrees with a maximum error of 3 dB up to a frequency of 280 MHz. Above this frequency the curve shapes show a maximum error of 10 dB.

The improvement of the results compared with free space calculation for both polarizations is obvious.

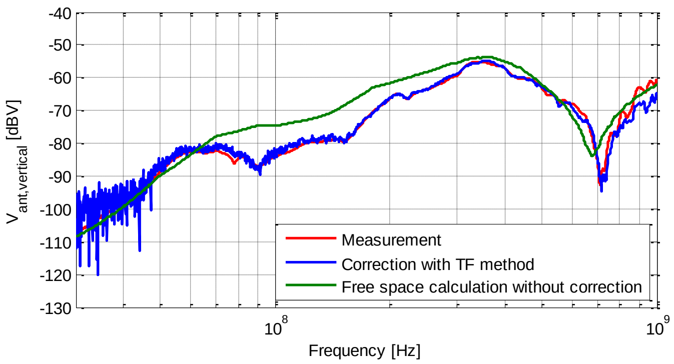

Fig. 15. Comparison of MoM simulation; TF method and real antenna measurement; vertical polarization

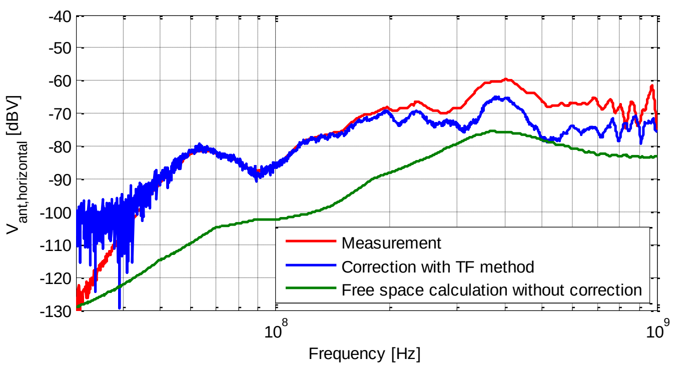

Fig. 16. Comparison of TF method and real antenna measurement; horizontal polarization

There are some possible reasons for the deviations, especially for the horizontal antenna orientation. Contrary to the vertical polarization - which is mainly influenced by the vertical currents, and transfer function computation is mainly based on the simple monopole antenna - the horizontal polarization is strongly affected by the more complex dipole antenna measurements and computations. Besides there is a small inconsistency due to the different heights of structure (3.5 mm) and dipole antenna (3 mm) above ground plane which can lead to a visible deviation too. Furthermore the signal strength and quality of the dipole antenna measurements is several dB lower than the monopole antenna measurements. Even uncertainties in obtaining correct equivalent dipole moments of both dipole antenna and monopole antenna and identifying an accurate multi dipole model of the structure under test is a possible source of errors.

IV. CONCLUSION

Field scan methods can become a good alternative to ALSE antenna measurements. E.g. lower space requirements and costs are benefits of these methods. More accurate determination of near and far fields of the measured system is possible.

As the models based on near field scans provide field data at any point assuming simple environmental conditions, the antenna measurements are done in a complex measurement environment. Environmental influences affect the resulting antenna voltage. To substitute ALSE antenna measurements by near field scans the influences have to be included in the calculation process.

In this paper a method for considering influencing factors from complex anechoic chamber field measurements in near field scanning is presented. It is based on measuring and computing transfer functions for impressed currents in x-, y- and z-orientation for a defined calibration area. The impressed currents are spatially correlated to the currents paths of the test structure. A near field scanning is done to find the current distribution and to create a radiation model. The desired antenna voltage is obtained by the sum of the electric fields from elementary sources and their related transfer functions.

To verify the presented approach measurement results for the vertical and horizontal polarization of a LPDA antenna in comparison to the TF (transfer function) method results were shown. The result for vertical orientation is very accurate in the whole frequency range. The horizontal orientation result only agrees in a limited frequency range due to some measurement uncertainties.

Further investigations to get more accurate results for the horizontal polarization in a higher frequency range are necessary. To improve the transfer function of horizontal impressed currents the symmetry of the dipole antenna field will be increased. This can be done by measuring both antenna arms separately and combining the results in the transformation of single-ended to mixed-mode S-parameters. Higher signal power (10 dBm used) for increasing the signal-to-noise ratio seems to be useful as well.

Transformation from S-parameters to currents and voltages will be done to allow the verification of the identified dipole moments according to the small antennas and the current distribution of structure under test. In a next step the method will be applied to real and more complex structures.

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