Numerical Evaluation of Near-Field to Far-Field Transformation Robustness for EMC

Andriy Radchenko [#1], Ji Zhang [#2], Keong Kam [#3], David Pommerenke [#4]

[#] *EMC Laboratory, Missouri University of Science and Technology*
4000 Enterprise Dr. Rolla, MO 65401, USA

[1] ar8r3@mst.edu, [2] jz7r9@mst.edu, [3] kwkx8d@mst.edu, [4] davidjp@mst.edu

***Abstract*—Near-Field (NF) to Far-Field (FF) transformation techniques are widely used for antenna radiation problems. To perform a NF to FF or a NF to NF transformation for EMC applications, the large frequency range, and a weak signals will require data in the reactive near field. In principle, the transformation can be performed if all sources are confined in the scanned area using Huygens' Principle, which requires knowledge of the exact phase and magnitude data of measured fields. In reality, this cannot be achieved, due to uncertainties in the field probe measurements, presence of active and passive cables and limited scan areas. Thus, it is attempted to perform a transformation based on an incomplete and uncertain data set. Results of a numerical simulation tool usage for NF to FF transformation based on NF-Scanning system measured data are demonstrated.**

I. Introduction

There are various approaches for NF to FF transformation. One of such approaches is to use Huygens' Surface surrounding radiating structure, replacing the original radiator by an equivalent source based on near field distribution. The technique works smoothly in theory, however in application for real electronic devices tests in EMC many challenges arise. First, the electric and magnetic fields are required to be measured close enough to the DUTs, to be able to detect operating signals, which could be low in magnitude. This forces requirement of NF measurements to be performed in the reactive NF-area surrounding a DUT, along with special treatment for the NF-probes calibration and compensation [1]. Secondly, NF to FF transformation techniques often rely on comprehensive NF-distribution information, which includes both amplitude and phase data. Some of the techniques can overcome difficulties associated with the phase measurement by using NF-scan magnitude-only data recorded on two separate planes, and then retrieve relative information from the mathematical processing of the field distribution difference over the considered planes [2], however application of such techniques for EMC-related tasks could be difficult due to low levels of the DUT on-board signals, which might not be detectable on lifted scanning plane. In this study Huygens' principle-based near field source (NF-Source) is used in full-wave three-dimensional Method of Moments (MoM) solver of commercial simulation tool EMCoS EMC Studio [3], however the conclusions are not tool and method specific and can be considered in other implementation versions of a NF-Source excitation [4].

II. Initial Tests

Initially NF to FF transformation using complete accurate NF information over the Huygens' surface is demonstrated.

Pictures in Fig.1 show a model of a simple radiating structure of typical cell-phone size (~12 cm x 5 cm) constructed from metallic plates and interconnecting wires, a Huygens' surface surrounding the model, and a near-field distribution, ready to be used as an equivalent radiating source.

The simulated DUT is fed by a voltage source applied between the wire and the large metal plate; the wire is routed with all X, Y and Z direction turns, includes loop-kind part and is terminated by a 50 ohm load between smaller metal plate and the wire end.

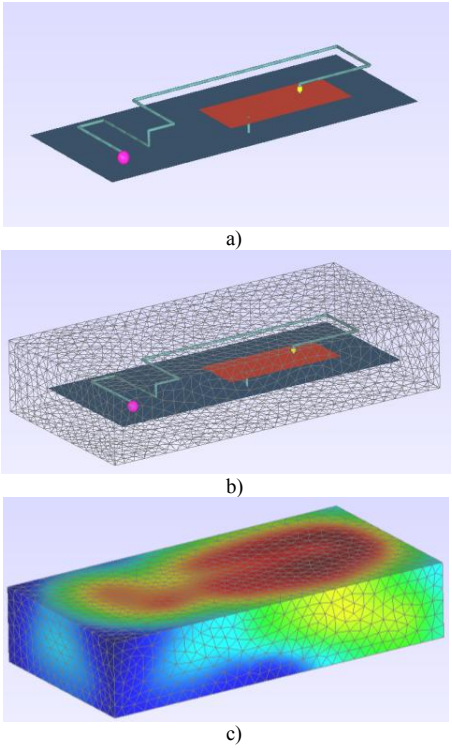


Fig. 1. a) Simple electronics device model; b) Meshed near-fields observation surface surrounding the device model; c) Calculated near-field distribution

The DUT model is placed at 1 m height over the infinite PEC ground plane, mimicking the semi-anechoic chamber EMC-test measurement environment. The Far-Fields are observed at the 3 m radius cylindrical area for Direct Solution, involving complete DUT model excitation and equivalent solution by NF-Source usage.

The Far-Fields are compared at the set of the discrete field probes placed at 0.25 m, 1 m and 1.75 m height over the ground plane. Fig.2 shows corresponding simulation model.

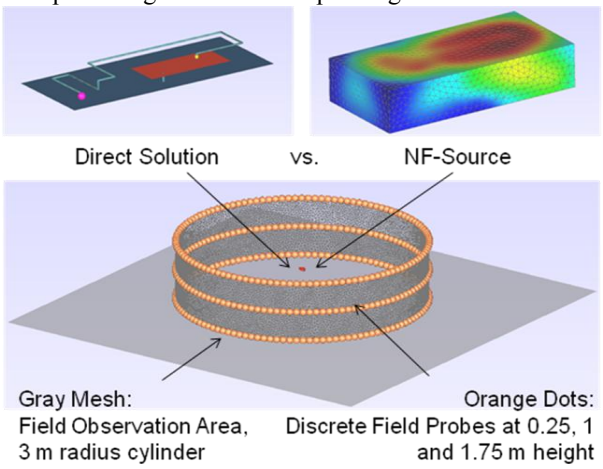


Fig. 2. Far-Field calculation model

Far-Field results are obtained using a complete set of Electric and Magnetic fields: X, Y and Z components, magnitude and phase, observed over the closed Huygens' surface. For equivalence principle application knowledge only of field's components tangential to the Huygens' surface is required. However, when the Huygens' surface is not just a plane, but has an arbitrary shape (e.g box, cylinder, sphere), all field components are effectively needed in simulation.

Results of the direct MoM simulation and the simulation using the equivalent NF-Source are nearly identical. Fig. 3 shows results for 50 MHz, while Fig. 5 shows results for 1 GHz.

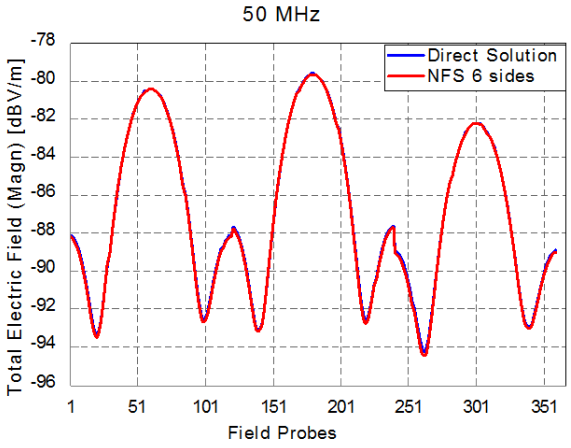


Fig. 3. Total electric field in the set of discrete field probes at 50 MHz

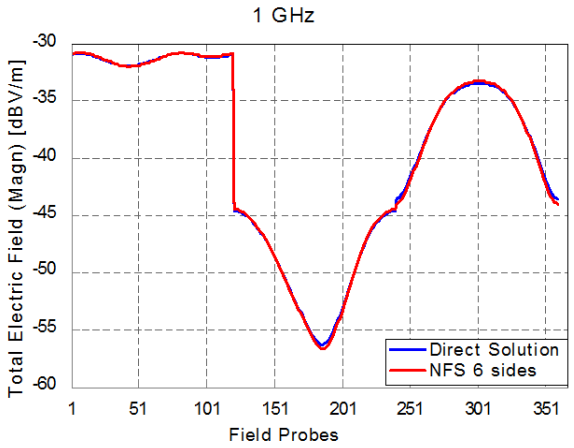


Fig. 4. Total electric field in the set of discrete field probes at 1 GHz

Field probes numbered (1:120) correspond to 25 cm height; (121:240) correspond to 1 m height and (241:360) correspond to 1.75 m height.

Considered case is an ideal demo – full set of near fields is calculated on all 6 sides of the Huygens' surface – so fields are recorded at top, sides and bottom surface as well. Such use of NF-Source in modelling can be applied for complex simulation model segmentation in simpler sub-models, where smaller component/device level model can be effectively solved by appropriate numerical techniques and then radiation from the sub-model element can be included into the larger system-level simulation [5].

From measurement perspective it is extremely difficult to obtain such complete field distribution information. Typically just 1-side planar NF-scan area right above the DUT is used. To construct more adequate NF-Source model from the NF-scan data a DUT can be rotated during the test and fields on separate intersecting planes from different sides of a DUT can be recorded. Alternatively cylindrical NF-Scan area can be used with dynamic DUT rotation during the scan, however in this case the distance from NF-probes to the DUT electronics body is varying and increasing compared to flat planar scan, which could lead to difficulties detecting low-energy signals.

Another uncertainty associated with a NF-scan process is a difference in electric and magnetic field measurement position. Normally different probes are used for electric and magnetic field measurements. Typical electric field probe for tangential component measurement is a small dipole printed at the probe tip, while for magnetic field it is a small loop. The probes response to an effective measuring space associated with the probe dimensions. Using different probes in series order for one and another tangential component (four different NF-scans) makes it almost impossible to measure different components of the near field data in exactly the same space location, while for numerical NF to FF transformation the input data is assumed to correspond to the same space spot.

III. Sensitivity Study

Listed above measurement uncertainties, as well probes dynamic range limitations and accurate compensated

calibration issues, make NF to FF transformation questionable in application for practical EMC problems. Here an exact prediction of the radiation pattern is unlikely to be achieved due to incompleteness of the data, such as missing field components, limited NF scan surface, and inaccuracies in magnitude and phase measurements. However, in EMC testing the maximum levels of the radiation is often of primary interest. Another important application for EMC is estimation of relative change of the emissions within various design versions or countermeasures applied. By these considerations NF to FF transformation can be accurate enough.

Sensitivity study on transformation accuracy degrading due to uncertainties in NF-Data can include testing on phase / magnitude noise, probes dynamic range, probes cross coupling, NF-Scan surface limitation and discretization step, close-proximity presence of the metal under the DUT during a NF-scan and attached cables effects. Next sub-sections provide results for a few of the listed studies.

A. Phase Noise

NF to FF transformation with degraded input information was tested by randomly varying phase of all of the NF-Source components in the range of [±1° : ±45°]. In Fig. 5 the NF-Source object obtained from initial tests is shown. The NF-Source is described by a triangular-meshed 3D surface (see Fig. 1b) and fields at the centers of each triangle in the mesh. Thus, the NF-Source is defined by fixed number of discrete field points, which are demonstrated in Fig. 5 as orange dots. There are about 3400 points on the complete 6-side surface of the NF-Source, with average discretization step about 5 mm.

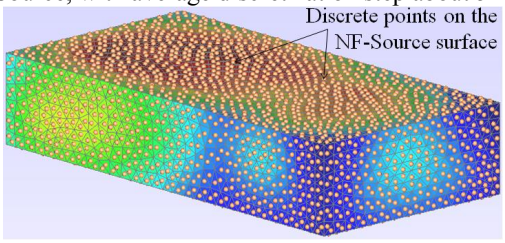


Fig. 5. Near Field Source with shown discrete field points

To introduce a noise-error into the NF data the accurate NF-Source file was manipulated by replacing original phase information with modified one, which included artificially generated noise in chosen levels. Fig. 6 shows sub-set of the phase information for the electric field X-component comparing original phase curve with results of [±45°: ±10°] phase noise addition into the original NF-data. The red curve shows sample of original data, while other curves show corresponding modified data sets. For each component of the near fields own set of random noise is applied, thus in NF-scanning process each component is measured independently.

Fig. 7 shows visual comparison of the electric far field calculated at 3 m distance from the NF-Source using original accurate and modified by ±45° phase noise NF-data. The top pictures correspond to 50 MHz frequency and show significant difference in obtained field distribution pattern; bottom pictures show very similar distributions at relatively high 1 GHz frequency.

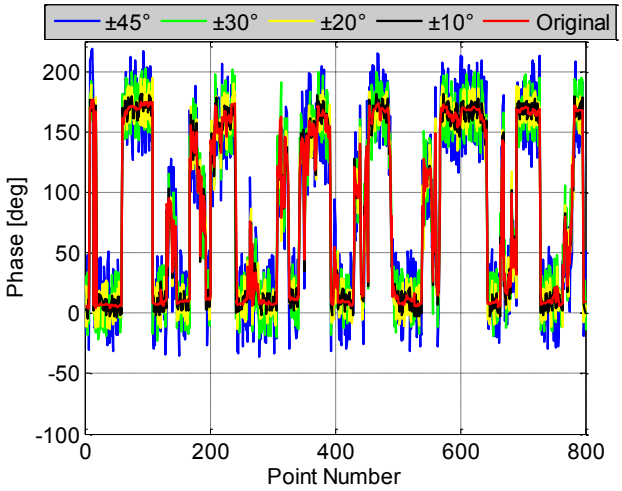


Fig. 6. Phase noise introduction into the original NF-data

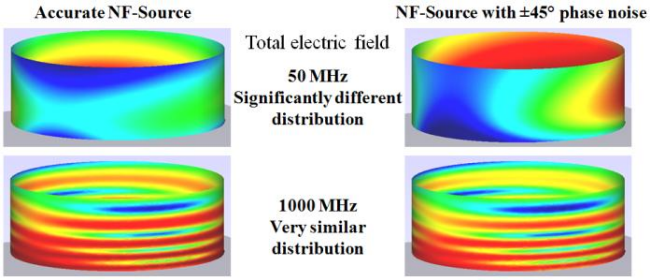


Fig. 7. Comparison of electric far field calculated using accurate NF-Source (left) and using modified NF-Source (right)

Fig. 8 shows comparison of the total electric field observed at some randomly chosen location at the FF-observation cylinder.

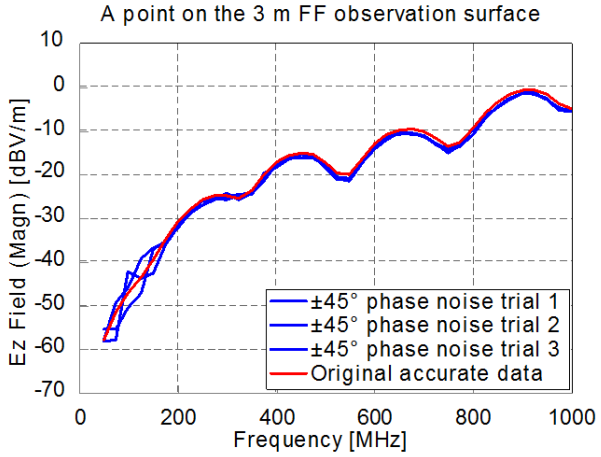


Fig. 8. Vertical component of the electric field in one of the observation points at 3 m radius field observation cylinder

The blue curves are for three separate trials of random ±45° phase noise addition; they demonstrate range of possible deviation from the original solution, shown in red.

At the frequencies over 200 MHz ±45° results are within 1.5 dB accuracy relative to reference accurate solution. For

the frequencies below 200 MHz the deviation range reaches 3-5 dB. However, obtaining the total maximum of radiated field over the FF observation area provide ±1.5 dB agreement in whole considered frequencies range. Results for lower noise levels (±1°, ±5°, ±20°) are even better (0.2 dB – 1 dB difference).

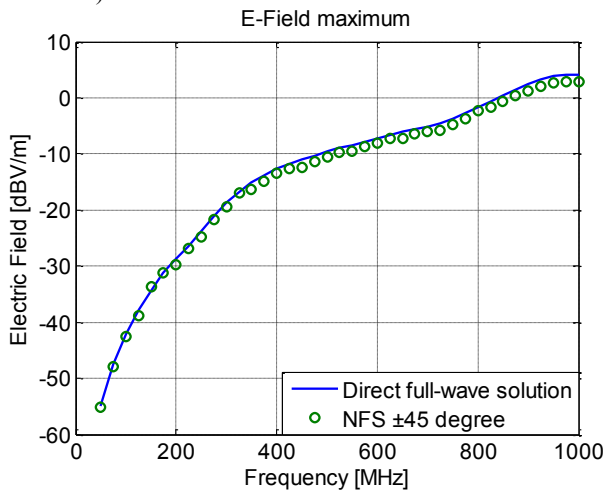


Fig. 9. Electric field on the cylindrical far field scan area extracted using max-hold feature for direct accurate solution and for ±45° phase noise case

In case when no phase information is available, either constant or random phase distribution could be used. Fig. 10 shows that constant phase assumption (0° for example) might be good enough for higher frequencies, while use of totally random phase distribution leads to dramatically wrong results.

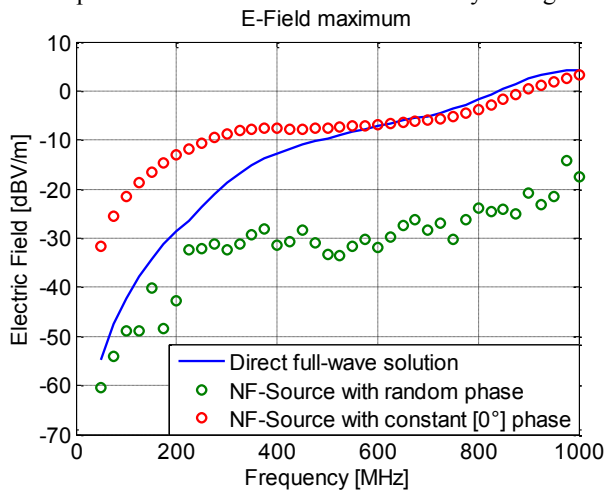


Fig. 10. Maximum electric field on the cylindrical FF scan area for direct accurate solution and for NF-Source solutions with assumed phase information

In considered problem better agreement is observed at frequencies over 600 MHz; however this frequency should not be considered as general frequency limit and it will vary from case to case due to DUT electrical size and / or radiating structure topology.

B. NF-Probes Dynamic Range

Next, the effect of NF-probes dynamic range limitation was evaluated. Typical NF-probe provides 20 dB - 40 dB dynamic range of sensed field. Limited dynamic range causes higher level of measured amplitude noise; during NF-data processing noise-level fields can be effectively assumed to be zeros. Then the electric field NF-Scan results for top-side of considered Huygens' surface will look like shown in Fig. 11 - left column provides 50 MHz scan, right column shows 1 GHz scan. The top plots are for unlimited dynamic range (original simulation results), next pictures show modelled 30 dB and 20 dB dynamic range limitation.

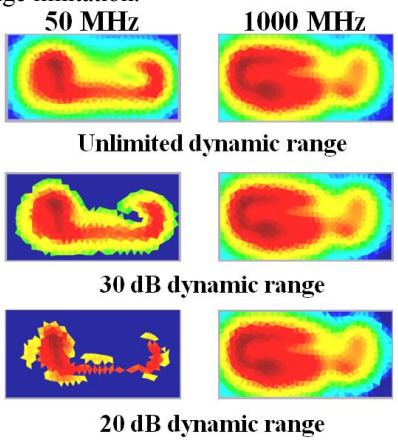


Fig. 11. Field probes dynamic range limitation effect on observed NF-distribution at Huygens' surface

Fig. 12 shows maximum far field observation results; with a dynamic range over 30 dB, maximum far-field results agree with the original estimation within a few dB.

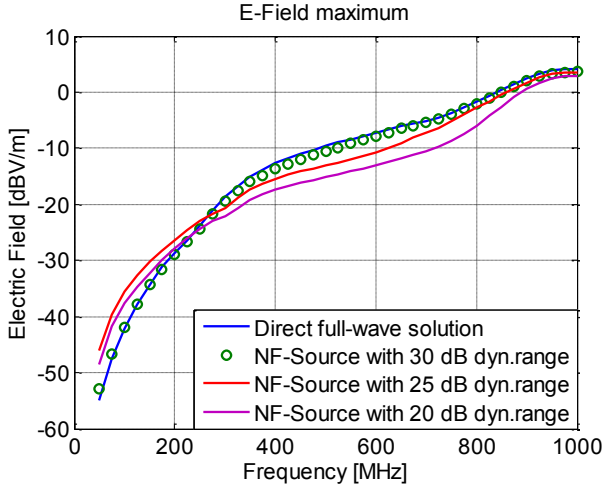


Fig. 12. Field probes dynamic range limitation effect on maximum observed far field

In real NF-scanning one of the most important limitations will be difficulty of complete NF-Source construction. However we expect the sensitivity of NF to FF transform accuracy to investigated particular uncertainties to be similar to the complete Huygens's surface and most often used in reality top-side-only NF-Scan.

IV. Experimental Validation

Experimental validation of NF to FF transformation using limited set of data was performed using scaled IC fixture shown in Fig. 13.

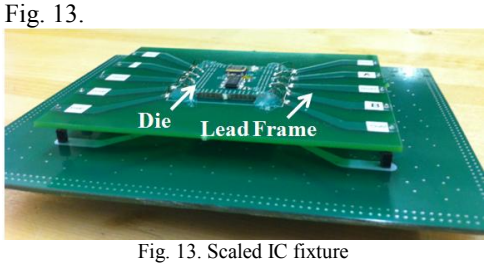
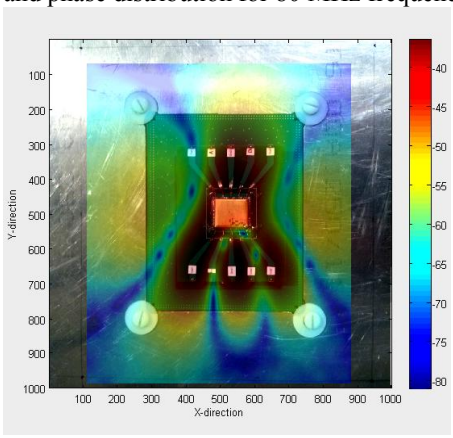


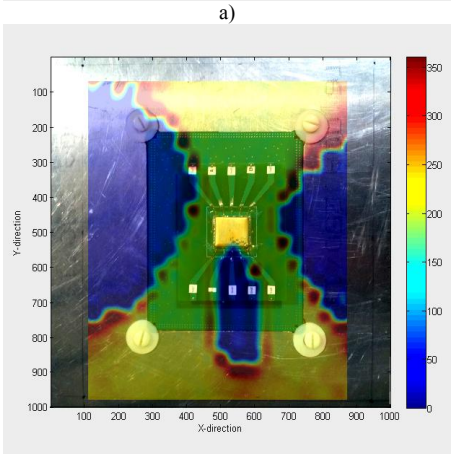
Fig. 13. Scaled IC fixture

The 'IC' consists of two printed-circuit boards and ten vertical pin-headers, which are used to mimic the DIE-substrate, the lead-frame package and foot print of an IC. An 80 MHz oscillator is mounted on the "DIE" to provide an active source; thus, the AC signal along the "Lead-frame Pin" of output channel and the switching noise along the pins associated with "Power Distribution Network" can be observed. This is a modification of a 'Large IC' model described in [6].

The API SmartScan EMI scanner was used for NF measurements over the planar surface above the Scaled IC fixture [7]. Fig. 14 shows magnetic field X-component magnitude and phase distribution for 80 MHz frequency.



a)



b)

Fig. 14. Scaled IC NF-scan results - magnetic field X component. 80 MHz: a) magnitude, b) phase

The scaled IC was mounted on the metal floor of a semi-anechoic chamber and far field radiation pattern was measured at 3 m distance, 1 m height. Use of such setup focuses on estimation of a single IC radiation, where the metal floor of the chamber resembles a scaled printed circuit board ground, and the scaled IC fixture models an operating on-board IC.

Fig. 15 shows corresponding simulation model for NF to FF transformation. The NF-Source created based on measured NF distribution on the only top-plate surface above the scaled IC fixture is placed in 3 cm height over the infinite PEC ground plane. The filed probe monitors are used to obtain the far field information.

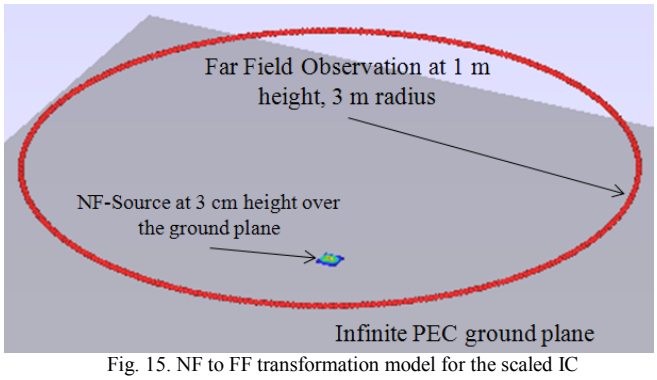


Fig. 15. NF to FF transformation model for the scaled IC

Fig.16 shows measured FF results comparison with performed NF to FF transformation for vertical and horizontal components of the electric field.

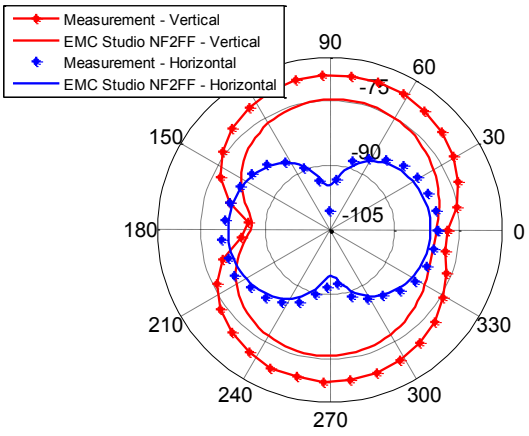
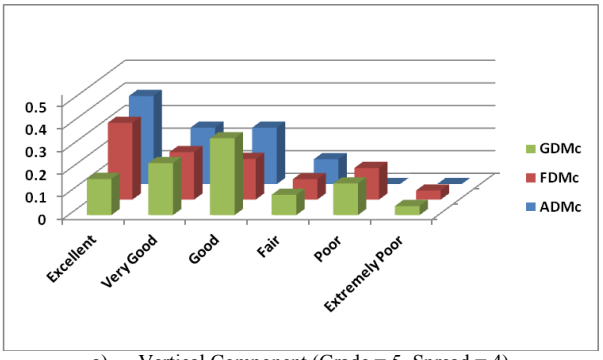
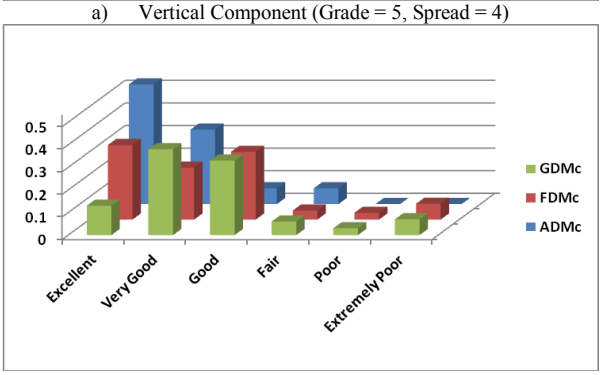


Fig. 16. Electric field pattern in dBV/m units at 1 m height, 3 m distance from the Scaled IC directly measured and obtained through NF-scan + NF to FF transformation technique

To estimate quality of the obtained FF results the Feature Selection Validation technique was applied [8, 9]. Fig. 17 shows confidence histograms for vertical (a) and horizontal (b) components. All three difference measures (amplitude, feature and global) tend to be in Good-to-Excellent range. However, the overall Grade-Spread values are medium-high.



a) Vertical Component (Grade = 5, Spread = 4)



b) Horizontal Component (Grade = 4, Spread = 4)

Fig. 17. Feature Selection Validation results: a) vertical, b) horizontal field component

While obtained results demonstrate reasonable accuracy of NF to FF transformation considering all of the mentioned before uncertainties, additional sensitivity studies with measured NF-data were performed – in particular the limitation of NF-Source active area was tested.

The NF-Source used in this test was constructed from 31 x 26 points grid with 5 mm grid step. The area outside the measured NF-region is assumed to have negligible levels of the fields. By the same assumption, border-edge layer can be cut out from the NF-Source structure creating smaller-area NF-Source excitation with less data points used. Then the same processing can be repeated iteratively with the smaller NF-Sources in series. This way thirteen NF-Sources with different source active area were obtained. Fig. 18 shows some of the stages of such processing: the original NF-Source and the NF-Sources with decreased surface area.

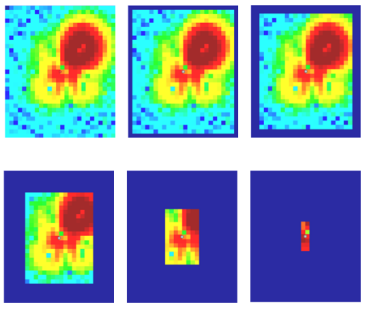


Fig. 18. A few samples of electric field distribution at NF-Source excitation with different active source area

The maximized electric far field for each of the sources was calculated. The observed results convergence by increasing NF-Source active area is shown in Fig. 19.

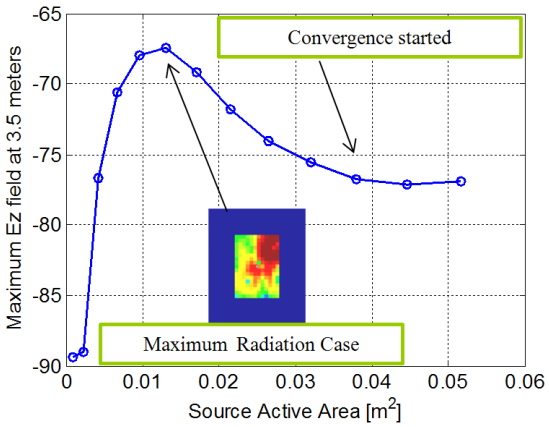


Fig. 19. NF to FF transformation convergence test

In these tests the regular NF-scan grid was used. However, for considered NF to FF transformation technique the regular grid is not a requirement. The NF-Source surface can be arbitrary meshed with adaptive selection of NF-Scan points, as it is proposed in [10]. For further development of adaptive NF-scan process the NF to FF transformation convergence by increasing scanned surface area can be considered for dynamic determination of a NF-scan area necessary for accurate FF estimation.

The presented FF simulation results are obtained using filed probe monitors at fixed position. However in reality large-scale hybrid bowtie log periodic antenna was used and the antenna output voltage was translated into the measured field strength by applying the antenna factor. This introduces additional uncertainty of location definition for a point field probe to be accurately corresponding to the effective antenna location at given frequency. Thus, further improvement of the results could be achieved by extending NF-Scan area, more accurate calibration, compensation and synchronization of the NF-probes and introducing the complete antenna model into the NF-to-FF simulation scenario.

V. Conclusion

Performed studies demonstrate possibility of effective combination of near field scanning systems with numerical modeling tools for practical EMC investigations.

It is shown that calculated maximum far-field levels are relatively robust against measurement uncertainties. In simulation, maximum FF can be predicted within a several dB difference even with ±45° phase error. The necessary dynamic range for the probes is approximately 30 dB.

Acknowledgment

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REFERENCES

[1] J. Shi, M. A. Cracraft, K. P. Slattery, M. Yamaguchi, and R. E. DuBroff, “Calibration and compensation of near-field scan measurements,” IEEE Trans. Electromagn. Compat., vol. 47, no. 3, pp. 642–650, Aug. 2005

[2] Bucci, O.M.; D'Elia, G.; Leone, G.; Pierri, R.;"Far-field pattern determination from the near-field amplitude on two surfaces", Antennas and Propagation, IEEE Transactions on. Volume: 38, Issue: 11, 1990, Pages: 1772 - 1779

[3] EMCoS Ltd., EMCoS EMC Studio, Version 7.0, www.emcos.com

[4] Haixiao Weng; Beetner, D.G.; DuBroff, R.E.; "Prediction of Radiated Emissions Using Near-Field Measurements". Electromagnetic Compatibility, IEEE Transactions on. Volume: 53 , Issue: 4, 2011, Pages: 891 - 899

[5] Tazi, H.; Bogdanov, F.; Eibert, T.F.; “Application of the equivalence principle and the multi excitation approach to method of moments simulations for optimizations of smart entry systems in vehicles”, Proceedings of the 40th European Microwave Conference, 28-30 September 2010, Paris, France.

[6] Ji Zhang; Beetner, D.G.; Moseley, R.; Herrin, S.; Pommerenke, D.; "Modelling electromagnetic field coupling from an ESD gun to an IC". Electromagnetic Compatibility (EMC), 2011 IEEE International Symposium on, 2011 , Pages: 553 - 558

[7] Amber Precision Instruments, Smart Scan system, www.amberpi.com

[8] IEEE Std 1597.2™-2010 IEEE Recommended Practice for Validation of Computational Electromagnetics Computer Modeling and Simulations

[9] V-FSV 1.0.0 tool available at http://ing.univaq.it/uaqemc/

[10] Deschrijver, D.; Vanhee, F.; Pissoort, F.; Dhaene, T.; "Automated Near-Field Scanning Algorithm for the EMC Analysis of Electronic Devices", Electromagnetic Compatibility, IEEE Transactions on. Volume: PP, Issue: 99, 2011, Pages: 1 - 9