Antenna Coupling Evaluation Based on Accurate Measured Source Models and Simulations

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***Abstract*—When numerically simulating antenna problems, the accuracy of the antenna representation is crucial to improve the reliability of the results. Integrating the measured near-field (NF) model of the antenna into Computational Electromagnetic (CEM) tools opens new horizons in solving such problems. This approach has been studied for complex and/or large scenarios, antenna placement, scattering issues, and EMC applications [1-3]. Another appealing use of merging measurements and simulations is the evaluation of antenna coupling [4-6].**

Previous investigations regarded an array of three identical cavity-backed cross-dipole antennas [7-8]. In all the experiments the coupling between elements was evaluated only between an NF source and an antenna represented by its full-wave model and fed by ports.

In this new study, following on the heels already presented in the publication [9] in which coupling between multiple simulated NF sources was illustrated using the commercial EM simulation tool Altair Feko [10], we want to show how antenna coupling between NF sources both coming from measurements can be evaluated in numerical simulations. The validation will be done combining two identical NF sources of MVG SMC2200 monocone antennas flush mounted on a rectangular plate. An additional demonstration will be shown on three NF sources of the same monocone on a rotorcraft model.

I. Introduction

Mutual coupling between antennas refers to the undesired transfer of energy between two neighboring radiating elements and this becomes particularly problematic when the antennas are positioned very close to each other. The impact of mutual coupling is a significant concern in electromagnetic compatibility (EMC) and in antenna placement problems, such as when two antennas are situated closely together in a test setup.

An effective approach for antenna coupling determination is based on the combination of measurements and simulations. This approach is very effective when for one of more antennas the full-wave model and/or the CAD model are not available and then measuring the antennas and simulating the coupling based on measured data is the only option.

Previous investigations of the method combining measurement and simulation have been carried out on an H/V polarized array of three identical cavity-backed cross-dipole antennas [7-8]. In the first step of that study only the radiation pattern of the central element of the array was measured (in a stand-alone configuration), while the other elements were simulated. Then the study has been continued exploring both an enhancement of the representation of the NF source by inclusion of placement boundary conditions and the use of measured NF source models to represent the other elements of the array, including the central element. A good agreement was found between the measured mutual S parameters on the real array and results obtained by the combination between measurement and simulations. In any case in all the experiments of this study the coupling between elements was evaluated only between an NF source and an antenna represented by its full-wave model and fed by ports.

In this latest research, building upon the previous findings published in [9], which demonstrated coupling between multiple simulated near-field (NF) sources using the commercial EM simulation tool Altair Feko [10], we aim to investigate the evaluation of antenna coupling between actual NF sources obtained from measurements using numerical simulations. The objective is to showcase how this coupling can be assessed. To conduct the demonstration, we will utilize two identical MVG SMC2200 monocone antennas flush mounted on a rectangular plate. Additionally, we will incorporate three NF sources of the same monocone type mounted on a rotorcraft model. By combining these setups, we can effectively analyze and illustrate the mutual coupling between the NF sources originating from real measurements. This investigation will shed light on the interactions and potential effects that arise when these NF sources are near each other, providing valuable insights into the behavior and performance of the system.

II. Validation with Monocone Antennas on a Rectangular Plate

The method has been validated initially with two identical MVG SMC2200 monocone antennas flush mounted on a rectangular plate. The first step consists of the preparation of the NF source by the Near- Field measurement of the antenna. Then the simulation placement set-up of the NF source is compared with the full-wave simulation.

Additionally different configurations for coupling (when the NF source is RX and TX) are investigated and coupling results are compared for final validation with the reference full-wave simulation.

A. *Preparation of the NF source from measurement*

Determining the electromagnetic model of a source antenna for flush mounted applications presents greater complexity compared to modelling a detached antenna from the scattering structure. The proximity of the scattering structure alters the current distribution on the antenna itself. An infinite ground plane boundary condition serves as a suitable approximation for correct boundary conditions. However, obtaining this condition directly in a realistic measurement scenario can be challenging. To address this, measurements of the source antenna installed on a finite ground plane are combined with measurement post-processing techniques, as discussed in [1-3].

The post-processing of measured data effectively eliminates diffractive contributions from the edges of the finite ground plane, thus creating the desired infinite ground plane boundary conditions. For most measurement source antennas, a circular ground plane with a minimum diameter of 2λ is considered adequate. In this specific case the monocone antenna was measured on a circular ground plane with a diameter of 4λ at the lower test frequency of 3.3GHz. The measurements were performed using the MVG, SL18GHz spherical near-field multi-probe system [11] at 3.3GHz and 5.28GHz.

The complete workflow starting measurement of the monocone, application of infinite plane boundary condition, preparation of the NF source [12]-[15] and an example of antenna placement in a simulation (rectangular plate) shown in Figure 1.

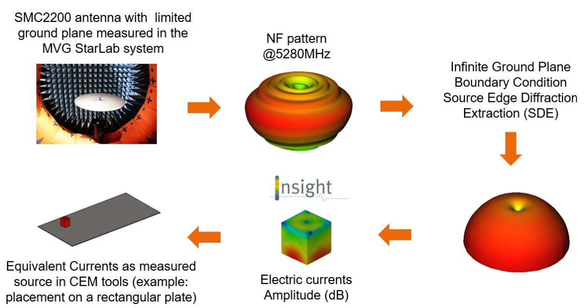

Figure 1. Measurement of the mono-cone antenna on a finite ground plane in the MVG, SL18GHz spherical near field multi probe system and conversion to NF Source using MVG INSIGHT software [15].

B. *Verification of the NF source placement*

To test the accuracy of the simulation set-up with the NF source on the reference rectangular plate (60cm x 30cm), a test was made comparing the results with the full wave simulation using Altair Feko [10], as shown in Figure 2.

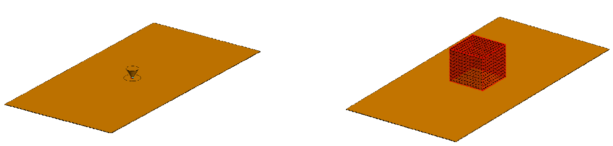

Figure 2. Antenna placement of the NF source (SMC2200) on a rectagular plate. Fullwave simulation (left); simulation with measured NF source (right).

The total gain radiation pattern at both 3.3GHz and 5.28GHz have been investigated and comparisons for cut plane phi=0° (longer side of the plate) are show in Figure 3. The good agreement between the curves confirms the accuracy of the simulation set-up.

Case study of a more complex scenario with measured NF sources placed on electrically large structures such as a rotor craft is presented in [16].

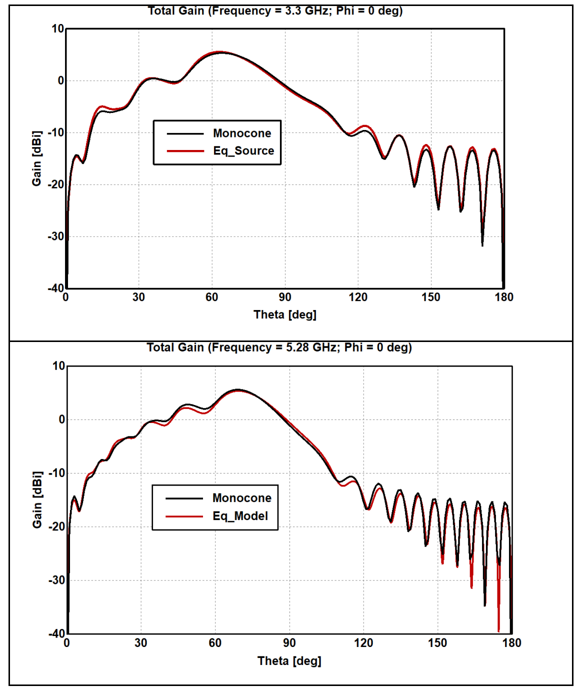

Figure 3. Total gain radiation pattern at both 3.3GHz (upper) and 5.28GHz (lower): comparisons bewteen full-wave simualtions and link between meausrement and simulation, cut plane phi=0°.

C. *Configurations of antenna coupling simulation*

Antenna coupling when the SMC2200 monocone antennas are used as RX and/or TX are shown in the following sections. Initially the full wave simulation of the antenna coupling between two monocone antennas on the rectangular plate is performed as reference.

1) Configuration 1: Reference fullwave simulation of the monocone antennas on a rectangular plate. The monocone antennas (1 and 2) are simulated both in TX and RX, so that S12 ans S21 parameters are evaluated. The monocone antennas are fed by coaxial modal ports [10]. Monocone 1 is at x, y = (0,0) cm , while monocone 2 are at x, y = (-180, -60) cm.

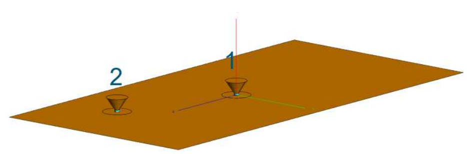

Figure 4. Configuration 1: Reference fullwave simulation of the monocone antennas on a rectangular plate.

2) Configuration 2: Simulation of monocone antennas on a rectangular plate. Monocone 1 (full-wave model) is TX antenna, while monocone 2 (NF source) is RX antenna, Monocone 1 is at x, y = (0,0) cm , while monocone 2 is at x, y = (-180, -60) cm.

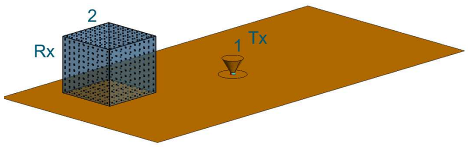

Figure 5. Configuration 2.

3) Configuration 3: Simulation of the monocone antennas on a rectangular plate. Monocone 1 (full-wave model) is RX antenna, while monocone 2 (NF source) is TX antenna, Monocone 1 is at x, y = (0,0) cm , while monocone 2 are at x, y = (-180, -60) cm.

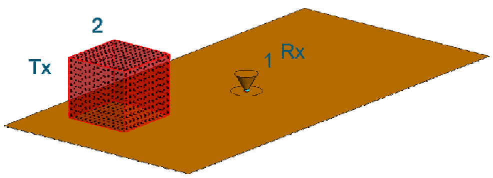

Figure 6. Configuration 3.

4) Configuration 4: Simulation of the monocone antennas on a rectangular plate. Monocone 1 (NF source) is RX antenna, while monocone 2 (full-wave model) is TX antenna, Monocone 1 is at x, y = (0,0) cm , while monocone 2 is at x, y = (-180, -60) cm.

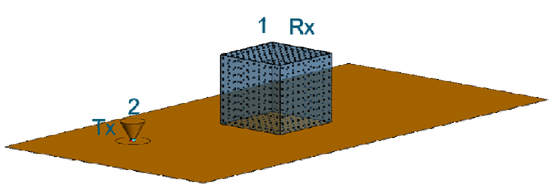

Figure 7. Configuration 4.

5) Configuration 5: Simulation of the monocone antennas on a rectangular plate. Monocone 1 (NF source) is TX antenna, while monocone 2 (full-wave model) is RX antenna, Monocone 1 is at x, y = (0,0) cm , while monocone 2 is at x, y = (-180, -60) cm.

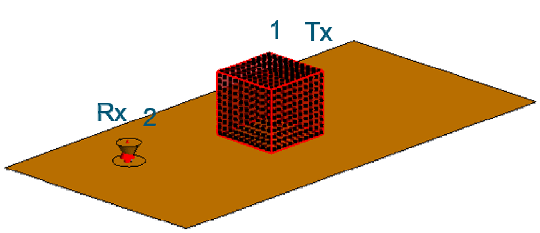

Figure 8. Configuration 5.

6) Configuration 6: Simulation of the monocone antennas on a rectangular plate. Monocone 1 (NF source) is TX antenna, while monocone 2 (NF source) is RX antenna, Monocone 1 is at x, y = (0,0) cm , while monocone 2 is at x, y = (-180, -60) cm.

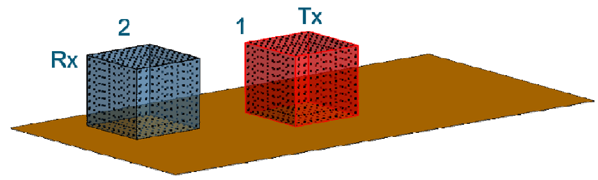

Figure 9. Configuration 6.

7) Configuration 7: Simulation of the monocone antennas on a rectangular plate. Monocone 1 (NF source) is RX antenna, while monocone 2 (NF source) is RX antenna, Monocone 1 is at x, y = (0,0) cm , while monocone 2 is at x, y = (-180, -60) cm.

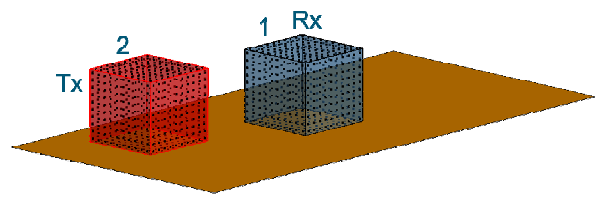

Figure 10. Configuration 7.

D. Results

Antenna coupling results from the different configurations at 3.3GHz are reported in Table I. The full-wave simulation (configuration 1) is considered as the reference (baseline -26dB) while the difference for this reference and all the configurations is reported in the last columns. The maximum deviation when only one measured NF source is used is 0.69dB while when NF sources are used for both antennas is about 0.78dB.

TABLE I. ANTENNA COUPLING RESULTS @3.3GHZ

Configuration	Coupling	Difference
(1)	S12: -26.08 dB S21: -26.08 dB	Baseline (-26dB)
(2)	-25.54 dB	0.46
(3)	-25.76 dB	0.24
(4)	-25.31 dB	0.69
(5)	-25.52 dB	0.48
(6)	-25.23 dB	0.77
(7)	-25.22 dB	0.78

Antenna coupling results from the different configuration at 5.28GHz are reported in Table II. The full-wave simulation (configuration 1) is considered as the reference (baseline -

28.41dB) while the difference for this reference and all the configurations is reported in the last columns. The maximum deviation when only one measured NF source is used is 0.63dB while when NF sources are applied for both antennas is about -1.11dB.

TABLE II. ANTENNA COUPLING RESULTS @5.28GHZ

Configuration	Coupling	Difference
(1)	S12: -28.41 dB S21: -28.49 dB	Baseline (-28.41dB)
(2)	-27.85	0.56
(3)	-27.87	0.54
(4)	-27.78	0.63
(5)	-27.81	-0.60
(6)	-27.30	-1.11
(7)	-27.31	-1.10

Coupling decreases as the working frequency increases because the electrical distance between the two antennas rises and the interaction with the edges of the rectangular plate also changes.

The very good agreement between the reference and various configurations confirms the effectiveness of the method combining measurements and simulations is in assessment of antenna coupling.

III. DEMONSTRATION WITH MONOCONE ANTENNAS ON A ROTOCRAFT MODEL

After validation with a simple platform model i.e., a rectangular plate, the method is demonstrated for a more complex scenario, such as antenna placement on a rotocraft model. The antennas are still the monocone antennas (three radiators) and there are positioned in three different locations, as is shown in Figure 11. The analysis has been done at 3.3GHz. A full-wave simulation is initially performed to create a reference data set and then different configurations are used where measured NF sources are applied as replacement of two of the three antennas.

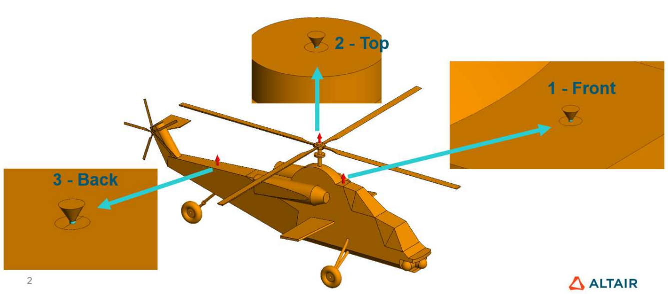

Figure 11. Antenna placement scenario: monocones antennas on a rotocraft model.

1) Fullwave simualtion (reference)

Full wave simulation of the monocones antennas on the rotocraft model is performed as is shown in Figure 12. Table III reports the S parameters for all the three sources. The monocone antennas are represented by small red arrows.

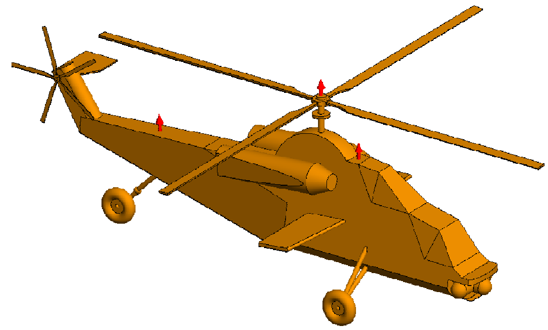

Figure 12. Monocones antennas on a rotocraft model: fullwave simulation (reference).

TABLE III. S MUTUAL PARAMETERS

Monocone	1	2	3
1	-14.39	-70.44	-61.91
2	-68.04	-13.98	-76.30
3	-61.16	-76.54	-14.63

2) Configuration 1: Simulation of the monocone antennas on a rotocraft model: Monocone 1 (full-wave model) is TX antenna, while monocone 2 and 3 (NF source) are RX antennas.

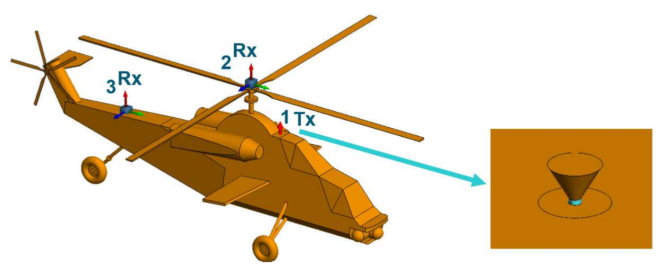

Figure 13. Rotocraft model – configuration 1.

The mutual S parameters (coupling) are shown in Table IV. The maximum difference between the full-wave simulation (Ref) and the results of configuration 1 (Link) is 0.39dB for S12 and 0.27.

TABLE IV. COUPLING – CONFIGURATION 1

	Link	Ref	Difference
S12	-70.05	-70.44	0.39
S13	-61.63	-61.907	0.27

3) Configuration 2: Simulation of the monocone antennas on a rotocraft model: Monocone 2 (full-wave model) is TX antenna, while monocone 1 and 3 (NF source) are RX antennas.

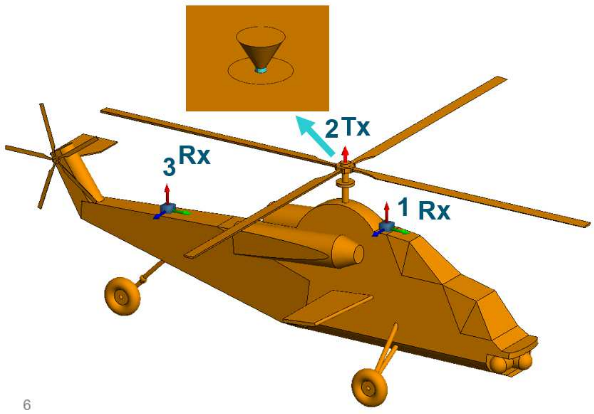

Figure 14. Rotocraft model – configuration 2.

The mutual S parameters (coupling) are shown in Table V. The maximum difference between the full-wave simulation (Ref) and the results of configuration 2 (Link) is 1.12dB for S21.

TABLE V. COUPLING – CONFIGURATION 2

	Link	Ref	Difference
S21	-71.05	-69.92	1.12
S23	-75.38	-75.28	0.10

4) Configuration 3: Simulation of the monocone antennas on a rotocraft model: Monocone 3 (full-wave model) is TX antenna, while monocone 1 and 2 (NF source) are RX antennas.

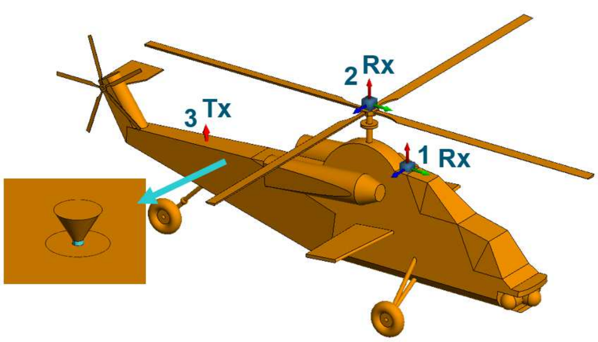

Figure 15. Rotocraft model – configuration 3.

The mutual S parameters (coupling) are shown in Table VI. The maximum difference between the full -wave simulation (Ref) and the results of configuration 3 (Link) is 0.57dB for S31.

TABLE VI. COUPLING – CONFIGURATION 3.

	Link	Ref	Difference
S31	-60.86	-61.42	0.57
S32	-77.00	-76.92	0.08

IV. CONCLUSION

In this new study, following on the heels already presented in [9] a method combining measurement and simulation has been shown to assess antenna coupling between NF sources both coming from measurements [1]-[3].

The method has been initially validated on a configuration of two identical NF sources of MVG SMC2200 monocone antennas flush mounted on a rectangular plate. For different configurations where the antennas are TX and or RX and both NF sources are used, the results show a very good accuracy when compared with the reference full-wave simulation (maximum deviation of 0.78dB).

Finally, the method of coupling assessment has been demonstrated on a more complex scenario as an antenna placement problem on a rotorcraft model with three identical monocone antennas. Different configurations have been investigated with three antennas (one antenna as full-wave model and two NF sources). Also, in this case the results coming from the comparison with the reference full-wave simulation are very good (maximum deviation of 1.12dB) confirming that this approach can be useful in case the simulated or CAD models of the actual antennas are not available.

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