# Combining Measurements and Simulations for Antenna Coupling Analysis

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***Abstract*— In numerical simulation of antenna problems, accuracy of antenna representations is essential to ensure the reliability of results. Integration of measured Near Field (NF) representation of antenna in Computational Electromagnetic (CEM) solvers opens new perspectives to solve this problem. This approach has been already studied for complex and/or large scenarios, antenna placement, scattering problems and EMC applications. Another interesting use of the combination between measurement and simulation is to enhance the evaluation of the antenna coupling. Previous investigations have been carried out on an H/V polarized array of three identical cavity-backed cross-dipole antennas. In 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. 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 this paper a continuation of the previous study will be performed, 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, not only the central one.**

## I. Introduction

In array antennas the mutual coupling is a crucial electromagnetic problem. Antenna coupling can modify the matching between the array elements and hence the antenna gain [1]. Sometimes the presence of coupling can degrade the array antenna performances, otherwise it can deal benefits in some cases [2]. Antenna coupling involves all types of arrays, from the simplest ones to the most modern and complex systems (MIMO, diversity and radar systems). Since its relevance, in recent years different methods have been proposed for coupling estimation and compensation [3]. Among all these techniques a method combining measurements and simulations for antenna coupling analysis has been recently presented [4]-[5]. This is based on the measurement and characterization of the single elements by the EQC method [6]-[9], hence the antenna data set, in terms of Huygens box or NF source, is integrated in the simulation of the entire array [10]-[11]. This technique allows the evaluation of array coupling also if the design of array antenna elements is not known. This occurs for example in case of on shelf antennas, therefore these radiators can be only measured. A continuation of the validation of this technique is here presented and tested on a three-element array in dual slant ± 45°, shown in Figure 1. In particular, an enhancement of the representation of the NF source by inclusion of placement boundary condition and a full analysis on all the antenna elements will be presented.

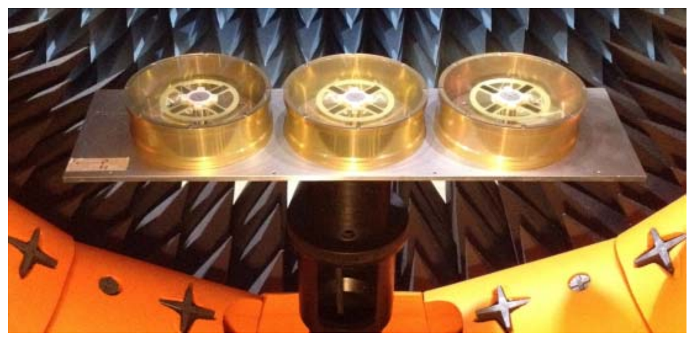


Figure 1. Three-element array in dual slant ± 45° polarization during measurement in SL18GHz.

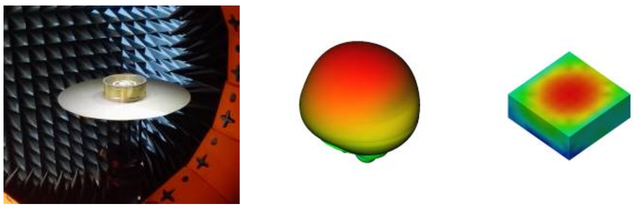
## II. NF Source by Inclusion of the Placement Boundary Condition

The first part of this study consists of the preparation of the NF source with a proper boundary condition for antenna placement of flush mounted antenna problems with respect to the antenna source generated and installed in [5]. An application in a simplified scenario is reported to demonstrate the accuracy of the simulation with this new EQC model.

### *A. Preparation of the measured NF source*

A dedicated procedure for flush mounted antennas is applied for the generation of the NF source of antennas operating on metallic structures. For this kind of application, the close surrounding of the antenna modifies the current distribution on the antenna itself. Therefore, this close boundary condition needs to be included in the measurements to ensure accurate results when installing the NF model in the final structure. In practice, such boundary condition is included measuring the antenna on a circular ground plane with a minimum radius of 2λ at the frequency of interest. In the generation of the NF model a dedicated post-processing procedure is applied to remove the diffractive contributions from the edges of the circular ground plane [12], restabilising the needed infinite boundary condition (IPBC).

Following the procedure described above, a cavity backed cross dipoles antenna has been measured on a circular ground plane of diameter 2.6λ at 1.94GHz. The measurement set-up [13] and the radiation pattern are shown in Figure 2 (a) and (b). After post-processing to establish IPBC, the EQC source is created by the tool INSIGHT [14] that implements [6], see Figure 2 (c). NF equivalent current representations of the antenna, at five frequency points (1710MHz, 1825MHz, 1940MHz, 2055MHz and 2170MHz) have been determined.



(a) (b) (c)

Figure 2. Measurement of the cavity backed cross dipoles on a limited ground plane in the MVG, SL18GHz spherical near field multi probe system (a); meaured radiation pattern @1.94GHz (b); EQC source (c).

### B. *Preliminary test on a limited ground plane*

As a preliminary result the new EQC model has been installed on a metallic plate. The shortest dimension of the plate is long as in the final plate where array elements will be installed. This structure has been chosen to include the realistic effects of the diffraction from the edges of the plate. The results of the simulation with the measured NF (at 5 frequency points) source (NFS), depicted in Figure 3 (right), are compared with the full wave simulation, shown in Figure 3 (left).

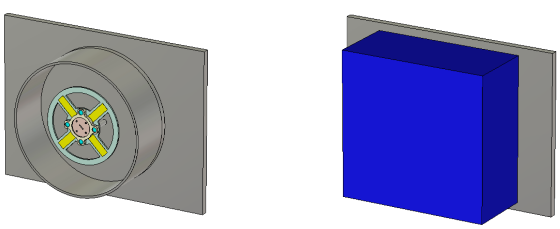


Figure 3. Simulation of the cavity backed cross dipoles on a limited ground plane in [15]. Full wave simulation pattern @1.94GHz (left); EQC source (blue box) without and with IPBC (right).

Simulation with the measured antenna has been computed considering the NF source without the IPBC [5] and with the IPBC (source prepared above). Comparisons of directivity radiation patterns for port 1 (-45°) for full wave simulations, simulations with the measured NF source with and without IPBC for both cut φ=0° and cut φ=90° @1940MHz, are shown in Figure 4. The array is oriented along the x-axis. Good agreement between the different curves is visually found.

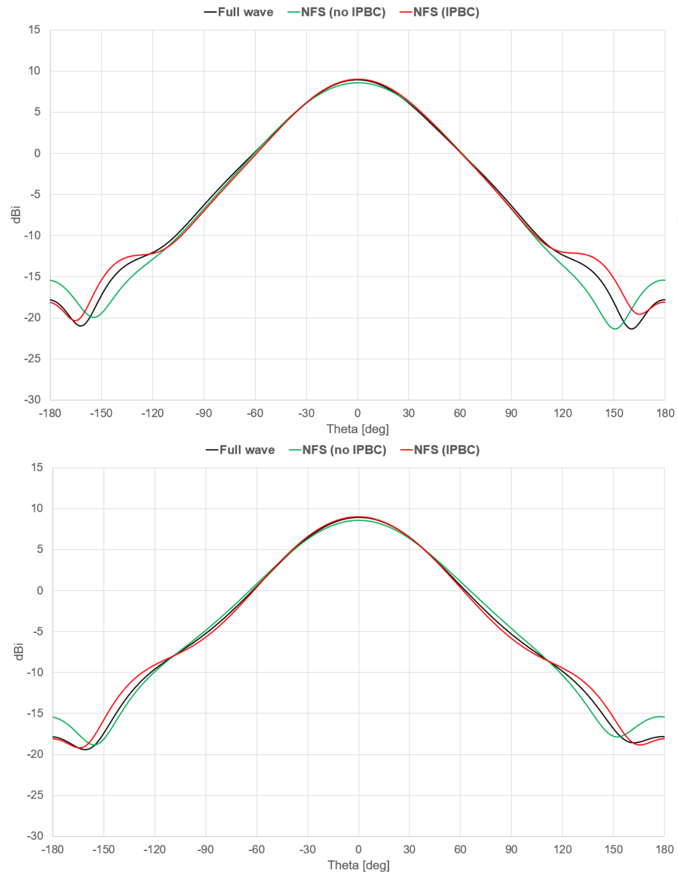



Figure 4. Directivity comparison for cut φ=0° (upper) and cut φ=90° (lower) @1940MHz of full-wave simulation of the cavity backed cross dipoles on a limited ground plane (black line), simulation with NFS source without IPBC [5] (green line) and with IPBC (red line).

To quantify numerically the accuracy of the results computed by using the new NF source, the Equivalent Noise Level (ENL) defined as,

$$ENL = 20\log_{10}\left(RMSE\left|\frac{E\,(\theta,\varphi) - \tilde{E}\,(\theta,\varphi)}{E\,(\theta,\varphi)_{MAX}}\right|\right)$$

is considered. In such expression E (θ,φ) is the reference and $\tilde{E}$ (θ,φ) is the pattern under analysis. The simulated full wave field has been considered as reference, while the patterns with the two NF sources are the ones under analysis. The ENL has been evaluated on the whole pattern considering the total field and it is reported in Table I.

TABLE I. EQUIVALENT NOISE LEVEL (NFS WITH AND WITHOUT IPBC)

| | NFS without IPBC | NFS with IPBC |
|---|---|---|
| **ENL [dB]** | -37.79 | -43.53 |

There is an improvement of 5.74dB in the ENL when the NF model with IPBC is used respect to the model without IPBC.

## III. Results

The performances of the array of 3 elements have been investigated in this section. Due to the improvements coming from the inclusion of the placement boundary condition, this new NF source data set, with respect to [5], has been used in all the calculations reported in the following. Different scenarios have been studied:

- Array with central element radiating.
- Array with all elements radiating.
- Array with one lateral element radiating.

### *A. Array with the central element radiating*

As first step, the array with the central element radiating has been investigated. The CAD model of the central element in the array has been replaced by the measured NF source, as is shown in Figure 5 where different antennas ports are illustrated. Ports 1, 3, 5 are polarized at -45° and ports 2, 4, 6 are polarized at +45°.

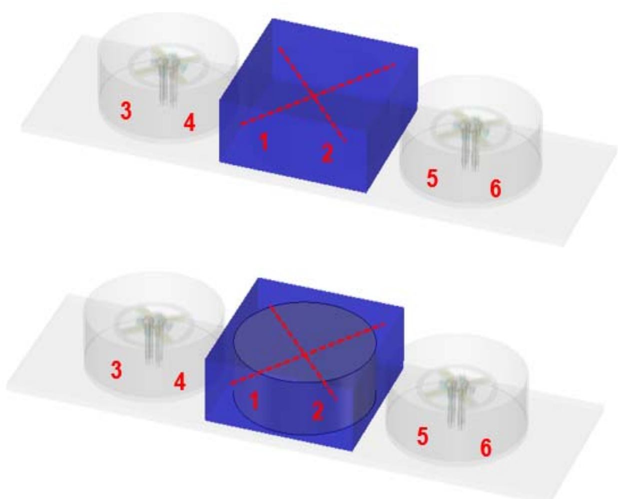



Figure 5. Intallation of the measured source in the simulated model of the array [15]. With no geometry inside the NFS (upper); with a simplified representation of the antenna source inside the NFS (lower).

For this kind of application, we have investigated the effect of the inclusion of a reduced/simplified CAD model into the NF source Huygens box, to identify the improvement in the accuracy of the simulation. In this case, to reproduce the condition of unknown electrical and/or mechanical antenna design a simple full metallic cylinder has been selected to represent the real radiator. Comparison of directivity radiation patterns for port 1 (-45°) for measurement of the array (meas), simulation with the measured NF source (link), and simulation with the NFS source with a reduced model (link & simplified geometry CYL), for cut $\varphi = 0°$ @1940MHz, is shown in Figure 6. The agreement between the different curves is visually good. Again, the ENL values have been calculated and reported in Table II. The measured field has been considered as reference.

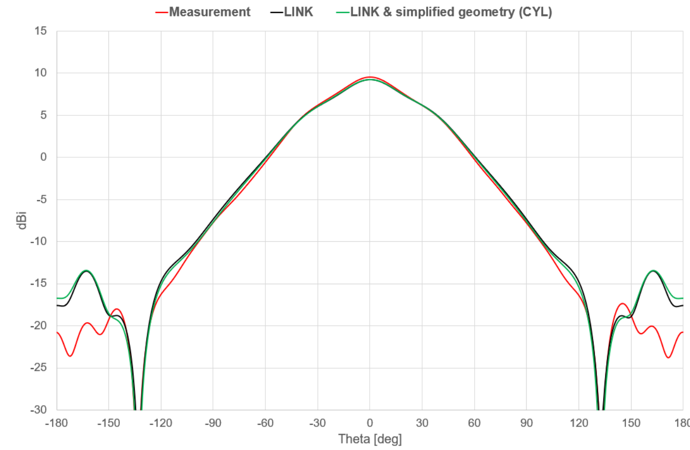



Figure 6. Directivity comparison of the array oriented along the x-axis (central element radiating) for both cut $\varphi=0°$ @1940MHz. Measurement (red line), simulation without the reduced model (black line) and with reduced model (green line).

TABLE II. Equivalent Noise Level (NFS with and without reduced model)

| | NFS without reduced model | NFS with reduced model (Cylinder) |
|---|---|---|
| **ENL [dB]** | -37.43 | -37.67 |

An improvement of 0.24dB in the ENL when the reduced model is integrated in the simulation shows how this shrewdness can increase the accuracy of the calculation.

The coupling of the measured central element with the other element of the array is evaluated. Port 1 (-45°) is fed and ports 3, 4 5 and 6 of the other elements are receiving. Comparisons of simulation using the NFS with the reduced model and measurement of the entire array (reference) are reported in Figure 7.

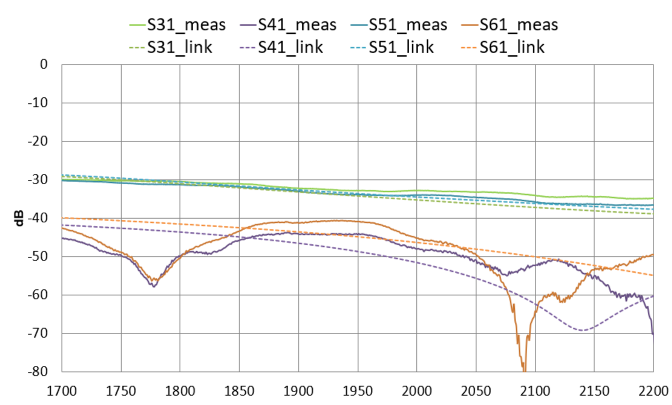



Figure 7. Simulation with the NFS model with reduced model. Antenna coupling between the central element (port 1) and the other two side elements (ports 3-6).

Comparison in terms of coupling average values over the range [1.7-2.2] GHz are reported in Table III. Deviation between the measured and simulated S41 and S61 corresponds to 0.17dB and 1.51dB and it is reduced with respect to the results from the previous study (1.40dB and 2.19dB) [5].

TABLE III. ANTENNA COUPLING: AVERAGE VALUES

| | **S31** | **S41** | **S51** | **S61** |
|---|---|---|---|---|
| **Measured [dB]** | -32,41 | -49,85 | -33,52 | -48,88 |
| **Link (NF model) [dB]** | -35,81 | -49.68 | -34.46 | -47.36 |

### *B. Array with all elements radiating*

As second step, the array with all elements radiating has been investigated. The CAD model of all elements of the array have been replaced by the measured NF sources, as is shown in Figure 8. The reduced model, metallic cylinder, has been integrated in the simulation for each NF source. Here, due to the absence of the physical excitation ports in the simulated model we have been able to compute with [15] only the radiation patterns.

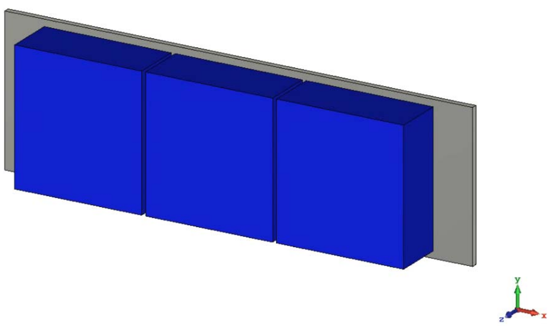


Figure 8. Intallation of the measured source in the simulated model of the array to replace all the elements [15].

The results of the simulation of the array with the NF sources have been compared with the full wave simulation where all the elements are excited (precisely ports 1, 3, 5, polarized at -45°, are fed).

Comparisons of directivity radiation patterns between the full wave simulation and the calculation with the measured NF source (link) where the reduced model is integrated for both cut φ=0° and φ=90° @1940MHz, is shown in Figure 9. The agreement between the different curves is visually good.

The ENL between the full wave simulation and the link is -46.51dB, that is considered acceptable for such kind of applications.

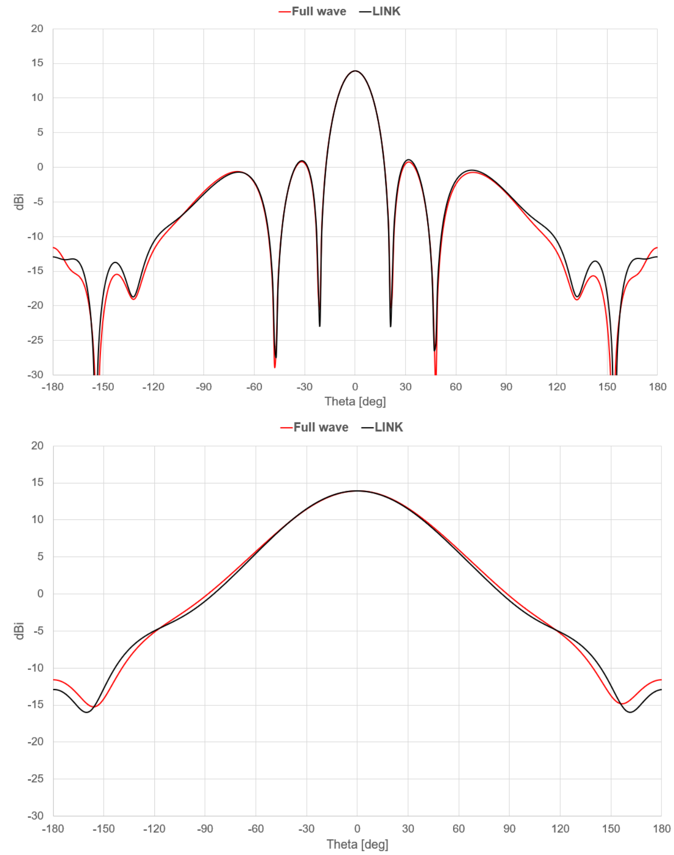



Figure 9. Directivity comparison of the array oriented along the x-axis (all elelments radiating) for cut φ=0° (upper) and cut φ=90° (lower) @1940MHz. Full wave simulation (red line), simulation using the NF source with reduced model (black line).

### *C. Array with one lateral element radiating*

Finally, the array, where only one of the lateral elements is radiating, has been investigated, see Figure 10.

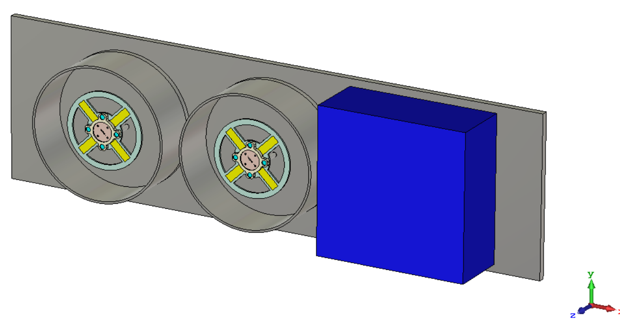


Figure 10. Intallation of the measured source in the simulated model of the array to replace one lateral element [15].

Comparison of directivity radiation patterns between the full wave simulation and the simulation with the measured NF source (link) with and without the reduced model for both cut φ=0° and φ=90° @1940MHz, is shown in Figure 11. The agreement between the different curves is good.

As, for the other test cases, the ENL has been evaluated and reported in Table IV. The full-wave field has been considered as reference. An improvement (3.05dB) in the ENL, due to the intregration of the reduced model in the NF source is confirmed also for this scenario.

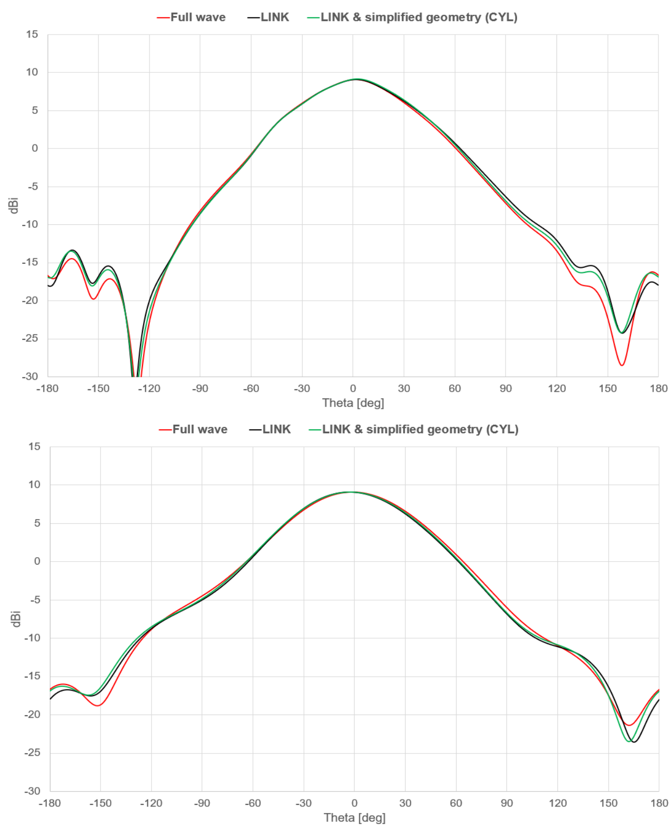



Figure 11. Directivity comparison of the array oriented along the x-axis (central element radiating) for cut φ=0° (upper) and cut φ=90° (lower) @1940MHz. Measurement (red line), simulation with NF source without the reduced model (black line) and with reduced model (green line).

TABLE IV. EQUIVALENT NOISE LEVEL (NFS WITH AND WITHOUT REDUCED MODEL)

| | NFS without reduced model | NFS with reduced model (Cylinder) |
|---|---|---|
| **ENL[dB]** | -42.03 | -45.08 |

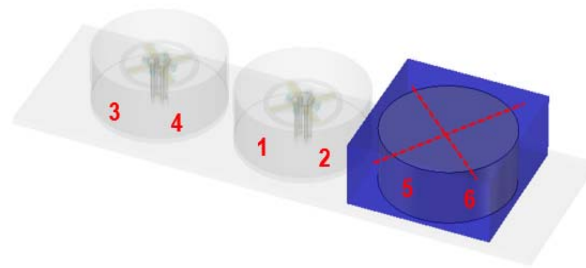



Figure 12. Port definition in the intallation of the measured source in the simulated model of the array to replace one lateral element [15].

The coupling of the measured lateral element with the other elements of the array is simulated. Port 5 (-45°) is fed and ports 1, 2 3 and 4 of the other elements are receiving. Comparisons of simulation using the NFS with the reduced model and full wave of the entire array (reference) are reported in Figure 13.

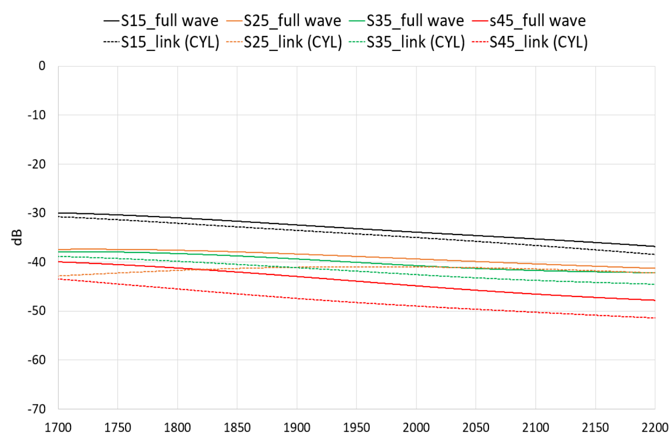



Figure 13. Antenna coupling between the lateral element (port 5) and the other two side elements (ports 1-4); full wave simulation (full wave) and simulation using the measured NF model of the lateral element with the reduce model (link - CYL).

Comparison in terms of coupling average values over the range [1.7-2.2] GHz are reported in Table V.

TABLE V. ANTENNA COUPLING: AVERAGE VALUES

| | S15 | S25 | S35 | S45 |
|---|---|---|---|---|
| **Full wave[dB]** | -33.18 | -39.00 | -40.02 | -43.90 |
| **Link (NF model) [dB]** | -34,36 | -41,51 | -41.80 | -47.94 |

## IV. Summary and Conclusion

A continuation of the validation of the method combining measurements and simulations for antenna coupling assessment, previously studied in [4]-[5], has been presented. The antenna under test is an array of three elements in dual slant ± 45° polarization. In particular, both enhancement of the representation of the NF source by inclusion of placement boundary condition and the use of measured NF source models to represent all the different elements of the array has been explored.

The inclusion of the proper boundary condition (IPBC) for antenna placement of flush mounted antenna problems leads to an improvement of 5.74dB in the ENL when the NF model with IPBC is used.

After that, the integration of the NF sources in the final array of three elements has been done. In case of central element replacement, the inclusion of a reduced model inside the NF source improves the accuracy of the simulation of 0.27dB in the calculation of radiation patterns. The analysis of the mutual coupling has been also preformed showing a reduced deviation between the measured and simulated S41 and S61 (0.17dB and 1.51dB) with respect to the results from the previous study [5].

Then, the installation of the NF sources to replace all the elements or only one lateral element of the array has been investigated. In this case the reference is the full wave simulation. Good accuracies of results combining measurements and simulation with respect to the reference have been found, both in terms of radiation patterns and mutual antenna coupling.

The encouraging results of this study demonstrates how the combination of measurement and simulation is a winning procedure in array coupling evaluation, when the design of some of the array elements is unknown and therefore these radiators can be only measured.

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