Feed-Array Design in Presence of Strong Scattering From Reflectors

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***Abstract*— Full-wave reflectors antenna modelling, especially when fed by strongly-interacting radiating structures, e.g. arrays coming into the reflector field-of-view, can be a difficult task for a single tool, which is typically not able to manage multi-scale sub-problems.**

This communication addresses the feasibility of a procedure for the design of feed-arrays in presence of strong scattering from the reflector (or any other nearby structure). The particular and novel feature is how using the "best tool" for each part of the model is achieved by means of an effective communication mechanism based on the EDX language.

I. INTRODUCTION

The full-wave modelling of reflectors antenna may pose significant challenges to engineers. In particular when the antenna is fed by radiating structures that interact significantly with the rest of the antenna structure, for example arrays coming into the reflector field-of-view under large beam-scanning conditions. An accurate prediction of antenna performances can then be a difficult task for a single tool, typically unable to manage multi-scale sub-problems.

In the specific case of reflector antennas, the feeder may operate at resonance (e.g. if a patch array or similar is used), part of the antenna support structure may be in the near-region of the feeder and all the rest further-away regions, were asymptotic theories are applicable. It may also be the case that individual elements are characterised by very different physical properties, e.g. feed-arrays printed on multi-layered dielectric substrates, supporting structure covered by multi-layer insulation and carbon-fibre reflectors, requiring the segmentation into sub-problems.

A mixed approach based on the concurrent use of more than one solver is appealing in such case. It offers multiple models each well suited to a sub-problem; it reduces the computational effort required to obtain the same accuracy of a complete full-wave solution; it does not require the development of new modelling capabilities (i.e. a new tool) . The drawback is the need of data exchange among multiple tools.

An activity was performed under ESA funding to demonstrate the applicability of the above procedure applied to commercial electromagnetic simulators. In particular, GRASP was used for the reflector and ADF-EMS for the feeder. Data were exchanged between them using EDX [1] language.

The proposed approach is founded on past activities in the field of array modelling [1] with ADF-EMS addressing an iterative method in which near/far-field information are used recursively, until a convergence criterion is satisfied. Similar iterative algorithms have also been proposed in literature by other authors [2], [3].

An equivalent surface S_e is defined around the feeder as the "port" at which the needed information is exchanged between GRASP and ADF-EMS. A near-field representation, based on "$\mathbf{J_e}$, $\mathbf{J_m}$ equivalent currents" distribution (equivalent model, EQM, in the following), projected on a RWG (Rao-Wilton-Glisson) base, has been selected as "electromagnetic model" on S_e.

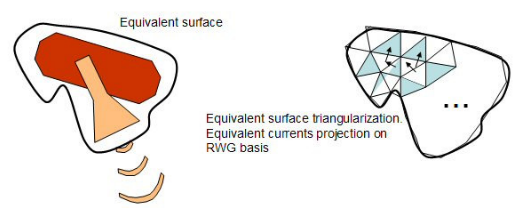

Fig. 1 Application of the equivalence theorem

[1] Data exchange through the EDX language [4], sustained by ESA and by European Community through a number of past projects, is becoming a standard in European electromagnetic modelling and measurement community and it is well suited to the objective of the work given its intrinsic flexibility and robustness.

Such a strategy has been preliminary checked on simple configurations (e.g. dipole-like antennas working in presence of a corner reflector), by comparing the obtainable accuracy with respect to a full-wave (Method of Moments) modelling of the whole structure. Next it has been applied to a reflector configuration.

In general, such a mixed procedure using Physical Optics (PO) on the reflector and MoM on the feeder is not ideal for strong interactions, however in practical cases of off-set reflectors interactions are efficiently handled with a few iterations, as shown in the following with details about accuracy and computational requirements.

II. ITERATIVE PROCEDURE

As already mentioned the main part of the methodology is based on an iterative approach in which near-field information is routinely exchanged by two modelling algorithms, until a convergence criterion is satisfied (i.e. no more significant changes occur with respect to the previous step of the procedure). The near-field information is exchanged in the form of an "equivalent currents" distribution, projected on a RWG base defined on a suitable surface surrounding the feeder.

More in detail, the proposed workflow is based on the following iterative scheme, which is depicted in Fig. 2.

1. A full wave model of the stand-alone feeder is solved (currents calculation) (ADF-EMS)
2. The radiated pattern of the feeder is computed in a suitable far-field grid and stored in an EDX file. A near field grid on a surface S_e "surrounding" the feeder is defined by ADF-EMS and passed to GRASP.
3. The pattern file is used in GRASP (possibly after some internal elaborations to illuminate the reflector model.
4. The E/H field scattered by the reflector is calculated by GRASP on the grid on S_e defined at step 2 and stored into an EDX near-field file.
5. The near-field is read by ADF, E/H field is transformed into "equivalent currents" (EQM) and used as "secondary" source to update the currents on the feed (and therefore also S-parameters) and the feeder pattern.
6. The procedure is restarted at step 3 and will be stopped at the convergence of some performance parameters such as the $|S_{11}|$ at the feed port and the power radiated by the feeder in selected directions.
7. Upon convergence, ADF provides to GRASP the final feeder pattern, which is used to calculate secondary antenna pattern and related performance parameters (spill-over, efficiency, etc.). At the same step ADF-EMS will provide the feed-related performance parameters S-matrix, VWSR, etc.

III. EXAMPLE APPLICATION

The procedure has been applied to a simple but realistic test case made of a reflector with a feeder. The reflector had the following characteristics.

- Focal length (f): 258.7 mm;
- First half axis – (vertical) (a): 185.9 mm;
- Second half axis – (horizontal) (b): 192.5 mm;
- Distance from reflector centre to parabola centre axis (x0): 177.7 mm.

The feeder was a horn antenna, with the following characteristics (Fig. 3).

- Circular aperture D_AP : 40 mm;
- Circular waveguide D_WG : 20.5 mm;
- Conical Flare L_FLARE : 30 mm;
- Total length L1 : 60.0 mm;
- Distance from feeding pin to horn aperture : 70.5 mm.

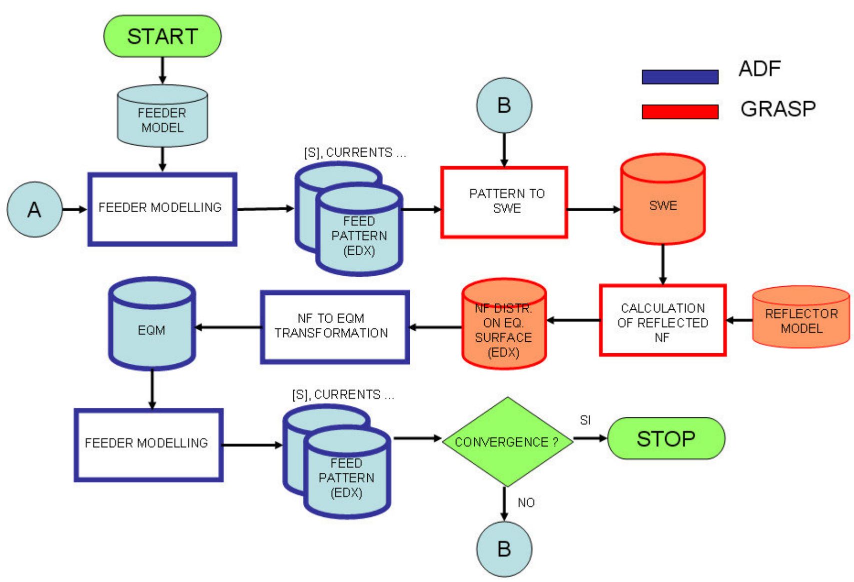

Fig. 2 Flow chart of the iterative procedure

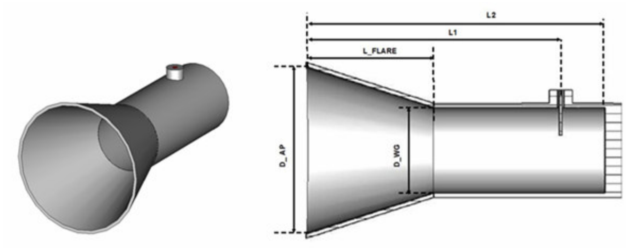

Fig. 3 Geometry of the feeder

The test case has been selected in such a way that a single MoM were applicable, in order to allow numerical verification of the proposed procedure. Therefore the whole test configuration (feeder + reflector) has been, initially, modelled by means of a full-wave method. Several cases were, preliminary, tested in order to identify a configuration in which the interactions between the reflector and the feeder are significant for verification purpose, as shown in Fig. 4.

The simulation has been performed using the MMMP (MoM-MultiPort) module of ADF-EMS and the Multi Level Fast Multipole Algorithm (MLFMA) has been applied to handle electrically large reflector antenna.

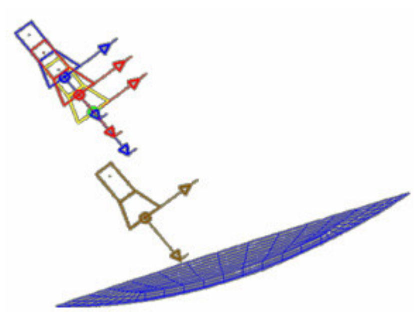

Fig. 4 Feeder positions:
1) Blue: Nominal, 2) Red, 3) Yellow, 4) Gold

First iteration

In the first iteration, the far field radiated by the circular horn in free-space has been calculated at f=10GHz by means of the MMMP, integrated in ADF-EMS.

GRASP has been then used to evaluate the near field radiated by the reflector on a sphere of 72 mm, centred on the horn. The equivalent current distributions obtained from the near-field in ADF-EMS are shown in Fig. 5 and Fig. 6.

Next the equivalent currents have been used as additional source to evaluate the effect of the interaction between the feeder and the reflector antenna and therefore to correct the far field radiated by the horn.

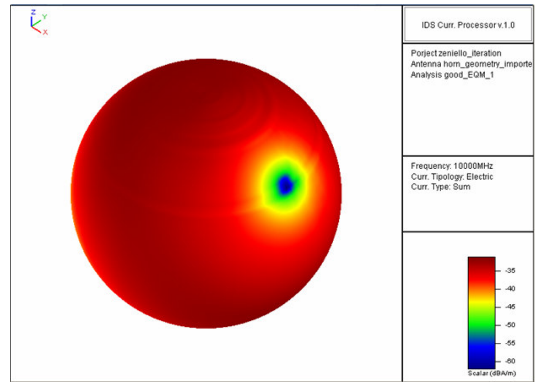

Fig. 5 First iteration. Equivalent electric currents [dBA/m]

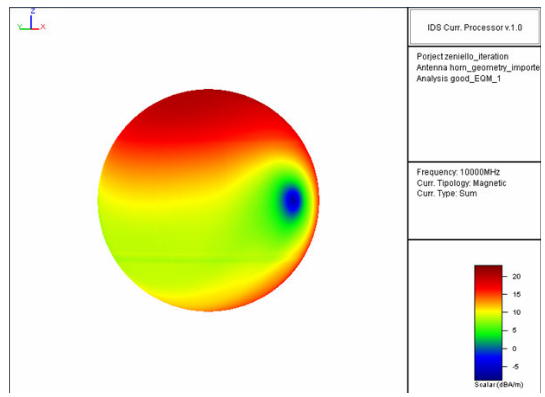

Fig. 6 First iteration. Equivalent magnetic currents [dBV/m]

Fig. 7 shows the comparison between the far field radiated by the horn in free-space and the one corrected by the first scattered contribution from the reflector.

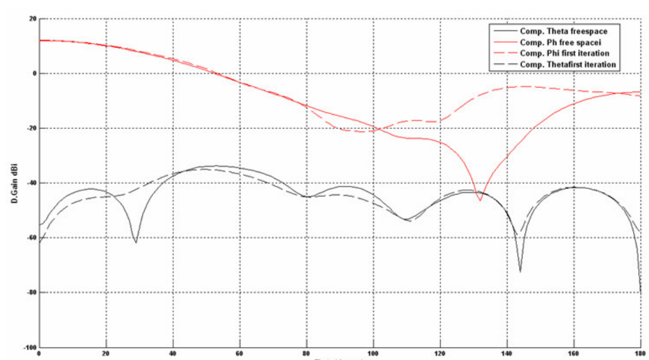

Fig. 7 First iteration. Feeder directivity gain [dBi]
Phi = 0°, Theta = 0°, 180°.
Solid: Free-space. Dashed: First iteration

Final iteration

The procedure has been iterated two times introducing further contributions for a better evaluation of the interactions between the feeder and the reflector.

It is worth noting that the feeder performances at the second iteration are almost coincident with the ones at third iteration thus confirming the fast convergence of the proposed procedure.

Fig. 8 shows the comparison between the far field radiated by the horn, in free-space, and the one corrected by the addition of the equivalent sources in the last iteration.

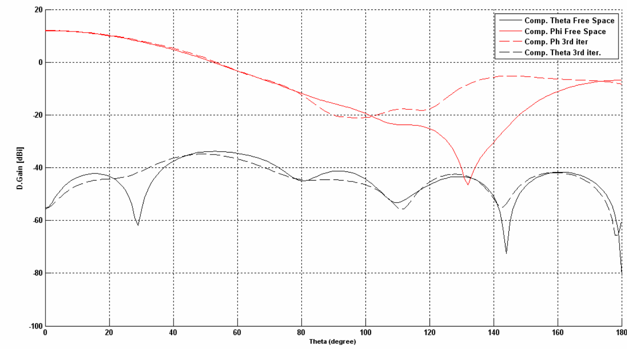

Fig. 8 Final iteration. Feeder directivity gain [dBi]
Phi = 0°, Theta = 0°, 180°.
Solid: Free-space. Dashed: Final iteration

IV. PROCEDURE VALIDATION.

The applicability of the proposed iterative method has been verified against the results of a full-wave analysis (MLFMA).

Fig. 9 reports the modulus of S_{11} of the horn in two positions (see Fig. 4) as a function of frequency. The interactions between the feeder and the reflector are clearly included as shown by the comparison with the behaviour of horn in free-space reported in the figure.

Fig. 10 reports the far field pattern radiated by the reflector antenna with the feeder in positions 1 and 3.

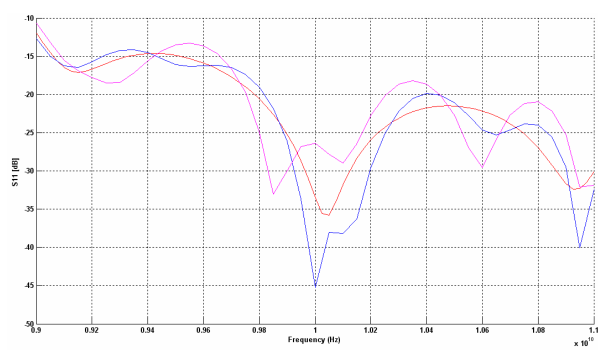

Fig. 9 Full-wave results S_{11} [dB].
Red: Horn in free space, Blue: Horn in nominal position (1).
Pink: Horn in position (3).

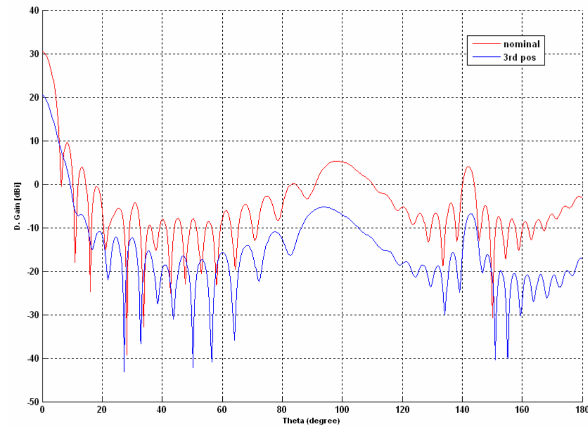

Fig. 10 Full-wave results. Reflector directivity gain [dBi]
Phi=0°, Theta=0°, 180°
Red: Nominal position (1), Blue: position (3)

Finally, the far field pattern radiated by the horn in presence of the reflector is compared in Fig. 11:

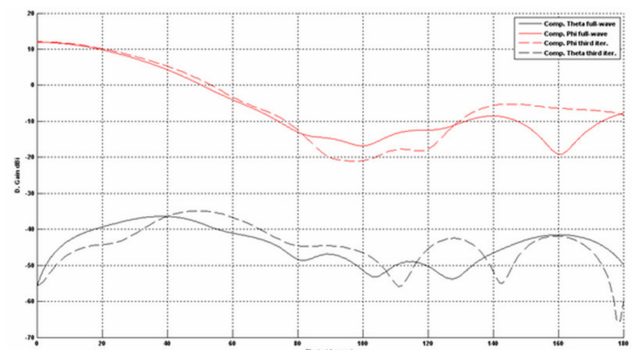

Fig. 11 Full-wave results vs. iterative method results. Feeder directivity gain [dBi] . Phi=0°, Theta=0°, 180°.
Solid: Full-wave, Dashed: Iterative method

The iterative method allows also evaluating the variation of the feeder input parameters. In particular, the variation of the return loss due to the interaction with the reflector can be evaluated.

The reference model shows that the return loss of the feeder at the frequency of 10 GHz changes from the value of about -33 dB in free-space to the value of -26.31dB when it is placed in the third position.

The feeder return loss at same frequency has been evaluated with the iterative procedure; Fig. 12 shows the variation of this feeder parameter with the number of iterations: the final value, reached at the third iteration, is -21.24 dB.

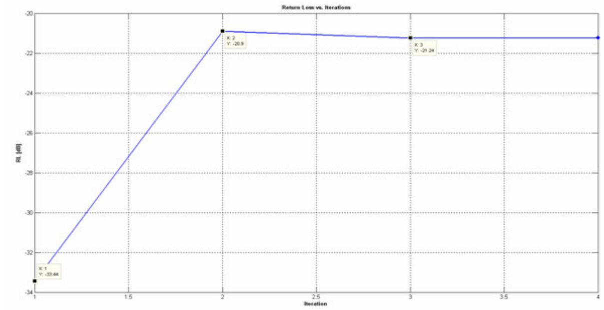

Fig. 12 Iterative method. Return Loss vs. Iteration

The previous results show that the convergence of the proposed iterative algorithm is very fast (as expected) and that a mixed "full-wave (for the feeder) – asymptotic (for the reflector)" implementation is able to detect quite small variations (in the range of -20/-30 dB).

The following elements of comparison between the proposed procedure and full-wave analysis emerge:

- The interaction between reflector and feeder (in terms of feeder return loss and pattern distortion) can be through proposed iterative method.
- The feeder stand-alone input parameters and radiation pattern are, iteration by iteration, modified and driven closer to the full-wave result.
- The residual small differences, of little engineering impact, can be attributed to the different accuracy of the full-wave and asymptotic methods.
- The proposed mixed iterative approach converges in just a few iterations (as expected).

V. Possible Applications to Feed Array Configurations

Feed array configurations are typically used to obtain a reflector antenna having one or more of the following features:

- shaped beam;
- multi-beam;
- multi-frequency.

In the design phase, one of the critical parameter is the input impedance at the array element ports. Dedicated full-wave tool (e.g. MoM solvers) are able to calculate accurately the input impedance taking into account the single cell features (by means of very realistic e.m. models) and the mutual coupling with the other cells of the array.

The geometrical dimensions of a feed array are usually larger than the dimension of a single feeder and therefore the interactions with the reflector are expected to be stronger. However full-wave tools are typically unable to model the entire reflector + feed array assembly and to take into account the effect of the scattered field on the feed array performance (input impedance and active radiation pattern).

The field scattered by the reflector could modify directly (1st order effect) the input impedance but also through the coupling with the other cells of the array (2nd order effect).

The knowledge of all these effects can help the engineer in the final steps of the design to obtain the best performances.

The proposed iterative procedure is able to take into account all the mentioned effects at a fraction of the computational cost of a full-wave approach (provided that it is available for the actual problem)

Furthermore the same iterative approach can be applied to manage more than one reflector or other scatterers by simply adding the effects of each of them at the level of equivalent currents.

Finally any kind of feeder or reflector can be modelled provided that a tool suitable for their analysis is available, i.e. a tool that can accurately model the object in isolation.

VI. Conclusions and Future Activities

The results reported show the feasibility of a mixed approach based on the concurrent use of a PO solver (GRASP) and a MoM solver (ADF-EMS) for the modelling of reflectors antenna were the interactions between feeder and reflector are not negligible.

In particular it is shown that:

- No modifications are necessary to the tools involved.
- The EDX language allows an easy e.m. data exchange.
- The convergence of the iterative algorithm is very fast (as expected from the physics of the problem).
- The procedure is sufficiently accurate to detect quite small variations (in the range of -20/-30 dB).
- The proposed procedure can be applied to more complex configurations.
- The iterative algorithm itself can handle multiple reflectors or scatterers.
- Any kind of feeder or reflector can be modelled provided that the right tool is available.

The results obtained fully justify future efforts to further verify the approach, gain deeper knowledge about its behaviour so as to improve both its accuracy and speed.

Acknowledgment

This work has been partially supported by the European Space Agency (Contract no. ESTEC/18802/04/NL/JD).

References

[1] Bandinelli, and R. Guidi, "An Iterative Integral Equation Method To Model Large Complex Arrays," URSI 2004.

[2] Mao-Kun Li, Weng Cho Chew, "Wave-Field Interaction With Complex Structures Using Equivalence Principle Algorithm", IEEE Transactions On Antennas And Propagation, Vol. 55, No. 1, January 2007

[3] Carr, M.; Volakis, J.L.; "A generalized framework for hybrid simulation of multi-component structures using iterative field refinement," *Antennas and Propagation Magazine, IEEE* , vol.48, no.1, pp.22-32, Feb. 2006

[4] M.Sabbadini, P.E.Frandsen, F.Mioc, F.Silvestri , G. A. E.Vandenbosch, "The Electromagnetic Data Exchange Language For Antenna Modelling And Measurement Data", Proceedings for the 30th ESA Antenna Workshop on Antennas for Earth Observation, Science, Telecommunication and Navigation Space Missions, ESTEC, Noordwijk, The Netherlands, May, 2008.