CONFORMAL ARRAY ANTENNA MODELLING WITHIN EUCLID CEPA-1 / MODERN RADAR TECHNOLOGY

H.J. Visser [1], G. Gerini [1], B.M. Zaragoza [1], F. de Hond [1], Th. Bertuch [2], W. Söntgerath [2], P. Knott [2], H. Gniss [2], O. Schmid [2], Chr. v. Winterfeld [2], D.L. Paul [3], I. Craddock [3], D.P. Economou [4], D.I. Kaklamani [4], G. Kyriakou [4], J.N. Sahalos [4], N.K. Uzunoglu [4], P. Backhouse [5], P. Fletcher [5], C.D. Watkins [5], R. Vitiello [6], U.F. D'Elia [6]

1. *TNO Physics and Electronics Laboratory, Netherlands, visser@fel.tno.nl*
2. *FGAN Research Institute for High Frequency Physics and Radar Techniques (FHR), Germany*
3. *University of Bristol, United Kingdom*
4. *Hellenic Research Team on Conformal Antennas, Greece*
5. *Defence Evaluation and Research Agency Malvern, United Kingdom*
6. *Alenia Marconi Systems, Italy*

INTRODUCTION

The mounting of antennas on military platforms, land-, sea- and air-based is a well-known problem due to the conflict it generates between platform and sensor interests. Most visibly this situation arises in aircraft where platform interests gain the highest priority and lead to sub-optimum antennas and antenna positions. Examples are limited field-of-view nose-mounted radar antennas and aerodynamically radomed communication antennas. Constraining the antenna aperture to conform to the external shape of the platform therefore will be beneficial. The benefits will not only be structural as in the case of removing the need for drag-inducing 'blister' radomes on aircraft, but can also be operational (e.g. increasing the field of view and reducing the RCS). One can envisage an active array antenna aperture conformal to the external structure of a platform, combining several tasks: a concept known as Smart Skin.

Active planar array antennas have been and are being developed for radar systems such as AMSAR, MESAR, COBRA, RAT-31DL and APAR. Some of these systems are on the point of becoming operational and therefore time is ready for research institutes to go one step further, i.e. investigate conformal array antenna technology. The technological challenges related to the development of active conformal array antennas are far from trivial and therefore seven Western European Armaments Group (WEAG) members (BE, FR, GE, GR, IT, NL, UK) agreed to collaborate on research on this topic. Under auspices of EUCLID[1] CEPA-1[2], operating as Joint Programme 1.3 (JP1.3) under the THALES [3]Memorandum Of Understanding (MOU), activities started mid 1997. The overall objective is to investigate technology and system issues relating to the use of active conformal antennas in military systems and to determine the feasibility of the use of conformal antennas (and smart skins) in future military systems. The work is organised in Work Packages dealing with: System Studies, Antenna Modeling, Array Demonstrators and Technology Demonstrators. A substantial part of the work is devoted to Antenna Modeling, the subject of this paper.

ANTENNA MODELLING

A major requirement in the design of high-performance array antennas is a thorough electromagnetic understanding of the radiating elements in their array environments. Full-wave numerical techniques are employed to allow for the antenna characterisation, as accurately as possible, given the constraints in CPU time and temporary storage requirements. Although 3D electromagnetic software is commercially available, most CAD packages – due to their general purpose characteristics – are not suited for the analysis and design of complete conformal array antennas. This justifies the development of dedicated software. In developing this software it is not possible to choose a 'best' numerical method; methods highly depend on the specific structure under investigation. By joining forces though we have gained the unique opportunity to have access to all classes of full-wave numerical techniques and the experience coming along with it from research institutes all over Europe. Once the possibility has been created to fully characterise conformal antennas, it will be possible also to loosen up some of the constraints on accuracy in a controlled manner and develop reduced analysis models. The reduced analysis or approximate models, being less demanding with respect to CPU time and temporary storage, can serve as engineering tools for first order designs. The full-wave analysis models can then be employed for fine-tuning purposes. Although, strictly speaking, measurement of experimental antennas – apart from being used for software validation – does not fit into a paragraph on antenna modeling, we still do

---

[1] EUCLID = European Co-operation for the Long term In Defence.

[2] CEPA = Common European Priority Area.

[3] THALES = TecHnology Arrangement for Laboratories for defence European Science.

incorporate it here. The reason is that experiments on itself, conducted on this relatively new class of antennas, will help in gaining insight on the relative importance of the different antenna parameters (e.g. polarisation and mutual coupling), thus contributing to the development of justified engineering models.

Full-Wave Analysis

Among the participants of the THALES JP1.3 programme, the following modelling techniques are being used: Finite Difference – Time Domain (FD-TD) methods, Methods of Moments (MoM), the Method of Auxiliary Sources (MAS), the Boundary Element Method (BEM) and various Modal Methods(MM).

A faceted circular cylindrical ring of wideband stacked patch antennas has been successfully analysed by FD-TD, see figures 1 and 2. In order to be able to analyse this large (in terms of wavelength) structure, a locally distorted grid has been applied [1]. Also within the context of FD-TD methods, a research is being conducted concerning the optimum choice of Absorbing Boundary Conditions (ABC's) in connection with conformal gridding [2].

MoM is used for numerically solving integral equations. MoM concepts are incorporated into a novel numerical technique [4] originating from a modification of the standard MAS to analyse planar and cylindrical patch antennas, see fig. 3. The method though is general and can be applied to arbitrarily shaped structures. In another technique, a Modal Method (MM) is applied to derive an integral equation that is numerically solved by MoM for infinite arrays of open-ended waveguide radiators on circular cylinders [2, 3]. This method has proved to work very well, even for finite sectoral arrays, see fig. 4.

Another integral equation method under development is the Boundary Element Method (BEM). This method (as well as the modified MAS method) is aimed at the analysis of arbitrarily shaped surfaces [6], see fig. 5. To take into account apertures, a hybrid method with Mode Matching is currently being developed.

A Mode Matching method has been developed for circular cylindrical sector arrays of axially infinite slots (slits) [7]. If radially oriented open-ended waveguides are approximated by the slits, this method should be classified as a reduced analysis method, but since it is a full-wave method for real slits, we have classified it as a full-wave method.

Reduced Analysis

We have chosen to divide the reduced analysis methods employed within THALES JP1.3 into three classes that we have named: High Frequency Methods (HFM), Semi Empirical Methods (SEM) and Practical Engineering Methods (PEM).

Within the context of HFM a fundamental mode only ray tracing method has been developed for analysing planar, faceted and curved array antennas of open-ended waveguides. The results agree very well with measurements [2, 3], see figure 4. The method is being extended for microstrip patch radiator arrays.

In the reduced analysis class of SEM, several of the partners have employed the cavity as well as the surface current model for single curved microstrip patch antennas [3, 5], see figure 6. In order to investigate the beamforming properties of large finite arrays, the single elements are represented by Huygen's sources. Mutual coupling is taken into account using a scattering matrix formulation [8], see fig. 7.

Within the class of reduced analysis techniques we classified as PEM, commercially available electromagnetic analysis software is used *partly* for the analysis and / or design of conformal array antennas. Examples are the use of ENSEMBLE© and HFSS© to design planar antennas for facetted arrays (including the in-plane, but excluding the inter-plane mutual coupling) [2, 3], the use of MOMENTUM© and an approximate method based on the Wiener-Hopf technique for the design of a circular sector ring array antenna of microstrip patches [5] and the use of MAFIA© and conformal array antenna factors for conformal array antenna design including embedded planar subarray mutual coupling effects. CLEMENTINE© is in use for the design of patch antennas on circular cylinders.

Experiments

Apart from the several antennas that have been constructed for software validation purposes (e.g. figures 1 and 4) or for specific tasks like Digital Beamforming, see figure 7, test antennas have also been made to study the behaviour of several parameters. Figure 8 shows some of these antennas. In the upper-left corner we see a 64 element array antenna mounted in the nose of a F16 fighter aircraft. The radiating elements are dual polarised patch antennas. With this configuration the mutual coupling in two orthogonal polarisations have been investigated, going over a doubly curved structure. In the upper-right corner of the figure we see a faceted approximation of the open-ended waveguide circular sector array shown in the lower-left. Mutual coupling measurements for these two configurations have shown that the behaviour of both antennas is almost identical. To investigate the similarity between curved and faceted arrays further, a variable angle faceted array carrier has been constructed, shown in the lower-right corner of figure 8. Inside this carrier we can mount dual polarised waveguide arrays and dual polarised patch arrays in order to investigate the effects in both co-and cross-polarisation. For validation of synthesis and analysis methods, an array of 16x16 patches on a cylinder has been realised (see fig. 9), one ring of it being fed, the other ones being loaded. By means of a synthesis tool employing optimisation routines, excitations have been calculated for obtaining a pencil beam with low side lobes. Array patterns have been calculated for both axial and circumferential polarisation and are compared with far-field measurements in fig. 9 and fig. 10. A 64-channel receiver with a digital beamformer has been constructed providing a testbed for measurements and beamforming investigations on conformal arrays [9].

CONCLUSIONS

Under the auspices of EUCLID CEPA-1, research institutes all over Europe have joined forces in the development of analysis methods for conformal array antennas. Within the THALES Joint Programme 1.3 we have now reached the exciting moment that the several techniques under development at the individual institutes are becoming of age and can be compared to one another and to measurements. Several bi-lateral test and comparison exercises are being planned and conducted at the moment of writing this paper, so for sure it can be concluded that the year 2000 will be known as a year of big progress in conformal array antenna research in Europe.

REFERENCES

[1] Y. Hao and Chr. Railton, 'Analysing electromagnetic structures with curved boundaries on cartesian FDTD meshes', IEEE Trans. On MTT, Vol 46, No. 1, Jan. 1998, pp. 82-88.

[2] H.J. Visser and G. Gerini, 'Theory and Experiments on Planar, Faceted and Curved ArrayAntennas', Proceedings COMCON 7, June 1999, Athens, Greece, to be published.

[3] G. Gerini et al., 'Efficient Full-Wave Analysis of Waveguide Arrays on Cylindrical Surfaces', Proc. 29th EuMC, Oct. 1999, Munich, Germany, pp. 167 –170.

[4] P. Shubitidze, D.I. Kaklamani and H.T. Anastassiu, 'Modified Method of Auxiliary Sources applied to the Analysis of Planar and Cylindrically Shaped Microstrip Antennas', Proc. Of ICEAA 99, Sept. 13-17, 1999, Torino, Italy, pp. 375-378.

[5] G. Kyriakou and J.N. Sahalos, 'The edge admittance model for microstrips on uniaxial substrate', Archiv für Elektrotechnik, Vol. 6, pp. 169-179, 1993.

[6] T. Bertuch, 'Use of the Boundary Element Method for the Modelling of Arbitrarily Shaped Surfaces in Conformal Antenna Design', Proc. IEEE Antennas and Propagat. Int. Symp., July 1999, Orlando, Florida, pp.2192-2195

[7] T. Bertuch, Chr. v. Winterfeld, 'Numerical Investigations of Cylindrical Sector Arrays of Aperture Antennas', Proc. JINA, November 1998, Nice, France, pp. 177-180

[8] P. Knott, Chr. v. Winterfeld, "A Polarimetric Antenna Model for Small Conformal Arrays Including Mutual Coupling Effects', Proc. IEEE Antennas and Propagat. Int. Symp., July 1999, Orlando, Florida, pp.2314-2317

[9] H. Gniss, 'Digital Rx-only Conformal Array Demonstrator', IRS 98 Int. Radar Symp., Sept. 1998, Munich, Germany, pp. 1003-1012.

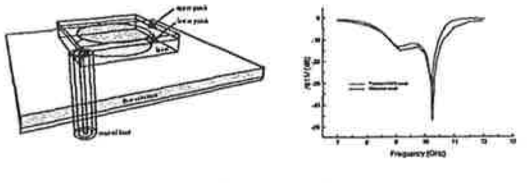

Fig. 1: Wideband Stacked Patch Antenna Element (DERA, Malvern and Computational Electromagnetics Group, University of Bristol).

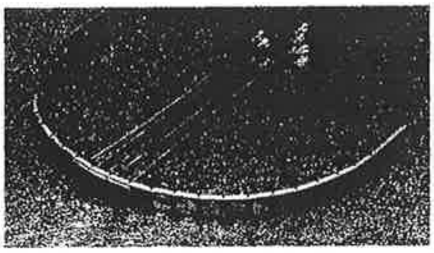

Fig. 2: Experimental circular cylindrical ring array of wideband stacked patches. (DERA, Malvern

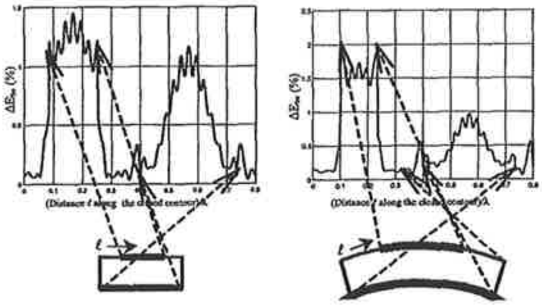

Fig. 3: Planar and cylindrically shaped microstrip antenna: plot of the boundary condition error ΔEbc along the structure surface (Dept. of Electrical and Computer Engineering, National Technical University of Athens).

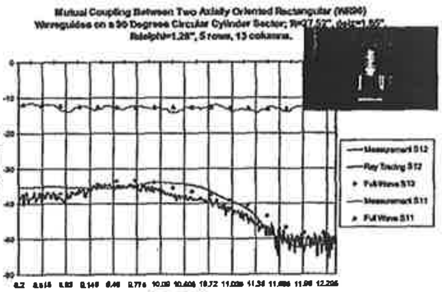

Fig. 4: Full-wave and approximate calculation of axial mutual coupling vs. measurements in circular sector array antenna (TNO-FEL).

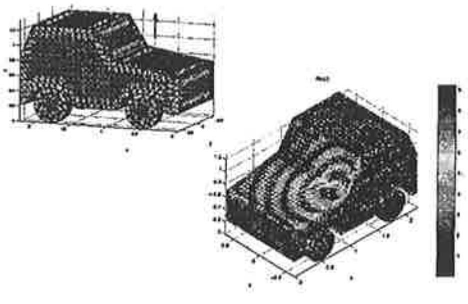

Fig. 5: Discretization of a PEC object with position of source dipole (700MHz) and real part of calculated surface currents (FGAN-FHR).

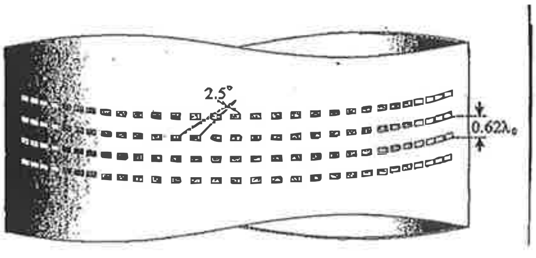

Fig. 6: Circular cylindrical sector ring array of single layer patch antennas (Dept. of Physics, University of Thessaloniki & Dept. of ECE, University of Thrace).

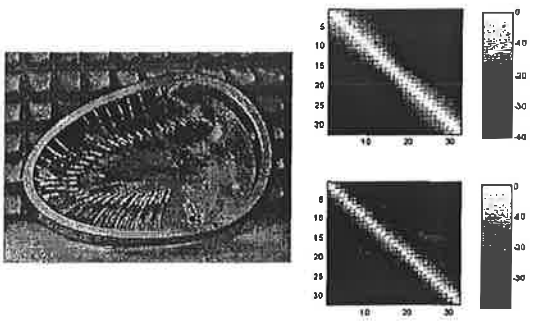

Fig. 7: Elliptical sector x-band array with 32 dual polarized microstrip elements and comparison of calculated (top) and measured (bottom) coupling coefficients (FGAN-FHR).

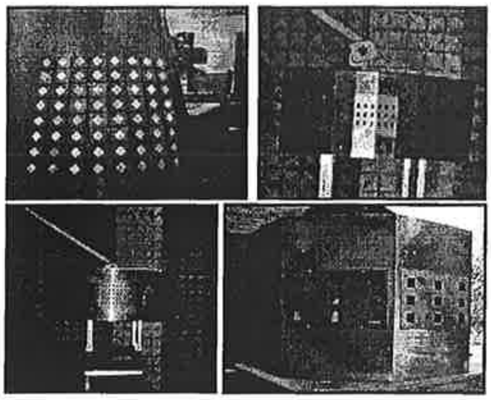

Fig. 8: faceted, single and dual curved patch radiator and open ended waveguide radiator array test antennas (TNO Physics and Electronics Laboratory).

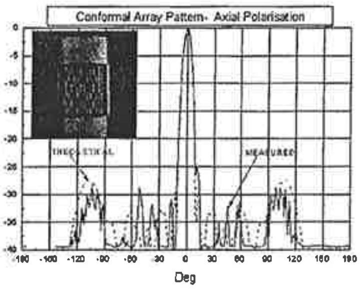

Fig. 9: Theoretical and experimental results on a cylindrical array; axial polarisation (Alenia Marconi Systems, Fusaro (Napoli), Italy)

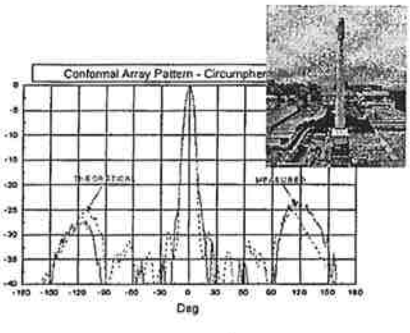

Fig. 10: Theoretical and experimental results on a cylindrical array; circumferential polarisation (Alenia Marconi Systems, Fusaro (Napoli), Italy)