ACE Activity 2.3 Structuring of Wideband & Multiband Antenna Research

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Abstract
Developments in wireless communications and sensing require increasingly wider frequency bands and that multiple functions can be provided by a single antenna system. This paper presents an overview of the current work in ACE Activity 2.3, which coordinates and structures European research on wideband and multiband antennas. The activity comprises three work packages: WP 2.3-1 on wideband & multiband radiators, WP 2.3-2 on reflector surface models, and WP 2.3-3 on antennas for subsurface radars. The paper discusses main areas of joint research and development, presents main results achieved, and relates the work to that of other ACE Activities. Main future challenges will be to maintain at least some of the current activities, when the funded period of ACE finishes by the end of 2007, and extend the cooperation to more partners in the ACE Community.

1. INTRODUCTION

Wideband and multiband antennas are vital to many applications ranging from handheld terminals, base stations, sensors, aircraft, satellites etc. As the number of services and functions increase, stringent constraints with respect to available space, mass limitations and the need to reduce cost dictate that several systems or functions use a single antenna. Applications like ultra-wideband communications and radar use unprecedented wide frequency bands and have demanding requirements, e.g. on antenna dispersion.

The EU FP6 Network of Excellence ACE – Antenna Centre of Excellence [1] – includes wideband and multiband antennas as one of its five vertical joint research activities. The activity is divided into three work packages: WP 2.3-1 on wideband and multiband radiators dealt with in Section 2, WP 2.3-2 on reflector surface models discussed in Section 3, and WP 2.3-3 on antennas for ground or surface probing radars including medical imaging described in Section 4. Cooperation takes place with Activity 2.1 on mm and sub-mm wave antennas, Activity 2.2 on small antennas (typically of lower cost and performance while our focus is on comparatively large radiating elements including reflector antennas with medium to high performance), Activity 2.4 on arrays, and the horizontal activities on software, measurements, education and dissemination. A special effort has been made to involve external partners also in the New Member States, either directly or via the ACE Community accessible from the ACE Virtual Centre of Excellence (VCE) [1].

2. WIDEBAND & MULTIBAND RADIATORS

2.1. Wideband radiator database

A main activity in WP 2.3-1 at the start of ACE was to generate the wideband radiator database accessible for ACE Community members from the VCE at [1] under Dissemination / ACE Results / A2.3. The database includes 29 antenna types divided into six groups and 22 antenna applications divided into five groups. The antenna applications provide both the context for the different antenna types, and the link to the system requirements for the appropriate wideband or multiband antenna system. Companies working in these fields have been active in producing these system-based antenna requirements.

A responsible appointed for each antenna type or application has prepared the corresponding reference document. The antenna type documents contain a definition including pictures or drawings, explanation of the principle of operation, list of typical performance and technology, and sources for further information. The antenna application documents give the background for the application, define frequency bands and antenna specifications for various requirements, and indicate sources for further information and potential antenna types for the application. The documents are extremely useful for future work. The system-based antenna requirements are essential for making new antenna research relevant and as a reference. They link the researchers and future engineers and scientists at universities with the evolving needs of the information society and join universities and industry.

2.2. Joint wide- & multiband radiator research

The restructuring of the WP 2.3-1 research activities is based on selected programmes going on and planned among the participants. The projects are organised in groups with similar orientation. The project groups form "clubs" with similar research interests and objectives. New projects and project groups are created as needed. The current research activities are divided in four different groups emphasising ultra-wideband (UWB) applications:

1. *WB/UWB Antenna Design Methods*
2. *WB/UWB Terminal Antennas*
3. *WB/UWB Antenna Verification*
4. *WB/UWB Radar Antennas*

Fig. 1 illustrates one joint research topic involving ICCS/NTUA, UP Catalunya and FOI on parallel Particle Swarm Optimisation of a UWB antenna. Other teams investigate other antenna types.

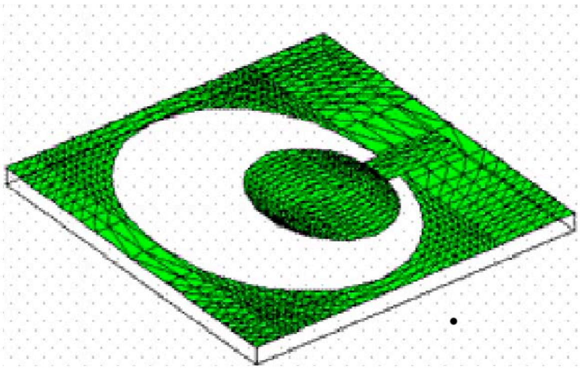

Fig. 1. Elliptical microstrip-fed UWB antenna.

Larger wideband, multiband and ultra-wideband radiators are used by radars, to measure other antennas, EMC measurements, satellite communications etc. As a example, the Czech Tech. Univ. in Prague has together with the wideband antenna spin-off company RFspin developed a new concept of double ridged antennas – see Fig. 2.

Fig. 2. Double ridged antenna (4-40 GHz).

The new European UWB regulation will strongly limit the use the lower part of the 3.1-10.6 GHz band and block the Wireless LAN band 5.1-6 GHz leaving mainly the 6-9 GHz band for use without additional mitigation techniques. A new important activity has therefore been to develop a set of UWB antenna specifications for the wideband radiator database.

3. REFLECTOR SURFACE MODELS

Reflector antennas may operate over very wide bands typically limited by the feed system. Special surfaces are used for polarisation control with gridded surfaces or for frequency diplexing using frequency selective surfaces. It may also be necessary to take into account special surface materials such as CFRP, mesh or paint. Reflector antennas find use in radio links and as antennas for geostationary satellites – both on the ground as terminals and onboard the satellite. Alternatively, special surfaces are used as radomes, e.g. to protect antennas under adverse climatic or environmental conditions, on vehicles, trains and aircraft, or onboard satellites.

At the start of ACE, the WP 2..3-2 partners carried out a survey of the literature and software for reflector surface models. This survey is available for ACE Community members from the VCE at [1] under Dissemination / ACE Results / A2.3.

3.1. Joint reflector surface model research

The current joint research work is divided in four subject areas:

1. *Improved design techniques*
2. *Measurements*
3. *Curved FSS*
4. *Strip grid with dielectric*

Much emphasis has been given to the study of homogenisation techniques, which are employed for problems where the applied wavelength is much larger than the microstructure. The idea is to replace a heterogeneous structure built up of small details with a fictitious, homogeneous structure, which would produce the same scattering characteristics. Strictly speaking, this can only be done in the limit where the wavelength is infinitely large compared to the microscopic details. However, in real engineering problems the homogenisation procedure still produces acceptable results for finite wavelengths. On the other hand, it is usually very difficult to deduce the range of validity for the homogenised results. Two separate questions are of particular interest:

1) *Under which circumstances is it possible to model a particular structure as a material?* For most structures there is in general an infinite number of degrees of freedom for the electromagnetic field, corresponding to the number of modal solutions. By choosing the frequency low enough, the number of modes can be reduced to only correspond to the possible polarisations of the electromagnetic field.

2) *Once the structure is modelled as a material, how strong is the dependence on the scale difference*

between the wavelength and the microscopic structure? This corresponds to identifying the spatial dispersion, which is given by the dependence of the effective permittivity on *ka,* where *k* is the wave number of the applied field and *a* is the typical size of the microstructure.

The main conclusion is that a heterogeneous structure may be modelled as a homogeneous material, even if the applied wavelength is not infinitely large compared to the microscopic scale. A sufficient condition for arbitrary geometries has been determined, but a wider range of validity for specific geometries is anticipated and is under investigation.

Both rigorous and approximate solutions for planar and curved strip grids as shown in Fig. 3 have been investigated and compared in particular investigating the effects of dielectrics supporting the strip grids. These grid types are important for so-called dual-gridded reflector antenna systems used onboard communications satellites. An important objective is to validate the approximate methods used by general antenna analysis software and improve them as necessary. One approach is to link the general antenna analysis software to dedicated accurate grid analysis software by fast interpolation methods for frequency selective surfaces such as the pole-zero method.

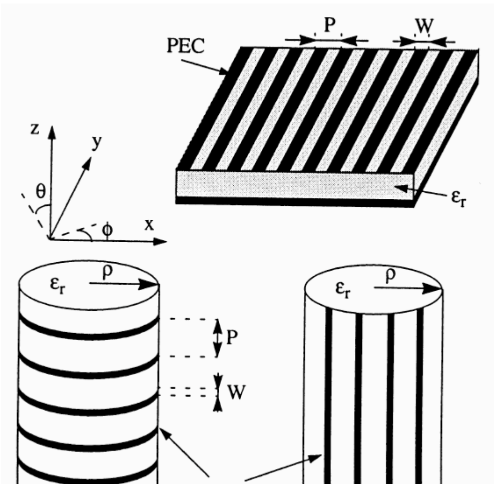

Fig. 3. Examples of strip grids with dielectrics.

We aim at extending the above work applicable to linear polarisation to circularly polarised antenna systems on a joint contract with a space agency involving all WP 2.3-3 partners. We anticipate a spin-off in, e.g. mobile base station applications.

4. ANTENNAS FOR SUBSURFACE RADARS

Recently a substantial interest has been paid to radars for imaging of subsurface objects. Ground Probing Radar (GPR) and medical imaging are the most well known applications. Development of antennas for such subsurface imaging system is a most challenging problem. The antennas should satisfy a number of demands. First of them is a wide frequency band. Secondly, antennas for an impulse system should have a linear phase characteristic over the whole operational frequency band as well as constant polarisation. Thirdly, due to the fact that a subsurface imaging system is essentially a short-range radar, its antenna system should possess low and short in time coupling between the Tx and the Rx antenna and both antennas should have short ringing. Finally, a specific feature of these antennas is that they operate very close to matter or even in contact with it. However, changes in the electrical properties of the matter, e.g. due to change of soil humidity or soil characteristics should not cause large variation of the antenna performance.

During the first part of ACE, WP 2.3-3 catalogued a large variety of GPR antennas developed by the partners. The antennas are grouped according to type:

- *Loaded bow-tie antennas*
- *Dielectrically loaded TEM horns*
- *Vivaldi antennas*
- *Antenna arrays*

The GPR antenna catalogue is available for ACE Community members from the VCE at [1] under Dissemination / ACE Results / A2.3.

4.1. Joint GPR antenna research

WP 2.3-3 has four main research activities:

1. *GPR antenna design*
2. *GPR antenna measurements*
3. *Medical imaging*
4. *Characterisation of loading materials*

In order to compare the performance of different antennas, also performance metrics (figure-of-merits) for different applications and the associated measurement protocols are being developed. The improved measurement facilities and procedures are expected to lead to improved and novel antenna designs. Medical imaging is becoming increasingly important. It is similar to GPR, but utilises higher frequencies than GPR. Subsurface radar antennas operate close to or in contact with high dielectric media and often make use of high dielectric loading materials. Achieving high operational bandwidth often requires the use of absorbing materials, which are poorly specified and limited in variety.

Fig. 4 shows the hemispherical array of stacked patches developed at Univ. Bristol for breast cancer detection. Results from laboratory phantoms show successful detection of tumour phantoms down to 4mm diameters, with a scan time of just 2 minutes.

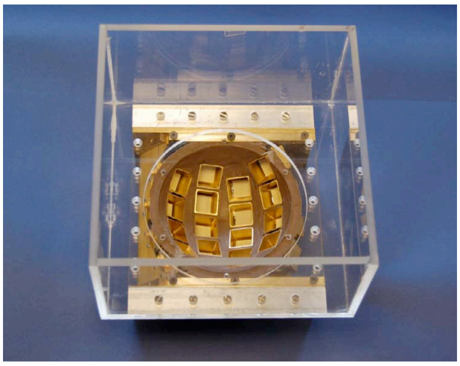

Fig. 4. Medical imaging array (4-9.5 GHz).

4.2. Joint subsurface radar antenna test facilities

Development of a GPR antenna system is impossible without an experimental verification, characterisation and tuning of the antenna design. The full characterisation is impossible without measurements in realistic working environments. Thus, both specialised measurement facilities and a set of measurement techniques for GPR antenna characterisation are necessary. The easiest check of the antenna operation is to measure its internal impedance under the operational conditions. However, good antenna matching to a transmission line does not guarantee the proper radiation properties of the antenna.

Therefore, the specialised, but complementary GPR antenna measurement facilities at Delft Univ, Technology (dry sand box) and Technical Univ. Denmark (soil box with humidity control) have greatly contributed to the success of the cooperation. The major test performed is measurement of the antenna subsurface footprint. Additionally, the measurement facility in Delft can measure the antenna elevation profile. Both facilities have been used for joint measurement campaigns during ACE. As medical imaging antennas operate at much higher frequencies than GPR antennas and radiate into a medium with a much higher dielectric permittivity, they require different facilities. Such a facility has been created at Univ. Bristol and is also open for joint measurements campaigns.

5. CONCLUSIONS

The paper has briefly reviewed some of the wideband and multiband antenna research restructuring carried out in ACE Activity 2.3. More examples and deeper details are available in overview papers [2, 3, 4, 5] presented elsewhere. Main future challenges will be to continue this work when the ACE funding ends by the end of 2007 at an adequate level and extend the cooperation to more ACE Community partners.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] http://www.antennasvce.org/

[2] M Bonnedal, E Angelopoulos, E Antonino, P Balling, K Chan, R Ericksson, M Mazanek, I Lager, W Sörgel, E Ubeda, A Yarovoy, "Activities in ACE WP 2.3-1 on wideband and multiband radiators", *Proc. of the First European Conf. on Antennas and Propagation (EuCAP 2006)*, Nice, Nov. 2006 (CD-ROM paper 435668mb).

[3] K Pontoppidan, P Balling, G Gerini, S Maci, Z Sipus, D Sjöberg, D Trinchero, F Vipiana, "Reflector surface modelling – a European collaboration", *Proc. of the First European Conf. on Antennas and Propagation (EuCAP 2006)*, Nice, Nov. 2006, 6 pages (CD-ROM paper 347914kp).

[4] A Yarovoy, P Meincke, J-Y Dauvignac, I Craddock, A Sarri, Y Huang, "Development of antennas for subsurface radars within ACE", 2007 Int'l. Conf. on Ultra-WideBand (ICUWB'2007), Singapore 24-26 Sep. 2007.

[5] H-R Lenler-Eriksen, P Meincke, A Sarri, G Alli, V Chatel´ee, J-Y Dauvignac, B Nair, Y Huang, I.J Craddock, R Nilavalan, D Lymperopoulos, "Joint ACE Ground Penetrating Radar antenna test facility at the Technical University of Denmark", *Special ACE Session at AP-S/URSI Symp.*, Washington, D.C., 3-8 July 2005.