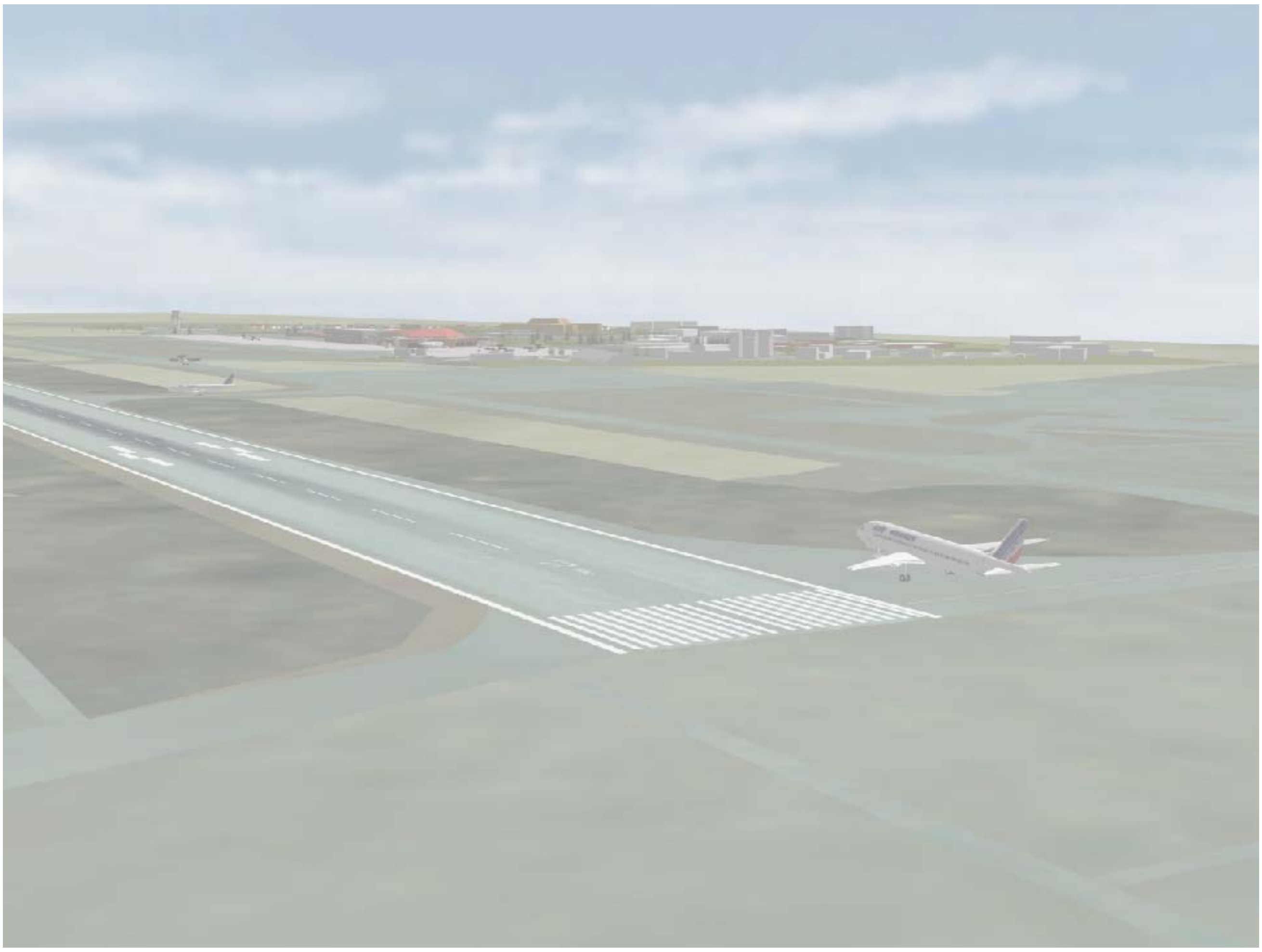
Contract N°: AST3-CT-2003-502817

EM Sources Modelling



DISSEMINATION REPORT

CONTENTS

1 Introduction

1.1 Aim

The scope of the WP4.2 is the creation of a database that will be enriched with the close environment of the different EM sources in the airport environment. Research undertaken focused on ways to make the data base become generic and easily adaptable to any other airport peculiarities. Depending on the distance to the aircraft, the sources are characterized using a far or a near field diagram.

1.2 Context

Previous work-packages provided the foundations and the scope for the EM sources modelling task

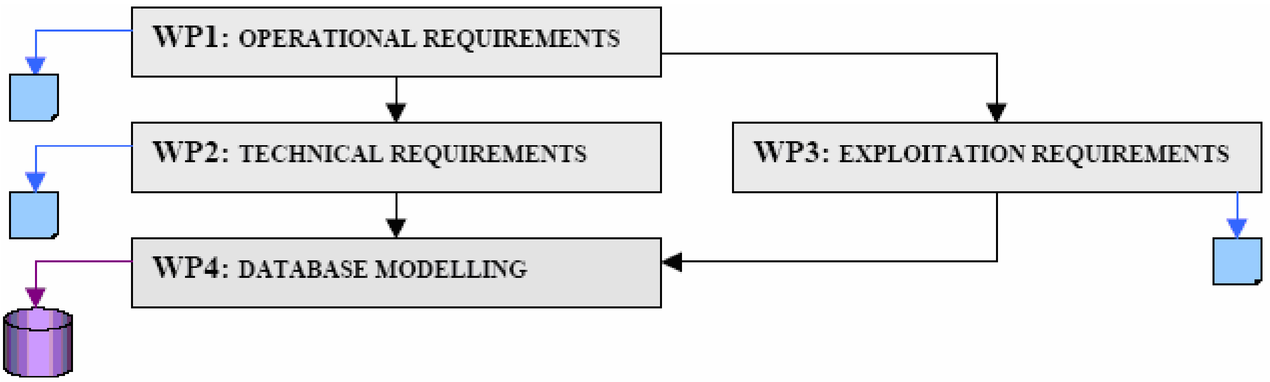


Figure 1 - Workpackages correlation

1.2.1 Technical Requirements (WP2)

Information for specific sources existing in the airport can be summarised by the antenna diagram, the wave polarisation and the emitted power. The diagram formulation should be obtained from far field computation, antenna specifications and / or validated by measurement of the radiated EM fields.

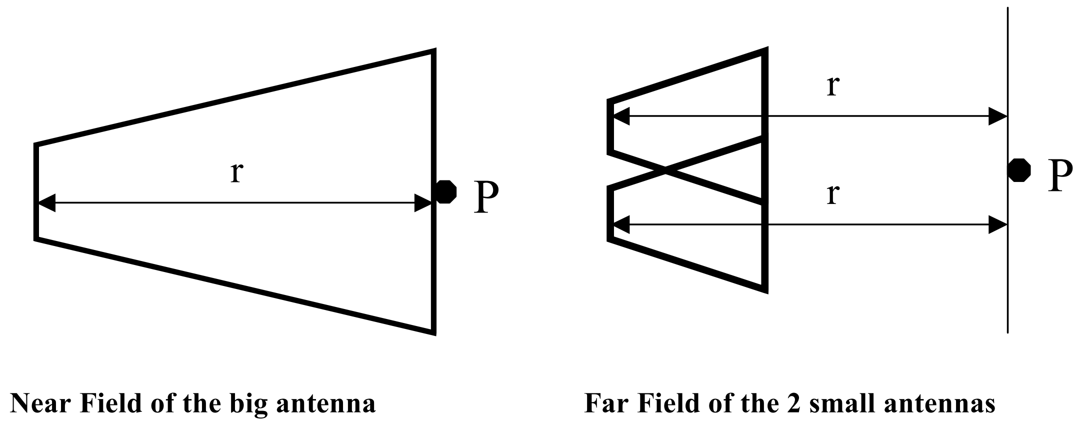


Figure 2 - Decomposition into elementary antennas

The distance from which, this condition of far field is established is proportional to the square of the size of the antenna and inversely proportional to the wavelength. If these requirements are not satisfied, one possibility consists in a specific subdivision of the whole antenna into "smaller" ones in order to reduce the far field distance.

1.2.2 Exploitation Requirements (WP3)

Aspects that deal with the identification of scenarios which possibly show limits of the simulation procedures, and/or are especially relevant for safety considerations were identified within WP3.

The second part of WP3 report laid out scenarios and measurements that will be performed during SIRENA project. Some of the simulated scenarios will also be measured in order to present a cross validation of the simulation software. Some additional tests will be performed in order to provide simple configurations that enable a physical understanding of the simulation versus real phenomena.

2 Analysis of requirements

Analysis of antenna systems that are well described is straightforward, if enough information is provided (type of antenna, analytical or numerical formulation).

More complex antenna structures can be evaluated as arrays of simpler antennas, making also possible the evaluation of near-field properties despite the employed asymptotic techniques limitations.

2.1 Antenna analysis requirements

Analysis of the radiation properties of an antenna array is straightforward as long as certain system characteristics are available:

1. Spatial configuration of the antenna array elements.
2. Array Factor (AF) can be analytically described for given geometries and phases.
3. Well defined complex excitation feeds (amplitude and phase).
4. Analytical or numerical description of the antenna element radiation properties.

In the absence of certain systems parameters knowledge, synthesis techniques can be utilized to obtain results within the constraints described by a set of design criteria.

2.2 Antenna synthesis requirements

Synthesis of antenna arrays consists of finding the complex excitations that produce a radiation pattern as close as possible to the desired one according to an established error criterion. Far-field synthesis can be achieved basically by two methods:

1. Varying the complex excitations of the array elements, having what is called a *fixed structure procedure*.
2. *A variable structure or fixed excitation*, in which the desired radiation characteristics are obtained for a fixed excitation by varying the geometric characteristics of the array.

For the SIRENA project framework it is sufficient to evaluate radiation pattern characteristics for fixed configurations.

It is also possible to classify synthesis in terms of the specifications of the radiation pattern in the far field. The phase of the far field can be defined as constant.

Power synthesis is more complicated than field synthesis but is also more important from a practical viewpoint.

Specifications of Blagnac airport equipment does not detail phase information (except for the cases of phased arrays). It is essential that the developed synthesis algorithms can also cope with the problem of power synthesis.

The complete problem of synthesis consists of two fundamental aspects. First, given the radiation pattern, determine exactly or approximately, the amplitude-phase excitations of each element that form the array. This procedure is known as the classical synthesis of the radiation pattern. These classical problems have been treated by methods (*Schelkunoff*, *Chebychev*, *Taylor*, and *Fourier*). However, it deals only with part of the whole problem and is in most cases inadequate for the problem at hand (Blagnac airport equipment).
The formulation of an objective function that evaluates design solutions against certain design criteria is in most cases a very difficult task. A generic algorithm of solving linear or quadratic system of equations is presented hereafter that produces satisfactory results (in most cases).

Due to the high overall complexity of the generalized synthesis problem, it was deemed that the simplest method to produce satisfactory results would be implemented. Good results were obtained for EM sources in the airport environment, employing techniques as simple as solving a system of equalities with the Least Squares Method.

2.3 Available tools (FERMAT / SPECRAY)

Special consideration should be given that the produced results of the analysis / synthesis are compatible with the input format of the FERMAT/SPECRAY tools. This is to ensure the inter-module communication of the complete software suite. There are two distinct implementations of the EM code within SPECRAY EM:

- The first one is a multistatic implementation.
- The second implementation is the monostatic one.

SPECRAY facilitates the loading of external evaluated antenna diagrams.

Horizontal and vertical aperture of the antenna can also be input (in degrees). If no vertical aperture is defined, the vertical aperture equals the horizontal one.

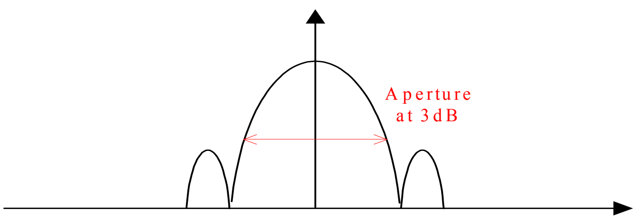


Figure 3 - Aperture definition at 3dB attenuation points

Also polarization of the radiated field can be defined (linear, circular and elliptic).

3 Software functionality

This section completely describes the functionality of the developed software. The array design problem is initially presented in a more formal way (analytical). Design of the antennas array requires the analysis of a given system thus the same formulation is valid for analysis.

3.1 Design problem formulation

Compilation of array design criteria is always dependant on particular systems under review. A typical problem might consist of finding the complex excitations of an array whose radiation pattern is specified by various *nulls* in definite positions, two or more *main beams* in specific angular positions, *side lobes with different relative levels*, or *control of the slope* of each main beam. In general, this is quite a difficult problem to solve with classical methods. Thus antenna array synthesis is formulated as an optimization problem subject to certain *restrictions*.

A general description of the array factor evaluation and derivative quantities is hence presented. The generality of the problem should give a good overview of the analysis and synthesis methodology, although further enhancements can be obtained when particular system characteristics are taken into account.

A *cost function* is formulated to guide the optimization process. The restrictions on the design parameters influence the process. It is difficult to find an antenna array design in which no restrictions are imposed. Two different strategies can be employed to incorporate the restrictions: transform the solution space of the design parameters without altering the cost function or modify the cost function by introducing some kind of penalty.

A more straightforward implementation is followed within the scope of the SIRENA framework that somehow lacks in generality but is able to produce satisfactory results: that of solving a *system of inequalities* with the classical method of *mean square error*. A clear distinction should be made between the cases of constraints imposed on the normalized diagram versus the logarithmic scaled diagram. That is essential because the problem of minimization becomes more difficult on the non-linear case.

3.2 Software specifications for Linear Antenna Synthesis Program

The purpose of the developed software will be dual: it will compute the EM fields emitted by existing antenna arrays in the airport environment as described in the scenarios and for the evaluation of sources that their electrical dimensions are comparable to EM radiation wavelength.

An overview of the proposed modular architecture is presented in the following sections.

3.2.1 Analysis Module – Antennas

The antennas can be divided into two basic categories based on the form of available data:

1. *Analytical models*: Analytical formulation for the computation of the EM fields exists for this type of antennas.
2. *Numerical models:* Horizontal and/or vertical radiation pattern cuts are given for antennas of complex geometries that no analytical solutions exists.

3.2.2 Analysis Module – Arrays

The requirements for the antenna array analysis modules are well described in previous sections. Within scope of the SIRENA project, *linear* arrays are mainly considered (and not *planar*).

3.2.3 Design module

Each required synthesis operation should be configurable based on the radiation characteristics of the EM source under study (synthesis specialization). Generalized design criteria can be defined in the form of:

1. Constraints as a system of inequalities
2. Nulls at certain angles in radiation patterns
3. Side-lobe suppression / generalized criteria

A set of design criteria has been compiled for each EM source that requires synthesis (determined by operational characteristics, radiation properties etc.).

3.2.4 Synthesis Module

Synthesis has been overviewed in the synthesis requirement section. Essentially the main task for fixed-structure optimization is the determination the complex excitation feeds (amplitude and phase) in order to yield desired radiation characteristics.

Fourier and Woodward-Lawson methods describe array beam-shaping based on the spatial Fourier transformation of the currents distributions (direct synthesis).

Schelkunoff's null steering method produces antenna patterns that possess nulls in desired directions (point- matching on radiation patterns described in general Antenna Synthesis Document).

There can also be used a more general methodology of applying restrictions on the computed radiation pattern, that lead to the formulation of a system of inequalities. This method is demonstrated in the ILS synthesis problem and can be solved by classical iterative methods.

Convex (quadratic programming) optimization can be used if there are no lower bound restrictions (non convex). This method was not implemented within the framework of the SIRENA project.

Stochastic methods such as GAs and Simulated Annealing have also been found to produce good results. These methods of optimization were not implemented within SIRENA project framework.

Determination of synthesis methodology should be particular to the antenna array modelled. Definition of a *system of inequalities* remains the most general methodology and easy to be implemented. Complicated methodologies were only considered if produced results were not satisfactory.

Software implementation of the synthesis library supports similar interfaces that enable the loading of the aforementioned design criteria. There is a coupling between criteria classes and synthesis methods.

3.2.5 Modules interface

Each software module (analysis, synthesis and design criteria) can have a graphical user interface counterpart (not required). Basic module functionality should also enable the input and loading of parameters, the output of the computed data to user selectable files based on the FERMAT/SPECRAY input format.

It should be emphasized that developing generic antenna array synthesis platform was *not* a SIRENA project requirement but the focus was on approximating EM sources in the airport environment. In other words the modules are loosely coupled based on their common input and output file formats.

4 Test cases

In this section results of analysis and synthesis are presented for key EM sources on the Blagnac airport. This review is designed to exhibit the functionality of the developed platform in terms of required performance and flexibility. A short review of systems operational functionality is hence presented.

4.1 Instrument Landing System (ILS)

ILS was the first case to be computed. This is the structure of the presentation of analysis and synthesis results:

- Presentation and discussion of analysis results.
- Presentation and discussion of synthesis results.
- Identification of specific design criteria.
- Discussion on the necessity of Glider synthesis.
- Discussion about validity of near-field calculations.

A numerical model was developed for the ILS *Localizer* module. Localizer module is used for the horizontal guiding of the aircraft with respect to the axis of the runway. An array antenna called *Glide* used for the vertical guiding of the aircraft.

The analysis effort was complemented by analytical models that were developed in MathCAD and Matlab and were used as the basis for the antenna software implementation.

4.1.1 Analysis

For the analysis of the ILS localizer module a preconfigured number of steps have been followed:

1. Results were computed with MathCAD for given excitations from ASERIS simulation.
2. Correlation with results obtained by Computational Electromagnetic Software.
3. “Proof of concept” implementation in Matlab.
4. Ground plane omission from calculations as a valid analysis approximation.

Radiation properties of the ILS localizer antenna array require a symmetrical feeding scheme of the elements.

Regarding the formulation of the AF the following propositions have been taken under consideration:

- Element and array coordinates are correlated.
- Specific mapping should be enforced to ensure proper translation of coordinates.
- This procedure is essential in order to produce valid 3D radiation patterns.
- Synthesis is done in 2D patterns and assumed to produce valid results for 3D patterns and near field calculations.

The following conclusions can be drawn by the analysis results:

- MathCAD results where very close to analytical and ASERIS simulation results.
- Theoretical analysis of the problem seems to be sound.
- Computation of the near field properties can be based on the vector sum of individual array components E-field values.
- The same analysis principles can be used in synthesis.
- Omission of the ground and reflector plane proved to be valid in terms of near-field calculations, especially considering the Physical Optics and Generalized Theory of Diffraction nature of EM kernel.

These results were also validated in CEM software. Some details of the simulation procedure and models are:

- Fully parametric model was fed by voltage source.
- Rectangular cross-section wires of arbitrary width were used.
- Open space radiation boundary conditions were used.
- Ground plane definition lead to serious results deviation.

Important observations regarding the simulation procedure are:

- Results were in accordance to theoretical formulation and ASERIS simulation.
- 3D radiation patterns provide a useful estimation of E-field spatial distribution.
- Optional evaluation of near-field properties is possible.
- Numerical results were streamed to Touchstone files and used for evaluation purposes.

4.1.2 Synthesis

The problem of synthesis has been introduced in two different contexts. Results were initially obtained in Matlab based on the use of constraints on the normalized gain pattern leading to the formation of a linear system of equations. The same idea was utilized in the Mathcad analysis but for the case of finding satisfactory solution of a non-linear system of equations.

The conclusions can be drawn from the Matlab synthesis results:

- Synthesized pattern obtains basic traits of original pattern.
- It retains main-lobes radiation properties while keeping a similar side-lobe suppression level.
- A more sophisticated method of synthesis can lead to more accurate results as it is later exhibited in MathCAD synthesis.

Non-linear search methods were employed because constraints are imposed on logarithmic patterns. As an alternative various stochastic, population-based or other multidimensional optimization techniques could also be considered for the problem at hand.

Summarizing:

- Synthesis produces results that closely match initial excitation values
- Values are normalized before computing their power rating
- Optimality of values found is confirmed by visual inspection of synthesized pattern.
- Best results were obtained when Conjugate Gradient was used.
- Synthesis produces results that closely match initial excitation values
- Values are normalized before computing their power rating
- Optimality of values found is confirmed by visual inspection of synthesized pattern

It can be assumed that fine tuning of parameters can lead to highly accurate results, if there is enough available data. Fast prototyping of other ILS localizer modules can also be accomplished only if a generic set of requirements is derived for each mode of operation.

ILS Glider analysis results can be summed up to the following points:

- Analytical formulation of Glider is based on these simple gain pattern constructs.
- Elevation angle of 3^o (descent angle) is the most important according to operational.
- Analysis based on radiating elements attributes is only required for near field computation.
- It is composed of a horizontally polarized $\lambda/2$ dipole on a perfect metallic reflector. Centre frequency is 330.2 MHz.

4.2 Microwave Landing System

There is close relationship in the functionality of ILS and MLS; azimuth and elevation modules roughly correspond to ILS localizer and glider modules. This system presents improved characteristics over ILS and it is though to be its successor. Some of MLS superior design features include a higher precision Distance Measure Equipment (DME/P) and reduced susceptibility to interference, while at the same time boasting higher capacity.

Azimuth station analysis requires the assumption of an antenna array of arrays. Elevation station analysis can be formed in terms of forming a vertical stack of planar dipoles. Finally distance measure equipment analysis is based on given data of excitation feeds.

In the azimuth station a fixed-phased vertical array of slotted radiators is used as radiating elements. The slots occupy the narrow-side of the waveguide. The result of this configuration is that the scanning beam presents a fixed radiation pattern along its wider dimension (vertical).

The MLS elevation station analysis is less complicated. Elevation antenna possesses omni radiation characteristics so it uses a simpler antenna design. It is composed by a linear array of dipoles. It has similar features to azimuth antenna except that the formed beam is oscillatory on the vertical direction. Fixed horizontal width of the beam is enough to cover the entire azimuth sector. Side-lobes scan at the main-lobe rate and are identified through amplitude comparison. A complementary sector antenna is used to transmit out of coverage identifications and other auxiliary information.

4.3 Radars

4.3.1 Description of the Radar Antenna Pattern Software

The radar antenna software is designed to generate an approximate 3D antenna lobe patterns for a limited number of rectangular radar antennas. The software has been developed as a result of the requirement for a radar antenna pattern for simulation of EMC in the SIRENA project.
The accuracy of the model is limited by the high frequency approximation giving the analytic model for the antenna and is only valid close to the main lobe. The intent of this program is to give an approximation of the antenna pattern of some typical radar antenna where few parameters are known, polarization and antenna dimension.

4.3.2 Descriptive radar antenna theory

In general the radar antenna comprises of a horn and a collimator, where the horn is radiating electromagnetic waves in the direction of the antenna. Depending on the orientation of the electric field transmitted from the horn, the polarisation is generally either vertical or horizontal – or combinations. The radiation is collimated in the direction of the antenna pointing direction, where the far field of the radiated pattern, is determined by the radiation properties of the feed antenna and the antenna size. Thus the antenna pattern can be determined analytically in some general cases. The solution is valid only in the vicinity of the main lobe and the first sidelobes.

4.4 GSM

Concerning the particular case of GSM ground stations, it is difficult to get information concerning each antenna structure. Currently, two frequencies of 900 MHz and 1800 MHz are in use. Only the maximum available radiating power can be known. In the scope of the SIRENA project a *Kathrein*

GSM antenna model was developed in CEM software and simulated to obtain radiation characteristics.