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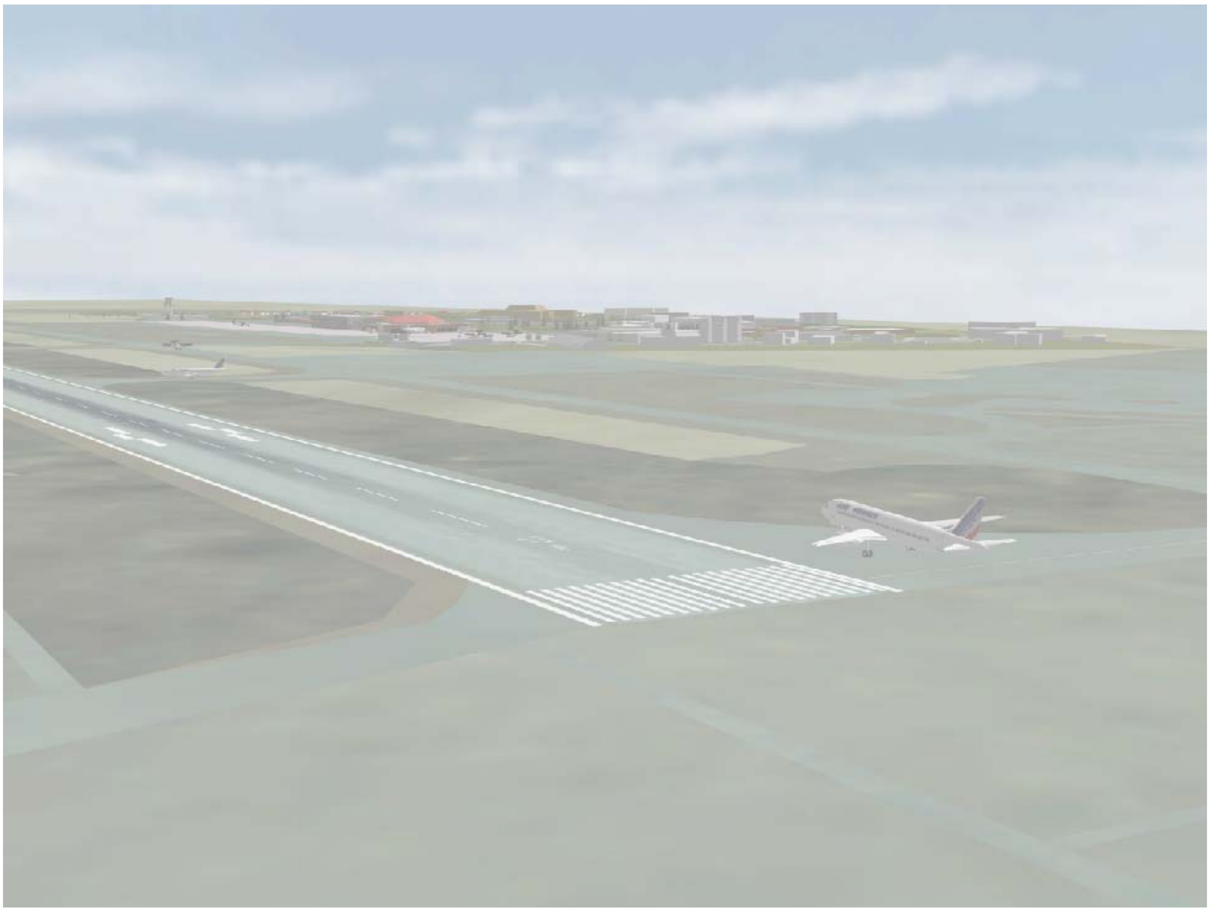
EM field computation



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INTRODUCTION

In previous workpackages, an automatic airport 3D modelling tool has been developed and led to the 3D mock up of Blagnac airport. In WP 4.2, the problem of EM sources modelling has been assessed. The database has been enriched with the different EM sources in the close environment of the airport specified by their power, polarisation and antenna patterns. The important sources, taken under consideration for SIRENA scenarios, have functional frequencies from 100 MHz to 1 GHz. In WP 4.3, in order to characterise every surface in the vicinity of the airport, classified categories of current materials and terrain have been provided with their electromagnetic properties..

This document describes the work performed on the SPECRAY EM/FERMAT simulation code in the scope of the SIRENA project. The objective is to define an efficient means in order to compute, from emitting sources at given frequencies and power, the EM field level at defined receiving points in given areas or volume.

PART I

1. Physical model presentation

The physical model research is guided by the technical requirements. The physical model is generic and associates different asymptotic formulations. Near field and far field scattering has been investigated and expressed in the same formulation.

High frequency asymptotic technique and shooting rays technique have been coupled in order to predict the scattering field from complex scenes. To evaluate the multiple interactions, each ray is followed from one part of the scene to another one. For meshed targets, two main methods are applied: Physical Optics (PO), for surface scattering, and Geometrical Optics (GO) coupled with previous method to take into account multiple interactions.

Contributions from all rays are summed up at the point of observation to calculate the final scattered field.

For edge diffraction, the Method of Equivalent Currents (MEC), the Uniform Theory of Diffraction (UTD) and the coupling between such methods and GO have been implemented. Thus, the scattering of intercepted surfaces throughout the multiple bounces, edge diffraction, reflection(s)-diffraction coupling can be considered.

Thus, this part of the document derived from theories of EM interactions physical models, aims at listing the different models of the electromagnetic domain used in SPECRAY EM. It presents all the formulas used to implement the model.

2. Architecture of the numerical simulation tool

This numerical simulation tool has the ambition to calculate scattered EM (ElectroMagnetic) fields at high frequencies, in a virtual 3D, geometrical and physical complex environment including natural and man made objects. EM fields calculations either on a surface or in a volume could be carried out according to specific applications. The observed complex scenes will be composed of CAD (Computer Aided Design) files or DEM (Digital Elevation Model) of terrain. From these files, millions of facets could represent these scenes.

To simplify the EM physical model, the EM model has been divided into several EM models as shown below: punctual, area, volume and edge models. The aim is to build a clear and modular EM model in order to ease future evolutions.

3. Conception choices

3.1. PO, GO formulations and phase reference

The chosen formulations are such as:

- the input field is defined as a virtual field at the interaction point,
- the output field is defined as the field at the next interaction.

Thus, the formulas for the reflection in near field coupling and the scattering in far field are adapted to this solution.

The incident half-distance can be calculated for the field at the previous interaction. The output half-distance can be substituted by the full-distance up to the next interaction.

This solution is in accordance with other equations (transmitting antenna, receiving antenna, backscattering speckle).

3.2. Coordinate base references

The coordinate base references are provided for:

- Area models
- Edge models

For the change of references, there are:

- **Incident reference:** The incident field is defined in its own reference. The equations are defined in a local reference. It is thus necessary to change from the incident reference to the local reference, which will be the current working reference.
- **Outgoing reference:** The electromagnetic model provides its own output reference in which the output field is defined.

3.3. The far field from the antenna

Geometrical Optics (GO) and Physical Optics (PO) are used to compute the interactions between the electromagnetic field and objects. Objects must be in far field from the antenna so that GO and PO assumptions are valid.

In the SPECRAY EM case, the largest dimension of the radiating element is the maximum dimension of the interaction of the incident beam formed by 4 elementary rays and the surface.
It is always possible to compute a field in the far field configuration using Physical Optics: when computing a field in an area closer from the source, the antenna is decomposed into a set of elementary sources, so that the PO assumptions are still valid.

4. Emitting Antenna model

The Transmitting antenna and the transmitter reference have been studied.

5. Receiving antenna model

This part of the modelling describes the steps that lead to the formulation of the equivalent resulting scalar electric field in the centre of phase of an antenna with unspecified polarisation in the presence of multidirectional and multipolarisation incident waves. It is assumed in this part that any near field scattering has been suitably processed by an adapted subdivision of the surface of interaction. So, we only consider the far field behaviour of the incident fields.

5.1. Propagation equation

It translates the power collected by a receiving antenna according to the radiated power, the gain of the emitting antenna and the distance between the two antennas:

5.2. Polarisation coupling

5.2.1. Receiving antenna polarisation

According to the IEEE standard, an antenna polarisation is always defined (even in receiving mode) by the emitted polarisation of this antenna.

5.2.2. Incident wave – receiving antenna coupling

Introduction

The equivalent received power density is obtained by multiplying the incident power density by the receiving antenna gain in the considered direction.

In other words, the modelling of the antenna behaviour is equivalent of an “isotropic” antenna.

Elementary TEM incident wave

An elementary TEM wave is incident to the receiving antenna according to a given direction of the antenna reference.

5.3. Power and voltage through the transmission line

The received power is transmitted to measurement device through a transmission line. Losses mismatch between the input antenna impedance and the line impedance have to be taken into account.

6. Electromagnetic interaction implemented models

6.1. Surface models

- Physical Optics for dielectric and metallic scattering in far field Application domain
- Backscattering of the clutter (Speckle)
- Geometrical Optics specular reflection in near field
- Scattering in near and very near field (In specific scenario dealing with complex scenes, volume computation in very near (in order of wavelength) field formulations are required).

6.2. Edge model

- Method of Equivalent Current for metallic edge diffraction
- Generalised MEC for dielectric edge diffraction

NOTE: Notations and references used to compute the diffracted field by the edge of a dielectric dihedron are the same as those defined for a metallic dihedron.

6.3. Volume model

- Atmospheric attenuation

7. Modelling of curved surfaces in GO with Specray EM/FERMAT

7.1. Introduction

When dealing with such surfaces, the first idea is to bypass the difficulty in using very fine meshing of the objects. Good results could be obtained when simple interaction has to be computed on these objects. But, if multiple interactions have to be taken into account, the divergence of the intermediate GO interactions could not be neglected anymore.

Formulations enabling to take into account the divergence of rays have been developed. In order to validate the development a specific test case has been defined under the acronym PLACYL. It aims at validating the accuracy of FERMAT in taking into account curved surfaces and dihedral effects. The geometrical modelling is an approximation of real geometries existing in SIRENA scenarios, but is still representative of the kind of interactions that occur in the scene.

The model and its dimensions have been designed so that it is compliant with various codes using different computation methods.

7.2. Description of the existing code

The version of FERMAT, existing at the beginning of the SIRENA project, does not take into account the geometrical divergence. In order to assess the accuracy of this model, the signal resulting from rays reflected by a cylinder and then scattered by a plate has been computed in two ways: with and without taking into account divergence on the plate.

7.3. Curvature model with SPECRAY

Classically in EM, one models interactions with curved surfaces with curved waves. The curvature of the incident wave is altered by the interaction.

The use of curvatures is difficult with SPECRAY because geometry is modelled with polygons, with vertex normals, with quite accelarerates computation times. Normals can be interpolated, but this is not sufficient to deduce exact curvatures.

The divergence coefficient in GO is purely geometrical and the surface elements managed by SPECRAY are small enough compared to the curvature (anti-aliasing). It is better to calculate the divergence using the ratio of apparent surfaces at the beginning of a beam.

It has been checked, in PLACYL test case, that this formula leads to the same result than the classical divergence formulation depending on curvatures.

The results of computations with this method have been compared with the “surfaces ratio” method.

When managing the divergence with the “surface ratio” method, the advantage is to get rid of the problem of the reflected wave’s main axis configuration.

The only assumption that remains is that there is no caustic in the simulated scene.

The accuracy of the meshing has a poor influence on the accuracy of the results. A computation with a sampling of 1° and 20° (with respect to PO criterion) leads to almost the same result, except for the part where the signal is low. This part corresponds to the dihedral part at the back of the plate, where interactions GO (plate) GO (cylinder) PO do not occur, apart from some high incidence interactions on the cylinder. A mesh of 1° means that the cylinder is facetted in 360 plates and a mesh of 20° corresponds to 18 facets model of the same cylinder.

7.4. Conclusions

This preliminary study leads us to draw the following conclusions:

- The management of curved surfaces with SPECRAY EM/FERMAT can be done with GO using a simple “beam surface” ratio method.
- The knowledge of surfaces curvature is not required with this method.
- This method can be applied to any surface for which normal vertices are known.
- The requirements in terms of accuracy of the meshing are poor, as shown in the test case.
- The accuracy of the meshing depends on the normals angular variation.
- It is assumed that the scene does not contain caustics.

7.5. PLACYL test case

Diffraction of a plane wave by a set of perfectly conducting half sphere and cylinder located over a perfectly conducting finite surface

For the test case PLACYL, the previous CAD geometry has been meshed into:

- facets
- diffracted edges.

The interactions of the rays with the geometry are calculated taking into account the factor of divergence.

The source is considered as a plane wave; in fact it is a spherical wave far (10 000 m) from the object.

If necessary, up to 6 GO (reflections) are used before a PO surface scattering or a MEC edge diffraction computation.

The time for up to order 6 calculation is less than 3 min.

PART II - MULTIPLE RECEPTION POINTS OPTIMISATION

8. EM contributors optimisation

The “shooting ray” technique, or “forward ray tracing” technique, is well adapted to the high frequency electromagnetic purpose. A set of rays representing the incident plane wave is shot toward the observed area composed by object facetted in triangles. More specifically, from a point of emission, this area is included in a cone in which elementary tubes of four rays are launched. Every tube is defined so that its intersection with the object constitutes a planar surface.

Time consumption has to be optimised. Even if current performances are nearly independent on scene complexity. To do this, the ray tracer uses a spatial subdivision method, which enables to get a perfect knowledge of the scene topology before computing the first image. An efficient method, with regard to physical requirements, is the adaptive one. The idea is that the density of rays is proportional to the local 3D complexity.
The most important antialiasing criteria are the number of different polygons in the ray spot, the number of different materials, and the normal vector variation within the ray spot.

This optimisation aims at reducing computation time of an EM simulation. Indeed, the model is assessed for each emitter of the scene. When the EM model calculation is significant regarding to the whole simulation time, it becomes an interesting optimisation.

8.1. Constitution of groups of unaliased pixels

Contributors are surface elements that have received an EM field and that scatter this field towards reception points.

Contributors are defined when sampling the scene through a grid of pixels, using the ray tracing technique.

In order to solve the problem, SPECRAY uses an « adaptive anti-aliasing technique » that consists in refining a grid, initially regular, into an irregular grid which more detailed where objects and details are located. With this technique, the amount of contributors is not the square of the resolution increase.

The technique of contributors grouping is all the more interesting in the case of a real scene. Indeed, even though adaptive anti-aliasing reduces notably the number of pixels, it is based on the refining of a regular grid. The grid’s resolution has to be small enough to include all important elements of the scene. Anti-aliasing will reduce the size of the grid in order to ‘catch’ all details of objects, but we assume that the initial grid has included all objects. Thus, for a real scene, a minimal sampling should be defined, in order to include all possible contributors.

Even though this primary sampling is compulsory yet, an important optimization consists in merging all homogeneous and contiguous contributors.

In the scope of SIRENA, a method has been implemented in order to perform this operation.

9. Filtering of the ‘poor contribution’ contributors

Another optimisation consists in removing from the calculation all contributors that do not have a significant contribution.

Assuming that most of the EM field at one location is induced by direct field contribution and near specular reflections, all other contributions can be removed.

9.1. Angular criterion

A first attempt consisted in using a contributor’s filtering depending on the angular deviation from the specular direction.

Results of these tests revealed to be deceiving. The quality of the result is not correlated with the level of filtering, and even a weak filtering can lead to bad results. This can be explained by the fact that even if contributors are all weak, their global phase coherence can create an important field. Thus, contributors can not be removed without taking their phase into account.

9.2. Optical path difference criterion

Considering the results, it seems better to use the concept of optical path difference compared to the specular path.

This solution meets the requirements, because:

- all contributors with the same optical path difference have the same phase
- the greater the optical path, the further from the specular direction
- the further from the reception point the contributor is, the faster the optical difference changes
- the nearer the contributor is, the less its optical difference changes.

Filtering contributors using their optical path difference is equal to:

- keep or remove all contributors with the same phase
- keep or remove all contributors located near or very near one from each other
- remove all distant contributors, excepted for the ones in the specular direction
- for an equivalent distance, remove contributors far from the specular direction.

9.3. Dichotomy

The aim of the filtering is to get rid of weak contributors with regard to the reception point. But this could become a very long operation in the case of multiple reception points.

Thus, it is necessary to remove entire groups of contributors with one single test.

When the optical path difference, minus the bounding volume, is greater than the optical path difference threshold, the whole volume of reception points can be removed.

9.4. Adaptive criterion for optical path difference

The optical path difference criterion is solely based on the configuration of a contributor regarding to the specular direction, which is a defect. In the case of a dihedron with an angle of 100°, there can not be contributors in the vicinity of the specular direction.

In order to enhance this method, the best optical path difference is stored for each reception point, and contributors are filtered regarding to this value.

10. Optimisation of the contributor's visibility assessment

Calculation of contributor's visibility towards reception points is critical for the computation time.

The computation time is linearly dependent on the amount of reception points. This would lead to months or years of computation in the case of SIRENA.

Also, due to the computation time issue, each ray can not be anti-aliased depending on the visibility of each reception point.

Thus, a good compromise has to be found in order to enhance the accuracy and decrease computation time.

10.1. General principle for the visibility optimisation

Basically, this consists in processing couples, and finding among them the widest/biggest elements for which the mutual visibility can be accurately assessed.

Two methods have been assessed for the computation of the visibility:

- a statistic method
- a deterministic calculation based on electromagnetic considerations.

10.2. Statistic visibility computation

A volume emits "visibility photons" in the scene. A white impact is marked at the first intersection. Then the photon is transmitted by the previously impacted surface, and the next intersection, is marked with a black impact.

The result of the emission is a map of photons impact in the scene. In order to assess the field emitted from a contributor towards a volume element, the visibility percentage is calculated using the ratio of white impacts by the total of impacts, for the contributor.

The criterion that stops the sampling (volume, surface) is based either on the majority of black or white photons, or on the small dimension of volume and surface.

The choice of the volume or surface sampling is based on the distribution of photons on the surface, and from their source in the volume. If black and white photons are not homogeneously distributed on the surface, the surface should be sampled consequently. If black and white photons come from different portions of the volume, it needs to be sampled consequently.

The implementing cost of such a method, as well as the technical risk, lead us to look for another solution based on electromagnetic assumptions.

10.3. Electromagnetic computation of the visibility

This solution is based on the following assumptions:

- Volumes are quite small in terms of occlusion, many reception points can be considered as identical regarding to the occlusion.
- The more important a contributor is, the more sensitive the final result will be.
- Even though a set of coherent contributors has a poor weight in the final signal, contributors can be individually weakly altered by occlusion, in particular when an object's boundary shades a part of contributors.

Then, it is possible to define an occlusion accuracy, which changes as a function of the optical path difference regarding to the virtual optical path from the virtual emitter to the receiver.

11. Contributors calculation optimisation

Once the number of contributors has been reduced and the occlusion calculation optimised, the remaining time consuming process is the OP contributors computation. Despite these calculations are optimized, the computation time is related to the numerous complex arithmetic operations.

The optimization consists in the following assumption: the field variation is weak in a volume located around the reception point, and thus can be extrapolated for a set of reception points.

12. Assessment of the optimisation criterion: performances and accuracy

The optimisations aim at reducing the simulation time in a multi-reception points computation. But some of them have a direct impact on the accuracy of results.

The computation time tendencies can be analysed depending on the different optimisation parameters. Then, starting from a computation with a poor accuracy, the computation time with more accurate optimisation parameters can be deduced.

13. Validation tests

Three test cases are used to assess the optimisation criterions. These cases are representatives of interactions to be simulated in SIRENA:

1. Test: plate with occlusion
2. Dihedron with occlusion
3. Trihedron with occlusion

Plates dimensions are 40 lambda wide, which is the maximum dimension of an object that can be built with a strictly plan surface.

Qualitative tests are performed along a vertical axis, located at the centre of the reception surface.

Performance tests are performed with volumes of various size and density, for which the front face is coplanar with the reception plan.

14. Filtering of occlusion

The following parameters vary:

- The occlusion filter (aims at improving both the computation time and accuracy of results)
- The source orientation (30° incidence, 60° incidence)
- The test case (among plate, dihedron, trihedron).

Of course, the results of a standard simulation would be less sensitive to the accuracy of occlusion computation since they would include the direct component of the field.

14.1. Qualitative conclusion concerning occlusion filtering

Occlusion is a complex phenomenon. Transition areas between "shadow" and "light" are sensitive to the occlusion accuracy. This sensitivity decreases when the scene and the object interactions are more complex because other signals have also a contribution.
A future investigation could be focused on reception areas sensitive to occlusion variations.

A method could consist in performing twice the same computation with two different occlusion accuracies.

15. Occlusion filtering performance

The tests are performed for:

- The Plate case
- The Dihedron case

16. Optical path difference filtering

The following parameters vary:

- The OPD (Optical Path Difference) Filter.
- The source orientation (30° or 60°).
- The test case (among plate, dihedron, trihedron).
- The kind of computation (with or without direct field).

16.1. Qualitative conclusion concerning the optical path difference filtering

The effect of this filtering is conform to expectations:

- the accuracy of the signal is less outside the specular area, but remains good inside
- the filter parameter value can be quite small, and remove a lot of contributors without decreasing the accuracy of the signal.
- when the computed field has a direct field component, the discrepancy due to the filtering is negligible
- 25 lambda is a good filtering value .

Also, new possibilities of future optimizations have been identified:

- decrease the filtering parameter value when a direct field component is detected
- decrease the filtering parameter value according to the amount of specular optical paths that reach a reception point
- use a greater initial filtering parameter value in order to better process points outside the specular area.

16.2. Optical path difference filtering performance

- Plate test case :
  The filtering is intended for a wide dimension scene, in particular, it enables simulations with multiple reception points.

- Dihedron test case :
  This test confirms that the volume with 2m edge is located in the specular direction, since the optical path difference filtering is less efficient for this volume.

17. Field approximation

In the present code, the field approximation works only when several reception points can be computed together.

For the following test, the occlusion filtering has been stopped so that all reception points are computed in the same visibility group. The tests concern:

- Plate, 30°
- Dihedron, 30°
- Trihedon, 30°

Conclusion about field approximation : This method has satisfying results.

17.1. Field approximation performance

The density of reception points should be high compared to the distance with contributors, so that the field approximation is being efficient.

18. Conclusion on the possibility of optimisation

In conclusion, computation time of simulations requiring a high number of reception points has been improved. This improvement uses several techniques, that complete each other. These optimisation techniques have to be parameterised by the user. The user can then choose between time performance versus quality. The artifacts due to the optimisation are generally localised on parts of the computation volume where there are some transitions from occulted areas to visible areas (occlusion filter artifact) or where there are no powerful contributors (Optical Path Difference filter artifact). Even if the parameterisation favours performances, the main part of the signal is kept.

The computation time is not directly evolving with the number of contributors anymore. It is mainly sensitive to the size, the location and the density of the reception volume. A good way to avoid very long computation time is to use first low quality parameterisation to get a first idea of the result quality and computation time. If the result is not satisfying, then a better quality parameterisation on the whole volume or only on a part of the volume is required.

CONCLUSION

This document describes the work performed on the SPECRAY EM/FERMAT simulation code from OKTAL SE in the scope of the SIRENA project. An airport 3D modelling tool led to the 3D mock up of Blagnac airport, enriched with the different EM sources in the close environment of the airport.
The EM field computation work package is in charge of defining an efficient means to compute all the possible EM energy paths with the 3D scene from sources to reception points included in a given volume.

The objective is to define an efficient mean in order to compute, from emitting sources at given frequencies and power, the EM field level at defined receiving points in given areas or volume.

A special packaging of SPECRAY EM, with specific adjustments, enabling to compute EM field at any location in the scene and, specially, close to a selected aircraft, in the vicinity of the airport is now available.