Scattered Electromagnetic Field Variations due to Building Facade Properties

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Abstract

A computation method based on the Green's functions associated with the interface between two semi-infinite media is used to obtain the scattered electric field in the near and far zones of a building. A simplified model taking account of the inhomogeneities on the building facade is considered. Different sources of uncertainty for the scattered electric field related to the building facade are presented, such as the main material property, the size, type and distribution of windows. An appropriate statistical distribution is attributed to each varying parameter and the influence on the scattered field from the facade is quantified.

1. Introduction

The wireless communications play an increasing significant role in telecommunications worldwide. Particularly the mobile networks experienced a great expansion recently. These networks are very dense in urban areas and the electromagnetic field distribution is highly dependent on the structure of the city: density, shape and nature of buildings. While a sustainable mobility and an optimum coverage are required for a reliable network, the constraints on the human exposure take an important place in today's research studies [1, 2]. To meet these multiple issues, it is essential to have predictive tools to assess as accurately as possible the distribution of electromagnetic fields in order to enable optimized implementation of base stations and to minimize both the dissipated and the radiated power of wireless systems. Wave propagation simulators are based on different models each with an appropriate calculation method and different assumptions concerning the building architectural details [3–5]. As the urban environment is complex and variable, a practical and rapid analysis of wave propagation requires a simplified model, it is thus necessary to limit the complexity of the description of buildings. A simplification is realistic only if less influent parameters are neglected in the model. A good knowledge of each parameter influence on the radiated EM field, allows the implementation of suitable approximations which speed up the computation while maintaining acceptable accuracy. Furthermore, the exact specifications of all buildings in a city cannot possibly be known and the influential parameters varying from one building to another are numerous. Therefore the environment can not be completely described by a simple deterministic model [6]. As the environment is approximately described, the simulated field can be predicted with a limited accuracy. It is thus important to interpret the results, to assess the associated uncertainties.

Here, we propose a model which takes architectural details on building facades into account and use a computation method based on the Green's functions associated with the interface between two semi-infinite media [7]. The method is able to give the scattered EM fields in different diffraction regions of a building facade with a good accuracy. We then insert the random concept into some input parameters, particularly here the main material permittivity, the size, the distribution and the type of windows, in order to quantify the influence of the parameters on the output variable which is the reflected electric field by buildings.

2. Statistical Studies

Sources of uncertainty for the scattered electromagnetic field are abundant in urban environment. We thus restrict ourselves to those arising from the building faces which influence only the reflected/scattered field. We can identify several parameters related to the architecture of buildings whose variations can influence the scattered field and thus create an uncertainty on the average calculated field. Some of these architectural parameters are: permittivity of the main material (ex. concrete) and the heterogeneities (ex. windows), type of windows (thickness of glass, number of slabs), dimensions and distribution of windows. The variation of one or more of these parameters, on a building (for example by a frequency change or due to an insufficient knowledge of the exact properties) or from one building to

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another, can cause some large or small modifications in the wave propagation in the vicinity of buildings. These influences vary according to different conditions such as incident angle, wave polarization and observation distance.

2.1 Main Material Permittivity

A generic building facade (12 m × 12 m) is shown in Fig. 1(a). This facade is mainly made of concrete with some windows made of glass. The electric characteristics of concrete or other masonries such as stone or brick are variable, specially the concrete complex permittivity depends on different parameters such as frequency, moisture ratio and fabrication process. The main material permittivity can thus be a source of uncertainty for the scattered electromagnetic field and can be considered as a random variable.

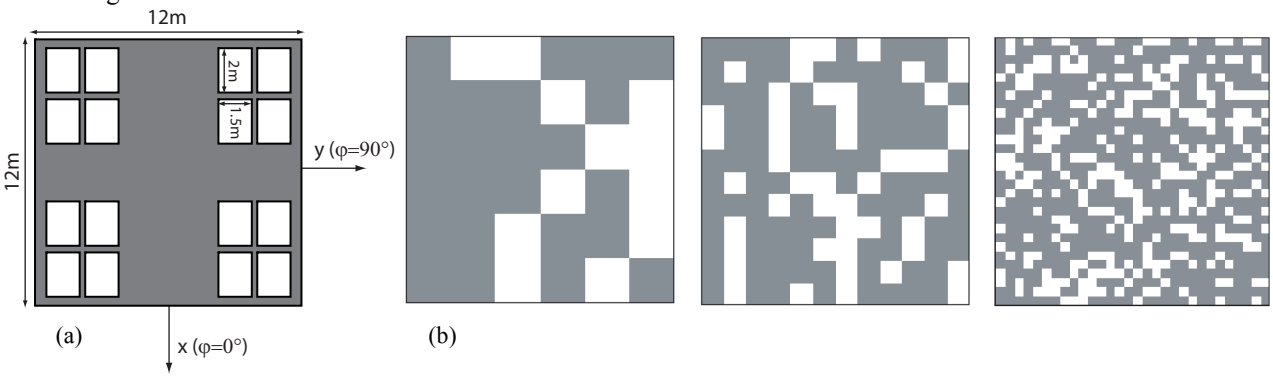

Fig. 1 (a) Generic concrete-glass building facade (b) Randomly generated building facades with 2 m × 2 m, 1 m × 1 m and 0.4 m × 0.4 m windows representing 33% of the total surface

We can simulate a category of buildings with a standard concrete type, thus with a nominal value for the concrete permittivity and some dispersion related to frequency variations or climate conditions. We suppose that the dielectric constant varies randomly following a normal distribution with a mean of 6.13 and a standard deviation of 0.25. Contrarily, in order to simulate all types of concrete with different raw materials and moisture ratios or other main materials existing in urban constructions, we assume that the uniform distribution is more appropriate. We suppose that the concrete permittivity varies uniformly between 2 and 9. These values are extracted from different documents concerning the concrete used in urban constructions [8–10]. The loss tangent is considered constant and equal to 0.02.

The windows (2 m × 1.5 m) are single glazed with a glass permittivity of 5.5 and a thickness of 10 mm. The facade is illuminated in zOy plane by a TE polarized plane wave at 900 MHz (|Ex|=1 V/m) both in normal and oblique incidences. For the given incidence angles (θ_i=0° and 30°) and polarization, the single glazed window, from the reflection point of view, is equivalent to a dielectric of infinite thickness with the equivalent permittivity of ε_{req}=0.62+j2.05 in normal incidence and ε_{req}=0.52+j1.79 in oblique incidence [11]. For 1000 samples of the concrete permittivity, the reflection coefficient is observed at 300 m from the facade and the values are recorded for both incidence directions: the main lobe (at θ_r=0° and 30°) and the first side lobe (at θ_r=2.4° in normal incidence and 32.8° in oblique incidence). The coefficient of variation (CV), a measure of dispersion, is defined as the ratio of the standard deviation to the mean. The coefficients of variation of the reflection coefficient, as well as the mean values in the case of normal distribution and the extreme values in the case of uniform distribution, are presented in Table 1. We conclude that the change in the permittivity of the major material of the facade affects:

- the main lobe of the reflected field more than the side lobes;
- the overall radiation pattern in normal incidence slightly more than in oblique incidence.

Table 1. Coefficient of variation of the scattered electric field for the main material permittivity change at 300 m from the facade

Incidence angle	Specular reflection θ_r=0° and θ_r=30°	Non-Specular reflection θ_r=2.4° and θ_r=32.8°
	Normal distribution N(6.13,0.25)	
θ_i=0°	1.4% ($E_{r\text{-}mean}$=0.5 V/m)	0.9% ($E_{r\text{-}mean}$=0.08 V/m)
θ_i=30°	1.2% ($E_{r\text{-}mean}$=0.49 V/m)	0.6% ($E_{r\text{-}mean}$=0.09 V/m)
	Uniform distribution U(2,9)	
θ_i=0°	15% ($E_{r\text{-}min}$=0.30,$E_{r\text{-}max}$=0.56 V/m)	10% ($E_{r\text{-}min}$=0.07,$E_{r\text{-}max}$=0.11 V/m)
θ_i=30°	14% ($E_{r\text{-}min}$=0.31,$E_{r\text{-}max}$=0.55 V/m)	7.2% ($E_{r\text{-}min}$=0.08,$E_{r\text{-}max}$=0.11 V/m)

This result reveals on the one hand that the simulators cannot use a fixed reflection coefficient for all types of building in urban environment and on the other hand, that when the category of concrete is defined, the simulators can use the nominal values of concrete permittivity while taking account of the uncertainty this permittivity value will bring on.

2.2 Distribution of Windows

Consider randomly created building facades (12 m×12 m) in Fig. 1(b) with the same material properties as the building in Fig. 1(a) and the same percentage of glass (33%) distributed differently on the surface. We consider three possible dimensions for windows: 2 m × 2 m, 1 m × 1 m and 0.4 m × 0.4 m. In order to quantify the influence of the distribution of windows, we generate 3000 samples of each type of random profiles. Even if the generated profiles do not look like a realistic building facade, the aim of this study is to push the case to its extreme, in order to observe the influence of architectural details distribution. The facades are illuminated by a TE polarized plane wave in normal and oblique incidences and the total reflection coefficient is observed at 300 m, 100 m and 10 m in specular and non-specular directions. The coefficients of variation of the reflection coefficients are presented in Table 2. At 10 m form the building face (near-field), the variation of the reflection coefficients is so strong and variable that we cannot find a general rule concerning the influence of windows distribution. In this region a precise description of windows size and position is necessary. For other regions, with slow variations of reflected field, we conclude that:

- for any window size, the side lobes of the reflected field, in normal and oblique incidences, are more sensitive to changes in the distribution of windows than the main lobe;
- the reflected field in normal incidence is slightly more sensitive to changes in the distribution of windows than in oblique incidence;
- any variation decreases when the window size decreases;
- any variation decreases when the observation distance increases.

These results are very important for simulators using homogenization techniques for field calculation. Thereby the homogenized facades give more realistic results if they are far from the observation zone specially if the inhomogeneities are small. Otherwise the actual position of inhomogeneities turns to be influential on the total reflection coefficient. Fig. 2 confirms this tendency by showing the reflected field from a homogenized building facade as a function of the observation distance compared to that of 5000 randomly created profiles with 2 m × 2 m windows in three diffraction zones.

Table 2. Coefficient of variation of the scattered electric field for windows distribution change at three different distances from the facade

	Observation distance 300 m		**Observation distance 100 m**		**Observation distance 10 m**	
Incidence angle	Specular reflection θ_r=0° and θ_r=30°	Non-Specular reflection θ_r=2.4° and θ_r=32.8°	Specular reflection θ_r=0° and θ_r=30°	Non-Specular reflection θ_r=2.4° and θ_r=32.8°	Specular reflection θ_r=0° and θ_r=30°	Non-Specular reflection θ_r=2.4° and θ_r=32.8°
	2m×2m windows		2m×2m windows		2m×2m windows	
θ_i=0°	2.8%	23%	13%	21%	20%	15%
θ_i=30°	2.1%	24%	8.3%	23%	16%	21%
	1m×1m windows		1m×1m windows		1m×1m windows	
θ_i=0°	1.4%	13%	7.2%	13%	36%	33%
θ_i=30°	1.0%	12%	4.4%	13%	31%	32%
	0.4m×0.4m windows		0.4m×0.4m windows		0.4m×0.4m windows	
θ_i=0°	0.6%	4.8%	3.0%	5.2%	31%	28%
θ_i=30°	0.4%	5.2%	1.9%	5.6%	27%	25%

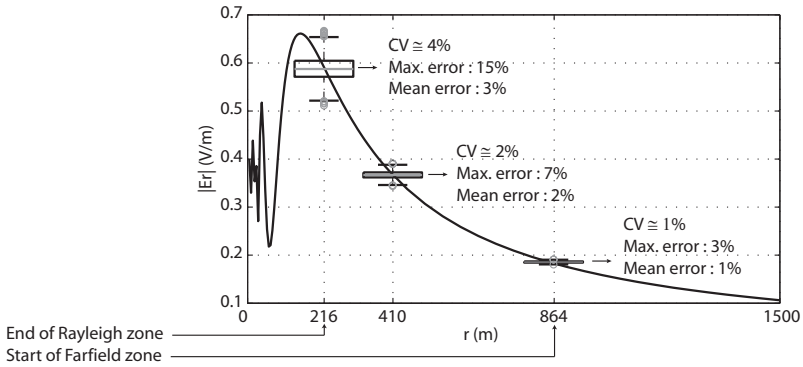

Fig. 2 Reflected electric field from homogeneous facade and detailed randomly created samples with large windows

2.3 Thickness of Windows

Suppose that the thickness of the simple glazed windows on the facade of Fig. 1(a) varies randomly following a uniform distribution U(1mm, 20mm). Each thickness value leads to a complex equivalent permittivity with a non-linear transformation according to the formulas presented in [11]. It is important to note that the thickness variation of glass distorts the radiation pattern of the building and we cannot get an angle which corresponds to the first side lobe of the radiation patterns for all thickness values. Therefore, in the results presented in Table 3, the angles in non-specular reflection column do not represent the first side lobe for all thickness values; this results in a very large coefficient of variation. We conclude that the change in the thickness (type) of windows:

- influences visibly the main lobe of the reflection coefficient;
- turns the behaviour of the reflected field in non-specular directions unpredictable.

Table 3. Coefficient of variation of the scattered electric field for windows thickness change at 300 m from the facade

Incidence angle	Specular reflection	Non-Specular reflection	
	$\theta_r=\theta_i$	$\theta_r=\theta_i$ +2.5°	$\theta_r=\theta_i$ +3.5°
	Uniform distribution U(1,20)		
θ_i=0°	16%	60%	9.2%
θ_i=30°	16%	60%	16%

This conclusion shows that the simulators should take into account the characteristics of windows as the major inhomogeneities on the building facade in order to have an accurate description of the reflected field.

3. Conclusions

Some of the sources of uncertainty for the scattered electromagnetic field from a building facade are studied. The coefficients of variation of the scattered E field are calculated as a result of a statistical distribution attributed to an input parameter. The results highlight the sensibility of the field to a change in a given architectural parameter. The results permit pertinent choices of model simplifications in wave propagation simulators and to evaluate the uncertainty of the evaluated fields in urban environment.

4. References

1. P. Bernardi, M. Cavagnaro, S. Pisa, and E. Piuzzi, “Human exposure to radio base-station antennas in urban environment,” *IEEE Trans. Antennas Propagat.*, vol. 48, pp. 1996–2002, Nov. 2000.
2. P. Bernardi, M. Cavagnaro, R. Cicchetti, S. Pisa, E. Piuzzi, and O. Testa, “A UTD/FDTD investigation on procedures to assess compliance of cellular base-station antennas with human-exposure limits in a realistic urban environment,” *IEEE Trans. Microw. Theory Techniques*, vol. 51, pp. 2409–2412, Dec. 2003.
3. S. Y. Seidel and T. S. Rappaport, “Site-specific propagation prediction for wireless in-building personal communication system design,” *IEEE Trans. Veh. Technol.*, vol. 43, pp. 879–891, Nov. 1994.
4. O. Landron, M. Feuerstein and T. S. Rappaport, “A comparison of theoretical and empirical reflection coefficients for typical exterior wall surfaces in a mobile radio environment,” *IEEE Trans. Antennas Propagat.*, vol. 44, pp. 341−351, March 1996.
5. P. Pongsilamanee and H. L. Bertoni, “Specular and nonspecular scattering from building facades,” *IEEE Trans. Antennas Propagat.*, vol. 52, pp. 1879–1889, July 2004.
6. M. F. Iskander and Z. Yun, “Propagation prediction models for wireless communication systems,” *IEEE Trans. Microw. Theory Techniques*, vol. 50, pp. 662–673, March 2002.
7. S. Mostarshedi, E. Richalot, J.-M. Laheurte, M.F. Wong, J. Wiart, and O. Picon, “Fast and accurate calculation of scattered EM fields from building faces using Green’s functions of semi-infinite medium,” *IET Microw., Antennas Propagat.*, vol. 4, pp. 72−82, Jan. 2010.
8. M. Adous, “Caractérisation électromagnétique des matériaux traités de génie civil dans la bande de fréquences 50 MHz–13 GHz, ” *PhD thesis*, Université de Nantes, Nantes, France, 2006.
9. A. Robert, “Dielectric permittivity of concrete between 50 MHz and 1 GHz and GPR measurements for building materials evaluation,” *Journal of Applied Geophysics*, vol. 40, pp. 89–94, Oct. 1998.
10. R. H. Haddad and I. L. Al-Qadi, “Characterization of portland cement concrete using electromagnetic waves over the microwave frequencies,” *Cement and concrete research*, vol. 28, pp. 1379–1391, Nov. 1998.
11. S. Mostarshedi, E. Richalot, and O. Picon, “Semi-infinite reflection model of a multilayered dielectric through equivalent permittivity calculation,” *Microw. Optic. Technol. Letters*, vol. 51, pp. 290−294, Feb. 2009.