SCATTERING COEFFICIENTS OVER 3-D FLAT DIELECTRIC SURFACES

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Abstract: Indoor radio channel planning tools implement different models to simulate propagation mechanisms as transmission or reflection. Specular reflection formulation is commonly used instead of more complex scattering models, as that is easier programmed as well as it is faster than scattering. In this work, results from measurements are presented, and modelled by means of traditionally reflection procedures, as well as by applying scattering pattern computations. Beckmann's scattering model is used as it was formulated, and then modified to take into account antenna pattern effects in the measurements. Comparison between measurements and simulations are also presented, showing good agreement.

1 INTRODUCTION

Indoor radio channel propagation is strongly conditioned by the environment. In this way, radio link performance considerably varies depending on the existence of line of sight between transmitter and receiver, as well as on the multipath pattern of the scenario. So, as building structure and furniture are determinant elements in the definition of multipath, they also determine the indoor radio link performance.

Several models have been developed to analyse the result of the incidence of a propagating wave on a surface. That phenomenon can be limited to the main direction, being known as reflection, or considered all around. Any obstacle in the radio channel generates its own scattering pattern, which depends on the electromagnetic characteristics of the material, the surface roughness, the frequency, and the angle of incidence. Along this paper, measurement results are presented, showing that there are several scattering directions as important as the main reflection one. And so, models that just consider the reflection but not the scattering can not be accurate in low reflective environments.

A Physical Optics based model is presented, and compared to measurement results in the 5.8 GHz band. Various slides of different materials have been used as obstacles to force scattering phenomena, and measurements have been taken. Simulation and measurement results fit better than previous models.

Results provided can be used in simulation tools. If just needing a fast and accurate planning tool, a good modelling of reflection phenomena is enough. But the actual word is more complicated than the simulated one: instead of reflection, scattering is the result of the incidence of a wave on an obstacle of any kind, even on a flat soft wall.

Section 2 contains the description of the measurement set-up used, as well as the measurement campaign performed. Section 3 contains the models used to obtain the electromagnetic characterisation from specular reflection measurements. Section 4 describes the Physical Optics based Beckmann formulation to describe the scattering in the incidence region. Finally, sections 5 and 6 show the results obtained and the conclusions extracted.

2 SCATTERING MEASUREMENT OVER STRUCTURAL ELEMENTS

2.1 Measurement Set-up

The procedure to measure the scattering pattern due to a wall consists of illuminating it with a directive

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transmitting antenna, while a receiver antenna is moved, plotting a semi circumference centred in the incidence point of the transmission. The receiver antenna is always pointed to the transmitter target. Transmitter antenna is placed at a fixed angle respect to the normal to obstacle surface, in a static location. Receiver antenna locations are selected along an arc, jumping one degree between adjacent ones. An automated set up has been designed and built, integrating the mechanical movement to the vector network analyser control.

The mechanical system performs the measurement in three steps, described in figure 2. Reflection due to metallic slab is used as a reference (unitary amplitude) to determine the reflection coefficient due to the wall.

A vector network analyser has been used to sweep the spectrum between 5.725 and 5.875 GHz, at each position.

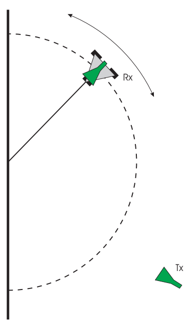


Figure 1: Measurement set-up.

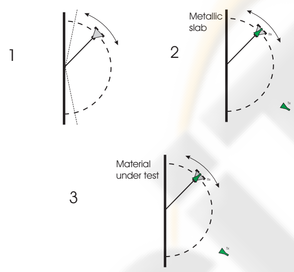


Figure 2: Measurement procedure.

2.2 Measurement Campaign

Reflection and scattering coefficients due to a wall, for different incidence angles, are obtained by comparing measurement outcomes from the obstacle and from the metallic slab. Materials considered are the metallic surface, used as a reference, a brick wall, and a chipwood panel.

At each receiver location, at a fixed incidence angle, the measured frequency response includes the coupling between antennas, the reflection contribution on the obstacle, and a complete multipath pattern. Filtering in time domain, all contributions but reflection on the wall are eliminated, resulting the amplitude and phase of the field received after reflection. The scattering pattern at a fixed incidence angle is obtained applying the previous procedure to all receiving locations. Reflection coefficient for metallic slab is assumed to be -1; and scattering coefficients are defined by equation:

$$\Gamma = \frac{-E^{r}_{obstacle}}{E^{r}_{metallic\ slab}\Big|_{spec}} = \frac{-S_{21,obstacle}}{S_{21,metallic\ slab}\Big|_{spec}} \qquad (1)$$

From measurement outcomes, and computing a value at each observation angle, a scattering pattern is obtained at each incidence angle.

Figures 3 to 5 show measured scattering patterns in the 5.8 GHz band, with parallel polarization, corresponding to a metallic surface, a brick wall and a chipwood panel. They are obtained for an angle of incidence of 20 degree.

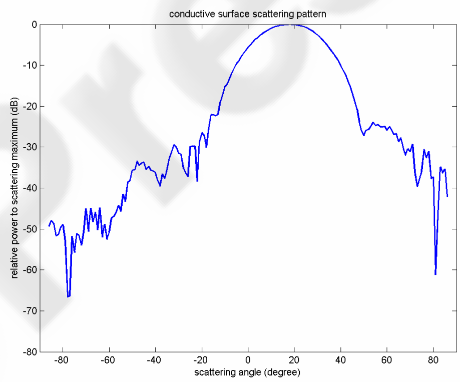


Figure 3: Measured scattering pattern for conductive surface, parallel polarisation, incidence 20 degree.

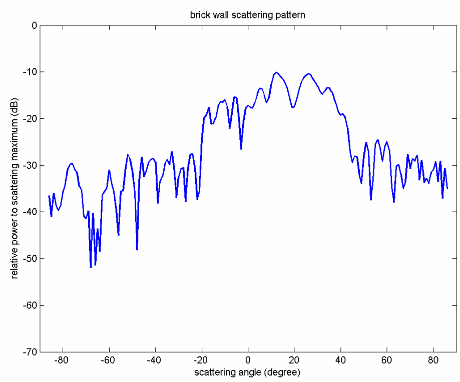
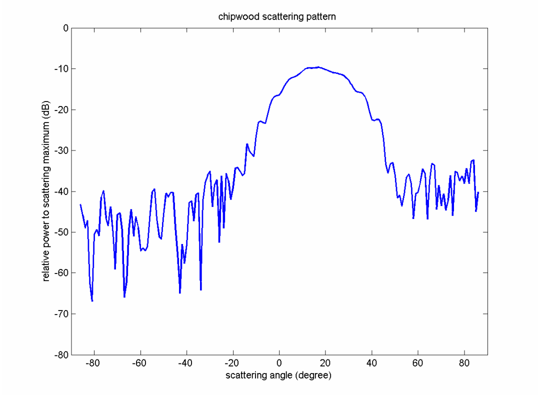


Figure 4: Measured scattering pattern for brick wall, parallel polarisation, incidence 20 degree.



chipwood scattering pattern
relative power to scattering maximum (dB)
scattering angle (degree)
0
-10
-20
-30
-40
-50
-60
-70
-80
-80
-60
-40
-20
0
20
40
60
80

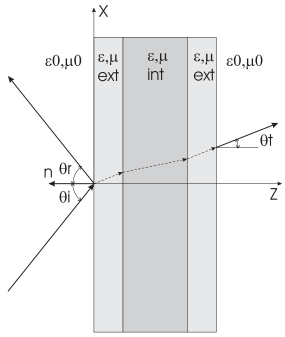


Figure 10: Multilayer model geometry.

Internal successive reflections model tries to explain the transmission and reflection phenomena as a result of the coherent sum of several multipath components generated in both boundaries of the obstacle with free space.

Multilayer model is intended to explain the behaviour of complex slab obstacles, which can be composed by several superposed layers.

All these models use the electromagnetic parameters of the materials composing the obstacle to compute transmission and reflection coefficients, in a more or less complicated formulation.

4 CHARACTERISATION OF SCATTERING COEFFICIENTS

As shown by measurements, the effect of walls over propagating waves is considerably more complex than just specular reflection. The incidence of a wave on a wall generates a scattering phenomenon in all space directions, defining a scattering pattern.

4.1 Beckmann Model

A good characterisation of scattering due to rough surfaces has to include all-direction effects. Beckmann's formulation fits this condition, and it is a classical method to characterise this kind of surfaces (Beckmann 1987). So, it is used in the processing of the measurement results.

Reflected and scattered fields are the basis to define the scattering coefficients. Figure 11 gives the axis criterion of the model.

The rough surface is defined by ξ, being z=0 its mean level. It is assumed the mean extended to z>ξ is the free space.

$$\xi = \xi(x, y) \tag{2}$$

The electric field strength, as well as its derivative respect to surface normal, are estimated by using Kirchhoff approximations (Physical Optics). So, it can be assumed the total field in a point on the surface is the same that in a tangent plane to the surface at the same point. The larger the roughness curvature radius is, the better the approximation is.

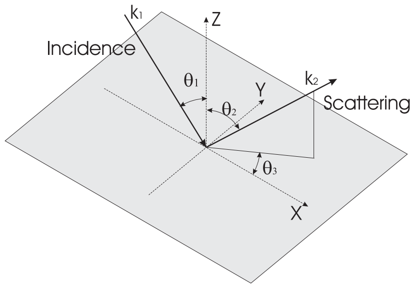


Figure 11: Beckmann model geometry.

One-dimensional rough surfaces are defined by the following equation:

$$\xi(x, y) = \xi(x) \tag{3}$$

So, normal vector to surface is always in XZ plane, and local incidence angle is defined by:

$$\theta = \theta_1 - \arctan(\xi'(x)) \tag{4}$$

Scattering coefficient is defined from the field scattered in any direction and that reflected in the specular direction by a flan perfectly conductive surface with the same size of the obstacle:

$$\rho = \frac{E_2}{E_{20}} = \frac{E_{scattered}}{E_{reflected,conductive\,surface}} \tag{5}$$

Assuming an electrically large obstacle, presenting a surface extended from x=-L to x=L, the scattering coefficient is defined as:

$$\rho = \frac{1}{4L\cos\theta_1}\int_{-L}^{L}(a\xi' - b)\cdot e^{jv_x x + jv_z \xi}\,dx \tag{6}$$

where

$$\vec{v} = k(\sin\theta_1 - \sin\theta_2)\hat{x} - k(\cos\theta_1 + \cos\theta_2)\hat{z}$$

$$a = (1-\Gamma)\sin\theta_1 + (1+\Gamma)\sin\theta_2$$

$$b = (1+\Gamma)\cos\theta_2 - (1-\Gamma)\cos\theta_1$$

This is the general formulation of scattering coefficient by Kirchhoff approximation. This equation can be simplified in those situations the integral has analytical solution, or can be extended to random surfaces which pattern is defined by its statistics instead of a deterministic function.

If the surface is flat, ξ=0 and ξ'=0. Then, the equation is transformed into

$$\rho = \frac{-b}{2\cos\theta_1}\cdot\frac{\sin(v_x L)}{v_x L} = \frac{-b}{2\cos\theta_1} sinc(v_x L) \tag{7}$$

Besides, if the surface is perfectly conductive, and the electric field is polarised perpendicularly to incidence plane (vertical polarisation in the measurement campaign), scattering coefficient can be defined as:

$$\rho_0 = sinc(v_x L) \tag{8}$$

With finite conductivity surfaces, there is no general, exact and explicit solution, but some approximations can be applied. Generally, these solutions come from converting a and b in constants using their means for any local incidence angles. When surface pattern ξ(x) is symmetric, this mean value can be obtained from Γ(θ=θ1). A more simply approximation is obtained by multiplying by Γ(θ=θ1) the scattering coefficient assumed perfectly conductive. This will be a good approximation in situations when

$$\max\{\arctan \xi'(x)\} << \theta_1, \tag{9}$$

which is fitted by surfaces with soft slopes, or with large curvature radii.

As a general conclusion, scattering due to non-conductive surfaces is affected by finite conductivity only if local reflection coefficients are dominated by local incident angle more than by electromagnetic properties of scattering material.

4.2 Application of Beckmann formulation

Application of Beckmann formulation is planned by three different strategies. Successive proposals have growing computational cost and complexity, but they give better concordance to actual situations. This can be checked by comparison with measurements. Obstacles are considering with flat surface and with determined electromagnetic characteristics.

First option (figure 12) consist on the direct application of Beckmann formulation, considering an incidence field on a flat surface, with an incidence angle determined by direct propagation path between transmitter antenna and the centre of illumination. This case does not consider the radiation pattern of the antenna.

Second option (figure13) is more advanced and consists on dividing the surface in several parallel segments of the same width and assumed infinite length. Local incidence angle at each segment is taken into account when applying Beckmann method.

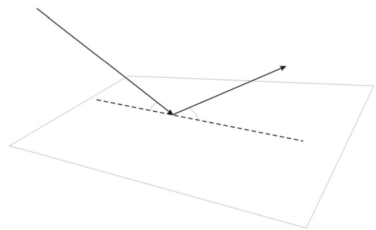


Figure 12: Direct application of Beckmann model.

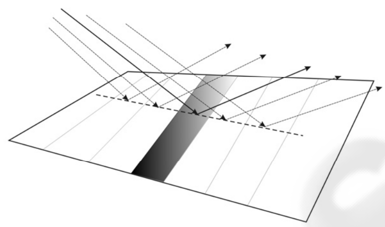


Figure 13: Application of Beckmann model by segments.

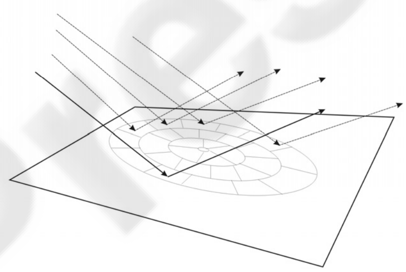


Figure 14: 3D Application of Beckmann model.

Third option (figure 14) consists on determine the illuminated surface on the obstacle, taking into account the radiation pattern of the transmitter antenna (Arias 1996). This surface is divided into rings, and then each ring is divided in several patches. Beckmann formulation is applied on each patch, considering the local incidence angle at each of them.

5 RESULTS

In this section, outcomes from measurement campaign are presented and explained. First among them are related to electromagnetic characterisation of different materials from specular reflection induced effects. Then, measured scattering patterns are compared with those computed by applying Beckmann formulation following the three strategies previously described.

Once reflection coefficients are measured, and applying the three models exposed in previous section, the electromagnetic characterisations of brick wall and the chipwood panel have been obtained. The fitting of reflection models provides the electromagnetic characteristic parameters of each material (dielectric constant: 5.0-j0.2 for brickwall, and 3.3-j0.1 for chipwwod). Using these characteristic parameters, and taking into account the geometric distribution of the experimental elements (obstacle, transmitter and receiver antennas relative locations), Beckmann formulation was applied following the three strategies enunciated in previous section.
Comparisons among measured scattering patterns and computed patterns using Beckmann in one step, by segments, and by patching the illuminated area are shown in figures 15 and 16. Results indicate better fitting when Beckmann application takes into account the geometry of the problem.

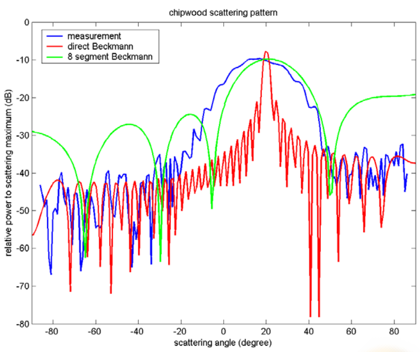


Figure 15: Scattering patterns, chipwood panel, parallel polarisation, incidence 20 degree.

6 CONCLUSION

Results of a measurement campaign of scattering pattern over flat obstacles are presented. From measurement outcomes, the involved materials are electromagnetically characterised in the 5 GHz band. Moreover, modelling of scattering patterns generated by flat obstacles is proposed, based on Beckmann formulation. Among three possible strategies of implementation, that based on patching the illuminated area on the obstacle surface, and then considering local contributions from every patch, is tested and provides the best results.
Comparison among simulation results and actual situation measurements show the good behaviour of the algorithm, the better as the flatter and more conductive the material is.
As low reflective materials presents reflection paths in several directions of the incident region, simulation tools taking into account scattering patterns instead of just specular reflection will obtain better predictions.

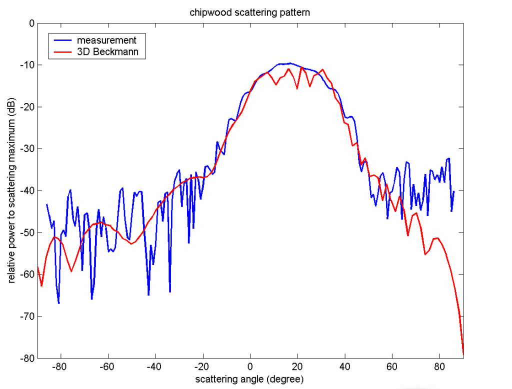


Figure 16: Scattering patterns, chipwood panel, parallel polarisation, incidence 20 degree

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