A Multilayer EM Simulation Tool to Assess RF Transparency Control of Building Wall Structures

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***Abstract*— This paper presents a multilayer electromagnetic (EM) simulation tool to assess the radiofrequency transparency control of building wall structures, developed in Matlab environment, that allows one to explore different layer arrangements and determine the overall frequency response. In particular, the deployment of frequency selective surfaces, either passive or active (electronically controlled), as well as the assessment of EM properties of different types of building walls commonly used in building construction, combined into one complete EM tool, is proposed.**

I. Introduction

Radio coverage of wireless communication systems in indoor environments is highly dependent on the type of wall, floor and ceiling layers present in the radio path. Several models have been proposed over the years to give better insight the propagation phenomena, varying in their complexity, and may be categorized under three different categories [1]–[4]: empirical, statistical and theoretical.

The integration of frequency selective surfaces (FSS) layers with building wall structures, with the purpose of achieving some degree of RF transparency control, is somewhat dependent on the target building construction materials, which subsequently may be dependent on the geographical location. Southern European countries may have different construction material requirements compared to Center and Northern countries, and some of these wall layers may already pose significant penetration loss at some frequencies rendering useless a band pass FSS centered at such null frequency band. To this extent, one must then study the combined effect of these layers to determine possible real-life implementation cases. This paper presents a summary of the work reported in [5].

II. Brief Description of the Electromagnetic Simulation Tool

The electromagnetic simulation tool developed in [5] has been validated by a large measurement campaign conducted inside an anechoic chamber. The tool is sought to reduce the burden of such type of measurements, as this may be cumbersome at times, since some of the wall samples have a substantial weight associated to them. And thus, this simulation platform may then use as input any combination of

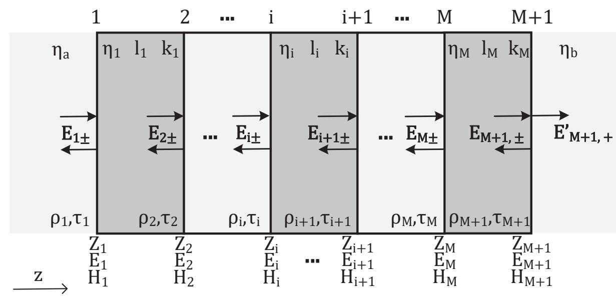

Fig. 1. Multilayer slab structure.

individual samples previously measured in a controlled environment. This tool allows to determine the overall transmission or reflection responses of random layers of heterogeneous or homogeneous materials, up to a maximum of 10 layers. The chosen approach to simulate multiple cascaded layers of homogeneous or heterogeneous materials was mainly based on transfer matrix theory described in [6]. Fig. 1 presents a diagram of multiple homogeneous cascaded slabs, more specifically i slabs, $i + 1$ layer transitions and $i + 2$ media, where are included the semi-infinite media η_a and η_b.

The functionalities provided bt the tool were identified in [5], in which a user may select input parameters such as incidence angle sweep, frequency range and wave polarization (linear vertical or horizontal), as long as these are within the range of the measurement database. The database includes all wall and FSS measurements carried out to date which may be made available upon request, as well as several dielectric parameters (appropriate of homogeneous layers) extracted from literature, more specifically: air, aluminum, brick, ceiling board, chipboard, concrete, fiberglass, glass, marble, Duroid 5880 PCB, FR4 epoxy PCB, plasterboard, polystyrene and wood.

III. Sample Database

The underlying tool formulations were also detailed in [5], being based on the theory of matching and propagating matrices described in the literature. The tool was validated against a select number of multilayer measurements performed

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TABLE I
MEASURED WALL LAYER VARIANTS

Layer sample #	Layer material	Type of finish
#1	Isolation board 3cm	None
#2	Isolation board 6cm	None
#3	Brick 11cm	None
#4	Brick 11cm	Smooth painted plaster (ds)
#5	Brick 11cm	Rough painted plaster (ss)
#6	Brick 11cm	Rough painted plaster (ds)
#7	Brick 15cm	None
#8	Brick 15cm	Smooth painted plaster (ds)
#9	Brick 15cm	Rough painted plaster (ss)
#10	Brick 15cm	Rough painted plaster (ds)
#11	Brick 20cm	None
#12	Brick 20cm	Rough painted plaster (ss)
#13	Concrete 10cm	None
#14	Eight-semicricle FSS	None
#15	3D Square Slot FSS	None
#16	Four-semicircle FSS	None
#17	Four-semicircle FSS	None

ss = single side; ds = double side.

in the anechoic chamber, achieving relatively good results with an overall average error below 10 dB for all 16 considered multilayer scenarios. One major benefit of this tool is the substantially fast computation times when compared with dedicated full-wave EM solvers. Additional multilayer scenarios were then considered and analyzed with the simulation tool, in which it was observed that certain building materials and layer combinations yield significant frequency-dependent transmission properties to incident EM waves and, thus, limit the radio coverage of existing and emerging wireless systems such as internet of things and 5G.

Table I includes the brick walls of different thicknesses and finish material, as well as insulation boards made from expanded polystyrene foam, a concrete wall, and four types of FSS of both bandpass (L#15 and L#16) and bandstop (L#14 and L#17) filter types.

IV. EM Tool Validation

The EM tool was validated against measurements by configuring the EM tool with several multilayer combinations that were previously measured in the anechoic chamber. Taking into consideration that all layers were also measured individually, their inclusion as inputs into the code was straightforward.

Fig. 2 provides a comparison between simulation and measurement for the scenarios using combination layer (L) L#9 + Air + L#1 + Air + FSS (L#14) + Air + L#5. Although this figure is associated to a 7-layered structure, a relatively good agreement is still visible, particularly below 7 GHz. Overall, a root-mean-square error (RMSE) below 10 dB was obtained for all analyzed wall and FSS combinations, which validates with some degree of accuracy, the implemented multilayer EM simulation tool, allowing for further studies using only this tool.

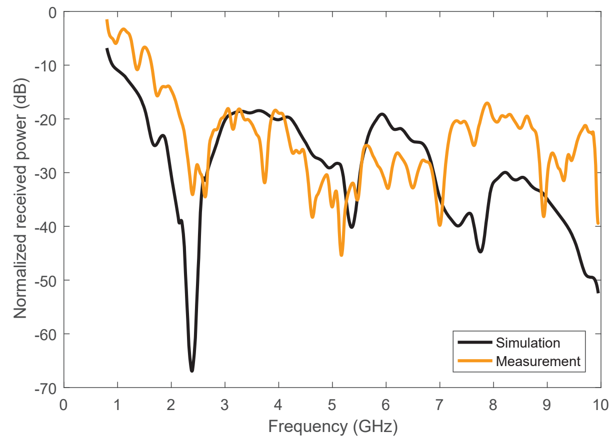

Fig. 2. Comparison between GUI simulation and measurement for combination L#9 + Air + L#1 + Air + FSS (L#14) + Air + L#5.

V. Conclusions

A multilayer EM simulation tool developed in Matlab environment was validated, with relatively good results, against measurements, and subsequently used to further assess combinations of building layers, mixing both measured samples as well as homogeneous layers such as concrete, wood and plaster, under the simulation GUI environment.

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