Transmission Loss Through Reinforced Concrete Between 30 and 2400 MHz

Dr Ir Thierry Gilles[1], Ir Ghilkrist Afomasse[1]
[1,2]Department CISS, Royal Military Academy, BRUSSELS, Belgium

***Abstract* - In this paper we investigate numerically the complex behavior of the transmission loss through a reinforced concrete slab between 30 and 2400MHz and compare it with the analytical and numerical solutions of the transmission loss of a concrete slab and of the rebar structure, separately.**

***Index Terms* — Transmission loss, concrete, rebar, Reinforced concrete.**

I. Introduction

Indoor to outdoor wireless systems operating through construction materials such as reinforced concrete are facing potentially high transmission losses. The attenuation by a rebar structure or by a dielectric slab alone is analytically well known, but much less is available in the literature regarding the attenuation by a rebar structure inside a concrete slab.

II. Transmission Loss Of Concrete Slab

Usual concrete is a more or less lossy dielectric non-magnetic medium consisting of cement, sand and gravel mixed with water. The moisture content greatly influences the relative complex permittivity $\varepsilon'_r - j\varepsilon''_r$ [1][2]. In this paper we consider three moisture contents, or relative humidity (RH), from very dry (RH=0.2%), moderately (RH=6.2%) to very humid (RH=12%). As depicted in Fig. 1, the extended Debye model applied to concrete [3][4] shows that the complex permittivity of concrete increases with the RH and decreases with frequency, between 30 and 2400MHz. It also shows that for frequencies below 1GHz the complex permittivity of concrete is frequency dependent, except at very low RH.

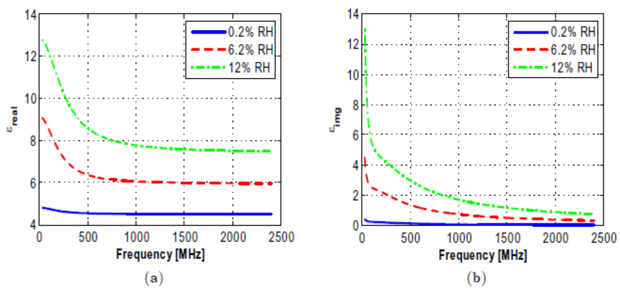

Fig. 1. Relative permittivity of concrete with frequency and RH

In the evaluation of the transmission loss through a concrete wall between 30 MHz and 2400 MHz, we may usually consider this medium as homogeneous whenever all constitutive elements of the concrete, in particular gravel, have their largest dimension smaller than a fraction of the smallest wavelength λ inside the concrete, namely 4 to 6cm.

The transmission loss T_c through an homogeneous isotropic concrete slab of thickness l and infinite transverse dimensions illuminated by a plane wave at normal incidence can be determined analytically, considering the multiple internal reflections inside the slab, as follows :

$$T_c(dB) = -20\log_{10}\left[\frac{(1-\rho^2)e^{-jkl}}{1-\rho^2 e^{-j2kl}}\right]. \qquad (1)$$

with k, the wavenumber and ρ, the Fresnel reflection coefficient of the first interface (air-to-concrete) encountered by the incident plane wave. The reflection coefficient ρ depends on the electromagnetic properties (ε, μ and σ) of both media.

The same infinite slab was simulated as a dielectric plane ground with the frequency domain 3D electromagnetic solver FEKO™. The transmission loss has been obtained in two concordant ways : via the built-in transmission coefficient calculator, and by dividing the electric near field observed 6cm behind the slab (at a distance where it is constant) by the incident electric far field.

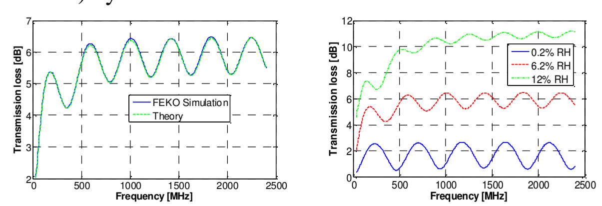

Fig. 2. Transmission loss through a concrete slab

Fig. 2 shows the excellent agreement between the overlayed analytical and simulation results for RH = 6.2% (left), and the higher transmission loss induced by higher moisture levels.

III. Transmission Loss Of A Rebar Structure

The transmission loss T_r through a square rebar structure of infinite dimension illuminated by a plane wave with normal incidence, polarized in any direction in the rebars plane, can be analytically very well approximated by [2]:

$$T_r(dB) = -20Log_{10}\left|\frac{2j\omega L_s/Z_0}{1+2j\omega L_s/Z_0}\right|. \qquad (2)$$

with

$$L_s = -\frac{\mu_0 D}{2\pi}\ln\left(1-e^{-\frac{2\pi r}{D}}\right). \qquad (3)$$

Z_0 = 120π is the free space impedance, D is the distance between rebar centres and r is the radius of the rebars (see Fig. 3). Equation (2) is only valid if D < λ.

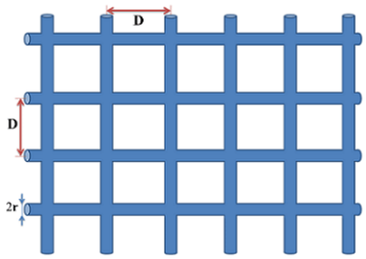

Fig. 3. Square rebar geometry

The same infinite rebar structure was also simulated with the electromagnetic solver FEKO^{TM}, defining an elementary cell DxD and repeating it with 2D periodic boundary conditions (PBC). The transmission loss has been obtained by dividing the electric near field computed 6cm behind the structure by the constant incident plane wave electric field.

Fig. 4. shows the good agreement between the analytical solution and the FEKO^{TM} simulation results for a rebar with D=10cm and r=2.5mm (left) and the influence of D for r=2.5mm. As long as λ > D, a rebar behaves as a high pass filter. At higher frequencies, the electromagnetic field beyond the rebar exhibits periodic spatial variations, making it impossible to define a unique transmission loss factor.

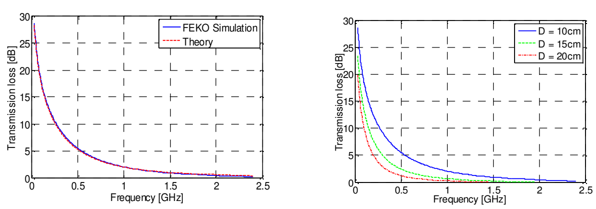

Fig. 4. Transmission loss through a rebar structure for D<λ

IV. Transmission Loss Of Reinforced Concrete

So far we have analysed the plane wave transmission loss of both a concrete slab and of a rebar structure in free space both having infinite transverse dimensions. Now we merge those two structures, the rebar being located in the middle of the slab depth, to analyse reinforced concrete slabs. To the knowledge of the authors, there is no analytical solution available in the literature, only numerical ones [6]. We will thus only resort to the FEKO^{TM} simulations, where a 2D-PBC elementary cell of dimension DxD is used and the transmission loss is obtained the same way as previously described in this paper.

In Fig. 5 we overlay the transmission loss characteristics of a 15cm thick concrete slab with 6.2% RH, a rebar with D=10cm and r=2.5mm, and a reinforced concrete resulting from merging the two previous structures. At frequencies lower than 100 MHz, the transmission loss of the reinforced concrete slab is mainly governed by the rebar structure. Careful inspection shows that the transmission loss of the reinforced concrete is actually lower than for the rebar alone. Surprising at first sight, this behavior is essentially due to the fact that λ, the wavelength in the concrete slab, is reduced as compared to λ_0 in free space. At frequencies higher than 100MHz, the transmission loss of reinforced concrete is mainly governed by the slab transmission loss, being for most frequencies somewhat higher than for the slab alone.

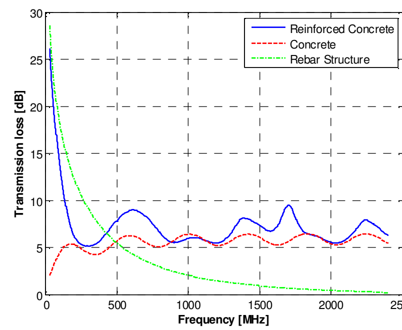

Fig. 5. (Reinforced) concrete at 6.2% RH - Rebar alone

V. Conclusion

The transmission loss of a rebar structure decreases with frequency while it globally increases for a slab. By immersing a reinforcement grid structure in the middle of the concrete slab, the transmission loss gets more complicated than the simple sum of the two transmission losses.

References

[1] Haddad, R. H. et Al-Qadi, I. L., "Characterization of Portland Cement Concrete Using Electromagnetic Waves over the Microwave Frequencies." *Cem. Concr. Res.*, vol. 28(10), pp. 1379, 1998

[2] Filali, B., "Étude des Propriétés Diélectriques du Béton par Sonde Coaxiale et par Antenne Radar", *Maîtrise ès science appliquées*, Université de Sherbrooke, Sherbrooke, 151 p, 2004

[3] L. Sandrolini, U. Reggiani, A. Ogunsola, "Modelling the electrical properties of concrete for shielding effectiveness prediction", *IOP Publishing, Journal of Physics D: Applied Physics*, pp. 5366-5372, Aug 2007

[4] M.N. Soutsos, J.H. Bungey, S.G. Millard, M.R. Shaw, A. Patterson, "Dielectric Properties of concrete and their in uence on radar testing", *NDT&E International* 34, pp. 419-425, Department of Civil Engineering, University of Liverpool, Liverpool L69 3GQ, UK, 2001

[5] Kendall F. Casey, "Electromagnetic Shielding Behavior of Wire-Mesh Screens",*IEEE Transactions on Electromagnetic Compatibility*, vol. 30, No 3, August 1988

[6] Elodie Richalot, Mathieu Bonilla, Man-Faï Wong, "Electromagnetic Propagation into Reinforced-Concrete Walls", *IEEE Transactions on Microwave Theory and Techniques*, Vol.48, No 3, March 2000