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ANALYSIS OF PROPAGATION OF ELECTROMAGNETIC WAVES IN VARIOUS MEDIA

Dušan ČERMÁK[1)], Ondřej FIŠER[2)]

KEEZ DFJP University of Pardubice[1)], UFA AV ČR[2)]

1. Introduction

The description of electromagnetic wave propagation in rain volume is worked out quite good. This description is based on wave equation solution in vacuum (in the air it is the same) being filed by dielectric scatterers, i.e. rain drops.

Signal transmissions through several layers can be analyzed using wave equations, when all non-homogeneities and individual boundaries between various media should be considered. This approach is possible but it would be very complicated, even if suitable numerical methods are used. Therefore, various approximations are used for microwaves such as geometrical or physical optics.

2. Propagation of electromagnetic waves in rain volume

Rain drop is a losing dielectrics absorbing as well as scattering the electromagnetic energy. The scattering function relates incident and scattered wave being a function of frequency, temperature, size and shape of rain drop as well as a function of the incident wave polarization.

There are various methods to compute the scattering functions. The Rayleigh approximation is suitable if the rain drop is much smaller in comparison with the wave length. This approximation is not demanding and not time consuming. Still quite simple method is the Mie scattering for all drop sizes, but for spherical shape model only.

Mie scattering is a good approximation to study the attenuation (especially for the circular polarization) and to study the dependence of rain attenuation on temperature and frequency as well. Mie scattering cannot describe the depolarization as bigger drops are not of the spherical shape, but they are oblate spheroids. The scattering functions corresponding to the actual drop shape are computed numerically (Point matching, Fredholm integral method, Perturbations method). These solutions were found in 70ties of last century.

The formulas for integral attenuation caused by rain volume are taken from Van de Hulsta (1957) who derived the attenuation formulas for optical waves.

The existing methods are able to compute rain attenuation, rain phase delay and depolarization. The multiple scattering (especially important in frequency bands above 30 GHz) and exact information about drop size distribution (DSD) is not at high level knowledge now (the drop size distribution describes how many drops of which size are present in the unit volume).

The Marshall-Palmer drop size distribution being broadly used corresponds to the average rain only. Maximum resolution is devoted to drizzle, continuous rain, thunderstorm and shower whereas enormous DSD variability is known.

Problems remaining is the knowledge of horizontal structure of rain cell – it is able to model it but for statistical purposes only and not for on-line values.

In practice, there are used engineering formulas being able to estimate (more or less exactly) the rain attenuation. According to author' knowledge the description of UWB signal transmission through the rain volume or through the combination wall-rain volume has not been done.

3. Through-Wall Electromagnetic Signal Propagation

The output signal can be calculated using input signal considering individual layers and boundaries. The geometrical optics model can be advantageously used. The calculations are done using matrixes. The user-friendly code has been done in University of Pardubice, which uses antenna analyses considering various input pulses. Numerous examples for published cases of one layer and several layers have been calculated to verify this model. All examples have demonstrated satisfactory agreement.

Numerical simulations have demonstrated that reflections and transmissions through dielectric and conductive substances are important frequency dependent phenomena. Two main effects are the frequency dependence of materials (that logically change reflections and transmissions) and even if that dependence is neglected, reflections and transmissions are changed with frequencies. Thanks to fact that ultra-wide-band (UWB) frequency spectra are not constant, the 3 – 4 GHz frequency band losses are lower than narrow-band 4 GHz signal. Edge obstacle diffractions are frequency dependent, too. It is well known that diffraction losses (especially at shadow volume) increase with frequency rising. Rough surface reflections are also frequency dependent.

Time responses demonstrated not only time delay given by signal transmission trough-wall delay but ringing due to multiple reflections on individual layer reflections. It is clear that multiple layers create ringing, which is more delayed and time duration is greater. Simultaneously, the next ringing (thanks to multiple reflections and transmissions) is subsequently attenuated. The great advantages of UWB signals are reduction of multipath effects. That is created by interferences of reflected and incident signals. These signals can be amplified or completely canceled. Therefore, very weak signals could be received, which cannot be detected. UWB technologies use possibilities of individual signal frequency components to propagate independently and allow fading reduction using suitable received signal processing. Moreover thanks to very short pulses, the signal is received before receiving of reflected signals and therefore the mutual signal interferences cannot take place.

4. Processing methods of rain volume signal propagation

Considering theoretical analyses the equivalent parameters of rain volume (such as equivalent relative permittivity, equivalent conductivity and equivalent phase shift) have been derived. That has allowed the utilization of homogenous volumes, which could behave at the same manner as studied non-homogenous rain volumes from electromagnetic wave propagation point of view. These equivalent parameters depend on the other parameter – the rain intensities. Considering the analyses the MATLAB code for equivalent parameters of rain volume has been done.

Graphs showing real and imaginary parts of relative permittivity of rain volumes and dependences of frequencies and rain intensities have been plotted. The frequency dependence has been chosen for 4-8 GHz range according to performed measurements of through-wall electromagnetic signal propagations. That is shown in the separate chapter. The rain intensities have been chosen in 1 mm/h to 200 mm/h range. That corresponds all possible rain intensities in the Czech Republic. Higher values (100 – 200 mm/h) have been only considered to evaluate the effect of the water amount per volume on the resultant equivalent parameters of rain volume.

5. Processing methods of through-wall electromagnetic signal propagation

Wall parameter measurements have been done by vector analyzer Anritsu 37347A and two horn antennas, faced with 1m distance. The aim of the measurements was the comparison of measurements and numerical simulation using geometrical optics. Moreover, the suitability of those methods has been tested.

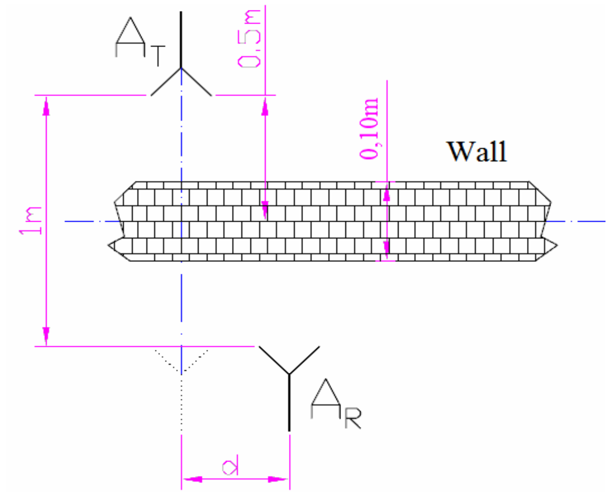

***Fig. 1** Measurements of UWB through-wall propagation, when the receiving antenna AR has been moved along a line parallel to the wall axis*

The parameter s21 (amplitude and phase) have been measured for both free space propagation and propagation through dry masonry wall with 10 cm thickness placed between antennas. The receiving antenna has been moved along a line parallel to the wall axis (see Fig. 1) with distances of 0.5 m up to 1.5 m from line perpendicular to the wall axis. That allows measurements for various incident angles.

Moreover, the comparison of measurements and numerical simulations using program coded in the University of Pardubice (see Fig. 2) has been done.

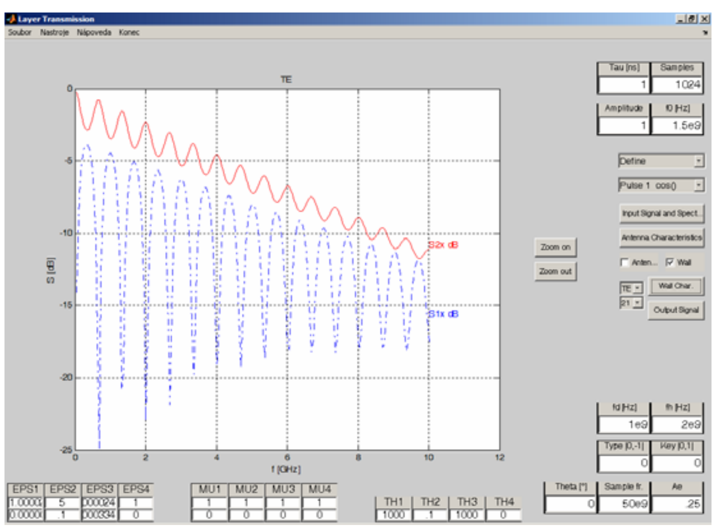

***Fig. 2** An example of calculation of S parameters*

The phenomena, which can occur during propagation through wall (parameters of which are not known exactly), have been discussed, analyzed in detail and roughly simulated. The emphases have been put on various phenomena connected with signal multipath and with possible non-homogeneities in the wall structure, which can change signal phases or even total shadow the Fresnel zone volumes.

6. Signal propagation through layers

The described program has allowed the numerical simulations of signal propagation through layers. That consists of rain volume and masonry wall for various layer thicknesses.

7. Results

The effective parameters of rain volume using rain intensities have been derived and the corresponding computations have been done (see Fig. 3).

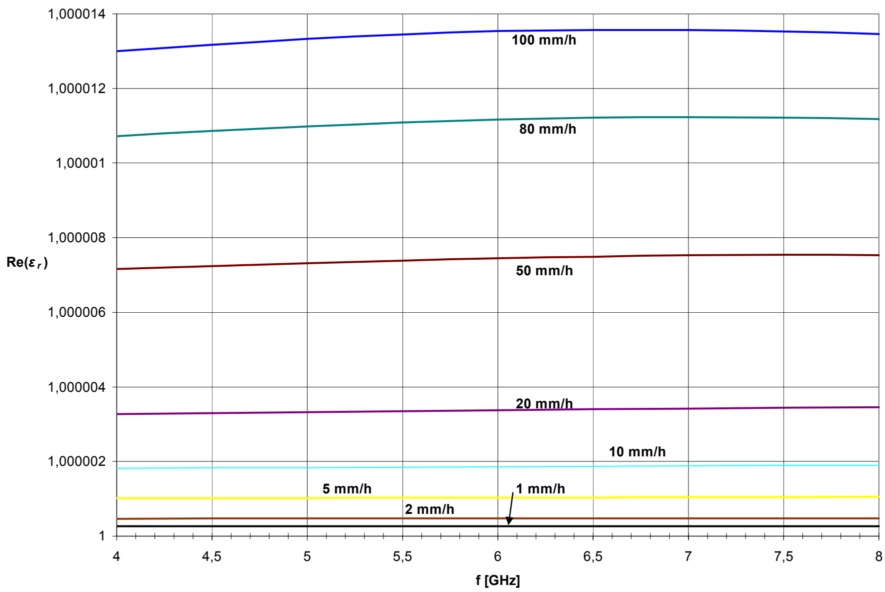

Fig. 3 *The effective parameters of rain volume using rain intensities*

The measurements of wall parameters have been done.

The measured s21 parameters for pro various positions of receiving and transmitting antennas are shown in Fig. 4.

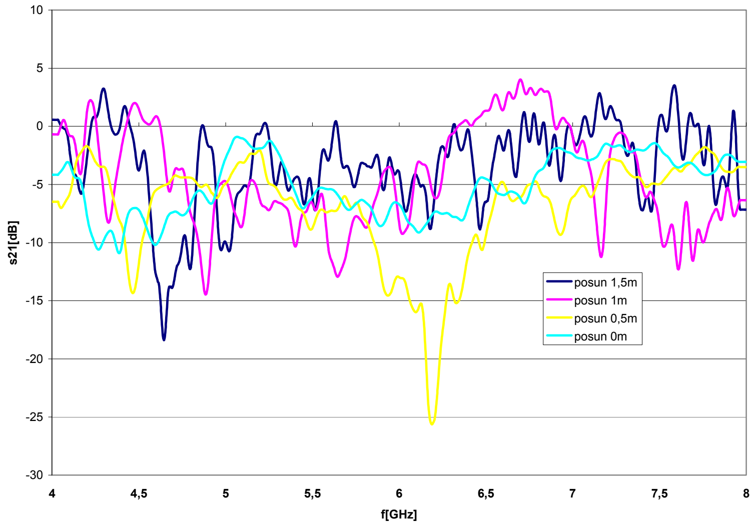

Fig. 4 *Measurements using various distances d*

The sharp interferences can be seen, which can be created due to both signal multipath, when receiving antenna received the direct signal as well as signals reflected from various objects such as floor and ceiling and due to shadowing of some Fresnel zones. That can create signal “amplification”.

The measurements have been compared with numerical simulations using the described program. The example is shown in Fig. 5.

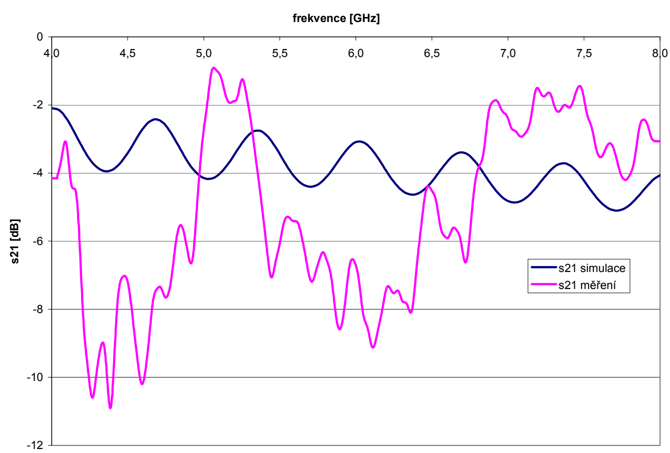

Fig. 5 *Comparison of measurements and numerical simulations for distance d = 0 m*

The phenomena, which can occurred during propagation through wall (parameters of which are not known exactly), have been discussed, analyzed in detail and roughly simulated. The emphases have been put on various phenomena connected with signal multipath due to reflection from various objects such as floor and ceiling (see Fig. 6 and 7) and with possible non-homogeneities in the wall structure, which can change signal phases or even total shadow the Fresnel zone volumes. Moreover, the suitability of geometrical optics has been discussed after appropriated numerical simulations.

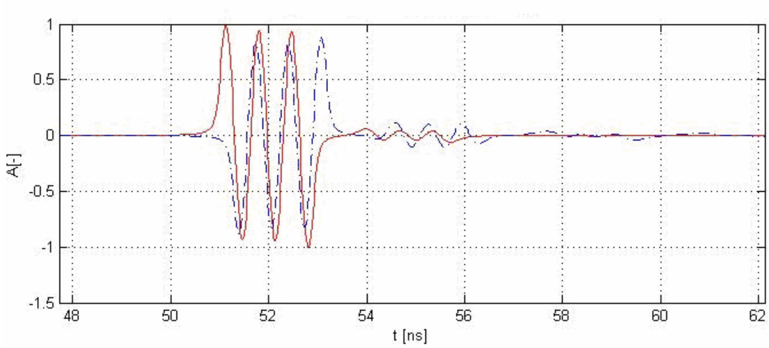

Fig. 6 *Direct (solid line) and reflected signals for small transmitting antenna, h1 = 1.5 m, h2 = 0.4 m and r = 15 m*

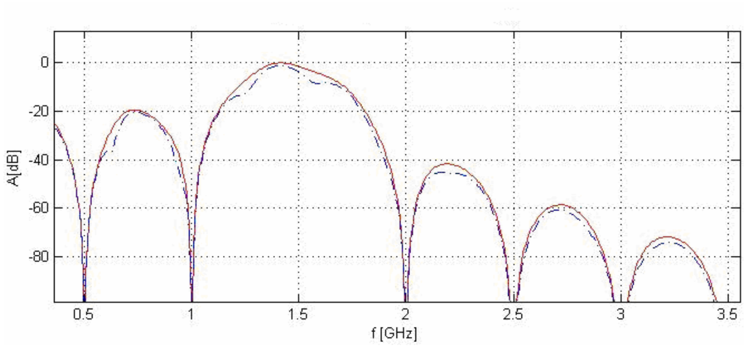

Fig. 7 *Direct (solid line) and reflected spectra for small transmitting antenna, heights h1 = 1.5 m and h2 = 0.4 m and distance r = 15 m*

Numerical simulations of signal propagation through layers, created by the layer of homogenous rain volume and the wall have been done. The example of results is shown in Fig. 8.

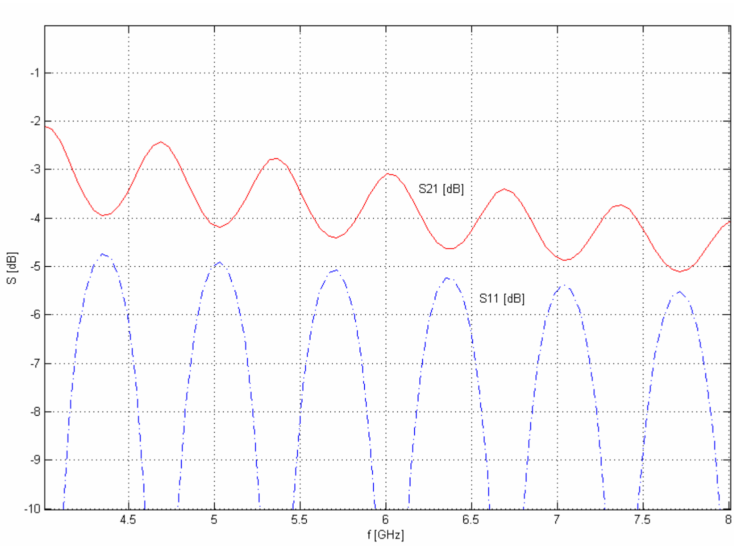

Fig. 8 *Numerical simulations of signal propagation through layers, created by the layer of homogenous rain volume (10m) and the wall (10cm)*

8. Contributions for Development of Scientific Branch and Practices

Effective parameters of rain volume using rain intensities have been derived and the corresponding computations have been done. That is quite new and non-published result. Up to now, the rain volume is analyzed as individual rain element system and scattering function computations for individual rain drops are studied. The quite different method is used – rain volumes are considered as homogenous volumes with certain properties given by rain intensities and the macroscopic constants characterizing that homogenous volumes – equivalent relative permittivity with parameter of rain intensity for given rain volume. The input values of rain intensities and frequencies should be only changed in the given procedure for derivation of equivalent parameters. Then using the same procedure the parameters describing rain effects on transmitted signals for any rain intensity parameter values can be obtained.

As the rain volume, created by many elementary rain drops, is considered as a homogenous volume with the electrical parameters defined by rain drops using equivalent parameters of the rain volumes, the unification of mathematical formalism has been created, which is suitable for description of phenomena connected with electromagnetic wave transmission through various volumes. Of course, that is simplification, which should be deeply analyzed as the phenomena connected with rain precipitation effects on communication quality are rather complicated. To keep a reasonable thesis extent and time, it has not been possible to deal with all related problems.

The whole procedure for calculation of rain volume equivalent parameters, given in the thesis as wall as the description of through-wall signal transmission and generally various substances with different electrical properties can be used in practice for design of terrestrial communications with transmitted wave of higher frequencies as well as for design of equipment, where the propagation through several layers with different electrical parameters occurs such as radars. For object searching behind parts of building constructions, the UWB Through Wall Radars or UWB Ground Penetrating Radars could be applied, when signal propagation problems should be analyzed such as transmissions through walls and generally various obstacles. The part of thesis has been done in connection with the grant of UWB Technology for Radars FT-TA2/030 (cooperation with Retia, Inc. Pardubice in 2005 - 2007). It is considered that the both theoretical and experimental analyses of through-wall signal propagation will continue thanks to expanded utilization of UWB technology.

Lektoroval: Prof.Ing. Vladimír Schejbal, CSc.

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Resumé

ANALÝZA ŠÍŘENÍ ELEKTROMAGNETICKÝCH VLN V RŮZNÝCH PROSTŘEDÍCH

Dušan ČERMÁK, Ondřej FIŠER

Tento článek se věnuje problémům vznikajícím při řešení úloh souvisejících s průchodem radarových signálů skrz zeď, které v současné době řešíme spolu s dalšími spolupracovníky na Univerzitě Pardubice v rámci řešení grantu FT-TA2/030 „Širokopásmová (UWB) technologie pro radary a systémy určování polohy“ (spolu s Retia a.s. Pardubice) a snaží se nastínit možnosti, jak využít získaných výsledků i pro takové problémy, jako je útlum signálu při průchodu obecným dešťovým prostředím, kterému jsme se věnovali v rámci projektu COST 280. Jsou zde mimo jiné uvedeny příklady simulace průchodu elektromagnetického signálu homogenním jednoduchým dešťovým prostředím, zdí, jejich kombinací, výsledky výpočtu ekvivalentních parametrů dešťového prostředí a srovnání vlastností průchodu signálu zdí a prostředím vyplněným deštěm.

Summary

ANALYSIS OF PROPAGATION OF ELECTROMAGNETIC WAVES IN VARIOUS MEDIA

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The paper addresses problems with signal transmissions through walls. These findings can be applied in areas such as the rain attenuation problem. The author has included simulations of an electromagnetic field passage through rain, wall(s) and their combination as well as calculations of equivalent parameters in rain and the comparison of the characteristics of signal passage through wall(s)and rain.

The autor collaborated with faculty members at the University of Pardubice on this work and it builds on his previous work with the COST 280 project. He also want to take this opportunity to acknowledge his grant: FT-TA2/030 UWB Technology For Radars and Positioning Devices (together with Retia a.s. Pardubice).

Zusammenfassung

DIE ANALYSE DER RADIOWELLENAUSBREITUNG IN VERSCHIEDENEM MEDIEN

Dušan ČERMÁK, Ondřej FIŠER

Dieser Beitrag befasst sich mit Problemen bei der Transmission von Signalen durch Wände. Diese Ergebnisse können für Gebiete wie "Probleme aufgrund von Abschwächung durch Regen" angewandt werden. Es wurden Simulationen einer Durchdringung eines elektromagnetischen Feldes durch Regen, eine Wand (Wände) und die Kombination beider eingeschlossen; weiterhin die Berechnung von äquivalenten Parametern in Regen und der Vergleich der Eigenschaften der Durchdringung des Signals durch eine Wand (Wände) und Regen. Der Autor kooperierte bei diesem Beitrag, der auf früheren Arbeiten des Autors im Rahmen des Projekts COST 280 basiert, mit Fakultätsmitgliedern der Universität Pardubice. Der Autor dankt außerdem für die Unterstützung durch die Förderung "FT-TA2 / 030 UWB Technologie für Radars und Ortungseinrichtungen (gemeinsam mit Retia a.s. Pardubice).