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ANECHOIC-CHAMBER MEASUREMENTS OF THROUGH-WALL PROPAGATION

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1. Introduction

The ultra wide band (UWB) concept is very useful for radars and communications [1] - [3]. The effects of various antenna receiving and transmitting responses as well as UWB signals (pulses) are analyzed in [4] - [9]. Various combinations of signals, transmitting or receiving antennas (small and aperture antennas) and wall structures as well as multipath propagation have been measured, calculated and compared both in frequency and time domains.

Measurements can be done by time-domain system or frequency-domain system [10] - [11]. The both systems have their advantages and disadvantages, which can be discussed. Time-domain systems have used pulse generators and sampling oscilloscopes for measurements. Obviously, the most important advantage of time domain measurement is that the multiple reflections (multipaths) could be clearly distinguished as time gating of multipath signals can be done on raw data measurements. The other benefits are: data from measurements are collected directly in the time domain, measurements of nonlinear materials are possible and wideband data can be obtained with single measurements. On the other hand, the drawbacks of time-domain systems are: calibrations are usually done in the frequency domain, good SNR requires averaging, wideband data require narrow pulse width and receivers have low dynamic ranges.

Frequency-domain systems use network analyzers which convert measured data to the time domains with the aid of Fourier analyses. The main advantages are: network analyzers have very stable signal sources and large dynamic ranges, calibrations are done at frequency domain and receivers are phase-locked. The disadvantages of frequency-domain systems are: long measurement times, data must be converted into the time-domain, portable systems are difficult to create and measurements of the time responses of nonlinear materials cannot be done (actually, that could be a very rarely case for real scenarios, as nonlinear properties of walls are not too likely, especially for used UWB transmitters or usual network analyzer signal sources, which transmit very low signal levels, and therefore even possibly nonlinear substances would not reveal nonlinearities).

Various UWB through-wall propagation measurements, performed in real scenarios (walls between laboratories or offices) in various frequency bands with various antennas and incident ray angles have been analyzed and calculated [4] - [8].

Numerous experiments of UWB through-wall propagation in real scenarios for various walls for time domain have been carried out. Several examples of experiments are given for time domain, which have been performed using very short pulses, for walls between university laboratories and offices [9]. Two printed circular disc monopole antennas have been used for these time domain measurements. Those are compared with numerical simulations, which consider used antennas and signals.

As the multiple reflections (multipaths) cannot be clearly distinguished for frequency measurements (using time gating of multipath), it is difficult to compare frequency and time domain measurements. Therefore, new experimental results for anechoic-chamber measurements and numerical simulations for frequency band from 4 to 8 GHz are analyzed and compared in this paper. That is briefly compared with the previous frequency and time domain experiments. Some questions concerning electromagnetic compatibility (EMC) are briefly mentioned.

This paper describes results of quite new measurements. These measurements were performed under entirely different conditions comparing with previous measurements [8]. The used method and devices were the same. However, the previous measurements of through wall propagation between the two rooms in ERA s.r.o. were affected with plenty of parasitic signals and reflections comparing with anechoic-chamber measurements.

2. Frequency Domain Anechoic-Chamber Measurements

The signal responses in the time domain are very important as they show various phenomena such as shape changes and time delays. On the other hand, the output signal spectra are certainly important for various purposes such as EMC analyses [7]. Therefore, Fourier transform (especially FFT) can be used for analyses of frequency spectra. The utilization of Fourier transform (especially FFT, when aliasing can occur) should be analyzed very carefully. It is necessary to consider Gibbs phenomena, sampling theorem, and simultaneously the number of sampling values N should be sufficient. That approach allows consideration of various phenomena from viewpoint of electromagnetic interferences and susceptibility.

Various cases have been studied such as small and aperture antennas [4] – [7] and traveling wave antennas, when a straight wire excited by a single traveling wave of current can be analyzed. That allows consideration of different cases such as two-wire transmission line radiation.

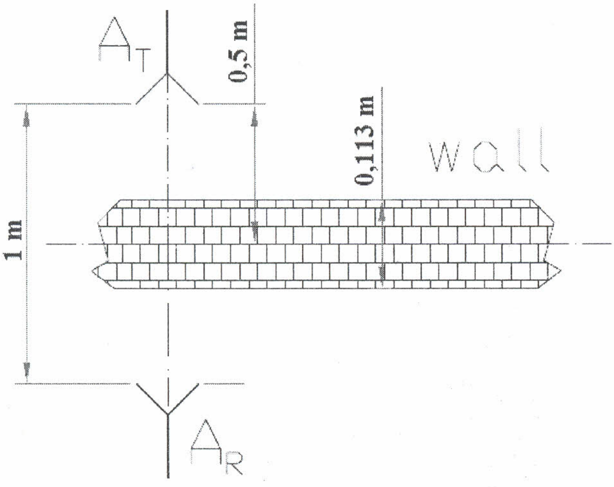

Fig. 1 *Measurements of UWB through-wall propagation*

The calculated spectra of time domain measurements have been shown [9]. New experiments have been performed to justify those results from spectral point of view. Two antennas (transmitting AT and receiving AR) covering the frequency band of 4 to 8 GHz has been used for measurement as is shown in ***Fig. 1*** in an anechoic chamber. The wall losses have been measured as differences between powers received for through-wall propagation (dB) and powers received for free space propagation (dB). The free space propagation measurements in anechoic chamber are shown in ***Fig. 2*** and the through-wall propagation measurements in anechoic chamber are shown in ***Fig. 3***. The Anritsu 37347A vector network analyzer has been used for these measurements.

The free-space propagation measurements in anechoic chamber have been done to obtain reference measurement values of s12. Two broadband horns for frequency band 4 to 8 GHz were used for amplitude and phase s12 measurements. The phase measurements are not considered in this paper.

The used measurement equipment was the same as for original measurements [8]. Differences consisted in utilization of absorbing elements (panels), shown in Fig. 2 and 3, which eliminated all possible sources of reflections from surrounding objects as well as from measuring constructions and devices. Therefore these measurements are more accurate and reliable. It was necessary to construct a movable wall to perform the through-wall propagation measurements in anechoic chamber. The 1 x 1 m POROTHERM brick wall was constructed with 113 mm thickness without any plaster. The glue was put on individual bricks. The front and rear faces are not flat but they are outfit with grooves. Moreover, any brick is furnished with numerous inside holes. The wall was set on the wooden support as can be partly seen in Fig. 2 and 3. The measurement equipment was assembled and all possible reflection sources were covered with absorber panels. The shielding of anechoic chamber was not excellent, and therefore various external interferences could be possibly expected. Three various measurements according to Fig. 1 have been done with the dry wall, wet wall (that was poured over the wall front face with water about 20 min.) and the same wet wall with less than 1 mm thick wet cloth put on the wall front face. Similar wet walls could be expected during firefighting and observing persons behind the wet walls.

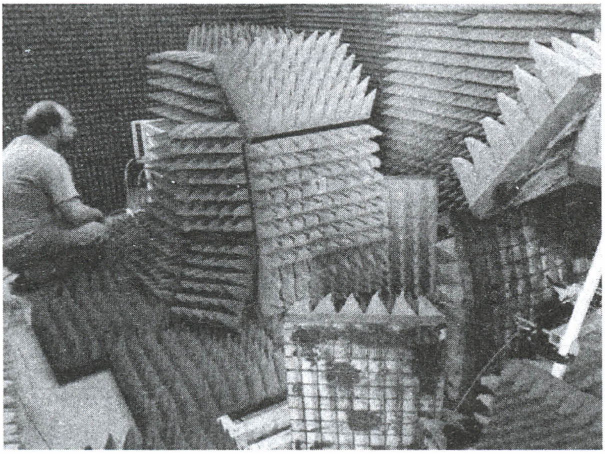

Fig. 2 *Free-space propagation measurements in anechoic chamber*

Measurements of electromagnetic wave propagation through dry wall are shown in ***Fig. 4***. It can be observed that slight interferences are only created thanks to utilizations of absorption panels for reductions of reflections from floor, ceiling and especially side walls in comparison with previous frequency domain measurements [8] (it would be very difficult to cover effectively at least side walls and neighboring objects in real laboratories). Similarly, measurements of electromagnetic wave propagation through wet wall and wet wall covered with wet cloth are shown in ***Fig. 5*** and ***Fig. 6***. The slightly greater interferences are created in these cases.

The comparison of measurements for above cases is shown in ***Fig. 7***. It can be seen that the interference minima and maxima occur for nearly the same frequencies. That means the interferences are not due to internal multiple reflections and differences of complex permittivity. Interferences are created by residue reflections, which are probably due to various reasons such as reflections from wall edges, support structures, uneven faces of wall and holes inside the wall (that effect is not probably substantial and causes slight deviations only). That cannot be simulated by the described numerical simulations [4], which are based on geometrical optics and very simple geometries (multiple layer structures) enabling numerical simulations of various UWB propagation scenarios.

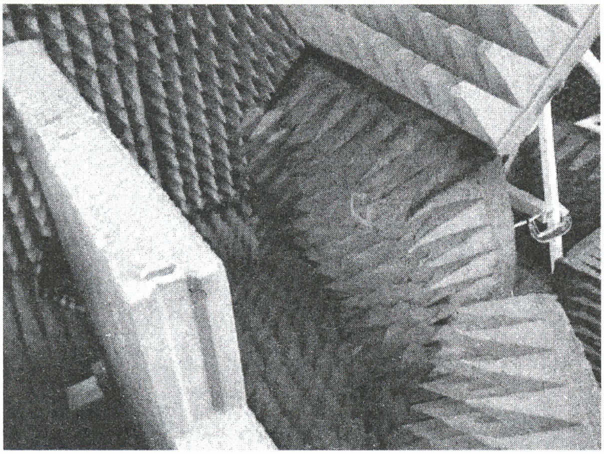

***Fig. 3** Through-wall propagation measurements in anechoic chamber*

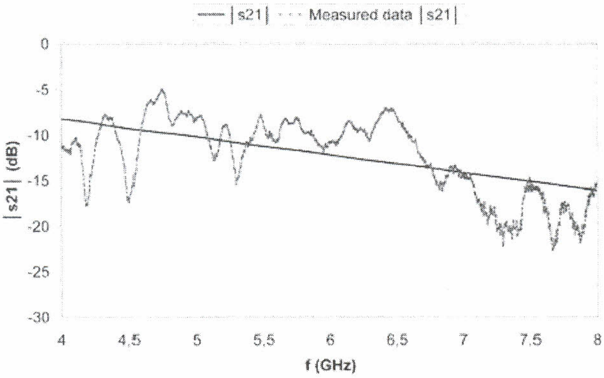

***Fig. 4** Dry wall measurements. $\varepsilon_r = 2.5 - 0.3\,j$ was used for numerical simulations*

Even if the geometrical optics can be successfully used for calculations of various reflection types (such as reflections from floor, ceiling and side walls), it is not generally valid for various phenomena such as diffraction. Therefore, it is reasonable to consider another method. A physical optics has been proved as very useful approximation for analyses of various diffraction phenomena. An excellent agreement between the numerical simulation [4] and a physical optics (approximate numerical integration) has been found [8]. Naturally, physical optics cannot describe all diffracted phenomena and for some special cases, the other methods should be considered such as the physical theory of diffraction (PTD) or possibly the various modifications of the geometric theory of diffraction (GTD) [12]. Even if the numerical methods for integral equations could be considered such as FDTD, they are very time consuming (considering the boundary conditions for real situations), and therefore they cannot be used for numerical analyses of typical propagation scenarios.

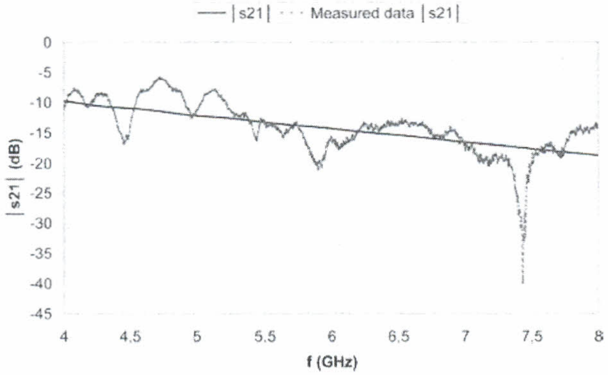

Fig. 5 *Measurements of wet wall.* $\varepsilon_r = 4 - 0.43\,j$ *was used for numerical simulations*

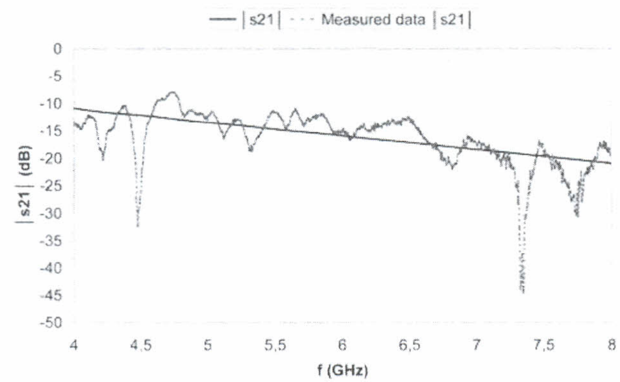

Fig. 6 *Measurements of wet wall covered with wet cloth.* $\varepsilon_r = 4 - 0.48\,j$ *was used for numerical simulations.*

It is difficult to determine the wall parameters for numerical simulations as these parameters depend substantially on wall moisture. That has been verified by measurement of various walls. Similarly, published values differ by the order of magnitude. The wall relative permittivity $\varepsilon_r = \varepsilon' - j\varepsilon'' = 5 - 0.1j$ and permeability $\mu = \mu_0$ have been chosen for numerical simulation of previous time domain measurements [9] of dry wall. The determination of ε_r could be performed separately as ε' is mainly governed by pulse time shift and ε'' is managed by wall losses (permeability $\mu = \mu_0$ has been chosen). The determination of parameters for frequency domain is rather more complicated and "cut and try" method should be used. Even if the frequency domain measurements can be transformed (using FFT) into time domain, the accuracy of results is substantially lower due to various measurement errors (especially phase errors and/or multipath). It could be noted that rather more complicated procedure is used not only for through-wall propagation analyses but for determination of dielectric properties of insitu concrete at radar frequencies [13], when the experimental radar signal was first corrected for the background signal before conversion from the frequency to time domain using an inverse fast Fourier transformation (IFFT) in order to give an equivalent radar pulse signal reflection. This signal was then time-gated to eliminate any unwanted interference components due to edge diffraction and any mismatch within the signal path.

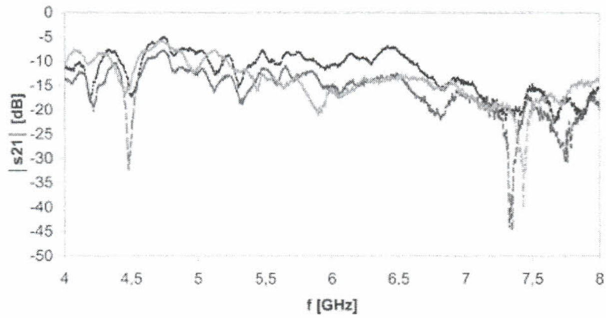

Fig. 7 *Comparison of measurements for previous cases*

It can be discussed, if the cut and try method for permittivity determination is correct but many scientific advances are achieved with a cut-and-try approach. Similarly, several experiments of UWB through-wall propagation for various walls both for frequency and time domains have been carried out and experimental results and numerical simulations are comparable.

After rather time consuming process, the following values have been determined: $\varepsilon_r = 2.5 - 0.3j$ for dry wall, $\varepsilon_r = 4 - 0.43j$ for wet wall and $\varepsilon_r = 4 - 0.48j$ for wet wall covered with wet cloth.

3. Conclusions

New experimental results for measurements performed in the anechoic chamber and numerical simulations for frequency band from 4 to 8 GHz are analyzed. It can be observed that slight interferences are only created thanks to utilizations of absorption panels for reductions of reflections from floor, ceiling and especially side walls in comparison with previous frequency domain measurements done in real scenarios (it would be very difficult to cover effectively at least side walls and neighboring objects in real laboratories). The comparisons of measurements and numerical simulations demonstrate that numerical simulations roughly correspond to average values of measurements.

The comparison of measurements for above cases is shown in ***Fig. 7***. It can be noticed that the interference minima and maxima take place for nearly the same frequencies. Therefore the interferences are not due to internal multiple reflections between boundaries (front and rear face) and differences of complex permittivity (multiple reflections for slabs with different complex permittivity would create maxima for quite different frequencies). Interferences are created by residue reflections, which are probably due to various reasons such as reflections from wall edges, support structures, uneven faces of wall and holes inside the wall (that effect is not substantial and causes only slight deviations). Of course, the slight interferences of ultra wide band systems are not very severe from system point of view.

Various cases of electromagnetic interferences have been studied such as small and aperture antennas and traveling wave antennas. Several experiments of UWB through-wall propagation for various walls both for frequency and time domains have been carried out. Several examples of time domain measurement are given for walls between university laboratories and offices. The described frequency experiments, performed in the anechoic chamber, and numerical simulations for frequency band from 4 to 8 GHz could be compared with the previous time domain experiments, which have been performed using very short pulses, when the multiple reflections (multipaths) could be distinguished. It can be concluded the agreement between the time-domain measurements of through-wall transmission and simulations is good both for time domain as well as for frequency domain (calculated by Fourier transform using time domain data).

Experiments performed for frequency and time domains demonstrate that the numerical simulations, which are very fast, could be reliable for analyses of UWB through-wall propagation phenomena, when suitable wall parameters are chosen.

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Resumé

MĚŘENÍ ŠÍŘENÍ SIGNÁLU SKRZ ZEĎ V BEZODRAZOVÉ KOMOŘE

Dušan ČERMÁK

V článku je analyzováno šíření elektromagnetického signálu pro UWB systémy. Signál je podstatně ovlivněn jevy, vznikajícími při šíření elektromagnetických vln skrz zdi a jiné podobné překážky. V tomto článku jsou uvedeny a porovnány nové experimentální výsledky měření v bezodrazové komoře a simulace pro frekvenční pásmo 4 až 8 GHz. Tyto výsledky jsou dále porovnány s předchozím experimentem, který byl proveden v reálných podmínkách (na zdech mezi laboratořemi a kancelářemi) na různých frekvenčních pásmech a také v časové oblasti pomocí velmi krátkých pulsů. Experiment provedený v časové a frekvenční oblasti ukazuje, že numerická simulace tohoto jevu, která je velmi rychlá, může dávat spolehlivé výsledky, pokud v simulaci použijeme vhodné elektrické parametry zdí.

Summary

ANECHOIC-CHAMBER MEASUREMENTS OF THROUGH-WALL PROPAGATION

Dušan ČERMÁK

The propagation of signals for ultra wide band (UWB) systems is analyzed. Signals can be substantially affected due to electromagnetic wave propagation through walls or similar obstacles. New experimental results of anechoic-chamber measurements and numerical simulations for

frequency band from 4 to 8 GHz are analyzed and compared. That is briefly compared with the previous experiments, performed in real scenarios (walls between laboratories or offices) in various frequency bands and time domain measurements, which have been done using very short pulses. Experiments performed for frequency and time domains demonstrated that the numerical simulations, which are very fast, could be reliable, when suitable wall parameters are used.

Zusammenfassung

MESSUNG DURCH DIE WAND DER AUSBREITUNG DES SIGNALS IN DER REFLEKTIONSLOSER KAMMER

Dušan ČERMÁK

Der Artikel befasst sich mit der Ausbreitung der elektromagnetische Signale des UWB Systems. Das Signal ist wesentlich beeinflusst durch Reaktionen, die entstehen bei der durch Mauer oder ahnliche Behinderungen strahlende elektromagnetischen wellen. Der Beitrag vergleicht neue experimentale Ergebnisse der Messung in der reflektionloser Kammer, simuliert bei der 4 bis 8 GHz Frequenzen.Die Ergebnisse sind dann weiter verglichen mit den im realem Bedienungen entstandenen Messungen (mit der Mauern zwischen Buro und Laboratorraumen) in verschiedenen Frequenzen und im Zeitraum mittels sehr kurzen Impulse.In der Zeit und Frequenz Zone entstandenes Experiment zeigt,dass die numerische Simulation dieses Ereignis, die sehr schnell ist, kann zuverlassige Ergebnisse liefern, wenn die elektrischen Parametre der bei der Simulation aplizierte Wande geeignet sind.