Impact of Different Concrete Types on Radio Propagation: Fundamentals and Practical RF Measurements

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***Abstract*—By the 1960's, European countries faced a massive housing shortage due to changes in social structure and migration from rural areas to towns. This led to a rapid growth of suburban areas in the 1960's and 1970's. Concrete, as a building material became popular as the prefabrication techniques of precast concrete structures developed rapidly during this era, and these trends continue even today. In the near future, the number of frequency bands used by mobile wireless communication systems will increase and, in general, the trend is towards higher frequencies. This paper presents the results of measurements in which the RF attenuations of several different concrete types were determined on the basis of the permittivity of the material samples. The frequency ranges used in the measurements were 4.5 to 19 GHz and 26 to 40 GHz. In particular, at higher frequencies, the attenuation of various concrete grades is very different, and the level of RF attenuation of the outer wall cannot be predicted without knowing the age of the building and the concrete quality used in the element.**

Keywords— Radiowave propagation, penetration loss, energy-efficient buildings, plastering net, outdoor-to-indoor propagation, RF measurements.

I. Introduction

In this paper, the RF-attenuation of various sorts of concrete samples, especially those used in residential construction, was investigated at frequencies of the 5G cellular network. The motivation of the study has been the observation that in new residential apartment buildings, the RF attenuation of the walls has increased compared to similar, but older wall structures. When evaluating possible changes in concrete over decades, it is advisable to get to know the construction of residential buildings in Europe and the structures of a typical concrete wall.

Generally, in Europe, the building construction of cities and suburban areas has been based on concrete-based elements since the 1960s. [1] Element building became quickly common after the Second World War due to reconstruction and, on the other hand, migration from rural to urban areas. For these reasons, a large number of apartments were needed quickly, and industrial methods were developed to meet the demand for new apartment buildings. The basic components of concrete are cement, aggregates and water. The usage of concrete in residential construction across Europe is challenging to obtain a reliable overall picture because the statistical methods for building construction field are different in different countries. However, it is generally reported that around 75% of Europe's total building stock is residential and from that group, on average, 36% are apartment buildings. About 35% of residential buildings are apartment buildings, but the situation varies greatly between different countries. [2] The extent of concrete construction can be estimated also on the basis of cement consumption. Over the past 65 years, cement consumption has increased by about 34 times, while the population has grown threefold. However, it should be noticed that only about 25% of the total cement consumption goes to the concrete used in the buildings. [3]

A. *Age of Building Stock*

Since the exact composition of concrete has varied over the decades, a brief overview of the average age distribution of the European building stock should be taken.

In most European countries, 20-39% of the total housing stock was built before World War II. The biggest exception to this estimate is Finland, where only 10% of the buildings are from this era. Between the war and the first oil crisis that emerged in the 1970s, construction accelerated sharply, and about one third of the entire European building stock have risen up during this period. The common feature of these buildings is that they have a rather weak insulation level and that the need of renovation for their exterior walls is high. After the oil crisis, between 1970 and 1990, residential buildings built in most European countries represent about a quarter of the total building stock. Exceptions are France and the Netherlands, in which more than 35 percent of buildings have been built in this period, and Finland, where even over 43 percent of buildings have been constructed in this era. The average percentage of new residencies built after 1990 is about 14% of the total building stock and varies widely in Europe from 8% to 22% depending on the country. [1,2]

B. Concrete Standardisation

There is a wide range of concrete products in different EU Member States. Their composition depends on local conditions, such as climate, available materials and even locally stabilized fabrication methods. Already in the 1970s, there existed an effort to harmonize the different types of concrete and structures used by different countries. The results of the work began to appear when the European Concrete Co-operative Organization (ERMCO) compiled a "Code of good practice for ready-mixed concrete". After that, there have been many proposals for unification, but still there are no single set of rules that all EU Member States would have accepted. However, as a general basic guideline, the European Cement Standard EN 197-1 [4], which concerns the most important raw materials for concrete, and which fulfills the requirements of the European Concrete Standard EN 206-1, can be considered. However, concrete production must always take into account the specific characteristics of the local cement type, so that the durability of the concrete and other relevant criterions are ensured by designing its own national implementation guidelines (NADS), which have been collected into their own groups within EN 206-1.

The European concrete standard EN 206-1 is an international agreement adopted in 2000 and it is designed to harmonize practices in different countries and therefore has the status of a framework document. [5] However, the framework document EN 206-1 did not succeed in the original objective of harmonization, but there are nationally defined limit values for the strength of concrete. In practice, this led to the fact that different types of concrete are still in use in building construction in Europe. [5] One example is Finland, where, on 1 July 2013, CE marking was introduced, which, for example, proved that the wall element complies with the national standard SFS-EN 14992. [6]

II. OVERVIEW OF CONCRETE'S BASIC PROPERTIES

A. Most Typical Concrete Structures of Buildings

The concrete panels used in exterior walls of multistorey residential buildings are prefabricated panels consisting of two thin concrete layers and a thermal insulation between them. Steel trusses penetrating the thermal insulation connect the concrete layers to each other. [7] When studying the RF attenuation of concrete sandwich elements at different frequencies, the total thickness of the concrete and the insulation between the concrete shells must of course be included in the research. Usually the insulation is mineral wool and it is assumed to be dry. The effect of dry insulation in total attenuation is so small that it can be considered insignificant. On the basis of the observations made in the measurements of this study, the moisture content of the insulation does not rise to a high level in practice because pure liquid form water leakages into the bottom part of the insulation, forced by gravity. Therefore, the effect of the insulating layer is mainly concerning the distance between the inner and outer concrete layer and the reflections based on the distance between layers. That distance is a result of the fact that sandwich elements produced in different decades have the thickness of the insulation layers that has been depending on energy efficiency requirements at that time. [8]

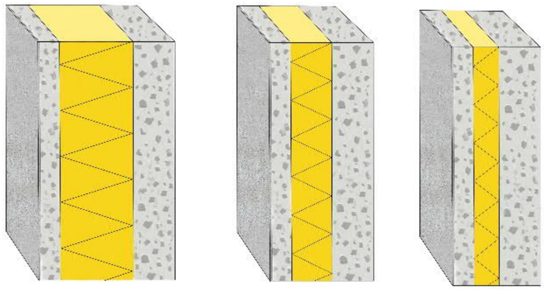

Fig. 1 Typical structures of sandwich wall elements

Although the distance between the outer layer of the wall structure and the different thicknesses of the insulation varies from one wall to another, the most important factor in the overall attenuation of the structure is the attenuation in concrete itself. The quality of concrete can be assumed to be essentially similar in both layers of the sandwich element, and the biggest difference is that the inner shell is usually about 150 mm thick, while the typical outer shell thickness is only about 50-80 mm [7,9,10]. The strength of the inner layer varies depending on the design of the building object. Generally, the thickness of the inner layer depends on whether the wall is load-bearing or nonbearing and on the height of the building. The load-bearing walls are often at the ends of buildings, whereas the sidewall of a building can be lighter and thinner. The height of the building affects the dimensioning of the wall structure because, in the tall buildings, the lower floors must support the weight of the upper floors. This also increases the amount of reinforcement steel of the bottom concrete layers. [7,9,10]

B. Composition of Concrete

This section presents the basic raw materials used in the production of concrete and the effect of their relationship on the final product. The basic components of concrete are cement, aggregates and water. In addition, separate additives have often been added to commercial concrete, which are usually intended to accelerate or slow down the hydration reaction of concrete or to increase the durability of the hardened concrete against freeze-thaw cycles. Raw material ratios can be roughly represented by the following Table 1.

Table 1. Ingredients of concrete

Component	*Percentage*
Cement	10
Water	20
Fine aggregate	28
Coarse aggregate	42
Total	100

Of the raw materials, cement is substantially more expensive than other ingredients. [11] Therefore, in commercial concrete, the proportion of cement has been reduced or partially replaced by other materials. However, cement is an essential part of concrete because it glues the various particles of concrete together. The cement composition has local differences in different countries and even in one country. Cement consists predominantly of limestone and is found on all continents and in almost all countries. In more detail, it has been found that the most common, the so-called Portland cement, consists mainly of four cement minerals, C3S, C_2S, C_3A and C_4AF. The role of these minerals in actual hydration of concrete is very different, but mainly, the properties of the final hydration product, i.e., the calcium silicate hydrate (C-S-H), are determined by the ratios of C_3S and C_2S. [11,30] The Portland cement is divided into different subcategories, and the traditional concrete construction is mainly based on them. Recently, however, for economic and ecological reasons, Portland cement types have been replaced with alloying elements. [5] As a raw material, clinker accounts for more than 60-95% of the other parts of the cement, and in particular it has recently been replaced by other minerals or substances. Typically, these substitutes have been obtained as by-products from other industries, such as blast furnace slag from cast iron production and fly ash obtained from coal combustion. [3]

C. *Water-Cement Ratio's Effect on Concrete's Properties*

In concrete production, water plays a crucial role. First, it dissolves cement minerals and releases ions in the mixing water. At this point, water turns into a pore solution that starts to precipitate quickly. Precipitation produces solid phases which are the final hydration products. Hydration is a continuous process in which the original cement minerals are replaced by hydration products.

In the manufacture of concrete, one of the most important parameters affecting concrete final properties is the ratio of water to cement (w/c-ratio). The amount of water needed for the actual chemical hydration of the concrete is obtained when the w/c-ratio is 0.4. A typical value for the w/c-ratio in commercial concrete is about 0.6. If there is not enough water [11], concrete becomes strong and hard, but it is difficult to process and shape it. Due to the difficulty of mixing the concrete, large empty spaces may remain in the mixture. By using a higher water-cement ratio, concrete becomes more homogeneous and easier to work with. [13,14] However, the price of flexibility is higher porosity, lower strength and smaller durability of concrete.

Concrete, which has high w/c-ratio, all the added water does not form the pore solution and does not deplete in the hydration process and that is why the capillary pores exists. The volume initially filled by this extra water remains in the intrinsic pore structure of the concrete, which weakens the properties of final concrete. However, the amount of suitable water is not easy to define, because different conditions often require different types of concrete. The second reason is that the hydration process is slow and may take years to progress. Many cement pastes never achieve complete hydration. However, the basic rule is that, after 28 days, the portion of the C-H-S gel is so high that the concrete can be considered to be hardened and the original porosity has been sufficiently reduced. [5,11]

III. Interesting Frequencies for RF Measurements

Since the RF attenuation of concrete used in building constructions depends very strongly on the frequency, it is appropriate to make a brief overview of the frequencies of the current and future wireless systems.

Recently, the usage of RF frequencies has been under reorganization. That is why there have been lot of proposals and changes for some of the RF frequency bands. Generally, the problem is that lower frequencies pierce better structures of buildings, but at those frequency ranges there are not available wide uniform frequency bands, which are required by fast data-rate cellular networks. Due to the lack of bandwidth in the lower RF frequencies, new cellular network technologies are planned to use higher frequencies. Because of this, even the small differences might produce obvious disparity in the RF attenuation.

At present, the frequencies that are widely used and planned for the usage of mobile phones start at a range of 700 MHz. The WRC-12 (World Radiocommunication Conference 2012) decided to divide the frequency range of 694-790 MHz partly for the mobile station. The reservation for this band came into effect immediately after WRC-15, which was held in November 2015. [15]

The current and planned use of the 800 MHz band is described in ECC's (The Electronic Communications Committee) Dec (09) 03. [16] It describes more details for the 790-862 MHz frequency range. The use of this range has been discovered as a one solution for the increasing capacity requirements of mobile phone systems in 2015, although many EU member states have TV systems in the same band.

The 900 MHz and 1800 MHz bands have been used in mobile phone communication, and their usefulness is still based on the wide coverage they offer nowadays, especially at sparsely populated areas. The standards for those frequency bands have been agreed since the mid-1990s. [17] In the past few decades, many other mobile communications systems and services that have been added to these frequency bands in addition to traditional GSM. [18]

In 2009, the European Commission authorized CEPT (European Conference of Postal and Telecommunications Administrations) to provide technical conditions for allowing LTE and possibly other technologies in the 880-915 MHz / 925-960 MHz and 1710-1785 MHz / 1805-1880 MHz (900 MHz and 1800) bands [19]. Frequency bands in the 900 MHz and 1800 MHz band are considered also for the use of EC-GSM-IoT (Extended Coverage GSM IoT) and NB-IoT (Narrowband IoT) systems. [20]

The frequency band 1452-1492 MHz has mostly been without any remarkable usage in most European countries. In 2002, the harmonization of broadcasting systems in this band was proposed but the proposal had to be revised later because there have not been existing expected activities. [21] Later, it was defined as the frequency band for the needs of mobile systems, but so that individual countries can use the band or part of it for terrestrial broadcasts and other applications. [22]. The frequency band 1452-1492 MHz, according to the ECC REC (15) 01, also contains a reservation, which states that this frequency range can be used without a coordination, as long as the base station power levels are kept sufficiently low. [23]

The 1800 MHz band is reserved for needs of cellular network already in 1995 according to ERC DEC (95)03 -document and it is complemented by ECC DEC (06)13, written in 2006 and later amended in 2018. These documents are concerning the frequency ranges of 1710-1785 MHz / 1805-1880 MHz. [18,24]

Usage of the 2 GHz frequency band for mobile communication is illustrated by ECC document ECC DEC (06)01, which dealt with frequencies 1920-1980 MHz and 2110-1270 MHz, as well as areas 1900-1920 MHz and 2010-2015 MHz. The abovementioned frequencies are now widely used in UMTS mobile networks. [24]

In Europe the 2.6 GHz band has been allocated for Long Term Evolution (LTE) and partly UMTS systems in operation, and that is stated in decision ECC DEC (05)05 and in CEPT report 62. [25]

For the upcoming 5G network spectrum and equipment, in December 2016, CEPT was mandated by the EU to harmonize the technical conditions within the EU. In the first phase, the measures concern the 3.6 GHz and 26 GHz bands. WRC-15 has subsequently suggested the frequencies in the range of 24.25 to 27.5 GHz, 31.8 to 33.4 GHz, 37 to 43.5 GHz, 45.5 to 50.2 GHz, 50.4 to 52.6 GHz, 66 to 76 GHz and 81 to 86 GHz to be in use for future wireless broadband in Europe. Of these frequencies, at the end of 2016, ECC conducted a survey and, in plenary session in 2017, selected 24.25-27.5 GHz, 40.5-43.5 GHz and 66-71 GHz as the priority frequency bands. [26]

IV. THEORY OF DETERMINING PERMITTIVITY OF MEASURED MATERIALS

The most appropriate way to start researching the RF-attenuation of various material types is by deploying a measurement method that can be used to identify the individual electrical parameters of the materials. The most important material parameters are permittivity and permeability.

Nicolson-Ross-Weir (NRW) method widely used for determining permittivity and permeability of homogenic and isotropic materials. This paper focuses on determining building materials, such as concrete's permittivity. Permittivity of material includes real and imaginary parts and can be expressed as

$$\varepsilon = \varepsilon_r \varepsilon_0 = (\varepsilon_r' - j\varepsilon_r'')\varepsilon_0, \tag{1}$$

where ε_o is permittivity of vacuum and ε_r is relative permittivity of the material. $\varepsilon_r{}'$ describes materials dielectric constant and $j\varepsilon_r{}''$ is imaginary dielectric loss factor. By utilizing the NRW-method, it is possible to determine materials permittivity by measuring the material with a vector network analyzer (VNA). It is essential to find out the S-parameters S_{11} and S_{21}, which describe transmission and reflection properties of the material. After clarifying the S-parameters, reflection coefficient Γ can be solved with following formulas

$$\Gamma = X \pm \sqrt{X^2 - 1}, \tag{2}$$

where

$$X = \frac{(S_{11})^2 + (S_{21})^2 + 1}{2S_{11}}. \tag{3}$$

The absolute value of the reflection coefficient (Γ) must be less or equal to 1, thus roots with higher absolute value should be ignored. After finding the correct root for the reflection coefficient, the propagation factor can be examined as follows

$$\gamma = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21})\Gamma}. \tag{4}$$

Correlation between reflection coefficient, propagation factor and S-parameters makes possible to calculate S-parameters S_{11} and S_{21} from the reflection coefficient and the propagation factor by the following way

$$S_{11} = \frac{\Gamma(1-\gamma^2)}{(1-\Gamma^2\gamma^2)} \text{ and } S_{21} = \frac{\gamma(1-\Gamma^2)}{1-\Gamma^2\gamma^2}. \tag{5}$$

The actual permittivity of the measured material can be calculated from the scattering parameters as

$$\varepsilon_r = \left(\frac{1-\Gamma}{1+\Gamma}\right)\frac{k}{k_0}, \tag{6}$$

where k_0 is free space wavenumber c/ω, and

$$k = \frac{j}{d}(\ln(\gamma) + n2\pi), \text{ n} = 0, \pm 1, \pm 2, \pm 3\ldots \tag{7}$$

The loss tangent term is often shown by following way

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}. \tag{8}$$

Using the formulas above, it is possible to calculate a few key factors, which determines the RF attenuator properties of the material sample. [27,28]

V. MEASUREMENT SET-UP

A free-space measurement system is used here for measuring electromagnetic material properties of planar slabs in the frequency range 5-40 GHz. The method is based on transmission and reflection measurements done by an automatic network analyser. The measurement setup consists of a pair of spot-focusing reflector antennas. The sample under measurement is placed in the common focal plane of the reflector antennas. Waveguide feeds are used as feeds for the reflector antennas. TRL (true, reflect, line) calibration method was used with time-domain gating.

A conventional method to measure the electrical and magnetic properties is to cut a sample of the material and put the sample in the resonator. By measuring the changes in the resonance effect one can calculate the electromagnetic properties of the sample. Another very often-used method is reflection-transmission (RT) method in which the reflected (s_{11}) and transmitted fields (s_{21}) from sample under measurement are measured. The properties of the sample can be calculated from these measurements. The RT-method is extremely suitable for planar samples. In many cases the sample is placed inside the waveguide or coaxial line or in other type transmission line. The disadvantage of these methods is that the samples must be machined very accurately. Even small air gap between the sample and the transmission line wall can cause a significant error. Small accurate samples can be avoided by making measurement in free space using two antennas (figure 1). If conventional antennas are used, the field and phase distribution along the sample surface is varied. In addition, the diffraction from the sample edges makes significant errors. Using focusing antennas instead of conventional ones, the RT-method can be applied for planar plates without any small sample preparation.

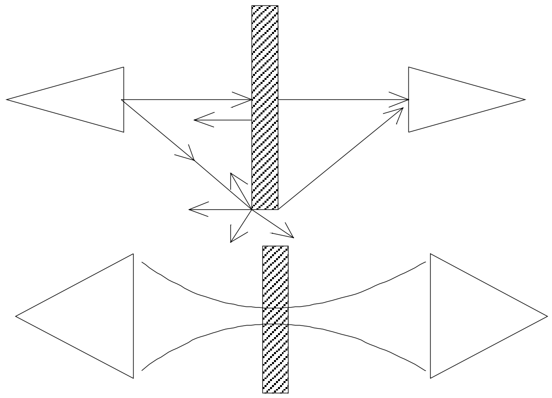

Figure 2. Differences in the free space measurement using conventional and focusing antennas

The free space measurement setup consists of two elliptical reflectors placed against each other so that their common focus is in the same point (figure 3). Open waveguide ends are used as feeds for the reflectors. The sample under measurement is placed in the common focus.

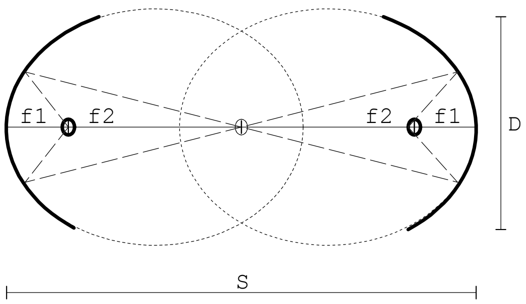

Figure 3. The basic operation of elliptical reflector antennas.

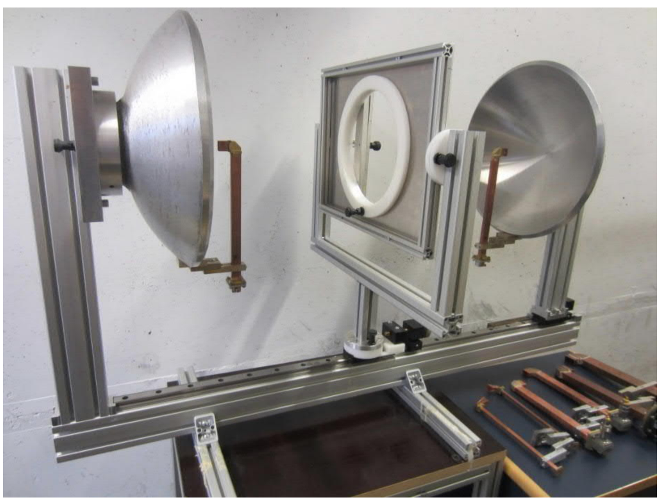

Figure 4. The free space measurement setup of this study

Figure 4 shows the measurement setup. The diameters of the reflectors is 40 cm. The focus area is about 1 λ (-3 dB). The waveguide feeds are changeable so with three waveguide feed sets we can cover the 5-40 GHz frequency range.

The measurements were made with an automatic network analyser. The calibration method is the TRL-method (true-reflection-line). The true is measured when no sample is in the sample holder, the reflection is measured when a metal plate is in the sample holder and the line is measured without any sample in the holder and when the reflector distance is changed about λ/4. In addition to the calibration, the time domain gating is used to avoid multiple reflections.

VI. MEASURED RESULTS

The measured concrete samples were made by casting concrete pieces of approximately 150 x 150 x 400 mm into a mold. The pieces were hardened in the molds for about two months, after which the molds were dismantled, and the resulting pieces were cut with a diamond saw to material samples of approximately 150 x 150 x 15 mm. The different samples were categorized based on the w/c-ratio of the samples. The highest w/c-ratio was 1.0 and the others were 0.7 and 0.4. In addition to these, a sample of concrete used for commercial buildings was also obtained directly by a concrete mixer truck.

Since no reliable research results were available concerning to the moisture behavior of the concrete during the fabrication of the sample pieces, it was decided to prepare two identical samples from each mold. The purpose was to form two groups. Reference or control group samples were dried in the normal manner in the room air and the samples from the another group in the oven for two days, while the oven temperature was constant, 105 degrees. Before the material pieces were placed into the oven, all the samples had been dried in the normal room conditions for two months. After drying the samples in the oven, those that had been in oven and also those which had not, have been left into the normal room environment again for two months. The purpose of that was to ensure all moisture would be stabilized according to the room circumstance for both groups similar way before the RF measurement.

The measured samples includes also special samples, in which the water/cement ratio was constant but the amount of additives were different. These samples were identified by notation S100B and SB45. The S100B is the standard concrete mixture and the SB45 has high amount of additives. The purpose of those additives in the SB45 mixture is particularly to increase the tolerance against to freezing and chemicals.

For the measurements, there were used two separate set up arrangements, one for lower frequencies (4.5 - 19 GHz) and another for higher (26-40 GHz) frequency range. The results from those frequency bands are in following table 2 separated by low- or high indication respectively.

The table below represents also values for some other typical materials used in the exterior walls of buildings, such as the brick, lightweight concrete and wood. The purpose of these samples is to provide general reference values for comparison.

Table 2. Properties of the measured samples

Sample	*Material*	*W/C-ratio*	*Type*	*Width[mm]*	*Oven*	*ε'r low*	*ε'r high*	*ε''r low*	*ε''r high*	*Tanδ low*	*Tanδ high*
1	Concrete	0.7	S100B	13.68	Yes	4.89	4.77	0.22	0.3	0.0450	0.0629
2	Concrete	0.7	SB45B	10.47	Yes	5.72	5.6	0.22	0.26	0.0385	0.0464
3	Concrete	1.0		15.60	Yes	4.89	4.76	0.18	0.22	0.0368	0.0462
4	Concrete	0.4		14.73	Yes	5.38	5.21	0.19	0.24	0.0353	0.0461
5	Concrete	Old		16.73	Yes	5.37	5.36	0.23	0.25	0.0428	0.0466
6	Concrete	Standard		13.23	Yes	5.04	5.24	0.17	0.23	0.0337	0.0439
7	Concrete	Standard		16.83	No	6.29	5.88	0.53	0.62	0.0843	0.1054
8	Concrete	1.0		14.83	No	5.45	5.13	0.33	0.37	0.0606	0.0721
9	Concrete	Old		14.26	No	5.95	5.84	0.36	0.39	0.0605	0.0668
10	Concrete	0.7	SB45B	14.37	No	6.99	6.66	0.66	0.72	0.0944	0.1081
11	Concrete	0.4		15.98	No	6.19	5.82	0.46	0.6	0.0743	0.1031
12	Concrete	0.7	S100B	13.21	No	5.24	5.17	0.33	0.43	0.0630	0.0832
13	Concrete	Old		15.34	No	5.8	5.56	0.35	0.4	0.0603	0.0719
14	Lightweight concrete			13.91	No	2.15	2.06	0.13	0.12	0.0605	0.0583
15	Brick			16.58	No	4.22	4.15	0.03	0.04	0.0071	0.0096
16	Wood			23.41	No	2.21	2.06	0.24	0.18	0.1086	0.0874

Samples of about 30 years old concrete element have been included in the table as a comparison. Due to the age of the samples, the water-cement ratio originally used in their fabrication could not be determined. For these samples, in the table, the values are marked with "old". Also in the table, concrete samples taken directly from a concrete mixer truck are identified by the term "standard".

From the results obtained directly from the network analyzer, only the graphs of sample No. 8 are exemplified below in Fig 5 and 6. The sample was a 14.8 mm thick concrete sample that was not dried in the oven. The variation in s11 and s22 values shown in the figure 5 is due to reflections from the front and back surfaces of the measured sample.

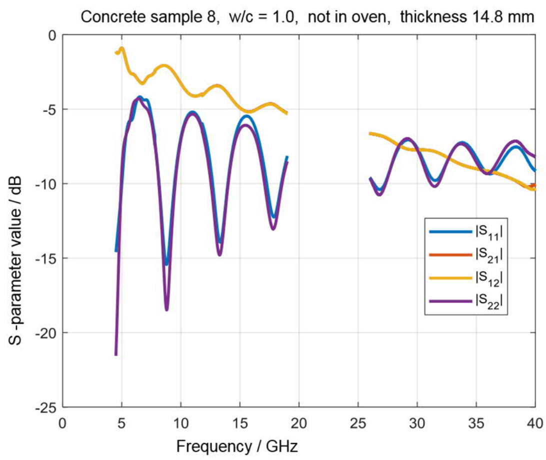

Fig 5. Measured S-parameters of one sample

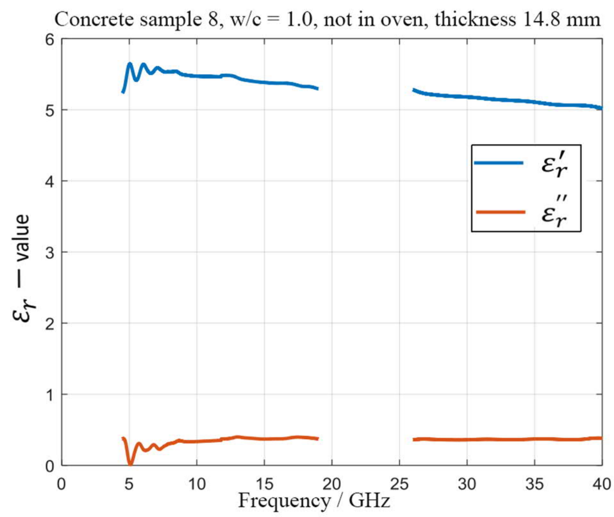

Fig 6. ε_r–values of a sample

The following figures 7 and 8 show the mean values of ε_r' and tanδ for different material samples calculated from the measured S-parameters. Based on the variation of the values in the table, it can be immediately stated that samples 1-6, which have been dried in the furnace, are approximately similar in losses and have a predictable frequency behavior. In other samples, on the other hand, the variation in loss is high and level of loss in general is higher than in the oven dried samples.

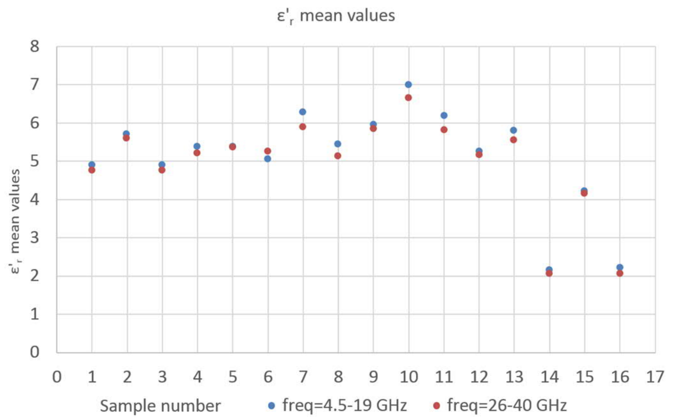

Fig 7. The ε_r' –values of measured samples

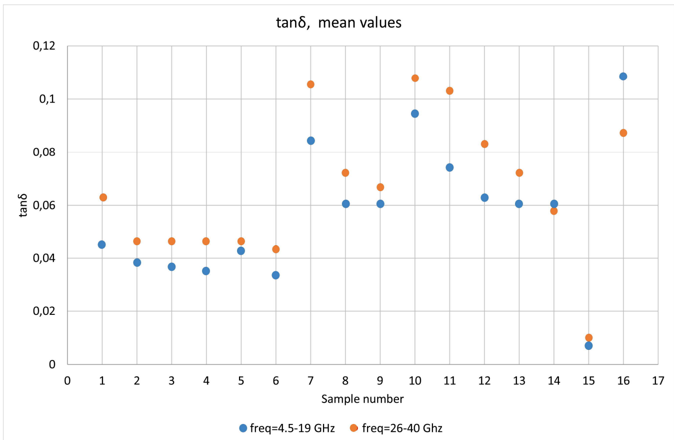

Fig 8. The Tanδ –values of the measured samples

The figure 9 represents the attenuation values calculated based on the permittivity values of the samples for a 200 mm thick concrete wall structure. The figure clearly shows that the attenuation of oven-dried concrete samples is considerably smaller than the attenuation obtained from the measurements of samples stored for 4 months in a standard room temperature.

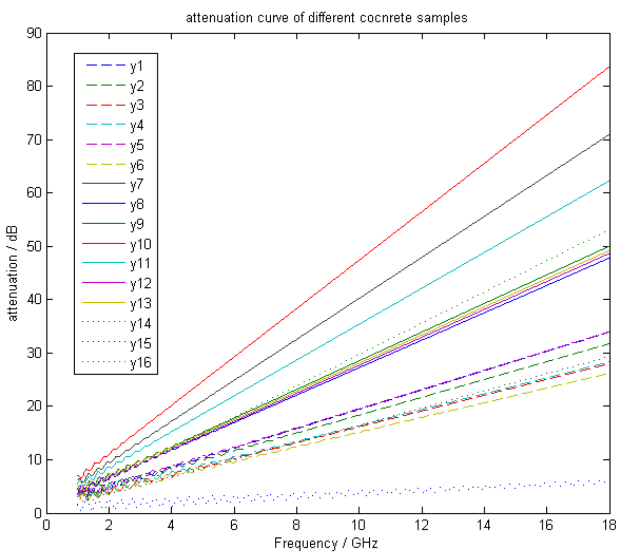

Fig 9. The RF-attenuations of the measured samples

Figure 9 clearly shows dotted lines of samples 1-6 as their own group with significantly lower RF attenuation at higher frequencies compared to curves of the other samples. The smallest attenuation in the figure was on the brick, which is represented by the lowest dotted line. The ripple of the brick curve is due to the fact that the signal components reflected from different surfaces of the sample are added to the straight going component. The fluctuation is more visible on bricks than other materials, because the small losses of brick material do not attenuate the reflected components.

VII. Conclusion

Several different types of building concrete samples were studied. The samples varied in terms of age, w/c-ratio, type of concrete used and whether the sample was dried in an oven or not. The attenuation levels of the samples dried in a ventilated oven (samples 1-6) were significantly lower compared to the other samples.

The temperature in which the samples 1-6 were dried was set to 105 °C, which is generally used when drying concrete in a laboratory. The majority of the samples were relatively new, approximately 30 days old when dried in a ventilated oven. Hydration is a continuous process, which can continue as long as there is non-hydrated cement and water in concrete. The drying causes water to evaporate from the pores of the concrete thus ceasing the hydration reaction. For the samples, which were not dried, the hydration could progress further compared to the samples exposed to the drying. It is also studied that drying concrete samples in 105 °C can cause microcracking around the aggregates inside the concrete. [29] Due the different conditions for hydration reaction and the potential microcracking of the dried concrete samples suggest that the microstructures of the samples were not identical during the measurements. The relative significance between the ceased hydration and the potential microcracking cannot be reliably determined based on the measurements carried out in this study.

Results of this research shows that the RF attenuation vary significantly between the different types of concrete samples. The main reason for the variation in attenuation is the variation in the permittivity of the material, which was particularly evident in the case where concrete samples were dried under normal conditions. Based on the results of this study, it can be stated that especially at higher frequencies, the RF attenuation of different type and different age concrete sandwich elements cannot be represented by one universal attenuation value. However, the impact of a specific characteristics of the concrete such as water/cement ratio, microstructure and moisture content to the RF attenuation levels requires further research.

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REFERENCES

[1] F. Meijer, L. Itard, M.Sunikka-Blank; Comparing European Residential Building Stocks: performance, renovation and policy opportunities [Accessed: Feb 22, 2019]

[2] Buildings Performance Institute Europe (BPIE) Europe's buildings under the microscope, ISBN: 9789491143014

[3] Eco-efficient cements: Potential economically viable solutions for a low CO_2 cement-based materials industry, United Nations Environment Programme, Paris 2017, Job Number DTI/2170/PA

[4] European Standard EN 197-1, Cement - Part 1: Composition, specifications and conformity criteria for common cements

[5] Christoph Muller; Use of cement in concrete according to European standard EN 206-1, https://doi.org/10.1016/j.hbrcj.2012.08.001, HBRC Journal. [Accessed: Feb 22, 2019]

[6] Arto Suikka, RTT ry / Betoniteollisuus; betonituotteiden CE-merkintä laajenee, [Accessed: Feb 22, 2019]

[7] Durability properties and actual deterioration of Finnish Facades and Balconies Tampere University of Technology. Faculty of Built Environment Tampere (2012) Publication 1028. 117 p. 37 app

[8] Esko Mikkola; Rakenteiden sisältämät palokuormat ja niiden suojaaminen, KK-Palokonsultti, Palotutkimuksen päivät, www.spek.fi/loader.aspx?id=07edf9f0-7091-4928-a5d3-de4dd57aec0b [Accessed: Feb 22, 2019]

[9] S .M. Bida, F. N. A. A. Aziz, M. S. Jaafar, F. Hejazi; Advances in Precast Concrete Sandwich Panels toward Energy Efficient Structural Buildings, preprints Posted 8 October 2018, doi:10.20944/preprints201810.0147.v1

[10] S. Gerges, P. Gkorogias; Concrete sandwich element design in terms of Passive Housing recommendations and moisture safety, Master Thesis in Building Technology, KTH Architecture and the Built Environment

[11] J.Thomas, H.Jennings; The Science of Concrete, http://www.iti.northwestern.edu/cement/ [Accessed: Feb 22, 2019]

[12] PCI Committee Report, State Of Art of Precast/Prestressed Concrete Sandwich Wall Panels, https://www.pci.org/ PCI_Docs/ PCI Northeast, /Technical_Resources/Sandwich-Wall-Panels-Guide.pdf [Accessed: Feb 22, 2019]

[13] S.B. Singh, P. Munjal, N. Thammishetti Role of water/cement ratio on strength development of cement mortar, journal of Building Engineering 4 (2015) 94-100

[14] V. G. Haach, G. Vasconcelos, P. B. Lourenço; Influence of aggregates grading and water/cement ratio in workability and hardened properties of mortars, Construction and Building Materials 25 (2011) 2980 – 2987.

[15] CEPT Report 53: to develop harmonised technical conditions for the 694 -790 MHz ('700 MHz') frequency band in the EU for the provision of wireless broadband and other uses in support of EU spectrum policy objectives,https://www.ecodocdb.dk/download/54e59598843d/CEPTREP053.PDF, [Accessed: Feb 22, 2019]

[16] ECC Decision of 30 October 2009 on harmonised conditions for mobile/fixed communications networks (MFCN) operating in the band 790-862MHzECC/DEC/(09)03)

[17] European Radiocommunication Committee, ERC Decision (97)02, 21 March 1997, on the extended frequency bands to be used for the GSM Digital Pan-European Communication System

[18] ECC DEC (06)13 Designation of the bands 880-915 MHz, 925-960 MHz, 1710-1785 MHz and 1805-1880 MHz for terrestrial UMTS, LTE, WiMAX and IoT cellular systems

[19] CEPT Report 41 on compatibility between LTE and WiMAX operating within the bands 880-915 MHz / 925-960 MHz and 1710-1785 MHz / 1805-1880 MHz (900/1800 MHz bands) and systems operating in adjacent bands, November 2010] ,

[20] ECC Report 266, The suitability of the current ECC regulatory framework for the usage of Wideband and Narrowband M2M in the frequency bands 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2.1 GHz and 2.6 GHz

[21] ECC Decision (13)03The harmonised use of the frequency band 1452-1492 MHz for Mobile/Fixed Communications Networks Supplemental Downlink (MFCN SDL)

[22] ECC/DEC/(17)06: the harmonised use of the frequency bands 1427-1452 and 1492-1518 MHz for terrestrial Mobile/Fixed Communications Networks Supplemental Downlink (MFCN SDL); Approved 17 November 2017

[23] Cross-border coordination for mobile / fixed communications networks (MFCN) in the frequency bands: 694-790 MHz, 1452-1492 MHz, 3400-3600 MHz and 3600-3800 MHz, Approved 13 February 2015, and Amended 5 February 2016

[24] ECC DEC (06)01, The harmonised utilisation of the bands 1920-1980 MHz and 2110-2170 MHz for mobile/fixed communications networks (MFCN) including terrestrial IMT systems, Approved 24 March 2006, Amended 02 November 2012

[25] CEPT Report 62, Coexistence studies between seaborne UMTS and LTE with terrestrial electronic communications networks operating in the 1710-1785 / 1805-1880 MHz, 1920-1980 / 2110-2170 MHz and 2500-2570 / 2620-2690 MHz bands

[26] CEPT, Spectrum for wireless broadband – 5G, https://www.cept.org/ecc/topics/spectrum-for-wireless-broadband-5g, Updated: 26 November 2018, accessed 13.2.2019

[27] HP Product Note 8510-3, Materials Measurement, Measuring the dielectric constant of solids with HP 8510 network analyzer.

[28] Lindell I.V., Sihvola A.H., Tretyaakov S.A., Viitanen A.J., Electromagnetic Waves in Chiral and Bi-Isotropic Media, Chapter 7 Meausrement Techniques, Artech House, 1994

[29] Castro, Javier & Bentz, D & Weiss, William. (2011). Effect of Sample Conditioning on the Water Absorption of Concrete. Cement and Concrete Composites. 33. 805-8013. 10.1016/j.cemconcomp.2011.05.007.

[30] Neville, A. 1995. Properties of concrete. Essex. Longman Group. 844 p.