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# Influencing factors of moisture measurement when using microwave reflection method

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**Abstract**

Using microwave reflection for detecting moisture content in building materials is a known method. By combining sensor heads with different microwave penetration depths make it possible to generate 3D moisture content maps. This is a problematic and not easy task because several problems exist: interference between waves reflected from different layers, calibration accuracy, inhomogeneity of the material under the test etc. To interpret real measuring results several artificial moisture content distributions for measurements were built up. We describe rules to catch information about moisture distribution in depth of material from data measured with sensors with different sensing depths.


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*Keywords:* Moisture content of stone; Microwave aquametry; 3D mapping; Dolostone; Mediaeval churches.

## 1. Introduction

Moisture is a wide-spread factor causing damages in Estonian mediaeval churches [1]. Knowing exact distribution of moisture in walls is very useful for planning protective activities in the building or for forestalling further damages.

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Many moisture content measurements exist for that purpose: conductivity measurements, capacitance measurements, equilibrium relative humidity (RH) measurements, neutron scattering measurements, thermography, microwaves reflection/transmission measurements and gravimetric are only some of them. The last method is used for calibration purposes in conjunction with other methods. Some reservations apply since a precise definition of moisture content in materials is missing in the existing standardization [2]. There are many reasons why each mentioned method gives a little bit different result: they have different sensitivity for bounded water, different sensitivity for moisture gradient that is always present, inhomogeneity of measured object, changes taking place in measured object during their preparation phase and/or measurement process (especially during drying) etc.

In current study influencing factors for results of microwave reflection moisture measurement method is analyzed and gravimetric method is applied for calibration purposes. Physics beyond the method is analyzed theoretically and feasibility of using this method is explored on a test object imitating a wall made of porous dolostone with varying moisture content. Material under the test - Kaarma - dolostone was chosen due to practical reasons since many mediaeval churches in western Estonia are built of this material and those facilities experience several moisture problems. Described method was chosen due to the fact that it does not impair mediaeval churches having high cultural value and being protected by the heritage board.

## 2. Theoretical background

Reflection and transmission of the microwaves from the material surface depends directly from the dielectric permittivity of the material and geometry of the material surface. Damp dolostone is solid rock having its pores filled with water. We consider a simplified situation where the pores have spherical shape (see Fig. 1). For the main material complex dielectric permittivity $\varepsilon$ can be written as $\varepsilon = \varepsilon' + \varepsilon''$ and for the water $\varepsilon_w = \varepsilon'_w + \varepsilon''_w$. For different dry lime- and dolostones $\varepsilon'$ it is between 4…8 and $\varepsilon'' \approx 0.7$ (for measurements a network analyzer with open end coaxial probe was used, at 2.45 GHz).

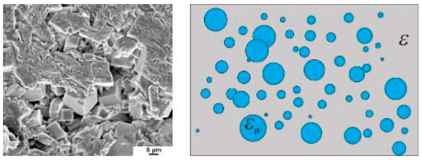


Fig. 1. Microscopic observations of the Kaarma dolostone (scanning electron microscope JEOL JSM 840A) and simplified model of the dolostone with water filled spherical pores.

Effective dielectric constant $\varepsilon_{eff}$ for such a model can be calculated using classical Maxwell Garnett formula for two-phase mixed materials [3], where $\varepsilon$ is dielectric permittivity and $f$ is volumetric fraction of the water.

$$\varepsilon_{eff} = \varepsilon + 3f\varepsilon \frac{\varepsilon_w - \varepsilon}{\varepsilon_w + 2\varepsilon - f(\varepsilon_w - \varepsilon)} \tag{1}$$

Formula is valid also in case where dielectric constants are complex [4]. Dielectric constant of damp stone material can then be calculated in complex form as: $\varepsilon_{eff} = \varepsilon_{eff}' + i\varepsilon_{eff}''$

Microwaves are part of the electromagnetic spectra and their behaviour transiting or reflecting from matter can be characterized by Fresnel equations. Mentioned equations describe all kinds of electromagnetic radiation, including light. This means that various calculators and software designed for analyzing reflection of light waves are applicable for microwaves as well. In optics a refraction index $n$ is used to characterize investigated matter. It could be expressed in complex form as $n = n' + in''$, in order to account for an absorption of radiation in matter.

In our case $n_{eff} = \sqrt{\varepsilon_{eff}}$ (dielectric permeability is $\mu = 1$) and direction of the microwaves is perpendicular to the surface.