UTILIZATION OF MICROWAVES TO DETECT CRACKS IN BIOMATERIALS

Maria Papezova, Dagmar Faktorova

Department of measurement and applied electrical, Faculty of Electrical Engineering, University of Zilina, Slovakia

Abstract

The integrity of any material has to be tested to avoid defection. Many non-destructive testing techniques (NDT) fail to detect the presence of cracks inside materials due to their complex nature. Microwave non-destructive testing (MNDT) utilizing waveguide are able to show results in detecting cracks inside the composite structure. The work of this article is a contribution to the numerical modelling of high frequency electromagnetic (EM) wave's propagation in material with defect and to the characterization of dental material at microwave frequencies.

1 Theoretical background

Application of materials in the microwave, communications demands an accurate knowledge of dielectric properties as complex permittivity, complex permeability and conductivity. These properties of material may be determined using scattering parameters (***S***-parameters), Figure1.

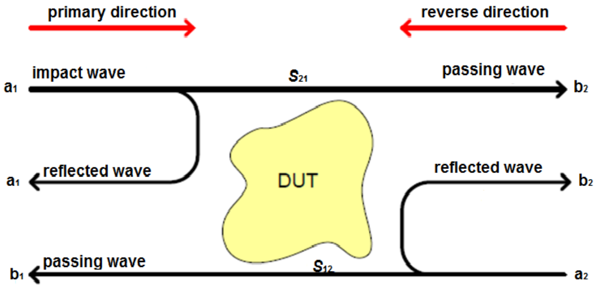

Figure 1: Graphical representation of EM wave distribution in the microwave frequency network (DUT – Testing device)

It is the first important numerical dependence of microwave frequency (GHz) and ***S***-parameter. The ***S***-parameters matrix expresses the changes of EM energy propagating through a multi-port transmission line, if the wave meets the impedance differing from the line's characteristic impedance.

Our aim is to analyse homogeneity and also heterogeneity in biomaterial (especially used in dentistry). The analysis is realized through the reflected EM signal $\boldsymbol{S}_{11}$ and the transmitted EM signal $\boldsymbol{S}_{21}$ at each port. These parameters can be calculated:

$$\boldsymbol{S}_{11} = \frac{\boldsymbol{b}_1}{\boldsymbol{a}_1} \Leftrightarrow \boldsymbol{a}_2 = 0 \qquad (1)$$

$$\boldsymbol{S}_{21} = \frac{\boldsymbol{b}_2}{\boldsymbol{a}_1} \Leftrightarrow \boldsymbol{a}_2 = 0 \qquad (2)$$

Reflection and transmission characteristic in layered structure become more complicated to analyse as human tooth is. Basic geometry structure of the human tooth in gingiva, and their relative permittivity (ε_r) is shown in Figure 2.

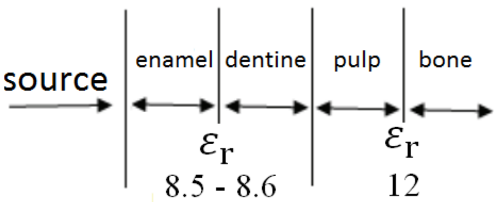

Figure 2: The geometry of the multi-layered human tooth in gingiva

Multiple reflections fall between boundaries of multi-layer model (Figure 2), with a causing modification of the reflection and transmission coefficients. The transmitted wave is vertical to the line interacts with the reflected wave. Both form standing waves in each layer. This effect increase, if the thickness of each layer is less than the permeation depth for that tissue. It means that model is independent not just on dielectric parameter (described upper) but also on the thickness of every layer.

2 Numerical validation and crack detection

The general numerical tool for solving and dielectric parameters of variety of EM structures is the fine element method (FEM). Basically, several structures can be reduces to 2D EM analysis. Comsol Multiphysics is applied to solve the field problem of 2D and also 3D structure full-wave analysis separately.

In Figure 3, there is presented a rectangular waveguide WR-90 of 80 mm length. The waveguide presents the X-band frequency, it means 8-12GHz and it is filled with DUT of 10mm length. DUT presents the jaw, which is the last two part of multi-layered geometry (shown in Figure 2), the jaw (pulp with bone). The microwave source is implemented only in port 1 (left side), port 2 (right side) presents short circuit.

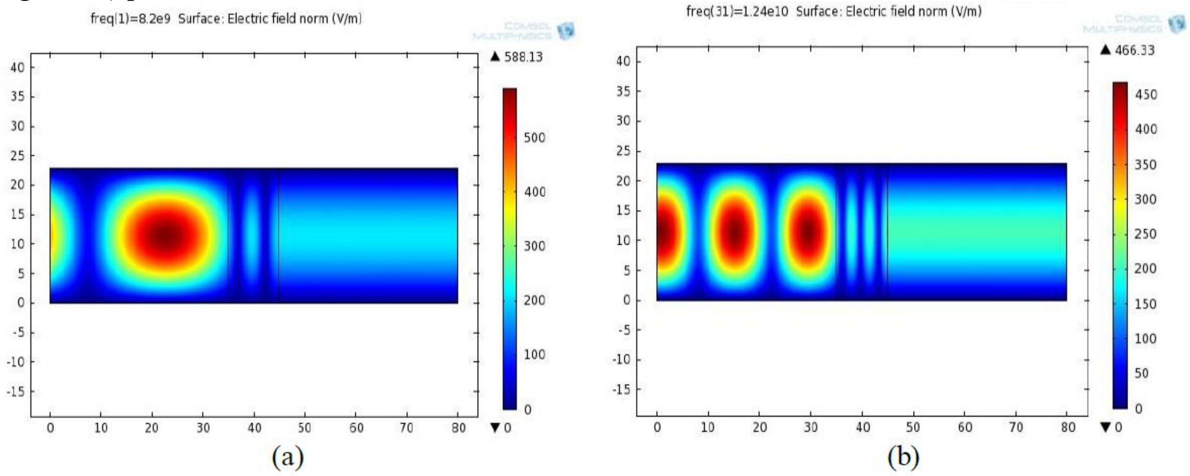

Figure 3: The calculated electric field distribution in the 2D case at 8.2 GHz (a) and 12.4 GHz (b). The DUT is just the jaw (pulp and bone, with ε_r=12)

The numerical model is realized in software tool COMSOL Multiphysics, concretely RF Module. This simulation tool allows quick and precise analysis of materials and microwave signals penetrate dielectric media relatively easily. Next intention is to simulate precise 3D analysis (shown in Figure 4).

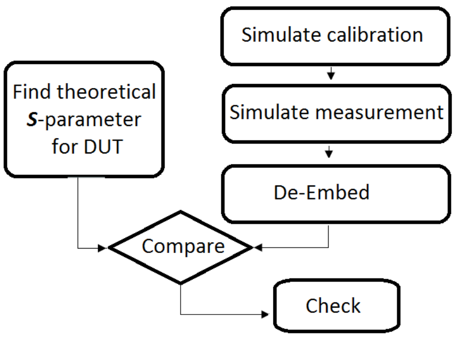

Figure 4: Flow chart to analyse the precision of the 3D EM waveguide simulations

This 3D analyse will contain crack (different size and geometry) in various materials (especially used in dentistry).

Polarizations properties of microwave signal can be used to increase the sensitivity to defects and flaws of certain orientation in the sample. There appears to be misconception that, because microwave signal may have wavelengths of the order of centimetre, the resolution of flaws and defects is limited to a large fraction of these relatively long wavelengths.

3 Conclusion and future work

Detection and sizing of cracks on the material and under surface of material have interested a lot of researches, due to the assessment of structural integrity between material and human tissue. There are many type of sensor for crack detection.

We are interest in MNDT, which sensors are sensitive to geometrical and dielectric variations in a sample. MNDT technique have advantages over other NDT methods (such as radiography, ultrasonic, and eddy current) regarding low cost, good penetration in non-metallic materials, good resolution and contactless feature of the microwave sensor (waveguide, antenna).

On the other hand, MNDT represents more an academic exploring, than a common procedure for practical applications. The reason for this is supposedly, that the microwave technique and the test results seem to be complicated.

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Maria Papezova
Department of Measurement and Applied Electrical, University of Zilina
Univerzitna 1, 010 26 Zilina
maria.papezova@fel.uniza.sk
Phone: +421 41 513 2131

Dagmar Faktorova
Department of Measurement and Applied Electrical, University of Zilina
Univerzitna 1, 010 26 Zilina
dagmar.faktorova@fel.uniza.sk
Phone: +421 41 513 2131 2112