International Journal of Scientific & Engineering Research, Volume 4, Issue 5, May-2013 1418
ISSN 2229-5518

Detection and Identification of Caries in Human Tooth at GHz Frequencies

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Abstract— In this study, numerical investigation has been carried out to determine the usefulness of electromagnetic wave for detection and identification of caries in a human tooth model at GHz frequencies. To carry out the investigation, a realistic three dimensional electrical model of human tooth has been developed and placed between a pair of dipole antennas designed at GHz frequencies. The model is simulated using Finite Integration Technique (FIT) based commercially available software CST Microwave Studio. Results obtained from the simulations show that significant electromagnetic energy absorption occurs due to the presence of caries within the tooth at GHz frequencies. The results obtained by this study suggest that it is possible to identify the caries composition. This data provided a powerful tool to differentiate between normal and abnormal or affected teeth.

Index Terms— Caries, Dipole pair, FIT, Human teeth.

1 Introduction

DENTAL caries is a serious chronic disease which not only causes to destruction of the tooth structure but also eventually to infection of the dental pulp and the surrounding tissues. Diet (mainly fermentable carbohydrates), microbes, and the host (amount and constituents of the saliva-habits) are the common factors for contributing to the formation and progression of the disease. The progression of a dental caries is a dynamic process with periods of dissolution and redeposition of minerals in the dental hard tissue. There are different stages of the disease are taken into account, from the initial to the clinically manifest lesion. In most industrialised countries 60%–90% of school-aged children are affected. The prevalence among adults is even higher and in most countries the disease affects nearly 100% of the population [1].

During the early stages of the disease the process is reversible and the progression of the disease can be arrested certainly and non-invasive intervention can convert the caries lesion from an active to an inactive state [2],[3]. But the diagnosis and/or detection of dental caries or tooth decay in the early stage of its formation are difficult and often inaccurate science. The difficulty of reliably diagnosing early stage of dental caries formation with a very few quantitative and valid methods to determine the health condition and integrity of tooth structure underneath the enamel surface, especially in inaccessible interproximal surfaces are well documented [4],[5],[6].

Over the past twenty years there has been carry out intensive research work in order to develop more sophisticated methods for early detection of dental caries and it is found that most of them are based on optical detection methods [7]. In one of the study where irradiation of the human premolar decay tooth with a short pulse Nd:YAG laser (1064 μm, 12 ns) and monitoring the laser-induced local thermal effects, microscopic caries in the tooth have been detected [8]. Another study reports a novel photo-acoustic technique modality utilizing a frequency- modulated Q-switch Nd:YAG laser at 1064 nm with pulse repetition frequencies from 5 Hz to 100 Hz to differentiate between normal and decay teeth [9].

Different numerical electromagnetic methods play significant roles to calculate various Radio Frequency (RF) characteristics inside living objects including tissues and cells. Among all numerical methods, Finite Difference Time Domain (FDTD) technique is used in several research investigations during Electromagnetic (EM) simulation of living tissues. Theoretical investigation has been carried out to determine the usefulness

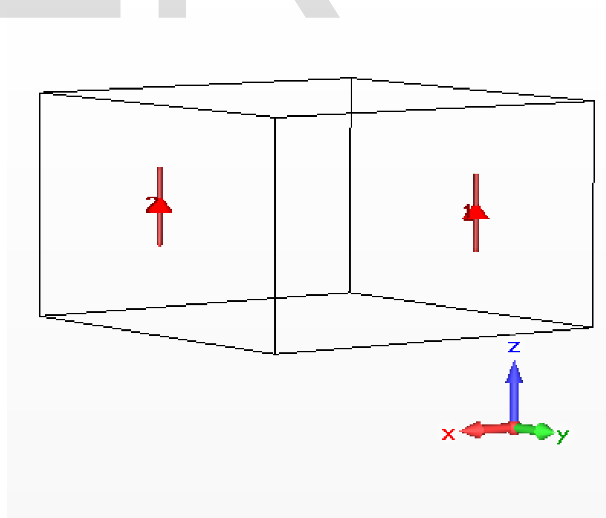

Fig. 1. Schematic diagram of a dual dipole antenna system.

of EM wave for detection and selective destruction of bacteria colony at THz frequencies using FDTD method. [10]. In the present work, FIT based commercially available software CST Microwave Studio has been used for detection and identification of caries in a human tooth model in the frequency range from 20 GHz to 100 GHz.

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ISSN 2229-5518

2 System Model

A pair of dipole antennas made of aluminium placed in the air media and aligned along z-axis with central feed gap on the same xy plane as shown in the Fig. 1 has been used for all the simulations. The pair of dipole antennas of 2.0 mm lengths (*L*) with resonant frequency near 58.8 GHz in free space is considered for study of EM energy absorptions in normal and affected teeth. The dipole-pair is separated by a distance of 6.0 mm.

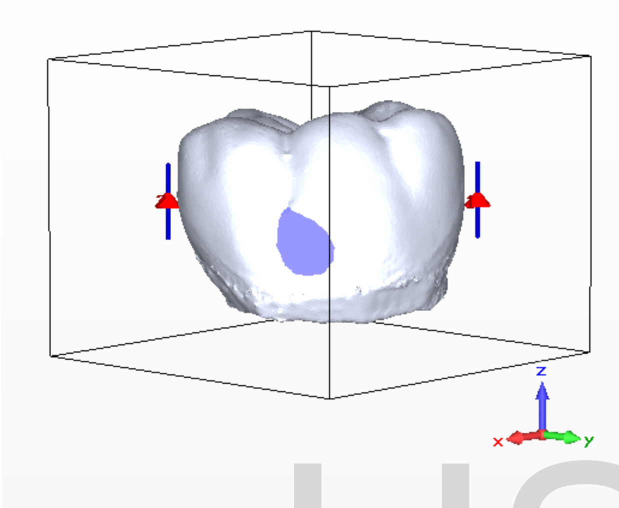

Fig. 2. Simulation model of human tooth model.

Tooth model used in this study is obtained from freely available 3D dataset of archive site [11]. An in-house program has been developed in CST Microwave Studio where 3D raw data from original data file of tooth model has been imported. Geometry of the tooth along with dipole antenna pair used in the simulation is shown in Fig. 2. The simulation domain consisting of 64,328 mesh cells of each having length equal to 0.039 mm.The tooth model is assumed to be comprised of only one type of tissue; i.e., tooth tissue. Values of relative dielectric constant (ε_r) and conductivity (σ) of the tooth material used in this study are obtained from literature [12].

The transmitting (Tx) antenna is excited using the Gaussian pulse of unit amplitude whereas other acts as receiving (Rx) dipole antenna. The voltage at the two ports of the systems is calculated to obtain S_{21} using the following equations [13]:

$$a_1 = \frac{V_1(f) + Z_0 I_1(f)}{2\sqrt{Z_0}} \quad (1)$$

$$a_2 = \frac{V_2(f) + Z_0 I_2(f)}{2\sqrt{Z_0}} \quad (2)$$

$$b_2 = \frac{V_2(f) - Z_0 I_2(f)}{2\sqrt{Z_0}} \quad (3)$$

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \quad (4)$$

where, $V_1(f)$ = I/P pulse at Tx, $I_1(f)$ = I/P current at Tx, $V_2(f)$ = received voltage at Rx, $I_2(f)$ = received current at Rx and Z_0 = characteristic impedance of Tx and Rx (50 Ω).

S_{21} is computed in dB by:

$$S_{21} = 20\log_{10}\left(\left|S_{21}\right|\right) \quad (5)$$

3 Results

The variation of S_{11} and S_{21} with frequency for the dipole-pair without presence of tooth is shown in Fig. 3. From the figure it can be observed that the value of S_{11} is -15.55 dB at 58.8 GHz

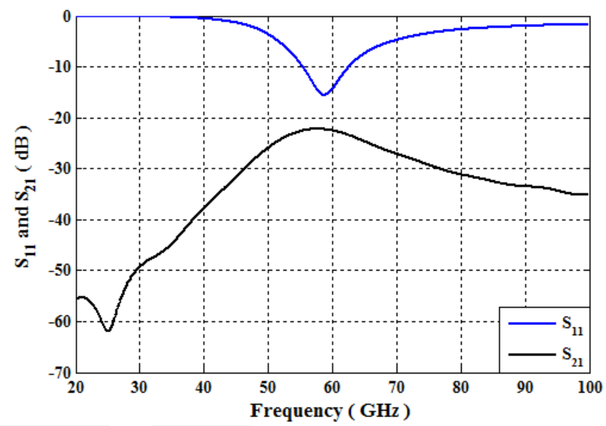

Fig. 3. Variation of S_{11} and S_{21} with frequency for the dipole-pair without presence of tooth.

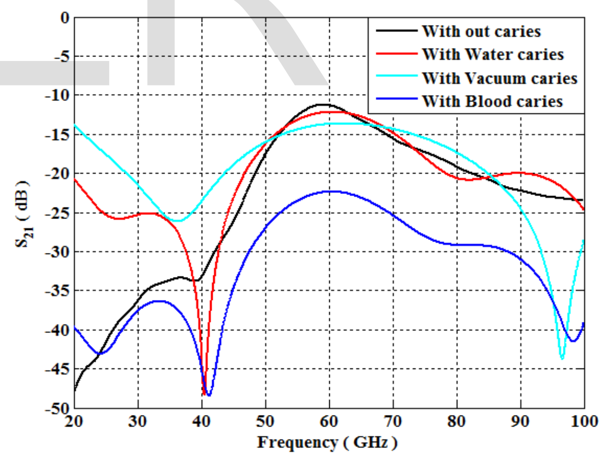

Fig. 4. Variations of S_{21} with frequency.

on the other hand the S_{21} shows peak value of -22.23 dB at 57.6 GHz, respectively for the reference system impedance of 50 Ω.

The variation of energy absorbing band for normal and affected teeth is analysed. Variations of S_{21} with frequency for different type of caries composition are shown in Fig. 4. From the Fig. 4, it is found that for the normal tooth peak value of S_{21} is higher than that for the affected tooth. Again, for different carries material peak value of S_{21} are different as shown in the Fig. 4. Peak values of S_{21} for the caries composed of water, vacuum/no material and blood are -12.18 dB, -13.64 dB and -22.37 dB respectively.

4 Conclussion

In this work, a FIT based EM simulation setup consists of a pair of dipole antennas and a human tooth is modelled and analysed to observe the EM energy absorptions in normal and affected teeth. Due to the absorptions of EM energy in the normal and abnormal teeth, different peaks are appeared in the S_{21} plots. It is observed that for different carries material peak value of S_{21} are different. This analysis shows that the GHz frequencies can be used to detect the presence of carries and their composition material but it is unable to give any idea about the position and size of the dental carries. Therefore, further research work is required to obtain data about the position and dimension of dental carries using EM wave.

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