STUDY ON DIAGNOSIS FOR TOOTH USING MILLIMETER-WAVES

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ABSTRACT

This paper presents applications of millimeter-waves for the characterization of teeth. This is done by measuring the complex permittivity over the frequency range from 0.04 to 40 GHz. These measurements have revealed that dental caries are significantly more lossy to microwaves and millimeter-waves than healthy tooth, and this difference can be used for dental diagnosis. The experimental results have been confirmed by using the Finite Difference Time Domain (FDTD) method at 35 GHz. In addition, higher frequency experiment have revealed that higher resolution for dental caries is possible by using a smaller applicator. It is concluded that millimeter-waves can be used for dental medical diagnosis.

INTRODUCTION

Conventional diagnosis of dental caries has been conducted by a dentist's subjective judgement based on observation of change of color, odor, surface hardness, and clinical symptoms such as pain. X-ray imaging provides a more objective diagnosis, but this technique can cause biological damage to human tissues. With X-ray diagnostic methods, the initial stage of dental caries can not be differentiated easily from the healthy tissues. Because of this, a more non-destructive and objective diagnosis is highly desired.

In the past, microwaves and millimeter-waves have been applied to various medical treatments. However, there seems to be no sufficient reports presenting the applicability of microwaves and millimeter-waves to the field of dental medical treatment. In this paper, the possibility of using millimeter-waves for dental diagnosis has been investigated by measuring the complex permittivity of enamel, dentin and dental caries. These results suggest that dental caries diagnosis using millimeter-waves can be based on differences in loss between dental caries and healthy tooth. At 35 GHz, experimental measurements of transmission coefficients have been conducted and confirmed by FDTD [1, 2] analysis to demonstrate a potential clinical procedure. Moreover, in order to differentiate the dental caries from the healthy tooth more clearly, transmission coefficient have been measured over the frequency range from 33 to 110 GHz.

MEASUREMENT OF CHARACTERISTICS

The reflection coefficient for various samples was measured using a Wiltron 360B Vector Network Analyzer along with an open-ended coaxial probe attached directly to the samples. The complex permittivities of samples were obtained by making a comparative calculation between samples and a standard material [3-5].

The tooth material was classified as enamel, dentin and dental caries. Some dental caries are composed of soft and watery tissues. The moisture content in dental caries changes as the condition of caries changes. In order to know the dental caries condition, they were classified by their moisture content as a function of time after being removed from a preservative solution. The moisture content will decrease as a function of time after removal from the preservative solution.

Fig. 1 shows the loss tangent of tooth calculated by the complex permittivity. In this figure, caries type 1 denotes the highest moisture content, followed by caries type 2 and 3 with lower moisture content, respectively. As shown in this figure, the loss tangent of dental caries decreases as the moisture content decreases. The loss tangent for dental caries is significantly higher than that for a healthy tooth. Dental caries are soft and have a high moisture content resulting in a high loss tangent. Based on these results, it is predicted that millimeter-wave transmission measurements would be different between a healthy tooth and dental caries.

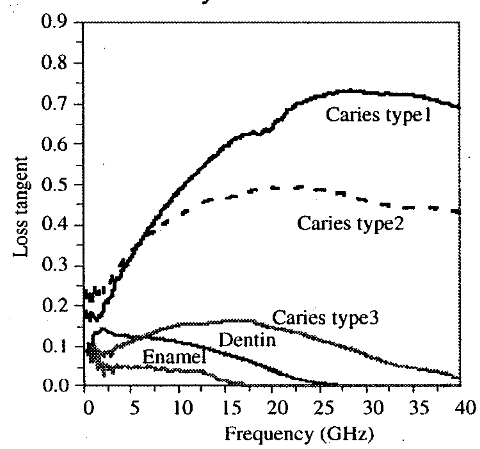

Figure 1: Loss Tangent of Tooth

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THEORETICAL CONSIDERATION

A. FDTD Simulation

A three-dimensional electromagnetic field analysis of the tooth was made using FDTD at 35 GHz. The simulation was made at 35 GHz because the wavelength was small enough relative to the tooth size to provide a large differentiation between dental caries and healthy tooth components. As shown in Fig. 2, two models were used: model A for a healthy tooth and model B which contains dental caries. The relative complex permittivities used for each medium are shown in Table I. The relative complex permittivity of the dental caries is the value of caries for type 2.

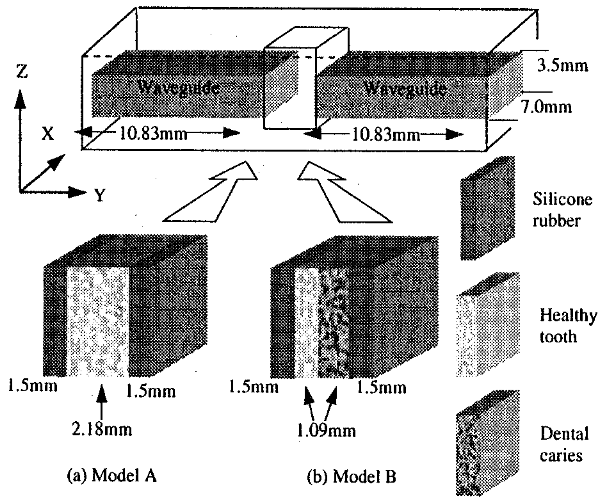

Figure 2: Analysis Model

TABLE I

RELATIVE COMPLEX PERMITTIVITY OF EACH MEDIUM

	Healthy tooth	Caries	Silicon Rubber
ε_r'	6.83	6.04	2.7
ε_r''	0.02	2.64	0.01

B. Simulated Results

Figs. 3 and 4 show the electric field distribution in the healthy tooth and in the tooth with dental caries. The wave penetrates each medium at the receiving waveguide. It is observed that the amplitude of transmitted waves through the dental caries is lower than that through the healthy tooth because of the greater loss tangent of the dental caries.

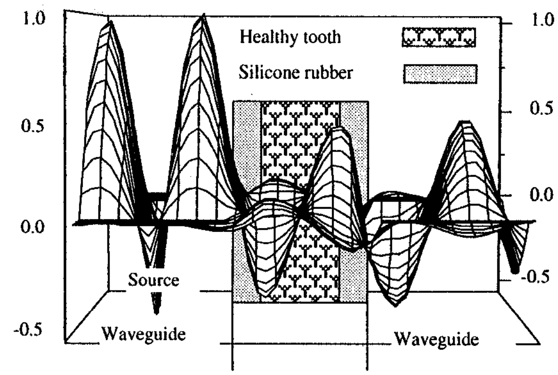

Figure 3: Electric Field Distribution in Healthy Tooth

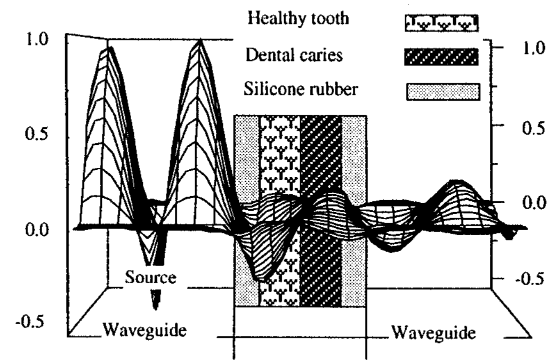

Figure 4: Electric Field Distribution in the Tooth with Dental Caries

EXPERIMENTS IN Q-BAND

A. Measurement

In order to compare the simulated and measured results, the transmission coefficient for the tooth was measured at 35 GHz. As shown in Fig. 5, a sample tooth was irradiated by the millimeter-waves using a rectangular waveguide. The transmission coefficient (S_{21}) was measured by a network analyzer. In order to reduce the effect of the mismatch of the air gap between the probe and the sample, silicone rubber sheets were placed in the apertures of both waveguides. Five samples were measured. Extracted adult's teeth were used for the samples. As shown in Fig. 6, samples 2-5 consist of two parts, one containing dental caries and the other part containing only healthy tooth. Sample 1, which had severe dental caries, was divided into a heavy caries part and a light caries part.

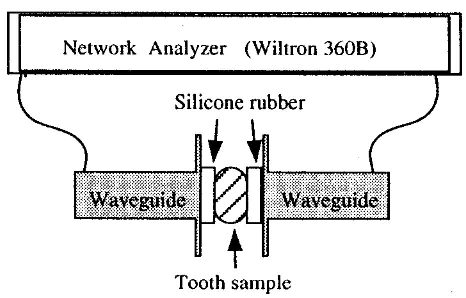

Figure 5: Experimental System

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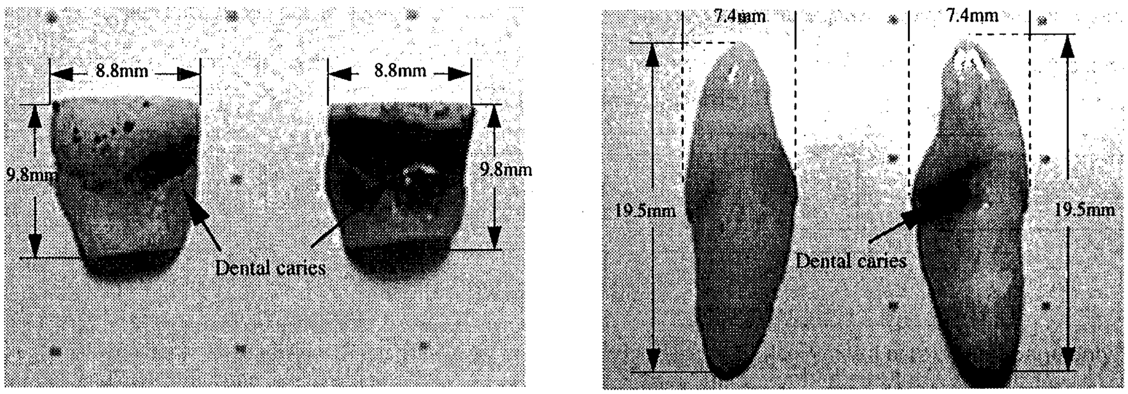

Sample 1 Sample 2

Figure 6: Photo of Tooth

B. *Experimental Results*

To evaluate and compare the data, the transmission coefficients [dB/mm] were obtained and shown in Fig. 7. For samples 2 to 5, it is shown that the value for dental caries is about 1 dB lower than that for a healthy tooth. In sample 1, the value for dental caries is about 3 dB lower than that for the healthy tooth. This result indicates that the transmission coefficient of dental caries is lower than that of a healthy tooth and varies strongly with the degree of caries. The transmission coefficients of the healthy tooth are very uniform, as shown with samples 2 to 5. However, the sizes of the dental caries were small in comparison with the aperture size for the waveguide. By using a smaller aperture, it should be possible to locate the dental caries more precisely within the tooth by measuring a greater deviation in transmission coefficient.

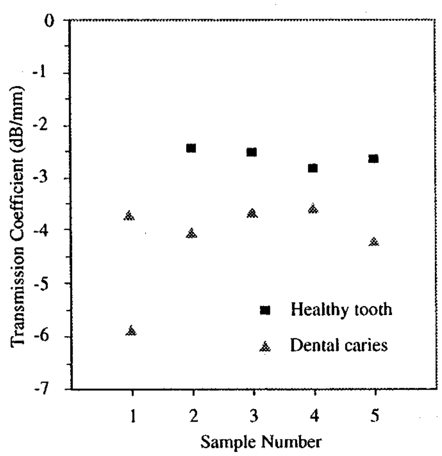

Figure 7: Transmission Coefficient of Millimeter-Waves (35 GHz)

EXPERIMENTS UP TO W-BAND

A. *Measurement*

In order to differentiate the dental caries from the healthy tooth effectively, transmission coefficient for tooth were measured by smaller applicators over the frequency range from 33 to 110GHz. Three types of waveguide applicators were used. From the lower frequency the aperture sizes were 5.6 mm x 2.8 mm, 3.8 mm x 1.9 mm and 2.6 mm x 1.3 mm, respectively. Millimeter-waves were directly irradiated to the tooth by direct contact waveguides. Propagated power were measured by horn antennas located on the opposite side. Since the aperture sizes were very small, it was possible to measure the propagated power of the dental caries and healthy tooth like Fig. 8.

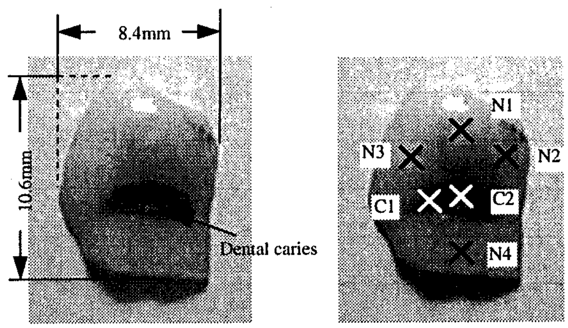

Figure 8: Photo of Tooth

B. *Experimental Results*

The experimental results are shown in Figs. 9-11. Over the frequency range from 33 to 50 GHz, the value for dental caries is about 4 dB lower than that for healthy tooth. It is difficult to differentiate the dental caries from the healthy tooth effectively because the aperture size is too large. However, the difference of each transmission coefficient increase as the aperture size becomes smaller. As shown in Fig. 10, there is about 7 dB difference between the value for dental caries and healthy tooth. Furthermore, as shown in Fig. 11, the value for center caries is about 10 dB lower than that for healthy tooth. And the value for edge caries is about 5 dB lower than that for healthy tooth. These results reveal that higher resolution is obtained when smaller applicator is utilized. Furthermore, it is revealed that below 3 mm applicator is effective for diagnosis of the caries.

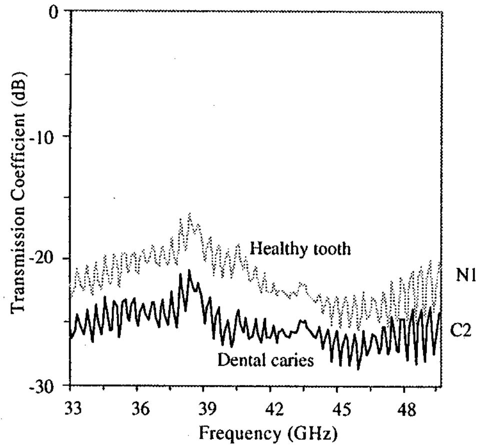

Figure 9: Transmission Coefficient of Millimeter- Waves (33-50 GHz)

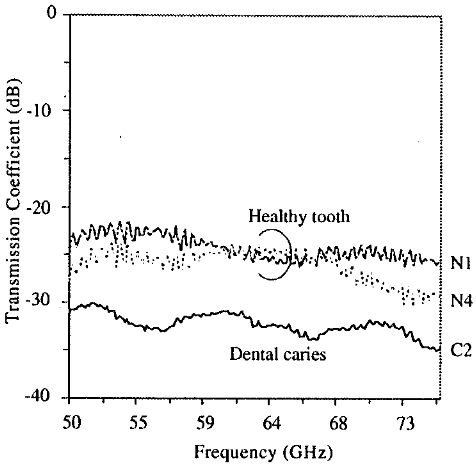

Figure 10: Transmission Coefficient of Millimeter- Waves (50-75 GHz)

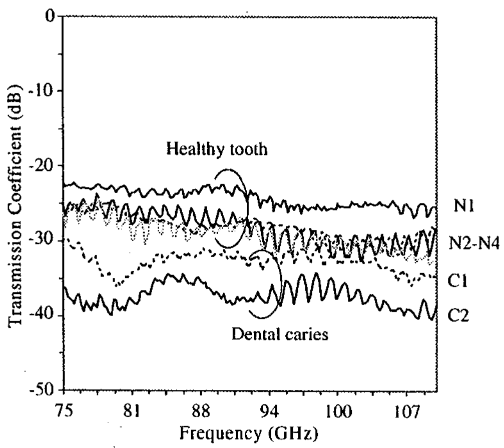

Figure 11: Transmission Coefficient of Millimeter- Waves (75-110 GHz)

CONCLUSIONS

The loss tangent of dental caries is shown to be significantly higher than that of a healthy tooth. This difference has been confirmed by measurement and FDTD simulations. This result can be applied to dental caries diagnosis. By this method proposed here, more scientific and objective diagnosis for the caries can be realized.

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