FUNDAMENTAL STUDY ON MEASUREMENT OF DIELECTRIC CONSTANTS OF HUMAN ABDOMEN BY WAVEGUIDE-PENETRATION METHOD

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Abstract

Permittivity of human tissues have been measured in vitro in many literatures. However, to use permittivity of human tissue for diagnoses or healthcare purpose, it is desirable to measure in vivo. The author's research group has studied about measurement method for permittivity of human fingers in vivo by waveguide penetration method. To measure permittivity of human abdomen, larger waveguide is necessary. In this paper, applicability of the method to measure dielectric constant of human abdomen is investigated by numerical simulations. A large size waveguide is designed to measure permittivity of human abdomen. Transparent coefficients and reflection coefficients of the waveguide are measured at multiple frequencies with existence of human abdomen for different thickness of muscle and fat layers. The results show the possibility to measure and to evaluate fat in human abdomen by using this technique for healthcare purpose. For future study, detailed conditions of measurement are investigated and comparisons with experiments are performed.

1. INTRODUCTION

In aging society, workloads of medical doctors and workers are huge problem. To reduce their workloads, essentially, preventive medicine is important. Accordingly, lifestyle related disease, such as cardiac disease, hypertension, metabolic syndrome, obesity, or diabetes mellitus, should be overcome by healthcare and preventive medicine. To prevent metabolic syndrome, Japan ministry of health, labor and welfare has employed abdominal circumference measurements in periodic health examinations from 2008. The criteria of this examination are below 85 cm for male, and below 90 cm for female. However it is easily supposed that measuring only abdominal circumference is not very exactly reflect the amount of internal organs fat, which is a major cause of metabolic syndrome. To exactly measure internal organs fat, a CT scanning or an MRI, which is high cost for the patients, is necessary. Wherewith, inexpensive and non-invasive measurement methods to estimate biological information of internal organs have been proposed. Lung density and air volume has been measured by electrical impedance tomography (EIT) [1]. Practical human abdominal fat imaging has been utilized by also EIT [2]. However, measurement methods that use electric impedance require electrodes attached on skin, and state of electrode contact greatly affect the measurement results. To overcome this, an electrode-less method is desired. Meanwhile, microwave technology enables us to measure dielectric constants of human tissues. As described in the literature [3], fat and muscle (or other human tissues) has very different value. Thus it is expected that amount of internal organs fat could be estimated by measuring dielectric constants of abdomen. The author has measured dielectric constant of human finger [4] by waveguide penetration method [5][6]. By extending this method to measure dielectric constant of human abdomen, it is expected that internal organs fat can be estimated for individual person. In this paper, basic considerations of wave guide penetration method to measure internal organs fat are described. This paper organized as follows. In the section 2, waveguide penetration method is briefly explained. In the section 3, application for the waveguide penetration method for abdomen is described, results of the simulations are presented, and possibility of this method is discussed. In the section 4, this paper is summarized.

2. DIELECTRIC CONSTANT MEASUREMENT BY WAVEGUIDE PENETRATION METHOD

Fig. 1 shows the basic geometry of the permittivity measurement by waveguide penetration method. The basic structure is a rectangular waveguide with two circular holes which cylinder shape specimen can be inserted. Two ports (port 1 and port 2) of a vector network analyzer (VNA) are connected to two sides of the waveguide by coaxial-waveguide transducers. By performing bi-directional two ports measurement by the VNA, scattering coefficients $(S_{11}, S_{12}, S_{21}, S_{22})$ of the rectangular waveguide inserted with specimen are obtained. Dielectric constant of the specimen is estimated by solving an inverse problem between the scattering coefficients and the dielectric constant of the specimen. In the literature [5], the problem is solved by the rigorous solution of the propagating wave in the rectangular waveguide with specimen. Dielectric constant of the specimen can also be estimated by calculating scattering coefficients by using numerical simulations and comparing the calculated scattering coefficients with measurements. The waveguide penetration method has been extended to measure dielectric constants of liquid or layered cylindrical materials [6]. Dielectric constants of Japanese sake [7] or human finger [4] have been measured by this method.

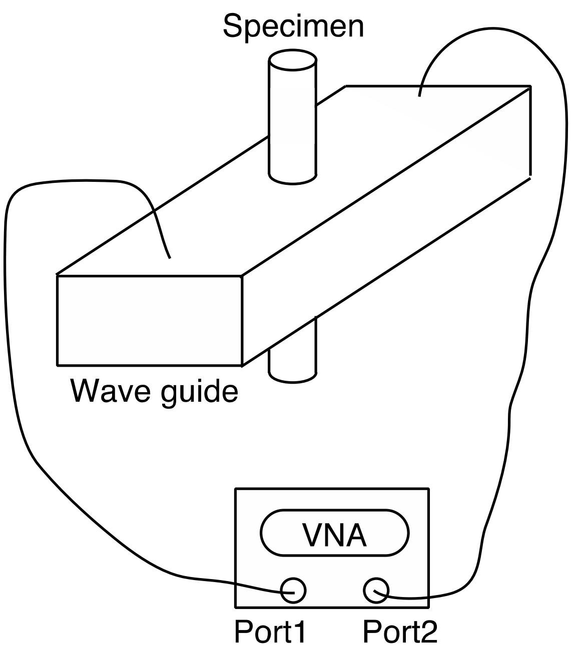

Figure 1. Basic geometry of waveguide penetration method

Fig. 2 shows the basic concept of a measurement of dielectric constant of human abdomen. The large size rectangular waveguide is connected to a VNA. Human abdomen penetrates the waveguide. The electromagnetic wave propagating in the wave guide is scattered and absorbed by human abdomen, thus the scattering coefficients measured by VNA reflects the shape and the dielectric constant of the abdomen and internal organs. The amount of internal organs fat might be estimated by measured dielectric constants. In this paper, as a preliminary consideration, numerical simulations of this measurement for several conditions are performed.

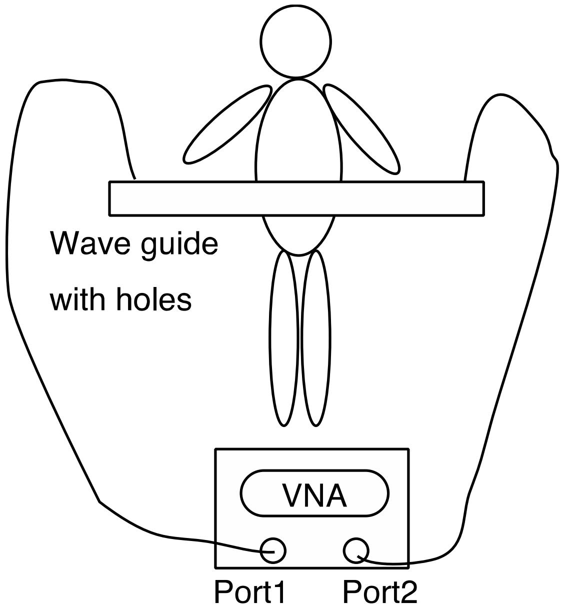

Figure 2. Basic concept of the measurement method of dielectric constant of human abdomen

3. NUMERICAL SIMULATIONS FOR MEASUREMENT OF DIELECTRIC CONSTANTS OF HUMAN ABDOMEN BY WAVEGUIDE PENETRATION METHOD

Fig. 3 shows the geometry of numerical simulations of measurement of dielectric constants of human abdomen by waveguide penetration method. In this paper, a commercial FEM (finite element method) software COMSOL Multiphysics is used for numerical simulations. Basically, the geometry is same as depicted in the Fig. 1, but the coaxial-waveguide transducers are replaced to rectangular wave ports for convenience in calculations. The abdomen is cut off to reduce calculation load, and the two holes are terminated by two hemispherical shaped absorbing boundaries. The size of the rectangular waveguide is 0.5 m $\times$ 0.05 m $\times$ 1 m, the radius of the circle holes is 0.15 m. The measurement frequency range is between 450 MHz and

550 MHz. The S_{21} of the rectangular waveguide without human body is -3 dB at 500 MHz due to outgoing waves from the holes. To emulate simplified human abdomen structure, two layers cylinder is used as specimens in simulations. Dielectric constants of inner and outer layer of cylinder are set as those of muscle and fat at 500 MHz, respectively.

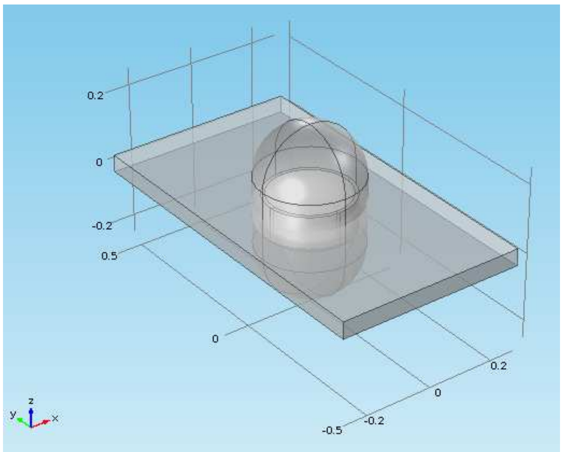

Figure 3. Geometry of numerical simulations of measurement of dielectric constants of human abdomen by waveguide penetration method

Table I shows the dielectric constants of human tissues [8] used in the simulations. As shown in the table, relative permittivity of muscle is above ten times grater than that of fat, and conductivity of muscle is twenty times smaller than that of fat. Thus the measured scattering coefficients are largely affected by amount of muscle and fat and, their shape.

Table I. Electric constants of human tissues at 500 MHz

Tissue	Relative Permittivity	Conductivity (S/m)
Muscle	77.063	0.67808
Fat	6.8758	0.034677

Fig. 4 shows the calculated distributions of electric field by a numerical simulation at 550 MHz. The circumference of abdomen is 80 cm, and the circumference of inner muscle is 70 cm. It is clearly shown that the excited electromagnetic field is attenuated by human abdomen and received at the port on the other side.

To investigate differences of scattering coefficients by amount of fat and muscle, calculations are performed for different size of abdomen and internal muscle. Table II summarizes the simulation conditions. The condition A is assumed as a standard condition. The condition B is assumed as an abdomen that has much fat. The condition C is assumed as an abdomen that has same circumference of abdomen as the condition B but has lessfat.

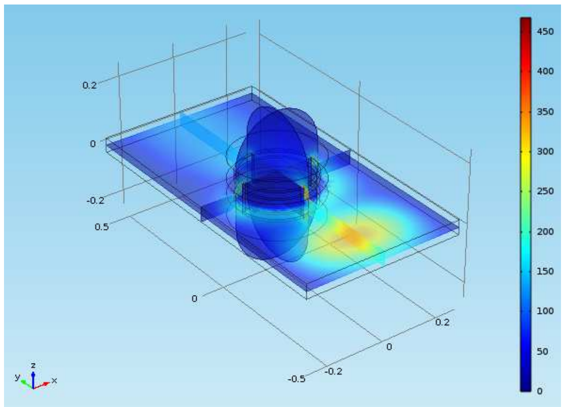

Figure 4. Calculation result of electric fields distribution (550 MHz)

Table II. Simulation conditions

Condition	Muscle		Fat	
	Circum. [cm]	Radius [cm]	Circum. [cm]	Radius [cm]
A	70	23.33	85	28.33
B	70	23.33	90	30.00
C	80	25.48	90	30.00

Fig. 5 and Fig. 6 show the calculated scattering coefficients of human abdomen for different conditions. Fig. 5 shows S_{11}, and Fig. 6 shows S_{21}, respectively. As shown in the figures, very different scattering coefficients are obtained depending on the size and amount of muscle and fat. These results suggest the possibility to measure amount of fat of human abdomen by the proposed method.

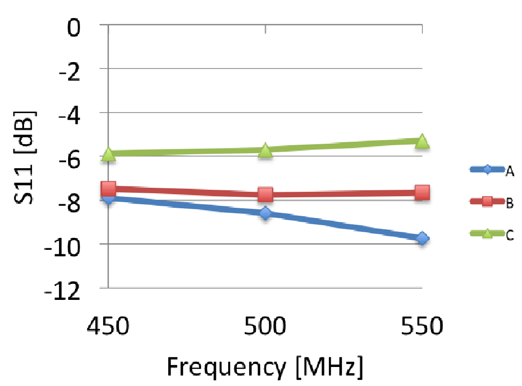

Figure 5. Scattering coefficients (S_{11}) of human abdomen for each condition

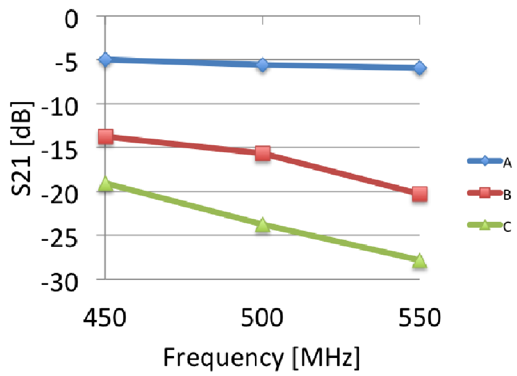

Figure 6. Scattering coefficients (S_{21}) of human abdomen for each condition

4. CONCLUSION

In this paper, a measurement method of human internal organs fat for health care diagnose by microwave waveguide penetration method is proposed. The basic concept and the geometry of the measurement method are explained. By performing the numerical simulations, possibility of the method is exhibited. There are manyfuture works to realize this method for practical use.

- Optimize the frequency and the size of the rectangular waveguide and holes.
- Consideration of analytic calculation of scattering coefficients to reduce calculation load.
- Consideration of higher mode and varied direction measurements to increase accuracy of measurements.
- Perform experimental measurements and compare with numerical simulations.

References

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