Complex permittivity, complex permeability and microwave absorption properties of human blood

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Abstract. This paper reports a method for measuring for the complex permittivity, permeability and microwave absorption properties of human blood of healthy human body. The proposed measurement method can be a useful technique for microwave absorption properties of human blood. The measurement using a waveguide in the microwave band. In order to measure the s-parameter of human blood, a sample should completely fill in the waveguide end and the samples holder using the vector network analyzer (VNA). The complex permittivity and permeability of human blood are resulted in the frequency range from 7 to 13 GHz. Their complex permeability and permittivity, microwave absorption properties values were calculated. The blood sample has the magnetic loss and magnetic energy dissipation. The reflection loss (RL) of blood sample has different absorption with its minimum value of -3.53 dB at 9.36 GHz.

1. Introduction

It is known that iron is an essential substance of human body. The iron distribution inside the body is as follow: circulating red blood cells, 1800 mg; bone marrow, 300 mg; muscle, 300 mg; splenic macrophages, 600 mg; and liver, 1000 mg; with 20-25 mg of iron cycles daily [1]. Iron is absorb by the divalent metal transporter of the enterocytes in duodenum and upper jejunum [2]. Iron intake into the plasma is control by the ferroportin which depends on the iron requirement of the body. Furthermore, the iron homeostatis is regulate by hepcidin, a peptide hormone which secrete by the liver [2]. Iron constructs many biological compounds inside the cells, such as proteins and enzymes or dissolve in blood plasma. Iron also plays role in many enzymatic process in the body, such as metabolism, oxygen transport, collagen and deoxyribonucleic acid (DNA) synthesis [2,3].It is available in two forms, the anorganic iron (ionic iron) and the organic iron (heme iron) [4]. In the organic form, iron takes the core
site of the heme phrostetic group which constructs hemoglobin [5]. It provides one oxygen-binding site in each of four heme, which means that every hemoglobin has the ability to carry four oxygen molecules [6].

Nowadays, electromagnetic (EM) interference pollution which can be harmful to the human beings, have attracted much attention [7–12]. The red blood cell that is important parts in human body and play important role in healthy human body [13,14]. In this paper, we have studied microwave absorption properties of human blood of healthy human body. The complex permittivity, permeability and reflection loss of human blood are measured using the vector network analyzer (VNA) in the frequency range from 7 to 13 GHz. The proposed measurement method can be a useful technique for microwave absorption properties of human blood.

2. Experimental methods
The human blood of healthy human body have been prepared and placed in a sample holder with a dimension of width 22.86 mm, height 10.16 mm and thickness 2 mm (see Figure 1). A vector network analyzer (VNA) Rohde-Schwarz ZVL13 to measure the reflected signal (S\(_{11}\)) and transmitted signal (S\(_{21}\)) was used to analyze microwave absorbing properties in the frequency range from 7 to 13 GHz. the permeability and permittivity values (real and imaginary parts) are used to calculate the reflection loss (RL) by Eq. (1) and result are shown in Figure 3.

Reflection loss (RL) were calculated and simulated with the electromagnetic parameters data through the Nicholson–Ross–Weir (NRW) formula and transmission line theory using the equation [15–18]:

\[
R\ (d\ ) = -20 \log \left( \frac{|\varepsilon - 1|}{|\varepsilon + 1|} \right)
\]  

(1)

where Z = √μ/ε tanh \((-j2π/\varepsilon)\sqrt{\mu-\varepsilon}\), μ = μ\(^{\prime}\) - jμ\(^{\prime\prime}\) (permeability) and ε = ε\(^{\prime}\) - jε\(^{\prime\prime}\) (permittivity), f is frequency and d is the thickness of the blood sample.

![Figure 1.](image1.png) (a) Sample holder and (b) schematic of transmission line methods for blood sample.

3. Results and discussion
According to scattering parameters of microwave reflection (S\(_{11}\)) and transmission (S\(_{21}\)) signal, the complex permittivity and complex permeability have been calculated by using the Nicholson–Ross–Weir method [17]. Figure 2 shows the complex permittivity and complex permeability of human blood sample. It can be found that real (μ\(^{\prime}\)) part value of blood sample is in the range of 0.25 – 0.45, at the 7 – 13 GHz frequency range. While the imaginary (μ\(^{\prime\prime}\)) part values of complex permeability decrease. These values have informed that blood sample has the magnetic loss and magnetic energy dissipation.
Figure 2. The real and imaginary parts of (a) permeability and (b) permittivity of human blood.

Based on the NRW formula and transmission line theory, the measured values of the real and imaginary parts of permeability and permittivity of human blood were used to calculate the reflection loss (RL) using Eq. (1) and results are shown in Figure 3. For blood sample, the microwave absorption curves show different absorption and the peaks shifts to the lower frequency with different thicknesses. It is also noticed that the RL value of blood sample is relatively poor with its minimum value of -3.53 dB at 9.36 GHz.

Figure 3. Reflection loss values of human blood with (a) thickness of 0.5 mm and (b) different thicknesses.

4. Conclusions

The human blood of healthy human body have been prepared. The complex permittivity and complex permeability have been calculated and showed fluctuation at the 7 – 13 GHz frequency range. The blood sample has the magnetic loss and magnetic energy dissipation. The reflection loss (RL) results are shown that blood sample has different absorption and the peaks shifts to the lower frequency with different thicknesses with its minimum value of -3.53 dB at 9.36 GHz.

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