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METHODICAL AND EXPERIMENTAL ANALYSIS OF BIOLOGICAL TISSUE FOR LOW POWER IN VIVO RF TRANSMISSION

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ABSTRACT

Periodical recording of vital parameters is an important fact in clinical routine. Especially in high risk groups such investigations are necessary. For example the measurement of the intraocular pressure can be useful for early diagnostics of the glaucoma. Therefore a short measurement interval is desirable. A wireless intra corporeal sensor is the best solution for patients. By using a wireless radio frequency (RF) transmitter there is no need of a percutaneous connection. Thereby the risk of an infection is reduced. For the design of such a transmitter the dielectrically characterization of representative biological tissue is required. In this article two methods are presented, the transmission line and the coaxial probe method. Furthermore the concept of an intra-corporeal transmitter is depicted and by involving the dielectric parameters, a miniaturized RF transmitter was realized. The built prototype was used to measure the transmission out of different phantoms with equivalent dielectric properties like human tissue.

Index Terms— radio frequency transmitter, dielectric parameter, biotelemetry, transmission line, coaxial probe

1. INTRODUCTION

Wireless communication is getting more and more into the focus of medicine. Up to the present vital and physical parameters of humans are measured and analyzed punctual and discontinuous, for example the measurement of blood glucose, blood pressure or the intraocular pressure (IOP). For high risk patients it is necessary to control these parameters continuously. For measuring the IOP there exists no device for home use. Therefore patients have to go to hospital for checking. This procedure is applied every three or four months at ambulant patients. Clinical measurements are carried out several times per day, but not at night. Consequently, during the night dangerous high peaks in pressure would not be detected. The fact that nearly 10 % of people with high IOP go blind, shows the need for a system, which is able to log the pressure periodically and in short time intervals. Such a system can be realized by an implemented biosensor. The information of the transmitter is send wireless by an intra-corporeal transmitter to an extra-corporeal receiver. Additionally the risk of an infection after the implantation is reduced. Furthermore the possibilities of an implanted biosensor are not only limited to diagnostic IOP. The use of sensors can expand to other fields in biotelemetry, e.g. blood pressure in vessel, blood flow, hemoglobin concentration, liquor pressure, joint pressure, temperature and even more.

2. TISSUE ANALYSIS AND METHODS

As a first step it is necessary to find the frequency band with the most suitable communication channel for a RF data transmission from the inner human body to an external receiver. For determining the dielectric parameter two formulas are given [1]. The dielectric loss angle δ is defined by the following expression:

$$\tan(\delta) = \frac{\epsilon''}{\epsilon'} = \frac{\sigma}{\omega\epsilon_0\epsilon_r'^2} \tag{1}$$

where ϵ'' is the imaginary part of the permittivity, ϵ' the real part of the permittivity, σ the conductance and ϵ_0 the permittivity of free space. The attenuation α is denoted by

$$\alpha = \frac{\omega\sqrt{\frac{\epsilon'}{2}\left(\sqrt{1+(\tan^2(\delta))}-1\right)}}{c} \tag{2}$$

where ω is the angular frequency. The dielectric parameters δ and α can be derived by measuring the reflection and the transmission of a Material Under Test (MUT). An appropriate equipment to obtain the material characteristics is a Vector Network Analyzer (VNA) [2, 3]. In the following two common measurement methods utilize the VNA are described.

Firstly thanks to our project partners, the IMN MacroNano®, Ilmenau University of Technology, faculty of micro mechanical systems, Ilmenau, Germany and the Fraunhofer Institute for Applied Solid-State Physics (IAF), Freiburg, Germany. I also would like to thank the company CE-Lab, especially M. Naß, for cooperation in the measurements of the transmission line method. I am also thankful to M. Helbig, through which the coaxial probe measurements were possible.

2.1. Transmission line method

By using this measurement technique the MUT has to be placed inside of an enclosed transmission line (Fig. 1). The enclosure is either a waveguide or a coaxial line. Within this project a coaxial tube made of copper was used, because the measurement with a coaxial line covers a high frequency range.

A specific software computes the permittivity by analyzing the measured reflected signal (S11 or S22) and the transmitted signal (S12 or S21). This method is commonly used for materials with medium up to high loss [3]. Besides the determination of the relative permittivity ϵ_r, it is also possible to compute the permeability μ_r.

Air gaps in the MUT and a sample length which is the multiple of one-half wavelength in the material limit the accuracy [3]. Another critical point is, that the MUT has to be part of the coaxial tube, thus there is no way to measure in vivo with this approach.

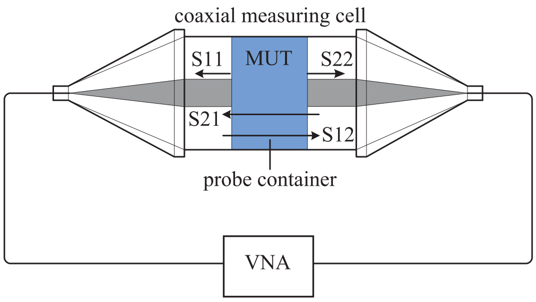

Fig. 1. Scheme of the transmission line method with VNA

2.2. Coaxial probe

The coaxial probe is a non-destructive method to determine dielectric parameters, even in vivo. With this technique it is possible to calculate the permittivity in the high frequency range from about 100 MHz up to some GHz. The inner and outer conductors are connected to the MUT (Fig. 2). During the measurement the probe is immersed into liquor or fitted on a surface of a solid material. At the end of the probe the fields will change if they are contacted with the MUT. The reflected signal can be measured and related to the relative permittivity ϵ_r [2].

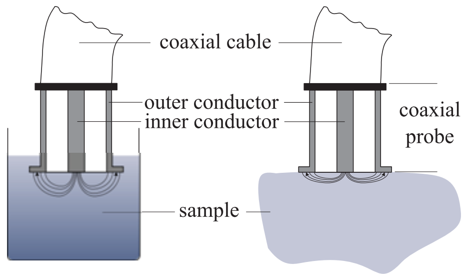

Fig. 2. Cross-section of the coaxial probe in a liquid (left) and on a surface (right) of a MUT

3. IMPLEMENTATION OF A WIRELESS RF-TRANSMITTER

The transmitted data has to pass several layers of tissue from an intra-corporeal system to an extra-corporeal receiver. Figure 3 shows a possible solution for a biotelemetry system, which can be placed intra-corporeal. An obstacle for implantable sensors is the limited space. Therefore the transmitter has to work in a confined space and with ultra-low power. To send the data from an intra-corporeal system, the signal is frequency modulated. The reason for this choice is the reduced circuit complexity compared to the digital transmission protocol, because there is no need for an analogue-digital conversion. Additionally the size and the power consumption are also reduced by using this assumption. A solution for such a transmitter provides an integrated circuit (IC) from MAXIM-Dallas. This IC generates the carrier frequency for the signal. Afterwards the carrier frequency is modulated with the signal by a voltage controlled oscillator (VCO). The mentioned product line covers a frequency range from 45 MHz to 650 MHz [4].

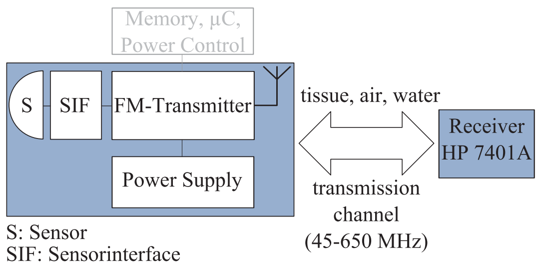

Fig. 3. Flow chart of a biotelemetry RF-transmitter

The first version of a transmitter is based on the ICs MAX2605-MAX2609 from MAXIM-Dallas [5]. The realized printed circuit board (PCB) is shown in Figure 4 (left). By using a frequency demodulation it is possible to transmit audio signals to a spectral analyzer.

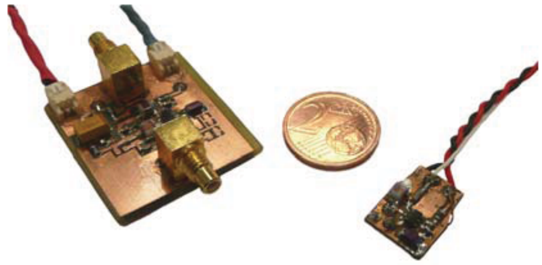

Fig. 4. Printed circuit board (left: first version; right: optimized version)

As a next step the transmitter has to be optimized. Not all of the devices at the board are necessary for low power transmission. The size of the revised PCB was reduced to a quarter of the predecessor version (Fig. 4 right). Furthermore a biocompatible capsule made of ABS plastics was manufactured. The total size of the prototype was 13 mm×33 mm. Due to this dimension the final PCB incorporated in a capsule can use for experimental animal tests (Fig. 5).

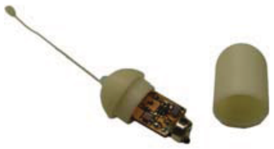

Fig. 5. Realization of a plastic capsule

4. RESULTS

4.1. Tissue analysis

In contrast to literature, where the tissue samples are mainly from sheep, the measured tissue samples (fat tissue, muscle tissue, skin) are derived from pigs [6, 7, 8]. Up to the time of measurement the refrigerated storage temperature was below 10°C. In figure 6 the transmission line method and coaxial probe method are compared with literature [7]. The Diagrams are sorted by the type of tissue for comparing the both methods with the database. The studies with transmission line method and coaxial probe provide nearly the same results as shown in literature [6, 7, 8]. Only fat tissue has a variance compared to other measured tissue samples.

4.2. Measurements out of phantom

A transmitter for testing a frequency range from 70-150 MHz was built. The middle frequency of the transmitter is 131 MHz and the antenna input power is 205 nW. The measurement setup consists of a water phantom (aquarium 30 cm×60 cm×20 cm) full of tap water. The transmitter unit was placed in the geometric

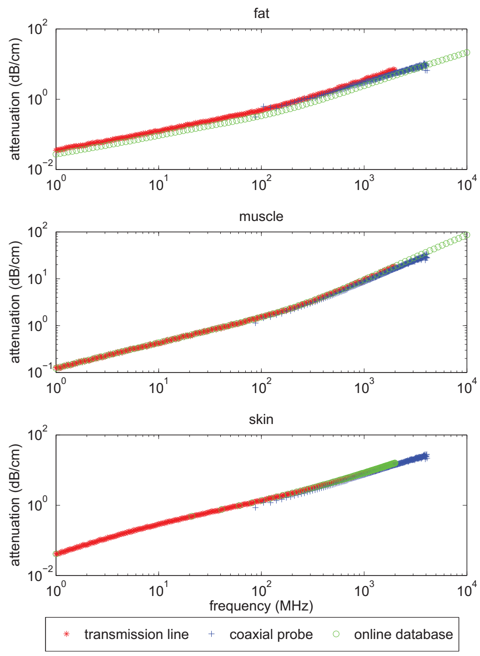

Fig. 6. Comparison of the applied methods for the attenuation of fat, muscle and skin

center and the receiving antenna was mounted at a distance of 100 cm to the phantom (Fig. 7). The used 0.9 % NaCl solution is equivalent to biological tissue and corresponds to its conductance. At the antenna an averaged power of 0.105 nW was measured. This corresponds to an overall loss of 32.9 dB (including antenna).

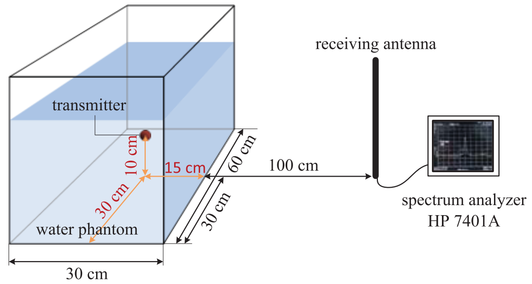

Fig. 7. Scheme of the water phantom

5. DISCUSSION

To ensure an efficient energy transmission, it is necessary to know the attenuation of biological tissue. The measurements depict a linear rising trend over the frequency range. That indicates that low frequencies are more suitable for the transmission which is also confirmed in literature [6]. It should be noted that with decreasing frequency the dimension of the antenna will increase. At the frequency range of the experiments the linear attenuation characteristics are mainly caused by the ß-dispersion [9], which is caused by the cellular membranes and their dipole orientation. Conspicuous is that the fat tissue samples show differences in its behavior. This is the result of the significant intra- and inter-individual differences, which depend on the water and lipid content of the cells. The results of the coaxial probe method can also be affected by the dryness of the surface.

6. CONCLUSION AND FUTURE WORK

Overall we can summarize that the experiments were successful. The achieved positive results will be a basement for future work. The measurements of the attenuation of the tissue show that there are no gaps in the frequency spectrum, which can be used for transmitting. For designing a wireless RF micro-transmitter it is necessary to find a compromise between the selected transmitting frequency range and the dimension of the antenna. A smaller frequency means a lower attenuation but a longer antenna design. In summary of these facts a frequency of 131 MHz was chosen. The first experiment with the designed transmitter shows that the transmission out of a phantom is possible.

In addition to the measured tissue samples, further investigations of other types of biological tissues are planned (blood, heart muscle, bone, etc.). For further studies the dependency of the water content should be classified and it is planned to use a gelatine phantom for additional measurements.

Moreover an animal experiment with a narcotized pig is still in preparation. Within this procedure the special capsule should be tested in the esophagus near the heart. To test five frequencies, five transmitters will be designed and the spatial distribution of the signal will be measured.

Another important fact is the dimension of the transmitter. The CMOS technology offers a solution to realize an aspired micro-transmitter. This will be achieved by the support of the project partners at the sector of micro and nano technology.

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