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CALCULATION OF THE PHYSICAL PROPERTIES OF THE LIVER IN RATS AT FREQUENCIES (8.2, 9.2 AND 10.2) GHZ WITHIN THE X-BAND[a]

CÁLCULO DE LAS PROPIEDADES FÍSICAS DEL HÍGADO EN RATAS A FRECUENCIAS (8.2, 9.2 Y 10.2) GHZ DENTRO DE LA BANDA X

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ABSTRACT: This study revolves around calculating some physical parameters like depth microwave penetration of the liver in rats laboratory at frequencies (8.2, 9.2 and 10.2) GHZ within the X-band and the relationship between it and the electrical properties of the skin such as ε' insulation constant, ε'' loss factor, and σ electrical conductivity. Both ε' and ε'' were measured using the cavity disturbance method at a frequency (10.201 GHZ) by taking a liver sample the size of the cavity hole and placing it inside the aperture and the value of both $\varepsilon' = 2.83$ and $\varepsilon'' = 0.849$. The connectivity values were calculated by frequencies used (8.2, 9.2, 10.2) GHZ, reaching (0.387, 0.434, and 0.482) S/m, respectively. The results showed that the electrical connectivity is directly commensurate with frequency and loss factor, while the penetration depth is inversely commensurate with frequency.

KEYWORDS: X-band; liver; connectivity; penetration depth; Microwave.

RESUMEN:. Este estudio gira en torno al cálculo de algunos parámetros físicos como la profundidad de penetración de microondas en el hígado en ratas de laboratorio a frecuencias (8,2, 9,2 y 10,2) GHZ dentro de la banda X y la relación entre ésta y las propiedades eléctricas de la piel como el aislamiento de ε' constante, factor de pérdida ε'' y conductividad eléctrica σ. Tanto ε' como ε'' se midieron utilizando el método de perturbación de la cavidad a una frecuencia (10.201 GHZ) tomando una muestra de hígado del tamaño del orificio de la cavidad y colocándola dentro de la abertura y el valor de ambos $\varepsilon' = 2.83$ y $\varepsilon'' = 0.849$. Los valores de conectividad se calcularon por las frecuencias utilizadas (8.2, 9.2, 10.2) GHZ, alcanzando (0.387, 0.434 y 0.482) S/m, respectivamente. Los resultados mostraron que la conectividad eléctrica es directamente proporcional a la frecuencia y el factor de pérdida, mientras que la profundidad de penetración es inversamente proporcional a la frecuencia.

PALABRAS CLAVE: Banda X; hígado; conectividad; profundidad de penetración; Microonda.

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1. INTRODUCTION

During life, humans are constantly exposed to direct (therapeutic and diagnostic medical applications) and indirect (natural radiation) radiation sources around them. It is also exposed to additional doses resulting from scientific development in which many modern techniques have been used in medicine, agriculture, and industry that can raise the background of radiation nature. Several scientists and environmental experts have also warned of the risks of pollution in so-called “Electronic pollution”. Some of the most dangerous types of pollution that have begun to draw attention in recent years are so-called electromagnetic pollution and magnetic fields (Altok, 2012). Resulting from the construction of giant electrical stations, as well as the antenna towers of telecommunications, radio, and television broadcasting and other household devices, as well as waves used for medical purposes, which are seized thanks to advanced technologies but a factor that cannot be forgotten. There are many scientific references concerning the impact of microwaves and radio that are part of the electromagnetic spectrum on the organism’s object when penetrating it and the resulting cellular effects on biological tissue Biological tissues (Stewart *et al.*, 2006).

The distance that semi-solid materials like meat and live tissue may be penetrated by microwave frequencies is directly proportional to their energy density. Because of this energy, the dielectric will heat up the tissues of the body. When the dielectric is heated, the thermal effect is released. Heat effects, or elevated core body temperature, are a consequence of electromagnetic fields (EMW). The absorption of electromagnetic radiation with high frequencies is the main cause of heat. Cell function and development can be disrupted by thermal impacts. When the rate of heat production is greater than the rate of heat dissipation, tissue temperature rises (Mohd, 2019).

Ions, polar compounds, and the cellular structure all contribute to the presence of both free and finite charges in biological tissues such as the liver. Living tissues undergo polarisation, ion drift, displacement, and conduction current generation when exposed to an external electric field, which causes the electric charges to be displaced from their initial positions. Consequently, the conductivity and permittivity of tissues are the dielectric qualities that define the interaction between electromagnetic fields and the organism’s body. Consequently, it is crucial to provide information regarding the dielectric characteristics of various tissues (Vanegas-Acosta, 2015).
This study aims to calculate the electrical properties of the liver in order to know the extent of the effect of frequencies (8.2, 9.2 and 10.2) GHZ within the X-band on some biological parameters when interacting with them and to reduce the risks when using these waves in medical or non-medical applications. The main reason to choose these frequencies It is that these frequencies are often used in linear accelerators in medical devices, so it is necessary to know the electrical properties of organs, including the liver.

1.1. Microwaves and their medical applications

It is an electromagnetic wave located at the lower e d of the electromagnetic spectrum between infrared and radio frequencies (RF). The frequency range of this radiation ranges from 300 MHZ to 300 GHZ which corresponds to the wavelength from 1mm to 1m (Solanki, 2010).

Wavelength ranging from 1mm to 25cm is widely used in radar broadcasting as well as microwave ovens and in medical applications through diathermy therapy. The remaining wavelengths are used in mobile communications (mobile, internet and TV) and other industrial applications (such as chemical industries, especially organic compounds manufacturing (Aweda *et al.*, 2010).

Microwave is one of the most important capabilities used in the medical field. It is radically different from other energies and has many advantages. One of these features is that it operates within the material (i.e. they penetrate the substance and interact with each atom of the substance) accordingly, although heat is generated in cold waves, the amount of heat generated depends primarily on the properties of the electrical material.Medical equipment that uses radiofrequency (RF) or microwave (MW) waves, among other frequencies, for therapeutic and diagnostic applications. This breakthrough is the outcome of advancements in electromagnetic theory and electronics, which created an unprecedented environment for the development of non-ionizing radiation therapy applications and diagnostic medical devices. In particular, microwaves (Jing *et al.*, 2016).

Since electromagnetic fields have been shown to have a variety of impacts on living things over the last thirty years, complementary and alternative medicine has been developing as an option for treating in these fields. Concerns over the potential health risks of electromagnetic wave (EMW) exposure have grown in recent years due to the growing use of gadgets that employ these waves. Since it is commonly recognized that high-frequency electromagnetic fields (EMFs) can harm biological cells, including human tissues, by causing partial structural damage and raising the body's core temperature, the elevated temperature is one of the adverse consequences of these waves being absorbed (Tanghid, 2017).

1.2. Materials and Methods

1. General information: This study was conducted at the University of Basra, College of Science, Department of Physics, in partnership with the College of Veterinary Medicine, Department of Surgery. This study was designed to measure the depth of frequency penetration (8.2, 9.2 and 10.2) GHZ into liver tissue and its relationship to other physical parameters such as conductivity and complex permittivity. To achieve this goal, eight healthy male rats whose weight ranged from (240 to 300) grams and were (12-14) weeks old were used. Three rats were dissected (histopathology) to determine the location, size, and shape of the liver in the abdominal cavity.

2. Liver biopsy: After anesthetizing the animals with (ketamine/xylazine) at a dose of (50 mg/kg + 5

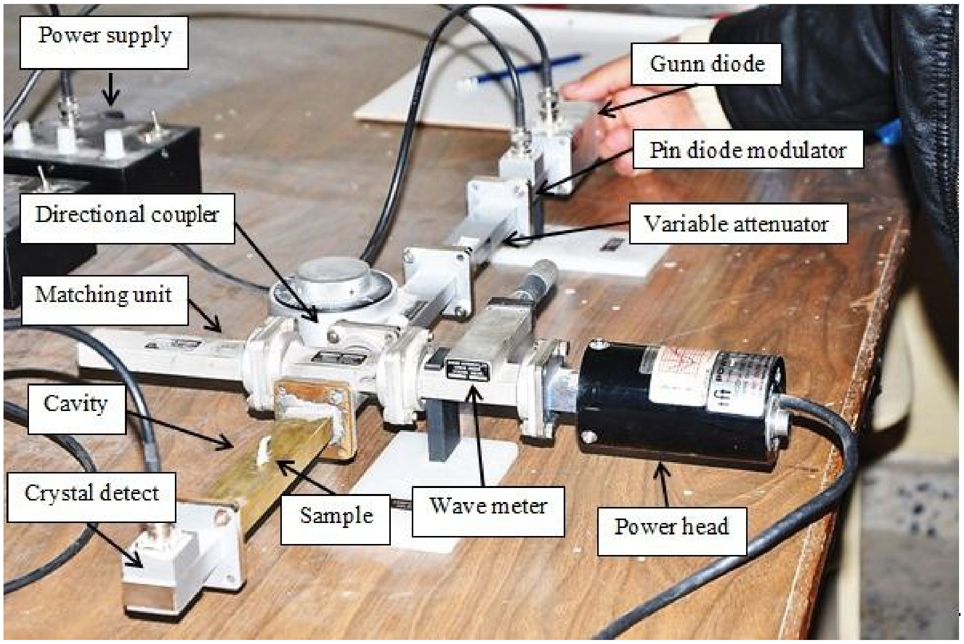

Figure 1: A picture showing the system used to measure the complex permittivity of the liver. Source: Author's Own Work.

mg/kg). BW (Lei *et al.*, 2001) after that, the animals were dissected, the liver was removed, and a biopsy was taken from it with the dimensions of the opening of the upper cavity.

3. Measurements and Calculations: This part includes the devices used in measurement in addition to the theoretical basis of the calculations.

1.2.1. Devices Used

Figure 1 between the devices and equipment used in the experiment. A picture showing the system used to measure the complex permittivity of the liver.

1.2.2. Measurement mechanism

1. Resonant frequency and quality factor.
   The two basic factors that express the two types of any resonant cavity are the resonant frequency and the quality factor. The resonant frequency, assuming that the cavity is lossless, depends primarily on its dimensions. The resonant frequency of any cavity can be calculated according to the propagation pattern determined by the following equation (Kamel *et al.*, 2023).

$$\bar{E}_t(x,y,z) = \bar{e}(x,y)\left(A^+ e^{-jB_{mn}Z} + A^- e^{-jB_{mn}Z}\right) \tag{1}$$

   This equation shows the transverse electric fields (EX) of the pattern (TE_{mn}) or (TM_{mn}) of the rectangular guide. The resonant cavity used in our research was made of a rectangular copper guide with dimensions (length, $d = 13.5$cm, $a = 2.286$ cm in width, and $b = 1.02$ cm in height, and in the middle of the wide part of the cavity there is an opening with dimensions (2.5×2 mm) to insert and remove the sample (part of the liver whose dimensions are $Ls = 1.21$ cm, $ws = 0.135$ cm, $a_s = 0.32$ cm. Where there is a fundamental resonant frequency (the lowest resonant frequency at the mode TM_{101}) of 10.109 GHZ, the other factor is the quality factor of the cavity, which expresses the efficiency of the cavity in storing energy (in the form of electrical and magnetic energy).

2. Complex permissibility measurement.
Measuring the complex permissibility of substances at microwave frequencies has gained increasing importance in many areas, such as materials science, microwave circuit design and biological research, etc. Many methods have been developed to measure the complex permissibility in the range of microwave frequencies and possibly their scales, which have been used in our research to convince cavity perturbation technique (Mathloom Ahmed *et al.*, 2021).

Measurement procedures require changes in quality factor (Q), resonance frequency (f0) or cavity length that must be measured.

Cavity disorder is a widely used technique for measuring the complex permissibility of materials due to their relative simplicity, accuracy, and data reduction are easy in addition to their sensitivity which makes it different from other technologies, this technique includes some conditions for the calculations to be correct are the sample size must be very small compared to the size of the cavity used so that the frequency change with the sample is small compared to the resonant frequency change of the cavity when it is empty and cavity by presence and lack of sample should be the same (Kamel *et al.*, 2023).

The first part of the practical aspect included measuring the electrical properties (dielectric constant, loss factor, and conductivity) of the liver at room temperature for different frequencies. The measurement method is done by exciting the empty resonant cavity with a range of frequencies using a frequency generator and recording the value of the transmitting wave (S21), where we obtain a graphic curve that represents the relationship between frequency and the transmitting wave energy, or what is known as lossless.

The method for measuring the complex permittivity ($\varepsilon = \varepsilon^{'}$ - j$\varepsilon^{''}$) of the liver was as follows. First, this technique was tested (calibrated) on well-known materials such as Teflon, where the microwave frequency of the empty cavity was set at 10.201 GHz, by knowing the upper limit of the power released around the frequency. The different.

Monitor the external capacitance level and measure the resonant frequency (f0), then measure the highest and lowest frequencies of the resonant frequency at the average capacitance and record the amount of capacitance. Note that the complex permittivity measurement process in this research took place within a (15-20) minute period to avoid losing the vital properties of the liver.

Then, by plotting between amplitude and frequency, the quality factor (Q_0) is calculated. After inserting the sample into the cavity, the above steps are repeated in the same way as the resonance frequency (f_S) and quality factor (Q_S) of the sample (liver) are calculated (Mathloom Ahmed *et al.*, 2021).

$$Q = \frac{f_0}{\Delta f}, \tag{2}$$

where f_0 the resonant frequency, Δf display the frequency package at the middle of the greatest resonance oscillation capability.

After the quality factor (Q) is measured in the relationship 2 for both the empty cavity and in the case of the sample using the circuit shown in Figure 1. The real part ($\varepsilon^{'}$) and the imaginary part ($\varepsilon^{''}$) for complex permissibility (ε) can be calculated using the following relationships (Kamel *et al.*, 2023):

$$\varepsilon^{'} - 1 = \left(\frac{V_c}{V_s}\right)\left(\frac{f_0 - f_s}{2 f_s}\right) \tag{3}$$

$$\varepsilon^{''} = \left(\frac{V_c}{4V_s}\right)\left(\frac{Q_0 - Q_s}{Q_s Q_0}\right), \tag{4}$$

where $\varepsilon^{'}$ is Dielectric constant, $\varepsilon^{''}$ is Loos factor. V_C, V_S cavity size and sample size test (liver) respectively. Q_S, Q_O the quality factor the sample's presence and the absence of the sample respectively. f_S, f_0 the resonant frequency with the presence of the sample and the absence of the sample respectively.

3. Penetration Depth.
The penetration depth of the electromagnetic wave is one of the important factors that must be known when studying the interaction between electromagnetic waves or radiation and the biological body (human or animal). From this standpoint, it is very difficult to distinguish the propagation of these waves in the human or animal body, due to the complexity and non-homogeneous nature. For biological tissues (Blank & Goodman, 2009).

Therefore, the interaction of microwaves with biological matter can be studied at two levels: the macroscopic level and the microscopic level, and the interaction phenomena at the two levels cannot be considered independently. It must take into account the distribution of energy that occurs within the body when it is placed under the field, as well as the macroscopic level of the interaction (Blank & Goodman, 2009).
Gives a brief explanation of energy penetration or dispersion. The microscopic level shows the study

of reaction mechanisms on smaller scales. The total effects resulting from the interaction between microwaves and biological tissue share several phenomena, the first and most important of which is the penetration of energy into the living system and its spread within it. Therefore, it is necessary to study this topic in some detail (Husian, 2011).

It is reported that the human body is transparent to the energy of microwaves at wavelengths greater than 200cm and above 300 MHz. It has been observed that the depth of energy penetration fluctuates rapidly with changes in frequency (Mathloom Ahmed *et al.*, 2022). Overall, the energy penetration of the body will decrease when the radiation frequency increases and as in the following relationship (Rodrigues *et al.*, 2018).

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}, \tag{5}$$

where f represents the frequency used, μ magnetic permeability (since biological tissue is non-magnetic material, the $\mu = \mu_{(0)} = 4\pi \times 10^{-7} Hm^{-1}$ (Abdulnabi, 2011), σ represents the alternating electrical conductivity and is dependent on frequency as in the following relationship (Mathloom Ahmed *et al.*, 2022).

$$\sigma = \omega \varepsilon_0 \varepsilon'', \tag{6}$$

where ε_0 is Vacuum permissibility.

1.3. Results and discussion

In this section, we will discuss the results we obtained in this study and discuss these results in some detail. We notice from Figure 2 that the empty cavity's resonance frequency and quality factor are approximately equal in value in the case of the cavity loaded with Teflon (where there is a very slight difference). This is because Teflon, as a standard material, is close to the vacuum in insulating properties. While the resonant frequency of the cavity loaded with the sample (liver) drops to a lower resonant frequency and the value of the quality factor is equal to ($Q_S = 92.39$). This difference is because the liver is an organ with a high water content, and due to this property, the electrical insulation parameters (electrical properties) change regularly with this property. Therefore, it directly affects the frequency shift, so that as the water content of the target material increases, the shift of the curve in the form above becomes more and more (in other words, the resonant frequency decreases significantly). That is, the frequency shift is larger and the quality factor is smaller this consistent with (Ahmed Rasool *et al.*, 2013), and this indicates that the absorption of the electric field (wave Electromagnetism) becomes greater and as a result leads to a greater biological effect.
Figure 2 shows the resonant frequency spectrum of the vacuum, the cavity loaded with the standard material (Teflon), the cavity with the sample inside it (liver).

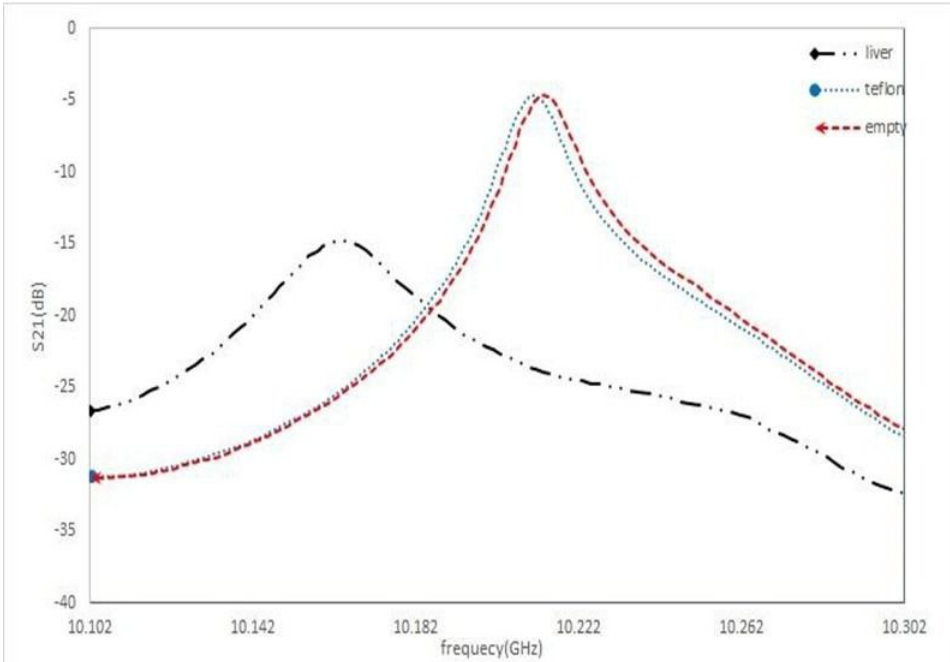

Figure 2: Resonant frequency spectrum of the vacuum, the cavity loaded with the standard material (Teflon), the cavity with the sample inside it (liver). Source: Author's Own Work.

We obtained the permittivity values for the real part based on the equation 2, where it was equal to both the vacuum and the liver ($\varepsilon^{'} = 2.83$) respectively. This part describes the interaction strength of the electric field (electromagnetic wave) and thus measures the extent of the biological effect caused by this radiation on the liver, while the imaginary part was its value for the liver equals ($\varepsilon^{''} = 0.849$). This part describes the energy loss associated with the electric field. These complex permittivity values are closely related to the water content of the target substance in terms of increase and decrease, as well as to the value of the applied frequency. This means that the higher the frequency, the lower the permittivity, and vice versa.

From the Table 1, which shows the values of conductivity and depth of penetration for the frequencies used in the study, based on the equations (4,5), we notice that there is a direct dependence on the frequency value, where as the frequency increases, the conductivity increases and the depth of penetration decreases, and vice versa, and this is consistent with Clément Buisson *et al.* (2023).

Table 1: Relationship between (depth of penetration and electrical conductivity) and frequency directed on liver.

Frequency (f) GHZ	Alternating electrical connection (σ) s?m	penetration depth (δ) m
8.2	0.387	8.93×10^{-3}
9.2	0.434	7.96×10^{-3}
10.2	0.482	7.18×10^{-3}

The calculated conductivity of the liver represents a measure of the lost energy and does not mean the amount of charges transferred in the material from one pole to another. Rather, it is a measure of the temperature resulting from the displacement of the dipoles of the molecules that make up the living tissue from their original positions or their collision with other molecules or ions.

Since the dependence of the electrical properties of tissues on frequency is a result of the many scattering mechanisms that affect tissues, and since the liver is one of the organs of the body with almost a high water content, its conductivity increases and its depth of penetration decreases, due to high absorption of the wave falling on the liver. It is worth noting that the electrical properties of tissues (dielectric properties such as permittivity and conductivity) are a measure of the effect of electromagnetic radiation on the vital system of both (humans and animals). Therefore, providing data on these properties of different tissues is necessary and extremely important.

2. CONCLUSIONS

One of the most important conclusions we reached in this study is that the depth of penetration and conductivity depend on the frequency and water content of the target organ. Therefore, since the liver is one of the organs with a high water content, radiation must be prevented from reaching it for direct and indirect medical uses when the body is exposed to it so that no tissue dysfunction occurs in the liver. Therefore, those working on the techniques used in medical applications in MRI and NMR should be alerted to adhere to the international specifications and instructions of the International Health Organization on the use of these devices and their caveats.

Authors contributions

Ahmed R. Mathloom: Overall supervision of the experiment and measurement process and frequency adjustment after the calibration of the frequency generator as well as writing core topics as well as the collection of sources.
Anwar N. Hussein: brought animals and supervised adaptation to the lab as well as equipped some of the tools we need in surgery to extract the liver and participate in the theoretical basis of some equations in the research.
Fatimah R. Jeji: Participate in the animal anatomy process and assist in the preparation of the main design of the experiment as well as repeat the process for more than one time to obtain controlled results as it played a role in the literary review of some of the key topics in the research.

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