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MEASUREMENT OF THE LEVEL AND ABSORPTION SPECTRUM OF MICROWAVE RADIATION BY BIOLOGICAL TISSUES

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Abstract. *This study presents the analysis of the existing methods for assessing the absorption capacity of biological tissues in the millimeter wavelength range. Problems that were encountered during it are shown. A functional diagram of the device, which provides an increase in the accuracy of measuring the level and absorption spectrum, is suggested. The algorithm of operation of the suggested device was described in detail. The results can be used to diagnose various pathological processes in the human body.*

Keywords: *electromagnetic radiation; biological tissues, millimeter range; absorption capacity; biologically active frequencies.*

Introduction

In the course of irradiation of biological tissues using electromagnetic radiation (EMR) of the millimeter range (30…300 GHz), narrow-band (resonant) absorption was observed at frequencies that are called biologically active. The relative width of the absorption bands is very small and does not exceed units of percent. Most often, the width of the absorption bands is at the level of tenths and hundredths of a percent [1].

The level of absorption of EMR depends on the radiation power and biophysical properties of tissues. Thus, in case of an increase in EMR power, absorption in living tissues decreases, especially in the biologically active points of the human skin. Therefore, biological effects in tissues and organs can be observed only at non-thermal EMR intensities (radiation power within 10^{-8}…-10^{-3} W/cm^2). The absorption of EMR approximately reaches 90…95% of the radiation power in case of non-thermal (bioinformatic) impact on biological material in the vicinity of active frequencies. Outside the absorption band, this indicator decreases to 10…15%. However, exact measurement of absorbed power and assessment of the absorption capacity of biological tissues are associated with a number of complications [2].

It is impossible to use the most sensitive and accurate measuring devices of the absorbed power (calorimetric) in case of a low intensity of EMR due to the lack of thermal effects in the irradiated medium. For the same reason, other types of heat measuring devices cannot be used (thermal resistance, thermoelectric, bolometric).

Absorbed power can be estimated according to the value of the reflection coefficient at stabilized radiated power. But the power of EMR reflected from biological tissues at an acceptable level of radiation (10^{-8}…10^{-3} W/cm^2) is so small that it is difficult to detect and measure the useful signal against the background of

noise and interference of measuring equipment. The task of measuring the absorbing ability of tissues becomes even more complicated in case if one takes into account the own EMR, which is generated by cells of a living organism and is overlapped on the reflected electromagnetic radiation [3].

Methods for solving the problem

In some cases, the absorption capacity of biological tissues is assessed with the help of devices [4] containing a generator of monochromatic signals, directional couplers of the incident and reflected waves that are connected between the generator and the measured object. The level of absorbed power shall be determined by the ratio of the output voltages of directional couplers. However, the nonidentity of the parameters of the channels of the incident and reflected waves, interference in the channel of the reflected wave and the zero volatility of the ratio measuring device circuit do not allow determining the absorption capacity of biological tissues at small levels of the compared signals.

Some authors [5] use amplitude modulation of the incident and reflected waves and resonant amplification of the detected signals in order to increase the accuracy of absorption capacity estimation. This allows measuring the reflection coefficient at low levels of irradiation of the object. Thus, as in the previous example, the non-identity and instability of the parameters of a two-channel measuring circuit does not allow measuring small values of the reflection coefficient and, therefore, reliably determining the level of absorbed EMR energy in the vicinity of biologically active frequencies.

A rod with a rectangular cross section, which is made out of radio transparent material, is used as an antenna for transmitting and receiving EMR in devices for determining the absorptive capacity of biological tissues [6]. Parts of the surface of the rod are metallized, and radio-transparent parts of the rod are in contact with the biological medium under study. In this case the power of the reflected wave depends not only on the absorbing properties of the medium being studied, but also on the reflective properties of the metallized sections of the antenna. The reflected signal is small and it is difficult to isolate it from the amplitude of the amplitude detector and high-frequency interferences against the background of own noises of amplitude detector in biological media with a high absorption level. The instability of the millimeter range generator power, causes informative changes in the power of both the incident and reflected oscillations. The instability of the parameters of the modulator, circulator, detector and other circuit elements directly affect the measurement result.

Thus, the improvement of the accuracy of assessing the absorption capacity of biological tissues is the main objective of this study.

Device for Determining the level and absorption spectrum of microwave radiation by biological tissues

The authors suggested a functional diagram of the device for determining the level and absorption spectrum of biological tissues, shown in Fig. 1.

The diagram shows:

1 - a microwave generator; 2, 5 - amplitude modulators; 3 - attenuator; 4 - circulator; 6 - antenna; 7 - amplitude detector; 8, 11 - selective amplifiers; 9, 12 - synchronous

detectors; 10, 13 - low-pass filters; 14 - measuring device; 15 - radio frequency (RF) generator; 16 - frequency divider; 17 - diode-capacitor chain; 18 - differential amplifier; 19 is a reference voltage source; 20 - integrator; 21 - biological tissue.

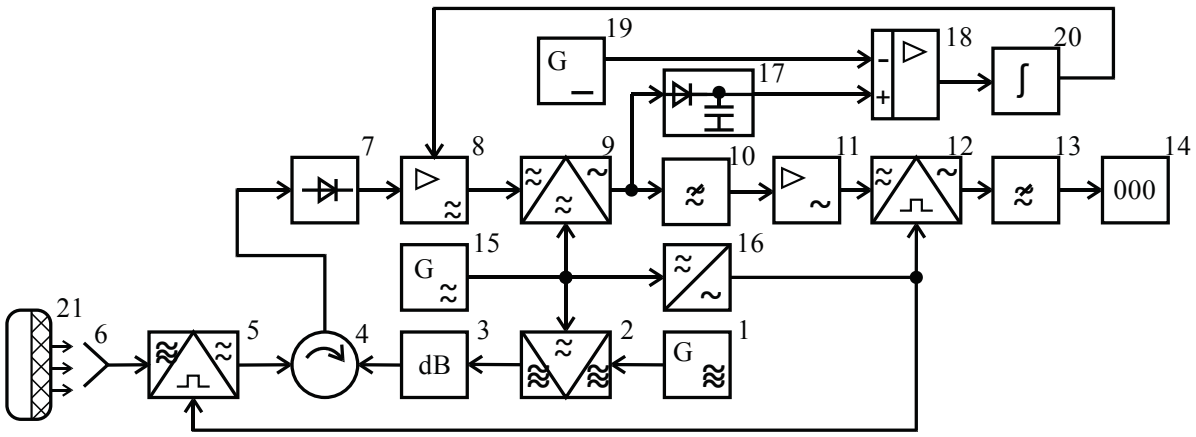

Fig. 1. Functional diagram of the device for determining the level and absorption spectrum of biological tissues

The device works in the following way. Microwave oscillations of the microwave generator 1 flow to an amplitude modulator 2, made on pin-diodes. A voltage of the RF generator 15 flows to the control input of the modulator 2. As a result of periodic changes of the transmission coefficient of modulator 2, the microwave oscillations will be modulated according to amplitude with a established depth of modulation (10…15%). Attenuator 3 sets the intensity of microwave oscillations at 10^{-14} … 10^{-12} W. The intensity-normalized oscillations pass through the circulator 4 and flow to the amplitude modulator 5. The control input of the modulator 5 is affected by the low-frequency voltage of a rectangular shape from the output of the frequency divider 16.

Modulator 5 operates according to the principle of full reflection of microwave oscillations when a blocking voltage is applied to its control input.

When the blocking voltage is removed, the modulator 5 skips the oscillations with a slight attenuation. Thus, the modulator 5 provides a modulation depth of up to 100%, i.e. operates in interrupt mode with simultaneous reflection of interrupted oscillations.

When the modulator 5 is open, the packages of the passed microwave oscillations enter the antenna 6 and are radiated as a microwave signal to the biological tissue 21 under study. Some absorption of the microwave signal occurs, and the unabsorbed part is reflected in case if the oscillation frequency does not coincide with the active frequency of biological tissue. The reflected signal is received by the antenna 6 and through the open modulator 5 and the circulator 4 is fed to the amplitude detector 7. At the same time, the antenna 6 receives its own super high frequency radiation of the millimeter range, which also flows to the amplitude detector 7.

When the modulator 5 is closed, the microwave oscillations from the output of the attenuator 3 are reflected from the input of the modulator 5 and through the

circulator 4 and flow to the amplitude detector 7 as well.

Both the falling and reflected microwave oscillations are weak signals. At the same time their intensity is comparable or even less than the intensity of instrumental and other noises. A mixture of high-frequency modulation frequency and wide-band noise oscillations is formed as a result of the detection of modulated super high frequency oscillation packages. The selective amplifier 8, which is tuned to the frequency of the RF generator 15, highlights and amplifies microwave modulating oscillation packages. The amplified RF voltage is detected by a synchronous detector 9, which is controlled directly by the voltage of the modulating generator 15.

As a result of synchronous detection of RF voltage packets, video pulses shall be formed with the following amplitudes:

$$U_1 = k_1^2 k_2^2 m_1^2 S_1 k_3 P_1, \quad (1)$$

$$U_2 = k_1^2 k_2^2 m_1^2 S_1 k_3 P_2, \quad (2)$$

where: k_1 - transmission ratio of attenuator 3; k_2 - transmission ratio of circulator 4; S_1 - conversion sensitivity of amplitude detector 7; k_3 - amplification gain of selective amplifier 8; P_1 - power of sounding (incident) oscillations; P_2 - power of reflected oscillations.

Low-pass filter 10 from a sequence of video pulses with amplitudes U_1 and U_2 allocates a low-frequency component of the interrupt frequency with an amplitude

$$U_3 = \frac{U_1 - U_2}{2} = k_1^2 k_2^2 m_1^2 S_1 k_3 \frac{P_1 - P_2}{2}. \quad (3)$$

AC voltage with amplitude U_3 is amplified by a selective amplifier 11, which is tuned to the output frequency of the divider16. The amplified voltage is rectified by a synchronous detector 12, which is controlled directly by the output voltage of the frequency divider 16. The low-pass filter 13, which has a large time constant, produces a constant voltage component, and low-frequency noises are suppressed. A constant voltage flows to a measuring device 14

$$U_4 = k_4 \frac{U_1 - U_2}{2} = k_1^2 k_2^2 m_1^2 S_1 k_3 k_4 \frac{P_1 - P_2}{2}, \quad (4)$$

where k_4 - amplification gain of the selective amplifier 11.

Video pulses (1) and (2) from the output of the synchronous detector 9 also flow on the diode-capacitor chain 17. The amplitude of the larger sequence of video pulses is memorized due to the fast charge and the slow discharge of the capacitor of the chain. Since the power of the incident oscillations is always greater than the power of the reflected oscillations ($P_1 > P_2$), the output voltage of the chain is set at the voltage level U_1. Therefore, a constant voltage is generated at the output of the diode-capacitor circuit 17

$$U_5 = U_1 = k_1^2 k_2^2 m_1^2 S_1 k_3 \frac{P_1}{2}. \quad (5)$$

Constant voltage U_5 affects one input of a differential amplifier 18. Its input is

affected by a constant voltage $U_6 = const$ from reference-voltage source 19. An amplified differential voltage is created at the output of the differential amplifier

$$U_7 = k_5\left(U_5 - U_6\right) = k_5\left(k_1^2 k_2^2 m_1^2 S_1 k_3 P_1 - U_6\right), \quad (6)$$

where k_5 - amplification gain of differential amplifier 18.

Voltage U_7 charges the integrator 20. Its output voltage controls the gain of the selective amplifier 8. The process of automatic gain control occurs until the input voltage of the integrator 20 is equal to zero ($U_7 = 0$). When setting equal the equation (6) to zero and solving it with respect to k_3, we'll receive the steady state amplification gain of the selective amplifier 8:

$$k_3 = \frac{2U_6}{k_1^2 k_2^2 m_1^2 S_1 P_1}. \quad (7)$$

Substituting the value of the gain (7) in the formula (4), we'll receive

$$U_4 = k_4 U_6 \frac{P_1 - P_2}{P_1}. \quad (8)$$

From the obtained formula (8) it can be seen that the voltage U_4, which is measured by the device 14, is proportional to the relative value of the absorbed power $\frac{P_1 - P_2}{P_1}$. This eliminates the influence of the variability of the power of electromagnetic radiation on the assessment of the absorption capacity of biological tissues. The measurement result is also not affected by the level of the intrinsic electromagnetic radiation of the tissue studied, as well as instrumental noise and interference of the conversion path due to the double synchronous detection of the compared oscillations in the single-channel path. In addition, the measurement result is not affected by the instability of the parameters of the super high frequency attenuator 3 (transmission ratio k_1), circulator 4 (transmission ratio k_2), amplitude detector 7 (conversion sensitivity S_1), as well as the variability of the modulation depth, which is set by the super high frequency amplitude modulator 2 (m_1).

The sensitivity of the device to the level of absorbed power can easily be regulated by changing the amplification gain k_4 of low frequency selective amplifier 11. The absorption capacity of biological tissues is estimated depending on the values of biologically active frequencies by varying the frequency of millimeter wavelength range generator 1. Thus, in case of the coincidence of the frequency of the generator 1 with the biologically active frequency, the absorption increases sharply and the coefficient of absorption capacity approaches one

$$k_n = \frac{P_1 - P_2}{P_1} \to 1. \quad (9)$$

Conclusion

Thus, biologically active tissue frequencies can be determined according to the maximum values of k_n. And the absorption band at these frequencies can be

determined by changing the value k_n while detuning the frequency. It is possible to register the absorption spectrum of the tissue under study at a given level of electromagnetic radiation millimeter wavelength range while tuning the frequency of the generator 1 in a wide frequency range.

Studies have indicated that the suggested device allows one to explore, in particular, the absorption capacity of human skin within the frequency range 50…80 GHz at the level of exposure $P_1 \le 10^{-6}$ W/cm^2. With a modulation frequency of 100 kHz and a switching frequency of 1 kHz, the absorption capacity can be determined according to the value of the absorption coefficient in the range from 0.001 to 0.998 with a relative error of no more than 0,5 %. At a fixed frequency, for example, 60 GHz, it is possible to determine the dependence of the absorption coefficient on the level of the irradiating signal (10^{-6}…10^{-1} W/cm^2). At irradiation levels $P_1 > 10^{-3}$ W/cm^2 the absorption coefficient decreases sharply and does not exceed the value 0,1…0,15.

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Анотація. *У цьому дослідженні представлено аналіз існуючих методів оцінки поглинальної здатності біологічних тканин у міліметровому діапазоні довжин хвиль. Показано, що основною проблемою вимірювання поглинальної здатності є низький рівень вимірюваних сигналів, порівняний з власними шумами приймальної антени та елементів вимірювального тракту. Проаналізовано існуючі двоканальні вимірювальні схеми та зроблено висновок про їх значні похибки, обумовлені неідентичністю вимірювальних каналів. Запропоновано функціональну схему пристрою, яка забезпечує підвищення точності вимірювання рівня та спектра поглинання біологічних тканин в мікрохвильовому діапазоні довжин хвиль. Підвищення точності обумовлене мінімізацією впливу на результат*

вимірювання параметрів елементів вимірювального тракту. Це досягається запропонованим авторами алгоритмом роботи пристрою вимірювання рівня та спектра поглинання. Результати роботи можуть бути використані для діагностики різних патологічних процесів в організмі людини, зокрема, запалювальних процесів, глибини опікових уражень та ін.

Ключові слова: *електромагнітне випромінювання, біологічна тканина, міліметровий діапазон, поглинаюча здатність, біологічно активні частоти.*

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