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DESIGN OF MINIATURIZED EXTERNAL DUAL-BAND MICROSTRIP CIRCULAR PATCH ANTENNA FOR MICROWAVE HYPERTHERMIA

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This paper designs a miniaturized in vitro dual-band microstrip circular patch antenna for microwave thermal therapy, with antenna resonant frequencies of 915 MHz and 2450 MHz and a circular patch size of 7 mm radius. It is capable of achieving a reflection coefficient of –25.51 dB at 915 MHz with a bandwidth of 30 MHz (S11 < –10dB) and –36.84 dB at 2450 MHz with a bandwidth of 270 MHz (S11 < –10 dB). The antenna can form an energy focusing area in the human surface tissue below the circular patch, and the focal point position is the same at both frequencies. After simulation, it is verified that 915 MHz can achieve a larger radiation area than 2450 MH with the same SAR field penetration depth. It is possible to select the appropriate frequency for the size of superficial tumor to achieve the effect of precise tumor treatment.

Keywords: microwave hyperthermia; non-invasive ; miniaturization ; dual band ; microstrip circular patch antenna

Introduction. Microwave hyperthermia for tumor, is the use of high-frequency electromagnetic waves in human tissue to produce thermal effects, the temperature of tissue cells to 41.5 °C above the effective treatment temperature, and maintain a period of time, thereby accelerating cancer cell death, while minimizing the damage to normal cells. At present, there are two main types of microwave hyperthermia antennas: invasive and non-invasive. The invasive antenna is directly inserted into the tumor area for heating treatment [1]. Non-invasive antennas use a single antenna or array antenna to gather energy to the tumor site and heat the tumor tissue to achieve the purpose of treatment [2]. Compared with invasive hyperthermia, non-invasive in vitro hyperthermia can not only reduce the damage to the human body during treatment, but also safely and effectively inhibit the development of tumors [2].

Microwave hyperthermia antenna usually uses ISM (industrial, scientific and medical) band of 434 MHz, 915 MHz and 2450 MHz three frequencies [3]. Single antenna form of hyperthermia antenna usually uses patch antenna [2–4], waveguide antenna [5], etc. Most of the existing microwave hyperthermia antennas work at a resonant frequency and can only ablate fixed-size tumors [6]. Because the frequency of electromagnetic wave is inversely proportional to the wavelength, the radiation area of electromagnetic wave is larger and the focus is larger at 915 MHz. At 2450 MHz, the radiation area of the electromagnetic wave is smaller and the focus is smaller.

In view of the above characteristics, this paper designs a hyperthermia antenna working at 915 MHz and 2450 MHz, which can select the appropriate frequency for different volumes of tumors, so as to achieve accurate ablation of tumors and reduce the damage to normal tissues.

Antenna design. In this paper, the electromagnetic field simulation software HFSS2021 is used to simulate and analyze the performance of the antenna. Figure 1 shows the electromagnetic (EM) simulation model of the coaxially fed dual-band microstrip circular patch antenna radiating homogeneous human tissue layer drawn in HFSS2021. The antenna is fabricated on a FR4 dielectric substrate with a thickness of 0.64 mm, a dielectric constant of 4.4, and a loss tangent of 0.02. The antenna patch structure is composed of a central circular patch and a microstrip antenna with four annular arms outside. The center of the patch is connected to the 50 ohm coaxial line by back-feeding. The main structure of the patch antenna is placed in a nylon cylindrical cavity with a radius of 30 mm, a height of 16 mm, and a thickness of 2 mm. The inner surface of the cavity on the back of the antenna is coated with copper as the ground plate of the antenna. The back cavity floor can make the patch antenna free from the influence of external environment changes, so that the antenna can obtain stable resonance [3]. The injection of deionized water into the nylon cylindrical cavity will form a slow wave structure when the microwave is transmitted in the high dielectric constant material of deionized water [7], which can greatly reduce the size of the antenna. At the same time, the skin surface temperature can be reduced by cold water circulation to prevent the antenna from scalding healthy tissues.

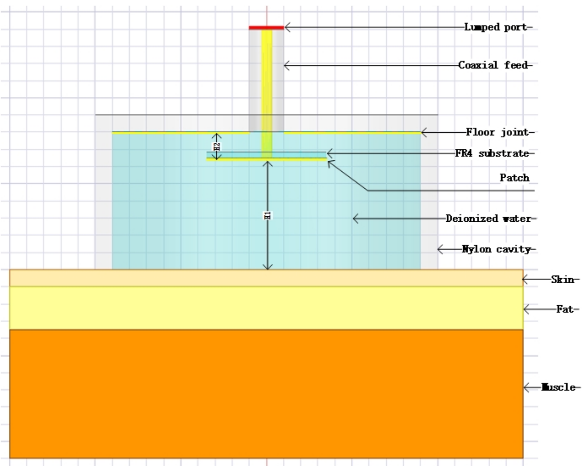


Fig. 1. EM simulation model:
$H1$ is the distance between the antenna and the skin;
$H2$ is the distance between the antenna and the back cavity floor

The final optimized structure of the dual-band microstrip circular patch antenna is shown in Fig. 2, and the design parameters and corresponding values are shown in Table 1. The dual-frequency is realized by loading a ring resonant circuit on the periphery of the circular patch, and the purpose of miniaturization is achieved by loading the meandering technology on the ring resonant circuit [8].

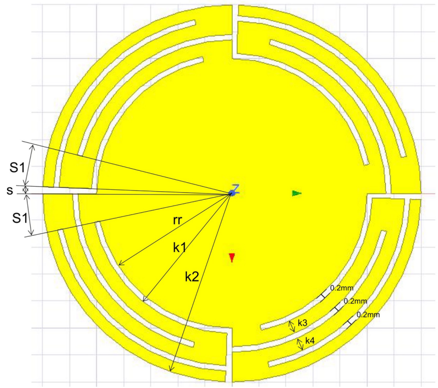


Fig. 2. The final optimized dual-band microstrip circular patch antenna structure

Table 1

Design parameters of proposed antenna

***H*1**	***H*2**	***rr***	***K*1**	***K*2**	***K*3**	***K*4**	***S*1**	***S***
13 mm	3 mm	5 mm	5.2 mm	7 mm	0.5 mm	0.5 mm	12 deg	2 deg

Figure 3 is the return loss of the dual-band microstrip circular patch antenna. It can achieve a reflection coefficient of –25.51 dB at the operating frequency of 915 MHz, and the bandwidth is 30 MHz (S11 < –10 dB). The reflection coefficient of –36.84 dB is achieved at the operating frequency of 2450 MHz, and the bandwidth is 270 MHz (S11 < –10 dB).

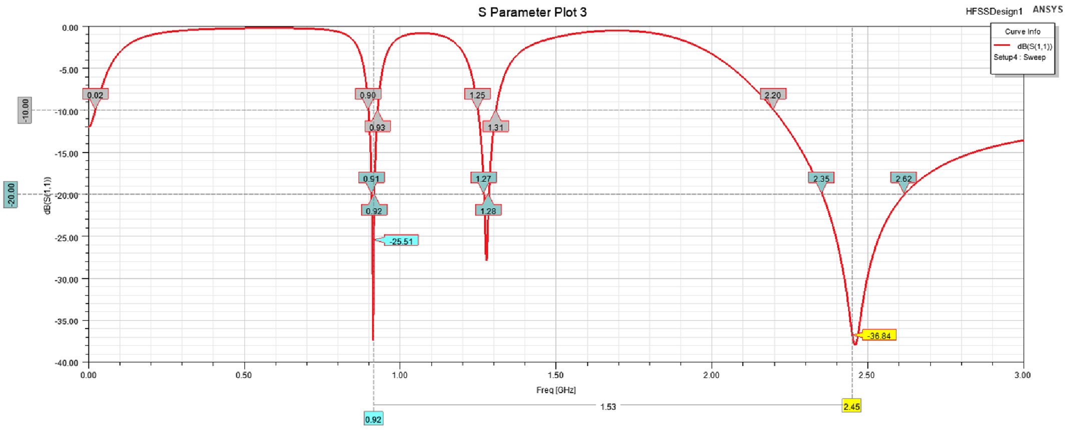


Fig. 3. Return loss of the proposed antenna

Simulation Results and Analysis

Homogeneous human tissue model. In order to simulate the influence of antenna on human tissue, a 60 mm × 60 mm × 22 mm homogeneous human tissue model was constructed. The model has three layers of skin, fat and muscle. Figure 4 is the structure of the homogeneous human tissue model, and the electrical parameters of the model are shown in Table 2.

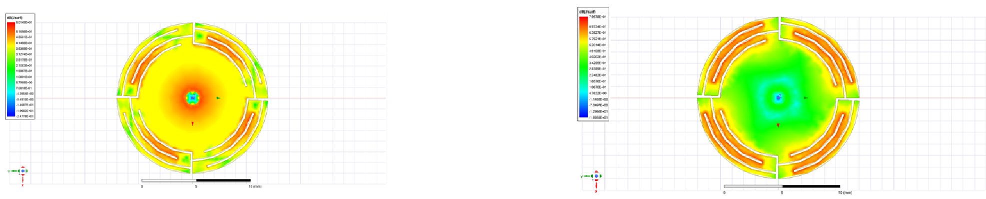
Fig. 4. Homogeneous human tissue model [2]

Table 2

Electrical parameters of homogeneous human tissue model [7]

Tissue	Relative permittivity	Bulk conductivity, S/m	Mass density, kg/m^3	Tissue thickness, mm
Skin	46.02	0.85	1085	2
Fat	5.45	0.05	1069	5
Muscle	54.99	0.948	1041	15

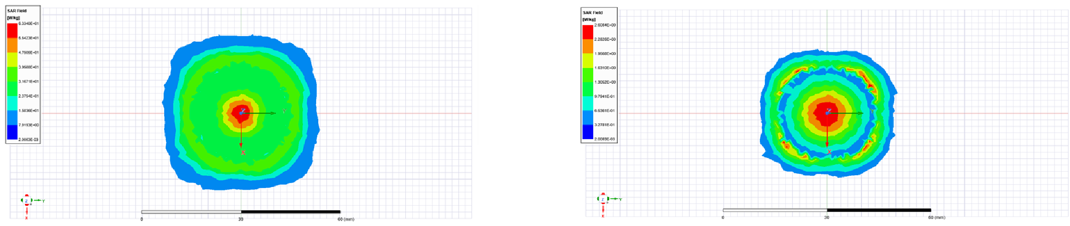
Surface current distribution. In order to evaluate the resonant principle of the dual-band microstrip circular patch antenna, the surface current distribution of the patch at two resonant frequencies is shown in Fig. 5. For 2450 MHz, the current is mainly distributed on both sides of the circular patch and the gap between the circular patch and the annular arm. For 915 MHz, the current is mainly distributed in the annular arm around the circular patch.



a) *b*)

Fig. 5. Surface current distribution of the proposed antenna 2450MHz (*a*) 915MHz (*b*)

Antenna performance analysis. HFSS is used to analyze the SAR field distribution in human tissue. For example, Fig. 6 shows the top view of the SAR field distribution of human tissue at two resonant frequencies. The antenna can form a regular circular energy focusing area directly below the center of the circular patch, and the focus positions of the two frequencies are the same, which ensures the convenience of actual operation.

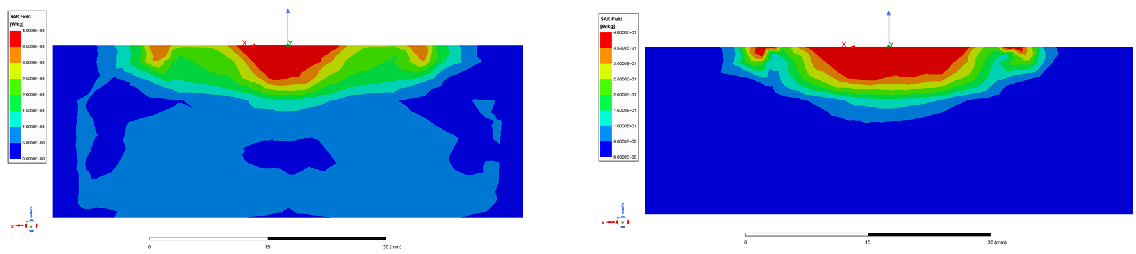


a) *b*)

Fig. 6. The SAR field distribution of the proposed antenna in human tissue
2450 MHz (*a*), 915 MHz (*b*)

Since the 915 MHz resonant frequency is formed by the current distribution of the ring arm around the circular patch, the current distribution of the 915 MHz in the patch antenna is more dispersed. Because the SAR value is proportional to the square of the electric field, the SAR value of 915 MHz is lower than that of 2450 MHz at the same power.

By adjusting the input power of the antenna, the SAR penetration depth of the antenna at two frequencies in human tissue can be the same. Fig. 7 shows the side view of SAR field distribution of human tissue under the same SAR penetration depth (5 mm) at two frequencies. The radiation area at 2450 MHz is about 133 mm^3, while the radiation area at 915 MHz is about 314 mm^3.



a) *b*)

Fig. 7. Side view of SAR field distribution of human tissue under the same SAR penetration depth (5 mm):
a – 2450 MHz; *b* – 915 MHz

Conclusion. In this paper, a miniaturized dual-frequency microstrip circular patch antenna for in vitro surface microwave hyperthermia is designed. The operating frequencies of the antenna are 915 MHz and 2450 MHz. The energy focusing area can be formed in the human body surface tissue below the center of the circular patch, and the focus positions of the two frequencies are the same. According to the simulation analysis, in the homogeneous tissue model of 60 mm × 60 mm × 22 mm, under the premise of the same SAR field penetration depth, 915 MHz can achieve a larger radiation area than 2450 MH. Therefore, the antenna can select the appropriate frequency to achieve the effect of precise ablation of tumors for different volume of surface tumor size.

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DESIGN OF MICROWAVE DIAGNOSIS AND TREATMENT INTEGRATED REAL-TIME DETECTION SYSTEM

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This project designs an integrated real-time detection system for microwave diagnosis and treatment. Non-invasive temperature estimation using microwave conformal array antenna and Nakagami distributed temperature calculation based on BP neural network can effectively assist doctors in better treatment of breast cancer patients.

Keywords: microwave ablation, Nakagam idistribution, ultrasonic noninvasive temperature monitoring, Thermal antenna, Breast cancer.

Introduction. In the treatment of cancer, microwave hyperthermia has been proved to be effective in making up for the deficiency of simple surgery, chemotherapy and radiotherapy, and can effectively improve the cure rate and remission rate of malignant tumors [1]. The microwave conformable array antenna is used to radiate the tumor area, and the data is collected through the ultrasonic data acquisition system. The collected data is transmitted to the server, and the temperature measurement algorithm is used to visualize the ablation area and predict the temperature, so as to assist doctors in better treatment [2]. The purpose of this project is to solve the problem that the location of microwave thermal field is not controllable, and the real-time visualization of the hyperthermia area and non-invasive temperature monitoring can not be carried out while microwave hyperthermia.

Research Content. An integrated real-time detection system for microwave diagnosis and treatment is designed, including microwave hyperthermia heating part, ultrasonic data acquisition part, ultrasonic signal processing part and interface display part.

Microwave hyperthermia module uses breast conformal array antenna. The antenna array mode is shown in Fig. 1. The staggered ring array is adopted to divide the entire antenna array into multiple rhomboid structures with 7 array elements as groups, so that the antenna radiation can better eliminate each other and form a beam with stronger energy, so as to enhance the penetration and focusing ability of the antenna array.