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DESIGN AND ANALYSIS OF MICROSTRIP PATCH ANTENNA FOR HYPERTHERMIA APPLICATIONS IN BREAST CANCER

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Abstract- In this paper, a new conformal and flexible Microstrip patch antenna for treatment under hyperthermia of cancerous tumors is proposed. First, a simple Microstrip antenna is introduced. Then, a phased antenna array is simulated as an antenna with thermal pattern control capability. In the following, the grid antenna array is proposed to reduce the input power amount and its thermal results are simulated. The performance of this design for achieving the maximum local SAR is evaluated carefully and step by step. The performance of this antenna is investigated in multi-stage biological tissue in various positions, including a three-layer tissue (skin, fat and muscle). The dimensions of the final studied antenna are 1.6×240×150 mm. In the last step , the microstrip antenna is conformally designed and the breast tissue with a radius of 5 cm is implemented on this antenna. And its results are visible.

Keywords: Microstrip Patch Antenna, Array Antenna, Grid Antenna, Hyperthermia, SAR.

I. INTRODUCTION

Cancer is one of the main causes of mortality in the world. Many people die from cancer types every year. Over the years, different methods have been used to treat various types of cancers, famous of which are surgery, chemotherapy and radiotherapy. Hyperthermia is one of the relatively new ways to treat cancer, which is accompanied by other methods of cancer therapy such as radiotherapy or chemotherapy. Hyperthermia is generally meant to increase the body temperature to excess of its natural amount.

The high temperature of the body is typically known as a fever or heat shock known as a disease, but the controlled increase in temperature known as hyperthermia can be used to accelerate the improvement of some types of cancer on the side of surgery and chemotherapy and radiotherapy. Research has shown that hyperthermia can cause cell death by destroying protein cell protein structure. One of the most important advantages of this method is that healthy tissue cells are less sensitive to heat than affected cells.

Therefore, it can be claimed that the ability to miniaturize the cancerous tumor may also cause damage to healthy cells around the tumor. Hyperthermia has two different types of use; one for increasing the temperature of the tumor tissue to 42 to 44 degrees Celsius, and the other to increase the temperature up to 60 °C. The aim of first type is increasing in blood circulation in the desired area which will improve the performance of chemotherapy drugs in that area. Also the aim of second type is directly damaging the affected cells [3].

Despite the long tradition of thermal therapy, the use of microwave energy for treatment as a treatment method for cancer patients faces many challenges. The proper focus of energy in the target areas and not engaging in non - target areas, the depth of greater influence of heat and etc. Such as these challenges which have direct relevance to the design of the antenna for the hyperthermia devices. In this paper, by investigating the Microstrip antennas and making necessary improvements in their performance, and investigating the grid antenna array integrated with optimal performance will be introduced.

II. ANTENNA DESIGN

The concept of Microstrip antenna was first introduced by Deschamps in late 1953 [4]. Over the past several decades, extensive research has been done on the structure of these antennas. In 1970, the first Microstrip antenna was developed by Howell and Munson [5]. A microstrip antenna is usually referred to as an insulating structure, on one side, on the ground plane and on the other side of the radiation plate. This conductor is designed in different forms, which is usually made of copper or gold. Some of analyzing and designing methods for microstrip antennas are transmission line method, resonator method, and the whole wave method. An example of this kind of antennas is shown in Figure 1, where rectangular patch antenna is fed by Microstrip line.

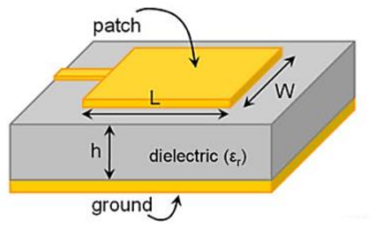

Figure 1. Geometry of Microstrip antenna with Microstrip feeding line

A. Design of a Simple Rectangular Microstrip Patch Antenna

Three basic parameters in design a Microstrip patch antennas are resonance frequency (f_o), dielectric constant (ε_r) and the height (h) of dielectric substrate. Usually height (h) and the loss tangent (tanδ) of the substrate are considered in low amounts [6]. First, the width of the patch is determined by Equation (1) [1].

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

where, c is speed of light, ε_r is the relative dielectric constant of the substrate and f_o is desired resonance frequency. Three allowed resonance frequency for hyperthermia applications are: 434 MHz, 915 MHz and 2.4 GHz. In this paper, the resonance frequency is selected 2.4 GHz, and by using FR4 as substrate (ε_r=4.5), the width of the patch is determined. Then effective permittivity is obtained by [1- 2]:

$$\varepsilon_{reff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{2}$$

Effective permittivity should be calculated due to the fringing fields. Fringing fields are a part of the electric fields that are partly in the air and partly in the substrate (Figure 2). Consequently, given that the propagation environment of this part of the electric fields does not occur only within the substrate, the dielectric constant is reduced and the effective dielectric constant is called [7-8].

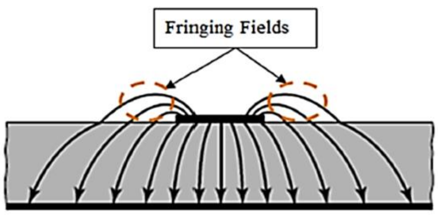

Figure 2. Fringing fields in Microstrip antennas

Due these fringing fields, the length of the Microstrip patch antenna is electrically larger than its physical length. This greater length is shown by ΔL, which is represented by the following equation [1]:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{3}$$

Because of this increasing in the electrically length of the patch, the physical length of the patch is found by the Equation (4) [1].

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

In this paper, for more simplicity, width and effective length of the rectangular Microstrip patch were obtained using online Microstrip patch antenna calculator [9]. In Microstrip antennas, the patch is stimulated by various methods.

In this paper, the patch is carried out by coupling the electric and magnetic fields of the transmission line. In this designed, attributes of the designed Microstrip path antenna with FR4 substrate are: dielectric constant (ε_r) is 4.7, loss tangent of substrate (tanδ) is 0.025, and the substrate and patch thicknesses are 0.16 mm and 0.02 mm, respectively. Also, the width and length of the patch antenna and its ground plane are W_{path} = 56 mm, L_{path} = 40 mm, L_{ground} = 60 mm, W_{ground} = 80 mm. Feeding method of this antenna is through a coaxial cable. The simulation has been performed using CST software, and its simulated return loss (S_{11}) has been shown in figure 3. The shown curve for return loss shows that the antenna operates correctly on 2.4 GHz.

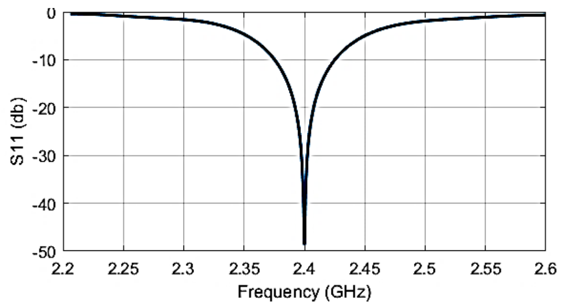

Figure 3. S_{11} of Single element rectangular Microstrip patch antenna

Microstrip antennas have several advantages but low power, low efficiency, high Q, poor scanning operation are their main disadvantages. For hyperthermia applications, the main disadvantage of single Microstrip antennas is lack of the ability to controlling on their radiation pattern. To obtaining this ability, some of these microstrip antennas are placed together as an array antenna [10].

B. Design and Implementation of Microstrip Patch Antenna Array

An array antenna is a set of multiple connected antennas that act as a single antenna for transmitting or receiving radio waves, in order to achieve better characteristics.

In fact, an array antenna is a radiation system that contains several radiator or individual elements. One of the most important challenges in designing an array of microstrip antennas is how to stimulate the elements and the antenna feed network [11, 12]. Usually element antennas of an array antenna are Microstrip patch antenna, because if other antennas are used as an array antenna element, the overall antenna size will be greatly increased and will not be practically useful for applications such as hyperthermia. S 2×2 Microstrip array antenna is shown in Figure 4. each element of this array is a simple rectangular patch. The used substrate for this array antenna is selected same as the pervious simple Microstrip antenna (FR4). Thus, dielectric constant, loss tangent and also height of substare are exactly the same as designing the previous section.

But the antenna dimensions are optimized so that the resonant frequency of the antenna is set to 2.4 GHz. Again, this antenna feeds through coaxial cable. The simulated array antenna and its obtained return loss (S_{11}) of are shown in figure 4 and 5, respectively.

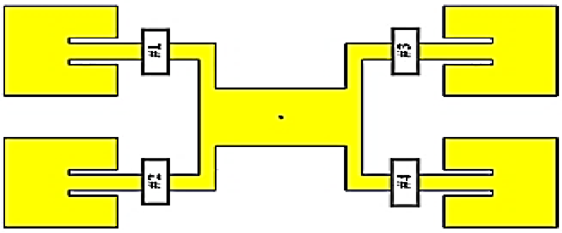

Figure. 4. 2×2 Microstrp patch array antenna with 4 phase shift elements

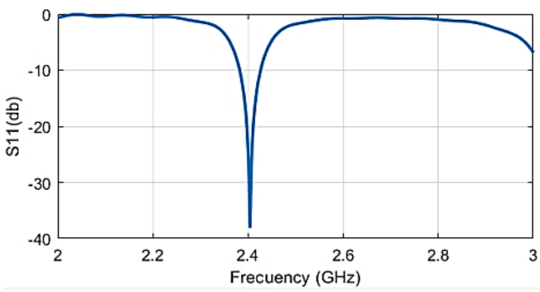

Figure 5. S_{11} of the Microstrip patch antenna array

The variation of radiation beam, and thermal control, can be done in this array antenna. For this reason, 4 phase shifter are used in the paths of each element. Phase of the input signal of each element is controlled to concentrate the array beam towards the desired orientation. For creating desired phase shift in input of elements phase shifter IC (980-2k) and microcontroller have been used. Various phase shifts in input signal of elements change radiation pattern of array antenna and thus the heat generated in the tissue located in front of the antenna also changes.

B.1. Specific Absorption Rate

Specific Absorption Rate (*SAR*), in fact, indicates the amount of the attracted radiant energy by antenna in various layers of body tissues and in various depths from skin's cover. The amount of *SAR* is dependent to the influence of internal electric field [13]. *SAR* is equal to absorbed energy in tissue mass unit in terms of watt/kg [1].

$$SAR = \frac{d}{dt}\frac{dw}{dm} = \frac{d}{dt}\frac{dw}{\rho dv} \tag{5}$$

The measurement of *SAR* in term of tissue temperature rise could be presented according to the below equation [1]:

$$SAR = C_h \frac{dT}{dt} \tag{6}$$

Also, SAR could be calculated by below formula [1]:

$$SAR = \frac{\sigma E^2}{\rho} \tag{7}$$

In above equations, *E* is the electric field strength in tissue in volt/meter unit. σ is the conductivity of tissue liquid in Siemens/meter unit, ρ is the density of tissue in kilogram unit, C_h is the heat capacity of tissue in joule/Kg Kelvin unit $\frac{dT}{dt}$ is the primary time derivative of tissue temperature in Kelvin unit. Therefore, by measuring the amplitude of the electric field, *SAR* is obtained [14].

The simulated SAR of the array antenna (Figure 5) is shown in Figure 6 for different values of applied phases. This *SAR* shows that the change in the phase of branches causes a change in the thermal pattern created in the tissue. This is the ideal feature of array antennas in hypothermic applications. It should be noted, however, that the maximum *SAR* obtained from the 1 Watt input power for the antenna is equal to 0.3 w/kg.

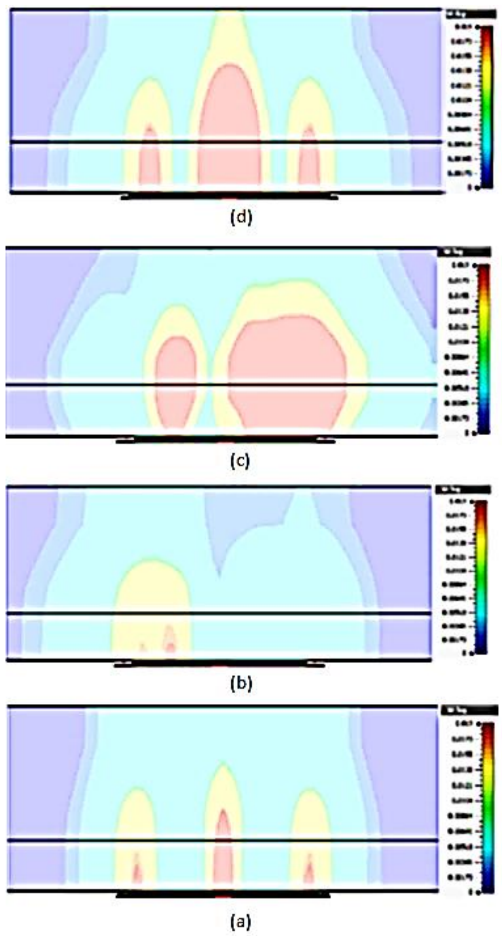

Figure 6. SAR results from proposed array antenna
(a) 45° shift phase in #1, (b) 45° shift phase in #2,
(c) 90° shift phase in #3, (d) 90° shift phase in #4

The dissipated power of designed array antenna is very high. In the other words, to generate a specific heat at a part of tissue, a large amount of power is emitted from the antenna. This high electromagnetic radiation is not suitable for healthy tissue areas. For solving this problem, grid array antenna with the same array antenna capabilities and less radiation power has been proposed.

C. Design and Implementation of Grid Antenna Array

Grid array antenna (GAA) was invented in 1964 by Krous. GAA or Brick Applicator is a kind of array antennas with several rectangular rings. The long segment of each loop is considered equal to a wavelength, and thus it works like a transmission line. Whereas the short side of the segment is half of the long segment and operates as a radiating element. Other parameters of grid array antennas can also be found, such as honeycomb wire antenna, chain antenna etc. [15]. Figure 6 shows the geometry of the grid antenna array.

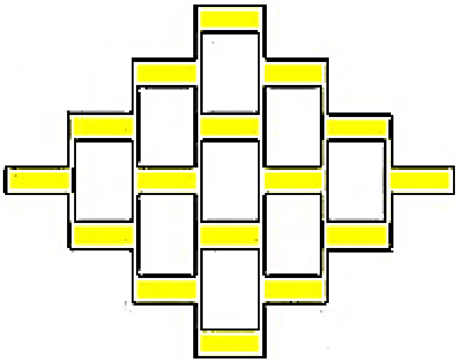

Figure 7. View of the geometry of the grid antenna array

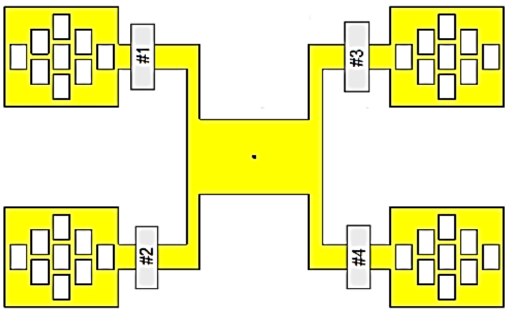

Figure 8. View of the proposed grid array antenna

D. Design and Implementation of Grid Array Antenna

Considering all the items in the previous sections, by combining a 2×2 Microstrip patch antenna array and grid antennas, a new antenna, such as shown in Figure 7, is proposed. In addition to the advantages of Microstrip antennas, this antenna also has the advantage of phase controlling of array antennas and low power consumption of the brick antennas. Figure 8 shows the simulated S_{11} of this antenna. Again, dimensions of the antenna are so optimized that the resonance frequency of the antenna is set to 2.4 GHz.

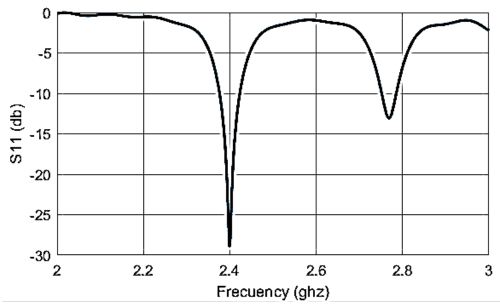

Figure 9. S_{11} of the proposed grid array antenna

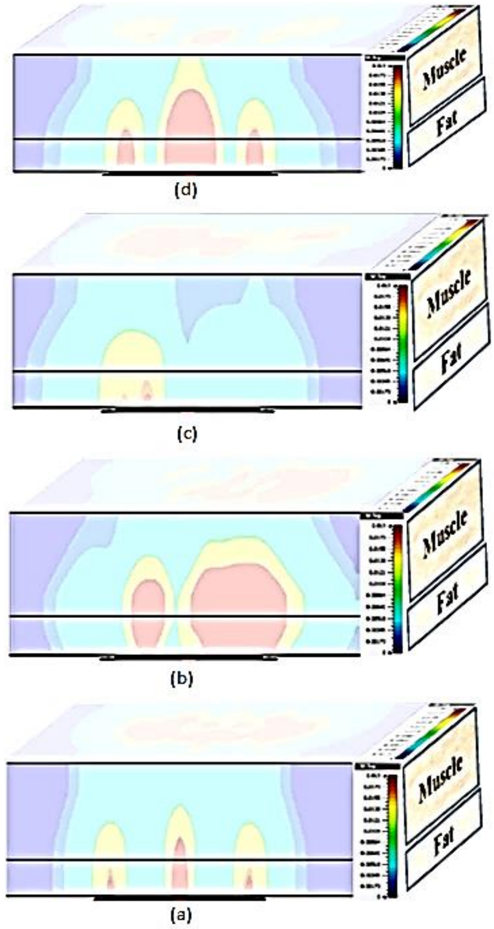

Figure 10. SAR results from array antenna simulation
(a) 45^0 shift phase in #1, (b) 90^0 shift phase in #3,
(c) 45^0 shift phase in #2, (d) 90^0 shift phase in #4

SAR results of array grid antenna shows, like the array antenna, the thermal pattern in the tissue can be controlled by creating phase shifts. The important point is that the amount of *SAR* generated for a fixed one-watt input power for a grid antenna is much higher (1.2 w/kg) than the amount of generated *SAR* for a simple array antenna. In other words, with less input power, more SAR can be created in grid antennas, and thus effectively prevented from unwanted radiation.

The Single Element Rectangular microstrip patch antenna and microstrip patch antenna array and grid array antenna is on a flat surface. These antennas, if placed on the breast tissue. They don't cover all parts of the breast tissue. For this purpose, conformal microstrip antenna have been proposed.

D. Design and Implementation of Conformal Microstrip Antenna

Conformal antennas were developed in the 1980s as avionics antennas. these antennas minimize aerodynamic drag by being mounted on or embedded in the curved surface of high-performance aircraft. conformal antennas can provide special antenna pattern requirement by an appropriate geometrical form. If the shape of planar antennas is determined by electromagnetic considerations such as radiation patterns and angular covering. It is in the category of conformal antennas. Normally, conformal antennas are cylindrical and spherical designed as conformal.

Figure 11 shows the design of a conformal microstrip antenna. In this design, conformal antenna of the Fr4 substrate with a dielectric constant εr=4.42 is a loss tangent 0.025 = tanδ, and the thickness of the substrate is 0.16mm. This antenna is tangent to a hypothetical spherical with a radius of 5cm.

Figure 12 shows the simulated S11 of this antenna. Again, dimensions of the antenna are so optimized that the resonance frequency of the antenna is set to 2.4 GHz. The design of conformal microstrip antenna on the breast tissues and an overview of the SAR generated by the conformal antenna are shown in figure 13 and 14, respectively.

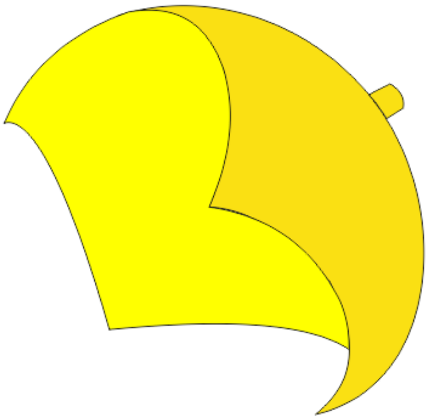

Figure 11. View of the proposed conformal microstrip antenna

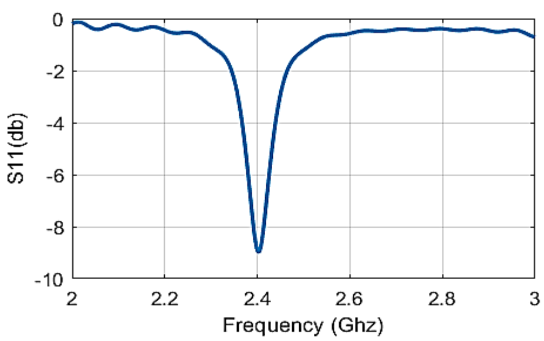

Figure 12. S_{11} of the proposed conformal antenna

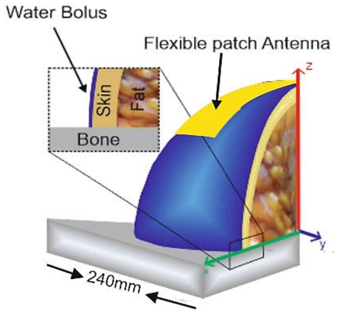

Figure 13. Conformal microstrip antenna on the breast tissues (right).

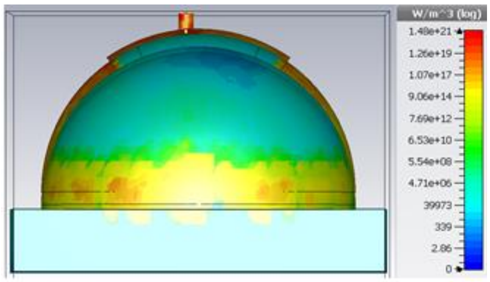

Figure 14. SAR results from conformal microstrip antenna simulation

III. CONCLUSION

In this paper, a light weight, flexible and simple antenna was designed on a lower thickness and loss tangent substrate than were reported previously.

But the main purpose of this article is to use a grid array antenna to give ability to control thermal pattern and to reduce radiated harmful power effects on body tissue.

A new proposed antenna that is combining of an array antenna and a grid antenna has the capability of array antenna for changing of radiation pattern by changing the phases of its elements and also it has capability of the grid antenna that radiates very lower than same category ordinary antennas. Since the antenna must cover all parts of the tissue. It is suggested that the antenna is designed in conformal.

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