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Design of Antennas with Small Dimensions for Medical Implant Applications in the Millimeter-Range

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Abstract

In this paper, two single-feed microstrip patch antennas at (31.5 & 60 GHz) have been designed and optimized for medical applications. The crow search algorithm (CSA) is utilized to optimize the antenna parameters. Our main idea in this paper was to improve the parameters of the microstrip antenna considering several limitations such as antenna dimensions, specific absorption rate, etc. The dielectric ranged from 1 to 3. In addition, the area is considered between 300 and 1500 square millimeters. The simulation results of the proposed method show that the design and optimization of the parameters of the antennas within the millimeter-wave band cut back the physical size of the antennas. Therefore, these antennas will be a good choice for medical applications.

Index Terms— Millimeter Waves, medical, Antenna design, Crow Search Optimization Algorithm, the implantable antenna.

I. INTRODUCTION

An antenna is a device that transmits data and signals in the form of electromagnetic waves between two points using air media. Antennas are a key element of any communication system and connect the two systems so that they play a vital role to find the specifications of those systems. There are various kinds of antennas. Antennas have several applications in engineering sciences. One of their significant applications in medicine is what we call biometrics[1]. Biometric technology has led to significant changes in the medical industry. Using wireless technology, which has medical implants and implants, due to the moment-to-moment transmission of physiological signals, it is potential to care for the patient outside the doctor's office and minimize the need to visit the doctor's office and check-up. The outline of the medical system based on antennas implanted in the body is shown in Fig.1[2]. It saves time and money. In-body communication includes an implantable device and an external device to observe the patient's health[3].

Fig.1: *Outline of a medical system based on antennas implanted in the body[2]*

To create a suitable link between the implant within the body and the monitors and control systems, etc. outside the body This requires special attention in terms of in-body implant design and channel response. In vivo communication is one of the extremely developing technologies and It helps comprehend the communication between implantable procedures.[4]Experimental channel response for in vivo communication will help recognize the real channel response and its impacts on communication. According to the International Telecommunication Union (ITU), the millimeter-wave band, furthermore, known as the super-frequency band, is in the range of 30 to 300 GHz. Millimeter waves have several advantages, particularly in trade applications, which are Broadband (for higher data rates), Higher resolution, Low interference, supplemental security, and Higher performance. In novel years, due to the popularity of the millimeter-wave spectrum, new research has been done to make antennas in this band. Millimeter waves are a portion of the electromagnetic spectrum that may be employed in a variety of goods and services, including high-speed, point-to-point, and wireless local area networks, as well as medical applications [5], [6]. In this study, two single-feed microstrip patch antennas in the millimeter-wave band were designed and optimized for medical applications. The crow search algorithm is employed to improve the antenna parameters. The Crow Search Algorithm is is inspired by crow behavior. and is one of the most attractive optimization algorithms. Proper antenna design can lead to a high degree of efficiency, better conductivity, and more bandwidth for long-distance transmission without data loss. The simulation results of the proposed method show that the design and optimization of the parameters of the antennas in the millimeter-wave band reduce the physical size of the antennas. Therefore, these antennas will be a perfect cucumber for medical applications.

A Microstrip patch Antenna

Patch antennas are one of the categories of flat antennas that have received a great deal of attention within the last 3 decades. The microstrip patch antenna is a screen antenna that has received considerable attention due to its plane geometry. These types of antennas are extremely popular among designers and are utilized in several applications. The patch antenna is fed in four ways: coaxial feeding, microstrip line feeding, coupled aperture feeding, and adjacent feeding. during this study, we tend to use of Microstrip line feeding type.. in this feeding method technique, a stripline is connected directly to the edge of the microstrip patch. The conductive tape is wider than the patch. The advantage of this method is that the power line can be installed on the same sub-layer of the patch and thus a plate structure is produced. Another advantage of this method is its simplicity in construction.

B OPTIMIZATION ALGORITHM

Optimizing a system means minimizing or increasing a function, which is a measure of system performance. This may ultimately improve system performance. In engineering and other applications, there are many optimization issues. Therefore, finding the optimum answer is very important would like. There are several ways that to resolve optimization problems that may have sensible results for some applications and sometimes work poorly. But these algorithms have other problems as well, such as many customizable variables. There are several algorithms for optimization[7].such as: Genetic Algorithm[8][9], and Particle swarm algorithm (PSO)[10] , and . In this research, we have selected the crow search algorithm[11] as the basic algorithm. The CSA algorithm is a population-based approach based on the idea that crows store up their surplus food in secret places and retrieve it when they need it. The code of the crow search algorithm is as follows in fig.3

Crow search algorithm
Randomly initialize the position of N crows in the search space
Evaluate the position of the crows
Initialize the memory of each crow
while iter <Maxiter
for i = 1 : N (all N crows of the flock)
Randomly choose one of the crows to follow (for example j)
Define an awareness probability
if $r_i \geq AP_j^{iter}$
$x_i^{iter+1} = x_i^{iter} + r_i * fl_i^{iter} * \left(m_j^{iter} - x_i^{iter}\right)$
else
x_i^{iter+1} *a random position of search space*
end if
end for
Check the feasibility of new positions
Evaluate the new position of the crows
Update the memory of crows
end while

Fig.2: *The crow search algorithm's code.*

II. RELATED WORK

A variety of related works have been carried out in this field. It ought to be noted that microstrip antennas have a distinct place in radar applications and wireless systems due to their advantages such as small size, lightweight, low cost, and low cross-section, high flexibility, etc. [[12]. Also, the rapid development of microstrip antenna technology is due to the good features of this type of antenna. These features include small size, lightweight, low cost, compatibility with the assembly structure, easy integration with flat circuits, suitable for circular, linear and dual polarizations, and the ability to feed several species[13]. Microstrip antennas are also widely used in microwave and millimeter-wave systems [14], [15].

Although microstrip antennas have several useful properties, one of their serious limitations is their low bandwidth. The bandwidth of a normal microstrip antenna is less than 1% to a few percent for substrates with a thickness-to-wavelength ratio of less than 0.023 and a permeability of 10 to a thickness of less than 0.07 with a permeability of 2.3. The bandwidth for common antenna elements such as dipole, aperture antenna, and horn is from 15 to 50%. Researchers have been working to remove this limitation for the past 20 years. Increasing bandwidth can be done in other ways, such as choosing the right power supply or the right impedance matching network. Recently, with the development of substrate waveguides, they have been used as small, low-cost waveguides to power microstrip patch antennas[16]. Millimeter waves are more costly and bring up more spectral possibilities. It has a frequency range of 30 to 300 GHz, falling between microwaves (1-30 GHz) and infrared (IR) waves. Millimeter waves have a wavelength of 1-10mm. Because of their tiny wavelength, mm-wave devices allow huge antenna arrays to be packed in a small physical space. Several studies on the usage of patch antennas in medicine have been conducted. In[17], helical and serpentine antenna designs were investigated, and the scientists used a single muscle mass and a genuine human shoulder to model the performance of these antennas. The findings were also confirmed in an experiment using a tissue simulant made up of TX-151, sugar, salt, and water. The influence of the dielectric's shape and size, as well as the feed point's placement, on the antenna's performance, is investigated. Spiral and planar inverted-F (PIFA) antennas are subjected to a similar examination in [18]. However, the authors employed a six-layer model to study the human brain (brain, cerebrospinal fluid, dura, bone, fat, and skin). The findings are confirmed once again using deionized water, sugar, salt, and cellulose-based human tissue imitating fluid. In both papers, the authors considered the 402-405 MHz frequency recommended by the European Radio Communication Committee (ERC) for active and highly robust medical implants In[19]This research presents the in-vivo communication channel characteristics in relation to the location of ex-vivo antennas, using a frequency range of 3.01 GHz to 10.6 GHz and a bandwidth of 500 MHz. It has been determined that in-vivo communication should take into account not only the positioning of antennas within the human body, but also the influence of antennas outside the human body.[20]–[22] these researches presented an exhaustive analysis and development and Evaluation of Ultra-Wideband in vivo radio channel bit error rate (BER) performance. A 31.5GHz patch antenna for medical implants was suggested in [23]. The model is created in CST and is based on the transmission line model. In terms of return loss and radiation efficiency, the patch antenna works well. The form factor, however, is the most appealing aspect of this design. The suggested design is lower in size but keeps all of the important characteristics of a dependable connection.[24] A single rectangular Microstrip Patch antenna (MPA) with 60 GHz internal feed is provided in this work using Frequency Selective Surface (FSS). It was discovered that the distance between the FSS and the antenna has a considerable impact on the best outcomes. In[25] For millimeter-wave (mm Wav500e) communications in the unlicensed industrial, scientific, and medical 60 GHz band, a four-element MIMO patch antenna with several types of EBG configurations were described. There is a variety of research, and the design, and analysis of wearable antennas have a wide scope.

III. PROPOSED METHOD

We first select the basic parameters (patch height, resonant frequency, and dielectric material). Then, we select the antenna parameters. Then, using the crow search optimization algorithm, we perform the parameter optimization operation. If the optimization result is not suitable, we perform the design operation again.

Based on the described formulas, a design process that leads to the practical design of a rectangular microstrip antenna is as follows. Consider Fig.2. The assumptions of this process are substrate with a dielectric constant ε_r, resonance frequency f_r , and substrate height h, so in the first step, we
select values for them. And for an effective radiator, the patch width that results in good radiant efficiency is equal to

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

The effective dielectric constant of the microstrip antenna is determined using the following equation.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{\mathbf{2}} - \frac{\varepsilon_r - 1}{\mathbf{2}}\left[1 + 12\,\frac{h}{W}\right]^{-\frac{1}{2}} \qquad \frac{w}{h} > 1$$

$$1 < \varepsilon_{reff} < \varepsilon_r$$

After determining W, the length ΔL is determined by the following formula.

$$\Delta L = 0.412\,\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

The actual length of the patch is now determined by solving the following equation.

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

The first design frequency is 31.5 GHz. our second frequency of choice in this study is 60 GHz. The 60 GHz frequency is an ultra-high frequency (EHF) bandwidth set by the IEEE (ranging from 40 GHz to 75 GHz). The frequency of 60 GHz is also considered a millimeter-wave frequency (mm-Wave).

A. Simulation results

Antenna Toolbox is one of the new MATLAB toolboxes that was added to MATLAB features from the MATLAB 2015 version. With the MATLAB antenna toolbox, the antenna can be designed, analyzed, and illustrated. Due to that in this study, in addition to antenna design, we also use parameter optimization, we have used this software. It should be noted that the version used is 2021.

B. antenna design results before Optimization

The proposed structure is considered a rectangular patch antenna. In Fig.3, this basic structure is presented. To design the antenna., the appropriate dielectric limit should be between 1 and 3. Note that the dielectric of air is equal to 1. In this study, WE used polyester dielectric with a coefficient of 2.55 and a loss tangent of 0.0001. (Default is air with 1 and loss tangent 0). The comparison table.1 shows our selected values with two similar studies.

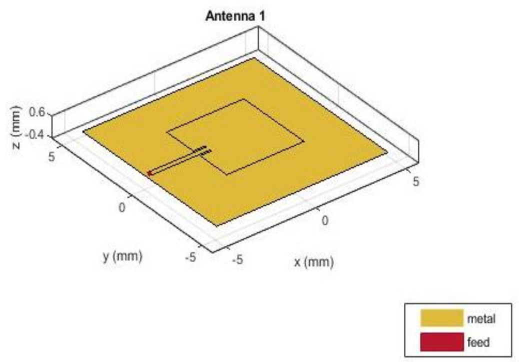
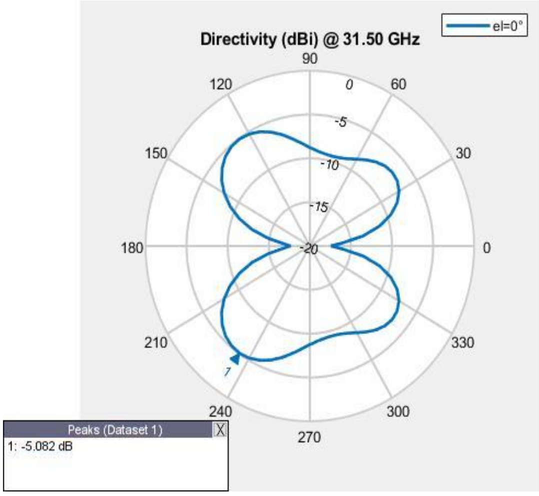


Fig.3: *rectangular patch antenna (line feed).*

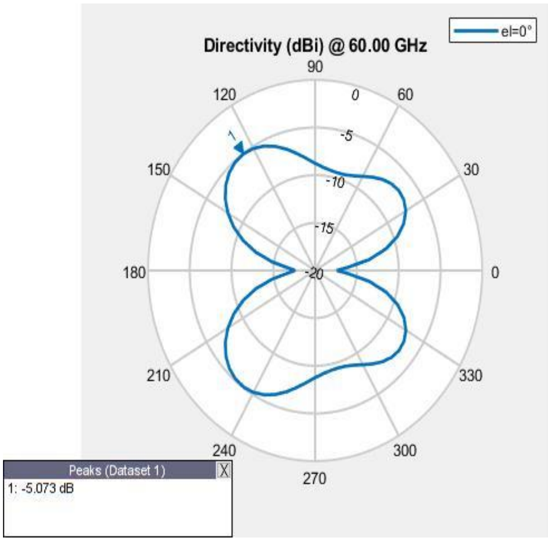
Table.1: *Initial selected parameters*

	Dielectric	ε	loss tangent	F (GHZ)
[26]	FR4	4.4	0.0001	2.45
[23]	RT6002	2.94	0.0012	31.5
Proposed method	Polystyrene (AIR)	2.55 1	0.0001 0	31.5 60

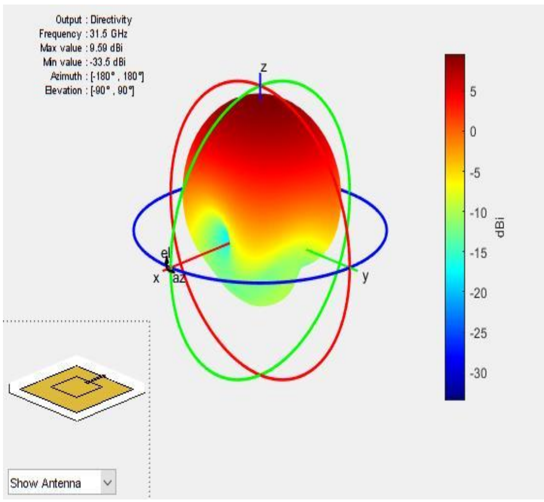
Fig.4, shows the not optimized diagrams (H-plane and 3D radiation pattern) for the antennas (31,5&60)GHZ



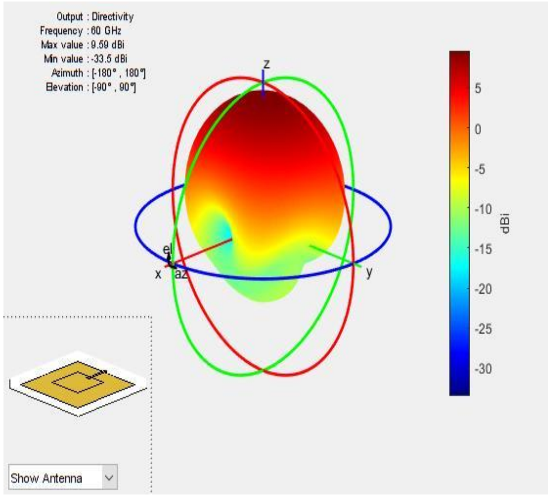
(a)



(b)



(c)



(d)

Fig.4: *not optimized diagram ((a), (b)H-plane and(c),(d)3D radiation pattern.*

The proposed antenna structure is powered by a 50-ohm microstrip power line. In table 2, the area is the product of length in patch width, which is easily calculated. Also, the area limit is between 300 and 1500 square millimeters. This value is also obtained by reading related papers. Diagrams (H-plane and 3D radiation pattern) are also shown in Fig.4.

$$300\ \text{mm}^2 < \text{Area} = \text{Length} \times \text{Width} < 1500\ mm^2$$

C. Optimization of antenna parameters with the crow search algorithm

After designing, the antenna parameters must be optimized. the crow search algorithm can be proposed as a good and fast algorithm for optimization. By applying this algorithm, while maintaining interest and maintaining quality, we seek to reduce the dimensions of the antenna. Fig.6 shows 100 repetitions for optimization (Convergence). Also based on table 2, In this case, the patch space has been reduced factors by 1.55 for 31.5GHZ and 1.31 for 60GHZ. This is a great result for medical applications.

$$31.5\text{GHZ} \quad \rightarrow \quad \frac{no_{opt}}{opt} = \frac{18.49}{11.9} = 1.55$$

$$60\text{GHZ} \quad \rightarrow \quad \frac{no_{opt}}{opt} = \frac{5.01}{3.82} = 1.31$$

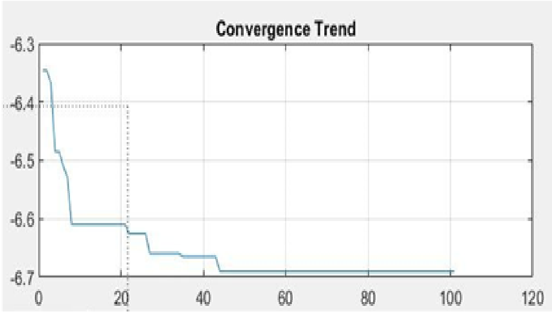
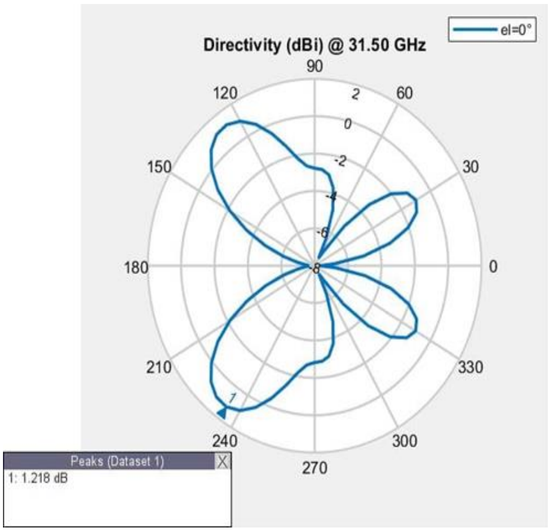


Fig.5: *100 repetitions for optimization (Convergence).*

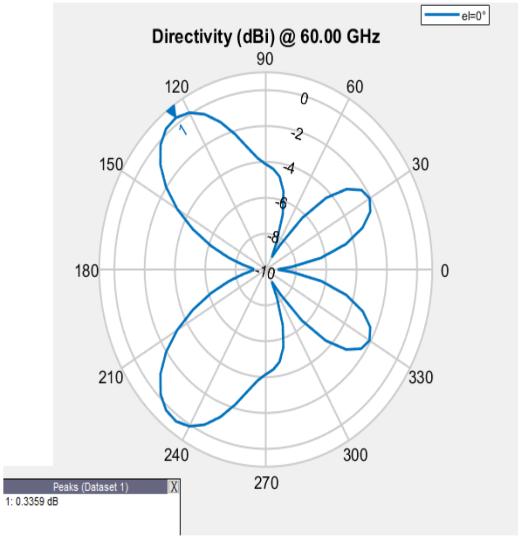
Table.2: *The not optimization and optimization results.*

	31.5GHZ (not optimization)	60GHZ (not optimization)
Length	4.3	2.24
Width	4.3	2.24
Height	2.37	0.12
Area	18.49	5.01
	31.5GHZ (optimization)	60GHZ (optimization)
Length	3.4	1.95
Width	3.5	1.96
Height	2.37	0.12
Area	11.9	3.82

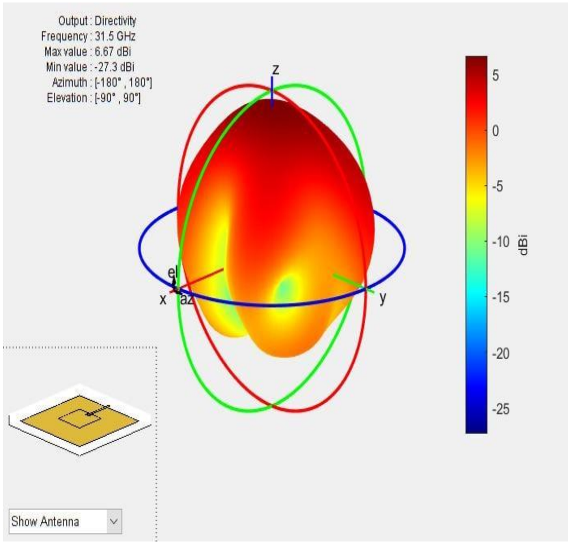
in this case, the desired diagrams are also shown in Fig.6 for 31.5GHZ and 60GHZ. It is clear from the diagrams that the gain of the antennas is better distributed in different directions, while the antenna area is reduced appropriately. That was the goal.



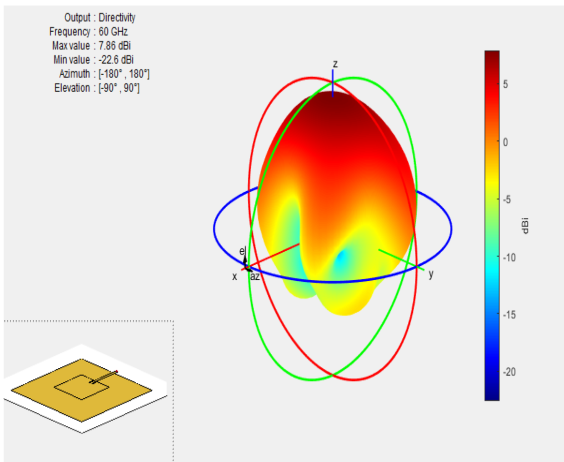
(a)



(b)



(c)



(d)

Fig.6: *optimized diagrams ((a),(b)H-plane and (c),(d)3D radiation pattern).*

IV. CONCLUSION

Antenna design for medical implant capabilities has several challenges. In alternative words, in designing antennas for medical implants, many limitations such as antenna dimensions, specific absorption rate, etc. Our main plan during this research was to optimize the microstrip antenna parameters considering these limitations. two single-feed microstrip patch antennas in the millimeter-wave band have been designed and optimized for medical applications. The dielectric range is considered to be between on1 &3. Also, the area is considered between 300 and 1500 square millimeters. The objective function in the optimization process is to maximize antenna gain. It ought to note that in this study, the size limit was considered, the antenna can be placed in the body tissue. The crow search algorithm is utilized to optimize the antenna parameters. The simulation results of the proposed method show that the design and optimization of the parameters of the antennas in the millimeter-wave range reduce the physical dimension of the antennas. Therefore, these antennas will be a good option for medical applications. Faster and more accurate optimization algorithms can also be used in the future. The use of intelligent algorithms and deep learning can also be used as a powerful tool in this field.

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