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Thesis

Design and Analysis of Microstrip Antenna for Medical Applications

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Dedication

My Parents: *Thank you for your unconditional support for my studies. I'm honored to have you as my parents. Thank you for giving me a chance to prove and improve myself through all my steps in life.*

My Brothers &Sisters: *Hoping that with this research I have proven to you that there is no mountain higher as long as Allah is on our side. Hoping that you will walk again and be able to fulfill your dreams*

My family: *Thank you for believing in me, for your support, love and cohesion I'm grateful.*

My Friends: *I'm grateful for your encouragement and support.*

My classmates: *Thank you for your cooperation through my one-year master program at El oued university.*

I dedicate this project to you all with much love, appreciation & respect

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Dedication

First and foremost, i thank Allah the most Graceful for giving me the Strength and Patience to undertake and complete this work.

To those who set me on the path of life, made me calm, and took care of me unit became old (my lovely parents)

To the owner of a fragrant biography and enlightened thought, to who had the first credit in attaining higher education (my beloved father), may God prolog his life.

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I dedicate this work with my sincerely love.

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Fatma.

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ABSTRACT

Recent years have witnessed a significant increase in the use of telecommunication technologies in the medical field especially through medical telemetry. This practice, which may be conducted by implementing a medical device in the human or animal body, allows to monitor its vital signs and collect data which can be used to diagnose its health state. This work proposes the design of a narrow-band antenna operating in the MICS band (Medical Implant Communication Service) for wireless telemedicine. The proposed antenna resonates at 404 MHz with a reflection coefficient of -52dB and a bandwidth of 2.25MHz. Simulation showed promising results with regard to the use of gallium arsenide in the antenna substrate as well as the utility of hexagonal and circular slots in obtaining smaller resonating frequencies.

Keywords: Microstrip, Antenna, HFSS, Medical, Design, MICS

ملخص

شهدت السنوات الاخيرة زيادة كبيرة في استخدام تكنولوجيات الاتصالات السلكية و اللاسلكية في المجال الطبي, ولا سيما من خلال القياس الطبي عن بعد. تسمح هذه الممارسة, التي يمكن اجراؤها من خلال تنفيذ جهاز طبي في جسم الانسان او الحيوان, بمراقبة علامتها الحيوية وجمع البيانات التي يمكن استخدامها لتشخيص حالتها الصحية. يقترح هذا العمل تصميم هوائي ضيق النطاق يعمل في نطاق (خدمة الاتصال بالزرع الطبي) للتطبيب اللاسلكي عن بعد. يتردد صدى الهوائي المقتح عن (404 MHz) مع معامل انعكاس(52dB-) وعرض نطاق ترددي (2.25 MHz). اظهرت المحاكات نتائج واعدة فيما يتعلق باستخدام الغاليوم ارسنايد في ركيزة الهوائي وكطالك فائدة الفتحات السداسية و الدائرية في الحصول على ترددات رنين اصغر.

الكلمات المفتاحية:الهوائيات,الطبية,الأجهزة, الترددات,تصميم

Résumé

Ces dernieres annees ont vu une augmentation significative de l'utilisartion des technologies de telecommunication dans le domaine medical notamment a traverse la telemetrie medicale. Cette pratique, qui peut etre conduit par la mise en place d'un dispositive medical dans le crops humain ou animal, permet de surveiller ses signes vitaux et de collecter des donnees pouvant etre utilisees pour diagnostiquer son etat de sante. Ce travail propose la conception d'une antenne a bande etroite fonctionnant dans la bande MICS (Medical Implant Communication Service) pour la telemedicine sans fil, l'antenne proposée résonne a 404 MHz avec une coefficient de réflexion de -52 DB et une bande passante de 2.25 MHz .la simulation a montré des resultats promotteurs enc e qui concerne l'utilisation de l'arséniure de gallium dans le substrat d'antenne ainsi que l'utilité des fentes hexagonales et circulaires pour obtenir des fréquencede resonance plus petites.

Mots Clés: HFSS, Medicale, MICS, Antenne, Télemetrie,

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1. Introduction :

Since the creation of the Microstrip antenna half a century ago, the demand for its use has been quickly expanding, particularly in the last two decades [1]. With the advancement of technology, particularly in communication systems, compactness of devices with a flexible integrated approach to other devices is becoming more desirable [2]. An antenna is a type of electrical conductor or conductor system that is "that part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves" [3]. The patch antenna concept was developed by Deschamps in 1953, and the practical antenna was developed by Muson and Howell in the 1970s [4].

Several numerical analysis techniques have been developed and converted to computer-aided design tools to better understand the performance of the Microstrip antenna and to simplify its design process. Some of these analysis techniques also enable the designer to gain physical insight into the electrical operating mechanism of the antenna [3]. This section discusses and emphasizes some of the technical features, physical and radiation mechanisms, feeding techniques, analysis methods, advantages and disadvantages, and applications of the Microstrip antenna.

2. Definition:

Microstrip Patch antennas are extremely important in today's wireless communication systems [5]. It is a low-profile antenna with several advantages over other antennas: it is lightweight, affordable, and electronics such as LNAs and SSPAs can be easily integrated with it. While the antenna might be a three-dimensional array it is usually flat because it is a construction (wrapped around a cylinder, for example) planar antennas are another name for patch antennas. The patch antenna's dielectric is usually made of printed circuit board material, while the substrate serves as the antenna's base. The bandwidth is determined by the distance between the patch and the ground plane – the substrate or dielectric height h [6].

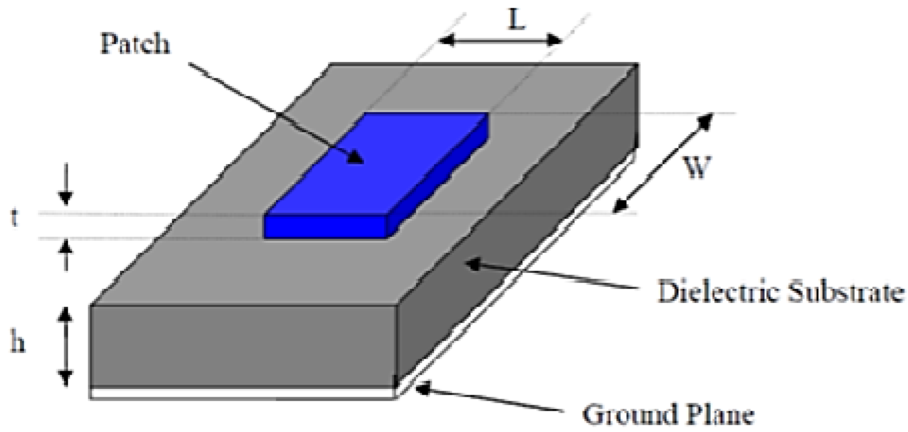


Figure1.1: Structure of a microstrip patch antenna [7].

3. Basic Principles of Operation:

The metallic patch effectively creates a resonant cavity, with the patch serving as the top of the cavity, the ground plane serving as the bottom, and the patch's edges serving as the cavity's sides. The patch's edges operate as an open-circuit boundary condition in a sense. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect “magnetic conductor” on the sides. This viewpoint is quite helpful in examining and comprehending the patch antenna's activity. The electric field inside the patch cavity is virtually z-directed and independent of the z coordinate. As a result, a double index is used to characterize the patch cavity modes (m, n). The electric field of the rectangular patch's (m, n) cavity mode is of the form [3]:

$$E_z(X,y)= A_{mn} \cos\left(\frac{m\pi x}{L}\right)\cos\left(\frac{n\pi y}{W}\right) \tag{1.1}$$

L: the patch length

W: the patch width

4. Types of Patch Antenna:

Microstrip patch antennas come in a variety of shapes, each tailored to a certain set of properties. The most frequent types for millimeter wave frequencies are rectangular, square, and circular patches, which are represented in figure.

Figure 1.2 depicts the most common configurations utilized in practice. Despite the differences in geometrical shape, their radiation characteristics are comparable because they have similar dipoles. Patch antennas, both rectangular and circular, are commonly employed. A patch antenna typically has a gain of 5 to 6 dB and a beam width of 3 dB between 700 and 900. Some of the patch shapes are utilized for unique purposes. Figure1.2 depicts them [8].

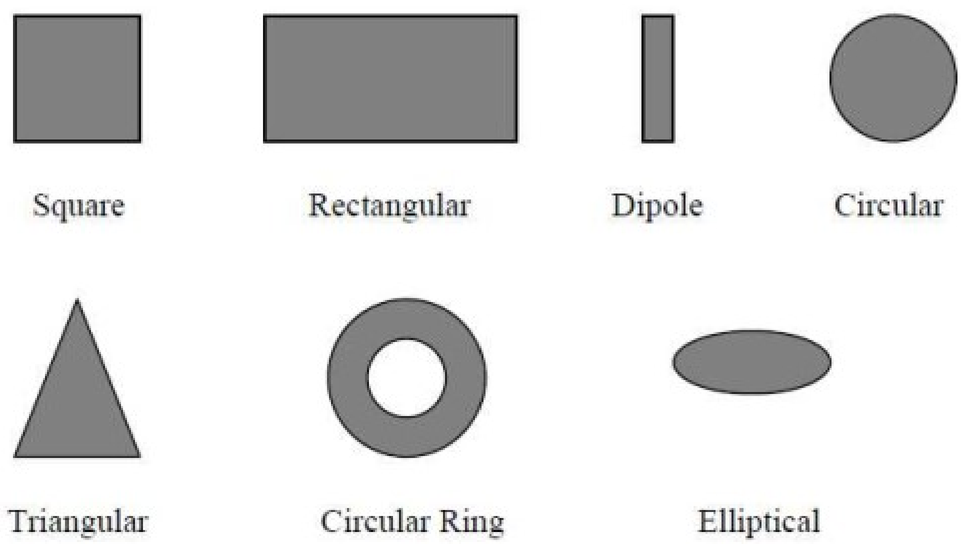


Figure1.2: Common shapes of microstrip patch elements [7].

5. Antenna Characteristics and Properties:

An antenna is a device that is designed to broadcast and receive electromagnetic waves efficiently, characterized by:

5.1. Gain:

The gain is a useful metric for describing an antenna's performance. Although the antenna's gain is closely related to its directivity, it is a metric that considers the antenna's efficiency as well as its directional capabilities. Remember that directivity is a metric that only defines the antenna's directional qualities, hence it is solely influenced by the pattern. An antenna's gain (in a given direction) is defined as "the ratio of the intensity in a given direction to the radiation intensity that would be obtained if the antenna's power was radiated isotropically." The power accepted (input) by the antenna divided by 4π equals the radiation intensity corresponding to the isotropically radiated power." This can be stated mathematically as [9]:

$$\text{Gain} = 4\pi \frac{U(\theta,\varphi)}{\text{Pin}} \tag{1.2}$$

$U(\theta,\varphi)$: radiation intensity.

Pin: total input power.

Gain can also be written in terms of directivity and:

Gain = directivity * efficiency

Gain (dB) = 10log (directivity * efficiency)

5.2. Polarization:

In wave propagation between the transmitting and receiving antennas, polarization is critical. The polarization plane is always perpendicular to the propagation plane because it contains the electric and magnetic field vectors. The wave polarization is described by the contour created by the tip of the electric field vector. This shape is either an ellipse, a circle, or a line. Unless otherwise noted, the polarization direction is considered to be in the direction of the main beam.

5.2.1. Linear Polarization:

Since the electric field only varies in one direction, the fundamental patch is linearly polarized. Depending on the patch's orientation, the polarization can be vertical or horizontal. A For optimal operation, a transmit antenna requires a receiving antenna with the same polarization. When the antenna is turned 90 degrees, the patch produces horizontal polarization. The current is vertically polarized after flowing in the vertical plane.

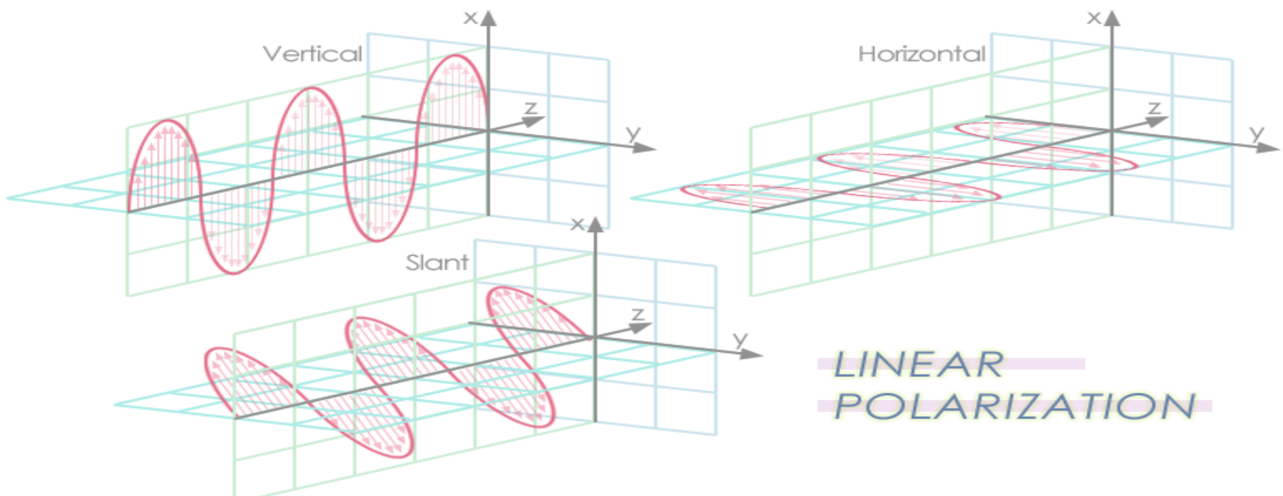


Figure1.3: Linear Polarization [10].

5.2.2. Circular Polarization:

The electric field varies in two orthogonal planes (x and y directions) with the same amplitude and a 90° phase difference in a circular polarized antenna. As a result, two modes, the TM10 mode (mode in the x direction) and the TM01 mode (mode in the y direction), are simultaneously excited (mode in the y direction). With respect to the other mode, one of the modes is excited with a 90° phase delay. We have two types of circular polarization:

- ❖ Right-hand circular polarized (RHCP)
- ❖ Left-hand circular polarized (LHCP)

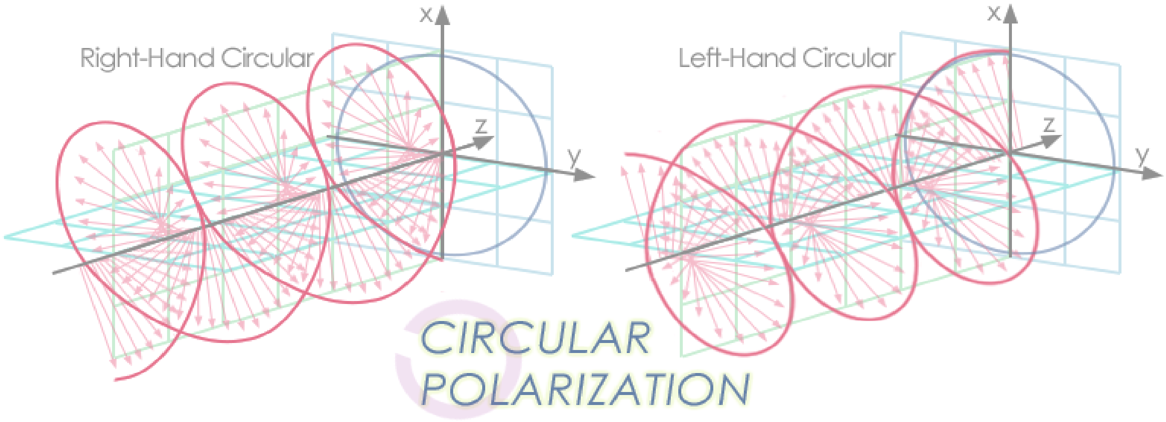


Figure1.4: types of circular polarization [10].

Some steps must be followed in order to get circular polarization:

- Divide the signal into two halves that are equal in size.
- One signal should be fed to a horizontal radiator, while the other should be fed to a vertical radiator.
- One of the signals' phases should be changed by 90 degrees [6].

5.3. Radiation Pattern:

An electric current model or a magnetic current model can be used to calculate the radiation field of the micro strip antenna. The current is directly employed to find the far-field radiation pattern in the electric current model. The (1,0) patch mode's electric current. The pattern can be found directly from image theory if the substrate is ignored (replaced with air) when calculating the radiation pattern. The reciprocity approach can be used to identify the far-field pattern if the substrate is taken into account and considered to be infinite. The equivalence principle is employed in the magnetic current model to replace the patch with a magnetic surface current that flows around the perimeter of the patch [9].

5.4. Directivity:

An antenna's directivity is defined as the ratio of its gain to its loss Radiation intensity from the antenna in a certain direction to the mean radiation intensity in all directions. The total power radiated by the antenna divided by four equals the average radiation intensity. In the event that the Although the direction is not explicitly stated, the maximum radiation intensity is assumed.

D is the non-isotropic source's directivity is the ratio of its radiation intensity in a specific environment in comparison to an isotropic source.

$$D = \frac{U}{U0} = \frac{4\pi U}{Prad} \qquad (1.3)$$

If no direction is supplied, the direction of maximal radiation intensity (maximum directivity) is assumed.

$$Dmax = \frac{Umax}{U0} = \frac{4\pi Umax}{Prad} \qquad (1.4)$$

D = directivity (dimensionless).

Dmax: maximum directivity (dimensionless).

U0: isotropic source's radiation intensity (W/unit solid angle).

U = radiation intensity (W/unit solid angle)

Umax: maximum source's radiation intensity (W/unit solid angle)

Prad: total radiated power (W).

To recapitulate, directivity is a metric that simply defines the antenna's directional qualities, and it is thus only controlled by the pattern [11].

5.5. Antenna Efficiency:

The efficiency of a microstrip element is defined as the power radiated divided by the power received by the element's input. The dielectric loss, conductor loss, reflected power (Voltage Standing Wave Ratio VSWR), cross polarized loss, and power dissipated in any loads in the element are all factors that impact the antenna's efficiency and determine whether it is high or low.

Surface-wave excitation, as well as conductor and dialect riclosses, affect the patch antenna's radiation efficiency, because the patch will excite the grounded substrate's dominant TM0 mode. As the substrate thickness decreases, the effect of the conductor and dielectric losses becomes more severe, limiting the efficiency. On the other hand, as the substrate thickness increases, the surface-wave power increases, thus limiting the efficiency. Surface-wave excitation is undesirable for a variety of reasons, including the fact that it contributes to mutual coupling between array elements and causes undesirable edge diffraction at the edges of the ground plane or substrate, which often leads to pattern distortions and back radiation. There is no surface-wave excitation for an air (or foam) substrate. Higher efficiency is achieved in this scenario by thickening the substrate to reduce conductor and dielectric losses (making the substrate too thick may lead to difficulty in matching,). When the substrate thickness is around λ_0 = 0.02 for a substrate with a modest relative permittivity, such as ε_r = 2.2, the efficiency is at its peak [3].

$$e_r = \frac{P_r}{P_{tot}} = \frac{P_r}{P_r + (P_c + P_d + P_{sw})} \tag{1.5}$$

P_r : radiated power.

P_{tot}: total input power.

P_c : power dissipated by conductors.

P_d : power dissipated by dielectric.

P_{sw} : power launched into surface wave.

5.6. Band Width:

An antenna's bandwidth is described as "the frequency range over which the antenna's performance, in terms of some attribute, complies to a set standard." The bandwidth is the range of frequencies on either side of a center frequency (usually the dipole's resonance frequency) where the antenna characteristics (such as input impedance, pattern, beamwidth, polarization, side lobe level, gain, beam direction, and radiation efficiency) are within an acceptable range of those at the center frequency. The bandwidth of a broadband antenna is commonly represented as the ratio of acceptable upper-to-lower frequencies. A 10:1 bandwidth, for example, means that the highest frequency is 10 times higher than the lower. The bandwidth of narrowband antennas is stated as a percentage of the frequency difference (upper minus lower) over the bandwidth's center frequency. A 5 percent bandwidth, for example, means that the permissible frequency difference is 5 percent of the bandwidth's center frequency. The return loss or voltage standing wave ratio can be used to define the bandwidth (VSWR). VSWR2 or return loss (S11 in dB) -10db are common values for tiny strip antennas. In addition, the BW is inversely proportional to the quality factor (Q) and is calculated as.

It's crucial to understand that bandwidth can be defined in a variety of ways.

- **Impedance Bandwidth/Return Loss Bandwidth:**

This is the frequency range in which the structure has usable bandwidth when compared to a specific impedance, which is usually 50Ω.

The impedance bandwidth is determined by a number of factors, including the quality factor of the patch antenna element and the type of feed used. The plot below shows the return loss of a patch antenna and indicates the return loss bandwidth at the desired S11/VSWR (S11 wanted/VSWR wanted). The bandwidth is typically limited to a few \percent. This is the major disadvantage of basic patch antennas.

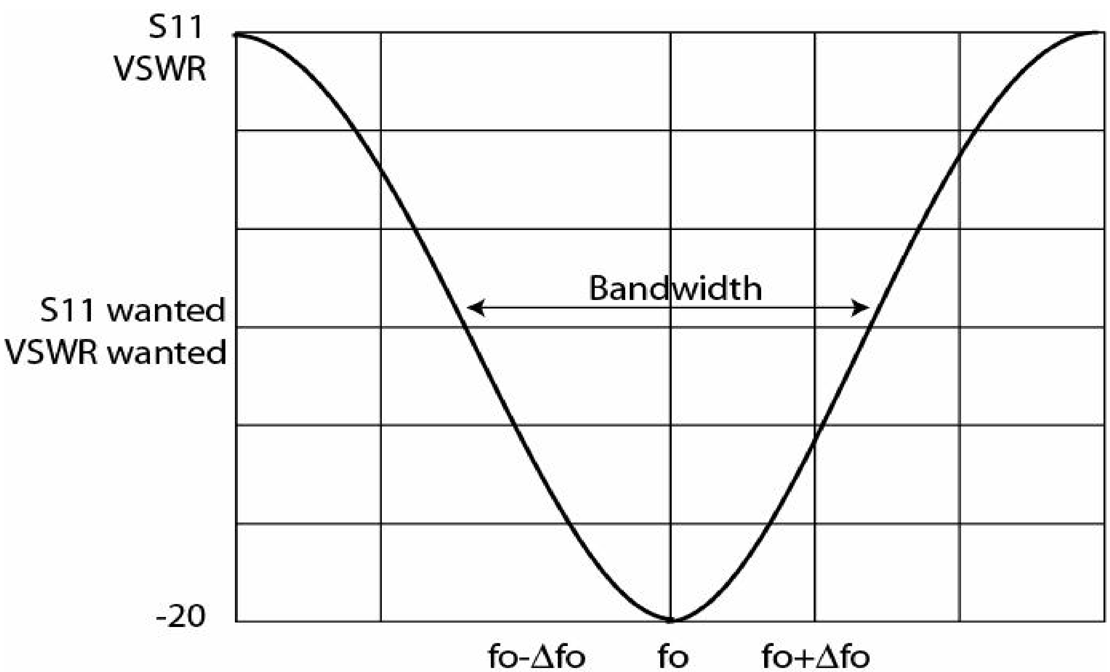


Figure 1.5: Impedance bandwidth definition [6].

- **Directivity/Gain Bandwidth:** This is the frequency range in which the antenna meets the required directivity/gain (e.g., 1 dB gain flatness).
- **Efficiency Bandwidth:** This is the frequency range in which the antenna has appropriate radiation/total efficiency (application dependent).

- **Axial Ratio Bandwidth:** This number expresses the quality of an antenna's circular polarization and is related to the polarization bandwidth [6].

5.7. Input Impedance:

Za is the impedance of an antenna at its terminals, or the voltage to current ratio at a pair of terminals, or the ratio of the appropriate components of the electric and magnetic fields at a given position.

$$Za = Ra + jXa \tag{1.6}$$

Ra: the resistance at antenna terminals.

Xa: the reactance at antenna terminals.

Additionally, the real parte of Za is made up of two parts:

$$Ra = Rr + RL \tag{1.7}$$

Rr: the radiation resistance.

Rl: the loss resistance of the antenna [11].

5.8. Return Loss RL:

This was initially used to measure the "echo" on various bidirectional circuits and lines in the telephone business. It's just the logarithmic scale the ratio of input power's relative magnitudes as well as reflected power.

$$\text{RL (dB)} = 10 \log_{10}\left(\frac{\text{Pin}}{\text{Pref}}\right) = -20 \log_{10}\left(\frac{\text{Er}}{\text{Ei}}\right) = -20 \log\left|\frac{Z_L - Z_S}{Z_L + Z_S}\right| \tag{1.8}$$

Pin: Incident power [watt].

Pref: reflected power [watt].

Er: incident electric field.

Ei: reflected electric field.

Z_L : Load impedance.

Z_S : Transmission line characteristic impedance.

The term "loss" was included in the original title of this parameter because reflected power cannot exceed input power. As a result, Pref< Pin and RL are both positive numbers [12].

5.9. Voltage Standing Wave Ration VSWR:

The voltage standing wave ratio, or VSWR, is a method of detecting transmission line flaws. Also referred as is the frequency range within which it is matched to the feed line within prescribed limits [13].

6. Feeding Methods:

A variety of methods can be used to power microstrip patch antennas. These methods are divided into two types: contacting and non-contacting. The RF power is fed directly to the radiating patch using a connecting element such as a microstrip line in the contacting method. Electromagnetic field coupling is used in the non-contacting scheme to transfer power between the microstrip line and the radiating patch [3]. The different feeding methods is as follows:

6.1. Microstrip Line Feed:

The microstrip feed line is a simple conducting strip attached directly to the edge of the patch that is smaller in dimension than the patch as shown in Fig (1.6(a)). It is one of the simpler methods to construct. It's pretty simple to model, and you may do it simply adjusting the inset position. The disadvantage of this approach is that as the thickness of the substrate increases, the amount of spurious radiation increases, limiting the bandwidth (typically 2-5 percent) [14]. Controlling the length and width of the patch allows for perfect matching [4].

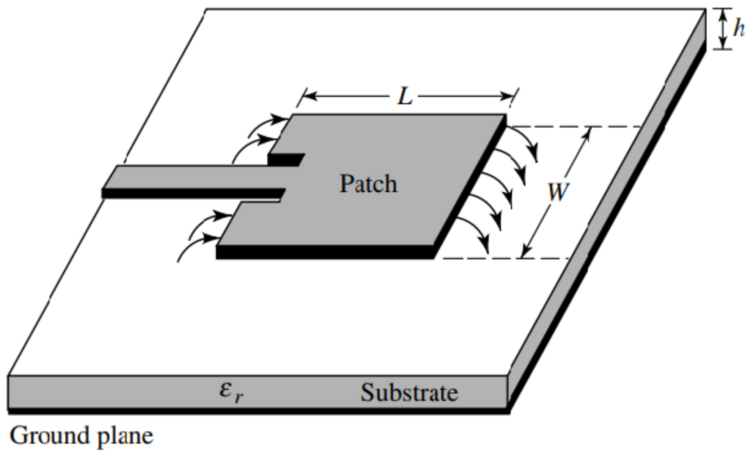


Figure1.6(a): Typical feed for microstrip antennas (Microstrip line feed) [14].

6.2. Coaxial Coupled Feed:

This is one of the most popular and widely used feeding techniques in microstrip patch antenna [2]. where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane, are also widely used Fig (1.6(b)). Coaxial probe feed is easy to fabricate and match but more difficult to model, and it has low spurious radiation. The main advantage of the coaxial probe feed method is that feed can be placed at any desired location in order to match the input impedance. And its disadvantages are narrow bandwidth, difficult to model especially for a thick substrate (h > 0.02λ0) [13].

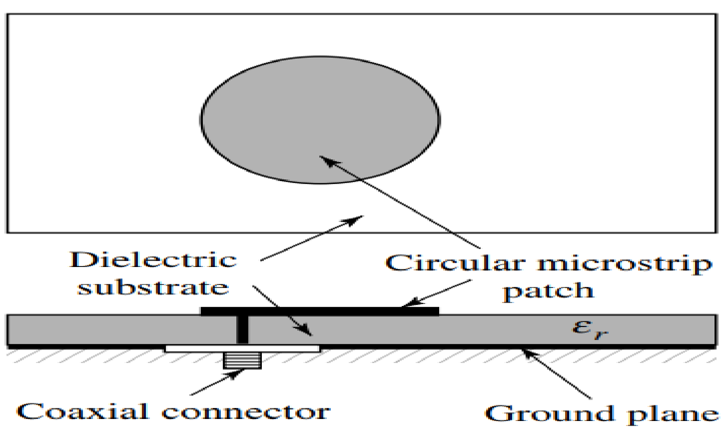


Figure 1.6 (b) : Typical feed for microstrip antennas (Probe feed) [14].

6.3.Aperture Coupled Feed:

The aperture coupling is a non-contacting type of feeding method, it is the most difficult of all four to fabricate and it also has narrow bandwidth. The patch's radiation is separated from the feed line's radiation. The two dielectrics shown in Fig (1.6(c)) are required for the basic design of a microstrip patch antenna with this type of feed. The substrate, the thickness of which can be varied and optimized for different frequencies. The advantage of this antenna is that it has low spurious radiations, a wider bandwidth, and is less susceptible to interference. To optimize radiations from the patch, a lower dielectric constant material is typically used for the upper substrate and a comparatively higher dielectric constant material for the lower substrate [2].

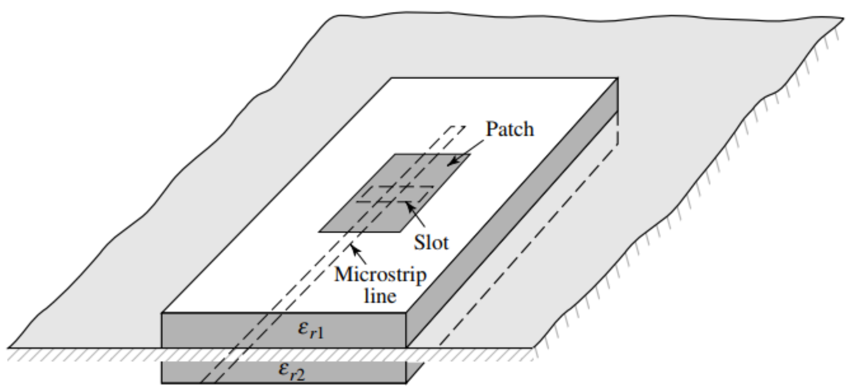


Figure 1.6(c): Typical feed for microstrip antenna (Aperture Coupled Feed) [14].

6.4. Proximity Coupling:

Electromagnetic coupling is often referred to as proximity coupling. The feed line as shown in Fig (1.6(d)) is placed between the patch and the ground plane which is separated by two dielectric media. The benefits of this feed configuration include the elimination of spurious feed network radiation, the option of using two distinct dielectric media, one for patch and another for the fed line, to optimize individual performance, and a 13 percent increase in bandwidth due to an increase in the overall Microstrip antenna substrate thickness. The main drawback of this feed method is that it is difficult to manufacture due to the two dielectric layers that must be properly aligned. In addition, the total thickness of the antenna has increased [14].

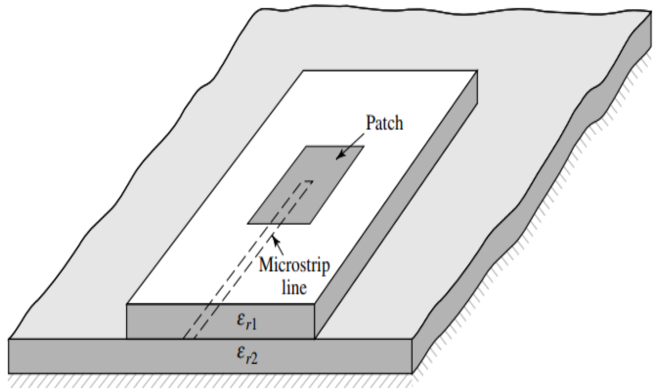


Figure 1.6(d): Typical feed for microstrip antenna (Proximity Coupling) [14].

In the diagram below, Fig 1.7, one set of equivalent circuits for each of the above feeds techniques is presented.

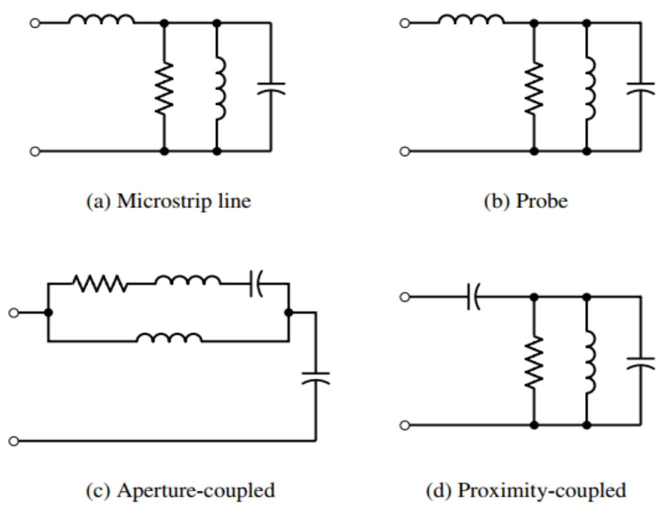


Figure 1.7: Equivalent circuits for typical feeds of Fig 6 [14].

All the above discussed types of feeding techniques are summarized in the Table I.

	Microstrip Line Feed	Coaxial feed	Aperture Coupled feed	Proximity coupled Feed
Spurious Feed Radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Fabrication	Easy	Requires soldering and drilling	Requires Alignment	Requires Alignment
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (with impedance matching)	2-5%	2-5%	2-5%	13%

Table 1.1: Comparison of feeding techniques [7].

7. Methods of Analysis:

The transmission line model, cavity model, and full wave model (which incorporate predominantly integral equations/Moment Method) are the preferred models for the analysis of microstrip patch antennas [3].

7.1. Transmission Line Model:

The transmission line model is the simplest and provides the most physical insights, but it is also the least accurate and a microstrip antenna is represented using two slots of height **h** and width **W** that is separated by a line of transmission of a certain length **L**. From figure 1.8 some of the field lines are in the air while the majority pass through the dielectric substrate [3].

Although the transmission line model is easy to use, it does have certain drawbacks. all types of configurations cannot be analyzed using this model since it does not take care of variation of field in the orthogonal direction to the direction of propagation. It is particularly helpful for rectangular patches and ignores field differences along radiating edges [15].

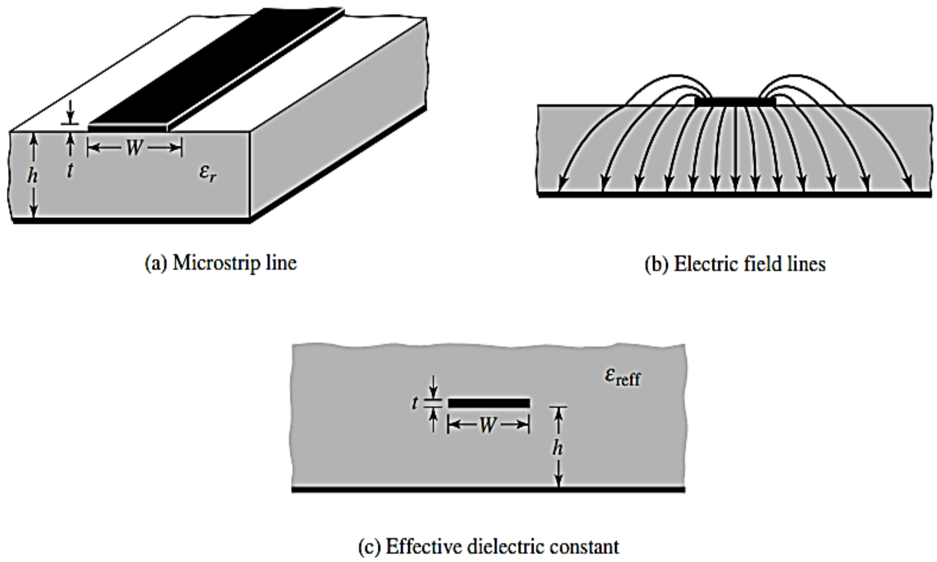


Figure 1.8: Microstrip line and its electric field lines, and effective dielectric constant geometry [14].

As a result, this transmission line cannot support pure transverse electric magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. For this case the mode of transmission is quasi transverse electric mode. As a result, an effective dielectric constant (ε_{reff}) must be calculated to account for fringing and wave propagation in the line, the effective dielectric constant is calculated Usually the ε_r is [3]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \qquad (1.9)$$

ε_{reff} = Effective dielectric constant.
ε_r = Dielectric constant of substrate.
h = Height of dielectric substrate.
W = Width of the patch

The value of $\boldsymbol{\varepsilon_{reff}}$ is slightly less then εr because the fringaing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 1.8 above [16].

For it to work in the fundamental TM10 mode, the length must be smaller than λ/2. is given by equation 1.10

$$\lambda = \lambda_0 / \sqrt{\varepsilon_{reff}} \tag{1.10}$$

λ = the wavelength in the dielectric medium

λ_0 = the free space wavelength

7.2. Cavity Model:

The cavity model presents a mathematical solution for the electric and magnetic fields of a designed microstrip antenna that is surrounded by magnetic walls on all sides and electric walls on the top and bottom Figure 1.9 shown. Because thin substrates are employed, the field inside the cavity is homogeneous along its thickness. The area between the ground plane and the patch is referred to as the cavity. Lo et al. presented this paradigm (1979). The fields underneath the patch for regular forms such as rectangular and circular shapes may be described as a sum of the two-dimensional resonator's numerous resonant modes [17][15].

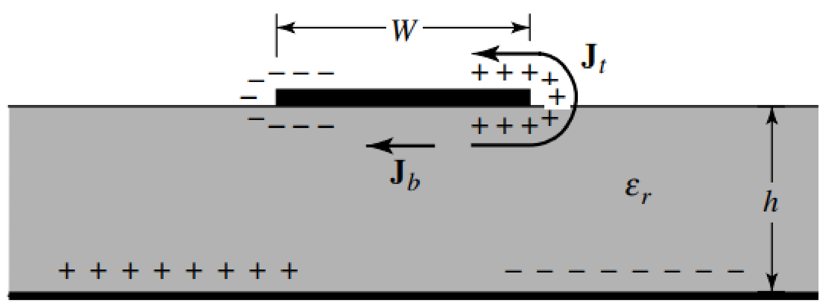


Figure 1.9: Charge distribution and current density creation on the microstrip patch[14].

7.2.1. Cavity Model for Circular Patch:

The cavity model, which is performed using cylindrical coordinates, is used to study a circular patch (Balanis, 1989). To estimate the electric and magnetic fields within the cavity of a circular patch antenna, the vector potential technique is employed Figure 1.9(a) shown. The magnetic vector potential Az is utilized for TMz, a major mode supported by a circular patch antenna where z is perpendicular to the patch, and it must satisfy the cylindrical circumference. Equation 1.11 is a homogeneous equation that takes into account the patch antenna's radial and border dimensions [17].

$$\nabla^2 A_z \rho, \emptyset, z + k^2 A_z \rho, \emptyset, z = 0 \quad (1.11)$$

k: is the wave number with respect to $\rho, \emptyset, z$ directions.

Which is solved using cylinder coordinates:

$$\frac{1}{\rho}\frac{\partial}{\partial\rho}\,\partial\frac{\partial A_z}{\partial\,\partial} + \frac{1}{\rho^2}\frac{\partial^2 A_z}{\partial\emptyset^2} + \frac{\partial^2 A_z}{\partial Z^2} + k^2 A_z = 0 \quad (1.12)$$

Using variables separation approach, equation 1.13 becomes.

$$k_\rho^2 + k_z^2 = k_r^2 = \omega_r^2 \mu\varepsilon \quad (1.13)$$

It may be demonstrated in TMz modes where the electric and magnetic fields are related to the potential Az (Balanis, 1997) [17].

$$E_\rho = -j\frac{1}{\omega\mu\varepsilon}\frac{\partial^3 A_z}{\partial_\rho \partial_z} \qquad H_\rho = \frac{1}{\mu}\frac{1}{\rho}\frac{\partial A_z}{\partial\emptyset} \quad (1.14)$$

$$E_\emptyset = -j\frac{1}{\omega\mu\varepsilon}\frac{\partial^3 A_z}{\partial_\rho \partial_z} \qquad H_\emptyset = -\frac{1}{\mu}\frac{\partial A_z}{\partial z} \quad (1.15)$$

$$E_z = -j\frac{1}{\omega\mu\varepsilon}\frac{\partial^2}{\partial z^2} + k^2 A_z \qquad H_z = 0 \quad (1.16)$$

The resonant frequency is determined by equation 1.17 when the fringing field is considered.

$$f = \frac{1.8412\, C}{2\pi a_e \sqrt{\mu_0 \varepsilon_r}} \quad (1.17)$$

f: is the resonant frequency, is the permeability of free space.

c: is the speed of light in free space.

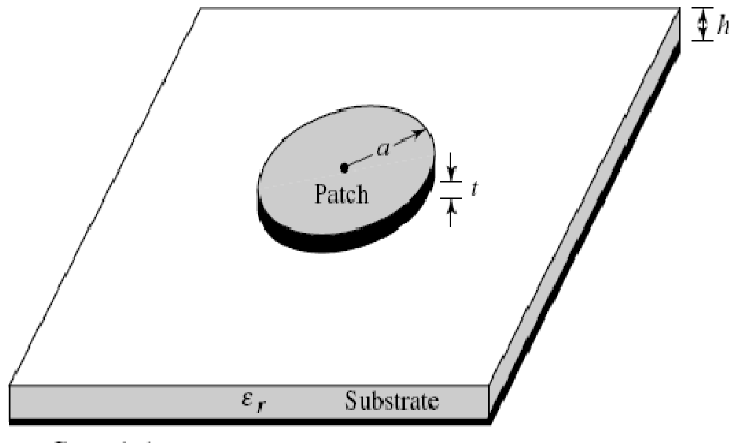


Figure 1.9(a): Circular patch antenna [14].

7.2.2. Cavity Model for Rectangular Patch:

Referring to Figure 1.9(b) the volume underneath the patch may be thought of as a rectangular cavity filled with a dielectric substance having a dielectric constant of Ir. The substrate's dielectric material is considered to be truncated and does not extend beyond the patch's boundaries. The homogeneous wave equation of must be satisfied by the vector potential Ax [17].

$$\nabla^2 A_x + k^2 A_x = 0 \quad (1.18)$$

whose answer is expressed in general, using variable separation, as:

$$\frac{\partial^2 A_x}{\partial x^2} + \frac{\partial^2 A_x}{\partial y^2} + \frac{\partial^2 A_x}{\partial z^2} + k^2 A_x = 0 \quad (1.19)$$

The Eigen equation is transformed using the variable separation approach:

$$k_x^2 + k_y^2 + k_z^2 = k^2 \quad (1.20)$$

At x = 0 and x = h, the tangential E-field components must disappear, implying that $E_Y = E_Z$:

$$E_x = \frac{1}{j\omega\mu\varepsilon}\frac{\partial^2 A_x}{\partial x^2} + k^2 A_x \ , \ E_y = \frac{1}{j\omega\mu\varepsilon}\frac{\partial^2 A_x}{\partial x \partial y} \ , \ E_z = \frac{1}{j\omega\mu\varepsilon}\frac{\partial^2 A_z}{\partial x \partial z} \quad (1.21)$$

Set a vanishing normal derivative for Ax on all sides, as well as at the top and bottom:

$$\frac{\partial A_x}{\partial x}_{x=0,h} = 0 \ , \ \frac{\partial A_x}{\partial x}_{z=0,h} = 0 \ , \ \frac{\partial A_x}{\partial y}_{y=0,h} = 0 \quad (1.22)$$

In the vanishing of Hy and Hx at z = 0 and z = L as well as vanishing Hz and Hx at y = 0 and y=w that is magnetic walls as follows from the relation between H- field and Ax:

$$H_x = 0 \quad , \; H_y = \frac{1}{\mu}\frac{\partial A_x}{\partial z} \quad , \quad H_z = \frac{1}{\mu}\frac{\partial A_x}{\partial y} \qquad (1.23)$$

The dominant mode has the lowest frequency. Because equation 1.24 gives the lowest frequency mode:

$$f_r = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\frac{\pi}{L}\frac{c}{2L\sqrt{\varepsilon_r}} \qquad (1.24)$$

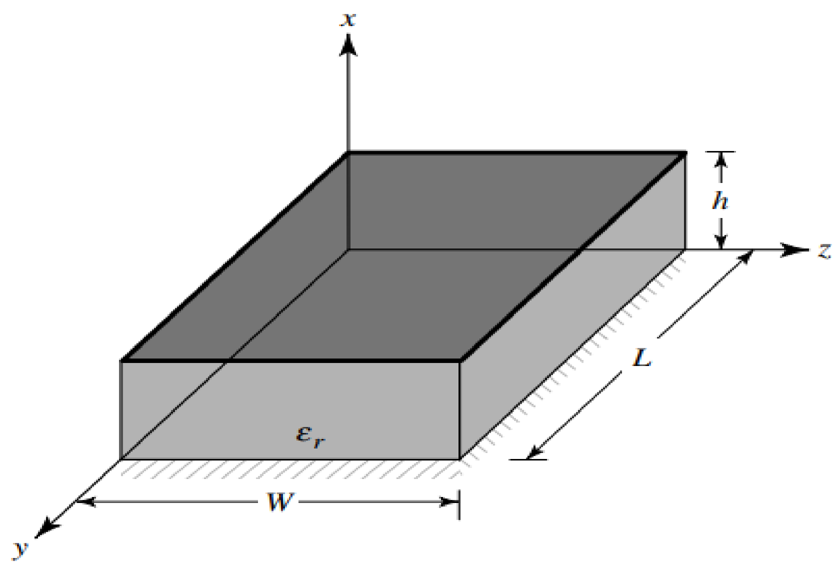


Figure 1.9(b): Rectangular microstrip patch [14].

7.3. Full Wave Analyses:

Full-wave analyses produce the most accurate findings since they apply Maxwell's Equations to the situation at hand and then confirm that the structure's boundary conditions are met. Full-wave analysis approaches are classified into two groups based on how Maxwell's equations are solved: differentially or by integrating. The Integral Equation technique is the most mature of the full wave analysis approaches, with the Spectral Domain formulation and the Spatial Domain formulation both being used to forecast the performance of a microstrip patch antenna since the early 1980s. Using both approaches, extremely excellent agreement between theory and experiment has been established over the years, and the degree of accuracy actually relies on how the programmer wishes to express the structure to be investigated. The first issue with employing Integral Equation techniques was the lengthy computing time necessary to solve the antenna in question. However, the speed of today's computers has remedied this problem [1].

Differential full-wave studies on microstrip patch antennas have been used since the late 1980s. The first approach was the Finite Difference Time Domain method, which was followed by the Finite Element Method. Initially, both suffered from unnecessarily long processing times; nonetheless, both methodologies enabled a more accurate simulation of the patch antenna's surrounding environment. Was the patch, for example, in a hollow or on a little handset? If so, unlike the earlier Integral Equation approaches, which often required the approximation that the ground-plane and substrate extended endlessly in the horizontal plane, modern processes may address such a problem [1].

8. Advantages and Disadvantages:

The microstrip antenna has both advantages and downsides. By thoroughly comprehending them, it is simple to build a microstrip antenna with maximum efficiency, little risk, and cheaper cost for a specific application [7].

8.1. Advantages:

Some of their principal advantages are given below [18]:

- Low volume and light weight.
- Low profile planar configuration which can be easily conformed to the host surface.
- It can be manufactured in large quantities, Because of the low cost of production.
- Both linear and circular polarization are supported.
- Microwave integrated circuits can be simply integrated (MICs).
- Dual and triple frequency operations are possible.
- When installed on hard surfaces, it is mechanically robust.

8.2. Disadvantages:

Microstrip patch antennas have more drawbacks than conventional antennas. Some of their major disadvantages are given below [18]:

- Narrow bandwidth
- Low efficiency
- Low Gain

- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity

9. Application:

Microstrip patch antennas are well known for their performance, robust design, fabrication, and wide application. The advantages of this Microstrip patch antenna are to overcome their disadvantages such as easy design, light weight, and so on. The applications are in a variety of fields such as medical applications, satellites, and of course military systems such as rockets, aircrafts, missiles, and so on. The usage of the Microstrip antennas is spreading widely in all fields and areas and is now booming in the commercial aspects due to their low cost of the suction. It is also expected that the increasing use of patch antennas in a wide range will supplant the use of conventional antennas for the majority of applications. There are numerous applications for microstrip patch antennas. Some of these applications are as follows [18]:

❖ **Satellite Communication Application:**

Although microstrip patches were used in satellite systems early on, it wasn't until the early 1990s that this type of printed antenna was to be used as the ‘main mission' antenna in satellite communication services. The Iridium communication system was a prime example of this. Although this system is no longer operational, it permitted numerous

significant advances in communication technologies, including the ability to construct a network of microstrip patch antennas capable of meeting the bandwidth and radiation performance required to make the technology practical. Microstrip patch elements are presently used (or are being considered for use) in the majority of satellite communication antennas. Figure 1.10 shows a shows a Iridium main mission printed antenna [18].

Figure 1.10: Iridium main mission printed antenna [19].

- **Global Positioning System Applications:**

Microstrip patch antenna for GPS use a microstrip patch GPS antenna that is thinner and less expensive than the thick ceramic patch antenna commonly used in automotive applications was proposed and tested. This configuration enables the easy integration of a low noise amplifier on the feeding circuitry's substrate. A gain reduction of about 1.5 D bias was observed when comparing a microstrip patch GPS antenna to a thicker high permittivity ceramic patch solution. The use of the quadrature feeding permits a better purity of the circular polarization and a wider impedance bandwidth allowing reducing the environment dependence with respect to ceramic antennas. Ceramic patches, on the other hand, are less sensitive to windscreen closeness due to their high permittivity substrate and, as a result, their smaller dimensions [18]. Consider Figure 1.11 shown:

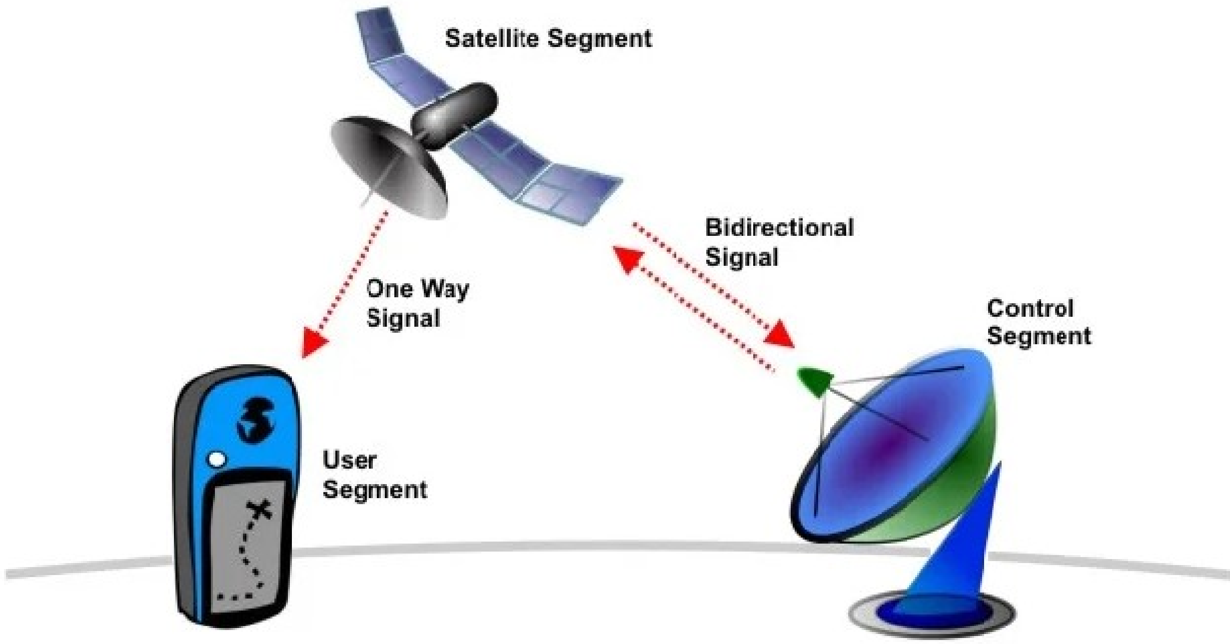


Figure 1.11: Global positioning system applications [20].

- **Worldwide Interoperability for Microwave Access (WiMAX):**

WiMAX refers to the IEEE 802.16 standard. It has a theoretical range of up to 30 miles and a data rate of 70 Mbps. MPA produces three resonant modes at 2.7, 3.3, and 5.3 GHz and can thus be used in WiMAX-compliant communication equipment [18]. Consider Figure 1.12 shown:

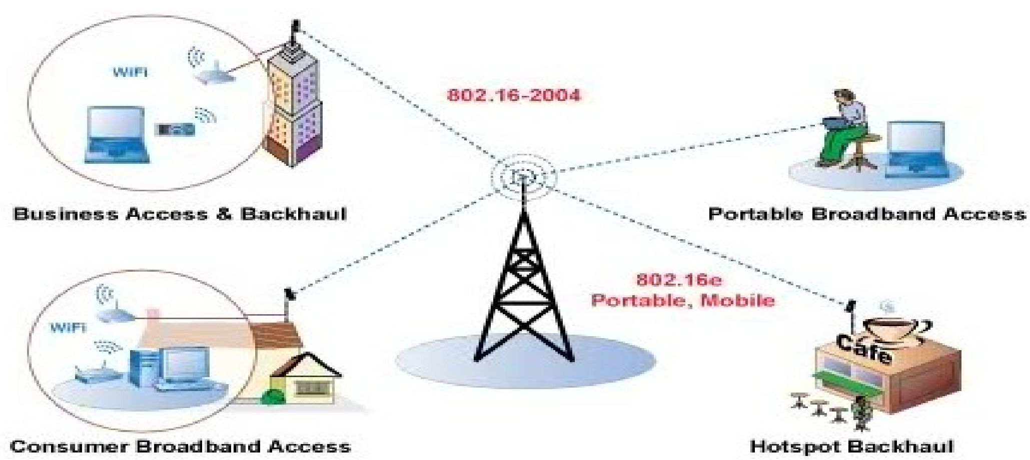


Figure1.12: Worldwide interoperability for microwave access (WiMAX) [21].

❖ **Radar Application:**

(Fixed frequency low bandwidth Radar and low-cost detection systems): Radar can detect moving targets, such as people and vehicles. Most early uses of the microstrip patch antenna took advantage of its distinguishing properties, particularly its tiny size and cheap production cost. Of course, the applications were often not mainstream (communication systems) since the inherent limitations (the most convincing being the extremely restricted bandwidth) would prevent them from being deployed in more common systems. Fixed frequency/low bandwidth radar applications were instances of where microstrip patch technology might be easily integrated. Several spacebome systems have been deployed to monitor environmental concerns on Earth, with microstrip patches serving as the primary radiator. The lightweight nature of printed antenna technology proved extremely beneficial in terms of decreasing the payload of the launched satellites. Figure 1.13 depicts a microwave patch array utilized in this application [18].

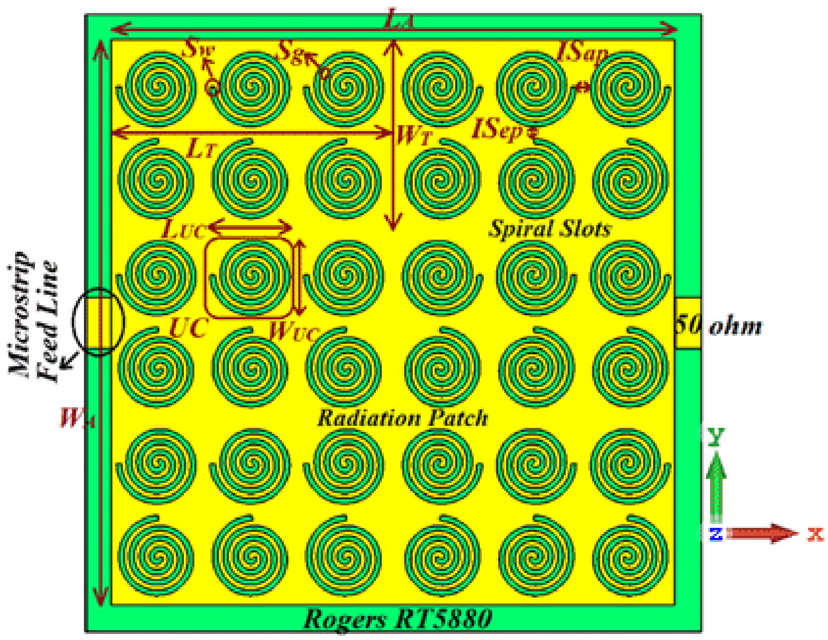


Figure 1.13: Example of microstrip patch array used for SAR applications [22].

Microstrip patch arrays have lately been used to construct low-cost motion detection and tagging systems. These systems do not require enormous bandwidths, and the most essential consideration is likely to be keeping development costs low. Patch antennas are a natural choice since microstrip technology allows the antenna to be readily integrated with the feed network and any active devices (surface mount oscillators, mixers, and detectors). Furthermore, because these systems typically operate in the intermediate microwave frequency ranges (5 GHz - 10 GHz), the total diameters of these antennas are fairly tiny, however numerous millimeter-wave printed antennas have been created for collision avoidance systems. Figure 1.14 microstrip patch array for collision avoidance system [18].

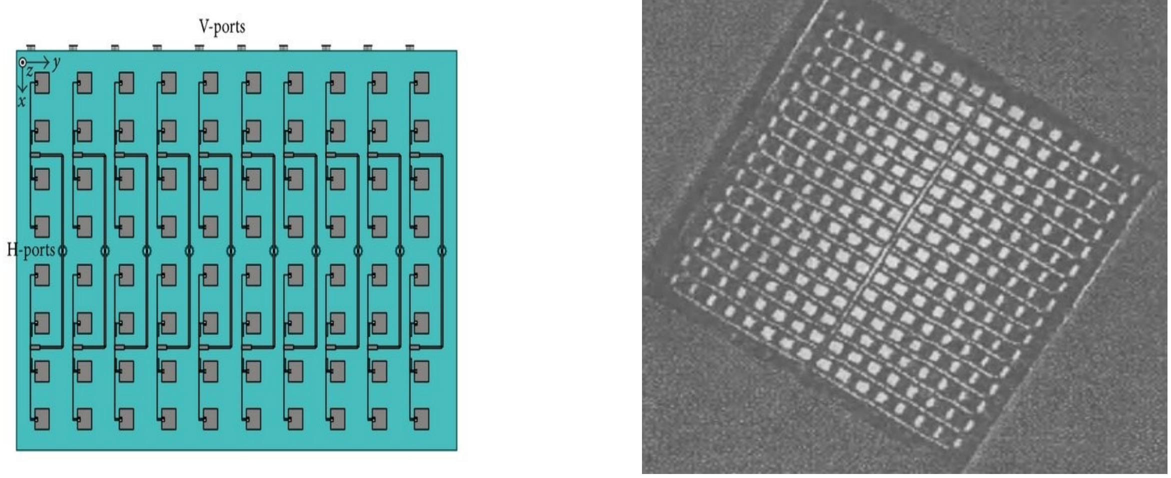


Figure 1.14: Microstrip patch array for collision avoidance system [18].

❖ **Telemedicine Application:**

The antenna in the telemedicine application operates at 2.45 GHz. Wearable microstrip antennas are appropriate for Wireless Body Area Networks (WBAN). The proposed antenna outperformed the other antennas in terms of gain and front to back ratio, as well as the semi-directional radiation pattern, which is preferred over the omni-directional pattern to avoid unnecessary radiation to the user's body and meets the requirements for on-body and off-body applications. An antenna with a gain of 6.7 dB, an F/B ratio of 11.7 dB, and a resonance frequency of 2.45GHz is appropriate for telemedicine applications [15]. A photograph of a A Wireless Body Area Network (WBAN) is shown in Figure 1.15.

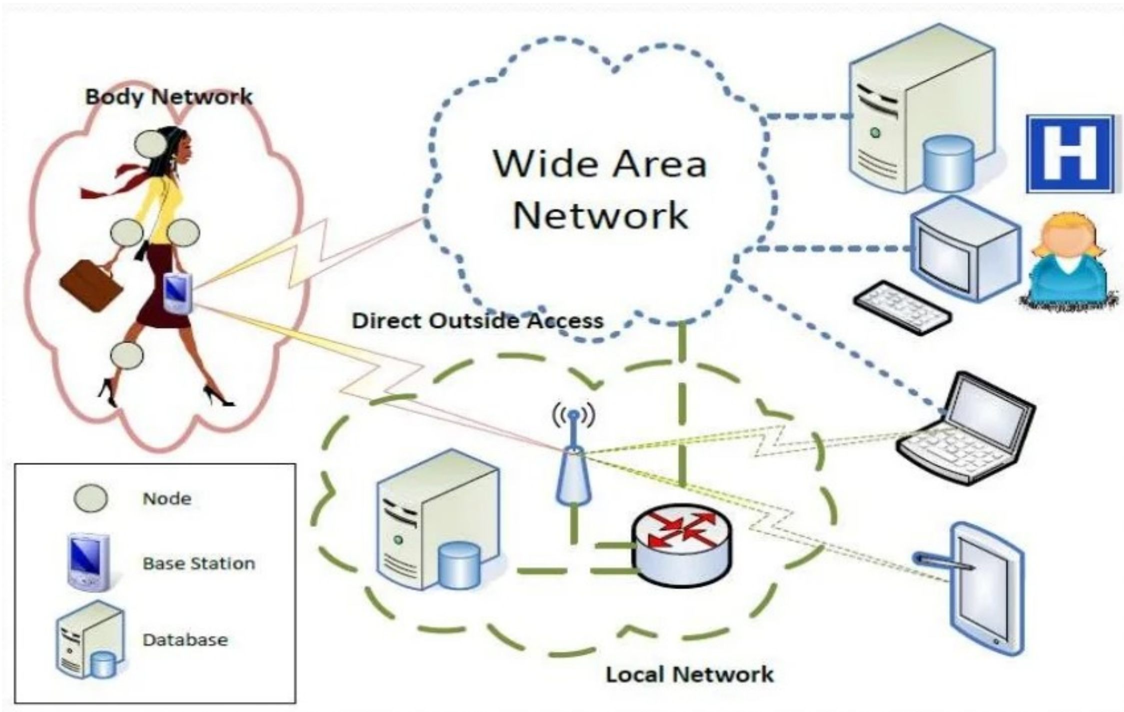


Figure 1.15: A Wireless Body Area Network **(**WBAN) [23].

❖ **Mobile Communication Base Stations:**

One of the most prevalent applications for microstrip patches nowadays is in mobile communication base stations. Similarly, to satellite communication systems, a form of the microstrip patch antenna has only lately, since the mid to late 1990s, been able to meet the strict criteria of a base station terminal. There are now a number of microstrip patches utilized for this purpose that have been conceived and produced by various businesses. Each strategy has its own unique characteristics, yet they all produce roughly the same performance. There are probably as many wire antenna solutions as patch antenna variants for mobile systems operating at close to 900 MHz Microstrip patch base station terminals, on the other hand, are far more common in higher frequency systems, such as 30. Figure 1.16 is an image of mobile communications base station antenna [18].

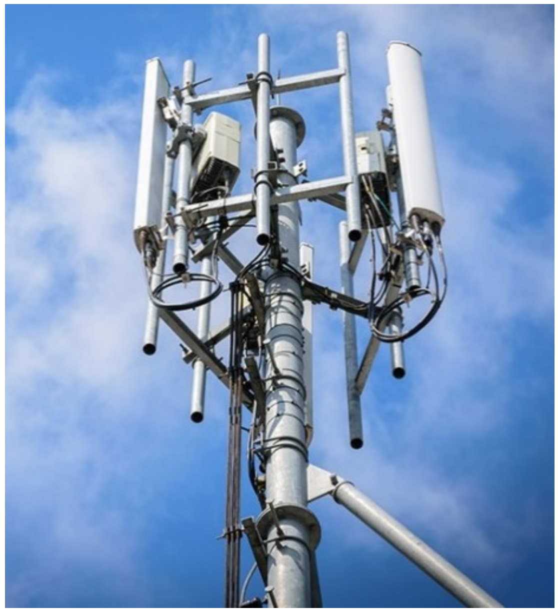


Figure 1.16 : Mobile communications base station antenna [24].

❖ **Medicinal Applications of Patch:**

Microwave energy is said to be the most effective way of inducing hyperthermia in the treatment of malignant tumors. The design of the specific radiator that will be used for this purpose should be light in weight, easy to handle, and rugged. Only the patch radiator meets these specifications. The instrument performs a simple operation in which two coupled Microstrip lines are separated by a flexible separation and used to measure the temperature inside the human body. The figure 1.17 below depicts a flexible patch applicator that operates [18].

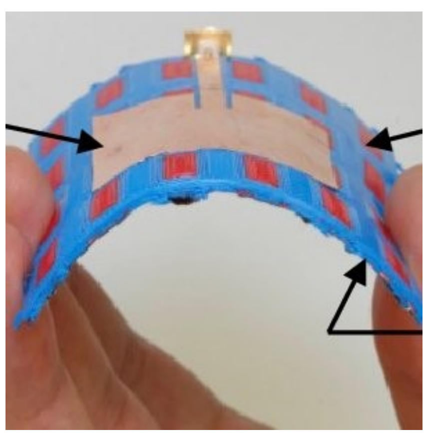


Figure 1.17: Flexible microstrip patch antenna [25].

10.Conclusion:

In this chapter a miniaturized, a microstrip patch antenna is investigated and its radio electric properties at a precise frequency including return loss, VSWR, radiation pattern and current distribution are simulated and discussed. We comprehend the patch antenna setup application feeding techniques, as well as their advantages and disadvantages. Aside from the ones mentioned above, there are several more design possibilities and patch antenna implementations available.

1. Introduction :

Telemedicine literally translates to "medicine at a distance". New advances in medical imaging, sensing, and wireless data transmission technologies are making it possible for telemedicine to offer healthcare at a distance with cheaper cost than before, enabling the creation of new extensive remote medicine projects [26]. One of the most important innovations in telemedicine is the antenna that have lately gained popularity and importance in biomedical telemetry applications and the medical field via wireless communication. It improves people's living standards by allowing them to live a more comfortable life in the domain of health through technological advancements; Since the first pacemakers were implanted in the early 1960s, implantable medical equipment have grown increasingly for healthcare services. Millions of people throughout the world rely on Telemedicine (or wireless medicine) to help them live better lives [27].

Microstrip (patch) antennas are a result of contemporary developments in medical and communication systems, it utilized to transfer biological data from within the human body tissues to an external receiver through wireless transmission [27], which focus on low-cost, low-profile antennas that provide great performance over a wide frequency range. Since the microstrip antenna's creation, the need for its use has increased dramatically, especially in the previous two decades in order to monitor patients in rural areas and give improved healthcare by transmitting physiological and pathology informations via wireless [28] [29].

However, designing antennas for implanted devices is a difficult issue. Small, low-profile, and multiband antennas are required. Antennas must also work in difficult conditions. In the design process, factors like small size, low power requirement, and impedance matching play a big role. There have been several antennas suggested for implanted medical devices [30].

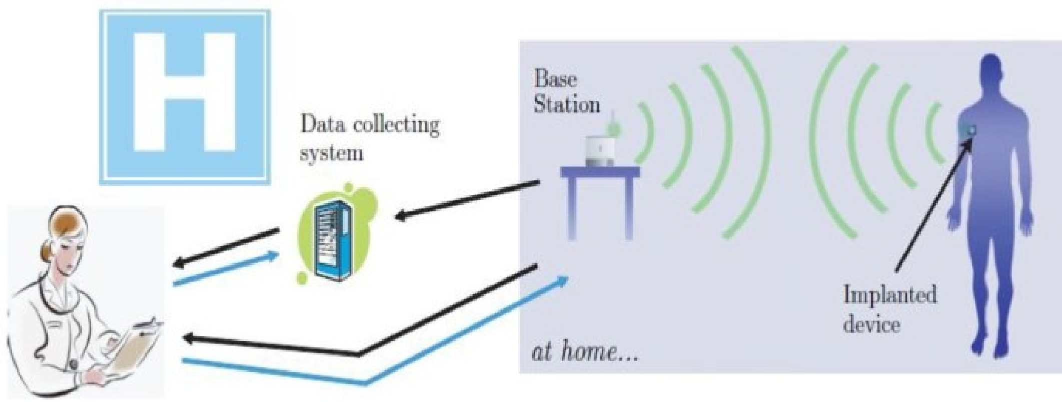


Figure 2.1: Remote healthcare using implantable devices [31].

2. Wireless Technology:

In the healthcare field, wireless adoption is strong and predicted to continue to rise. Broadband wireless technology has made it feasible to create telemedicine services that were previously only available through cable connections. Rural areas or disaster-stricken communities can benefit from advanced medical care that unable to be reached by cable connections by cable connections in a fraction of the time and at a fraction of the cost. Wireless telemedicine is very useful in locations where cable connections are not available or in locations where cable connections are difficult to install, expensive, or impossible in some cases. The table below lists the various wireless technologies utilized in telemedicine [26].

Type	Sub-type	Frequency band	Data transfer rate
GSM	GSM-900	900MHZ	9.6-43.3 kbps
	GSM-1800	1800MHZ	9.6-43.3 kbps
	GSM-1900	1900MHZ	9.6-43.3 kbps
GPRS	GPRS	900/1800/1900MHZ	171.2kbps
Wireless LAN	IEEE 802.11a	5GHz	20Mbps
	IEEE 802.11b	2.4GHz	11Mbps
	Hiperlan1	5GHz	20Mbps
	Hiperlan2	5GHz	54Mbps
	Bluetooth	2.4GHz	723.2Mbps
Satellite	ICO	C,S band	2.4kbps
	Globalstar	L,S,C band	7.2kbps
	Iridium	L,Ka band	2.4kbps
	Cyberstar	Ku,Ka band	400kbps-30Mbps
	Celestri	Ka bandand 40-50GHz	155Mbps
	Teledesic	Ka band	16kbps-64Mbps
	Skybridge	Ku band	16kbps-2Mbps

Table 2.1: Different wireless technology for telemedicine [26].

3. Implantable Devices and Biomedical Applications:

There are many uses of implantable antennas in the medical field, among them:

- **Implant Antenna for Blood Pressure Measurement:**

Patients can have a stroke or develop serious cardiovascular disease if their blood pressure falls and rises often, therefore an exact blood pressure estimation is essential to help medical workers in treating a variety of diseases linked to blood pressure. The use of an implanted antenna system placed inside the heart to detect blood pressure will be an ideal option for heart patient observing [32].

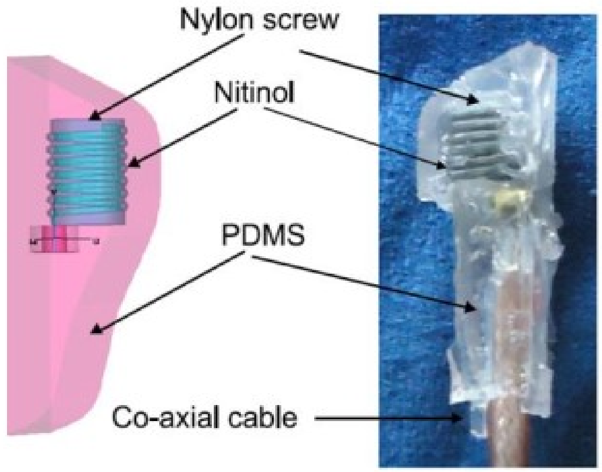


Figure 2.2: Snapshot of implant antenna for blood pressure measurement [32].

- **Implant Antenna for Glucose Level Monitoring in Blood:**

In order to diagnose life-threatening disorders, glucose levels in the blood must be monitored. Diabetes patients are usually required to examine blood samples day by day to monitor their glucose amount in the blood. The present approach for determining blood glucose levels is invasive and uncomfortable. Biosensors that can be implanted in the body have recently been created to monitor blood glucose amounts, allowing diabetic patients to get frequent updates on their glucose levels [32].

- **Implant Antenna for Monitoring of the Healing of Bone Fracture:**

The mending process of a broken bone is a risky process, that needs constant monitoring with mechanical help in order to restore the damaged bone to its original state. The time it takes to restore a broken bone depends on the age of the patient, the number of broken bones, and the location of the fracture. For continuous surveillance of shattered bones, an implanted antenna with a mechanical mechanism that promotes bone repair might be a great option [32].

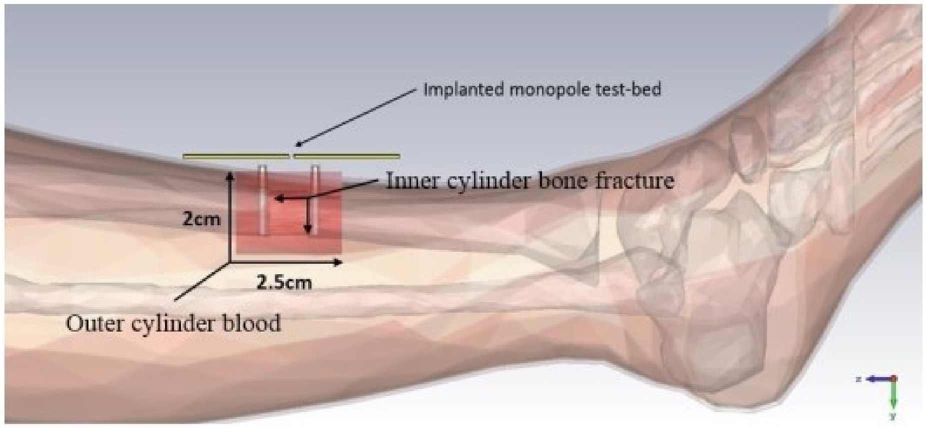


Figure 2.3: Implant antenna for monitoring of the healing of bone fracture [32].

- **Implant Antenna for Diagnosing Brain Diseases:**

As a future medical technology, an implanted antenna will be a fantastic option for identifying brain illnesses and neurological problems during treatment. An implanted antenna is now being utilized to restore memory loss and initial epileptic seizure exposure, where it contains a transmitter with a neural recorder [32].

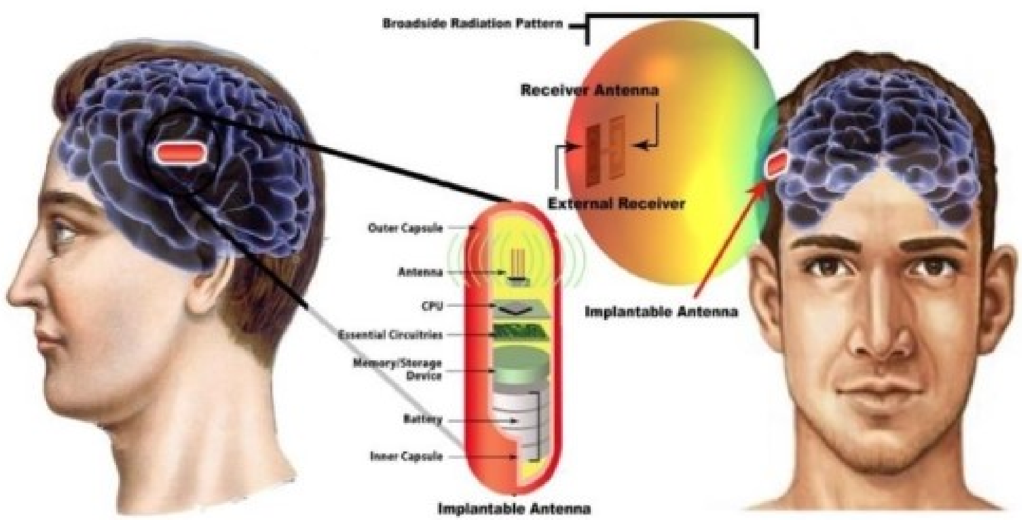


Figure 2.4: The basic mechanism of wireless for diagnosing brain [32].

4. Medical Antennas:

Antennas are an important component of medical devices, which can be implanted or ingestible that are increasingly being utilized to monitor wirelessly communicating and physiological informations with other inside body or exterior devices. Implantable antennas provide several benefits over other techniques, such as increased communication range, and including decreased invasiveness, greater transmission data rate, inductive links, also lower sensitivity to coil orientation. Implantable antennas have been studied in a variety of therapeutic and diagnostic uses, including monitoring of cardiovascular and intracranial pressure, as well as blood glucose [33].

Several factors must be taken into account in order to make the implanted antenna appropriate for use inside the human body. First and foremost, because the limited area available inside the human body, implanted antennas should be small. A lot of miniaturization techniques, such as using stacked structures, adding shorting pins, meandering patches, and using high permittivity substrates, are listed in. These complicated arrangements, increase the total size and the difficulty of antenna production. The structure of fractal geometry could increase the effective current path and reduce the antenna's size because of its self-similarity and space-filling qualities .Several fractal antennas have been suggested including the Koch modified microstrip antenna, Fern fractal-shaped microstrip antenna, and Minkowski fractal antenna. However, these fractal geometries are too complicated to produce. These kinds of antennas should work at relative lower frequency ranges due to the dissipation of electromagnetic waves via human tissues rises with frequency. As a result, the range of 402–405 MHz ((MICS) band), which has been approved by the Federal Communications Commission as the operational frequency of the implanted antenna, is widely employed for medical devises [34].

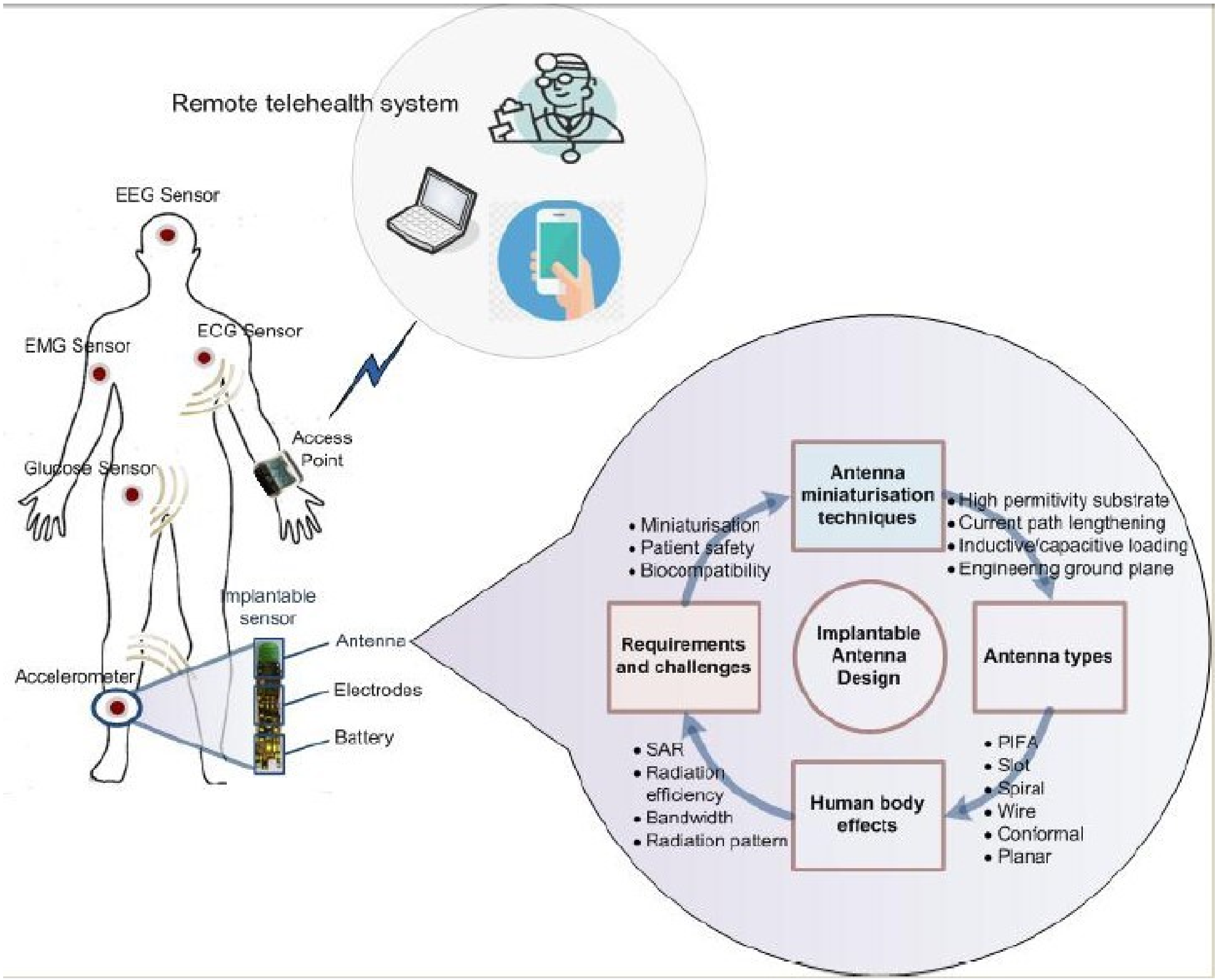


Figure 2.5: Antenna design considerations for implantable devices [31].

5. Frequency Bands:

Virtually, Antennas that can be implanted and/or ingestible should be tiny size and operate in the frequency ranges of medical, and be safe for humans. In the health and medical fields there are four common frequency bands used in wireless communications [35]:

- **Medical Implanted Communication System (MICS):**

Medical implants were given the bandwidth 402–405 MHz by the International Telecommunication Radio sector (ITU-R) in 1998. To enable future higher data rate connections .At any given time, MICS devices can utilize up to 300 kHz of bandwidth [36].

- **Industrial, Scientific and Medical (ISM):**

Internationally, ISM bands were initially intended for non-commercial radio frequency use. However, because government approval is not necessary, it is currently utilized for numerous commercial standards. The ITU-R allocates this bandwidth, and each nation utilizes it differently owing to regional regulations [36].

- **Wireless, Medical Telemetry Services (WMTS):**

Because of authorized radio users like police and emergency medical technicians cause electromagnetic interference. The Federal Communication Commission (FCC) has allocated a part of radio spectrum in the United States, 608–614 MHz and 1395–1400 MHz, as well as 1427–1432 MHz, for telemetry devices that operate with a wireless network in order to remote monitoring the health of patient; however, this frequency bands do not exist in Europe. With the exception of voice and video, WMTS is allowed for biological emissions suitable for communications [36].

- **Ultra-Wide Band (UWB):**

It's a communication system with a spectral occupancy of more than 20% or 500 MHz It was exclusively dedicated just in the United States and Singapore, However, the Office of Communications (OFCOM) allowed the usage of wireless ultra-wideband technologies in the United Kingdom without the need for a license on August 13, 2007 [36].

Name	Band (MHz)	Max Tx power (dBm EIRP)	Regions
MICS	402.0–405.0	−16	Worldwide
ISM	433.1–434.8	+7.85 E	Europe
ISM	868.0–868.8	+11.85	Europe
ISM	902.8–928.0	+36 w/spreading	Not in Europe
ISM	2400.0–2483.5	+36 w/spreading	Worldwide
ISM	5725.0–5875.0	+36 w/spreading	Worldwide
WMTS	608.0–614.0	+10.8	USA only
WMTS	1395.0–1400.0	+22.2	USA only
WMTS	1427.0–1432.0	+22.2	USA only
UWB	3100.0–10,600.0	−41.3	USA, etc.
UWB	3100.0–10,600.0	−41.3 (low duty cycle)	EU
MM WAVE	57–64 GHz	+82	USA
MM WAVE	57–64 GHz	+55	Europe
THZ	0.1–10 THz	+20	Worldwide

Table 2.2: Unlicensed frequencies available for personal area networks [35].

6. Types of Medical Antenna:

Medical antennas have been developed over time. Some are protected by patents; some are effective while others have never achieved the expected level of popularity. The technology of medical antennas is a prominent research area, starting with basic monopole antennas to most sophisticated phased array antennas. Depending on the use, some antennas should be mounted on the human body directly, also it can be reduced in size because of the body's dielectric scaling in comparison to air [37].

6.1. Wearable Antenna:

The wearable antenna is a principal part of the wearable network because it is accountable for getting and communicating the transmission between the implanted device and the network of wearable devices. Since the human body is a poor platform for EM waves, the antenna ought to be made as effective as could be possible .A unique design consideration is necessary for the antenna to have the most minimal conceivable in backward radiations (SAR), which might cause tissue damage in human body. Concurrently, careful consideration must be given to the antenna's overall size. The antenna's total size should be as minimal as feasible [38].

6.2. Implantable Antennas:

Implanted antennas into the bodies of humans and animals are generally utilized in biomedical telemetry, and treatment applications. the implanted antennas are utilized to send signals either in or out of the host body during treatment applications [39].

Designing implantable antennas has various difficulties including testing, and fabrication, for that it's now garnering a lot of research focus. Implantable antennas should be designed numerically rapidly and in a manner that addresses in the best possible way a variety of difficulties related to patient safety, influence of the implantation location, exhibited radiation performance, and miniaturization, etc [40].

Medical Implanted Communication Service (MICS) and Industrial Scientific and Medical (ISM) are the typical frequencies ranges for implanted antennas with (402-405 MHz) band for MICS and (2.4-2.5 GHz) band for ISM. The frequency range selected determines the size of the implanted antenna as well as power loss within the host body. MICS band antennas have lower loss and a bigger antenna size than ISM band antennas, which have a lesser size and greater loss [39].

6.2.1. Types of Implantable Antenna:

Here are some forms of the various implantable antenna types:

- **Dipole Antenna:**

Printed dipole antennas in the horizontal plane with an omnidirectional design have received a lot of attention for their design benefits including ease of fabrication, conformance, and low cost. Nonetheless, a major disadvantage of these antennas is that their bandwidth is often limited, making them unsuitable for some applications. Several endeavors have been attempted to extend the bandwidth of the dipole antennas, such as printed dipoles with PBG forms, as well as using of double-sided printed dipoles [41].

- **Loop Antenna:**

Antennas of this type are made up of rectangular, square, or round plating. They're sized to facilitate the conversion of electrical energy into electromagnetic energy, where the antenna shape has no effect on the parameters of the radiated field. In fact, all loop antennas with identical surfaces emanate energy in the same manner; in other words, they have the same properties. The loop antenna has many of the same helpful attributes as dipole antennas, in devices that are part of the human body tiny coil antennas are more efficient, because their performance will not be harmed by the body's poor conductivity [42].

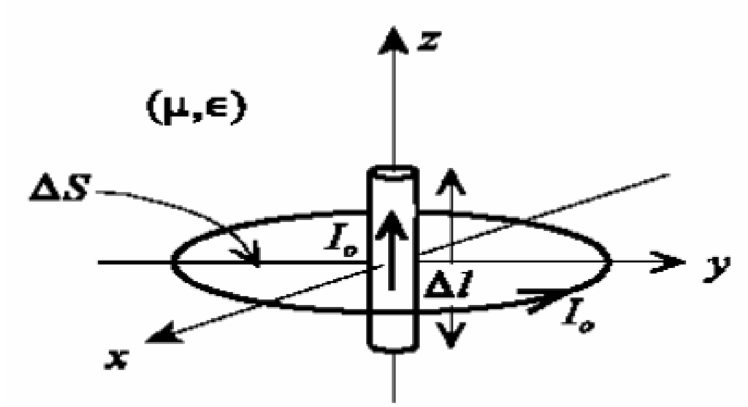


Figure 2.6: Loop antenna orientation [42].

They are typically categorized based on their perimeter into two categories: electrically large and electrically small. If the antenna's circumference is $\leq \frac{\lambda}{10}$ it's referred to be electrically small, and if the circumference is around λ it's considered electrically large [42].

- **Microstrip Patch Antenna:**

A microstrip patch antenna is a low-cost, flat-shaped antenna for getting and communicating electromagnetic waves [43]. It comprises of a ground plane on a side of a dielectric substrate and a conducting patch of any form, whether planar or non-planar on the other. It's a resonant antenna that's been printed for microwave wireless networks that need semi-hemispheric coverage in narrow bands. The microstrip patch antenna has been widely used because of its planar form and simplicity of coordination with microstrip innovation. The most basic and widely used microstrip antennas are rectangular and round patches [44].

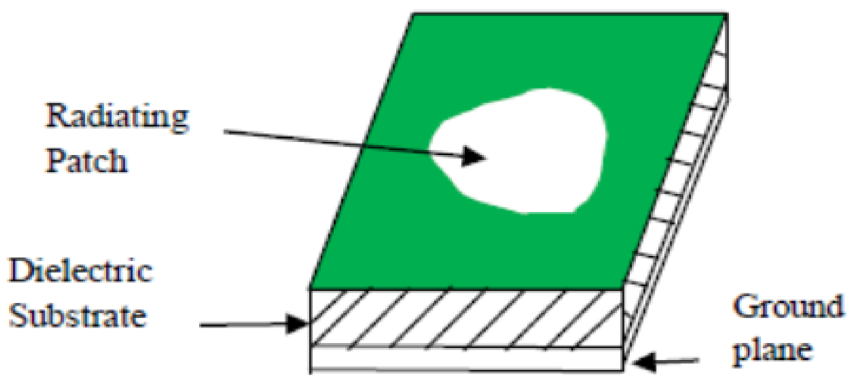


Figure 2.7: Microstrip antenna configuration [44].

7. Biological Tissues Properties:

Implantable antennas are designed to operate inside the human tissue of different people, it becomes critical to figure out how sensitive they are to the shape of the tissue environment around them, or, the individual's anatomical characteristics, equivalently; and the intersubjective variation and uncertainty of the dielectric properties of the tissue [45].

7.1. Electromagnetic Characteristics of Human Tissues:

According to new study, the electromagnetic field penetration profundity into the tissue might be asymptotically autonomous of frequency at high frequencies, and the gigahertz range is the ideal frequency for implanted antennas with a size of millimeters. An implanted antenna that works in the gigahertz frequency band might be constructed to have a very tiny profile, as well as overcoming the challenges of building efficient data rate [46]. Communications that are focused on the body includes the electromagnetic waves and the human body's interplay with it. Understanding the electromagnetic characteristics of bodily tissues is critical in order to study this interaction. The frequency and type of tissue have a major impact on these characteristics. Modeling of the body is required to make it possible for antennas to be developed and transceivers for these types of communications systems. Physical phantoms or numerical phantoms incorporated in numerical electromagnetic symbols can be used to simulate the human body [47].

The dielectric characteristics of biological tissues at microwave and radio frequencies have been analyzed by several creators. Perhaps the most difficult challenge related with determining tissue parameters is obtaining samples. Due to the necessity to have the measuring equipment in touch with the tissue, measurements on live tissue are not possible. As a result, all research relies on dead tissue. A model based on the collecting of 4-Cole-Cole equations is utilized because the dielectric properties differ greatly with frequency:

$$\varepsilon(\omega) = \varepsilon_{\infty} + \sum_{m=1}^{4} \frac{\Delta\varepsilon_m}{1+(j\omega\tau_m)^{(1-\alpha_m)}} + \frac{\sigma_j}{j\omega\tau_0} \tag{2.1}$$

Where:

ε_{∞}: the material permittivity at terahertz frequency.

ε_0 : the free-space permittivity.

σ_j : the ionic conductivity.

ε_m , τ_m , α_m : the material parameters for each dispersion region.

This table below displays depth of penetration, loss tangent, relative permittivity, and conductivity pertaining to these tissues at a frequency of 2.5 GHz. Due to of the difference in water content, tissue characteristics change with age. However, the depth of penetration varies greatly over this frequency range, according to (1-1). Because penetration depths at 100 MHz are huge, frequencies in this range are utilized to communicate with medical devices via penetrating the body. The penetration depth decreases as the frequency rises [47].

	ε_∞	$\Delta\varepsilon_1$	τ_1 (ps)	α_1	$\Delta\varepsilon_2$	τ_3 (ns)	α_2	σ	$\Delta\varepsilon_3$	τ_3 (ns)	α_3	$\Delta\varepsilon_4$	τ_4 (ms)	α_4
Aorta	4.000	40.00	8.842	0.100	50	3.183	0.100	0.250	1.00E+5	159.155	0.200	1.00E+7	1.592	0.000
Bladder	2.500	16.00	8.842	0.100	400	159.155	0.100	0.200	1.00E+5	159.155	0.200	1.00E+7	15.915	0.000
Blood	4.000	56.00	8.377	0.100	5200	132.629	0.100	0.700	0.00E+0	159.155	0.200	0.00E+0	15.915	0.000
Bone (cancellous)	2.500	18.00	13.263	0.220	300	79.577	0.250	0.070	2.00E+4	159.155	0.200	2.00E+7	15.915	0.000
Bone (cortical)	2.500	10.00	13.263	0.200	180	79.577	0.200	0.020	5.00E+3	159.155	0.200	1.00E+5	15.915	0.000
Brain (gray matter)	4.000	45.00	7.958	0.100	400	15.915	0.150	0.020	2.00E+5	106.103	0.220	4.50E+7	5.305	0.000
Breast fat	2.500	3.00	17.680	0.100	15	63.660	0.100	0.010	5.00E+4	454.700	0.100	2.00E+7	13.260	0.000
Cartilage	4.000	38.00	13.263	0.150	2500	144.686	0.150	0.150	1.00E+5	318.310	0.100	4.00E+7	15.915	0.000
Cerebro spinal fluid	4.000	65.00	7.958	0.100	40	1.592	0.000	2.000	0.00E+0	159.155	0.000	0.00E+0	15.915	0.000
Cornea	4.000	48.00	7.958	0.100	4000	159.155	0.050	0.400	1.00E+5	15.915	0.200	4.00E+7	15.915	0.000
Eye tissues (sclera)	4.000	50.00	7.958	0.100	4000	159.155	0.100	0.500	1.00E+5	159.155	0.200	5.00E+6	15.915	0.000
Fat (average infiltrated)	2.500	9.00	7.958	0.200	35	15.915	0.100	0.035	3.30E+4	159.155	0.050	1.00E+7	15.915	0.010
Gall bladder bile	4.000	66.00	7.579	0.050	50	1.592	0.000	1.400	0.00E+0	159.155	0.200	0.00E+0	15.915	0.200
Heart	4.000	50.00	7.958	0.100	1200	159.155	0.050	0.050	4.50E+5	72.343	0.220	2.50E+7	4.547	0.000
Kidney	4.000	47.00	7.958	0.100	3500	198.944	0.220	0.050	2.50E+5	79.577	0.220	3.00E+7	4.547	0.000
Liver	4.000	39.00	8.842	0.100	6000	530.516	0.200	0.020	5.00E+4	22.736	0.200	3.00E+7	15.915	0.050
Lung (inflated)	2.500	18.00	7.958	0.100	500	63.662	0.100	0.030	2.50E+5	159.155	0.200	4.00E+7	7.958	0.000
Muscle	4.000	50.00	7.234	0.100	7000	353.678	0.100	0.200	1.20E+6	318.310	0.100	2.50E+7	2.274	0.000
Skin (dry)	4.000	32.00	7.234	0.000	1100	32.481	0.200	0.000	0.00E+0	159.155	0.200	0.00E+0	15.915	0.200
Skin (wet)	4.000	39.00	7.958	0.100	280	79.577	0.000	0.000	3.00E+4	1.592	0.160	3.00E+4	1.592	0.200
Small intestine	4.000	50.00	7.958	0.100	10000	159.155	0.100	0.500	5.00E+5	159.155	0.200	4.00E+7	15.915	0.000
Stomach	4.000	60.00	7.958	0.100	2000	79.577	0.100	0.500	1.00E+5	159.155	0.200	4.00E+7	15.915	0.000
Testis	4.000	55.00	7.958	0.100	5000	159.155	0.100	0.400	1.00E+5	159.155	0.200	4.00E+7	15.915	0.000
Tongue	4.000	50.00	7.958	0.100	4000	159.155	0.100	0.250	1.00E+5	159.155	0.200	4.00E+7	15.915	0.000

Table 2.3: Parameters needed to find body tissue dielectric constant and conductivity at any frequency [47].

7.2. Electrical Characteristics of Human Tissues:

For several reasons, the electrical characteristics of cell suspensions and biological tissues have attracted researchers' attention for more than a century. They decide how current flows inside the body. As a result, they're crucial in the analysis of a variety of biological applications such as effective electrical stimulation and the treatment and diagnosis of different physiological problems with feeble electric currents, Electrocardiography, radiofrequency hyperthermia, as well as the structure of the body. knowing these electrical parameters can lead to a better understanding of the essential biological processes [48].

The majority of biological materials are made up of water, which makes up 72 percent of the human body. Commonly, four components make up 99% of tissue mass: nitrogen, oxygen, hydrogen, and carbon. Water content varies with biological tissues. The dielectric steady, also known as permittivity, is an essential measuring parameter for microwave characteristics, this has a direct relationship with water substance. When a material is put in an electric field, permittivity describes the material's loss properties and capacity to retain energy. Due to their polar nature, molecules of water try to align themselves inside an electric field [37].

Tissue	Conductivity(S/m)		Permittivity	
	403 MHz	2.45 GHz	403 MHz	2.45 GHz
Small intestine	1.9	3.17	66	54.4
Stomach	1	2.2	67.5	62.1
Colon	0.86	2	62.5	53.8
Skin	0.69	1.46	0.69	38
Muscle	0.79	1.74	57.1	52.7

Table 2.4: Electric of human body tissues at 403 MHz and 2.45 GHz [31].

8. The Effect of the Human Body on the Implanted Antenna Performance:

When we implant a medical antenna into a patient, the antenna will act differently whenever put in an arm, somewhere down in the midsection, or just underneath the skin in the chest. The kind of surrounding tissue will also have an impact. The thickness of this layer varies across individuals, and changes over the long haul, when a patient's weight is gained or lost .As well as when the patient moves, the environment around the

implanted antenna changes. In air, the MICS frequency band equates to a wavelength of around 74 cm, whereas inside the body, it corresponds to approximately 9 cm. The implanted antenna is in close proximity to the body surface. As a result, the far-field pattern is altered by changing posture, it also has an impact on the radio channel among the medical implant and the outside base station. This radio channel variant relates to a type of slow fading. Measurements and simulations can be used to illustrate this effect [49].

An antenna's efficiency, gain, and directivity have standard definitions. The antenna's efficiency factor is $0 \leq \eta \leq 1$, which indicates how much power is wasted in the antenna and inside the body. Because of tissue losses, the perfect lossless antenna, with $\eta = 1$, is impossible to achieve for an implant. The gain definition is based on an antenna that is completely matched. As a result, reflection losses owing to mismatch are excluded from the gain. Gain is calculated in free space at the antenna's furthest zone, which in the case of an implant complies to the most distant zone of the body containing the implant [49].

9. Requirements, Standards and Challenges of Implantable Antennas:

Implantable systems encounter additional obstacles and problems in constructing antennas than traditional wireless communication methods because of the electromagnetic characteristics of the human body [50]. To be appropriate for usage with IMDs, the antenna design must meet the following requirements:

9.1. Miniaturization:

The conventional half-wavelength (l/2) and quarter-wavelength (l/4) antenna are worthless for implanted and ingestible medical devices (IIMDs) applications due to their dimensions in the frequency bands allotted for IIMDs, particularly in the low-frequency bands The size of an implanted or ingestible antenna should be as tiny as feasible to fit within the IIMD case. For example, an implantable intracranial pressure sensor should be tiny enough to pass through conventional 12 mm burr holes in the skull, yet a normal ingestible capsule should not be larger than a big vitamin. On the other hand, the size of the outside receiving antennas is unrestricted, except if they are expected to be worn by the patient, wherein patient comfort should be considered. As a result, one of the most difficult aspects of antenna design for IIMDs is miniaturization [51].

Human tissue in which implantable antennas are planned to work displays generally high permittivity. For example, skin tissue has a relative permittivity of 46.7 at 402 MHz, or equivalently, decreased wave-spread speed, which helps to miniaturize the antenna's physical size. However, when a biocompatible low-permittivity layer is added around the antenna, the worth of the effective permittivity diminishes, and miniaturization attained by the high-permittivity tissue substance is deteriorated [52].

The usage of patch forms for implantable antennas enables for a number of other miniaturization approaches. The goal is to minimize the antenna size while retaining appropriate electromagnetic performance at a particular operating frequency. The following are some of the miniaturization strategies for implantable patch antennas that have been suggested in the literature [52]:

- The usage of dielectric (substrate/superstrate) materials with high permittivity.
- Extending of the current-flow on the patch surface.
- Patch-stacking.
- The use of shorting pins.

9.2. Biocompatibility:

The antenna should be biocompatible in order to avoid harming the patient, as well as durable enough to withstand the effects of bodily fluids. This necessitates the utilization of a superstrate. due to its high permittivity, toughness, and thermo-conductivity, ceramic alumina (εr = 9.4; tanδ =0.006 [31].) was chosen for the superstrate and substrate. Since the 1970s, alumina has been employed in medical devices, it is still the preferred material for many hip substitution prosthetics due to its solidity in in heavy weight-bearing joints, characteristics of hydrophilic, and also, it’s resistant to scratches, resulting in less wear and lowering of particle burden on the soft tissues surrounding [53]. However, it is important to mention that drilling and circular cuts are difficult on ceramic substrates. Another common use are MACOR (ε*r* = 6.1; tan 0.005 δ =) and Teflon (ε*r* = 2.1, tan δ = 0.001) [31].

9.3. Radiation Performance:

Because of the considerable path loss, the implanted antenna ought to have the highest gain feasible in the intended direction in order to ensure the contact between the antenna and the outside equipment. Omni-directional radiation is essential for capsule endoscopy antennas to ensure that all directions are covered when the capsule endoscopy equipment fluctuates. On the other hand, implanted antenna radiation should comply with SAR prerequisites and emitted power standards [50].

9.4. Specific Absorption Rate:

The quantity of radiofrequency energy consumed by human tissues is known as the Specific Absorption Rate (SAR). It is utilized as a measurement to guarantee the security of biological tissues in case of electromagnetic exposure. There are two guidelines for SAR which are universally embraced. As per IEEE C95.1-1999 norm, the SAR ought to be under 1.6 W/kg averaged over 1 g cubic of tissue volume. The IEEE C95.1-2005 norm determines that the SAR ought to be under 2 W/kg averaged over 10 g cubic of tissue volume. The FCC recommends 1 g averaging, whereas the ICNIRP utilizes 10 g. 4-6 W/kg with a middle value over 1 g cubic tissue would be equivalent to 2W/kg more than 10 g cubic tissue. Low output power must be used by the implanted devices in order to preserve standard SAR values. The Specific Absorption (SA) per pulse is typically calculated using [31]:

$$SA = SAR \times T_P \qquad (2.2)$$

Where T_P represents the duration of the pulse. The temperature of bodily tissue can be raised by electromagnetic power consumed by the tissue. Human body tissue temperature close to the implanted device ought not rise over 1-2℃ [31].

10. State of the Art Implantable Antennas Design:

Countless implanted antennas have been introduced the literature. However, they can be characterized into two classifications: the first one is antennas that are implanted under the skin or antennas to be set in a fixed region of the body, and the second one is implantable antennas which can circulate inside the body like capsule endoscopy devices [50].

Diathermy, nerve energizing and neural prosthesis, upgrade of bone and wound recuperating, hyperthermia for cancer treatment, and heart ablation are all examples of therapeutic uses. Tumor detection, mensuration of lung water content, imaging, are only a few examples of diagnostic uses. EM coupling into and/or out of the body is used in the majority of these medicinal and biological applications. Electromagnetic coupling within and/or outside the body is used in the majority of these medicinal and biological uses.

This coupling normally necessitates the use of a device, like as an antenna, to transmit or receive a signal into or from a body. The device is referred to as an applicator rather than an antenna at lower frequencies, because it is generally short in comparison to a wavelength and doesn't work in the same way as a radiating antenna. The equipment used at higher frequencies is generally some type of classic radiating antenna. The antenna working conditions in numerous biological and medical applications are not the same as the more classic free space, far-field conditions. Nearfield and reciprocal interactions are frequently dominant, and the antenna environment is generally lossy [54].

11.Conclusion:

In this section the study of implantable medical antennas is mentioned, as some cases where these antennas are used, such as their use for monitoring blood pressure or monitoring the amount of glucose in the blood and other uses are mentioned. The frequencies of these antennas have also been mentioned, as they have certain frequencies in which they operate if they are intended for medical devices such as MICS and ISM, and we have studied the types of these antennas. In the second part of this study, we studied the tissues of the human body and their characteristics. We also mentioned the effect of these antennas on the human body and what are the standards and requirements that must be met in the stages of preparing this antenna so that it is ready for use on the human body.

1. Introduction:

The invention of antennas revolutionized human civilization like no other technology, antennas are widely used in the field of telecommunications and we have already seen many applications for them in the previous chapters, antennas receive an electromagnetic wave and convert it to electrical signal or receive an electrical signal and radiate it as an electromagnetic wave.

In this chapter an inverted-F antenna for medical applications has been designed and miniaturized, Miniaturization is the most crucial and difficult aspect of medical antenna design hence There are a variety of ways to miniaturize an antenna, including the addition of shorting pins, substrate materials with a large dielectric constant or transforming the patch into a spiral shape, the designed antenna has a rectangular shape with hexagonal and circular slots in its conductor, the design and simulation procedures are carried out using HFSS(High frequency Structural Simulator) V15.0.

HFSS can simulate the high frequency electromagnetic field of any three-dimensional passive structure, and can obtain the characteristic impedance, propagation constant, Scattering parameters, electromagnetic field, radiation field, antenna pattern etc. The software is widely used in wireless and cable communications, computers, satellites, radar, semiconductor, microwave integrated circuits, aerospace and other fields to help customers design world -class products [55]. The proposed antenna operates in MICS band (Medical Implant Communication Service) 402–405 MHz for wireless telemedicine, it resonates at 404 MHz with a reflection coefficient of -52 dB with a bandwidth of 2.25 MHz, the substrate material used for the design is gallium arsenide dielectric with a high permittivity of 12.9 and a dielectric loss tangent of 0.0004.

2. Design procedure:

The design approach is based on reducing slots with different shapes from the rectangular patch such as hexagons and circles, this helped us to minimize antenna size and made it resonates in lower frequencies, with the help of adding shorting pin. Then the best design for which has the best performance, to be selected. The antenna dimensions are listed in Table 3.1

Parameter	Value(mm)	Parameter	Value(mm)
L1	28.00	L19	1.00
L2	21.5	L20	9.62
L3	26.86	L21	4.12
L4	18.10	L22	9.60
L5	13.43	L23	3.00
L6	17.05	L24	12.83
L7	6.45	L25	5.97
L8	5.43	L26	3.62
L9	3.95	L27	2.00
L10	5.50	L_F	4.53
L11	9.32	L_S	2.00
L12	9.60	D1	2.40
L13	3.00	D2	1.40
L14	9.50	G1	7.00
L15	4.33	G2	8.00
L16	2.00	G3	2.00
L17	1.80	G4	1.75
L18	0.80	H	14.50

Table 3.1: The optimized parameters of the proposed antenna.

While the geometrical structure of the proposed microstrip pifa is shown in the bellow figure 3.1, as we mentioned earlier, we have got this shape after several attempts of modifying each time different parameters including substrate thickness, feed position, slots shapes and shorting pin position as well. The height of the patch is considered 1.6 mm and the substrate thickness is 14.5 mm; The designed antenna is fed by a coaxial cable which has a dielectric of ε = 2.1

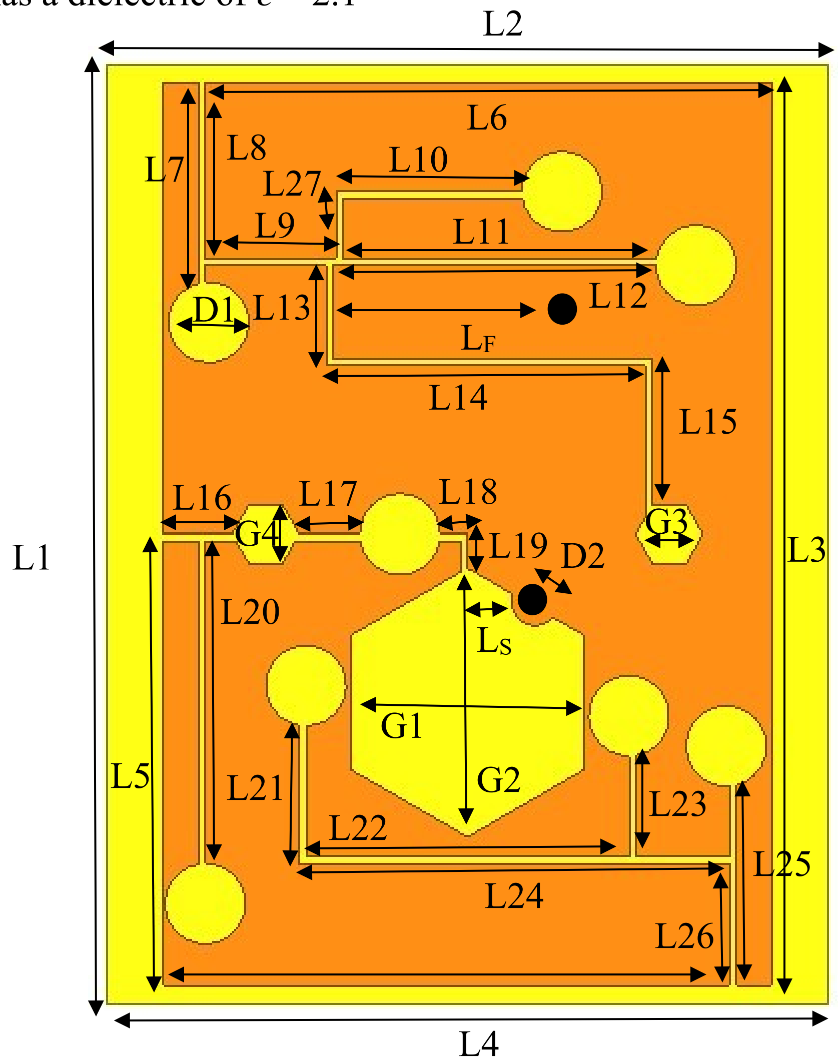
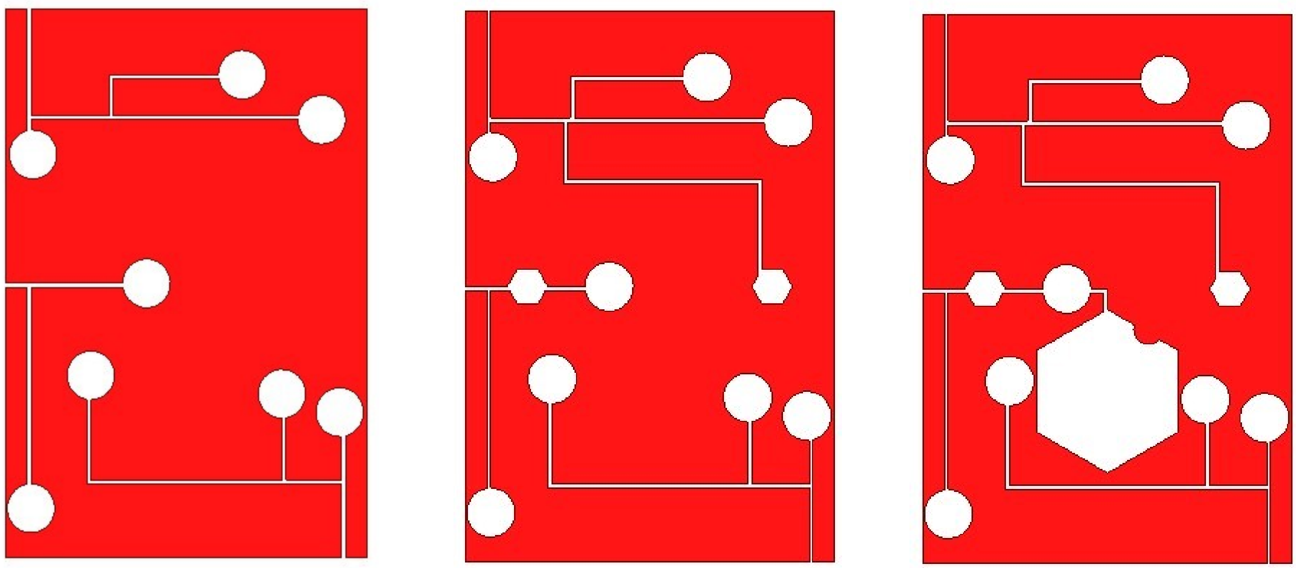


Figure 3.1: Geometrical structure of the proposed antenna.

3. Design Evolution Process:

After doing literature survey, slots with hexagonal and circular shapes are chosen because of their impact in miniaturization and shifting the operating frequency band to lower at the desired frequency as well, different length rectangular slots are connected to hexagonal and circulars slots in order to have impedance matching and exhibiting better results, the antenna performance also depends on the height and dielectric constant of the substrate as discussed in the following stages.

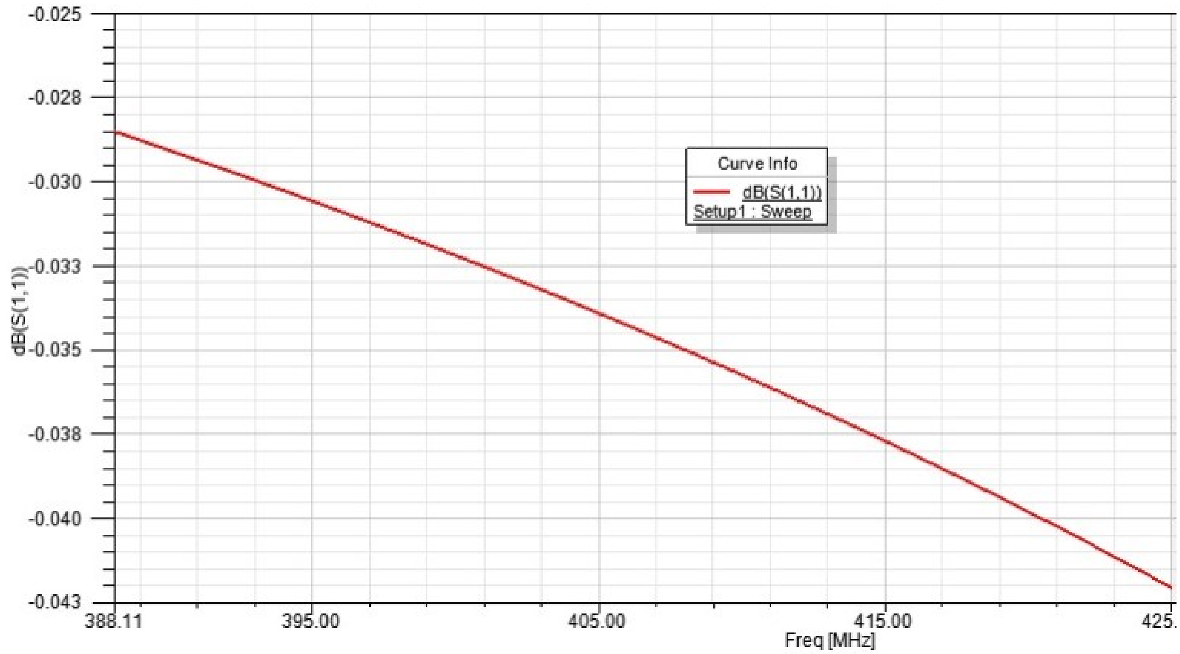


(a) **(b)** **(c)**

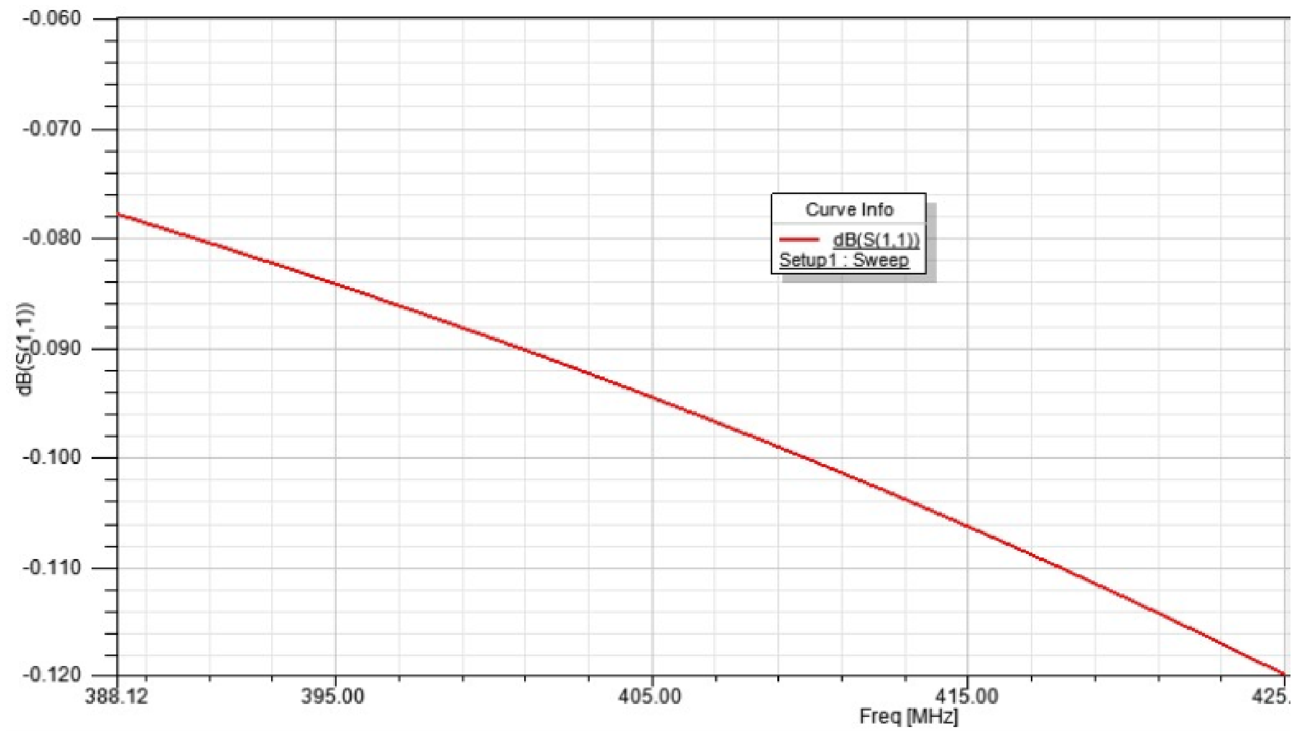
Figure 3.2: The geometries of design approaches.

4. Simulation and Results:

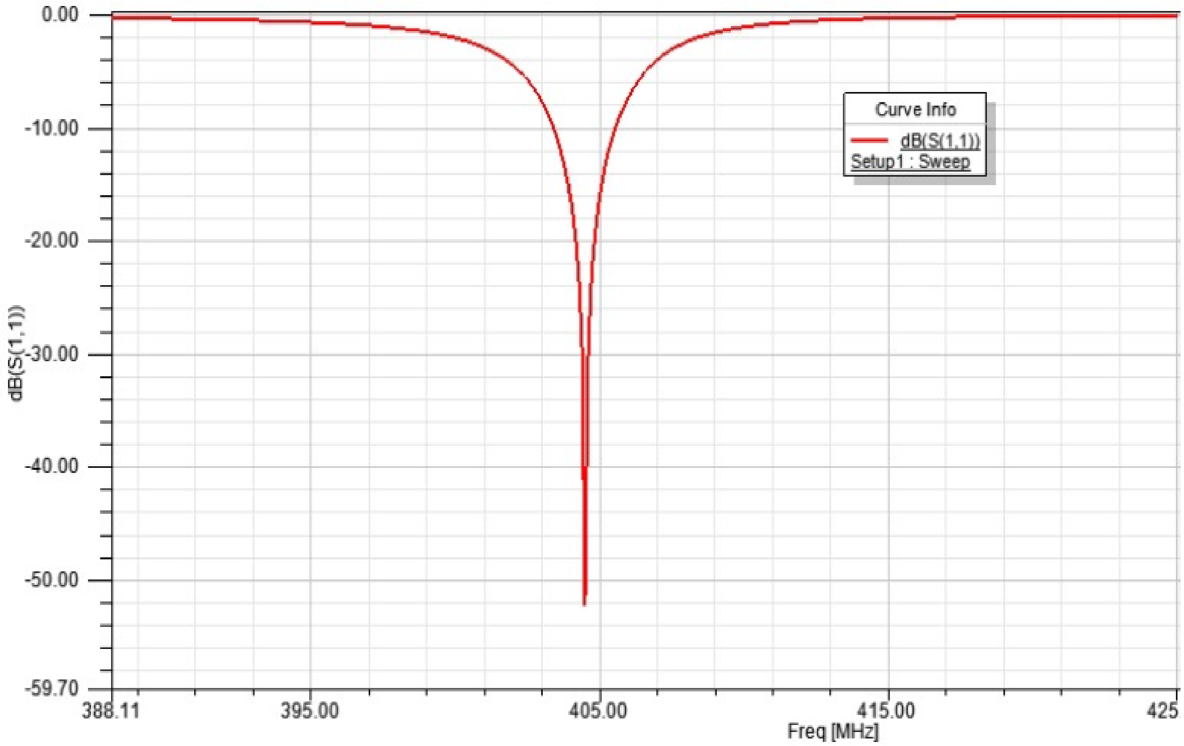
The figure reports the simulated reflection coefficient with respect to the frequency as shown in a b c, the reflection coefficient.


-0.025
-0.028
-0.030
-0.033
-0.035
-0.038
-0.040
-0.043
dB(S(1,1))
Curve Info
dB(S(1,1))
Setup1 : Sweep
388.11
395.00
405.00
415.00
425.
Freq [MHz]

(a)


-0.060
-0.070
-0.080
-0.090
-0.100
-0.110
-0.120
dB(S(1,1))
Curve Info
dB(S(1,1))
Setup1 : Sweep
388.12
395.00
405.00
415.00
425.
Freq [MHz]

(b)



(c)

Figure 3.3: return loss vs frequency of the approached designs

The simulated S-parameter of the proposed pifa is shown in figure 3.4, It displays a zoomed in result for accuracy, The antenna resonates at 404 MHz its return loss is higher than 50 dB and has a very narrow bandwidth which is preferable in medical applications.

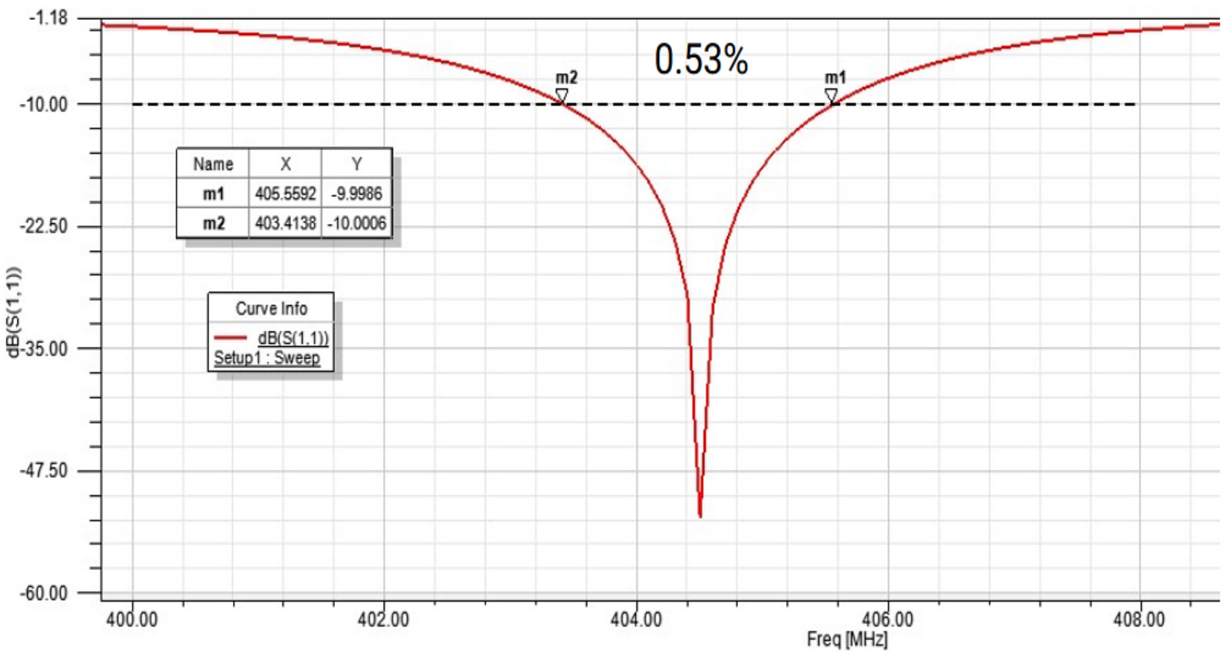


Figure 3.4: Simulated reflection coefficient of the proposed antenna.

At -10 dB the proposed antenna has a bandwidth of 2.25 MHz ranging from 403.41 MHz to 405.56 MHz (BW: 0.53%) which covers MedRadio as shown in Figure3.4

The computed bandwidth of the proposed antenna is shown below:

$$\mathrm{BW} = \frac{405.56 - 403.41}{404.5} \times 100\% = 0.53\%$$

5. Radiation Pattern:

A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. Figure 3.5 and Figure 3.6 show the 2D and 3D radiation patterns, the blue refers to phi = 90 deg while the pink refers to phi = 0 deg

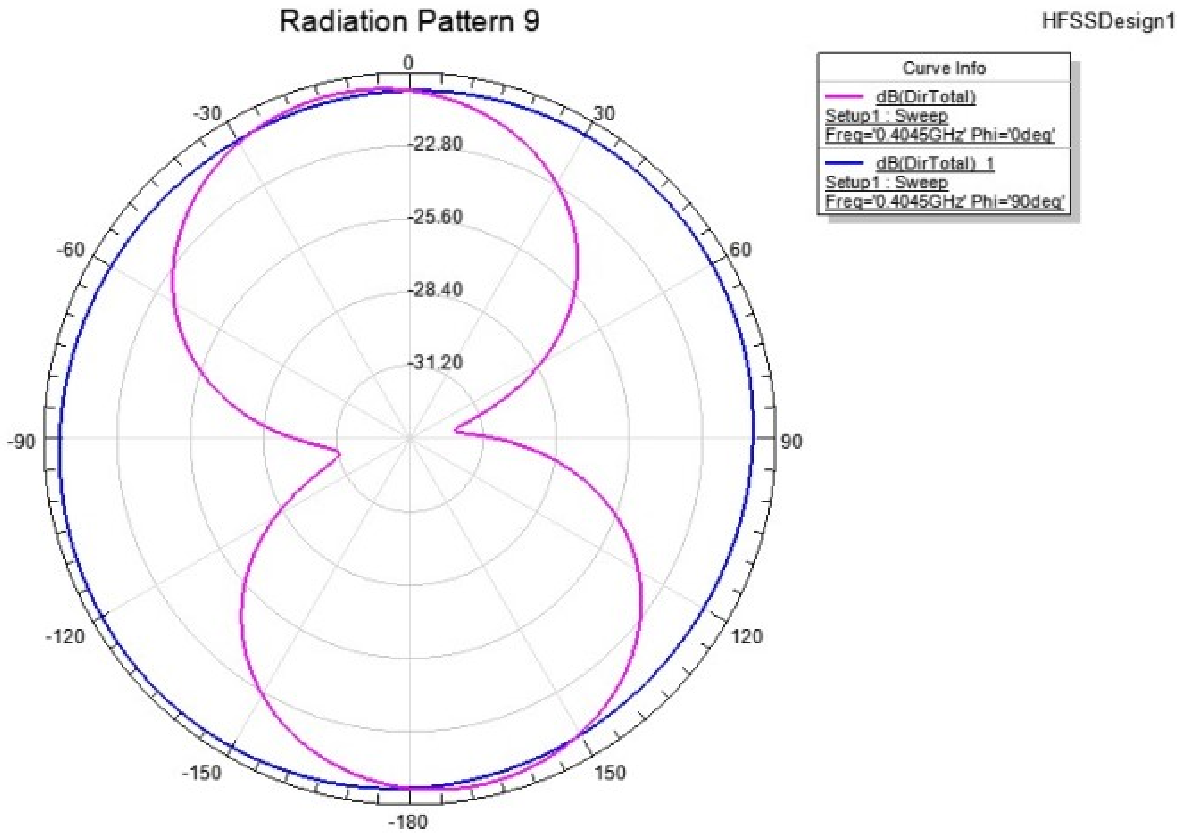


Figure 3.5: 2D radiation pattern.

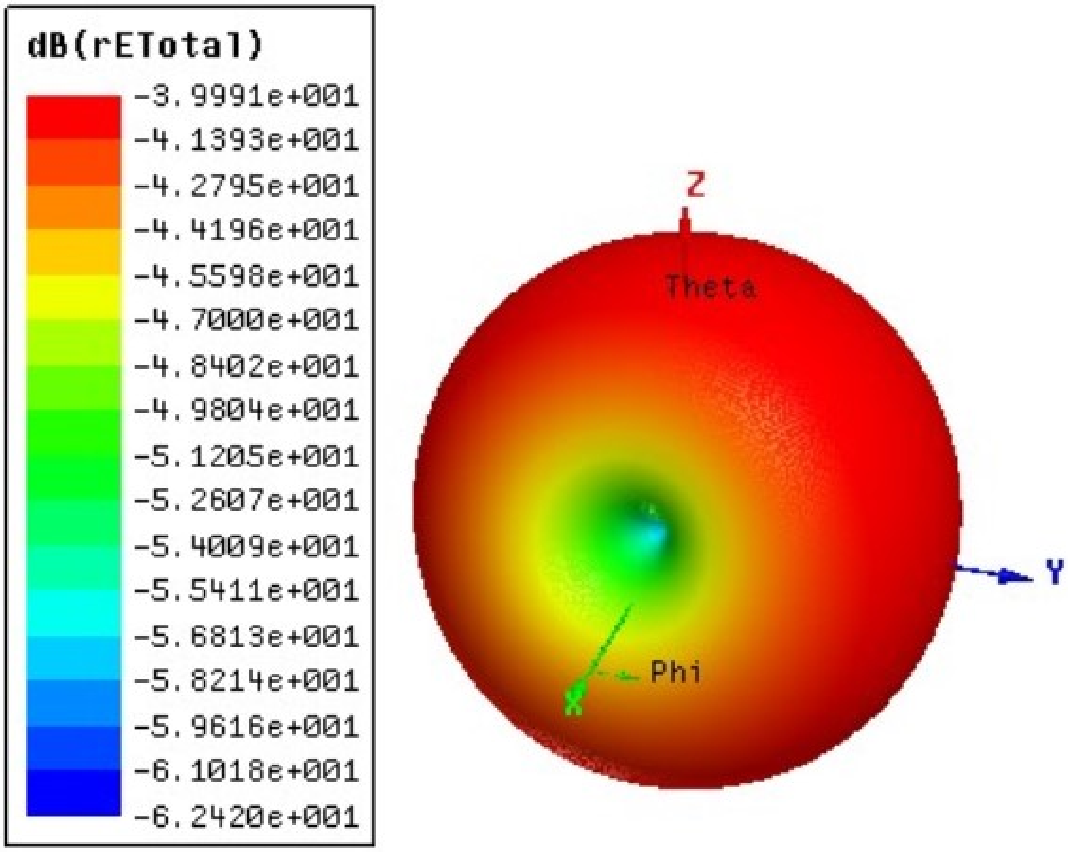


Figure 3.6: 3D radiation pattern measured at 404MHz.

6. **Feed Point Position Performance:**

The effect of changing different values of feed positions on the proposed antenna performance is shown in Figure 3.7 as we can see it affects the return loss s11 values and the resonant frequency slightly changes as well.

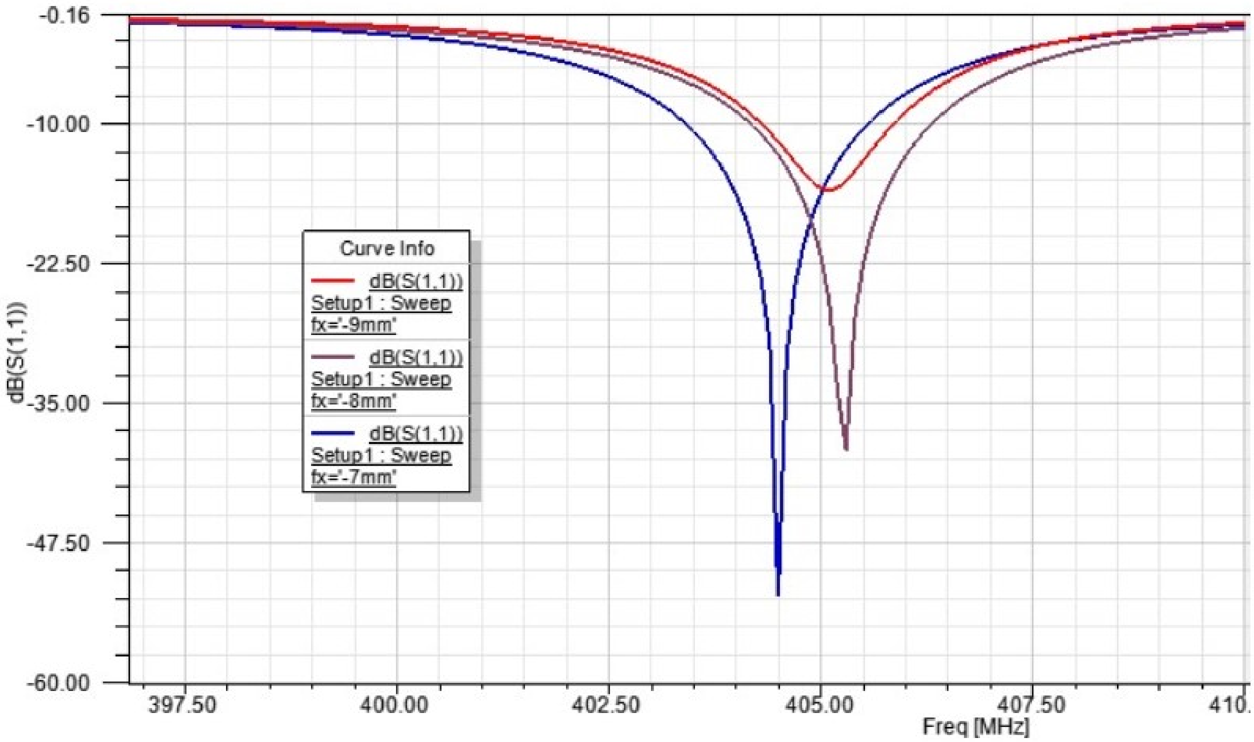


Figure 3.7: Effect of variation of feed position.

7. Effect of variation of shorting pin position:

From Figure 3.8 it can be observed that the shorting pin position plays an important role not only in the return loss values but also the shifting of resonant frequency.

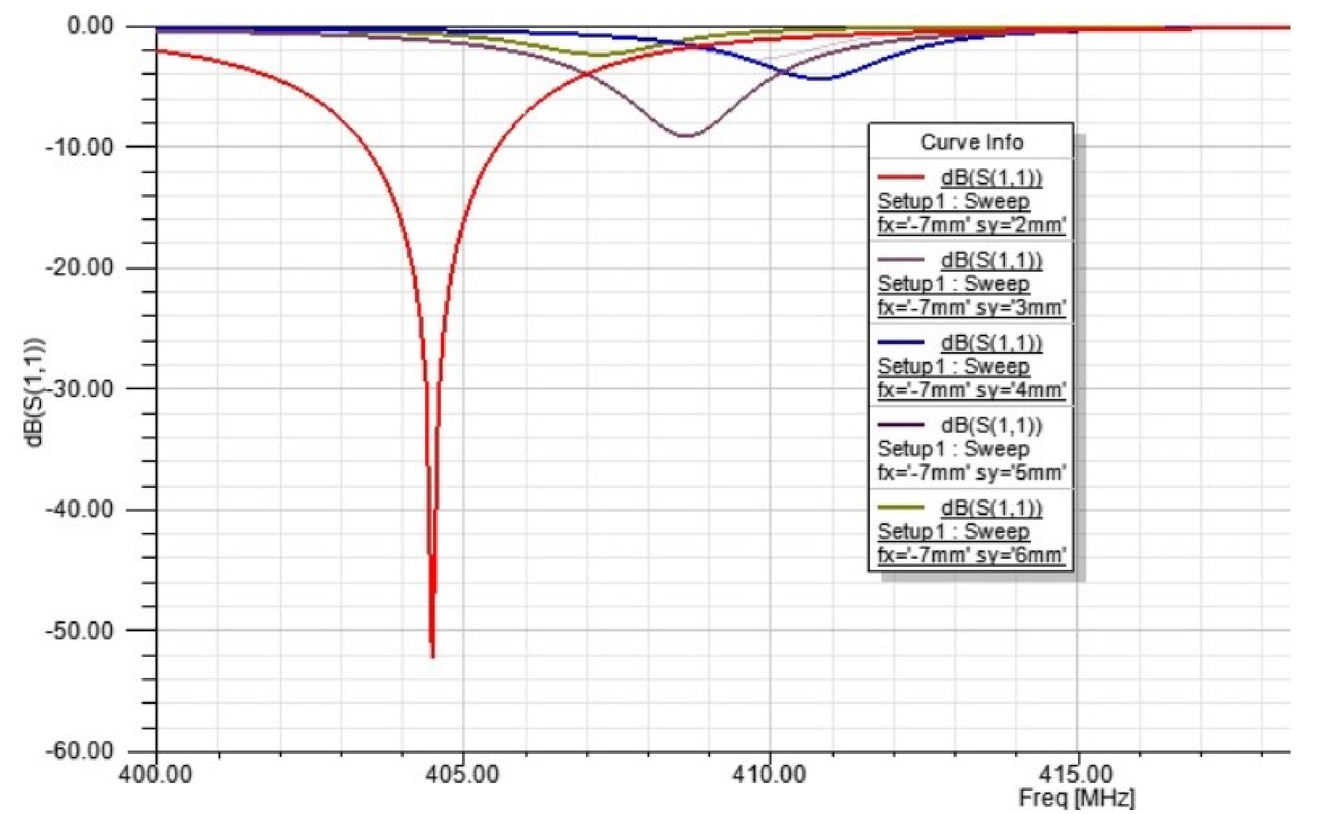


Figure 3.8: Effect of variation of shorting pin position.

8. **Effect of variation of substrate thickness:**

From the Figure 3.9 we can see that different substrate thicknesses also plays an important effect on the bandwidth results and slightly changes the resonant frequency, the chosen substrate thickness in the proposed antenna has the highest performance in both return loss and operating frequency among all other values of thickness.

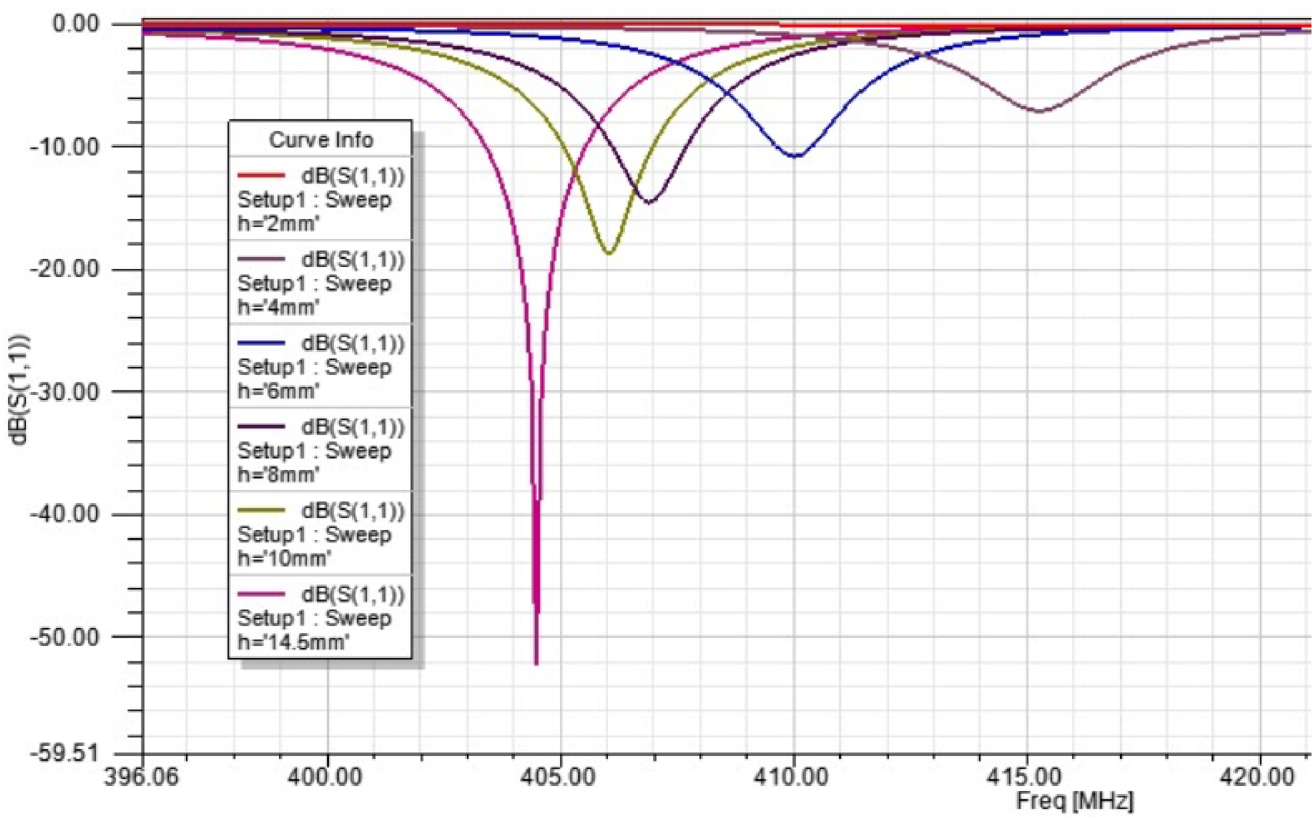


Figure 3.9: Effect of variation of substrate thickness.

9. Current Distribution:

As we can observe from Figure 3.1 0 the electric field distribution at 404 MHz concentrated at the edges of hexagons and circles slots, therefore it's obvious that the Hexagonal and circular shapes play an important role on the antenna designing to operating in MICS band.

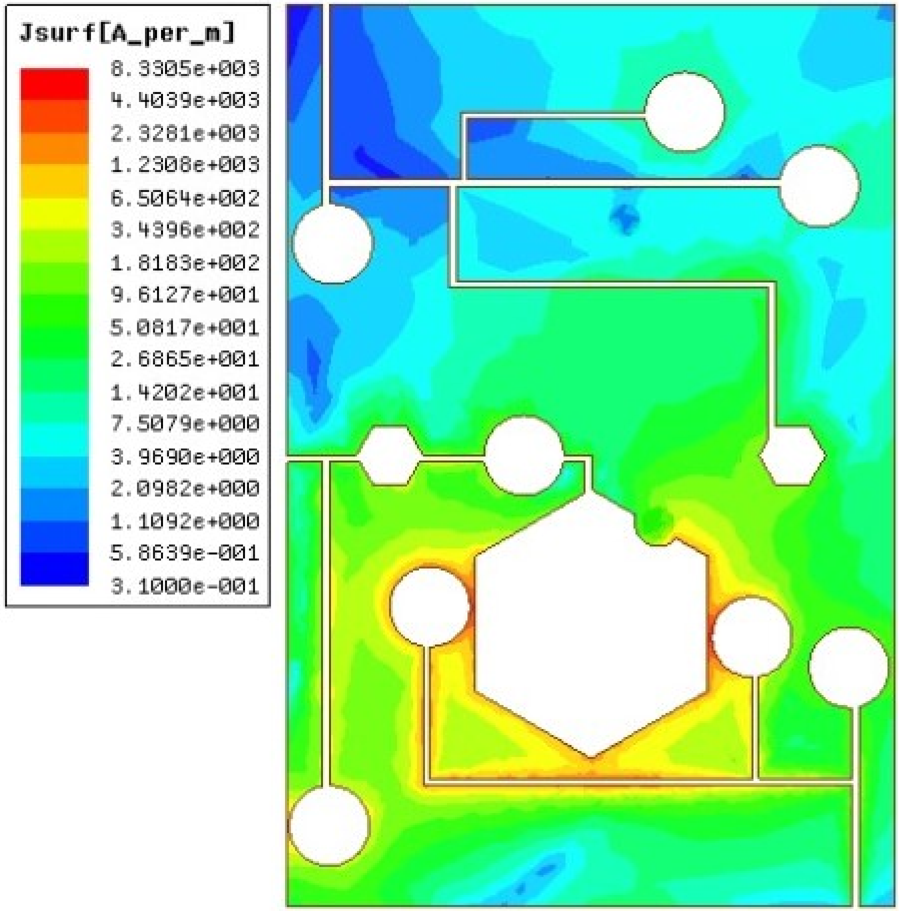


Figure 3.10: Current distribution at 404 MHz.

CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

The presented research contributes to the design of a new prototype Microstrip Planar Inverted-F Antenna for Implantable Medical Telemetry Devices, the simulation was carried out using HFSS software, The aim of this research is to design a narrow-band antenna operating in the MICS band (Medical Implant Communication Service) for wireless telemedicine.

A review of antennas of different applications has been presented in both chapter 1 and 2. In the last chapter a Planar Inverted-F antenna has been designed to operate at 404 MHz band for medical application. A parametric study of its performance including substrate thickness, dielectric material, feed position and shorting pin position has been conducted using HFSS software. The proposed antenna has higher return loss of -52 dB and narrow bandwidth of 2.25 MHz which covers only MICS frequencies band. Moreover, gallium arsenide has been used in the designed antenna and compared to other dielectric materials, it has shown that the utility of gallium arsenide has an important role of improving the antenna performance.

As a future work, it would be interesting to

- Fabricate the proposed antenna;
- Investigating in reducing the antenna size;
- Suggest a new type of implantable antenna;
- Investigating on multiple-band implantable antenna;

Finally, we hope that this work will be beneficial for further implantable antennas applications.

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