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# Bridging the Gap: Investigating New Developments in Biomedical Antennas and Outlining the Future

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**Abstract:** Antennas have extensive usage in Biomedical applications such as in implanted devices, biotelemetry, diagnostic imaging, and biosensing. A Wide range of literature is available that covers various aspects of biomedical antennas. But a consolidated study article is required, one that compares and highlights the design, performance, and difficulties of such antennas using a range of design strategies to enhance performance metrics, like size, bandwidth, efficacy, and the right kind of biocompatible material for data transmission from the human body. Biomedical antenna design is challenging because of the need to minimize electromagnetic interference (EMI), fit the antennas into small devices, ensure biocompatibility with the body, allow for adaptation to biological structures, minimize attenuation of signal and propagation within the body, maintain high power effectiveness, and ensure regulatory compliance. Antennas that transmit diagnostic data from the body to a computer outside the body can be ingested, inserted, or placed. After then, a doctor or other suitable individual can get this data via the Internet. This review investigates non-invasive illness detection using electrical parameters such as resistance and reflection coefficients. Antennas are linked to brain tumors, motion, and breast cancerous growths, but their customization is proving difficult for manufacturers.

**Keywords (in English):** *Biomedical Antennas; Implantable sensors and antennas; MRI; endoscopy*

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# Introduction

Antennas are thought to be crucial parts of a wireless communication system. The size, geometry, composition, and performance parameters (such bandwidth, gain, and efficiency) of a basic antenna design define it. Applications for antennas may be found in many different domains, including power management, RFID (Radio Frequency Identification), Bluetooth, Internet of Things (IoT), wireless local area networks (WLAN), enhanced communication of mobile, and 4G, 5G, and 6G technologies [1].

Among the above-mentioned applications, the use of antennas in health monitoring systems has substantially increased due to recent developments in the field of antenna design. During treatment doctors and patients are more susceptible to exposure to contagious diseases as they are in close contact which can worsen the patient's condition. Because of this, healthcare systems must quickly implement telemedicine-based treatment. Antennas can be used to detect and transmit biological data. The antennas that perform detection functions perform crucial tasks in medical diagnostic techniques, for example, CT scans, ultrasound, magnetic resonance imaging (MRI), etc. Detection antennas transform the acquired signals into data that can be examined using AI to diagnose, monitor, and provide medical care to an individual patient [2]. The act of exchanging information or ideas between individuals or groups. Antennas, on the other hand, serve the purpose of facilitating communication among medical sensors, implants, or wearable devices. In addition to this, individual counseling is necessary to put the telehealth model into practice, which improves patient outcomes despite resource constraints; telehealth and eHealth systems should be promptly taken into consideration [3]. In [4], a T-shaped and U-slot antenna with improved gain and bandwidth was created for health monitoring. Similar to the previous one, this u-shaped microstrip antenna was created for use in medical systems by utilizing a flexible substrate with a broad bandwidth [5]. To obtain circular polarization and a suitable Axial Ratio (AR) bandwidth, the authors of [6] proposed a wide-band implantable antenna with circular polarization and an L-shaped slot. It was now apparent that body-centering wireless networks (BCWNs) were urgently needed for transferring data from a body of patients to a healthcare organization. On the other hand, there has been a significant advancement in wireless communication technology recently. There have been three several kinds of communication utilized in BCWNs: off-body, in-body, and on-body [7].

"On-body communication" type of device is the one which communicates between the devices that have been placed on the body or wearable clothing or affixed on the patient's skin. Conversely, the "off-body communication" devices are the ones that exchange data with other devices that are situated outside of the body's immediate vicinity [8]. In order to facilitate communication with external devices, the "in-body communication" method involves the insertion of electronics inside the body [9]. The category of inbody antennas, as specified in reference [10], encompasses implantable, ingestible, and injectable antennas, which encompass both on-body and off-body varieties. The in-body devices are referred to as implantable when they are surgically inserted into the human body. The most prevalent kind of in-body device is the pacemaker. Those implants can also be made within the body by ingesting devices [11]. One known traditional edible device in wireless capsule endoscopy was discovered in 2000. The ingestible capsules have the ability to monitor medication reactions due to their advanced embedding features [12]. The more sophisticated versions of them are the imaging capsules, that could transmit images from the colon, esophagus, and small bowel without the need for traditional endoscopic techniques. In addition, their variation might incorporate ingestible sensors and capsules for drug delivery. Injectable devices are the last category of micro devices that have been inserted- into the human body using needles. Three categories apply to them: 3D microelectronics, micro-stimulators, and micro-sensors. The injectable microdevices can even reach areas of the body that cannot be accessed using conventional implants. Also, injectable microdevices offer minimal invasive medical procedures.

Methods for illness diagnosis, particularly for skin, brain, and breast cancer, could employ off-body communication without necessitating the antenna to be in close contact with the body. Under such conditions, to detect and identify dangerous transmissions, a communication antenna, often known as an "off-body communication antenna," may be placed on the body or at a specific distance.

A summary of the design concerns and various methods presented in the literature to address application-based challenges has been published. The structure of the paper is given below. Section 2 outlines the survey on literature. Section 3 covers details of Antennas used in detection, diagnosis, and treatment. Section 4 goes on to show examples of various implantable antenna types. Finally, the final thoughts are presented in section 5.

# 1 Literature survey

The introduction of a minuscule three-dimensional spiral antenna designed for application in the field of biomedicine was documented in [5-7]. The MICS band is utilized by the antenna that is being showcased. Achieving a bandwidth of 225.5 MHz (55.7%) is possible with a frequency of 405MHz. The suggested antenna has dimensions of 14 x 14 × 15 mm³. In order to achieve these dimensions, a process of optimization is conducted, initially evaluating various spiral designs and subsequently choosing the most optimal dielectric material. The study discovered that using a material with greater relative permittivity results in the creation of a smaller as well as more effective antenna. An additional method of optimization had been presented with PIFA (Planar Inverted-F Antennas) grounded via pins. A remarkable achievement is the reduction of volume by 55%, while only experiencing a minimal loss of 1.4dB in antenna gain and bandwidth. Several homogeneous phantoms exhibit stable behavior from the developed antenna. Homogeneous muscle equivalent phantom SAR (Specific Absorption Rate) was used to calculate body model power absorption. The antenna power must be 7.4mW, according to the results.

In [6], the miniaturized slot PIFA construction with triple band insertion is presented. The antenna can function at 433 MHz in the MICS band, 1430 MHz in the WMTS band, and 2.4GHz in the ISM band. The antenna that is being presented has dimensions of 19 × 30 × 1.6 mm³ and a volume of less than 1 cm³, which is approximately 50% smaller in comparison to that of typical E-shaped patch antennas [13]. This had been accomplished by using shorting pins and settling the appropriate feed locations. In [9], an implantable folded dipole antenna with adjustable settings that operates at 2.45GHz in the ISM band is presented. The antenna's resulting bandwidth is approximately 50.2%, and its dimensions are 8.5 × 25.9 × 3.2 mm³. The polydimethylsiloxane (PDMS) substrate and superstrate had been utilized in the procedure of optimizing the antenna dimensions. A particular liquid has been used to replicate the tissue of human muscles. Although the antenna's SAR value is acceptable, its size prevents it from being implanted right away. The created antenna can be used to track vulnerable individuals and animals, as well as monitor blood pressure and temperature [14].

The IPD (Integrated Passive Devices) design had been used to create an electrically tiny antenna, as demonstrated in [15]. There have been two suggested antennas. First, there is a planer antenna measuring 18 × 50 mm², and then there is a monopole antenna measuring 5.3 × 3.25 mm². There has also been a discussion of the managed monopoles fed by microstrip as well as CPW (Coplanar Waveguide) lines of transmission. The RF front-edge and planner antennae are connected via small bumps. The system that is inserted is enclosed in a capsule and has a microphone and batteries. The arm has been deliberately curved to decrease the monopole antenna size. Both antennas' results at 1.9 GHz demonstrated good efficiency, with quality factors of 9.4 and 10.9.

## 2 Antennas Used in Detection, Diagnosis and Treatment

Biomedical antennas can be used in detecting critical diseases. Applications for biomedical antennas include detecting a paralyzed person's muscle movement, detecting tumors using magnetic resonance imaging, and using microwave imaging. Body tissue function is diagnosed using antenna characteristics such as near-field radiation, impedance, and reflection coefficient.

### 2.1 Breast Cancer Detection Antennas

Antenna designs for breast cancer detection normally comprise many antennae that are placed on the breast or chest in order to pinpoint the precise spot where cancer cells are present. A number of publications have suggested using antenna arrays for this purpose. Using a spiral microstrip topology, the maximum gain of 17 dBi was obtained at 2-4 GHz in reference. In addition, other authors' designs have taken advantage of the FR-4 substrate. Other flexible materials that some authors suggest are polyester, denim, cotton, and Kapton. The majority of antennas utilized for this application operate in the 2–15 GHz range, with the exception of a few THz frequencies that are specified in . The following provides an overview of the research on antenna designs for breast cancer detection.

In, a 3D phantom model of breast tissue was created in the CST studio using a THz band antenna. Antennas, both horizontal and vertical, operating at a frequency of 0.302 THz were positioned apart from breast tissue. Over a 2 mm matrix, the antennas were permitted to move. A 2-D front view of the breast tissues is created from data that is received at the receiver antennas. The final image is composed of various colors, with blue denoting fat and yellow representing the tumor. As a result, the tumor's location can be accurately determined with this scheme without the need for antennas on the breast tissue. The results show a bandwidth of 22.68 GHz and a gain of 5.6 dB.

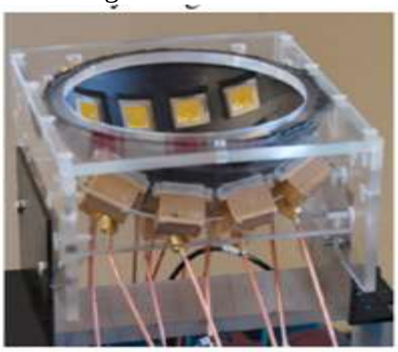

Figure 1. Antenna for breast cancer detection

### 2.2 Skin Cancer Detection with Antennas

For skin cancer detection, antennas need to have high directivity, narrow beamwidth, high gain, and wide bandwidth. The best gain of 12dBi and highest bandwidth were achieved by the (SIW)-based antipodal Vivaldi antenna in, which also had the highest return loss of −60dB. The UWB Microstrip with circular slots came in second with a 50dB return loss. Additionally, smaller antenna designs are favoured for the detection of skin cancer.

The Vivaldi antenna, is intended to function at four sub-GHz bands. In, authors proposed the use of artificial magnetic conductors, or AMCs, to reduce the size of the antenna. Figure 6 shows AMC, which is metallic repeating patterns on the dielectric substrate. The reflective plane in this design allows the phase of reflection coefficient to vary from -180o to 0o depending on the antenna size, whereas the conventional ground plane only permits 180o of reflection. Dimensions of the suggested antenna Using Felt as the substrate material, the 36 × 48 × 6.12mm$^3$ operated between 8 and 12 GHz ($\epsilon_r$ = 1.22). The electro-textile, called Zelt, is flexible enough to deform and provides a superior level of protection. The antenna offered a 4 GHz bandwidth

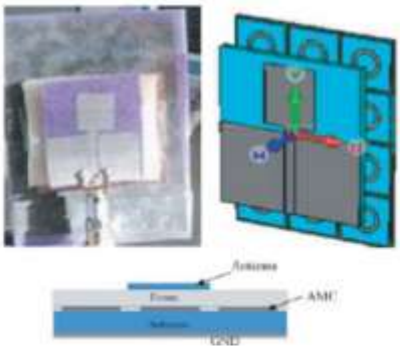

Figure 2. Antenna for Skin cancer detection

It had been recommended in to use a rectangular slot antenna operating at 0.8 THz for early-stage skin cancer. The improved Q-factor was made possible by the rectangular slot and array. Although metasurfaces is thought to be a good candidate for high-quality cancer diagnosis it makes the design complicated. The Q-Factor for the healthy cell was 11.24, which was more than the 8.6 for the malignant cell. A Vivaldi antenna with a grating reflector and a series of photonic crystal shields have been integrated to enhance the antenna's capacity to detect cancer. The antenna carries on with its analysis using Debye's model for skin and breast tissue. Analysis of the reflection and transmission characteristics, pulse response, and phase variation of both tumor and normal tissue are necessary for the reorganization of cancer [24]. It is challenging to incorporate the photonic crystal and grating into the design, though.

### *2.3 Endoscopy Antennas*

The Loop antennas are preferred because they can be wrapped around the capsule during endoscopy. A maximum gain of −40 dBi was achieved with the meandered line structure designed in whereas the microstrip antenna design mentioned in [16] offers the best return loss of −45 dB. Biocompatible and pliable materials such as Kapton, Silica, polyamide, and Parylene-C are selected as substrates in this scheme; additional materials are listed in Since the size of the antenna and the capsule are similar, small antenna sizes are recommended. The discussion that follows is an overview of the endoscopy antennas.

A dual polarization omnidirectional dielectric resonator antenna (DRA) was proposed by authors. If the internal antenna's linear polarization causes changes in the implantable and external antenna's angles, the main issue is polarization mismatch thus it will have an impact on how well they communicate with one another. If the implantable antenna moves and rotates inside the intestine, it will not be possible to identify the antenna's direction of polarization. To reduce the size of the antenna, the authors suggested using variable-length curved slots. 200 MHz is the bandwidth that the antenna offers. The antenna measures 3.5 mm × 0.3 mm and has a gain of -13 dBi to -15 dBi.

The use of meandered loops, or Hilbert curve-type fractals, to achieve the antenna's reduced size and broadband properties was shown. The addition of a meandered lines structure yields several benefits, such as increased electrical length, miniaturization, and bandwidth improvement. The antenna measures 6 × 6 mm$^2$ and is made of a flexible liquid crystal polymer (LCP) substrate. With a gain of -41dB, this design offers superior size reduction along with a high bandwidth of 1200MHz. Figure 6 displays the creation [26].

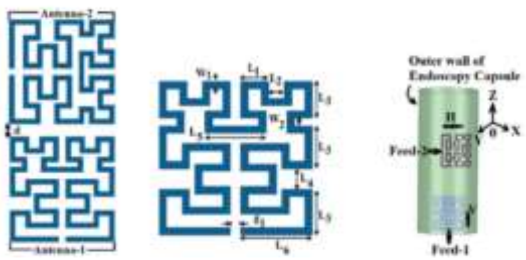

Figure 3. Antenna for capsule endoscopy

### *2.4 Detection Antennas for Glucose*

The best option for glucose monitoring is the CSRR antenna in which has the highest return loss of −60dB and a gain of 9.5 dBi. In contrast, the largest bandwidth is offered by a pyramid-shaped antenna that operates at 4.7 GHz. Glass, FR-4, and RT/Duroid 5880 are good substrate materials for glucose detection. contains details and a summary of the literature, which is mentioned below.

In [27], a non-invasive technique for measuring blood glucose was presented. Using an RT/Duroid 5880 substrate with antenna dimensions of ($36 \times 36 \times 1.57$ $mm^3$), the variation in blood relative permittivity aids in measuring the concentration of glucose. The measurement is done at the 27.76 GHz band. The indicated antennas have a 9.5 dBi gain. The complementary split ring resonator reduced the size of the antenna while increasing its gain, efficiency, return loss, and bandwidth.

In a textile substrate-based monopole antenna-based sensor antenna for glucose detection was suggested shown in figure 7. The design takes into consideration all glucose levels associated with diabetes. The antenna is 35 x 35 $mm^2$ and operates at 2.4 GHz. By modifying its resonance frequency, an antenna-based sensor's reflection response may be modified to detect variations in glucose concentration [38,39].

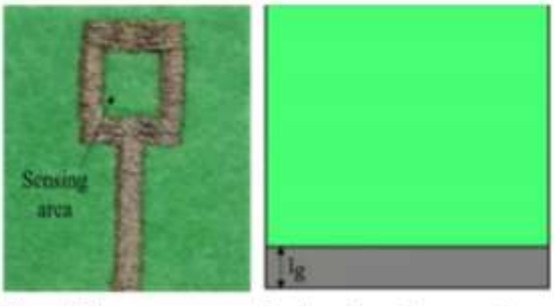


Figure 4. Antenna for glucose detection [26,27]

### 2.5 Brain Tumor Detection Antennas

Most antennas in this scheme are designed with the FR-4 Substrate, primarily operating in the 2 to 8 GHz frequency range. The microstrip antenna in claims the best return loss and gain, but the antenna designed in offers the largest bandwidth. The following details are discussed:
In [39,40], the authors proposed the Vivaldi antenna. The frequency range that the antenna covered was 2.33–7.09 GHz. The maximum gain offered by the designed antenna is 6.62 dB. The performance was improved with the addition of a U-shaped slot, yielding a return loss of 35.28%, a gain of 10%, and a bandwidth of 2.7%. The dimensions are measured using FR-4 substrate and are 55 mm by 65 mm. A confocal microwave imaging algorithm uses the S-parameter data from an x-y scanning mode to reconstruct tumor images inside the human brain. Reconfigurable antenna array for early-stage brain tumor detection; reconfigurable was made possible by three single pole double throw switches, as described . The suggested antenna uses a FR-4 substrate and runs at 2.4 GHz. Reflection coefficient curves show that as tumor size increases, there is a frequency shift toward the left.

Figure 5. Antenna for brain tumour detection [34]

Table 1. Diseases using biomedical antennas of Challenges and possible solution)

| Diagnosis of diseases using biomedical antennas | Issue | Challenge | Solution |
|---|---|---|---|
| Breast cancer antenna | Frequency Selection | The antenna's effectiveness and its capacity to distinguish between distinct tissue structures are impacted by its wavelength selection. [17] | It is important to run thorough electromagnetic simulations to make sure the SAR levels stay within acceptable bounds. |
| skin cancer antenna | Skin contact and coupling | Precision measurements depend on establishing adequate interaction with the skin and making sure there is an effective coupling between the and the skin. [21] | Include adaptive and responsive technologies in the structure of the transmitter to ensure consistency and adaptability to the skin's contours. [23,27] |
| Endoscopy | Penetration | Antenna efficiency and quality of signal | Although greater wavelengths have |

| | | | |
|---|---|---|---|
| antenna design | Depth | can be impacted by the attenuation and distortion of electromagnetic signals caused by the structure of human materials [26]. | restricted transmission but offer greater clarity, smaller frequencies may compromise accuracy in favor of more effective penetration. [22] |
| Brain tumor antenna design | Signal propagation in Brain Tissue | Differential electrostatic properties in brain cells can impact signal transmission and potentially result in imprecise recognition [34]. | Enhance the antenna's substance and hydrophobic characteristics. By carefully choosing an antenna substance with the right dielectric qualities, you may lower signal losses in brian tissue and increase signal effectiveness [33]. |
| glucose detection antenna | Power Efficiency | The battery life of implanted glucose monitors is restricted. [24] | Employ low-power antenna structure: To increase the battery life of the gadget, and maximize radiation efficiency and power consumption of the antenna. [26] |

## 3 Antennas For Treatment Applications

Through image-guided thermal ablation (hyperthermia), antennas are now an effective treatment for several diseases, including cancer, hepatocellular carcinoma (HCC), and tumors. It offers a less invasive and more affordable form of treatment for the patients as well as susceptible to tumor locations that are not ideal . It increases chemotherapy's effectiveness and radiotherapy, with a success rate of more than 90% for eliminating small tumors (less than 1.5 inches in diameter) and a patient survival rate of 33-57% over 5 years.

*Image-guided thermal ablation*: Two popular therapeutic modalities used globally are microwave ablation (MWA) and radiofrequency ablation (RFA). Thermal ablation uses the difference in thermal sensitivity between the tumor and normal tissue as a therapeutic tool. RFA delivers therapeutic energy to the tissue by inducing an electromagnetic field at frequencies between 460 and 550 KHz [26,27]. By increasing the temperature to 1000 C for roughly fifteen minutes, this energy kills the tumor. For patients with stage 0-A hepatocellular carcinoma (HCC) who are unable to undergo surgery, RFA is the recommended course of treatment, according to BCLC [28].

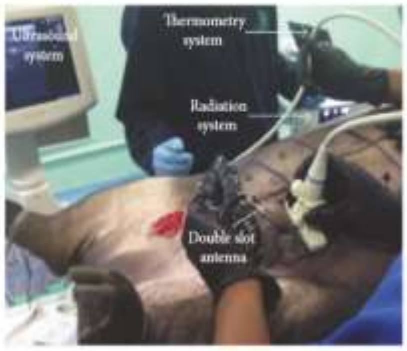


Figure 6. In vivo swine mammary gland experimentation [43]

*Antenna design specifications for the ablation process*

*Antenna shape*: To inject into the tumor, long, interstitial coaxial antennas in the shape of a needle are needed. A variety of design strategies, including choke, slot, dipole, and monopole, are employed to reduce the reflection coefficient.

*Changes in tissue characteristics during heat ablation*: The mechanical, thermal, and dielectric characteristics of tissue are altered by thermal ablation; the size of the ablation zone is established by the interaction between the tissue and electromagnetic waves. As a result, the FDTD computation is used to carry out EM calculations in the near field zone. Thus, antenna designers need to take into account the modifications to tissue properties during the design phase [46,47].

*Reducing radiation along the antenna axis*: surface current travels the length of the coaxial conductor, but interstitial antennas deposit energy close to the aperture of the tip. Since it overheats the healthy tissue, backward heating should be prevented by using the right procedures [49,50].

*SAR growth in spherical Ablation zone:* SAR is assessed after the EM field computation. It describes the tissue's heating temperature. According to SAR distribution, the majority of the antenna's ablation zone has an ellipsoidal shape, but a spherical shape is preferred for safe therapy. Tissue temperature is numerically determined using the finite difference model and the bioheat transfer equation once the ablation zone has the correct shape [51,52].

# 4Types of Implantable Antenna

Many implantable antenna types exist, and this section will cover the main varieties based on the intended use.

## *4.1* Planar Antennas

In, a proposed wideband implantable antenna with dimensions of 12×7.5×0.25 $mm^3$ and a Rogers 6010 LM substrate (with $\varepsilon_r$ =10.2) is suggested to be probe-fed. The five frequency bands in which the antenna operates are 403–405, 433.1–434.8, 868–868.6, 902.8–928.0, and 2.4–2.48, as stated in reference. A meandered line implantable antenna at 2.45 GHz and 915 MHz for intracranial pressure monitoring was proposed [24]. The antenna uses Rogers 6010 as the substrate and has a volume of 8×6×0.5 $mm^3$. The substance is enclosed in ceramic alumina for biocompatibility. A 200×200×200 $mm^3$ human skin tissue model is used to test the effectiveness. At 915MHz, the antenna's gain and bandwidth are 9.84% and -22.8 dBi and 8.57%, respectively, while its efficiency is not stated.

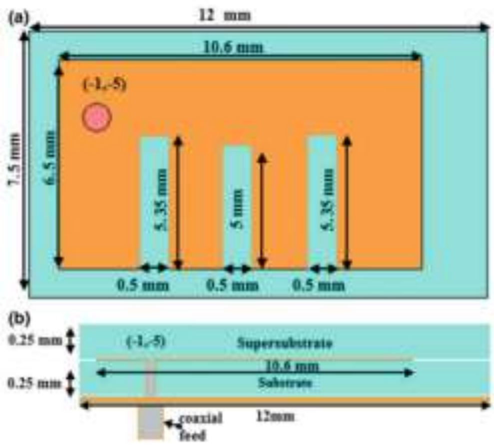


Figure 7. Planar Antennas [24]

## *4.2 Wire Antennas*

They propose an implantable antenna with a circular polarization (CP) helical structure for use in edible capsules. Operating at 2.4 GHz, the antenna has a bandwidth of 290 MHz and a gain of -19.83 dBi. Antenna reflection coefficient and 3D capsule model [27].

A 50 Ω coaxial probe fed conical spiral antenna with a 10 MHz bandwidth and 450 MHz operation is shown in [29]. There is no mention of the antenna's efficiency or gain. The measurements are performed using a liquid phantom with εr=0.83 S/m and εr=56. Reflectivity coefficient and antenna design.

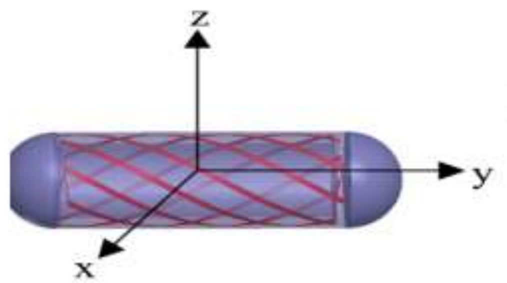


Figure 8. Wire Antennas [29]

## *4.3 Conformal Antennas*

A 2.45 GHz conformal CP implantable antenna with a biocompatible PDMS, $\varepsilon_r$=2.2 and tanδ = 0.013, is described in [30]. 25.9 × 8.5 × 2.54 $mm^3$ is the antenna's dimensions. Antenna gain and frequency - 23.98 dBi and 31% bandwidth. It is not stated how efficient the antenna is. Muscle phantom is used to test antenna performance $\varepsilon_r$ = 52.74 and σ = 1.95 S/m, and dimensions of 80×50×20 $cm^3$. The antenna's geometry and reflection coefficient.

## *4.4 Spiral Antennas*

They propose a CP loop antenna. This antenna in [37] uses 0.635 mm Roger 3010 as the substrate and superstrate material, with $\varepsilon_r$ =10.2 and tanδ = 0.0035. The antenna has dimensions of 13 x 13 × 1.27 mm3 and operates at a central frequency of 915 MHz. The antenna possesses a bandwidth of 18.2% and a gain of -32 dBi. The testing is conducted on minced pork, gel with a texture similar to skin, and models of skin tissue.

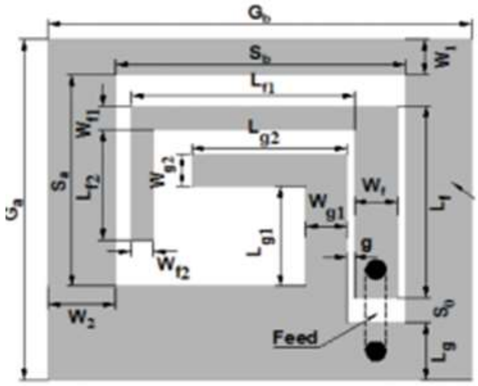


Figure 9. Spiral Antennas [37]

## *4.5 Slot Antennas*

In [38], a coplanar waveguide-fed triangle slot antenna is suggested. As illustrated in Fig. 13, the antenna measures 10×10 and has a resonant frequency of 2.45 GHz. When tested in a liquid phantom, the antenna with Al2O3 as the substrate exhibits a peak gain of -6 dBi and a bandwidth of 8.2 percent. Antenna radiation efficiency is 0.4%. present a wideband flexible antenna in [39]. The Kapton polyimide substrate, with $\varepsilon_r$ =2.91 and tan δ=0.005, is used to design the antenna. The superstrate is Rogers 6010 with $\varepsilon_r$ =10.2 and tanδ=0.0023. To increase the gain, a metamaterial array is positioned at the top of the superstrate.

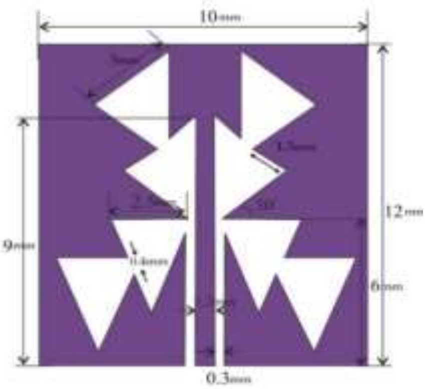


Figure 10. Slot Antennas

### *4.6 Planar Inverted F Antennas (PIFA)*

In[41], a small, 402 MHz implantable broadband PIFA with dimensions of 23 × 16.4 × 1.27 $mm^3$ is proposed. The substrate has tanδ=0.0023 and $\varepsilon_r$ =10.2. The antenna is achieving a gain of -34.9 dBi and a 52 MHz bandwidth.

In [42], a PIFA with a slotted ground plane. The substrate and superstrate used in the antenna are a layer of Rogers 3010 ($\varepsilon_r$ =10.2 and tanδ=0.005), 0.635 mm thick, with an overall size of π × 5.352×1.34 $mm^3$. the antenna resonates at 402 MHz and 2.45 GHz. The antenna's bandwidth and gain at 402 MHz are 41% and -21.3 dBi, respectively, whereas at 2.45 GHz they are 27.8% and -21.3 dBi. The measurements are based on minced pork

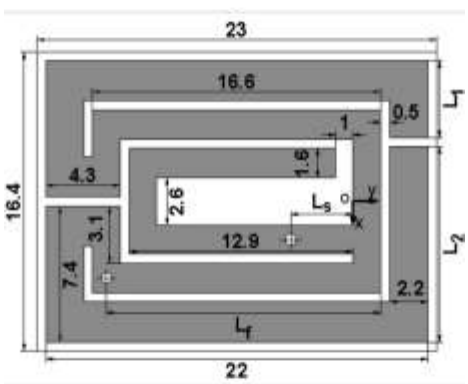


Figure 11. Planar Inverted F Antennas (PIFA) [42]

### 4.7 ***Fractal antenna***

In [31] a compact hybrid fractal antenna is designed using an FR4 substrate with a thickness of 1.6mm with εr =4.4 and tanδ=0.02. The antenna resonates at 2.44 GHz and 5.44 GHz. The peak gain at 2.44 GHz is 4.69dB and at 5.44 GHz is 15.11 dB.

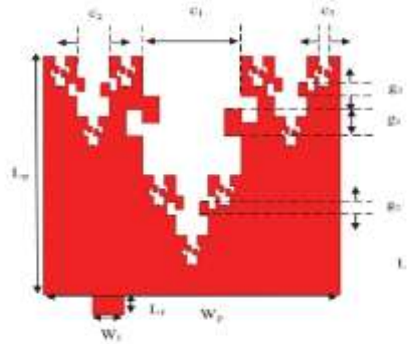

Figure 12. Fractal Antenna [32]

Table 3. Comparative analysis of implantable antennas.

| Antenna and Application | Reference | Frequency | Gain (dBi) | Bandwidth | Detection Scheme |
|---|---|---|---|---|---|
| Planar and Brain implant | [41] | 433 MHz | - | 33.5% | Reconstruction Image |
| Intracranial pressure PIFA | [31] | 2.4 GHz | 24.9 | 22% | Difference of Electrical Field Distribution |
| Retinal implant | [16] | 1 MHz | 28.5 | 14.9% | S parameter difference |
| Cochlear implant Wire | [42] | 915 MHz, 2.45 GHz | 19.63 | 8.57% | Reconstruction Image |
| Brain implant and pacemaker | [52] | 860 to 960 MHz | 36.82 | - | Communication |
| Glucose monitoring | [36] | 2.07 GHz | 1.38 | 3.4% | SAR variation |

| | | | | | |
|---|---|---|---|---|---|
| Glucose sensing | [37] | 2.45 GHz | 2.17 dB | - | Microwave Imaging |
| Cell rover | [38] | 11 MHz | 3 | 12.2% | Variation in received signal amplitude |
| MIMO | [12] | 2.40 to 2.48 GHz | 17 | 8.9% | Reconstruction Image |
| Solt | [32] | 402.5 MHz | - | - | |

# 5 Challenges and Research Gap

The antenna's polarization, biocompatibility, miniaturization, and SAR limitations are just a few of the challenges that the author addresses which are as discussed below:-

### *5.1 Miniaturization of Antenna Size*

An additional approach to achieving the antenna's small size is to add a meandered line to the current flow of the antenna, which reduces the radiator's effective length as noted in [48], and stack the substrate, as covered in [19]. Some have proposed ground plane modifications as a means of achieving **miniaturization.** But along with poor polarization, reducing the ground plane may have an impact on the input impedance. Furthermore, a decrease in the front-to-back ratio is observed as a result of the edge diffraction effect, leading to an increase in back radiation

The miniaturization recommended in [45] and [46] is also made possible by loading and shorting pin techniques. Although the antenna size can be decreased by applying a short pin between the ground and the patch, the electric field is greatest at the edges and lowest in the center. On the other hand, the gain and directivity can also be decreased [47] defining the short pin relation with antenna bandwidth

### *5.2 Biocompatibility Materials*

The most promising material for the design of flexible antennas is polyamide (Cardura), while copper tape is used to make the conductive components. P1168 material is regarded as a flexible, highly conductive fabric [53,54], as it indicates. Another problem is that the biocompatible layer on the antenna has low permittivity values, which lower effective permittivity and deteriorate the miniaturization that was made possible by the tissue's high permittivity material.

When choosing insulation materials, there are a few key factors to take into account. For example, a higher permittivity value allows the near field to concentrate more inside the encapsulation, reducing power losses. Since the capsule comes into close contact with human tissues, biocompatibility, and mechanical compatibility should be taken into account to minimize physical damage to the tissue and protect electrical components from corrosion. TiN, or titanium nitrate, is thought to be an extremely conductive and robust substance that [55] may be utilized for medical implantable devices Additionally, this content is appropriate for upcoming implantable gadgets and communication systems

### *5.3 Antenna Polarization*

A dual-band textile antenna with dual circular polarization for off-body communications was proposed in [33], where authors also mentioned the need for SAR consideration, antenna deformation structure, and polarization mismatch in early-stage antenna design for wearable applications. About the human body, authors [56,57] in proposed the use of omnidirectional radiation patterns and vertical polarization with large ground. According to research work mentioned the wearable antenna should be properly coupled with the human body to minimize polarization mismatch caused by the change in reflected wave polarization caused by head, arm, and leg rotation.

### *5.4 Stretchable Materials for Antenna*

According [58] to stretchable materials have drawn a lot of attention because of their capacity to reshape without endangering the structure. One of the main issues with stretchable antennas is their low radiation efficiency. Several conductive materials have been suggested by authors as a solution to this problem. They recommended using conductive doping materials, such as silicone embedded with silver flake, silver-loaded fluorine rubber, carbon nanotube-based films, liquid metals inserted into the stretchable substrate, or stretchable cloth[59]. Therefore, it's important to choose stretchable material carefully.

### *5.5 Specific absorption rate (SAR)*

Developing the biomedical antenna presents significant challenges related to specific absorption rates (SAR). It is a measurement of the body's absorption of radio frequency (RF). The standard FCC regulations stated in [60] state that the average weight of 1g of tissue from any part of the head or body cannot be more than 1.6 W/g and that the hands, wrists, ankles, and feet can have an average weight of 4 W/g over 10g. The Antenna was in [19] placed on the shoulder and chest, and the SAR was determined. Using phantoms, CST/HFSS is already available in their library to evaluate the performance of the antenna, particularly for SAR computations.

# 6 Emerging Areas of Biomedical Antenna Research

### *6.1 Advancements in Antenna Design*

The design of biomedical antennas is reshaping the wireless healthcare sector by enhancing performance, miniaturizing size, and improving flexibility. Creating small and light weight flexible antennas tailored to the human body will aid in the comfort and ergonomics of implanted and wearable electronics. Modern research focuses on improving the radius of efficiency, bandwidth, and gain for biocompatible structures using metamaterials and plasmonic structures. For medical telemetry and monitoring, reliability of information transmission is ensured by multiband and ultra-wideband antennas using continuous connection throughout the frequency ranges. Besides, passive systems with ultra-low power consumption strategies built by energy scavenging or backscattering are offered by these implanted systems. The integration of these advancements with adaptive beamforming and AI powered optimization is enabling the development of more robust, low-power, high-performance biomedical wireless systems to improve patient care and increase the role of telemedicine.

### *6.2 Advancements in Material*

The introduction of innovative, biocompatible materials is helping to reshape the design of biomedical antennas by enhancing performance, lifespan, and safety during medical procedures. The use of biopolymers, hydrogels, and liquid metals are being studied for the purpose of fabricating flexible and stretchable antennas that can be attached to biological tissues. Mg-based and silk-based composites are being studied as bioresorbable candidates for temporary implants that do not need to be surgically extracted. 2D nanomaterials, including graphene, have excellent electrical conductivity and mechanical strength, which make them ideal for small and low power biomedical antennas. Biocompatible polymeric nanocomposites are able to retain good electromagnetic characteristics and are additionally able to withstand large mechanical stresses due to the presence of conductive nanostructures. Such advancements lead to the creation of more capable and efficient wearable and implantable devices of the future, which will support better communication in the healthcare system, lower immunological reactions, and better overall performance during implementation in healthcare.

### *6.3 Advancements in Signal Processing and Non-Invasive Diagnostics*

The development of biomedical antennas for high power yet low efficiency healthcare communication together with advancements in signal processing technologies creates new possibilities for communication enhancement. Modern biomedical telemetry uses artificial intelligence technologies and machine learning models to achieve accurate data collection and eliminate interference. The use of smart channel modelling combined with adaptive beam formation adjusts transmission responses based on human body tissue interactions to enhance wireless communication capabilities. Microwave and RF imaging technology supports non-invasive early disease diagnosis along with applications such as tumor detection and stroke evaluation. Constant monitoring of health issues such as glucose levels and dehydration through RF powered sensors has facilitated advancements in wireless bio-sensing technologies. The integration of biomedical antennas with 5G and IoMT networks enhances remote patient monitoring and telehealth capabilities while smart health devices continue to expand their functionality. These advances allow for enhanced treatment quality and immediate responses to specific diseases while enabling smart diagnostics that operate more efficiently and with less intrusion.

# 7 Conclusion And Future Work

A rapidly developing field of technology, antenna design has the potential to link body sensor nodes wirelessly, provide a minimally invasive, inexpensive, and straightforward method for thermal ablations, and be a safe, non-invasive, and extremely sensitive instrument for medical diagnosis. Several antenna types are studied qualitatively in a variety of application domains.The many implantable antenna designs that are available in the public domain, such as planar, wire, conformal, spiral, slotted, and PIFA structures, are thoroughly reviewed critically. Although the choice of antenna type is often application-specific, patch structures have shown a greater potential to effectively meet the majority of the requirements.

A review of biomedical antennas for the detection of various diseases is presented in this paper. Breast cancer, skin cancer, brain tumors, lung cancer, glucose detection, and endoscopy are among the illnesses taken into consideration. The talk revolves around the appropriate frequency bands that are employed to detect the diseases listed above. Since a small antenna is needed for several applications, the techniques for reaching miniaturization which are covered in the literature review are also covered. Furthermore, the antenna must be biomedically compatible to be placed on or inside the human body various types of antennas concerning gain, bandwidth, frequency, cancer detection method, and substrate material for the aforementioned diseases. The Specific Absorption Rate (SAR) for 1g and/or 10g tissue is determined for antennas positioned at different body sections or phantom sites. Because of the affects the human body has on these devices, it is crucial to consider them while building antennas. The paper concludes with a preliminary presentation of results from an efficient miniaturized antenna design for implanted devices that aims to meet the requirements discussed in earlier parts.

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