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Medical Communication Systems Utilizing Optical Nanoantenna and Microstrip Technology

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Abstract
Many technical approaches were implemented in the antenna manufacturing process to maintain the desired miniaturization of the size of the antenna model which can be employed in various applied systems such as medical communication systems. Furthermore, over the past several years, nanotechnology science has rapidly grown in a wide variety of applications, which has given rise to novel ideas in the design of antennas based on nanoscale merits, leading to the use of antennae as an essential linkage between the human body and the different apparatus of the medical communication system. Some medical applications dealt with different antenna configurations, such as microstrip patch antenna or optical nanoantenna in conjugate with sensing elements, controlling units, and monitoring instruments to maintain a specified healthcare system. This study summarizes and presents a brief review of the recent applications of antennas in different medical communication systems involving highlights, and drawbacks with explores recommended issues related to using antennas in medical treatment.

Keywords
Microstrip patch antennas, Nanotechnology, Optical Nanoantennas, Medical Systems.

I. Introduction

The word antenna was first introduced in the fifteenth century as a compilation of Aristotle's writings and used to assign a lateen's sailing yard including those of tents or ships [1]. It referred to the "Greek" word "Kerala" related to the "horns" of insects and derived from the Latin language antenna which combines the prefix 'an' which means 'up' and the Indo-European root ten meaning 'to stretch' to point to various kinds of posts. In the late nineteenth century, the scientist Marconi presented the term antenna in the context of his first wireless communication invention while performing wireless radio apparatus [2]. In his experiment, the antenna was represented by an elevated sheet made of copper and connected to a Righi spark gap that was powered by an inductive coil via a telegraph key on-off switch to spell out text messages in Morse code [1]. With the rapid evolution in the aspects of modern life; An antenna was defined as a device used for transmitting or receiving radio waves that serve as a bridge between free space and a guiding mechanism in radio engineering applications. Conventional antennas are widely used in a variety of communication systems with different properties and configurations such as active loop antennas, horn antennas, mono loop antennas, wide pole antennas, and correction antennas [3]. The huge development in communication apparatuses results in conventional antennas becoming unable to respond to these enlarged requirements and increasing demands of high-speed communication systems, so different engineering techniques of manufacturing antennas employing different industrial technologies such as nanotechnology were carried out to realize the required performance of the communication systems [4]. Different antenna configurations in the field of nanoantenna technology can be categorized as nanometer-scale antennae made of metallic structures that are capable of enhancing the optical radiation interaction with

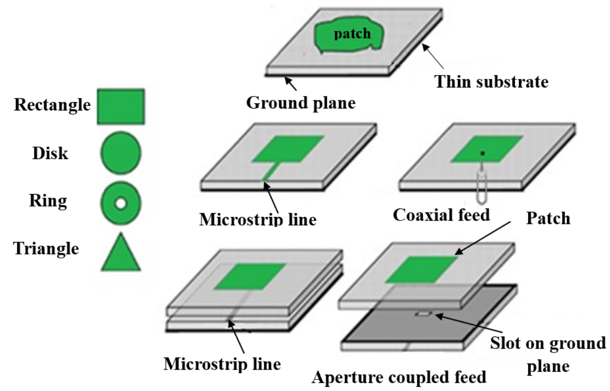

Fig. 1. The Microstrip Patch Antenna Basic Shapes and The Feeding Methods [5].

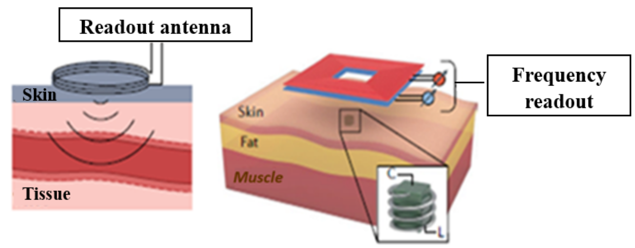

Fig. 2. Implementation of the wearable antenna on the skin of the human body [18].

the object based on the merits of nanotechnology that allow a lot of domains in manipulating materials on nanoscale dimensions [5]. Some medical applications deal with different antenna configurations, such as microstrip antennae and optical nanoantenna in conjugate with sensing elements, controlling units, and monitoring instruments to maintain a specified healthcare system. Much research and development has gone into the planar antennas known as microstrip antennas and has found extensive use in commercial and medical wireless communication applications [2–5]. One of the most common types of microstrip antenna is known as a patch antenna made of various shapes like rectangular, circular, or diamond as shown in Fig 1.

These configurations of microstrip patch antennae can be made of several materials such as copper, silver, and gold as well as composite materials with proper technology to construct the required antenna used in medical applications and the design steps of an optical antenna and microstrip patch antennas require specific procedures that must be implemented in the scaled-down [6, 7]. It can be noted that microstrip patch antennae are frequently used in portable wireless communication devices due to their special advantages of miniature, conformal, and low-cost characteristics besides their compactness and simplicity of construction. Different antenna configurations based on nanotechnology merits offer a lot of domains in manipulating materials on nanoscale dimensions made of metallic structures capable of enhancing the optical radiation of antenna interaction with the object [6–10]. In contrast to conventional antennas that seem like elements connected throughout a feeding circuit, an optical antenna converts the energy from free propagating radiation to positional energy and vice versa object [11]. It operates in the optical frequency range of the electromagnetic spectrum and manages electromagnetic waves. This type of antenna has been attractive and trendier in recent years in various communication systems and has received interesting attention in several research in nano-antenna applications [11, 12]. The design of optical antennas in physical optics is still in progress. It has been projected to be a substitute device for detection in the millimeter, infrared, and visible regimes. The fabrication process of optical antennas has been necessitated to employ based on the featured characteristics of nanostructured material leading to potential advantages in the detection of light, including polarization dependency, the ability of tuning, and high-speed response [13–15]. Both microstrip patch antennas and optical nanoantennas can be implemented in medical systems incorporation with human body sensors to provide a safer and more beneficial manner for human body scanning [16–18]. They can be used in some medical applications to send information about the human body status as bio-signals to the external device invoked in the measurement readout unit. These data will be displayed in the monitoring unit to allow analysis and diagnosis of the collected received information of the patient by medical experts as shown in Fig. 2.

It must be taken into account that the design of the medical communication system merged with the antenna required several parameters such as the patient's safety, the compact size of the employed antenna, the electrical properties of the antenna as well as the biocompatibility process [18, 19], Moreover, the overall size and weight of the applied antenna represent the major factor in setting up the bio-integrated electronics devices for detecting either biological skin, tissue, or organs of the human body [20]. These factors can be considered the basic factors in selecting the required antenna model to design a biocompatible antenna that interferes with the human body. In several cases, the antenna in many medical systems can be placed in touch with the skin as shown in Fig.3.

Although radio antennas were widely used as a major part of medical communication systems, the invention of optical antennas can allow a considerable opportunity to design medical systems based on nanotechnology design to gain the benefit of biosensing emerging with bio-nano actuation [21].

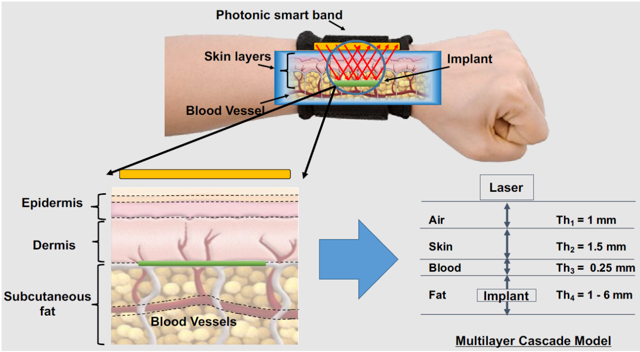

Fig. 3. Modeling of wearable communication channels using a multilayer cascade of skin tissue [19]

The new era of the Internet and telecommunications is being advanced by the advancement of communication devices and wireless network technologies. Every physical object on the earth, including communication equipment, will also be connected to the Internet and managed through sensor networks with antennae for the various ”things” [21, 22]. The nanoantenna plays an important role in this system and emerged with an appropriate controller unit to deliver communicated information data about individuals and analytics have been used by various domains of objectives in the healthcare system as shown in Fig.4.

The need for a higher range of bandwidth and bit rates in recent communication systems motivated many researchers to attempt to design nanoantennas using materials with special characteristics, such as graphene, and using the graphene characteristics which make them suitable for optical communications and sensing applications [23], [24]. The collected results from these studies offer a quantitative description of the antenna's operation and a helpful tool for analyzing the design of microstrip patch antennas and optical nanoantennas in medical systems [25].Due to the importance of an antenna in medical systems, this survey is devoted to discussing the many configurations and technologies utilized for constructing nano and microstrip antenna structures and their application in medical apparatus. Along with a general review of the many configurations of employed antennas that are used to diagnose illnesses and treat patients, Section II. also discusses the various techniques of implemented antennas in medical systems and connected to health care communication systems. Section III. provides the outcomes for the antennas used in various medical communication systems. In Section IV. , the manuscript is concluded.

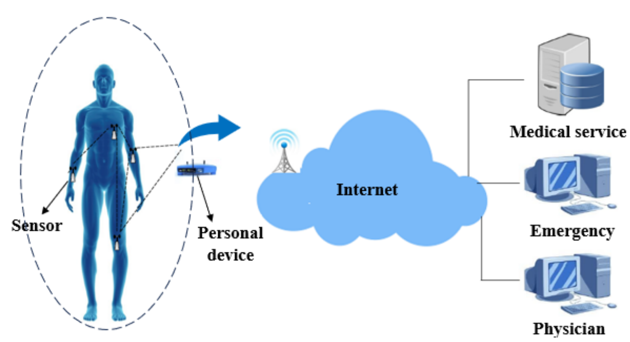

Fig. 4. The antenna in IoNT architecture [21].

II. Some Applications of Antenna in Medical Systems

As indicated in the preceding section, the idea of medical applications systems using various antenna configurations has attracted interest from a range of literary and scientific domains. The antennas were important in these applications, and several kinds of literature were carried out in the medical systems to enhance the performance of the antenna and get the best results involving issues of miniaturization, biocompatibility, and patient safety as shown in the following.

A. *Applications of Microstrip Patch Antennas*

Many medical applications might be regarded as the fastest-growing use of industrial, scientific, and medical (ISM) frequency bands that have been short-range and low-power wireless communications systems [26]. Considerations for these antennas must take into account a variety of factors, including variations in the dielectric characteristics of human tissue, which have an impact on antenna performance, and the specific factor for patient safety systems [27]. In [26] both off-body (free space with room temperature) and on-body (human arm and human chest) scenarios using the microstrip patch antenna functions in the (ISM) band with a resonant frequency of (2.45 GHz) were employed. A rectangular-shaped nickel-copper ripstop conductive textile material was provided along with a microstrip patch denim textile antenna for use in the suggested medical applications. To ensure that the employed wearable antenna system meets the human body's safety recommendations, the antenna's operation at the chosen frequency bands was simulated and tested via a computer software package. In [27], an ultra-wideband antenna design for use in microwave medical imaging applications was presented. The proposed antenna was simulated to gain lower return loss and measurement results are analyzed and discussed which is regarded as appropriate for imaging applications. In [28]a dual-band flexible folded-shorted patch antenna for wearable applications was demonstrated. Flexible polydimethylsiloxane material was chosen as the substrate for the proposed antenna due to its affordability and suitability for wearable applications. In this work, the suggested antenna operates at

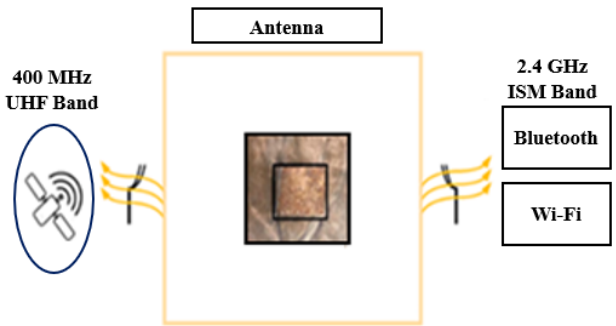

Fig. 5. Wearable antenna for medical care [28].

(400 MHz) and (2.4 GHz) frequency bands appropriate for demanding wearable applications like medical care, emergency response teams, and rescue operations as shown in Fig. 5.

In [29], a flexible microstrip implantable antenna that could be in contact with a person's breast skin was presented. The suggested antenna works with a low rate of power consumption and the longest wavelength transmissions to get essential information on the tissues of the breast and lessen the impact of signal reflection from the breast skin. The recommended antenna was placed in direct contact with the breast skin to improve the tumor detector's sensitivity. In [30], a proposed implanted antenna with a circular maze shape for (ISM) band (2.40–2.48 GHz) has been concentrated.
The measured data and the obtained results from the computer simulation work are proper for use with health safety requirements and permit acceptable wireless communication ranges of biomedical applications. In [31], an implanted microstrip antenna design with a compact geometry was proposed for use in dual-band operations (MICS and ISM) bands in wireless medical telemetry applications. It employed dual-band operation, to enable power savings by enabling the implanted device to remain in sleep mode until an (ISM) signal was received. Data is then sent from the antenna to a base station outside the tissue via the (MICS) frequency. The antenna transmits data in the (MICS) band for patient monitoring, to verify the device's status and battery life, but it won't start sending data until it receives a wake-up signal in the (ISM) band as shown in Fig. 6.

In [32], the requirements of the design process and testing steps of a microstrip patch antenna operating at a 2.4 GHz band used in biomedical implantation were introduced. The chosen antennas are suitable for (IOT) monitoring systems that monitor patient health and provide bio information to distant locations. The suggested design of this antenna has drawn a lot of interest since it addresses issues with miniaturization, biocompatibility, patient safety, and improved communication quality.

In [33] microstrip patch antenna worked on a resonating frequency of 2.4 GHz and suitable for Wireless Local Area Networks (WLAN) was introduced. The proposed antenna was constructed with flexible polyethylene, polyester, and polyamide materials. The results show that types of antenna materials were employed most effectively overall by comparing the voltage standing wave ratio (VSWR) and low return loss.
In [34], a frequency band between (2 GHz - and 4 GHz) has been selected for the proposed antenna array of wireless medical applications. The array antenna's applicability for on-body medical wireless applications has been demonstrated by simulations of the antenna in the low-frequency S-band range. The suggested array's radiation characteristics support body medical wireless applications with a trapezoidal patch microstrip antenna made of FR4 material. A 2×2 array with the same dimensions as the original single-element, 30×70 mm, trapezoidal patch antenna has been illustrated as shown in Fig. 7.

In [35] the design of a rectangular microstrip patch antenna for the (ISM) band is the main subject of this research. The proposed antenna has three regions: a substrate made of a composite of glass fabric and flame-retardant epoxy resin FR4 was used as the basic material for printed circuit boards material, then a patch, and a ground composed of copper material. It was considered best suited for biomedical applications that track patients' health and transmit biodata to distant locations.
A flexible ultra-wideband (UWB) antenna for use in a wearable medical electronic system was suggested in [36]. It used a microstrip patch antenna operating at a resonant frequency equal to 5.6 GHz for use in wireless body-worn applications. Simulation results for the proposed antenna showed low specific absorption rate (SAR) values offered by the antenna and low transmitted power that meet the requirements of a wireless body-worn network.
In [37], the Kapton polyimide substrate was used to manufacture the antenna used in this study with operating frequency

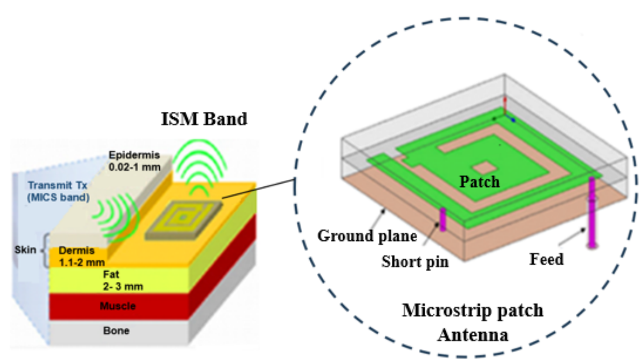

Fig. 6. The dual-band implanted microstrip antenna [31].

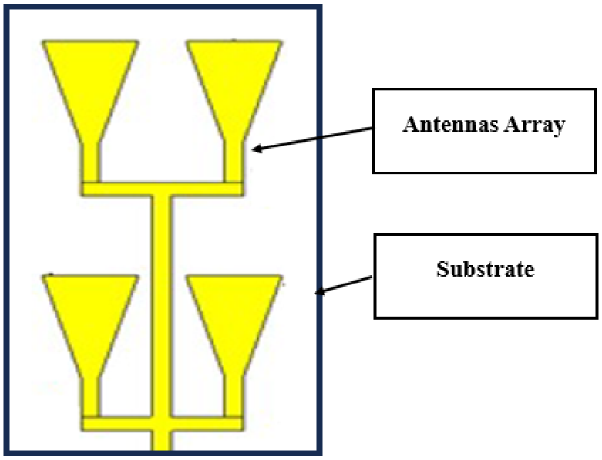

Fig. 7. The suggested antenna array [34].

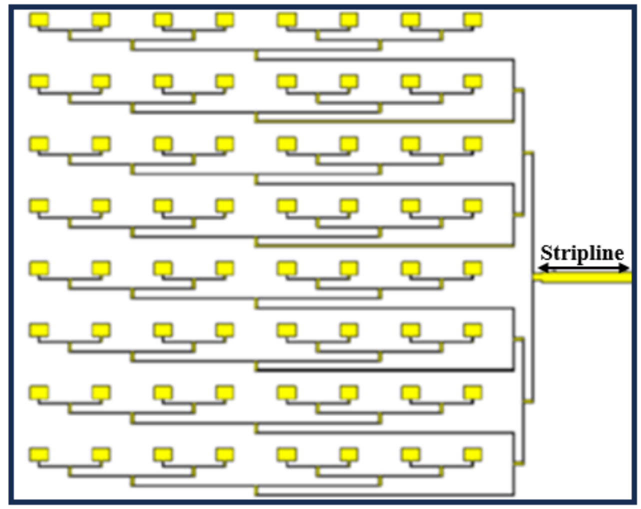

Fig. 8. The layout of the 8×8 array of microstrip patch antenna [39].

bands (2.4 GHz to 7.1 GHz). This study provides a detailed explanation of the substrate selection, design limitations, fabrication procedure, and bending test of the proposed flexible (UWB) antenna. A constructed antenna has been simulated using computer simulation and the proposed antenna was suitable for wearable electrical and biological applications due to its flexible nature, wide frequency bands of operation, and strong bending performance. A wearable antenna can be used for communications like mobile computing, public safety, tracking, and navigation as well as biomedical applications like cancer detection and heart attack detection.

In [38], wearable antenna types that work in the (2.4-2.5 GHz) of ISM bands frequency range were designed using Textile materials like silk, polycot, and denim to construct the substrates of these antennas. The employed antennas are used for both on- and off-body communication applications as well as biomedical ones. Experimental analysis was used to establish the return loss, radiation, and impedance characteristics of the antennas for both the human phantom model and free space settings. The experimental study of the employed antennas in this work showed that the antenna has a specific absorption rate of less than (1 W/Kg), indicating resistance to loading by human tissue. The outcomes of return loss, radiation pattern, gain, and directivity metrics for each of the applied antenna designs are all in the desired range. In [39], demonstrated antenna has higher gain, better return loss, and an acceptable level of voltage standing wave ratio values, for each bandwidth, making it useful for medical applications. The proposed antenna operated at frequencies (22.99/24.24/26.35) GHz with bandwidths of (0.287 GHz, 0.327 GHz, and 0.767) GHz respectively. It used an (8×8) microstrip array patch antenna with spacing between each antenna element designed for ISM and K Band applications as shown in Fig.8.

In [40], a modified meander form microstrip patch antenna for Internet of Things applications (IoT) in the (2.4 GHz ISM) with Commercial, Research, and Health bands was designed. The selected performance of the antenna combined with IoT sensors and a (2.4) GHz radio frequency module was used for the simulation process. It has been performed effectively in IoT applications due to its small size and high fractional bandwidth.

B. *Optical Nanoantennas Applications*

The nanotechnology applied in medical systems employs a variety of downsizing merits to reduce the size of the antennas attached to the human body. Combining optical spectroscopic and nanotechnology components was used in the rapidly growing field of nanotechnology in modern medical communication fields [41]. These fields include immune system support, bio-hybrid implants, drug delivery systems, health monitoring, and genetic engineering which are involved in healthcare and intra-body health monitoring and medicine delivery systems. The field of an optical nanoantenna is a rapidly evolving one via the nanotechnology field and the optical nanoantennas are formulated, and important characteristics pertinent to these structures are recognized. Metal and dielectric nanoantennas are created and addressed as a class of optical antennae. In [41], metallic nanoparticles made of silver were used to create bow-tie (triangular) nanoantennas, which operate in the optical spectrum. In contrast to dipole antennas, bow-tie antennas are preferred because they have a larger bandwidth and more flexible optical spectra. The employing of the sug-

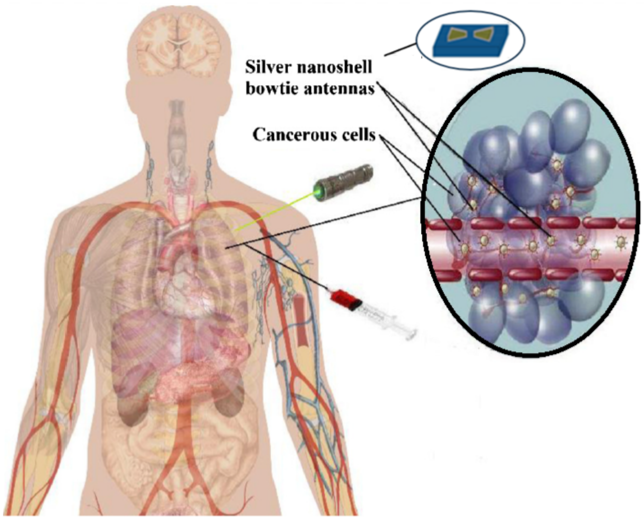

Fig. 9. The proposed nano shell bow-tie antenna in human tissue tumors for hyperthermia therapy [41].

gested bowtie nanoantennas in their various uses of medical treatments is depicted as shown in Fig.9.

In [42], an Infrared optical nanoantenna was presented to be used in the healthcare system for detecting and measuring blood glucose levels. The suggested technique employs an inverse geometry reflection flow cell, flushed by attached tube connections that feed the desired solutions into and out of the flow cell. The major parts of the employed sensor are a variety of linear gold antenna arrays produced by electron beam lithography on transparent calcium fluoride substrates. It was using the optical nanoantenna with the ability to modify and control the optical performance associated with the human body.

In [43], a plasmonic bow-tie nanoantenna operating in the near-infrared range was used to improve the temperature confinement in the skin tissue. It used gold nanostructure with silicon carbide dioxide to formulate the optical nanoantenna at resonance wavelength (1064nm). The diameter of the proposed tumor tissue was equal to 100 nm at the position in the middle of the skin structure. These dimensions have been selected according to the employed antenna structure as shown in Fig. 10.

In [44], two distinct sensors were tested on a specific structure based on the spectra obtained from the parameter analysis. The first one is based on a gold nanoantenna and the second one is made from aluminum with an infrared gain peak (near 1000 nm). The simulations process for on-air–gold–quartz and air–aluminum–quartz structures nanoantennas were performed. It was found that a nanostructure built around a

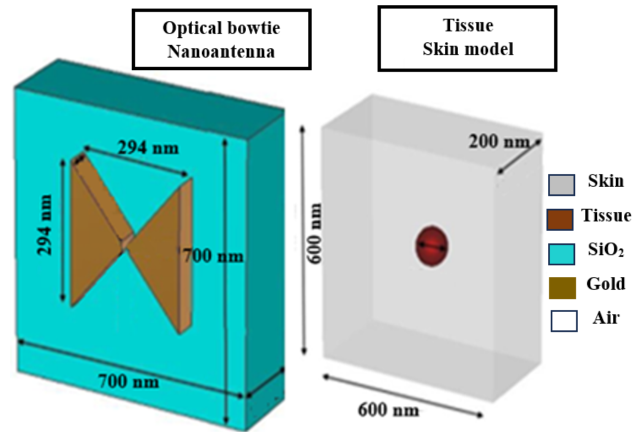

Fig. 10. The schematic diagram of the proposed optical antenna in [43].

nanoantenna can function as a sensor for a variety of applications. A method of treating cancer based on an optical nano-antenna operating at Terahertz frequency bands has been described in [45]. It used a nano-antenna worked at 257.04THz to detect in-vivo cancer using a rectangular gold patch attached to a Gallium Arsenide substrate. It concluded that gallium arsenide is poisonous and not biocompatible applicable. It was found that in order to prevent any damage to human tissues, a biocompatible layer of a suitable material known as a superstrate may be put over the antenna.

In [46], a method of thermal ablation used electromagnetic radiation transmitted through a nano-antenna and absorbed by the tissue, was used to heat cancer cells and prevent damage to healthy cells. It was suggested that a nano-antenna configuration with an L-shaped frame made from a gold patch and glass substrate could be inserted into biological liver tissue as shown in Fig. 11. To optimize the nano-antenna, the radiation

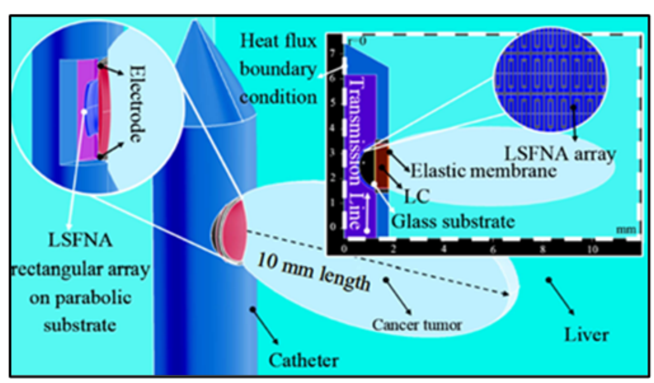

Fig. 11. Simplified layout of optical nano-antenna in liver tissue in [46].

properties of this optical antenna are investigated, including near- and far-field intensities, directivity, and sensitivity to its gap width and it can be utilized to treat cancer of different biological tissues, such as the kidney, lung, and breast [46].
In [47], conventional plasmonic nanoantennas and sensors used biofunctionalized metallic gratings that have a frequency response in transmission as well as reflect changes in response to the presence of particular biomarkers. This approach provides comprehending the activity, biomechanical properties, and state of health all of which directly impact the behavior of cardiomyocytes. It used the concept of plasmonic sensing nanoantennas to enable integrated nanoscale communication and detection. This method involves a two-dimensional structure and is based on the superior electrical properties of graphene as a popular material for antenna applications. This material has outstanding surface plasmon tunability, durable confinement, and minimal losses, making it one of the most materials suitable for Terahertz operations.

In [48], information about disease diagnosis, drug screening, and tissue engineering for heart-related investigations was given using an optical nano-antenna array and a piezo-photonic sensor. In this work, an aligned array of InGaN/GaN nanopillars was designed and created. A force mapping technique based on a nano-antenna array was developed with the support of the piezo-phototronic effect. For force mapping, a spatial resolution of 800 nm and a temporal resolution of 333ms has been established. By determining the antennas' placements and measuring the light intensities of the piezo-phototronic optical nano-antenna array, it was possible to directly derive the dynamic mapping of the cell force of live cardiomyocytes.

In [49], an instrument topology of 15nm-gap plasmonic dimer arrays nanoantenna, and selective amplification for glucose sensing was demonstrated. It enhanced near-infrared and non-invasive glucose detection using plasmonic nano-antennas. The results displayed that at wavelengths of 880 nm, systems with 180 nm dimer optical nanoantennas arrays can establish linear relationships between photocurrent and glucose concentrations.

In [50], a graphene-based monopole nanoantenna was employed at terahertz frequency bands (THz) for healthcare applications. The proposed antenna was made of a graphene ring placed on the SiO2 substrate. This antenna's design makes use of graphene to change the radiation pattern and bandwidth without changing the operating frequency. The performance of the antenna was evaluated at an operating frequency equal to (1.65 THz). Its applications done with a compact footprint and required performance were produced by the proposed optical nanoantenna and the suggested technique can be used in cancer treatment.
In [51], an optical nanoantenna for single-molecule-based plasmonic biosensing was introduced to regulate the interaction of a target molecule with the excited localized surface plasmon resonance at the location of a plasmonic nanoparticle. It was prepared to separate a sample of three DNA origami structures on the surface and incubated with a 100 nm optical nanoantenna made of composite material based on gold under optimal formation conditions to control the distance of its surface to a molecule in the hotspot of optical antenna structures for fluorescence enhancement.

In [52], plasmonic sensing nanoantenna-based combined nanoscale communication and biosensing systems were presented. This approach includes sensing nano nodes that can connect amongst one another for intra-body networks and from one nano node to a wearable device. It was attempted to accurate diagnoses and less strain on the infrastructure for medical tests.

In [53], a silicon-doped material with high excess carrier concentrations was proposed for the dipole nanoantenna. High-index dielectric nanoantennas are superior to plasmonic ones in several ways, including CMOS compatibility and minimal ohmic losses, which may be useful for nanophotonic applications. Both the augmented localized field and the wavelength of the enhancement peak are influenced by the substance in the vicinity. The proposed dipole nanoantenna uses silicon material with high carrier concentrations for sensing and biological applications in the mid-IR spectral region.

In [54], the design and analysis of a nano patch circular antenna made of the gold patch and operated at terahertz frequency band were presented. The suggested antenna was simulated at 3.93 THz and the result of this method can be used for a wireless body area network (WBAN) communication system and deal with the human body via gathering patient health information.

In [55], an architecture for creating plasmonic bio-sensors in which sense was accomplished using optical beam steering. The proposed trapping technique structure consisted of a network of optical bowtie nanoantennas that was used to precisely control and manage items in mesoscopic systems with length scales ranging from tens of nanometers to hundreds of nanometers scale. The construction of the proposed antenna is based on a silicon (Si) - dielectric constructed with two tip-to-tip triangle semiconductor elements. The trapping of a virus sample species with 100 nm in diameter is suggested to use in classical medicine. for this purpose. the analytical approach with numerical simulations employing a footprint of 0.96 µm2 sample was implemented taking into account preserving the temperature of the sample.

In [56], an integrated platform for polarimetric and spectroscopic sensing was introduced for real-time health monitoring and medicinal applications. The suggested approach used an infrared nanoantenna-mediated graphene photodetector based on Si/SiO2 substrate that can provide early illness diagnosis systems and improved tissue imaging and sensing techniques of biostructures. The employed strain engineering plays an important role among biomedical applications that have already used polarization imaging in the field of flexible and wearable electronics systems. These systems, which require entails precise strain control are frequently used in medical and monitoring equipment systems.

In [57], an approach to determine optical anisotropy by using a microscope to scan the whole region of unstrained nanoantennas at a single frequency was demonstrated. Due to the method's adaptability, nondestructive mechanical characterization of multi-material components, such as wearable electronics, can be done without causing damage to the component. This method studies the breaking of the lattice symmetry by straightforward resistance measurements and semiconductor optical devices.

In [58], the concept of a bio-nanoantenna was used to pioneering solutions to the issue of electrical transduction in the process of taking an electrical input and translating it into a biological one. It was found that bio-nanoantenna was able to convert remote electrical field input bio-signaling for use in healthcare applications.

In [59], a plasmonic bow-tie nanoantenna made of gold and SiO2 substrate was designed for a single structure and applied to a suggested skin tissue in a specific environment at two resonance rates (532, 1064) nm. In this method, the effectiveness of the rise in tissue temperature as a tool to destroy cancer cells is evaluated. The temperature is raised more effectively when the distinct antenna is closer to the treated tissue. It was observed that the proposed nanoantenna at resonance wavelength 532 nm has greater near-field intensity than one at 1064 nm and this method can be considered as an efficient therapy for eliminating cancer cells.

In [60], a healthcare model made up of a nanoantenna that can be implanted into wireless communication systems was presented. The Terahertz (THz) band has been chosen for operating the suggested antenna to make the medical network more efficient and faster. The designed proposed nanoantenna was simulated in the computer software package including the feeding line, dimensions of the patch beside the substrate, and the ground plane. This nanoantenna was made of gold with a RO4003C substrate and can be used for wireless human body applications in healthcare systems.

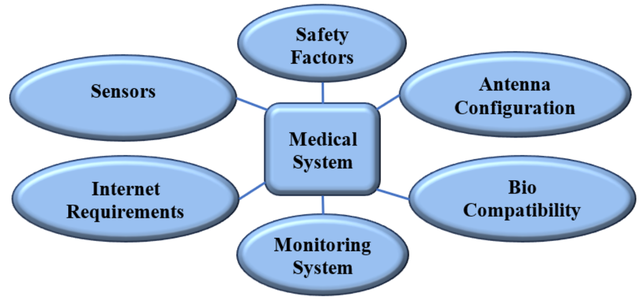

Fig. 12. The schematic diagram of the health care system based on Antenna [introduced by researcher].

III. Results and Discussions

As mentioned in the preceding section, engineers, researchers, and designers have given careful thought to the many configurations of antennas. a variety of antennas with diverse structures can be utilized in various communication system applications. Some of these antennas were created to be used in medical applications in conjunction with human body sensors to gather the necessary information about the human body while also taking into account safety requirements. Such wireless medical systems form a healthcare network when they are connected to a sensor and situated on or within the human body. This network meets numerous obstacles such as the size of the antenna and employed devices. The ability to regulate the size, shape, and distribution of the structures over a wide region might be expected from a quick and inexpensive manufacturing process, but each fabrication technique has advantages as well as drawbacks. Therefore, it is essential to choose the proper production processes for each application in conjunction with human body sensors to gather the necessary information about the human body, as illustrated in Fig. 12.

The use of microstrip patch antennas and optical nanoantennas for healthcare systems or diagnosing the human body as well as for patient treatment are listed as shown in Table I and Table II respectively.

TABLE I.
SOME ARE USED FOR MICROSTRIP ANTENNAS IN MEDICAL SYSTEMS

Item	Ref.	Title	Proposed Antenna	Application	Patch Material	Substrate Material	Antenna Characteristics	Date
1	[26]	” Implementation of flexible denim nickel copper ripstop-textile antenna for medical application”	Rectangular patch microstrip antenna	The medical application related tothe human arm and human chest	Copper	Denim textile material	Operated at 2.45GHz frequency band, power radiated of 4.98mW, directivity 5.102 dBi with a gain of 5.10684 dB.	2019
2	[27]	“Design of compact ultra-wideband antenna for microwave medical imaging application”	Hexagon Microstrip patch antenna	Medical imaging applications.	Copper	FR4 substrate	Frequency 6.08 GHz Gain 2.98 2.304 dB Return Loss -18.58 dB and Bandwidth 503& 520 MHz	2019
3	[28]	Analysis and Design of Dual-Band Folded-Shorted Patch Antennas for Robust Wearable Applications	Microstrip & Folded-Shorted Patch Antennas	Robust Wearable Medical Applications	Copper	Flexible Polydimethylsiloxane	Frequency at 400 MHz and 2.4 GHz. return losses are below -25 dB with gains of 1.37 dBi and 3.10 dBi.	2020
4	[29]	“A Compact Size Implantable Antenna for Bio-medical Applications”	Compact size implantable antenna Microstripantennas	Medical applications	Copper	Rogers RT3010	Operated at 915 MHz with a gain of 3.22 dBi and a bandwidth of 240 MHz with return losses of -21 dB.	2020
5	[30]	”A miniaturized circular maze-shaped antenna for implantable health care application”	Maze-shaped circular ring Implantable antenna	Health care system	Copper	Polyamide substrate	Operated at ISM (2.42–2.4815) GHz band with a bandwidth of 286 MHz and return losses is -23 dBi.	2021
6	[31]	“Design of dual-band (MICS and ISM) implantable antenna for wireless medical telemetry applications”	Microstri Rectangular Patch antenna	Wireless medical-telemetry applications	Copper	Silicon	Operated frequency (402 – 405) MHz and (2.40 - 2.48) GHz, return losses of -18.42 dB at 2.45 GHz and -23.70 dB at 403 MHz .	2021
7	[32]	“Design and analysis of square microstrip patch antenna at 2.4GHz band used for IoT based health care monitoring”	Micro-strip Square patch antenna	Medical applications that monitor patient health	Copper	FR4	frequency of 2.49 GHz and bandwidth of 0.06 GHz, with a gain of 4.96 dBi, directivity of 5.363 dBi, and return loss of 20.84 dB.	2022

8	[33]	"Design and Comparative Analysis of Microstrip Patch Antenna by Using Various Materials in HFSS"	Flexible wearable Microstrip-patch antenna	IoT wearable health care system	Copper	Polyamide	Wireless Local Area Network (WLAN and antenna operated at a frequency of 2.4 GHz	2022
9	[34]	"Trapezoidal Microstrip Patch Antenna Array for Low-Frequency Medical Applications"	Trapezoidal Microstrip patch antennas array	Medical applications	Copper	FR4 substrate	Operated frequency of 1.891 GHz and gain of low return loss equal to -26.19 dB with directivity of 4.48 dBi.	2022
10	[35]	"Design and fabrication of rectangular microstrip patch antenna at ISM band for medical applications"	Rectangular Microstrip patch -antenna	Health care System and medical applications	Copper	FR4 substrate	ISM bandwidth of 0.15 GHz and gain of 3.906 dBi, with directivity 4.34 dBi, and return loss as -17.61dB	2022
11	[36]	"Design of UWB wearable microstrip patch antenna for wireless body worn applications"	Rectangular Microstrip patch antenna	Medical applications	Copper	Polycot fabric	The frequency band is (3.01-10.6) GHz at 5.6 GHz with a gain of 8.22 dB, directivity of 8.18dB return losses of 15.2 dB.	2023
12	[37]	"Multiband flexible ultra-wideband antenna for wearable electronics and biomedical applications"	Flexible Microstrip patch -antenna	Biomedical applications	Copper	Kapton polyimide substrate	Frequency band ranges 2.4GHz to 7.1GHz. The return loss is greater than -10dB in all the operating bands.	2023
13	[38]	"Design and Evaluation of a Fractal Wearable Textile Antenna for Medical Applications"	Wearable Microstrip Patch-antenna	Medical applications	Copper	textile materials like silk, polycot, jeans	Wearable antennas are designed which operate in the (2.4–2.5) GHz ISM band	2023
14	[39]	Design of 8× 8 Microstrip Array Antenna for ISM and K-Band Applications	Microstrip Array patch Antenna	Medical applications	Copper	Roger RT5880	Operated frequency includes 22.4 GHz, 24 GHz, and 26 GHz, gains are 16.81 dB, 18.41 dB, and 12.38 dB, respectively. Return losses are -22.65 dB, -23.54 dB, and -24.58 dB	2023
15	[40]	"IoT Application using a Rectangular 2.4 GHz Microstrip Patch Antenna"	Rectangular Microstrip patch antenna	Medical applications	Copper	Meander shaped substrate	IoT applications in 2.4 GHz with a gain of up to 4.01 dBi and a directivity of 7.14 dB.	2023

TABLE II.
THE OSE OF OPTICAL NANOANTENNAS IN SOME MEDICAL SYSTEMS

Item	Ref.	Title	Proposed Antenna	Patch Material	Substrate Material	Antenna Characteristics	Application	Date
1	[41]	"Potential applications of nanoshell bow-tie antennas for biological imaging and hyperthermia therapy"	Bowtie optical Nano-antennas	Silver	Dielectric substrate, with refractive indices of 1.5 and 1.33	Wavelength range (700 to 1100 nm)	Biological imaging and hyperthermia therapy medical system.	2019
2	[42]	"Adaptive Method for Quantitative Estimation of Glucose and Fructose Concentrations in Aqueous Solutions Based on Infrared Nanoantenna Optics"	A rectangular patch array of optical Nanoantennas	Gold	Transparent calcium fluoride substrates	Infrared spectrum in the wavelength ranges from (750 nm to 1 mm)	Robust health care system to predict the level of glucose and fructose in the human body.	2019
3	[43]	"Thermal response of skin diseased tissue treated by plasmonic nanoantenna"	Triangular patch Optical Nanoantenna	Gold	Silicon carbide dioxide	Operated at the near-infrared region with (1064 nm) resonance wavelength	Medical application to enhance tissue temperature control.	2020
4	[44]	"A Sensor Based on Nanoantennas"	Rectangular Nano-antenna	Gold and Aluminum	Quartz (SiO_2) substrate	Operated at the near-infrared region around (1000nm)	Medical applications human tissues.	2020
5	[45]	"Design of optical antenna operating at terahertz frequency for in-vivo cancer detection"	Rectangular Nanoantenna	Gold	Gallium Arsenide substrate	Wavelength spectrum (1167nm)	Medical systems using optical nanoantenna.	2020
6	[46]	"Design and optimization of nano-antenna for thermal ablation of liver cancer cells"	L- shaped optical Nano-antenna	Gold	Dielectric substrate (glass)	The antenna is excited with a pulsed sinusoidal voltage of input powers of (20-50) mW	Bio-medical applications, thermal ablation therapy.	2021
7	[47]	"Joint Nanoscale Communication and Sensing Enabled by Plasmonic Nano-antennas"	Optical Nano-antenna of rectangular patch	Gold	The dielectric substrate with a bi-functional layer	Operated at a Plasma Frequency of 13.35 PHz	Bio-medical applications.	2021

8	[48]	"Dynamic real-time imaging of living cell traction force by piezo-phototronic light nano-antenna array"	Optical nano-antennas rectangular array	Nickel metal	Sapphire substrate	The array of the antenna is excited by a laser diode of 405 nm and a peak wavelength of about 460 nm	Disease diagnosis, drug screening, and tissue engineering for heart.	2021
9	[49]	"Plasmonic Nano-antennas Enhanced Near-infrared Non-invasive Glucose Detection"	Plasmonic optical dimer arrays nanoantenna	Gold film	SiO_2 substrate	Operated wavelength of (880 nm) with (180 nm) dimer arrays	Wearable glucose monitoring equipment for medical applications	2022
10	[50]	"Designing Graphene-Based Antenna for Terahertz Wave Ablation (TWA) System"	Graphene-based rectangular optical anoantenna	Graphene ring	SiO_2 Substrate	two-layer monopole antenna designed to operate at 1.65THz	Healthcare applications and treatment of cancer.	2022
11	[51]	"Maximizing the Accessibility in DNA Origami Nanoantenna Plasmonic Hotspots"	Plasmonic Optical dimer nanoantenna	Gold	Composite material	Optical nanoantenna 100 nm	Bio-sensing applications	2022
12	[52]	"Joint Communication and Bio-Sensing with Plasmonic Nano-Systems to Prevent the Spread of Infectious Diseases in the Internet of Nano-Bio Things"	Plasmonic optical wearable nanoantenna	Plasmonic nano-antenna	Bio-functionalized substrate	Bio-function plasmonic nano-antenna operated at optical and THz frequencies band	Internet of Nano-Bio Things for Healthcare System	2022
13	[53]	"Dielectric Nanoantennas Enhanced Localized Surface Plasmon Resonance for Sensing Applications"	Optical Nanoantenna	Plasmonic nano antenna	Silicon substrate material	Mid-IR spectral region	Bio-sensing applications	2022
14	[54]	"Design of Optical Gold Printed Antenna in Terahertz Band for ON Body WBAN Applications"	Circular patch optical Nano antenna	Gold nano patch	Silicon substrate material	Microwave frequencies which are from [0.1–10] THz	Medical application based on wireless body area network	2022
15	[55]	"Nanoscale Optical Trapping by Means of Dielectric Bowtie"	Bowtie Optical Nanoantenna	Silicon	SiO_2 substrate	An operating wavelength is 1550 nm	Bio-sensing medical application	2022

16	[56]	"Zero-Bias Long-Wave Infrared Nanoantenna-Mediated Graphene Photodetector for Polarimetric and Spectroscopic Sensing"	Infrared optical Nano antenna	Graphene	SiO_2 substrate	Resonance at 6.5 μm with a gap of 300 nm	Bio-medical screening and monitoring system	2023
17	[57]	"Scanning Reflectance Anisotropy Microscopy for Multi-Material Strain Mapping"	Rectangular optical Nano antenna	Gold	Poly-carbonate substrate	The resonance falls within a length of 100 nm, a width of 50 nm, and a pitch of 150 nm.	Health care and monitoring devices	2023
18	[58]	"Wireless Electrical-Molecular Quantum Signaling for Cancer Cell Induced Death"	Bio-nanoantenna based on copper nanoparticles	Gold Nano particles	Bio-nano antenna	The light scattered from the biofunctionalized nanoantennae was split by a wavelength of 500 nm	Health care and quantum-based medical diagnostics and treatments system	2023
19	[59]	"Plasmonic Optical Nano-Antenna for Biomedical Applications"	Bowtie Optical and implantable Nano-antenna	Gold	SiO_2	Nanoantenna wavelengths of 532 nm and 1064 nm respectively	Medical applications	2023
20	[60]	"Nano rectangular Printed Gold Antenna for On-Human Body Wireless Body Network Applications"	Rectangular Nano-antenna	Printed Gold	RO4003C substrate	Nanoantenna works at 0.74 THz, 1.148 THz, and 1.734 THz respectively	Medical applications based on the human body's wireless communication system	2023

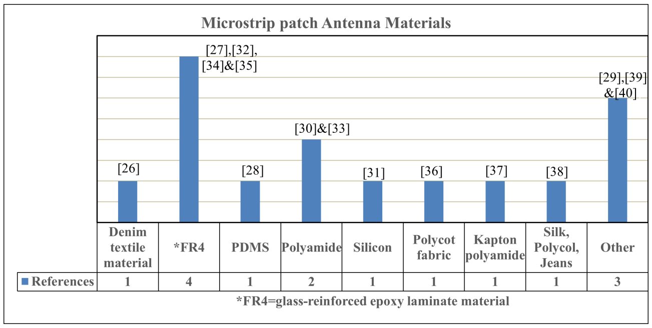

Fig. 13. Several substrate materials of microstrip patch antennas.

From Tables I and II, it can be noted that the most common materials of microstrip patch antennas are copper, However, the substrate of materials is made of various materials such as glass-reinforced epoxy laminate material (FR4), polyamide, and silicon as shown in Fig. 13.

Gold, silver, and aluminum are the most popular materials for optical nanoantennas, however transparent materials like graphene and silicon or germanium are also employed, as illustrated in Fig. 14.

It can see in Tables I and II, that the construction of the proposed antennas was made of various materials. Hence, the performance of microstrip patch antennas and optical nanoantennas depends mainly on the chosen substrate materials as well as the operating frequency bands.

One of the essential nanoscale communication technologies that can support the concept of nanoantenna networks is terahertz band communication. Terahertz frequency band communication systems have been Supported for large-capacity networks and they can be applied inside the body for medical applications such as biomolecule monitoring and intelligent drug delivery systems.

Some major properties of various antennae such as gain and reflected coefficients with a variety of substrate materials employed in the medical system are listed as shown in Table III.

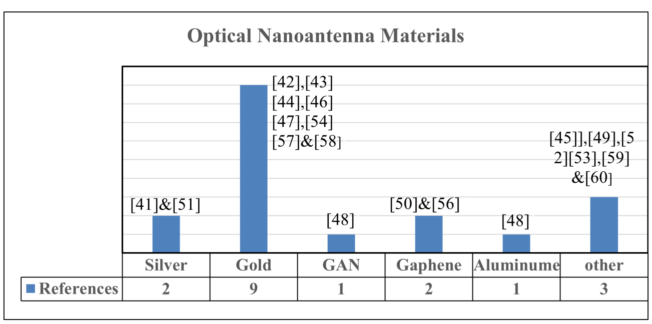

Fig. 14. Some materials of optical nanoantennas.

TABLE III.
SOME PROPERTIES OF OPTICAL ANTENNAS USED IN MEDICAL SYSTEMS

Ref.	Substrate material	Dielectric constant	Freq. (THz)	Gain (dB)	Return losses (dB)
[26]	Denim	1.5	0.0025	5.10	-20.48
[43]	SiO_2	1.5	281.9	——	-43.84
[45]	Gallium	12.94	257.04	3.33	-54.67
[50]	SiO_2	3.9	1.65	——	8.52
[54]	Silicon	11.9	3.93	5.4	-54.96

Figure 15 illustrates how the measured gain in THz bands using an optical nanoantenna, a circular patch structure consisting of gold, and various substrate materials can be observed.

IV. CONCLUSION

With the rise in the healthcare industry and medical engineering system, wireless communication technology has enjoyed a rich diversification in research and patents. It was accepted that medical instruments that incorporate wireless transmission and receiving antennas in addition to sensors be a foundational technology for monitoring a patient's health and hence handling their wellness activities with higher precision even at a distance. This approach may effectively reduce the stress of medical staff, leading to better time management when they are connected to a sensor and situated on or within the human body. The following phases illustrate the many requirements that must be met during the designing process of the proposed healthcare systems using the antenna configuration:

Step 1: The characteristics of the selected antenna and the design of the employed antenna for medical applications. Step 2: Safety factors of the human body including human factors and the parameter of the suggested system. Step 3: The exterior

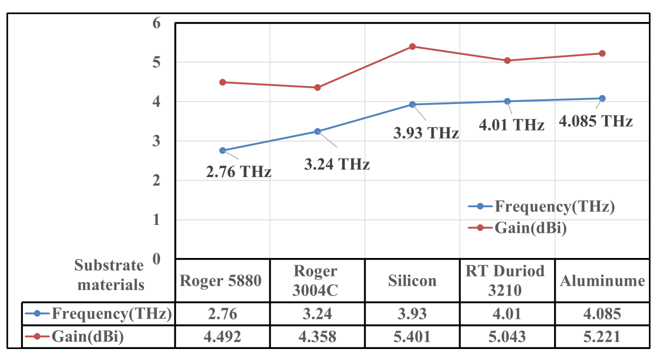

Fig. 15. Gain of the optical nanoantennas with various substrate materials in THz bands [54].

devices such as sensors and power supply to set up the combination of the required system either wearable or implantable antennae.
Step 4: The overall size of the employed antenna device and the biocompatibility issue.
Step 5: Apply the computer simulation process to test and analyze the obtained results.

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CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

REFERENCES

[1] P. Bharadwaj, B. Deutsch, and L. Novotny, "Optical antennas," *Adv Opt Photonics*, vol. 1, no. 3, p. 438–483, 2009.

[2] M. Leone and N. Robotti, "Guglielmo marconi, augusto righi and the invention of wireless telegraphy," *The European Physical Journal H*, vol. 46, no. 1, p. 16, 2021.

[3] C. A. Balanis, *Antenna theory: analysis and design*. John wiley & sons, 2015.

[4] A. Singh and S. Singh, "A trapezoidal microstrip patch antenna on photonic crystal substrate for high speed thz applications," *Photonics and Nanostructures-Fundamentals and applications*, vol. 14, p. 52–62, 2015.

[5] K. F. Lee and K.-F. Tong, *Microstrip patch antennas*. 2016.

[6] W. Grabssi, S. Izza, and A. Azrar, "Design and analysis of a microstrip patch antenna for medical applications," in *in 2017 5th International Conference on Electrical Engineering-Boumerdes (ICEE-B)*, p. 1–6, 2017.

[7] Z.-J. Yang, S.-Q. Xiao, L. Zhu, B.-Z. Wang, and H.-L. Tu, "A circularly polarized implantable antenna for 2.4-ghz ism band biomedical applications," *IEEE Antennas Wirel Propag Lett*, vol. 16, p. 2554–2557, 2017.

[8] D. M. A. S. Dhillon and E. Sidhu, "Thz rectangular microstrip patch antenna employing polyimide substrate for video rate imaging and homeland defence applications," *Optik (Stuttg)*, vol. 144, p. 634–641, 2017.

[9] E. Mauriz, "Recent progress in plasmonic biosensing schemes for virus detection," *Sensors*, vol. 20, no. 17, p. 4745, 2020.

[10] S. M. Shamim, N. Arafin, U. S. Dina, S. Shemu, and R. Karim, *Analysis and Design of Microstrip Patch Antenna on Photonic Band Gap (PBG) Substrate at Terahertz Regime*. 2022.

[11] P. B. qnd J.-S. Huang and B. Hecht, "Nanoantennas for visible and infrared radiation," *Reports on Progress in Physics*, vol. 75, no. 2, p. 024402, 2012.

[12] R. Liang, *Optical design for biomedical imaging*. SPIE press Bellingham, WA, 2010.

[13] S. K. K. et al., "Design and fabrication of flexible nanoantenna-based sensor using graphene-coated carbon cloth," *Advances in Materials Science and Engineering*, vol. 2022, 2022.

[14] M. Tejasree, A. Taguru, M. Praneetha, K. Naveen, and P. V. Naidu, "Hybrid plasmonic nano-antenna design and analysis for optical applications," *in 2022 IEEE Delhi Section Conference (DELCON)*, p. 1–4, 2022.

[15] C. Divya and V. Koushick, "Design and implementation of slotted metamaterial stacked microstrip patch antenna for broadband applications," *in Journal of Physics: Conference Series, IOP Publishing*, p. 012067, 2020.

[16] X. An, S. Erramilli, and B. M. Reinhard, "Plasmonic nano-antimicrobials: properties, mechanisms and applications in microbe inactivation and sensing," *Nanoscale*, vol. 13, no. 6, p. 3374–3411, 2021.

[17] G. Isiklar, I. C. Cetin, M. Algun, , and . ERGÜL, "Design and analysis of nanoantenna arrays for imaging and sensing applications at optical frequencies," *Adv. Electromagn*, vol. 8, no. 2, p. 18–27, 2019.

[18] M. Lin, H. Hu, S. Zhou, and S. Xu, "Soft wearable devices for deep-tissue sensing," *Nat Rev Mater*, p. 1–20, 2022.

[19] P. Johari, H. Pandey, and J. M. Jornet, "Interconnecting wearable devices with nano-biosensing implants through optical wireless communications," *in Optical Diagnostics and Sensing XVIII,Toward Point-of-Care Diagnostics, SPIE*, p. 281–292, 2018.

[20] E. Mauriz and L. M. Lechuga, "Plasmonic biosensors for single-molecule biomedical analysis," *Biosensors (Basel)*, vol. 11, no. 4, p. 123, 2021.

[21] T. Khan, M. Civas, O. Cetinkaya, N. A. Abbasi, and O. B. Akan, "Nanosensor networks for smart health care," *in Nanosensors for Smart Cities, Elsevier*, p. 387–403, 2020.

[22] Q. Rubani, G. R. Begh, and S. H. Gupta, "Design and investigation of a mimo nanoantenna operating at optical frequency," *Optik (Stuttg)*, vol. 223, p. 165481, 2020.

[23] S. Dash and A. Patnaik, "Impact of silicon-based substrates on graphene thz antenna," *Physica E Low Dimens Syst Nanostruct*, vol. 126, p. 114479, 2021.

[24] D. Samanta, M. P. Karthikeyan, A. Banerjee, and H. Inokawa, "Tunable graphene nanopatch antenna design for on-chip integrated terahertz detector arrays with potential application in cancer imaging," *Nanomedicine*, vol. 16, no. 12, p. 1035–1047, 2021.

[25] S. S. Singhwal, L. Matekovits, I. Peter, and B. K. Kanaujia, "Application of dielectric resonator antenna in implantable medical devices," *in 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), IEEE*, p. 80–81, 2021.

[26] E. Thangaselvi and K. M. alias Jeyanthi, "Implementation of flexible denim nickel copper rip stop textile antenna for medical application," *Cluster Comput*, vol. 22, p. 635–645, 2019.

[27] A. Othman, N. I. S. Shaari, A. M. Zobilah, N. A. Shairi, and Z. Zakaria, "Design of compact ultra-wideband antenna for microwave medical imaging application," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 15, no. 3, p. 1197–1202, 2019.

[28] R. J. et al., "Analysis and design of dual-band folded-shorted patch antennas for robust wearable applications," *IEEE Open Journal of Antennas and Propagation*, vol. 1, p. 239–252, 2020.

[29] N. A. Malik, T. Ajmal, P. Sant, and M. Ur-Rehman, "A compact size implantable antenna for bio-medical applications," *in 2020 International Conference on UK-China Emerging Technologies (UCET), IEEE*, pp. 1–4, 2020.

[30] C. Gayathri and S. Venkatanarayanan, "A miniaturized circular maze shaped antenna for implantable health care applications," *J Ambient Intell Humaniz Comput*, vol. 12, p. 4757–4763, 2021.

[31] H. Zerrouki and S. Azzaz-Rahmani, "Design of dual-band (mics and ism) implantable antenna for wireless medical telemetry applications," *Journal of Electrical Systems*, vol. 17, no. 3, 2021.

[32] K. Ramamoorthy, K. R. Kiran, E. Thangaselvi, S. Karthikeyan, and T. Chelladurai, "Design and analysis of square microstrip patch antenna at 2.4 ghz band used for iot based health care monitoring," *in AIP Conference Proceedings, AIP Publishing LLC*, p. 030020, 2022.

[33] G. P. Ramesh, H. Abdullah, and B. D. Parameshachari, "Design and comparative analysis of microstrip patch antenna by using various materials in hfss," *in Distributed Computing and Optimization Techniques: Select Proceedings of ICDCOT 2021, Springer*, p. 303–312, 2022.

[34] S. Suganthi and P. T. Selvan, "Trapezoidal microstrip patch antenna array for low frequency medical applications," *Wirel Pers Commun*, vol. 126, no. 2, p. 1721–1732, 2022.

[35] E. Thangaselvi, E. Kumaraswamy, K. Ramamoorthy, S. Karthikeyan, and T. Chelladurai, "Design and fabrication of rectangular microstrip patch antenna at ism band for medical applications," *in AIP Conference Proceedings, AIP Publishing LLC*, p. 030015, 2022.

[36] S. S. V. et al., "Design of uwb wearable microstrip patch antenna for wireless body worn applications," *in AIP Conference Proceedings, AIP Publishing LLC*, p. 020158, 2023.

[37] R. Prasanna, G. T. Selvi, K. Annaram, K. Venkatalakshmi, M. Jenath, and B. P. Prathaban, "Multiband flexible ultra-wideband antenna for wearable electronics and biomedical applications," *Int J Multiscale Comput Eng*, vol. 21, 2023.

[38] H. Kaur and P. Chawla, "Design and evaluation of a fractal wearable textile antenna for medical applications," *Wirel Pers Commun*, vol. 128, no. 1, p. 683–699, 2023.

[39] P. K. S. Purnendu, A. B. Anwar, R. Islam, D. Mollik, M. A. Hossain, and M. Ahmad, "Design of 8× 8 microstrip array antenna for ism and k-band applications," *in Proceedings of International Conference on Information and Communication Technology for Development: ICICTD 2022, Springer*, p. 153–162, 2023.

[40] M. S. Rana, O. Islam, S. A. Shikha, and M. Faisal, "Iot application using a rectangular 2.4 ghz microstrip patch antenna," *in 2023 International Conference for Advancement in Technology (ICONAT), IEEE*, p. 1–4, 2023.

[41] E. Karooby and N. Granpayeh, "Potential applications of nanoshell bow-tie antennas for biological imaging and hyperthermia therapy," *Optical Engineering*, vol. 58, no. 6, p. 65102, 2019.

[42] B. Schuler, L. Kühner, M. Hentschel, H. Giessen, and C. Tarín, "Adaptive method for quantitative estimation of glucose and fructose concentrations in aqueous solutions based on infrared nanoantenna optics," *Sensors*, vol. 19, no. 14, p. 3053, 2019.

[43] R. H. Mahdi and H. A. Jawad, "Thermal response of skin diseased tissue treated by plasmonic nanoantenna," *International Journal of Electrical and Computer Engineering*, vol. 10, no. 3, p. 2969, 2020.

[44] R. A. M. Lameirinhas, J. P. N. Torres, and A. Baptista, "A sensor based on nanoantennas," *Applied Sciences*, vol. 10, no. 19, p. 6837, 2020.

[45] M. Kumar, S. Goel, A. Rajawat, and S. H. Gupta, "Design of optical antenna operating at terahertz frequency for in-vivo cancer detection," *Optik (Stuttg)*, vol. 216, p. 164910, 2020.

[46] M. J. Rabienejhad, A. Mazaheri, and M. Davoudi-Darareh, "Design and optimization of nano-antenna for thermal ablation of liver cancer cells," *Chinese Physics B*, vol. 30, no. 4, p. 048401, 2021.

[47] A. Sangwan and J. M. Jornet, "Joint nanoscale communication and sensing enabled by plasmonic nano-antennas," *in Proceedings of the Eight Annual ACM International Conference on Nanoscale Computing and Communication*, p. 1–6, 2021.

[48] Q. Z. et al, "Dynamic real-time imaging of living cell traction force by piezo-phototronic light nano-antenna array," *Sci Adv*, vol. 7, no. 22, p. eabe7738, 2021.

[49] C. Hou, K. Wang, W. Zhang, S. Wang, and L. Dong, "Plasmonic nano-antennas enhanced near-infrared non-invasive glucose detection," *in 2022 IEEE International Conference on Manipulation, Manufacturing and Measurement on the Nanoscale (3M-NANO), IEEE*, p. 482–486, 2022.

[50] M. D. GEYİKOĞLU, K. O. . Hilal, B. ÇAVUŞOĞLU, M. ERTUGRUL, and K. ABBASİAN, "Designing graphene-based antenna for terahertz wave ablation (twa) system," *Erzincan University Journal of Science and Technology*, vol. 15, no. 2, p. 507–514.

[51] C. Close, K. Trofymchuk, L. Grabenhorst, B. Lalkens, V. Glembockyte, and P. Tinnefeld, "Maximizing the accessibility in dna origami nanoantenna plasmonic hotspots," *Adv Mater Interfaces*, vol. 9, no. 24, p. 2200255, 2022.

[52] A. Sangwan and J. M. Jornet, "Joint communication and bio-sensing with plasmonic nano-systems to prevent the spread of infectious diseases in the internet of nano-bio things," *IEEE Journal on Selected Areas in Communications*, vol. 40, no. 11, p. 3271–3284, 2022.

[53] A. M. Ghanim, A. E. Alsayed, A. Yahia, and M. A. Swillam, "Dielectric nanoantennas–enhanced localized surface plasmon resonance for sensing applications," *in 2022 Photonics North (PN), IEEE*, p. 1, 2022.

[54] S. F. M. Bouchra and Z. K. Djalal, "Design of optical gold printed antenna in terahertz band for on body wban applications," *Microwave Review*, vol. 28, no. 1, 2022.

[55] G. Brunetti, N. Sasanelli, M. N. Armenise, and C. Ciminelli, "Nanoscale optical trapping by means of dielectric bowtie," *in Photonics, MDPI*, p. 425, 2022.

[56] J. Xie, Z. Ren, J. Wei, W. Liu, J. Zhou, and C. Lee, "Zero-bias long-wave infrared nanoantenna-mediated graphene photodetector for polarimetric and spectroscopic sensing," *Adv Opt Mater*, p. 2202867, 2023.

[57] J. Sendra, F. Haake, M. Calvo, H. Galinski, and R. Spolenak, "Scanning reflectance anisotropy microscopy for multi-material strain mapping," *arXiv preprint arXiv 2302*, p. 04095, 2023.

[58] A. J. et al., "Wireless electrical-molecular quantum signalling for cancer cell induced death," *bioRxiv*, p. 2023, 2023.

[59] R. H. Mahdi and H. A. Jawad, "Plasmonic optical nano-antenna for biomedical applications," *in Plasmonic Nanostructures-Basic Concepts, Optimization and Applications, IntechOpen*, 2023.

[60] B. Moulfi, S. Ferouani, and D. Ziani-Kerarti, "Nanorectangular printed gold antenna for on-human body wireless body network applications," *Telecommunications and Radio Engineering*, vol. 82, no. 1, 2023.