A Novel Flexible Microstrip Patch Antenna with Different Conductive Materials For Telemedicine and Mobile Biomedical Imaging Systems

Emine Avşar Aydın (eaydin@atu.edu.tr)
Adana Alparslan Turkes Bilim ve Teknoloji Universitesi https://orcid.org/0000-0002-5068-2957

Research Article

Keywords: antenna performance, graphene-based conductive, microstrip patch antenna, 3-dimensional (3D) printing, ultrawideband

Posted Date: July 9th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-664932/v1

A NOVEL FLEXIBLE MICROSTRIP PATCH ANTENNA WITH DIFFERENT CONDUCTIVE MATERIALS FOR TELEMEDICINE AND MOBILE BIOMEDICAL IMAGING SYSTEMS

Emine Avsar Aydin
Adana Alparslan Turkes Science and Technology University, Department of Aerospace Engineering, Saricam, Adana, Turkey.
Corresponding Author: rasvaenime@gmail.com or eaydin@atu.edu.tr

Abstract
Telemedicine and mobile healthcare communication devices require compact antennas with superior performance and reduced size and weight. The design and development of such antennas for broadband applications are challenging for many researchers. In this study, a wearable rectangular microstrip antenna was designed and implemented to detect many tumors. The patch and ground part of the antenna, which can be used as both a transmitter and a receiver in microwave imaging systems, are made of copper tape, graphene, conductive paint, and the substrate is made of felt (εr = 1.3). Antenna parameters were optimized using the CST Microwave Studio program. The conventional microstrip antennas have a narrow band and low gain. The antenna in this study is designed and implemented differently from the conventional microstrip antennas and can be easily used in applications requiring ultra-wideband. In addition, the radiation characteristic of the designed antenna is quite good, and the electric field change around it is at a level that will not cause any health problems. The variation of the conductivity values of the organs in the human body is high in the 1 GHz-10 GHz frequency band. The antenna, which is designed based on the fact that the conductivity values of healthy tissues and tumor/cancer tissues are different, can be used in microwave imaging systems to detect tumors in organs such as the lung, brain, liver, and kidney. Also, the designed antenna is in a wearable form, allowing continuous monitoring of patients with high cancer risk. In this article, a microstrip patch antenna with a flexible substrate with copper tape, conductive paint, and graphene-based conductor that can be used for imaging and telemedicine applications is proposed, and its performance is experimentally analyzed. A standard and low-cost 3D printer are used to produce the graphene-based conductive part. In addition, copper tape and conductive paint materials were used to produce the patch part with an easier and cheaper method without a special device. The performance, return loss, and gain of the produced antennas were analyzed both in simulation and experimentally.

Keywords: antenna performance, graphene-based conductive, microstrip patch antenna, 3-dimensional (3D) printing, ultrawideband

1. Introduction

Cancer is a severe public health problem worldwide and is the second most common cause of death after cardiovascular diseases [1]. According to the 2018 data of the World Health Organization (WHO), the total number of cancer cases in the total world population is 0.23%. The mortality rate in these cases is 52.8%, and 11.6% of these deaths are due to lung cancer [1, 2]. Lung cancer is the most common cancer-related cause of death worldwide, and the incidence of lung cancer in men is 25% [2]. Early diagnosis in cancer treatment is vital for survival. Various methods are currently used for the early detection of cancer. These can be summarized under two headings as medical imaging and blood tests.

Medical imaging methods such as x-ray, computed tomography, magnetic resonance imaging, and PET are widely used today to determine whether a person has cancerous cells in their body [3, 4]. Although X-ray is a cheap and simple imaging technique, it can cause harm to the body due to its ionizing feature. Since the X-ray cannot pass through the bone, information about the areas under the bones cannot be obtained. In addition, the x-ray does not contain three-dimensional information. Computed tomography (CT) can provide high-resolution three-dimensional data and anatomical information. It contains higher doses of radiation than X-rays. It has its margin of error as to whether it is benign or malignant in soft tissues. Magnetic resonance imaging (MRI) also provides three-dimensional imaging by aligning the hydrogen atoms in the molecules in the human body by giving and receiving electromagnetic energy. It provides excellent imaging in soft tissues. MRI is both very expensive and slow compared to other imaging devices. The most significant advantage of MRI is that it does not contain X-rays. Ultrasound is an imaging technique based on sound waves at a frequency that the human ear cannot hear and provides real-time low-resolution imaging. It is cheap and does not pose a health hazard, and it is used in limited areas (viewing the child in the womb, etc.). Nuclear imaging (positron emission tomography, PET) provides three-dimensional imaging for diagnosing and treating cancer (metastasis) by administering radioactive material to the human body intravenously.

Detection of cancer tumors/cell in the human body using microwave imaging techniques is among the popular study topics of recent years. Microstrip antennas are the essential elements of microwave imaging techniques, and developments in microstrip antenna technology have increased the interest in microwave imaging techniques. Deschamps designed the first microstrip antenna in the USA in 1953 [5]. In 1955, Gutton and Baissinot patented a flat microstrip antenna that can be used in the UHF region in France [6]. Munson made the first practical microstrip antenna in 1974 [7]. Howell made the design of rectangular and circular microstrip antennas in 1975 [8]. After 1990, microstrip antennas started to be used in biomedical applications. Since this date, the use of microstrip antennas in the biomedical field has increased day by day. Some of these studies, especially those with ultra-wideband (UWB) biomedical applications, are summarized. A wearable microstrip antenna that can be placed on the arm and operates between the 3-6 GHz frequency band has been designed [9]. The design of a wearable UWB antenna operating at a frequency of 3.1 GHz-10.6 GHz and specific absorption rate (SAR) analysis on the Voxel body model was performed [10]. Four wearable rectangular antennas operating at a frequency of 2.45GHz, made of cotton polyester as dielectric material, have the same dimensions and different dielectric coefficients under bending conditions [11]. Using the Finite Integration Technique (FIT) of wearable antennas, a triangular microstrip antenna operating between 4-11GHz was designed to evaluate the biological effects of SAR and contact with the environment [12]. They designed a broadband (2.4 GHz-12.8 GHz) elliptical antenna compatible with the human body surface [13]. A very wideband (2-19 GHz) textile-like circular microstrip antenna has been designed, capable of monitoring and warning when hospital emergencies are needed [14]. The design and analysis of a trapezoidal microstrip antenna with rubber dielectric material operating in the wireless body area network (WBAN), UWB (3.1 GHz-10.6GHz) band have been carried out [15]. Two rectangular wearable antennas operating at the frequency of 1.43 GHz-6.5 GHz were designed using High-Frequency Structure Simulator (HFSS) [16]. For wearable applications, the performance of three rectangular, circular and equilateral triangle-shaped wearable antennas operating at 2.4 GHz, 3 GHz, and 5.8 GHz frequencies using three different (denim, velvet, felt) dielectric textile fabrics with equal patch area was investigated [17]. For biomedical applications, antennas operating in the 3 GHz-12 GHz frequency band and having different characteristics have been designed [18]. A compact, low-profile wearable rectangular array antenna operating at a frequency of 2.65GHz with six elements was designed on a mesh body to be used for breast cancer diagnosis [19]. A wearable broadband (1.6 GHz – 11.2 GHz) microstrip antenna was designed to detect breast cancer [3].

Every organ in the human body has an electrical property, and these properties change with frequency. While determining the electrical model of any organ, the conductivity (σ), electrical (εr), and magnetic permeability (μr) values of the organ should be determined depending on the operating frequency. The change of conductivity values of some organs in the human body in the frequency band of 10 MHz – 10 GHz has been reported [20]. The main distinction between tumor/cancer tissue and normal tissue in the human body is that their electrical properties are different. Depending on the different electrical properties, the reflections of electromagnetic waves sent on these tissues are also different. Using this difference in electrical properties forms the basis of microwave imaging systems. In microwave imaging systems, the transmitting antenna is used to send the electromagnetic wave on the tissue, and the receiving antenna is used to collect the components reflected wave from the tissue. The antennas' operating bandwidth to be used to detect tumors in organs such as the lungs, brain, liver, and kidney should be between approximately 1 GHz and 10 GHz.

Applications such as the shrinking of circuits in electronic technology, the necessity of purpose-oriented flexible applications, and the reduction of dimensions to nano dimensions have made wearable technology one of today's most popular topics [21]. Accessories and clothes used in 3ort life can be transformed into smart devices by adding sensors and necessary equipment, and they can communicate with each other. Therefore, the user can easily perform operations such as data transmission and calculation without the need for larger computers, thanks to the electronic circuits that can be mounted on his body or the calculation and communication ability of the clothes he/she wears. This type of equipment, which we encounter in health, education, sports, entertainment, and many other areas, has created the wearable technology sector according to its usage methods. Common features include high-capacity wireless communication and hosting sensors that can measure internally [21]. However, wearable 3ort his33es, like every new technology, were applications that could be considered a luxury at the beginning, but now they have become a necessity in many fields, especially in the field of medicine. The aim of this study is on antennas that can 3ort his3 need simpler, more usable, cheaper, and higher quality 3ort hi an integral part of wireless transmission.

Microstrip antennas are common in flexible antenna designs since the frequencies studied are high. Antenna dimensions can be reduced at high frequencies. So wearable antennas are usually microstrip. Microstrip antennas (MSA) have many advantages as well as disadvantages. These include bandwidth and efficiency. Generally, radiating in all directions is desired in wearable applications. The problem is to design antennas that can radiate in all directions, have good bandwidth, have high efficiency, and provide good performance in other electrical parameters. The way to achieve this is to choose the right material.

Using these properties of MSAs, the performance of flexible materials was tested for different materials in this study. Besides the importance of patch shapes, size and resonance frequencies of antennas, dielectric values are also of great importance. Especially the dielectric properties of materials used at high frequencies can change the parameters of microstrip antennas. Therefore, it can affect the performance of antennas. This study aims to investigate these effects, determine the most suitable material, and examine the effects of different materials' physical structure and dielectric properties. 3ort his purpose, flexible-based microstrip antenna designs were carried out in the range of 2 to 10 GHz, which are widely used with different flexible products [21] such as felt, photographic paper, and fiber-glass.

In microwave imaging systems, the most commonly used method to detect cancerous tissue/cell in the body using a microstrip antenna is using a receiving antenna to record the reflections of the signal sent by the transmitting antenna on the relevant part of the body and then analyzing the received signals with signal processing methods. Since the electrical properties of healthy tissue and tumor tissue are different, the amplitudes of the signal values that reach the receiver by reflecting from these tissues will also be different. By recording these different reflection values and examining their changes, it is possible to determine whether there is a tumor in the interested part of the body. In this study, a small-sized microstrip antenna that can operate between 2 GHz and 10 GHz was designed to detect tumors in organs such as the lung, brain, liver, and kidney. A soft-flexible material that will not disturb the person is required for the antenna to be used comfortably in practice. Therefore, in order not to disrupt the person/patient, the conductive parts of the antenna are made of conductive copper tape, graphene, and conductive paint, and the substrate is made of felt which is a wearable and flexible material. In addition, the antenna has been chosen not to be large for any part of the human body, not to cause any discomfort to the human.

The main contribution of this work is to present a new flexible, compact UWB antenna on a microstrip fed and substrate material felt ($\varepsilon_r = 1.3$). Three different flexible UWB antennas are produced. The conductive radiation patch of these three antennas is produced from copper tape, conductive paint, and a graphene filament. These antennas are cheaper and easy to manufacture than conventional antennas. As a result, the effects of different conductive materials on antenna performances were investigated, and the results were found to be quite satisfactory in terms of working well in very wide bands. In particular, the fact that conductive paint performs quite well compared to others and its production is very simple and cheap. This study especially will contribute a high-performing and easy-to-produce antenna to the literature.

2. Methodology

The desired features of smart and flexible antennas are that they are stretchable, foldable, and bendable. Poly-Tetra-Fluoro-Ethylene (PTFE), polyethylene naphthalate (PEN), polyimide, paper, laminated copper sheet, fabric, etc. materials are used by many researchers for flexible antennas. Paper has been chosen as the substrate in some antenna designs, but the paper-based flexible substrate is more fragile than other substrates and has a high loss tangent that can reduce antenna efficiency [21, 22]. Again, denim and glass fiber materials are also used in flexible antennas, but they are not stretchable, so it is difficult to use them for frequency-tunable applications [22]. Felt, as another material, is also flexible and has a low loss tangent, making it usable for work. On the other hand, various materials are used in the conductive parts of antennas [15, 21]. In this study, copper tape, graphene filament, and conductive paint were preferred for the conductive part, and their effects on antenna performance were compared.

2.1 Graphene Material

Graphene has a wide range of applications due to its powerful properties. One of these application areas is the biomedical applications of graphene-based polymer nanocomposites. After the first study on the biomedical application of graphene appeared in 2008 [23, 24], graphene and graphene-based nanomaterials have been used in numerous bio applications.

The surface conductivity of graphene is defined as a function that includes the frequency of the excitation electromagnetic wave, its temperature (T), its chemical potential (E_f), and the diffusion rate of the carriers (Γ) [25]. This conductivity formula is usually illustrated by the Kubo equation [25, 26] and is also directly related to the effects of in-band and inter-band transitions. The σ_{intra} term, based on a Fermi-Dirac distribution, allows for temperature, doping effects, and limiting transitions. The contributions of the σ_{intra} and σ_{inter} terms vary depending on the frequency range considered. The σ_{intra} and σ_{inter} formulas are shown in Equations 1 and 2. Azizi et.al. gave the graph containing the real and imaginary parts of the normalized complex surface conductivity of graphene at their study, and it is clear that the contribution of inter-transitions to the conductivity is negligible compared to between bands [25].

$$\sigma_{intra} = -j\frac{e^2 k_B \mathrm{T}}{\pi h^2(\omega - j\Gamma)}\left(\frac{E_F}{k_B \mathrm{T}} + 2\ln(e^{-\frac{E_F}{k_B \mathrm{T}}} + 1)\right) \tag{1}$$

$$\sigma_{inter} = -j\frac{e^2}{4\pi h}\ln\left(\frac{2|E_F| - (\omega - j\Gamma)h}{2|E_F| + (\omega - j\Gamma)h}\right) \tag{2}$$

The terms used in the equations are given below:

ω : the angular frequency or the pulsation of electromagnetic wave

E_F : the Fermi level

Γ : the diffusion rate

T : the temperature

τ : the relaxation time

k_B : the Boltzmann constant

h : the reduced Planck constant

Composite Conductive Graphene filaments have recently been introduced, allowing graphene to be used with a 3D printer [27]. In this study, the antenna 2 (graphene-based patch design) is produced using Conductive Graphene Filament for the core of the antenna and felt for the dielectric substrate part. The volume resistivity of the used Graphene filament is 0.6 ohm-cm [27].

2.2 Conductive Paint

Bare conductive is a non-toxic, water-based, water-soluble, electrically conductive paint [28]. The painted resistor element in circuits can be used as a capacitive electrode or act as a conductor in designs that can tolerate high resistance. It is designed for applications with circuits that use low DC voltages at low currents. The conductive paint adheres to a wide variety of surfaces and can be applied using screen printing equipment. Major benefits include low cost, water solubility, and good screen life. It is black and can be overpainted with any material compatible with water-based paint. Due to its conductivity and many advantages, conductive paint is preferred instead of copper and similar hard plates in antenna production [29–31]. In this way, appropriate, cheap, easy-to-apply productions can be achieved. In this study, conductive paint of the bare conductive was preferred. The surface resistivity is 55 Ω/sq at 50 microns thickness. The resistance graph, which shows the relationship between length/width ratio and resistivity, is given in Figure 1 below [28].

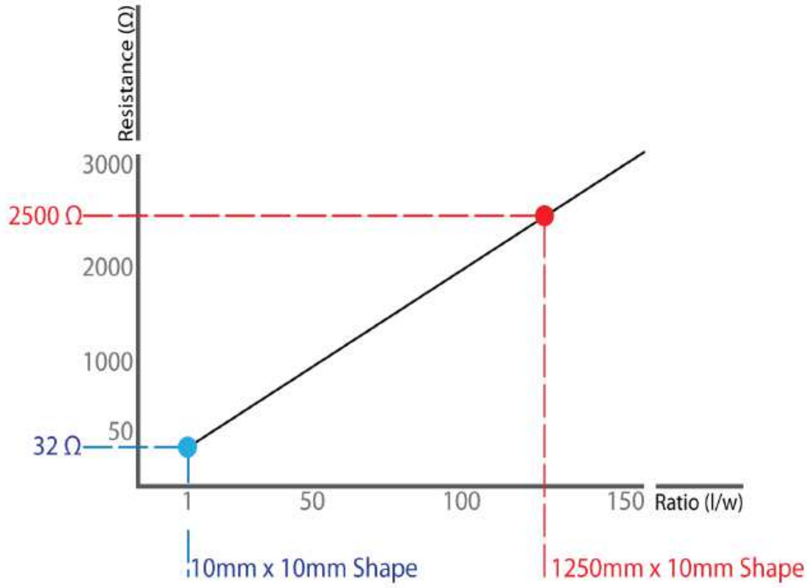


Figure 1. Resistance graph of the relationship between length/width ratio and resistivity.

2.3 Antenna Design and Manufacturing

A microstrip fed structure was designed and analyzed to improve the antenna's performance in healthcare systems. The design and simulation work of the proposed antenna was carried out in CST Microwave Studio. The antennas were designed in Tinkercad, an online 3D design platform developed by Autodesk Inc. and produced with the Creality Ender 3 Pro 3D printer. Material selection is one of the most important issues to be considered in the design process as it has a significant impact on antenna performance. Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) are effective in antennas' performance. It is often preferred in the production of dielectric parts of antennas and microwave components. However, in this study, instead of PLA with $\varepsilon r = 2.54$, felt was preferred. Since the felt is flexible and cheap, its low dielectric constant reduces the surface wave loss more than PLA.

On the other hand, graphene is a suitable material for producing the conductive part of Microwave and Radio Frequency (RF) products due to its excellent properties such as high charge mobility, zero bandgap, high thermal conductivity, high surface area, and excellent biocompatibility. Composite Conductive Graphene filaments have recently been introduced that allow graphene to be used with a 3D printer [27]. In addition, before deciding on the antenna substrate material to be used in the experimental analysis, felt, photo paper, and epoxy resin glass fiber was selected as substrate pieces in the CST Microwave Studio simulation program and analyzed in a simulation then the obtained results are shown in Figure 3. Felt was also preferred in experimental analyses since the results obtained using felt were more satisfactory. In addition, the effects of substrate material differences on antenna performance are also shown with the simulation program. In this study, designed antennas, copper tape, conductive paint, and graphene filament for the conductive part of the antenna, and a felt (Ɛr = 1.3) for the dielectric substrate was used.. The antenna structure is given in Figure 2, and antenna dimensions are in Table 1.

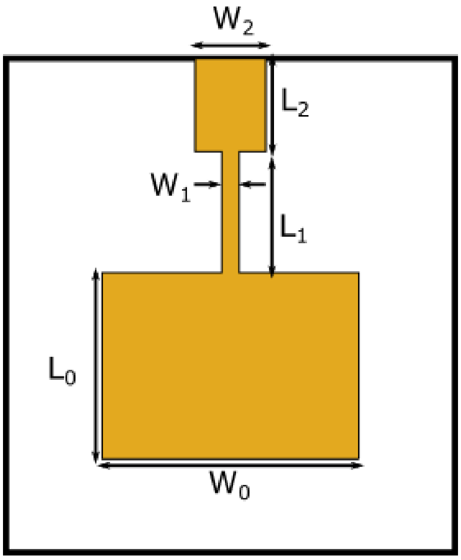


Figure 2. Proposed antenna structure.

Table 1. Proposed antenna dimension parameters

Parameter	**Optimized Value (mm)**
H (substrate thickness)	5.0
h (patch height)	0.5
L_0	32.7
W_0	44.0
L_1	20.1
W_1	3.5
L_2	15.0
W_2	11.4

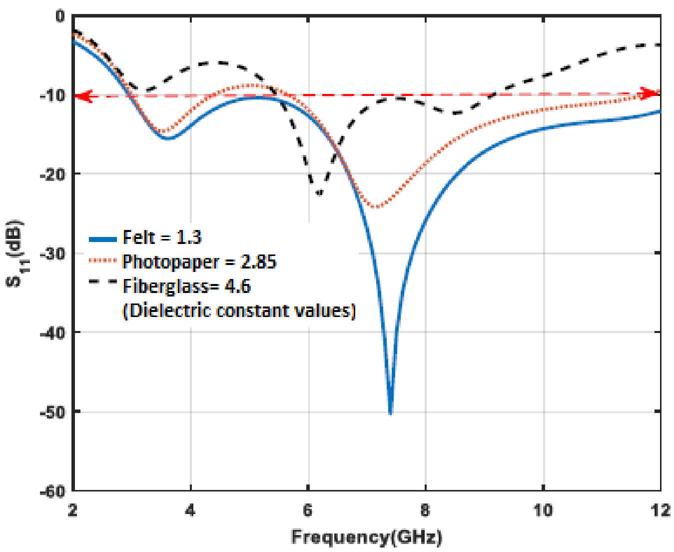


Figure 3. Comparison of the substrates with different dielectric constants in the simulation environment.

The design and dimensions of the microwave antennas were optimized by simulations using the CST Microwave Studio software. The CAD design was created using Tinkercad, and Ultimaker Cura was used to generating the gcode for the 3D printer. A piece of the felt substrate was purchased, and a commercial Creality Ender 3 Pro printer was used to produce the conductive piece also from graphene. Bed and nozzle temperatures were set at 50 °C and 220 °C for graphene. An intermediate printhead speed of 30 mm/s was chosen for graphene. A 0.5 mm nozzle is used for printing. Figure 4 shows the used 3D printer for the fabrication of the antenna. Antenna measurements were made in the 2-10 GHz operating frequency range using a PNA-L Agilent Vector Network Analyzer. Before the measurement was made, the vector network analyzer (VNA) was calibrated with a calibration kit with a short circuit, open circuit, and loading apparatus, respectively. After the calibration process, the produced antennas were connected to the VNA, and the return loss parameter was obtained.

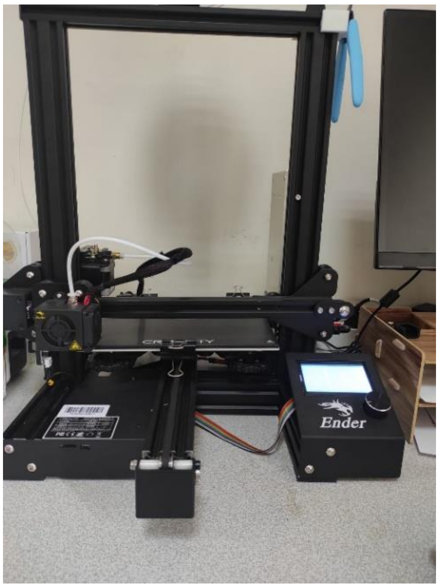
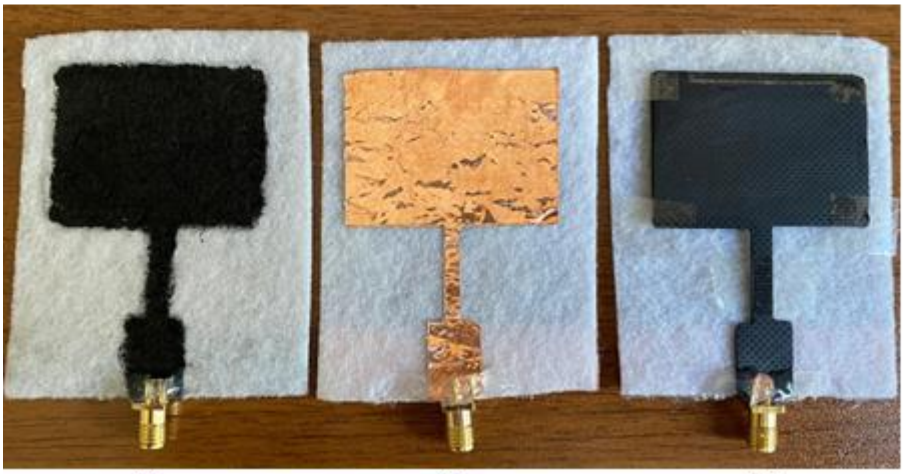


Figure 4. The used 3D printer.

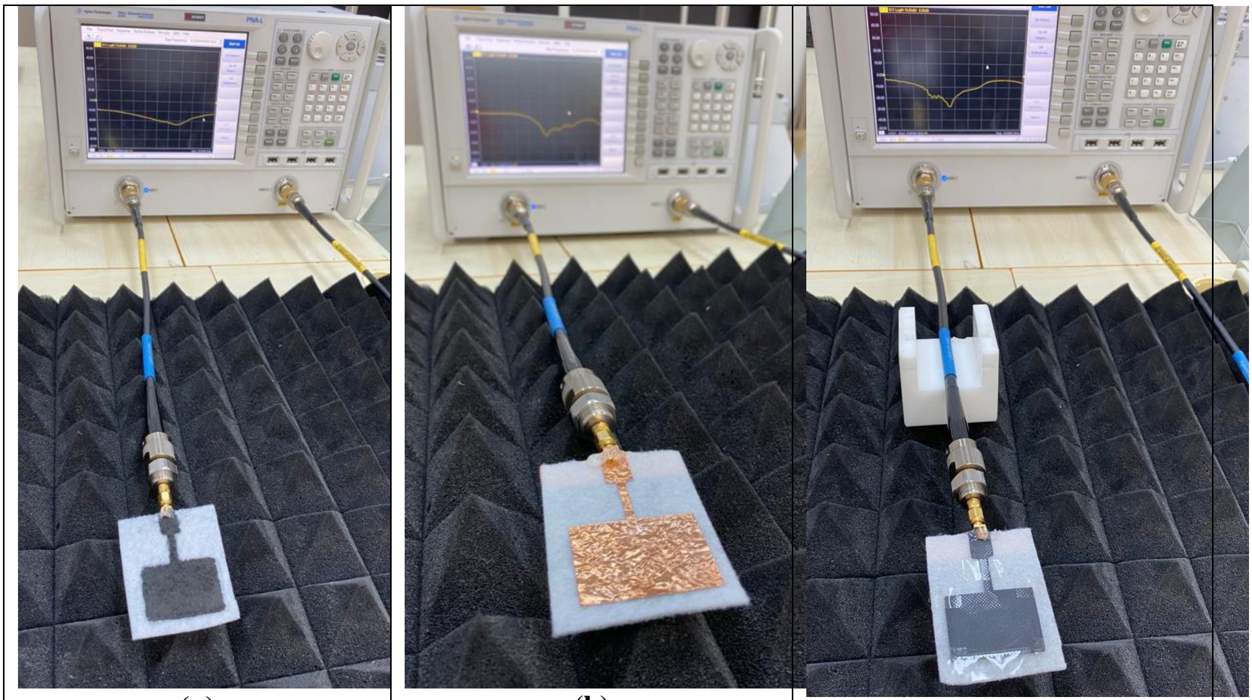
The antennas designed with the CST program were fabricated, and the SMA connector was used for antenna feed. The images of the realized antennas are given in Figure 5.



(a) (b) (c)

Figure 5. The manufactured antennas: (a) Conductive Paint, (b) Copper Tape, and (c) Graphene antenna with a felt substrate.

The S11 parameter of the implemented antenna was measured using Agilent PNA-L Vector Network Analyzer. The measurement photo of the antennas is given in Figure 6.



(a) (b) (c)

Figure 6. Measurement setup: (a) Conductive Paint, (b) Copper Tape, and (c) Graphene antenna with felt substrates.

3. Results

Variation of the spreading patch, cutting slot, substrate, feed width, and any ground causes antenna dimensions and electrical parameters to change. Therefore, the performance of the antenna is also changed. The primary antenna was put through different iterations in patch and ground to find the proposed design that produced various broadband performances.

Impedance matching is affected by the change in substrate material property and changes from 50 Ω of the characteristic impedance of the microstrip feed. The proposed antenna performance was analyzed with a felt substrate of the same dimensions, as shown in Figure 2. In the case of 2.85 and 4.6, the return loss (S11) and bandwidth are greatly affected. However, the felt substrate offers greater bandwidth (2–10 GHz) between the three substrates (Figure 3) due to its low dielectric constant (1.3) and reduces surface wave loss.

When the |S11| plots of the antennas given in Figure 7 are examined, it is seen that the antennas are below the -3 dB reference and resonate in the range of 2 GHz to 11 GHz, but perform successfully in one frequency band. Each frequency band has similarities within itself. It is seen that the graphene-based antenna performs well in the first frequency band between 5 GHz and 6 GHz. It is also clear that the conductive paint-based antenna also performs well in this band. The copper band antenna performs well in the 6 GHz to 7 GHz range. In the 7 GHz to 8 GHz range, the conductive paint-based antenna offers higher bandwidth than other antenna designs. It is also around -10 dB outside this range. In the 8 GHz to 10 GHz range, all designs started to exhibit similar performance. As a result, all three antennas produced perform quite well for ultra-wideband applications, but apart from the good performance of the conductive paint-based antenna, it is the preferred approach in terms of ease of production, cheap, and usefulness. The simulated and measured results for antenna prototypes with copper tape, graphene, and conductive paint patch elements are summarized and compared in Table 2.

Table 2. Simulation and measurement results for the designed copper tape, graphene, and conductive paint-based patch antennas on the felt substrate.

Parameters	Copper tape patch element	
	Measured[1]	Simulated[2]
f_r(GHz)	6.321	6.301
S11 (dB)	-22.83	-15.01
BW (MHz)	680	600
Z(Ω)	41.14- j0.66	54.36 + j4.15
Parameters	**Graphene patch element**	
	Measured[1]	Simulated[2]
f_r(GHz)	5.68	5.28 / 8.225(f_{r2})
S11 (dB)	-27.54	-26.52 /-29.88
BW (MHz)	760	750 / 305
Z (Ω)	38.95- j0.66	53.56 + j2.96
Parameters	**Conductive bare patch element**	
	Measured[1]	Simulated[2]
f_r(GHz)	7.320	6.495
S11 (dB)	-23.45	-24.89
BW (MHz)	598	601
Z (Ω)	50.95- j0.66	52.55 + j3.01

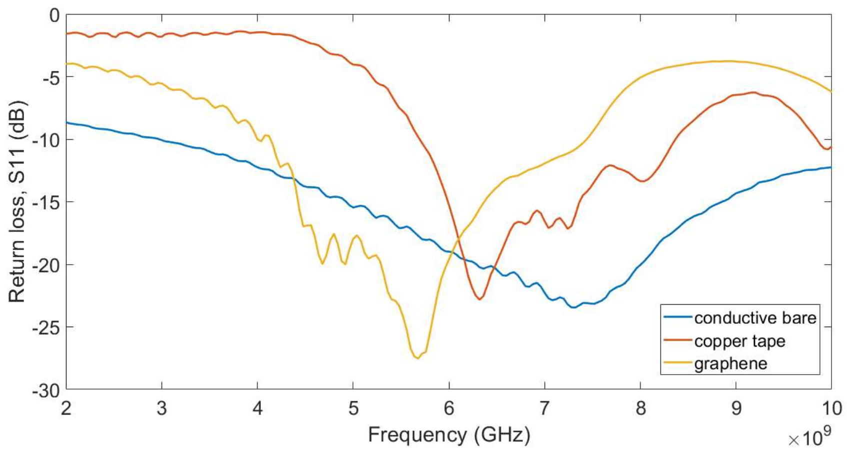


Figure 7. Comparison of measured return loss values for copper tape, graphene, and conductive bare, respectively.

When we examine it in terms of gain, while all three antenna structures provide a good gain, the conductive paint-based antenna provides an excellent gain. Figure 8 shows the gain graph.

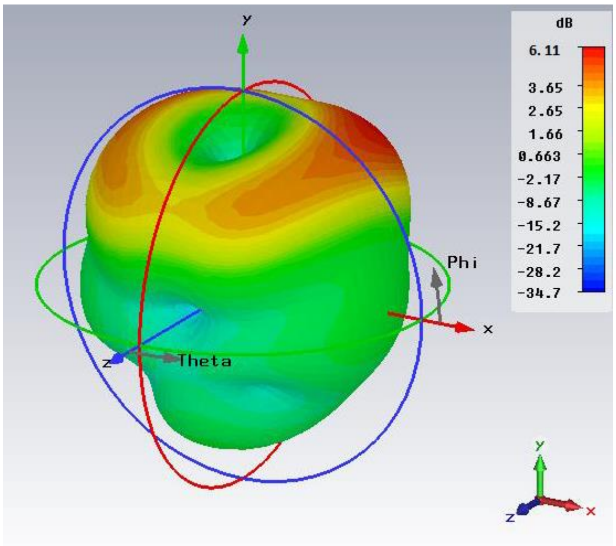


Figure 8. Gain change depending on the angle value of the designed antenna for conductive paint.

4. Discussion

Three separate conductive materials have been investigated for which the impedance bandwidth can be quite good for a low-cost fabrication application in antenna design. Before the conductive material trials were started, it was thought that the substrate material should be both cheap and light and also flexible. For this reason, three flexible materials, which are frequently used in the literature, were used in the simulation environment, and according to the results obtained, graphene filament was used for the conductive patch parts to be used in production since it is very easy to produce with a 3-dimensional printer and has good conductivity. Then, according to the results obtained from the simulation studies, it was observed that the use of copper tape and conductive paint materials for the conductive patch parts was also better than graphene. It was concluded that copper tape and conductive paint would be more suitable in terms of preference, being quite cheap compared to graphene.

The gains provided by these materials applied for the conductive patch parts are kept close to each other, but it is given in Table 3 that the conductive paint is slightly higher than the graphene. In addition, looking at Table 3, it is seen that the antennas in this study are quite good in performance compared to previous studies.

As a summary of the contribution, in this study, a textile substrate-based microstrip antenna that does not harm the human body is presented. Felt material was used in the experimental study since it was revealed that it was much more efficient. This proposed antenna has a very low radiation effect, which is a very important factor in human applications. It is also a highly efficient and innovative antenna for ultra-wideband applications. Simulation studies have been carried out to prove that it performs well in ultra-wideband applications, and it has been observed to be successful. These antennas will make an important contribution to the literature since they are produced in a cheap way and the damage to humans is very low.

Table 3. A comparison of previous designs with the proposed antenna [21].

Antenna type	Size (mm) and Application	Bandwidth	Conductive Material (S/m)	Substrate Material	Gain(dBi)
Microstrip Patch Antenna	65x46x0.127 ISM band application	N/A	Flexible Copper tape	Kapton Polymide	N/A
Microstrip-based Koch Fractal	39x39x0.508, WBAN applications	2.36-2.55	Cu	Vinyl Polymer based substrate	2.06
Microstrip Patch	60x60x0.110, C-band and future organic electronics applications	4.43-4.76	PANI/MWCNTs	Rogers RT/Duroid 5870	5.18
Multilayer Microstrip Fractal Patch Antenna	22x31x0.125, On-package, and on-chip printed antennas	4.79-5.04	Ag NP	Kapton Polymide	4.5
Microstrip Patch Antenna	40x35x0.6, Intrabody telemedicine systems in the 2.4 GHz ISM bands	2.33-2.53	Cu strips	Photopaper	2
Z-shaped Microstrip Patch Antenna	45x36x0.135, dual-band Wi-Fi and wearable devices	N/A	Ag NP	PET	16.74 and 16.24
This work (Antenna 1)	65x65x0.5, telemedicine, and health systems	2.0-10.0	Copper Tape	Felt	5.66
This work (Antenna 2)	65x65x0.5, telemedicine, and health systems	2.0-10.0	Graphene Filament	Felt	5.98
This work (Antenna 3)	65x65x0.5, telemedicine, and health systems	2.0-10.0	Conductive Paint	Felt	6.11

5. Conclusion

In this study, a wearable rectangular microstrip antenna that can be used as both a transmitter and a receiver in microwave imaging systems has been designed to detect tumors in organs such as the lung, brain, liver, and kidney. First, it was implemented after the antenna designed simulated in the CST environment. It has been observed that the parameters of the antenna designed in the CST environment of the antenna analyzed under VNA and room conditions are very close to each other. Therefore, the gain of the designed antenna is relatively high (6.11 dB) compared to conventional microstrip antennas for conductive paint.. Considering the working frequency range of the designed antenna, it is seen that it is around 8 GHz for both theoretical and real antenna value. When compared with very narrow band (0.1 GHz) classical microstrip antennas, these values are seen to be very good. For the antenna to be designed as wearable, its dielectric part is realized by using a flexible material felt. Thus, the designed antenna can be easily used in the continuous monitoring of patients with a high risk of cancer.

ACKNOWLEDGEMENTS

We would like to thank İskenderun Teknik University Engineering Faculty Electrical and Electronics Engineering Department for their support in the measurements.

FUNDING

There is no fundig.

CONFLICT OF INTEREST

There is no conflict of interest.

ETHICAL APPROVAL

This article does not contain any studies with human participants performed by any of the authors.

REFERENCES

1. WHO report on cancer: setting priorities, investing wisely and providing care for all. https://www.who.int/publications/i/item/who-report-on-cancer-setting-priorities-investing-wisely-and-providing-care-for-all. Accessed 13 Jun 2021
2. Cancer trends - statistics per cancer type | WCRF International. https://www.wcrf.org/diet-and-cancer/cancer-trends/. Accessed 13 Jun 2021
3. Alsharif F, Kurnaz C (2018) Wearable Microstrip Patch Ultra Wide Band Antenna for Breast Cancer Detection. 2018 41st Int Conf Telecommun Signal Process TSP 2018 456–459. https://doi.org/10.1109/TSP.2018.8441335
4. Rao PK, Mishra R (2019) Ultra-wide-band Flexible Antenna for Breast Cancer Detection. 5th Int Conf Converg Technol. https://doi.org/10.1109/i2ct45611.2019.9033875
5. G.A. Deschamps, "Microstrip Microwave Antennas," Presented at the third USAF Symposium on Antennas, 1953. http://www.sciepub.com/reference/126221. Accessed 13 Jun 2021
6. CA627967A - Flat aerial for ultra high frequencies - Google Patents.

https://patents.google.com/patent/CA627967A/fi. Accessed 13 Jun 2021
7. Munson RE (1974) Conformal Microstrip Atennas and Microstrip Phased Arrays. IEEE Trans Antennas Propag AP-22:74–78. https://doi.org/10.1109/TAP.1974.1140723
8. Howell JQ (1975) Microstrip Antennas1. IEEE Trans Antennas Propag 23:90–93. https://doi.org/10.1109/TAP.1975.1141009
9. Zasowski T, Althaus F, Stager M, et al (2003) UWB for noninvasive wireless body area networks: Channel measurements and results. 2003 IEEE Conf Ultra Wideband Syst Technol UWBST 2003 - Conf Proc 285–289. https://doi.org/10.1109/UWBST.2003.1267849
10. Chahat N, Zhadobov M, Sauleau R, Ito K (2010) Design and characterization of an UWB wearable antenna. In: 2010 Loughborough Antennas and Propagation Conference, LAPC 2010. pp 461–464
11. Sankaralingam S, Gupta B (2010) Development of textile antennas for body wearable applications and investigations on their performance under bent conditions. Prog Electromagn Res B 22:53–71. https://doi.org/10.2528/PIERB10032705
12. On the Evaluation of Biological Effects of Wearable Antennas on Contact with Dispersive Medium in Terms of SAR and Bio-Heat by Using FIT Technique - PDF Free Download. https://hobbydocbox.com/109999138-Radio/On-the-evaluation-of-biological-effects-of-wearable-antennas-on-contact-with-dispersive-medium-in-terms-of-sar-and-bio-heat-by-using-fit-technique.html. Accessed 13 Jun 2021
13. Faria J V. (2015) Flexible antennas design and test for human body applications
14. Sharma C, Rana SB, Singh H (2015) Design and Analysis of Modified Bowtie Antenna. Int J Technol Enhanc Emerg Eng Res 3:119–121
15. Lakshmanan R, Sukumaran SK (2016) Flexible Ultra Wide Band Antenna for WBAN Applications. Procedia Technol 24:880–887. https://doi.org/10.1016/j.protcy.2016.05.149
16. Akalya CG, Nandalal V (2017) On-Body Adhesive Microstrip Antenna for Wearable Application. Int J Commun 2:137–145
17. Gharbani A (2014) Karbon İplik Dolgulu Grafen/Epoksi Nanokompozitlerin Özellikleri, YL. Tezi, Ege Üniversitesi, İzmir
18. Design and analysis of different substrate materials for uwb antenna used for biomedical applications. https://www.researchgate.net/publication/324692753_Design_and_analysis_of_different_substrate_materials_for_uwb_antenna_used_for_biomedical_applications. Accessed 13 Jun 2021
19. AlShehhi H, Alzarouni M, AlYammahi N, et al Compact Low-Profile Wearable Antennas For Breast Cancer Detection
20. Chen B, Wang J, Qi H, et al (2017) The specific absorption rate of tissues in rats exposed to electromagnetic plane waves in the frequency range of 0.05–5 GHz and SARwb in free-moving rats. Australas Phys Eng Sci Med 40:21–28. https://doi.org/10.1007/s13246-017-0522-x
21. Kirtania SG, Elger AW, Hasan MR, et al (2020) Flexible antennas: A review. Micromachines 11:. https://doi.org/10.3390/mi11090847
22. Vashi R, Upadhyaya T (2020) Cpw fed flexible graphene based thin dual band antenna for smart wireless devices. Prog Electromagn Res M 89:73–82. https://doi.org/10.2528/pierm19120906
23. Liu Z, Robinson JT, Sun X, Dai H (2008) PEGylated nano-graphene oxide for delivery of water insoluble cancer drugs. J Am Chem Soc 130:10876–10877
24. Sun X, Liu Z, Welsher K, et al (2008) Nano-Graphene Oxide for Cellular Imaging and Drug Delivery. Nano Res 1:203–212

25. Azizi MK, Ksiksi MA, Ajlani H, Gharsallah A (2017) Terahertz graphene-based reconfigurable patch antenna. Prog Electromagn Res Lett 71:69–76. https://doi.org/10.2528/pierl17081402
26. Gusynin VP, Sharapov SG, Carbotte JP (2007) Magneto-optical conductivity in graphene. J Phys Condens Matter 19:. https://doi.org/10.1088/0953-8984/19/2/026222
27. Supermarket G Conductive, Graphene, PLA, Flament. https://graphene-supermarket.com/Conductive-Graphene-PLA-Filament.html. Accessed 2 Mar 2021
28. Floor F, Kingdom U, Properties T (2012) Bare Paint Technical Data Sheet. 44:1–4
29. Andriambeloson JA, Wiid PG (2015) A 3D-printed PLA plastic conical antenna with conductive-paint coating for RFI measurements on MeerKAT site. Proc 2015 IEEE-APS Top Conf Antennas Propag Wirel Commun IEEE APWC 2015 945–948. https://doi.org/10.1109/APWC.2015.7300188
30. Pell BD, Sulic E, Rowe WST, et al (2011) Experimental study of the effect of modern automotive paints on vehicular antennas. IEEE Trans Antennas Propag 59:434–442. https://doi.org/10.1109/TAP.2010.2096182
31. Rizwan M, Khan MWA, Sydanheimo L, et al (2017) Flexible and Stretchable Brush-Painted Wearable Antenna on a Three-Dimensional (3-D) Printed Substrate. IEEE Antennas Wirel Propag Lett 16:3108–3112. https://doi.org/10.1109/LAWP.2017.2763743