Design of UTeM logo-shape wearable antenna for communication application by graphene silver nanocomposites

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Article Info

Article history:

Received Sep 17, 2021
Revised Mar 10, 2022
Accepted Mar 18, 2022

Keywords:

Graphene
Silver
Textile substrate
Wearable antenna
Wireless communication

ABSTRACT

Previously, the antenna conductive patch was made of copper, which was costly, susceptible to multi-fading, bulky, environmentally sensitive, and difficult to produce. Because of their exceptional electrical conductivity and superior strength to metal, while remaining versatile, the miracle nanotechnology of graphene has made them a possible candidate to replace uncompromising copper metallic content. As a result, graphene is incorporated into conductive silver nanocomposites in this work. With the microstrip feeding technology, the suggested antenna design features a logo-shaped made of graphene and silver patch on a textile substrate and radiates at 2.45 GHz frequency. The antenna's total dimensions are 60×60×1.6 mm. The simulation results were generated using computer simulation technology (CST) studio suite program software, which improved antenna properties including far-fields, return loss, and voltage standing wave ratio (VSWR). Wearable antennas are promising and have a bright future, especially with the advent of wireless communication technologies, so this new design is essential for the materials revolution in advanced communication and IR4.0 applications, as well as wireless sensor applications.

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1. INTRODUCTION

Wireless body area networks (WBAN) were introduced in the last decade as a result of the development of wearable antennas and sensors that can monitor and send crucial signals in various body-worn applications such as health monitoring and geo-positioning of rescue or military personnel [1]. Bands such as the ultra-wideband (UWB) 3.1 to 10.76 GHz, the industrial, scientific, and medical (ISM) band 2.4 to 2.48 GHz, the medical implant communication services (MICS) band 402 to 405 MHz, and others have been created for the study and commercialization of WBAN communication systems. The IEEE 802.15 standards group was established to define applications for on-body, off-body, and in-body communication [2]. The scientific community is also quite interested in antenna design for body-worn applications [3]. Small, low-profile, mechanically resilient, and lightweight antennas are required for wearable antennas. Furthermore, the electromagnetic radiation emitted by these body-worn antennas must comply with regulatory authorities in the United States (US) and the European Union (EU) specific absorption rate (SAR) [4].

Planar monopoles, vertical monopoles [5], planar inverted-F [6], and patch antennas are only a few of the design configurations that have been examined in the recent literature for the applicability of flexible body-worn antennas [7]. The described antennas, on the other hand, have a big footprint, a small impedance bandwidth (BW), and a high front-to-back ratio (FBR) [8]. When utilized near to a person's body or when structural deformation occurs due to bending, several of them perform badly [9]. There is a suitable choice for flexible body-worn applications because of the increased flexibility, minimal humidity absorption, and modest loss tangent [10]. When textiles are integrated with metals, meeting the requirements for the ability of textile preforms to conform to the surface of molds, touch, lightness, and washability introduce additional obstacles in making the fabrics wearable. According to their respective professions, researchers are investigating various design solutions for the integration of electrical components. Smart textiles, like many other e-textile applications, such as health monitoring in MedTech, wearable computing, battery design, and energy-harvesting textile design, still rely largely on the usage of metal in wearable communication in the internet of things (IoT) era.

This paper examines a novel logo-shaped wearable antenna idea built of graphene and silver nanocomposites for the future generation of lightweight wearable antenna applications [11]. Because of their exceptional electrical conductivity and superior strength to metal, while remaining versatile, the miracle nanotechnology of graphene has made them a possible candidate to replace uncompromising copper metallic content [12]. The key disadvantage of graphene is the lack of an energy band distance, which restricts the applications of many electronic devices [13]. As a result, in this study, graphene oxide (GO) will be combined with a silver (Ag) conductive material. The combination of GO and Ag is perfecting each other in terms of improving existing electrical conductivity properties while opening up new possibilities, especially for the development of robust wearable antennas. New materials formulations of GO/Ag-textile nanocomposite and related fundamental understanding for such applications, as well as a standard methodological approach for smart clothing wearable textile antenna fabrication, are expected to be developed and proposed as a result of this research.

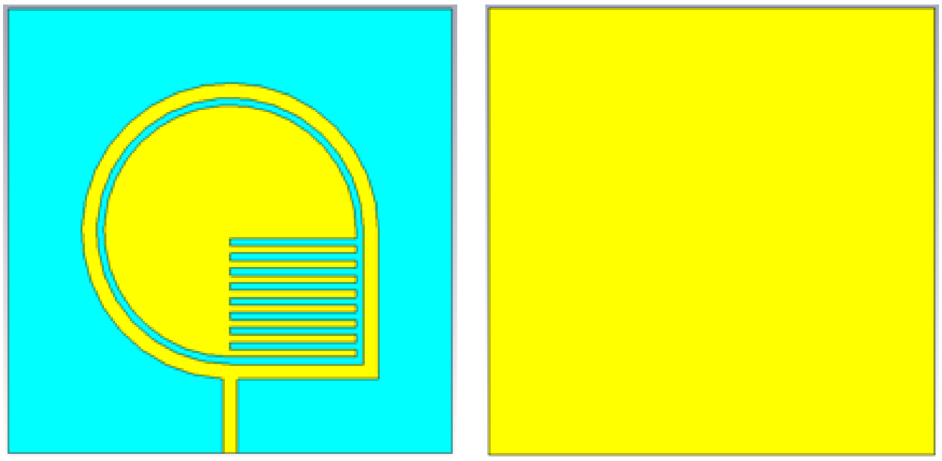
2. ANTENNA DESIGN

In antenna design, the most important parameters are the efficacy, affordability, and total size of the wearable antenna. The wearable antenna design in the evaluated work [14]-[16] has a low direct current (DC) output voltage due to its low efficiency. The size of a wearable antenna determines what applications it may be used for. The design of the wearable antenna allows it to collect more radio frequency (RF) signals while simultaneously expanding its overall size [17]. The performance of wearable antennas can be improved by using a coplanar waveguide. However, the size and cost of wearable antennas have increased [18]. The benefits of using different types of dielectric materials in wearable antenna designs include the creation of novel formulations of combination materials that may aid in the elimination of interference, as shown in [19], [20]. The path of study should be described with references, so that the explanation may be accepted scientifically [21], [22]. Despite the benefits of conductivity, it has the downside of increasing the wearable antenna size and cost.

2.1. UTeM logo design

The microstrip transmission line is the most common among researchers in evaluating the electrical characteristics of dielectrics even at extremely high frequencies in telecommunication. This research offered a novel combination design for the feedline and the patch infrequent form. The Universiti Teknikal Malaysia Melaka (UTeM) logo is depicted in Figure 1 as the overall perspective of the logo-shaped patch antenna design. To arrive at the ultimate optimum geometry, simulations with the software computer simulation technology (CST) were employed. The antenna, which operates at 2.45 GHz, was made with a textile substrate and a silver-graphene oxide ground plane. The textile, which is primarily based on this, has excellent thermal and mechanical characteristics as well as good tensile resistance [23]. As a result, textile has an excellent mix of electrical, thermal, mechanical, and chemical characteristics, making it a potential electronic packaging substrate.

Not to mention that graphene and silver were utilized for the patch and the feed line in this project. For the examination of the antenna's efficiency, three types of material for one patch antenna design experiment were carried out. The initial version used copper and silver as the top layer of the patch and also for the feedline. Meanwhile, the design was implemented using silver-graphene [24] as the top layer patch and also the patch feedline. The antenna built for 2.45 GHz ISM band applications may be effectively [25] used since it lowers the equipment's production cost. In comparison to existing antennas for military and medical applications, the suggested antenna improves gain and directivity.



(a) (b)

Figure 1. The 2D view for antenna logo-shape design for (a) front view and (b) back view

2.2. Wearable antenna specifications

The antenna is made of a textile substrate with a relative permittivity (r) of 1.2 and a tangent loss of 0.005, as well as a patch made of silver-graphene oxide (Ag/GO) and a microstrip feeding line and ground plane. The operating frequency (fr) for each antenna is set to 2.45 GHz, and the height of the dielectric substrate (Hs) is set to 1.60 mm. The antennas patch width (W), effective permittivity (Reff), length of the patch extension (L), the effective length of the patch (Leff), length of the patch (L), ground plane width (Wg), length of the ground plane (Lg), the width of the substrate (Ws) and length of the substrate (Ls), and length of feedline (Fi) are all calculated for (fr) and (r). Table 1 shows the geometrical parameters for the logo-shaped graphene and silver wearable antenna patch planes, textile substrate planes, ground planes, and feed line planes are listed below.

Table 1. General specification of logo-shaped microstrip patch antenna

Antenna parts	Parameters (symbols)	Values in (mm)
Substrate plane	Ls	60
	Ws	60
	Hs	1.60
Patch plane	W	38
	L	60
	Thickness (Ht)	0.05
Feedline plane	Wf	10
Ground plane	Lg	60
	Wg	38
	Thickness (Ht)	0.05

The size of the patch is noticeably larger than the size of the feedline based on this basic standard. This is due to the fact that the form of the logo patch was large, the length and width of the feedline were very important as can affect the operating frequency. It is also worth noting that the conductivity, or resistivity, of silver, is higher than that of copper.

3. RESULTS AND DISCUSSION

For 2.45 GHz wearable antenna applications, the simulated antenna settings were successful. The antenna works at 2.449 GHz for copper, 2.4495 GHz for silver and 2.4499 for silver-graphene. Figures 2 to Figure 6 show parametric experiments to explore the influence of design factors on antenna properties. The results also show the comparison between silver, copper, and silver-graphene. Table 2 summarises recently reported antennas in terms of antenna type, operating dielectric material, antenna gain, and radiated efficiency from higher to lower antenna gain.

Table 2. Literature review summary of different types of wearable antenna designs

Ref	Freq	Antenna type	Dielectric material	Gain
[26]	2.45	Fractal patch antenna	Jeans textile	9.13 dB
[27]	2.45	Square microstrip patch antenna	Jeans textile	8.6 dB
[3]	2.45	Modified logo patch	Rogers 4003C	7.3 dB
Proposed	2.22	UTeM-logo patch antenna	Go/Ag-textile	6.51 dB
[28]	2.45	Rectangular patch antenna	Jeans textile	6.34 dB
[29]	2.45	Square ring patch antenna	Polyester taffeta fabric	5.3 dB
[18]	2.45	Rectangular coplanar patch antenna	Felt	5.2 dB
[15]	2.45	Square patch antenna	Polydimethylsiloxane	4.73 dB
[30]	2.45	Square patch antenna	Acrylonitrile-butadiene Styrene	4.67 dB
[31]	2.45	F-shaped patch antenna	Copper foil tape and Shieldex	4.48 dB
[32]	2.45	Half diamond waveguide topology	Polyester taffeta fabric	4.1 dB
[17]	2.45	Circular quarter waveguide topology	Polyester taffeta fabric	3.8 dB
[33]	2.45	Circular patch antenna	Polydimethylsiloxane	3.67 dB
[34]	2.45	Inverted-F patch antenna	Denim textile	2.3 dB
[14]	2.45	Quadant circular microstrip antenna	Rogers duroid 5870	2.1 dB
[16]	2.45	Koch fractal triangular patch antenna	Roger duroid 5880	2.06 dB

3.1. Return loss and bandwidth

The highest return loss (S11) for silver-graphene is -49.459 dB at 2.4499 GHz with a bandwidth of 37.70 MHz, according to the design. Copper has a return loss of -29.014 dB at 2.4494 GHz with a bandwidth of 38.19 MHz, while silver has a return loss of -29.080 at 2.4495 GHz with a bandwidth of 38.08 MHz. This comparison shows that the silver-graphene has better results compared to copper and silver which is suitable to be the wearable antenna. The antenna should be at least -10 dB in order to execute successfully, according to the design obtained a tolerable value for the return loss (S11). If the antenna receives a -10 dB input, it implies that 10% of the incoming power is transferred to the source. If the rate is lowered from -10 dB, the antenna is operating with minimal return loss, or in other words, the antenna has a high RF efficiency. When the substrate thickness is increased, the bandwidth rises, but the antenna size reduces and the center operating frequency moves away from the ideal resonance frequency. Furthermore, when the patch size grows, a rapid change in resonance frequency happens for the wearable design. Figure 2 shows that silver-graphene has a better return loss than copper and silver.

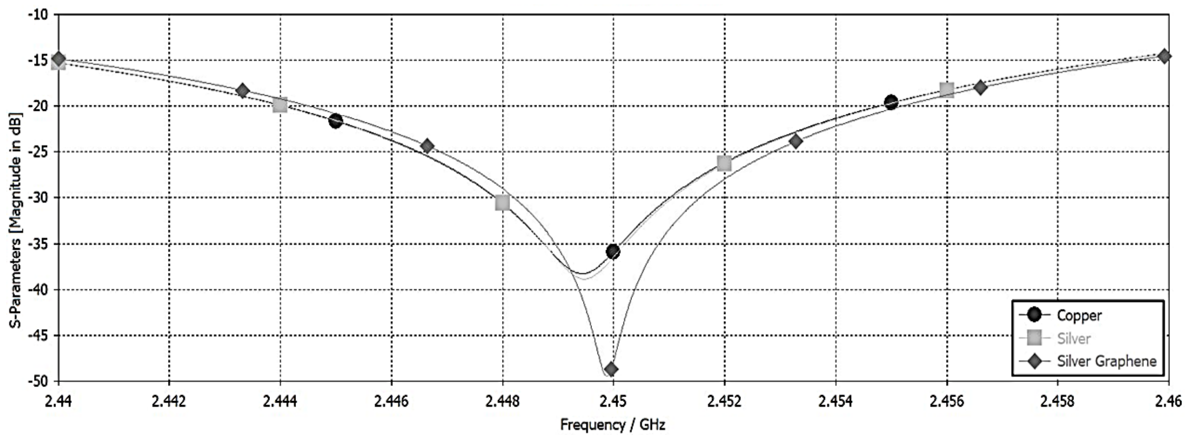


Figure 2. The return loss of the logo shape patch antenna for silver, copper, and silver-graphene

3.2. Voltage standing wave ratio (VSWR)

Surprisingly, the design for silver-graphene received around 1.007 at a frequency of 2.4499 GHz. While copper is 1.024 and silver is 1.023. According to the research done for the VSWR parameter, all architectural structures have greater than 1. According to the VSWR definition, the lower the VSWR value. The more energy is transmitted to the antenna, the closer the antenna is aligned to the transmission line. This also proves that the VSWR obtained is a real and positive figure for designing microstrip patch antennas. Figure 3 shows that silver-graphene has a better VSWR value than copper and silver.

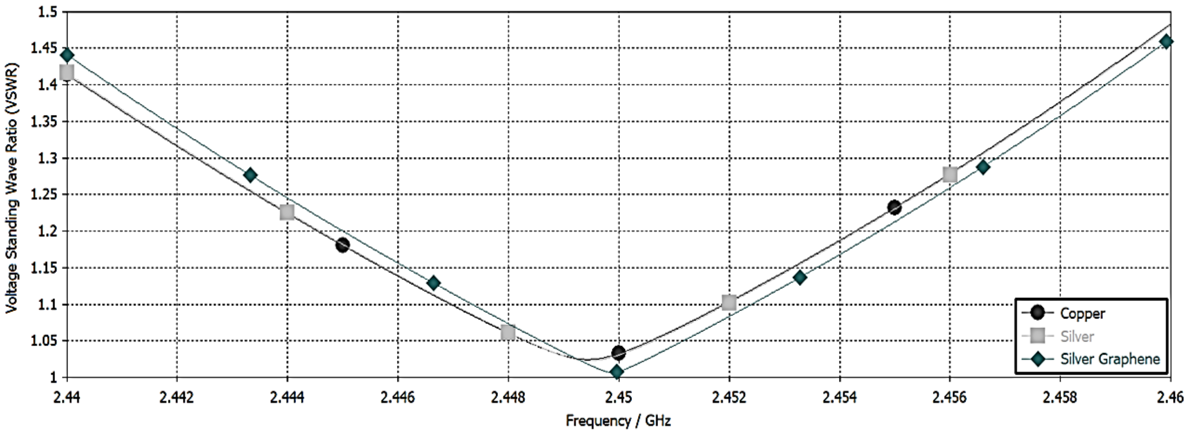


Figure 3. The voltage standing wave ratio comparison for silver-graphene, copper, and silver

3.3. Total efficiency

Using the value of the dielectric constant $\varepsilon' r$ and substrate height (Hs), the simulation value of overall efficiency achieved for silver-graphene design is -1.035 dB, for copper is -1.117 dB and silver is -1.110 dB. This has shown that silver-graphene has efficiencies better than copper and silver material. Figure 4 shows the comparison of total efficiency between silver-graphene, copper and silver.

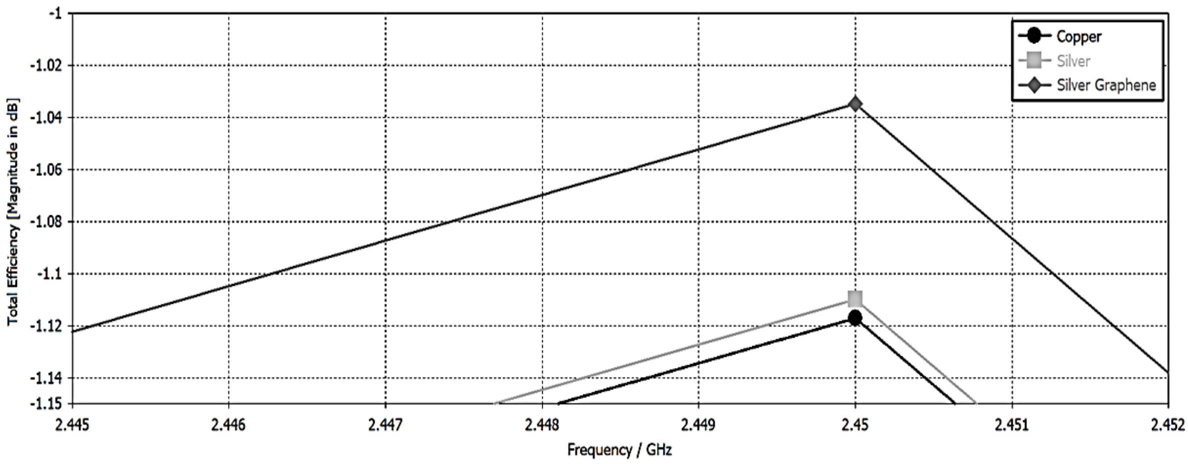


Figure 4. The total efficiency of the logo shape antenna between silver-graphene, copper, and silver

The logo form patch antenna has a slightly greater efficiency rating than the design. The total performance of the microstrip patch antenna is influenced by the conductivity of the ground plane, as well as the permittivity and thickness of the dielectric substrate, which determines whether it is positive or negative. In this study, a textile substrate with a permittivity of 1.2 and a thickness of 1.6 was used (Hs). A textile substrate is employed for these designs instead of other substrates because it has a constant dielectric substrate and may be used as a lightweight substrate for microstrip antenna manufacturing. Furthermore, the antenna’s simulated overall performance in the specified frequency range is quite constant.

3.4. Radiation pattern of directivity

The silver-graphene design provides a directivity of 6.5719 dBi, while copper and silver are 6.5764 dBi and 6.5765 dBi respectively as can be seen in Figure 5. The structure is disturbed by a directed pattern that propagates at frequencies of 2.65 GHz, according to the study of the radiation directivity process. The directivity of a conventional patch antenna with a single substrate is 6-8 dB. As a result of this fact, the directivity achieved for the design is well within the spectrum’s value. The breadth of the main beam in the design is 98.3 degrees for silver graphene, 97.4 degrees for copper, and 97.5 degrees for silver according to the findings. The pace of transition from primary to secondary lobes should be as fast as possible. This reveals that the design variation with silver and copper as a patch antenna has the highest directivity compare to silver-graphene as can be seen in Figure 5.

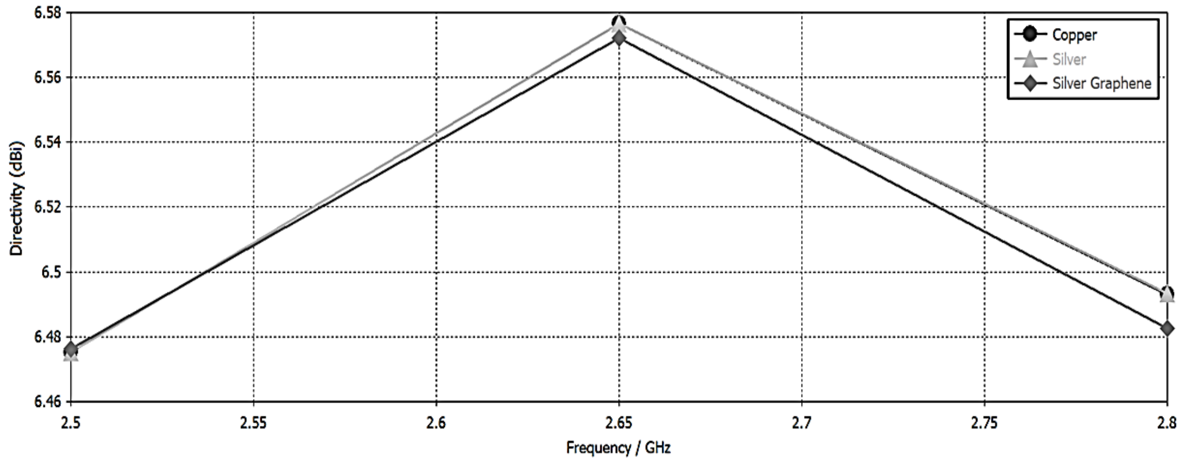


Figure 5. Directivity of the logo-shape patch antenna for silver-graphene, copper, and silver

3.5. Gain

The silver-graphene design achieved a gain of 6.517 dB, while copper is 6.313 dB and silver is 6.329 dB. The maximum gain of a microstrip patch antenna is usually around 6 to 9 dB. Based on the data, this design had a somewhat greater benefit than the prior study. Figure 6 shows that silver-graphene has better gain than copper and silver. This is reflected in the characteristics of the materials used in each building. Each design has two conductive materials, one for the patch and the other for the feedline. However, the amount of material size employed in the modeling work of the logo shape framework varies across prototypes. It can also be deduced that using silver and graphene oxide content for the patch and textile as the substrate enhances the gain of the designed antenna substantially. In terms of the conductivity of the patch and feedline materials, simulations show a very high agreement.

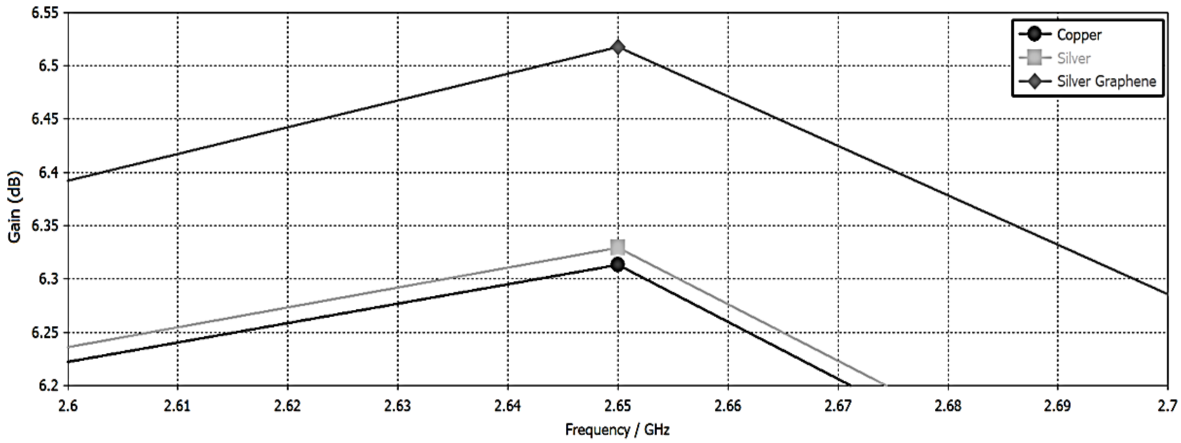


Figure 6. The antenna gain of the design for silver-graphene, copper, and silver

The CST software, which provides the foundation for creating the logo-shaped microstrip patch antenna, was used to reproduce the findings. The relative antenna parameter values for the proposed antenna design are shown in Table 3. According to the results of the comparison, silver-graphene outperforms copper and graphene.

Table 3. Comparison of different types of wearable antenna results

Parameter analysis	Logo design		
Patch	Silver-graphene	Copper	Silver
Feedline	Silver-graphene	Copper	Silver
Conductivity (S/m)	19.8e+7	5.8e+7	6.3e+7
Resonant frequency (GHz)	2.4499	2.4494	2.4495
Bandwidth (MHz)	37.70	38.19	38.08
Return loss (S11) (dB)	-49.459	-29.014	-29.080
VSWR	1.007	1.024	1.023
Total efficiency (dB)	-1.035	-1.117	-1.110
Directivity (dBi)	6.5719	6.5764	6.5765
Gain (dB)	6.517	6.313	6.329

4. CONCLUSION

The microstrip patch antenna in the shape of a logo is composed of graphene and silver and operates at a frequency of 2.45 GHz, making it suitable for wearable applications. The proposed wearable antenna design improves antenna parameters such as directivity and gain of 6.5719 dBi and 6.517 dB, as well as return loss of -49.459 dB and overall efficiency of -1.035 dB. It results in higher overall efficiency for these prototypes. For the 2.45 GHz working frequency, the design has a VSWR of 1.007 and a bandwidth of 37.70 MHz. The most essential wearable antenna characteristics, including conversion efficiency, antenna size, antenna gain, and overall wearable antenna performance, are shown and analyzed in this article. This paper presents several strategies for improving the overall wearable antenna design, increasing conversion efficiency, and shrinking the size so that it may be utilized in WBAN and radio frequency identification (RFID) applications.

ACKNOWLEDGEMENTS

The Malaysian Ministry of Higher Education (MOHE) and Universiti Teknikal Malaysia Melaka have jointly funded this study through grant (FRGS/1/2020/FTKEE-COSSID/F00424) and (PJP/2020/FTKEE/PP/S01749). Special appreciation to the Faculty of Electronics and Computer Engineering, Faculty of Engineering Technology Electricals and Electronics, and Faculty of Manufacturing Engineering at Universiti Teknikal Malaysia Melaka for their superb research facilities.

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