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Development of 3.5GHz enhanced graphene patch antenna for 5G applications

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ABSTRACT

This paper explores the development of a circular patch antenna designed for 5G applications at 3.5 GHz. Enhanced graphene polylactic acid filaments were utilized to create 3D printed substrates with improved electrical and mechanical properties. Rapid prototyping techniques, specifically 3D printing and automated xurography, were employed to craft the antenna's conductive structures. The integration of nanomaterials into the substrate not only improved the antenna's performance but also addressed challenges related to dielectric constants, potentially eliminating the need for multiple board types. The prototype demonstrated a notable -47.9 dB return loss (S11) and a bandwidth of 3.63 GHz. This study highlights the potential of combining nanotechnology with rapid prototyping in antenna design, offering a cost-effective solution for small-scale laboratories. The proposed methodology supports green technology initiatives, the Environment, Social and Global (ESGs) values and ensures safety in nanomaterial handling, paving the way for advancements in nanoelectronics.

Keywords: *Microstrip antennas, S-parameters, Bandwidth, Rapid prototyping, Enhanced-graphene, Nanocomposites*

1. INTRODUCTION

Future high data-rate communications will be made possible by fifth generation (5G) communication, which has received a lot of attention. The comprehension of the propagation channels is crucial for the design and testing of the 5G communication system, requiring a substantial body of channel measurements. The spectrum of 5G mobile systems is now being expanded to allow a high data rate. The following frequency ranges have been suggested during discussions of the 5G potential frequency bands below 6 GHz at the World Radio Communication Conference (WRC) in 2015: 3.3-3.8 GHz, 470-694 MHz, 1.427-1.518 GHz, 4.5-4.99 GHz. Among them, 3.5 GHz has received the greatest attention because it may be used in most nations [1]–[5]. As a result, the 3.5 GHz band propagation channel characterizations were the main emphasis of this paper.

In patch antenna design, the selection of the feeding technique is crucial because there are two types of feeding techniques: conductive and non-conductive methods. In the fabrication's point of view, conducting feeds method is much popular due to its low level of difficulty in assembling the antenna's structures. On the other hands, non-conducting feeds method, such as proximity or aperture is less favourable feeding technique due to the difficulties in designing and assembling. One of the objectives of this study is to design and fabricate a circular patch antenna using proximity feeding technique. The complexity of this design lies in aligning two substrates [2]. Even though the fabrication of this feeding is known to be challenging, it promised good bandwidth performance—as patch antennas are limited and have very narrow bandwidth performance—as well as high gain, good impedance matching, a reduction in spurious radiation for improved radiation pattern performance, and no contact with the radiating patch, which permits flexibility and simpler tuning adjustments. The selection of proximity feeding technique was expected to improve the performance of the patch antenna design in terms of bandwidth. It was expected to give broader bandwidth since the patch antenna is well-known of its narrow bandwidth performance.

This design normally has the same size of substrate. The existing design presents challenges in securing the connector to the prototype, which is necessary for proper measurement and operation. This study proposes modifying the upper layer of the substrate to facilitate the attachment of the connector directly to the lower layer. This approach eliminates the need for complex coaxial feed installations [6], simplifying the assembly process and ensuring accurate performance, as illustrated in Figure 1.

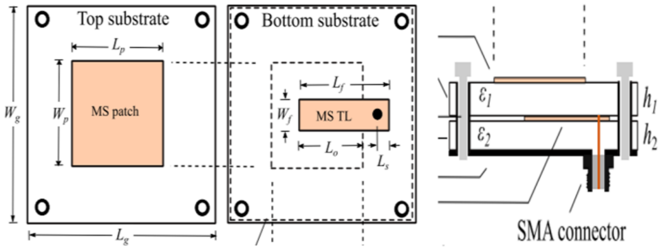

Figure 1. Example of Proximity feed patch antenna with drilling fixed connector.[1]

The 3D printing technology was used to fabricate the upper layer of the substrate using two types of filaments as shown in Figure 2. The filaments were made of improved graphene poly-lactic acid (PLA) and regular PLA. The dielectric of PLA filament has been reported to be between

2.25 and 3.25 [7][8]. In contrast, the enhanced-PLA is said to be between 2.5 and 11 [8][9]. The improved materials were made of graphene and iron.

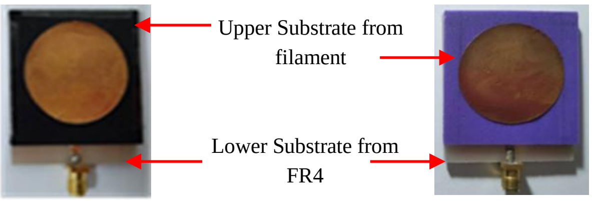

Figure 2. Substrates layer in Proximity feed patch antenna design.

Table 1 displays the matrix table of the literature search on proximity feeding in microstrip patch antennas. The search was conducted using the IEEE database, filtering just journals and particular years between 2017 and 2023.

Table 1. The matrix table of literature search on the topic of proximity feeding in microstrip patch antenna.

	Substrates		Dielectric		
Ref	**Top**	**Bottom**	**ε_1, Top**	**ε_2, Bottom**	**Op. Freq**
[2]	Rogers^{TM} 5880 Duroid	Rogers^{TM} 5880 Duroid	2.2	2.2	S-band 3 GHz
[8]	Glass	Glass	5.5	5.5	3.55 GHz centered freq.
[9]	Rogers 5870	Rogers 4003C	2.33	3.55	5.15 GHz centered freq.
[10]	FR-4	FR-4	4.4	4.4	2.45GHz or 3.50 GHz

Four results—the patch antenna with proximity feedings operating across the frequency range of 1 GHz to 5.2 GHz—satisfy the requirements for this investigation. In three of the four earlier research projects, the substrates used in both layers had the same dielectric value. The use of different substrates for the antenna structure of proximity feed configurations was only documented in one study [9]. For the upper layer substrate in this study, Roger 5870 with a dielectric value of 2.33 was used, and for the lower layer substrate, Roger 4003C with a dielectric value of 3.55.

The investigation's goal is to analyse 3D printed substrates made of two different types of filaments. One form of filament is a nanocomposite material that was purposefully included to patch antenna prototypes' structural design. To maximize the antenna's performance for practical applications, it is also necessary to determine how these 3D printed substrates, when matching with proximity feeding can improve bandwidth, radiation efficiency, and impedance matching while simplify the construction process. Finally, functional prototypes of the patch antenna were developed and tested to verify the theoretical conclusions and real-world applications of the study. These prototypes emphasize proving the workability and practicality of the suggested design, which includes the integration of nanocomposite materials with proximity feeding techniques, and potential of the prototype to meet the requirements for 3.5 GHz operations.

This study finishes with a number of experiments of the bandwidth performances and S-parameters that the proximity-fed circular patch antenna showed comprehensively. This investigation focuses on the working prototype, which is based on the creative use of new printed substrates. The prototype must function flawlessly at the crucial 3.5 GHz frequency to meet the requirements for success. This frequency corresponds exactly with the sub-6 GHz spectrum that is relevant to 5G communication technology [4][11].

This work combines state-of-the-art material sciences with hybrid fabrication techniques to push the boundaries of antenna development, placing it at the forefront of technological inquiry. Analysing 3D printed substrates adds to the growing body of knowledge in antenna engineering by providing insights into the complex interactions[12]–[14].

The outcome of this research not only aspires to meet the immediate operational expectations at 3.5 GHz but also seeks to contribute significantly to the broader landscape of 5G communication technology. Through an exploration of the complexities surrounding proximity-fed circular patch antennas, this research not only contributes to the theoretical understanding but also showcases tangible improvements in antenna design and fabrication, addressing contemporary challenges in the field and offering a pathway for future technological advancements.

2. METHODOLOGY

2.1. Antenna Design Specifications

This study deals with the development of circular patch antenna design employed proximity feeds as the transmission line. Circular topology was chosen as the subject of this study because this design offers a single degree of freedom to control [6], which is the radius of the radiator patch design. The radius of circular patch is the key to manipulate the resonant operating frequency of the antenna. The design development and electromagnetics field simulation were performed using Computer Simulation Technology (CST Studio Suite) for this study. The electromagnetic model simulation for the pilot investigation and the working prototype were made using FR4 substrates, and they both ran at 2.4 GHz presented in Figure 3.

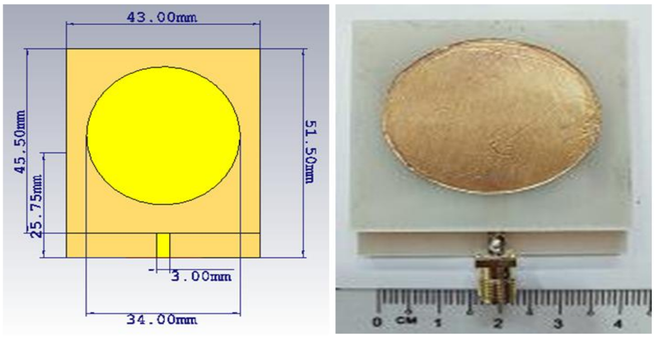

Figure 3. Single configuration of circular patch antenna. design and the fabricated prototype.

The preliminary design was simulated and prototype was fabricated with the operating frequency at 2.4 GHz [15]–[18]. FR4 substrates were employed for both structural layers.

Table 2 shows the parameters involved in designing and fabricating the antenna. Materials information for each structure, upper layer substrate and lower layer substrate were listed respectively. All the parameters were kept constant and fixed as preliminary design. For the purposes of the inquiry, a new printed substrate has replaced the top layer substrate. The modification made to the upper layer substrate structure, where the FR4 was replaced by 3D printed substrate to examine the novelty of the printed substrates in the patch antenna construction. The FR4 substrate was retained as the bottom layer due to its capacity to keep connectors in place and heat resistance.

Table 2. The parameters involved in designing the circular patch antenna with proximity feeding technique.

	Measurements	**Material**
Circular Patch radiator diameter	34mm	Copper foil
Upper layer substrate	xyz; 43mm x 45.5mm x 1.6mm	3D Printed
Lower layer substrate	xyz; 43mm x 51.5mm x 1.6mm	FR-4; Ɛ = 4.125
Ground plane	xyz; 43mm x 51.5mm x 1.6mm	Copper foil
Feedline type size	3.2mm x 2.75mm x 0.1mm	Copper foil
Feedline type	Proximity	-
Ground plane	Full ground	Copper foil
Connector	SMA	-

2.2. Tools and Configurations

Printer A and Printer B are the two types of 3D printers that were employed in the development and construction stages of this antenna. The features of these 3D printers vary. The printer A specification was shown in Table 3. There are three different setup settings available for this printer. There were three available setting configurations: standard, fine, and fast. The fill density of the printed object was automatically set using printer A. Additionally, a number of parameters were automatically established for every printing assembly.

The infill parameter's standard and fine settings both have the same infill percentage which is 15%. But for the fast-setting mode, it only provides 10% infill printing. This printing machine has limitations when it came to changing the infill arrangement. Therefore, this machine is unable to achieve the purpose of this research study on the impact of infill for the substrate. Printer B was thus used to investigate the infill effect of the enhanced-graphene PLA filament as the substrate. The comparison of the 3D printers used in this research study was shown in Table 4. The materials utilized, the extruder's nozzle size, and the benefits and drawbacks of each printer were all listed in tabulated form, respectively.

To acquire measurement data for the prototype sample, the vector network analyser (VNA) operating frequency setting was calibrated for a range of 0.1 MHz to 5 GHz during the test and measurement phase. The measurement frequency range is 0.1 MHz to 5 GHz in order to minimize the quantity of frequency band analysis.

Table 3. 3D printers A' specifications and configurations.

Configurations 3D Printer A			
	Standard	***Fine***	***Fast***
Layer height	0.18mm	0.12mm	0.3mm
Fill Density	15%	15%	10%
Print Speed	60mm/s	50mm/s	80mm/s
Shell count	2	3	2
Est. time	19minutes	29minutes	14minutes
Est. material used	3.37g/1.13m	3.21g/1.08m	4.06g/1.36m

Table 4. Comparison of 3D printers.

3D Printer machine	**Printer A**	**Printer B**
Material	Flash forge- PLA 1.75mm	PLA, TPU, ABS, PLA Wood
Nozzle size	0.4 mm	0.1 – 0.4mm
Advantage	Double nozzle extruder. Auto-setting – Standard, Fine, Fast. Fast heating time approximate <2minutes	Single nozzle extruder. Custom setting for printing.
Disadvantage	Manipulation of infill is impossible.	Manipulation of infill and shell is possible. Long heating time, approximately 5-7minutes.

3. RESULT AND DISCUSSION

This section included the topic from the perspectives of the fabrication stages, the amount of time needed to construct the prototype, the working prototype's measurement results, and the data analysis. It was found that the actual time spent printing the substrates was longer than the estimated time. This resulted from giving the printer bed and nozzle more time to heat up. The extra time needed for the printing process was estimated to be around two minutes.

The width and length of the feedline have an impact on the amount of return loss S_{11} [19] when it comes to the development and fabrication of the feeds line for this patch antenna design. The return loss performance is decreasing as the width increases. However, in the case of the proximity feeding technique, the feedline length may cause the frequency to be changed to a higher or lower range. This scenario will move to the lower range frequency by extending the feed length.

3.1. 3D Printing Analysis

Physical examination of the printed substrates revealed that, in contrast to the fast created sample, the substrates printed using 3D printer A's standard and fine setting seemed fine and smoother surface. This was assumed to be the outcome of the automated 15% fill density infill factor for both standard and fine settings. Nevertheless, it was only set to 10% fill density for the rapid printed setting. For both kinds of filaments, the fast-sampling surface was uneven and wavy. The completed printed substrate sample for each of the two filaments shown in Figures 4 and 5.

The measured dielectric value of the printed substrate was examined using the parametric analysis. From the analysis results, a lower dielectric value will cause the frequency to shift to a higher range band when the dielectric values are altered using CST simulation on the proximity feeds circular patch antenna design. The frequency will shift to the lower range band with a higher dielectric value. From this parametric analysis, the typical PLA with a dielectric value of 2.6 was predicted to operate at a higher band based on this simulation observed. It was anticipated that enhanced graphene PLA would raise the filament's dielectric value and might have an effect on the resonant frequency's ability to function between 2.4 and 3.5 GHz. As a result, it is possible to manipulate the dielectric value by using a 3D printed substrate made of PLA filament augmented with graphene.

Figure 4 . 3D Printed substrates using standard PLA filament (purple) and enhanced-graphene PLA filament (black).

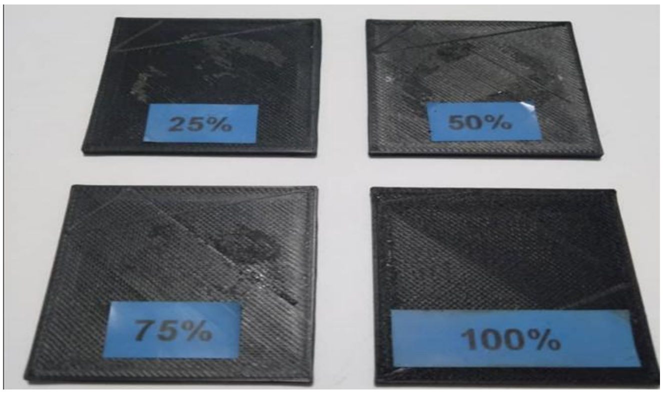

Figure 5. 3D printed substrates using enhanced-graphene PLA with manipulation of infill setting configuration.

The time required to build the substrates in accordance with printing setups is displayed in Table 5. The heating procedure of the nozzle and bed caused the actual time required to print the substrates to exceed the predicted time. For every printer, there is an additional heating period for the bed and nozzle.

Table 5. Time taken based on printing configurations.

3D- Printer A	**Standard**	**Fine**	**Fast**
Time taken	22minutes	32minutes	17minutes

The completed, functional prototypes of the antennas using various top layer substrates were shown in Figure 6. The antenna prototype, seen on the left, was created utilizing FR-4 substrates for both structure's layers. In the following, a working prototype with an upper layer structure made of printed enhanced graphene PLA filament was shown. Graphene-infused PLA filaments usually have a dark grey or black appearance. Graphene, a type of carbon that resembles graphite and is naturally black or dark grey, is responsible for this colour. The lower layer substrate is still the FR-4 substrate. Ultimately, the third functional prototype was created by maintaining the FR-4 substrate at the base of the antenna structure and printed poly-lactic acid PLA filament for the upper layer structure, accordingly

Figure 6. Prototypes of the proximity feed circular patch antenna. (left) FR-4 substrates upper and lower layers. (center) FR-4 substrate at lower layer and printed Enhanced-PLA Graphene at upper layer. (right) FR-4 substrate at lower layer and printed standard PLA at upper layer.

3.2. Poly-lactic acid (PLA) Filament

The measurement results from the patch antenna design prototype, which used PLA filament made of polylactic acid as the upper layer substrate, are reported in Table 6. Three samples with three different properties were measured from three different printing setup configurations. Based on the measurement observation, the resonance frequencies of all three samples were double band.

Table 6 Results of Polylactic acid (PLA) Filament substrate.

		Polylactic acid (PLA) Filament		
Performance	*unit*	**Standard**	**Fine**	**Fast**
Resonant Freq.	*GHz*	4.5	4.5	4.5
Return loss S11	*dB*	-12.06	-10.75	-11.08
Bandwidth	*GHz*	0.52	0.33	0.42

The sample printed using the standard setting resonates with double-band frequencies that meet the < -10 dB, according to the data obtained. There are two distinct resonance frequencies: the first at 2.4 GHz with a -10.06 dB gain and the second at 4.5 GHz with a -12.06 dB gain. However, only the second band of the other two prototypes, the fast sampling and fine sampling—fulfills the antenna operating requirement and is resonating at

4.5G Hz with a return loss of -11.08 dB and -10.75 dB, respectively.

The results of the three samples for the PLA filament substrate are displayed in Figure 7. For the fine printed sample, the impedance bandwidth was less than 0.33 GHz. The observed bandwidth ranged from 4.37 GHz to 4.7 GHz. The impedance bandwidth of the standard prototype operates between 4.27 GHz and 4.79 GHz, yielding a result of 0.52 GHz.

Ultimately, the fast printed sampling's impedance bandwidth ranged from 4.33 GHz to 4.75 GHz, indicating a 0.42 GHz bandwidth measured in this sample.

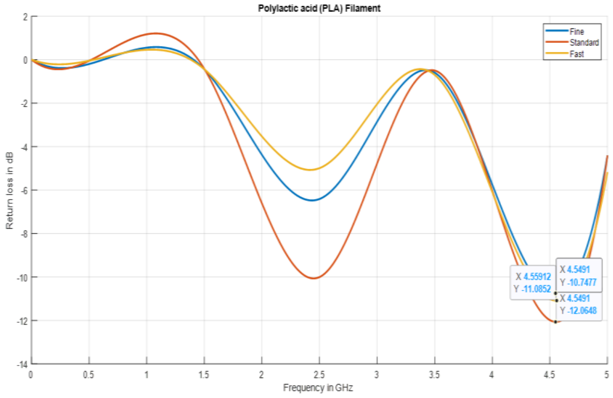

Figure 7. Results of measurement for circular patch antenna with proximity feeding employed a PLA printed substrate serving as the upper layer component structure. These printed substrates have a *fine, standard,* and *fast* setting configuration.

3.3. Enhanced Graphene PLA Filament

In this sub-section, the discussion on the prototype employed the enhanced graphene PLA filament printed substrate for the upper layer structure is presented. The measurement results from these prototypes were reported in Table 7. Output results within the operational frequency range of 100 kHz to 5 GHz were only seen in two prototypes. With a broad bandwidth of 2.65 GHz, the standard sampling prototype operates between 1.6 GHz and 4.25 GHz. At 3.5 GHz, the fine-tuning sampling produced a return loss of -41.9 dB S_{11}. No data were gathered for the *fast*-setting sample since it did not generate any resonate pulse within the operational frequency.

Table 7. Results of Enhanced Graphene PLA Filament substrate.

		Enhanced Graphene PLA Filament		
Performance	*unit*	**Standard**	**Fine**	**Fast**
Resonant Freq.	*GHz*	2.75	3.5	na
Return loss S_{11}	*dB*	-18.9	-37.8	na
Bandwidth	*GHz*	2.65	2.2	na

The performance of working prototypes with the enhanced graphene PLA filament substrate is displayed as a graph in Figure 8. Both the fine-printed sample and the standard printed sample's impedance bandwidth were observed and measured. The impedance bandwidth for the standard printed sample was found to be between 1.6 GHz and 4.25 GHz. In contrast, the impedance bandwidth for the fine printed sample was found to be between 2.05 GHz and 4.25 GH. This prototype's performance can be regarded as wide band patch antenna.

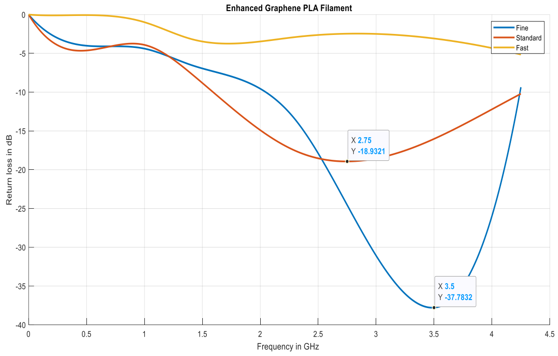

Figure 8. Results of measurement of a circular patch antenna for proximity feeding with an enhanced-PLA graphene printed substrate serving as the upper layer component structure. These printed substrates were configured to a standard, fine, and fast setting.

The comparison of measurement data from each prototype employed the enhanced graphene PLA filament substrate was listed in Table 8. The performances of each prototype are compared in this table according to the infill setting for the substrates, the measured resonant frequency, the achieved return loss S_{11}, and the gained bandwidth. For printing configuration, there were four different percentage settings which were 25%, 50%, 75%, and 100% infill.

Table 8 Comparison results of Enhanced Graphene PLA Filament substrate based on infill setting Printer B.

Enhanced Graphene PLA Filament					
		Infill setting			
Performance	*unit*	25%	50%	75%	100%
Resonant Freq.	GHz	3.7	3.5	3.5	3.45
Return loss S_{11}	dB	-18.8	-47.9	-39.4	-21.4
Bandwidth	GHz	2.64	3.63	3.0	1.6

The infill manipulation for enhanced graphene PLA filament substrate were measured and analysed. Four printed substrates were assembled, and the data were collected. From the graph shown in Figure 9, presented the return loss S_{11} performances for all the samples prototypes. This graph shows that the working prototypes resonate at the centred frequency of 3.5 GHz. All four-results performance observed < - 10 dB return loss S_{11}.

Based on the graph and tabulated results from Table 8, it shows that all four prototypes operate within the frequency of 3 GHz to 4 GHz and centred at 3.5 GHz frequency. All sample results show the performance observed < - 10 dB return loss S_{11}. For the 25% infill's sample result observation, the impedance bandwidth falls between 2.06 GHz and 4.7 GHz. This gives 2.64 GHz total bandwidth. Next, the 50% infill's sample gives 3.63 GHz bandwidth that falls in between 1.07 GHz to 4.7 GHz frequency. For the 75% infill's sampling, the impedance bandwidth operates between 0.8 GHz to 4.8 GHz frequency which result in 3.0 GHz bandwidth. Finally, for 100% infill's sampling, the impedance bandwidth operates within 2.9 GHz to 4.5 GHz frequency that resulting 1.6 GHz bandwidth.

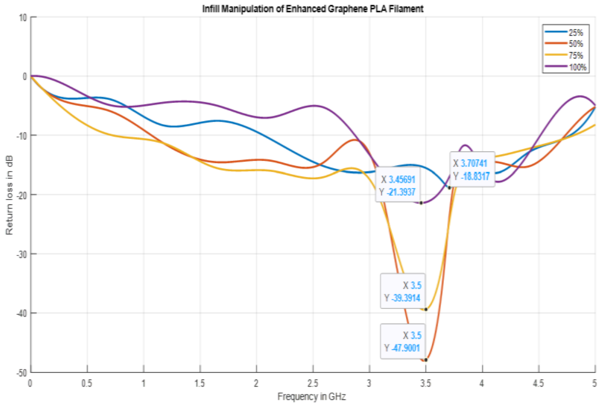

Figure 9. Results of measurement of a circular patch antenna for proximity feeding with an enhanced-PLA graphene printed substrate serving as the upper layer component structure. These printed substrates were configured to different infill printing settings from 25%, 50%, 75%, and 100%.

Therefore, from these results observation, prototypes with enhanced graphene PLA filament as upper substrate offers better S_{11} return loss performance and broader bandwidth performance compared to substrate printed from poly-lactic acid PLA filament.

Figure 10 presented the parametric analysis of the EM model for this antenna design. The goal of this investigation was to duplicate the return loss S_{11} result observed from the working prototype samples data. To develop an intellectual assumption on the dielectric value of the novel enhanced graphene PLA printed substrate, the parametric analysis results were compared and cross-checked with working prototype's result. The novel printed substrate's estimated range of values was predicted by this analysis.

The improved graphene PLA filament printed substrate samples offer a consistent operating frequency at the centre of 3.5 GHz based on this parametric study. The dielectrics value was adjusted to a range of 1 to 10 for the parametric analysis, which was carried out using CST software. 1 is the dielectrics value for air [10], [19].

In parametric research graph shows in Figure 10, by comparing the findings in this study with previous published discoveries [20]–[23], the circular patch antenna with proximity feeds design was able to generate ideas of the novel printed substrates fabricated using enhanced graphene PLA filament. The results of the CST parametric analysis were contrasted with the measurement results from the assessed prototypes. The prototypes' centre frequency was found to be 3.5 GHz based on the enhanced graphene PLA filament's measured resonant frequency range. This study provides the new range of dielectric value for the novel substrate printed using enhanced graphene PLA filament. Therefore, it can be anticipated that the dielectric properties fall within the range of 3.5 to 4, as supported by the insights gained from the conducted experiments and the established trend in the existing literatures shows in Figure 10 and Table 9. In the subsequent study to investigate printed substrate with enhanced graphene PLA filament, this value was used as a benchmark.

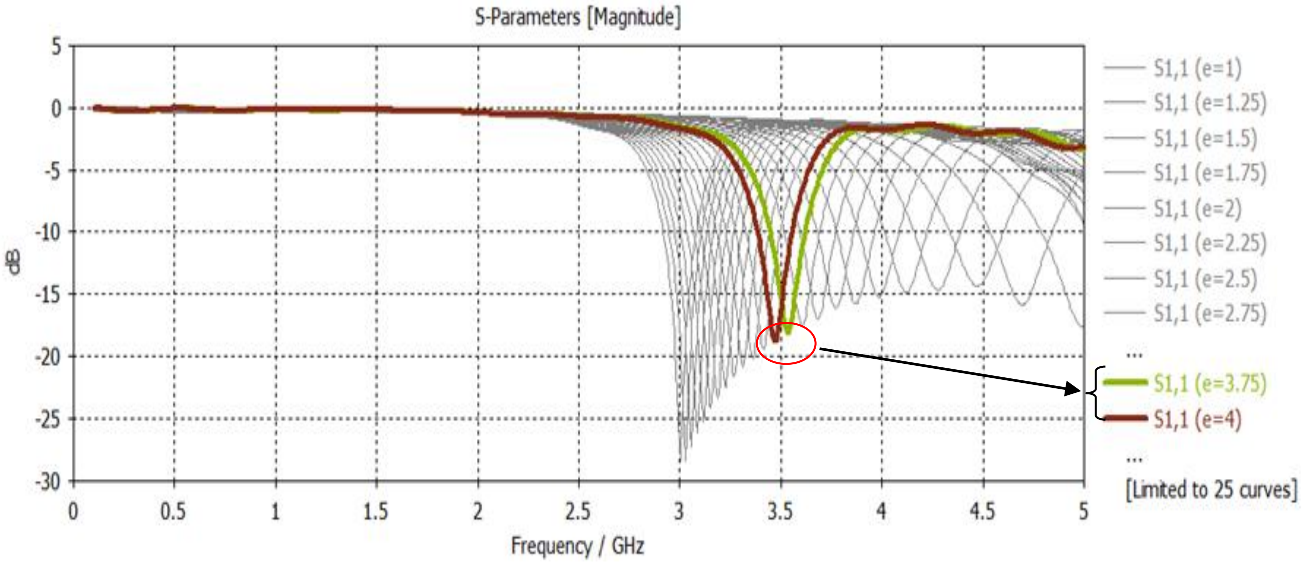

Figure 10. CST Parametric analysis for the unknown novel printed substrates.

The utilization of the rapid prototyping technique facilitated by 3D technology in this study underscored the adept realization of the fabrication process. Demonstrating a noteworthy stride forward, all instances of the operational antenna prototypes exhibited seamless functionality, attesting to the ability of the rapid prototyping approach compared to conventional PCB fabrication methods. The 3D-printed substrates, representing an innovative departure from conventional materials, were instrumental in diversifying the dielectric characteristics, thereby potentially mitigating the challenges associated with constant dielectric values across boards and the need for multiple board types catering to distinct dielectric values. The range value of enhanced graphene PLA filament was found within the range of 3.75-4. It was proved by this study that dielectrics value of PLA filament substrates that within 2.25-3.25 [7][24] was enhanced by the graphene.

Table 9. Novelty of this study.

		Substrates		Dielectric		Op. Freq	Fabrication method
Ref	Title, Author, Year	Top	Bottom	$\varepsilon_{1,\text{Top}}$	$\varepsilon_{2,\text{Bottom}}$		
[6]	An Accurate Analytical Model to Calculate the Impedance Bandwidth of a Proximity Coupled Microstrip Patch Antenna (PC-MSPA), 2020	Rogers™ 5880 Duroid		2.2	2.2	S-band 3 GHz	*Not reported*
[8]	A Transparent Proximity-Coupled-Fed Patch Antenna with Enhanced Bandwidth and Filtering Response, 2021	Glass		5.5	5.5	3.55 GHz centered freq.	standard photolithography and lift-off process
[9]	A Wideband Circularly Polarized Patch Antenna with Enhanced Axial Ratio Bandwidth via Co-Design of Feeding Network, 2018	Rogers 5870	Rogers 4003C	2.33	3.55	5.15 GHz centered freq.	*Not reported*
This study	Proximity Feeds Circular Patch Antenna with Enhanced Graphene PLA substrate.	Enhanced graphene PLA	FR-4	3.75-4	4.125	3.5 GHz centered freq.	Rapid prototyping; xurography and 3D printing.

From a fabrication perspective, using a unique combination of enhanced graphene and polylactic acid filament with 3D printed substrates is a method to depart from conventional practices. The automated xurography approach was utilized to carefully design the conducting components that are essential to the patch antenna. Notably, the dielectric properties of the new printed substrates were examined and found to provide a wide range of values. This feature has the potential to ease the complexity, and difficulties associated with board dielectric constants, hence eliminating the requirement for several board types with different dielectric values.

Simultaneously, considerations for safety, health, and environmental practices converge with an economic wise approach, particularly relevant for smaller laboratories constrained by monetary limitations. Conventional antenna manufacturing techniques frequently imply photolithography, which is a wasteful and possibly hazardous procedure. Using rapid prototyping methods and additive manufacturing i.e. 3D printing, this research can help minimize hazardous waste and promote greener production methods.

The use of rapid prototyping technologies in this research can minimize material waste compared to traditional manufacturing methods. This sustainable approach to fabrication conserves resources and reduces environmental impact.

In summary, the enclosed approach emerges as a practical and sustainable alternative, presenting a paradigm shift in the landscape of fabrication of prototype of patch antenna methodologies. This approach also aligned with the value of Sustainable Development Goals (SDGs), contributes significantly to Environmental, Social, and Governance (ESGs) values by promoting environmental sustainability through energy-efficient and waste-reducing technologies, addressing social needs by enhancing access to clean energy and supporting education, and following to governance principles through ethical innovation and risk management. Beyond technological advancement, the incorporation of green technology in the fabrication process aligns with contemporary environmental requirements.

4. CONCLUSION AND RECOMMENDATION

Ultimately, the creation and assessment of an enhanced graphene circular patch antenna prototype with proximity feeding that is intended to operate at 3.5 GHz in the context of 5G applications have been completed with considerable success. Rigorous measurement, collection, and analysis of the S-parameters and bandwidth for each sample were carefully undertaken, with the subsequent presentation and discussion of results. The comprehensive evaluation extended to the examination of both S-parameter performance and bandwidth characteristics. This study also gives an indication to project that the dielectric properties of enhanced graphene PLA filament as substrate was predicted within the range of 3.5 to 4. This study's findings also interpret the equality between outcomes derived from rapid prototyping fabrication techniques for patch antennas and their conventionally fabricated counterparts. Most of the working prototype, meeting and even exceptional the required specifications for 3.5 GHz operations, testifies to the reliability and strength of the proposed methodology. Consequently, the research study offers this fabrication methodology as a compelling alternative for rapid prototype development in patch antenna designs for 5G application.

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