Graphene Inkjet-Printed Ultrawideband Tapered Coplanar-Waveguide Antenna on Kapton Substrate

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***Abstract*—This paper presents an ultra-wideband graphene antenna with tapered coplanar-waveguide feed. The proposed antenna covers the 2.7-8.2 GHz bandwidth (2.6-10 GHz measured), with two main resonance frequencies at 3.1 and 5.5 gigahertz (3.1 and 5.8 measured). Simulations show a radiation pattern that looks quasi-omnidirectional with a maximum gain limited to 3.15 dBi and efficiency above 84.7%. In order to post-process the graphene ink and to provide flexibility, Kapton Polyimide is used as a substrate. The flexibility, as well as the lightweight and ease in the fabrication of accurate designs, turns this antenna into a suitable candidate for wearable and flexible wireless applications.**

***Index Terms*—flexible antenna, UWB, CPW feed, inkjet, graphene.**

I. Introduction

Wearable wireless technology is a hot topic at present and with a promising forecast for the near future [1]. Wearable devices can play a key role in the development of a wide range of applications among sports analytics [2], positioning systems [3], and healthcare [4]. Flexible antennas play a key role within wearable systems, allowing the user to freely enjoy the system without constraining the user activity and causing the minimum disturbance.

The dynamic environment of body-centric devices requires compact, low-profile, and flexible devices. Novel solutions should explore flexible materials, remaining ergonomic and comfortable, but can endure being worn by a subject. Among these solutions, carbon-based materials such as graphene are a very promising eco-friendly candidate, due to their unique properties and characteristics [5]. Graphene is a two-dimensional (2D) carbon crystal, it is an atomic-scale hexagonal lattice made of carbon atoms, in a honeycomb pattern. It has exceptional electrical conductivity to allow the spread of high-frequency signals [6]. Graphene-based gadgets are effective in developing flexible, conformal, or even stretchable options in any application [7]. Recent progress in graphene fabrication processes suggests a feasible future for the use of this technology in several fields.

Together with these innovative materials novel fabrication methods should be explored. Additive manufacturing processes have raised as accurate and low-cost procedures and among them two printing techniques: screen printing and inkjet printing [8-11]. Inkjet printing is an additive electronic fabrication method that has been attracting a lot of attention for both research and commercial applications as a highly scalable and environmentally friendly alternative to more conventional fabrication schemes [12]. It allows multilayer fabrication onto any rigid or flexible substrate.

This work proposes a conformal wearable antenna in the microwave band, fabricated by inkjet printing carbon-based inks onto flexible substrates such as Kapton films.

II. Antenna Design and Materials

A. Antenna Design

The designed antenna consists of a UWB antenna model with a tapered coplanar-waveguide (TCPW) feed [13-15]. The model employs a simple CPW feed, therefore, easing the often complex feeding network, suitable for inkjet printing. Furthermore, it offers a consistent characteristic impedance over a wide range of bandwidth (BW) [16]. A 3-D CAD model is shown in Fig. 1 (a), where its geometry defines operational bandwidth. The width of the antenna is 16 mm (0.28 λ_g) and the length of the antenna is 27 mm (0.47 λ_g) where λ_g is the wavelength at 3 GHz. The slot follows an exponential curve, in cartesian coordinates:

$$y = se^{rx} \tag{1}$$

where s indicates the gap from the feeding pin.

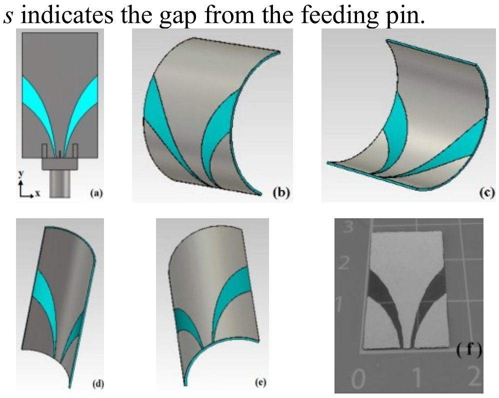

Fig. 1. 3-D CAD model representation of the antenna (a) front view with SMA connector attached; (b) X-convex; (c) X-concave; (d) Y-concave; (e) Y-convex and (f) fabricated prototype.

Graphene ink (793663) from Sigma-Aldrich with 30 dyn/cm surface tension and a particle size smaller than 3 µm, compatible with the inkjet printing process (Dimatix-2800) was employed. It reaches conductivity values of $2.5 \times 10^4 \pm 0.2 \times 10^4$ S/m, after optimizing an annealing time of 20/30 min at 250/350 °C [17]. For the antenna realization, Kapton polyimide-based substrate has been chosen due to their excellent thermal, chemical, mechanical, and electrical properties [18-20]. It can withstand the temperatures for the annealing process, but such films feature an inert and highly hydrophobic surface so a pre-treatment with plasma is necessary. Kapton polyimide film with a dielectric constant (ε_r) of 3.4, loss tangent (*tanδ*) of 0.002, and a substrate height of 125 µm was employed.

III. Antenna Performance Analyses

The antenna performance is evaluated by the numerical analysis (2019 CST Microwave Studio software) of S-parameters, bending performance, radiation pattern, realized gain, and efficiency.

A. Impedance matching

Fig. 2 displays the simulated value of the S11 parameter, covering the complete 2.7–8.2 GHz band, with resonant frequencies at 3.1 and 5.5 GHz. While previous inkjet-printed graphene antennas were narrowband [21]. Graphene and PEC comparison exhibits consistently similar behaviour for both cases. Measurements results show a 7.4 GHz BW, 2.6–10 GHz band, with resonant frequencies at 3.07 and 5.8 GHz. Good agreement between simulations and measurement was achieved.

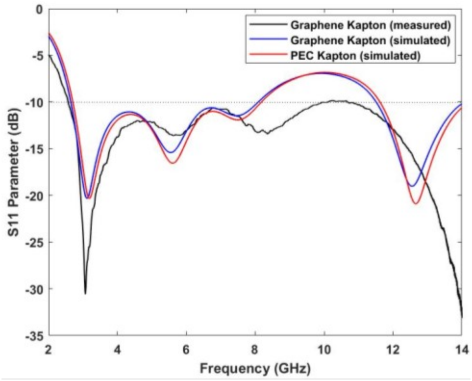

Fig. 2. Comparison of S11 Parameter between Graphene and PEC (simulated) of the proposed antenna model and Graphene (measured).

B. Bending Conditions

Four bending scenarios were considered in Fig 3. A cylinder with a radius of 35 mm has been used for the four cases analysis, as it shows in Fig. 1 (b-e).

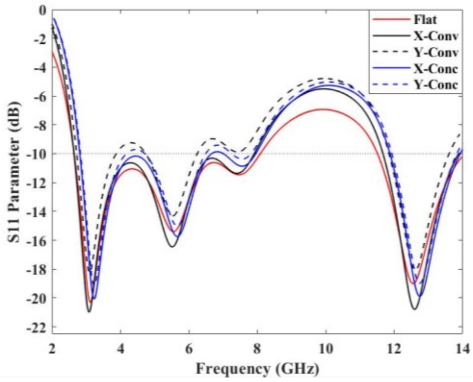

Fig. 3. Simulated S11 Parameter for flat and four bending scenarios.

It has been observed from the parametric analyses that the antenna onto the Kapton substrate is showing almost the same result in all four cases plus the initial (flat) situation. It is an expected result as it was previously simulated in recent research works [22, 23]. Fig 4. shows the experimental results, with behaviour as simulated for both positions (convex and concave) in the X-axis. While for the Y-axis, tends towards lower frequencies and increasing the depth of the valley around 8 GHz. This variation is due to the physical tension generated at the interface between the antenna connector.

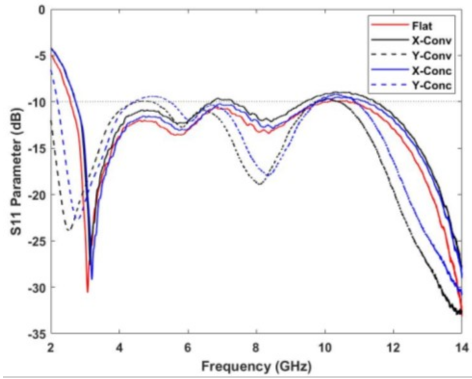

Fig. 4. Measured S11 Parameter for flat and four bending scenarios.

C. Surface Current Distribution

The surface current distribution at the resonating frequencies helps to understand the performance of a multiband antenna. The current distribution is shown in Fig. 4(a-d). Fig. 4 (a) shows that at 3 GHz, the current is concentrated around the TCPW feed whereas at 5.5 GHz (Fig. 4 (b)) and 6 GHz (Fig. 4 (c)) more current concentration is on the radiating patch.

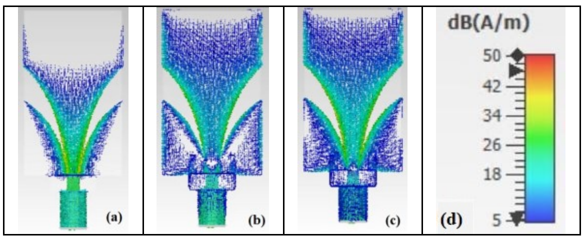

Fig. 5. Simulated Surface Current at (a) 3; (b) 5.5; (c) 6 GHz and (d) Scale.

D. Radiation Pattern

Maximum radiation in broadside direction can be observed from the simulated E-plane (φ=90°) and H-plane (φ =0°) of the presented antenna prototype. An omnidirectional pattern for 3 GHz and a quasi-omnidirectional patterns at 5.5, and 6 GHz are shown in Fig. 5 and Fig. 6. These monopole-like radiation patterns, respectively making it compatible with diverse wireless communications applications.

The numerically calculated realized gain along with the peak efficiency for four frequencies are listed in Table I.

Where it can be seen a peak realized gain of 3.15 dBi for the highest frequency case (6 GHz) and a minimum efficiency of 84.7 %. Realized gain values at 3 and 6 GHz are lower than reference values at similar frequencies [15]. On the other hand, simulated estimations of efficiency (84.7 %) are higher than previously reported values of 47.7% [24] or 48.6% at 5.5 GHz [25].

TABLE I. FARFIELD PROPERTIES

Graphene + Kapton This research work			Copper + RT Duroid Reference work [15]	
Frequency (GHz)	Realized Gain (dBi)	Efficiency (%)	Frequency (GHz)	Realized Gain (dBi)
3	1.37	88	3.4	1.9
5.5	2.91	89	5	2.9
6	3.15	84.7	5.8	3.6

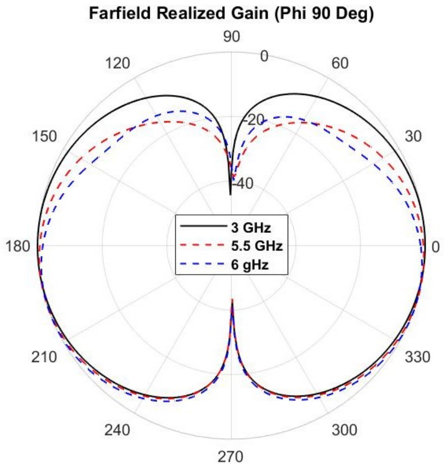

Fig. 6. Simulated radiation pattern of the proposed graphene-based antenna; E-plane cut, at φ = 90˚.

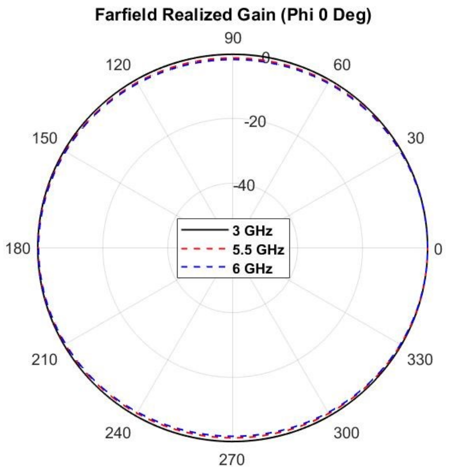

Fig. 7. Simulated radiation pattern of the proposed graphene-based antenna; H-plane cut, at φ = 0˚.

IV. CONCLUSION

A flexible UWB TCPW graphene antenna working at microwave frequencies is presented and analysed. The measured antenna has attained a total impedance bandwidth of 7.4 GHz ranging from 2.6 to 10 GHz. The omnidirectional radiation has been observed due to the co-planar structure. The simulated results have shown a peak realized gain of the antenna ~3.15 dBi, similar to previously reported in the literature, with an antenna efficiency above 84%. The Kapton substrate allows the annealing process of the graphene ink, resulting in a proposed flexible, compact, lightweight, and robust design along with good radiation characteristics. The suggested antenna has potential in advanced materials devices, suitable for various wireless applications for future conformal and flexible electronic devices. Further experimental analyses are required with respect to this point.

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