Graphene-based ultra-wide band printed bow-tie antenna for remote tracking

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***Abstract*—Printed antennas are cheap, lightweight, easy to-fabricate with high precision, and adaptable to mass production. These features are desirable for both indoor and outdoor handheld UWB antenna applications. In this paper, we consider planar versions of a high performance ultra-wide band bow-tie antenna with omnidirectional radiation characteristics.**

***Index Terms*—Antenna, RFID, Graphene, Bow-tie.**

I. Introduction

In the last few years, the development of low cost flexible electronic devices [1]–[3] has attracted significant attention due to their possible implementation in consumer electronics [4]. The rapidly evolving market of flexible and printed devices [5] has pushed the development of components such as transistors [6], sensors [7] and wearable electronics [8] and, consequentially an interest towards the advance of printed electronic devices. The aim is to avoid conventional patterning techniques that require expensive equipment and many process steps including lithography and etching. Pursued applications of printed electronics include radio-frequency identification (RFID) tags and different types of wireless sensor [9], [10]. In the state of art, some models of RFID antennas are proposed, as well as a prototype made of two elliptic apertures cut in an elliptic metallic patch [11], a patch antenna with transformer based on textile materials [12], and a tag geometry combining folded conductors and tuning slots [13], designed for wearable device. The realization of devices on lightweight and foldable substrates is creating a growing demand for cheap and easy to implement RFIDs in packaging and logistics. [2], [6], [14], [15]. On the other hand, the diffusion of RFIDs is limited by the cost with a target of less than 5 cents per RFID tag [4], [16]. Printed metal-based inks [17] currently represents the most economical alternative to the standard fabrication methods. There are different prototypes of this type of RFID antennas, such as one designed on a polyethylene terephthalate (PET) substrate and implemented by inkjet printing using a conductive ink, with a very simple geometry based on meander-line antenna with a suitable inductive serpentine path [17]. Unfortunately, copper and nickel-based ink performance are seriously affected by oxidation, while silver ink is expensive [18]. Graphene and related materials (GRMs) appear as promising candidates for the formulation of functional inks for printable electronic applications. Graphene possesses many remarkable properties. It is transparent, highly conductive both from an electrical and thermal standpoint, mechanically robust, flexible and chemically stable [19]. Graphene also represents a valid choice in terms of cost, due to the natural abundance of graphite [20]. Its electronic, mechanical and electromagnetic properties make graphene an ideal candidate for the implementation of the next-generation antennas. Graphene based inks can be deposited on substrates by means of several techniques. Among them, stencil printing is a straightforward, cost effective technique, which enables direct deposition of inks onto rigid or flexible substrates [21], [22]. The stencil printing technique allows printing strips with uniform morphology, compatibility with flexible substrates, and high tolerance to bending stresses [23]. For these reasons, stencil printing is a simple and low cost solution towards the realization of flexible electronics.

In this paper, a printed graphene/silver hybrid ink-based antenna is presented. A few layers graphene (FLG) powder, obtained by a patented wet-jet milling process [20]–[23], is mixed with a water-based commercial binder, an alcoholic solvent and a small percentage of silver ink (silver/FLG ratio < 0.1). The as produced ink is then deposited on cardboard at room temperature. Our antennas, suitable for use in the UHB RFID frequency range, show an ultra-wide bandwidth response (UWB) at $\sim$ 2 GHz with a fractional bandwidth close to 0.5 and a $\sim$ 30% efficiency. Its UWB response makes it ideal for low-cost printed RF applications, including RFID, smart sensors and high-speed short-range data transfer [24]. This system, in addition to the previously mentioned fields, could be used e.g. in medical [25] and agro-industrial [26] applications in the frequency band between 2.40 and 2.48 GHz, for the Wi-Fi communication connections in the Body Area Network (BAN).

II. Materials and Methods

A. Antenna design

In order to develop a high-performance UWB antenna, the bow-tie design, shown in Fig. 1, represents an optimal tradeoff between ease of implementation and efficiency. The antenna is fed through an element by a conductive strip painted in the middle of dipoles. With the theory of cavity model, an empirical formula of resonant frequency was given for the antenna in ref. [27]. The structure consists of a graphene conductive side printed on a dielectric substrate of thickness h = 0.48 mm having a dielectric constant $\varepsilon_r = 2.3$. The feed point is specified in terms of the coordinates (X_0, Y_0). The resonant frequency of the structure is calculated as follows:

$$f_r = 1.152cR_t/(2\varepsilon_e^{0.5}) \quad (1)$$

where:

$$R_t = 1/2((W + 2dl) + (W_c + 2dl))/((W + 2dl)(S + 2dl)) \quad (2)$$

$$dl = 0.412h(\varepsilon_e + 0.3)(w_l/h + 0.262)/((\varepsilon_e - 0.258)(w_l/h + 0.813)) \quad (3)$$

$$\varepsilon_e = (\varepsilon_r+1)/2+(\varepsilon_r-1)/2(1+12h/W_c)^{0.5} \quad (4)$$

$$w_l = (W+W_c)/2 \quad (5)$$

where ε_r and h are the relative dielectric constant and the thickness of the dielectric substrate, respectively, c is the velocity of electromagnetic wave in free space and S is the separation between the two parallel sides of the antenna.
The obtained f_r is 2 GHz with a W_c of 11 mm, a W of 35 mm and a S of 4 mm.

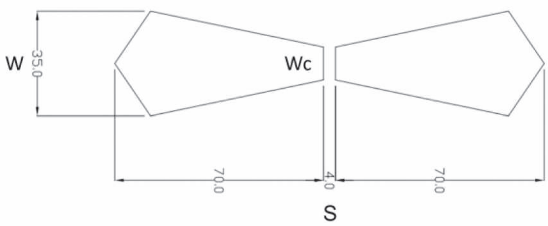

Fig. 1: The bow-tie antenna design.

B. Experimental

Graphene powder was produce by the exfoliation of graphite using wet jet milling technique [20]. The resulting powder is readily dispersed in a solvent, allowing for the tailoring of inks for the deposition. In particular, dispersion of this material in select organic solvents enables deposition on a cardboard of graphene by stencil printing technique. Subsequently, ~ 10% of silver nanoparticles was added in order to increase the conductivity. The return loss (S_{11}) of the antenna has been measured using Hewlett-Packard 8720C Vector Network Analyzer (VNA) while the antenna radiation pattern was measured in E- and H- planes into the Anechoic Chamber. A LPRS Straight 50 Ω SMA connector, welded to the terminal with the CircuitWorks silver-Epoxy conductive paste, has been used to connect and excite the bow-tie antenna as shown in Fig. 2.

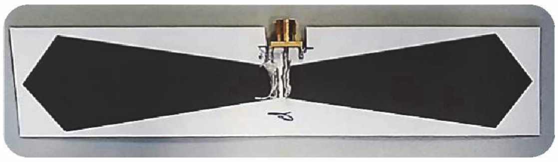

Fig. 2: Realized bow-tie antenna.

III. Results

The antenna presents a bandwidth of 900 MHz, corresponding to a reflected power less than 10% around the center frequency of 2 GHz, which covers the frequency range from 1.65 to 2.5 GHz in L-band and S-band as shown in Fig. 3.

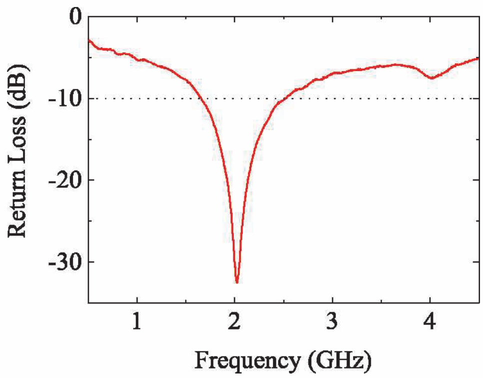

Fig. 3: The reflection coefficient S_{11} of the antenna.

Thanks to its wideband, the antenna provides a measured reflection coefficient below -10 dB in the overall operating frequency band. The nature of the bow-tie shape of the half-wavelength dipole antenna body allows for a broadband operation. Shown in Fig. 4 are presented 2D radiation patterns for E- and H- planes respectively. From the figures, we can see that the antenna presents a dipole-like behavior. In fact, the radiation pattern of H-plane, as shown in Fig. 4, is almost uniform (omnidirectional) at 2 GHz with a maximum gain of 0.4 dBi, while the E-plane presents a minimum lobe at 90° and 270° and a maximum lobe at 0° and 180°. The calculated efficiency is 33.2%. The different beam width in opposite directions is due to the presence of the paper layout.

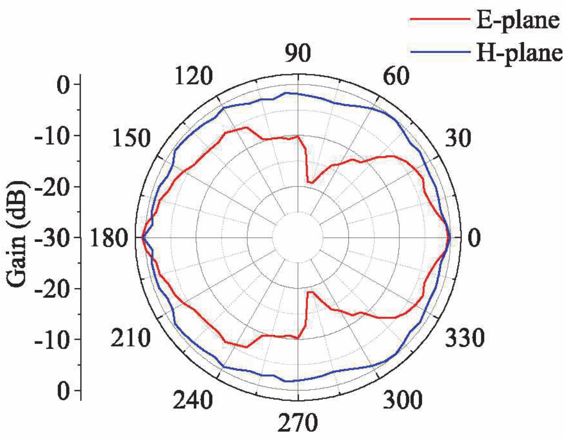

Fig. 4: The E-plane and H-plane radiation pattern measured.

IV. Conclusions

The paper presents simple and low cost design of a bow tie antenna based on the current trends of radio frequency identification (RFID) technology. Lightness and ease of manufacture with high precision make this antenna suitable for mass production. These great advantages make this antenna appropriate for package tracking system because it is possible to print the antenna directly on the package with a low cost technique. Design of the antenna have been described in detail. The antenna design has been experimentally verified on the prototypes realized with a hybrid graphene/Ag conductive ink on a cheap cardboard substrate. From the return loss measurements, it is possible to see that the antenna works in the complete Bluetooth frequency band. We can conclude that the antenna presents cheap and excellent solutions for RFID tagging and Bluetooth applications.

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