A Novel Polyimide Flexible Antenna Design for S- Band Applications

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***Abstract*— Technological advances in electronics devices and the Internet of Things bring us to be surrounded by multiple sensors in the coming years. The devices should be conformable and adapted to small or irregular shapes and surfaces. This is why flexible materials are taking an important part in this field thanks to their stretchability and resistance especially in wearable electronics to get integrated on clothes for biomonitoring. Our proposal in this paper concerns the design, printing process, and performance of a novel antenna on a polyimide flexible substrate. It is based on a loop antenna and has dimensions of 40 × 35 × 0.127 mm^3. Its very wideband behavior from 2.4 GHz to 4 GHz allows targeting S-Band applications such as LTE and WIFI. An interesting performance is also achieved in terms of radiation patterns. At 2.45 GHz, the maximum antenna gain is about 2.6 dBi with an omnidirectional pattern but at higher frequencies, the antenna is more directive with a higher gain.**

***Index Terms*—Flexible antenna, polyimide, wideband, flexible electronic devices, S-Band, wireless applications.**

I. Introduction

Faced to the new demand on thermal, moisture, water resistance and new applications as medical, wearable, mobile, aerospace and retail, the rigid Printed Circuit Board (PCB) on conventional materials are being limited. Electronic devices trend to be more flexible, stretchable, pliable, and recyclable by using non-conventional materials. New generation of consumer electronics products aims to cover several markets and are motivated by using flexible electronics. The use of alternative substrate also allows the development of smart wearable devices for sensing and communication applications. In addition, in the context of Internet of Things (IoT), recent developments in printed electronics demonstrate the ability of to use organic and inorganic materials allowing a new form factor, a high-volume manufacturing, a huge deployment [1]. Research is also being carried out on flexible microfluidics which has an impact the chemistry, electronics, biology, and medicine areas [2]. Wireless communicating devices require the use of an antenna to transmit and receive the data wirelessly. Depending on the frequency range, flexible material can be used for a large application. In [3], a review of many flexible antennas in different material types and applications is presented. For instance, at Microwaves Frequencies, a 60 GHz patch antenna is designed and fabricated with Kapton substrate in [4]. However, the use of a flexible antenna is more relevant when operating in the low frequency range with a large radiative surface. The flexibility allows the sheet to be bent into different geometries and to have a smaller final antenna.

The proposed design of the antenna is based on polyimide substrate for S-band applications. The S-Band is a part of electromagnetic spectrum from 2 to 4 GHz. It is mainly used for mobile Long Term Evolution (LTE) and Wireless Fidelity (WIFI) applications and several practical radar applications, communication satellites devices. This band also covers 5G Sub-6GHz (3-4GHz band) which is intended to connect devices to each other.

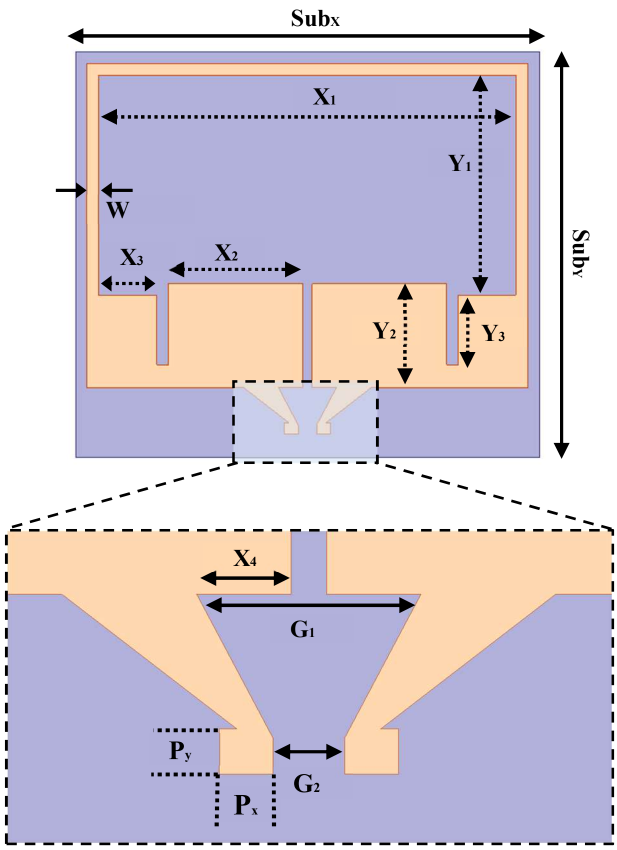

Fig. 1. Layout and main dimensions of the proposed antenna and the feed pad (metallization is represented by gold color)

TABLE 1. DIMENSIONS OF THE PROPOSED ANTENNA

Dimensions (mm)												
SubX	***SubY***	***X1***	***X2***	***X3***	***Y1***	***Y2***	***Y3***	***W***	***Px***	***Py***	***G1***	***G2***
40	35	36	11.6	5	19	9	6	1	1.2	1	5	1.5

This paper focuses first on the presentation of flexible materials and their characteristics, and then in a second part is presented the design of the proposed antenna, optimized for S-Band applications. The last part of this paper is devoted to the fabrication process and characterization of the flexible antenna.

II. FLEXIBLE SUBSTRATE MATERIAL

The replacement of conventional rigid substrate has facilitated the development and improvement of several flexible materials with different properties. They can offer several advantages such as flexibility, stretchability, compactness, moisture resistance, low cost. Flexible materials can be separated in categories: synthetic and natural polymers, paper and textile materials. There are several polymer materials: polydimethylsiloxane (PDMS), liquid crystal polymer (LCP), Parylene, polyethylene naphtalate (PEN), Polyethylene terephthalate (PET), and Polyimide (PI). They are considered as the best candidate for flexible antenna design [2]. Paper substrates also offer advantages such as printability with an easy printing technique, recyclability. In addition, scientists have been working on flexible electronic devices based on nanocellulose [5]. The first flexible design started with polyimide material. Due to it good Radiofrequency (RF) performance and heat resistance, it is mostly used for wireless application using antenna. In [6], a novel multiband monopole CPW antenna is proposed. In some applications, the substrate should be carefully chosen considering its dielectric parameters and environment resistance and the fabrication process.

III. ANTENNA DESIGN AND SIMULATION

The proposed antenna in this paper is a novel design based on loop antenna, modified to increase the bandwidth and efficiency for S-band frequencies range. The simulation was performed by Ansys HFSS software on polyimide substrate (dielectric constant = 3.4; loss tangent = 0.012; thickness = 127 µm; copper thickness = 35 µm). The geometry and dimensions of the proposed antenna are presented in Fig.1. It is based on a full wave loop antenna approximately at 2.5 GHz with a width of 1mm as presented in Fig. 2 (A1). Then, a feeding pad was carefully designed to characterize the antenna easily and carefully with a soldered SMD connector in Fig 2 (A2). Thus, a U. FL connector from Hirose [7] was chosen but may have limitations above 6 GHz. In the same step, the width Y_2 was adjusted to optimize the return loss and bandwidth.

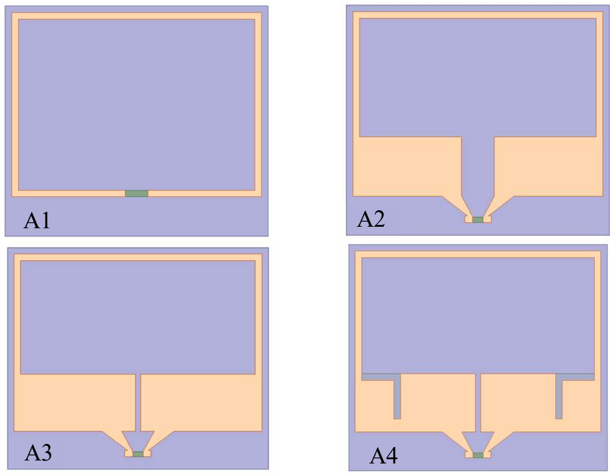

Fig. 2. Antenna design evolution (green rectangle is the lumped port on simulation).

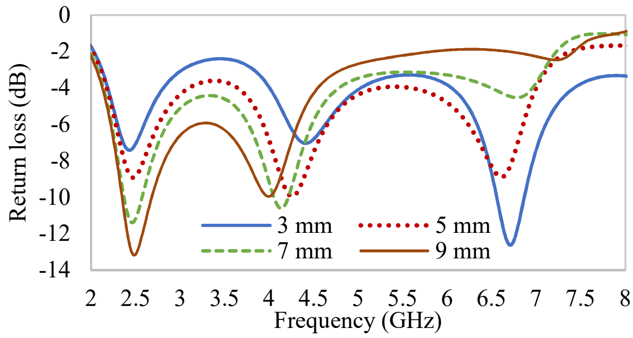

Fig. 3. Simulated return loss of antenna A2 with different Y_2 values.

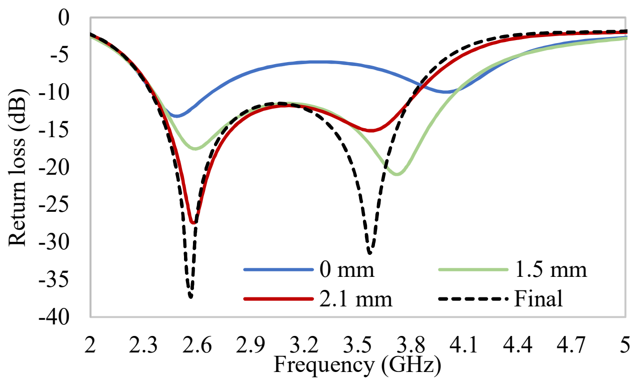

Fig. 4. Simulated return loss of antenna A3 with different X_4 values.

As seen in Fig. 3, the A2 antenna with Y_2 equals to 3 mm, has three resonant frequencies spaced approximately by 2 GHz from each other (@f1 = 2.5 GHz, @f2 = 4.4 GHz and @f3 = 6.7 GHz. By increasing Y2, we also decrease the total real part of the antenna and increase the imaginary part at a higher frequency (around @f3), thus increasing the bandwidth of the antenna between @f1 and @f2. The second step of the optimization is to decrease the real part of the impedance again achieve a good matching at 50 ohms ($S11 \leq -10$ dB). It is presented on A3 by tuning the X_4 parameters.

Reducing this parameter tends to decrease the real part of the impedance (at 3 GHz it goes from 134 Ω to 76 Ω) and make @f2 at 3.55 GHz, first located at 4 GHz (Fig.4). At the last step, we optimize the return loss by adding an inverted L slot (1mm width) at the inner corner of the antenna as presented in Fig.2 (A4). Thus, we can observe in Fig.4, the increasing of peak resonance at 2.55 GHz and 3.5 GHz.

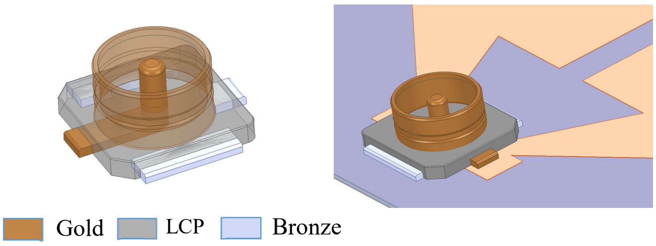

Fig. 5. (a) 3D model of the U.FL connector and materials assignement ; (b) Connector placement on the antenna feed pad.

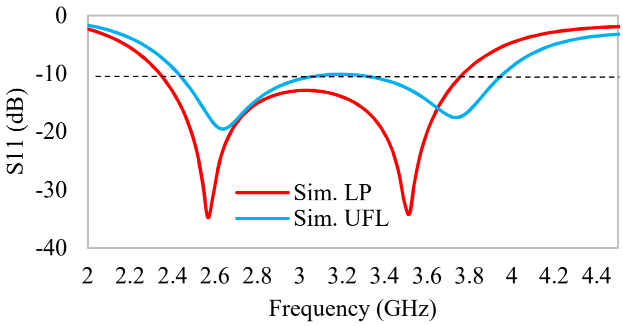

Fig. 6. Simulated antenna return loss with and witout U.FL connector.

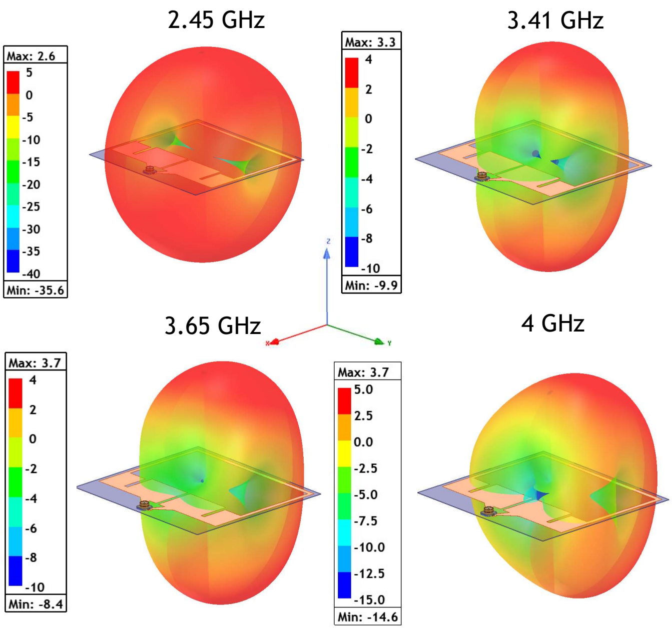

Fig. 7. Simulation of the 3D radiation pattern of the proposed antenna at different frequency.

An accurate simulation must include the behaviour of the used connector for measurement. The U. FL 3D model is shown in Fig.4. It consists of a Liquid Crystal Polymer (LCP) housing and gold-plated brass contacts. In the simulation performed, the larger pads constituting the ground, were affected as the bronze part. Despite the effect of the connector as expected, the antenna remains matched for 50 Ω but the return loss is slightly shifted of 100 MHz (Fig.5). The antenna has a very wide bandwidth from 2.3 GHz to 4 GHz for S11 ≤ -10 dB. Fig.7 presents the simulated 3D radiation patterns for the proposed antenna. At 2.45 GHz, the antenna radiates as an omnidirectional antenna and is more directive at high frequency. It is noticed that antenna radiation pattern is more oriented on YZ plane with an improvement gain.

IV. PRINTED ANTENNA PROTOTYPE

A. *Printing processing of the flexible antenna*

Various printing processes on flexible material exist. They can be separate in two categories: subtractive (Laser ablation, dry or wet ech) and Additive (photolithography, flexography, inkjet, and screen-printing). Each process is specific in terms of ink thickness and adhesion on substrate, printing resolution, mass production, etc.… Photolithography technic was the one be used for the antenna printing process as seen in Fig 9. The sheet used is 127 µm thick polyimide film coated on both sides with 35 µm thick copper (AP9151) [8]. It is cut to size with a cutter and then covered with a 1 µm thick ECI photosensitive resin. The resin is first annealed on a hot plate at 90°C for 60 s. The sheet with the resin is UV exposed through a glass mask with the desired pattern. The sheet is then annealed on a 110°C hot plate for 60 s, and some areas of the resin are dissolved in a developer to reveal the copper. The remaining resin hides the copper parts corresponding to the desired structures. The foil is then immersed in an acid bath to etch the copper that is not protected by the resin. Once the copper is etched, the foil is rinsed with water. The resin is then removed with acetone, rinsed with water and dry with nitrogen (N2). This leaves the polyimide and some copper depending on the desired shape. The photo of the obtained antenna after the process is presented in Fig. 8.

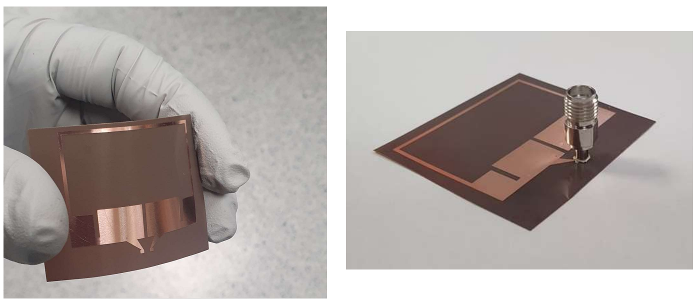

Fig. 8. Photo of the manufactured antenna in cleanroom and with U.FL connector and SMA adaptator mounted.

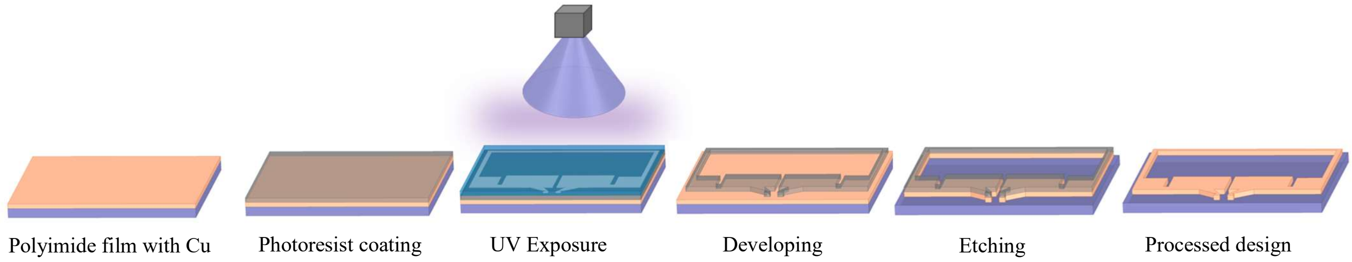

Fig. 9. Schematic representation of the photolithographic process.

B. *Antenna Characterization: Results and Discussion*

The performance of the antenna is tested in flat position. To perform the characterization accurately, the antenna was fixed on a flat Rohacell (with a dielectric constant around 1.03) surface, and the connector soldered at the feeding pad as located in Fig. 5. A U. FL to SMA adapter is plugged to allow measurement with the Vector Network Analyzer (VNA). It can be noted that the measurement with U. FL connector fit very well with the simulation. The same bandwidth from 2.3 GHz to 3.8 GHz is obtained as expected (Fig.10).

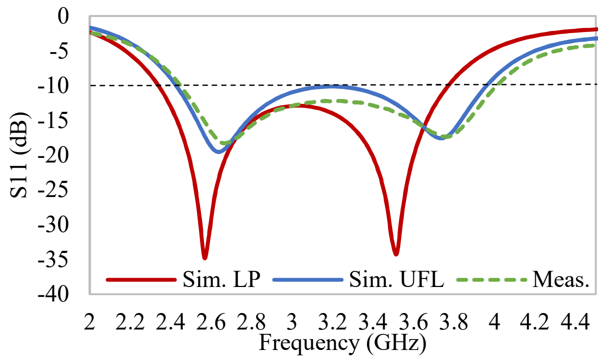

Fig. 10. Comparison of the simulated and measured return loss of the printing antenna.

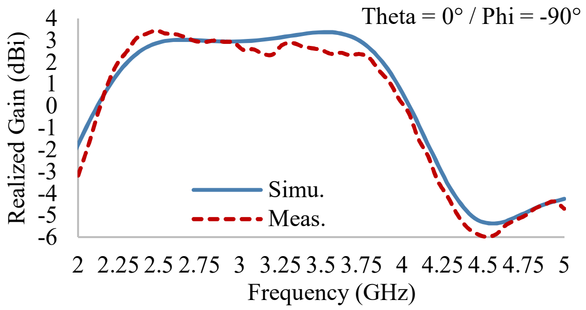

Fig. 11. Comparison between measured and simulated Realized Gain as function of the frequency on the E-plane.

In addition, the radiation pattern measurement is performed in an anechoic chamber (by using the far field antenna measurement facilities existing at LAAS-CNRS) and was carried out in the E-plane where the antenna under test is rotated in the azimuth plane. In Fig.11, a good agreement between simulation and measurement of the gain as function of the frequency can be observed.

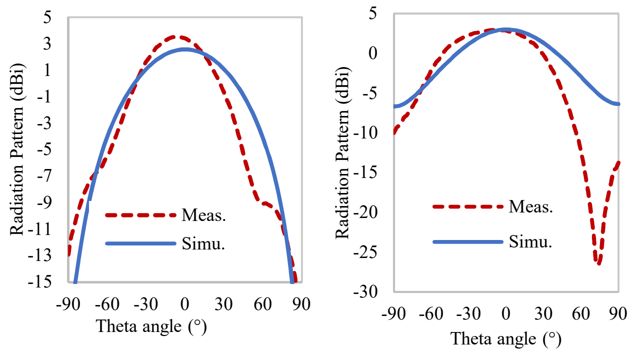

Fig. 12. Comparison of the measured and simulated radiation pattern in the E-plane (Phi = -90°) at 2.45 GHz (left) and 3.41 GHz (right).

We can observe that the maximum gain on the E-plane stay around 3dBi in the bandwidth matched 50 ohms (S11≤-10 dB). The simulation performed at 2.45 GHz for the radiation pattern at 2.45GHz is equal to the measurement the E-plane. However, the measurement and simulation at higher frequency (3.41 GHz) have the same maximum but the radiation pattern is modified as function of the theta angle. This difference can probably be justified by the

V. CONCLUSION

Flexible antennas take an important part in wireless devices and allow a great freedom in the design and operation of the target application while rigid PCB antennas are limited. In this paper, we propose a novel antenna design that offers a very wide bandwidth. In the literature, such ultra-wide band antenna are most often designed with a Coplanar Waveguide (CPW) fed technique, as presented in Table 2. Our proposal consists of modified loop antenna covering a very large bandwidth from 2.45 GHz to 4 GHz. This antenna may offer the possibility to be used for LTE, Wireless Local Area Network (WLAN) applications as well as for WIFI and 5G Sub-6GHz (3.4 GHz to 3.8 GHz) mobile networks. The radiative behaviour at higher frequency can be useful when transmitting or receiving signal in a specific direction where the antenna radiate specially in certain directions. In conclusion, the proposed antenna of flexible polyimide substrate is a novel design and offers a good trade-off between bandwidth, compactness and gain as compared with the state of the art.

TABLE 2. COMPARISON WITH THE STATE OF THE ART.

Ref.	Type	Substrate // Conductive ink	Process	Bandwidth & Frequency	Gain (dBi)	Dimensions
[9]	CPW Monopole	Kapton // Silver	Inkjet	54.4 % (1.2 GHz) / 14 % (2 GHz) / 23.5 % (2.6 GHz / 17.2 % (3.4 GHz)	-1.2 / 0.6 / 2.1	70×20×0.11 mm^3
[10]	Loop	Polyimide // Copper	Chemical Etching	BW 35MHz at 2.45 GHz	--	55×50×0.05 mm^3
[11]	CPW Monopole	Paper // Silver	Inkjet	2 - 10 GHz	-0.92 (2.45 GHz) / 1.52 (5.5 GHz)	50×28×0.254 mm^3
[12]	Microstrip Patch	SU-8/PDMS // Copper	Photo.	6.2 - 6.4 GHz	2.17 dBi	46.4×20×0.5 mm^3
[13]	Inverted F-shaped monopole	Kapton // Silver	--	2.4 - 5 GHz / 3 GHz	1.5 dBi	25×32×0.125 mm^3
[14]	CPW-fed T-shaped patch	PET // Silver	Inkjet	26 - 40 GHz 42 % (33 GHz)	4.35 (27GHz) / 7.44 (39GHz)	16×16×0.135 mm^3
This work	Modified loop	Polyimide / Copper	Photo.	2.45 - 4 GHz 48% (3.225 GHz)	2.6 (2.45 GHz) / 3.3 (3.41 GHz)	40×35×0.127 mm^3

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