

Flexible Printed Microstrip Antenna for IoT Devices

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Abstract. To enhance and improve wireless connectivity for heterogeneous IoT devices to communicate, they need multiple antennas one for each band or a wideband antenna. The typical challenge relies on finding enough space to hold such antennas into one small device. In this paper, we propose a promising solution that relies on using a single compact-size antenna printed on flexible substrates. Moreover, such flexible antenna exposed to special treatment by multilayer and annealing to enhance antenna bandwidth. This single multilayer flexible monopole wideband printed-antenna can operate over different wireless communication bands. Additionally, this paper presents a practical experiment by integrating the fabricated flexible antenna within a Wi-Fi- operating network. Results showed the proposed antenna design is worked perfectly for IoT applications.

Keywords— Flexible- microstrip Antenna, Internet of Things, Signal Strength, Wideband-Antenna

I. INTRODUCTION

Traditional wireless systems assign a frequency band for each device services and the vast amount of signals bursting into the air. Therefore, such amounts of signals require a special treatment and handling to optimally enable signal exchanges between devices using the current IoT technology. Therefore, the optimal exploitation of IoT technology requires interconnection enablement between devices over different communication bands. This means each IoT device needs various antenna designs with multitude sizes to serve each band and ensure connectivity at the same time. Such exploitation raises a challenge to find enough space to support multiple antennas deployment into one small IoT device.

Several developments are achieved by using a single, compact-size and wideband-antenna that can perform multi-function, adapt and operate over several wireless bands at the same time. This enables a dynamic antenna that can serve and operate at different bands instantaneously. While, a design of such small and compact-size antenna is quite challenging due to degradation of antenna electric parameters (current, impedance) with small-size [1], [2].

Recently, researchers investigated different approaches to overcome problems of current path-flow and impedance matching [3–5]. These approaches are used monopole antenna designs that provide a broadband impedance matching due to coplanar waveguide feed [6–8]. Moreover, current flow can be enhanced by applying modifications on ground plane, or using protruded L-shape stubs, slot antenna [5], [9], [10].

In this paper, we present the usage of the recent printing technology on flexible materials as substrates for antennas. Such usage leads to massive improvement in devices' size and antenna metric. The flexible monopole wideband antenna design has low profile, compact, small-size and cost-effective fabrication process that printed on paper-based flexible substrates. Therefore, if such flexible antenna is printed on a credit card, it can serve several bands and perform multiple functions at the same time, such RFID door access, tracking item, RF energy harvest unit ... etc in addition to its main function.

The proposed antenna design was discussed before in [11], but in this paper we print antenna on different flexible substrates. Moreover, we expose this antenna design for special treatment (annealing and multilayer printing) to enhance the performance metric and enable wideband antenna. The proposed multilayer flexible printed-antenna can cover a wideband frequency range (100 MHz 13 GHz) with minimum power loss. The main contributions of this paper summarize as follows:

- Presenting the gain of the combination of flexible-substrate, inkjet-printed, and wideband compact-size antenna that can be attached to single small IoT devices to serve and operate at different bands with high gain and lower power loss.

- Presenting a practical experiment setup by integrating the fabricated flexible antennas that are printed on different substrates within a Wi-Fi-operating network.

The remaining part of paper is organized as follows: Section II shows printing technology on flexible materials. Section III presents the design of the proposed monopole wideband antenna. Section IV presents the simulation and experimental results of the proposed flexible antenna. While, Section V shows a practical case study for the proposed antenna. Finally, Section VI presents our conclusion.

II. PRINTING ON FLEXIBLE SUBSTRATES

Advanced technology refers to the importance of using flexible substrates to provide wearable, portable and low energy consuming devices [12]. This technology investigated for suitable and efficient printing technique for implementing electronic circuits and RF structures on flexible substrates. Inkjet printing on flexible substrates nominated over the traditional techniques, as it accurately jets a single ink droplet from the printer's nozzles to the desired position, so there is no ink waste [13]. Inkjet printing takes a place for small manufacturing scale as it provides a fast, low cost, and simple printing technique.

Currently, the new trend of printing on flexible substrate relies on finding suitable, commercially available, and environmental materials [14–16]. Therefore, the selection of substrate type and its thickness play vital role in determining the characteristics of antennas, such as impedance bandwidth, radiation efficiency ... etc. In this paper, we use glossy paper and PET film as substrates. Such flexible sheets have a thickness equals to 0.25 and 0.26 mm, loss tangent 0.05 and 0.008, and relative permittivity 4.01 and 3.2 for glossy paper and PET film respectively.

III. ANTENNA DESIGN GEOMETRY

which has been introduced detailed in [11]. This design was printed on rigid substrate (FR-4) to operate only at frequency selective notches 2.4 GHz and 5.8 GHz [11]. In this paper, the proposed design is printed on flexible substrates (glossy paper and PET film), considering the optimum conditions of printing and thermal treatments to reach optimal performance [13]. The usage of flexible printed antenna aid to achieve new compact and small-size antenna that can be attached to different devices easily and serve several bands.

The fabricated prototype antenna with full dimension is shown in Fig.1 and Fig. 2. A 50 Ω microstrip line is used for the excitation. Antenna has an overall area of 35 x 37.5 mm. The folded strip width and protruding stub width equals to the width of the microstrip line = 3 mm.

The presented work in [13] is used with the proposed antenna design to enhance the performance metric. Therefore, such flexible antennas that are printed on both substrates exposed to multilayer printing and thermal treatments as in [13].

IV. SIMULATION RESULTS

Antenna design is simulated using high frequency simulation software (HFSS) tool. The experimental results of the proposed antenna (both printed antennas on glossy and PET film) compare with FR-4 antenna. Figure 3 shows the results of return loss (S11), which indicate minimum loss of S11 when using PET film and glossy paper are used as substrate, compare to FR-4. Such flexible printed antennas provide two notches at (2.48, and 6.18 GHz) and (2.48, and 6.2GHz) for PET film and glossy paper antenna, respectively.

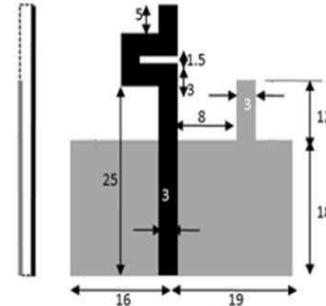


Fig. 1: Geometry of antenna front and back side



Fig. 2: The proposed antenna design printed on glossy paper

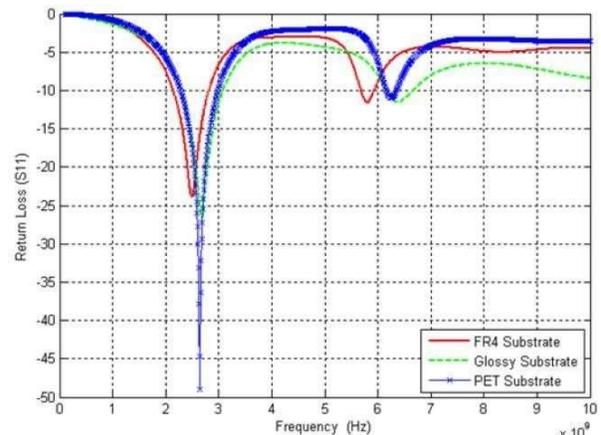


Fig. 3: Simulated return loss S11 of the proposed antenna on different substrates

Moreover, annealing and multilayer printing technique causes a wideband antenna, as shown in Fig. 3. Such flexible multilayer wideband antenna is suitable to operate at several bands of different wireless communication systems.

For examples, this antenna can serve WLAN (5.15 5.825 GHz), (2.4 2.48 GHz), WiMAX (5.25 5.85 GHz) according to IEEE 802.11 standard, DCS (1.71 1.88 GHz), PCS (1.75 1.87 GHz), and UMTS (1.92 2.17 GHz).

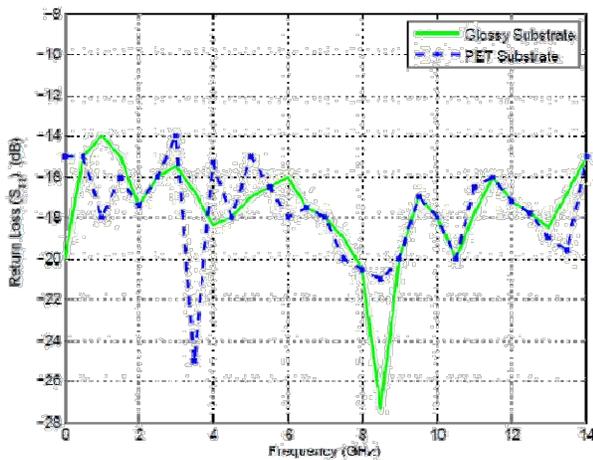


Fig. 4: Measured return loss S11 of the proposed wideband antenna on different substrates

The proposed multilayer flexible printed-antennas have omnidirectional radiation, so antennas can radiate in all directions with same power, which is suitable for HWCS interconnections. Figures 5, 6, and 7 show the 3D model of the radiation pattern of the printed antennas. Moreover, antenna gain enhances for multilayer flexible printed-antenna onto PET film followed by glossy paper compared to printed-antenna onto FR-4 substrate.

V. CASE STUDY

Given the fact that IoT devices operate on Wi-Fi frequency, so we conducted the aforementioned simulation results in a practical experiment setup. In this test, we replace the typical 3dB monopole router antenna with the proposed multilayer flexible paper-based inkjet printed antenna. Figure 8 shows different antenna configurations that are attached to a conventional router. These configurations assume different positions for attached antenna in vertical and/or horizontal to improve signal reception. During this test, the transmission and reception process of data has a reception rate with 100% within 4 meters away from router in all directions.

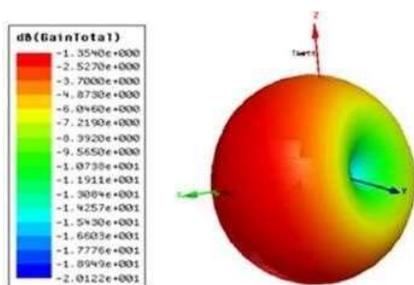


Fig. 5: Simulated 3D model of total gain in (dB) of the proposed antenna printed on RF4 Antenna

These measurements were done by using free android program called "Wi-Fi Signal Strength", and a typical wireless router over WLAN frequency bands.

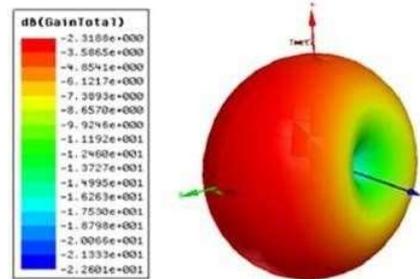


Fig. 6: Simulated 3D model of total gain in (dB) of the proposed antenna printed on Glossy Antenna

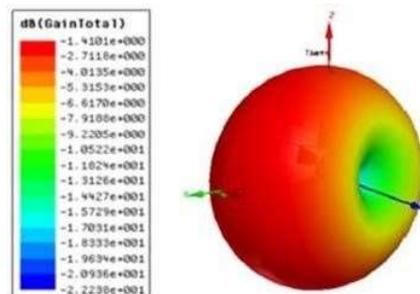
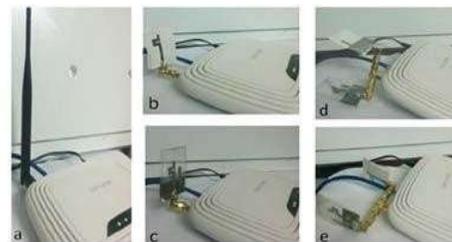


Fig. 7: Simulated 3D model of total gain in (dB) of the proposed antenna printed on PET film Antenna



(a) Normal monopole antenna (b) Printed antenna on Glossy paper (c) Printed antenna on PET film (d) Double antennas in vertical position (e) Double antennas in horizontal position
Fig. 8: Different antenna configurations with router

Figure 9 shows changing in signal strength in (dBm) for different antenna configuration with distance in meter. Signal strength results shows that PET film antenna is better than normal 3 dB monopole router antenna for short distance less than 30 cm (near-field devices). Moreover, different antenna configurations in horizontal or vertical position enhances the performance, which became close to normal monopole router antenna in case of large distance. The configuration of two antennas printed on different substrates (glossy and PET) combines the advantages of each type and enhance the performance of router. A high gain is obtained by using glossy paper antenna (increased by 30% compare to FR-4), and minimum power loss is achieved due to PET film antenna.

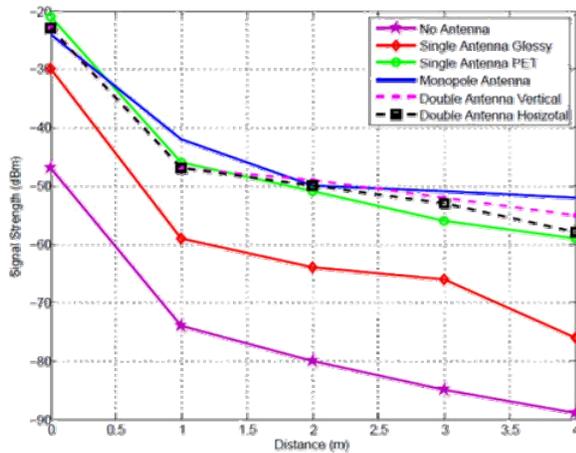


Fig. 9: Signal strength for variable distance with different antenna configurations

VI. CONCLUSION

This paper showed the advantages and benefits of using Inkjet-printing for microstrip wideband antenna on flexible substrates. Such flexible antenna is paper-based is suitable to be integrated with small IoT devices as it offers size-efficient, low-cost fabrication process. The proposed monopole antenna works on a wideband frequency ranges with low power loss over such bands. This antenna has small footprint dimensions of 35 x 37 mm. The structure exhibits reflection below -10 dB in 2.4 and 5.8 GHz for single printed layer. While, such antenna can serve and operate at different frequency bands instantaneously by applying multilayer printing and thermal treatments. This treatment enables new bands such as, RFID, WLAN, WiMAX, DCS, PCS and UMTS. This means that the proposed multilayer flexible antenna can be part of different IoT devices as it operated at wide range from 100 MHz to over 13 GHz. Moreover, antenna radiation pattern is omnidirectional, so antenna radiated in all direction with same power. In this paper, we used the proposed antenna structure in a practical experiment by replacing typical 3dB monopole router antenna and measure signal strength. Results showed the transmission and reception process of data has a reception rate with 100% within 4 meters away from the connected router over Wi-Fi-operating network.

[17]

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