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Flexible-Screen-Printed Antenna with Enhanced Bandwidth by Employing Defected Ground Structure

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Abstract— **A flexible, wideband, and screen-printed antenna is proposed. The antenna is coplanar-waveguide (CPW) and composed of two inverted L-shape elements, a matching stub, and a defected ground structure (DGS), with a total area of 55 × 40 × 0.125 mm^3. Studies show that the DGS can significantly increase the antenna bandwidth from 30% to 119% without sacrificing the size. The antenna has a wide measured bandwidth of 1.77 - 6.95 GHz, and a measured peak gain and efficiency in the ranges of 2.5-5.9 dBi and 60%-90%, respectively. Furthermore, both simulation and measurement confirm that the performance of the antenna is relatively stable under the bending conditions with various curvature radii.**

Index Terms— **Flexible antenna, Defected ground plane, Wideband antenna, 5G antenna, IoT, Screen printed antenna**

I. INTRODUCTION

USING cost-effective additive-manufacturing process to fabricate antennas has been attracted a great deal of interest among researchers and in electronic industries [1-10]. The advances of current wireless communication systems are targeting at the 5th generation (5G) systems, where wireless devices are able to communicate with each other like the Internet of things (IoT). As a result, designs of low-cost and flexible antennas for 5G devices of various shapes and sizes with wide bandwidths have attracted much attention [11-19]. Flexible materials such as papers [8 - 10], polyethylene terephtalate (PET) [11], liquid crystal polymer (LCP) [12], thin glass [13], Kapton [14, 15] and Rogers [16, 17] have been proposed for uses in flexible antennas. However, these designs have either narrow bands or relatively large sizes. Some other designs have investigated the effects of bending only on the reflection coefficient [11, 16], while ignored the effects on the bandwidth, radiation pattern, gain and efficiency.

Monopole antenna has been widely studied and typically has narrow bandwidth. Different monopole designs have been reported to achieve multiple-band and wideband performances by employing various techniques such as using the shape of ground plane [20], E-shape slot [21], parasitic elements [22], metamaterial [23], periodical structures electromagnetic band gap (EBG) [24], and defected-ground structure (DGS) [19]. Study of DGS was started in 1999 [25], and then DGS had been used in various applications such as filters [26], microwave amplifiers [27] and antennas to improve the performances [28]. In antennas designs, DGSs usually used as resonators to create more bands or to disturb the currents on the radiators or the ground planes to enhance the bandwidths or gains. Recently, DGS has been used to produce multiband [29,30], notch band in an UWB antenna [31], high polarization isolation [32], reduction of coupling effects in MIMO antenna [33] and enhancements of antenna bandwidth [34 - 41]. However, the aforementioned antennas either had large sizes or limited bandwidths. The proposed antenna employs DGS to enhance the bandwidth without sacrificing the size. Table I compares the size and bandwidth of the proposed antennas with other antennas also employing DGS for bandwidth enhancement. The proposed antenna in this letter has the smallest overall size and second widest bandwidth with quite a low frequency. Moreover, the other reported antennas were designed on rigid substrates, which are not favorble for flexible applications.

In this paper, a flexible, wideband, compact and screen-printed antenna is proposed. The antenna employs a DGS to significantly enhanced the bandwidth from 30% to 119%. The antenna is fabricated on a flexible Kapton substrate using a low-cost screen-printing technology. The proposed antenna has the advantages of low profile, simple structure, small size, cheap production, and without vias or lumped element components. The performance of the proposed antenna under different bending conditions is investigated using simulation and measurement.

TABLE I
COMPARISON WITH OTHER WORKS USING DGS FOR BANDWIDTH ENHANCEMENT*

Ref.	Total Size L x W x H mm^3	BW Enhancement	**Flexible?**	Lowest Fre. GHz
34	345.6	140%	**No**	3.09
35	9200	112%	**No**	0.7
36	2190.4	80%	**No**	2.23
37	3556	>6.5%	**No**	2.4
38	1628.16	12.2%	**No**	8
39	133696.5	40.4%	**No**	1.65
40	987.55	56.67%	**No**	9.8
41	1638.4	40%	**No**	6.48
Proposed	275	119%	**Yes**	1.77

*ONLY DESIGNS OPERATING BELOW 10 GHZ ARE CONSIDERED

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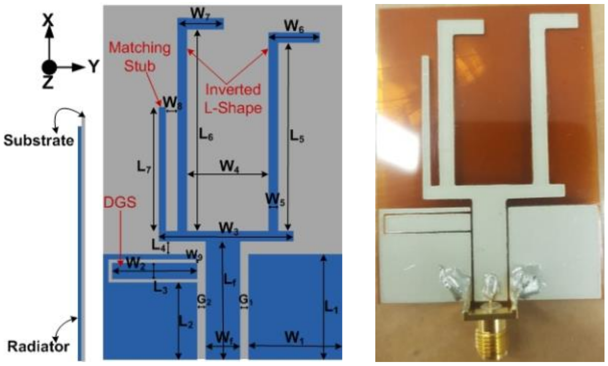


(a) (b)

Fig. 1 (a) Geometry of the proposed antenna, and (b) prototype of the fabricated antenna

TABLE II
DIMENSIONS OF MAIN PARAMETERS OF PROPOSED ANTENNA (MM)

L_f	L_1	L_2	L_3	L_4	L_5	L_6	L_7	G_1	**G_2**
19	17	12.5	3	2	29.5	30.5	25	0.5	**0.5**
W_f	W_1	W_2	W_3	W_4	W_5	W_6	W_7	**W_8**	**W_9**
6	16.5	15.5	26	15	2.5	8.5	9	**2**	**0.5**

II. ANTENNA DESIGN AND RESULTS

A. *Layout of Antenna and Fabrication*

The design layout of the proposed flexible wideband screen-printed antenna is shown in Fig. 1(a), with key optimized dimensions listed in Table II. The antenna has a 50-Ω Coplanar-wave-guide (CPW) feedline, a radiator with two inverted L-shape elements, a matching stub and a DGS. The radiator has an overall area of 55×40 mm^2. The two inverted L-shape elements act as monopoles to create multiple frequency bands. The matching stub is for matching (will be discussed later). The DGS is designed to enhance the antenna bandwidth. The substrate used is flexible Kapton material with a thickness of 125 µm, a relative permittivity of ε_r=3.5 and a loss tangent of tan δ=0.007. The computer simulation tool, Ansoft HFSS software v18, has been used to study the performance of the antenna.

Our main objectives are to design a flexible and wideband antenna which can be fabricated using low-cost screen printing technique. We use CPW-feeding with only one layer of printing to avoid the possible misalignment between the top and bottom layers, as discussed in our earlier work [8, 9]. Fabrication of the antenna is as follows. First, we deposit a layer of commercial silver ink (PE819 from DuPont) on a Kapton substrate through screen printing to form the radiator layer [1]. A mask of the antenna pattern as shown in Fig. 1(a) is cut using a CO_2 laser system and placed on a blank screen mesh. After printing the silver traces, the antenna is heated at 120 °C for 5 min to evaporate the solvents, which is followed by annealing in a vacuum oven at 150 °C for 1 hour. The ink layer has a conductivity 1.7 x 10^7 S/m with a thickness of approximately 4 µm. Finally, an SMA connector is mounted on the antenna using conductive epoxy and the final prototype of the antenna is shown in Fig 1(b).

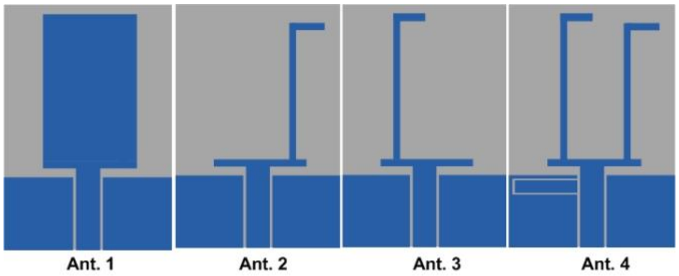


Fig. 2 Antennas used for analysis

Fig. 3: Simulated S_{11} of the antenna using different parts

B. *Analysis of Proposed Antenna*

To analyse the operating mechanism of the proposed antenna, we use four antennas with the similar dimensions, as shown in Fig. 2, with the following studies and explanations.

1) Ant. 1 is a reference antenna. It is a λ/4-monopole antenna designed to operate at around 2.6 GHz. The simulated S_{11} in Fig. 3 shows that it has an impedance bandwidth of only 30%.
2) Ants. 2 and 3 have the right and left inverted L-shape elements, respectively, of the proposed antenna. Fig. 3 shows that both antennas have similar bandwidths, but the frequency band of 2.6-GHz has been shifted to 1.7 GHz with a narrower bandwidth and two weak bands are generated at about 5 and 6 GHz.
3) Ant 4 employs the DGS with both inverted L-shape elements. Fig. 3 shows that the bandwidth of the antenna has been improved, but the frequency range from 1.77 to 2.5 GHz is not well matched.
4) The simulated S_{11} of the proposed antenna with the matching stub added are compared in Fig. 3. It can be seen that the matching stub helps improve matching from 1.77 to 2.5 GHz. As a result, the antenna achieves a wideband from 1.77 to 6.95 GHz with 119% bandwidth.

C. *Simulated and Measured S_{11}*

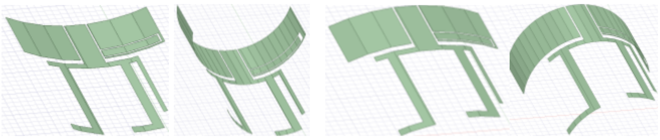
The simulated and measured S_{11} of the proposed antenna is shown in Fig. 4. The result shows that, the antenna has an impedance bandwidth (S_{11}<-10 dB) of 1.77-6.95 GHz or 119%, which can cover most of the wireless and mobile applications as shown in Table III. The measured result of S_{11} shows relatively good agreement with the simulation result.

Fig. 4: Simulated and measured S_{11} of proposed antenna

Table III

APPLICATIONS THAT CAN BE COVERED BY THE PROPOSED ANTENNA

App.	Freq. GHz	App.	Freq. GHz	App.	Freq. GHz
PCS	**1.85-1.99**	**UMTS**	**1.92-2.17**	**WLAN 802.11 b/g/y**	**2.4-2.484**
GSM 1800	**1.71-1.88**	**LTE 2300**	**2.305-2.4**	**LTE 2500**	**2.305-2.4**
WiMAX I	**2.6-2.7**	**WiMAX II**	**3.4-3.69**	**WiMAX III**	**5.25-5.85**
S-DMB	**2.63 - 2.655**	**5G (N77)**	**3.3-4.2**	**5G (N78)**	**3.3-3.8**
5G (N79)	**4.4-5**	**WLAN IEEE 802.11 a/n**	**(5.15 - 5.35) & (5.725 – 5.825)**	**HiperLAN/ 2**	**5.470–5.725**



(a) (b) (c) (d)

Fig. 5 Antenna models used in simulation for bending effect studies: (a)-(b) upper bending with R = 50 and 20 mm, and (c)-(d) lower bending with R = -50 mm and -20 mm

III. EFFECTS OF BENDING

Here, we study the bandwidth and radiation pattern of the proposed antenna when it is bent in five bending curvature radii of R=50, 20, ∞, -50 and -20 mm, as shown in Figs. 5(a)–(d), using computer simulation. While in measurements, we only select the conditions with more severe bending of R = -20 and 20 mm for studies, as shown in Figs. 6(a)–(b). Note that when R is positive or negative, the antenna is bent upward or downward, respectively, and when R= ∞ mm, the antenna is flat without bending.

A. S_{11} and Impedance Bandwidth

The simulated bandwidths of the antenna with flat, upper bending and lower bending are shown in Fig. 7(a). As a wide bandwidth is our target, the level of acceptability in terms of S_{11} has been defined to maintain the bandwidth of the antenna at flat state. It can be seen from Fig. 7(a) that bending has negligible effect on the performance of the antenna. Under all the bending conditions, the antenna has the bandwidth (with S_{11}<-10 dB) from 1.77 to 6.95 GHz (119%). The measured results in Fig. 7(b) show that bending with R=±20 mm also has no significant effect on the bandwidth. The measured results in Fig. 7(b) indicate good agreements with the simulated results in 7(a). The simulated result for R= 20 mm is added to Fig. 7(b) for comparison.

(a) (b)

Fig. 6 Practical antenna used in measurements for bending effect studies: (a) upper bending with R = 20 mm, and (b) lower bending with R = -20 mm.

(a)

(b)

Fig. 7 S_{11} of the antenna with different curvature radii: (a) simulation **with R=±20 and ±50 mm** and (b) measurement, as well as the **simulated result with R =+20mm for comparison.**

B. Radiation Patterns, Gain and Efficiency

The radiation patterns, gain, and efficiency of the proposed antenna with severe bending of R=20, ∞, and -20 mm are measured using the Satimo StarLab System at the King Abdullah University for Science and Technology (KAUST) [42, 43]. As the antenna has a wide bandwidth of 1.77–6.95 GHz, we select the frequencies of 2.4, 3.5, and 5.2 GHz to study the radiation patterns. The measured E-field and H-field for co-polarization in the Y-Z and X-Z planes at 2.4, 3.5, and 5.2 GHz are shown in Figs. 8(a)–(c). Fig. 8 shows that the unbent antenna has a monopole- shaped radiation pattern in the E-plane and nearly an omnidirectional radiation pattern in the H-plane.

Y-Z **(a)** **X-Z**

Y-Z **(b)** **X-Z**

Y-Z **(c)** **X-Z**

Fig. 8 Measured co-polarizations and simulated x-polarizations in Y-Z and X-Z directions at (a) 2.4 GHz, (b) 3.5 GHz and (c) 5.2 GHz for flat and bent antennas with R = +20 mm

When the antenna is bent with R = 20 and R = -20 mm, the radiation patterns are slightly affected, as shown in Fig. 8. Some energies are lost from one side of the antenna, but is gained in other side with no null in the broadside direction. The simulated x-polarization for the flat antenna is also shown in Figs. 8(a)–(c). Results have also shown that the bending has insignificant effect on the x-polarization component. For brevity, the results are not included.

The simulated and measured peak gains and efficiencies of the antenna with flat, upper bending and lower bending are shown in Fig. 9 (a)-(b) for better comparison. It can be seen that all the results follow similar trends in gain with a range of 2.5-5.9 dBi. The maximum difference between the simulated and measured results is about 1.5 dB as shown in Fig. 9(a). For efficiency, the maximum difference between the simulated and measured results is about 25% for the flat, upper bending and lower bending as shown in Fig. 9 (b).

(a)

(b)

Fig. 9: Simulated and measured (a) gains and (b) efficiencies of antenna with flat and R = ±20 mm

IV. CONCLUSIONS

A wideband and flexible antenna fabricated using low-cost screen printing technique has been proposed. The antenna is composed of two inverted L-shape elements, matching stub, and DGS, with a total size of $55\times40\times0.125$ mm^3. Studies have shown that the DGS can increase the bandwidth from 30% to 119%. As a result, the antenna achieves a bandwidth of 1.77-6.95 GHz and hence it is suitable for various wideband communication systems, especially working in the sub 7 GHz bands, such as the 5G applications. Both the simulated and measured results have shown that the performance of the proposed antenna under different bending conditions is relatively stable. The antennas have the advantages of small size, low profile, simple configuration, and low cost for mass production, which make it a promising design for upcoming compact, slim, and flexible mobile and wireless devices. Future work will be considered to study the proposed antenna when it is bent in the y-direction rather than only the x-direction.

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