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A compact low profile wideband U-shape antenna with slotted circular ground plane

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ABSTRACT

In this article a compact low profile U-shape patch antenna for high gain and wide bandwidth is presented. By introducing an inverted U-shape slot on the circular ground plane (diameter of 40 mm) an adjustable wide impedance bandwidth is achieved. The simulated results are confirmed experimentally. An impedance bandwidth ($S_{11} \le -10$ dB) up to about 100.35% is achieved by individually optimizing its parameters. The proposed antenna exhibits nearly stable radiation pattern with a maximum gain of 3.2 dBi. It makes the proposed antenna suitable for in wideband applications.

1. Introduction

With booming demand in wireless communication system, microstrip antennas have attracted much interest due to their low profile, light weight, ease of fabrication and compatibility with printed circuits. A main challenge of microstrip antenna design includes its commercialization that requires wide bandwidth and high gain along with compactness at a low cost in a single design. For over two decades, researchers and scientists have developed several methods to increase the bandwidth and gain of patch antenna. The bandwidth of the microstrip antenna increases with an increase in the substrate thickness h [1,2] or with a decrease in the dielectric constant ε_r. However, there is a practical limit on increasing the h, and if increased beyond $0.1\lambda_0$, surface-wave propagation takes place, resulting in degradation in antenna performance. An impedance bandwidth larger than 25% can be achieved using gap-coupled coplanar microstrip resonators [3]. The resulting broadband microstrip antenna also has a much increased antenna size compared to a single resonator. Two or more patches on different layers of the dielectric substrates are stacked [4] on each other to achieve higher bandwidth. Another established broad-banding technique includes the use of thick air [5] or foam substrate [6]. However, simultaneously enhancements of gain, bandwidth and size reduction are becoming major design considerations for commercial applications of microstrip antennas as the improvement of one of the characteristic, normally results in degradation of the other.

In recent years, many techniques have been reported to achieve wideband patch antenna for modern wireless communication devices. That includes use of different shaped slot, slit and patch like U-shape slot antenna [7,8], wideband E-shape antenna [9]. However, the achievable bandwidths of these antennas are below 30%. Many more broad banding techniques that hybridized the use of slots, shorting pins or shorting walls and use of thick air or foam filled substrate have been also reported. A rectangular microstrip antenna [10] with two U-shaped slots on the patch and using a foam layer as the supporting substrate, an impedance bandwidth of 44% is achieved. A square microstrip patch antenna [11] with an air-filled substrate of thickness around $0.1\lambda_0$ and one patch edge shorted by three symmetrical shorting pins provides an impedance bandwidth of 67.5%. Wide-slot and microstrip line feed [12–15] is another established method to achieve wideband. For example, in Ref. [12], a compact 37 mm × 37 mm antenna consisting of a printed wide slot, a coupled patch embedded in the center of the slot, and a pair of parasitic patches along the microstrip feed line is proposed. Its measured impedance bandwidth is about 136% ranging from 2.1 to 11.1 GHz. Sung [13] carried out an investigation on a printed wide-slot antenna with a parasitic patch. This antenna exhibits wideband performance from 2.23 to 5.35 GHz. A compact open-slot antenna for bandwidth enhancement is presented in Ref. [14]. Asymmetrical rectangular patch with a U-shaped open-slot is used to generate multiple resonances. This antenna with a small size (24.1 mm × 24.1 mm × 1 mm), provides a wide impedance bandwidth of 122% from 2.95 to 12.1 GHz. A heptagonal slot antenna [15] provides an impedance bandwidth

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of 104.12% and maximum gain of 4.5 dBi. However, the antenna does not possess a physically compact profile, having a dimension of 71 mm × 71 mm. All these antennas exhibited wideband by using microstrip line feed but the proposed antenna provides higher or same order bandwidth using coaxial probe feed. Honari et al. proposed an aperture-coupled antenna [16] with single modified ring patch for bandwidth and gain enhancement. The simulated bandwidth with a VSWR lower than 1.5 and 1-dB gain ripple bandwidth is 34% and 42%, respectively. The peak gain of 9.2 dB and radiation efficiency above 96% over the bandwidth has been achieved. This antenna provides larger gain and lower bandwidth with larger size compare to the proposed design. Wideband circularly polarized antenna with wide beamwidth is presented in Ref. [17]. The wide impedance bandwidth is achieved by using the modified inverted-L feeds and stacked patches. Impedance bandwidth of 30.1% and half-power beamwidth (HPBW) $\geq 100^0$ are achieved with much larger dimension (120 mm × 120 mm × 25.5 mm). U-slot and L-probe feeding techniques have been used to design patch antennas [18] with dual- and multi-band characteristics. More recently, a U-shape patch antenna with modified ground plane with maximum gain of 4.1 dBi is achieved with 86.79% bandwidth [19].

This article presents a design that provides wide bandwidth, high gain and compactness simultaneously. The design employs use of U-shape patch and slot loaded circular ground plane to meet the design goals. By optimizing the arm length of U-shape patch and slot, a wider impedance bandwidth of 100.35% and a gain of 3.2 dBi are achieved. Compared to the reference U-shaped patch antenna, this antenna achieves reduction in size up to 69.68% and reduction in first resonant frequency of 43.75%. Details of the proposed antenna structure and parametric studies are described in Section 2 and the measured results are discussed in Section 3.

2. Antenna design and parametric study

2.1. Antenna configuration

The configuration of the proposed antenna is illustrated in Fig. 1. The antenna consists of a U-shape patch as the radiating plane and a circular-shape ground plane with an inverted U-shape slot. The slotted ground plane and the patch are printed on the opposite sides of an inexpensive glass PTFE (Poly Tetra Fluoro Ethylene) substrate of thickness h = 1.6 mm, relative permittivity ε_r = 2.4 and loss tangent = 0.0022. The circular ground plane of diameter D = 40 mm is defected by cutting an inverted U-shape slot just below the U-shape patch to achieve wide bandwidth and higher gain. The slot in the ground plane has strong coupling to the U-shape patch. Dimensions of different parameters of patch and slot have been chosen after a good number of parametric studies. The dimensions of optimized parameters for the proposed antenna are given in Table 1. A 50 Ω co-axial probe is employed to excite the structure. The feed position, yielding good impedance matching to 50 Ω, has been found to be at the middle point of U-shape patch as shown in Fig. 1. Photograph of the prototype is also shown in Fig. 2.

Table 1
Specifications of proposed antenna.

D	S	L_P	d_P	G_P	Δ_P	L_S	d_S	G_S	Δ_S
40	7.5	25	5	10	3	25	5	10	5

All the parameters are in mm.

2.2. Parametric study

Based on this design, some sensitive parameters have been studied numerically in order to investigate the influence of the parameters on antenna performance. The frequency response of the antenna strongly depends on the geometry of the radiating patch and the ground plane. So, to optimize the antenna performances, extensive parametric analyses have been performed with respect to the (a) presence of inverted U-shape slot on the ground plane; (b) L_P and L_S: arm length of patch and slot respectively; and (c) Δ_S: width of the connecting arm of slot. All simulation has been carried out by employing MoM based software ANSOFT designer.

2.2.1. Effects of U-shape slot

To study the effect of slot on the antenna performance a simulation is carried out in absence of the slot on the ground plane keeping all other optimized parameters fixed. The corresponding simulated reflection coefficient (S_{11}) is presented in Fig. 3. From Fig. 3 one can find that the slot insertion on the ground plane has significant effects on the bandwidth of the proposed antenna. The conventional U-shape patch antenna without DGS provides double resonating behavior at 8 GHz and 11.2 GHz with negligible reflection coefficient and bandwidth. Whereas the same antenna with DGS provides four resonating frequencies at 4.5 GHz, 6.7 GHz, 8.7 GHz and 12.4 GHz, which are unifying to produce wide bandwidth of 8.41 GHz (98.42%) starting from 4.34 to 12.75 GHz considering −10 dB reflection coefficient. So the insertion of slot

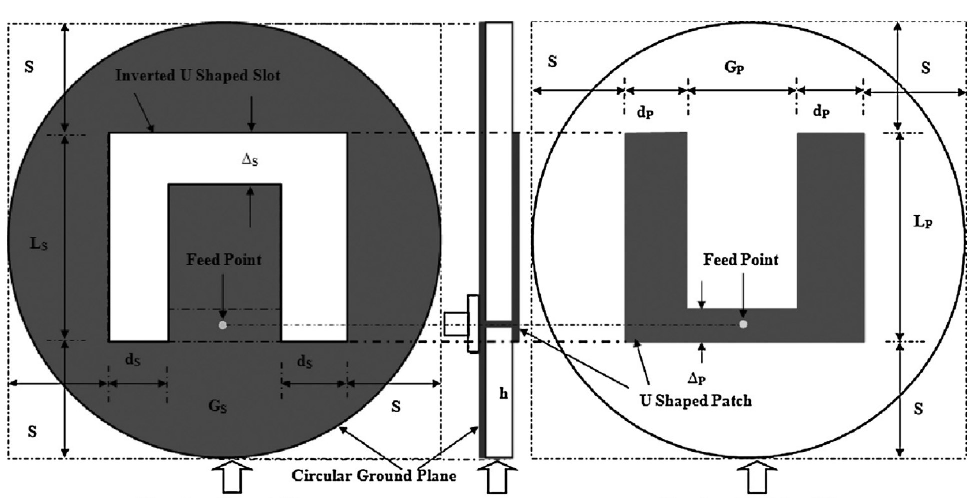

Fig. 1. Schematic diagram of the proposed antenna.