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A circularly polarized planar antenna on flexible substrate for ultra-wideband high-band applications

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ABSTRACT

This paper presents the design of a circularly polarized slot antenna on a flexible substrate for ultra-wideband (UWB) high-band applications, as well as the behavior of the antenna near a human body. We used two slots that were crossed perpendicularly to obtain a circularly polarized wave. We realized wideband impedance matching to optimize the lengths and widths of the antenna slots and substrate. The impedance bandwidth of proposed antenna is 5.60 GHz from 7.11 to 12.71 GHz, and the antenna size is 16 mm × 16.3 mm × 0.254 mm.

1. Introduction

In 2002, the Federal Communications Commission (FCC) in the United States released regulations for Ultra wide band (UWB) technology, and a variety of UWB systems such as sensor networks, body area networks, and radar systems have been developed [1,2]. There are many reports on planar UWB antennas, for example, U type monopole antennas [3], one-sided directional slot antennas [4,5], and omnidirectional slot antennas [6]. UWB has low power consumption, low power output, and high range resolution, which are the reasons for the expected use of UWB in indoor position detection in wireless sensor network systems [7]. In this application, it is conceivable that an antenna can be set at various places such as a wall, a pillar, and a human body; thus, flexibility is required for an antenna [8]. Moreover, it is profitable to use circularly polarized antennas, which do not require the arrangement of the antenna directions [9,10].

UWB is divided into the low band (3.4–4.8 GHz) and the high band (7.25–10.25 GHz) in Japan because interference from 5-GHz-band wireless LAN (IEEE 802.11a) systems is a serious problem. Moreover, in the low band, there is interference from other mobile applications. Therefore, the high band attracts attention. Thus, in high-band UWB applications, the device size, including the antenna, becomes small.

In this paper, a circularly polarized slot antenna on a flexible substrate for UWB high-band (7.25–10.25 GHz) applications is proposed [11]. Generating a circularly polarized wave in the UWB high-band, our proposed antenna has two slots that are crossed perpendicularly. The antenna has many parameters, and each parameter affects the impedance matching and axial ratio. Additionally, we studied the flexibility of the proposed antenna by bending the antennas and by measuring the characteristics near a human body. For the measurement near a human body, we measured the antenna characteristics under two situations considering body area network applications. In one situation, the antenna is placed on the skin of the arm directly. In the other situation, the antenna is placed on the clothes. Sections 2 and 3 describe the layout and parameter and simulation results of our proposed antenna. In Section 4, the experimental results are presented, and a summary and conclusions are provided in Section 5.

2. Antenna design

Fig. 1 shows the configuration of the proposed circularly polarized planar antenna for UWB high-band systems and the cross section of the substrate. The values of all the parameters of the proposed antenna are listed in Table 1. This antenna is on a substrate with flexible characteristics. The substrate has a dielectric constant (ε_r) of 3.5 and a loss tangent (tan δ) of 0.0015. The thicknesses of the dielectric and metal (Cu) layer are 0.254 mm and 20 μm, respectively. The +*y*-direction slot (slot *A*) and +*x*-direction slot (slot *B*) generate circularly polarized waves, and the lower right slot and the upper left slot are useful for impedance matching. An RF signal

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Table 1
Value of each parameter of the proposed antenna.

W	*W*1	*W*2	*W*3	*W*4	*W*5	*W*6	*W*7
16.3	2.0	0.5	0.1	0.4	12.0	2.0	6.0
L	*L*1	*L*2	*L*3	*L*4	*L*5	*L*6	*L*7
16.0	2.0	0.5	5.8	1.0	1.0	4.0	7.2

(Unit = mm).

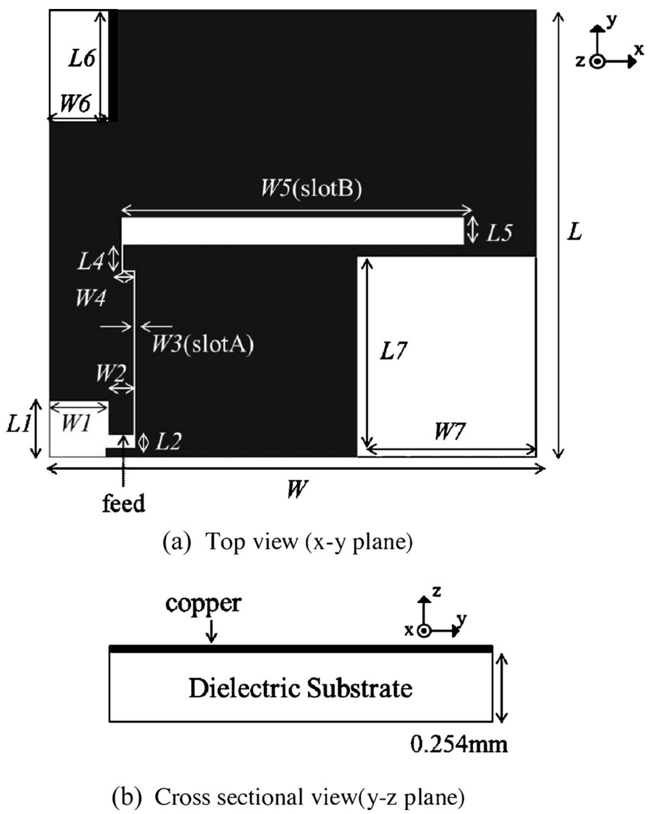

Fig. 1. Layout of the UWB high-band circularly polarized antenna: (a) top view (*x*–*y* plane). (b) Cross sectional view (*y*–*z* plane).

is generated through the surface-mounted connector at the feed point.

3. Antenna characteristics

Fig. 2(a) and (b) shows the frequency dependence of the reflection coefficient (S_{11}) and an axial ratio (*AR*) with different values of length *L*. Generally, a circularly polarized antenna has an *AR* of less than 3 dB. As shown in Fig. 2(a), the resonance frequency does not change when *L* changes; thus, the impedance bandwidth S_{11} is lower than −10 dB and shows almost no change. However, the *AR* is significantly changed by changing *L*, as shown in Fig. 2(b), and the optimal size of *L* is 16 mm. In this case, the simulated *AR* bandwidth of the proposed antenna is 4.26 GHz from 7.06 GHz to 11.32 GHz, which satisfies the UWB high-band requirements.

Fig. 3(a) and (b) shows the frequency dependence of S_{11} and an *AR* with different values of length *L7*. As shown in Fig. 3(a), the resonance frequency follows the variation of *L7* closely. However, the value of the S_{11} is changed, implying that impedance matching is realized by changing the length of *L7*, and *L7* is determined as 7.2 mm. In this case, *AR* satisfies the UWB high-band regulation, as shown in Fig. 3(b).

Fig. 4 shows the simulated radiation patterns of the proposed antenna on the *y*–*z* plane at (a) 7.5 GHz, (b) 8.5 GHz, and (c) 9.5 GHz. The proposed antenna radiates a left-handed circular polarization (LHCP) in the +*z*-axis direction and a right-handed circular polarization (RHCP) in the −*z*-direction. The realized gain is 2.0 dBic at 7.5 GHz, 3.2 dBic at 8.5 GHz, and 3.2 dBic at 9.5 GHz. The beamwidth for the +*z*-direction becomes narrow as the frequency increases; however, the radiation patterns are similar in the UWB high band.

Our proposed antenna is designed to be set on various places such as a wall, a pillar, and a human body; thus, flexibility is tested in this study.

Fig. 5(a) shows the cross section of the proposed antenna (*x*–*z* plane) under bending. In the figure, *A* is the bending angle. Fig. 5(b) and (c) shows the frequency dependence of S_{11} and an *AR* with a varying bending angle *A*. As shown in Fig. 5(b), the resonance frequency is slightly shifted lower; however, the −10-dB bandwidth of S_{11} is almost identical, and the bandwidth of the proposed antenna is 5.60 GHz from 7.11 GHz to 12.71 GHz, which satisfies the UWB high-band application requirements. On the other hand, the *AR* bandwidth becomes narrow as the *A* increases, and the simulated 3-dB *AR* bandwidth is 3.14 GHz from 7.24 GHz to 10.40 GHz ($A = 10°$) and 2.88 GHz from 7.25 GHz to 10.13 GHz ($A = 20°$), as shown in Fig. 5(c). However, the *AR* of this antenna satisfies the UWB high-band application requirements if $A = 20°$. Therefore, our proposed antenna can operate as a circularly polarized wideband

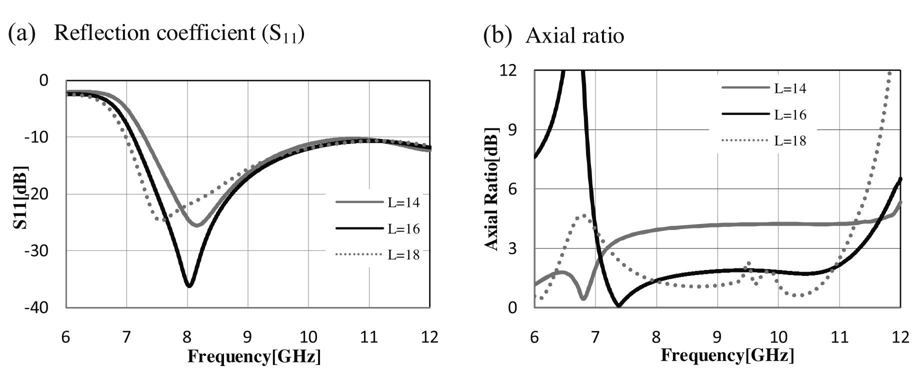

Fig. 2. Frequency characteristics of the reflection coefficient and axial ratio with variation of *L*.