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RESEARCH PAPER

Study on miniaturization of planar monopole antenna with parabolic edge shape with a notch slot

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This paper proposes a planar monopole antenna with a parabolic edge shape. This antenna, which has notch characteristics in the wireless local area network (WLAN) band, can be miniaturized. To obtain the notch characteristics in the WLAN band, a slot with a parabolic edge shape identical to that of the monopole structure was implemented. Because the planar monopole antenna with a parabolic edge shape possesses characteristics similar to those in self-complementary structure conditions, it can be miniaturized by reducing the antenna components at the same proportion. For the antenna fabrication, an FR4 dielectric substrate with a dielectric constant of 4.7 was used. The size of the miniaturized antenna that satisfies the ultra-wide band requirement was 15.6 × 18.6 mm², and the 10-dB band was 3.013–12.515 GHz. At each frequency, the radiation pattern was similar to that of a dipole antenna.

Keywords: Monopole antenna, Parabolic edge shape, Notch slot, Miniaturization, Scale variation

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I. INTRODUCTION

The most widely used shape for an ultra-wide band (UWB) antenna is the modified monopole structure. In addition, attempts are continuously made to improve the properties of the UWB antenna using different monopole shapes such as ellipse, triangle, fractal, and diamond or by modifying the ground with the addition of a sleeve [1–4]. The important requirement of a UWB antenna is antenna miniaturization. Recently, many research works have been conducted to miniaturize the UWB antenna. For example, some techniques such as loading of inverted L-strip [5], using fractal structure [6], modifying the ground [7], and half-cutting a monopole structure [8] have been applied to realize antenna miniaturization. The antenna proposed in this paper was designed to have parabolic curvatures at the edge of the conductor, which comprises the ground, and at the edge of the monopole conductor [9]. The two parabolic curvatures were combined to create different variations and the conductor and slot parts were made similar to those of a self-complementary structure condition. At the coplanar waveguide (CPW) feeder, a discontinuous structure was added to vary the characteristic impedance, and an impedance matching effect was obtained. To prevent interference in the wireless local area network (WLAN) band, a notch slot was applied to the antenna. In contrast to the conventional shape of a notch slot, a parabolic notch slot structure was designed similar to the shapes of the monopole and ground conductors. In addition, miniaturization of the antenna was done through scale changes in the structure, excluding the feeder and the notch slot.

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II. BASIC ANTENNA STRUCTURE

In a basic antenna, the monopole and ground conductors are located on the same plane, and the edges of the planar monopole and ground have a parabolic structure [1].

The impedance varies by converting the feeder to a discontinuous CPW structure, instead of a coaxial cable. The step-type discontinuous CPW disturbs the electromagnetic field of a normal CPW and adds a reactance component [10]. First, the transmission line length CL, as shown in Fig. 1, is 0.8 mm, which varies starting from 0.625 mm above the bottom side of the antenna. The part that determines the width of the signal line in the middle of the transmission line is denoted as CW. The impedance of the transmission line is determined by the variation in the length of CW. Table 1 shows the impedance of the calculated transmission line as the value of CW increases. When the CW value increases, the impedance also increases, and the return loss value of the upper frequency band increases.

Figure 2 shows the change in return loss value for the change of the CW when there is no notch. The CL value for the result is 0.8 mm. Overall, it is confirmed that the return loss value has increased aside from the 7–9 GHz section where the return loss value slightly decreased when CL

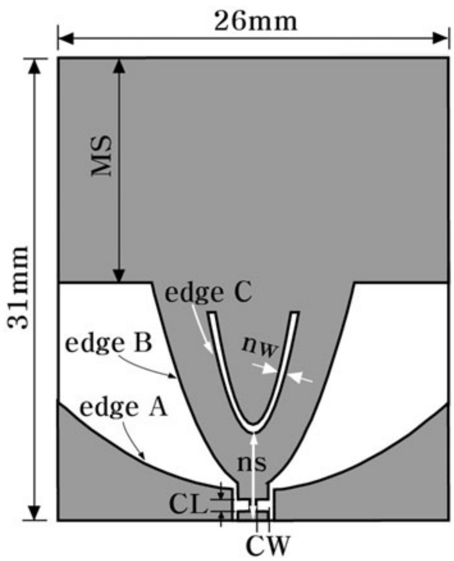

Fig. 1. Basic structure of the antenna with a notch slot.

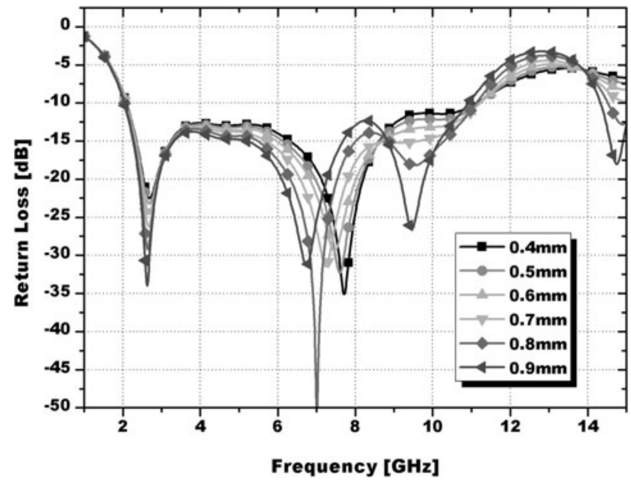

Fig. 2. Return-loss simulation results for various CW of the no-notch antenna.

value increased. From the optimization result of this parameter, CW was determined to be 0.8 mm.

According to the changes in MS, which is the width of the matching step, impedance matching in the high-frequency band was effective. Further, the largest 10-dB band was obtained when MS was 15 mm. In addition, the band-rejection center frequency of the proposed antenna, which is 5.4875 GHz, was the median value of the WLAN band (5.15–5.825 GHz). $\lambda/4$ was calculated to be 13.6 mm at 5.49 GHz. The length of the notch slot was determined based on this calculated value. By making the notch slot assume a parabolic edge shape similar to that of the monopole and ground conductors, the band rejection characteristics was obtained. The following is the parabolic equation of a basic antenna.

$$\begin{aligned} Y_A &= a_A X_A^2 \\ Y_B &= a_B X_B^2 + g \\ Y_C &= a_C X_C^2 + ns \end{aligned} \tag{1}$$

In equation (1), ground edge A is expressed as Y_A, monopole edge B is expressed as Y_B, and notch slot edge C is expressed as Y_C. The coefficient of the quadratic term in the parabolic expression for the notch slot edge is designated as a_C. nl and nw are the length and width, respectively, of the notch slot. nl is a variable that moves the center frequency of the notch slot. a_C and nw affect the size and the return loss value of the notched band. Based on the simulation results using different parameters, the obtained optimal values were as follows: $a_C = 0.5$, $nl = 17.5$ mm, $nw = 0.4$ mm, and $ns = 4.5$ mm.

Table 1. Impedance of transmission line for various CW.

CW(mm)	Impedance (Ω)
0.4	75.2
0.5	82.4
0.6	90.6
0.7	100.5
0.8	113.7
0.9	134

Figure 3 shows the return-loss simulation results of the notch-slot-applied antenna and the no-notch antenna. The 10-dB bandwidth is 2.015–11.185 GHz, and in the middle, the notch band is 5.06–5.795 GHz. The notch band did not completely match the WLAN band, and the error rate was approximately 0.5%.

III. ANTENNA MINIATURIZATION BY APPLYING SCALE CHANGES

The important requirements for a UWB antenna include miniaturization of the UWB antenna itself. For the antenna miniaturization, a scale change was performed to reduce all components in the same proportion. For the feeder, the scale was maintained to be the same because its impedance was set to 50 Ω. The overall size of the antenna was reduced by 1, 0.9, 0.8, 0.7, 0.6, and 0.5 times. Excluding the feeder and notch slot, the overall size and structure of the antenna

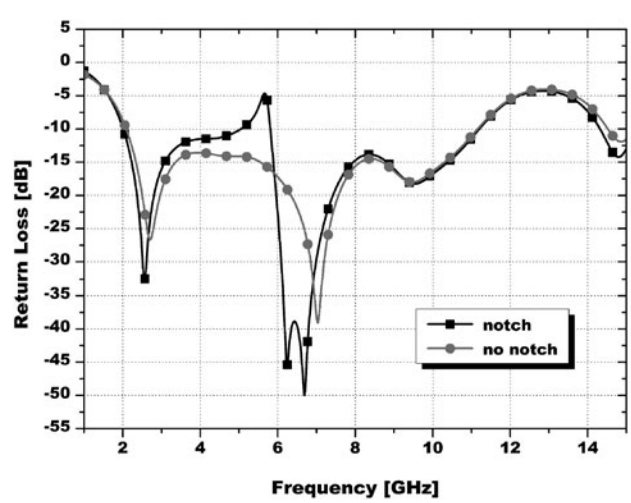

Fig. 3. Return-loss simulation results of the notch-slot-applied antenna and the no-notch antenna.

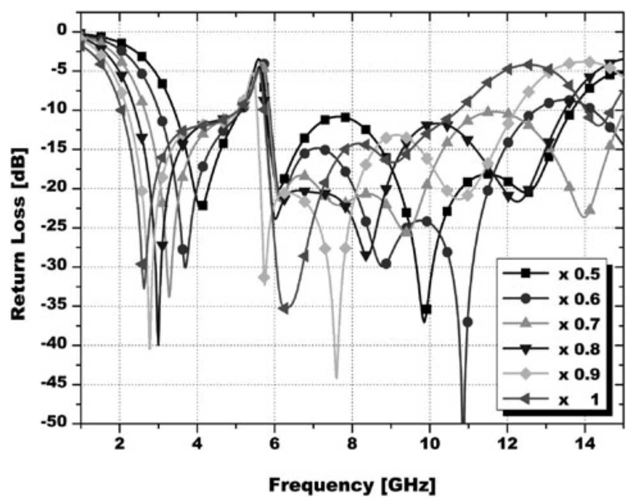

Fig. 4. Simulation results of the return loss according to the antenna scale changes with notch slot.

were reduced in the same scale compared with the original size. Equation (2) shows the substitution of variables using the scales, instead of variables X and Y in equation (1). Here, the scale was set as n. By assuming that the new variables are X' and Y', then $X' = nX$, $Y' = nY$, and $g' = ng$.

$$Y'_A = \frac{a_A}{n} X'^2_A$$
$$Y'_B = \frac{a_B}{n} X'^2_B + g'. \quad (2)$$

As the scale decreases, the coefficients of the quadratic terms in the parabolic expressions for the monopole and ground edges increase at a certain proportion according to the scale, whereas the antenna's overall size, MS, and g decrease in the same proportion. Because the antenna structure was similar to a self-complementary structure, we expected that the dependence on the angle formed by the monopole and ground conductors would be larger than that by the total length.

Figure 4 shows the results obtained through simulation of the return-loss characteristic according to the changes in the antenna scale. As the scale decreases from 1 to 0.5, small changes are observed at the lower frequency where the 10-dB band started, and noticeable differences are observed at the upper frequency part. In the results, the size of the antenna became small, and simultaneously, the overall 10-dB band became wide. In addition, while the notch slot was applied to the antenna at each scale, we confirmed that band rejection occurred well in the WLAN band. The antenna scale with the smallest antenna size, while satisfying the UWB band requirement was 0.6. Here, the 10-dB band was 3.013–12.725 GHz, and the notch band was 5.165–5.865 GHz.

IV. ANTENNA FABRICATION AND MEASUREMENT

Figure 5 shows an actual photograph of the antennas with a notch slot. For the antenna fabrication, an FR4 dielectric substrate with dielectric constant of 4.7 was used. Figure 6 shows the measurement results of the actually fabricated antenna. Figure 7 shows the return-loss characteristics at the scale of 0.6. The 10-dB band is 3.013–12.515 GHz, and the notch band is 5.235–5.848 GHz. A high-frequency result of 0.085 GHz is observed in the low limit frequency for the notch band. Figures 8 and 9 show the graphs illustrating the frequency radiation patterns in the E- and H-planes, respectively, when the scale is 0.6. All the four frequencies display similar radiation patterns, and these patterns are similar to those of a dipole antenna. In the case of the E-plane, an average gain difference of 5 dB is observed at the frequency of 5.5 GHz due to band rejection compared with that at 3.5 GHz. In the case of the H-plane, a small gain is observed

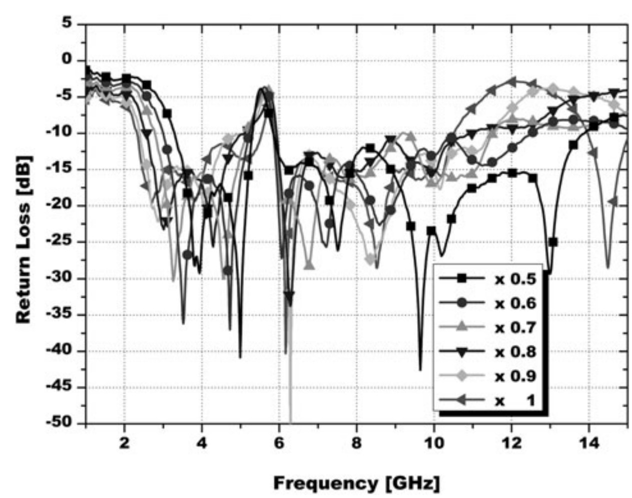

Fig. 6. Return loss of the antenna with notch slot at various scales (measured result).

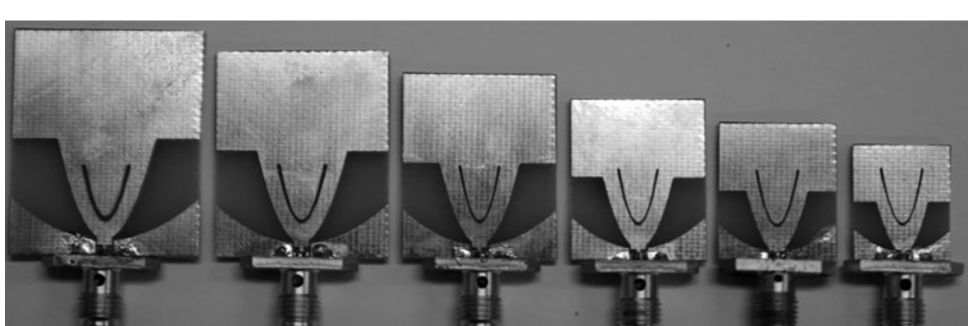

Fig. 5. Photograph of the miniaturized antenna with notch slot.

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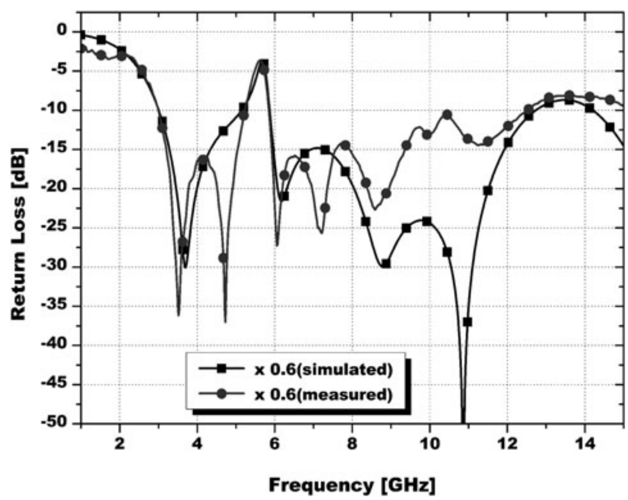

Fig. 7. Return loss at a scale of 0.6.

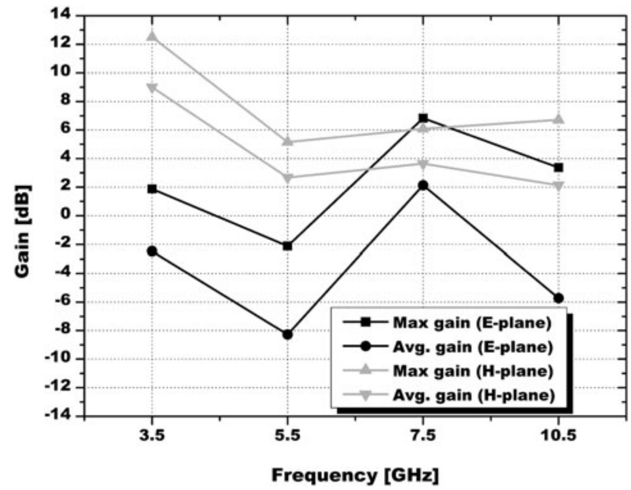

Fig. 10. Gain at each frequency.

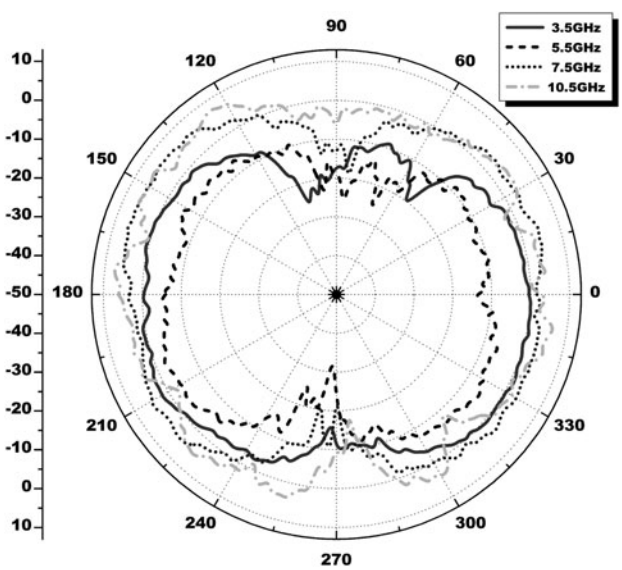

Fig. 8. Radiation pattern at each frequency (*E*-plane).

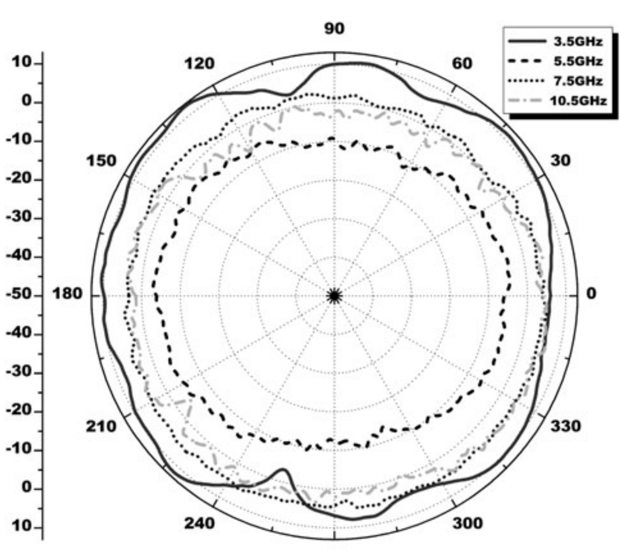

Fig. 9. Radiation pattern at each frequency (*H*-plane).

Table 2. Comparison of the size of the reference antenna and the proposed antenna.

Reference no.	Reference [7]	Reference [8]
Size	20.5 mm × 29 mm = 594.5 mm²	14.1 mm × 25 mm = 352.5 mm²
Size reduction from reference antenna to proposed antenna	51%	18%

compared with those of the other frequencies and the band-rejection characteristics could be clearly observed.

Figure 10 shows the graph of the maximum and average gains on the *E*- and *H*-planes. Because gain reduction occurs at the frequency of 5.5 GHz, band-rejection characteristic is confirmed in the notched bands. Outside the rejection band, the average gain is practically not attenuated in the range from −2.5 to −5.7 dB on the *E*-plane and from 2.1 to 9 dB on the *H*-plane.

Table 2 shows comparison of the size of the reference antenna and the proposed antenna. While the dimension of antenna in [7] was 20.5×29 mm² and in [8] was 14.1×25 mm², this paper showed a very small size of 15.6×18.6 mm². Thus, it was confirmed that the area became 51% smaller about in [7] and 18% about in [8].

V. CONCLUSION

In this study, the feed of a parabolic edge-type monopole antenna was converted to discontinuous CPW, and a notch slot was applied. Antennas with band rejection in the WLAN band were simulated and fabricated. In contrast to the conventional shape, the parabolic edge shape applied to the monopole and ground conductors was also identically applied to the notch slot. Using the characteristic similar to the self-complementary structure condition, the antenna was downsized by adjusting the scale of the antenna components, excluding the feeder and notch slot. Through downsizing of the antenna size, we confirm that the performance of the

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antenna did not significantly change. We can clearly confirm the effectiveness of the scaled model of the parabolic edge antenna. The rather smaller scale is also beneficial in widening the whole band. Here, the 10-dB band of the antenna was 3.013–12.515 GHz, and the notch band was 5.235–5.848 GHz. The radiation patterns of the antennas with a notch slot all displayed results similar to those of dipole antennas. At the 5.5-GHz frequency, smaller gains were displayed compared with the other frequencies in each case because of band rejection, and the band-rejection characteristics could be clearly observed.

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