A Very Compact Ultrawideband Printed Omnidirectional Monopole Antenna

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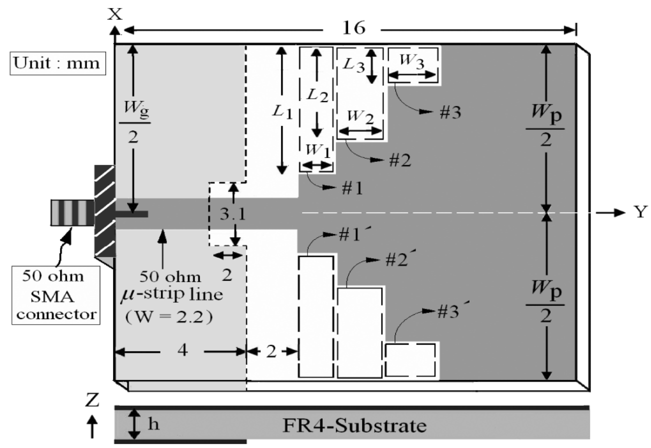
***Abstract*—A new form of the microstrip-fed monopole antenna with truncated ground plane is presented. In comparison to the previous monopole structures, the miniaturized antenna dimension is only about 11 $(0.11\lambda_r)\times$ 16 mm^2 $(0.17\lambda_r)$, where λ_r is the wavelength of the lowest frequency of the band (i.e., 3.2 GHz). By only sequentially inserting the three notches with proper sizes and positions in two corners of the quasi-square radiating patch, very good radiation and impedance characteristics are obtained. The measured impedance bandwidth of the realized antenna with optimal parameters is from 3.9 to 21.4 GHz (5.5:1, 138%) for VSWR <1.5. Moreover, unlike the conventional omnidirectional monopole antennas, the stability of the H-plane radiation patterns of the proposed antenna is maintained in omnidirectional form within the frequency bandwidth up to 16 GHz. The improvement process of the impedance and radiation properties is completely presented and discussed.**

***Index Terms*—Compact antenna, omnidirectional, printed monopole antenna, ultrawideband (UWB).**



$L_1 = 3.7$	$W_1 = 1$	$L_2 = 2.5$	$W_2 = 2$	$L_3 = 1$	$W_3 = 1.5$	$W_P = W_g = 11$

Fig. 1. Configuration of the proposed antenna with optimal parameters.

I. Introduction

FUTURE wireless communication systems, and ultrawideband (UWB) systems in particular, require antennas characterized by simple geometry, small size, and quasi-uniform radiation characteristics within the enhanced frequency band of interest. Among the newly proposed antenna designs, the printed monopole antennas are the most promising candidate for more improvement in the frequency bandwidth [1]–[5] and radiation properties [4], [5]. It was shown that by symmetrically etching two rectangular [1] and L-shaped slots [2] in the ground plane and using a hexagonal ground plane [5], the bandwidth of the antenna is increased. However, the uniform H-plane radiation patterns are only detected from 3 to 10 GHz. In [3], a new CPW-fed monopole antenna with a ratio bandwidth of 22.1:1 (0.4$\sim$8.86 GHz) was presented. However, its H-plane radiation patterns are completely nonuniform at 6 and 8 GHz, which is not suitable. The recently presented compact antenna in [4] is the only model of the printed monopole antennas that has stable H-plane radiation patterns at frequencies greater than 11 GHz up to 15 GHz.

In this letter, a new printed monopole antenna with very compact size and good impedance and radiation characteristics is presented. Here, we show that by sequentially embedding several pairs of rectangular notches in two corners of the radiation patch, the stability of the H-plane patterns is improved, especially at the higher frequencies between 11 and 17 GHz. Moreover, the bandwidth enhancement and matching improvement are noticeably obtained. In addition, the effect of width variation of the patch on the radiation performance, in comparison to the width of the ground plane, is finally analyzed.

II. Monopole Antenna Configuration and Design

Fig. 1 shows the geometry of the proposed small antenna, which consists of a simple rectangular patch with three pairs of notches, (1 and 1′), (2 and 2′) and (3 and 3′), illustrated by dash lines, with dimensions of $W_1 \times L_1$, $W_2 \times L_2$, and $W_3 \times L_3$, respectively. In a simple square patch without notches, there is a sharp and sudden discontinuity in the connection point between the microstrip-fed line and the patch, which may be a significant factor for lowering the bandwidth and degrading the radiation performance at the higher frequencies. By using these notches, we try to obtain a balance between the vertical and horizontal surface currents on the patch. Therefore, the more stable radiation patterns at the high frequencies may be achieved. Moreover, because of the existence of these sequential discontinuities on the patch, it is expected that several resonances will be generated. In this case, the total bandwidth of the antenna can be improved [6], [7]. The width of the patch is $W_{\rm P}$, which is equal to the width of the substrate and ground plane $(W_{\rm g})$ simultaneously. It will be shown that this equality is an important factor for having the stable radiation characteristics. The antenna is printed on an FR4 substrate with permittivity of 4.4 and compact dimension of $11\times 16\times 1$ mm^3 $(= {\rm h})$. The slotted ground

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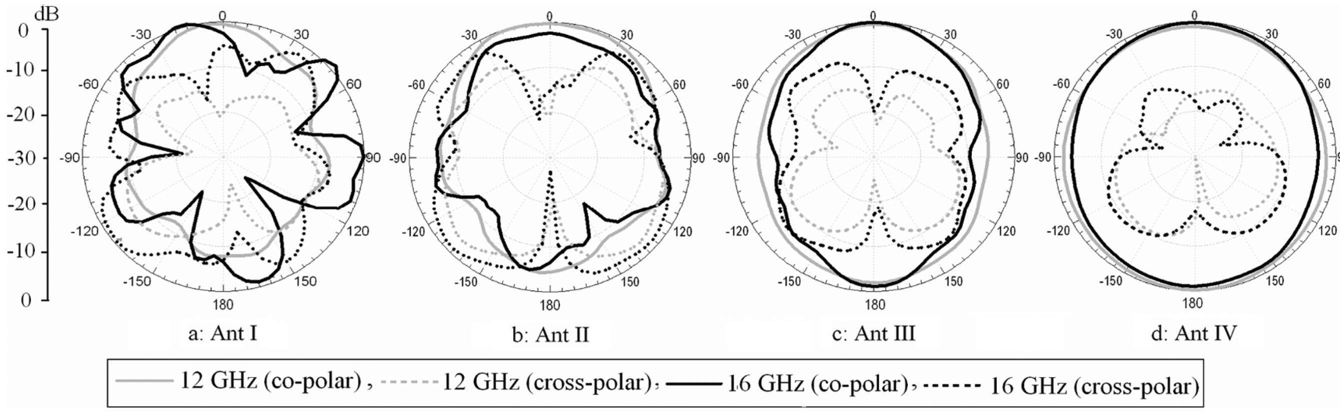

Fig. 2. Normalized H-plane patterns of the four antennas (I, II, III, and IV) at 12 and 16 GHz using optimal parameters mentioned in Fig. 1.

plane (Fig. 1) with a rectangular notch (2×3.1 mm^2) acts as an impedance matching element [6].

III. Simulated and Measured Results and Discussion

The proposed antenna structure is simulated using a High Frequency Structure Simulator (HFSS, ver. 11). During the simulation process, by adding various metal strips and blocks to the antenna structure, the effects of bad soldering and great SMA connector are considered. At first, for clarifying the improvement process, four different antennas are defined as follows: Ant I, without three pairs of notches (the quasi-square patch); Ant II, the square patch with only one pair of notches (1 and 1′); Ant III, the square patch with two pairs of notches (1 and 1′, and 2 and 2′); and Ant IV (the proposed antenna), with three pairs of notches (1 and 1′, 2 and 2′ and 3 and 3′, simultaneously). To analyze the antenna performance at the higher frequencies between 11 and 17 GHz, two sample frequencies, 12 and 16 GHz, are selected. The normalized H-plane patterns of the above-mentioned antennas, at 12 and 16 GHz, are presented in Fig. 2. It is clearly seen that by adding the notches into the patch structure (from Ant I to Ant IV), the stability of the H-plane radiation patterns is remarkably improved. We see in this figure that the proposed antenna (Ant IV) has uniform radiation pattern with low cross polarization at 12 and 16 GHz, simultaneously. In Ant IV, the maximum nonuniformity and the minimum difference between co- and cross components at 16 GHz are 3.9 and 9.1 dB, respectively, which are acceptable. To clarify the phenomenon behind this stability improvement of the H-plane patterns, the surface currents of two antennas (I and IV) at 16 GHz are shown in Fig. 3 for comparison. It is observed that the sharp and sudden discontinuity, detected in Ant I, is completely degraded in Ant IV. In this case, the sudden variation in surface currents at two corners of the patch that are the active areas in high frequencies is not seen. Moreover, to study of the impedance and matching characteristics, the simulated VSWRs of the four antennas are also plotted in Fig. 4. The enhancement of antenna bandwidth and improvement of the matching is completely noticeable. The bandwidths of four antennas (I, II, III, and IV) for VSWR <1.5 are 3.5, 6, 16, and 17.4 GHz, respectively. Finally, the expected improvements in the impedance and radiation characteristics are obtained. It must be mentioned that the effects of the dimension variation of the monopole antenna ground plane and one notch in the patch on the radiation and impedance characteristics are previously investigated [4]–[6].

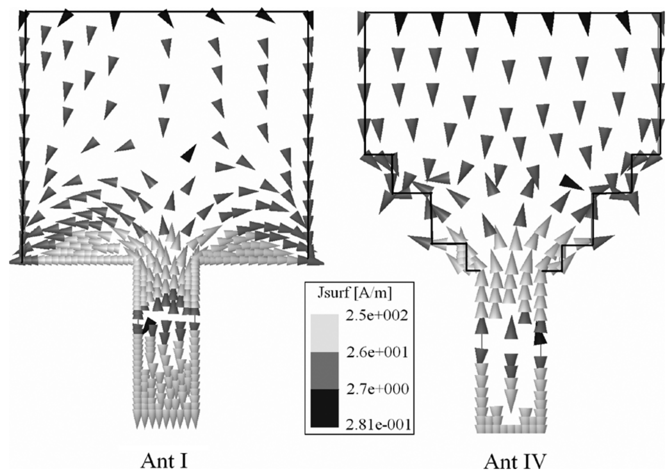

Fig. 3. Simulated surface currents for Ant I and IV at 16 GHz.

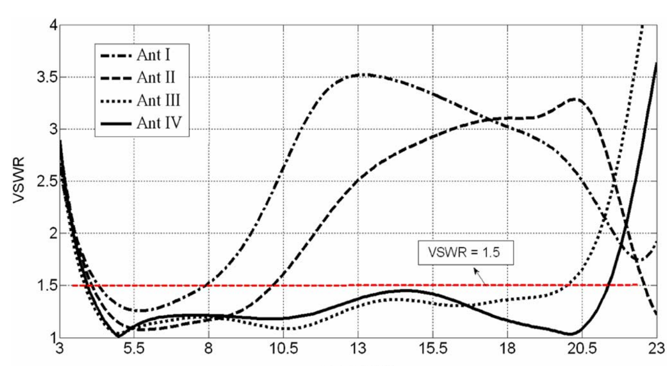

Fig. 4. Simulated VSWRs of the four antennas (I, II, III, and IV).

In this study, the other effective parameter is W_{P}, whose variation is analyzed when W_{g} is constant of about 11 mm. In this case, the lengths of L_1, L_2, and L_3 are constant and provided in Fig. 1. It is observed through HFSS simulations that by increasing W_{P} from 9 to 13 mm, the impedance and matching characteristics are improved, but the uniformity of the H-plane patterns and the cross-polarization components are degraded, especially at high frequencies between 11 and 17 GHz. Finally,

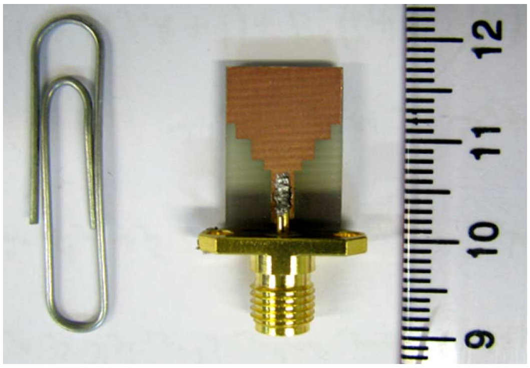

Fig. 5. Photograph of the realized compact monopole antenna.

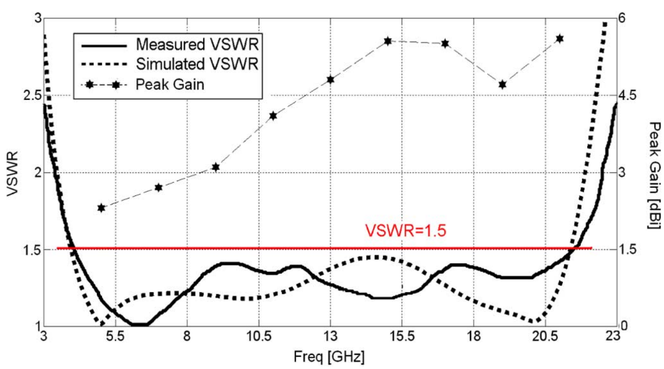

Fig. 6. Simulated and measured VSWR and measured peak gain of the proposed antenna (Ant IV).

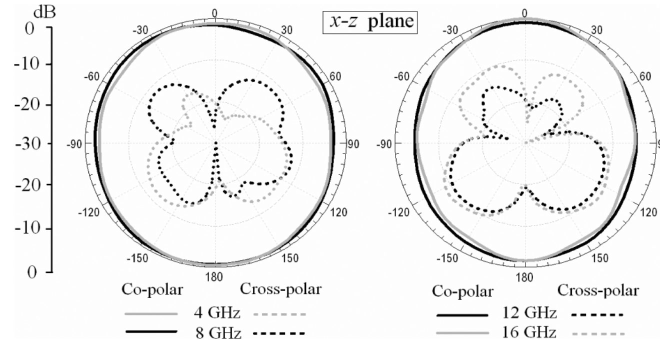

Fig. 7. Measured H-plane patterns of the antenna at 4, 8, 12, and 16 GHz.

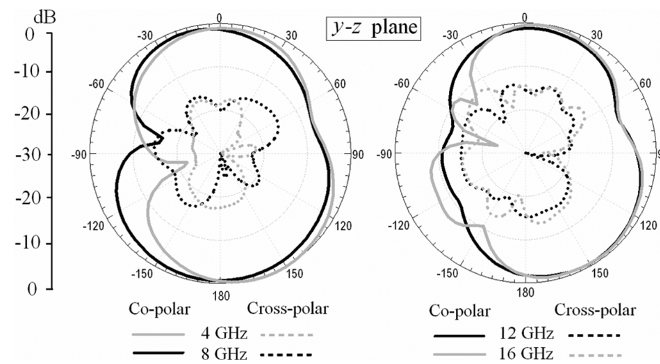

Fig. 8. Measured E-plane patterns of the antenna at 4, 8, 12, and 16 GHz.

it is discovered from simulations that for providing a tradeoff between stable radiation patterns and good impedance characteristics, the value of $W_{\rm P}$ should be equal with the width of the ground plane ($W_{\rm g} = 11$ mm).

The photograph of the realized very compact monopole antenna with its soldered SMA connector is shown in Fig. 5. The measured VSWR of the realized antenna is plotted in Fig. 6, where a very good agreement between the simulated and measured results is observed. In the simulated and measured VSWR graphs of the proposed antenna in Figs. 4 and 6, we recognize four different resonances, generated due to the existence of four serial discontinuities in direction of the microstrip-fed line. In the structure of Ant IV, there are four different and unequal coupling distances between the slotted patch and the ground plane that could help to improve the impedance and matching properties.

In addition, the measured peak gain of the antenna versus frequency is also shown in Fig. 6, from 4 to 22 GHz. We can see that the antenna gain is about 2.2–5.85 dBi at most frequencies of operation. Figs. 7 and 8 show the measured H- and E-plane radiation patterns of the antenna, respectively. The expected behaviors within the bandwidth are clearly detected, especially at 12 and 16 GHz.

It is also interesting to notice that the proposed antenna has an area of 176 mm^2 (11 mm $\times$ 16 mm), which is less than the area of the presented antenna (240 mm^2) in [4] with dimension of 8 mm $\times$ 30 mm. Moreover, unlike the proposed ground plane of the antenna in [4], the ground plane of the proposed structure has no limitation in shape and size.

IV. Conclusion

A novel printed monopole antenna with a very compact size was presented and investigated. We showed that by sequentially embedding three pairs of notches with the proper dimensions and positions in the square patch, very good impedance matching and improved bandwidth are obtained. The measured results illustrate that the proposed antenna offers a very wide bandwidth from 3.9 to 21.4 GHz for VSWR <1.5 and stably omnidirectional H-plane patterns up to 16 GHz. As a result, the proposed simple antenna can be very suitable for various applications of the future developed UWB systems.

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