A Miniature UWB Planar Monopole Antenna with 5 GHz Band-Rejection Filter

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Abstract — **A noble planar monopole antenna with a staircase shape and very small volume (25 × 26 × 1 mm^3) is proposed in this paper. With the use of a half-bowtie radiation element, the staircase-shape, and a modified ground plane structure, the proposed antenna has a very wide impedance bandwidth measured at about 11.6 GHz (2.9 GHz ~ 14.5 GHz, bandwidth ratio about 1:5) below VSWR 2 including the WLAN band notched in the vicinity of 5 GHz. An omni-directional radiation pattern is obtained. The electrical and physical characteristics of the proposed antenna make it attractive for use in ultrawide band systems.**

I. Introduction

Recently, the development of Ultra Wideband (UWB) antennas enabling high data transmission rates and low power consumption, and simple hardware configuration in communication applications such RFID devices, sensor networks, radar, and location tracking, have been in the spotlighted [1]-[3]. The UWB antennas of such systems are required for small size, non-dispersive and wideband properties. Its commercial usages of frequency band, from 3.1 GHz to 10.6 GHz, were approved by the Federal Communications Commission (FCC) in 2002 [4]. UWB antennas are also necessary for the rejection of an interference with existing wireless networking technologies such as IEEE 802.11a in the US (5.15 GHz - 5.35 GHz, 5.725 GHz - 5.825 GHz) and HIPERLAN/2 in Europe (5.15 GHz - 5.35 GHz, 5.47 GHz - 5.725 GHz) [5]. This is due to the fact that UWB transmitters should not cause any electro-magnetic interference on nearby communication system such as Wireless LAN (WLAN) applications. Therefore, UWB antennas with notched characteristics in WLAN frequency band are desired. The various types of UWB antennas, such as the planar volcano-smoke slot antenna, bowtie patch antenna, and the modified bowtie antenna with a triangular shape, have been developed for UWB systems. In particular, the planar patch antenna is extensively used in wireless communications because of its light weight, low cost, and ease of fabrication. It is well known, however, that its bandwidth is inherently narrow. Thus, many researches have been attempted to widen the bandwidth of the conventional printed antennas. Although the bowtie antenna is one of the promising techniques for UWB antenna systems [8], it is not sufficient to cover the UWB frequency band. Thus, various structures have been proposed to overcome the narrow bandwidth. Parasitic elements around the antenna bring about broad bandwidth operation, but increase the size of the antenna [7], [8]. Broadband performance can be obtained by using a monopole antenna with a modified bowtie shape.

In this paper, we propose a modified triangular (or half-bowtie shape) ultrawide band monopole antenna etched on a thin substrate with a staircase shape to achieve wide bandwidth. The bowtie antenna is modified to apply to UWB systems. One of the two opposite-sided triangles is cut and the edge of the remaining one is fed by a microstrip-line. This antenna is also applied to the impedance matching method which utilizes two slits near the feeding region and an extended ground plane on the bottom side of the antenna [9]. By utilizing the band-rejection filter with a U-shape in the radiation element, it eliminates the additional band pass filter in the system module and also prevents interference with WLAN systems.

II. Antenna Design and Performances

Fig. 1 shows the geometry of the proposed staircase-bowtie planar antenna. It consists of a triangular-shaped patch with the staircase to achieve broad bandwidth, a U-shaped slot which prevents interference with the WLAN band in the vicinity of 5 GHz on the top side of the proposed antenna, and a partial modified ground plane on its bottom side of it. Additionally, there are two slits near point ***A*** where the 50 Ω microstrip-line fed by the SMA connector is connected with a radiation element to enhance impedance matching. The total volume of this antenna is 25 × 26 × 1 mm^3 and it is printed on both the top (the radiation element and feeding line) and bottom face (the ground plane) of substrate FR-4 with a thickness of 1 mm and relative permittivity (ε_r) of 4.6. In Fig.1, the height (h) of the radiation patch was optimized to cover the low frequency of the UWB band. The greater the height, the wider the low frequency band in the vicinity of 3.1 GHz, a starting frequency of UWB antennas. However, we should consider both the small volume and the impedance bandwidth. Thus, the height is traded-off and determined with h = 18 mm. The staircase shape of the proposed antenna brings about many frequency resonances and achieves enhanced bandwidth as a result. Another technique to broaden the bandwidth is to adjust the length and width of the slit near the starting point of the radiation element, marked as ***A*** in Fig. 1. As shown in Fig. 2(a) and (b), the small changes of slit height (s_h) and width (s_w) have significant effects

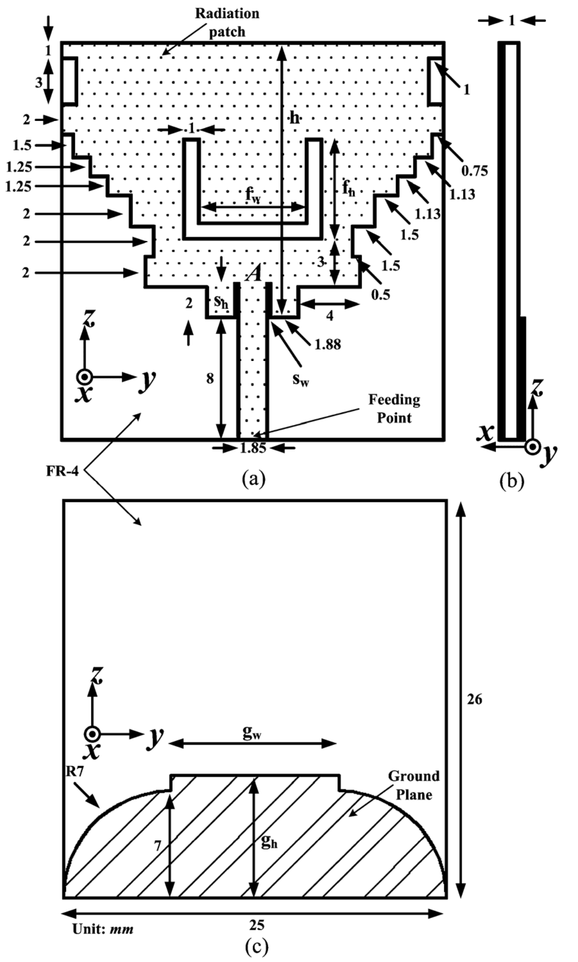

Fig. 1. Geometry of the proposed antenna
(a) Top view (b) Side view (c) Bottom view

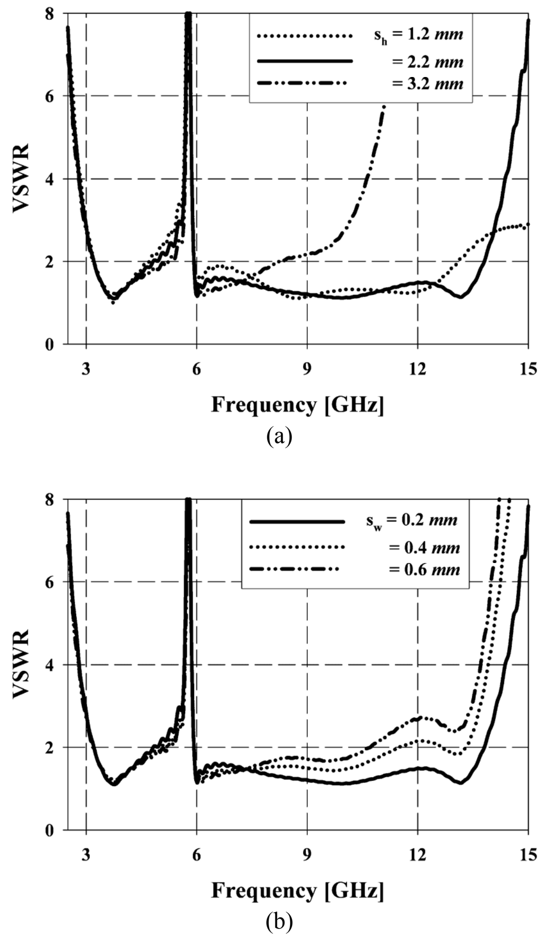

Fig. 2. Simulated VSWR as a result of the parameters of each slit
(a) Variations of s_h with a fixed value of s_w = 0.2 mm
(b) Variations of s_w with a fixed value of s_h = 2.2 mm

on the bandwidth of the proposed antenna. This is because stronger current distributions – more than any other region of the radiation element – exist in the vicinity of point ***A*** on the radiation element. Therefore, that region plays an important role in impedance matching. In other word, it is a sensitive part of the tuning region. The optimized value of s_h is selected as 2.2 mm, as shown in Fig. 2(a). On the other hand, the bandwidth is further widened when the slit width (s_w) is narrower, as shown in Fig. 2(b). Nevertheless, the slit width of s_w is determined at 0.2 mm due to the manufacturing tolerance. In Fig. 1(c), the modified ground plane is shown on the bottom side of the substrate. Both side edges of the ground plane were constructed in a circular shape which consists of a quadrant with a radius of 7 mm in order to reduce the beam tilting and to obtain wide bandwidth [10],[11]. The radiation pattern of the monopole antenna is not the same as that of the dipole antenna because it does not an infinite ground plane. The size of ground plane is finite in actual usage. The direction of maximum radiation tilts somewhat upwards from the horizontal plane due to the finite ground plane. To reduce this beam tilting, the ground plane of the proposed antenna is designed to have a circular shape rather than a rectangular shape. To achieve wider bandwidth, some upper part of the ground plane is extended [9]. As shown in Fig. 3(a), the small changes in the height of the extended ground plane (g_h) has an effect on the bandwidth of the proposed antenna. But the width changes have a negligible influence, as shown in Fig. 3(b). The reason is that the extended ground plane is located in the opposite side of the sensitive point where the current distribution is the strongest. As in the preceding explanation, the changes of height (g_h) of the extended ground plane have significant effects on impedance matching. Additionally, the extended ground plane reinforces capacitance. The reinforced capacitance that results from the extended ground plane cancels the inductance of the antenna [9]. However, the width variation of the extended ground plane does not affect the bandwidth quiet as much because although the width is wider, the geometry of its sensitive area is almost constant. The values of g_h and g_w are optimized at 8 mm and 11 mm, respectively. Fig. 4 shows that the U-shaped slot plays a role in the band-rejection filter. It is necessary to notch out portions of the band to avoid interference with existing wireless networking technologies such as IEEE 802.11a. The ability to provide this function in the antenna can relax the requirements imposed upon the filtering electronics within the wireless device. In Fig. 4 (a) and (b), there are similar variations of in each graph. This means that the resonant frequency of a notched band is determined by

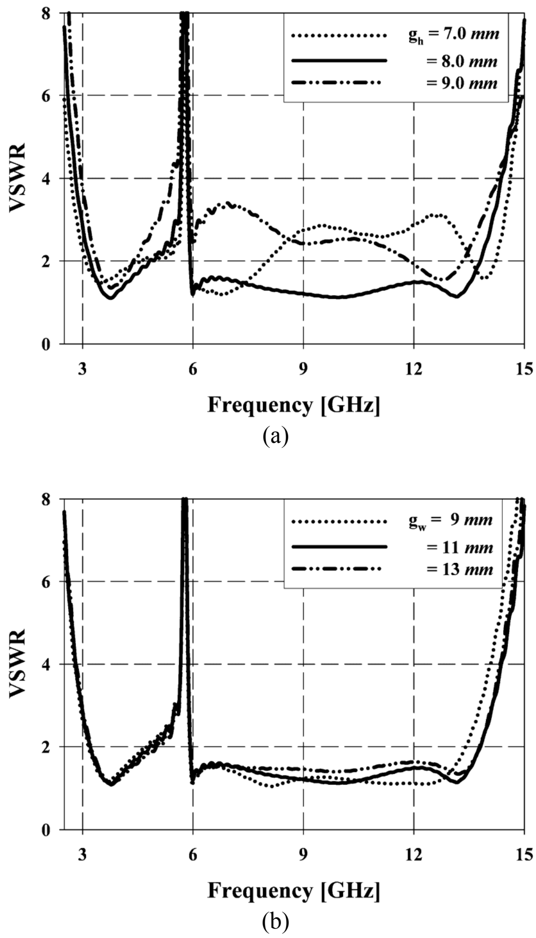

Fig. 3. Simulated VSWR as a result of the parameters of each extended ground plane
(a) Variations of g_h with a fixed value of g_w = 11 mm
(b) Variations of g_w with a fixed value of g_h = 8 mm

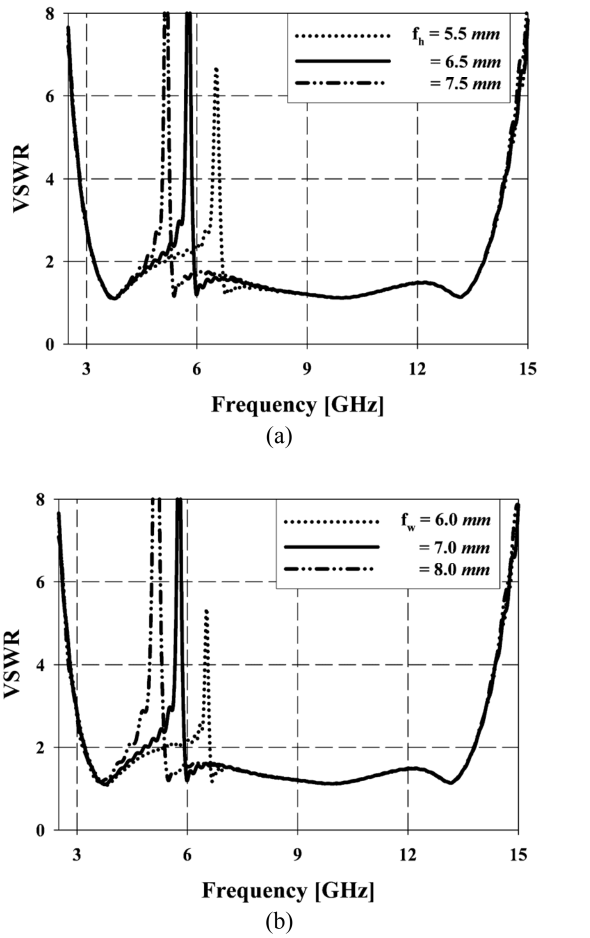

Fig. 4. Simulated VSWR as a result of the parameters of each inserted band-notched filter
(a) Variations of f_h with a fixed value of f_w = 7 mm
(b) Variations of f_w with a fixed value of f_h = 6.5 mm

the total length of the slot, not the geometry. The shorter the total length of the U-shaped slot, the higher the resonant frequency. The optimized values of f_h and f_w are 6.5 mm and 7 mm, respectively. To understand the behavior of the antenna model and obtain the optimum parameters, simulations were performed with the CST MWS (Microwave Studio) based on the Finite Integration Method. The optimized values of each physical dimension of the proposed antenna are shown in Fig. 1 and Table I.

III. RESULT

The measured and simulated VSWR values in terms of frequency are compared in Fig. 5. The measured impedance bandwidth (VSWR ≤ 2) is about 11.6 GHz starting from 2.9 GHz to 14.5 GHz including the notched bands of the IEEE 802.11a in the US and the HIPERLAN/2 in Europe, and its bandwidth ratio is about 1:5. Fig. 5 also shows the measured value without the U-shaped slot filter. When the slot is omitted, the notched band is removed. The notched bandwidth of a measured value is 860 MHz from 5 GHz to 5.86 GHz. The measured and simulated radiation patterns of the proposed antenna at 7 GHz are plotted in Fig. 6. The proposed antenna has an acceptable omni-directional radiation pattern. This shows that the measured and simulated results agree well with each other. Fig. 7 shows the measured maximum gain of the proposed antenna with and without a U-shaped slot filter. A sharp decrease of maximum antenna gain in the notched frequency band at 5.5GHz is shown. For other frequencies outside the notched frequency band, the antenna gain with a filter is similar to those without it. All measured results are performed with an Agilent 8510C network analyzer.

h	18
s_h	2.2
s_w	0.2
g_h	8
g_w	11
f_h	6.5
f_w	7

Unit: mm

TABLE I
OPTIMIZED VALUE OF EACH PARAMETER

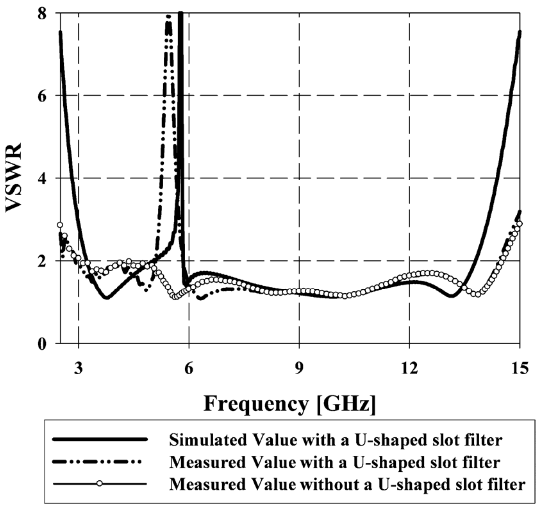

Fig. 5. Measured and simulated results of VSWR

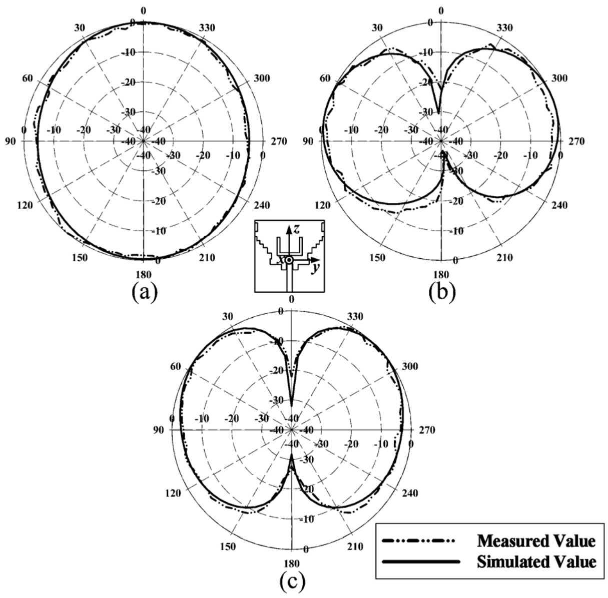

Fig. 6. Measured and simulated radiation patterns for the proposed antenna at 7 GHz.
(a) *x-y* plane. (b) *x-z* plane. (c) *y-z* plane.

IV. CONCLUSION

A planar monopole triangular (or half-bowtie shape) antenna with a staircase shape and a band-rejection filter is proposed. In this paper, we investigated the tuning parameters affected by antenna performances. The area near point ***A*** where current distributions are strong is a sensitive part of the tuning point. Capacitance and inductance can be easily controlled by the extended ground plane and two slits in the vicinity of point ***A***, respectively. By adjusting them, a wide impedance bandwidth can be achieved. Additionally, the staircase shape also helps to enhance impedance bandwidth. The total length of the U-shaped filter determines the center frequency of the notched WLAN band. The proposed antenna has attractive features such as very small volume, wide impedance bandwidth, WLAN band rejection, omni-directional radiation pattern, and reasonable gain.

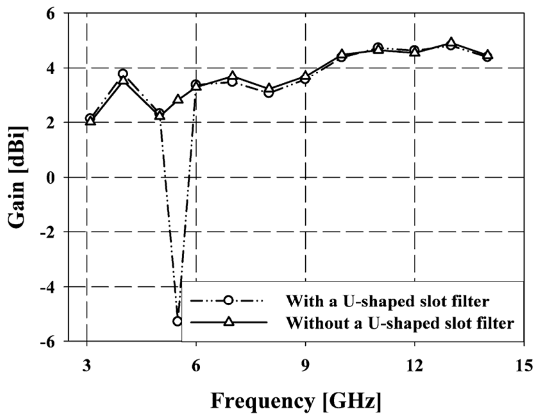

Fig. 7. Measured gains of the antennas with and without the U-shaped slot filter

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