This paper describes an ultra-wideband (UWB) antenna that uses a ring resonator concept. The proposed antenna can operate in the entire UWB, and the IEEE 802.11a frequency band can be rejected by inserting a notch stub into the ring resonator. The experiment results indicate that the measured impedance bandwidth of the proposed antenna is 17.5 GHz (2.5 GHz to at least 20 GHz). The proposed UWB antenna has omnidirectional radiation patterns with a gain variation of 3 dBi (1 dBi to 4 dBi).

Keywords: UWB system, ring resonator, group delay, MB-OFDM, DS-CDMA.

I. Introduction

Ultra-wideband (UWB) systems were assigned 7.5 GHz of spectrum for unlicensed use by the FCC (Federal Communications Commission) in 2002 for indoor communication applications in the 3.1 GHz to 10.6 GHz frequency band [1]. For the desired antenna in UWB communication, the antenna pattern must be omnidirectional regarding the UWB frequency, and the change of the phase must be small. There are two main approaches to resolve this in the IEEE 802.15.3a standard: multiband orthogonal frequency division multiplexing (MB-OFDM) and direct-sequence code division multiple access (DS-CDMA). DS-CDMA uses three spectral modes of operation: a low band mode at 3.1 GHz to 5.15 GHz, a high band mode at 5.825 GHz to 10.6 GHz, and a multiband mode. MB-OFDM divides its full band of 3.1 GHz to 10.6 GHz into 14 subbands, each with a bandwidth of 528 MHz. Each subband is composed of 128 tones and is modulated using OFDM. MB-OFDM uses the lower three bands (3.1 GHz to 4.8 GHz) as a mandatory mode [2]. Many researchers have developed MB-OFDM systems at over 3.1 GHz to 4.8 GHz or that use a low DS-CDMA band, such as a compact UWB chip antenna design that uses the coupling concept [3], a compact filter-combined UWB antenna for UWB applications [4], a UWB monopole antenna using parasitic open loops [5], and a compact UWB antenna with a pi-shaped matching stub [6]. The UWB frequency band includes the IEEE 802.11a frequency band. UWB communication applications may generate interference with IEEE 802.11a. Various UWB antennas [7]-[11] and UWB notch antennas [12]-[22] were recently developed for UWB systems. The frequency-band-rejected UWB antennas were realized using ring resonators [23]-[25].
and quadruple [24] band notches were achieved by vertically aligning three and four ring resonators on multilayered planes, respectively. Such an antenna has the advantage of having a multinotch band, but the drawback is that the fabrication of the antenna can be complicated. As was recently reported, using a split ring resonator (SRR) may be particularly helpful in improving the band notch characteristic of a UWB antenna, such as a 5.2-GHz notched UWB antenna using a slot-type SRR [26], a CPW-fed UWB antenna with a triple-band notch function [27], and a dual band notched UWB antenna using complementary split ring resonators [28]. For UWB antennas using an SRR, the split ring resonator is attached to the side or bottom plane of the antenna. Consequently, the size of the antenna is enlarged and the antenna structure is complicated.

In this paper, a UWB antenna using a ring resonator is proposed. The proposed antenna satisfies the entire UWB frequency band (2.5 GHz to at least 20 GHz). We obtain a bandwidth enhancement of the UWB antenna by using a ring resonator and partial ground plane. The notch stub is added inside the ring resonator, the IEEE 802.11a frequency band is removed, and the antenna is miniaturized. The measured antenna gain varies from 1 dBi to 4 dBi over the operating frequency range. The measured group delay variation is less than 2 ns.

II. UWB Antenna Design and Experiment Result

Figure 1 shows the geometry of the UWB antenna that uses a ring resonator. The proposed antenna is 45 mm × 35 mm in size, and an FR-4 substrate (thickness = 1.6 mm, permittivity = 4.5) is used.

The proposed UWB antenna consists of a ring resonator, a matching stub, and a notch stub. The antenna is excited using a 50-Ω feed line. The optimal parameters can be chosen as shown in Table 1.

The approximate relation between the operating frequency and ring resonator radius can be expressed using (1).

\[ e^{j \beta \alpha} = e^{j \frac{2 \pi r}{\lambda_{g}}}, \quad n = 1, 2, 3, \ldots \]

For the periodicity,

\[ \beta a = \frac{2 \pi r}{\lambda_{g}} = \frac{2 \pi r \sqrt{\varepsilon_{r}} f_{0}}{c} = n \]

\[ f_{0} = \frac{nc}{2 \pi r \sqrt{\varepsilon_{r}}}; \quad n = 1, 2, 3, \ldots \]

(1)

where \( \lambda_{g} \) is the wavelength of the operating frequency, \( r \) is the ring resonator radius, \( f_{0} \) is the resonant frequency, \( c \) is the speed of light in free space, \( n \) is the mode number, and \( \varepsilon_{r} \) is the relative permittivity of the dielectric substrate.

A numerical analysis conducted using Ansys HFSS and the experiment results are presented. To obtain the wideband characteristic, the proposed antenna uses a partial ground plane [8] and the radiator uses a ring resonator. The matching stub is added to the top of the ring resonator for the impedance matching of the antenna.
The proposed antenna is measured using an Agilent Network Analyzer (E8362B) in an anechoic chamber. The measured and simulated voltage standing wave ratios (VSWRs) of the designed antenna are shown in Fig. 2. As shown in Fig. 2(a), the UWB antenna without a notch stub can cover the entire UWB from 2.5 GHz to at least 20 GHz below VSWR 2:1. Agreement between the simulation and measurement is achieved. By inserting a notch stub, the frequency band reject function is obtained. The frequency band rejection feature of the proposed antenna is designed experimentally. Different prototypes, each with a notch stub of a different length ($N_L$), are fabricated and measured. As shown in Fig. 2(b), by controlling the length of $N_L$, the desired notch characteristic at the target band (5.15 GHz to 5.825 GHz) can be obtained.

We study the effects of the matching stub on the return loss. Figure 3 shows the simulation with and without a matching stub. As shown in the figure, without a matching stub, the return loss level increases and the antenna impedance becomes poor around 8 GHz. The use of a matching stub results in improved impedance matching.

Figure 4 shows the simulated return losses as a parameter of the ground plane size. The length of the ground plane is one of the important factors that affect broadband and impedance matching characteristics, so it is important to detect the optimum length in the antenna design. As shown in the figure, for 26 mm and 27 mm, desirable performance is achieved in the entire UWB frequency, but $G_L = 27$ mm is the outstanding matching characteristic in this design.

The surface current distribution at 3 GHz, 5.5 GHz, 6 GHz, 9 GHz, 12 GHz, 15 GHz, and 18 GHz is simulated using Microwave Studio, as represented in Fig. 5(a) through 5(g), respectively. The surface current distribution is relatively constant at all frequencies except 5.5 GHz. We therefore conclude that the patterns produced at these seven frequencies will be comparable to one another, as conventional planar monopole antennas behave similarly. However, the surface current distribution around the inside ring resonator and notch stub increase drastically at 5.5 GHz, which implies that the
Fig. 5. Surface current distribution at seven different frequencies: (a) 3 GHz, (b) 5.5 GHz, (c) 6 GHz, (d) 9 GHz, (e) 12 GHz, (f) 15 GHz, and (g) 18 GHz.

The notch stub operates at near 5.5 GHz. According to both the measured VSWR and the simulated surface current distribution, it is clear that the notch stub \( (N_L) \) introduces the frequency band rejection function.

The radiation patterns at the \( xz \)-plane (E-plane) and \( yz \)-plane (H-plane) are measured at 3 GHz, 6 GHz, 9 GHz, 12 GHz, 15 GHz, and 18 GHz and are described in Figs. 6(a) through 6(l), respectively. The radiation patterns are similar with those of a dipole antenna in the E-plane and an omnidirectional antenna in the H-plane. All radiation patterns are comparatively constant over the entire operating UWB frequency range, as expected from the simulated current distribution, shown in Fig. 5. The E-plane radiation patterns at 5.5 GHz (rejected frequency band) for an antenna with and without a notch stub are then measured and compared. As shown in Fig. 7, the radiation pattern at the central notched frequency is considerably distorted due to the sharply increasing current distribution near the notch stub. The antenna gain at 5.5 GHz is observed to be reduced to about 20 dB lower.

Figure 8 shows the measured antenna peak gain of the proposed antenna versus the frequency. The antenna peak gain variation in the full band (3 GHz to 18 GHz) is 3 dBi. The antenna peak gain varies from 1 dBi to 4 dBi over the operating frequency range, whereas at the rejected band, the antenna gain is reduced to \(-6\) dBi minimum, owing to the frequency rejection function.

The group delay, which signifies the pulse distortion, is an important factor in a UWB antenna design. To estimate the dispersion characteristic of the designed UWB antenna, the group delay and pulse distortion are measured. For the measurement setup, the distance between the transmitting and receiving antenna is 30 cm, and the antenna axis is face to face. We measure the group delay using a vector network analyzer in an anechoic chamber.

Figure 9 shows the measured group delay for an antenna with \( (N_L = 6.4 \text{ mm}) \) and a without notch stub. As shown in the figure, the group delay variation is less than 2 ns in the case of a UWB antenna without a notch stub. When a UWB antenna with a notch stub is used, the group delay variation is suddenly increased at the rejected frequency band \( (f_{\text{notch}}=5.5 \text{ GHz}) \).

III. Experiment Results of Proposed Antenna in Time Domain

The essential factor of a high-quality UWB antenna is minimal pulse distortion. The pulse performance of the proposed antenna is measured in an anechoic chamber. The measurement setup for measuring the pulse feature of the UWB antenna is shown in Fig. 10. As shown in the figure, the transmitting antenna is connected to the pulse generator (PulsOn200TM). The receiving antenna is connected to a digital storage oscilloscope (TDS6604). A digital oscilloscope has a 20-GS/s sampling rate and 6-GHz bandwidth [29]. The antennas are separated by a distance of \( R \), and the antenna orientation is face to face. The distance between the antennas is based on the far field conditions \( (R=30 \text{ cm}) \).

Figure 11 shows the source signal of the pulse generator. The source signal is a monocycle Gaussian pulse having a 600-ps pulse width and magnitude of \( V_{pp} = 2 \text{ V} \).

\[
f(t) = \sin\left[2\pi f_c (t - 1)e^{-\frac{(t-1)^2}{\alpha}}\right],
\]

where \( f_c \) is the center frequency, and \( \alpha \) is the pulse parameter \( (\alpha = 600 \text{ ps}) \).

The proposed antenna is featured at different directions of the receiving antenna. The receiving antenna is positioned at the
Fig. 6. Measured radiation patterns of E- and H-planes: (a) E-plane at 3 GHz, (b) E-plane at 6 GHz, (c) E-plane at 9 GHz, (d) E-plane at 12 GHz, (e) E-plane at 15 GHz, (f) E-plane at 18 GHz, (g) H-plane at 3 GHz, (h) H-plane at 6 GHz, (i) H-plane at 9 GHz, (j) H-plane at 12 GHz, (k) H-plane at 15 GHz, (l) and H-plane at 18 GHz.
following azimuths and $\theta$ is fixed: $\Phi = 0^\circ$, $\Phi = 30^\circ$, $\Phi = 60^\circ$, $\Phi = 90^\circ$, $\Phi = 120^\circ$, $\Phi = 150^\circ$, and $\Phi = 180^\circ$.

Figure 12 shows the received signal from the proposed antenna as a function of $\Phi$. The received signals as a function of $\Phi$ are alike in the source signal and are attenuated at approximately 1/40 (250 mV) in amplitude for all cases. The received signals show a negligible chirp and rarely a reflected signal.

All the results for the pulse duration, pulse type, and peak amplitude for different antenna structures are summarized in Table 2. The shortest pulse is obtained by the biconical antenna. The most efficient transmission and overall best performance are achieved by the TEM horn antenna. However, in spite of its small size and patch type, the proposed antenna obtains the second best pulse characteristic. The pulse duration result shows that a dispersion characteristic is not generated.

IV. Conclusion

A UWB antenna using a ring resonator was proposed. The proposed antenna satisfies the UWB frequency band (2.5 GHz to at least 20 GHz). We obtained a bandwidth enhancement of the UWB antenna using a ring resonator and partial ground plane. The notch stub was added inside the ring resonator, the IEEE 802.11a frequency band was removed, and the antenna was miniaturized. The antenna gain varied from 1 dBi to 4 dBi over the operating frequency range. The measured group delay
Fig. 12. Received signal of proposed antenna as function of azimuth angle $\Phi$: (a) $\Phi = 0^\circ$, (b) $\Phi = 30^\circ$, (c) $\Phi = 60^\circ$, (d) $\Phi = 90^\circ$, (e) $\Phi = 120^\circ$, (f) $\Phi = 150^\circ$, and (g) $\Phi = 180^\circ$. 
variation was less than 2 ns. The pulse features were simulated and measured as a function of the azimuth angle, \( \Phi \). The measured and simulated results indicate that the proposed ring resonator UWB antenna has a negligible chirp and a small dispersion and can be used in UWB applications.

### References


### Table 2. Comparison of UWB antennas [30].

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Pulse duration (ns)</th>
<th>Pulse type</th>
<th>Peak received amplitude (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vivaldi</td>
<td>0.50</td>
<td>Damped sinusoid</td>
<td>19.0</td>
</tr>
<tr>
<td>Ridged TEM horn</td>
<td>2.74</td>
<td>Damped sinusoid</td>
<td>24.0</td>
</tr>
<tr>
<td>TEM horn</td>
<td>0.40</td>
<td>Damped sinusoid</td>
<td>63.0</td>
</tr>
<tr>
<td>Biconical antenna</td>
<td>0.20</td>
<td>Damped sinusoid</td>
<td>9.5</td>
</tr>
<tr>
<td>LPTTA</td>
<td>11.00</td>
<td>Chirp</td>
<td>5.0</td>
</tr>
<tr>
<td>CBAS</td>
<td>13.50</td>
<td>Chirp</td>
<td>1.1</td>
</tr>
<tr>
<td>Monopole (5 GHz)</td>
<td>1.00</td>
<td>Damped sinusoid</td>
<td>1.5</td>
</tr>
<tr>
<td>Monopole (1.1 GHz)</td>
<td>5.00</td>
<td>Damped sinusoid</td>
<td>2.4</td>
</tr>
<tr>
<td>Proposed antenna</td>
<td>0.60</td>
<td>Damped sinusoid</td>
<td>25.0</td>
</tr>
</tbody>
</table>

1082 Jung-Nam Lee et al. ETRI Journal, Volume 35, Number 6, December 2013 http://dx.doi.org/10.4218/etrij.13.0113.0472


Jung-Nam Lee received his B.S. and M.S. degrees from the Department of Information and Communication Engineering, Hanbat National University, Daejeon, Rep. of Korea, in 2004 and 2006, respectively. He received his Ph.D. in radio wave engineering from Hanbat National University, Daejeon, Rep. of Korea, in 2010. He thereafter joined the Mobile RF Research Team of ETRI, where he is currently a senior member of the engineering staff. His research interests are small antennas, RFID antennas, UWB antennas, and small base station antenna design.

Heon-Kook Kwon received his BS and MS in electronics engineering from Chungnam National University, Daejeon, Rep of Korea, in 1997 and 1999, respectively. From 1999 to 2004, he worked as a researcher for Mobens Inc., Daejeon, Rep. of Korea, where he developed RF systems of testing and measuring for mobile communication. In 2004, he joined ETRI, Daejeon, Rep. of Korea, and is currently with the Mobile RF Research Department as a senior researcher. His current research includes RF system design for mobile communication, such as the RF system of mobile stations and base stations.

Byung-Su Kang received his BS and MS degrees in electronics engineering from Kyungpook National University (KNU), Daegu, Rep. of Korea, in 1997 and 1999, respectively. Since 1999, he has been with the Mobile RF Research Team at ETRI. His main research field is RF device and system design for mobile communication systems.

Kwang-Chun Lee received his BS and MS degrees in electronics engineering from Chung-Ang University, Rep. of Korea, in 1986 and 1988, respectively. He received his PhD degree in information and communication engineering from Chungbuk National University, Rep. of Korea, in 2013. Since 1988, he has been with ETRI. His main research interests include high efficiency power amplifiers and RF technologies for mobile communication system design.