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A Study of Unidirectional UWB Array Antenna using Leaf-Shaped Bowtie Elements and a Flat Reflector

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1. Introduction

Ultra-wideband (UWB) radio technology has attracted much attention for wireless communication and other applications. Since the FCC announced its decision to allow the unlicensed use of the bandwidth of 3.1 to 10.6 GHz [1], many UWB antennas have been studied [2]– [4]. Most of these antennas have omnidirectional radiation patterns and the gains of these antennas are relatively low, approximately 0–3 dBi. The disadvantage of using omnidirectional antennas is that the antenna performance can be degraded by adjacent walls or metals. If unidirectional UWB antennas are utilized, the degradation on the antenna performance due to omnidirectionality can be avoided. In addition, higher speed and lower power consumption communication system can be realized because of the directivity. Therefore, the development of UWB antenna having unidirectional radiation characteristics and high-directivity is highly desirable.

The authors have recently proposed a unidirectional UWB antenna using leaf-shaped bowtie elements [5], [6]. In this paper, we propose a 4-element UWB array antenna using leaf-shaped bowtie elements, which has unidirectional radiation characteristics and higher-directivity. The reflection coefficient, and far field radiation patterns of this antenna are presented. Furthermore, the waveform distortions caused by the proposed antenna are evaluated by calculating cross-correlation coefficient between source and received pulses.

2. Antenna Design

Fig.1 shows the proposed antenna configuration. Parameters of the antenna are given in Table 1. Four pairs of leaf-shaped bowtie elements are arranged on upper and lower surfaces of a dielectric substrate with a thickness of $h = 0.762$ mm, a dielectric constant of $\varepsilon_r = 2.17$, and a loss tangent ($\tan\delta$) of 0.0009. In order to realize unidirectional radiation characteristics, an aluminum plate having a thickness of 0.5 mm is used as a reflector. The leaf-shaped radiating element is designed by rounding the corner of the square copper sheet. The curvature radius is set to 7.1 mm. The element size L_e is set to 12 mm. These values are optimized for operating in the UWB frequency band when a reflector is not attached [4]. The separation between the antenna and the reflector (d) and the element spacing (S) are set to 9 mm and 18 mm, respectively, because the widest −3 dB gain bandwidth was obtained at $d = 9$ mm and $S = 18$ mm. The −3 dB gain bandwidth is defined as the relative bandwidth between the two frequencies at which the antenna gain degrades by 3 dB from the maximum gain. The leaf-shaped radiating elements are excited by a tapered microstrip line and a two-stage microstrip line T-junction. The remaining parameters of the antenna are shown in Table 1.

3. Numerical and Experimental Results

The measured reflection coefficients (S_{11}) of the 4-element leaf-shaped bowtie antenna are illustrated in Fig.2. The reflection is almost less than −10 dB and the measured results and the calculation results are in good agreement.

The actual gain evaluated in the maximum radiation direction (y-direction) as a function of frequency are plotted in Fig.2. Although the frequency interval of the calculated results is 1 GHz, The measured

ISBN: 978-4-88552-223-9 C3055©IEICE

results coincide with the calculated results. The −3dB gain bandwidth is 91% (from 4.1GHz to 11.0GHz) and the maximum gain is 13.3 dBi at 5.72 GHz in the measured results.

The radiation patterns in the H-plane (xy-plane) were measured. Some of these results are shown in Fig.3. As can be seen from these figures, unidirectional radiation patterns are obtained from 4.0 to 11.0 GHz. The half power beam width is 45°, 35°, 30°, 29°, 23°, 23°, 21°, and 24° in ascending order by the frequency. The maximum sidelobe levels are −21 dBi, −6.5 dBi, 1.2 dBi, −2.8 dBi, 4.0 dBi, 1.8 dBi, 2.1 dBi, and 3.1 dBi in ascending order by the frequency.

The measured transmission loss and group delay are plotted in Fig.5. These values are observed when the directions of the transmitting and receiving antenna are fixed at the maximum radiation direction ($\phi_{\mathrm{TX}} = \phi_{\mathrm{RX}} = 90°$). The transmission loss is from −36 up to −25 dB at frequencies of 3.0–11.0 GHz. The group delay is within a band of 6.3–6.7 ns over the frequency range of 3.0 to 9.8 GHz.

For evaluating waveform distortions caused by the antenna, we calculate the cross-correlation coefficient between source and received pulses. We employed a modulated cosine roll-off pulse as a source pulse $s(t)$, which is defined as:

$$s(t) = \frac{\sin(\pi Bt)}{\pi Bt} \cdot \frac{\cos(\alpha\pi Bt)}{1 - (2\alpha Bt)^2} \cdot \cos(2\pi f_c t) \tag{1}$$

where α is the roll-off factor, B is the pulse bandwidth, and f_c is the frequency of the modulating wave. In this report, we select the values of $\alpha = 0.25$, $B = 7.5$ GHz, and $f_c = 6.85$ GHz.

Calculated correlation coefficients and received energies are shown in Fig.6. In the evaluation, the total energy of the source pulse is normalized to 1 J. The maximum received energy of the proposed antenna is 161 μJ at $\phi = 95°$ and the half-power beam width is approximately 30°. The correlation coefficients of the antenna are 0.83–0.87 in the range of $\phi = 80°$ to $\phi = 110°$. Therefore, the waveform distortion caused by the proposed antenna is relatively small within the HPBW.

4. Conclusion

In this paper, we have proposed a unidirectional 4-element UWB array antenna using leaf-shaped bowtie elements and a flat reflector. The antenna characteristics are investigated by FDTD analysis and measurements. The proposed antenna has the actual gain of 10.3 to 13.3 dBi at the maximum radiation direction over the frequency bandwidth of 4.1 to 11.0 GHz (the −3 dB gain bandwidth is 91%). The radiation patterns are unidirectional in the frequency range of 4.0 to 11.0 GHz. Furthermore, from the measured results of transmission characteristics, the fluctuations of group delay of the proposed antenna are small. The correlation coefficient, which is a measure of the degree of the waveform distortions, is between 0.83 and 0.87 in the HPBW. Therefore, the waveform distortion caused by this antenna is relatively small. From these results, it is confirmed that the proposed antenna is useful for impulse-based UWB communication systems.

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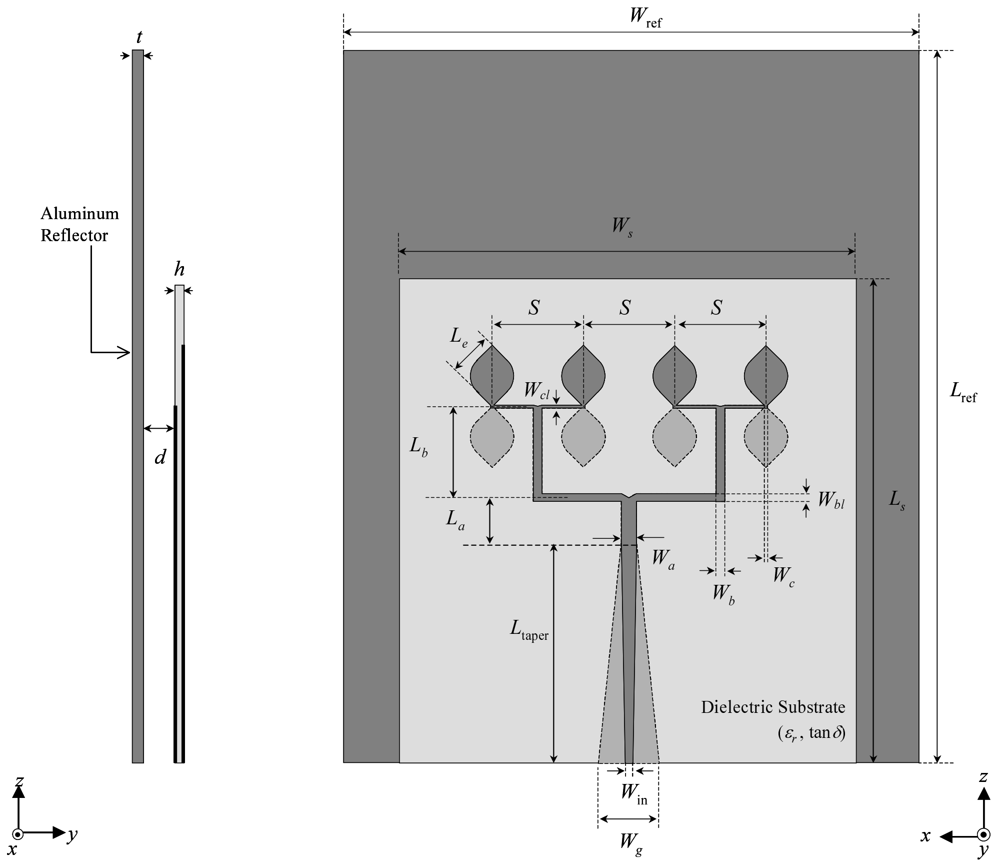

(a) Side View (b) Top View

Figure 1: Antenna geometry and coordinate system.

Table 1: Antenna parameters.

W_{ref}[mm]	L_{ref}[mm]	t[mm]	h[mm]	ε_r	$\tan\delta$	W_s[mm]
160	180	0.5	0.762	2.17	0.0009	120

L_s[mm]	S[mm]	d[mm]	L_e[mm]	W_{in}[mm]	W_g[mm]	L_{taper}[mm]
130	18	9.0	12	2.4	12	50

L_a[mm]	L_b[mm]	W_a[mm]	W_b[mm]	W_{bl}[mm]	W_c[mm]	W_{cl}[mm]
20	20	3.0	1.2	1.2	0.3	0.3

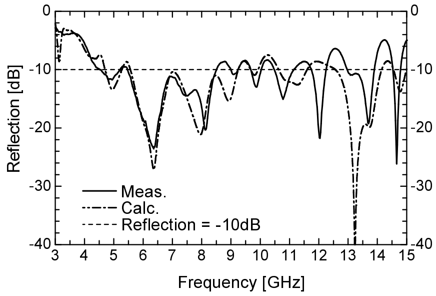

Figure 2: Frequency response of reflection coefficients

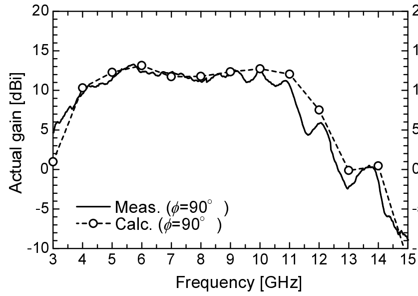

Figure 3: Frequency response of actual gain (*y*-direction).

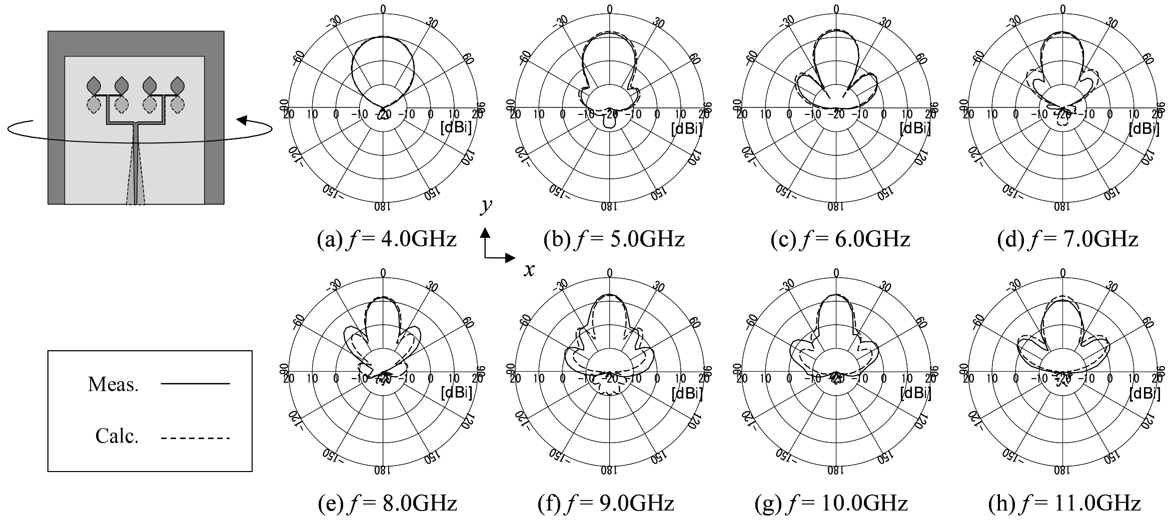

Figure 4: Radiation patterns in H-plane (*xy*-plane).

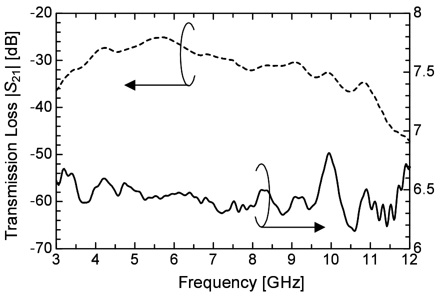

Figure 5: Measured transmission loss and group delay at $\phi_{\mathrm{TX}} = \phi_{\mathrm{RX}} = 90°$.

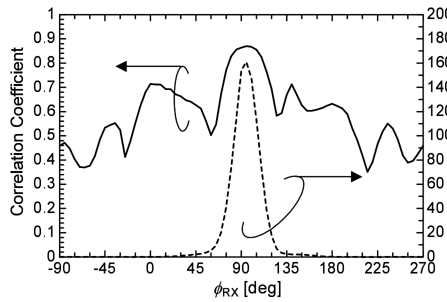

Figure 6: Correlation coefficient and received energy versus azimuthal angle.