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Experimental Study on 2-Element UWB Array Antenna using Leaf-Shaped Bowtie Element

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1. Introduction

Recently, Ultra-wideband (UWB) communication systems have attracted considerable attention. Since the FCC granted permission for unlicensed use of the bandwidth of 3.1 to 10.6 GHz [1], many UWB antennas have been reported [2]– [4]. These antennas have omnidirectional radiation patterns and low directivity, approximately 0–3 dBi. The disadvantage of using omnidirectional antennas is the performance degradation caused by adjacent walls or metals. If unidirectional UWB antennas are used, 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 and a reflector [5]. The gains of this antenna are 5.2–8.2 dBi in the frequency range of 4.2–10.2 GHz. In this paper, we propose a 2-element UWB array antenna using leaf-shaped bowtie elements and a reflector, which has unidirectional radiation characteristics and higher-directivity. In addition, the effects of arraying elements are investigated by comparing a 1-element leaf-shaped bowtie antenna with the proposed 2-element array antenna. Furthermore, the waveform distortions caused by this antenna are evaluated by calculating cross-correlation coefficient between source and received pulses.

2. Antenna Configuration

The antenna geometry and the parameters of the proposed antenna are shown in Fig. 1 and Table 1, respectively. Two pairs of leaf-shaped bowtie elements are arranged on upper and lower surfaces of a dielectric substrate with thickness $h = 0.762$ mm, dielectric constant $\varepsilon_r = 2.17$, and $\tan\delta = 0.0009$. In order to realize unidirectional radiation characteristics, an aluminum plate having a thickness of 0.5 mm is used as a reflector. For simplicity, the reflector shape and the substrate shape are square ($W_{\mathrm{ref}} = L_{\mathrm{ref}}$, $W_s = L_s$). The leaf-shaped radiating element is designed by rounding the corner of the square copper sheet. The curvature radius of the rounded corner R_s 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 leaf-shaped radiating elements are excited by a tapered microstrip line and a microstrip line T-junction. The reflector dimensions are set to 300 mm ×300 mm in order to minimize the influence of diffracted waves from the reflector edges. 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 remaining parameters of the antenna are shown in Table 1.

3. Simulation and Experimental Results

The measured reflection coefficients (S_{11}) of the 2-element leaf-shaped bowtie antenna are illustrated in Fig.2. For comparison purposes, the reflection coefficients of a 1-element leaf-shaped bowtie antenna are also shown in this figure. The reflector dimensions ($W_{\mathrm{ref}}, L_{\mathrm{ref}}$) and the separation ($d$) of the

ISBN: 978-4-88552-223-9 C3055©IEICE

1-element antenna are the same values as those of the proposed 2-element array antenna. As shown in this figure, the reflection of the 2-element array antenna is less than −10 dB in the frequency range of 5.0 to 13.4 GHz. On the other hand, the frequency range where the reflection is less than −10 dB is 5.7 to 13.3 GHz for the 1-element antenna. Consequently, the −10 dB reflection bandwidth of the 2-element array antenna is wider than that of the 1-element antenna.

The actual gain evaluated in the maximum radiation direction (y-direction) as a function of frequency are plotted in Fig.3. The −3 dB gain bandwidths of the 2-element array antenna and the 1-element antenna are 86% (from 4.4GHz to 11.0GHz) and 71% (from 4.5GHz to 9.4GHz), respectively. By arraying the antenna, the −3 dB gain bandwidth increased by 15%. The maximum gains are 11.2 dBi at 9.48 GHz and 8.56 dBi at 7.28 GHz, respectively. The cross-polarization level of the 2-element array antenna is less than −20 dBi over the whole frequency range, while that of the 1-element antenna is about −10 dBi. The difference in cross-polarization level occurred because the cross-polarization components of each element were canceled out by the symmetric property in the xz-plane of the 2-element array antenna.

The radiation patterns of the 2-element array antenna and the 1-element antenna in the H-plane (xy-plane) are measured. Some of these results are shown in Fig.4. For both antennas, unidirectional radiation patterns with small frequency dependence are obtained from 4.0 to 11.0 GHz. In the case of the 2-element array antenna, the half power beam width is 78°, 73°, 66°, 62°, 63°, 54°, 51°, and 52° in ascending order by the frequency. For the 1-element antenna, the HPBW is 99°, 104°, 105°, 114°, 121°, 127°, 132°, and 92° in ascending order by the frequency. From these results, the HPBW of the 2-element array antenna is narrower than that of the 1-element antenna.

In order to investigate the transmission characteristics of the proposed antenna, the transmission loss and group delay characteristics were measured. The measurement setup and the measured transmission loss and group delay are shown in Figs.5, 6, and 7. Transmission loss and group delay are observed when the directions of the transmitting and receiving antenna are fixed at the maximum radiation direction ($\phi_{\mathrm{TX}} = \phi_{\mathrm{RX}} = 90°$). For the 2-element array antenna, the transmission loss is from −39 up to −33 dB at frequencies of 4.1–10.5 GHz and the group delay is within a band of 5.7–6.1 ns over the frequency range of 4.0–11.4 GHz. In the case of the 1-element antenna, the transmission loss is from −42 up to −36 dB at frequencies of 3.1–8.9 GHz and the group delay is within a band of 5.7–6.0 ns over the frequency range of 3.0–10.8 GHz.

For evaluating waveform distortions caused by these antennas, the cross-correlation coefficients between source and received pulses are calculated. The cross-correlation coefficient (CC_{sync}) can be expressed as follows:

$$CC_{\mathrm{sync}} = \int_{-\infty}^{+\infty} \hat{s}(t) \cdot \hat{r}(t + \tau_{\mathrm{sync}}) dt \tag{1}$$

where τ_{sync} is synchronization time, $\hat{r}(t)$ and $\hat{s}(t)$ are the normalized form of the received pulse $r(t)$ and source pulse $s(t)$, respectively. Note that the source pulse and received pulse were assumed to be synchronized in this calculation. We employ a modulated cosine roll-off pulse as a source pulse $s(t)$, which is defined as:

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

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, the values of $\alpha = 0.25$, $B = 7.5$ GHz, and $f_c = 6.85$ GHz are selected.

Calculated correlation coefficients and received energies are shown in Fig.8. In the evaluation, the total energy of the source pulse is normalized to 1 J. The maximum received energy of the 2-element array antenna is 24.5 μJ at $\phi_{\mathrm{RX}} = 95°$ and the half-power beam width (HPBW) is approximately 60°. On the other hand, the maximum received energy of the 1-element antenna is 8.9 μJ at $\phi_{\mathrm{RX}} = 90°$ and the HPBW is approximately 90°. The correlation coefficients of the 2-element array antenna are 0.82–0.86 in the range of $\phi_{\mathrm{RX}} = 65°$ to $\phi_{\mathrm{RX}} = 125°$, while the correlation coefficients of the 1-element antenna are 0.80–0.82 in the range of $\phi_{\mathrm{RX}} = 45°$ to $\phi_{\mathrm{RX}} = 135°$. Therefore, the waveform distortion caused by the 2-element array antenna is smaller than that caused by the 1-element antenna within the HPBW.

4. Conclusion

In this paper, a 2-element UWB array antenna using leaf-shaped bowtie elements and a flat reflector has been proposed. The effects of arraying antenna are experimentally evaluated by comparing a 1-element leaf-shaped bowtie antenna with the proposed 2-element array antenna. The proposed 2-element array antenna has the actual gain of 8.2 to 11.2 dBi at the maximum radiation direction over the frequency range of 4.4 to 11.0 GHz (the −3 dB gain bandwidth is 86%). The radiation patterns are unidirectional and the cross-polarization level at the maximum radiation directions is less than −20 dBi in the frequency range of 3.0 to 15.0 GHz. Furthermore, the correlation coefficient, which is a measure of the degree of the waveform distortions, is between 0.82 and 0.86 in the HPBW. Therefore, the waveform distortion caused by this antenna is relatively small. From these results, it is confirmed that the proposed 2-element array antenna is useful for impulse-based UWB communication systems.

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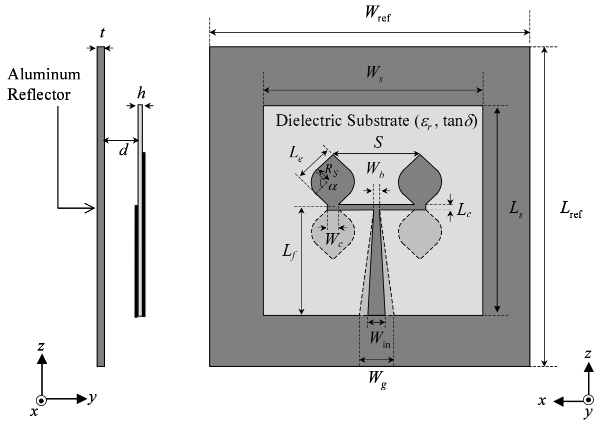

(a) Side View (b) Top View

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]	L_s[mm]	S[mm]	d[mm]
300	300	0.5	0.762	2.17	0.0009	100	100	18	9

R_s[mm]	α[deg]	L_e[mm]	W_{in}[mm]	W_g[mm]	L_f[mm]	L_c[mm]	W_c[mm]	W_b[mm]
7.1	90	12	2.4	12	50	0.3	0.3	1.2

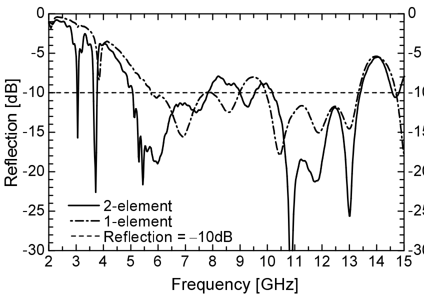

Figure 2: Frequency response of reflection coefficients

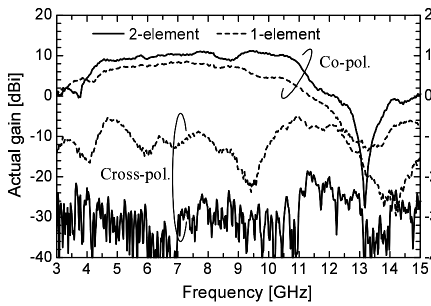

Figure 3: Frequency response of actual gain (y-direction).

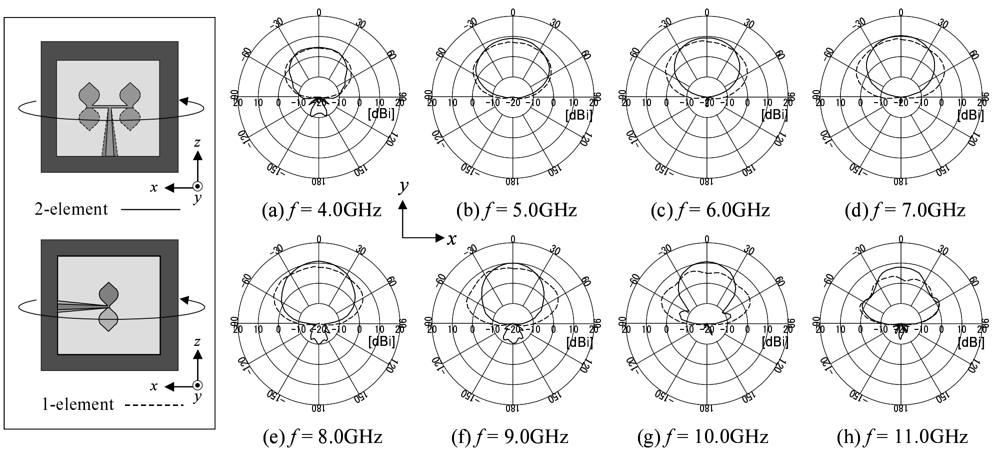

Figure 4: Radiation patterns in H-plane (xy-plane).

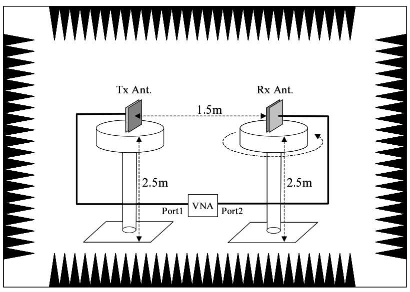

Figure 5: Measurement setup for transmission characteristics.

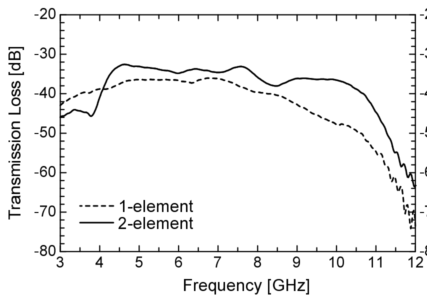

Figure 6: Measured transmission loss for 1-element and 2-element leaf-shaped bowtie antenna at $\phi_{TX} = \phi_{RX} = 90°$.

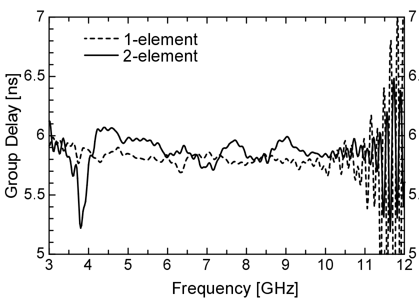

Figure 7: Measured group delay for 1-element and 2-element leaf-shaped bowtie antenna at $\phi_{TX} = \phi_{RX} = 90°$.

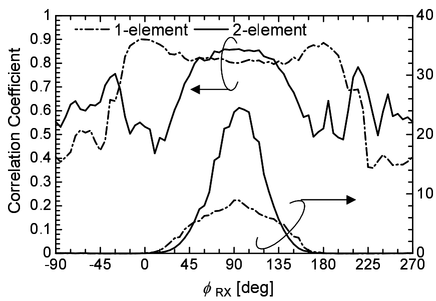

Figure 8: Correlation coefficient and received energy versus azimuthal angle.