60GHz Wideband Shaped-Beam Antenna
Using Closely-Spaced Waveguide Slots for Wireless LAN

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1. Introduction

60GHz band is attractive for realizing wireless local area networks (WLANs) of a transmission rate over Gbps [1]. We have already proposed a WLAN system using eight-sector antenna [1], [2], which has a beam-switching mechanism in order to cover the entire room with high-gain antennas. In the eight-sector antenna, a slot array antenna forms a cosecant beam pattern for compensation of the propagation loss [2]. However, our previous antenna has the limitation of 5% bandwidth, which can cover a part of 60GHz band. Typical slot array antennas have several slots successively arranged at the distance of half a guide wavelength, resulting in a narrow bandwidth since a slot resonance is essentially narrow. To enhance the bandwidth of slot element itself, various configurations such as microstrip-fed or CPW-fed slots [3–5] have been investigated. But in 60GHz band, a waveguide feed is preferred rather than a microstrip feed because of its low transmission loss. To our knowledge, a wideband shaped-beam antenna satisfied with our 60GHz-band WLAN specifications has not been developed yet.

This paper first proposes a new wideband array-antenna structure for 60GHz-band WLAN. Our proposed array antenna consists of closely-spaced waveguide slots, of which lengths are different from each other. The novel slot arrangement proposed in this paper provides the wideband operation using a coupled resonance between the slots. To find key parameters of the wideband antenna, the dependence on the geometrical parameters of slots is studied. As a result, it is shown that 20% bandwidth (10dB return loss) at 60GHz band can be achieved, and also a shaped beam required from system design can be realized by the proposed antenna. Finally, a wideband slot array antenna for 60GHz-band WLAN is designed and evaluated.

2. Structure of Wideband Antenna

Figure 1 illustrates the configuration of access point (AP) and user terminals (UTs) in our proposed WLAN system [1], [2]. The antenna of AT and UTs possesses radially-arranged eight sectors, as shown in the inset of Fig. 1. The antenna in each sector covers a specified area shown in Table 1, and has a gain pattern required from a link budget design [1], [2]. One sector from eight sectors is selected by RF switch according to positions of AP and UTs.

Let us consider the antenna in one sector. Figure 2 shows the antenna structure. The proposed antenna is constructed by making a series of slots with ascending lengths in the direction of \( x \) axis to form a gain pattern, and making an array in the direction of \( y \) axis to obtain a specified gain. The slots are fed by a waveguide called post-wall waveguide [6] or substrate-integrated waveguide, resulting in low-profile planar structure and low cost. The significant difference from conventional slot arrays is the spacing \( g \) between adjacent slots parallel to \( y \) axis. The distance of the spacing in the proposed antenna is less than 0.15\( \lambda_g \), where \( \lambda_g \) denotes wavelength in the waveguide. The slot arrangement
Table 1 Specifications of antenna.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>59GHz – 66GHz</td>
</tr>
<tr>
<td>Number of sectors</td>
<td>8</td>
</tr>
<tr>
<td>Coverage area of one sector</td>
<td>$0 \leq \theta \leq 66^\circ, -11.25^\circ \leq \phi \leq 11.25^\circ$</td>
</tr>
<tr>
<td>Gain pattern</td>
<td>$G_{\text{spec}}(\theta, \phi) = G_{\text{max}} + 20 \log_{10} \sqrt{\frac{\cos \theta_{\text{max}}}{\cos \theta}}$</td>
</tr>
<tr>
<td>Maximum gain</td>
<td>$G_{\text{max}} = 13$[dBi] @ $\theta_{\text{max}} = 66^\circ$ ($h = 2$[m], $r = 5$[m])</td>
</tr>
<tr>
<td>VSWR</td>
<td>$\leq 2$</td>
</tr>
</tbody>
</table>

Fig. 2. Array antenna consisting of closely-spaced waveguide slots for one sector.

Fig. 3. Analysis model of wideband antenna.

yields coupled resonance for the bandwidth enhancement. Also, the multiple different-length slots make it possible to realize a shaped beam in vertical $x$-$z$ plane.

3. Reflection and Radiation Characteristics

To investigate the wideband operation of the proposed antenna configuration, the parametric study is performed using a commercial finite-element-method simulator (HFSS). The analysis model of the proposed antenna is shown in Fig. 3. The length and width of slot $#_i$ are represented by $l_i$ and $w_i$, respectively. For less computation burden, the post-wall waveguide is modeled by a perfect-electric-conductor-wall waveguide filled with a dielectric. The relative permittivity of a dielectric substrate is $\varepsilon_r = 2.17$ with loss tangent $0.6 \times 10^{-3}$ and its thickness is $t = 1.2$[mm]. The slot width and the waveguide width are fixed to be 0.3mm and 3.5mm, respectively. The distance $d$ between the shorted waveguide end and the slot $#1$ is set here to be 1.8mm, which is about $\lambda_g/2$. In the radiation-pattern calculation, the edge diffraction of the ground plane (the waveguide end to the edge: $p = 8$[mm]) is taken into account.

Figure 4 gives the bandwidth as a function of increment $\Delta$ of the slot length and the spacing $g$ between adjacent slots. The number of slots is set to be four, and the slot lengths $l_i$ are expressed by $l_1 + (i - 1) \times \Delta$ where the increment $\Delta$ is changed from 0.0mm to 0.4mm. As can be seen from Fig. 4, the bandwidth is improved drastically by arranging the slots with different length. It can be found from Fig. 4 that over 20% bandwidth can be achieved by the proposed antenna. Especially, comparing the bandwidth of 15dB return loss, the slots arranged closely with the spacing $g = 0.5$[mm] realize wider bandwidth than those with $g = 1.0$[mm] and 1.5[mm].

To obtain the specified gain given by the equation in Table 1, Fig. 5 evaluates the relative gains $G(\theta)$ in vertical plane at $\theta_{\text{min}} = 0^\circ$ and $\theta_{\text{max}} = 66^\circ$ normalized by the specified gain $G_{\text{spec}}(\theta)$. The evaluation of gains is performed by changing the number of slot elements. In the figure, a positive value in the vertical axis represents that gain at elevation angle $\theta$ is satisfied with a specified one. The slot lengths are chosen here to be linearly increased by 0.4mm up to the waveguide width, namely $l_1 = 1.7$[mm], $l_2 = 2.1$[mm], $l_3 = 2.5$[mm], $l_4 = 2.9$[mm], and $l_5 = l_6 = 3.3$[mm]. It can be seen from Fig. 5 that as the number of slot elements increases, the gain at $\theta = 66^\circ$ is higher and that of $\theta = 0^\circ$ is lower than the specified gain. This means that the beamwidth sharpens with the increase of the slot elements, and also the beam is tilted toward the direction of $\theta = \theta_{\text{max}}$. The performance shown
4. Designed Antenna for 60GHz Wireless LAN

4.1 Design Procedure

The design procedure using the results shown in the previous section is as follows. First, the spacing $g$ between adjacent slots is determined based on Fig. 4 from the return loss and the bandwidth of the specification. Second, the number of slot elements is determined from Fig. 5 so as to satisfy a specified gain pattern $G_{\text{spec}}(\theta)$. Third, the slot lengths $l_i$ are adjusted so as to satisfy the specified gain pattern and return loss. Once the slot arrangement of a one-dimensional array is determined, the design of a shaped beam in $x$-$z$ plane is finished. Finally, a two-dimensional array is constructed so that the maximum gain $G_{\text{max}}$ can be obtained.

4.2 Design Example

As an example, the wideband antenna shown in Fig. 3 are designed based on the specifications shown in Table 1. The spacing $g$ between slots is set here to be $g = 0.5$[mm], since the low return loss can be obtained as shown in Fig. 4. It is found from Fig. 5 that the number of slots is four, since the four-slot antenna is satisfied with the specified gain both at $\theta_{\text{min}} = 0^\circ$ and at $\theta_{\text{max}} = 66^\circ$. After the adjustment of the slot lengths, the obtained slot lengths are $l_1 = 1.7$[mm], $l_2 = 1.9$[mm], $l_3 = 2.7$[mm], and $l_4 = 2.9$[mm]. Figure 6 shows the reflection characteristic of the designed one-dimensional slot array antenna. The 20% bandwidth obtained by the proposed antenna covers full 60GHz band.

The two-dimensional array ($4 \times 4$ slot elements) using the designed wideband antennas is constructed to satisfy the maximum gain $G_{\text{max}}$ given in Table 1. Shown in Fig. 7 are the gain patterns in vertical plane at $\phi = 0^\circ$ in comparison with the required gain. The gain in the coverage area for one sector ($0^\circ \leq \theta \leq 66^\circ, -11.25^\circ \leq \phi \leq 11.25^\circ$) is also evaluated. Figure 8 shows the gain margin in one sector. Here the margin means the difference between the obtained gain and the required one. Although the gain does not reach the required gain at the edge of sector, the proposed antenna is satisfied with the required gain in the area of 80%, 90%, and 93% at 59.0GHz, 62.5GHz, and 66.0GHz, respectively.

5. Conclusions

A wideband slot array antenna for 60GHz-band multi-sector antenna has been proposed. The structural feature is the closely-spaced arrangement of different-length slots, while the spacing between...
slots in conventional arrays is half a guide wavelength. The antenna performance has been evaluated by the parametric study. As an example, a wideband slot array antenna has been designed for a multi-sector antenna in 60GHz wireless LAN. The designed antenna achieves both the bandwidth of 20\% and the coverage area of over 80\% in one sector in 60GHz band.

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References