the circuit simulation that is shown in Fig. 2, and the suitable action of the actual MMIC's. The conversion gain of the W-band down-converter (W-Band 2; IF signal connected at point P in Fig. 1) is 8.0 dB. Therefore, the rat-race circuit without the IF amplifier has a −6.5-dB conversion gain. We also measured another design (W-Band 1; IF signal connected at point Q in Fig. 1), and found its conversion gain to be 7.7 dB. This is a comparable value within measurement errors. The rat-race circuit without the IF amplifier has a −6.8-dB conversion gain. These values are close to the estimated value shown in Fig. 2(a). We think the errors mainly arise from the power measurement of the millimeter-wave signal performed using a spectrum analyzer with a harmonics mixer. The leakage from LO to RF of W-Band 1 and W-Band 2 are −24 and −25 dB, respectively. In conclusion, we can use either point P or Q in Fig. 1 as an IF signal connecting point under a proper diode bias.

As compared to that of the W-band down-converters, the conversion gain of the V-band down-converters is slightly lower. At first, we considered this to be due to the conductive loss of the CPW of the rat-race circuit, because the length of the CPW for V-band down-converters is 1.67 times longer than that for W-band down-converters. However, Fig. 2 shows that there is no significant difference. We think that the difference comes from the error of the power measurement in the millimeter-wave range.

IV. Conclusion

We have described the millimeter-wave diode down-converters with an HBT amplifier. The combination of high cutoff SBD's and HBT's works very well as a high-frequency down-converter. This combination can be used for the integration of other circuits such as an HBT oscillator [7], [8]. In addition, HBT's have the ability of power handling, so an LO amplifier using HBT's might be a good choice for the frequency converters. We believe that the device combination can be used for many applications in this frequency range.

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A Switchable Multi-Sector Antenna for Indoor Wireless LAN Systems in the 60-GHz Band

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***Abstract*—A switchable multi-sector antenna for indoor wireless local-area network (LAN) systems in the 60-GHz band has been proposed. The antenna has a pyramidal configuration. Each isosceles-triangular surface of the pyramid has been inclined 30° from the vertical axis in order to cover an appropriate elevation angle range. This antenna excites a right-handed circularly polarized wave to suppress unwanted multipath delayed waves. The low-loss curved microstrip-line feeding has been introduced at the junction between antenna feed lines and monolithic microwave integrated circuit (MMIC) amplifiers at the bottoms of the pyramid. Using this antenna, the terminal receiver for indoor wireless LAN systems in the 60-GHz band has been developed.**

***Index Terms*—Curved microstrip lines, millimeter-wave LAN's, multi-sector antenna, patch antennas.**

I. Introduction

Recently, demand for high-speed and large-capacity wireless local-area network (LAN) systems is growing. Millimeter-wave wireless LAN's are expected to achieve a data transmission rate as high as 156 Mb/s, which is compatible with asynchronous transfer mode (ATM) cable networks.

In Japan, the millimeter-wave band between 59.0–60.0-GHz band has been allocated for use in developmental experiments for millimeter-wave wireless LAN systems [1]. The effectiveness of the circular polarization and directive antennas to suppress the unwanted multipath delayed waves [2], and the reflection and transmission coefficients of typical structures in modern offices [3] have been evaluated. These results indicate that the use of circular polarization can reduce the influence of single-bounce multipath reflected waves experiencing single-bounce reflections, which are the main contributors to deteriorating transmission quality. Shadowing caused by human bodies is another important issue to be considered. The effects of shadowing to millimeter waves were discussed in [4]. One of solutions to this problem is the implementation of macroscopic diversity, in which each remote terminal (RT) can communicate with

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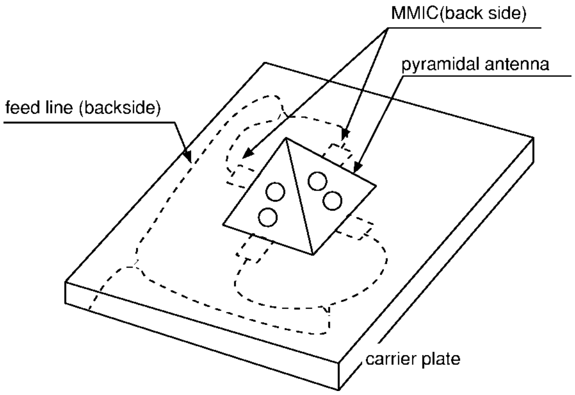

Fig. 1. Perspective view of the proposed CP-FSA.

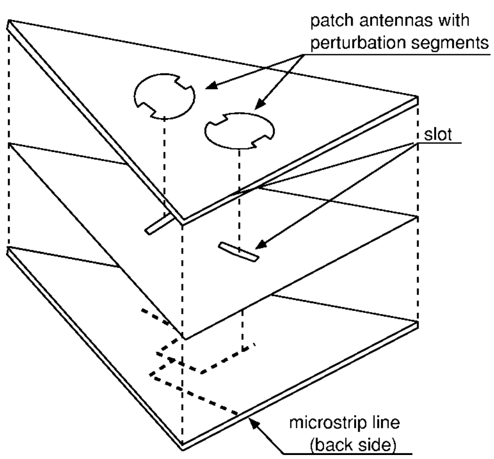

Fig. 2. Paired-element patch antenna on an isosceles-triangular plate.

at least two base stations (BS's) and select one of them, depending on propagation environment.

In this paper, we present a circularly polarized four-sector antenna (CP-FSA) suitable for millimeter-wave wireless LAN's. The antenna has four sectors to cover the entire azimuth plane. In order to cover an appropriate elevation angle range, each antenna was inclined from the vertical axis, which led to the pyramidal antenna configuration [5]. To realize a low-loss connection between antennas and monolithic-microwave integrated-circuit (MMIC) amplifiers for the proposed pyramidal antenna, we have introduced a curved microstrip–antenna feeding to connect them.

II. Antenna Configuration

Fig. 1 shows the schematic view of the proposed switchable CP-FSA. Each triangular plate is inclined 30° from the vertical axis, in order to cover an appropriate elevation-angle range. The number of sectors is determined to be four, by using patch antennas with 90° half-power beamwidth. The antenna is mounted on a planar carrier plate. Four MMIC amplifiers (power or low-noise amplifiers) are mounted on the back side of the carrier plate. Each antenna on an isosceles-triangular plate is connected to each MMIC amplifier at the bottom of the isosceles-triangular plate. Beam switching is achieved by switching bias dc voltages of MMIC amplifiers on and off.

Fig. 2 depicts one of the isosceles-triangular plates of the CP-FSA. Two patch-antenna elements are etched on an isosceles-triangular substrate. Each patch-antenna element is fed from its back side via slot coupling, and excites the right-hand circularly polarized wave (RHCP) using perturbation segments [6]. To achieve a low axial ratio over a wide bandwidth, a paired-element configuration [6] is used. The parameters of paired-element patch antennas are listed in Table I. The antenna and feed substrates were adhered with an adhesive sheet.

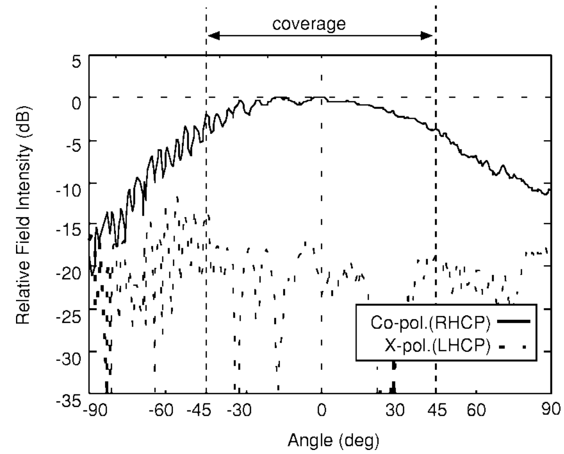

Fig. 3. Radiation pattern of paired-element patch antenna on an isosceles-triangular plate in the azimuth plane at 59.5 GHz.

TABLE I
Parameters of Paired-Element Patch Antenna

Item	Value
Dielectric constant (both sides)	2.20
Substrate thickness (both sides)	0.127 mm
Patch radius	0.91mm
Perturbation Segment	3.25 % of the whole patch area
Slot length	0.8 mm
Slot width	0.1 mm
Baseline length and height of an isosceles triangular	11.0 mm
Element spacing	2.75mm($=0.55\lambda_0$ @59.5GHz)

III. Measurement Results of CP-FSA

Fig. 3 depicts the radiation pattern in the azimuth plane at 59.5 GHz. In this figure, a solid line indicates copolarization RHCP components, while a broken line indicates cross-polarization LHCP components. From this figure, half-power beamwidth of 89° was obtained. Therefore, it is confirmed that the pyramidal configuration can cover the entire azimuth plane with a variation less than 3 dB. On the other hand, a half-power beamwidth of 37° in the elevation plane was obtained.

The return loss of this antenna was less than -10 dB within the frequency range of between 59.0–60.0 GHz. The gain of more than 5.4 dBi and the axial ratio of less than 2.5 dB was obtained in the boresight direction. The gain of this antenna was about 2 dB lower than the calculated one (ideal case). This may be due to transmission-line losses, pattern deterioration due to the isosceles-triangular ground plane [7], and the impurity of circular polarization.

For the pyramidal structure of the proposed antenna, the connection between antenna feed lines and MMIC amplifiers with an angled junction is a serious problem in terms of integration. We have overcome this problem by introducing the curved microstrip lines at the angled junction. The antenna feed-line substrates (PTFE substrate) are curved along with the curved part of the carrier plate. Fig. 4 compares $|S_{21}|$ characteristics of the microstrip line on the flat plate and the curved microstrip line whose radius of curvature was 5 mm.

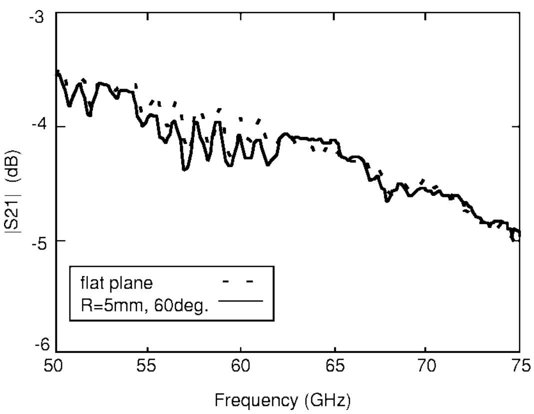

Fig. 4. Comparison of transmission characteristics of the curved microstrip line with that of the microstrip line on a flat plate.

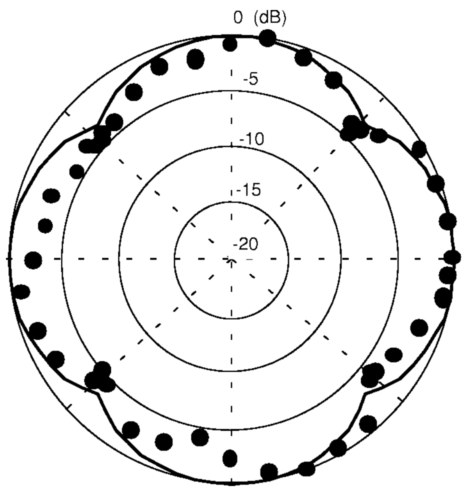

Fig. 5. Radiation pattern of the RT receiver at 59.5 GHz when the wave incident is from 30° above the horizontal plane.

In the measurement, the same line was used for both flat and curved cases. From Fig. 4, $|S_{21}|$ characteristics for both cases were almost the same within the entire V-band (50–75 GHz). The maximum loss caused by a curved microstrip line was 0.3 dB. Because curved microstrip lines with the radius of curvature lines less than 5 mm make lines tend to crack, the radius of curvature was chosen to be 5 mm.

Fig. 5 shows the azimuth pattern of CP-FSA mounted on the top of the RT housing at 59.5 GHz, when the elevation angle was 30°. The housing is 500-mm-long, 340-mm-wide, and 225-mm-high. The antenna was offset 165 mm along the longitudinal direction from the center of the top plate. In the measurement, the sector was selected automatically by comparing the received power of each antenna. In this figure, the solid line indicates the calculated pattern and the black circles indicate the measured data. The measured pattern agrees reasonably with the calculated pattern. As expected, each antenna was found to cover a quadrant sector in azimuth plane.

IV. Conclusion

A circularly polarized four-sector antenna for RT's in the 60-GHz wireless LAN systems has been proposed and developed. This antenna has a pyramidal configuration. In order to achieve low-loss connection between pyramidal antennas and MMIC amplifiers, a curved microstrip-line feeding is introduced. Experimental results confirm that this antenna can be used for millimeter-wave wireless LAN systems.

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