Effectiveness of Four-Branch Height and Polarization Diversity Configuration for Street Microcell

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***Abstract*—This paper proposes a four-branch height and polarization diversity configuration that achieves almost constant received signal power over any terminal inclination in a street microcell communication environment. An example of the four-branch diversity antenna is also presented. Our measurement results in cell-size comparison among height diversity, polarization diversity, and height and polarization diversity configurations confirm the effectiveness of the proposed diversity configuration.**

***Index Terms*—Mobile antennas, mobile communication, urban areas.**

I. Introduction

RECENTLY, microcell mobile communication systems such as personal handy phone systems (PHS) have received much attention all over the world [1]. In urban areas, since microcell system base stations are generally located lower than the surrounding buildings, the communication cell follows the street and, thus, is usually called a "street cell." Moreover, since the propagation environment of microcell systems is mainly line-of-sight (LOS), the waves radiating from base-station antennas and handy phones retain their original polarization state during propagation.

Vertically polarized antennas (such as collinear antennas) are commonly used as base-station antennas in microcell systems. Whip antennas are also common for the handy phones. Since handy phones are generally inclined during use [2] and are carried at various angles, the polarization of the incident waves reaching the base station varies. Therefore, the signal power received at the base station degrades due to a mismatch of the polarization state of the base station antenna and that of the incident wave. Since the transmitting power of the handy phones cannot increase to save the battery, the signal power degradation in uplink becomes problem.

Diversity technique is effective to improve the transmission performance and various diversity techniques have been studied so far [3]–[5]. Vaughan [4] has reported the effectiveness of the polarization diversity in cellular-type system without direct LOS ray. Kukushkin *et al.* [5] has addressed space and polarization diversity configuration in a microcell environment. However, no paper has addressed about overcoming the influence of the terminal polarization variation in microcell systems.

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This paper first shows the dependency of diversity characteristics using an ordinary two-branch height diversity collinear antenna (HCA) and a two-branch polarization diversity antenna on the inclination of a handy phone in a street-cell environment by conducting measurements in an urban area in Japan. The advantage and problem related to the two-branch polarization diversity antenna are shown. In order to overcome the described problem, the effectiveness of a four-branch diversity configuration incorporating both polarization and height diversity schemes are investigated. Moreover, a novel four-branch bidirectional rod antenna with height and polarization diversity (BIRA-HPD) is proposed as an example of the four-branch diversity antenna. Finally, the cell lengths possible with a BIRA-HPD and a HCA are compared by measurement.

II. Influence of Handy Phone Inclination on Signal Reception

Diversity gain is influenced by the correlation and the received power difference between branches. The correlation and the difference in received power in an actual street-cell environment were investigated by measurement.

A. Measurement Scenario

Fig. 1 shows the environment in which the measurements were taken in a street cell. A terminal was the transmitting site and a base station was the receiving site. A sleeve antenna was used as the transmitting antenna. An HCA with five elements and a dual-polarized antenna (DPA) comprising a bidirectional narrow patch and slot antenna [6] with two elements were placed at the receiving site. The gain of the collinear antennas and the dual-polarized antennas were 7.4 and 8.0 dBi, respectively. The spacing between the collinear antennas was 3.8 wavelengths. The road width was about 25 m. The frequency was 2.2 GHz. The center of the upper collinear antenna and the dual-polarized antenna were placed at height of 3.5 m. The height of the terminal antenna was 1.5 m. The terminal antenna was inclined in the xz plane as indicated in Fig. 1. In this paper, an area within 230 m from the base station where the propagation loss was less than 100 dB was considered as a communication cell.

B. Correlation Characteristics

Fig. 2 shows the dependency of the correlations between the branches of the HCA and DPA on the inclination of the terminal antenna. The angle of 0° in the horizontal axis in

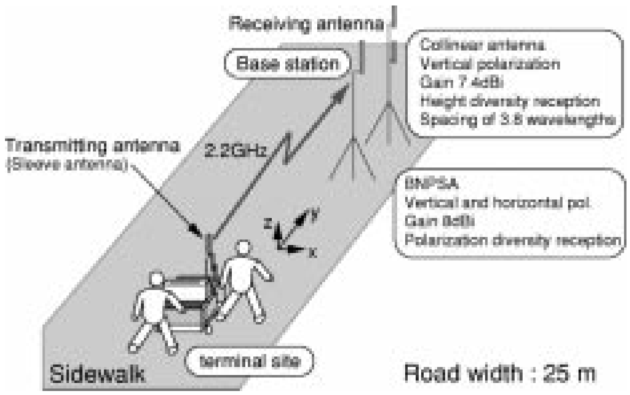


Fig. 1. Measurement scenarios.

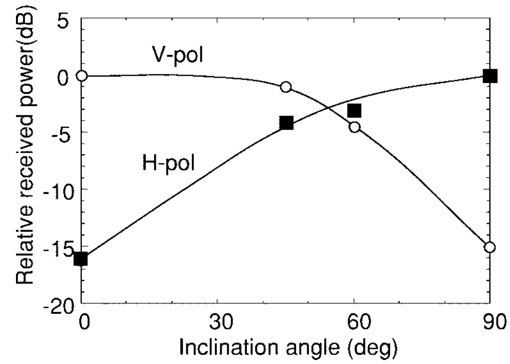


Fig. 3. Dependency of the power received by vertically and horizontally polarized elements on the inclination angle of the transmitting antenna.

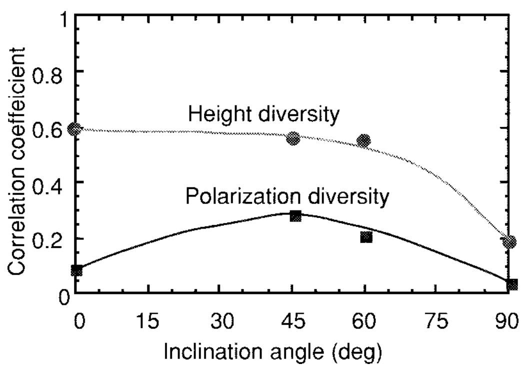


Fig. 2. Correlation characteristics of HDA and DPA against the inclination angle of the transmitting antenna.

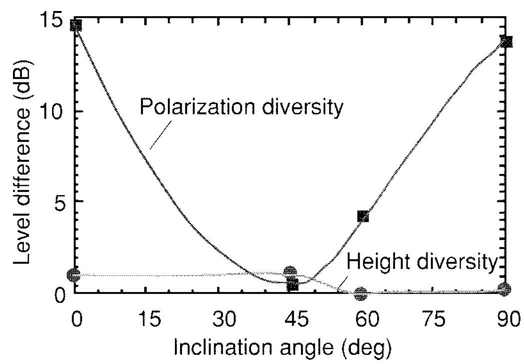


Fig. 4. The difference in received power between the branches of the HCA and the DPA versus the inclination of the terminal antenna.

Fig. 2 means the sleeve antenna was vertical. The correlations were the mean values over the considered area. As indicated in Fig. 2, when the terminal antenna was held vertically, the correlation of the HCA was approximately 0.64. The correlation decreases as the inclination angle of the terminal antenna surpasses 60°. This is because when the transmitting antenna is horizontal, the collinear antennas receive the cross-polarized component of the incident waves, which should be reflected or diffracted by objects situated along the street (such as buildings or trees). On the other hand, the correlation of the DPA was less than that of the HCA. The maximum correlation was 0.3 at the inclination angle of 45°. This is because when the polarization of the incident wave is horizontal or vertical, the polarization of one DPA element coincides with that of the incident waves and the other element receives the cross-polarized component, i.e., reflected or diffracted waves, hence, the correlation should be low. When the inclination angle of the terminal antenna is 45°, since the contribution of the direct waves to both elements is almost the same, the correlation becomes high.

C. Received Power Difference

Fig. 3 shows the dependency of the power received by the vertically and horizontally polarized elements of the DPA on the inclination of the terminal antenna. These values represent the median received power over the considered area. As indicated in Fig. 3, it can be confirmed that the received power of the vertically polarized element decreases as the terminal antenna is inclined and that of the horizontally polarized one, on the other hand, increases. It can be also confirmed that the polarization state of propagated waves in a street-cell environment is maintained. The degradation due to the polarization mismatch was about 15 dB.

Fig. 4 shows the difference in received power between the branches of the HCA and the DPA with respect to the inclination of the terminal antenna. As indicated in this figure, the difference in received power of the HCA is less than 1 dB. Note that the absolute received power decreases according to the inclination of the terminal as describe above. On the other hand, in the case of the DPA, the differences in received power at the terminal angle of 0° or 90° are about 15 dB and that at the angle of 45° becomes almost 0 dB due to the reason described above.

III. DIVERSITY CHARACTERISTICS OF TWO-BRANCH HCA AND DPA

The diversity gain characteristics are evaluated by theoretical analysis of the selective combining transmission diversity [7]. The medium values of the diversity gain in the considered area were used here. The diversity gain of two-branch diversity in a Rayleigh fading environment with no correlation and the same received power between the branches is 10 dB. The correlation and the received power difference between the branches degrade the diversity gain.

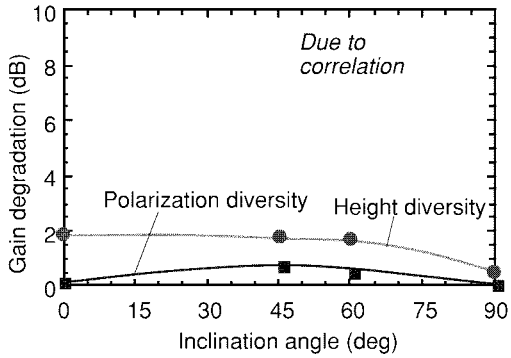


Fig. 5. Degradation of the diversity gain caused by correlation between the branches.

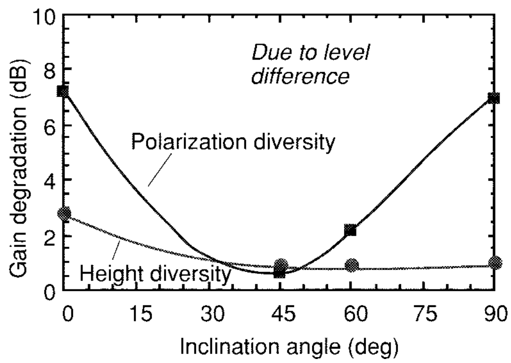


Fig. 6. Degradation of the diversity gain caused by the difference in received power between the branches.

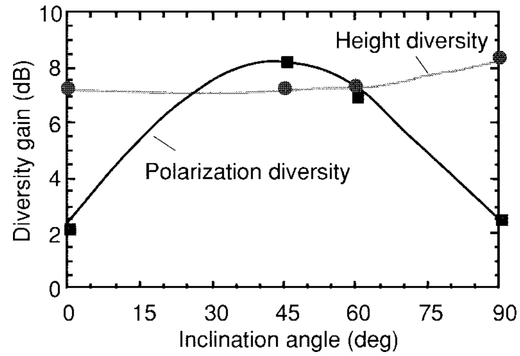


Fig. 7. Diversity gain of HCA and DPA against the inclination of the transmitting antenna.

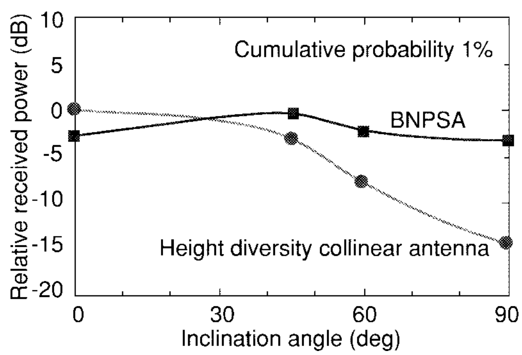


Fig. 8. Absolute power received by the HCA and the DPA taking the above diversity gain into consideration.

Fig. 5 shows the degradation of the diversity gain caused by the inclination of the transmitting antenna. As indicated in this figure, the maximum degradation of the HCA due to the correlation is about 2 dB when the transmitting antenna is vertical. When the inclination of the transmitting antenna is over 60°, since the correlation decreases, the gain degradation decreases. The degradation is 0.5 dB when the transmitting antenna is horizontal. On the other hand, since the correlation of the DPA branches is lower than that of the HDA, the degradation of the diversity gain of the DPA is less than 1 dB.

Fig. 6 shows the degradation of the diversity gain caused by the received power difference between the branches. As indicated in this figure, since the difference in received power of the HCA is only 2 dB, the degradation is about 1–2.7 dB. On the other hand, in the case of the DPA, since the maximum difference in received power between the branches was 15 dB, the diversity gain degrades by approximately 8 dB when the transmission antenna is 0° or 90°.

The diversity gain of the HCA and the DPA is shown in Fig. 7. As indicated, the HCA attains 7-dB diversity gain with no influence of the handy phone inclination. The diversity gain of the DPA, on the other hand, is severely influenced by the handy phone inclination.

Fig. 8 shows the absolute power received by the HCA and the DPA taking the above diversity gain into consideration. The values in Fig. 8 are normalized by the value of the HCA when the inclination was 0°. As indicated in the figure, the DPA holds the received signal power almost constant against inclination. Note that the degradation in HCA performance as the inclination of the transmitting antenna approaches 90° is due to polarization mismatch. However, when the inclination angle is 0°, the signal power output by the DPA is lower than that by the HCA due to the degradation of the diversity gain.

IV. Four-Branch Polarization and Height Diversity Configuration

Taking the above results into consideration, the four-branch diversity configuration (which is the height diversity configuration of two two-branch polarization diversity antennas) should eliminate the received signal degradation and the diversity gain degradation caused by the handy phone inclination. The dependency of the signal power received by the four-branch diversity configuration is shown in Fig. 9. Note that the other line in Fig. 9 indicates the two-branch HCA. The upper polarization diversity antenna was placed at the height of 3.5 m and the lower antenna was spaced at 2.2 wavelengths from the upper antenna. As was expected, the four-branch diversity configuration holds the received signal power constant against inclination and it yields a 2-dB higher signal power than the HCA when the inclination is 0°. Moreover, from Fig. 8 and 9, the four-branch diversity configuration can obtain 2–5-dB gain improvement to the two-branch DPA.

V. Configuration and Characteristics of BIRA-HPD

As an example of the four-branch diversity antenna, a four-branch bidirectional rod antenna is proposed with height

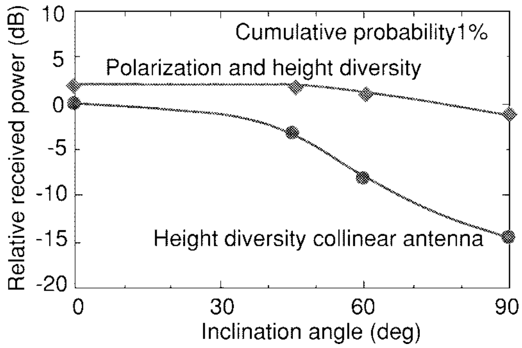


Fig. 9. The dependency of the signal power received by the four-branch diversity configuration.

TABLE I
THE PROTOTYPE SPECIFICATIONS OF THE BIRA-HPD AND AN ORDINARY COLLINEAR ANTENNA

	Collinear antenna	BIRA-HPD
Diameter	17 mm ϕ	30 mm ϕ
Length *	1610 mm	740 mm
Gain	7.8 dBi	8.0 dBi
Polarization	V pol.	V & H pol.
Radiation pattern	Omni	Bidirectional
Diversity configuration	Height	Polarization &height
Number of branches	2	4

* Including a connector for installation

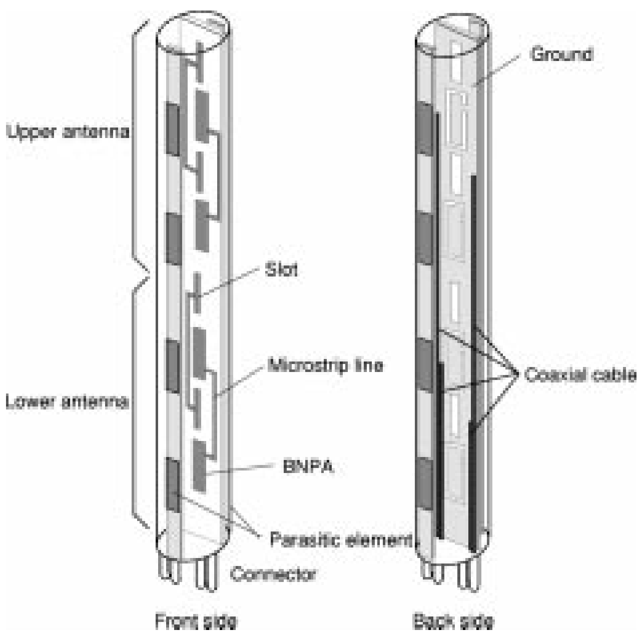


Fig. 10. Configuration of BIRA-HPD.

and polarization diversity (BIRA-HPD), which is suitable for street-cell environments [8]. Fig. 10 shows the BIRA-HPD configuration. This configuration comprises two bidirectional narrow patch and slot antenna (BNPSA) arrays [6] that are arranged vertically, as shown in Fig. 10. bidirectional narrow patch antennas (BNPA) [9], which are printed antennas on a substrate with parasitic elements, are used as the vertically polarized elements of the BNPSA shown in Fig. 10. The feeding networks for the elements are printed circuits on the substrate. The excited patches of the back side are surrounded by the ground. The ground makes it easy to form the beam-forming network on the substrate and sharpens the beam in the vertical plane. A spacing of 1.1 wavelengths is selected between the adjacent BNPA's in order to maximize the gain. Slot antennas, which are formed on the ground side of the substrate, are used as the horizontally polarized elements. Each slot is located between adjacent BNPA's. Thus, the BNPSA is a dual-polarized antenna that has almost the same antenna length as a single-polarized antenna. Coaxial cables are used to connect the beamforming networks to the connectors located at the bottom of the BIRA-HPD. These cables are placed at the back side and contact the ground to eliminate the influence of the cables on the radiation characteristics. Therefore, the proposed antenna achieves four-branch configuration with a rod type.

Table I shows the specifications of a prototype of the BIRA-HPD and an ordinary collinear antenna. The frequency is 2.2 GHz. The length of the antennas include the parts for placement. The proposed BIRA-HPD achieves four-branch diversity configuration with half-length of the collinear antenna and the diameter of 30 mm.

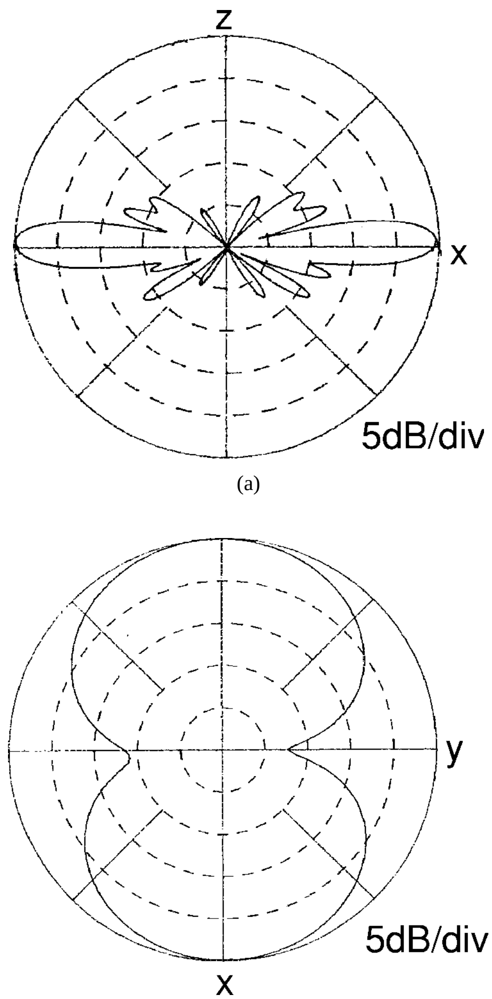
Fig. 11 shows the radiation patterns of the upper antennas in the BIRA-HPD, which has two elements for each antenna. Fig. 11(a) shows the patterns of the vertically polarized antenna in the vertical and horizontal plane (E-plane and H-plane) and Fig. 11(b) shows those of the horizontally polarized one. As indicated in these figures, the patterns in the horizontal plane of both antennas are bidirectional and the patterns of both antennas are almost identical. The 3-dB beamwidth of both patterns is about 90°. The measured gains of the BIRA-HPD are 7.8 and 8.1 dBi for the upper vertically and horizontally polarized antennas, 8.0 dBi for the lower vertically and horizontally polarized antennas.

VI. Comparison of the Cell Length

Fig. 12 compares the measured cell lengths offered by a BIRA-HPD, a BNPSA, and a HCA when those antennas were used as the base-station antenna to receive the waves transmitted from the sleeve antenna previously described. As indicated in the figure, when the sleeve antenna is vertical, the BIRA-HPD cell length is the longest of the three. When the sleeve antenna is horizontal, the HCA cell length is reduced by almost half. On the other hand, the BNPSA and the BIRA-HPD can achieve almost the same cell length as that of the vertically polarized incident wave. Therefore, the BIRA-HPD offers the longest cell length of the three without any significant dependency on the handy phone's inclination.

VII. Conclusion

The diversity characteristics of the height diversity and the polarization diversity configurations in a street-cell environ-



(a)

(b)

Fig. 11. Radiation pattern of the prototype of BIRA-HPD with two elements.

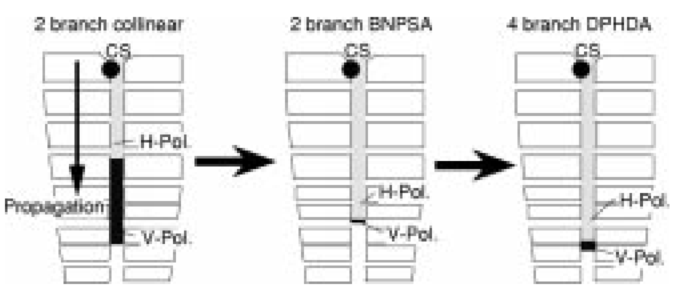


Fig. 12. Comparison of the cell lengths offered by HCA, DPA, and BIRA-HPD.

ment were investigated by conducting measurements in an urban area in Japan. The effectiveness of a four-branch height and polarization diversity configuration was shown as the base-station antenna of microcell mobile communication systems. Moreover, a four-branch bidirectional rod antenna with height and polarization diversity (BIRA-HPD) was proposed as one implementation example. The proposed antenna has almost half length of the two-branch height diversity collinear antenna and uses patch and slot elements on the same substrate, no additional work is needed to make the elements against the vertically polarized antenna, which uses only patch element. Therefore, the production cost of the proposed antenna is not so high than the ordinary two-branch antenna. In addition, four-branch scheme is now adopted in Japanese commercial microcell systems. Therefore, four-branch antenna is acceptable for actual commercial systems. The measurements also clarified that the proposed BIRA-HPD achieves longer cell lengths than the ordinary two-branch height-diversity collinear antenna, while eliminating the received signal degradation caused by the inclination of the handy phones.

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