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The Optimum Propagation Condition of Polarization Diversity Reception in Indoor Wireless Communications

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ABSTRACT

In this paper, in order to optimally reduce the fading signals measured by a vehicle in motion in indoor building, a polarization diversity reception method are considered. In our measurements, signal strengths are measured by using a circularly polarized antenna and vertical, horizontal polarized antennas in LOS(line-of-sight) and NLOS (non-line-of-sight) environments, and then reduction degree of the fading are analyzed. From these analyses, in case of LOS condition the fading reduction effect for the circularly polarized antenna shows high efficiency, but in case of NLOS condition it is not so good. Using the correlation coefficient for the polarization diversity branches, the diversity effect is also evaluated. From this evaluation results it was found that the polarization diversity effect which use a circularly polarized antenna at the transmitting end and the vertical and horizontal polarized antenna branches at the receiving end is markedly excellent.

In conclusion, it can be inferred that the effective fading reduction method in indoor radio environments is to create LOS condition between the transmitting end and the receiving end, and then to form the polarized diversity branches at the receiving end by using a circularly polarized antenna at the transmitting end.

Ⅰ. Introduction

According to the rapid growth of industry, the economic activities become more complicated and varied. Therefore, high-speed transmission for every kinds of information is demanded; expectation that system is high bit rate, large capacity information transmission among radio systems in a building is also increased. So, to increase flexibility and convenience of cellular phone and wireless terminals in indoor the experimental analysis of radio propagation characteristics under indoor wireless environments is very important and the countermeasure of fading reduction is also necessary.

Many research activities for indoor wireless propagation have been reported, for examples characteristics of 900MHz wave in a building[1], a statistical model translating of indoor multipath wave[2], equalizer technique in indoor wireless channel[3], diversity which is solution for reducing fading[4], and modulator and demodulator[5], and etc.

Recently, we have been studying about fading reduction effect using by omni-directional circularly polarized antenna in indoor wireless environments[6, 7, 8, 9]. From our study activities, it was found that the polarization diversity reception which use a circularly polarized antenna at the transmitting end and the vertical and horizontal polarized antenna branches at

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the receiving end is markedly excellent[10].

In this paper, we investigate the optimum condition that is the best propagation condition to remove the multipath fading when polarization diversity reception is adopted. In our measurements, we use 1.2GHz which frequency is comparatively easy to transmit because it is amateur radio band. We received signal power by using vertical and horizontal polarized antenna and circularly polarized antenna under LOS and NLOS conditions. Especially, in our measurements, we changed the transmitting antenna height in NLOS environments to examine the fading reduction effect and to investigate the optimum condition of polarization diversity reception. From the measurement analysis, it was found that the effective fading reduction method in indoor radio environments is to create LOS condition between the transmitting end and the receiving end, and then to form the polarized diversity branches at the receiving end by using a circularly polarized antenna at the transmitting end.

Ⅱ. Circularly Polarized Effect in Indoor Wireless Communications

We call two orthogonal polarized waves are not in-phase but the sum of two waves, electric field vector elliptically turn around an axis of propagation. This is called an ellipse polarized wave. Specially, when amplitude of two components are same and the phase is $\pm\pi/2$ [rad], this is called circularly polarized wave. In the Figure 1, since verticality to horizontal component shift $\pm\pi/2$ [rad], circularly polarized wave is made.

Usually, the complex reflection coefficients $R_H e^{-j\theta_H}$ and $R_V e^{-j\theta_V}$ of the radio wave are given as follows[11]:

$$R_H e^{-j\theta_H} = \frac{\cos\theta - \sqrt{n^2 - \sin^2\theta}}{\cos\theta + \sqrt{n^2 - \sin^2\theta}} \quad (1)$$

$$R_V e^{-j\theta_V} = \frac{n^2\cos\theta - \sqrt{n^2 - \sin^2\theta}}{n^2\cos\theta + \sqrt{n^2 - \sin^2\theta}} \quad (2)$$

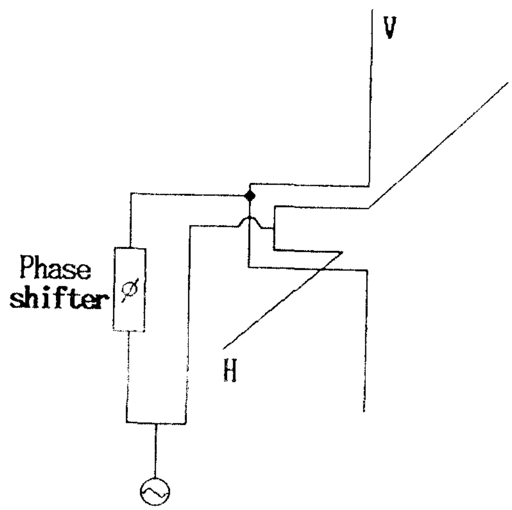


Fig. 1 Circularly polarized antenna

where θ is an incident angle, n is the complex refraction index

R_H and R_V are the amplitudes of reflection coefficients

θ_H and θ_V are the phases

The sub-character H and V mean the horizontally polarized wave and vertically polarized wave respectively.

Figure 2 show an example of the change of phase angle and the absolute reflection coefficient for the horizontal and vertical polarized waves. In the Figure 2, R_H and R_V indicate the changing shape of reflection coefficient for the horizontal and vertical polarized waves. Also, θ_H, θ_V indicate the changing shape of phase angle of the horizontal and vertical polarized waves. In the Figure 2(a), when the vertical polarized wave is at an incident angle corresponding to the brewster angle θ_b, the reflection coefficient R_V becomes to minimum. That is, all incident waves progress to the second medium without reflection. Also, when the incident angles of both R_H and R_V become to maximum at the angle of 90° the reflection coefficient for the both cases becomes 1. In the Figure 2(b), θ_H change into nearly 180° regardless of the incident angle vari-

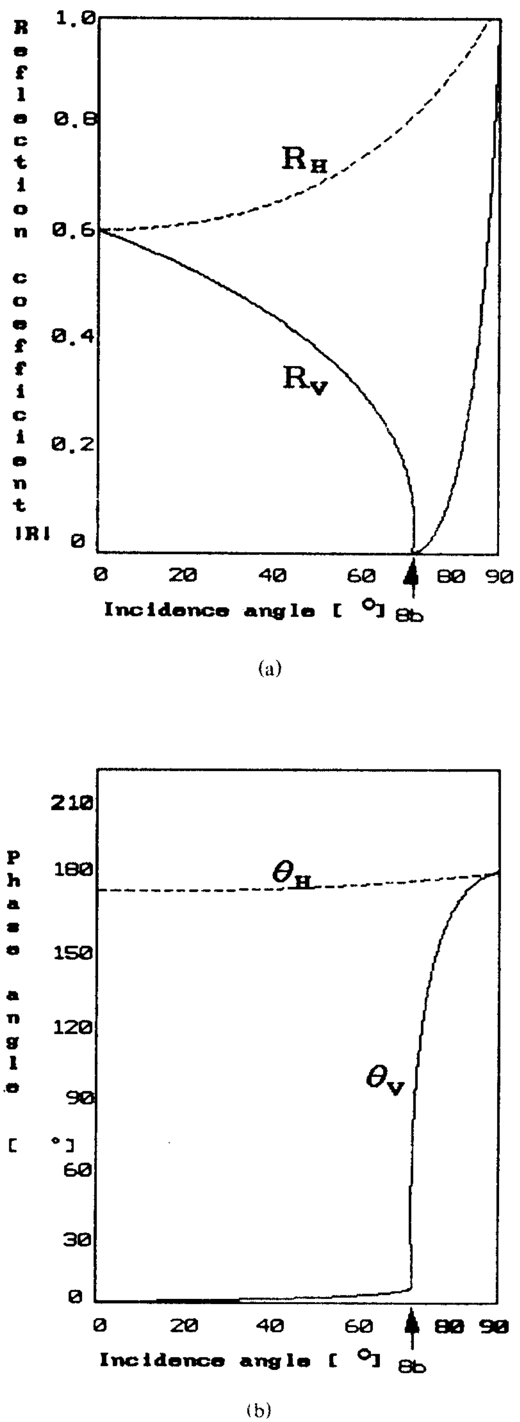


Fig. 2 Change of phase angle and reflection coefficient for the incident angle

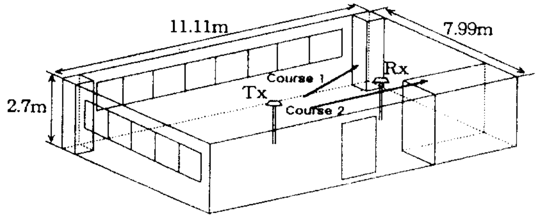
ation and θ_V does not change until the brewster angle.

As like this, when the circularly polarized wave reflected by odd multiple times from the obstacle (in the range, angle of incidence $< \theta_b$) the only horizontal polarized wave component change about 180°. Therefore, it becomes a left-handed polarized wave which the turning direction of original electric field vector is reversed. Also, since it is not correctly to change 180°, odd multiple time reflection wave becomes the left-handed polarized wave. Therefore, receiving antenna can not receive like this reflection waves theoretically, so the circularly polarized antenna can reduce the multipath waves. Even multiple reflected waves such as two times reflection wave can be received theoretically because the reflected waves become to a right-handed polarized wave. However, considering the propagation loss due to reflection and the fact that the polarized wave is not a complete circularly polarized wave but an elliptic polarized wave, the received signal strength of reflection wave will be small level. It can be seen that using the circularly polarized antenna in indoor wireless communication the multipath fading may be remarkedly reduced.

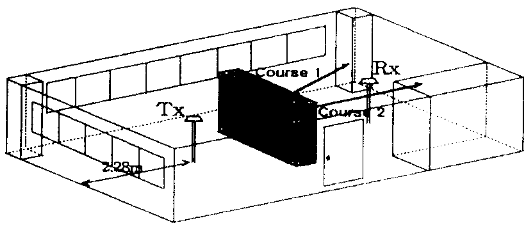
Ⅲ. Outline of Radio Wave Experiments

3.1 Measuring method and plane

Radio wave measurements are conducted in a conference room which size is general office scale. Measuring places and courses, which shows LOS and NLOS, are illustrated in Figure 3. Figure 4 shows a picture of measurement place. The width of office is 11.11m×7.99m, height is 2.7m and two sides are windows and the other sides are walls. A measuring distance is about 4.5m, receiving signal strength are measured every 1.32mm interval. Figure 5 shows a schematic diagram of moving measurement system. Table 1 shows measuring conditions of the omni-directional circularly polarized antenna. Table 2 shows the combination of transmitting and receiving polarized waves.



(a) LOS(line-of-sight) condition



(b) NLOS(non-line-of-sight) condition

Fig. 3 Measurement plane and course

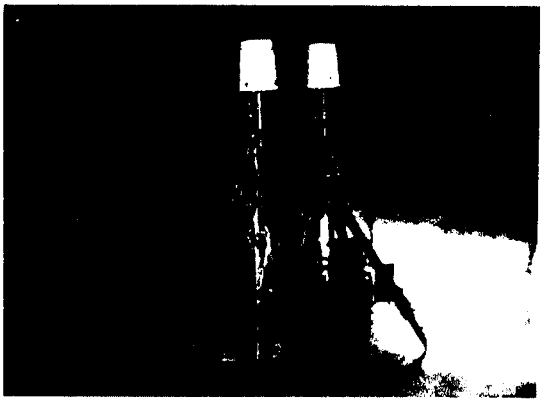


Fig. 4 Practical measurement place

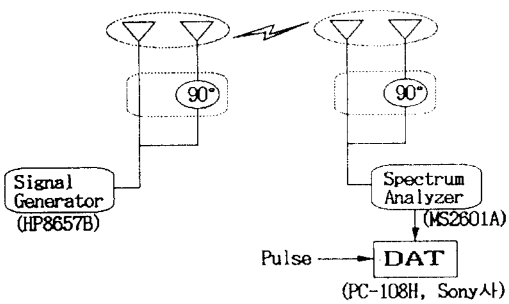


Fig. 5 Measurement system

Table 1. Measuring condition of the omni-directional circularly polarized antenna

Transmitting Power	0 dBm	
Input impedance	50Ω	
Frequency	1.29875 GHz	
Gain	−1.45 dB(0.7dBi)	
Transmitting and receiving antenna height	Transmitting antenna	1.5m/2.7m
	Receiving antenna	1.5

Table 2. Combinations of transmitting and receiving polarized wave

Transmitting	Receiving	Abbreviation
Circular(height:1.5m)	Circular	C-C
Circular	Inverse Circular	C-X
Circular(height:2.7m)	Circular	TC-C
Circular	Vertical	C-V
Circular	Horizontal	C-H
Horizontal	Horizontal	H-H
Horizontal	Vertical	H-V
Vertical	Vertical	V-V
Vertical	Horizontal	V-H

3.2 Conversion method of field strengths

The formula of free space is used for calculating the field strength of received power to be measured. When it radiate signal power $P_t(w)$ from transmitting antenna with G_t gain in free space, field strength E which is r(m) distant toward maximum fixed direction from the receiving spot, is approximately given as follows.

$$E = \frac{7\sqrt{P_t G_t}}{r} \tag{3}$$

where P_t; Transmit power(ω)

G_t; Gain to half wavelength dipole of transmitting antenna

r; Distance from transmit point

Therefore, we used following formula to conversion the received field strength.

$$E_0[\mathrm{dB}] = E_{in} - 20\log h_e + L_f - G_t - G_r \tag{4}$$

where E_0; received field strength

E_{in}; received field strength conversion value from transmitting power

h_e; Antenna effective height

L_f; Feeder loss

G_t; Transmit antenna gain

G_r; Receive antenna gain

Ⅳ. Measuring Results and Consideration

4.1 Fading improvement effect by circularly polarized wave

Figure 6 shows the measured signal strength for circularly polarized wave(C-C) compared with the several cases of polarized wave reception in LOS radio wave propagation environments. In the Figure 6, it is clearly seen that circularly polarized wave(C-C) has not severe damping and shows remarkable fading reduction compared to the reception results of several polarized waves. On the other hand, in the case of NLOS condition(see Figure 7), it was found that the fading reduction is not improved as much as the case of LOS condition.

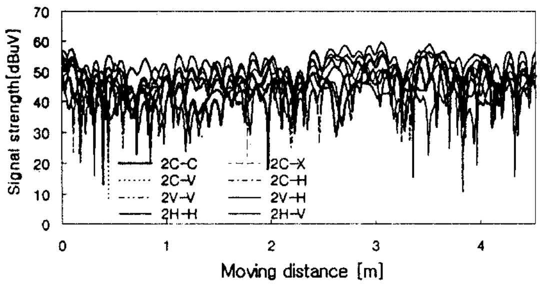


Fig. 7 Signal strengths for NLOS condition

4.2 Fading improvement effect by diversity reception

When a circularly polarized wave is transmitted, the signal strengths received by vertical and horizontal polarized antenna(C-V, C-H) in LOS condition are shown in Figure 8. From the Figure 8, it can be seen that the received signal strengths for C-V and C-H branches are inversely fluctuated with each other corresponding to the most parts of moving distance. This means that the correlation coefficient between C-V and C-H branches has negative value, and then the diversity branches has considerable fading reduction effect. Figure 9 shows correlation graph of the C-V and C-H branches for the Figure 8. Table 3 shows correlation coefficient of each polarized wave branches for the course 2 in LOS condition. And the simulation result of combining and switching selection diversity reception for the Figure 8 is illustrated in Figure 10.

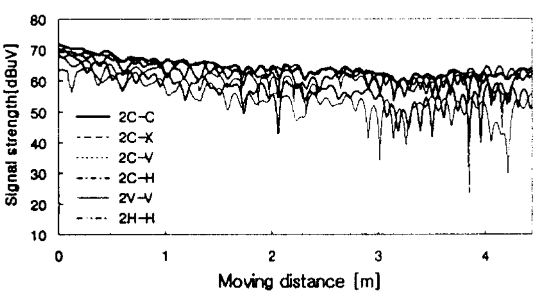


Fig. 6 Signal strengths for LOS condition

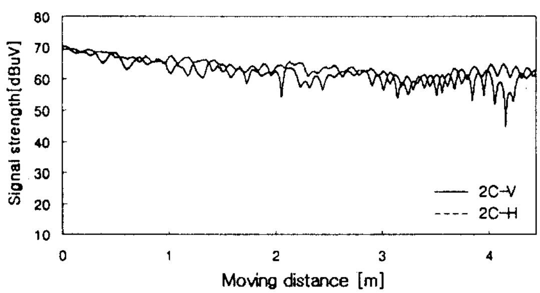


Fig. 8 Signal strengths of the C-V, C-H in Fig. 6

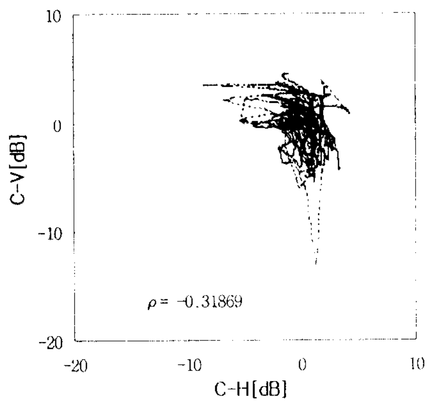


Fig. 9 Correlation graph of the C-V, C-H in Fig. 8

Table 3. Correlation coefficient of the branches (LOS condition)

Branches of transmitting and receiving antenna	CV-CH	CC-CV	CC-CH
Course 2	-0.31869	0.39710	0.33202

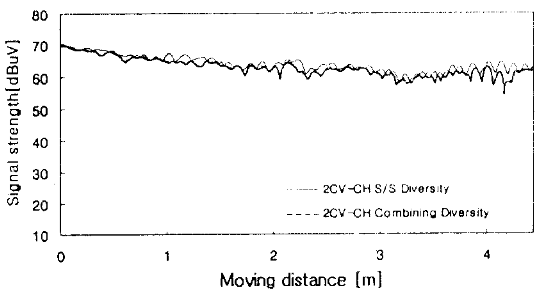


Fig. 10 Polarization diversity reception of Fig. 8

From the Figure 10, it is clearly seen that the polarization diversity reception using C-V and C-H branches in LOS environment can markedly remove the multipath fading.

Figure 11, 12 shows the signal strengths(C-V, C-H; from the Figure 7: course 2) received by vertical and horizontal polarized antenna in NLOS environment when a circularly polarized wave is transmitted in course 1, 2. In the Figure 11, 12 inverse fluctuation between C-V and C-H branches is also shown as like as the LOS condition(see Figure 10: course 2). Table 4 indicates correlation coefficients for the signal strength of each polarized wave branches on the course 1, 2 in NLOS environment. In this case, C-V and C-H branches shows the best correlation(negative value), as like as LOS condition(see Table 3). Figure 13, 14 shows correlation graph of C-V and C-H branches for the Figure 11, 12. Figure 15, 16 shows the result of polarization diversity reception of Figure 11, 12. From the Figure 15, 16, it is also seen that the polarization diversity reception using C-V and C-H branches can remove the multipath fading in NLOS environment. But this fading reduction effect is not good enough as much as LOS condition.

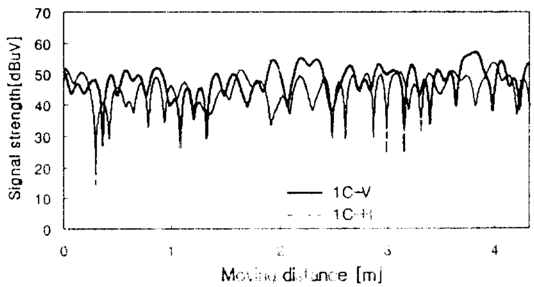


Fig. 11 Signal strengths of the C-V, C-H

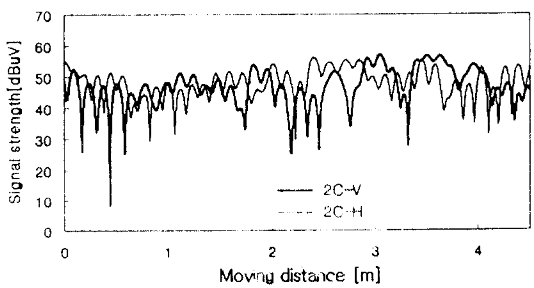


Fig. 12 Signal strengths of the C-V, C-H in Fig. 7

Table 4. Correlation coefficient of branches (NLOS condition)

Branches of transmitting and receiving antenna	CV-CH	CC-CV	CC-CH
Course 1	-0.05214	0.21539	0.42341
Course 2	-0.07499	0.19215	0.25112

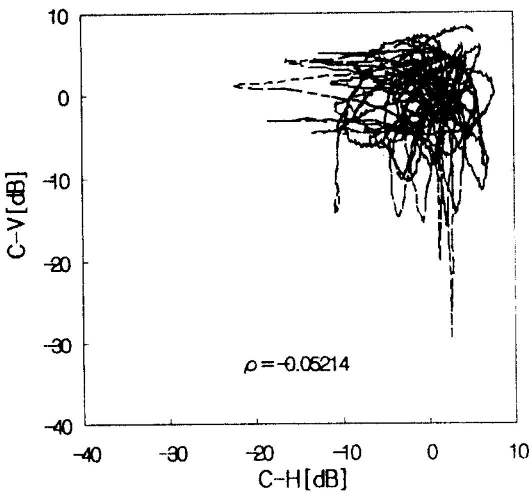


Fig. 13 Correlation graph of the C-V, C-H in Fig. 11 (course 1)

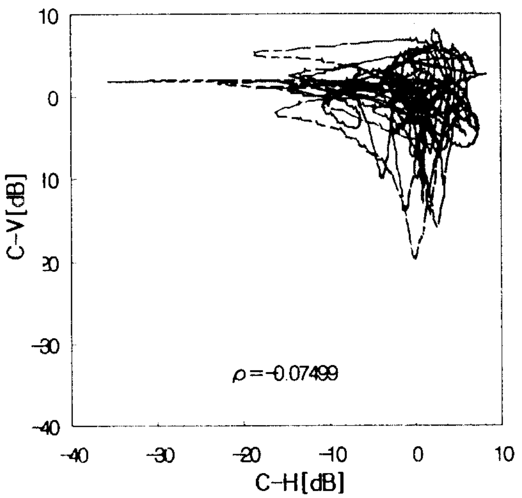


Fig. 14 Correlation graph of the C-V, C-H in Fig. 12 (course 2)

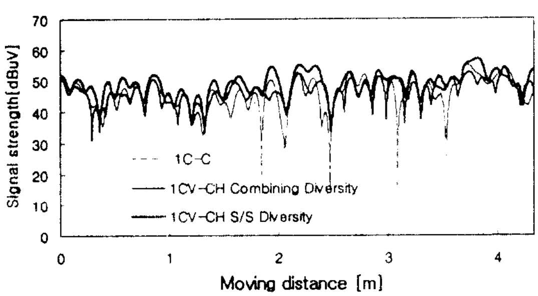


Fig. 15 Polarization diversity reception of Fig. 11 (course 1)

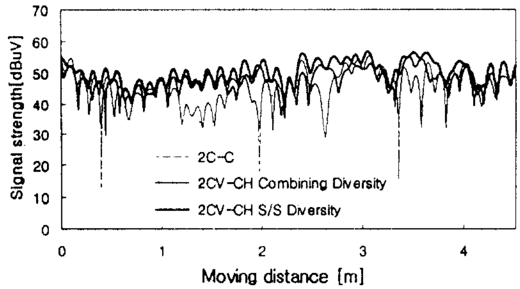


Fig. 16 Polarization diversity reception of Fig. 12 (course 2)

4.3 Fading improvement effect from transmitting antenna height

In NLOS condition, in order to get optimum condition for the polarization diversity, a fading reduction effect due to the variation of transmitting antenna height(2.7m and 1.5m) is examined. Figure 17, 18 shows the received signal strengths for the TC-C and C-C in the test course 1, 2. Figure 17 shows almost the LOS condition due to the receiving point and Figure 18 shows the LOS and NLOS condition due to the receiving point, when the transmitting antenna is located in the ceiling height. It can be seen that the signal strength of 2TC-C, from the 2m to the 4.5m in the Figure 18(see the 2.5m from the wall in the Figure 19; LOS condition), is markedly escaped from multipath fading compared to the 2C-C. It means that the circularly polarized wave, to get the effective fading reduction in indoor wireless environment, must be used in LOS/NLOS condition.

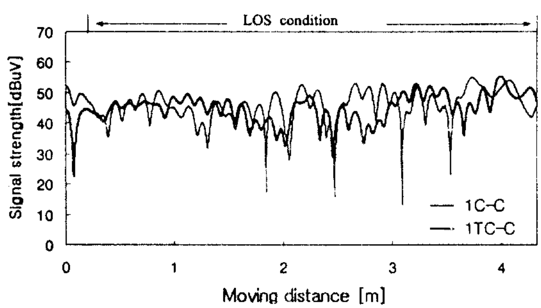


Fig. 17 Signal strength of 1C-C, 1TC-C (existence of an obstacle)

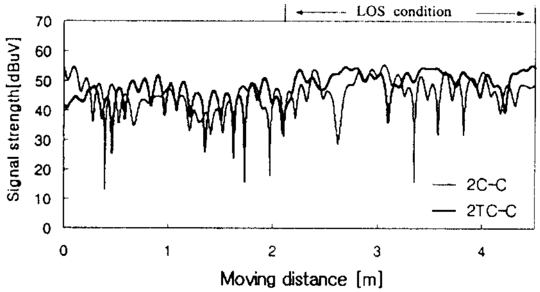


Fig. 18 Signal strength of 2C-C, 2TC-C (existence of an obstacle)

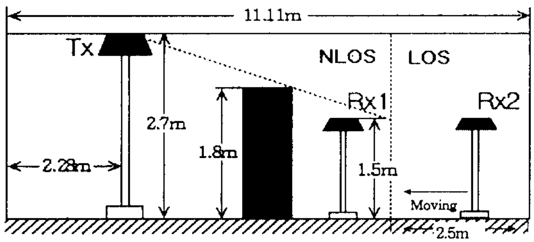


Fig. 19 Changing position of LOS and NLOS condition (course 2)

4.4 Comparison of fading reduction by cumulative distribution

Figure 20 shows cumulative distribution for the received signal strengths of C-C, C-V and C-H waves in LOS condition, including the cumulative of diversity reception result for the C-V and C-H branches. From the Figure 20, fading reduction effect of C-C wave is the best.

Figure 21, 22 shows cumulative distribution curves for the NLOS condition. In this cases, polarization diversity reception of C-V and C-H branches shows the best reduction effect for the multipath fading.

Therefore, to reduce the multipath fading in indoor wireless environment, it can be inferred that a circularly polarized wave should be used in LOS condition and polarization diversity reception composed of C-V and C-H branches must be needed in NLOS condition.

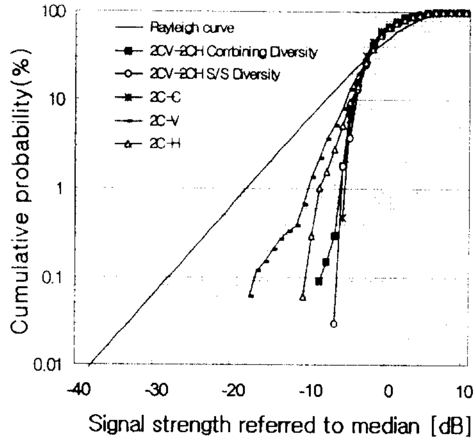


Fig. 20 Cumulative distribution for the LOS

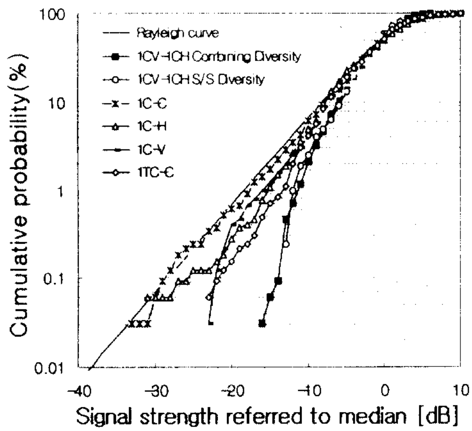


Fig. 21 Cumulative distribution for the NLOS (course 1)

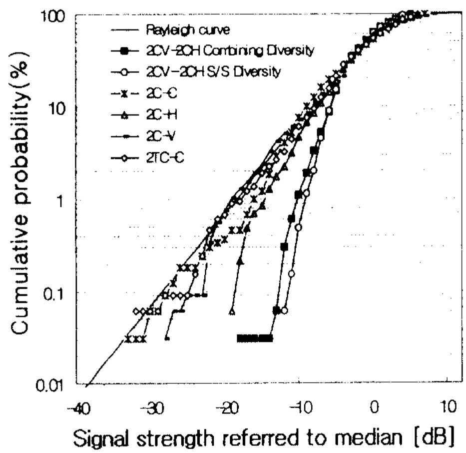


Fig. 22 Cumulative distribution for the NLOS (course 2)

V. Conclusions

In this paper, In order to optimally reduce the fading signals received by a vehicle in motion in indoor wireless environments, omni-directional circularly polarized antenna and polarization diversity reception methods are adopted. Also, to make sure the fading reduction effect for the circularly polarized waves in LOS/NLOS condition the transmitting antenna height was changed on the ceiling high.

From the experimental results, in case of LOS condition, it was found that fading reduction effect by a circularly polarized wave is remarkable. On the other hand, in case of NLOS condition, fading reduction effect using by only circularly polarized wave can not be seen as much as the case of LOS condition. But, in the case of NLOS condition the polarization diversity reception composed of C-V and C-H branches is an effective method to get remove the fading signals.

In conclusion, it can be inferred that the effective fading reduction method in indoor radio environments is to create LOS condition between the transmitting end and the receiving end, and then to form the polarized diversity branches at the receiving end by using a circularly polarized antenna at the transmitting end.

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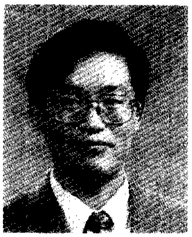

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