A Study on Polarization Diversity for The Next Generation Mobile Radio Communications

Hee-Chang Jung, Seung-Keun Park and Deock-Ho Ha

Abstract

In this paper, in order to investigate the fading reduction effect of narrowband and broadband signals in an indoor multipath propagation environment, both the received narrowband signal while a vehicle unit in motion and the frequency sweeped broadband signal received by vertical polarized antenna, horizontal polarized antenna and circularly polarized antenna are analyzed. Specifically, in order to evaluate polarization diversity effect, we examined the difference of fading reduction effect between the polarization diversity reception and the space diversity reception. Using the correlation coefficient and correlation graph for the polarization diversity branches, the diversity effect is evaluated. And also, using the cumulative distribution for the received signal strength simulated by diversity reception, the diversity effect is also estimated. From the evaluation results it was found that the polarization diversity 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.

I. Introduction

Recently, the need for a global telecommunication system has been tremendously growing since the successful digital mobile telecommunication services such as PCS and CDMA digital cellular. Therefore, the international standards for FPLMTS called by the third generation mobile system are suggested and are discussing about international roaming considering the bit rate system of 2Mbps.

In the personal communications, because the person usually use the radio terminals with more inclined state than vertical state the polarized plane of the transmitting and/or receiving radio wave will be changed with ease. So, we must improve this interference fading for the future mobile communication environments, by considering both the polarization characteristic and the fact that the future system requires multimedia service with high-speed data transmission. And, it must be also considered to investigate the fading characteristic of broadband signals related to high-speed transmission rate. In this paper, we present a polarization diversity reception scheme which has a remarkable effect of fading reduction for the future mobile communications. 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 an omni-directional circularly polarized antenna in indoor wireless environments[6,7,8,9]. And also, we have analyzed the polarization characteristic of the indoor radio wave and then their theoretical results were verified from the measured real data[10,11]. From these analysis results, it can be clearly seen that the difference between the two average signal strengths due to the cross-polarization reception for the vertically polarized wave is higher than the case of the horizontally polarized wave in indoor radio environments. And also, for the case of transmitting the circularly polarized wave, the average received signal strength for the vertically polarized wave is lower than the case of the horizontally polarized wave. In the case for the transmitting of circularly polarized wave, the circularly polarized receiving antenna cannot receive the anti-directional circularly polarized waves caused by odd-times reflection. Therefore, it was also clearly seen that the circularly polarized antenna can remarkedly reduce the multipath fading in indoor radio propagation.

In this paper, we investigate the optimum condition which is the best diversity reception condition to remove the multipath fading when polarization diversity reception is

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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 NLOS(non-line-of-sight) environments. From the measurement analysis, it was found that the effective fading reduction method in indoor radio environments is to form the polarization diversity branches at the receiving end when a circularly polarized antenna is used at the transmitting end.

III. Fading Reduction Effect by Circularly Polarized Wave

1. Polarization diversity reception

In land mobile communication, it is well known that the diversity reception technique at the base station is effective to get large power and to reduce the interference in the mobile station. In this case it can be used a space diversity or a polarization diversity scheme. In particular, the most effective diversity reception is to make small correlation coefficient between the two diversity branches. In case of the space diversity it is difficult to obtain small correlation coefficient. Namely, it is difficult to install the diversity antennas in the transmitting site because the distance interval between the two antennas must be several tens of wave length.

There is a report that polarization diversity scheme is more efficient for the fading reduction strategy than that of space diversity because the correlation coefficient between the two received waves resulting from the polarization diversity is extremely small[12]. And also, this technique is profitable for installing antenna because it does not need to isolate the antenna.

In case of polarized wave, there is a characteristic which the plane of polarized wave is easily rotated by the reflection from the wall in indoor environments. For this reason, if we transmit a vertically(or horizontally) polarized wave in the mobile station and then receive other polarized wave(ex. $\pm 45^\circ$ polarized wave) in the base station, then we can remove the multipath waves with effective. But, the antenna elements of polarization diversity system should be easily inclined from the vertical direction. Thus, this scheme was avoided from the practical use because of disadvantage of falling down the mean level of signal strength compared with vertical polarized wave reception. To solve this problem an omni-directional circularly antenna should be made on the horizontal plane, and then the polarization diversity must be installed in mobile communication environment. Actually, although it has been well known that multipath fading can be reduced by using the circularly wave[13,14], but, so far, there is no attempt to use polarized wave on mobile communication. Because it was difficult to make the omni-directional circularly polarized antenna on the horizontal plane.

But, most recent an omni-directional circularly polarized antenna could be manufactured[15,16]. So that, we can plan to conduct the propagation experiment using this antenna in multipath wave environment, handling the indoor radio wave that is relatively simple wave structure. From the indoor experiment, it was found that the multipath fading can be reduced by using the circularly wave. And also we confirmed that the odd ordered reflection wave(interference wave) from the wall can be removed by only a circularly polarized antenna[9]. Therefore, it is expected that not conventional concept of polarized diversity at the base station but installing the circularly polarized omni-directional antenna at the base station and polarized antenna with two branches of vertical, horizontal wave at the mobile station is profitable for installing the antenna and reducing the fading.

2. Characteristics of circularly polarized antenna [10,11]

In mobile radio communication, electromagnetic radiation is composed of two mutually dependent vector fields, electric and magnetic. The electric and magnetic fields are both transverse to the direction of propagation and orthogonal to each other. The term characterizing the orientation of the field vector is polarization. In radio, polarization usually refers to the electric vector. Horizontal polarization means that the electric vector lies in a plane parallel to the earth surface. In vertical polarization the electric vector is vertical to the earth surface. When the electric vector describes an ellipse in the plane perpendicular to the direction of propagation over one cycle of the wave, we call it elliptically polarized wave. When the amplitudes of the rectangular components are equal and their phases differ by some odd integer multiple of $\pi/2$, the polarization ellipse becomes a circle and the wave is circularly polarized. It is customary to describe as a right-handed circularly polarized wave, which electric field has clockwise rotation to the propagation direction. And counterclockwise rotation is referred to a left-handed polarization.

Meanwhile, when the circularly polarized wave reflected one time from the obstacle the only horizontal polarization element changes into about 180 degree. Therefore it becomes a reverse polarized wave which the turning direction of original electric field vector is reversed. In this situation, the receiving antenna which is composed by a circularly polarized antenna can not receive the reflected waves theoretically, so the multipath fading can be remarkedly reduced.

From the polarization characteristic of circularly polarized wave, a circularly polarized antenna that combine vertical and horizontal polarization elements has a reasonable fading reduction effect in indoor multipath fading environments. This circularly polarized antenna was designed especially combining the horizontal and vertical antenna using phase shift as shown in Figure 1, therefore it can be used as a vertical antenna or horizontal antenna individually.

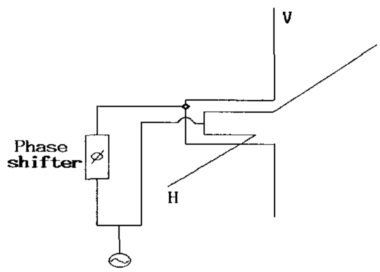


Fig. 1. Composition of the circularly polarized antenna.

III. Outline of Radio Wave Experiments

From the our recent research activities, in case of LOS environments 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 the receiving end is markedly excellent[17]. In this study, to analyze fading reduction effect of circularly polarized antenna and to evaluate the polarization diversity effect, we examined both the polarization diversity reception method and the space diversity reception method from the propagation measurement in indoor NLOS(Non-Line-of-Sight) environment. Specifically, by considering broadband mobile wireless communication system, the signal strengths for the broadband are measured by frequency sweeping method, and then the fading reduction effect between the polarization diversity and the space diversity are also compared.

Radio wave measurements are conducted in a conference room which size is general office scale. Measurement plane and course which shows NLOS is illustrated in Figure 2. 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 3 shows a schematic diagram of moving measurement system for the narrowband signal.

In the moving measurement system, we used vertical, horizontal polarized antenna and omni-directional circularly polarized antenna as the transmitting and receiving antenna. Circularly polarized antenna was composed slip antenna and notch antenna composed of four elements, each antenna can be used vertical and horizontal antenna, respectively. Table 1 shows measuring conditions of the omni-directional circularly polarized antenna. The circularly polarized antenna used in this experiment, omni-directional in horizontal plane, consists of vertical and horizontal elements, each being monopole and notch antennas, respectively[15,16]. The combinations of transmitting and receiving polarization are shown in Table 2. In the moving measurement, transmitting and receiving antenna was fixed at 1.5m high, and the signal generator transmit the 1298.75MHz of non-modulation carrier wave. While a vehicle unit is travelling to the distant direction from the starting spot, which distance is 1 m apart from the transmitting point, the signal strength are measured from the spectrum analyzer connected with a receiving antenna. The first receiving spot is 1 m distant from the transmitting point, and according to the movement until 4.5m distance the received signal strength is measured per 0.0132cm in the path 1 and 2, respectively.

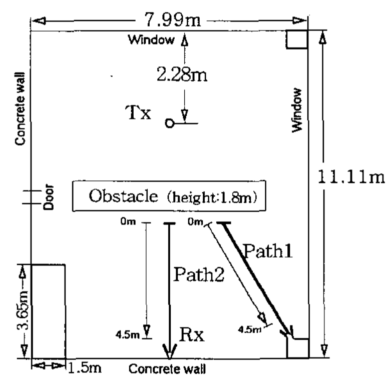


Fig. 2. Measurement plane and course.

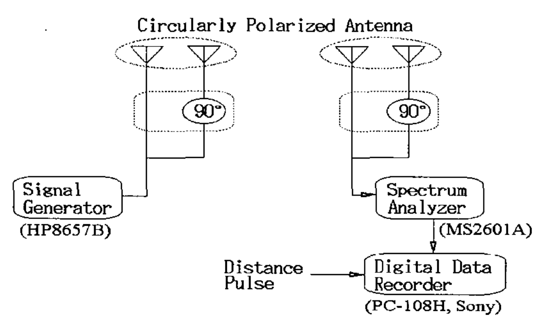


Fig. 3. Moving measurement system.

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

Transmitting Power	0 dBm	
Frequency	1.29875 GHz	
Gain	-1.45 dB	
Transmitting and receiving antenna height	Transmitting antenna	1.5m
	Receiving antenna	1.5m

Table 2. Combinations of transmitting and receiving polarization.

Transmitting	Receiving	Mark
Circular	Circular	C-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

In the case for measuring the broadband signals which show the characteristic of amplitude fluctuation within broad bandwidth, the broadband measurement system illustrated in Figure 4 is used. Spectrum analyzer received the signal strength of non-modulation carrier wave which transmitted from sweep generator with the transmitting power 0dBm, and also that data are recorded in the personal computer. At that time, the transmitting frequency sweeping from 1.1GHz to 1.3GHz.

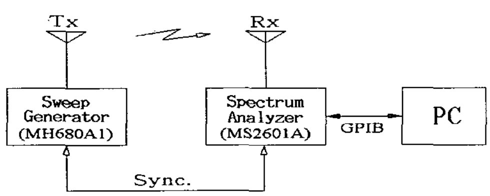


Fig. 4. Broadband measurement system.

In the broadband signal measurement, we fixed receiver in each measuring point on path 1 and 2, and then measured the fluctuation characteristics of signal strength within 200MHz bandwidth. In case of path 1, the measuring range was from 35cm of wall to 510cm(the minimum distance from the receiving point), and measured in total 68 points. Measuring interval was every 30cm point when the vehicle unit was standing from the 510cm to 420cm place of the wall, per 20cm when it was from 420cm to 300cm, per 10cm when it was from 300cm to 200cm, per 5cm when it was from 100cm to 35cm. As like this, the case of the path 2 is also measured in 64 measuring points from 42.5cm to 480cm.

IV. Measurement Results and Consideration

1. Fading improvement effect for the narrowband signal

1) Improvement effect by polarization diversity.

From the our recent research results of indoor LOS propagation experiments, so far, it was found that the technique of transmitting and receiving using a circularly polarized antenna can markedly reduce the fading. But, in NLOS radio wave environment, it was found that fading reduction effect is not so much better than the case of LOS environment. In this case, when a circularly polarized wave is transmitted at the transmitting end the correlation coefficient between the two received polarized waves(vertical polarized branch(C-V) and the horizontal polarized branch(C-H)) at the receiving end shows the characteristic of negative correlation. Thus, it was clearly seen that the polarization diversity reception using those branches has an excellent fading reduction effect.

In this paper, for a more detailed review, we investigated the fading reduction effect by polarized branches of every kind. Figure 5 is an example of the narrowband signal strength for the VV-VH, HH-HV and CV-CH branch in the path 1 and 2. Table 3 shows the correlation coefficient for the two branches of each case in the path 1 and 2. From the Figure 5, it can be seen that the local mean level of the received signal strength for the CH branch is the highest compared with that of the other branches. The next higher order is HH, CV and HV. But, in the Figure 5 (c),(f) it can be seen that the envelope of the received signal strength for the CV and CH branch inversely fluctuates with each other in the almost measurement point. This phenomenon can induce the best condition of the correlation coefficient. It can be also confirmed from the negative correlation coefficient data in the Table 3. Figure 6 shows the correlation graphs for the each polarization branches in the Figure 5. From the Figure 6, it was also found that the correlation between the two polarized branches of the CV and CH(CV-CH branch)) indicates the best inverse characteristic compared with that of the others.

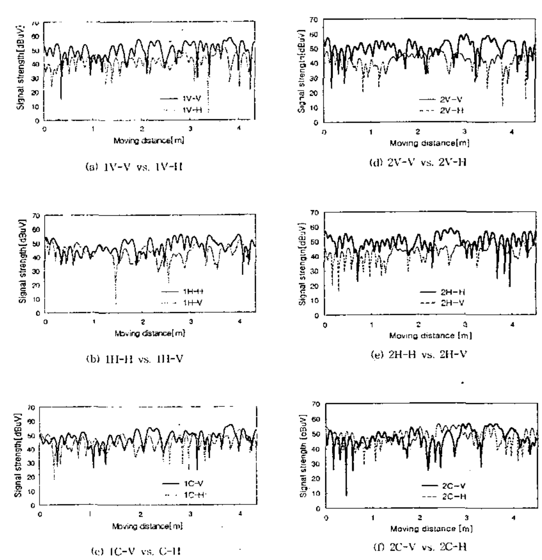


Fig. 5. Signal strength characteristic for the two branches on the path 1 and 2.

Table 3. Correlation coefficient of the two branches.

	CH-CV	HH-HV	VV-VH
Path 1	-0.05214	0.129469	-0.07705
Path 2	-0.07499	0.06188	-0.02039

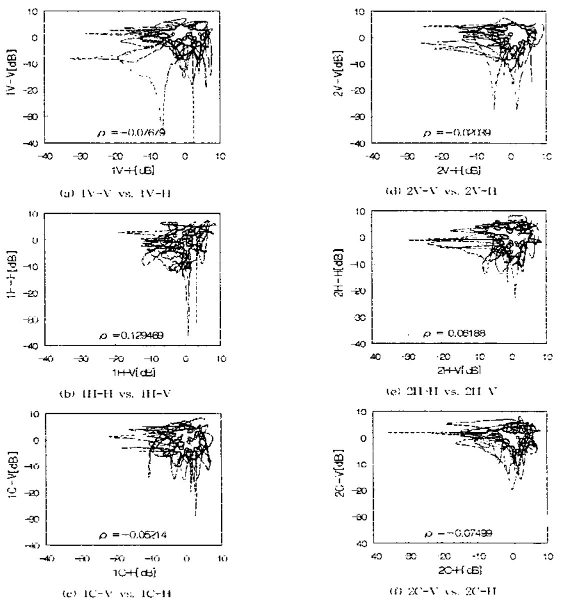
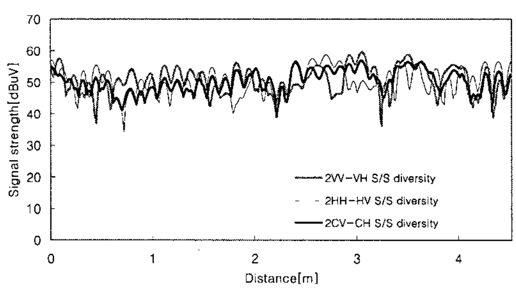


Fig. 6. Correlation graphs for the two branches of the Figure 5.



Fg. 7. Simmulation results for switching selection(S/S) polarization diversity.

Figure 7 shows the signal strength resulting from the switching selection diversity reception for the two polarized wave signals of the Figure 5 (d),(e),(f) which signals indicate the received signal strength on the path 2. The diversity receptions are conducted by computer simulation from the measured data. In case of switching selection diversity reception, the maximum data are selected from the measured two branches data. Figure 8 shows the cumulative distribution curves that indicate the fading reduction effect due to the polarization diversity. In the Figure 8, the 2C-C curve which is obtained from the signal strength received by a circularly polarized antenna when the circularly polarized wave is transmitted are also compared with the other polarized branches. Each curves except the 2C-C is obtained from the switching selection(S/S) simulation for the signal strength in the Figure 7 by the personal computer. In the Figure 8, it can be seen that the polarization diversity reception using the two CV and CH branches indicates the best fading reduction effect in the NLOS environments.

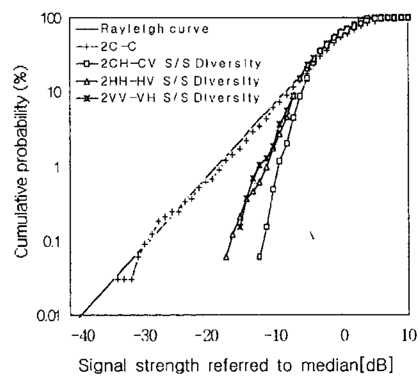


Fig. 8. Cumulative distribution for the polarization diversity.

2) Improvement effect by the space diversity

Table 4 shows the correlation coefficient for the signal strength resulting from the space diversity of the $\lambda/2$ spacial distance in the path 2. Figure 9 shows the cumulative distribution curves for the signal strengths obtained from the $\lambda/2$ space diversity reception of CC, HH and VV branch on the path 2. The diversity was conducted by selection switching with the measured data in the personal computer. From this result, it can be understood that there is no difference between the space diversity effect for each branch. And also, we confirmed that the space diversity effect for the branches of CH, CV, HV and VH show the same effect as the result of the Figure 9.

Table 4. Correlation coefficient of $\lambda/2$ spacial branches.

C-C	C-H	C-V	H-H	H-V	V-V	V-H
0.3675	0.2972	0.0861	0.2040	0.0866	0.0700	0.0085

2. Fading improvement effect for the broadband signal

1) Improvement effect by polarization diversity

Figure 10 (a), (b), (c) show the broadband signal strengths received by frequency sweeping with 200MHz wideband including the S/S diversity result at the point of 240cm from the wall in the path 2. From the Figure 10, it was found that the result of switching selection(S/S) diversity reception for the two polarized branches(CV and CH) indicates the best effect compared with the other branches of HH-HV and VV-VH. Table 5 shows the examples of correlation coefficient for the two polarized waves received by frequency sweeping with 200㎒ wideband at the fixed measuring points in the path 1 and 2. Figure 11 shows the cumulative distribution curves for the broadband signals of the S/S diversity in the Figure 10, including the 2CC of non diversity curve which is obtained from the broadband signal strength received by a circularly polarized antenna when the circularly polarized wave is transmitted in the path 2. From the Table 5 and Figure 11, it can be also seen that the space diversity effect for the two polarized branches(CV-CH) indicate the best result because the correlation coefficient of the CV-CH branches is the smallest at the almost measuring point.

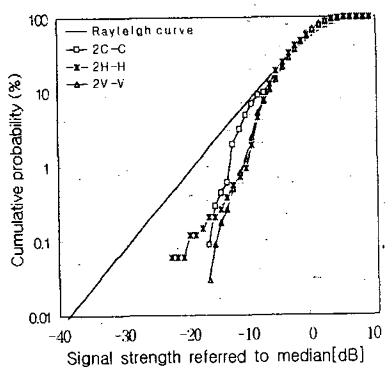


Fig. 9. Simulation results for the space diversity with $\lambda/2$ interval.

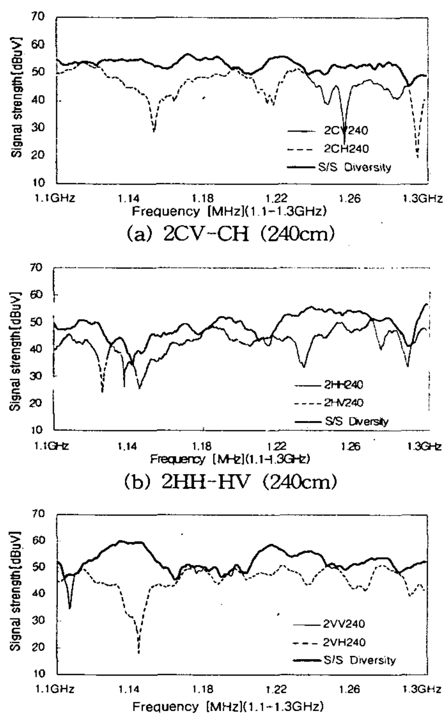


Fig. 10. Simulation results for polarization diversity reception of broadband signals.

Table 5. Correlation coefficient of the two branches.

	Measuring Point(cm)	CV-CH	HH-HV	VV-VH
Path 1	40	-0.24222	-0.31986	0.032813
	90	-0.09958	-0.08666	0.263236
	140	-0.01882	-0.36857	0.464487
	190	-0.46117	0.182339	-0.25399
	240	0.02924	-0.06127	-0.26688
	290	-0.02616	-0.28864	-0.2616
	340	-0.14176	-0.45101	-0.1999
	380	-0.06216	-0.26686	0.200186
	430	-0.23207	-0.37533	0.104206
Path 2	40	0.07041	-0.21572	-0.31651
	90	-0.33896	0.172764	0.075211
	140	0.003633	-0.30317	0.191559
	190	-0.01462	0.029462	0.14923
	240	-0.27616	0.340311	-0.39635
	290	-0.17018	0.07009	0.001295
	340	0.444684	0.113537	0.37022
	380	-0.07307	-0.08417	-0.08174
	430	-0.39863	-0.00403	-0.20721
	490	-0.24972	-0.00539	0.167758

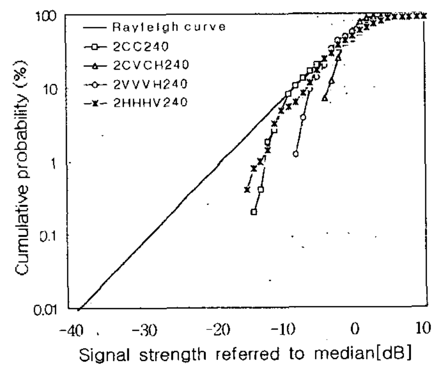


Fig. 11. Cumulative distributions for polarization diversity of broadband signal.

2) The Improvement effect of broadband signal by the space diversity

The two broadband signal strengths received by frequency sweeping for the CC branch on the fixed point of 42cm and 55cm from the wall(the case for $\lambda/2$ spacial interval) in the path 2 and their simulation result of the S/S space diversity for the two signals are illustrated in Figure 12. Figure 13 shows an example of the cumulative distribution for the broadband signal strengths and their space diversity signal in the Figure 12. From the Figure 13, in case of broadband signal strength received by frequency sweeping, it was found that the fading reduction effect by space diversity could not be clearly seen. Table 6 shows the correlation coefficient for the space diversity of the $\lambda/2$ spacial interval. From the Table 6, by comparing the Table 5, it was also found that the space diversity for the broadband signals is not a reasonable diversity scheme in indoor wireless environments.

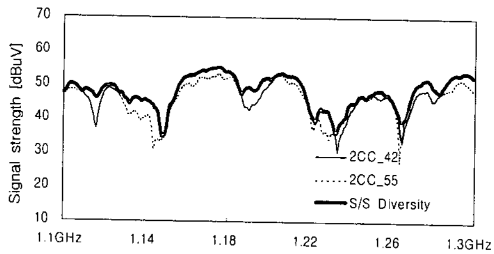


Fig. 12. Example of space diversity for the broadband signal.

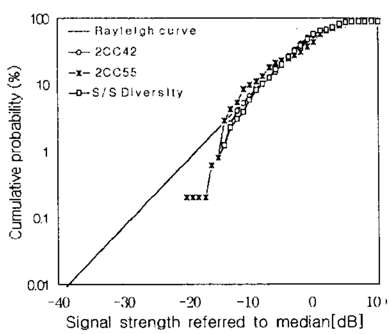


Fig. 13. Cumulative distribution of Fig. 12.

Table 6. Correlation coefficient for the $\lambda/2$ spacial interval

	Space diversity interval(cm)	CC	HH	VV
Path 1	40-52	0.572691	0.595537	0.199236
	45-57	0.203325	0.756376	0.13836
	50-62	0.249448	0.765226	0.008207
	55-67	0.198718	0.741571	0.15394
	60-72	-0.10811	0.337841	-0.13347
	65-77	-0.20385	0.468657	-0.22081
	70-82	-0.11695	0.636473	0.339484
	75-87	0.469504	0.755075	0.755505
	80-92	0.485105	0.199761	0.772158
	85-97	0.760881	0.426202	0.629172
Path 2	40-52	0.619519	0.705794	0.537783
	42-55	0.808384	0.555453	0.415764
	50-62	0.258288	0.785541	0.237196
	55-67	-0.2828	0.570257	0.26733
	60-72	0.719676	0.597581	0.451679
	65-77	0.381162	0.659676	0.494224
	70-82	0.418454	0.583139	0.638625
	75-87	0.647472	0.687678	0.440403
	80-92	0.425227	0.70058	0.457879
	85-97	0.358082	0.735625	0.232593

V. Conclusion

By using the omni-directional circularly polarized antenna, the fading reduction effect and the diversity effect are measured and investigated in indoor non-line-of-sight propagation environments. Particularly, the polarization diversity and space diversity effect are examined. As a result, in the future mobile communication environments considering the broadband wireless transmission system, it can be concluded that the polarization diversity reception using the two polarized branches of the CV and CH(CV-CH branch) may be used to reduce the multipath fading in indoor wireless communications because the fading reduction of the polarization diversity is much better than that of the space diversity reception. And also, it was found that the composition of the effective diversity branches for the polarized waves is to install a circularly polarized omni-directional antenna at the transmitting end and to compose the vertical and/or horizontal polarized antenna at the receiving end. Although the diversity of switching selection method is only presented in this paper, it was also found that the combining method indicates the same result. It will be necessary to compose the real experimental diversity system and also to include other BER improvement experiments into the polarization diversity for the next generation communications. This will be done in further research.

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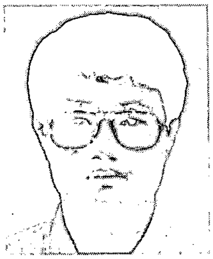
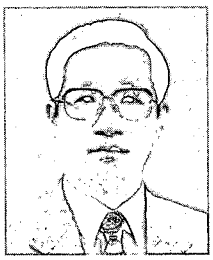
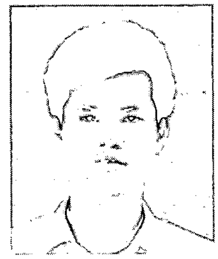


Hee-Chang Chung was born in Kangwon province korea, on June 12, 1954. He received the B.S. degree in electronics engineering form Korea University, seoul, korea in 1980, and the M.S. and Ph.D. degrees from Ajou University, Kyonggi, korea, in 1989 and 1997, respectively. In 1980 he joined the researcher of ETRI, taejon, korea, where he is a principal researcher. His research interests include the radio regulation and spectrum management for GMPCS and Mobile communications.



Deock-Ho Ha was born in Kyong-Gi Prefecture, Korea, on February 18, 1954. He received the B.S. degree in electronics engineering from Hanyang University, Seoul, Korea in 1979, and the M.S. and Ph.D. degrees from Kyoto Univeristy, Kyoto, Japan, in 1984 and 1987, respectively. From 1979 to 1981 he was a Research Engineer with The Central Research Institute of LG Group in Seoul, Korea. From March to August 1987 he was a Research Engineer with The Wireless Research Institute of Matsushita Electric Industrial Co. Ltd. From 1990 to 1991 he was a Visiting Scholar with The Digicom Laboratory in University of California at Davis. In 1987 he joined the faculty of Pukyong National University, Pusan, Korea, where he is an Associate Professor. His research interests include antenna and propagation, transmission code theory, and digital communication systems for the mobile radio. Dr. He is a member of the Korean Institute of Communication Science and the Korea Electromagnetic Engineering Society and the Korea Institute of Telematics and Electronics and the Institute of Electronics, Information and Communication Engineers of Japan.



Seung-Keun Park was born in Seoul, received the B.S. and M.S. in statistics from the University of Korea in 1991 and 1993, respectively. Since 1993 he has been at ETRI, where he is currently a member of engineering staff. His research interests are in the area of RF spectrum, nonlinear estimation, and radio regulation.