The Circular Polarization Diversity Effect Considering XPD Factor in an Indoor Radio Propagation Environment

Je-Sung Ahn[1] · Deock-Ho Ha[1] · Pyung-Dong Cho[2]

Abstract

In this paper, we analyzed new two-branch polarization diversity at the receiving end of a mobile link which a transmitter emits circularly polarized wave. To analyze the correlation coefficient considered by XPD(Cross Polarization Discrimination) between the two received signals, a simple theoretical model of circular polarization diversity is adopted and experimental measurements are also conducted. From both theoretical and measurement results, it can be seen that the proposed circular polarization diversity scheme is more effective than that of the conventional linear polarization diversity.

Key words : XPD(Cross Polarization Discrimination), Circular Polarization Diversity.

Ⅰ. Introduction

In wireless radio environment, diversity technique is very useful method for combating multi-path fading. Both space diversity and polarization diversity have been mainly utilized in the base station diversity reception system[1],[2]. In general, it is also well known that effective diversity can be achieved by the correlation coefficient, that is less than approximately 0.7 [3],[4]. To keep the value below 0.7, space diversity requires antenna separation up to the 20 wavelengths. It is sometimes difficult to mount the diversity antenna on a tower with two antennas spaced by 20 wavelengths.

On the other hand, polarization diversity at the base station does not require antenna space because of the co-planer antenna configuration. If a micro-strip antenna implemented by two co-planer polarization antenna is used, the polarization diversity system can be easily implemented without space intervals. In [5] and [6], an expression of correlation coefficient is derived from signal envelopes received by each polarization diversity branch at the station where the elevation angle of ray is zero. In [7], an expression for the correlation coefficient and average branch signal levels is also derived for the case of oblique incidence where the elevation angle is not zero. In this case two-branch polarization diversity at the receiving end of a mobile link is analyzed when the transmitter emits a linearly polarized signal.

In this paper, we discuss a new circular polarization diversity reception scheme in which circularly polarized signals radiated from the transmitting end are received by two linear polarized base station antenna with an ($\pm\alpha$) angle. An expression of correlation coefficient considered XPD factor for the circular polarization diversity model is derived from oblique incidence which the elevation angle is not occurs. And also, we estimate the performance of circular polarization diversity system from the measurement data which are carried out in an indoor NLOS environment.

Ⅱ. Theoretical Model of Circular Polarization Diversity

Fig. 1 shows the configuration of a circular polarization(CP) antenna[8]. We fabricated a circular polarization antenna, which is composed by two co-planer micro-strip antenna(a vertical and a horizontal micro-strip antenna with 90 degree phase shifter).

Fig. 2 is the model of circularly polarized diversity. As shown in Fig. 2, a transmitting antenna emits circularly polarized signal while the receiving end uses a two-branch polarized diversity antenna. Let the receiving antenna system be positioned at the origin, and the angular location of the transmitter is given by ϕ and θ from the origin, both of which are oriented at an angle α from the positive z-axis. It is also assumed that the transmitter and receiver ends are located in an urban environment and they are sufficiently far away to produce a Rayleigh-distributed signal at the receiver.

Generally, the circular polarization is expressed as follows;

$$E_{RC} = E_H + jE_V, \quad (1a)$$

$$E_{LC} = E_H - jE_V \quad (1b)$$

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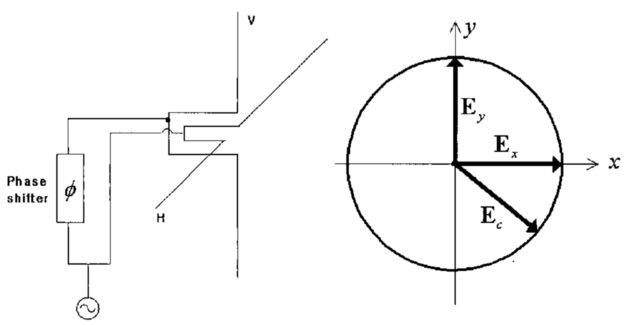


(a) CP antenna (b) CP wave with axial ratio

Fig. 1. Circular polarization antenna configuration.

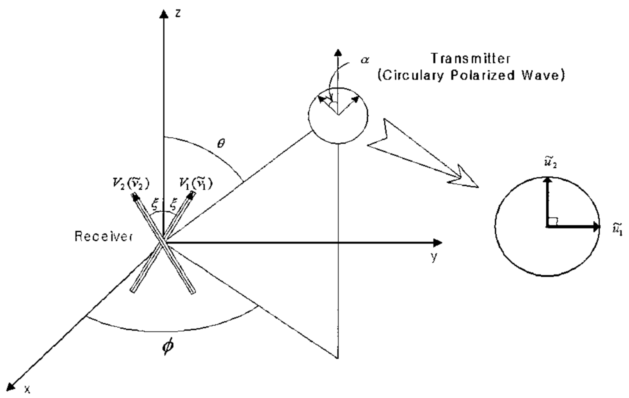


Fig. 2. Reception model of circular polarization diversity.

Where, E_{RC} is the electric field of right-handed circular polarization and E_{LC} is the electric field of left-handed circular polarization. Also, the signal arriving at the receiving end consists of vertical and horizontal polarized components (E_S, E_H) and the two polarized components are expressed as follows;

$$E_H = r_1 \cos(\omega t + \phi_1), \tag{2a}$$

$$E_V = r_2 \cos(\omega t + \phi_2) \tag{2b}$$

Where, it is assumed that r_1 and r_2 are Rayleigh-distributed and uncorrelated. ϕ_1 and ϕ_2 are random, uniformly distributed, and uncorrelated. The vector form of equation (1) can be represented as follows;

$$\tilde{E}_{RC} = e_R \cos(\omega t + \phi_R)\,\tilde{u}_1 + e_R \cos(\omega t + \phi_R + \frac{\pi}{2})\,\tilde{u}_2 \tag{3a}$$

$$\tilde{E}_{LC} = e_L \cos(\omega t + \phi_L)\,\tilde{u}_1 + e_L \cos(\omega t + \phi_L + \frac{\pi}{2})\,\tilde{u}_2 \tag{3b}$$

Where, the unit vector $\tilde{u}_1$ and $\tilde{u}_2$ are perpendicular to the direction of propagation. The unit vector $\tilde{u}_1$ lies in the horizontal plane and $\tilde{u}_2$ is non-horizontal and tilted from the vertical axis by the elevation angle, $\alpha(\alpha = \frac{\pi}{2} - \theta)$. e_R and e_L are Rayleigh-distributed random variables of right-handed and left-handed circular polarization signals, respectively. The unit vector $\tilde{u}_1$ and $\tilde{u}_2$ in Fig. 2 are represented as follows;

$$\tilde{u}_1 = -\sin\phi\,\tilde{x} + \cos\phi\,\tilde{y}, \tag{4a}$$

$$\tilde{u}_2 = -\sin\alpha\cos\phi\,\tilde{x} - \sin\alpha\sin\phi\,\tilde{y} + \cos\alpha\,\tilde{z} \tag{4b}$$

And also, in Fig. 2, when the expression of each unit vector of two-branch received diversity branches is the same as equation (5), the received electric field to each branch is represented as equation (6). In this case, the diversity branches V_1 and V_2 are tilted from the z-axis by the angle, ξ. The unit vector $\tilde{v}_1$ and $\tilde{v}_2$ are represented as follows;

$$\tilde{v}_1 = \sin\xi\,\tilde{y} + \cos\xi\,\tilde{z}, \tag{5a}$$

$$\tilde{v}_2 = -\sin\xi\,\tilde{y} + \cos\xi\,\tilde{z} \tag{5b}$$

Using equations (1a)~(5b) we can show that the received signal by antenna V_1 (branch1) is proportion to:

$$\begin{aligned} V_1 &= E_{RC}\,\tilde{u}_1 \cdot \tilde{v}_1 + E_{LC}\,\tilde{u}_2 \cdot \tilde{v}_1 \\ &= \{-e_R\cos(wt+\phi_R)(\cos\phi\sin\xi) \\ &\quad + e_R\sin(wt+\phi_R)(-\sin\beta\sin\phi\sin\xi) \\ &\quad + e_R\sin(wt+\phi_R)(\cos\alpha\cos\xi)\} \\ &\quad + \{e_L\cos(wt+\phi_L)(\cos\phi\sin\xi) \\ &\quad + e_L\sin(wt+\phi_L)(\sin\alpha\sin\phi\sin\xi) \\ &\quad - e_L\sin(wt+\phi_L)(\cos\alpha\cos\xi)\} \end{aligned} \tag{6a}$$

Where,

$a = \sin\xi\cos\phi$,

$b = \cos\alpha\cos\xi - \sin\alpha\sin\phi\sin\xi$,

Similarly, the received signal by antenna V_2(branch 2) is proportional to:

$$\begin{aligned} V_2 &= E_{RC}\,\tilde{u}_1 \cdot \tilde{v}_2 + E_{LC}\,\tilde{u}_2 \cdot \tilde{v}_2 \\ &= \{-e_R\cos(wt+\phi_R)(\cos\phi\sin\xi) \\ &\quad + e_R\sin(wt+\phi_R)(\sin\alpha\sin\phi\sin\xi) \\ &\quad + e_R\sin(wt+\phi_R)(\cos\alpha\cos\xi)\} \\ &\quad + \{-e_L\cos(wt+\phi_L)(\cos\phi\sin\xi) \\ &\quad - e_L\sin(wt+\phi_L)(\sin\alpha\sin\phi\sin\xi) \\ &\quad - e_L\sin(wt+\phi_L)(\cos\alpha\cos\xi)\} \end{aligned} \tag{6b}$$

Where,

$$c = \cos\alpha\cos\xi + \sin\alpha\sin\phi\sin\xi \tag{7}$$

The amplitudes of the received signals by V_1 and V_2 are therefore proportional to:

$$A_1=\{(a^2+b^2)(e_R^2+e_L^2)$$
$$+2e_Re_L((a^2-b^2)\cos(\phi_R-\phi_L)$$
$$+2ab\sin(\phi_R-\phi_L))\}^{1/2} \tag{8}$$
$$A_2=\{(a^2+c^2)(e_R^2+e_L^2)$$
$$+2e_Re_L((a^2-c^2)\cos(\phi_R-\phi_L)$$
$$-2ab\sin(\phi_R-\phi_L))\}^{1/2} \tag{9}$$

In [7], a General equation of correlation coefficient (ρ) is represented as equation (10).

$$\rho=\frac{\langle A_1^2\cdot A_2^2\rangle-\langle A_1^2\rangle\langle A_2^2\rangle}{[(\langle A_1^4\rangle-\langle A_1^2\rangle^2)(\langle A_2^4\rangle-\langle A_2^2\rangle^2)]^{1/2}} \tag{10}$$

By substituting equation (8), (9) into equation (10), correlation coefficient is given by equation (11).

$$\rho=\frac{(a^2+b^2)(a^2+c^2)(I+\Gamma^2)+2\Gamma(a^2-b^2)(a^2-c^2)-8\Gamma a^2bc}{[(a^2+b^2)^2(a^2+c^2)^2(I+\Gamma)^4]^{1/2}} \tag{11}$$

Where,

$$XPD=\frac{\langle e_R^2\rangle}{\langle e_L^2\rangle}\cong\Gamma \tag{12}$$

Assuming that the reception model of circular polarization diversity, we calculated a correlation coefficient (ρ) considering XPD. In this model, a transmitting antenna emits circularly polarized signal while the receiving end uses a two-branch polarized diversity antenna. It is also assumed that the transmitter and receiver unit are located in the wireless environment, and they are sufficiently far away to produce a Rayleigh distributed signal at the receiver.

Ⅲ. The Measurement Results of an Indoor Radio Environment

In order to certify the better performance of circular polarization diversity we implemented a circular polarization diversity system for measuring the signal strength in indoor wireless environments. The diversity system is composed of vertical and horizontal polarization antennas and $\frac{\pi}{2}$ Hybrid combiner(with a phase shifter of 90°) using micro-strip substrate[8].

To estimate the performance of fabricated circular polarization diversity system, we have conducted moving measurements in an indoor NLOS environment. Fig. 3 shows the measurement environment. The transmitting unit is propagated at a center frequency of 2.4 GHz using the signal generator. The received signal strength and distance pulse data are recorded automatically by a DAT(Digital Audio Tape-recorder). The signal data are gathered every 1.375 mm sample distances. The measured distance of Path 1 and 2 is about 4.5 m.

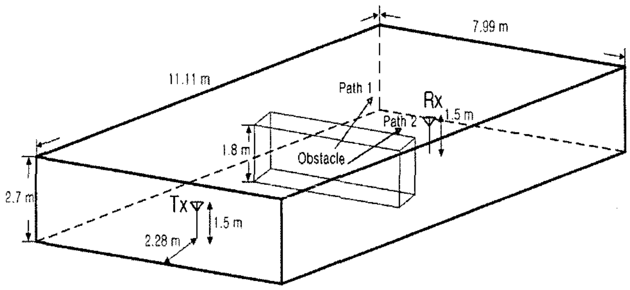
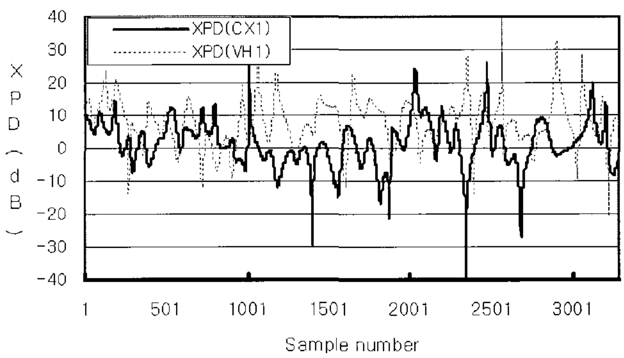
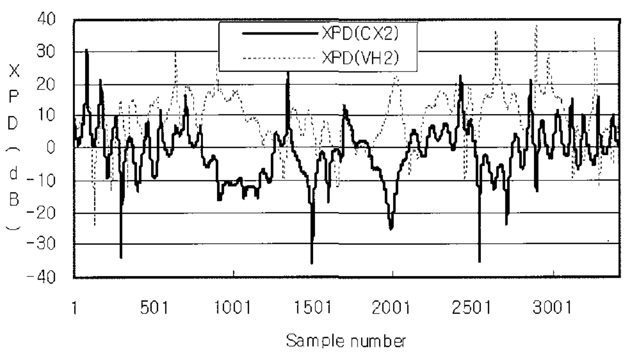


Fig. 3. An indoor NLOS mobile measurement environment.

Fig. 4 shows the XPD value for the circular and linear polarized wave in path 1 and 2, respectively. In this Fig. 4, the character CX indicates that transmitting antenna uses a circular polarization antenna and receiving antenna is cross-handed circular polarization antenna. And the character VH means vertical and horizontal antenna combination. From the Fig. 4 and Table 1, it can be clearly seen that the XPD value for the case of using circular polarized wave at the transmitting end is lower 6~7 dB than that of using vertically polarized wave. This means that the XPD value using circularly



(a) XPD for path 1



(b) XPD for path 2

Fig. 4. XPD of path 1 and 2 in indoor NLOS environment.

Table 1. Mean and standard deviation for XPD of path 1, 2.

		XPD (dB)	
		Mean	Standard deviation
Path 1	CX	1.43	6.96
	VH	8.01	7.06
Path 2	CX	1.44	8.08
	VH	8.66	7.93

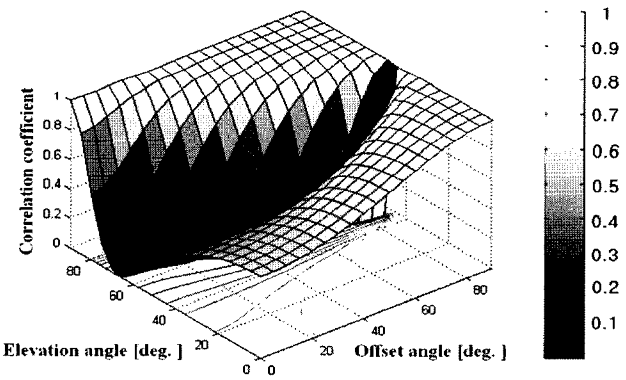
polarized diversity system indicate lower value than that of the case of using linear polarization at the transmitting end. Because CX can not receive the reflected waves which are reflected by odd time.

From this reason, to investigate the effect of XPD factor we investigated the correlation coefficient difference between circular polarization and linear polarization diversity. Using the correlation coefficient showed in the equation (11), we adopted the measured XPD value in the equation (11) and compared the correlation coefficient between the two diversity schemes.

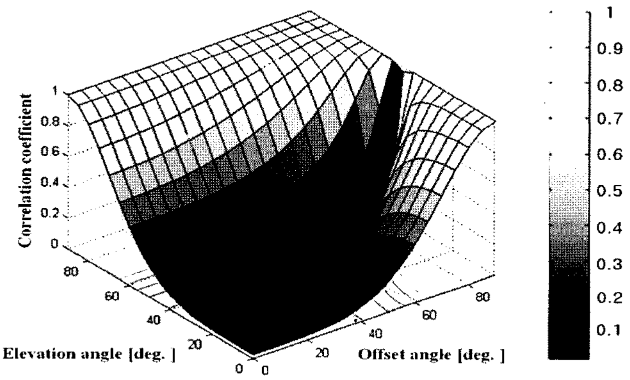
Fig. 5 shows a correlation coefficient in 3-D diagram when linearly polarized antenna and circularly polarized antenna are used at the transmitting end, respectively. As shown in Fig. 5, correlation coefficient value of circular polarization diversity is much lower than that of conventional linear polarization diversity because in the case where the circular polarized wave is applied, therefore XPD value is also much lower than that of the linear polarized wave. So it can be predicted that circular polarization diversity is a more effective diversity technique to reduce the multi-path fading in indoor wireless environments.

Fig. 6 shows the fading reduction characteristic of the received signals for the circular polarization diversity and linear polarization diversity, respectively. From the measurement results, it can be also seen that the fading reduction effect for the case of circular polarization diversity shows more effective.

Fig. 7 shows the correlation diagram for the two diversity schemes. From these correlation diagram, it can be also seen that the circular polarization diversity scheme(C-VH diversity branch: transmitting antenna is a circular polarization antenna and two receiving branches of vertical and horizontal antenna) indicates more reverse correlation characteristic compared to the linear

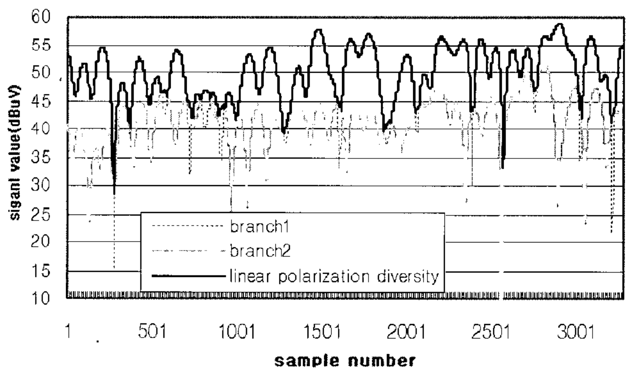


(a) The conventional linear polarization diversity (XPD: 8.3 dB, ξ=45°)

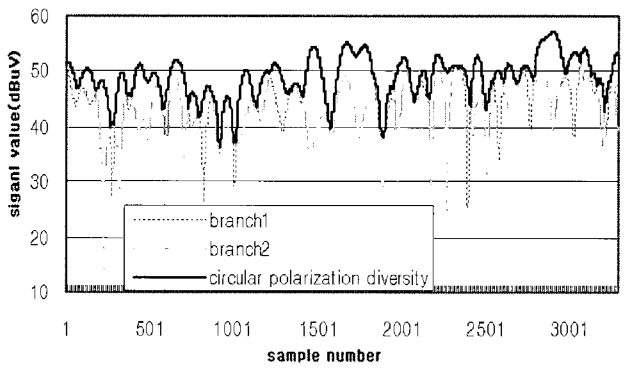


(b) The circular polarization diversity (XPD: 1.4 dB, ξ=45°)

Fig. 5. Correlation coefficient for the two models.

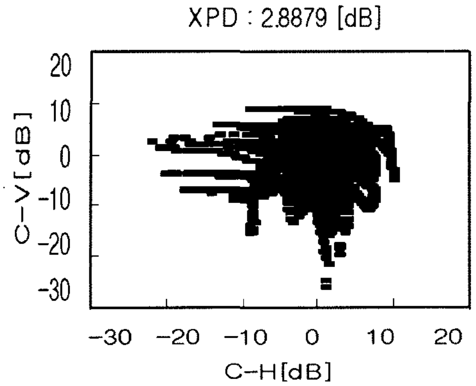


(a) Result of linear polarization diversity

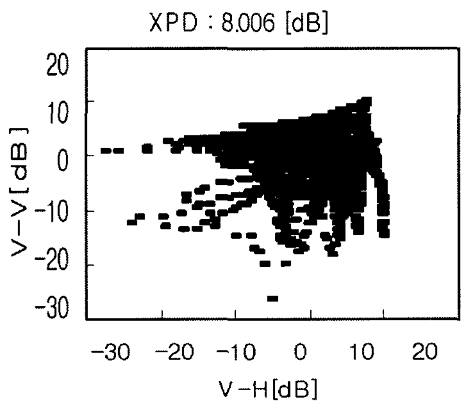


(b) Result of circular polarization diversity

Fig. 6. Fading reduction characteristic of each diversity scheme.



(a) C-VH diversity branch



(b) V-VH diversity branch

Fig. 7. Estimation for correlation diagram.

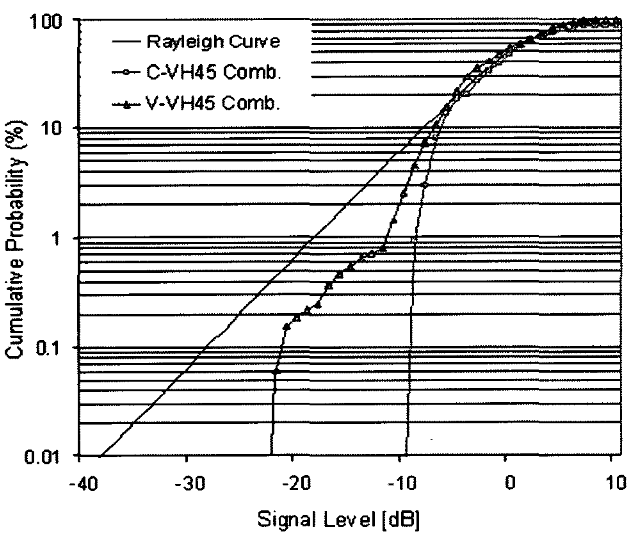


Fig. 8. Performance estimation for polarization diversity probability distribution.

polarization diversity(V-VH diversity branch: transmitting antenna is a vertical polarization antenna and two receiving branches of vertical and horizontal antenna).

Fig. 8 shows a cumulative probability distribution for the Fig. 6. From the Fig. 8, it confirms that the circular polarization diversity scheme shows more effective fading reduction method compared to the conventional linear polarization diversity. Fig. 8 shows that the circular polarization diversity(C-VH45) has about 3 dB gain in comparison with the linear polarization diversity(V-VH45). In this case, the angle ξ=45°.

As shown in Fig. 6~Fig. 8, the circular polarization has a characteristic that it can effectively remove the reflected waves which are reflected by odd time. By reducing the influences of the reflected wave, the circular polarization can reduce the time delay spread and the inter-channel interference.

Ⅳ. Conclusion

We have studied that the circular polarization diversity system, it was found that correlation coefficient value of the proposed circular polarization diversity system show lower value than that of conventional linear polarization diversity. To estimate proposed system performance, we have also measured propagation characteristic with a vehicle in motion using the implemented circular and conventional polarization diversity systems in indoor NLOS environments. From the measurement results, it was also found that the proposed circular polarization diversity scheme has better diversity gain than that of the conventional linear polarization diversity in an indoor radio propagation environment.

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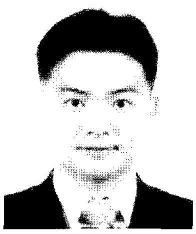

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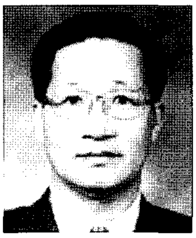

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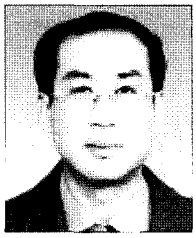

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