Line-of-Sight Transmission Performance of 42-GHz Band Cross-Polarized MIMO Multiplexed Transmission

Shinichi Suzuki (member)[†], Naoto Kogo (member)[†], Takayuki Nakagawa (member)[†],
Tetsuomi Ikeda (member)[†]

Abstract We are developing a millimeter-wave mobile camera that wirelessly transmits 100 Mbps class High-definition TV (HDTV) video at low compression and with low latency. To realize an uninterrupted wireless transmission while maintaining a high transmission rate, we are investigating the application of multiple-input multiple-output (MIMO) multiplexed transmission technique and millimeter-wave band that enable the use of wide bandwidth. In this article, with the aim of enabling this camera to operate in outdoor line-of-sight (LOS) environments, we performed an evaluation of cross polarized MIMO multiplexed transmission with a horizontally/vertically polarized omni antenna using a film polarizer. As a result, we were able to suppress the transmit correlation between MIMO propagation channels to 0.45 or less, and we achieved a substantial improvement in bit error rate (BER) performance (median value reduced to about 1/30 or less). On the other hand, we have confirmed that the range within which uninterrupted wireless transmission is possible becomes smaller due to the reduction in received power in cross polarization, and we have clarified the cross polarization power ratio (XPR) suitable for LOS transmission environments.

Key words: millimeter-wave, wireless HDTV camera, MIMO, cross polarization, line-of-sight, channel correlation

1. Introduction

By using wireless HDTV cameras for the TV program production, we can expect to achieve benefits such as a greater range of visual expression due to the improved mobility of these cameras, and better safety for performers due to the absence of camera cables. We are developing a wireless HDTV camera that can transmit high-quality compressed HDTV video of comparable quality to cable-connected HDTV cameras. Even when moving freely, this camera is required to transmit HDTV video with high link reliability (no interruptions), high picture quality based on a compressed video bit rate of approximately 100 Mbps (no viewer discomfort), and low latency (video latency of 1 frames or less)¹⁾. We are therefore investigating a millimeter-wave mobile camera with a wireless system that uses the broadband of millimeter-wave band (42/55 GHz) in combination with MIMO multiplexed transmission for greater transmission capacity and diversity effects.

MIMO multiplexed transmission uses multiple transmitting and receiving antennas to transmit different signals by multiplexing them at the same frequency and the same time²⁾³⁾. This technology can be expected to greatly increase the transmission capacity in multi-path rich environments like indoor environments, but its signal separation performance is greatly impaired in LOS environments where there are few reflected waves and a strong correlation between propagation channels⁴⁾. It has been reported that a high transmission capacity can be maintained even in LOS environments by suppressing the correlation between propagation channels through the use of orthogonal polarization with vertically and horizontally polarized antennas in many papers^{5)~9)}. In addition, other reports have described the design of a dual-polarized antenna that combines vertically and horizontally polarized antennas into a single unit to make the transmitter more compact and space-saving. In these reports, the investigation of MIMO multiplexed transmission by using the dual-polarized antenna that improves the cross-polarization discrimination (XPD) between antennas that are situated very close together relative to the wavelength^{10)~12)}. However, in the majority of these reports, the vertical and horizontal antennas are directional, and there are few

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[†] Science & Technology Research Lab, Japan Broadcasting Corporation (NHK)

(1-10-11, Kinuta, Setagaya-ku, Tokyo 157-8510, Japan)

studies that use omni-directional antennas suited to mobile transmission systems where the transmitter can move freely. While there have been studies of omni-directional dual-polarized antennas¹⁰⁾, but it's difficult to apply the dual-polarized antennas to our target due to the structural difficulty of creating prototypes for millimeter-wave and the widely different radiation patterns because the vertical and horizontal polarization antennas have different structures. In particular, in mobile transmissions, since the signal should ideally be transmitted from each transmitting antenna with the same radiation pattern in MIMO multiplexed transmission, these omni-directional antennas cannot be said to have adequate characteristics as transmitting antennas in mobile communications.

On the other hand, according to the above reports of cross-polarized MIMO multiplexed transmission, the transmit correlation is suppressed by the orthogonal polarization, and the transmission characteristics are improved in outdoor line-of-sight environments. However, although some references point out that the received carrier-to-noise ratio (CNR) is reduced by this orthogonal polarization⁷⁾¹¹⁾, there have been no reports of studies that demonstrate experimentally how XPR affects the transmit correlation, and that investigate how the XPR and received CNR affect the mobile communication range of transmitter.

With the aim of developing a millimeter-wave mobile camera to allow the transmitter to move around freely even in non-line-of-sight environments, we have produced a prototype millimeter-wave band omni-directional antenna which has same radiation pattern between vertically and horizontally polarized waves. We confirmed that this prototype antenna works effectively by performing outdoor transmission tests of cross-polarized MIMO multiplexed transmission. Furthermore, to increase the mobile range of the transmitter, we investigated the XPR that minimizes the reduction of received CNR and receiving diversity by orthogonal polarization based on the experimental results. As a result, we found that by implementing XPD where the XPR takes a value of approximately 8 [dB], it is possible to increase the range of mobility of the transmitter in the line-of-sight environment where the experiments were performed.

Section 2 of this paper presents an overview of the millimeter-wave mobile camera system. In section 3, we describe the design policy and structure of the prototype omni antenna, and we discuss the results of

Fig. 1 Millimeter-wave mobile Camera system.

radiation pattern measurements. Then in section 4, we discuss the results of outdoor MIMO multiplexed transmission tests with orthogonal polarization using the prototype omni antenna. Finally we present our conclusions in section 5.

2. Millimeter-wave mobile camera system

Fig. 1 shows an overview of the millimeter-wave mobile camera system. It is assumed that the millimeter-wave mobile camera transmits compressed HDTV video with a data rate of at least 100 Mbps and a low delay of 1 frame or less.

We also aim to implement a high level of link reliability even when the camera is moved around freely within a range of 100 [m] or more. Therefore, in the millimeter-wave mobile camera, MIMO multiplexed transmission using a dual transmitting antenna and a quad receiving antenna is applied.

The captured HDTV video is compressed by an MPEG-2 encoder into a 160 [Mbps] TS signal, which is output as two OFDM signals by a MIMO-OFDM modulator. The two OFDM signals are transmitted from the 42-GHz transmitter by each transmitting antenna at the same frequency in the 42 [GHz] band. At the receiver side, these OFDM signals are received by the quad receiving antenna, and are output as IF signals from each of the 42-GHz receivers. The original OFDM signals are then separated and demodulated in the MIMO-OFDM demodulator and are passed through the MPEG-2 decoder to yield the original TS signal. Assuming that a camera operator equipped with this transmitter will want to move around freely without having to worry about the antenna directionality, we used a horizontal omni-directional antenna for the transmitting antenna. On the other hand, the receiver equipment has a fixed configuration in order to cover the camera's operating range.

By calculating the link design according to standard regulations for millimeter-wave mobile cameras¹³⁾, in the case that 16QAM modulation with a 1/2 convo-

lutional code was used for transmitted signals, the receiving antenna should have a gain of at least 10 [dBi] to achieve a transmission range of at least 100 [m]. Consequently, a horn antenna with a gain of at least 10 [dBi] is used for the receiving antenna.

3. 42-GHz band vertical/horizontal polarization omni antenna

To build a prototype transmitting antenna for orthogonal polarized MIMO multiplexed transmission, the design policies based on the operating conditions of the millimeter-wave mobile camera were as follows:

- (1) Omni-directional radiation pattern in the horizontal plane
- (2) Vertical polarization and horizontal polarization antennas have the same radiation pattern
- (3) In the vertical plane, the radiation pattern should have a half-power angle of 60° centered on the horizontal plane
- (4) The antenna must be as small as possible

The reason for condition (1) has already been explained in the section 2. Condition (2) is necessary because the transmitter must perform MIMO multiplexed transmission while moving freely over a wide range. Condition (3) is necessary for the system to operate when the receiver is installed diagonally upwards from the transmitter, e.g., on a tower or lighting baton.

Condition (4) is necessary because there are constraints on the size of transmitter that can be mounted on cameras. Therefore, the antenna units must be small enough so as not to affect their respective radiation patterns. Also, in cross-polarized MIMO multiplexed transmission, the XPD of the vertical and horizontal polarization antennas must be larger than some value to improve the transmission characteristics in line-of-sight environments⁷⁾⁽¹¹⁾⁽¹⁴⁾. Therefore, The prototype antenna was designed with the aim of achieving an XPD of more than 10 [dB] over the radiation range shown in condition (1) and (3).

We built a prototype 42-GHz band vertically polarized omni-directional antenna (referred to as "vertical omni" below), and a 42-GHz band horizontally polarized omni-directional antenna (referred to as "horizontal omni" below) consisting of this vertical omni and a film polarizer for millimeter-wave band¹⁵⁾. This film polarizer for the millimeter-wave band has the property of causing a 90° rotation of the polarization plane of a radio waves that pass through it. Since the radio waves hardly lose any power as they pass through the

Fig. 2 42-GHz band omni antennas (left: vertical omni; right: horizontal omni).

Fig. 3 Structure of the horizontal omni antenna.

Table 1 Vertical/horizontal omni antenna parameters.

Frequency band	41 - 42[GHz]
Antenna Gain	Vertical : 1[dBi], Horizontal : 0[dBi]
Antenna shape	Biconical antenna
Directivity	Horizontal : Omni-direction
	Vertical : FWHM : 60°
External dimensions	40(depth) × 40(width) × 40(height)[mm]

film polarizer, this technique causes very little difference in the antenna radiation patterns of the polarization converted and original radio waves. Fig. 2 shows the vertical omni and horizontal omni, Fig. 3 shows the structure of the horizontal omni, and Table 1 shows the antenna parameters.

As for the shape of the prototype antenna, considering the need to be wrapped in a film polarizer and to operate over a wide bandwidth from 41 [GHz] to 42 [GHz], we opted for a bi-conical antenna that can take a cylindrical shape and operates over a broad bandwidth. In the vertical omni, as shown in Fig. 3, the core is connected through a pedestal to an upper metal plate, and the upper and lower metal plates have an insulated bi-conical antenna¹⁶⁾⁽¹⁷⁾ structure. Impedance matching was achieved by setting the antenna height to 4 [mm], which is slightly longer than the half-wavelength of ra-

Fig. 4 Measured antenna pattern (x-y plane).

Fig. 5 Measured antenna pattern (z-x plane).

dio waves at 41 [GHz]. In the horizontal omni, a film polarizer is wrapped around the cylindrical metal plate of this vertical omni to convert the waves radiating from the the vertical omni from vertical polarization to horizontal polarization. If this film polarizer is placed too close to the feed point of the antenna, the induced field tends to directly excite the metal wires of the slit, degrading the XPD. We therefore studied how to make the antenna as small as possible while maintaining an XPD of at least 10 [dB], and designed the metal plates of the antenna with a diameter of approximately 20 [mm]. **Fig. 4** and **Fig. 5** show the results of measured radiation patterns from the vertical omni and horizontal omni in the x-y and z-x planes respectively.

In Fig. 4, a comparison of the co-polarizations of each omni antenna in the x-y plane shows that the average antenna gain is -2.5 [dBi] for the horizontal omni, and -1.2 [dBi] for the vertical omni. Although some attenuation is observed in the radiation pattern of the horizontal omni antenna due to the effects of the film polarizer, the difference in average gain is only about 1.3 [dB], which means that the vertical and horizontal omni achieved roughly the same radiated power. With

regard to the cross-polarization, it can be seen that it was possible to maintain XPD > 15 [dB].

Fig. 5 compares the co-polarizations of each omni antenna in the z-x plane, and confirms that the radiation patterns of the horizontal omni and vertical omni are identical over the ranges $-120^\circ < \theta < -40^\circ$ and $+40^\circ < \theta < +120^\circ$. With regard to the cross-polarization, our results confirm that it is possible to maintain XPD > 10 [dB] over the ranges $-120^\circ < \theta < -40^\circ$ and $+40^\circ < \theta < +120^\circ$. It can thus be seen that the prototype vertical and horizontal omni produce very similar radiation patterns and achieve a high level of XPD over a $\pm 30^\circ$ range from the x-y plane.

On the other hand, in the region directly above the antenna where $-20^\circ < \theta < +20^\circ$ in Fig. 5, the XPD is greatly reduced due to effects such as stray currents occurring in the upper antenna metal plate. However, since our camera system has multiple receivers distributed in different locations, it does not rely solely on receiving the signals transmitted directly upwards from the antenna, so the effect of this phenomenon on the transmission performance of MIMO multiplexed transmission are expected to be very small.

4. Evaluation of outdoor transmission performance

4.1 Outdoor transmission experiments

In MIMO multiplexed transmission, multiple OFDM signals at the same frequency are separated based on differences of each channel characteristics. Thus the signal separation performances are greatly impaired in LOS environments where there are few reflections and the propagation channels are all strongly correlated. It has been proved experimentally that this correlation between channels can be suppressed by using orthogonal polarizations⁶⁾, and we are investigating the use of orthogonal polarization for MIMO multiplexed transmission in LOS environments. Therefore, in an outdoor LOS environment with no obstacles, we measured the transmission performance of MIMO multiplexed transmission both with and without orthogonal polarization. **Fig. 6** shows the measurement system including MIMO transmission system and real-time recorder, **Fig. 7** shows the measurement environment, **Table 2** lists the OFDM signal parameters, and **Table 3** shows the transmitting and receiving antenna conditions in this experiment.

4.2 Delay profile

In this experiment, we used four receivers equipped

Fig. 6 MIMO transmission system.

Fig. 7 Outdoor transmission experiment set-up.

Table 2 OFDM signal parameters.

Occupied frequency bandwidth	54.40 [MHz]
Output power (OFDM)	100 [mW] $\times$ 2
Effective symbol length(T_e)	15.75 [μ sec]
Guard interval length	$T_e \times \frac{1}{16}$ [μ sec]
Number of FFT points	1024
Number of carriers	Data: 672 Pilot: 108
Carrier modulation scheme	Data: 16QAM Pilot: BPSK

Table 3 Transmitting and receiving antenna conditions.

Transmitting antenna	Type	Horizontal omni
	Height/spacing	1.9[m]/0.125[m]
Receiving Antenna	Type	Horn (gain: 10 dBi)
	Height/spacing	1.5[m]/0.67, 2.7[m]

Table 4 Delay profile measurement results.

	Number of delayed waves	Delay spread (r.m.s.)	Rice factor
Average	4.26	55.89 [nsec]	12.87 [dB]
Standard deviation	5.55	64.66 [nsec]	6.66 [dB]

with horn antennas to receive two OFDM signals output from a transmitter equipped with two of our prototype 42-GHz band omni antennas as shown in Fig. 6. We also performed an experiment with two antenna layouts — one without cross polarization where all the transmitting and receiving antennas were vertically polarized, and another with cross polarization where the transmitting and receiving antennas were allocated to horizontal and vertical polarization (Tx1, Rx1, Rx3: vertical polarization; Tx2, Rx2, Rx4: horizontal polarization). In this experiment, the transmitters were each moved in the direction of the arrow along the dotted lines drawn at 10 [m] intervals as shown in Fig. 7, and a pseudo-random signals applied to the data carrier of

two OFDM signals and transmitted from the two omni antennas. These OFDM signals are received by four receivers arranged in a row as shown in Fig. 7. Pilot signals are obtained by OFDM demodulator and the bit streams are obtained by MIMO demodulator using QR decomposition¹⁸⁾. These signals are continuously recorded by real-time recorder and parameters such as the BER and average received CNR are calculated for each frame (comprising 408 OFDM symbols).

The delay profile is obtained by applying an inverse Fourier transform (IFFT) to the channel response estimated from a pilot signal, and this is used to calculate the number of delayed waves, the r.m.s. delay spread, and the Rice factor. Here, the resolution of the delay profile is 0.015 [μ sec], and the measurable range of delayed waves is 1.97 [μ sec]. In addition, each parameter is calculated by regarding delayed waves with a received power within -20 [dB] of the direct wave received power. The average value and standard deviation of this delay parameter are shown in Table 4.

As shown in Fig. 7, the experimental environment is enclosed by a wall approximately 1.5 [m] high, and the results obtained near this wall are strongly affected by reflected waves. However, since the average value of the Rice factor for the experimental environment as a whole is greater than 10 [dB], it can be said that delayed waves have little effect and the experimental environment is dominated by direct waves.

4.3 Change in channel characteristics due to orthogonal polarization

The BER performance of MIMO multiplexed transmission are strongly affected by the received CNR and the channel correlation. For the results obtained without orthogonal polarization (referred to as "V-V polarization" below) and with orthogonal polarization ("V-H polarization"), Fig. 8 shows the cumulative probability distribution of the received CNR, Fig. 9 shows the cumulative probability of the transmit correlation, and Fig. 10 shows the cumulative probability distribution of XPR. Here, for the channel responses h_{k1} and h_{k2} for the first and second transmitting antennas coupled with each of the receiving antennas ($k = 1 \dots 4$), the transmit correlation is calculated from Equation (1)¹⁹⁾, and the XPR is calculated from Equation (2).

$$\rho_{Tij} = \frac{\sum_{m=1}^{672} \sum_{k=1}^4 h_{k1}^*(m) h_{k2}(m)}{\sqrt{\sum_{m=1}^{672} \sum_{k=1}^4 |h_{k1}(m)|^2} \sqrt{\sum_{m=1}^{672} \sum_{k=1}^4 |h_{k2}(m)|^2}} \quad (1)$$

$$\Delta_P = 10 \log \left\{ \left(\sum_{k=1,3} \frac{|h_{k1}|^2}{|h_{k2}|^2} + \sum_{k=2,4} \frac{|h_{k2}|^2}{|h_{k1}|^2} \right) / 4 \right\} \quad (2)$$

In Equations (1) and (2), the transmit correlation and XPR are obtained for each of the $m(=1 \cdots 672)$ data carriers, and are averaged together. In this transmission experiment, the separation between the transmitting antennas is very small compared with the separation between the receiving antennas, so in this paper we used a transmit correlation that would have a larger effect on the transmission performance.

From Fig. 8, the median value of the average received CNR is 27.5 [dB] in V-V polarization and 25.2 [dB] in V-H polarization, corresponding to a reduction of 2.3 [dB]. This reduction arises because the use of orthogonal polarization means that waves are not received between transmitting and receiving antennas with different polarizations, so the overall received power is smaller. In Fig. 9 and Fig. 10, the use of orthogonal polarization causes the median value of the transmit correlation to decrease from 0.45 to 0.12, whereas the median value of the XPR increases from 0.97 [dB] to 15.5 [dB]. This increase in XPR is also accompanied by a reduction in the correlation between each channel, and the maximum value of the transmit correlation is suppressed from 0.95 to 0.45. It can thus be seen that all the transmit correlations are below the value of 0.8 at which the error rate deteriorated sharply in an earlier outdoor transmission experiment conducted using a standard horn antenna²⁰⁾, and that the transmit correlation can be adequately suppressed by orthogonal polarization MIMO multiplexed transmission using our prototype vertical and horizontal omni antennas. On the other hand, according to Fig. 10, XPR takes a wide range of values from 0 [dB] to 25 [dB] when using orthogonal polarization, with low values of 5 [dB] or less in 10[%] of all cases. XPR represents the power ratio of each propagation path allocated to different polarizations. Therefore, low XPRs mean that there is a large ratio of interference wave components at the receiver. This shows that even in an environment where direct waves are predominant, such as an outdoor line-of-sight environment, transmitted signals whose polarization is rotated due to reflection effects are received as interference components at the receiving antenna. Therefore, when the transmitter moves around freely like a millimeter-wave mobile camera, it can be said that it is difficult to apply simple polarization division multiplexing that preserves the independent propagation with polarized waves that

Fig. 8 Change in received CNR due to orthogonal polarization.

Fig. 9 Change in transmit correlation due to orthogonal polarization.

Fig. 10 Change in XPR due to orthogonal polarization.

are suitable for fixed transmission.

4.4 MIMO transmission performance

With regard to the BER distribution in the column for $X=10, 50, 90$ [m] in Fig. 7, **Fig. 11** and **Fig. 12** show the BER of MIMO demodulation using QR decomposition in V-V polarization and V-H polarization respectively. In this experiment, to evaluate the BER distribution characteristics more clearly, we determined the BERs by using the results of MIMO demodulation using QR decomposition without forward error corrections.

Fig. 11 Distribution of BER performance in V-V polarization.

Fig. 12 Distribution of BER performance in V-H polarization.

In Fig. 11, we obtained a larger overall BER than when using orthogonal polarization as shown in Fig. 12. In particular, although an adequate received CNR was ensured when the transmitter was moved to a position near the center of the measurement area (around $Y=25$ [m]), the BER varies greatly at this position in Fig. 11 without orthogonal polarization, resulting in severe degradation. This is because the strong correlation between the propagation channels causes the signal separation characteristics of QR decomposition to deteriorate. On the other hand, even when using orthogonal polarization as shown in Fig. 12, the BER increases sharply at the edges ($Y \leq 10$ [m], $Y \geq 40$ [m]) of the column where the transmitter is positioned at $X=10$ [m]. This is thought to be because when the transmitter moves outside the directivity of the receiving antenna of the receivers arranged in a row, it becomes harder to receive waves of different polarization with an external receiver, and the separability of the QR decomposition which needs more than two received signals for demodulation deteriorates sharply. It can thus be said that the use of orthogonal polarization can be expected to improve the BER performance of MIMO multiplexing transmission in LOS environments, but leads to a smaller area within which it is possible to receive waves of adequate power.

Fig. 13 shows the cumulative probability distribution of BERs in V-V polarization and V-H polarization. This figure also shows the cumulative probability distribution of BERs in an environment where the aver-

age received CNR is at least 27 dB. The median value of the BER (cumulative probability 50[%]) decreased from 6.1×10^{-6} without orthogonal polarization to 1.9×10^{-7} with orthogonal polarization, which is about 1/30th as large. This demonstrates how the prototype system based on developed vertical omni and horizontal omni antennas can improve the BER performance. In particular, in an environment where the average received CNR is 27 [dB] or more, the BER obtained with orthogonal polarization is less than 1.1×10^{-3} , and it can be seen that the cumulative distribution of the BER is greatly improved. However, the overall BER when using orthogonal polarization is about 3[%] greater than the BER obtained without orthogonal polarization. It shows that achieving a lower received CNR due to outside the directivity of the receiving antenna can cause the BER to deteriorate substantially. On the other hand, with regard to the cumulative distribution of the BER in V-V polarization, it can be seen that the distribution changes little regardless of the average received CNR, and especially when the BER is large, there is hardly any change between distribution of all BERs and BERs over 27 [dB]. This is thought to be because the BER without orthogonal polarization is influenced more by the channel correlation than by the average received CNR, and in particular the effects of the correlation characteristics become predominant when the BER is large.

To clarify how the BER performance of MIMO multiplexed transmission is affected by the correlation char-

Fig. 13 Change in BER due to orthogonal polarization.

Fig. 14 BER due to transmit correlation without orthogonal polarization (V-V polarization).

acteristics, we investigated the relationship between the channel correlation and BER in an environment where a high received power can be obtained. **Fig. 14** shows the relationship between the transmit correlation and BER in an environment with an average received CNR of at least 27 [dB] when orthogonal polarization is not used. This figure also shows the median value of BER corresponding to each XPR value with solid line. In this figure, the BER gradually increases as the transmit correlation increases, and deteriorates particularly sharply when the transmit correlation is 0.7 or more. When the transmit correlation is 0.8 or more, the minimum value of the BER also increases sharply, and a pronounced deterioration of BER performance becomes evident due to the increased transmit correlation. Consequently, in order to suppress the deterioration of transmission performance in this outdoor experimental environment, it can be seen that it is necessary to somehow maintain a high average received CNR while suppressing the transmit correlation value to 0.7 or less.

Fig. 15 shows the relationship between XPR and transmit correlation without orthogonal polarization

Fig. 15 Relationship between XPR and transmit correlation with orthogonal polarization.

and with orthogonal polarization. This figure also shows a curve representing the theoretical values of the transmit correlation when the XPR is varied in a MIMO channel with a correlation of 1.0. The theoretical curve represents the maximum value of the transmit correlation that can be obtained for each XPR value. From **Fig. 15**, we can confirm that the measured transmit correlation values become much smaller as the XPR increases. In particular, when using orthogonal polarization, the transmit correlation value decreases sharply when the XPR is in the range above 15 dB. This change in the maximum value of the transmit correlation with the XPR closely matches the theoretical curve, so the maximum value of the transmit correlation can be estimated from the XPR value. It can thus be seen that by suppressing the value of XPD, it is possible to keep the transmit correlation within the target value while optimally suppressing the reduction in received power due to the increase in XPR. For example, since it was necessary to suppress the transmit correlation to 0.7 or less in this environment, the ideal solution is to use MIMO multiplexed transmission with orthogonally polarized omni antennas having an XPR of about 8 dB, even from the viewpoint of received power. Furthermore, if the XPR value is low, then it will become possible for transmitted signals to be received by the receiver allocated to the other polarization. This simply increases the number of receivers that can receive the transmitted signals, thus leading to an increase in the mobile communication range of the transmitter. From this result, it seems that it is possible to further improve the BER performance of orthogonal polarization MIMO transmission by using a design where the degree of XPD is even smaller than these antennas used in the experiment.

In this way, by judging the transmit correlation characteristics of a propagation environment for MIMO multiplexed transmission and using orthogonal polarization omni antennas with a suitable XPD, we have shown the prospect of being able to perform MIMO multiplexed transmission in outdoor environments where the reduction of received power is kept as small as possible.

5. Conclusion

With the aim of implementing low-latency wireless transmission of HDTV video at low compression, we have been developing a millimeter-wave mobile camera that uses the millimeter-wave band and MIMO multiplexed transmission technology. To enable this camera to operate in LOS environments, we investigated the use of orthogonal polarization to suppress the channel correlation, and we used a film polarizer to build prototype vertical/horizontal polarization 42-GHz band omni-directional antennas. We have also ensured a high XPD (at least 10 [dB]) and equivalent radiation patterns for the vertical and horizontal polarization omni-directional antennas, which is essential for MIMO multiplexed transmission using orthogonal polarization.

Using these antennas, we performed a MIMO multiplexed transmission experiment in a LOS outdoor environment with no obstructions, and we confirmed that the use of orthogonal polarization makes it possible to suppress the maximum value of the transmit correlation from 0.95 to 0.45, and allows the median value of the BER to be made approximately 30 times smaller. On the other hand, due to the reduction in received power we also observed a phenomenon whereby the area within which signals can be received becomes narrower, so although the use of orthogonal polarization is effective in LOS environments, we found that the receiving antennas have to be arranged carefully. Also, in this outdoor experimental environment, we showed that the transmit correlation must be suppressed to 0.7 or less regardless of the received CNR, and we clarified that it is possible to implement stable outdoor MIMO multiplexed transmission while keeping the reduction of received power due to orthogonal multiplexing to the smallest possible value. In future studies, we plan to continue our investigation of receiving antenna arrangements and suitable XPD levels that are effective for orthogonal polarization MIMO multiplexed transmission, and we will conduct research aimed at shooting TV programs using the camera in LOS environments.

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Shinichi Suzuki received his B.E. and M.E. degrees in Electrical and Electronic Engineering from Tokyo Institute of Technology, Tokyo, Japan in 2000 and 2002, respectively. In 2002, he joined NHK Science and Technology Research Lab. Since joining NHK, he has been engaged in the research and development of millimeter-wave link system and signal processing technique, such as OFDM and MIMO.

Naoto Kogo received the B.E. degree in Electrical and Computer Engineering and M.E. degree in Artificial Environment Systems, from Yokohama National University, Japan, in 1999 and 2001, respectively, and D.E. degree in Artificial Systems Science from Chiba University, Japan in 2010. Since 2004, he joined Science and Technology Research Laboratories, NHK and has been engaged in research on small antennas for broadcasting and evaluation of the interaction between electromagnetic fields and the human body.

Takayuki Nakagawa received the B.E. degree from Waseda University, Tokyo, Japan in 1995. He joined Japan Broadcasting Corporation (NHK) in 1995. Since 2000, he has been with the Science and Technology Research Laboratories of NHK, where he has been engaged in research on millimeter-wave radio propagation and digital transmission systems.

Tetsuomi Ikeda received the B.E. degree from Muroran Institute of Technology, Hokkaidou, Japan in 1984. He joined Japan Broadcasting Corporation (NHK) in 1984. Since 1989, he has been with the Science and Technology Research Laboratories of NHK, where he has been engaged in research on terrestrial digital broadcasting transmission technology and so on.