Development of Millimeter-wave Link for 8K Super Hi-Vision Program Contribution

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Since the test satellite broadcasting of 4K/8K Super Hi-Vision (4K/8K) started in 2016, increasing the number of 4K/8K programs has been required. For current HDTV productions, portable wireless links are used for electronic news gathering and outside broadcasting. To meet the increasing needs of diverse 4K/8K program production, a wireless link that can transmit to 4K/8K has also been desired. In light of this, we have developed a millimeter-wave wireless link system that achieves 600-Mbps-class 4K/8K program transmission using a dual polarized MIMO technology and a wideband signal processing technique for the MIMO-OFDM scheme. We confirmed that the millimeter-wave link was capable of 4K/8K program transmission through laboratory and field experiments.

1. Introduction

NHK has been researching 4K/8K Super Hi-Vision for the provision of ultrahigh-definition and high-presence content as a television broadcasting service. Preparations are now being made toward the launch of regular service in 2018 following 4K/8K test satellite broadcasting that began in 2016. In 4K/8K field pickup units (FPUs), which perform the wireless transmission of program material to base stations, must support 4K/8K transmission and their transmission capacity must be increased.

The 42 GHz millimeter-wave band is one frequency band that can be used for the transmission of program contributions. It is currently being used by radio transmission equipment in a HD (2K) wireless camera\(^1\). The authors have developed a millimeter-wave-band 4K/8K FPU with expanded transmission capacity based on this transmission system for 2K wireless camera. This paper describes the specifications of this millimeter-wave-band 4K/8K FPU and reports on the results of an evaluation experiment and outdoor transmission experiment that were performed to test its transmission characteristics.

2. Overview of Millimeter-wave-band 4K/8K FPU

2.1 Transmission system and technology for increasing transmission capacity

For 4K and 8K video (typical spatial resolution: 7,680 × 4,320; typical frame frequency: 59.94 Hz) using H.265/HEVC (High Efficiency Video Coding), appropriate bit rates for 4K/8K program contribution have been reported to be 108 – 325 Mbps for a transport stream (TS) signal with a packet length of 204 bytes\(^2\). However, in anticipation of higher frame frequencies in the future and an increase in the bit rate to decrease the delay time caused by 8K video coding and decoding, the goal is to achieve bit rates greater than 325 Mbps as the transmission capacity for the millimeter-wave-band 4K/8K FPU.

The transmission system for 2K wireless camera implemented in the 42 GHz band is shown in Fig. 1. Channel bandwidths in the 42 GHz band have been specified on

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\(^1\) The authors have developed a millimeter-wave-band 4K/8K FPU with expanded transmission capacity based on this transmission system for 2K wireless camera.

\(^2\) For 4K and 8K video (typical spatial resolution: 7,680 × 4,320; typical frame frequency: 59.94 Hz) using H.265/HEVC (High Efficiency Video Coding), appropriate bit rates for 4K/8K program contribution have been reported to be 108 – 325 Mbps for a transport stream (TS) signal with a packet length of 204 bytes.
the basis of criteria related to Japanese Radio Law as 62.5 MHz, 125 MHz, 500 MHz, and 1 GHz. In this transmission system for the 2K wireless camera, the channel bandwidth is set to 62.5 MHz assuming use in a mobile environment. Up to now, there has been no example of implementing this system using another channel bandwidth. The transmission capacity of the transmission system for 2K wireless camera is 160 Mbps for a subcarrier modulation scheme of 16QAM and a code rate of 1/2 using a multiple-input multiple-output-orthogonal frequency division multiplexing (MIMO-OFDM) system which includes a two-transmitter and two-receiver.

The transmission system of our newly developed millimeter-wave-band 4K/8K FPU is shown in Fig. 2. Assuming use in a fixed and line-of-sight environment between the transmitting and receiving points, we designed this millimeter-wave-band 4K/8K FPU using high-gain parabolic antennas. Furthermore, as a dual-polarized antenna can be easily achieved with a parabolic antenna, we adopted polarized MIMO3) using orthogonal vertically and horizontally polarized channels with the same frequency. Using dual-polarized antennas makes it unnecessary to adjust the antenna direction for each polarized channel. Moreover, even if interference should occur owing to an offset in the polarization planes between the transmitter and receiver antennas when installing the FPU, this interference can be detected and canceled by MIMO processing, therefore providing an additional benefit in terms of operation4).

This dual-polarized parabolic antenna obtains a cross-polarization discrimination of 20 dB or greater owing to its high gain, and since cross polarization interference can be canceled by MIMO processing as mentioned above, it has been reported that the transmission capacity can be increased using 4096QAM with a required carrier-to-noise ratio (C/N) of 30 dB or greater2). On the other hand, the millimeter-wave-band power amplifier used by the transmitter of the millimeter-wave-band 4K/8K FPU suffers from significant distortion, causing the C/N of the transmitting signal to degrade to approximately 25 dB. Taking into account the equipment-implementation margin, multipath fading margin, and so forth, the theoretical value of the required C/N in circuit design is thought to be limited to 15 dB. For this reason, we have set the transmission parameters of the millimeter-wave-band 4K/8K FPU to be those of a subcarrier modulation scheme of 32QAM with a code rate of 3/4, corresponding to a theoretical required C/N of 15.5 dB. As a result, the transmission capacity can be increased to as much as 1.875 times that of the transmission system for 2K wireless camera. In addition, the channel bandwidth of the modulated signal can be increased to 125 MHz, double that of the transmission system for 2K wireless camera, so combining these two methods enables a maximum transmission capacity of 600 Mbps.

2.2 Specifications of millimeter-wave-band 4K/8K FPU
This section describes the specifications of the millimeter-wave-band 4K/8K FPU. The transmitter and receiver systems of the developed 4K/8K FPU incorporating the technology described above for increasing the transmission capacity are shown in Fig. 3. This millimeter-wave-band 4K/8K FPU consists of MIMO-OFDM modulator/demodulator and transmitter/receiver systems supporting either a 62.5 MHz or 125 MHz channel bandwidth and uses dual-polarized parabolic antennas as described above. An external view of the millimeter-wave-band 4K/8K FPU is shown in Fig. 4 and the transmission parameters and transmission capacities are listed in Tables 1 and 2, respectively. The following describes the main blocks of the transmitter/receiver systems of Fig. 3 in order of the signal flow.

![Figure 2: Transmission system of 42 GHz band 4K/8K FPU](image-url)
Data frame synchronization

The input interface of the millimeter-wave-band 4K/8K FPU is TS streams in the Digital Video Broadcasting–Asynchronous Serial Interface (DVB-ASI) format which is commonly used in HD FPUs. However, given that the upper limit of the DVB-ASI bit rate is 213 Mbps, it is assumed that 4K/8K video encoder will divide a high-rate TS streams into two DVB-ASI to be processed and output. Therefore we designed the input of the millimeter-wave-band 4K/8K FPU to support up to two TS streams. Here, the number of input TS streams can be determined by detecting the code word 47_hex which is fixed byte.

In the “data frame synchronization” block of Fig. 3, we first consider the case of inputting one TS system. Here, a data frame consists of eight TS packets, and the code word 47_hex of the TS packet at the front of the data frame is replace into a data-frame synchronization word B8_hex through bit inversion of code word 47_hex. Next, for the case of inputting two TS streams with bit rates assumed to be the same, the TS packets of these two streams are alternately selected one packet at a time to configure a data frame. The number of TS packets making up this data frame is eight, as in the
case of one TS input, and the manner of preparing a synchronization word is likewise the same.

On outputting data frames from the “data frame synchronization” block, the output destination switches for each data frame, therefore outputting two streams of data frames. The reason for this is that error correction coding takes place in two circuits in parallel as described in the following section.

(2) Error correction coding

Error correction coding in the millimeter-wave-band 4K/8K FPU uses a Reed-Solomon (RS) code (204, 188) as the outer code and a convolutional code as the inner code. Convolutional coding is performed in units of bits, and since the data rate of a convolutional coding circuit using a field-programmable gate array (FPGA) used in the implementation is approximately 400 Mbps, it was decided to perform the coding of two data frames in parallel on two error-correction-coding circuits. The parallel processing of error correction coding in this way increases the upper limit of the total bit rate for adding parity bits to information bits (TS) in error correction coding to 800 Mbps.

(3) Intertransmission-scheme allocation

The data subjected to error correction coding is next divided up among two transmitters for horizontally and vertically polarized transmission. In this allocation process, data output from one error-correction-coding circuit is divided up among the two transmitters in bit units in the order of transmitter 1 → transmitter 2 → transmitter 1, and so on. While data output from the other error-correction-coding circuit is divided up among the two transmitter systems in the order of transmitter 2 → transmitter 1 → transmitter 2, and so on. Therefore allocating the data while mutually switching between these two sources of data. In polarized MIMO, alternating the allocation of data between two differently polarized transmissions in this way improves the error correction performance even if the receiving conditions of one of the polarized transmissions should be degradation.

(4) Interleaving

Interleaving is a technique for improving the error correction performance by distributing burst errors. In the millimeter-wave-band 4K/8K FPU, interleaving technique is used the order of data by the three methods of bit inter-
leaving, frequency interleaving, and time interleaving in that order.

In the case of multilevel modulation, bit interleaving performs data in units of bits to prevent errors from becoming burst errors within an OFDM carrier. Taking QPSK with two bits of data per carrier as an example, data distribution is achieved by giving only the second bit a certain amount of delay.

Frequency interleaving can improve degradation of frequency-selective fading due to mixture of multipath signals. It performs the order of carriers within a single OFDM frame in random data to distribute burst errors caused by such frequency-selective fading.

Time interleaving performs data within a time range longer than the OFDM symbol length. Rearranging data across OFDM symbols in this way improves robustness to burst errors caused by an instantaneous drop in received power such as in flat fading.

(5) QAM mapping and OFDM frame configuration

Starting at the front of the data sequence output from interleaving, the QAM mapping process maps the data to OFDM data carriers two bits at a time for QPSK, four bits at a time for 16QAM, and five bits at a time for 32QAM. It also allocates transmission multiplexing configuration and control (TMCC), continual pilot (CP), and auxiliary channel (AC) signals to prescribed carriers to complete the configuration of the OFDM frame. Here, the TMCC signal is a synchronization signal for synchronizing OFDM frames and informs the subcarrier modulation scheme, the number of TS inputs, and so forth, to the receiving side. The AC signal is used when the user wishes to transmit additional information. The CP signal is a pilot signal known to the receiving side for use in estimating the channel response. In addition, MIMO detection can be performed on the receiving side using the orthogonally (horizontally and vertically) polarized CP streams (see Table 1).

(6) IFFT, GI addition, and orthogonal modulation

The OFDM frame is next subjected to an inverse fast Fourier transform (IFFT) in units of symbols and transformed to an I-axis/Q-axis (real-axis/imaginary-axis) time-domain signal. Then, after adding a guard interval (GI) of a specified length to the front of the OFDM symbol, the I-axis/Q-axis time-domain signal is subjected to orthogonal modulation to obtain an intermediate frequency (IF) signal with a center frequency of 400 MHz, which is passed to the transmitter (transmitter section).

(7) Transmitter section and antenna

The function of the transmitter section performs frequency conversion the IF signal to a radio frequency (RF) signal (frequency conversion) on a specific channel and amplifies the RF signal to a prescribed level of transmission power using a power amplifier. This function is implemented for both horizontal and vertical polarization. Both amplified signals are dual-polarized by an orthomode transducer (OMT)\(^1\) and transmitted from a parabolic antenna.

The millimeter waveband suffers from high rain attenuation compared with the microwave band, so it is desirable to make the transmission power large to achieve long-distance transmissions. Although related regulations currently prescribe a maximum transmission power of 1 W (the total transmission power of all signals in the case of MIMO) in the 42 GHz band, this FPU features a transmission power per polarized signal of 250 mW (a total of 500 mW for both polarized signals), taking into account the performance of the power amplifier using a millimeter-wave solid-state device and the back-off of the OFDM signal.

The parabolic antenna has a diameter of 30 cm and an antenna gain of 40 dBi\(^2\) with a structure having a circular-waveguide interface to support either horizontal or vertical polarization.

The receiver section first separates polarization of the received signal by the OMT. Then, it performs frequency conversion for both the horizontally and vertically polarized signals and outputs the respective IF signals adjusted to a prescribed level by automatic gain control (AGC).

(8) Received signal processing

The scheme for demodulating the received signal is basically the inverse of the modulation scheme on the transmission side. The process estimates the channel response from the received CP signal and performs MIMO detection to remove the cross-polarization interference components. As a result, the estimated values of the horizontally and vertically polarized transmitted symbols were obtained. Here,

\(^{1}\) A waveguide component that either combines or separates horizontally polarized and vertically polarized signals propagating within the waveguide.

\(^{2}\) dBi is a standard unit of antenna gain for isotropic antennas.

\(^{3}\) A MIMO signal detection technique that multiplies the received signal by the inverse matrix of the channel response matrix and decodes the transmitted signal.

\(^{4}\) A numerical value expressing in logarithmic form the ratio of the probability that the received bit is zero to the probability that it is one.
assuming FPU transmission in a line-of-sight environment in which there is hardly any degradation in cross-polarization discrimination, we adopt the zero-forcing technique\cite{3,4}, which has low computational complexity for MIMO detection. Next, to demap a received symbol after MIMO detection, the process calculates the log-likelihood ratio (LLR)\cite{4} as a soft-decision value and uses Viterbi decoding to decode the inner code. Finally, after error correction decoding, the process outputs TS signals based on the number of input TS streams transmitted by TMCC.

3. Evaluation Experiment of MIMO-OFDM Modulator and Demodulator

We performed an experiment using IF signals to evaluate the transmission characteristics of the MIMO-OFDM modulator and demodulator of the millimeter-wave-band 4K/8K FPU. The configuration of the experimental system is shown in Fig. 5. This system directly connects the MIMO-OFDM modulator and demodulator by cable and adds a noise signal generated by a noise source (a signal source generating a flat spectrum over a wide band) to each IF signal. A variable attenuators are used to adjust the level of the noise signal so as to vary the C/N of the signal input to the MIMO-OFDM demodulator.

(1) Constellations of demodulated signal

To evaluate the demodulation operation in the MIMO-OFDM modulator/demodulator, we confirmed the constellations directly after the “MIMO detection” block in the demodulator. Received-signal constellations are shown in Fig. 6. Here, the amount of attenuation generated by the variable attenuator was set so that the C/N of the received signal was maximum. The results in Fig. 6 show that the constellations corresponding to the data carrier modulation scheme could be restored in the received signal. This experimental system, however, inputs the horizontally and vertically polarized IF signals independently into the demodulator, so it does not test the actual MIMO separation effect. In the constellations shown here, the CP signal and TMCC signal are displayed on the I-axis and Q-axis, respectively, and the null signal

<table>
<thead>
<tr>
<th>Data carrier modulation scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
</tr>
</tbody>
</table>

![Figure 5: Experimental diagram for evaluating MIMO-OFDM modulator and demodulator](image)

![Figure 6: Received constellations (pilot and null including)](image)
(dummy data for rate adjustment, etc.) is displayed at the origin.

(2) Bit error rate

We measured the bit error rate (BER) in the MIMO-OFDM modulator/demodulator while varying the C/N of the signal input to the demodulator. Specifically, we transmitted a PN (pseudo random noise) signal generated by the modulator as a data signal and compared the data signal after demodulation with the known data signal and measured BER.

The BER before error correction is shown in Fig. 7. These results were obtained by comparing the PN signals at point A in Fig. 3. In Fig. 7, the horizontal axis corresponds to the C/N of the received signal with the broken lines representing the results of a computer simulation. As in the case of the experimental system, simulation results were calculated assuming no correlation between the two signals input into the demodulator (no mutual interference between the two polarized signals). In the figure, the measured BER agrees for the most part with the simulation results, indicating that the degradation of the BER due to equipment implementa-

tion is small.

Values of C/N required for the MIMO-OFDM modulator/demodulator are listed in Table 3 and the relationship between the required C/N and the transmission capacity for various code rates is shown in Fig. 8. Here, the required C/N values in the table and figure are those resulting in quasi-error-free performance after RS decoding (BER of $1 \times 10^{-4}$ after Viterbi decoding).

4. Transmission Experiment

4.1 Transmission characteristics of transceiver

We measured the BER characteristics of the developed millimeter-wave-band 4K/8K FPU with a millimeter-wave-band transmitter and receiver included. The diagram of BER measurement is shown in Fig. 9. With this system of the diagram, we measured the BER while connecting the transmitter and receiver via a waveguide and adjusting the received power by millimeter-wave-band variable attenuators. The transmission power was set to 250 mW per polarized signal.

The results of measuring the BER characteristics before error correction and after Viterbi decoding (code rate $= 1/2$, 2/3, 3/4) with respect to the received power of one polarized signal for 32QAM subcarrier modulation are shown in Fig. 10.

First, turning our attention to the BER characteristics before error correction, an error floor$^5$ can be observed for a

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Subcarrier Modulation & Code rate & $1/2$ & $2/3$ & $3/4$ \\
\hline
QPSK & 4.7 dB & 6.7 dB & 8.0 dB \\
16QAM & 10.0 dB & 12.8 dB & 14.4 dB \\
32QAM & 13.1 dB & 15.9 dB & 17.6 dB \\
\hline
\end{tabular}
\caption{Required C/N for MIMO-OFDM modulator/demodulator}
\end{table}

$^5$ The phenomenon in which the value of the BER limits decreasing despite an increase in the received power due to effects such as nonlinear distortion.
large received power, but this can be attributed to distortion in the power amplifier of the transmitter. Since the peak to average power ratio (PAPR) of an OFDM signal is large, distortion will occur in the nonlinear domain of the power amplifier’s input/output characteristics. At present, achieving high output in a power amplifier using a solid-state device for millimeter-wave-band is difficult, and operating only in the power amplifier’s linear domain is likewise difficult. Developing technology to decrease distortion in a wideband signal is therefore an issue for future study.

We next obtain the BER characteristics after Viterbi decoding. The thermal noise power of the receiver was calculated to be -88.5 dBm given an occupied bandwidth of 109.2 MHz and a noise figure of 5 dB. Table 4 lists the required receive power (6) obtain from Fig. 10, the required C/N calculated from the thermal noise power of the receiver (-88.5 dBm), the required receive power, and the increase (degradation) in the required C/N relative to that of the MIMO-OFDM modulator/demodulator in Table 3, all for different code rates. This increase in the required C/N owing to the transceiver is mainly caused by the distortion in the power amplifier as described above. The effect of equivalent noise due to this distortion in the power amplifier increases with the increase in the required C/N, so the amount of degradation in the required C/N increases with the code rate.

4.2 Outdoor transmission experiment

We conducted an outdoor transmission experiment to examine the feasibility of using the developed millimeter-wave-band 4K/8K FPU for program contribution. The specifications and link budget of the outdoor transmission experiment are listed in Tables 5 and 6, respectively.

The transmitting and receiving points were NHK Broadcasting Center (Shibuya Ward, Tokyo) and NHK Science & Technology Research Laboratories (STRL) (Setagaya Ward, Tokyo), a transmission distance of approximately 8 km. The transmission system for this experiment is shown in Fig. 11. To test the transmission of an 8K signal with this FPU, we

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6 The received power corresponding to quasi-error-free performance after RS decoding (BER of 1×10^-4 after Viterbi decoding).
first recorded an 8K signal for program contribution on a TS player, encoding it at 213 Mbps by an H.265/HEVC encoder. Next, we input the TS from the TS player into the MIMO-OFDM modulator. Therefore generating two OFDM signals with horizontal and vertical polarization for transmission. Although the TS bit rate here was 213 Mbps, the maximum transmission rate of this FPU is 600 Mbps, so we adjusted the rate by inserting dummy TS packets at the MIMO-OFDM modulator. Then, the received signal was demodulated by the MIMO-OFDM demodulator and restored to an 8K signal by an H.265/HEVC decoder.

A view of the receiving point in this outdoor transmission experiment is shown in Fig. 12 and the results of demodulating the transmitted 8K signal are shown in Fig. 13. Additionally, by displaying the received 8K signal on a monitor, we confirmed that the signal could be played back normally without video signal distortion or block noise.

The received power was -44 dBm for horizontal polarization and -45 dBm for vertical polarization. These values were slightly lower than the received power in Table 6, which we surmised to be caused, for example, by the error in the adjusting antenna direction. Nevertheless, the received power obtained in the experiment was roughly the

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**Table 5: Specifications of outdoor transmission experiment**

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission power</td>
<td>500 mW (27 dBm) total for both horizontal and vertical polarization*</td>
</tr>
<tr>
<td>Center frequency</td>
<td>41.0625 GHz</td>
</tr>
<tr>
<td>Occupied bandwidth</td>
<td>109.2 MHz</td>
</tr>
<tr>
<td>Transmission scheme</td>
<td>Dual-polarized MIMO-OFDM</td>
</tr>
<tr>
<td>Number of data carriers</td>
<td>1,344</td>
</tr>
<tr>
<td>FFT length</td>
<td>2,048</td>
</tr>
<tr>
<td>Effective symbol length</td>
<td>15.75 µs</td>
</tr>
<tr>
<td>Guard interval length</td>
<td>0.98 µs</td>
</tr>
<tr>
<td>Carrier modulation scheme</td>
<td>32QAM</td>
</tr>
<tr>
<td>Error correction code</td>
<td>Inner code: convolutional code (code rate: 3/4) Outer code: RS(204,188)</td>
</tr>
<tr>
<td>Antenna</td>
<td>Dual-polarized parabolic antenna (diameter Φ= 0.3 m, 40 dBi)</td>
</tr>
<tr>
<td>Transmitting point</td>
<td>NHK Broadcasting Center, Shibuya Ward, Tokyo</td>
</tr>
<tr>
<td>Receiving point</td>
<td>NHK STRL, Setagaya Ward, Tokyo</td>
</tr>
</tbody>
</table>

* 250 mW (24 dBm) per polarization

**Table 6: Link budget of outdoor transmission experiment**

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission power</td>
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</tr>
<tr>
<td>Center frequency</td>
<td>41.0625 GHz</td>
</tr>
<tr>
<td>Transmitting antenna gain</td>
<td>40.0 dBi</td>
</tr>
<tr>
<td>Transmitter feeder loss</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>Effective isotropic radiated power</td>
<td>63.5 dBm</td>
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<tr>
<td>Transmission distance</td>
<td>8.0 km</td>
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<tr>
<td>Free-space propagation loss</td>
<td>143.0 dB</td>
</tr>
<tr>
<td>Rain attenuation</td>
<td>0.0 dB</td>
</tr>
<tr>
<td>Atmospheric absorption loss</td>
<td>1.6 dB</td>
</tr>
<tr>
<td>Receiving antenna gain</td>
<td>40.0 dBi</td>
</tr>
<tr>
<td>Receiver feeder loss</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>Received power</td>
<td>-41.6 dBm</td>
</tr>
<tr>
<td>Noise bandwidth</td>
<td>109.2 dB</td>
</tr>
<tr>
<td>Noise figure</td>
<td>5.0 dB</td>
</tr>
<tr>
<td>Receiver thermal noise</td>
<td>-88.5 dBm</td>
</tr>
<tr>
<td>Required C/N by modulator/demodulator</td>
<td>17.6 dB</td>
</tr>
<tr>
<td>Transmission margin</td>
<td>29.3 dB</td>
</tr>
</tbody>
</table>

* 250 mW (24 dBm) per polarization
same as the calculated value. Furthermore, we confirmed that restored bit data by RS and Viterbi decoding was no error because the BER was measured to be $1 \times 10^{-4}$ before error correction. We considered that this large value of the BER before error correction, despite the sufficiently large transmission margin shown in Table 6, originated from the distortion of the power amplifier.

We next discuss the transmission distance of an 8K signal using this millimeter-wave-band 4K/8K FPU. Allocating the 29.3 dB transmission margin in Table 6 to free-space propagation loss and atmospheric absorption loss, a transmission distance of about 50 km is estimated. Under rainfall, however, attenuation occurs according to rainfall intensity, therefore shortening the transmission distance. Assuming rainfall intensity of 20 mm/h, generally considered to be heavy rainfall, an International Telecommunication Union Radiocommunication Sector (ITU-R) Recommendation states that attenuation of 5.8 dB/km will occur under rainfall in the 42 GHz band. Therefore the transmission distance under rainfall conditions should be about 5 km for this FPU system.

5. Conclusion

We have developed a millimeter-wave-band 4K/8K FPU having a maximum transmission capacity of 600 Mbps for transmitting 4K/8K program contributions such as program for news and sports relay broadcasts over wireless links. It was shown by an outdoor transmission experiment that the FPU can be used for 8K program contribution over an 8 km wireless link. On the basis of link budget, this millimeter-wave-band 4K/8K FPU is expected to be capable of transmissions at a distance of approximately 50 km under fair weather conditions and about 5 km under rainfall of 20 mm/h.

In the future, we plan to conduct long-term transmission experiments, test transmission characteristics under rainfall, and make upgrades toward stable operation with the goal of putting this millimeter-wave-band 4K/8K FPU to practical use in 4K/8K program production.

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References