Hardware Performance of Optical Distribution Equipment for 12-GHz Band Satellite Broadcasting using Dual-polarization

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In 2018, practical broadcasting of 4K/8K ultra-high-definition television will start with 12-GHz band satellite broadcasting using right- and left-hand circular polarization in Japan. For 4K/8K satellite broadcasting reception, the Association of Radio Industries and Businesses standardized specifications of distribution equipment for home use. Therefore, we fabricated a dual-polarization receiving antenna and optical distribution equipment in accordance with the specifications. We measured the aperture efficiency and cross-polarization discrimination of the fabricated antenna, and the respective results indicated that they were more than 74% and 26 dB. We also confirmed that the fabricated optical distribution equipment was able to deliver 50 modulated signals with C/N degradation of 0.1 dB.

Key Words: Satellite Broadcasting, 12-GHz Band, Dual-polarized Antenna, Radio on Fiber, UHDTV

1. Introduction

In 2018, practical satellite broadcasting of 4K/8K ultra-high-definition television (UHDTV)¹⁾ will start in Japan with 12-GHz-band (11.7–12.75 GHz) satellite broadcasting using right- and left-hand circular polarization. The Association of Radio Industries and Businesses (ARIB) standardized specifications of distribution equipment for home use for the reception of UHDTV satellite broadcasting.

ARIB STD-B63²⁾ defines the intermediate frequency (IF) of right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) to deliver signals of both polarizations on a single cable simultaneously. The IF-band of RHCP, which is currently used in Japan, is 1032.23 to 2070.25 MHz, and the IF-band of LHCP is 2224.41 to 3223.25 MHz so as not to overlap with digital terrestrial television broadcasting or the RHCP-IF band.

Because the frequency band of LHCP-IF is higher than that of the currently used RHCP-IF, the loss in coaxial cables increases when IF signals of both polarizations are delivered. Therefore, ARIB STD-B63 also defines the specifications of optical distribution equipment. This equipment consists of a radio-over-fiber system that can deliver the IF signals with low loss.

We describe in this paper the results of evaluating a dual-polarization receiving antenna and optical distribution equipment, which were fabricated in accordance with the specifications of ARIB STD-B63.

2. Dual-Polarization Receiving System

Figure 1 schematically shows a dual-polarization receiving system for 12-GHz-band satellite broadcasting using RHCP

and LHCP, which are transmitted by a satellite whose orbital position is 110 degrees east. The dual-polarization receiving system is composed of a dual-polarization receiving antenna and distribution equipment. This system enables simultaneous reception of UHDTV programs provided with both forms of polarization.

The receiving antenna has a dual-polarized feed horn antenna and a low noise block converter (LNB) that has two converter circuits. The LNB performs frequency conversion using different local oscillation frequencies and outputs two consecutive IF bands corresponding respectively to RHCP and LHCP. In the distribution equipment, the satellite broadcasting IF signals are combined with digital terrestrial television broadcasting signals and delivered to each room via coaxial cables or optical distribution equipment.

Fig. 1. Outline of dual-polarization receiving system.

3. Prototype Dual-Polarization Receiving Antenna

3.1. Requirement for dual-polarization receiving antenna

We fabricated and tested a dual-polarization receiving antenna. The requirements for this antenna are listed in Table 1. The receiving frequency is 11.7 GHz to 12.75 GHz, and it is possible to receive RHCP and LHCP signals simultaneously. The aperture efficiency was 70% or more, which is the same as that of the satellite broadcast receiving antenna currently used in Japan. The co-polarization and cross-polarization characteristics are in accordance with Rec. ITU-R BO.1213,³⁾ which is a reference pattern for 12-GHz-band receiving antennas. The required cross-polarization discrimination (XPD) is 25 dB, which is derived from the boresight value of the reference pattern of Rec. ITU-R BO.1213.

The frequency allocation of the 12-GHz band and the IF-band is shown in Fig. 2. ARIB STD-B63 specifies 10.678 and 9.505 GHz as local oscillation frequencies of an LNB for RHCP and LHCP, respectively. Hence, we can convert the same radio frequency (RF) bands for both polarizations into two consecutive IF signals. The LHCP is located so as to be converted to the upper frequency band of RHCP. These local oscillation frequencies were applied to our fabricated LNB.

Table 1. Requirements for dual-polarization receiving antenna.

Receiving frequency	11.7 to 12.75 GHz
Receiving polarizations	Right-hand circular polarization (RHCP) and Left-hand circular polarization (LHCP)
Aperture efficiency	70% or more
Main polarization and cross-polarization characteristics	Rec. ITU-R BO.1213
Cross-polarization discrimination (XPD)	25 dB or more (at 0 deg.)
Local oscillator frequency	RHCP: 10.678 GHz LHCP: 9.505 GHz
Output frequency	RHCP: 1032.23 to 2070.25 MHz LHCP: 2224.41 to 3223.25 MHz
Output impedance	75 Ω

Fig. 2. Frequency relationship of converter output.

3.2. Antenna configuration

Figures 3 and 4 show our prototype dual-polarization receiving antenna and the antenna parameters, respectively. Offset parabolic reflector antennas with a 45-cm diameter are popular for home use in Japan. However, for apartment buildings or in the fringe area of satellite broadcasting, antennas with an aperture diameter of 60 cm or larger are used. Therefore, we fabricated two reflector antennas with aperture

diameters of 45 and 60 cm. The designs of the feed antenna were the same. The ratio of the focal length to the aperture diameter (F/D) was 0.47, and the offset angle was 58.8 degrees, which are equal to those of commercial antennas. The parabolic reflectors were fabricated using the same method as for commercial antennas. The 45-cm reflector was made of pressed aluminum, and the 60-cm reflector was a molded metal mesh with fiber-reinforced plastic.

Fig. 3. Prototype dual-polarization receiving antennas.

Fig. 4. Parameters of prototype antenna.

3.3. Structure of horn antenna for dual-polarization

The prototype antenna has a horn antenna supporting dual-polarization that can separate the received signal into RHCP and LHCP. The internal structure of the dual-polarized horn antenna is illustrated in Fig. 5. The aperture of the horn is circular and is connected to a circular polarizer of the square waveguide by a tapered structure. We chose a septum type polarizer that is suitable for mass production because the septum structure does not require adjustment.

Fig. 5. Structure of dual-polarized horn antenna.

3.4. Converter configuration

A block diagram of our fabricated LNB with two converter-circuits for RHCP and LHCP is shown in Fig. 6. The LNB is integrated with the feed horn antenna. The converters for RHCP and LHCP have the same configuration except for the local oscillation frequency and the mixing filter. Each LNB amplifies the 12-GHz-band input signal with a low noise amplifier and removes unnecessary waves with a band pass filter (BPF). Then, the LNB converts the 12-GHz RF band to the IF-band signal. The circuit then amplifies the IF-band signal, removes the out-of-band noise with a low pass filter or high pass filter (LPF or HPF), and mixes the signal with the other LNB's output signal.

Fig. 6. Block diagram of LNB.

4. Performance of Prototype Antenna

4.1. Antenna gain, cross polarization discrimination

Tables 2 and 3 list the measured results of the antenna gain and the XPD. The measurement frequency was set according to six points described in JEITA CP-5104C.⁴⁾ The measured results showed that the gain and the XPD of the 45-cm diameter antenna were 33.6 dBi (aperture efficiency: 74%) and 26 dB, respectively. The gain and the XPD of the 60-cm antenna were 36.1 dBi (76%) and 27 dB. We confirmed that the prototype antennas satisfied the requirements of an aperture efficiency of 70% and XPD of 25 dB, regardless of the aperture diameter and received polarization.

Table 2. Measured results of antenna gain.

Frequency [GHz]	Gain [dBi] (Aperture efficiency [%])			
	Diameter: 45 cm		Diameter: 60 cm	
	RHCP	LHCP	RHCP	LHCP
11.70	33.7 (76.2)	33.6 (74.6)	36.1 (76.1)	36.1 (76.0)
11.85	33.8 (77.0)	33.7 (74.6)	36.3 (77.2)	36.3 (77.5)
12.00	33.9 (76.9)	33.8 (74.4)	36.5 (77.6)	36.5 (78.7)
12.25	34.1 (77.5)	34.0 (75.1)	36.6 (77.2)	36.7 (79.4)
12.50	34.3 (77.8)	34.2 (75.2)	36.8 (77.6)	36.9 (79.3)
12.75	34.6 (78.9)	34.3 (74.5)	36.9 (76.5)	37.1 (78.9)

Table 3. Measured results of XPD.

Frequency [GHz]	XPD [dB]			
	Diameter: 45 cm [dB]		Diameter: 60 cm [dB]	
	RHCP	LHCP	RHCP	LHCP
11.70	32.5	39.6	33.9	37.2
11.85	29.5	38.4	39.5	44.2
12.00	27.7	31.7	49.0	33.1
12.25	29.5	29.6	33.3	27.6
12.50	33.5	34.1	29.7	27.7
12.75	26.2	31.4	28.7	29.4

4.2. Radiation pattern

The measured radiation patterns and reference patterns of Rec. ITU-R BO.1213 are plotted in Figs. 7 to 10. We selected 12.0 GHz and 12.5 GHz for the measurement frequencies as the centers of the broadcasting satellite service (BS, 11.7–12.2 GHz) and the fixed satellite service (CS, 12.2–12.75 GHz) bands. In each figure, the left and right graphs respectively plot the characteristics of the RHCP and LHCP antennas. We confirmed that the prototype antennas satisfied BO.1213 in both co-polarization and cross-polarization.

Fig. 7. Measured radiation patterns of 45-cm antenna (12.0 GHz).

Fig. 8. Measured radiation patterns of 45-cm antenna (12.5 GHz).

Fig. 9. Measured radiation patterns of 60-cm antenna (12.0 GHz).

Fig. 10. Measured radiation patterns of 60-cm antenna (12.5 GHz).

5. Evaluation of Optical Distribution Equipment

5.1. Prototype of optical distribution equipment

We also fabricated and tested optical distribution equipment. Figure 11 shows the prototype equipment, which consists of an optical transmitter (E/O) and optical receiver (O/E). Table 4 lists the specifications, which comply with ARIB STD-B63. The prototype was assumed to be for home use, and thus, the transmission frequency was 76 to 3,224 MHz, which includes the transmission band of FM radio broadcasting, terrestrial television broadcasting, and satellite broadcasting (IF).

Fig. 11. Prototype of optical distribution equipment.

Table 4. Specifications of optical distribution equipment.

Parameters	Value
Transmission frequency	76 to 3,224 MHz
IF input level	-47.8 dBm
Optical wavelength	1,550±10 nm
Optical output level	+6 dBm
Optical input level	-12 dBm to -6 dBm
IF output level	-23.8 dBm

The results of measuring the frequency characteristics are given in Fig. 12. The ratio of the input power of the E/O to the output power of the O/E is shown as a gain. The optical input level of the O/E was set to -6 dBm, which is the upper limit of the fabricated O/E. From this figure, we can confirm that the prototype optical distribution equipment had a transmission frequency band of 76 to 3,224 MHz, which meets our requirement. In addition, it can be seen that the gain deviation of the satellite broadcasting IF band (1,032 to 3,224 MHz) was suppressed to ± 1 dB.

Fig. 12. Frequency characteristics of optical distribution equipment.

5.2. Evaluation of optical distribution equipment by measuring BER

The performance of the optical distribution equipment was evaluated by measuring the bit error rate (BER) for ISDB-S3. Figure 13 is a schematic outline of our measurement system to evaluate the optical distribution equipment. Table 5 lists the experimental parameters for ISDB-S3 modulator and demodulator. The 50 modulated waves were input to the optical equipment to simulate the transmission of the RHCP- and LHCP-IF signals. Table 6 lists the channel numbers and center frequencies of satellite broadcasting in Japan. We used frequency converters to evaluate the performance in the LHCP-IF band because our prototype modulator and demodulator for ISDB-S3 only conformed to the RHCP-IF band at the moment.

Fig. 13. Outline of measurement system.

Table 5. Main transmission parameters for experiment.

Modulation (code rate)		16APSK (7/9)
Information bit rate		99.95 Mbps
Symbol rate		33.7561 Mbaud
Roll-off factor		0.03
FEC	Inner code	LDPC (code length 44,880)
	Outer code	Shortened code of BCH

Table 6. Channel allocation of BS/CS-IF (center frequency).

Band	Channel	Frequency [MHz]	Band	Channel	Frequency [MHz]
BS-IF RHCP	BS 1	1049.48	BS-IF LHCP	BS 2	2241.66
	BS 3	1087.84		BS 4	2280.02
	BS 5	1126.20		BS 6	2318.38
	BS 7	1164.56		BS 8	2356.74
	BS 9	1202.92		BS 10	2395.10
	BS 11	1241.28		BS 12	2433.46
	BS 13	1279.64		BS 14	2471.82
	BS 15	1318.00		BS 16	2510.18
	BS 17	1356.36		BS 18	2548.54
	BS 19	1394.72		BS 20	2586.90
	BS 21	1433.08		BS 22	2625.26
	BS 23	1471.44		BS 24	2663.62
CS-IF RHCP	ND 26	1550	CS-IF LHCP	ND 25	2726
	ND 2	1613		ND 1	2766
	ND 4	1653		ND 3	2806
	ND 6	1693		ND 5	2846
	ND 8	1733		ND 7	2886
	ND 10	1773		ND 9	2926
	ND 12	1813		ND 11	2966
	ND 14	1853		ND 13	3006
	ND 16	1893		ND 15	3046
	ND 18	1933		ND 17	3086
	ND 20	1973		ND 19	3126
	ND 22	2013		ND 21	3166
	ND 24	2053		ND 23	3206

The BS17 and ND24 channels were selected in this experiment because BS17 is currently used for UHDTV test satellite broadcasting, and ND24 is nearest to the center frequency of the satellite broadcasting IF. We measured the BER for 16APSK (7/9).^{5,6)} Here, the optical input level of the O/E was set to -6 dBm.

Figures 14 and 15 show the signal waveform and constellation of the O/E output. Figure 16 plots the C/N versus BER characteristics. Table 7 lists the required carrier-to-noise ratio (C/N) obtained from our BER measurement of Fig. 16. The measurements were observed until the BER reached 10^{-8} when 10^{10} bits were transmitted. The required C/N (P4) was defined as the C/N at which the BER was 1×10^{-11} and the C/N value was derived from an extrapolation of three measurement points (P1, P2, P3). By setting C/N and BER at each point as P1(CN1, BER1), P2(CN2, BER2), P3(CN3, BER3), the required C/N (CN4) was obtained from Eq. (1).⁶⁾

Required $C/N = CN4$

$$= 2 \cdot \frac{\log(10^{-11}) - \log(BER3)}{\frac{\log(BER2) - \log(BER1)}{CN2 - CN1} + \frac{\log(BER3) - \log(BER2)}{CN3 - CN2}} + CN3 \quad (1)$$

Fig. 14. Output-signal waveform of O/E (50 modulated waves).

Fig. 15. Output-signal constellation of O/E (16APSK (7/9)).

(a) Measured results in BS17

(b) Measured results in ND24

Fig. 16. Measured results of C/N vs. BER.

※Measurement result when excluding E/O, optical ATT, and O/E in Fig. 13.

Table 7 indicates that the degradation of the required C/N was 0.1 dB for the fabricated optical distribution equipment.

Table 7. BER measurement results.

Channel	BS 17		ND 24	
	IF return※	Optical transmitter and receiver	IF return※	Optical transmitter and receiver
Required C/N	11.07 dB	11.19 dB	11.25 dB	11.35 dB
Degradation of required C/N		0.12 dB		0.10 dB

※Measurement result when excluding E/O, optical ATT, and O/E in Fig. 13.

6. Conclusion

We fabricated a dual-polarization receiving antenna and optical distribution equipment for 12-GHz-band satellite broadcasting, in accordance with the specifications of ARIB STD-B63. The measurement results for the receiving antenna showed that the aperture efficiency was more than 74% and that the XPD was more than 26 dB throughout the 12-GHz band. The radiation patterns were in accordance with the reference pattern of Rec. ITU-R BO.1213. We also confirmed that the fabricated optical distribution equipment was able to deliver 50 modulated IF signals simultaneously with C/N degradation of 0.1 dB.

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