International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R BO.2397-1
(09/2022)

Satellite transmissions for UHDTV satellite broadcasting

BO Series

Satellite delivery

International Telecommunication Union

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BO.2397-1

Satellite transmissions for UHDTV satellite broadcasting

(Question ITU-R 292/4)

(2016-2022)

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Abbreviations/Glossary

AAC	Advanced audio coding
ARIB	Association of Radio Industries and Businesses
APSK	Amplitude and phase shift keying
AWGN	Additive white gaussian noise
BPSK	Binary phase shift keying
BCH code	Bose-Chaudhuri-Hocquenghem code
BER	Bit error rate
BSS	Broadcasting-satellite service
C/N	Carrier to noise ratio
D/C	Down converter
EPG	Electronic Program Guide
FIR	Finite impulse response
HEVC	High efficiency video coding
HPA	High power amplifier
HDR	High dynamic range
HTML	Hyper text markup language
IF	Inter frequency
ISDB-S3	Integrated Services Digital Broadcasting for Satellite, 3rd generation
LCD	Liquid crystal display
LDPC code	Low density parity check code
MPEG	Moving Picture Experts Group
MMT	MPEG Media Transport
OBO	Output back off
OBW	Occupied bandwidth
PAPR	Peak to average power ratio
PN	Pseudo noise
PSK	Phase shift keying
QPSK	Quadrature phase shift keying
RMP	Rights management and protection
TDM	Time division multiplexing
TLV	Type length value
TMCC	Transmission and multiplexing configuration control
TS	Transport stream
TOC	Technical operation centre
TTML	Timed text markup language
TWTA	Traveling Wave Tube Amplifier

UHDTV Ultra-high definition television

U/C Up converter

1 Introduction

Ultra-high definition television (UHDTV) is one of the major applications of next-generation satellite broadcasting. New technologies such as amplitude and phase shift keying (APSK), low density parity check code (LDPC), and spectrum shaping by lowering the roll-off factor are required to implement UHDTV services via satellite within the same bandwidth as conventional high definition television.

This Report provides useful information of UHDTV satellite broadcasting including satellite transmission experiments and the latest status of UHDTV satellite broadcasting. Administrations are encouraged to contribute further information on the implementation of the UHDTV services via satellites.

2 Status of ITU-R standardization of UHDTV broadcasting

The ITU-R Recommendations relevant to UHDTV broadcasting are listed below as informative references.

Informative references

Recommendation ITU-R BT.1122 – User requirements for codecs for emission and secondary distribution systems for SDTV, HDTV, UHDTV and HDR-TV

Recommendation ITU-R BS.1196 – Audio coding for digital broadcasting

Recommendation ITU-R BT.1852 – Conditional-access systems for digital broadcasting

Recommendation ITU-R BT.1869 – Multiplexing scheme for variable-length packets in digital multimedia broadcasting systems

Recommendation ITU-R BT.1870 – Video coding for digital television broadcasting emission

Recommendation ITU-R BS.1873 – Serial multichannel audio digital interface for broadcasting studios

Recommendation ITU-R BT.1887 – Carriage of IP packets in MPEG-2 transport stream in multimedia broadcasting

Recommendation ITU-R BT.2020 – Parameter values for ultra-high definition television systems for production and international programme exchange

Recommendation ITU-R BS.2051 – Advanced sound system for programme production

Recommendation ITU-R BT.2073 – Use of the high efficiency video coding (HEVC) standard for UHDTV and HDTV broadcasting

Recommendation ITU-R BT.2074 – Service configuration, media transport protocol, and signalling information for MMT-based broadcasting systems

Recommendation ITU-R BT.2075 – Integrated broadcast-broadband system

Recommendation ITU-R BT.2077 – Real-time serial digital interfaces for UHDTV signals

Recommendation ITU-R BO.2098 – Transmission system for UHDTV satellite broadcasting

Recommendation ITU-R BT.2100 – Image parameter values for high dynamic range television for use in production and international programme exchange

3 Satellite transmissions for UHDTV satellite broadcasting

Annex 1 provides the details on the UHDTV satellite broadcasting system used in Japan including transmission experiments to confirm the feasibility of the system and the latest status of UHDTV satellite broadcasting. The geostationary satellites BSAT-3 and BSAT-4 located at 110 degrees east longitude are used for transmission in the 12 GHz BSS band. The results of the experiments confirmed that all of the combinations of modulation and inner coding rate defined for the ISDB-S3 system are feasible and 16-APSK (7/9) transmission provides an approximately 100 Mbit/s transmission capacity in a 34.5 MHz-bandwidth single satellite transponder.

Annex 2 provides techniques for APSK modulation signals in satellite transmission, which enable transmission capacity for UHDTV to be increased. However, the APSK modulation signals are more susceptible to non-linear characteristics of the RF components in the broadcasting satellite network, therefore there is a trade-off for TWTA operation in a satellite transponder between the output power and the transmission performance. An evaluation formula for the overall performance is considered to analyse the link margin. The results of the transmission experiments show that the evaluation formula is useful to improve the link margin.

Annex 1

UHDTV satellite broadcasting in Japan

1 Introduction

A 4K/8K UHDTV satellite broadcasting system named as ISDB-S3 was standardized as ARIB STD-B44 in Japan in 2014. The system is also specified in Recommendation ITU-R BO.2098.

The key technologies in ISDB-S3 include highly efficient video coding with the HEVC/H.265 standard [1], a flexible multiplexing scheme with the MMT protocol [2], and a larger channel capacity by the new transmission system. The target channel capacity for a single satellite transponder in the BSS band is set to 80-100 Mbit/s [3], which is shown as one of the basic parameters for UHDTV broadcasting using the HEVC standard in ITU-R BT.2073. 16-APSK and LDPC code with a coding rate of 7/9 and a symbol rate of 33.7561 Mbaud by lowering the roll-off factor of 0.03 can provide a capacity of approximately 100 Mbit/s in a satellite transponder with a 34.5 MHz bandwidth.

Satellite transmission experiments were conducted using a 12 GHz band broadcasting satellite in 2015 [4] to demonstrate the feasibility of this system. The geostationary satellite BSAT-3b located at 110 degrees east longitude was used for transmission on the 12 GHz BSS band. The results indicated that all of the combinations of modulation and inner coding rate are feasible and 16-APSK (7/9) provides a 100 Mbit/s transmission capacity in a 34.5 MHz-bandwidth single satellite transponder.

Practical UHDTV satellite broadcasting has been in operation since December 2018 via BSAT-4a after the test broadcasting conducted in 2016-2018 via BSAT-3b satellite.

Section 2 gives the technical specifications for the ISDB-S3 transmission system. Section 3 presents the satellite transmission experiments. The experimental results are summarized with the results obtained from C/N vs. BER measurements in § 3.2. Section 4 introduces the UHDTV satellite broadcasting in Japan.

2 Technical characteristics (ISDB-S3) for transmission system and main parameters used in satellite transmissions

The technical specifications are summarized in Table 1. This system has adopted 0.03 as the roll-off factor for the raised-cosine square-root Nyquist filters implemented in the transmitter and receiver. Lowering the roll-off factor to 0.03 enables the symbol rate to be increased to 33.7561 Mbaud, and this combination also meets the occupied bandwidth (OBW) of 34.5 MHz [5].

ISDB-S3 does not specify the specific symbol rate. Japan chose 33.7561 Mbaud according to domestic regulation in the experiments. The symbol rate of ISDB-S3 can be set according to the various kinds of satellite transponder bandwidth flexibly.

A transmitter and receiver that satisfied the technical specifications listed in Table 1 were developed. The Finite Impulse Response (FIR) raised-cosine square-root Nyquist filter that achieved a roll-off factor of 0.03 was implemented in the transmitter and receiver, and the numbers of tap coefficients were 678 for the former and 512 for the latter. The centre frequency of the transmitter was 140 MHz, which is the inter frequency (IF) of the 17 GHz feeder link. The spectrum of transmitter output is shown in Fig. 1.

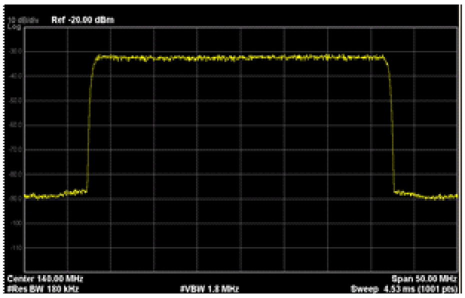
TABLE 1

Technical specifications for the ISDB-S3 system

Item		Description
Input signal format		MPEG-2 TS, TLV
Modulation scheme		π/2-shift BPSK, QPSK, 8-PSK, 16-APSK, and 32-APSK
Transmission control		TMCC
Forward error correction	Inner code	LDPC code (code length: 44880)
	Coding rate	1/3 (41/120), 2/5 (49/120), 1/2 (61/120), 3/5 (73/120), 2/3 (81/120), 3/4 (89/120), 7/9 (93/120), 4/5 (97/120), 5/6 (101/120), 7/8 (105/120), 9/10 (109/120) (nominal value (true value))
	Outer code	BCH (65535, 65343, T = 12) shortened code
TMCC	Modulation scheme	π/2-shift BPSK
	Inner code	LDPC (31680,9614), LDPC (44880,22184) shortened code
	Outer code	BCH (9614,9422, T = 12), BCH (65535,65343, T = 12) shortened code
	Control unit	Transmission control in units of slots
TDM frame structure		120 slots per frame
Symbol rate		Not specified The symbol rate of ISDB-S3 can be set according to the various kinds of satellite transponder bandwidth flexibly.
Roll-off factor		0.03
Nonlinear compensation signal		Pilot signal, which can transmit unique word sequence by using same modulation scheme as that for input signal. Averaged pilot signal was used on receiver side for reference point of LDPC decoding.

FIGURE 1

Spectrum of Transmitter Output



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3 Satellite transmission experiments in the 12 GHz BSS band in Japan

3.1 Measurement system

Figure 2 shows schematic and photographs of the measurement system used in the satellite transmission experiments with the BSAT-3b satellite. The earth station with a 5.5-m transmitting and receiving antenna was located at NHK, Nippon Hoso Kyokai (JAPAN BROADCASTING CORPORATION) Broadcasting Station, Shibuya, Tokyo, Japan. The uplink frequency was in the 17 GHz band and that of the downlink was in the 12 GHz band. Figure 3 shows schematic of the measurement system. The satellite transmission experiments were conducted from 31 August to 14 September 2015.

FIGURE 2

Measurement system

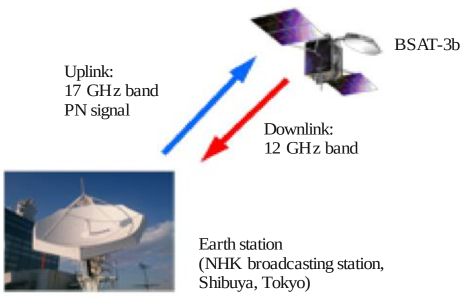

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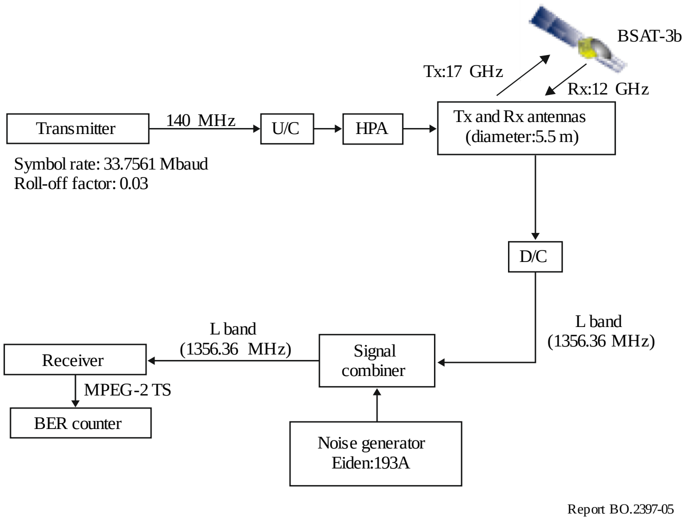
FIGURE 3

Schematic of measurement system



3.2 Results from measurements

The results obtained from C/N vs. BER measurements are plotted in Figs 4-1 to 4-5. Tables 2-1 to 2-5 summarize the required C/N[1] obtained from Figs 4-1 to 4-5. These Tables list the information bit rate for type length value (TLV) input, the calculated required C/N for ideal performance[2], and the measured required C/N for satellite-transmission-loopback using BSAT-3b. The output back off of the satellite transponder is set to 2.2 dB. Figure 5 shows the relationship between the information bit rate for TLV input and required C/N obtained from Tables 2-1 to 2-5. This indicates that 99.9552 Mbit/s transmission was achieved using 16-APSK (7/9). It also can meet a worst-month service availability of 99.7% using a 45 cm receive antenna in Tokyo [6].

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1 The required C/N is defined as the smallest C/N at which the bit error rate (BER) is 1×10^{-11}. The noise bandwidth of C/N is set to 33.7561 MHz equivalent to the symbol rate in units of baud for the experiments.

2 The ideal performance is defined as the computer simulation results for the AWGN channel where the maximum number of iterations for LDPC decoding is set to 50.

FIGURE 4-1

Results from *C*/*N* vs. BER measurements of π/2-shift BPSK

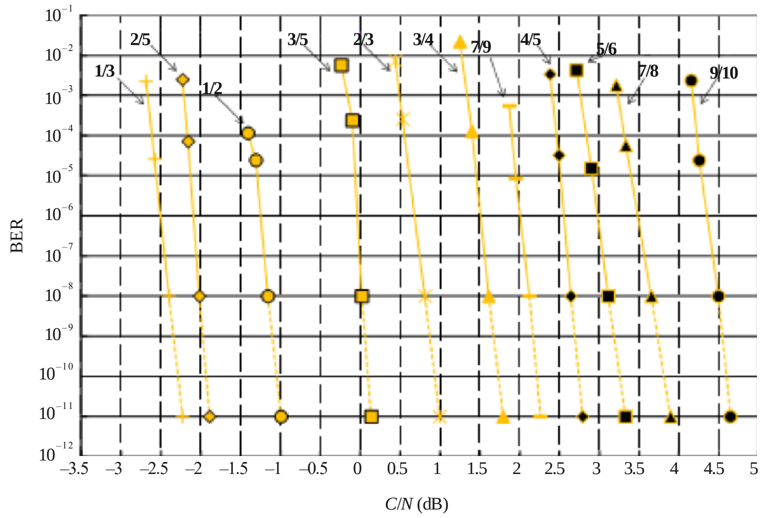

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FIGURE 4-2

Results from *C*/*N* vs. BER measurements of QPSK

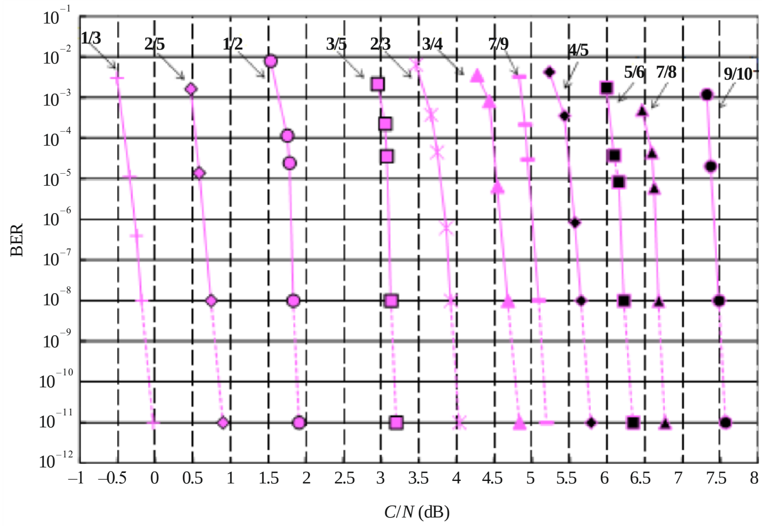

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FIGURE 4-3

Results from *C*/*N* vs. BER measurements of 8-PSK

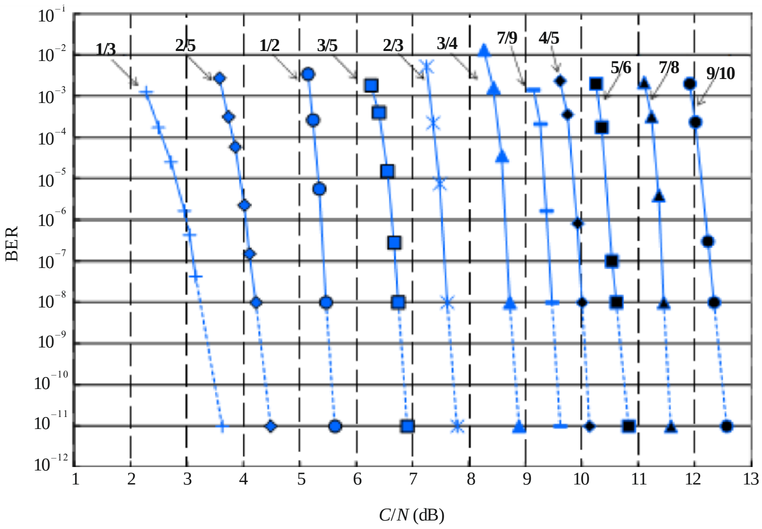

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FIGURE 4-4

Results from *C*/*N* vs. BER measurements of 16-APSK

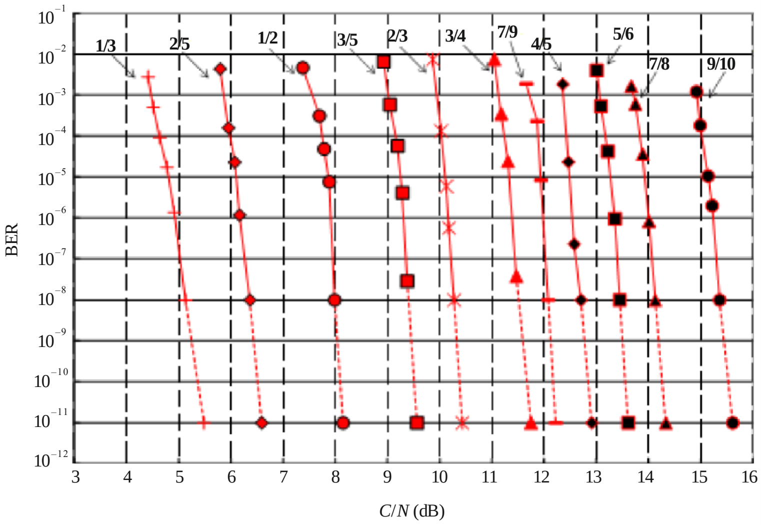

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FIGURE 4-5

Results from *C*/*N* vs. BER measurements of 32-APSK

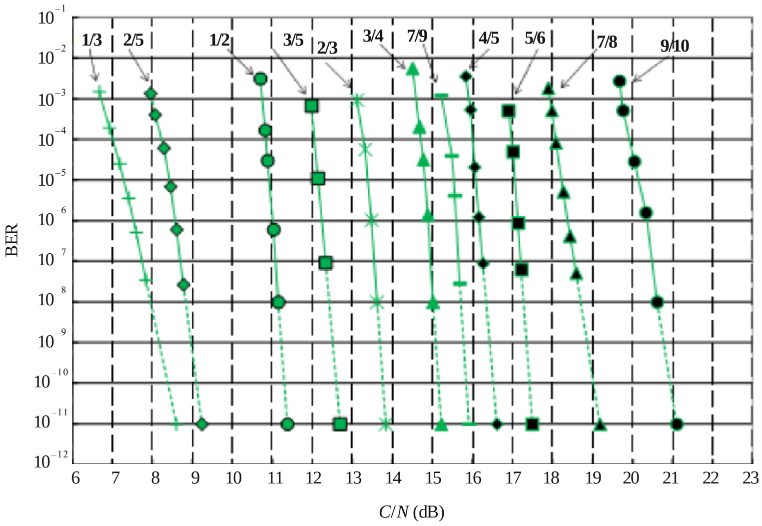

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TABLE 2-1

Required *C*/*N* for satellite transmission experiment of π/2-shift BPSK

Inner coding rate	Information bit rate (Mbit/s)	Calculated required *C*/*N* (dB)	Measured required *C*/*N* (dB)
1/3	10.8647	−4.0	−2.2
2/5	13.0376	−3.0	−1.9
1/2	16.2971	−1.8	−1.0
3/5	19.5565	−0.5	0.1
2/3	21.7294	0.3	1.0
3/4	23.9023	1.0	1.8
7/9	24.9888	1.5	2.3
4/5	26.0753	2.0	2.8
5/6	27.1618	2.5	3.3
7/8	28.2482	2.9	3.9
9/10	29.3347	3.8	4.6

TABLE 2-2

Required *C*/*N* for satellite transmission experiment of QPSK

Inner coding rate	Information bit rate (Mbit/s)	Calculated required *C*/*N* (dB)	Measured required *C*/*N* (dB)
1/3	21.7294	−1.0	0.0
2/5	26.0753	0.0	0.9
1/2	32.5941	1.2	1.9
3/5	39.1129	2.5	3.2
2/3	43.4588	3.3	4.0
3/4	47.8047	4.0	4.8
7/9	49.9776	4.5	5.2
4/5	52.1506	5.0	5.8
5/6	54.3235	5.5	6.3
7/8	56.4964	5.9	6.8
9/10	58.6694	6.8	7.6

TABLE 2-3

Required *C*/*N* for satellite transmission experiment of 8-PSK

Inner coding rate	Information bit rate (Mbit/s)	Calculated required *C*/*N* (dB)	Measured required *C*/*N* (dB)
1/3	32.5941	2.2	3.6
2/5	39.1129	3.1	4.5
1/2	48.8912	4.4	5.6
3/5	58.6694	5.7	6.9
2/3	65.1882	6.7	7.8
3/4	71.7070	7.9	8.9
7/9	74.9664	8.6	9.6
4/5	78.2258	9.1	10.1
5/6	81.4853	9.7	10.8
7/8	84.7447	10.4	11.6
9/10	88.0041	11.4	12.6

TABLE 2-4

Required *C*/*N* for satellite transmission experiment of 16-APSK

Inner coding rate	Information bit rate (Mbit/s)	Calculated required *C*/*N* (dB)	Measured required *C*/*N* (dB)
1/3	43.4588	4.1	5.5
2/5	52.1506	5.1	6.6
1/2	65.1882	6.6	8.1
3/5	78.2258	8.0	9.6
2/3	86.9176	9.1	10.4
3/4	95.6094	10.2	11.7
7/9	99.9552	10.8	12.2
4/5	104.3011	11.3	12.9
5/6	108.6470	11.9	13.6
7/8	112.9929	12.5	14.3
9/10	117.3388	13.5	15.6

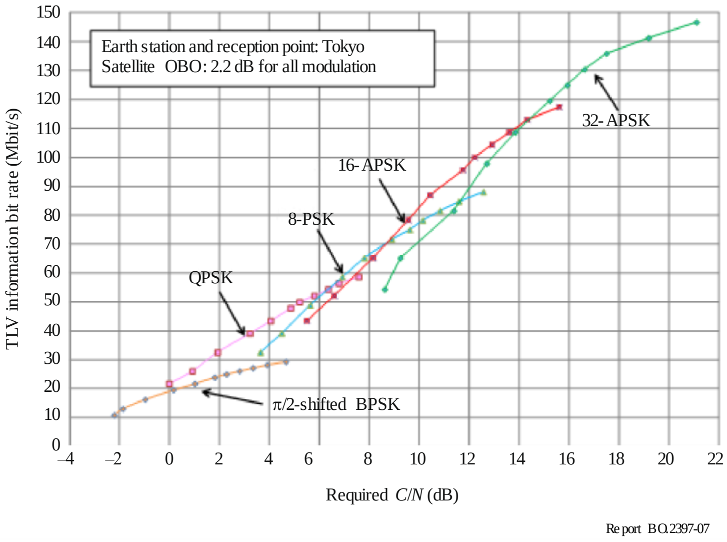
TABLE 2-5

Required *C*/*N* for satellite transmission experiment of 32-APSK

Inner coding rate	Information bit rate (Mbit/s)	Calculated required *C*/*N* (dB)	Measured required *C*/*N* (dB)
1/3	54.3235	6.4	8.6
2/5	65.1882	7.2	9.2
1/2	81.4853	9.2	11.4
3/5	97.7823	10.6	12.7
2/3	108.6470	11.7	13.8
3/4	119.5117	12.8	15.2
7/9	124.9441	13.4	15.9
4/5	130.3764	14.0	16.6
5/6	135.8088	14.5	17.5
7/8	141.2411	15.3	19.2
9/10	146.6735	16.3	21.1

FIGURE 5

Relationship between measured required *C*/*N* and TLV information bit rate



4 UHDTV satellite broadcasting in the 12 GHz BSS band in Japan

4.1 Roadmap for UHDTV satellite broadcasting

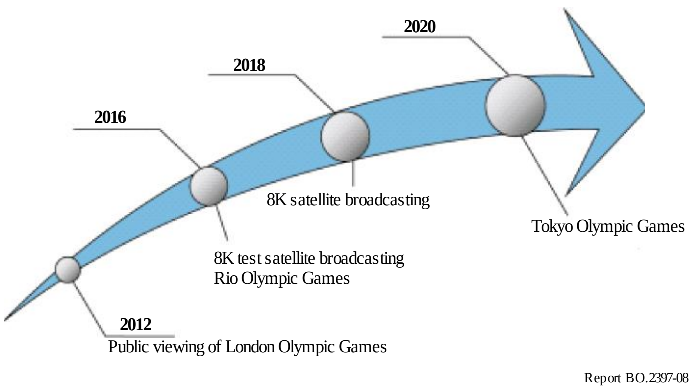
The Ministry of Internal affairs and Communications (MIC) in Japan issued a roadmap for initiatives for UHDTV satellite broadcasting in Japan in 2015. Figure 6 shows the overview of the roadmap to launch UHDTV satellite test broadcasting in 2016 and UHDTV satellite broadcasting in 2018.

NHK successfully launched UHDTV satellite test broadcasting on August 1st 2016. The Association for Promotion of Advanced Broadcasting Services (A-PAB) in Japan [7] also launched 4K UHDTV satellite test broadcasting in December 2016. Both organizations share the common transmission facility at NHK Broadcasting Station in Tokyo.

The broadcasting satellite BSAT-4a designed to use ISDB-S3 for UHDTV services for general public in Japan was launched in September 2017. Practical UHDTV satellite broadcasting has been in regular operation since December 1st, 2018. The transmission capacity of 100 Mbit/s in a 34.5 MHz-bandwidth single satellite transponder provides one 8K UHDTV program or three 4K UHDTV programs.

FIGURE 6

Roadmap for UHDTV satellite broadcasting in Japan



4.2 Summary of UHDTV satellite broadcasting

Table 3 shows the technical specifications adopted for the UHDTV satellite broadcasting in the 12 GHz BSS band in Japan. 16-APSK and an LDPC coding rate of 7/9 are chosen as the transmission parameters.

Figure 7 shows the console and the wall-type display at the Technical Operation Center (TOC). Figures 8 and 9 show the ISDB-S3 modulator and the uplink antenna installed in the earth station respectively. Figure 10 shows an ISDB-S3 receiver for 8K UHDTV with the basic function to decode 8K video and 22.2-multichannel sound. HTML 5 and ARIB-TTML [8] are supported so that subtitles and data broadcasts can be presented on the screen.

TABLE 3

Technical specifications adopted for UHDTV satellite broadcasting in Japan

Item	Description
Frequency	Uplink: 17.3-17.8 GHz Downlink: 11.7-12.2 GHz
Channel bandwidth	34.5 MHz
Symbol rate	33.7561 Mbaud
Roll-off factor	0.03
Modulation	16-APSK
Inner coding rate	7/9
TLV information bit rate	99.9952 Mbit/s
Multiplexing	MMT
Video format	7680×4320/59.94/P, 3840×2160/59.94/P (Wide colour gamut, HDR/SDR)
Video coding	H.265|MPEG-H HEVC Main10
Audio format	22.2 ch, 7.1ch, 5.1 ch, 2 ch
Audio coding	MPEG-4 AAC LC MPEG-4 ALS
Multimedia coding	HTML5, ARIB-TTML
Transport	MMT/TLV
CAS	AES

FIGURE 7

Technical operation centre

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FIGURE 8

ISDB-S3 Modulator

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FIGURE 9

Earth station transmitting antenna

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FIGURE 10

ISDB-S3 receiver for 8K UHDTV

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5 Summary

4K/8K UHDTV broadcasting via a broadcasting satellite in the 12 GHz BSS band has been in regular operation in Japan since December 2018, following the standardization of a new satellite UHDTV transmission system called ISDB-S3 in 2014, transmission experiments in the 12 GHz band in 2015, and test broadcasting. The system uses 16-APSK and LDPC code with a coding rate of 7/9 and a symbol rate of 33.7561 Mbaud by lowering the roll-off factor of 0.03 to provide a capacity of approximately 100 Mbit/s in a satellite transponder with a 34.5 MHz bandwidth.

Annex 2

Satellite transmission techniques for APSK modulation signals

1 Background

APSK modulation increases transmission capacity, but it is also more susceptible to non-linear characteristics of the RF components in the broadcasting satellite network because its peak to average power (PAPR) is larger than PSK modulation. In particular, non-linear distortion of a traveling wave tube amplifier (TWTA) in a satellite transponder is a dominant factor for the transmission performance of APSK modulation when considering conventional receivers with an adaptive linear equalizer. It is desirable for the TWTA to operate at or near the saturation point to achieve high output power and high power efficiency. On the other hand, it is desirable for the transmission performance to operate in the near-linear region to reduce the deterioration due to non-linear distortion. There is therefore a trade-off for the TWTA operations between the output power and the transmission performance.

2 Relationship between operating point of satellite transponder and transmission performance

A TWTA is often used in high-frequency satellite transponders because it has the capability of high output power and high power efficiency, However, since its non-linearity affects the transmission performance, it is desirable to operate in the near-linear region especially for APSK transmission which is sensitive to non-linear distortion. The operating point of the satellite transponder using a

TWTA is defined by an output back-off (OBO) [dB] that indicates the reduction of the average output power level compared to the saturation power. The OBO at saturation is set as 0 dB, and any increase in the OBO indicates a drop in the output power. Figure 11 shows the relationship between the OBO and the constellation of APSK signals. When the OBO is small (operating point A), the constellation is dispersed because the high-power portion of the signal in the saturation range of the AM/AM characteristic is clipped, and the constellation suffers from non-linear distortion as a result. On the other hand, when the OBO is large (operating point B), the constellation is less dispersed because most of the signal is in the linear range of the AM/AM characteristic. The greater the dispersion in the constellation, the higher the required *C/N* (dB). The relationship between the OBO (dB) and the required *C/N* (dB) is thus a trade-off.

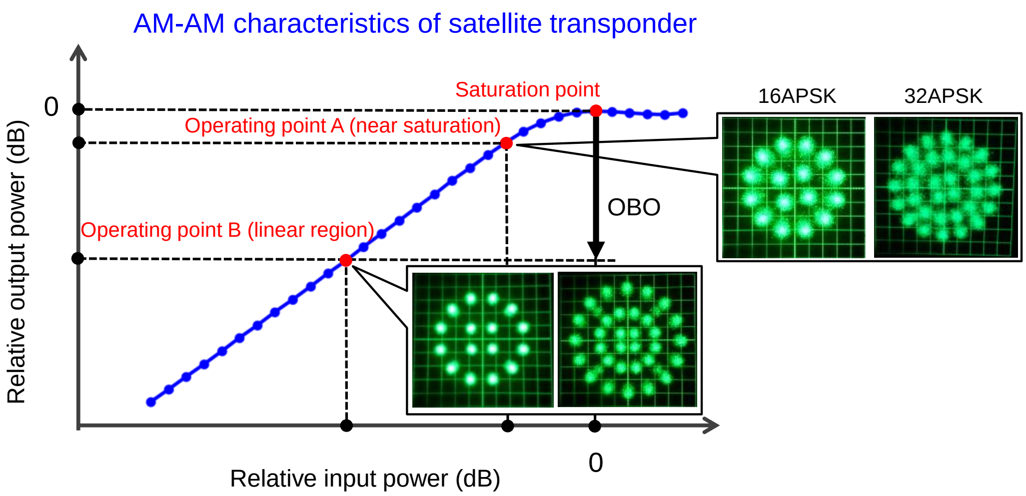
Therefore, an evaluation formula for the overall performance which can analyse the link margin is proposed as follows:

$$\mathrm{OBO} + Required\ C/N \quad (\mathrm{dB})$$

Here, the link margin is maximized when the above value is set to minimized.

FIGURE 11

Relationship between OBO and transmission performance of APSK modulation



3 Transmission experiment for improvement of link margin

3.1 Overview

Transmission experiments were conducted to analyse the overall performance on the basis of the link-margin evaluation formula by using an indoor satellite transponder model [9] and an actual broadcasting satellite. In the experiments, 16-APSK (7/9) and 32-APSK (3/4) of the ISDB-S3 system shown in Table 1 in Annex 1 were used by applying a symbol rate of 33.7561 Mbaud.

3.2 Experiment using indoor satellite transponder model

The indoor experiment was conducted by using a 12 GHz-band satellite transponder model consisting of input/output filters and TWTA. Figures 12 and 13 show the experimental system and AM/AM characteristics of the satellite transponder model, respectively. Seven different OBOs were used in the range of 1.20 to 2.40 dB for 16-APSK (7/9) and of 1.80 to 3.00 dB for 32-APSK (3/4), with the variable attenuator inserted in the front section of the TWTA.

Figure 14 shows *C*/*N* vs. BER measurements of 16-APSK (7/9) and 32-APSK (3/4) for each OBO through the satellite transponder model. The IF loopback indicates the performance when the transmitter and receiver are directly connected. The experiment results show that the required *C*/*Ns* increase (degrade) as the OBOs become smaller (the output powers become higher). This means that the transmission signals suffer from the non-linear distortion occurring in the saturation range, thereby the transmission performance was deteriorated.

The evaluation formula for the overall performance was applied to evaluate the link margins. Table 4 summarizes the values for the OBO, the required *C*/*N*, the evaluation formula, and the degradation. In the case of 16-APSK (7/9), the value of the evaluation formula was minimized when the OBO was set to 1.8 dB. This point was the optimal OBO considering the trade-off between the OBO and the required *C*/*N*. When compared with the optimal OBO, in the case of the OBO of 1.20 dB which was 0.60 dB higher power, the required *C*/*N* was 12.71 dB which was increased by 0.97 dB. Therefore, the overall performance degraded by 0.37 dB due to the increase in non-linear distortion even though the output power was higher. Moreover, in the case of the OBO of 2.40 dB which was 0.6dB lower power, the required *C*/*N* was 11.43 dB which was decreased by 0.31 dB. However the overall performance also degraded by 0.29 dB.

Similarly, in the case of 32-APSK (3/4), the optimal OBO based on the evaluation formula was 2.60 dB considering the trade-off between the OBO and the required *C*/*N*.

The result indicates that there is the optimal OBO to improve the link margin in accordance with modulation scheme. Moreover, the optimal OBO for 32-APSK (3/4) is larger than that for 16-APSK (7/9) due to susceptibility to non-linear distortion.

FIGURE 12

Indoor experiment system

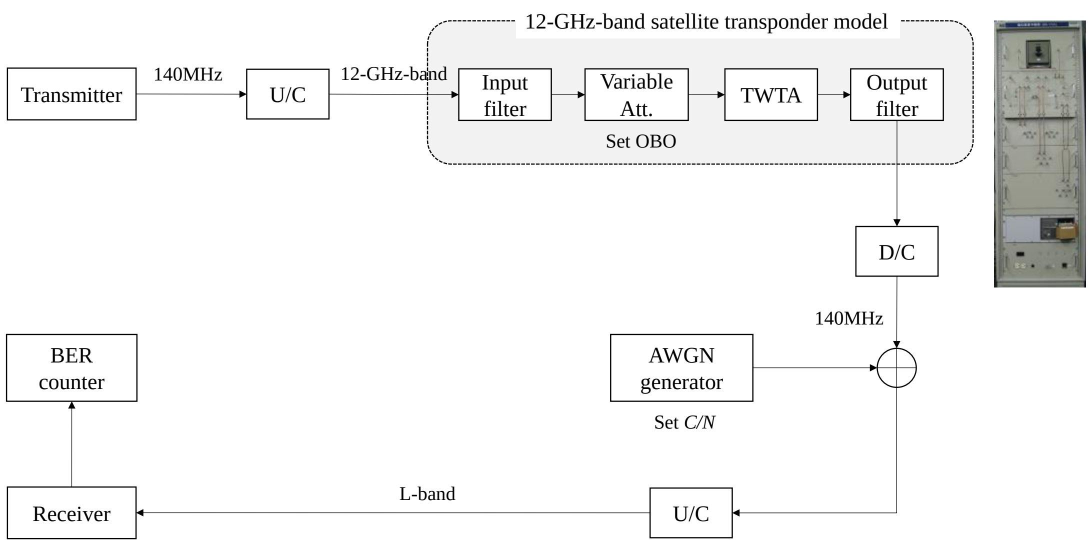


FIGURE 13

AM/AM characteristics of satellite transponder model in indoor experiment

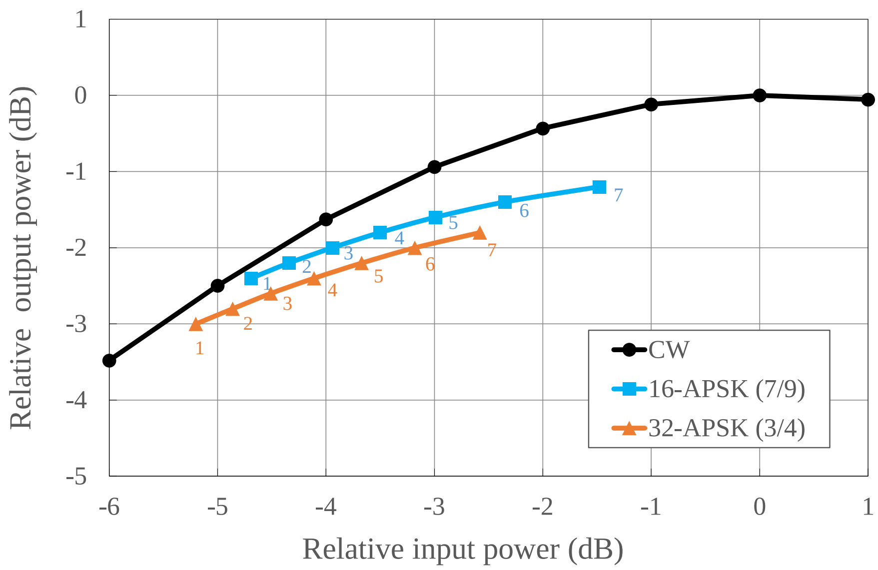


FIGURE 14

***C/N* vs. BER measurements for each OBO in indoor experiment**
(a) 16-APSK (7/9), (b) 32-APSK (3/4)

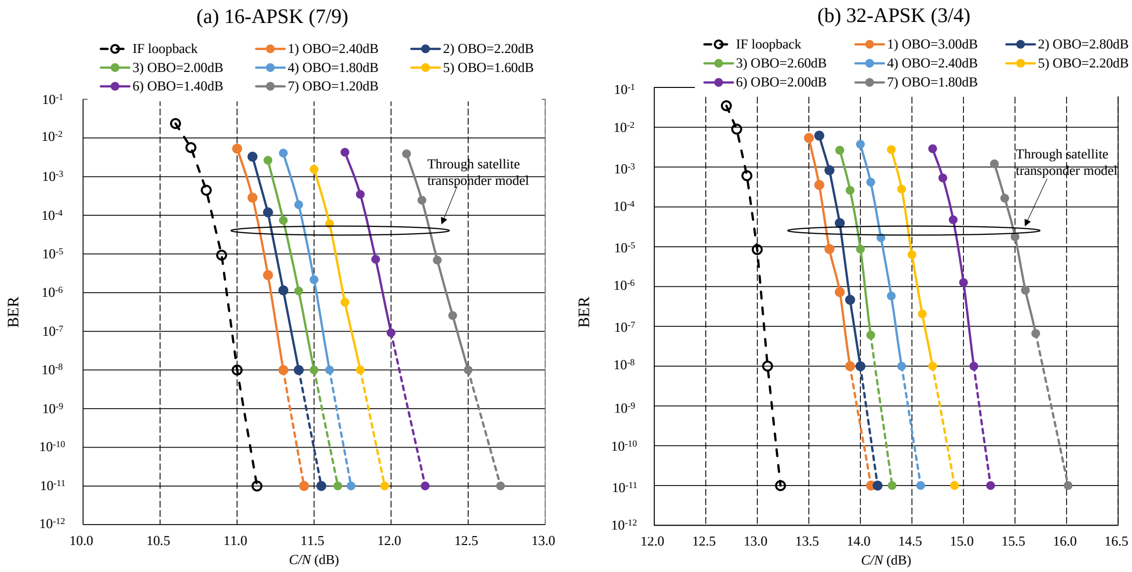


TABLE 4

Application of the evaluation formula to indoor experiment

(a) 16-APSK (7/9)

Point	**IF loopback**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A) OBO (dB)	–	2.40	2.20	2.00	1.80	1.60	1.40	1.20
B) Req.*C*/*N* (dB)	11.13	11.43	11.55	11.65	11.74	11.96	12.22	12.71
Evaluation formula A) + B) (dB)	–	13.83	13.75	13.65	13.54	13.56	13.62	13.91
Degradation (dB)	–	0.29	0.21	0.11	0.00	0.02	0.08	0.37

(b) 32-APSK (3/4)

Point	**IF loopback**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A) OBO (dB)	–	3.00	2.80	2.60	2.40	2.20	2.00	1.80
B) Req.*C*/*N* (dB)	13.23	14.10	14.17	14.31	14.59	14.91	15.26	16.01
Evaluation formula A) + B) (dB)	–	17.10	16.97	16.91	16.99	17.11	17.26	17.81
Degradation (dB)	–	0.19	0.06	0.00	0.08	0.12	0.35	0.90

3.3 Experiment using broadcasting satellite transponder

An outdoor experiment using the broadcasting satellite BSAT-4b was conducted to analyse the overall performance on the basis of the evaluation formula. Figure 15 shows the experimental system. Five different OBOs were used for 16-APSK (7/9) and six OBOs for 32-APSK (3/4). The OBO is defined as the relative value (relative OBO) compared with each maximum power among the setting points (five in 16-APSK (7/9) or six in 32-APSK (3/4)). Figure 16 shows *C*/*N* vs. BER measurements of 16-APSK (7/9) and 32-APSK (3/4) for each relative OBO, respectively. Similar to the indoor experiment, the required *C*/*Ns* tend to increase (degrade) as the OBOs become smaller (the output powers become higher).

Table 5 summarizes the values for the relative OBO, the required *C*/*N*, the evaluation formula, and the degradation. It also indicates the trade-off between the relative OBO and the required *C*/*N*. The optimal relative OBOs were 0.32 and 1.14 dB for 16-APSK (7/9) and 32-APSK (3/4), respectively. The results indicate that the optimal relative OBO that improve the link margin can be obtained by the evaluation formula in satellite transmission.

FIGURE 15

Outdoor experiment system using BSAT-4b

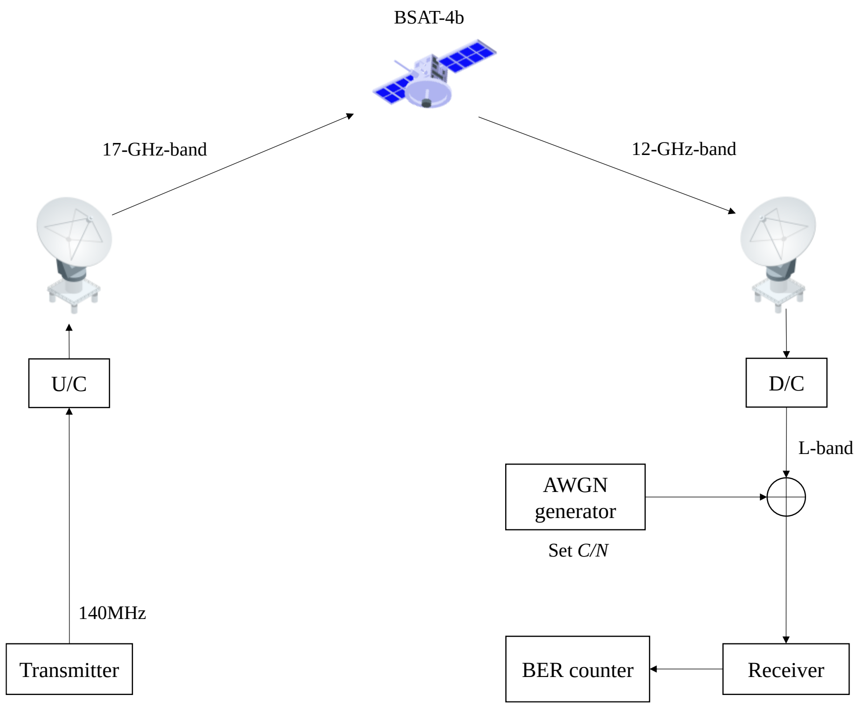


FIGURE 16

***C/N* vs. BER measurements for each OBO through BSAT-4b**
(a) 16-APSK (7/9), (b) 32-APSK (3/4)

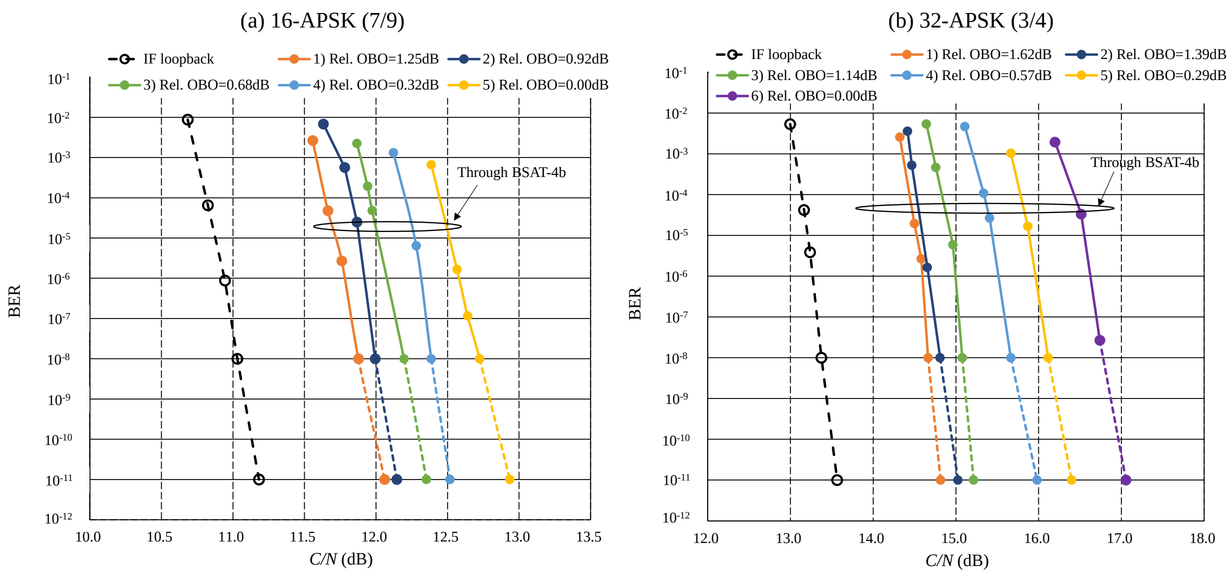


TABLE 5

Evaluation results for finding optimal relative OBO through BSAT-4b

(a) 16-APSK (7/9)

Point	IF loopback	1	2	3	4	5
A) OBO (dB)	–	1.25	0.92	0.68	0.32	0.00
B) Req.*C*/*N* (dB)	11.13	12.06	12.15	12.35	12.52	12.93
Evaluation formula A) + B) (dB)	–	13.31	13.07	13.03	12.84	12.93
Degradation (dB)	–	0.47	0.23	0.19	0.00	0.09

(b) 32-APSK (3/4)

Point	IF loopback	1	2	3	4	5	6
A) OBO (dB)	–	1.62	1.39	1.14	0.57	0.29	0.00
B) Req.*C*/*N* (dB)	13.23	14.81	15.02	15.21	15.98	16.40	17.05
Evaluation formula A) + B) (dB)	–	16.43	16.41	16.35	16.55	16.69	17.05
Degradation (dB)	–	0.08	0.06	0.00	0.20	0.34	0.70

4 Summary

Satellite transmission for APSK modulation signals was studied considering non-linear distortion of TWTA in a satellite transponder. It was found that there is a trade-off for TWTA operations between the output power and the transmission performance. An evaluation formula for the overall performance was proposed to maximize the link margin considering the OBO and the required *C*/*N*. Indoor and outdoor experiments were conducted to analyse the overall performance on the basis of the evaluation formula. The experimental results show that there is a trade-off between the OBO and that the required *C*/*N* and the evaluation formula enables the detection of the optimal OBO that maximize the link margin in accordance with each modulation scheme.

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