Source Coding and Transmission Technology of 4K/8K UHDTV Satellite Broadcasting

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1. Introduction

Direct satellite broadcasting service to the home was launched in Japan in 1984. Starting with test broadcasting of analog standard-definition television, it eventually shifted to the main service in 1989 and has since spread across the country, during which time it incorporated new broadcasting technologies such as high-definition television and digital broadcasting (Fig. 1). Meanwhile, NHK began research and development of Super Hi-Vision (8K) as a successor to high-definition television in 1995. 8K was internationally standardized as Ultra-High Definition Television (UHDTV) together with 4K, and it has been put to use as a next-generation broadcasting system.

The Ministry of Internal Affairs and Communications (MIC) had held the Study Group on Advanced Broadcasting Services since 2012 in order to realize next generation broadcasting services in 4K and 8K and published the "Roadmap for 4K/8K Promotion". The roadmap was revised in 2015, in which the goal was set of achieving "widespread use of 4K/8K broadcasting and the enjoyment of 4K/8K programs on commercial TV sets" by 2020, when the Tokyo Olympic and Paralympic Games were supposed to be held. Moreover, on the basis of this roadmap, satellite test broadcasts of 4K and 8K started in 2016, and commercial 4K/8K satellite broadcasting services started on December 1, 2018. Although the Tokyo 2020 Olympic and Paralympic Games have been postponed for one year due to COVID-19, the number of receivers ready for viewing 4K/8K satellite broadcasting had exceeded 6 million units by the end of October 2020, and it continues to grow steadily.

This article describes the features and technologies of information coding and transmission of 4K/8K UHDTV satellite broadcasting.

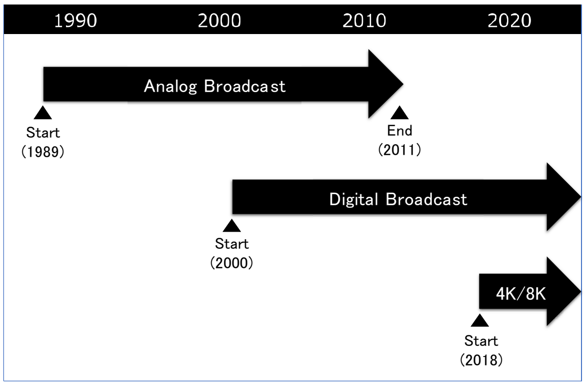


Fig. 1 History of Satellite Broadcasting (BS) in Japan.

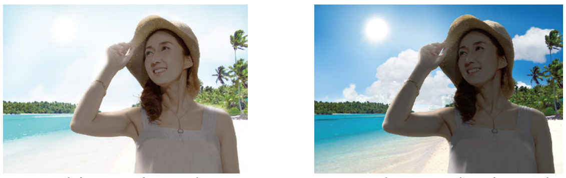
2. Features of 4K/8K UHDTV Satellite Broadcasting

2.1 Video System

The 4K/8K satellite broadcast video system conforms to International Telecommunication Union Radiocommunication Sector (ITU-R) Recommendation’s BT.2020 [1] and BT.2100 [2], which are high-quality video formats aiming to provide higher quality service than is possible with the current digital high-definition television broadcasting. These standards specify 4K video with 3840x2160 pixels and 8K video with 7680x4320 pixels. Whereas BT.2020 is capable of representing the same dynamic range as conventional video systems (i.e., standard dynamic range, or SDR), BT.2100 is capable of representing a wider dynamic range (i.e., high dynamic range, or HDR). The 4K and 8K video systems are both called UHDTV as opposed to HDTV. Although UHDTV tends to be thought of as being just a higher resolution version of HDTV, it is a progressive format that presents 59.94 (60P) or 119.88 (120P) frames per second, as well as high-resolution images. In addition, it enables new forms of video expression through its adoption of HDR and wide color gamut (WCG) that can reproduce virtually all of what can be seen by the naked eye.

Here, HDR and WCG are explained. HDR is a technology that widens the range of brightness that can be expressed in an image; it can display the range of dark to bright areas in images with unprecedented accuracy. For example, in conventional video systems, when shooting a person against the sun, the person is often blacked out when the amount of light that enters an image sensor is reduced to capture a clear background, whereas the background is often overexposed when the aperture is opened to capture the face of the person. This phenomenon is caused by the fact that the range of brightness of the subject (dynamic range) is wider the range of brightness that can be expressed. When one of the subjects is shot clearly, the other results in exceeding the expressible range. HDR

HDR (High Dynamic Range) image



Subject-oriented Background-oriented
SDR (Standard Dynamic Range) images

Fig. 2 Differences between SDR and HDR expression.

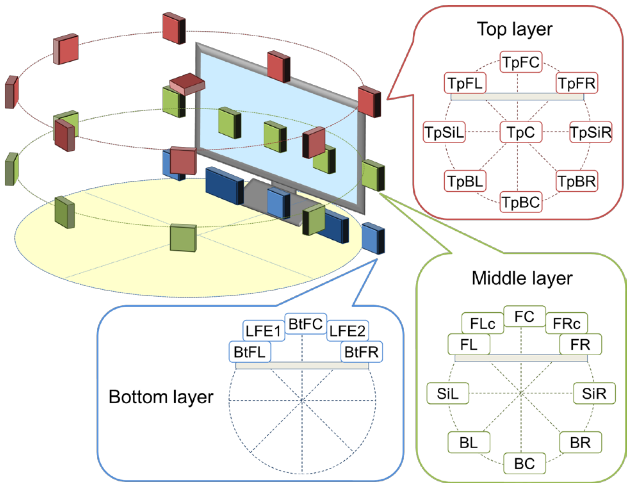


Fig. 3 Channel Arrangement and Channel Labeling for 22.2ch Sound.

can clearly represent the background and the subject at the same time (Fig. 2).

Wide color gamut, or WCG, is an extended range of color expression that enables reproduction of colors that can not be reproduced by a conventional video system. The result is color reproduction as close as possible (99.9% coverage of the object colors versus 74.4% on HDTV). In other words, HDR and WCG are expected to reproduce wide range of brightness and vivid colors that cannot be expressed by conventional video systems and to enable new forms of video expression. To achieve this, the video signal is extended to 12 bits, as opposed to the maximum bit depth of 10 bits for the conventional high-definition television signal.

The features of the new video format have been incorporated not only in UHDTV but also in the existing HDTV service. The multi-channel HDTV service can be offered as a low-layer service, to alleviate viewing difficulties caused by low received signal levels during rainfall. Since some HDTV programs are already produced in progressive mode and content down-converted from UHDTV to HDTV is expected to be broadcasted, progressive HDR and/or WCG HDTV services can also be provided.

2.2 Sound System

The 4K/8K UHDTV satellite broadcasting system has a 22.2 multi-channel sound system (22.2ch sound system). This is a high-presence sound system capable of providing audio services at a quality level beyond that of current digital HDTV broadcasting. The 22.2ch sound system is the largest among the three-dimensional sound systems specified in ITU-R recommendation BS.2051-1 [3], and it can reproduce a natural and high-quality three-dimensional sound field. The channel layout, shown in Fig. 3, consists of 24 channels arranged in three dimensions: 9 channels in the upper layer above the listening position, 10 channels in the middle layer corresponding to the height of the listener's ears, 3 channels in the lower layer below the listening position, and 2 low frequency effects (LFE) channels. The sound image can be localized anywhere on the screen, and sounds coming from all directions around the listening position can be reproduced. The system is capable of representing a natural, high-quality three-dimensional sound field and provides a high-quality acoustic experience, therefore it has been adopted for 4K/8K UHDTV satellite broadcasting.

3. Information Source Coding Technology [4]

3.1 Video Coding

Since the amount of data in a UHDTV signal is ten times that of an HDTV signal, due to not only the larger number of pixels, but also the faster frame rate and higher bit depth, highly efficient data compression techniques are required to transmit it. Here, it was decided to adopt the ISO/IEC 23008-2|ITU-T recommendation H.265 High Efficiency Video Coding (HEVC) [5][6], which is the latest international standard system for video coding. HEVC was standardized by ISO/IEC and ITU-T, which are international standardization organizations. HEVC was developed by the Joint Collaborative Team on Video Coding (JCT-VC), established by ISO/IEC JTC1/SC29/WG 11 (more commonly known as MPEG: Moving Picture Experts Group) and SG16/WP3/Q.6 (known as VCEG: Video Coding Experts Group) as a successor to MPEG-2 and MPEG-4 AVC|H.264 (AVC). It consists of block decomposition, prediction, orthogonal transformation of predicted residual signals, quantization, loop filter, and entropy coding, as well as conventional coding methods. One of the major differences between HEVC and existing coding schemes is that it has been developed in consideration of UHDTV from the beginning of the standardization. Especially for high resolution video, the coding block

Table 1 Comparison of Major Encoding Tools in Broadcasting.

	MPEG-2	AVC	HEVC
Encoding Block Size	16 x 16	16 x 16	64 x 64 to 8 x 8
Orthogonal Conversion	real number precision DCT (8 x 8)	integer precision DCT (8 × 8, 4 × 4)	integer precision DCT, DST and transform skipping (32 x 32 to 4 x 4)
In-screen Prediction	none	DC prediction + up to 9 directions	DC prediction + up to 33 directions + planar prediction
Motion Compensation Prediction	no vector prediction	median MV projection from adjacent blocks	optimal MV prediction from adjacent blocks + merge
In-loop Filter	none	deblocking filter	deblocking filter + SAO
Entropy Encoding	2D-VLC	CAVLC or CABAC	CABAC
HDR/WCG	×	×	○
Time-scalable Function	none	none	available

Table 2 Summary of the Video Coding specification.

Video Format	Spatial Resolution		1,920 × 1,080		3,480 × 2,160		7,680 × 4,320	
	Temporal Resolution		60/I	60/P	60/P	120/P	60/P	120/P
	SDR	Bit Depth	8.10 bit		10.12 bit			
		Colorimetry/Transfer Function	Rec. ITU-R BT.709, xvYCC		Rec. ITU-R BT.2020			
	HDR	Bit Depth	10 bit					
		Colorimetry	Rec. ITU-R BT.2020					
		Transfer Function	ARIB STD-B32. SMPTE ST-2084					
Encoding			ISO/IEC 23008-2 |Rec. ITU-T H.265 （HEVC）					
Profile	SDR		Main, Main10		Main10			
	HDR		Main10					
Tier			Main					
Level			4.1		5.1	5.2	6.1	6.2

size (macro block in MPEG-2 and AVC), which had been fixed in conventional coding schemes, was extended to allow the selection of variable coding blocks of up to 64x64. HEVC supports time scalability as a standard feature, so when 120P broadcasts become available in the future, it will remain backward compatible with 60P receivers. Because HEVC supports HDR and WCG and has many features such as 10-bit signal coding, it was selected as the coding for 4K/8K UHDTV satellite broadcasting. Table 1 shows the differences between MPEG-2, AVC, and HEVC coding tools used in HDTV digital broadcasting.

The Association of Radio Industries and Businesses (ARIB) is dedicated to studying standardization in the field of communication and broadcasting in Japan. ARIB has released ARIB STD-B32, which specifies the video format, coding levels, profiles, and restrictions on coding for 4K/8K UHDTV satellite broadcasting [7]. Table 2 is a summary of video coding specification.

Table 3 Summary of Audio Coding specification.

Sampling Frequency	48 kHz
Input Quantization Bits	16 bits or more
Maximum Number of Input Channels	22.2ch
Coding Method	MPEG-4 AAC, MPEG-4 ALS

3.2 Audio Coding

The MPEG-4 AAC LC (Advanced Audio Coding Low Complexity) profile was adopted as a new broadcasting coding format for transmitting audio data increased to a maximum of 22.2 channels. MPEG-4 AAC did not initially support 22.2 channels, so an extended technology was standardized to implement coding for each channel by combining SCE (Single Channel Element: compression coding for a single channel), CPE (Channel Pair Element: compression coding that treats two channels as a pair) and LFE

Table 4 Technical Specifications of ISDB-S3 (for UHDTV) and ISDB-S (for HDTV).

Standard	ISDB-S3	ISDB-S
Modulation Scheme	16APSK	TC8PSK
Bandwidth (99% Energy)	34.5 MHz	34.5 MHz
Symbol Rate	33.7561 Mbaud	28.86 Mbaud
Roll-off Rate	0.03	0.35
FEC	Outer FEC : BCH Inner FEC : LDPC (Coding Rate 7/9)	Outer FEC : Reed Solomon Inner FEC : Convolution (Coding Rate 2/3)
Transmission and Control Signal	TMCC signal （π/2shift BPSK）	TMCC signal （BPSK）
Information Rate per Transponder	99.9552 Mbps	52.17 Mbps
Multiplexing System	MMT･TLV	MPEG-2 TS

(LFE Element: compression coding for LFE channel), and it was decided to broadcast in accordance with this extended standard. In addition, by using MPEG-4 ALS (ALS stands for Audio Lossless), which enables lossless coding, it is possible to realize a distortion-free audio service. The summary of audio coding specification is shown in Table 3.

4. Satellite Broadcasting Technology

4.1 Transmission System

Integrated Services Digital Broadcasting - Satellite (ISDB-S) [8,9] has been used for many years as a transmission system for BS and 110-degree east longitude CS satellite broadcasting in Japan. It has many features, such as broadcasting two to three HDTV programs on a single satellite transponder, mixing high-definition and standard-definition programs, transmitting various types of data broadcasting by using Electronic Program Guide (EPG) or Broadcast Markup Language (BML), enabling multiple operators to independently provide services over a single satellite transponder, having a hierarchical transmission scheme to reduce service interruptions due to rain fade events, and notifying receivers of transmission parameters and program multiplexing configuration information by always sending transmission and multiplexing configuration control (TMCC) signals. However, the maximum rate of information that can be transmitted in a single transponder with ISDB-S is about 52 Mbps, and it is not possible to transmit high-capacity video services such as 8K. Therefore, a new broadcasting system, called the Advanced Broadband Satellite Digital Broadcasting System (ISDB-S3) [10,11], has been developed for transmitting such services. Table 4 shows the main technical specifications of ISDB-S3 (for UHDTV) and ISDB-S (for HDTV).

ISDB-S3 has the following features in addition to the ones of ISDB-S.

(1) It enables a single 8K program or three 4K programs to be broadcast over a single satellite transponder.

(2) By adopting the MPEG Media Transport (MMT) and Type Length Value (TLV) multiplexing method, integrated broadcasting and communication services can be flexibly provided.

(3) Introduction of a pilot signal enables optimal error correction and decoding even under the influence of the nonlinear characteristics of the satellite.

Regarding feature (1) above, a roll-off ratio of 0.03 (0.35 for ISDB-S) is adopted for the roll-off filter, which limits the bandwidth of the modulation signal during transmission, to make the spectral waveform of the modulation signal closer to a rectangle. The symbol rate can be increased to 33.7561 Mbaud while satisfying the bandwidth of 34.5 MHz per satellite transponder required by the Radio Regulation. This improves the frequency utilization efficiency by about 17% compared with the ISDB-S symbol rate of 28.86 Mbaud. The required carrier-to-noise (C/N) ratio, which is the minimum ratio of signal power to noise that can be transmitted error-free, is improved by employing amplitude phase shift keying (APSK) that optimizes the distance between modulation signal points of different amplitudes, and by employing low-density parity check (LDPC) code that has a strong error correction capability. The combination of modulation method 16APSK and error correction coding ratio 7/9 enable a broadcasting satellite to transmit an 8K program taking up a transmission capacity of about 100 Mbps through a single transponder to a standard parabolic antenna with a 45-cm diameter while ensuring a service time of 99.5% in

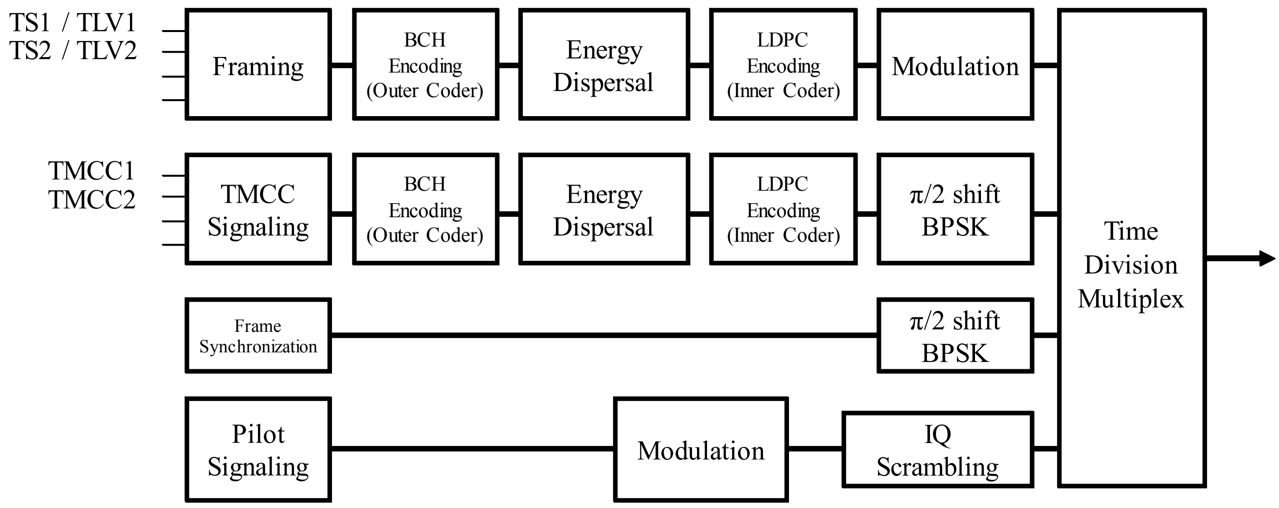


Fig. 4 Block Diagram of ISDB-S3.

the worst month (the month with the highest rainfall throughout the year) in Tokyo.

In ISDB-S3, a $\pi/2$ shift BPSK signal is periodically and intermittently inserted in the modulated signal to ensure stable synchronization even when the received C/N is less than 0 dB. In addition, the TMCC signal can be used as a synchronous reinforcement signal by transmitting the same $\pi/2$ shift BPSK signal as the transmission control signal.

ISDB-S3 supports hierarchical transmission using time division multiplexed combinations of modulations, for stable broadcasting services even during rainfall. By multiplexing part of the transmitted signal with a low C/N modulation scheme such as QPSK, it is possible to reduce the number of broadcast service interruptions during rain fade events.

Regarding feature (2), in addition to the conventional MPEG-2 TS multiplexing, ISDB-S3 supports MMT and TLV multiplexing, which enables transmission of variable-length data. MMT allows signals to be transmitted through multiple transmission channels, such as through broadcasting and communications together, and synchronized using common time information. This feature will enable the realization of advanced joint broadcasting and communications services. The encoded UHDTV and multi-channel audio components are packetized in MMT packets and transmitted in IP packets, and then multiplexed in TLV packet format. In ISDB-S3, as the positions of the first and last bytes of variable length packets are indicated in the TMCC signal as pointer information, the location of multiple variable-length packets in a transmitted frame can be identified.

Regarding feature (3), the effect of the nonlinear characteristics of the traveling wave tube amplifier (TWTA) of the satellite transponder is compensated for by introducing a pilot signal that periodically and intermittently transmits known signal points with the same modulation scheme as that of the main signal. Even if nonlinear distortion occurs in the transponder, the deviation from the ideal signal point caused by it can be measured by averaging this known signal at the receiver. This value is used in the log-likelihood ratio calculation for LDPC decoding of the error correction codes; i.e., it enables optimal LDPC decoding even in the case of nonlinear distortion.

Figure 4 shows the block diagram of ISDB-S3. ISDB-S3 was standardized by ARIB as a domestic satellite broadcasting system in 2014, and it was internationally standardized by ITU-R as Recommendation BO.2098 in December 2016 [12].

4.2 Reception Technology

Satellite broadcasting over BS and 110-degree east longitude CS uses circularly polarized radio waves, in which the electromagnetic field of the wave rotates with time. The 4K/8K UHDTV satellite broadcasting newly uses left-handed circularly polarized (LHCP) waves in addition to the right-handed circularly polarized (RHCP) waves that have been conventionally used (Fig. 5). LHCP and RHCP waves can be handled

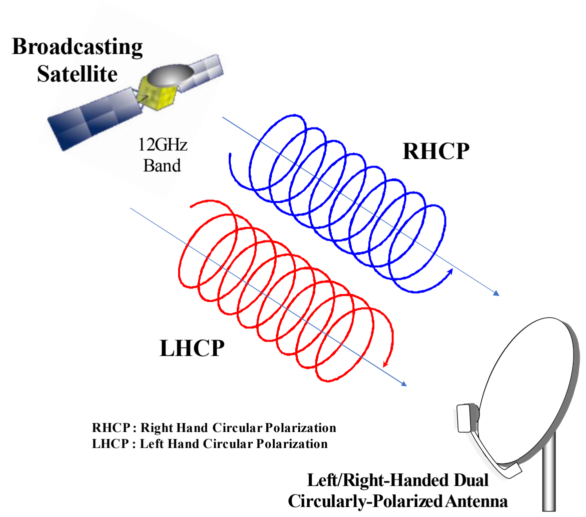


Fig. 5 LHCP and RHCP Waves.

independently of each other and are transmitted in the same frequency band. In order to receive both waves, a receiving antenna system capable of picking up RHCP and LHCP waves is required.

12-GHz signals received from the broadcast satellites are converted to intermediate frequency (IF) signals by the receiving antenna's low noise block converter (LNB). The conventional RHCP waves of the BS and 110-degree CS have IF frequencies between 1.0 GHz and 2.1 GHz, while the LHCP waves have ones between 2.2 GHz and 3.2 GHz. Therefore, to receive 4K/8K UHDTV satellite broadcasting, it is necessary to prepare a reception system with a parabolic antenna for both RHCP and LHCP waves, as well as amplifiers, splitters and distribution equipment corresponding to the IF band from 1.0 GHz to 3.2 GHz.

The IF band between 2.2 GHz and 3.2 GHz for LHCP wave is the same frequency band as the general-purpose ISM band that is used by low-power data transmission systems, satellite telephones, broadband wireless access (BWA), etc., so these waves affect the radio waves emitted by wireless LAN and microwave ovens. In case of improper installation of the satellite broadcasting receiver system, there is a possibility of interference with all systems using the same frequency as the IF frequency band; for this reason, power leakage from the receiver system should be less than or equal to -49.1 dBm (46.2 dBμV/m or less at 3m distance) / 33.7561 MHz, which is regulated by the Ordinance Regulating Radio Equipment. The MIC has compiled guidelines to be followed in the implementation of television reception facilities for satellite broadcasting [13].

5. Conclusion

The world's first 4K/8K UHDTV satellite broadcasting began in 2018 in Japan, and a number of ultra-high definition programs have continued to be broadcast on many channels since then. In 2021, the year of the Tokyo Olympic and Paralympic Games, it is expected that many people will have UHDTV TVs on which they can enjoy the broadcasts of the events with highly realistic images and sound. 4K/8K UHDTV broadcast services will become more widespread in the future.

6. References

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