Technologies and Services of Digital Broadcasting (11)

Satellite Digital Broadcasting Systems

1. BS digital broadcasting system

[1] Features of the BS digital system

The Japanese digital Broadcasting Satellite (BS) system named ISDB-S system internationally is based on ITU-R Recommendation BO.1408.

The basic configuration of the digital BS system is shown in Fig. 1. The system consists of a source coding section that converts the video, audio, and data signals into efficient digital signals; a multiplexing section that multiplexes the digital signals; a conditional access section that scrambles the signals and distributes unscrambling keys to subscribers of pay-per-view broadcasts; and a channel coding section that performs signal processing such as error correction and modulation. This configuration differs significantly from the Communication Satellite (CS) digital system described later in its capability of transmitting multiplexed signals on one satellite channel.

As it is intended for a system that can broadcast multiple high-definition television programs with one transponder, the channel coding section of the BS digital system was developed from a viewpoint different than that of the existing CS digital broadcasting system whose channel bandwidth is 27 MHz. New technologies like the TC8PSK modulation scheme were adopted for this section to increase the transmission capacity as much as possible and to enable multiple transport streams (TS) to be handled by one carrier. This channel coding system has consequently become a system standard known for its flexibility and extendibility.

The other sections besides the ones for the channel coding were developed in adherence to the principle that they be applicable to a widest possible media cross section while taking into account compatibility with the CS digital system. For these reasons, MPEG-2 Video and MPEG-2 Systems were adopted for video coding and multiplexing, and Multi-2 was chosen for the scrambling system. In addition, the new MPEG Advanced Audio Coding (AAC) system standard was chosen for the audio coding with the aim of increasing the coding rate.

The features of the BS digital system are summarized below.

(1) It adopts trellis-coded 8PSK modulation and enables the broadcasting of two high-quality digital HDTV programs with one transponder by setting a wide frequency bandwidth.

(2) It enables switchover between or joint use of multiple transmission systems so that the most optimal system can be selected in accordance with the operator's service content.

(3) It enables multiple MPEG-TS's to be transmitted with one transponder, and because transmission systems can be switched for each TS signal, it enables TS signals produced by each broadcaster to be transmitted independently.

(4) It allows an operator to exert control over the transmission system such as by selecting one or changing the mixture of multiple modulation schemes and by changing its assigned ratio in each TS. This is achieved by multiplexing a Transmission and Multiplexing Configuration Control (TMCC) signal.

(5) It adopts MPEG-2 Video (with MP@HL as a precondition) for its video coding system and MPEG-2 Audio (AAC) for its audio coding system. Together they achieve a high compression rate while ensuring high-quality video and audio broadcasting.

(6) It enables stable reception of digital broadcasts using the same receiving antenna as that of existing analog BS broadcasts by multiplexing a burst signal for stable carrier recovery.

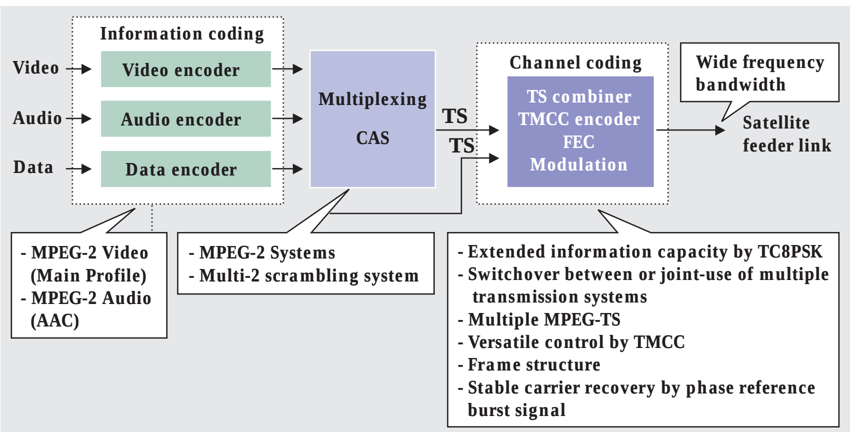

Figure 1: Basic configuration and features of the BS digital system

[2] System overview

Table 1 provides an overview of the BS digital broadcasting system. In particular, the system has a high transmission capacity at its maximum rate of 52 Mbps with a bandwidth per channel of 34.5 MHz. It also has flexibility and extendibility, such as the ability to change or use more than

Table 1: Overview of the BS digital system

Bandwidth (99% energy)	34.5 MHz			
Information rate *1	About 52 Mbps			
Channel coding system				
Main-signal *2 modulation scheme	A maximum of 4 of the 7 systems may be used together: TC8PSK (r=2/3), QPSK (r=1/2, 2/3, 3/4, 5/6, 7/8), BPSK (r=1/2)			
Main-signal error-correction scheme	Inner code: 8PSK→trellis; QPSK, BPSK→convolutional Outer code: Reed-Solomon(204,188)			
Main-signal energy dispersal	15th-order M-series pseudo-random signal ($X^{15}+X^{14}+1$) addition reset every superframe (8 frames)			
Main-signal interleave	8×203 byte block interleave; byte interleave every slot in superframe direction			
TMCC system	BPSK modulation, convolutional (coding rate 1/2), Reed-Solomon(64,48) Information on modulation scheme and TS can be set for every slot by 384-bit information transmission every superframe			
Burst signal for stable carrier recovery	4 symbols are inserted every 203 symbols of the main signal in BPSK modulation			
Roll-off rate	0.35, raised cosine characteristics, transmit/receive route allocation, aperture correction on the transmit side			
Conditional-access scrambling system	MULTI2			
Multiplexing system	MPEG-2 Systems			
Source coding system				
Video coding	MPEG-2 Video			
Video format		Effective Pixels	Aspect Ratio	Scanning System
	1080 i	1920 ×1080	16:9	Interlaced
	480 p	720 × 480	16:9	Progressive
	480 i	720 × 480	16:9, 4:3	Interlaced
	720 p	1280 × 730	16:9	Progressive
	1080 p*3	1920 ×1080	16:9	Progressive
Audio coding	MPEG-2 Audio (AAC)			

Notes: *1: The amount of information that can be transmitted by 1 repeater (for TC8PSK modulation)
*2: The signal consisting of 203 bytes created by adding 16 bytes of Reed-Solomon error correction to the 188-byte MPEG packet less the first byte of the slot
*3: Video display method whose technical feasibility must be demonstrated in the future

one modulation scheme in accordance with the frame configuration.

[3] Channel coding section

Figure 2 outlines the configuration of the channel coding section developed for the BS digital system.

The following describes each of the technical elements making up channel coding.

(1) Modulation and error correction schemes

The channel coding section shown in Fig. 2 adopts convolutional code as the inner-code error correction scheme. Convolutional code, which is adept at handling random errors, demonstrates high error-correction performance in combination with Reed-Solomon (204,188) code, which is strong with respect to burst errors.

"Pragmatic code" as shown by the configuration of the inner-coding device and the phase mapping in Fig. 3 is adopted for the 8-phase trellis

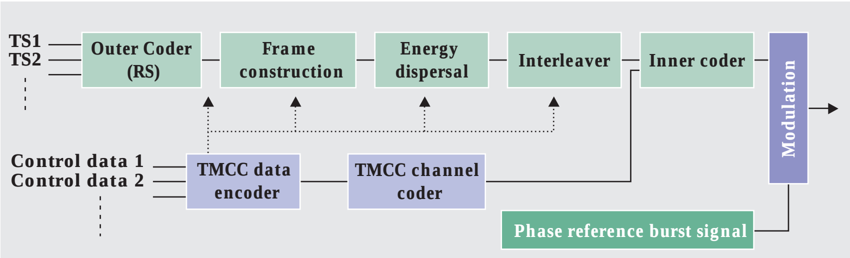

Figure 2: Configuration of the channel coding section

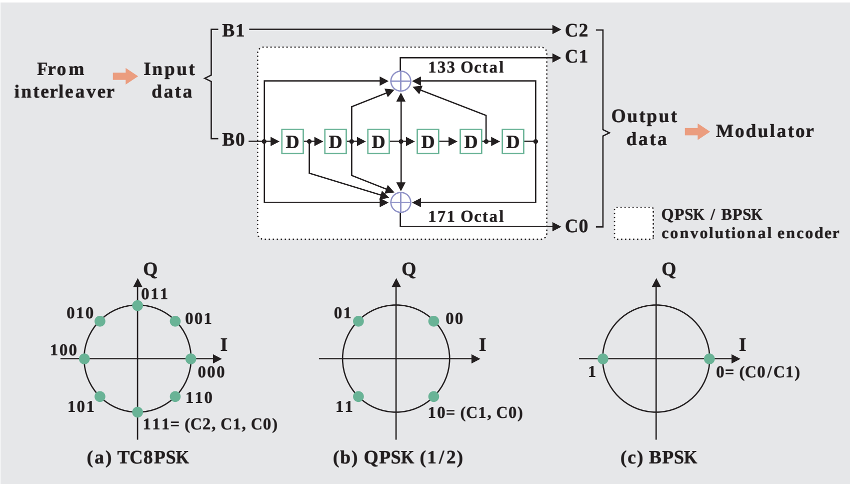

Figure 3: Configuration of error-correcting (inner-coding) device and phase mapping

coding. By introducing this inner-coding system with 8PSK modulation, the QPSK/BPSK convolutional inner-coding circuit can be commonly used for the 8-phase trellis coding.

(2) Frame configuration

A frame configuration that specifies a fixed information length is adopted so that multiple modulation schemes and multiple TS's can be used with one transponder. As shown in Fig. 4, a 204-byte signal (slot) consisting of an MPEG-TS and outer-code error correction is taken to be the minimum unit of data. A modulation scheme and TS number can be specified for each slot. A frame consists of 48 slots and is the basic unit of channel transmission. A superframe, moreover, consists of 8 frames and serves as the unit of processing for energy dispersal and interleaving.

Here, as the first byte of each slot is fixed as an MPEG-TS synchronization byte (its data is represented as 47H in hexadecimal), channel coding will replace this byte with frame-synchronization signals or TMCC information at the beginning of each frame. Energy-dispersal signal processing is performed next with respect to the 203×48×8 bytes of the superframe excluding the first byte of each slot. Then, as shown in the same figure, interleaving is performed in byte signal units across 8 frames for the 203 bytes of each slot among those slots having the same slot number in a superframe (interleave depth of 8). This makes for uniform interleaving regardless of the transmission system configuration in each slot.

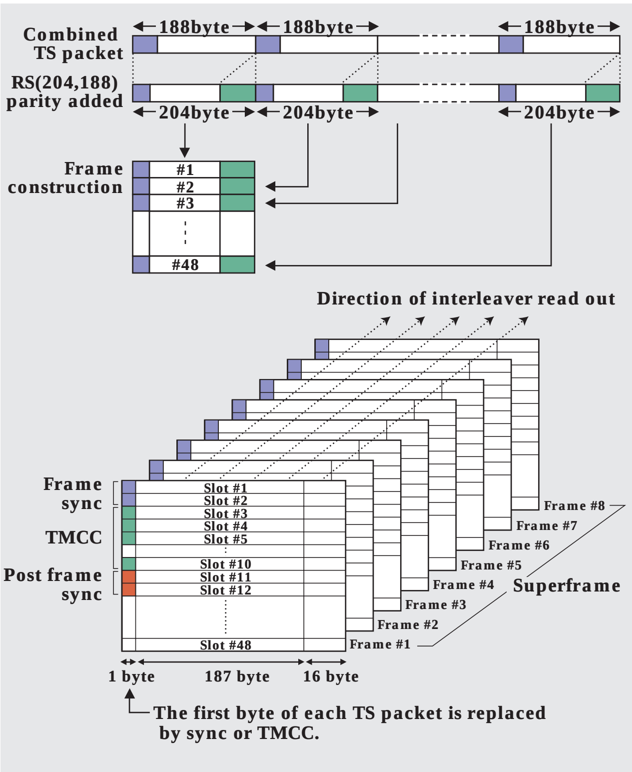

Figure 4: Frame signal processing

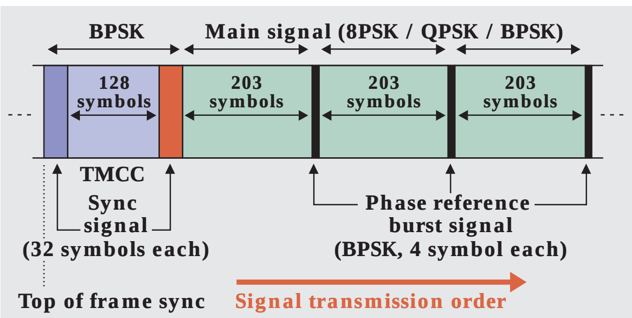

Figure 5: Relationship between TMCC transmission and burst signal transmission

Given this frame configuration, a baseband signal using TC8PSK can be completely transmitted in 48 slots. Moreover, a baseband signal using QPSK (coding rate r=1/2), for example, whose transmission efficiency is half that of TC8PSK, will result in effective data for at most 24 slots in a frame at the time of frame configuration. The remaining slots could then be treated as dummy slots and only effective information would be modulated. In this way, different modulation schemes can be transmitted at the same symbol rate.

[4] Burst signal for stable carrier recovery and the TMCC signal

When a digital receiver demodulates a signal, a synchronization detection function in the form of a carrier-recovery circuit becomes necessary. In general, a stable carrier can be recovered in the modulated-wave order of BPSK, QPSK, and TC8PSK. In BS digital broadcasting where multiple transmission schemes can be used together, the optimal conditions for this carrier-recovery circuit differ according to the content and assigned ratio of each transmission system in one carrier. It is for this reason a BPSK-modulated wave is inserted at a position decided beforehand (a 4-symbol reference burst is multiplexed intermittently every 203 symbols of the main signal) in addition to the main signal and the TMCC signal described above. Using this as a reference for carrier recovery at the receiver enables stable carrier recovery even for low C/N ratios. Multiplexing a burst signal for stable carrier recovery in this way makes for stable reception even when using an old 12-GHz antenna converter.

Furthermore, while a TMCC signal is transmitted at the beginning of each frame, a synchronization signal is also transmitted before and after the TMCC information. This synchronization signal is set with a previously decided signal stream that serves as a means of fast frame synchronization when the receiver is turned on or the BS channel is changed. This situation is shown in Fig. 5.

As shown in the same figure, TMCC information is transmitted in 128 symbols of every frame. This, however, equates to 8 bytes per frame, as this section is transmitted by BPSK (coding rate r=1/2) to improve reception whereever there is rain attenuation.

[5] Transmission system control by TMCC

The transmit side can set the number of slots and the modulation scheme for each TS signal independent of other TS's. This information is written as a TMCC signal every eight frames (superframe) and is therefore time-multiplexed within one RF carrier. The receiver demodulates this TMCC information every superframe as a basis for demodulating and decoding each TS signal, and finally selects the TS desired by the viewer and performs service decoding. A feature of TMCC signal control is that each TS signal can be regarded as transmitting a single TS independently at both the transmit side and the receive side without referring to the transmission channel. In addition, while 8 bytes of TMCC information is transmitted per frame, only 384 bits are transmitted per superframe since only six frames worth of TMCC information is used per superframe with the remaining two frames used for Reed-Solomon error correction of the TMCC information.

Appropriate setting of the TMCC information makes the following possible for each BS channel.

(1) Transmission of multiple TS's (eight maximum)

(2) Selection of one of seven modulation schemes (TC8PSK, QPSK (five coding rates), and BPSK) or their simultaneous use (four maximum)

Figure 6 shows the bit configuration of this TMCC information. The transmit-mode/slot-information section in the figure specifies the modulation scheme for each slot, while the relative-TS-ID-information section specifies the relationship between slots and relative TS numbers allocated within the same BS channel. This information together with the table that comes next describing the correspondence between relative-TS-ID and TS-ID enables the receiver to determine the TS ID (16 bits) actually transmitted.

[6] Example of signal transmission

Figure 7 shows an example of signal transmission when using TC8PSK (46 slots/frame) and QPSK (1-effective-slot/frame) jointly.

In this example, one slot of information transmitted by QPSK (r=1/2) requires twice the transmission time of one slot of TC8PSK (since the

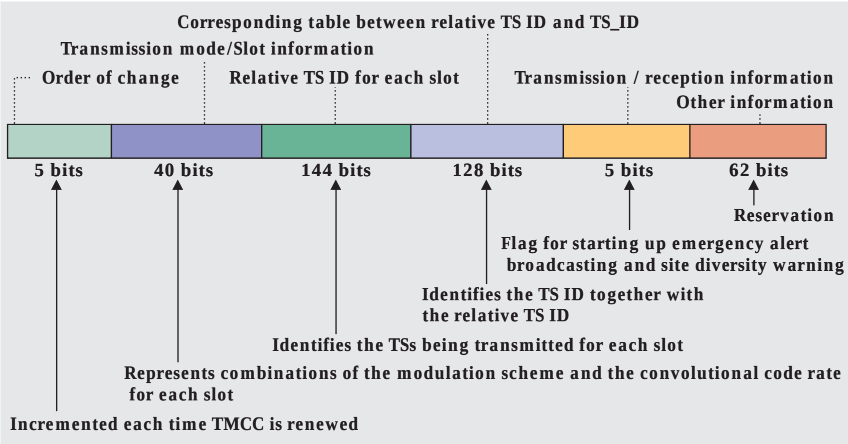

Figure 6: TMCC bit configuration

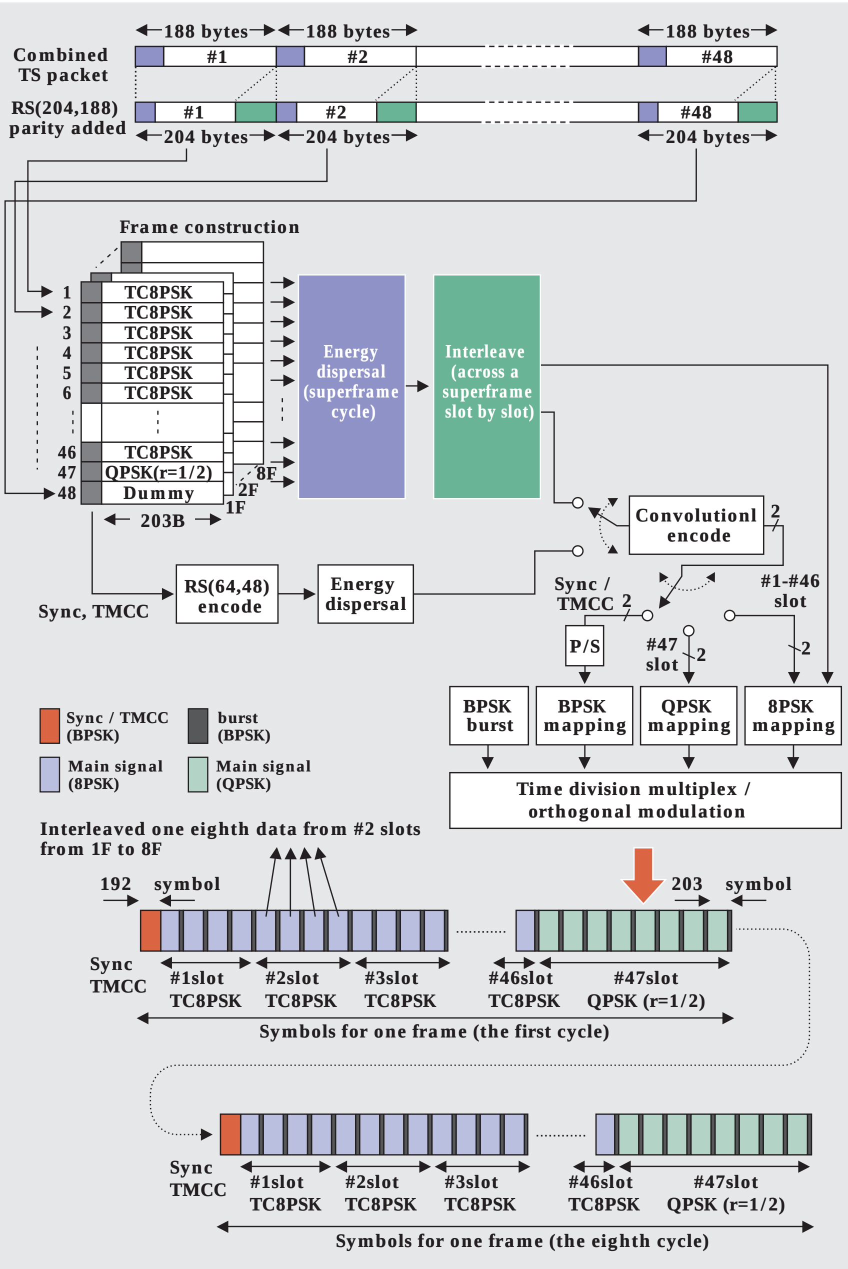

Figure 7: Example of signal transmission by channel coding

transmission efficiency of QPSK is half that of TC8PSK). This means that the transmission time must be adjusted by inserting dummy slots. Although QPSK (r=1/2) is advantageous with respect to rain attenuation since it means a lower C/N cutoff limit during periods of rainfall, there is a tradeoff as it also means there is a lower transmission capacity. In short, modulation schemes can be selected as desired and transmissions can combine a modulation scheme having a large transmission capacity, like TC8PSK, with one that is robust against rain attenuation, like QPSK.

[7] Broadcast-satellite transmission technology and receiver

(1) Broadcast-satellite transponder

Figure 8 shows the configuration of a satellite transponder used for broadcasting. A specialized transponder is not needed even in the case of digital satellite broadcasting-a configuration similar to that of the one used in conventional analog satellite broadcasting is sufficient. The receiving section has functions for receiving a wideband signal (about 300 MHz) from a ground transmitter and converting the uplink frequency (17-GHz band) into a downlink frequency (12-GHz band). The transmitting section, on the other hand, divides the signal by using a filter and obtains a 100 W or greater output by using a traveling wave tube (TWT) amplifier for each BS channel. Here, to maintain the intensity of the radio wave from the satellite so that a compact receiving antenna can be used, the TWTs of the satellite payload are made to operate at maximum output, resulting in nonlinear transmission characteristics.

Because TC8PSK, QPSK, and BPSK modulation schemes used in broadcast satellites change not only phase but amplitude components as well, deterioration occurs due to the nonlinear transmission characteristics of the TWTs. The spectral components of the modulated wave will also change because of this non-linear operation, and deterioration due to spectrum deletion from the filter on the TWT output side will occur. While the extent of deterioration depends on the filter's group delay and amplitude characteristics and on the TWTs' nonlinear characteristics, it is desirable that it be limited to about 1 dB.

(2) Digital receiver

Figure 9 shows the configuration of a receiver for satellite digital broadcasts. The antenna converter shown in the figure enables existing analog BS antennas to be used for digital broadcasts as well. The output signal from the converter is passed via cable into a tuner placed inside a room, and the received signal is demodulated and decoded. The demodulation section converts each PSK signal into a digital signal, reconfigures signal frames based on information decoded from the TMCC signal, and performs reversed interleaving and energy-dispersal processing to decode multiple TS signals. The viewer then selects one service that consists of video and audio from one TS signal to be decoded by the MPEG decoder.

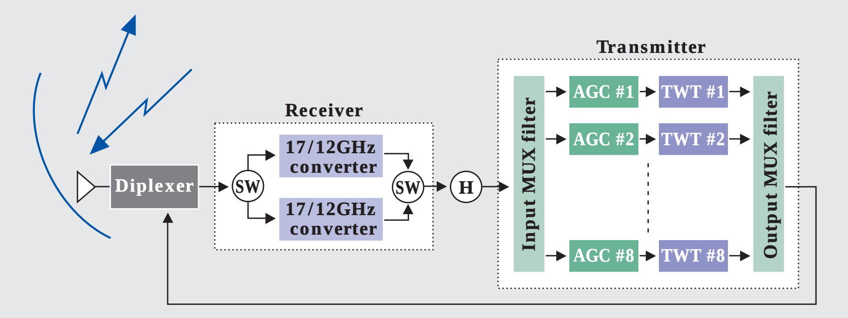

Figure 8: Configuration of a broadcast-satellite transponder

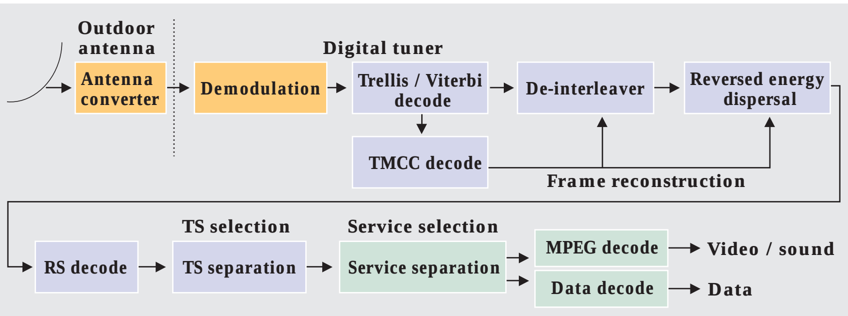

Figure 9: Configuration of a satellite digital broadcast receiver

2. CS digital broadcasting system

[1] Configuration of the CS digital system

The CS digital broadcasting system, Japan's first digital television system standardized in 1995, is based on the DVB-S system developed in Europe. This system consists of source coding, multiplexing, and channel coding systems, the same as the BS digital system shown in Fig. 1. Its channel coding system, however, is different from that of BS in that it can transmit only a single MPEG-TS over one channel carrier.

The source coding and multiplexing systems adopt MPEG-2, a de facto international standard, on the basis of cross-media studies that emphasized the need for international compatibility with baseband signals and for interchangeability with other media. In particular, the MPEG-2 Video (MP@ML) system is used for video coding, and the MPEG-2 Backward Compatible (BC) system is used for audio coding.

MPEG-2 Systems was adopted for multiplexing. This system treats a 188-byte transmission packet as a unit of

Table 2: Main parameters of the CS digital system

Applicable range of system	12.2-12.75 GHz band, 27-MHz bandwidth
Transmission bit rate	42.192 Mbps
Information bit rate ( ) specifies coding rate	19.4 Mbps (1/2), 25.9 Mbps (2/3), 29.2 Mbps (3/4), 32.4 Mbps (5/6), 34.0 Mbps (7/8)
Channel coding system	
Transmission frame and synchronization	The synchronization code is reversed every TS8 packet and 1 transmission frame is pseudo-formed.
Energy dispersal	An M-series 15th-order PN signal is added to the frame signal with synchronization removed.
Error-correction outer code	Shortened Reed-Solomon (204,188)
Interleaving	Convolutional system with depth 12
Error-correction inner code	Variable coding rate (1/2, 2/3, 3/4, 5/6, 7/8) by punctured FEC
Waveform shaping	Roll-off rate of 0.35, transmit/receive route allocation by raised cosine characteristics, x/sin(x) aperture correction on the transmit side
Modulation scheme	QPSK
Multiplexing system	Packet multiplexing as specified by MPEG-2 Systems (ISO/IEC 13818-1)
Conditional access system	Scrambling system; block encryption (ISO 9979/009) Associated information: program, control, and individual information are transmitted by ECM and EMM; encryption is optional
Source coding system	Video coding: MPEG-2 Video (ISO/IEC 13818-2) (Input format is 525 scan lines (interlaced, progressive) with aspect ratios of 4:3 and 16:9) Video coding: MPEG-2 Audio (ISO/IEC 13818-3,11172-3) (BC)

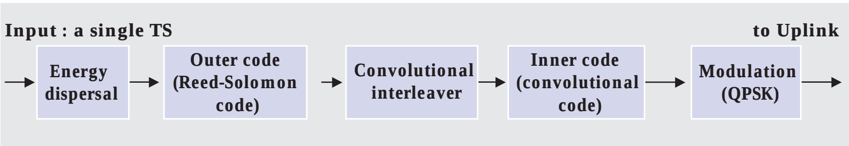

Figure 10: Configuration of channel coding system

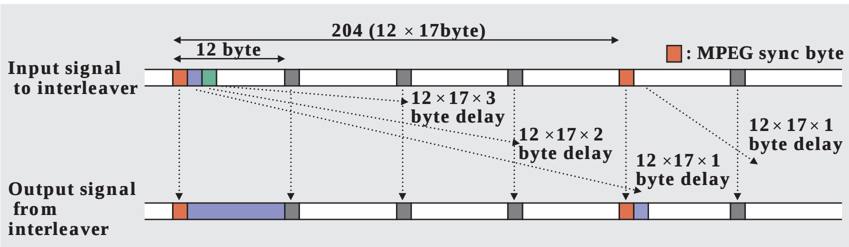

Figure 11: Configuration of convolutional interleaving

information and can transmit various services in a flexible manner by referring to the header information in each packet. To facilitate transmission control of this type, the contents of the Program Association Table (PAT), Program Map Table (PMT), Network Information Table (NIT), and Conditional Access Table (CAT) are being established as private standards.

A block encryption system (MULTI-2) was adopted for the conditional access scrambling system in order to take into account international trends and the need for security in pay-per-view broadcasts. Here, although the associated information system that distributes deciphering keys to individual viewers specifies three kinds of information (program, control, and individual), its design reflects the particular requirements of each business.

Table 2 lists the main parameters of each section of the CS digital system.

[2] Channel coding system

A system conforming to the European DVB-S standard was adopted for channel coding, with the input being a multiplexed MPEG-2 TS-packet sequence. The configuration of this system is shown in Fig. 10. Signal processings such as energy dispersal and interleaving in transmission scrambling are performed in units of pseudo frames that are configured every 8 packets by reversing the synchronization byte (47H) at the beginning of each packet. Taking into consideration the need for compatibility with the 188-byte packet length, shortened Reed-Solomon (204,188) that can correct errors in byte units is used as the error correction of the outer code. Convolutional coding is used as the error correction of the inner code near the modulation side, as it provides sufficient error-correcting capability. Although the basic convolutional coding rate is 1/2, punctured code techniques can be used to select rates of 1/2, 2/3, 3/4, 5/6, and 7/8. In addition, the signal interleaving is simple convolutional interleaving (interleave depth of 12), which improve the linked error-correcting ability of outer and inner code. Figure 11 shows the basic principle of convolutional interleaving.

QPSK was chosen as the modulation scheme , because of its long record of success in handling non-linear satellite transmissions.

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