Technologies and Services of Digital Broadcasting (12)

Terrestrial Digital Television Broadcasting

There are currently three terrestrial digital television systems in the world. These are, in the order of their development, Digital Television (DTV) in the United States, Digital Video Broadcasting-Terrestrial (DVB-T) in Europe, and Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) in Japan. In terms of transmission system, DTV employs a single-carrier system, while DVB-T and ISDB-T employ multicarrier systems (OFDM: Orthogonal Frequency Division Multiplexing).

The intent for each of these systems is to have a variety of features depending on the broadcasting services they target. ISDB-T features various reception formats, from fixed reception to mobile reception. It will also function as the sole broadcasting system for terrestrial digital television and terrestrial digital audio broadcasting.

In October 2000, with the aim of assisting countries to introduce terrestrial digital broadcasting, ITU-R (International Telecommunication Union, Radiocommunications Sector) drew up a list of system features (requirements) and a set of guidelines for selecting a system. These guidelines are summarized in Table. The remainder of this section provides an overview of the ISDB-T system developed by Japan with a focus on its transmission system.

Table: Guidelines for selecting a terrestrial digital television system (ITU-R)

Requirements		Suitable systems
Maximum data rate in a Gaussian channel for a given C/N threshold	Required	DTV
	Not required	DTV, DVB-T, ISDB-T
Maximum ruggedness against multipath interference	Required	DVB-T, ISDB-T
	Not required	DTV, DVB-T, ISDB-T
Single frequency networks (SFNs)	Required	DVB-T, ISDB-T
	Not required	DTV, DVB-T, ISDB-T
Mobile reception	Required	DVB-T, ISDB-T
	Not required	DTV, DVB-T, ISDB-T
Simultaneous transmission of different quality levels (hierarchical transmission)	Of primary importance	ISDB-T
	Required	DVB-T, ISDB-T
	Not required	DTV, DVB-T, ISDB-T
Independent decoding of data sub-blocks (for example, to facilitate sound broadcasting)	Required	ISDB-T
	Not required	DTV, DVB-T, ISDB-T
Maximum coverage from central transmitter at a given power in a Gaussian environment	Required	DTV
	Not required	DTV, DVB-T, ISDB-T
Maximum ruggedness against impulse interference	Required	DTV
	Not required	DTV, DVB-T, ISDB-T

1. ISDB-T transmission system

Figure 1 outlines the entire ISDB-T system. The transmission system, called Band Segmented Transmission-OFDM (BST-OFDM), configures a transmission band made up of OFDM segments each having a bandwidth of 6/14 MHz. In this system, transmission parameters may be individually set for each segment, making for flexible channel composition.

Furthermore, to achieve an interface between multiple MPEG-2 transport streams (TSs) and the BST-OFDM transmission system, these TSs are remultiplexed into a single TS. In addition, the channel segment configuration, transmission parameters, and other types of information are sent to the receiver by using a Transmission

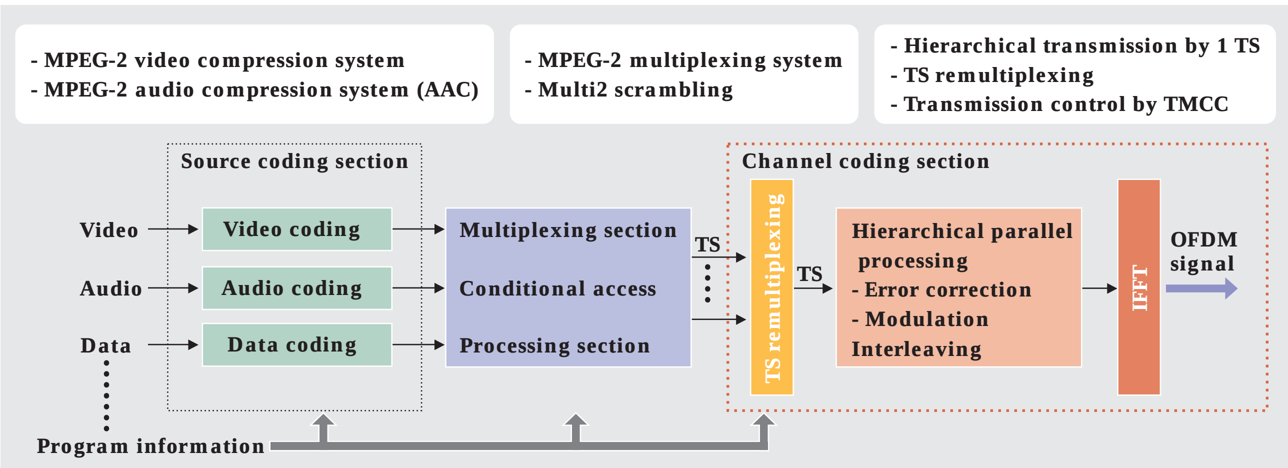


Figure 1: ISDB-T system configuration

Multiplexing Configuration Control (TMCC) signal as the transmission control information.

[1] Basic transmission parameters

ISDB-T features three transmission modes having different carrier intervals in order to deal with a variety of conditions such as the guard interval determined by the network configuration and the Doppler shift occurring in mobile reception. Table 1 lists the basic parameters of each mode.

One OFDM segment corresponds to a frequency spectrum having a bandwidth of 6/14 MHz (about 430 kHz). In Mode 1, one segment consists of 108 carriers, while modes 2 and 3 feature 216 and 432 carriers, respectively. Television broadcasting employs 13 segments with a transmission bandwidth of about 5.6 MHz. Terrestrial digital audio broadcasting, on the other hand, uses one or three segments.

A digital signal is transmitted in units of symbols. One symbol consists of two bits in Differential Quadrature Phase Shift Keying (DQPSK), four bits in 16QAM, and six bits in 64QAM. Here, the effective symbol length is the reciprocal of carrier interval-it is the condition preventing carriers in the band from interfering with each other. The guard interval is a time-redundant section of information that adds a copy of the latter portion of a symbol to the symbol's "front porch" in order to "absorb" interference from multipath-delayed waves. Accordingly, increasing the guard interval ratio in the signal decreases the information transfer rate.

An OFDM frame consists of 204 symbols with guard intervals attached regardless of the transmission mode. The time interleave length in real time depends on the parameters set at the digital-signal stage and on the guard-interval length, and the figures shown in the table for this parameter are consequently approximate values.

Frequency interleaving is performed for differential-modulation segments and coherent-modulation segments.

Error-correction schemes are concatenated codes, namely, Reed Solomon code (204,188) and convolutional code. The information bit rate takes on various values depending on the selected modulation system, inner-code coding rate, and time-redundant guard interval. The range shown in the table reflects the minimum and maximum values for 13 segments.

Table 1: Basic transmission parameters for terrestrial digital television broadcasting

Transmission Parameter	Mode 1	Mode 2	Mode 3
No. of OFDM segments	13		
Bandwidth	5.575 MHz	5.573 MHz	5.572 MHz
Carrier interval	3.968 kHz	1.984 kHz	0.992 kHz
No. of carriers	1405	2809	5617
Modulation system	QPSK, 16QAM, 64QAM, DQPSK		
Effective symbol length	252 μs	504 μs	1.008 ms
Guard-interval length	1/4, 1/8, 1/16, 1/32 of effective symbol length		
No. of symbols per frame	204		
Time interleave	4 maximum values: 0, about 0.13, 0.25, 0.5 sec		
Frequency interleave	Intra-segment or inter-segment interleaving		
Inner code	Convolutional coding (1/2, 2/3, 3/4, 5/6, 7/8)		
Outer code	RS (204, 188)		
Information bit rate	3.65 Mbps - 23.23 Mbps		
Hierarchical transmission	Maximum 3 levels		

[2] Configuration of channel coding section

Figure 2 shows the system diagram for the channel coding section. This system passes a TS from the MPEG-2 multiplexer to the TS remultiplexing section (remux) where it converts the TS to a 204-byte packet stream with null bytes attached. The TS is a stream signal consisting of 188-byte transport stream packets (TSP). Here, the attached null bytes can be substituted by parity bits in Reed-Solomon code as outer code. In the case of hierarchical transmission, the resulting stream can be divided into units of packets

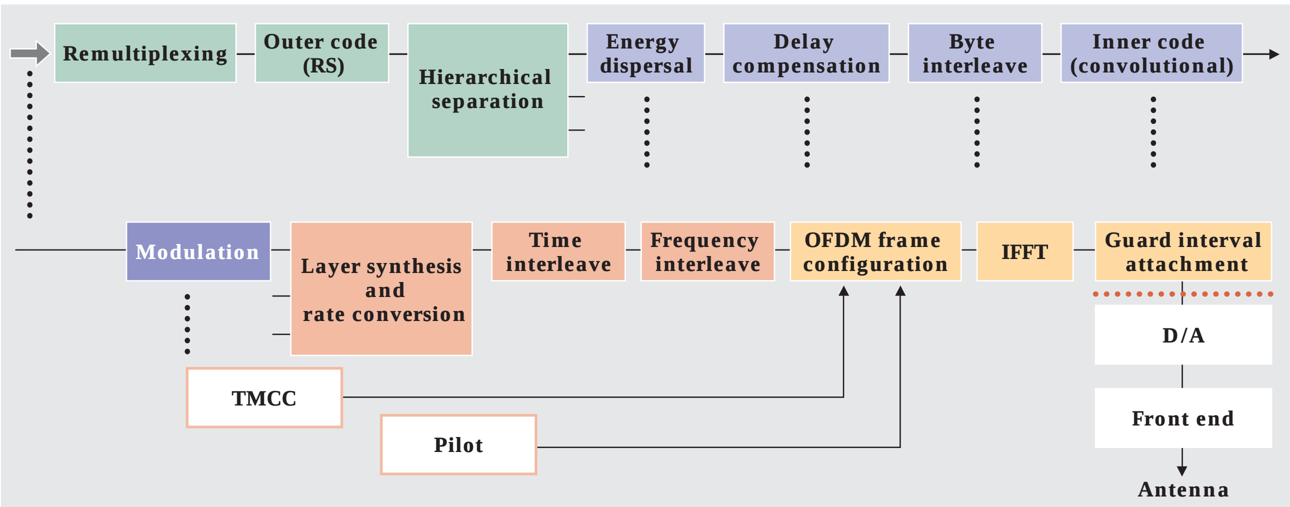


Figure 2: Configuration of channel coding section

according to program information and input into a maximum of three parallel-processing systems. This process is called hierarchical separation.

The parallel-processing section begins by performing energy dispersal, byte interleaving, and other processing with the aim of minimizing forward and backward correlation in the digital signal in both time and frequency directions. It then carries out channel coding according to the parameters selected to satisfy the required transmission characteristics such as reception format. These parameters include the coding rate of convolution code (inner code) and the digital modulation system such as QPSK.

Because the hierarchical layers subjected to parallel processing have different information bit rates, the system performs temporary data storage in buffer memory and reads out data in units of symbols according to an Inverse Fast Fourier Transform (IFFT) sampling clock. This process is referred to as layer synthesis and rate conversion. Next, to improve mobile reception and robustness to multipath interference, the system performs, in symbol units, time interleaving plus frequency interleaving according to the arrangement of OFDM segments. Pilot signals for demodulation and control symbols consisting of TMCC information are combined with information symbols to an OFDM frame. Here, information symbols are modulated by Differential Binary Phase Shift Keying (DBPSK) and guard intervals are added at the IFFT output.

[3] Hierarchical transmission

A mixture of fixed-reception programs and mobile-reception programs in the transmission system is made possible through the application of hierarchical transmission achieved by band division within a channel. "Hierarchical transmission" means that the three elements of channel coding, namely, the modulation system, the coding rate of convolutional correction code, and the time interleave length, can be independently set. Time and frequency interleaving are each performed in their respective hierarchical data segment.

As described earlier, the smallest hierarchical unit in a frequency spectrum is one OFDM segment. Referring to Fig. 3, one television channel consists of 13 OFDM segments and up to three hierarchical layers can be set with regard to these segments. Taking the channel-selection operation of the receiver into account, a frequency spectrum segmented in this way must follow a rule for arranging segments. Specifically, DQPSK segments using differential modulation are placed in the middle of the transmission band while QPSK and QAM segments using coherent modulation are placed at either end of the band. In addition, one layer can be set for the single center segment as a partial-reception segment targeting receivers of terrestrial digital audio broadcasts. Using the entire 5.6-MHz band in this way is called "ISDB-T." Audio broadcasts feature a basic 1-segment format as well as a 3-segment expanded format, both referred to as "ISDB-T_{SB}."

[4] Multiplex frame and TS remultiplexing

As shown in Fig. 2, a broadcast program is input as multiple TSs having various information bit rates. On the other hand, modulation, inner code, and time interleave must be set as needed for one OFDM segment, the smallest unit of the transmission band, independent of these input TSs.

For this reason, the remultiplexing section rearranges the multiple input TSs as one TS within a multiplex frame so as to create an interface between the digital and OFDM signals.

In addition to the basic function of allocating and sending an integral number of TSPs per OFDM segment in

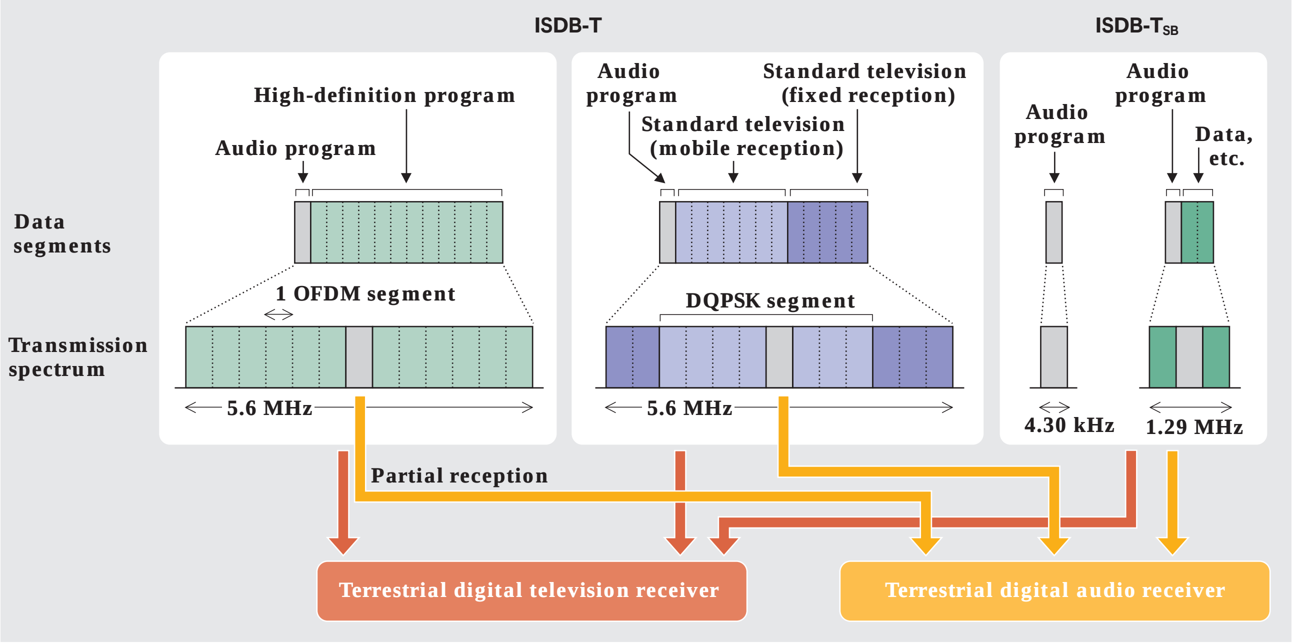


Figure 3: ISDB-T service examples and transmission signals

a multiplex frame, the system has the following features.

- A fixed-length frame is created regardless of the hierarchical configuration by establishing an interface with multiple TS inputs at a clock signal four times the IFFT sample clock used to create the OFDM signal and by inserting null packets.
- Given that the length of an OFDM frame is equal to an integral multiple of multiplex frames, synchronization can be improved by generating TS synchronization from OFDM signal synchronization. In Mode 1, data of one multiplex frame are sent as one OFDM frame, while in Mode 2 and Mode 3, data of two multiplex frames and four multiplex frames, respectively, are sent as one OFDM frame.
- A rule is established for arranging TSPs in a multiplex frame to facilitate TS regeneration at the receiver.

Figure 4 shows an example of a multiplex frame configuration and parallel processing for the case of two hierarchical layers. Here, TSPs of TS A and TS B that generally have different bit rates will be supplemented with 16 null bytes to form 204-byte packets.

These TSPs are then multiplexed to create one TS according to the program information by using a clock signal four times that of the IFFT sample clock (Fs). In the case of excess time, a 204-byte null packet can be inserted so as to generate a multiplex frame having a consecutive string of 204-byte packets.

[5] Modulation and error correction

A digital signal contained in one TS is first subjected to Reed-Solomon coding as outer code and then divided into hierarchical layers for channel coding in parallel. Figure 5 shows an example of a two-layer case.

Four digital modulation systems are possible here: DQPSK, QPSK, 16QAM, and 64QAM.

DQPSK is a differential type of modulation that transmits the difference between the present symbol and the next symbol as information. As such, it does not require a reference signal and is consequently appropriate for mobile reception. The particular form of DQPSK adopted here features a phase shift of $\pi/4$ every symbol so that signal points after differential demodulation turn out to be the same as QPSK. Figure 6 shows the modulation circuit including bit interleaving and the phase diagram. The 120-bit delay after series/parallel conversion is a form of bit interleaving that is performed to reduce inter-carrier interference.

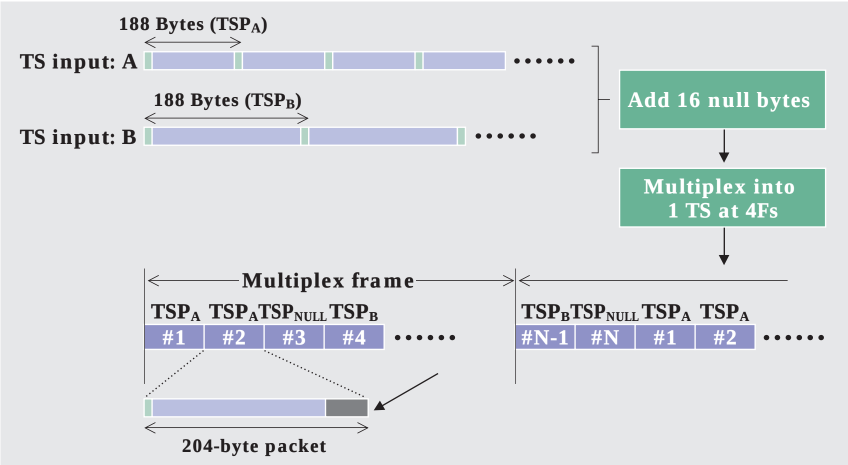


Figure 4: Example of multiplex frame configuration

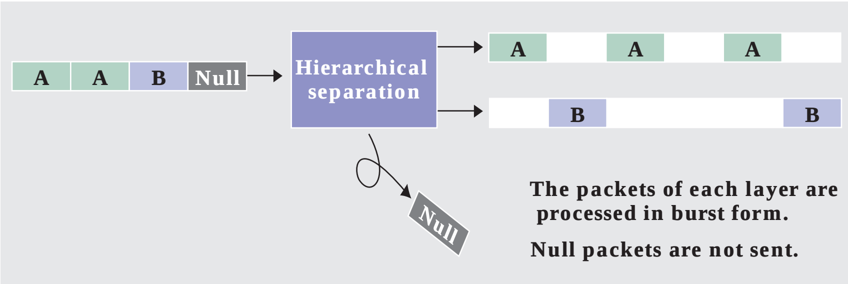


Figure 5: Hierarchical separation and parallel processing (2-layer example)

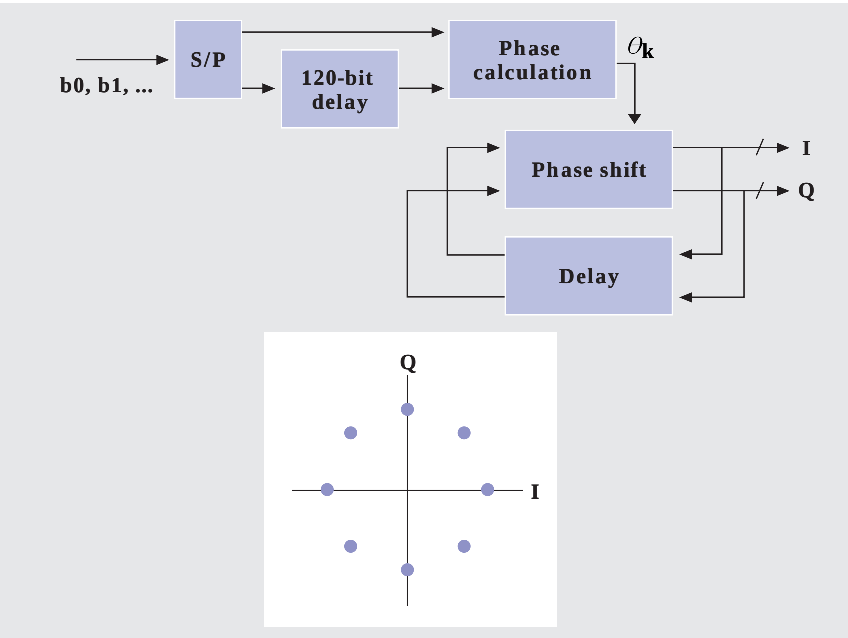


Figure 6: $\pi/4$ shift DQPSK

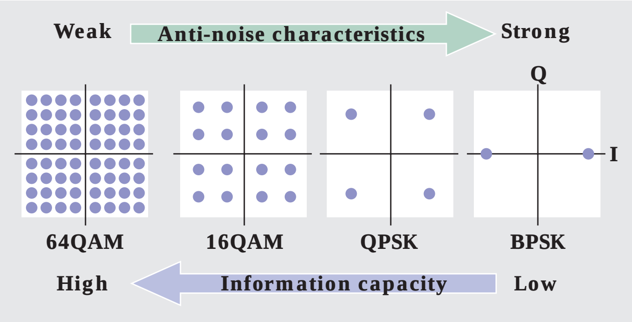


Figure 7: Robustness against noise in modulation systems

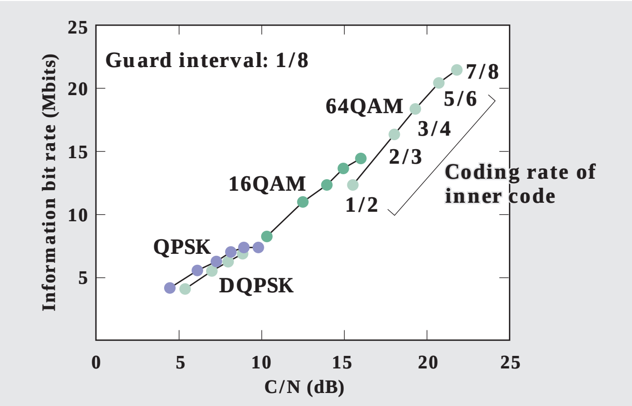


Figure 8: CN ratio versus transmission capacity determined by channel coding

Figure 7 shows the amplitude-phase diagrams for QPSK, 16QAM, and 64QAM coherent types of modulation. As the number of bits carried by a symbol increases from two to four and six bits, the bit rate increases. At the same time, however, the distance between signal points becomes smaller and the signal becomes less robust to noise and other disturbances. Figure 8 plots transmission capacity versus the CN ratio with modulation system and convolutional coding rate as parameters.

If the bit error rate after inner code decoding is less than 2×10^{-4}, a quasi-error-free error rate of 10^{-11} can be obtained through Reed-Solomon coding of outer code.

TMCC control information and auxiliary channels (AC) described below will also be transmitted via DBPSK modulation.

[6] OFDM frame

The transmission frame format of BST-OFDM is described here, using Mode 1 segments as an example. In this mode, one segment uses 96 data carriers for transmitting information and the remaining 12 carriers for transmission control. The arrangement of control carriers differs according to the modulation system applied to the segment, and thus, there are two types of segment frames, as shown in Fig. 9. The broadcast OFDM signal features 13 segment frames of these two types sequenced in the frequency direction.

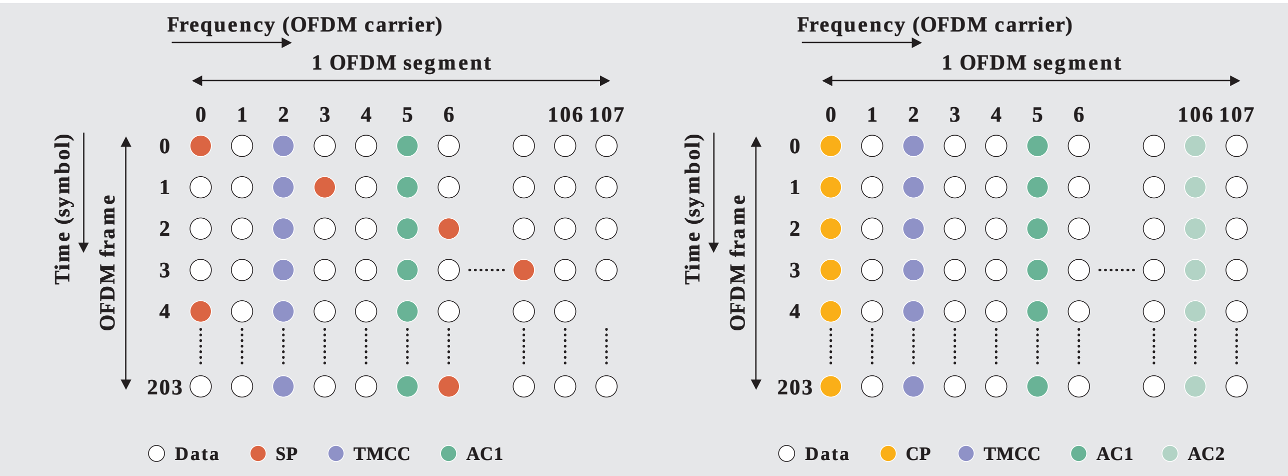
Figure 9 (a) shows OFDM segment frames for coherent-modulation use each having one TMCC carrier, two AC carriers, and an equivalent of nine scattered pilots (SP) arranged in a dispersed fashion. An SP is inserted once every 12 carriers in the carrier direction and once every four symbols in the symbol direction.

On the other hand, SPs are not needed for the case of differential modulation shown in Figure 6.2.1.9 (b). Here, a segment frame consists of five TMCC carriers, six AC carriers, and one continual pilot (CP) placed consecutively at the low frequency end of each segment. When arranging segments as described in "(3) Hierarchical transmission" above, this CP acts as a high-frequency-end reference signal for a coherent-modulation OFDM segment adjacently situated at a lower frequency.

In addition, AC plays the role of an additional channel that can also function as a reference signal for demodulation.

[7] TMCC signal and control information

A variety of transmission and reception formats such as hierarchical transmission and partial reception can be



(a) Frame for QAM modulation

(b) Frame for DQPSK modulation

Figure 9: OFDM frame

considered for terrestrial digital broadcasting. In this regard, the TMCC signal, which is transmitted via DBPSK modulation, includes system control information like the segment configuration that the receiver must decode first. Figure 10 shows the configuration of the TMCC signal. In the figure, frame synchronization is a 16-bit word that inverts every frame, and three bits are used to distinguish between coherent modulation and differential modulation in a segment.

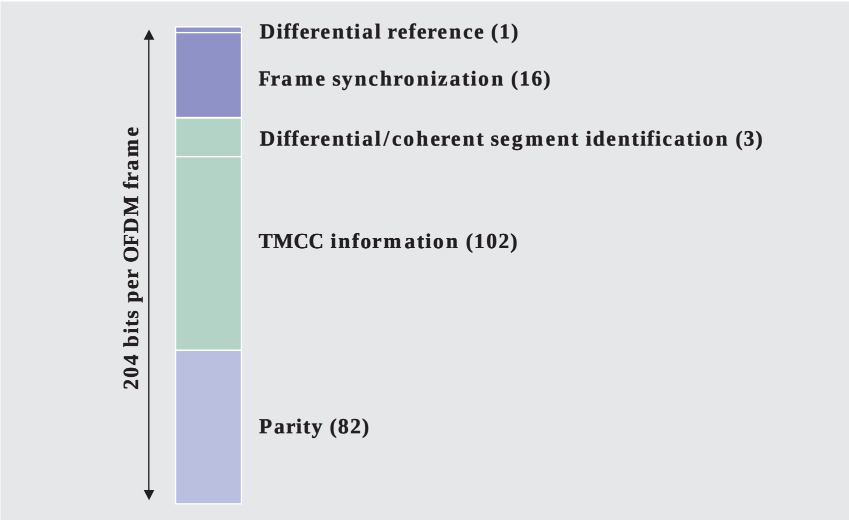


Figure 10: TMCC signal configuration

Table 2: Configuration of the 102 TMCC control bits

No. of Bits	Control Information	
2	System (TV/audio) identification	
4	Current/next switching countdown	
1	Emergency alarm flag	
1	Current	Partial reception flag
13		A-level hierarchical transmission parameters
13		B-level hierarchical transmission parameters
13		C-level hierarchical transmission parameters
40	Next	Same as above
6	For narrow-band I (audio) system control	
12	Reserved	

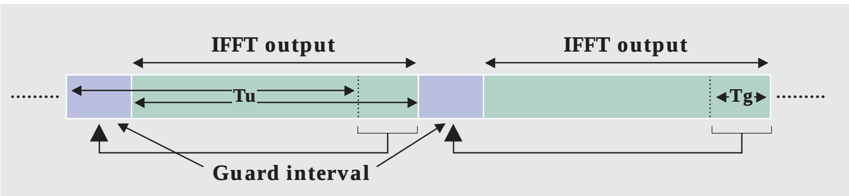


Figure 11: Addition of guard interval

The TMCC control information is common to all TMCC carriers and error correction is performed by using difference-set cyclic code. Because there are multiple TMCC carriers in a differential-modulation OFDM segment used for mobile reception, a majority decision is taken with regard to transmitted control bits to raise the reliability of the control information.

Table 2 summarizes the configuration of the 102 TMCC control bits and their functions. Thirteen bits are allocated to the hierarchical transmission parameters of the inner-code coding rate, modulation system, and time interleave with space for three layers worth of such bits always provided.

[8] Guard intervals

Symbol data for 13 OFDM segments are converted at one time to symbols of period Tu by performing IFFT calculations. As shown in Fig. 11, the guard interval is formed by directly adding waveform data at the end of the symbol to its "front porch." The resulting transmission symbol of period Tu+Tg is continuous, which means that the effective symbol Tu can be demodulated as long as it is found somewhere in this period.

References

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