

Transmission System for ISDB-T

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Invited Paper

The Association of Radio Industries and Businesses in Japan decided the specifications for a digital terrestrial broadcasting system called ISDB-T in 1998. The ISDB-T transmission system is recommended in ITU-R Recommendation BT.1306. Planning criteria of the ISDB-T system are recommended in ITU-R Recommendation BT.1368. This paper describes the transmission scheme of the ISDB-T system. First, it explains features of the ISDB-T system. Second, it describes transmission systems such as modulation, error correction, orthogonal frequency division multiplexing framing, transmission and multiplexing configuration control, guard interval, etc. Finally, it concludes discussion of the ISDB-T transmission system and describes transmission parameters used in Japan.

Keywords—digital terrestrial television broadcasting (DTTB), hierarchical transmission, Integrated Services Digital Broadcasting-Terrestrial (ISDB-T), orthogonal frequency division multiplexing (OFDM), transmission system.

I. FEATURES OF ISDB-T TRANSMISSION SYSTEM

The Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) system is designed to provide reliable high-quality video, sound, and data broadcasting not only for fixed receivers but also for mobile receivers. The system is also designed to provide flexibility, expandability, and commonality/interoperability for multimedia broadcasting.

The system is rugged because it uses orthogonal frequency division multiplexing (OFDM) modulation, two-dimensional (frequency-domain and time-domain) interleaving, and concatenated error-correcting codes. Its modulation scheme is called Band Segmented Transmission-OFDM (BST-OFDM), and it consists of 13 OFDM segments.

The system has a wide variety of transmission parameters for choosing the carrier modulation scheme, coding rate of the inner error-correcting code, length of time interleaving,

etc. These transmission parameters can be set individually for each segment.

The system supports hierarchical transmissions of up to three layers (Layers A, B, and C). The transmission parameters can be changed in each of these layers. In particular, the center segment of this hierarchical transmission can be received by one-segment handheld receivers. Owing to the common structure of the OFDM segment, a one-segment receiver can “partially” receive a program transmitted on the center segment of a fullband ISDB-T signal (partial reception is the name given to the means by which a receiver picks out only part of the transmission bandwidth).

The system has three transmission modes (Modes 1, 2, and 3) to enable the use of a wide range of transmitting frequencies, and it has four choices of guard-interval length to enable better design of a single-frequency network (SFN).

This system uses MPEG-2 Video coding and MPEG-2 advanced audio coding (AAC). Moreover, it adopts MPEG-2 Systems for encapsulating a data stream. Therefore, various digital contents such as sound, text, still pictures, and other data can be transmitted simultaneously. It has commonality and interoperability with other MPEG-2 System adopting systems, such as ISDB-S, ISDB-C, ISDB-T_{SB}, and the Satellite Digital Sound Broadcasting System in Japan.

II. ISDB-T TRANSMISSION SYSTEM

A. Outline of Transmission System

Fig. 1 outlines the entire ISDB-T system. The transmission system, BST-OFDM, configures a transmission band made up of OFDM segments, each having a bandwidth of 6/14 MHz. The 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, transmission control information such as channel segment configuration, transmission parameters, etc., are sent to the receiver in the form of a transmission multiplexing configuration control (TMCC) signal.

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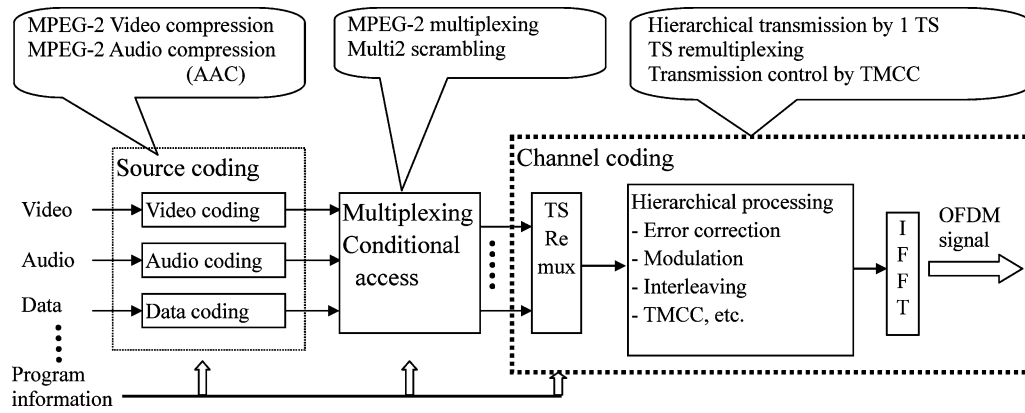


Fig. 1. ISDB-T system configuration.

Table 1
Basic Transmission Parameters for ISDB-T

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
Carrier modulation	QPSK, 16QAM, 64QAM, DQPSK		
Effective symbol length (T_u)	252 μ s	504 μ s	1.008 ms
Guard-interval length (T_g)	1/4, 1/8, 1/16, 1/32 of effective symbol length		
No. of symbols per frame	204		
Time interleave	Maximum 4 values : 0, 0.1, 0.2, 0.4 sec		
Frequency interleave	Intra-segment and 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 (Layer A, B, and C)		

B. 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 variable guard interval as 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 two times and four times that number of 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 sets of symbols. One symbol consists of 2 b in QPSK and DQPSK, 4 b in 16QAM, and 6 b in 64QAM. Here, effective symbol length is the reciprocal of carrier interval—this 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" with the aim of absorbing interference from multipath-delayed waves. Accordingly, increasing the guard-interval ratio in the signal decreases the information bit 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 values shown in the table for this parameter are consequently approximate values.

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

C. Configuration of Channel Coding Section

Fig. 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 into a 204-B packet stream with null bytes attached. A TS is a stream signal consisting of a 188-B transport stream packet (TSP). Here, the attached null bytes can be substituted by parity bits in Reed–Solomon code as the outer code. In the case of hierarchical transmission, the resulting stream can be divided into sets of packets according to the

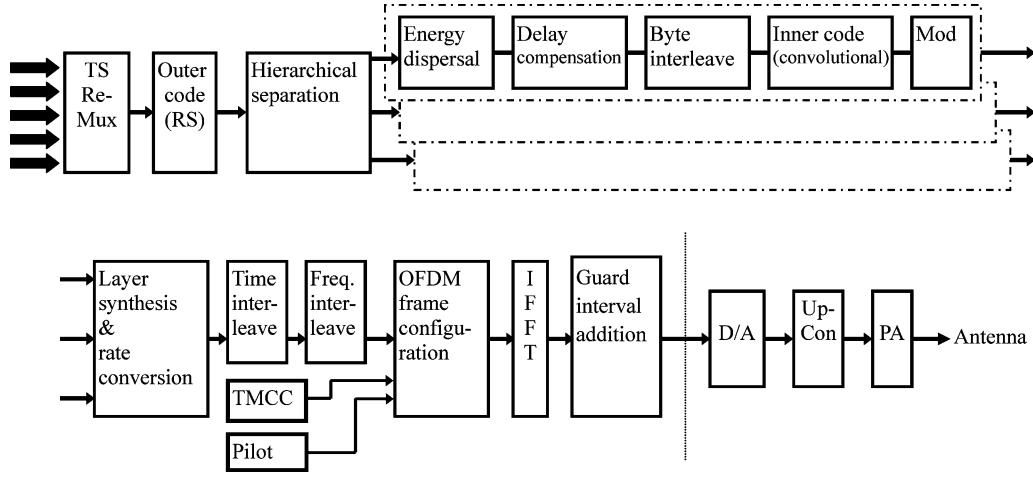


Fig. 2. Configuration of channel coding section.

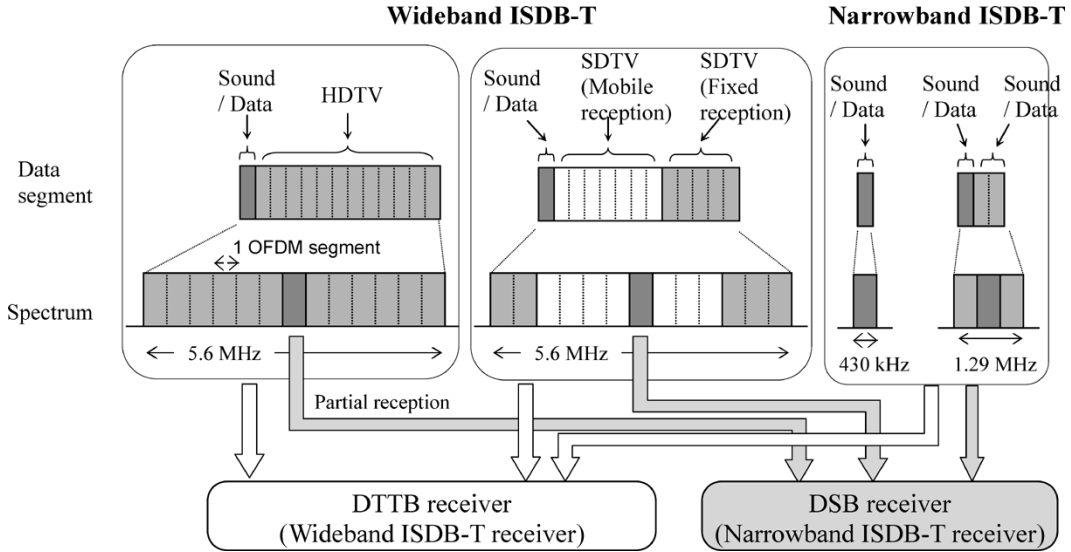


Fig. 3. ISDB-T service examples and transmission signals.

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 the time and frequency domains. 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 those of the digital modulation scheme 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, with the aim of improving 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 configure an OFDM frame. Here, information symbols are modulated by differential binary phase shift keying (DBPSK) and guard intervals are added at the IFFT output.

D. Hierarchical Transmission

A mixture of fixed-reception programs and mobile-reception programs 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 scheme, the coding rate of convolutional error-correcting code, and the time interleaving length, can be independently selected. 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,

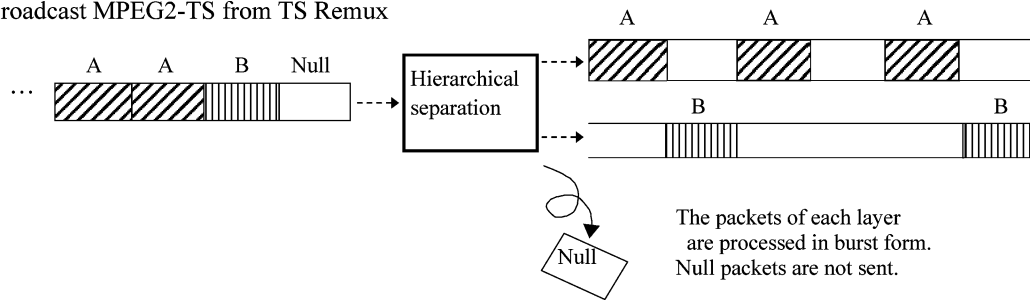


Fig. 4. Hierarchical separation and parallel processing (two-layer example).

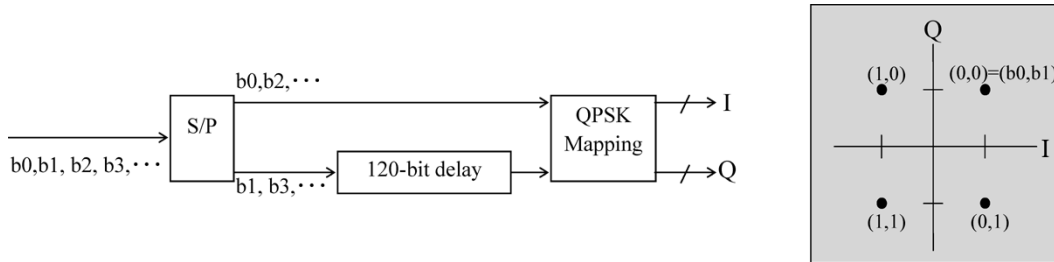


Fig. 5. QPSK modulation and bit mapping.

one television channel consists of 13 OFDM segments and up to three hierarchical layers (Layers A, B, and C) can be set with regard to these segments. If the OFDM signal is transmitted using only one layer, the layer is A. If the signal is transmitted using two layers, the center “rugged” layer is A and the outer layer is B. If the signal is transmitted using three layers, the center “rugged” layer is A, the middle layer is B, and the outer layer is C. Taking the channel-selection operation of a 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 frequency band. In addition, one layer can be set for the single center segment as a partial-reception segment for receivers of terrestrial digital audio broadcasts. In this case, the center segment is Layer A. Using the entire 5.6-MHz band in this way is called wide-band ISDB-T. Audio broadcasts feature a basic one-segment format as well as a three-segment expanded format, both referred to as narrowband ISDB-T.

E. Modulation and Error Correction

A digital signal contained in one TS is first subjected to Reed–Solomon coding as the outer code and is then divided into hierarchical layers for channel coding in parallel. Fig. 4 shows an example of a two-layer case.

Four digital modulation schemes 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 features a phase shift of $\pi/4$ every

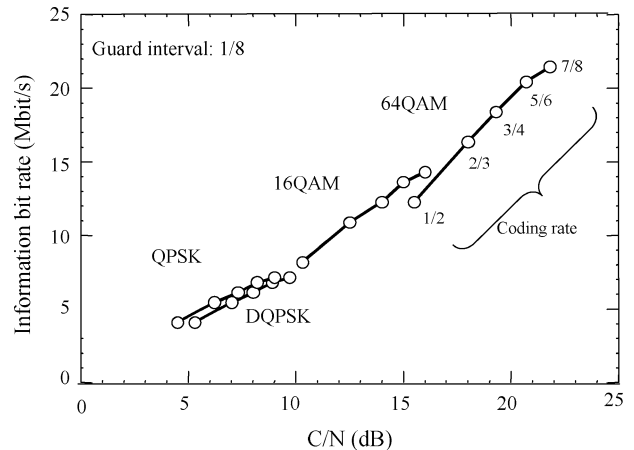


Fig. 6. CN ratio versus transmission capacity determined by channel coding.

symbol so that signal points after differential demodulation turn out to be the same as in QPSK.

The others (QPSK, 16QAM, and 64QAM) are 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. Fig. 5 shows the modulation circuit of QPSK including bit interleaving and the phase diagram. The 120-b delay after serial/parallel conversion is a form of bit interleaving performed to reduce intercarrier interference.

Fig. 6 plots transmission capacity versus CN ratio with the modulation scheme 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 bit error rate of 10^{-11} can be obtained through the Reed–Solomon decoding as the outer code.

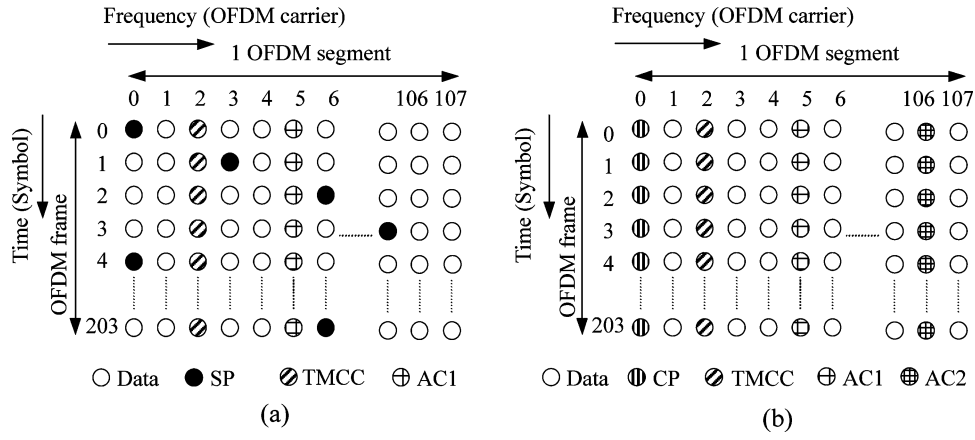


Fig. 7. OFDM frame structure. (a) Frame structure for QAM. (b) Frame structure for DQPSK.

The TMCC control information and auxiliary channels (ACs) described below are also transmitted via DBPSK modulation.

F. OFDM Frame Structure

The transmission frame format of BST-OFDM is described 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. Here, the arrangement of control carriers differs according to the modulation scheme applied to the segment, and there are therefore two types of segment frame as shown in Fig. 7. The broadcast OFDM signal features 13-segment frames of these two types sequenced in the frequency domain at the same carrier.

Fig. 7(a) shows OFDM segment frames for coherent-modulation cases, each having one TMCC carrier, two AC carriers, and an equivalent of nine scattered pilots (SPs) arranged in a dispersed fashion. An SP is inserted once every 12 carriers in the frequency domain and once every four symbols in the time domain.

On the other hand, SPs are not needed for the case of differential modulation shown in Fig. 7(b). Here, a segment frame consists of five TMCC carriers, six AC carriers, and one continual pilot (CP) placed consecutively at the lowest end in frequency domain of each segment. When arranging segments as described in Section II-D, this CP acts as the highest frequency reference signal for a coherent-modulation OFDM segment adjacently situated at a lower frequency band.

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

G. TMCC Signal and Control Information

A variety of transmission and reception formats such as hierarchical transmission and partial reception can be considered for terrestrial digital broadcasting. In this regard, the TMCC signal, which is transmitted via DBPSK modulation, includes system control information, such as the segment configuration that the receiver must decode first. Fig. 8 shows the configuration of the TMCC signal. In the figure, the frame synchronization code is a 16-b word that inverts every frame

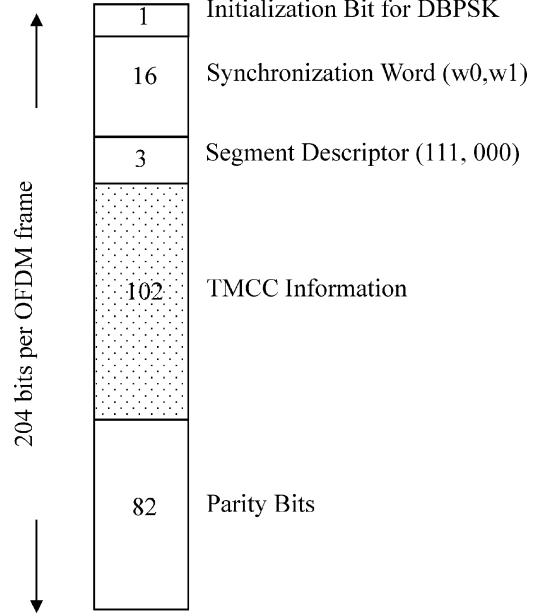


Fig. 8. TMCC signal configuration.

and 3 b are used to distinguish either coherent modulation or differential modulation in a segment.

TMCC control information is common to all TMCC carriers, and error correction is performed with 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 inner-code coding rate, modulation scheme, and time interleave, and the space for three layers of these bits is always reserved for actual usage.

H. Guard Intervals

Symbol data for 13 OFDM segments are converted at one time into symbols of a period T_u by performing IFFT cal-

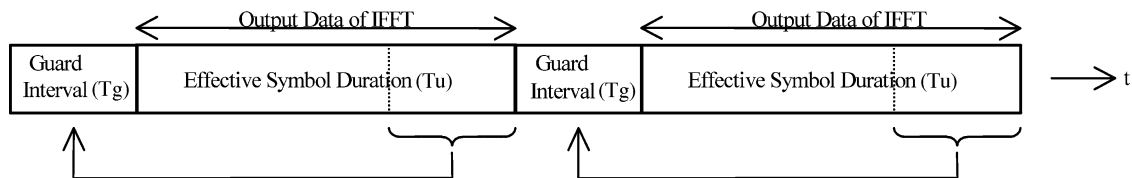


Fig. 9. Guard interval.

Table 2

Configuration of the 102 TMCC Information

No. of Bits	Control Information
2	System (TV/audio) identification
4	Current/next switching countdown
1	Emergency alert flag
1	Current
13	Partial reception flag
13	Layer A transmission parameters
13	Layer B transmission parameters
13	Layer C transmission parameters
40	Next
3	For narrow-band ISDB-T _{SB} system control
12	Reserved

culations. As shown in Fig. 9, a guard interval is formed by directly adding a portion of waveform data at the end of a symbol to its "front porch." The resulting transmission symbol of period $T_u + T_g$ is continuous, which means that the effective symbol T_u can be demodulated as long as it is found somewhere in this period.

III. CONCLUSION

As described earlier, the transmission scheme of the ISDB-T system is designed to provide reliable high-quality video, sound, and data broadcasting not only for fixed reception but also for mobile reception. The system is also designed to provide flexibility, expandability, and commonality/interoperability for multimedia broadcasting.

In Japan, we launched digital terrestrial television broadcasting (DTTB) using the ISDB-T system at the end of 2003. Considering the distance between transmitter sites, most broadcasters use Mode 3 and a guard-interval ratio of 1/8, which implies the guard-interval length equal to 126 μ s. HDTV programs are broadcasted using transmission parameters of 64QAM modulation, 3/4 inner-coding rate, and about 0.2-s time interleaving. HDTV programs are currently broadcast to fixed reception receivers. However, technologies making it practical to receive HDTV programs in moving cars or buses have also been developed. Right

now, almost of all broadcasters in Japan transmit HDTV programs using only one layer; however, in the spring of 2006, broadcasters will start a medium-quality video broadcasting service to handheld/portable receivers using the central segment. That means we will soon be able to watch TV programs on our cellular phones with digital TV receiving capability.

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