Preface

Transmission system of ISDB-T is most feature of ISDB-T. Different from another DTTB standard, ATSC and DVB-T.

For examples, (1)One segment service within same bandwidth, (2)High performances for mobile/portable reception, (3)Robustness against multi-path and impulse noise, etc. These features re mainly led from ISDB-T transmission system.

So, it is very important to study the structure of ISDB-T transmission system for understanding the background of the features of ISDB-T.

This seminar document is prepared according ARIB STD-B31. But, as described in seminar #2, SBTVD-T 01 is almost same as B31. Therefore, it is useful for Brazilian engineer to know this section.

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   1.1 Features of ISDB-T and technical baseline
   1.2 Block diagrams of transmission system
   1.3 transmission parameter
2. Principle of segment construction and hierarchical transmission
3. Transmission coding
   3.1 Channel coding
   3.2 Mapping and Interleaving
4. OFDM modulation
   4.1 OFDM modulation and Guard interval adding
   4.2 Quadrature modulation
5. Outline of ISDB-TSB
   5.1 outline of ISDB-TSB transmission system
   5.2 Consecutive transmission system
   5.3 example of consecutive transmission station
Requirements for transmission system → Solutions

- High-Quality, Multi-Channel
- Multimedia Service
- Flexible/Versatile
- Efficient Spectrum utilization
- Mobile and handheld service
- Commonality of receiver

Features of ISDB-T transmission system

- High-Quality, Multi-Channel
- Multimedia Service
- Flexible/Versatile
- Efficient Spectrum utilization
- Mobile and handheld service
- Commonality of receiver

ISDB-T system

Band Segmented OFDM: Orthogonal Frequency Division Multiplexing

- 6MHz
- 13 Segments
- 429KHz

Features
- 1HDTV or N SDTV/channel
- Net data rate: 23.42Mbps (6MHz)
- Single Frequency Network
- Mobile reception (time interleaving)

Segmented Structure and Partial Reception

(Example: 1seg + 12seg)

Layer B
(HDTV or Multi-SDTV with Data)

13 segments
(6MHz bandwidth)

QPSK constellation

64QAM constellation

Difference of required C/N
Between 64QAM and QPSK is about 12 dB

*13 segments are divided into layers, maximum number of layers is 3.
* Any number of segment for each layers can be selected (totally 13 segment)
* Transmission parameter sets of each layer can be set independently
(In above example, modulation index of each layer are different)
Feature of ISDB-T transmission system

1. Efficient frequency utilization
   (1) Adopt OFDM transmission system; SFN operation
   (2) Adopt hierarchical transmission; service for different type of reception in one frequency channel

2. Mobile/ handheld service in one transmission standard
   (1) Time interleave; Improve mobile reception quality
   (2) Partial reception; handheld service in same channel

3. Robustness against interference
   (1) Adopt concatenated error correction with plural interleave
   (2) Time interleaver; very effective for impulse noise (urban noise)

4. Flexibility for several type of service/ reception style

5. Commonality of TV/audio transmission standard

6. Auxiliary (AC) channel can be used for transmission network management

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Parameters of ISDB-T (6MHz Bandwidth)

<table>
<thead>
<tr>
<th>ISDB-T mode</th>
<th>Mode 1 (2k)</th>
<th>Mode 2 (4k)</th>
<th>Mode 3 (8k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of OFDM segment</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Useful bandwidth</td>
<td>5.575MHz</td>
<td>5.573MHz</td>
<td>5.572MHz</td>
</tr>
<tr>
<td>Carrier spacing</td>
<td>3.968kHz</td>
<td>1.984kHz</td>
<td>0.992kHz</td>
</tr>
<tr>
<td>Total carriers</td>
<td>1405</td>
<td>2809</td>
<td>4992</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM, DQPSK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of symbols / frame</td>
<td>204</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active symbol duration</td>
<td>252μs</td>
<td>504μs</td>
<td>1.008ms</td>
</tr>
<tr>
<td>Guard interval duration</td>
<td>1/4, 1/8, 1/16, 1/32 of active symbol duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner code</td>
<td>Convolutional code</td>
<td>(1/2, 2/3, 3/4, 5/6, 7/8)</td>
<td></td>
</tr>
<tr>
<td>Outer code</td>
<td>RS (204,188)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time interleaver</td>
<td>0 ~ 0.5s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Useful bit rate</td>
<td>3.651Mbps ~ 23.234Mbps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Equation for calculating bit rate

**STEP 1: calculate the bit rate of one(1) segment**

ISDB-T is composed 13 segments, so, to calculate transmission bit rate, at first, calculate the bit rate of one(1) segment, and multiply number of Segment of each layer. Then lead total bit rate of each layer

1. reed-Solomon coding rate; (188/204), fixed value
2. r: convolutional coding rate( depends on coding rate)
3. M: modulation index(bit/ symbol); QPSK=2, 16QAM=4, 64QAM=6
4. Ts/(Ts+Tg); ratio of total symbol length and effective symbol length
5. (effective data carrier)/(total carrier) =96/108 – fixed value for mode 1, 2, 3 (note) total carrier; including pilot carrier, TMCC, and scattered pilot symbol
6. Nf : Number of carrier in one segment; mode 1=108,mode 2=216, mode 3=432
7. (note) total carrier spacing = effective symbol transmission speed
   Mode 1=6/(14)*10^3 kHz = 3.6682540kHz, mode 2= 12/(1/2) of mode 1
   Mode 3=3/(1/4) of mode 1
   (note) (6/14)*10^3 kHz = bandwidth of one(1) segment
**Example**

Mode 3, guard interval ratio=1/16, modulation=QPSK, coding rate(r)=2/3

Bit rate of 1 segment = 

\[
\text{Bit rate} = 0.9920635 \times \frac{432}{(16/17)} \times 2 \times \frac{2}{(3/4)} \times \frac{188/204}{(2/3)} \times r = 440.56 \text{ kbps}
\]

**Example 1**

1 layer fixed reception, mode 3, guard interval ratio=1/16,
Modulation = 64QAM, coding rate(r)=3/4

Number of segment

Bit rate of 1 segment = 

\[
\text{Bit rate} = 0.9920635 \times \frac{432}{(16/17)} \times 6 \times \frac{3/4}{(188/204)} \times 13 = 19.329 \text{ Mbps}
\]

**Example 2**

2 layer, 1 segment for portable, 12 segment for fixed
Layer A: Nseg=1, mode 3, Tg/Ts=1/16, M=2(QPSK), r=2/3

Bit rate of A layer = 

\[
\text{Bit rate} = 0.9920635 \times \frac{432}{(16/17)} \times 2 \times \frac{2}{(3/4)} \times \frac{188/204}{(2/3)} \times 1 = 440.56 \text{ kbps}
\]

Layer B: Nseg=12, mode 3, Tg/Ts=1/16, M=6(64QAM), r=3/4

Bit rate of A layer = 

\[
\text{Bit rate} = 0.9920635 \times \frac{432}{(16/17)} \times 6 \times \frac{3/4}{(188/204)} \times 12 = 17.842 \text{ Mbps}
\]

2. Segment construction and Hierarchical Transmission

**2.1 Concept and feature of hierarchical transmission system**

Hierarchical transmission is the feature of ISDB-T, this concept is not in DVB-T system. The concept of hierarchical transmission system is shown in figure.2-1 after. The transmission parameters can be assigned as each service ID. This transmission system is called “hierarchical transmission”

For example, the service which should be strong against interference such as noise should be assigned to QPSK layer, other service is assigned to 64QAM layer.

In this case, service of QPSK layer could be received under serious receiving condition such as handheld reception.

In case of DVB-T system, for handheld reception service, another frequency should be prepared separately. But, in ISDB-T system, different reception service can be achieved within one frequency channel by making use of this transmission system.

TSP’s are divided into plural layers at Re-multiplexer, and re-arranged in each layer. After re-arranged, these TSP’s are combined to 1 transport stream and feed to OFDM modulator. (see figure. 2-2)
2.2 The rules of hierarchical transmission

(a) The strongest hierarchy layer should be able to be demodulated and decoded alone.
Reason: to be able to demodulate and decode, PCR and minimum required PSI should be transmitted by strongest layer. (see Fig. 2-4)

(b) Transmission delay difference between hierarchy should be compensated at the transmission side. The compensated transport stream is called "Multi-frame pattern". The image of Multi-frame pattern is shown in Fig. 2-5 later.

(c) Multi-frame pattern should be completed within 1 OFDM frame.

(d) The number of packet in 1 segment should be integer in any combination of transmission parameter and coding rate.
Reason: minimum unit of hierarchical transmission is the segment.

(e) Even though the information transmission speed is different because of its transmission parameter, the clock rate of TS at the output of receiver RS decoder should be constant (for TV, clock rate is 4fs). To adjust the clock rate, Null packets are inserted. See details in fig. 2-6 later.
Fig. 2-4 Concept of hierarchical transmission
(strongest layer should be recovered alone)

Transmit TSP (RS input)

A-1 B-1 B-2 A-2 B-3 B-4 A-3 B-5 B-6 A-4 B-7

Received TSP (RS output)

A-1 X X X A-2 X X X X X A-3 X X X X X A-4

The B layer packets are interfered and broken

Recovered TSP’s

A-1 ... A-2 ... A-3 ... A-4 ...

TSP’s of layer A should include PCR and minimum required PSI which are necessary to recover TSP

As shown above, Transmission delay of each layer is different according to each layer transmission parameter set. As a result, because of its transmission parameter set. Therefore, order of TSP of receiver side is different from transmitter side.

Fig. 2-5 Concept of hierarchical transmission (delay adjustment of each layers)

Transmit TS

A-1 B-1 B-2 A-2 B-3 B-4 A-3 B-5 B-6 A-4 B-7

Transmission in layer A

A-1 A-2 A-3 A-4

Received layer A TS

A-1 A-2 A-3

Transmission in layer B

B-1 B-2 B-3 B-4 B-5 B-6 B-7

Received layer B TS

B-1 B-2 B-3 B-4 B-5 B-6

Layer A + layer B order is different from transmission side (operation of S1 in Fig.2-7)

As shown above, Transmission delay of each layer is different according to each layer transmission parameter set. As a result, because of its transmission parameter set. Therefore, order of TSP of receiver side is different from transmitter side.

Fig. 2-6 Concept of hierarchical transmission
(How to adjust constant clock rate)

Transmit TS

A-1 null null A-2 null null A-3 null null A-4 null null

(RS coder input)

Null packets are not transmitted

transmission

A-1 A-2 A-3 A-4

Received TS

A-1 null null A-2 null null A-3 null null

(RS decoder output)

Packet output timing

A-1 null null A-2 null null A-3 null null

(operation of S2 in Fig.2-7)

At the output portion of receiver RS decoder, TS is read by same clock rate of transmit TS (for TV, clock rate is 4fs). At the timing of head packet, packet does Not decoded yet, in this case, RS decoder feeds null packet. If decoded, RS decoder feeds decoded packet.
2.3 Segment construction and hierarchical transmission

Segment of ISDB-T is the concept for hierarchical transmission. The segment is decided as follows considering the rule shown in clause 2.2:

1. Number of TSP in one OFDM frame is integer for all cases of transmission parameter set. Number of TSP is shown in Table 2-1.
2. For easy tuning operation of receiver, bandwidth of 1 segment is set to 6/14 MHz.
3. Number of multi-frame pattern is proportional to number of set of hierarchy. For this reason, number of hierarchy is limited as many as 3.

### Table 2-1 Number of TSP in one OFDM frame

<table>
<thead>
<tr>
<th>Coding Rate</th>
<th>1/2</th>
<th>2/3</th>
<th>3/4</th>
<th>5/6</th>
<th>7/8</th>
</tr>
</thead>
<tbody>
<tr>
<td>DQPSK/QPSK</td>
<td>12</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>16QAM</td>
<td>24</td>
<td>32</td>
<td>36</td>
<td>40</td>
<td>42</td>
</tr>
<tr>
<td>64QAM</td>
<td>36</td>
<td>48</td>
<td>54</td>
<td>60</td>
<td>63</td>
</tr>
</tbody>
</table>

(note 1) number of TSP/segment

(note 2) in case of mode 2, number of TSP is twice, and in case of mode 3, four times.

### 3. Channel coding

Relating clause of ARIB standard; B31 clause 3.3 – clause 3.11
Energy Dispersal

Energy dispersal is conducted at each hierarchical layer using a circuit, shown in Fig. 3-8, that is generated by a PRBS (Pseudo Random Bit Sequence). All signals other than the synchronization byte in each of the transmission TSPs at different hierarchical layers are EXCLUSIVE ORed using PRBSs, on a bit-by-bit basis.

\[ g(x) = x^{15} + x^{14} + 1 \]

PRBS-Generating Polynomial and Circuit (B31, Fig. 3-8)
**Puncturing Pattern**

- **Data Input (1 bit)**
  - Convolutional Coding (K=7)
  - **Puncure**
  - **Output (x bits)**

<table>
<thead>
<tr>
<th>Coding Rate</th>
<th>Number of Input Bits</th>
<th>Number of Output Bits</th>
<th>Puncturing Pattern</th>
<th>Output of Puncturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>1</td>
<td>2</td>
<td>X:1, Y:1</td>
<td>X1, Y1</td>
</tr>
<tr>
<td>2/3</td>
<td>2</td>
<td>4</td>
<td>X: 10, Y: 11</td>
<td>X1, Y1, Y2</td>
</tr>
<tr>
<td>3/4</td>
<td>3</td>
<td>6</td>
<td>X: 101, Y: 110</td>
<td>X1, Y1, Y2, Y3</td>
</tr>
<tr>
<td>5/6</td>
<td>5</td>
<td>10</td>
<td>X: 100101, Y: 111010</td>
<td>X1, Y1, Y2, Y3, Y4, Y5, Y6, Y7</td>
</tr>
<tr>
<td>7/8</td>
<td>7</td>
<td>14</td>
<td>Y: 1000101, Y: 111010</td>
<td>(8)</td>
</tr>
</tbody>
</table>

---

**Example of input C/N vs BER characteristics**

- **Mode:** 1, GI=1/8, 64QAM, I=0, RS: OFF
- **FEC**
  - FEC=7/8
  - FEC=5/6
  - FEC=3/4

---

**Effect of interleave**

- Interleave is one of important technology in transmission system.
- Error correction system is most effective when the characteristics of noise is random.
- The purpose of interleave is to randomize the burst error occurred in transmission path.

- **Burst error:** FEC does not work well
- **Random error:** FEC works well

- **Transmitter before interleave**
- **Transmitter after interleave**
- **Burst error occurs at transmission path**

- **Receiver before de-interleave**
- **Receiver after de-interleave**

---

**Kind of interleave and these effect**

- **RS coder**
- **Byte interleave**
- **Convolutional coding**
- **Bit interleave**
- **Mapping**
- **Time interleave**
- **Frequency interleave**

- **Byte interleave**
  - Byte interleave is located between outer coder and inner coder. Randomize the burst error of Viterbi decoder output

- **Bit interleave**
  - Bit interleave is located between convolutional coding and mapping. Randomize the symbol error before Viterbi decoding

- **Time interleave**
  - Time interleave is located at the output of mapping(modulation). And randomize the burst error of time domain which is mainly caused by impulse noise, fading of mobile reception, etc.

- **Frequency interleave**
  - Frequency interleave is located at the output of time interleave. Randomize the burst error of frequency domain which is mainly caused by multi-path, carrier interference, etc.
Byte interleave

The 204-byte transmission TSP, which is error-protected by means of RS code and energy-dispersed, undergoes convolutional byte interleaving. Interleaving must be 12 bytes in depth. Note, however, that the byte next to the synchronization byte must pass through a reference path that causes no delay.

Switching between paths every byte

FIFO shift register

Relation between OFDM frame and interleave

Frequency interleave

Effect of time interleave

Without bit interleave; burst error

With bit interleave; errors are randomized

Bit interleave (B31, clause 3.9.3)

Bit interleave circuit is different according to carrier modulation. Following diagram is an example of 16QAM.

Without bit interleave; burst error

With bit interleave; errors are randomized

40 carriers

40 carriers

Effect of time interleave

(with time interleave)

Transmitter side

Receiver side

Error symbol

Frequency

Transmitting delay

Receiving delay

Field strength varied

Error randomized

Burst error

Transmitting side

Receiving side (After de-interleave)
3-2. What is the merit of Time-Interleave? (2/2)

**How much improved by using Time-Interleave**

Following graph shows degradation by impulse noise, which is dedicated by Mackenzie Presbyterian University measured in Autumn 2005.

![Graph showing degradation by impulse noise](image)

- ATSC Latest Generation - 19.39Mbps-8 VSB 2/3
- ATSC Previous Generation - 19.39Mbps-8 VSB 2/3
- DVB Latest Generation - 19.3Mbps-64QAM 8k 3/4 1/16
- DVB Previous Generation - 19.3Mbps-64QAM 8k 3/4 1/16
- ISDB Latest Generation - 19.3Mbps - 64QAM 8k 3/4 1/16
- ISDB Previous Generation - 19.3Mbps - 64QAM 8k 3/4 1/16

(7dB improved)

Switched every IFFT sample clock

**Time interleaver block diagram (B31, 3.11.1)**

Provided that \( m_i = (i \times 5) \mod 96 \)

\( n_c \) is 96, 192, and 384 in modes 1, 2, and 3, respectively.

**Table 3-12: Time Interleaving Lengths and Delay Adjustment Values**

<table>
<thead>
<tr>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (I)</td>
<td>Number of delayed frames in transmission and reception</td>
<td>Number of delayed frames in transmission and reception</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>56</td>
<td>28</td>
</tr>
<tr>
<td>16</td>
<td>112</td>
<td>56</td>
</tr>
</tbody>
</table>

(Notice: 109)
Frequency characteristics distortion caused by multi-path

This drawing shows the effect of multi-path. As shown, received signal level is varied in frequency domain.

Frequency characteristics distortion caused by multi-path

Envelope of combined wave

Reciprocal of delay time

Multi-path

Direct path

In-band

Received signal

Vector diagram

Effect of frequency interleave

As shown above, function of frequency interleave is to disperse the error caused by multi-path.

The input signal must be 2 bits per symbol and QPSK-mapped to output multi-bit I- and Q-axes data. To conduct mapping, the 120-bit delay element shown in Fig. 3-14 is inserted into the mapping input for bit interleaving.

Figs. 3-14 and 3-15 show the system diagram and mapping constellation, respectively.

Mapping
The input signal must be 4 bits per symbol and 16QAM-mapped to output multi-bit I- and Q-axes data. To conduct mapping, the delay elements shown in Fig. 3-16 are inserted into b1 to b3 for bit interleaving. Figs. 3-16 and 3-17 show the system diagram and mapping constellation, respectively.

Fig. 3-16: 16QAM Modulation System Diagram

Fig. 3-17: 16QAM Constellation

Input C/N vs BER characteristics

Mode; 1, GI=1/8 FEC=3/4, RS=OFF

4. OFDM modulation

(1) IFFT
(2) Pilot signal
(3) AC
(4) TMCC
(5) Guard interval
(6) Quad. Modulation and RF format

Note: these data are simulation data at early stage, but recently, receiver LSI shows more good data.
Blockdiagram of ISDB-T Transmission coding

These functions are presented in this section

Nyquist separation and orthogonal FDM

Fourier transform and inverse FFT

Orthogonal division multiplex

At the adjacent carrier position, all other carrier energy is zero.

OFDM signal generation by IFFT

Symbol length = \( T \)

Sample point

\( x \): Sample point to generate sine wave of \( f=1/T \) cycle

\( o \): Sample point to generate sine wave of \( f=2/T \) cycle
Example of OFDM signal waveform

TV signal spectrum

OFDM frame structure (DQPSK, mode 1)

OFDM frame structure (QPSK, 16QAM, 64QAM, mode 1)
**Frequency characteristics distortion caused by multi-path**

This drawing shows the effect of multi-path. As shown, received signal level is varied in frequency domain.

**Effect of scattered pilot (SP) signal**

Scattered pilot (SP) is used to compensate the frequency distortion caused by multi-path.

**Example of AC, TMCC (mode 1, QPSK, 16QAM, 64QAM)**

(a) AC and TMCC Carrier Arrangements in Mode 1

<table>
<thead>
<tr>
<th>Segment No.</th>
<th>11</th>
<th>9</th>
<th>7</th>
<th>5</th>
<th>3</th>
<th>1</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL_1</td>
<td>10</td>
<td>53</td>
<td>61</td>
<td>11</td>
<td>20</td>
<td>74</td>
<td>35</td>
<td>76</td>
<td>4</td>
<td>40</td>
<td>8</td>
<td>7</td>
<td>98</td>
</tr>
<tr>
<td>ACL_2</td>
<td>28</td>
<td>83</td>
<td>100</td>
<td>101</td>
<td>40</td>
<td>100</td>
<td>79</td>
<td>97</td>
<td>89</td>
<td>89</td>
<td>64</td>
<td>89</td>
<td>101</td>
</tr>
<tr>
<td>TMCC</td>
<td>70</td>
<td>25</td>
<td>17</td>
<td>86</td>
<td>44</td>
<td>47</td>
<td>49</td>
<td>31</td>
<td>83</td>
<td>61</td>
<td>85</td>
<td>101</td>
<td>23</td>
</tr>
</tbody>
</table>

**What is AC?**

AC; (Auxiliary Channel)
AC is a channel designed to convey additional information on modulating signal-transmission control.
AC’s additional information is transmitted by modulating the pilot carrier of a type similar to CP through DBPSK. The reference for differential modulation is provided at the first frame symbol, and takes the signal point that corresponds to the Wi value stipulated in Section 3.13.1.

- Details of AC is specified in ARIB STD-B31 reference
- Recently, new utilization of AC has been proposed, that is, the transmission network management information can be carried to relay station by using AC. Details will be explained in seminar #9

In DVB-T system, CP is inserted for carrier synchronization instead of AC, but CP cannot carry any information. This is the feature of AC.
The TMCC signal is used to convey information on how the receiver is to perform demodulation of information such as the hierarchical configuration and the OFDM-segment transmission parameters.

### Table 3-20: Bit Assignment

<table>
<thead>
<tr>
<th>Bit Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_1$ - $B_{10}$</td>
<td>Reference for differential demodulation</td>
</tr>
<tr>
<td>$B_{11}$ - $B_{16}$</td>
<td>Synchronizing signal (w0 = 0011010111101110, w1 = 110010000010001)</td>
</tr>
<tr>
<td>$B_{17}$ - $B_{18}$</td>
<td>Segment type identification (differential: 111; synchronous: 000)</td>
</tr>
<tr>
<td>$B_{19}$ - $B_{20}$</td>
<td>TMCC information (102 bits)</td>
</tr>
<tr>
<td>$B_{21}$ - $B_{23}$</td>
<td>Parity bit</td>
</tr>
</tbody>
</table>

See details of TMCC information in 3.15.6 of ARIB STD-B31

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### Effect of guard interval

(a) Transmitted OFDM symbol

(b) GI: Guard Interval, td: delay time of multi-path

(c) FFT Window

FFT window of receiver cuts a signal with $T_s$ (effective symbol) length, this signal is fed to FFT to demodulate OFDM signal. If FFT window can be set within the interval of "transmitted OFDM symbol", Inter Symbol Interference (ICI) is not occurred. As a result, if multi-path delay time is no longer than GI, multi-path interference is almost compensated.

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### Performances under multi-path condition

The following graph shows degradation by single multi-path, which is dedicated by Mackenzie Presbyterian University measured in Autumn, 2005.

- **ATSC Latest Generation**: 19.39M bps, 8VSB 2/3
- **ATSC Previous Generation**: 19.39M bps, 8VSB 2/3
- **DVB-T Latest Generation**: 19.76M bps, 64QAM 8k 3/4 1/16
- **DVB-T Previous Generation**: 19.76M bps, 64QAM 8k 3/4 1/16
- **ISDB-T Latest Generation**: 19.3M bps, 64QAM 8k 3/4 1/16
- **ISDB-T Previous Generation**: 19.3M bps, 64QAM 8k 3/4 1/16

As shown above, within guard interval length (+/- 63 us), ISDB-T work well almost 0dB D/U ratio. In addition, newest ISDB-T demodulator LSI adopt adaptive compensation technology, so, widen the low D/U area up to 250us.
5. ISDB-T<sub>SB</sub> transmission system

1. Outline of ISDB-T<sub>SB</sub> transmission system

2. Consecutive transmission system

3. Example of consecutive transmitter station

Relating clause of ARIB standard; B31 clause 3.12 – clause 3.15

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1. ISDB-T<sub>SB</sub> transmission system

(1) What is ISDB-T<sub>SB</sub>

ISDB-TSB transmission system is unique in ISDB-T family. This transmission system has been standardized for narrow band ISDB-T transmission system, which is focused to audio and data service, therefore, called ISDB-TSB.

(a) Same segment transmission construction. But, considering narrow band reception, only 1 segment and 3 segment transmission systems are standardized

(b) Adopt same transmission parameters as ISDB-T.

(c) Commonality of 1 segment receiver with ISDB-T partial reception

(3) Efficient use of frequency resource

(a) Consecutive transmission system. This system is unique for ISDB-TSB, this transmission system is to transmit plural channel without guard band

(b) To achieve consecutive transmission, phase compensation technology at transmitter side is adopted

---

ISDB-T<sub>SB</sub> transmission and partial reception

![Diagram showing ISDB-T<sub>SB</sub> transmission and partial reception](image)
### Transmission parameters

<table>
<thead>
<tr>
<th>Mode</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment(s)</td>
<td>1 or 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>430kHz or 1.3MHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrier spacing</td>
<td>3.97kHz</td>
<td>1.98kHz</td>
<td>0.99kHz</td>
</tr>
<tr>
<td>Total carriers</td>
<td>109 / 325</td>
<td>217 / 649</td>
<td>433 / 1297</td>
</tr>
<tr>
<td>Data carriers</td>
<td>96 / 288</td>
<td>192 / 576</td>
<td>384 / 1152</td>
</tr>
<tr>
<td>TMCC, AC, CP, SP carriers</td>
<td>13 / 37</td>
<td>25 / 73</td>
<td>49 / 145</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM, DQPSK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Transmission parameters (continued)

<table>
<thead>
<tr>
<th>Mode</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol duration</td>
<td>252μs</td>
<td>504μs</td>
<td>1.008ms</td>
</tr>
<tr>
<td>Guard interval</td>
<td>1/4 ~ 1/32 of symbol duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbols/frame</td>
<td></td>
<td></td>
<td>204</td>
</tr>
<tr>
<td>Frame duration</td>
<td>53 ~ 64ms</td>
<td>106 ~ 129ms</td>
<td>212 ~ 257ms</td>
</tr>
<tr>
<td>Inner code</td>
<td>Convolutional code (1/2, 2/3, 3/4, 5/6, 7/8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outer code</td>
<td>(204,188) RS code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interleaving</td>
<td>Time and Frequency</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Example of information bit-rate (TS rate)

<table>
<thead>
<tr>
<th></th>
<th>1segment</th>
<th>3segment</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK, r=1/2, Tg=1/4</td>
<td>280kbps</td>
<td>0.84Mbps</td>
<td>Minimum rate</td>
</tr>
<tr>
<td>QPSK, r=1/2, Tg=1/16</td>
<td>330kbps</td>
<td>0.99Mbps</td>
<td></td>
</tr>
<tr>
<td>QPSK, r=2/3, Tg=1/16</td>
<td>440kbps</td>
<td>1.32Mbps</td>
<td></td>
</tr>
<tr>
<td>16QAM, r=1/2, Tg=1/16</td>
<td>660kbps</td>
<td>1.98Mbps</td>
<td></td>
</tr>
<tr>
<td>64QAM, r=7/8, Tg=1/32</td>
<td>1.87Mbps</td>
<td>5.20Mbps</td>
<td>Maximum rate</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>430kbps</td>
<td>1.3Mbps</td>
<td></td>
</tr>
</tbody>
</table>

The information bit rates do not depend on transmission mode 1, 2 or 3. They depend on modulation, coding rate and guard interval.

### Spectrum utilization (1)

Broadcasting frequency bands are looked upon as a sequence of segments, which have a bandwidth of one fourteenth of a TV channel.

BST-OFDM scheme provides followings.

- DTV uses 13 segments, remaining one: guard band,
- DSB uses 1 or 3 segments
- 1-segment reception of 13 segment-TV signal by DSB receiver
- Consecutive-segment transmission without guard bands
- Systematic frequency re-packing towards total digital age
Frequency allocation of consecutive transmission

Concept of sub-channel

Sub-channel bandwidth = 1/7 MHz

Allocation of sub-channel

1/7 MHz

3/7 MHz

guard band

guard band

ISDB-TSB allocation with guard band

ISDB-TSB allocation for consecutive transmission

Spectrum utilization (2)

Consecutive-segment Transmission of DSB channels

Transmission from single transmitter keeping OFDM-condition

Conventional allocation

Example of allocation

Frequency utilization efficiency will be improved up to 150%.

Image of consecutive transmission and reception

Why is the phase compensation of segment necessary for consecutive transmission?

Center of IFFT

Center of FFT

Frequency allocation for 5 one segment channel consecutive transmission

Select channel D at receiver side

The center of IFFT and FFT is different, as a result, each carrier of received OFDM signal rotate during Guard interval period. (see next page)

This phase rotation is compensated at the transmitter side.
During guard interval ($T_g$) period, phase rotation ($=2*N*\pi*T_g/TS$) occurs. Consequently, each carrier seems to rotate in every symbol period.

Phase rotation in every symbol

- $F = 4/T_s$: Rotate $2\pi$ in every symbol
- $F = 3/T_s$: Rotate $3\pi/2$ in every symbol
- $F = 2/T_s$: Rotate $\pi$ in every symbol
- $F = 1/T_s$: Rotate $\pi/2$ in every symbol

Relationship between IFFT and FFT for consecutive transmission

<table>
<thead>
<tr>
<th>Frequency slot No.</th>
<th>Center of FFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F = (4N+2)/Ts$</td>
<td>$F = 2/T_s$</td>
</tr>
<tr>
<td>$F = (4N+1)/Ts$</td>
<td>$F = 1/T_s$</td>
</tr>
<tr>
<td>$F = 0$</td>
<td>$F = 0$</td>
</tr>
<tr>
<td>$F = -1/T_s$</td>
<td>$F = 1/T_s$</td>
</tr>
<tr>
<td>$F = -2/T_s$</td>
<td>$F = 2/T_s$</td>
</tr>
<tr>
<td>$F = -(4N+1)/Ts$</td>
<td>$F = (4N+1)/Ts$</td>
</tr>
</tbody>
</table>

(note) $F = 0$ means the frequency which is the center of FFT and IFFT

Phase of Each carrier in consecutive transmission

- Center frequency of FFT
- Center frequency of IFFT
- Frequency slot No.
- Frequency slot No.
- After phase compensation
- Phase of each carrier at the front end of guard interval
- Center frequency of FFT
- Receiver side
- Transmitter side

Example of phase compensation

- $F = (4N+2)/Ts$
- $T_g = (1/4)*Ts$

- Without phase compensation
- With phase compensation

In this example, center frequency of FFT is equal to $F = (4N+2)/Ts$ of IFFT. Therefore, if $T_g$ is equal to $(1/4)*Ts$, at the front end of every symbol rotate $\pi$.

In case of consecutive transmission, center frequency of IFFT and FFT is different. Therefore, during guard interval, each carrier phase rotate according to above figure. To avoid such phase rotation at receiver FFT, phase compensation is done at transmitter side.
Phase compensation in every symbol

<table>
<thead>
<tr>
<th>GI</th>
<th>1 segment</th>
<th>3 segment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mode 1</td>
<td>mode 2</td>
</tr>
<tr>
<td>1/32</td>
<td>-3/8</td>
<td>-3/4</td>
</tr>
<tr>
<td>1/16</td>
<td>-3/4</td>
<td>-1/2</td>
</tr>
<tr>
<td>1/8</td>
<td>-1/2</td>
<td>0</td>
</tr>
<tr>
<td>1/4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Upper adjacent channel format

<table>
<thead>
<tr>
<th>GI</th>
<th>1 segment</th>
<th>3 segment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mode 1</td>
<td>mode 2</td>
</tr>
<tr>
<td>1/32</td>
<td>-6/8</td>
<td>-2/4</td>
</tr>
<tr>
<td>1/16</td>
<td>-2/4</td>
<td>0</td>
</tr>
<tr>
<td>1/8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1/4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Number of segment of received channel

Details of ISDB-TSB transmitter block diagram

After RE-MUX, frame and clock of each channel are synchronized

END of Seminar #3

Thank you for your attention