Abstract-- We have been conducting research on an advanced digital terrestrial TV broadcasting system (advanced ISDB-T) that can transmit 4K/8K UHDTV content. The advanced ISDB-T has the segmented structure similar to ISDB-T. Therefore, advanced ISDB-T can provide both mobile reception service and fixed reception service using hierarchical transmission by frequency division multiplexing (FDM). Furthermore, the transmission capacity is increased by using a large-sized fast Fourier transform (FFT). Although large-sized FFT degrades speed tolerance in mobile reception, the advanced ISDB-T can mitigate this influence by selecting an appropriate scattered pilot (SP) pattern. In this paper, we analyze the influence of large-size FFT in mobile reception and evaluate the reception performance caused by differences in SP patterns through computer simulation and field experiments.

I. INTRODUCTION

We have been conducting research on an advanced digital terrestrial TV broadcasting system (advanced ISDB-T) that can improve frequency usage efficiency compared to Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) [1]-[3].

The advanced ISDB-T inherits the segmented structure of ISDB-T, which follows a hierarchical transmission. The transmission capacity is increased by using large-size fast Fourier transform (FFT). However, large-sized FFT degrades speed tolerance in mobile reception [4]-[6].

Further, the advanced ISDB-T has several transmission parameters such as coding rate and modulation scheme, and therefore, a flexible transmission parameter can be selected according to the requirements. Although ISDB-T uses only one type of scattered pilot (SP) pattern for channel estimation, the advanced ISDB-T has several types of these SP patterns.

In this paper, we analyze the influence of large-sized FFT in mobile reception and evaluate the difference in reception performance caused by different SP patterns through computer simulations and field experiments.

II. FEATURES OF THE ADVANCED ISDB-T

The segment structure of ISDB-T and advanced ISDB-T is shown in Fig. 1. In ISDB-T, the transmission bandwidth in one channel is divided into 13 segments; the central segment is used for mobile services, and the other 12 segments are used for fixed service. In the advanced ISDB-T, the transmission bandwidth in one channel is divided into 35 segments; the central 9 segments are called “partial reception bandwidth.”

The number of segments for mobile services in the partial reception bandwidth can be selected up to the 9 segments (a narrowband receiver can receive only 9 segments for partial reception).

To increase the transmission capacity, transmission parameters such as occupied bandwidth, modulation scheme, FFT size of the advanced ISDB-T were modified from those of ISDB-T. The FFT size can be selected up to 32k (32768) points, which is four times larger than that for 8k (8192) points operated by ISDB-T. The increase in the FFT size leads to an increase in the OFDM symbol length. Thus, when the guard interval length is set as constant, the transmission capacity increase owing to a decrease in the guard interval ratio in the entire transmission symbol length. Meanwhile, the carrier spacing is narrowed, which causes multiple doppler shifts in the mobile reception that deteriorates the reception.

The SP pattern can be selected among several patterns based on FFT size and guard interval length. An example of SP pattern is shown in Fig. 2. In this paper, the SP pattern is represented by Dx and Dy, where they denote the spacings in the frequency and time directions of SP, respectively. The SP pattern of ISDB-T is (Dx=3, Dy=4).

As an example of the SP pattern in the advanced ISDB-T, the mobile service can be used (Dx=6, Dy=2). The SP insertion ratio in the time direction is increased compared to that in ISDB-T. The fixed service is used (Dx=6, Dy=4). The SP insertion ratio is reduced compared to ISDB-T.

As a result, the tracking ability for the time fluctuation can be improved in the mobile reception layer, and the transmission capacity can be increased in the fixed reception layer. Therefore, it is possible to use different SP patterns for the mobile reception and fixed reception layers in the advanced ISDB-T.
III. EVALUATIONS OF SP PATTERN FOR MOBILE RECEPTION

A. Computer Simulation

The reception performance of the advanced ISDB-T with a different SP pattern was evaluated through computer simulation. Table I summarizes the simulation parameters; the transmission parameters for mobile reception are shown. In this simulation, the required carrier-to-noise ratio (C/N) of the transmission parameter is 3 dB higher than that of the 1 segment service of ISDB-T (QPSK R=2/3) in a white Gaussian noise environment. The common SP pattern is used for mobile reception and fixed reception. The TU6 model [7] is used as the propagation model for mobile reception. The required C/N is defined as the C/N to achieve a bit error rate (BER) = $1.0 \times 10^{-7}$ after low density parity check code (LDPC) decoding.

Prior to the evaluation of the SP pattern, the influence of the expansion of the FFT size on the mobile reception is evaluated. 8k FFT and 16k FFT are compared using (Dx=6, Dy=4) of the SP pattern. The results of the simulation are shown in Fig. 3, which illustrates the relationship between the required C/N and the moving speed at a transmission radio frequency (RF) of 605 MHz. The figure shows that when the FFT size is doubled, the upper limit of the allowable moving speed is halved. When the FFT size is doubled, the symbol length is doubled, and the influence of the channel fluctuation in the symbol is also doubled.

To enhance the speed tolerance in the 16k FFT, the accuracy of channel estimation needs to improve by increasing the SP in the symbol direction. Fig. 4 shows the result of the comparison of the three types of SP patterns (Dx=6, Dy=1), (Dx=6, Dy=2), and (Dx=6, Dy=4) using 16k FFT; in the case of R = 7/16, the transmission capacities are 1.34 Mbps, 1.48 Mbps, and 1.55 Mbps, respectively. As the insertion of SP decreases, the transmission capacity increases.

The difference in Dy indicates that the number of symbols used for channel estimation (equalization symbol length) is different. First, the SP signal of 7 symbols for Dy=4, 3 symbols for Dy=2, and 1 symbol for Dy=1 are used in the receiver. Next, linear interpolation is performed in the symbol direction; channel estimation is estimated at Dx intervals in the carrier direction. Finally, channel estimation with FIR filter is performed in the carrier direction. Fig. 4 shows that the deterioration of the required C/N with the high moving speed is small when the Dy is small. Further, when Dy is small, the equalization symbol length is short, and therefore, the channel estimation error decreases in the time-dependent channel.

B. Field Experiments

To evaluate the mobile reception characteristics due to differences in the SP pattern, Field experiments are conducted using the Higashiyama experimental station in Nagoya city. The radio waves from the experimental station were received while moving by the measurement vehicle. The transmission parameters are listed in Table II. In this experiment, 16k FFT is used, and (Dx=6, Dy=2) and (Dx=6, Dy=4) are used as the
TABLE II
SPECIFICATIONS OF EXPERIMENTAL STATION

<table>
<thead>
<tr>
<th></th>
<th>UHF 35ch (605.142857 MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx channel (Center frequency)</td>
<td>UHF 35ch (605.142857 MHz)</td>
</tr>
<tr>
<td>Tx power</td>
<td>1.0 kW</td>
</tr>
<tr>
<td>Polarization</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Tx antenna height</td>
<td>203 m above sea level</td>
</tr>
</tbody>
</table>

SP patterns. Other transmission parameters are the same as listed in Table I.

The measurement route is shown in Fig. 5. The measurement route was selected from the place where the calculated value of the field strength is greater than 60 dBμV/m which is a contour for fixed reception service area. The driving distance is about 350 km including the highway.

The reception system diagram for the receivers installed on the measurement vehicle is shown Fig. 6. Omnidirectional antennas were used as the receiving antenna. The packet error rate (PER) per second was recorded using the transport stream packet (TSP), which are output signals from the receiver. Furthermore, information on the location and speed of the measurement vehicle obtained from GPS and the reception field strength are recorded simultaneously. Using two receivers, these measurement items for 1 branch and 4 branches were recorded simultaneously. The samples of the case wherein the measurement vehicle was stationary, such as when it stopped at traffic lights, were excluded from the measurement data. The total number of effective samples were about 33,600.

The correct reception rate for field strength was calculated, using samples containing no packets with errors (PER = 0.0) as correct reception samples.

The correct reception rate was the rate when the total number of samples for each reception field strength was the denominator, and the number of correct reception samples containing the denominator was the numerator. The required field strength is set to achieve the correct reception rate of 95%.

Reception field strength and correct reception rate results for each transmission parameter are shown in Fig. 7. From the figure, in the case of 1 branch reception, the required field strength using (Dx=6, Dy=2) is 53.8 dBμV/m. However, the required field strength using (Dx=6, Dy=4) does not achieve the correct reception rate of 95%. On the other hand, in the case of 1 branch reception, the required field strength is 45.0 dBμV/m for both SP patterns.

To analyze the performance of the 1 branch reception, Fig. 8 shows the results of the correct reception rate for each moving speed and field strength (color-coded). In (Dx=6, Dy=4), when the speed exceeds about 40 km/h, the correct reception rate decreases regardless of the field strength. This tendency is equivalent to the simulation result shown in Fig. 4.

Next, we analyzed the correct reception position. The measurement route is divided every 25 m, and the sections where correct reception was possible is calculated. Sections that contain error packets are defined as reception fail. Fig. 9 shows the comparison of the sections where correct reception was possible in the 1 branch reception. The difference in the reception availability of the two SP patterns is remarkable in
the circled section (the section of the highway) in Fig. 9.

Fig. 10 shows the comparison of the sections where correct reception was possible in the 4 branches reception. There were no significant differences in reception due to differences in SP pattern. In the contour for fixed reception service area, the correct reception was confirmed in both cases.

Table III summarizes the results of calculating the coverage of the sections where correct reception was possible. The transmission capacity of (Dx=6, Dy=2) is reduced to 4.5% compared with (Dx=6, Dy=4). However, the coverage of the sections where reception was possible is doubled in the case of the 1 branch reception. In the 4-branches reception, the coverage of the sections where reception was possible is equal. From above, in the mobile reception, the transmission capacity decreases by increasing the SP in the symbol direction; however, the channel estimation improves and the speed tolerance of the transmission also improves. In addition, for a 4 branches reception, there was no difference in reception because of the difference in SP pattern, and correct reception was possible over the entire area in this experiment.

![Fig.9 Comparison of the sections where correct reception was possible in 1 branch reception](image1)

![Fig.10 Comparison of the sections where correct reception was possible in 4 branches reception](image2)

### IV. Conclusion

Mobile reception performance using different SP patterns in the advanced ISDB-T were evaluated through computer simulation and field experiment. In the computer simulation, the upper limit of moving speed was greatly improved by increasing the SP insertion ratio in the symbol direction.

In the field experiment, measurements were conducted comparing (Dx=6, Dy=2) and (Dx=6, Dy=4) in highways and urban areas. In 1-branch reception, selecting (Dx=6, Dy=2) improved the speed tolerance and greatly improved the correct reception rate compared to (Dx=6, Dy=4). Speed tolerance has the same tendency as the computer simulation. In the case of 4 branches reception, it was received almost well regardless of SP pattern in the whole area.

However, the select of SP pattern need to be determined considering the cost of the receiver.

### ACKNOWLEDGMENT

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### REFERENCES


[7] Digital cellular telecommunications system (Phase2+); Radio transmission and reception (GSM 05.05 version 8.5.1 Release 1999)”, ETSI EN 300 910 V8.5.1, 2000.