Experimental Analysis of the Relation between Time Diversity and Spatial Diversity in Mobile Performance of DTV Receivers

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***Resumo*—A televisão digital terrestre permite o oferecimento de serviços móveis. O emprego de diversidade espacial, ou seja, a recepção com mais de uma antena, é uma das propostas para melhorar o desempenho da recepção nestas condições desafiadoras. Este trabalho, apresenta os resultados de experimentos de campo e de laboratório que investigam a relação entre diversidade espacial e diversidade temporal, na forma de entrelaçamento temporal empregado no ISDB-T. Os resultados obtidos confirmam a efetividade do uso de diversidade espacial para melhorar o desempenho da recepção móvel e, provêem dados úteis à comparação de desempenho entre receptores que empregam diversidade no padrão ISDB-T e com implementação similar ao DVB-T.**

***Palavras-Chave*—Televisão Digital, DVB-T, ISDB-T, diversidade espacial e entrelaçamento temporal.**

***Abstract*—Mobile and portable reception are two new target services for digital terrestrial television. Spatial diversity reception is one of the proposed strategies to improve digital terrestrial broadcasting services in such severe multipath environments. This paper presents the results of laboratory and field trials, which investigate the relation between spatial diversity and time diversity (time interleaving). The obtained results confirm the effectiveness of spatial diversity for improving mobile reception and provide useful data for comparing the performance of ISDB-T and "DVB-like" diversities receivers.**

***Index Terms*—Digital Television, DVB-T, ISDB-T, spatial diversity, time interleaving.**

1. INTRODUCTION

Propagation characteristics of mobile environments are significantly degraded when compared to the fixed reception performance. Spatial diversity reception is one of the proposed strategies to improve digital terrestrial broadcasting reception for these new services.

Space diversity is a technique that selects and combines signals received by different antennas. Particularly, in wide-band mobile reception where the transmission bandwidth exceeds 1MHz, propagation characteristics can be severely degraded not only due to the variations in received signal level arriving over multiple paths, but also due to selective fading, manifested as a distortion of the bandwidth frequencies characteristics. Proper combination of input signals yields a resultant signal with greatly reduced severity of fading and correspondingly improved reliability of reception, by increasing the probability of receiving a useful signal.

The OFDM diversity receiver used in this test is a 2-branch diversity receiver in which the input signal is combined after the FFT processing. The diversity processing essentially involves using orthogonal transformation to divide signals received from the antennas into narrow sub-bands. Received signals are combined in order to maximize the carrier-to-noise ratio, using the maximum-ratio combining method as described in [1].

Another possible way to obtain similar effect is to consider sequential amplitude samples of random fading signal, sufficiently separated in time, and therefore uncorrelated with each other. Thus, the time interleaving tool implemented in ISDB-T, the Japanese digital television standard for terrestrial broadcasting, can also be seen as a diversity technique in the time domain.

The trial described in this paper aimed to evaluate the contribution of each of these techniques to improve receiver performance, bearing in mind that time diversity is a standard defined technique and spatial diversity is a merely a receiver implementation function.

2. DESCRIPTION OF THE EXPERIMENTS

The mobile reception environment was simulated using a fading simulator configured to the GSM ensemble, the propagation model used to describe typical urban propagation as described in Table 1.

The indoor test consisted of recording the required carrier-to-noise ratio as a function of the Doppler frequency. The failure criterion is a BER lower than 2×10^{-4} after Viterbi decoding and before Reed Solomon.

In the field trial, NHK transmission station was used. The transmitting station specification is listed in Table 2. The tested parameter set is presented in Table 3.

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TABLE 1
GSM CHANNEL

Path	1	2	3	4	5	6
Delay (us)	-0.2	0	0.3	1.4	2.1	4.8
Attenuation (dB)	13	10	12	16	18	20

TABLE 2
TRANSMISSION STATION

Transmission station	NHK
Frequency	509,15MHz
Antenna height	98 m
Transmitter Power	29.3 W
Antenna Gain	7.5dB
Feeder and Distribution loss	7.6dB
ERP	88.5W
Polarization	Linear Horizontal

TABLE 3
TESTED PARAMETER SETS

Number of Segments	13 segments
Mode	Mode 3
Guard Interval	1/8
Carrier Modulation	16QAM and QPSK
Coding Rate	1/2
Length of Time Interleaver	0 or 430ms

The schematic of the receiving test vehicle is shown on Figure 1. Reception test was performed using two cross-dipole antennas mounted at 1,8 meters height on the roof of the vehicle. Field strength, position and speed of the test vehicle and bit error rate, both for the diversity and the single branch receiver, were recorded simultaneously in each trial.

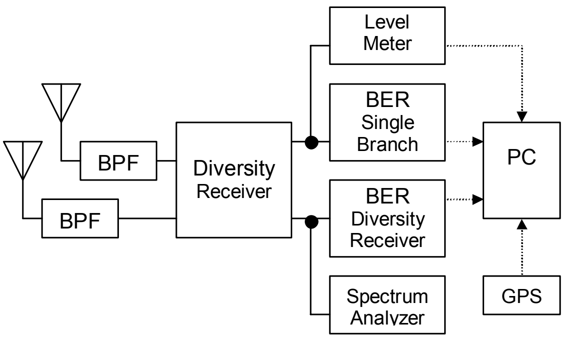


Fig. 1. Receiving block diagram

The failure criterion adopted was the absence of errors in the one-second-sample interval. The BER is measured after Reed Solomon and samples are collected at one sample per second. The failure criterion is based on the absence of errors, that is, the correct reception percentage is calculated for the data yielding error free reception, BER=0, in the one-second-sample interval.

3. MEASUREMENT COURSE DESCRIPTION

The test was conducted on a 30km measurement course and the maximum distance from the transmitter was about 8km. The average duration to complete the course was about 2 hours.

The trial was conducted on non-highway avenues in the suburban area of Tokyo. The course is general low speed with an average speed of 15 km/h. In spite of this, the maximum speed of 100km/h was registered. The selected measurement course includes Rayleigh fading environment where direct wave do not reach the receiver due to urban obstacles such as buildings.

The distribution of the receiver input voltage among nine trials is shown in Figure 2. There was no significant difference in the mean field strength level among trials. The position of the vehicle along the test route is obtained from the GPS data.

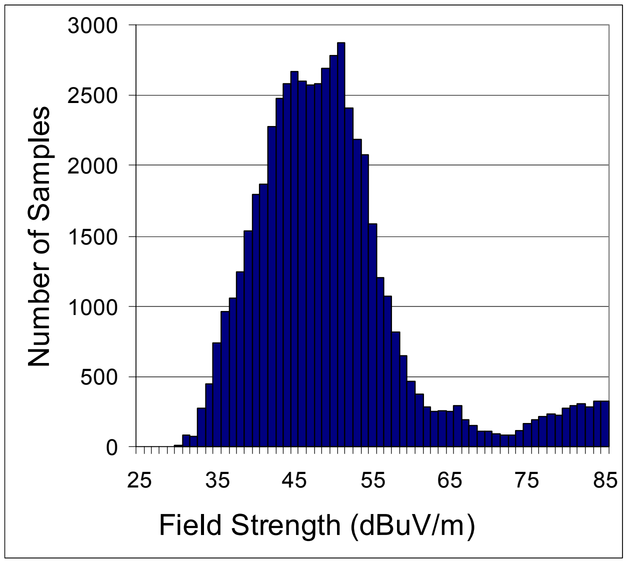


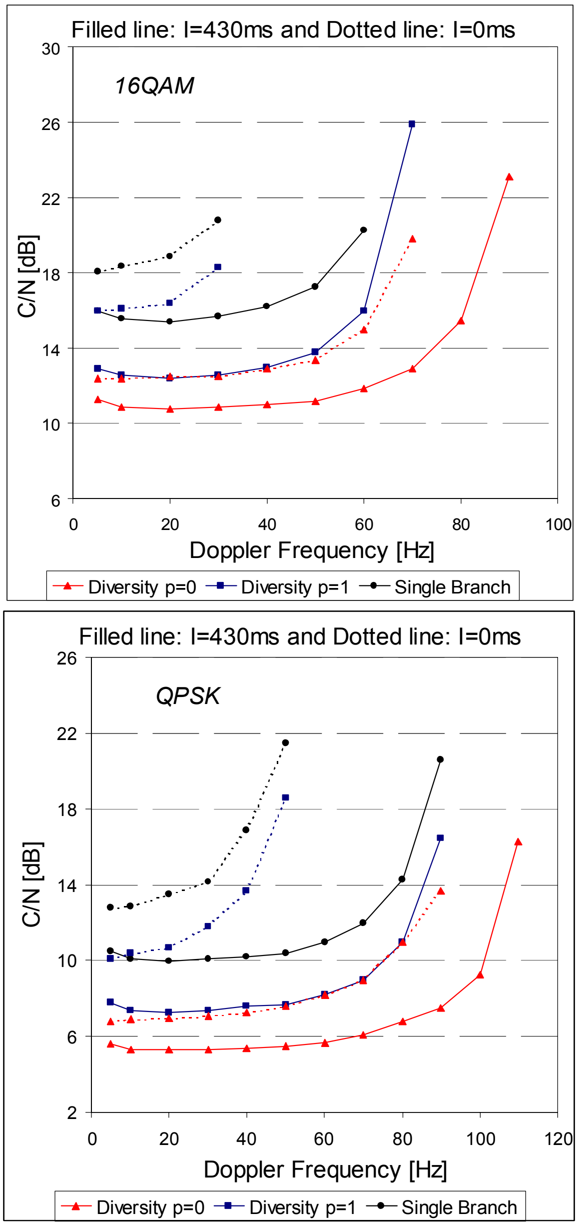
Fig. 2: Field strength distribution

4. LABORATORY TEST RESULTS

The comparative result for diversity receiver (two branches) and the single branch receiver in the indoor trial are in the graphics of Figure 3, which present results for 16QAM and QPSK respectively. The experimental data confirms [2] and quantify the performance improvements in digital television reception at high moving speeds.

Results for both, the QPSK and the 16QAM modulation system show there is a 5 dB improvement on performance when comparing the receiver with two branches to the single branch receiver.

It is a well known results that correlation coefficient is, together with mean signal level, a major parameter for estimating diversity gain [5]. Therefore presented result emphasizes not only the effect of the time interleaving according to the Doppler frequency but also the differences according to the input signal correlation [3].



Mode 3, GI=1/8, FEC=1/2 and 13 segments

Fig. 3. Indoor Results

- Analyzing the filled line and dotted line of the same color it is possible to compare the performance of the system with and without time interleaving. The length of the time interleaving is 0 or 430ms.
- Analyzing the red and black lines, either filled or dotted, it is possible to compare the performance of the system with and without spatial diversity. The 2-branch diversity and maximum-ratio combining method was selected.
- Analyzing the red and blue lines, either filled or dotted, it is possible to compare the effect of input signal correlation. The minimum correlation is ρ=0 (uncorrelated) and maximum correlation is ρ=1 (totally correlated).

It can be noted that for the single branch receiver the increase in the maximum accepted Doppler frequency by the addition of a second antenna is about 30Hz for the 16QAM parameter set and about 40Hz for the QPSK test system.

Results show that time interleaving and spatial diversity can improve mobile reception performance. Similar effect of spatial diversity is obtained by the time interleaving implemented in ISDB-T system. But best performance is obtained by associating both techniques because they complement each other.

The result of the diversity receiver at 20Hz shows a 1.7dB difference in carrier-to-noise ratio of threshold between the test system with time interleaving and without it. The same kind of comparison for a single branch receiver showed a carrier-to-noise difference of 3.5dB.

This comparison suggests that diversity and time interleaving are not independent effects. The improvement of the diversity for mobile reception is greater on a transmission without time interleaving than in a transmission using time interleaving.

In the indoor experiment, when the input signals are uncorrelated, diversity receiver without time interleaving performs better than a single branch receiver with time interleaving. This result suggests that diversity is more important than time interleaving for mobile reception where antenna spacing can be made large and, therefore, small values of correlation between input signals can be easily obtained.

However, when input signals are highly correlated, the diversity receiver without time interleaving, perform worse than a single branch receiver with time interleaving. This suggesting that time interleaving is more important than diversity for portable reception where signal correlation is normally high due to the size constrains of portable equipments.

5. FIELD TRIAL RESULTS

The field trial results for the parameter set of Table 3 and QPSK modulation are presented in Figure 4. The errors are marked in each graphic with black dots.

The qualitative comparison of these graphics clearly shows that the performance improvement of the diversity receiver measured in the indoor experiment is reflected in practical situations. This result is also in accordance to the results of reference [2].

The overall error-free reception rate for each parameter set is shown in Table 4. The values of the minimum required field strength to achieve 90% of correct reception rate are presented in Table 5.

The above results also allow a direct comparison of the single branch receiver with time interleaving (normal ISDB-T receiver) and the diversity receiver without time interleaving (diversity "DVB like" receiver).

The red arrows in Tables 4 and 5 indicate that the single branch receiver with time interleaving of 430ms has equivalent performance of the diversity receiver without time interleaving.

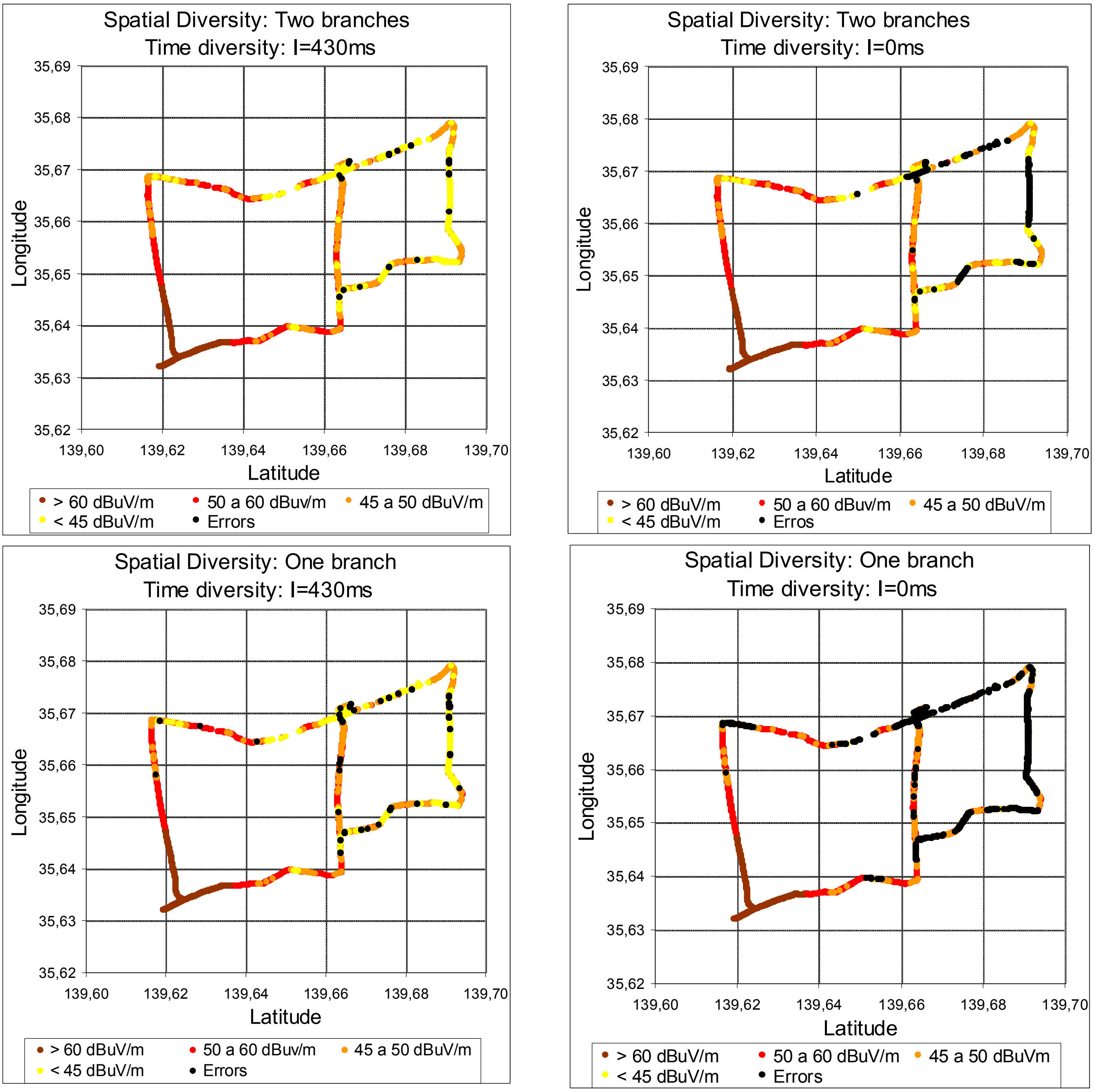


Fig. 4. Comparison of spatial diversity and time

TABLE 4
ERROR-FREE RECEPTION RATE (%)

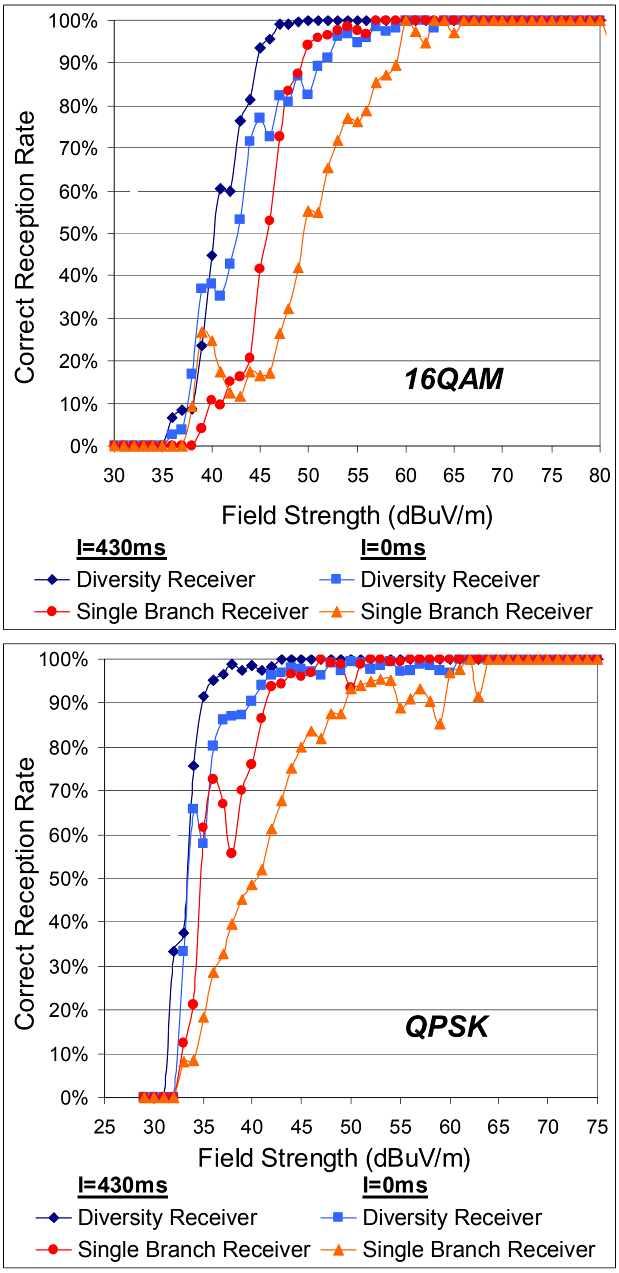
Modulation	Time Interleaving	Diversity Receiver	Single Branch Receiver
16QAM	430 ms	90,3%	74,2%
16QAM	0 ms	74,1%	47,6%
QPSK	430 ms	99,0%	93,0%
QPSK	0 ms	95,2%	77,1%

TABLE 5
MINIMUM FIELD STRENGTH (dBµV/m) FOR A CORRECT RECEPTION RATE GREATER THAN 90%

Modulation	Time Interleaving	Diversity Receiver	Single Branch Receiver
16QAM	430 ms	45	50
16QAM	0 ms	52	60
QPSK	430 ms	35	42
QPSK	0 ms	41	50

Results of Table 5 show there is a significant difference on the minimum field strength that is necessary to achieve 90% of error free reception from the system with and without time interleaving. The average difference is of about 7dB either by the addition of a second antenna or by the implementation of a 430ms time interleaving.

The field strength requirement defines the coverage area of the service. The decrease in the minimum field strength implies in the extension of the coverage area for the same transmitted power.



Mode 3, GI=1/8, FEC=1/2 and13 segments

Fig. 5. Field Results

Although the overall mobile performance of the diversity receiver without time interleaving is equivalent to the performance of the single branch receiver with time interleaving, the correct reception rate function exhibits differences.

The correct reception time rate as a function of the measured field strength is plotted in Figure 5. Results include the parameters test set with and without time interleaving and for QPSK and 16QAM modulation.

In all the trials, the diversity receiver without time interleaving could achieve 80% of successful percentage rate with lower signal strength. For very high successful percentage rates, however, the single branch receiver with time interleaving had better performance.

6. SPEED ANALYSIS

Another interesting result of the test is the comparison of failure points along the route according to the vehicle speed. The selected route had heavy traffic and the percentage of the time fraction that the vehicle is not moving is over 40% of the total time as presented in Table 6.

The error rate comparison regarding the speed of the test vehicle is presented in Table 7. This speed analysis is motivated by the fact that in stationary environments the time interleaving is essentially useless, in sharp contrast to spatial diversity.

TABLE 6
TIME PERCENTAGE ACCORDING TO THE SPEED

Modulation	Time Interleaving	Speed= 0 km/h	Speed> 0 km/h
16QAM	430 ms	40.8%	59.2%
16QAM	0 ms	41.6%	58.4%

TABLE 7
ERROR PERCENTAGE ACCORDING TO THE SPEED

Errors	Diversity Receiver		Single Branch Receiver	
	Speed= 0 km/h	Speed> 0 km/h	Speed= 0 km/h	Speed> 0 km/h
I=430 ms	9.9%	9.6%	21.5%	28.8%
I=0 ms	22.1%	28.6%	43.5%	58.7%

The analysis of the error percentage of the moving and stooped vehicle for the system with time diversity and spatial diversity of Table 7, confirms the effectiveness of the association of these two techniques.

The performance of the diversity receiver with time interleaving is such that the error percentage rate along the test route is the same regardless if the vehicle is stopped or moving and the total error rate drops bellow 10%.

Another important conclusion is that, in this "low speed" route, time interleaving and spatial diversity have equivalent impact on performance. The error percentage rate for the diversity receiver without time interleaving and the single branch receiver with time interleaving is the same for the vehicle stooped and for the moving vehicle.

7. CONCLUSION

In the urban mobile environment, the predominant channel degradation in wide-band signals, such as television signals, is frequency selective fading. The impressive performance improvement of the diversity receiver compared to the single-branch receiver shall be attributed to the technique implemented in the receiver, which divide the signal in very narrow sub bands before selection or combination.

Indoor and field trials show that diversity reception can significantly improve mobile reception performance of the DTV signals. Test results also show that the improvement of spatial diversity for mobile reception is greater on a transmission without time interleaving than in a transmission using time interleaving.

The direct comparison of the "diversity" receiver without time interleaving (diversity DVB-T like receiver) and the "single branch" receiver with time interleaving (normal ISDB-T like receiver) leads equivalent performance.

Discussed test results also showed that time interleaving and spatial diversity have complementary effects. Time interleaving is a powerful time diversity tool and cannot be substituted by the use of spatial diversity. Nevertheless, it is important to bear in mind that time diversity is a standard technique and spatial diversity is a merely a receiver implementation issue.

8. REFERENCES

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