

地上波デジタル OFDM 受信用 時間領域ダイバーシティ回路のシミュレーション評価

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あらまし 日本の地上波デジタル放送 (ISDB-T) の放送方式として OFDM (直交周波数分割多重) 方式が採用された。車載テレビなどの移動体で受信を行う場合、チャネルの時間的変動により受信性能が劣化する。本稿では受信装置として回路規模が小さい時間領域でのダイバーシティ合成回路を設計し、シミュレーション評価によりその性能の評価を行ったのでその詳細について報告する。

キーワード OFDM, multipath fading, space diversity, MRC

A performance optimization of time-domain space diversity combiner for Digital Terrestrial Video Broadcasting

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Abstract OFDM has been adopted as a next generation of terrestrial TV broadcasting (ISDB-T) and will be applied in December 2003 in Japan. Since the ISDB-T standard was primarily designed for stationary and portable reception, the performing degradation of mobility receptions due to the effect of time-varying channel model is necessary to overcome. In this paper, space diversity combiner in the time-domain which requires computation simplicity is proposed; operation of the diversity reception is analyzed in comparison with a conventional reception in multipath fading environment. It is showed that the performance of diversity reception is improved by significantly reducing the probability of severe fading conditions. The diversity combiner's circuit parameters are also object of optimizing in this paper.

Keyword OFDM, multipath fading, space diversity, MRC

1. Introduction

Orthogonal frequency-division multiplexing (OFDM) is a modulation technique that is capable of effective frequency utilization and high-speed digital transmission. Recently, OFDM has been applied for digital transmission over telephone line (ADSL), for digital audio and digital video broadcasting, and for wireless local area network (WLAN). In Japan, OFDM has been adopted as the next generation of TV broadcasting (ISDB-T), which will be applied in

2003.

Since the ISDB-T standard was primarily designed for stationary and portable reception, the performance degradation of mobility receptions due to the effect of time-varying channel model is necessary to overcome. Several methods are employed to improve the system's performance; one is an antenna array with an adaptive beamforming [1]. The other well-known method to cope the fading effect is space diversity. The attractive aspect of the space diversity for the TV mobility reception is that

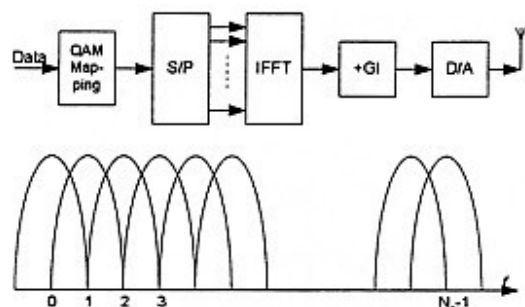


Fig. 1. OFDM Transmission block diagram and spectrum of OFDM signal.

the power level of the received signal can be significantly improved without the requirement of increasing the power level of transmission antenna. In [2], the space diversity with Maximum Ratio Combiner (MRC) in frequency-domain is proposed and investigated, yielding the optimum performance in term of BER. However, due to the time-frequency duality of OFDM modulation technique, the frequency-domain diversity combiner requires a great deal of computation complexity, since the number of FFT is corresponded to the number of antennas.

In this paper, the time-domain space diversity combiner which requires low computation is described and analyzed. The rest of this paper is organized as follow: section 2 introduces the OFDM transceiver system and the time-domain space diversity reception briefly. In section 3, the algorithm of time-domain space diversity reception is proposed. Simulation results of diversity receptions in the multipath fading environment are shown in comparison with conventional reception. The optimum circuit is also given in this section. Finally, our conclusions are given in section 5.

2. System description

2.1. OFDM system

The OFDM signal is generated by the transmitter depicted in Fig. 1. The binary input data is firstly converted to complex symbol by QAM mapping block. Next, the QAM symbol stream is serial-to-parallel converted into many parallel subcarriers for the purpose of increasing the symbol duration. In order to utilize the frequency resource efficiently, subcarriers are overlapped and orthogonal in the frequency domain as illustrated in Fig. 1. The OFDM modulation can be efficiently

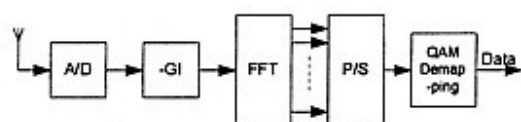


Fig. 2. The conventional OFDM reception block diagram.

implemented by using the Inverse Fast Fourier Transform (IFFT). Therefore parallel subcarriers are applied to the IFFT block to generate the baseband modulated signal in time domain. The guard interval is intentionally inserted to eliminate the Inter-Symbol Interference (ISI). OFDM symbol is transferred to analog signal by the Digital-to-Analog converter and is fed to transmitted antenna.

The transmitted OFDM signal in its sampled equivalent low-pass representation is given by

$$s(n) = \sum_{k=0}^{N_c-1} X_k \exp(j2\pi \frac{k}{N_c} n) ; -N_g < n < N_c$$

where N_c is number of subcarriers, N_g is guard interval samples.

Fig.2 shows the conventional OFDM reception with one antenna. The received signal which is distorted in the multipath fading is firstly converted to digital signal by Analog-to-Digital converter. The guard interval is removed, and then demodulated by

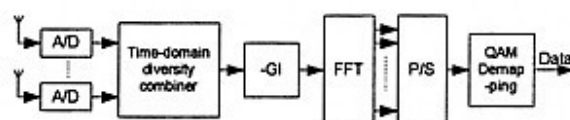


Fig. 3. The time-domain diversity combiner and OFDM reception block diagram.

Fast Fourier Transform (FFT) to yield the received data symbols.

Since the transmitted signal is distorted in the multipath fading channel, the channel estimation and equalizer are required for the coherent demodulation. In order to estimate the impact of multipath fading channel, in the transmission stage, pilot symbols are scattered among subcarriers in the frequency dimension and among the OFDM signal sequence in the time dimension. Consequently, channel transfer function (CTF) is extracted by evaluating received pilots; the channel transfer function can be approximated by the interpolating procedure in the

frequency and the time direction. After compensating the channel impairment, the output of equalizer is applied to QAM demapping block to attain data.

2.2. OFDM reception with the time-domain space diversity combiner

In the multipath fading environment, RF signal arrives to the reception antenna via several paths; therefore the received signal is the sum of several versions of the transmitted signal with different phases that caused the fluctuation of CTF in the frequency domain. Furthermore, in case of mobility receptions, reception antenna moving through the field experiences the varying of the CTF which is characterized by a Doppler frequency; therefore the multipath fading channel can be modeled as the time-variant frequency-selective fading channel. As the result, the signal envelop is subject to rapid fading varying in both time and the frequency domain. A burst error mainly occurs as the channel attenuation is severe, i.e. the reception antenna falls into a deep-null fading region. As it is indicated in [5], fades with a depth less than 20dB are frequent, with deeper fades in excess of 30dB being less frequent but not uncommon.

To cope with fading effect, the space diversity technique is employed for the mobility reception of digital terrestrial video broadcasting. As illustrated in Fig. 3, number of branch signals is supplied via equivalent number of diversity branches. Signal obtained from each diversity branch is firstly digitalized by the Analog-to-Digital converter. Consequently, branch signals are combined by the time-domain space diversity combiner. The guard interval is removed, and the signal is demodulated by the FFT block. The equalizer block is used and followed by the QAM demapping block to attain the binary data.

3. Time-domain space diversity combining algorithm

Fig.4 shows the principle of the time-domain space diversity combiner. Let us assume the number of diversity branches is M . The diversity branch $\#m$ received the corresponding branch $r_m(n)$ which is transmitted via the corresponding multipath channel $\#m$ with the channel impulse response $h_m(n)$.

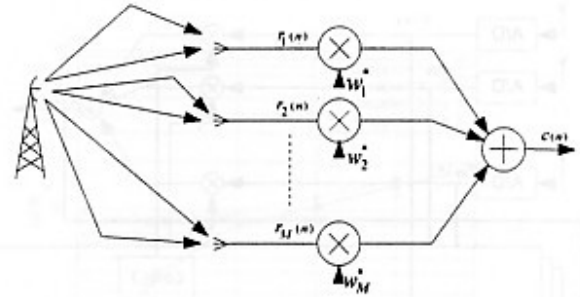


Fig. 4. The space diversity combiner block diagram in general.

$$r_m(n) = \sum_i h_{m,i}(n)s(n-\tau_i) + z_m(n) \\ = h_m(n) \otimes s(n) + z_m(n)$$

Output of the combiner is given as

$$c(n) = \sum_{m=1}^M w_m^* r_m(n)$$

where $*$ is the complex conjugation, w_m is the coefficient corresponding to the antenna branch $\#m$.

To improve the performance of the space diversity combiner, reception antennas should be separated about several wavelengths [5] in order to ensure the independence among branch diversities. Thus, the probability of severe fading is drastically reduced as increasing diversity branches.

The output of FFT at k -th subcarrier is given as

$$Y_k = \sum_{n=0}^{N_c-1} c(n) \exp(-j2\pi \frac{n}{N_c} k) \\ = \sum_{m=1}^M w_m \sum_{n=0}^{N_c-1} r_m(n) \exp(-j2\pi \frac{n}{N_c} k) \\ = \sum_{m=1}^M w_m (H_{m,k} X_k + Z_m)$$

where $H_{m,k}$ is the CTF at k -th subcarrier corresponding to the diversity branch $\#m$, Z_m is the AGWN at the diversity branch $\#m$.

Again, let us assume that the multipath fading channel is composed of one strongest path and a number of weaker paths. The dominant path that has the strongest average power level contributes mainly to the power level of received signal. Therefore CTF of the multipath channel is relatively coherent in the frequency domain, i.e. the large number of subcarriers suffers the same fading conditions. The above assumption is led to the consequence that the

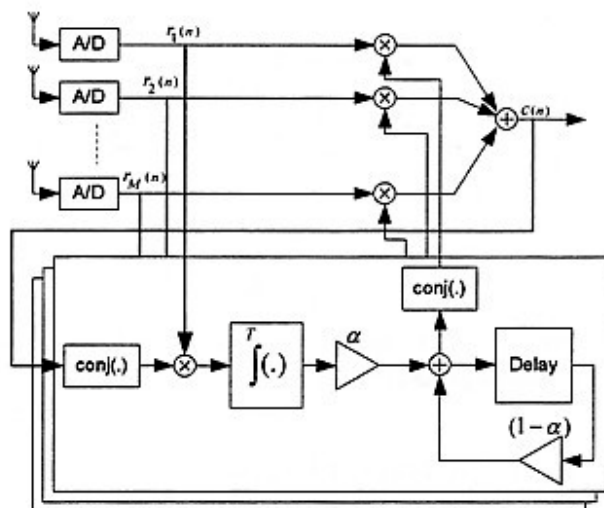


Fig. 5. The time-domain space diversity combiner using the MRC algorithm.

burst error mostly occurs as the severe fading happens in the time domain.

To improve the power level of resultant signal, the Maximum Ratio Combiners (MRC) is applied. The received signal of each diversity branch is weighted in proportion to its own power level before combining. It is also required to co-phase the received signals of antenna branches. Since the terrestrial TV is broadband utilization system, its transmitted signal can be assumed to be a white process. Therefore correlations among versions of signal are employed directly in the time domain in order to obtain average CTFs of all multipath channels and coefficients of the time-domain diversity combiner, consequently.

In spite of estimating the correlations among branch signals, the cross-correlations between the output of the space diversity combiner and branch signals are employed equivalently, yielding coefficients of the diversity combiner as

$$w_m = E(r_m c^*)$$

Fig. 5 shows the circuit diagram of the time-domain space diversity combiner. The cross-correlation estimation is implemented by mean of integral. An integral period should be considered as a sampling period of time-variant multipath channels. To avoid a sudden change of coefficients, the first-order IIR filter is used with the forgetting factor α .

Table 1. System configuration

FFT size	4096
Number carrier	2809
Guard interval	512
Symbol duration	567microsec
Modulation	64QAM
Multipath channel	2 paths Rayleigh fading AWGN

4. Simulation result

4.1. Time-domain space diversity combiner

The performance of the proposed time-domain space diversity reception in case of using 2 antennas and 4 antennas were evaluated by computer simulations in comparison with the conventional reception. The OFDM transmitter operated in mode 2 of ISBN-T standard of Japan Terrestrial Video Broadcasting. The simulation parameters are listed in Table 1.

We define the Level Crossing Rate (LCR) as the

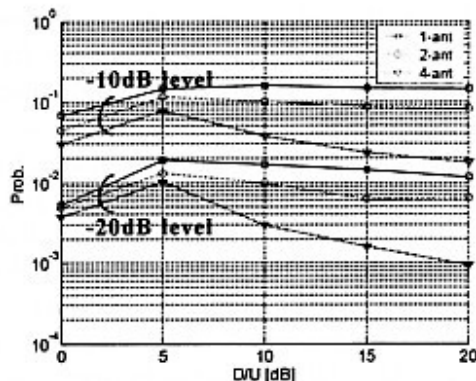


Fig. 6. Level Crossing Rate versus D/U (delay spread=0.4 μ s, Doppler freq.=30Hz)

ratio between number of received pilots whose magnitude is smaller than the specific value and the total number of received pilots. Hence the higher value of LCR is corresponding to severe multipath fading condition is suffered. The LCR term is employed to compare performances of the conventional reception and the proposed diversity reception. Fig. 6 shows the LCR versus D/U (Desired/Undesired ratio) of the conventional, 2-antenna and 4-antenna receptions. In case of small D/U, i.e. average power levels of 2 paths of the fading channel are identical, the assumption of having a dominate path is violated, therefore LCRs are similar. In case of high D/U, i.e. the assumption of having a dominate path is fulfilled, the 2-antenna

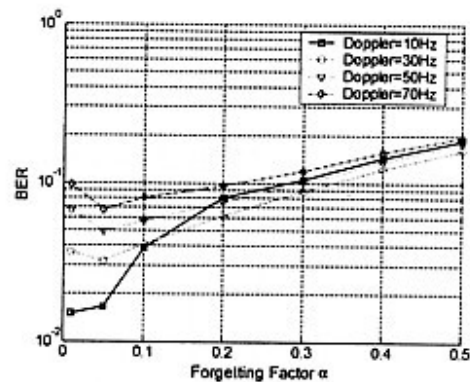
and the 4-antenna space diversity cope the multipath fading channel significantly. In case $D/U=10\text{dB}$, the -20dB LCR of conventional reception, 2-antenna reception and 4-antenna reception are 1.5%, 0.98% and 0.3% respectively.

BER performances of the conventional reception, 2-antenna reception and 4-antenna receptions in different multipath fading environments with D/U ratio of 0dB , 10dB and 20dB are shown in Figs. 7(a), (b) and (c), respectively. The performance of the time-domain space diversity reception is improved drastically in case the assumption of having a dominant path is fulfilled, i.e. high D/U in Figs. 7(b) and (c). The diversity gain of 2-antenna reception and 4-antenna reception comparing with the conventional reception are 6dB and 12dB respectively. Even that assumption is violated as D/U of 0dB , BER performance of 4-antenna reception is slightly better than that of conventional reception at the low C/N . The performance of the conventional reception is matched with that of the diversity reception only if the value of C/N is high.

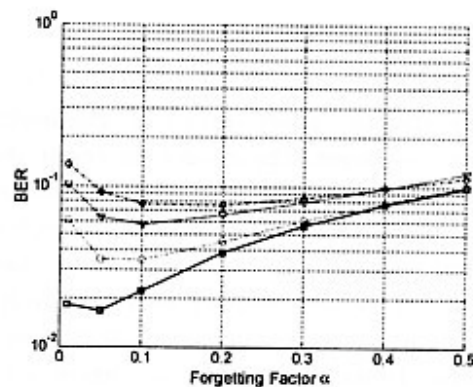
Fig. 8 shows the performance of the conventional, 2-antenna and 4-antenna reception in the time-selective fading channel. In the slow fading environment, diversity receptions outperform the conventional reception, since the probability of falling into deep-null fading are significantly reduced as increasing number of diversity branch. In contrast, in the fast fading environment, due to the degradation of the cross-correlation estimation, performance of diversity receptions are deteriorated, but are still slightly better than that of the conventional reception. BER performance losses in fast fading environment are also due to the degradation of channel estimation and equalizer.

4.2. Optimization of circuit parameters

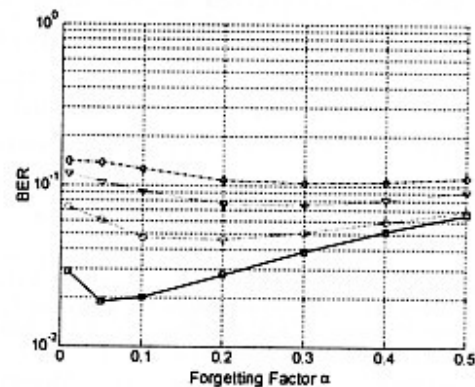
As it is indicated above, increasing number of antennas drastically improves the performance of the space diversity. Since 4 antennas are reasonable and feasible to deploy in vehicle, the 4-antenna reception is chosen to be an object of optimizing. Figs. 9(a), (b) and (c) show the BER performance of 4-antenna reception with integral period of $32\ \mu\text{s}$, $128\ \mu\text{s}$ and $512\ \mu\text{s}$, respectively. The integral period should be considered as the sampling period of CTF which is inherently related to Doppler frequency. As showed



(a) Integral period= $32\ \mu\text{s}$



(b) Integral period= $128\ \mu\text{s}$



(c) Integral period= $512\ \mu\text{s}$

Fig. 9. BER performance versus Forgetting Factor α

in Figs. 9, performance of diversity reception is as the function of Doppler frequency and the forgetting factor α , the curve provides optimum values of forgetting factor corresponding to different Doppler frequencies. For instant, the forgetting factor α should be in $[0.05, 0.10]$ corresponding to integral period of $128\ \mu\text{s}$.

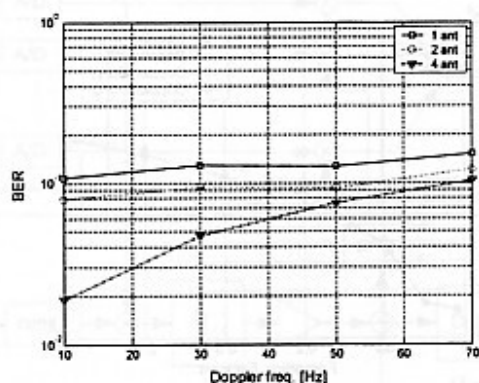


Fig. 8. BER performance versus Doppler freq. ($C/N=20\text{dB}$, $D/U=10\text{dB}$, delay spread= $0.4\ \mu\text{s}$).

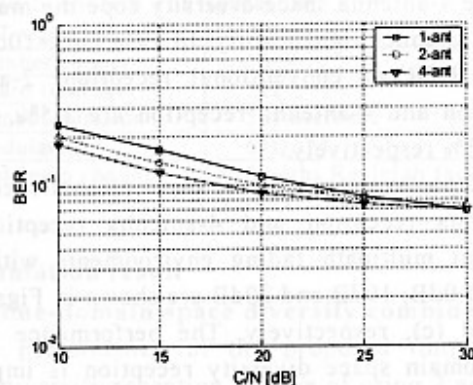
5. Conclusion

The time-domain space diversity combiner is analyzed in this paper. The simulation result shows that the performance of diversity reception is drastically improved in comparison with conventional reception in multipath fading environment. It is also showed that the diversity reception significantly copes severe fading in the time-domain. Those simulations are based on the condition of independent diversity branches. In case of dependent diversity branches, the space diversity combiner could be considered as the directional pattern controller by which the strongest path is emphasized.

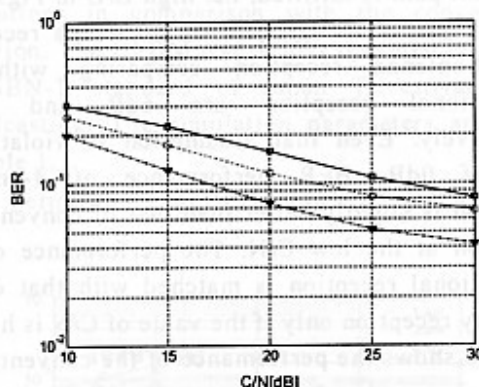
Circuit parameters of the diversity combiner are also optimized by simulation. Optimum parameters are given for specific multipath scenarios in order to improve the performance of diversity reception.

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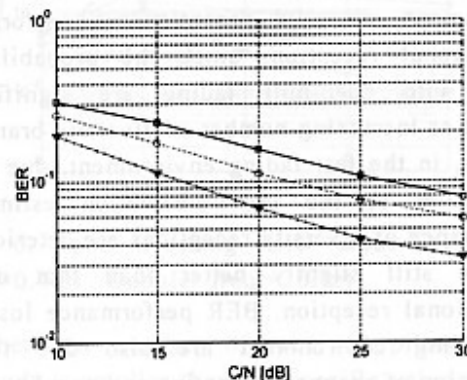
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(a) $D/U=0\text{dB}$



(b) $D/U=10\text{dB}$



(c) $D/U=20\text{dB}$

Fig. 7. BER performance versus C/N (delay spread= $0.4\ \mu\text{s}$, Doppler rate= 30Hz)