Single-RF Diversity Receiver for OFDM System Using ESPAR Antenna with Alternate Direction

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ABSTRACT

This paper presents a single-RF diversity scheme for orthogonal frequency division multiplexing (OFDM) receiver using Electronically Steerable Passive Array Radiator (ESPAR) antenna whose direction changes alternately at the OFDM symbol rate. OFDM is widely used for mobile communication systems because of its broadband wireless transmission capability in a severe time dispersive multipath propagation channel. OFDM is, however, not efficient for mitigating the performance degradation due to fading. Diversity is an efficient technique for solving this problem. Although maximal ratio combining diversity is the most efficient technique, it requires the same number of RF front-end circuitry and analog-to-digital converters (ADC) as antennas. Although ESPAR antenna-based diversity technique requires only a single-RF and ADC, the convergence is not fast enough to track fast variation of the channel state. Furthermore, it is not efficient in a frequency selective channel. In this paper, we propose a new OFDM diversity scheme using ESPAR antenna. The proposed scheme is capable of obtaining the diversity gain in a frequency selective fading environment and avoids the slow convergence rate problem in the conventional technique using ESPAR antenna. Computer simulation results show that the proposed scheme gives diversity gain in a frequency selective fading channel.

Keywords: OFDM, ESPAR Antenna, Frequency Selective Fading, Diversity

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a promising technique capable of establishing broadband wireless communication systems, because it is robust to a severe time-dispersive multipath propagation channel. However, OFDM does not have a capability of improving the bit error rate performance which is degraded due to fading.

Space diversity is an efficient technique to solve the performance degradation. Among them, maximal ratio combining diversity is known to be the optimum in terms of maximizing the signal-to-noise power ratio (SNR) after combining. However, it requires the same number of radio frequency (RF) circuitry, analog-to-digital converters and multiple discrete Fourier transform (DFT) blocks as of diversity branches.

Electronically Steerable Passive Array Radiator (ESPAR) antenna [1] based diversity is one of the solutions to reduce the size of the circuit. However, the convergence is not fast enough to track the fast variation of the channel state. Furthermore, the conventional ESPAR antenna based diversity scheme is not efficient in a frequency selective channel.

In order to solve the problems, we propose a new diversity scheme based on ESPAR antenna, whose beam direction changes alternately at the same frequency as the OFDM symbol rate. This fast variation in directivity causes the interference amongst adjacent subcarriers or inter-channel interference (ICI). The frequency domain equalizer followed by the DFT processor is not only capable of suppressing this ICI, but also gives implicit space diversity effect even in the frequency selective fading environment.

On previous reports [2] [3], we have carried out the computer simulation using the simplified ESPAR antenna and channel model. The results showed that the proposed scheme had a possibility of obtaining diversity gain. For the confirmation, we employ the practical simulation model for computer simulation analysis. The simulation result shows that the proposed scheme gives the diversity gain in a frequency selective fading channel.

This paper is organized as following. In section 2, an ESPAR antenna is introduced. Then a configuration of the proposed receiver and baseband signal processing for obtaining the diversity gain are described in section 3. In section 4, computer simulation results are shown. A brief conclusion is given in section 5.

2. ESPAR ANTENNA

ESPAR antenna is a kind of reactively controlled antenna which has single RF port. For example, Fig. 1 shows a photograph of a seven-element ESPAR antenna which works in 2.4GHz industrial, scientific and medical radio band. There is only one feeder-element at the center of the ESPAR antenna. Fig. 2 depicts

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an example configuration of the ESPAR antenna for diversity scheme. In this case, the antenna consists of seven quarter-wavelength elements. The center element, that is radiator, is connected to the RF input of a receiver. The other six elements surrounded by the centre element, namely, parasitic elements, are terminated with variable capacitance diodes (Varicaps). Radiation patterns can be controlled by changing the capacitance of the Varicaps.

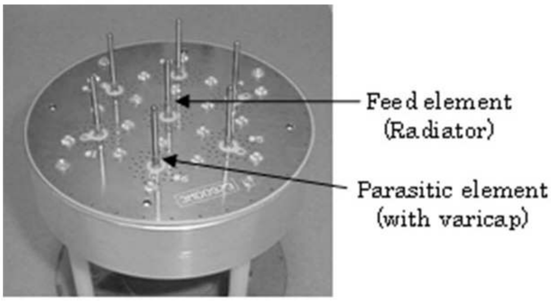

Fig.1: *Photograph of a seven-element ESPAR antenna.*

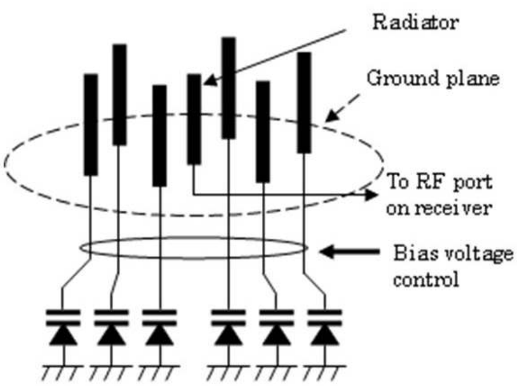

Fig.2: *An example configuration of the seven-element ESPAR antenna for diversity scheme.*

ESPAR antenna is applied for many applications. The direction-of-arrival (DoA) estimator has been proposed in conjunction with the multiple signal classification (MUSIC) or the estimation of signal parameters via rotational invariance techniques (ESPRIT) algorithm. [4] and [5]. The diversity receiver based on ESPAR antenna is also proposed. However, the conventional ESPAR-antenna-based receiver has problems in frequency selective fading and convergence rate.

3. PROPOSED RECEIVER

3.1 Configuration of the proposed receiver

The fig. 3 shows the block diagram of the proposed diversity receiver. In this paper, we assume a two-element ESPAR antenna since it is enough to

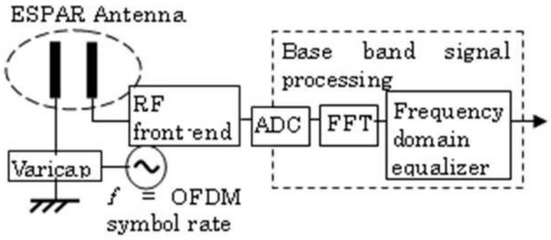

Fig.3: *Block diagram of Proposed Receiver.*

evaluate the proposed scheme. When an ESPAR antenna that has three or more elements is used for a receiver, it can achieve better performance by selecting the suitable direction pair. The radiator element is connected to an input of the receiver while the varicap which terminates the parasitic element, is controlled by the oscillator. The frequency of the oscillator is the same as the OFDM symbol rate. In case of widely used IEEE802.11a/g wireless LAN, the frequency of the oscillation is 250 kHz.

A direction of the antenna is alternatively changed by the control voltage. When the control voltage becomes low, the capacitance of varicap is increased; the element works as director. The antenna direction is from radiator to director. It pointed to the beam direction A in fig. 4. When the control voltage becomes high, the capacitance of varicap is decreased. The element works as reflector and beam direction is changed to the opposite side that is direction B. It is described in fig. 5. This direction control is performed rapidly since no mechanical part intervenes.

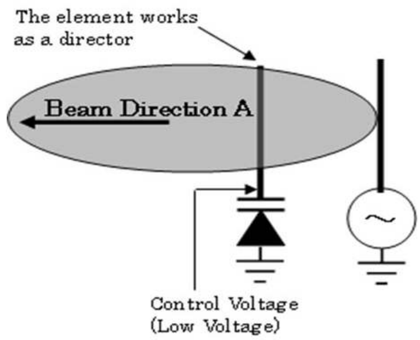

Fig.4: *Antenna Beam Direction at Low Control-Voltage.*

Some subcarriers in OFDM signals faded when the signal through a time-dispersive multipath propagation channel. This fading effect is generally different by the direction. Fig.6 shows an example image of spectral pattern after taking multipath fading. When the direction of antenna is changed alternatively, averaging effect between two directions is promising. Proposed scheme can reduce the number of faded subcarriers. Fig.7 shows an example spectral pattern of received signal. Since the antenna

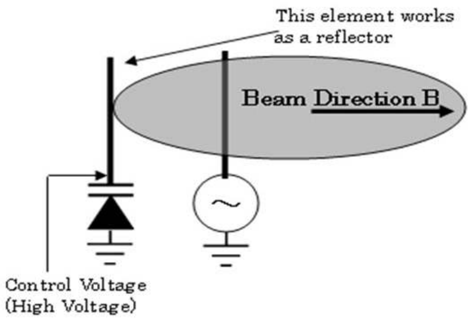

Fig.5: *Antenna Beam Direction at High Control-Voltage.*

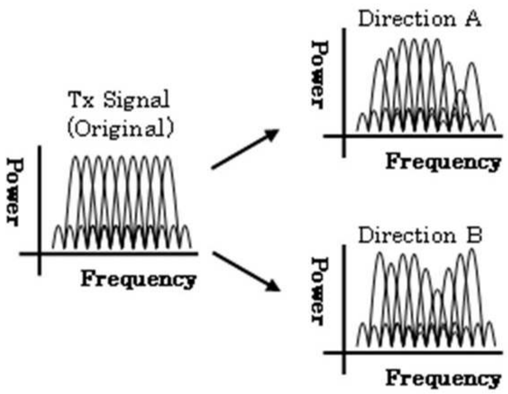

Fig.6: *An Example Illustration of Spectral Pattern changed by Multipath Fading.*

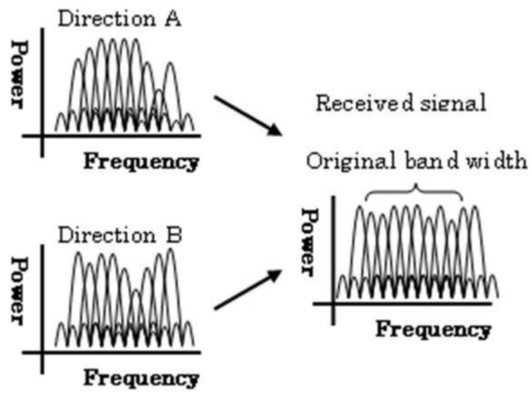

Fig.7: *An Example Illustration of Spectral Pattern of Received Signal by Proposed Scheme.*

direction is changed alternately, the receiving signal was modulated like amplitude modulation. It causes the spectrum spread from original band width, that makes the interference amongst adjacent subcarriers or inter-channel interference (ICI), but the interference can be equalized at the frequency domain equalizer.

Again go back to fig.3. This receiver is composed of RF front-end, analog-to-digital converter (ADC) and baseband digital signal processing unit. The received signal from the radiator is applied to the RF front-end, which is followed by the ADC, and the received signal is converted in the equivalent low-pass expression. The output of ADC is first applied to FFT (fast Fourier transform) processor to decompose the received OFDM signal to sub-carrier components. Because the FFT output was deteriorated by ICI due to fast directivity variation of ESPAR antenna, suppression of ICI is required. ICI suppression is divided into two stages, say, a channel response estimation stage and a frequency domain equalization stage.

3.2 Channel estimation and compensation

The channel response is estimated using a pilot symbol which is transmitted prior to the data symbols. Let us suppose that a pilot symbol is transmitted before the data symbols are transmitted. The pilot symbol vector $\mathbf{p}$ is defined as

$$\mathbf{p} = [p_0, p_1, \cdots, p_{N-1}]^T, \tag{1}$$

where p_k is the pilot symbol of k-th subcarrier; N is a number of subcarriers. The transmitted pilot symbol $\mathbf{p}$ is then propagated through the multipath fading channel. The received pilot symbol after FFT is given by.

$$\mathbf{u} = (\mathbf{G}_{-1}\mathbf{H}_{-1} + \mathbf{H}_0 + \mathbf{G}_1\mathbf{H}_1)\mathbf{p} + \mathbf{v}, \tag{2}$$

where $\mathbf{H}_i$ is a diagonal matrix, whose diagonal elements represents the frequency response corresponding to the i-th element, and $\mathbf{z}$ is the thermal noise component in the frequency domain. $\mathbf{G}_i = [g^i_{kl}]$are the negative ($i = -1$) and positive ($i = 1$) frequency shift matrices where

$$g^i_{kl} = \begin{cases} 1(k+i=l) \\ 0(otherwise)' \end{cases} \tag{3}$$

We can rewrite Eq. (1) as

$$\mathbf{u} = \mathbf{G}_{-1}\mathbf{P}\mathbf{h}_{-1} + \mathbf{P}\mathbf{h}_0 + \mathbf{G}_1\mathbf{P}\mathbf{h}_1 + \mathbf{z} \tag{4}$$

where $\mathbf{P} = \text{diag}(\mathbf{p})$ is the diagonal matrix, whose diagonal elements correspond to the pilot symbols. The minimum mean square error (MMSE) estimate of $\mathbf{h}_i$ is then given by

$$\tilde{\mathbf{h}}_i = (\mathbf{R}^{-1}\mathbf{B}_i)^H\mathbf{u}, \tag{5}$$

where

$$\begin{aligned} \mathbf{R} &= E[\mathbf{u}\mathbf{u}^H] \\ &= \mathbf{G}_{-1}\mathbf{P}\mathbf{R}_h\mathbf{P}^H\mathbf{G}_{-1}^H + \mathbf{P}\mathbf{R}_h\mathbf{P}^H \\ &\quad + \mathbf{G}_1\mathbf{P}\mathbf{R}_h\mathbf{P}^H\mathbf{G}_1^H + \sigma_z^2\mathbf{I} \end{aligned} \tag{6}$$

is the covariance matrix for the frequency domain received signal and

$$\mathbf{B}_i = E[\mathbf{u}\mathbf{h}_i^H] = \mathbf{G}_i\mathbf{P}\mathbf{R}_h, \tag{7}$$

is the cross correlation matrix between the received signal and the i-th channel response vectors, $\mathbf{R}_h = E[\mathbf{h}_i\mathbf{h}_i^H]$ is the covariance matrix for channel response vector. $\mathbf{R}_h$ corresponds to the delay profile of the channel.

After channel estimation carried out by using Eq. (6), the frequency domain equalization is performed. The received data symbol in the frequency domain is given by

$$\mathbf{u} = (\mathbf{G}_{-1}\mathbf{H}_{-1} + \mathbf{H}_0 + \mathbf{G}_1\mathbf{H}_1)\mathbf{d} + \mathbf{z} = \mathbf{H}\mathbf{d} + \mathbf{z}, \quad (8)$$

where $\mathbf{d} = [d_0, d_1, \cdots, d_{n-1}]^T$ is the data vector. Let us employ an MMSE equalizer. The data vector can be estimated by the following equation:

$$\mathbf{d} = (\mathbf{R}_d^{-1}\mathbf{H})^H\mathbf{u}, \quad (9)$$

where

$$\mathbf{H} = \mathbf{G}_{-1}\mathbf{H}_{-1} + \mathbf{H}_0 + \mathbf{G}_1\mathbf{H}_1, \quad (10)$$

is the estimated channel response matrix where $\mathbf{H} = \mathrm{diag}(\mathbf{h}_i)$. Furthermore,

$$\mathbf{R}_d = \mathbf{H}\mathbf{H}^H + \sigma_z^2\mathbf{I}, \quad (11)$$

is the estimated covariance matrix.

The other type of frequency domain equalizer such as zero forcing and maximum likelihood sequence estimation equalizers can be used for the receiver. In the following, we have analyzed the bit error rate performance using the MMSE equalizer depicted in eq. (9).

4. COMPUTER SIMULATION

The system configuration, in order to run the simulation, is shown in table 1. In the simulation, we did not apply forward error correction coding. Fig. 8 shows the bit error rate (BER) performance of the proposed diversity scheme in a two-ray Rayleigh fading environment. The solid and dashed lines show BER of the proposed scheme and theoretical BER in a Rayleigh fading channel [6], respectively. The theoretical BER is given by the following equation:

$$BER = 0.5 * \left(1 - \sqrt{E_bN_0/(E_bN_0 + 1)}\right), \quad (12)$$

where E_bN_0 is the normalized signal-to-noise ratio.

The proposed diversity receiver effectively gives the diversity gain in a frequency selective two-ray Rayleigh fading channel.

5. CONCLUSION

This paper presented a single-RF diversity scheme for OFDM receiver using ESPAR antenna whose direction changes alternately in the symbol time period. Difference between Conventional ESPAR antenna diversity and proposed one was described. Then a principle of proposed diversity receiver was explained. Finally, computer simulation results were shown for performance verification of the proposed scheme. It is confirmed that the proposed scheme gives diversity gain in a frequency selective fading channel.

Table 1: *The Result of Three FS Approaches..*

OFDM FFT size	64
Number of data subcarriers	48
Modulation type of subcarriers	QPSK
Length of pilot symbol for channel estimation	2 symbols
Guard interval ratio	1/8 symbol
Path model	Two rays Rayleigh fading
Power of rays	Identical
Doppler	Static during symbol period
Noise type	AWGN
Synchronization of symbols	Perfect
Trial sequence	10000 times

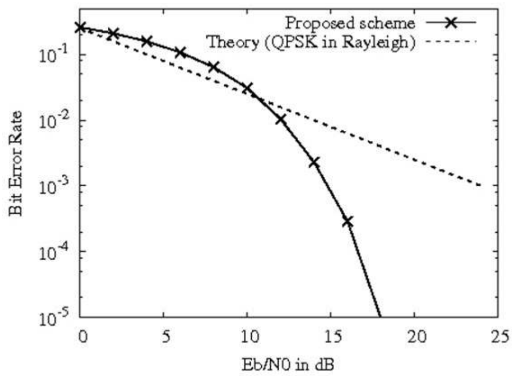

Fig.8: *Signal-to-noise ratio versus bit error rate.*

6. ACKNOWLEDGMENT

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