

## Two suggestions for Wideband OFDM Systems using frequency diversity

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**Purpose:** This presentation presents the concept for the proposed new diversity scheme feature.

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Two suggestions for Wideband OFDM  
Systems using frequency diversity

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# Objective

## Idea

Efficient utilized methods  
of frequency diversity  
in OFDM system

### Problem of STBC-OFDM

- Limitation in Performance
- Complexity increase  
as Number of Antenna increase
- Transmission rate decrease  
as Number of Antenna increase

### Advantage of STFBC-OFDM

- enhancement in BER  
( using Frequency Diversity)
- simple structure  
(do not increase number of antennas)

STBC: space time block code

STFBC: space time frequency block code

# Introduction

- Diversity Techniques

- Time Diversity : Channel Coding, Interleaving
- Frequency(Path) Diversity : Coded-OFDM, Spread Spectrum
- **Space(Antenna) Diversity**
  - Transmit Diversity
    - Space-Time Code (Space-Time Trellis Code, Space-Time Block Code)
  - Receiver Diversity
    - Rake Receiver, Selection Diversity

- MIMO Systems

- Spatial Multiplexing
  - Capacity → increase in transmission rate (BLAST)
- MIMO Diversity
  - Diversity gain → **Performance Improvement** (Transmit Diversity using Space-Time Code)

# Space-Time Block Coding - I

- Space-Time Block Code
  - STBC is one of the simplest STC schemes.
    - Only simple linear processing at the receiver is required.
  - Maximum diversity gain
    - # of Tx antenna  $\times$  # of Rx antenna
- Space-Time Block Coded OFDM (STBC-OFDM)
  - OFDM: robust in channel Environments  
+ STBC: Diversity Gain

# Space-Time Block Coding - II

- Encoding Process

Transmitted  
Signal

$$[c_1 \quad c_2] \rightarrow \begin{bmatrix} c_1 & c_2 \\ -c_2^* & c_1^* \end{bmatrix}$$

- Decoding Process

Received  
Signal

$$\begin{aligned} r_1 &= h_1 c_1 + h_2 c_2 + n_1 \\ r_2 &= -h_1 c_2^* + h_2 c_1^* + n_2 \end{aligned} \rightarrow \mathbf{r} = [r_1 \quad r_2^*]^T = \mathbf{H}\mathbf{c} + \mathbf{n}$$

Channel  
Matrix

$$\mathbf{H} = \begin{bmatrix} h_1 & h_2 \\ -h_2^* & h_1^* \end{bmatrix} \rightarrow \mathbf{H}^H \mathbf{H} = \rho \cdot \mathbf{I}, \quad \rho = |h_1|^2 + |h_2|^2$$

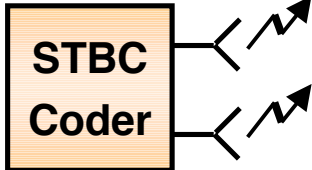
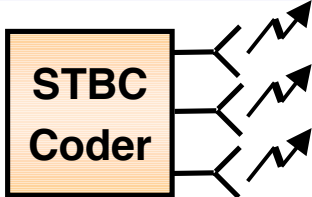
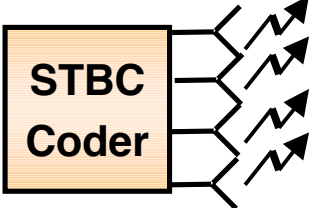
ML  
Decoder

$$\hat{\mathbf{c}} = \arg \min_{\hat{\mathbf{c}} \in \mathcal{C}} \|\mathbf{r} - \mathbf{H} \cdot \hat{\mathbf{c}}\|^2 \rightarrow \hat{\mathbf{c}} = \arg \min_{\hat{\mathbf{c}} \in \mathcal{C}} \|\tilde{\mathbf{r}} - \rho \cdot \hat{\mathbf{c}}\|^2,$$

where  $\tilde{\mathbf{r}} = \mathbf{H}^H \mathbf{r} = \rho \cdot \mathbf{c} + \tilde{\mathbf{n}}$

# Space-Time Block Coding - III

- Some STBC Examples for Multiple Transmit Antennas
- In the case of using more than three transmission antennas, simultaneously satisfy code orthogonality and transmission rate of STBC as 1, do not exist (Proved by V. Tarokh)

| Num. of Tx. Ant. | Space-Time Block Code  | BW  |
|------------------|--|-----|
| 2                |  <ul style="list-style-type: none"> <li>• <math>(2 \times 2)</math> Matrix</li> <li>: 2 symbol transmission in <math>2T_s</math></li> <li>(Proposed by Alamouti)</li> </ul> | 1   |
| 3                |  <ul style="list-style-type: none"> <li>• <math>(8 \times 3)</math> Matrix</li> <li>: 4 symbol transmission in <math>8T_s</math></li> <li>(Proposed by Tarokh)</li> </ul>  | 1/2 |
| 4                |  <ul style="list-style-type: none"> <li>• <math>(8 \times 4)</math> Matrix</li> <li>: 4 symbol transmission in <math>8T_s</math></li> <li>(Proposed by Tarokh)</li> </ul> | 1/2 |

- V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space-time codes for high data rate wireless communication: Performance analysis and code construction," IEEE Trans. on Inform. Theory, vol.44, pp.744-765, Mar.1998.
- Vahid Tarokh, Hamid Jafarkhani, and A. R. Calderbank, "Space-Time Block Codes from Orthogonal Designs," IEEE Trans. on Inform. Theory, vol.45, Jul.1999.
- V. Tarokh, H. Jafarkhani, A. R. Calderbank, "Space-time block coding for wireless communications: performance results," IEEE Journal on Selected Areas in Communications, IEEE Journal on, vol. 17 no.3, March 1999.

# Space-Time and Frequency Block Coding for Wideband OFDM - I

## • Motivation

- Request More reliable system in next generation comm. system
  - Request of higher Diversity Gain → should increase the number of antennas
- Diversity Gain of STBC Depends on number of Tx antennas
  - To improve in performance should increase number of tr antenna
  - Of number of antenna increase HW load seriously increases.
  - Especially, In the case of STBC-OFDM compare to single carrier system, operational complexity increases depends on sub-carrier number. → operational complexity greatly increases
- In OFDM, an STBC-OFDM system that have more than 3 tx antennas is not easy in implementation.
- The STBC using more than 3 tx antennas transmission rate decreases.
- OFDM can obtain frequency diversity in simple method.



# Space-Time and Frequency Block Coding Wideband OFDM - II

## Design consideration

- **Maximum Frequency Diversity Gain**
  - # of Tx antenna  $\times$  # of rx antenna  $\times$  frequency gain
- **Simple Structure**
  - Should not increase number of transmission antenna.
  - To earn frequency Diversity Gain in Decoding process it should be incorporated with Linear Processing
- compatibility with **STBC-OFDM system**

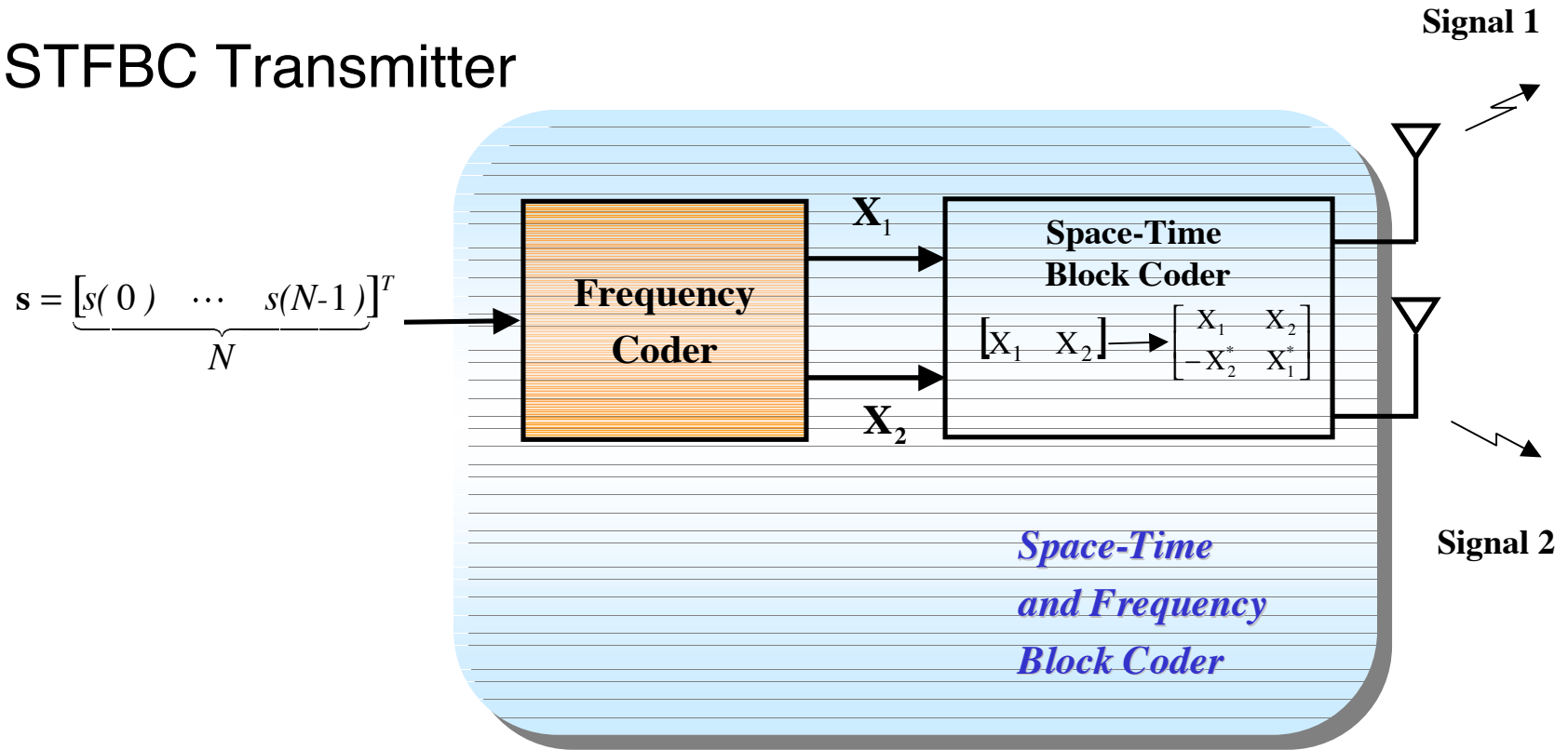
• Minimize complexity increase

• Maximize Diversity Gain

→ Space-Time and Frequency Block Coding Technique

# Space-Time and Frequency Block Coding Wideband OFDM - III

- STFBC Transmitter



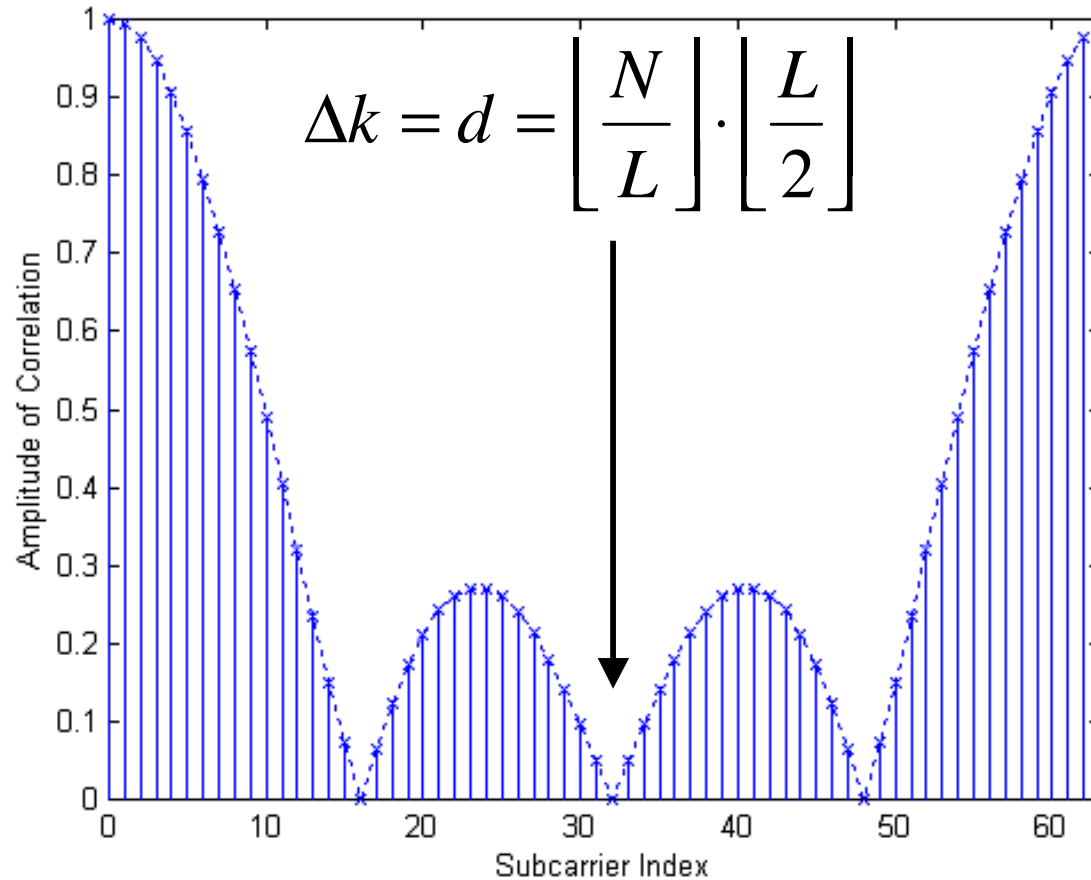
**Frequency Coder : Frequency diversity enabling part in STBC-OFDM system**

# Frequency Coder

- Replicate original signal
- Cyclically shift sub-carrier  $X_1$  produce  $X'_1$
- $X_1$  and  $X'_1$  is get into the original STC symbol mapping such as
- $X_1 = s = [s(0), \dots, s(N-1)]^T$
- $X_2 = X'_1 = [s(N-d), \dots, s(N-1), s(0), \dots, s(N-d-1)]^T$
- The shift term  $d$  can be obtained as following

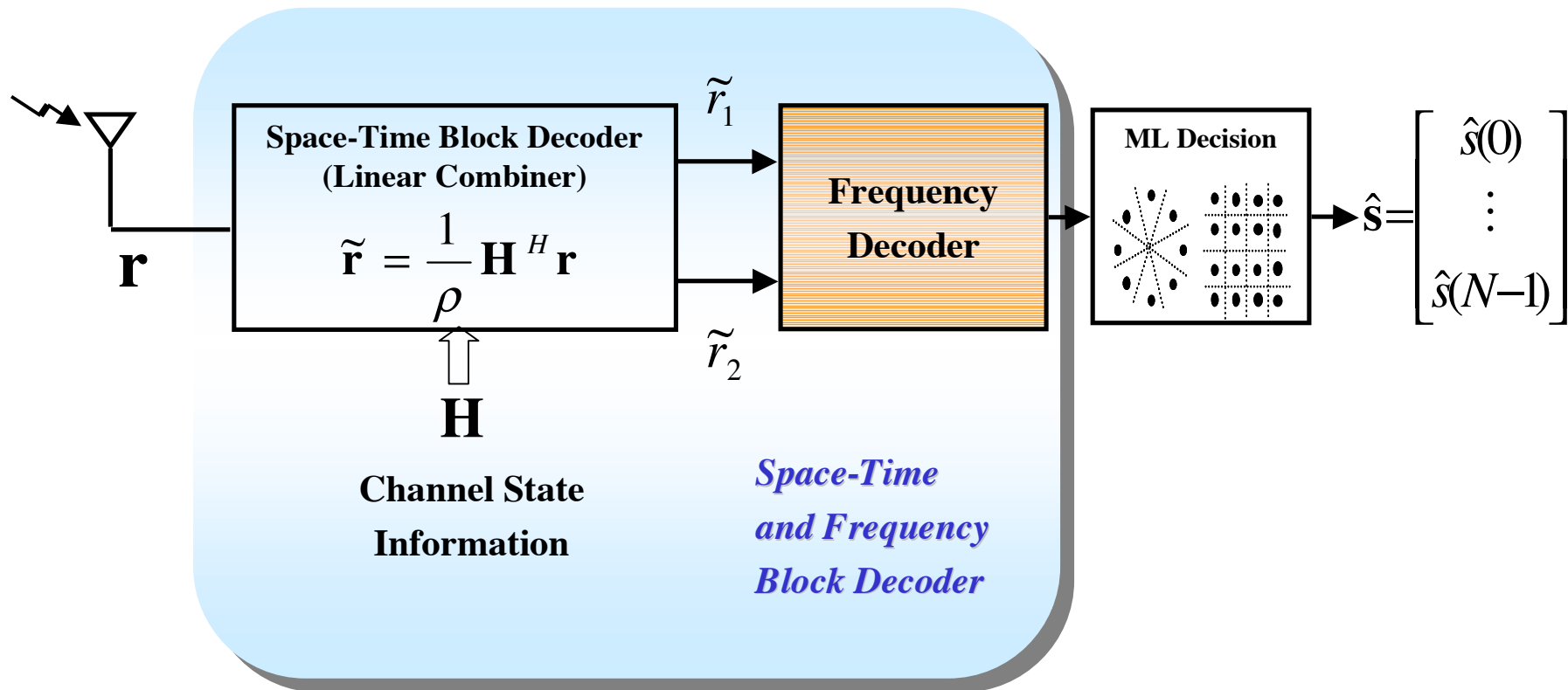
$$\Delta k = d = \left\lfloor \frac{N}{L} \right\rfloor \cdot \left\lfloor \frac{L}{2} \right\rfloor$$

# Correlation of sub-carriers with 0<sub>th</sub> sub-carrier



# Space-Time and Frequency Block Coding Wideband OFDM - IV

- STFBC Receiver

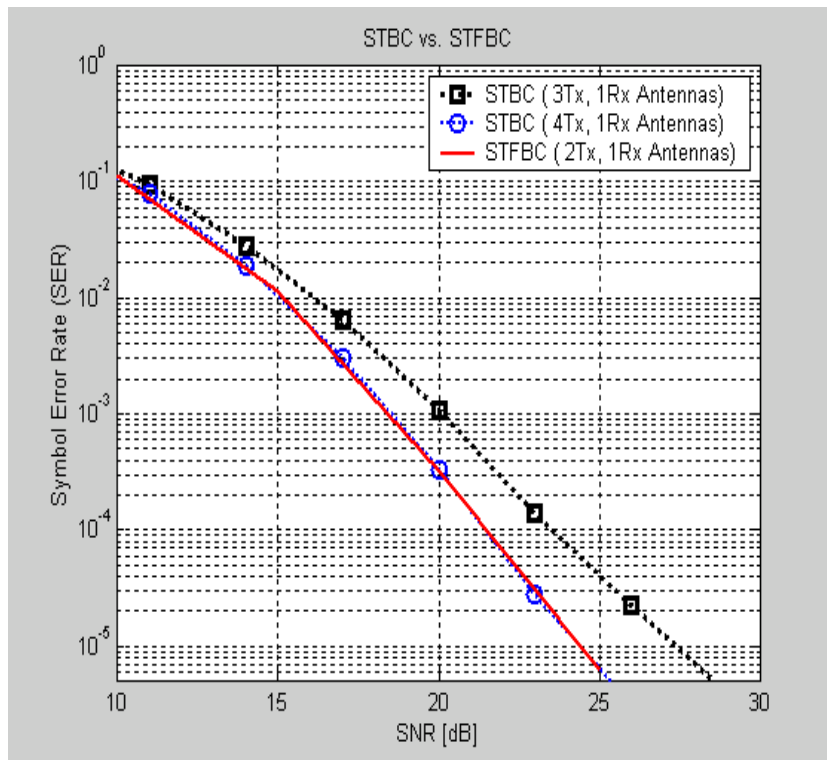


# Frequency Decoder

- Inverse cyclically shifted sub-carrier of the estimated symbol  $X_2$  to produce the “replication” of symbol  $X_1$ .
- $X_1$  and  $X_2'$  is combined as frequency diversity manner such that
- $X_1 = s = [s(0), \dots, s(N-1)]^T$
- $X_2' = X_1(k-d)_{\text{mod } N} = [s(0), \dots, s(N-1)]^T$
- The inverse shift term  $d$  can be obtained from channel estimation process, proportional to **Channel impulse response L**.

# Space-Time and Frequency Block Coding Wideband OFDM - V

- Performance Result (1)

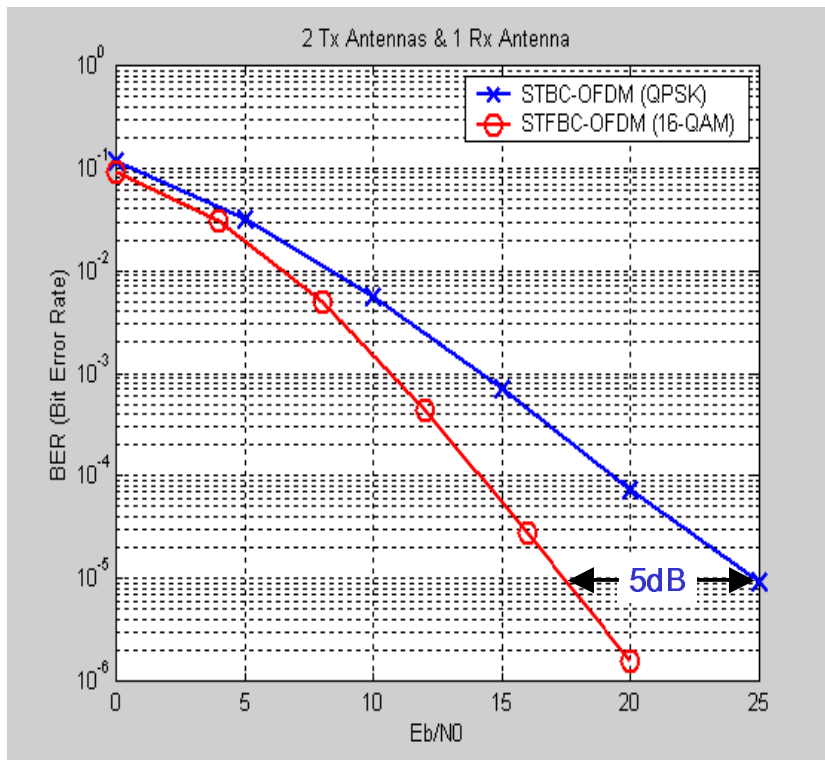


- Simulation environments

- Channel Order : 10
- 16-QAM
- Independent Rayleigh Fading Channel
- Perfect Channel & Order Information
- 4 tx antenna using STBC and 2 tx antenna using STFBC shows same performance
- Compare to 3 tx antenna using STBC in  $10^{-4}$  SER shows approx. 2.5dB SNR gain

# Space-Time and Frequency Block Coding Wideband OFDM - VI

- Performance Result (2)



- Simulation environments

- Channel Order : 10
- Independent Rayleigh Fading Channel
- 2 tx antennas and 1 rx antenna
- Perfect Channel & Order Information
- 2bits/sub-carrier
- In  $10^{-5}$  BER **approx. 5dB** performance improvements.
- If correlation between tx antennas increases, the performance improves impressively



# Closing Comment

- **Space-Time Block Coding (STBC)**

- Simple structure and Full space diversity gain
- But there are many problem when using more than 3 antennas in OFDM system ( HW and operational complexity, decrease in tx rate)

- **Space-Time and Frequency Block Coding (STFBC)**

- Overcome the problem of STBC-OFDM
- A scheme, Not only Maximize Space Diversity but also frequency Diversity gain
- Using frequency diversity so that increase the number of tx antenna is not require d.
- Compatible to existing STBC-OFDM

- **Two suggestion**

- **Tx diversity scheme for OFDM system is desirable to use the STFBC is strongly requested.**
- **The code combining in H-ARQ is also desirable to adapt the frequency diversity in this proposal.**