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Simulation of Differential Space Time Block Coding

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Abstract

In such a coherent system, the underlying assumption is that the channel does not change during one frame of data. Thus, it can also be interpreted as the frame length is chosen such that the path gain change during one frame is negligible. This is basically the quasi-static fading assumption that we have used so far. There is a bandwidth penalty due to the number of transmitted pilot symbols. Of course, choosing a longer frame reduces this bandwidth penalty; however, on the other hand, the quasi-static assumption is less valid for longer frames. So, there is a compromise between the frame length and the accuracy of the channel estimation. DSTBC requires that the transmission of symbols is known to the receiver at the beginning and hence is not truly differential. So, we can interpret as the joint channel and data estimation which can lead to error propagation.

Keywords: *DSTBC (Differential space time block coding), MIMO (Multiple input multiple output), DPSK (Differential phase shift keying), STBC (Space time block code), CSI (Channel state information)*

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INTRODUCTION

For single transmit antenna, differential detection schemes exist that neither require the knowledge of the channel nor employ pilot symbol transmission. In the same way the scheme can be generalized for the case of multiple transmit antennas [1]. A fractional solution to this problem is planned where it is assumed that the channel is not known [2]. The detected sequence at previous time t- 1 is used to estimate the channel at the receiver and these are used to detect the transmitted data at present time t. Here truly differential detection schemes for multiple transmit antennas is presented. Initially we are presenting the concept of differential coding for single transmit antenna. And then we will show results for two transmit antennas. To be precise, the details of differential PSK (DPSK) modulation are presented in Figure 1.

Consider a system consisting of two transmit antennas. Also, assume that a signal constellation with 2^b elements is used. For each block of 2b bits, the encoder calculates two symbols and transmits them using an orthogonal STBC. The 2 × 2 transmitted codeword of the orthogonal STBC [3], or the corresponding pair of transmitted symbols also depends on the codeword and symbols transmitted in the previous block [4].

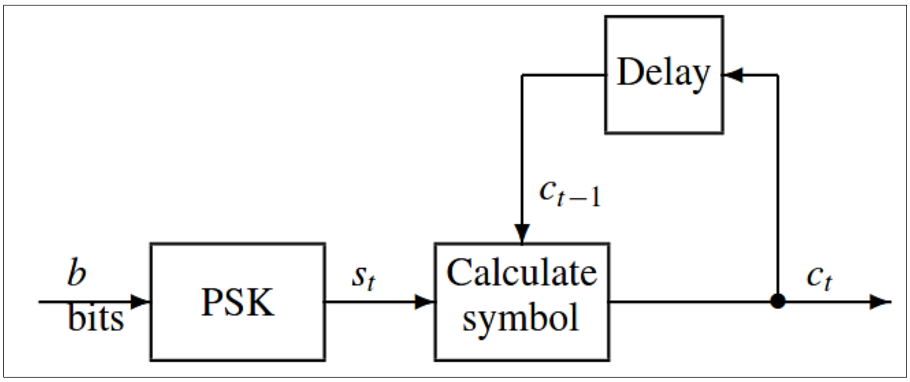

Fig. 1: *DPSK Encoder Block Diagram.*

This is comparable to the case of DPSK where the transmitted symbol at each time depends on both the input bits and the previously transmitted symbol. The main challenge is how to generate the two symbols or corresponding orthogonal codeword such that the receiver can decode them without knowing the path gains. The solution to this problem can be in two ways. One is to replace the PSK modulation in the block diagram of Figure 1 with an orthogonal design [5]. The other approach is to add an intermediate step and generate the pair of transmitted symbols first and then send them by an orthogonal design. The block diagram of such a system is provided in Figure 2.

We group the two symbols for the l^{th} block in a vector S^l as follows by Eqn 1:

$$S^l = \begin{pmatrix} s_1^l \\ s_2^l \end{pmatrix} \qquad (1)$$

The symbol vector for block l, S^l, is generated from S^{l-1}, the symbol vector for block $l-1$, and the $2b$ input bits.

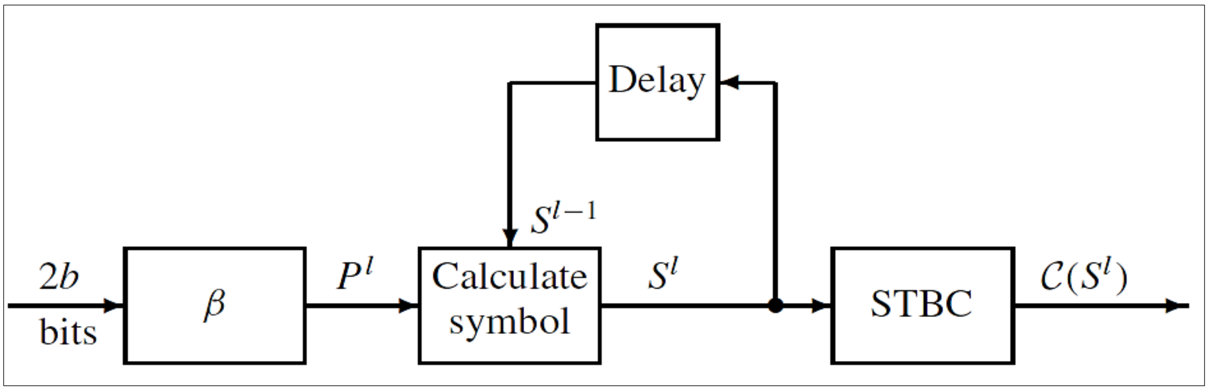

Fig. 2: *Differential Space Time Encoder Block Diagram.*

To describe how we generate S^l, let us consider the following two vectors that construct an orthogonal basis Eqn 2:

$$V_1(S^l) = S^l = \begin{pmatrix} S_1^l \\ S_2^l \end{pmatrix}, \quad V_2(S^l) = \begin{pmatrix} (S_2^l)^* \\ -(S_1^l)^* \end{pmatrix} \qquad (2)$$

Note that for a unit-length vector S^l, the lengths of $V_1(S^l)$ and $V_2(S^l)$ will be unity. Otherwise, an orthonormal basis is also possible by a simple normalization. We fix a set V which consists of 2^{2b} unit-length distinct vectors $P_1, P_2 \ldots P_{2^{2b}}$, where each vector P_v is a 2×1 vector, $P_v = (P_{v1}, P_{v2})^T$. We define an arbitrary one-to-one mapping which maps 2b bits onto V. Note that the choice of the set V and the mapping $\beta(\cdot)$ is completely arbitrary as long as vectors $P_1, P_2 \ldots P_{2^{2b}}$ are unit-length and the mapping $\beta(\cdot)$ is one-to-one [5]. However, there exist structured mappings that do not require an exponential amount of memory to be saved. A few examples will be provided in the sequel.

$P_1, P_2 \ldots\ldots P_{2^{2b}}$ and when we need to refer to its index in set V, we use the notation of P_v.

Assuming that the encoding starts with the transmission of an arbitrary vector S^0. For block l, we use the 2b input bits to pick the corresponding vector P^l in V using the one-to one mapping $\beta(\cdot)$. Note that P^l is one of the vectors S^{l-1} is transmitted for the $(l-1)^{th}$ block, we calculate S^l by Eqn 3:

$$S^l = P_1^l V_1(S^{l-1}) + P_2^l V_2(S^{l-1}) \qquad (3)$$

Where; P_1^l and P_2^l are the first and second elements of the vector P^l, respectively. Note that since $V_1(S^{l-1})$ and $V_2(S^{l-1})$ create an orthogonal basis, P_1^l and P_2^l can be derived from multiplying S^l by $[V_1(S^{l-1})]H$ and $[V_2(S^{l-1})]^H$, respectively. Therefore, we have Eqns 4 and 5.

$$P_1^l = [V_1(S^{l-1})]^H . S^l = s_1^l (s_1^{l-1})^* + s_2^l (s_2^{l-1})^* \qquad (4)$$

$$P_2^l = [V_2(S^{l-1})]^H . S^l = s_1^l s_2^{l-1} + s_2^l s_1^{l-1} \qquad (5)$$

The length of the vector P^l is constant and with an appropriate normalization of the initial vector S^0, a unit-length vector P^l can be obtained. Figure 2 shows the block diagram of the encoder.

A SPECIAL CASE

The above differential encoding scheme is general and works for any set V and mapping ß (·) as long as the vectors in V have the same length. One special case is if we use the input bits to pick signals from a unit-length constellation, for example PSK [6]. In other words, let us assume that the 2b input bits for block l pick z_1^l and z_2^l we set Eqns 6 and 7 as:

$$P_1^l = z_1^l, \qquad \text{and} \qquad P_2^l = -z_2^l. \tag{6}$$

Then, using (2.3),

$$S^l = z_1^l \cdot \begin{pmatrix} s_1^{l-1} \\ s_2^{l-1} \end{pmatrix} - z_2^l \cdot \begin{pmatrix} \left(s_2^{l-1}\right)^* \\ -\left(s_1^{l-1}\right)^* \end{pmatrix} = \begin{pmatrix} z_1^l s_1^{l-1} - z_2^l \left(s_2^{l-1}\right)^* \\ z_1^l s_2^{l-1} + z_2^l \left(s_1^{l-1}\right)^* \end{pmatrix} \tag{7}$$

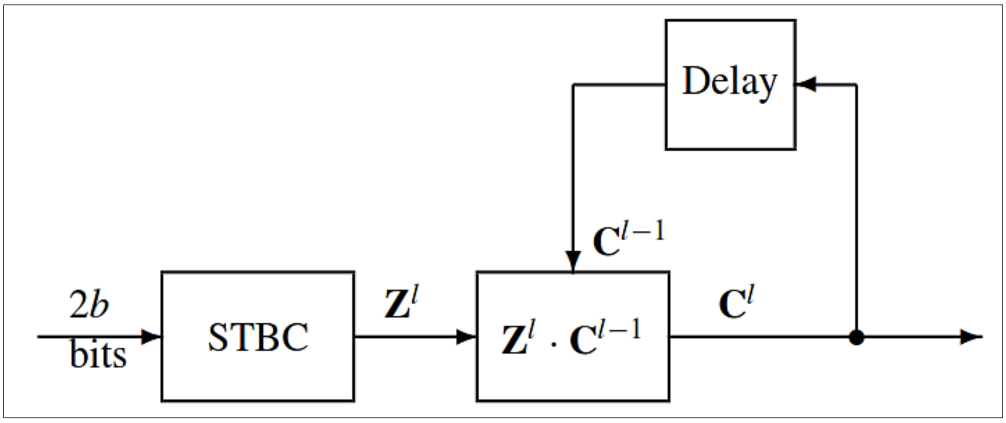

Fig. 3: *Differential Space Time Encoder Block Diagram.*

Then, using S^l in the STBC,results in transmitting the following code word (Eqns 8 and 9):

$$C(S^l) = \begin{pmatrix} z_1^l s_1^{l-1} - z_2^l \left(s_2^{l-1}\right)^* & z_1^l s_2^{l-1} + z_2^l \left(s_1^{l-1}\right)^* \\ -(z_1^l)^* (s_2^{l-1})^* + \left(z_2^l\right)^* s_1^{l-1} & (z_1^l)^* (s_1^{l-1})^* - \left(z_2^l\right)^* s_2^{l-1} \end{pmatrix}. \tag{8}$$

Now taking,

$$V_2(S^l) = \begin{pmatrix} -\left(s_2^l\right)^* \\ \left(s_1^l\right)^* \end{pmatrix}, \tag{9}$$

Instead of $V_2(S^l)$, and $P_2^l = z_2^l$ instead of P_2^l also results in the same codeword. This is equivalent to the differential-encoding block diagram in Figure 3. The input codeword $Z^l$is constructed using the 2b input bits for the lth block and the corresponding input symbols z_1^l and z_2^l (Eqns 10 and 11).

$$Z^l = \begin{pmatrix} z_1^l & z_2^l \\ -\left(z_2^l\right)^* & \left(z_1^l\right)^* \end{pmatrix}. \tag{10}$$

Then C^l is calculated based on C^{l-1} as follows:

$$C^l = \begin{pmatrix} z_1^l s_1^{l-1} - z_2^l \left(s_2^{l-1}\right)^* & z_1^l s_2^{l-1} + z_2^l \left(s_1^{l-1}\right)^* \\ -(z_2^l)^* s_1^{l-1} + \left(z_1^l\right)^* \left(s_2^{l-1}\right)^* & -(z_2^l)^* s_2^{l-1} + \left(z_1^l\right)^* \left(s_1^{l-1}\right)^* \end{pmatrix} \tag{11}$$

The code-words in Eqns 9 and 11 are the same which means the differential encoder in Figure 3 is a special case of the encoder in Figure 2.

DIFFERENTIAL DECODING

In this section, we consider the decoding of the differential space-time modulation for two transmit antennas. For the sake of simplicity of presentation, we consider only one receive antenna [6].

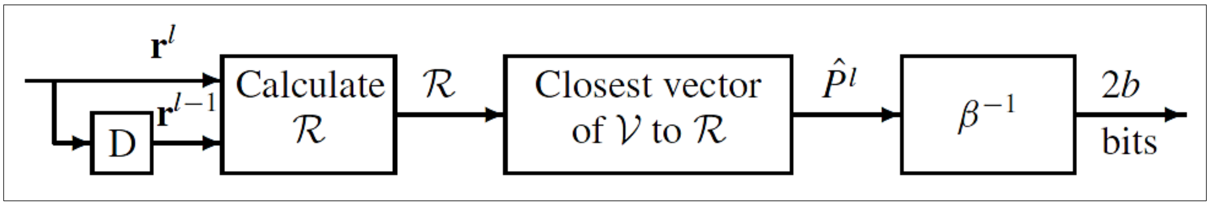

Fig. 4: *Differential Space Time Decoder Block Diagram.*

The general case of M receive antennas is easily handled by maximum ratio combining. Let us denote the two received signals for block l by r^l_1 and r^l_2. We have Eqn 12:

$$\begin{cases} r_1^l = \alpha_1 s_1^l + \alpha_2 s_2^l + \eta_1^l \\ r_2^l = -\alpha_1 \left(s_2^l\right)^* + \alpha_2 \left(s_1^l\right)^* + \eta_2^l \end{cases} \quad (12)$$

Where; η^l_1 and η^l_2 are the noise samples for block l. We define a vector R to reconstruct a noisy version of the scaled P^l as follows Eqn 13:

$$R = \begin{pmatrix} \left(r_1^{l-1}\right)^* r_1^l + r_2^{l-1}\left(r_2^l\right)^* \\ \left(r_2^l\right)^* r_1^{l-1} - r_1^l\left(r_2^{l-1}\right)^* \end{pmatrix} = (|\alpha_1|^2 + |\alpha_2|^2) P^l + N \quad (13)$$

Then, similar to the dispute for the DPSK decoding wherein the scaling does not change the geometry of the detection regions and so, the decoder finds the closest vector P^l in V and declares it as the best estimate of the transmitted vector. The inverse mapping provides the decoded bits as depicted in Figure 4. Similar to the case of DPSK for one transmitter, the result of the differential decoding is a 3 dB loss in performance due to the doubling of the effective noise. To find the closest vector of V to R, denoted by $\widehat{P^l}$, the most complex method is to perform a full search over all vectors in set V. In general, this may need 2^{2b} comparisons. However, depending on the structure of the vectors in V. In the case of DPSK, the detection regions are bordered by lines passing the origin. Therefore, to find the adjoining constellation point, the angle of the decision variable in a polar coordinate is found. For many examples of set V, a similar simple approach in a higher dimensional space is possible [4]. The separate decoding of space-time modulation schemes for two transmit antennas is shown and later can be extended for more than two antennas, it is demonstrated that similar to coherent detection of STBCs, the decoding complexity of the differential space-time modulation grows linearly by rate and number of antennas.

SIMULATION RESULTS

The results are taken for 2 transmit and 2 receive antennas as well as 1 transmit and 1 receive antenna. The input bit sequence is fixed 130 bits which are equiprobable. Random Gaussian noise is added and the results are taken under Rayleigh fading channel.

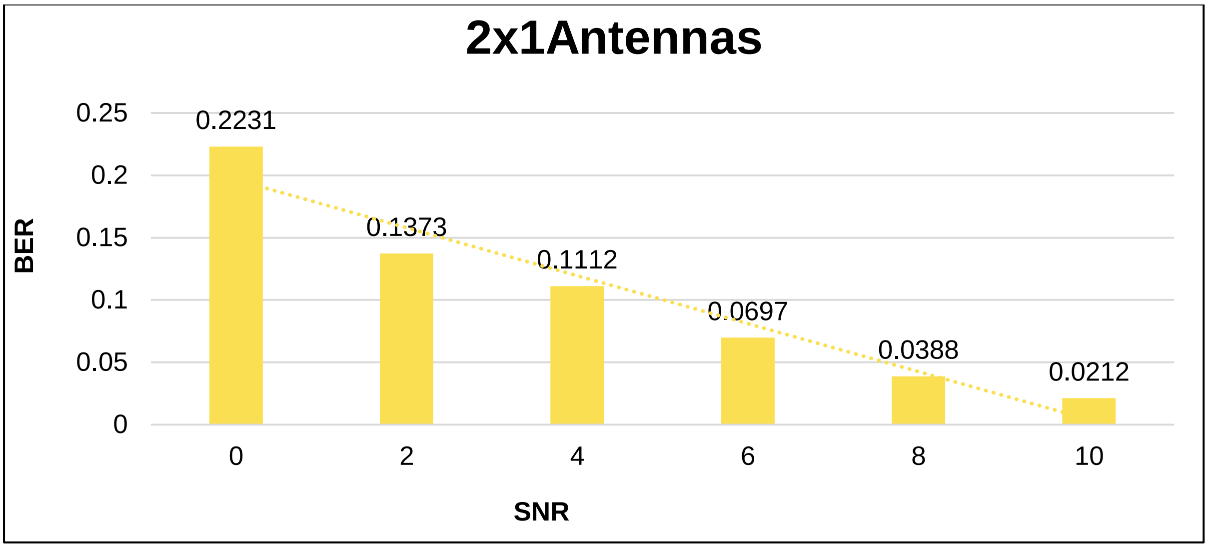

Fig. 5: *BER for 2 Transmit and 1 Receive Antenna (Numeric Graph).*

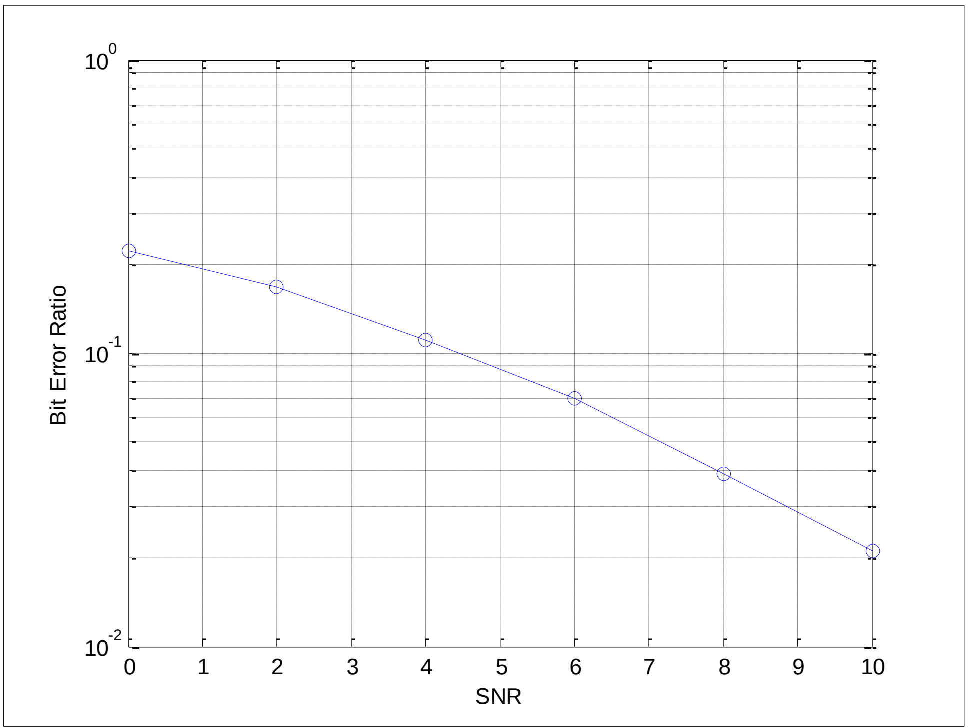

Fig. 6: *BER for 2 Transmit and 1 Receive Antennas.*

Table 1: *BER of DSTBC for 2x1 Antennas.*

SNR	0	2	4	6	8	10
BER2x1	0.2231	0.1373	0.1112	0.0697	0.0388	0.0212

Figures 5 and 6 shows that as SNR increases BER decreases in DSTBC. Tables 1–3 shows the numeric value of BER with its corresponding SNR.

Now, if we increase the number of receiving antennas to two, the same result is obtained as shown in Figures 7 and 8.

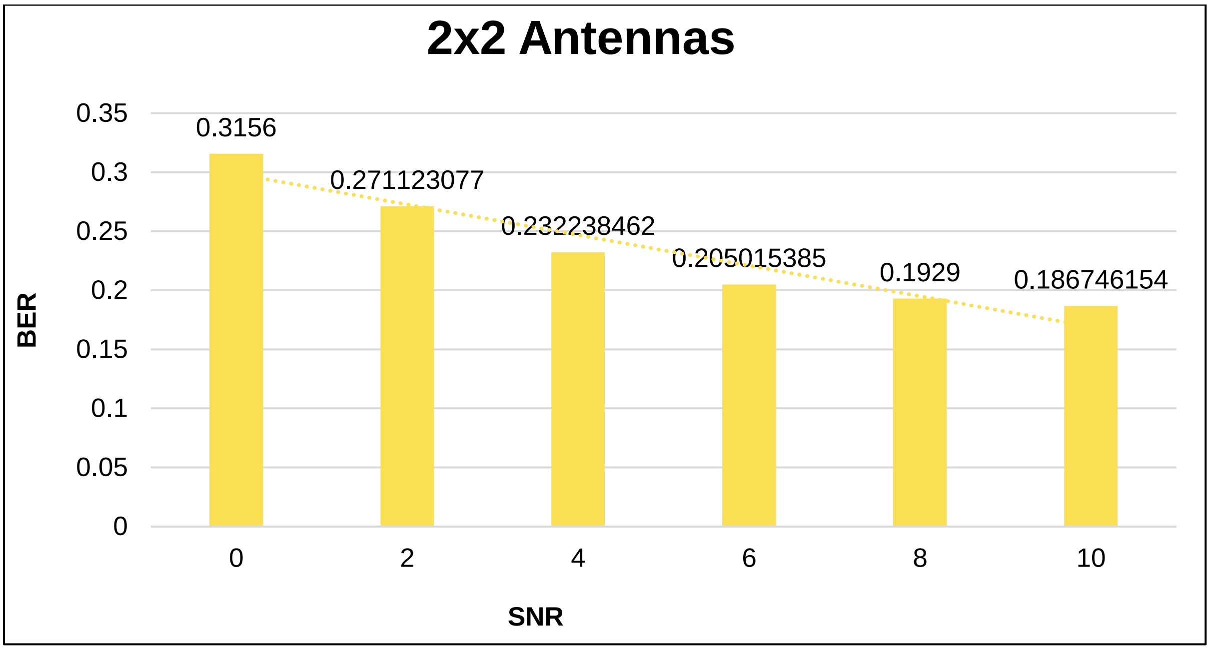

Fig. 7: *BER for 2 Transmit and 2 Receive Antennas (Numeric Graph).*

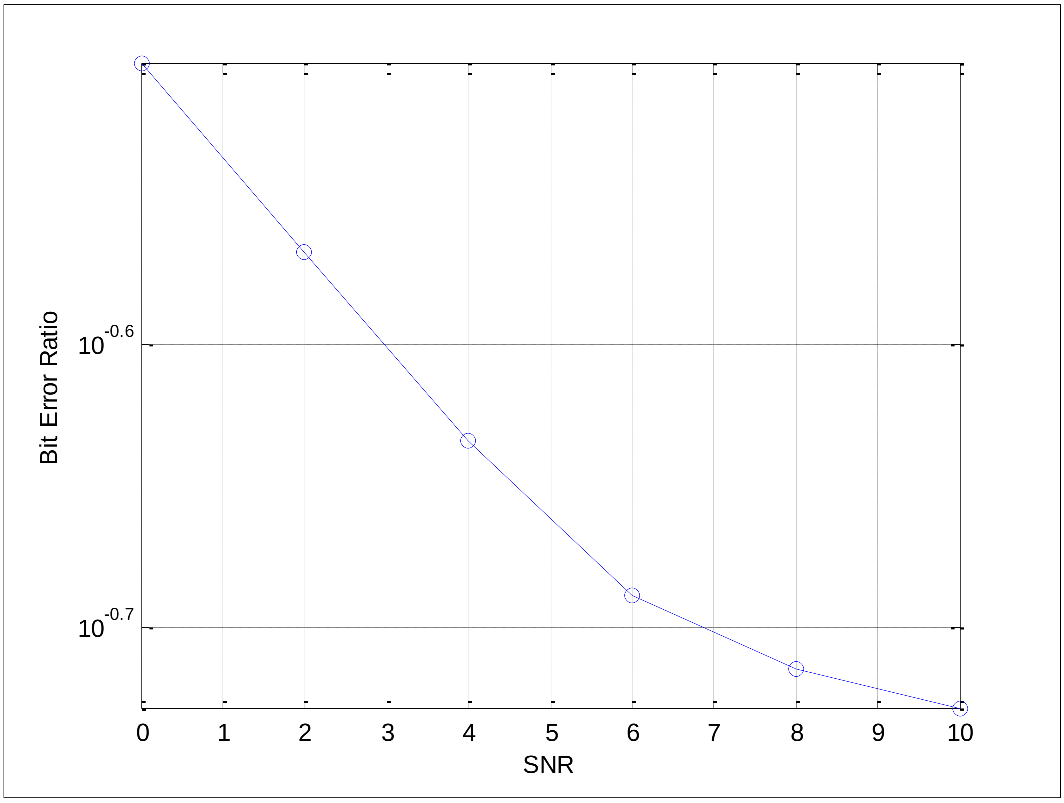

Fig. 8: *BER for 2 Transmit and 2 Receive Antennas.*

Table 2: *BER of DSTBC for 2x2 Antennas.*

SNR	0	2	4	6	8	10
BER2x2	0.3156	0.271123	0.232238	0.205015	0.1929	0.186746

Table 2 Shows the Numeric Values of BER with its Corresponding SNR.

CONCLUSION

The primary focus of the codes that are discussed so far has been on the case when only the receiver knows the channel. A scheme without CSI (Channel State Information) at the receiver, however, would be desirable in some situations. DSTBC are the codes which do not require CSI. Here the first case is considered with two transmit and one receive antenna and its BER is compared with the second case in which there are two transmit and two receive antennas. In DSTBC as the number of antenna increases the BER decreases.

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