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Title	Closed Loop MIMO Pre-Coding using Givens Rotation
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Re:	IEEE 802.16-REVe/D5a, BRC recirc
Abstract	This contribution proposes an efficient closed loop MIMO unitary beam-forming method based on the Givens rotation technique. The unitary beam-former is first represented by Givens parameters, then a set of scalar Givens parameters are quantized against a codebook, the index of the codebook is feedback the BS transmitter to reduce the UL feedback requirement, furthermore the Givens parameter can be quantized by using delta modulation. Harmonization with IEEE C802.16e-04/516r3 and
Purpose	To incorporate the changes here proposed into the 802.16e D5a draft.
Notice	
Release	
Patent Policy and Procedures	

Closed Loop IMO Pre-Coding using Givens Rotation

1. Introduction

In this contribution, we propose two closed-loop MIMO transmission methods, where the transmitted symbols are precoded using Givens rotation matrices.

In the first method that we call *codebook-based Givens pre-coding (C-Givens)*, a codebook of unitary rotation matrices formed using Givens rotations is generated; this codebook is known both to the receiver and to the transmitter. Given the received data, the receiver determines the optimum rotation matrix for each OFDM sub-band that will result in best performance (see e.g. [2], or to compose right singular matrix of the MIMO channel into Givens rotation matrices). It will then transmit *only* the index of the optimum rotation matrix to the transmitter, where it is reconstructed and employed to precode the transmitted symbols. With a very few number of rotation matrices in the basis codebook, the amount of feedback involved in such a scheme is much less than if the full set of channel coefficients are sent back from the receiver to the transmitter.
In the second method, the Givens angle parameters are first quantized by using simple 1-bit scalar delta modulation to allow reduction of the redundancy in time/frequency and then sent back to the transmitter. At the transmitter, the from these recovered Givens angle parameters, the Givens rotation matrices can be reconstructed for pre-coding. We will refer to this technique as *differential Givens pre-coding (D-Givens)*. . .

2. Pre-Coding using Givens Rotation Codebook (C-Givens)

An alternative to sending the complete channel state information is to define a codebook containing a finite set of N unitary rotation matrices, which is known to both the transmitter and the receiver. Based on a metric that maximizes post-processed signal-to-noise ratio (SNR), the receiver determines a precoding rotation matrix from the codebook for each OFDM sub-band. The index of this matrix is then sent to the transmitter via a feedback path, where exactly the same matrix is reconstructed and used to precode the transmitted symbols. This operation requires only bits to be fed back from the transmitter to the receiver per OFDM sub-band. For example, if the set has eight rotation matrices, then three bits per sub-band need to be sent back.

2.1 2_2 MIMO Example

For the sake of clarity, we will treat the simpler 2_2 case first. For MIMO, we define the codebook with a set of N rotation matrices denoted by

,

where

and .

Note that for each sub-band, the index of the rotation matrix may be sent from the receiver to the transmitter only once per frame. This is assuming that the channel stays static over the frame duration.

2.2 *PXP* MIMO

Let us now consider the general case, where . We generate the <u>*real*</u> unitary rotation by applying a sequence of / Givens rotations to the channel matrix as follows

,

where the Givens rotation matrix is given is

with and . Since is orthogonal, it is clear that the resulting rotation matrix is unitary.

Note that each Givens rotation in the above product can be associated with a different rotation angle. For example, for , is the product of three Givens rotations, the beamformer matrix is a product of $P(P-1)/2 = 3(3-1)/2 = 3$ Givens rotations

.

We quantize the Givens rotation angles and form a codebook of unitary matrices as:

,

where

and .

The feedback requirement in this case is again bits. We use 4 level quantizations for each rotation, i.e. , this results in a total of *real* unitary rotation matrices. This implies a feedback of 6 bits per OFDM sub-band.
To summarize, with 4-level quantization for each Givens rotation, the Givens rotation codebook size is listed in Table 1

Table 1 C-Givens Codebook Feedback Requiresment

# of streams		1		2		3		4	
		# Givens Rotations	Feedback (bits)	# Givens Rotations	Feedback (bits)	# Givens Rotations	Feedback (bits)	# Givens Rotations	Feedback (bits)
# of antennas	2	1	2	2	4				
	3	2	4	3	6	3	6		
	4	3	6	4	8	5	10	6	12

3. Pre-Coding using Differential Given Rotation (D-Givens)

Consider the Given rotation complex matrix

,

which is completely represented by two real Givens parameters and . These parameters are further compressed by using the simplest delta modulator of Figure 1 to exploit the channel correlation in time or frequency domain.

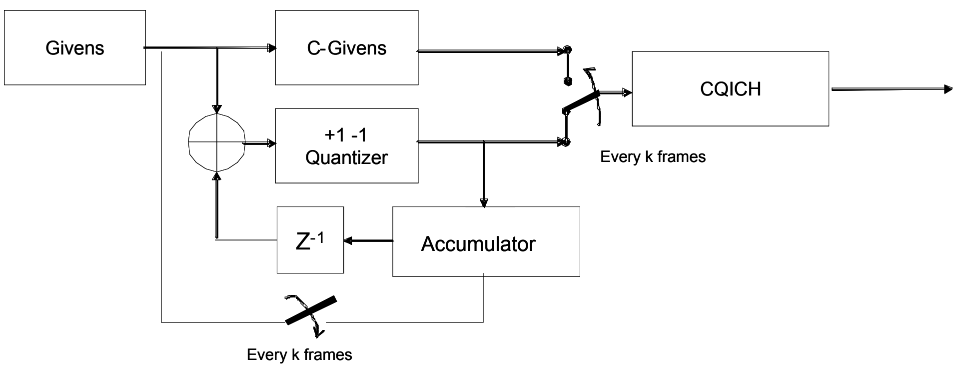

Figure 1: Delta modulator to quantize Givens parameters.

The quantized parameters of each Givens rotations are fed back to the transmitter, where the unitary matrix is re-constructed for pre-coding. In this case, we can alternative the quantization parameters and , namely for the *even* frame the parameter is quantized and for odd frame the parameter quantized. The required feedback bits for D-Givens is listed Table 2.

The key advantage of D-Givens is that we can use higher level of quantization to minimize the quantization error, in this case, the quantization level for the Givens parameters can be 8 level to achieve every high tracking accuracy.

Table 2 Feedback requirement for D–Givens (bits)

# of streams		1		2		3		4	
		# Givens Rotations	Feedback (bits)	# Givens Rotations	Feedback (bits)	# Givens Rotations	Feedback (bits)	# Givens Rotations	Feedback (bits)
# of antennas	2	1	1	2	2				
	3	2	2	3	3	3	3		
	4	3	3	4	4	5	5	6	6

4. Proposed Solution

The proposed solution consists of the following key aspects:

1. To use the C-Givens method to support the burst allocation
2. To use the C-Givens to support the initial feedback of the unitary beam-former and to use D-Givens to track the beam-former feedback for the continuous transmission
3. To use the C-Givens method periodically to reset the D-Given to prevent the error propagation.
4. The D-Givens feedback is supported via CQICH and C-Givens is supported via the MAC header feedback.

5. Simulation Results

The simulation conditions and set-up is listed in Table 1

Table 3 Simulation Set Up

Configurations	Parameters	Comments
Optional BAND AMC sub-channel		The band allocation in time-direction shall be fixed at center band
Coding Modulation Set	CTC	Coded Symbol Puncture for MIMO Pilot
	QPSK _, QPSK, _, 16QAM _, 16QAM R=_, 64QAM R=1/2, 64QAM R= 3/4	
Code Modulation Mapping	Single encoder block with uniform bit-loading	
MIMO Receiver	MMSE-one-shot for SVD MLD receiver for OL and CL SM	
FFT parameters	Carrier 2.6GHz, 10MHz, 1024-FFT Guard tone 79 left, 80 right CP=11.2ms, Sampling rate = 8/7, Sub-band spacing = 11.2kHz	
Frame Length	5ms frame, DL:UL=2:1	
Feedback delay	2 frames	
MIMO Configurations	4x2	
Channel Model	ITU-PA, 3km/h, Antenna Correlation: 20% Perfect Channel Estimation	
Feedback	SVD: perfect pre-coding matrix V D-Givens Compact code book	

5.1.1 <u>Performance</u>

Figure 4 shows the throughout curve for comparing perfect SVD, Givens and Compact codebook and antenna selection based methods with 2-frame delay. For the Givens method we chose 4-level quantification, the C-Givens is employed as initial beamformer and D-Givens is employed as tracking beamformer.

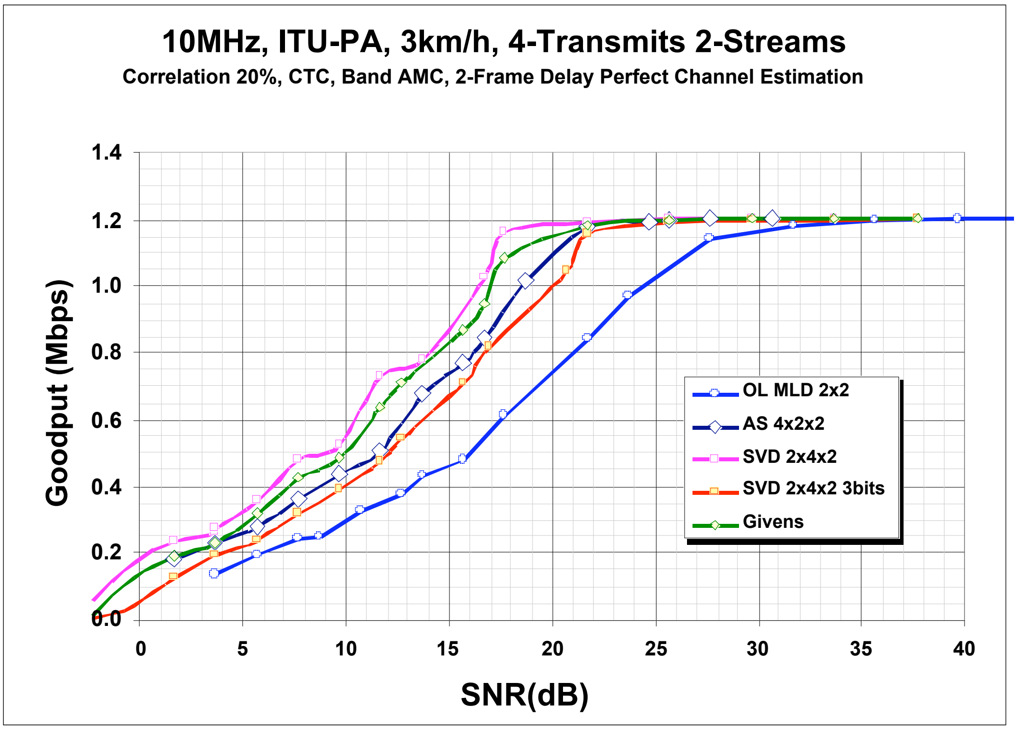

Figure 2 Comparison of perfect SVD, D-Givens, Compact Codebook and Antenna Selection

It can be seen that the Givens beamformer achieves the better performance. It can be also seen that the D-Givens can achieve superior performance than 6-bit compact codebook (C80216e-04_515r3.doc)

5.1.2 Feedback Resource Requirement

The feedback resources requirement and comparison is shown in Figure 5. As we can see the D-Givens requires less 6-bit feedback resources for all the antenna configurations.

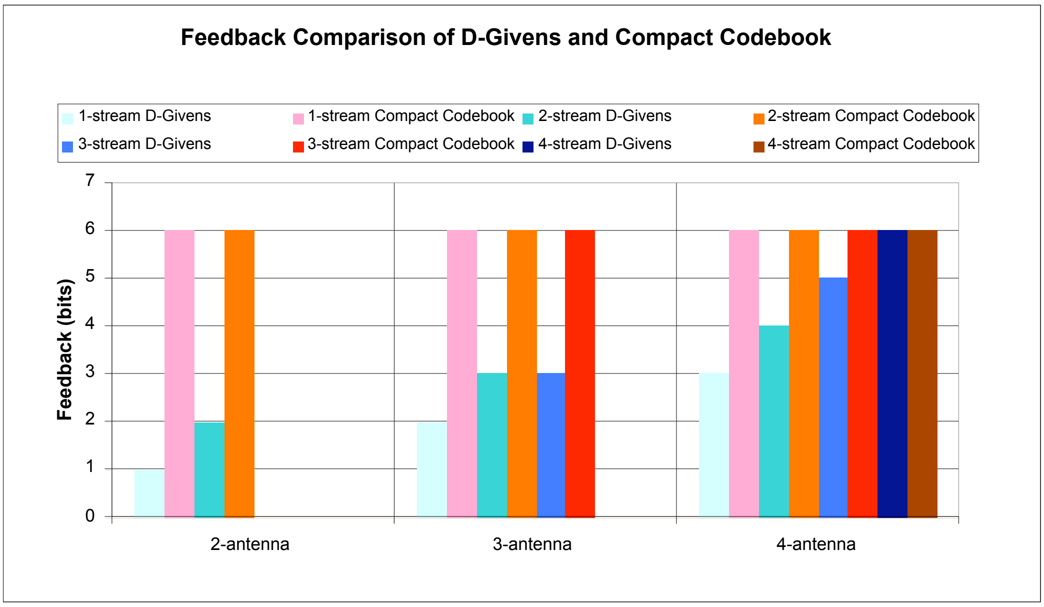

Figure 3a Feedback Resources Comparison

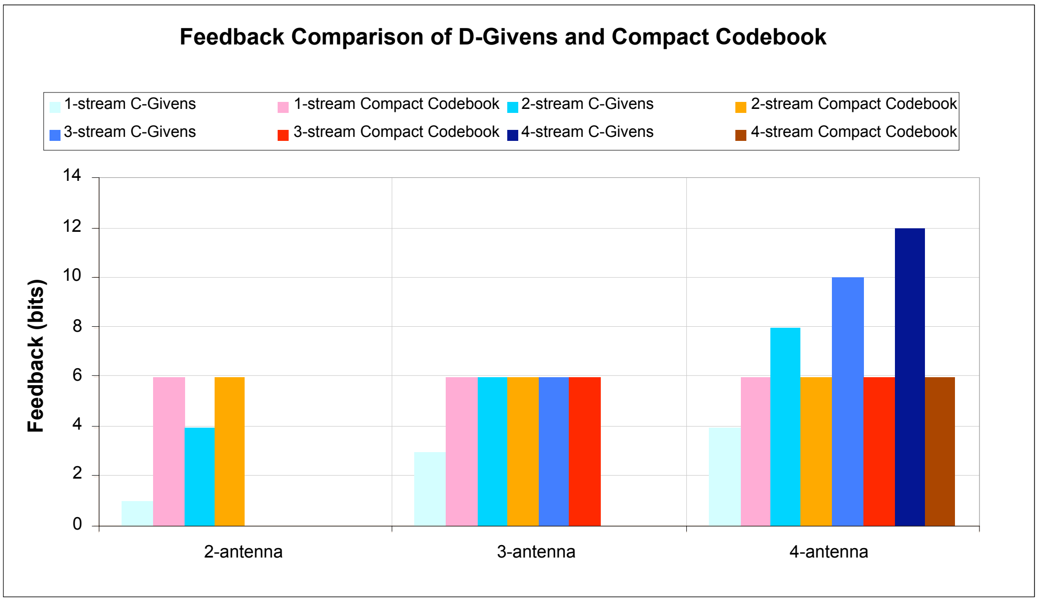

Figure 4b Feedback Resources Comparison

6. Text Proposal

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[Add a new section 8.4.8.3.6.2 as follows]

8.4.8.3.6.1 Unitary Matrix Pre-coding for 2, 3 and 4 Transmit Antennas

A unitary matrix V can be applied at BS actual transmit antennas to perform the closed loop MIMO pre-coding with s transmit streams. The V matrix is expanded by using real Givens decomposition as[7]: $V = \prod_{i=1}^{S}\prod_{j=i+1}^{N} G(i,j,\theta_{i,j})$ where

$$G(i,j,\theta_{i,j}) = \begin{bmatrix} 1 & \cdots & 0 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots & & \vdots \\ 0 & \cdots & \cos(\theta_{i,j}) & \cdots & \sin(\theta_{i,j}) & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & -\sin(\theta_{i,j}) & \cdots & \cos(\theta_{i,j}) & \cdots & 0 \\ \vdots & & \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & 0 & \cdots & 1 \end{bmatrix},$$

the parameter of each Givens rotation is quantized by using a 4-level uniform quantizer

$\theta_{i,j}(l_{i,j}) = \frac{2\pi}{2N} l_{i,j}, l_{i,j} = 1,2,3,4$ and the quantized Givens ration expansion constitutes a beamformer codebook, the quantization level for each Givens $l_{i,j}$ and concatenated by binary representation as $\log_2(l_{i,j})$ or $i = 1,2 \ldots j = 1,2 \ldots$ and to feed back to BS to re-generate the unitary matrix V.

The V matrix is expanded by using complex Givens decomposition as[7]:

$V = \prod_{i=1}^{S}\prod_{j=i+1}^{N} G(i,j,\theta_{i,j},\varphi_{i,j})$ where

$$G(i,j,\theta_{i,j},\varphi_{i,j}) = \begin{bmatrix} 1 & \cdots & 0 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots & & \vdots \\ 0 & \cdots & \cos(\theta_{i,j}) & \cdots & e^{j\varphi_{i,j}}\sin(\theta_{i,j}) & \cdots & 0 \\ \vdots & & \vdots & \ddots & \vdots & & \vdots \\ 0 & \cdots & -e^{-j\varphi_{i,j}}\sin(\theta_{i,j}) & \cdots & \cos(\theta_{i,j}) & \cdots & 0 \\ \vdots & & \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & 0 & \cdots & 1 \end{bmatrix}$$

For the consecutive sub-channel mapping in both time and frequency direction with index k, the delta modulation is further applied to the parameters $\theta_{i,j}(2k)$ and $\varphi_{i,j}(2k+1)$. For $\theta_{i,j}(2k)$, delta $d_{i,j}(2k) = \theta_{i,j}(2k) - \hat{\theta}_{i,j}(2k-1)$ is quantized by a 1-bit quantizer which outputs $\tilde{\theta}_{i,j}(2k) = Q[d(2k)]$. $\hat{\theta}_{i,j}(2k-1) = \sum_{i=1}^{2k}\tilde{\theta}_{i,j}(i)$ is the reconstruction of $\theta_{i,j}(2k-1)$. For $\varphi_{i,j}(2k+1)$, delta $e_{i,j}(2k+1) = \varphi_{i,j}(2k+1) - \hat{\varphi}_{i,j}(2k)$ is quantized by a 1-bit quantizer which outputs $\tilde{\varphi}_{i,j}(2k+1) = Q[e(2k+1)]$. $\hat{\varphi}_{i,j}(2k) = \sum_{i=1}^{2k}\tilde{\varphi}_{i,j}(i)$ is the reconstruction of $\varphi_{i,j}(2k)$. The 1-bit quantization index for $\hat{\theta}_{i,j}(2k)$ and $\tilde{\varphi}_{i,j}(2k-1)$ is mapped onto CQICH with the bit concatenation of $\hat{\theta}_{i,j}(2k)$ for $i = 1,2\ldots j = 1,2\ldots$ and $\hat{\varphi}_{i,j}(2k+1)$ for $i = 1,2\ldots j = 1,2\ldots$ and to feed back to BS to re-generate the unitary matrix V.

--------------------------- *End text proposal* ---

[Modify the following table at the end of section 6.3.2.1.4.1]

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Table 7b. Feedback Type and feedback content.

Feedback Type	Feedback contents	Description
0b0000	Set as described in table 296d.	MIMO mode and permutation. Feedback
0b0001	DL average CQI (5bits)	5 bits CQI feedback
0b0010	Number of index, L (2 bits) + L occurrences of Antenna index (2 bits) + MIMO coefficients (5 bits, 8.4.5.4.10.6)	MIMO coefficients feedback
0b0011	Preferred-DIUC (4 bits)	Preferred DL channel DIUC feedback
0b0100	UL-TX-Power (7 bits) (see table 7a)	UL transmission power
0b0101	Preferred DIUC(4 bits) + UL-TX-Power(7 bits) + UL-headroom (6 bits) (see Table 7a)	PHY channel feedback
0b0110	Number of bands, N (2 bits) + N occurrences of 'band index (6 bits) + CQI (5 bits)'	CQIs of multiple AMC bands
0b0111	Number of feedback types, O (2 bits) + O occurrences of 'feedback type (4bits) + feedback content (variable)'	Multiple types of feedback
0b01000	Feedback of index to long term precoding matrix in code book (6 bits), rank of precoding code book (2 bits) and FEC and QAM feedback (6 bits) according to Table Z.	Long term precoding feedback
0b01001	Life span of short term precoding feedback (2 bits) according to Table Z.	The recommended number of frames the short term precoding feedback can be used for.
0b1001	The codebook index of Given rotations	
0b1010-0b1111	Reserved for future use	

Table Z –Givens Rotation Codebook Index in MAC feedback header message

MAC-header feedback type bit indication	Feedback element	Number of bits	Description
0b01001	The codebook index of Given rotations	P(P-1)/2	P is number of antenna

Table 298a. CQICH Enhanced allocation IE format

Syntax	Size (bits)	Notes
CQICH_Enhanced_Alloc_IE() {		
Extended UDIUC	4	0x09
Length	4	Length in bytes of following fields
CQICH_ID	variable	Index to uniquely identify the CQICH resource assigned to the MSS
Period (=p)	24	A CQI feedback is transmitted on the CQICH every 2^p frames
Frame offset	3	The MSS starts reporting at the frame of which the number has the same 3 LSB as the specified frame offset. If the current frame is specified, the MSS should start reporting in 8 frames
Duration (=d)	3	A CQI feedback is transmitted on the CQI channels indexed by the CQICH_ID for 10 x 2^d frames. If d==0, the CQICH is de-allocated. If d == 111, the MSS should report until the BS command for the MSS to stop.
NT actual BS antennas	3	001 = Reserved 010 = 2 actual antennas 011 = 3 actual antennas 100 = 4 actual antennas 101 = 5 actual antennas 110 = 6 actual antennas 111 = 7 actual antennas 000 = 8 actual antennas
Feedback_type	3	000 = Fast DL measurement/Default Feedback 001 = Precoding weight matrix information 010 = Channel matrix H 011 = MIMO mode and permutation zone 100 = Open loop precoding 101-111 = Reserved
CQICH_Num	4	Number of CQICHs assigned to this CQICH_ID is (CQICH_Num +1)
for (i=0;i<CQICH_Num+1;i++) {		
Feedback_type	3	000 = Fast DL measurement/Default Feedback with antenna grouping 001 = Fast DL measurement/Default Feedback with antenna selection 010 = Fast DL measurement/Default Feedback with reduced code book 011 = Quantized precoding weight feedback 100 = Index to precoding matrix in code book

		101 = Channel Matrix Information 101 = Per stream power control 110 = Adaptive bit loading 111 = Differential Feedback
Allocation index	6	Index to the fast feedback channel region marked by UIUC=0
}		
~~if ((Feedback_type != 011) & (! 6-bit CQICH)) {~~ ~~MIMO_permutation_feedback cycle }~~	~~2~~	~~This field exists only for 4-bit and 5-bit CQI payload.~~ ~~00 = No MIMO and permutation mode feedback~~ ~~01 = the MIMO and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 4 frames. The first indication is sent on the 8th CQICH frame.~~ ~~10 = the MIMO mode and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 8 frames. The first indication is sent on the 8th CQICH frame.~~ ~~11 = the MIMO mode and permutation mode indication shall be transmitted on the CQICH indexed by the CQICH_ID every 16 frames. The first indication is sent on the 16th CQICH frame.~~
Padding	variable	The padding bits are used to ensure the IE size is integer number of bytes.
}		

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7. References

[1] Nokia/Intel: Compact Codebooks for 802.16e Closed-Loop MIMO Jan. 05, 2004 OFDMA/OFDM Systems
[2] Beceem: Closed Loop MIMO Pre-coding
[3] Motorola: Closed-Loop MIMO for IEEE 802.16e
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[6] IEEE P802.16-REVd/D5-2004 Draft IEEE Standards for local and metropolitan area networks part 16: Air interface for fixed broadband wireless access systems
[7] G. H. Golub and C. F. Van Loan, *Matrix Computations*, Baltimore: Johns Hopkins, 1996.