13.6.3 PRECODING MATRIX INDICATOR

- The Precoding Matrix Indicator (PMI) allows the UE to report its preferred precoding for downlink transmissions on the PDSCH. The PMI is applicable to closed loop and semi-open loop transmission schemes. In the case of semi-open loop transmission schemes a partial PMI report is provided to the Base Station
- In the case of smaller antenna configurations, e.g. a single cross polar panel antenna, the PMI can indicate the preferred precoding for MIMO. In the case of larger antenna configurations, e.g. a 64 transceiver active antenna, the PMI can indicate the preferred precoding for both MIMO and beamforming
- It is not mandatory for the Base Station to apply the precoding indicated by the PMI, and the Base Station does not provide the UE with explicit information regarding the precoding which has been applied. Instead, the UE relies upon using the Demodulation Reference Signal (DMRS) when decoding the PDSCH. The DMRS is precoded in the same way as the PDSCH so it can be used to determine the composite impact of the propagation channel and the Base Station precoding
- The release 15 version of the 3GPP specifications relies upon 'implicit' Channel State Information. This means that the UE reports its preferred precoding for the current propagation channel conditions, but the UE does not explicitly specify the propagation channel which has been measured. 'Explicit' Channel State Information involves the UE reporting the actual propagation channel measurements, e.g. a set of multi-path components with a range of delays and amplitudes. It is likely that 'explicit' Channel State Information will be introduced within a later version of the 3GPP specifications
- The precoding matrices specified by 3GPP are based upon a specific set of assumed antenna configurations. These antenna configurations are specified by defining the number of rows and columns of cross polar antenna elements. For example, a smaller antenna may have 1 row and 2 columns of cross polar antenna elements, supporting a total of 4 transceivers. A larger antenna could have 4 rows and 4 columns of cross polar antenna elements, supporting a total of 32 transceivers. The set of antenna configurations assumed by 3GPP does not restrict live network deployments from using other configurations. The maximum antenna configuration assumed by 3GPP supports a total of 32 transceivers and is thus able to transmit 32 CSI Reference Signals. An actual network deployment could use an active antenna with 64 transceivers but for the purposes of CSI reporting it could transmit CSI Reference Signals using up to 32 of its transceivers
- The release 15 version of 3GPP TS 38.214 defines four solutions for PMI reporting. These solutions are summarised in Table 297 and are described in greater detail within the following sub-sections

	Type 1 Single Panel	*Type 1 Multi Panel*	*Type 2 Single Panel*	*Type 2 Port Selection*
Primary Utilisation	Single User MIMO		Multi-User MIMO	
MIMO Ranks	1 to 8	1 to 4	1 to 2	
Resolution	Normal		High	
Reporting Stages	Dual Stage reporting of Wideband and Sub-band information			
Reporting Content	Beam selection and co-phasing phase shifts		Weighted combination of beams with relative amplitudes and co-phasing phase shifts	
CSI RS Ports	2, 4, 8, 12, 16, 24, 32	8, 16, 32	4, 8, 12, 16, 24, 32	
Solution Type	Standalone			Hybrid, or combined with information from Beam Management or Channel Reciprocity
CSI RS Beamforming	CSI RS typically transmitted without Beamforming			CSI RS Beamformed

Table 297 – Solutions for PMI Reporting

- The 'Type 1 Single Panel' solution includes support for basic 2×2 MIMO without beamforming, e.g. when using a single cross polar panel antenna. It also provides support for 4×4 and 8×8 MIMO using larger antenna configurations which are also able to support beamforming. The 'Type 1 Multi-panel' solution provides support for Non-Uniform Antenna Arrays, i.e. the antenna element spacing between antenna panels is not equal to the antenna element spacing within a panel
- Both of the Type 1 solutions support PMI reporting in 2 stages. The first stage provides wideband information which does not change rapidly over time. This can involve beam selection, or beam group selection. The second stage provides sub-band information which changes more rapidly over time. This can involve beam selection from within a group and phase shift selection for co-phasing between polarisations, layers and antenna panels
- The Type 2 solutions focus upon providing more detailed Channel State Information for the purposes of Multi-User MIMO. They support a maximum Rank of 2 corresponding to a maximum of 2 layers per UE. The maximum number of layers per cell is likely to be higher to allow multiple UE to use 2×2 MIMO simultaneously while sharing a common Resource Block allocation
- Type 2 reports are based upon selecting a set of beams and then specifying relative amplitudes and phases to generate a weighted combination of beams for each layer of transmission. The 'Type 2 Port Selection' solution relies upon the Base Station having some advance information to allow beamforming of the CSI Reference Signal transmissions. This advance information can originate from uplink measurements if channel reciprocity is available. Otherwise it can originate from Beam Management reports or it can use the wideband reports from a different PMI reporting solution (this is known as a hybrid solution when a combination of PMI reporting solutions is used)

- The majority of parameters associated with PMI reporting are configured using the *CodebookConfig* parameter structure presented in Table 298. This parameter structure uses the combination of *codebookType* and *subtype* to identify the relevant PMI reporting solution. The following sub-sections describe each of these PMI reporting solutions and the relevant parameter sets
- In the case of the 'Type 1 Single Panel' codebook, the Base Station specifies the use of two antenna ports, or more than 2 antenna ports. If only 2 antenna ports are used then the codebook provides precoding for MIMO. If more than 2 antenna ports are used then the codebook provides precoding for both MIMO and beamforming. When using more than 2 antenna ports, the Base Station specifies the 'n1-n2' antenna configuration to be assumed by the UE (described in the next sub-section)
- Each 'n1-n2' antenna configuration has an associated bit string which is used for codebook subset restriction (these bit strings are not shown in Table 298). For example, the '2-1' configuration uses a bit string of length 8 to specify its codebook subset restrictions. These restrictions can be used to limit the set of beams available for selection by the UE. 3GPP specifies an 'Oversampling' factor of 4 to increase the number of beams available for selection. This means that a '2-1' antenna configuration supports a total of $2 \times 4 = 8$ beams and these 8 beams correspond to the bit string of length 8. As a second example, the '4-4' configuration uses a bit string of length 256 to specify its codebook subset restrictions. In this case, the 'Oversampling' factor of 4 leads to a total of $(4 \times 4) \times (4 \times 4) = 256$ beams and these 256 beams correspond to the bit string of length 256. Note that in the first example, the number of beams was given by 2×4 and was not given by $(2 \times 4) \times (1 \times 4)$. This is because beamforming in the elevation direction is not possible when 'n2' = 1
- The *CodebookConfig* specifies a second codebook subset restriction for the 'Type 1 Single Panel' codebook using the *typeI-SinglePanel-codebookSubsetRestriction-i2* information element. In this case, the restriction refers to 'i2' which corresponds to the second stage of PMI reporting (the first stage is based upon beam selection and generates 'i1'). The second stage of PMI reporting can be used to select 1 beam from a group of 4 beams (when using *codebookMode* = 2) and can also be used to select 1 phase shift from a set of 4 phase shifts. This leads to 16 combinations available for selection and thus a bit string of length 16 has been specified for the codebook subset restriction
- In addition, it is possible to restrict the rank values reported by the UE. The 'Type 1 Single Panel' codebook supports up to rank 8 and so a bit string of length 8 has been specified

CodebookConfig							
codebookType	CHOICE						
type1	subType	CHOICE					
		typeI-SinglePanel	nrOfAntennaPorts	CHOICE			
				two	twoTX-CodebookSubsetRestriction		
				moreThanTwo	n1-n2	CHOICE	
						2-1, 2-2, 4-1, 3-2, 6-1, 4-2, 8-1, 4-3, 6-2, 12-1, 4-4, 8-2, 16-1	
					typeI-SinglePanel-codebookSubsetRestriction-i2	BIT STRING {SIZE 16}	
			typeI-SinglePanel-ri-Restriction		BIT STRING {SIZE 8}		
		typeI-MultiPanel	ng-n1-n2	CHOICE			
				2-2-1, 2-4-1, 4-2-1, 2-2-2, 2-8-1, 4-4-1, 2-4-2, 4-2-2			
			ri-Restriction	BIT STRING {SIZE 4}			
	codebookMode		1, 2				
type2	subType	CHOICE					
		typeII	n1-n2-codebookSubsetRestriction	CHOICE			
				2-1, 2-2, 4-1, 3-2, 6-1, 4-2, 8-1, 4-3, 6-2, 12-1, 4-4, 8-2, 16-1			
			typeII-RI-Restriction	BIT STRING {SIZE 2}			
		typeII-PortSelection	portSelectionSamplingSize	1, 2, 3, 4			
			typeII-PortSelectionRI-Restriction	BIT STRING {SIZE 2}			
	phaseAlphabetSize		4, 8				
	subbandAmplitude		True, False				
	numberOfBeams		2, 3, 4				

Table 298 – *CodebookConfig* parameter structure

13.6.3.1 TYPE 1 SINGLE PANEL CODEBOOK

- ‘Type 1’ codebooks are primarily intended for Single User MIMO (SU-MIMO) with support for both high and low order transmissions, i.e. 8×8, 4×4 and 2×2 MIMO. The single panel version is based upon the assumption that the UE receives its downlink transmissions from a single antenna panel
- The Type 1 Single Panel codebook is configured using the *CodebookConfig* within the *CSI-reportConfig*. The *codebookType* must be set to ‘type1’, while the *subtype* must be set to ‘typeI-SinglePanel’
- The Base Station is then expected to transmit CSI Reference Signals from a specific number of antenna ports. The number of antenna ports is configured using the *nrofPorts* information element within the *CSI-RS-ResourceMapping*. The UE uses the CSI Reference Signals to identify its preferred precoding, i.e. the UE selects the precoding weights which it would like the Base Station to apply in order to maximise the downlink signal quality
- If the CSI Reference Signal is configured with 2 antenna ports {3000, 3001}then it is assumed that the Base Station is configured with a single column cross polar panel antenna, i.e. the Base Station is not capable of beamforming. In this case, the UE selects a codebook index from the set of values presented in Table 299. This table includes two columns of precoding matrices. The first column is applicable if the UE is reporting a Rank Indicator (RI) = 1, whereas the second column is applicable if the UE is reporting a Rank Indicator = 2. The precoding matrices represent the set of preferred phase shifts between layers transmitted by each antenna element

	1 Layer	2 Layers
Codebook Index 0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
Codebook Index 1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
Codebook Index 2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	Not Applicable
Codebook Index 3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	Not Applicable

Table 299 – Codebooks for 1 and 2 layer CSI Reporting when CSI Reference Signal uses antenna ports 3000 and 3001

- Figure 392 illustrates the precoding which corresponds to the single layer column of Table 299. The Layer Mapping function is transparent and modulation symbols are passed directly to the precoding. All codebook entries have a ‘1’ in the upper position so antenna port 1 transmits the Layer 1 modulation symbols directly (after scaling the amplitude by $1/\sqrt{2}$). Each codebook entry has a different value in the lower position and these different values correspond to phase shifts of 0, 90, 180 and 270 degrees. The selected phase shift is applied to the Layer 1 modulation symbols before transmission using antenna port 2

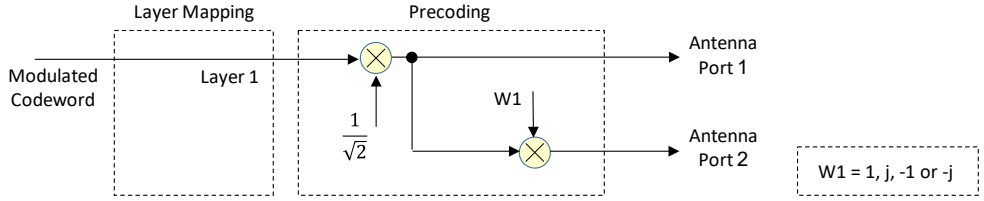

Figure 392 – Single layer precoding applicable when CSI Reference Signal uses antenna ports 3000 and 3001

- Figure 393 illustrates the precoding which corresponds to the dual layer column of Table 299. In this case, the Layer Mapping function generates two layers from a single codeword by distributing alternate modulation symbols between the two layers. Both codebook entries have a ‘1 1’ in the upper row so antenna port 1 transmits a simple summation of the two layers (after scaling the amplitude by 1/2). The two codebook entries have different values in their lower rows which correspond to phase shifts of (0, 180) degrees and (90, 270) degrees. The selected pair of phase shifts is applied before transmission using antenna port 2

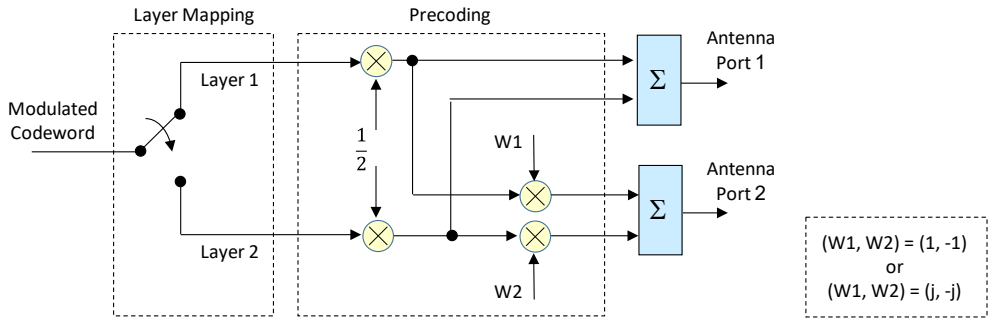

Figure 393 – Dual layer precoding applicable when CSI Reference Signal uses antenna ports 3000 and 3001