Table 5.2.2.2.2-5: Codebook for 3-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***codebookMode* = 1, $N_g \in \{2,4\}$**				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q=1,\dots,N_g-1$	i_2	
$0,\dots,N_1O_1-1$	$0,\dots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(3)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(3)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{3}}\begin{bmatrix} W^{1,N_g,1}_{l,m,p,n} & W^{1,N_g,1}_{l',m',p,n} & W^{2,N_g,1}_{l,m,p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

***codebookMode* = 2, $N_g = 2$**				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q=1,2$	$i_{2,q}$, $q=0,1,2$	
$0,\dots,N_1O_1-1$	$0,\dots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(3)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(3)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{3}}\begin{bmatrix} W^{1,N_g,2}_{l,m,p,n} & W^{1,N_g,2}_{l',m',p,n} & W^{2,N_g,2}_{l,m,p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

Table 5.2.2.2.2-6: Codebook for 4-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

***codebookMode* = 1, $N_g \in \{2,4\}$**				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q=1,\dots,N_g-1$	i_2	
$0,\dots,N_1O_1-1$	$0,\dots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(4)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{4}}\begin{bmatrix} W^{1,N_g,1}_{l,m,p,n} & W^{1,N_g,1}_{l',m',p,n} & W^{2,N_g,1}_{l,m,p,n} & W^{2,N_g,1}_{l',m',p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

***codebookMode* = 2, $N_g = 2$**				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}$, $q=1,2$	$i_{2,q}$, $q=0,1,2$	
$0,\dots,N_1O_1-1$	$0,\dots,N_2O_2-1$	$0,1,2,3$	$0,1$	$W^{(4)}_{i_{1,1},i_{1,1}+k_1,i_{1,2},i_{1,2}+k_2,i_{1,4},i_2}$
where $W^{(4)}_{l,l',m,m',p,n} = \frac{1}{\sqrt{4}}\begin{bmatrix} W^{1,N_g,2}_{l,m,p,n} & W^{1,N_g,2}_{l',m',p,n} & W^{2,N_g,2}_{l,m,p,n} & W^{2,N_g,2}_{l',m',p,n} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

5.2.2.2.3 Type II Codebook

For 4 antenna ports {3000, 3001, …, 3003}, 8 antenna ports {3000, 3001, …, 3007}, 12 antenna ports {3000, 3001, …, 3011}, 16 antenna ports {3000, 3001, …, 3015}, 24 antenna ports {3000, 3001, …, 3023}, and 32 antenna ports {3000, 3001, …, 3031}, and the UE configured with higher layer parameter *codebookType* set to 'typeII'

- The values of N_1 and N_2 are configured with the higher layer parameter *n1-n2-codebookSubsetRestriction*. The supported configurations of (N_1, N_2) for a given number of CSI-RS ports and the corresponding values of (O_1, O_2) are given in Table 5.2.2.2.1-2. The number of CSI-RS ports, $P_{\text{CSI-RS}}$, is $2N_1N_2$.

- The value of L is configured with the higher layer parameter *numberOfBeams*, where $L=2$ when $P_{\text{CSI-RS}}=4$ and $L \in \{2,3,4\}$ when $P_{\text{CSI-RS}}>4$.

- The value of N_{PSK} is configured with the higher layer parameter *phaseAlphabetSize*, where $N_{\text{PSK}} \in \{4,8\}$.
- The UE is configured with the higher layer parameter *subbandAmplitude* set to 'true' or 'false'.
- The UE shall not report RI > 2.

When $\upsilon \le 2$, where υ is the associated RI value, each PMI value corresponds to the codebook indices i_1 and i_2 where

$$i_1 = \begin{cases} \begin{bmatrix} i_{1,1} & i_{1,2} & i_{1,3,1} & i_{1,4,1} \end{bmatrix} & \upsilon = 1 \\ \begin{bmatrix} i_{1,1} & i_{1,2} & i_{1,3,1} & i_{1,4,1} & i_{1,3,2} & i_{1,4,2} \end{bmatrix} & \upsilon = 2 \end{cases}$$

$$i_2 = \begin{cases} \begin{bmatrix} i_{2,1,1} \end{bmatrix} & \textit{subbandAmplitude} = \text{'false'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,1,2} \end{bmatrix} & \textit{subbandAmplitude} = \text{'false'},\ \upsilon = 2 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} \end{bmatrix} & \textit{subbandAmplitude} = \text{'true'},\ \upsilon = 1 \\ \begin{bmatrix} i_{2,1,1} & i_{2,2,1} & i_{2,1,2} & i_{2,2,2} \end{bmatrix} & \textit{subbandAmplitude} = \text{'true'},\ \upsilon = 2 \end{cases}.$$

The L vectors combined by the codebook are identified by the indices $i_{1,1}$ and $i_{1,2}$, where

$$\begin{aligned} i_{1,1} &= [q_1 \quad q_2] \\ q_1 &\in \{0,1,\ldots,O_1-1\} \\ q_2 &\in \{0,1,\ldots,O_2-1\} \end{aligned}$$

$$i_{1,2} \in \left\{0,1,\ldots,\binom{N_1N_2}{L}-1\right\}.$$

Let

$$\begin{aligned} n_1 &= \left[n_1^{(0)},\ldots,n_1^{(L-1)}\right] \\ n_2 &= \left[n_2^{(0)},\ldots,n_2^{(L-1)}\right] \\ n_1^{(i)} &\in \{0,1,\ldots,N_1-1\} \\ n_2^{(i)} &\in \{0,1,\ldots,N_2-1\} \end{aligned}$$

and

$$C(x,y) = \begin{cases} \binom{x}{y} & x \ge y \\ 0 & x < y \end{cases}.$$

where the values of $C(x,y)$ are given in Table 5.2.2.2.3-1.

Then the elements of n_1 and n_2 are found from $i_{1,2}$ using the algorithm:

$s_{-1} = 0$

for $i = 0,\ldots,L-1$

Find the largest $x^* \in \{L-1-i,\ldots,N_1N_2-1-i\}$ in Table 5.2.2.2.3-1 such that $i_{1,2} - s_{i-1} \ge C(x^*, L-i)$

$e_i = C(x^*, L-i)$

$s_i = s_{i-1} + e_i$

$n^{(i)} = N_1N_2 - 1 - x^*$

$n_1^{(i)} = n^{(i)} \bmod N_1$

$$n_2^{(i)} = \frac{\left(n^{(i)} - n_1^{(i)}\right)}{N_1}$$

When n_1 and n_2 are known, $i_{1,2}$ is found using:

$n^{(i)} = N_1 n_2^{(i)} + n_1^{(i)}$ where the indices $i = 0,1,\ldots,L-1$ are assigned such that $n^{(i)}$ increases as i increases

$i_{1,2} = \sum_{i=0}^{L-1} C\left(N_1 N_2 - 1 - n^{(i)}, L - i\right)$, where $C(x,y)$ is given in Table 5.2.2.2.3-1.

- If $N_2 = 1$, $q_2 = 0$ and $n_2^{(i)} = 0$ for $i = 0,1,\ldots,L-1$, and q_2 is not reported.
- When $(N_1, N_2) = (2,1)$, $n_1 = [0,1]$ and $n_2 = [0,0]$, and $i_{1,2}$ is not reported.
- When $(N_1, N_2) = (4,1)$ and L=4, $n_1 = [0,1,2,3]$ and $n_2 = [0,0,0,0]$, and $i_{1,2}$ is not reported.
- When $(N_1, N_2) = (2,2)$ and L=4, $n_1 = [0,1,0,1]$ and $n_2 = [0,0,1,1]$, and $i_{1,2}$ is not reported.

Table 5.2.2.2.3-1: Combinatorial coefficients $C(x,y)$

x \ y	1	2	3	4
0	0	0	0	0
1	1	0	0	0
2	2	1	0	0
3	3	3	1	0
4	4	6	4	1
5	5	10	10	5
6	6	15	20	15
7	7	21	35	35
8	8	28	56	70
9	9	36	84	126
10	10	45	120	210
11	11	55	165	330
12	12	66	220	495
13	13	78	286	715
14	14	91	364	1001
15	15	105	455	1365

The strongest coefficient on layer $l, l = 1,\ldots,\upsilon$ is identified by $i_{1,3,l} \in \{0,1,\ldots,2L-1\}$.

The amplitude coefficient indicators $i_{1,4,l}$ and $i_{2,2,l}$ are

$$i_{1,4,l} = \left[k_{l,0}^{(1)}, k_{l,1}^{(1)}, \ldots, k_{l,2L-1}^{(1)}\right]$$
$$i_{2,2,l} = \left[k_{l,0}^{(2)}, k_{l,1}^{(2)}, \ldots, k_{l,2L-1}^{(2)}\right]$$
$$k_{l,i}^{(1)} \in \{0,1,\ldots,7\}$$
$$k_{l,i}^{(2)} \in \{0,1\}$$

for $l=1,\ldots,\upsilon$. The mapping from $k_{l,i}^{(1)}$ to the amplitude coefficient $p_{l,i}^{(1)}$ is given in Table 5.2.2.2.3-2 and the mapping from $k_{l,i}^{(2)}$ to the amplitude coefficient $p_{l,i}^{(2)}$ is given in Table 5.2.2.2.3-3. The amplitude coefficients are represented by

$$p_l^{(1)}=\left[p_{l,0}^{(1)},p_{l,1}^{(1)},\ldots,p_{l,2L-1}^{(1)}\right]$$
$$p_l^{(2)}=\left[p_{l,0}^{(2)},p_{l,1}^{(2)},\ldots,p_{l,2L-1}^{(2)}\right]$$

for $l=1,\ldots,\upsilon$.

Table 5.2.2.2.3-2: Mapping of elements of $i_{1,4,l}$: $k_{l,i}^{(1)}$ to $p_{l,i}^{(1)}$

$k_{l,i}^{(1)}$	$p_{l,i}^{(1)}$
0	0
1	$\sqrt{1/64}$
2	$\sqrt{1/32}$
3	$\sqrt{1/16}$
4	$\sqrt{1/8}$
5	$\sqrt{1/4}$
6	$\sqrt{1/2}$
7	1

Table 5.2.2.2.3-3: Mapping of elements of $i_{2,2,l}$: $k_{l,i}^{(2)}$ to $p_{l,i}^{(2)}$

$k_{l,i}^{(2)}$	$p_{l,i}^{(2)}$
0	$\sqrt{1/2}$
1	1

The phase coefficient indicators are

$$i_{2,1,l}=\left[c_{l,0},c_{l,1},\ldots,c_{l,2L-1}\right]$$

for $l=1,\ldots,\upsilon$.

The amplitude and phase coefficient indicators are reported as follows:

- The indicators $k_{l,i_{1,3,l}}^{(1)}=7$, $k_{l,i_{1,3,l}}^{(2)}=1$, and $c_{l,i_{1,3,l}}=0$ ($l=1,\ldots,\upsilon$). $k_{l,i_{1,3,l}}^{(1)}$, $k_{l,i_{1,3,l}}^{(2)}$, and $c_{l,i_{1,3,l}}$ are not reported for $l=1,\ldots,\upsilon$.
- The remaining $2L-1$ elements of $i_{1,4,l}$ ($l=1,\ldots,\upsilon$) are reported, where $k_{l,i}^{(1)}\in\{0,1,\ldots,7\}$. Let M_l ($l=1,\ldots,\upsilon$) be the number of elements of $i_{1,4,l}$ that satisfy $k_{l,i}^{(1)}>0$.
- The remaining $2L-1$ elements of $i_{2,1,l}$ and $i_{2,2,l}$ ($l=1,\ldots,\upsilon$) are reported as follows:

- When *subbandAmplitude* is set to 'false',
  - $k_{l,i}^{(2)} = 1$ for $l = 1, \ldots, \upsilon$, and $i = 0,1,\ldots,2L-1$. $i_{2,2,l}$ is not reported for $l = 1, \ldots, \upsilon$.
  - For $l = 1, \ldots, \upsilon$, the elements of $i_{2,1,l}$ corresponding to the coefficients that satisfy $k_{l,i}^{(1)} > 0$, $i \neq i_{1,3,l}$, as determined by the reported elements of $i_{1,4,l}$, are reported, where $c_{l,i} \in \{0,1,\ldots,N_{\mathrm{PSK}}-1\}$ and the remaining $2L - M_l$ elements of $i_{2,1,l}$ are not reported and are set to $c_{l,i} = 0$.
- When *subbandAmplitude* is set to 'true',
  - For $l = 1, \ldots, \upsilon$, the elements of $i_{2,2,l}$ and $i_{2,1,l}$ corresponding to the $\min\left(M_l, K^{(2)}\right) - 1$ strongest coefficients (excluding the strongest coefficient indicated by $i_{1,3,l}$), as determined by the corresponding reported elements of $i_{1,4,l}$, are reported, where $k_{l,i}^{(2)} \in \{0,1\}$ and $c_{l,i} \in \{0,1,\ldots,N_{\mathrm{PSK}}-1\}$. The values of $K^{(2)}$ are given in Table 5.2.2.2.3-4. The remaining $2L - \min\left(M_l, K^{(2)}\right)$ elements of $i_{2,2,l}$ are not reported and are set to $k_{l,i}^{(2)} = 1$. The elements of $i_{2,1,l}$ corresponding to the $M_l - \min\left(M_l, K^{(2)}\right)$ weakest non-zero coefficients are reported, where $c_{l,i} \in \{0,1,2,3\}$. The remaining $2L - M_l$ elements of $i_{2,1,l}$ are not reported and are set to $c_{l,i} = 0$.
  - When two elements, $k_{l,x}^{(1)}$ and $k_{l,y}^{(1)}$, of the reported elements of $i_{1,4,l}$ are identical ($k_{l,x}^{(1)} = k_{l,y}^{(1)}$), then element $\min(x,y)$ is prioritized to be included in the set of the $\min\left(M_l, K^{(2)}\right) - 1$ strongest coefficients for $i_{2,1,l}$ and $i_{2,2,l}$ ($l = 1, \ldots, \upsilon$) reporting.

Table 5.2.2.2.3-4: Full resolution subband coefficients when *subbandAmplitude* is set to 'true'

L	$K^{(2)}$
2	4
3	4
4	6

The codebooks for 1-2 layers are given in Table 5.2.2.2.3-5, where the indices $m_1^{(i)}$ and $m_2^{(i)}$ are given by

$$m_1^{(i)} = O_1 n_1^{(i)} + q_1$$
$$m_2^{(i)} = O_2 n_2^{(i)} + q_2$$

for $i = 0,1,\ldots,L-1$, and the quantities $\varphi_{l,i}$, u_m, and $v_{l,m}$ are given by

$$\varphi_{l,i}=\begin{cases} e^{j2\pi c_{l,i}/N_{\text{PSK}}} & subbandAmplitude = \text{'false'} \\ e^{j2\pi c_{l,i}/N_{\text{PSK}}} & subbandAmplitude = \text{'true', } \min\left(M_l,K^{(2)}\right) \text{ strongest coefficients (including } i_{1,3,l}\text{) with } k_{l,i}^{(1)}>0 \\ e^{j2\pi c_{l,i}/4} & subbandAmplitude = \text{'true', } M_l-\min\left(M_l,K^{(2)}\right) \text{ weakest coefficients with } k_{l,i}^{(1)}>0 \\ 1 & subbandAmplitude = \text{'true', } 2L-M_l \text{ coefficients with } k_{l,i}^{(1)}=0 \end{cases}$$

$$u_m=\begin{cases}\begin{bmatrix}1 & e^{j\frac{2\pi m}{O_2N_2}} & \cdots & e^{j\frac{2\pi m(N_2-1)}{O_2N_2}}\end{bmatrix} & N_2>1 \\ 1 & N_2=1\end{cases}.$$

$$v_{l,m}=\begin{bmatrix}u_m & e^{j\frac{2\pi l}{O_1N_1}}u_m & \cdots & e^{j\frac{2\pi l(N_1-1)}{O_1N_1}}u_m\end{bmatrix}^T$$

Table 5.2.2.2.3-5: Codebook for 1-layer and 2-layer CSI reporting using antenna ports 3000 to 2999+$P_{\text{CSI-RS}}$

Layers	
$\upsilon=1$	$W^{(1)}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}}=W^{1}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}}$
$\upsilon=2$	$W^{(2)}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1},p_2^{(1)},p_2^{(2)},i_{2,1,2}}=\frac{1}{\sqrt{2}}\begin{bmatrix}W^{1}_{q_1,q_2,n_1,n_2,p_1^{(1)},p_1^{(2)},i_{2,1,1}} & W^{2}_{q_1,q_2,n_1,n_2,p_2^{(1)},p_2^{(2)},i_{2,1,2}}\end{bmatrix}$
where $W^{l}_{q_1,q_2,n_1,n_2,p_l^{(1)},p_l^{(2)},c_l}=\frac{1}{\sqrt{N_1N_2\sum_{i=0}^{2L-1}\left(p_{l,i}^{(1)}p_{l,i}^{(2)}\right)^2}}\begin{bmatrix}\sum_{i=0}^{L-1}v_{m_1^{(i)},m_2^{(i)}}p_{l,i}^{(1)}p_{l,i}^{(2)}\varphi_{l,i} \\ \sum_{i=0}^{L-1}v_{m_1^{(i)},m_2^{(i)}}p_{l,i+L}^{(1)}p_{l,i+L}^{(2)}\varphi_{l,i+L}\end{bmatrix},\ l=1,2$, and the mappings from i_1 to q_1, q_2, n_1, n_2, $p_1^{(1)}$, and $p_2^{(1)}$, and from i_2 to $i_{2,1,1}$, $i_{2,1,2}$, $p_1^{(2)}$ and $p_2^{(2)}$ are as described above, including the ranges of the constituent indices of i_1 and i_2.	

When the UE is configured with higher layer parameter *codebookType* set to 'typeII', thebitmap parameter *typeII-RI-Restriction* forms the bit sequence r_1,r_0 where r_0 is the LSB and r_1 is the MSB. When r_i is zero, $i\in\{0,1\}$, PMI and RI reporting are not allowed to correspond to any precoder associated with $\upsilon=i+1$ layers. The bitmap parameter *n1-n2-codebookSubsetRestriction* forms the bit sequence $B=B_1B_2$ where bit sequences B_1, and B_2 are concatenated to form B. To define B_1 and B_2, first define the O_1O_2 vector groups $G(r_1,r_2)$ as

$$G(r_1,r_2)=\left\{v_{N_1r_1+x_1,N_2r_2+x_2}:x_1=0,1,\ldots,N_1-1;x_2=0,1,\ldots,N_2-1\right\}$$

for

$$\begin{aligned}r_1&\in\{0,1,\ldots,O_1-1\}\\ r_2&\in\{0,1,\ldots,O_2-1\}\end{aligned}.$$

The UE shall be configured with restrictions for 4 vector groups indicated by $\left(r_1^{(k)},r_2^{(k)}\right)$ for $k=0,1,2,3$ and identified by the group indices

$$g^{(k)}=O_1r_2^{(k)}+r_1^{(k)}$$

for $k=0,1,\ldots,3$, where the indices are assigned such that $g^{(k)}$ increases as k increases. The remaining vector groups are not restricted.

- If $N_2=1$, $g^{(k)}=k$ for $k=0,1,\ldots,3$, and B_1 is empty.
- If $N_2>1$, $B_1=b_1^{(10)}\cdots b_1^{(0)}$ is the binary representation of the integer β_1 where $b_1^{(10)}$ is the MSB and $b_1^{(0)}$ is the LSB. β_1 is found using:

$$\beta_1=\sum_{k=0}^{3} C\left(O_1O_2-1-g^{(k)},4-k\right),$$

where $C(x,y)$ is defined in Table 5.2.2.2.3-1. The group indices $g^{(k)}$ and indicators $\left(r_1^{(k)},r_2^{(k)}\right)$ for $k=0,1,2,3$ may be found from β_1 using the algorithm:

$s_{-1}=0$
for $k=0,\ldots,3$
Find the largest $x^*\in\{3-k,\ldots,O_1O_2-1-k\}$ such that $\beta_1-s_{k-1}\geq C\left(x^*,4-k\right)$
$e_k=C\left(x^*,4-k\right)$
$s_k=s_{k-1}+e_k$
$g^{(k)}=O_1O_2-1-x^*$
$r_1^{(k)}=g^{(k)} \bmod O_1$
$r_2^{(k)}=\frac{\left(g^{(k)}-r_1^{(k)}\right)}{O_1}$

The bit sequence $B_2=B_2^{(0)}B_2^{(1)}B_2^{(2)}B_2^{(3)}$ is the concatenation of the bit sequences $B_2^{(k)}$ for $k=0,1,\ldots,3$, corresponding to the group indices $g^{(k)}$. The bit sequence $B_2^{(k)}$ is defined as

$$B_2^{(k)}=b_2^{(k,2N_1N_2-1)}\cdots b_2^{(k,0)}$$

Bits $b_2^{(k,2(N_1x_2+x_1)+1)}b_2^{(k,2(N_1x_2+x_1))}$ indicate the maximum allowed amplitude coefficient $p_{l,i}^{(1)}$ for the vector in group $g^{(k)}$ indexed by x_1,x_2, where the maximum amplitude coefficients are given in Table 5.2.2.2.3-6. A UE that does not report parameter *amplitudeSubsetRestriction* = 'supported' in its capability signaling is not expected to be configured with $b_2^{(k,2(N_1x_2+x_1)+1)}b_2^{(k,2(N_1x_2+x_1))}$ = 01 or 10.